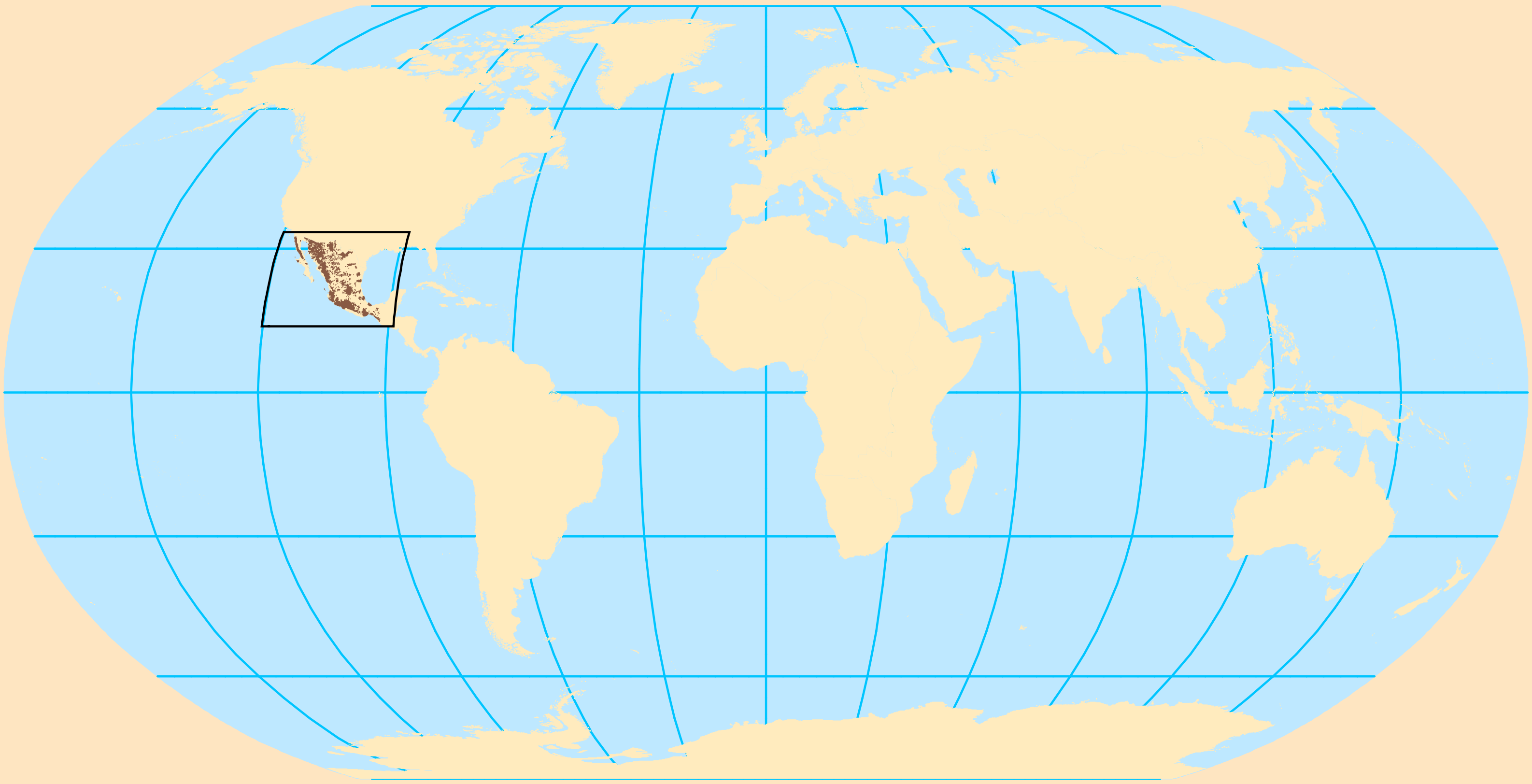
Global Mineral Resource Assessment

Porphyry Copper Assessment of Mexico



Prepared in cooperation with the Servicio Geológico Mexicano

Scientific Investigations Report 2010–5090–A

U.S. Department of the Interior
U.S. Geological Survey

This page intentionally left blank

Global Mineral Resource Assessment

Michael L. Zientek and Jane M. Hammarstrom, editors

Porphyry Copper Assessment of Mexico

By Jane M. Hammarstrom, Gilpin R. Robinson, Jr., Steve Ludington, Floyd Gray, Benjamin J. Drenth, Francisco Cendejas-Cruz, Enrique Espinosa, Efrén Pérez-Segura, Martín Valencia-Moreno, José Luis Rodríguez-Castañeda, Rigoberto Vásquez-Mendoza, and Lukas Zürcher

Prepared in cooperation with the Servicio Geológico Mexicano

Scientific Investigations Report 2010–5090–A

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2010

This report and any updates to it are available online at:
http://pubs.usgs.gov/sir/2010/5090/a/

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov/
Telephone: 1-888-ASK-USGS

Suggested citation:
Hammarstrom, J.M., Robinson, G.R., Jr., Ludington, Steve, Gray, Floyd, Drenth, B.J., Cendejas-Cruz, Francisco, Espinosa, Enrique, Pérez-Segura, Efrén, Valencia-Moreno, Martín, Rodríguez-Castañeda, José Luis , Vásquez-Mendoza, Rigoberto, and Zürcher, Lukas, 2010, Global mineral resource assessment—porphyry copper assessment of Mexico: U.S. Geological Survey Scientific Investigations Report 2010-5090-A, 176 p.

Contents

Figures

Tables

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	0.4047	square hectometer (hm^2)
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, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton, long (2,240 lb)	1.016	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
square kilometer (km^2)	247.1	acre
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)
megagram (Mg)	1.102	ton, short (2,000 lb)
megagram (Mg)	0.9842	ton, long (2,240 lb)

This page intentionally left blank

Porphyry Copper Assessment of Mexico

By Jane M. Hammarstrom[1], Gilpin R. Robinson, Jr.[2], Steve Ludington[3], Floyd Gray[4], Benjamin J. Drenth[5], Francisco Cendejas-Cruz[6], Enrique Espinosa[7], Efrén Pérez-Segura[8], Martín Valencia-Moreno[9], José Luis Rodríguez-Castañeda[10], Rigoberto Vásquez-Mendoza[11], and Lukas Zürcher[12]

Abstract

Mineral resource assessments provide a synthesis of available information about distributions of mineral deposits in the Earth's crust. A probabilistic mineral resource assessment of undiscovered resources in porphyry copper deposits in Mexico was done as part of a global mineral resource assessment. The purpose of the study was to (1) delineate permissive areas (tracts) for undiscovered porphyry copper deposits within 1 km 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 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 undiscovered deposits for each permissive tract. The assessment was conducted using a three-part form of mineral resource assessment based on mineral deposit models (Singer, 1993). Delineation of permissive tracts primarily was based on distributions of mapped igneous rocks related to magmatic arcs that formed in tectonic settings associated with subduction boundary zones. Using a GIS, map units were selected from digital geologic maps based on lithology and age to delineate twelve permissive tracts associated with Jurassic, Laramide (~90 to 34 Ma), and younger Tertiary magmatic arcs. Stream-sediment geochemistry, mapped alteration, regional aeromagnetic data, and exploration history were considered in conjunction with descriptive deposit models and grade and tonnage models to guide estimates.

The 12 permissive tracts delineated for this assessment are grouped by age (Jurassic-Early Cretaceous, Laramide (~90 to 34 Ma), Tertiary) and range in size from ~3,000 to 184,000 km^2. Probabilistic estimates of numbers of undiscovered deposits were made for 10 tracts. A qualitative discussion is included for one Jurassic tract that extends into the U.S. from northern Mexico, and a preliminary outline of the northernmost part of a Tertiary tract that continues well to the south of Mexico is included in summary figures for reference.

This assessment estimates that 39 undiscovered deposits contain an arithmetic mean estimate of ~144 million metric tons of copper or more in ten tracts for which probabilistic estimates were made, in addition to 21 porphyry copper deposits that contain identified resources of ~52 million metric tons of copper. Approximately 70 percent of the estimated mean undiscovered copper resources are associated with permissive tracts that contain identified resources; the remaining estimated resources are associated with permissive tracts with no reported porphyry copper resources. In addition to copper, the mean expected values of undiscovered byproduct resources predicted by the simulation are ~4 million metric tons of molybdenum, ~48 thousand metric tons of silver, and 4 thousand metric tons of gold. The probability associated with these arithmetic means is on the order of 30 percent. Median expected amounts of metals predicted by the simulations may be ~ 50 percent lower than mean estimates, and in some cases, zero.

For tracts that contain identified resources, the ratios of undiscovered to identified copper resources indicate that:

- Jurassic-Early Cretaceous tracts MX-J1 and MX-J2 contain fewer estimated undiscovered copper resources (ratios <1) than identified resources;
- Laramide tract MX-L1 may contain significantly more copper than has been identified;
- Laramide tract MX-L2, the tract that contains most of the known deposits in Mexico, including the world-

[1]U.S. Geological Survey, jhammars@usgs.gov.
[2]U.S. Geological Survey, grobinso@usgs.gov.
[3]U.S. Geological Survey, slud@usgs.gov.
[4]U.S. Geological Survey, fgray@usgs.gov.
[5]U.S. Geological Survey, bdrenth@usgs.gov.
[6]Servicio Geológico Mexicano, fcendejas@sgm.gob.mx.
[7]Servicio Geológico Mexicano, eespinosa@sgm.gob.mx.
[8]Departmento de Geologia, Universidad de Sonora, efrenpese@yahoo.com.
[9]Estacion Regional del Noroeste, Instituto de Geologia, Universidad Nacional Autónoma de México, valencia@geologia.unam.mx.
[10]Estacion Regional del Noroeste, Instituto de Geologia, Universidad Nacional Autónoma de México, jlrod@servidor.unam.mx.
[11]Servicio Geológico Mexicano, rigov@sgm.gob.mx.
[12]University of Arizona, lzurcher@email.arizona.edu.

class deposits at Cananea and La Caridad, may contain about as much copper, molybdenum, and silver in undiscovered deposits and more gold than has been identified;

- Tertiary tracts MX-T1 and MX-T2, where no porphyry copper deposits are known, may contain undiscovered deposits;
- Tertiary tract MX-T3 may contain about three times more copper than has been identified; and
- Permissive tracts with no known deposits (MX-J3, MX-J5, MX-L3, MX-T1, MX-T2) contain approximately 30 percent of the total estimated undiscovered copper resources.

Most porphyry copper exploration in Mexico focused on the exposed northern parts of the Laramide arc. This assessment suggests that the exposed and shallowly buried (<1 km) parts of the Laramide and Tertiary arcs delineated as permissive tracts are more likely to contain undiscovered deposits than are older (Jurassic-Early Cretaceous) arc segments. Interest in gold has prompted exploration of historical precious metal prospects and small mines in Mexico, some of which may represent high-sulfidation epithermal systems overlying or adjacent to porphyry copper systems.

This report includes a brief overview of porphyry copper deposits in Mexico, a description of the assessment process used, a summary of results, and appendixes. Appendixes A through K contain summary information for each tract, as follows: 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 (shapefiles) provide permissive tract outlines, assessment results, and data for deposits and prospects in a GIS format (appendix L).

Introduction

Mexico is one of the world's leading copper-producing countries. Mexican copper primarily comes from porphyry copper deposits, including the giant deposits at Cananea and La Caridad in northern Mexico. Porphyry copper deposits are the most important large tonnage, low-grade sources of global copper supply. The primary ore mineral in porphyry copper deposits is chalcopyrite, $CuFeS_2$, distributed in stockwork veinlets and disseminations in hydrothermally altered porphyry and adjacent rock. In some deposits, supergene processes make chalcocite (Cu_2S) the most important ore mineral. Molybdenum, silver, and gold are important byproducts in many deposits.

A probabilistic mineral resource assessment of undiscovered resources in porphyry copper deposits in Mexico was done as part of a global mineral resource assessment. The purpose of the study was to (1) delineate permissive areas (tracts) for undiscovered porphyry copper deposits 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 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 undiscovered deposits for each permissive tract. The study was conducted by the U.S. Geological Survey (USGS) in collaboration with geologists from the Servicio Geológico Mexicano (SGM), the Universidad Nacional Autónoma de México, the University of Sonora, and the University of Arizona.

The assessment of undiscovered porphyry copper deposits in Mexico was done using the three-part form of mineral resource assessment based on mineral deposit models (Singer 1993, 2007a, b; Singer and Berger, 2007). In applying the three-part form of mineral resource assessment, areas (permissive tracts) are delineated according to the types of deposits permitted by the geology, the amount of metal in typical deposits is estimated by using grade and tonnage models, and the number of undiscovered deposits of each type is estimated by using a variety of subjective methods (Singer, 2007a). Operational procedures used for porphyry copper assessments conducted for the global mineral resource assessment are described in Hammarstrom and others (in press,), along with definitions of terms, explanations of assessment methods, a discussion of guidelines and tools for delineating permissive tracts for porphyry copper deposits, models, estimation strategies, statistical tests, and an explanation of the Monte Carlo simulation (Root and others, 1992) that is used to combine estimates with grade and tonnage models to produce a probabilistic estimate of undiscovered resources.

The assessment data and results for each permissive tract are presented in a standardized format in appendixes A through K. Permissive tract boundaries and point locations of significant deposits and prospects are included in a GIS that accompanies this report (appendix L). The descriptive porphyry copper models of Berger and others (2008) and Cox (1986) were used along with the grade and tonnage models of Singer and others (2008). Political boundaries are based on Hearn and others (2003).

Mexico is an area of active exploration. This report reflects the porphyry copper projects known to the authors as of May 2009. Most of the recent exploration projects focus on large concessions that attracted attention due to reported gold associated with historical workings. Epithermal gold, breccias, skarn, and (or) polymetallic veins are the initial targets of many projects due to the current high price of gold. Company reports mention porphyry systems associated with some of these targets, but delineation of a porphyry copper deposit, if present, awaits further exploration in most cases.

Porphyry Copper Assessment of Mexico

Porphyry Copper Deposits in Mexico

Geologic Setting

Most of the known porphyry copper deposits in Mexico lie along a 1,500 km-long, northwest trending belt subparallel to the western coast of Mexico (fig. 1). This belt extends from the U.S. border through the states of Sonora (Cananea, La Caridad), western Chihuahua, Sinaloa, Michoacán (Inguarán), and Guerrero. These deposits are part of a globally important belt of porphyry copper deposits in the southwestern United States and Mexico that is Laramide (~90 to 40 Ma) in age. The deposit at Cananea (>20 Mt contained copper) in Sonora (fig. 1) is among the 15 largest porphyry copper deposits in the world (Singer and others, 2008).

The oldest known porphyry copper deposit in Mexico, the pre-Laramide mid-Jurassic El Arco deposit (fig. 1), in the central part of the Baja Peninsula, formed in an island arc setting as part of the Alisitos volcanic arc. The volcanic and related rocks of the Santa Ana/Alisitos terrane (fig. 2) were accreted to North America between about 115 to 105 Ma (Sedlock, 2003). The youngest known porphyry copper prospects, all south of the Trans-Mexican Volcanic Belt (TMVB, fig. 3), are related to post-Laramide volcanic-arc activity associated with subduction of the Cocos plate (fig. 4). The youngest porphyry copper prospect, Tolimán (fig. 1), in the state of Chiapas, is Pliocene in age.

The Laramide deposits formed in a continental arc tectonic setting related to subduction of the Farallon plate[13] beneath the North American craton (fig. 4). The age of the Laramide orogeny is generally considered to range from Late Cretaceous (~90 to 80 Ma) to Middle Eocene time (~40 Ma). For this assessment, we included rocks as young as Late Eocene (34 Ma) as "Laramide" due to uncertainties in ages. This places our Laramide/post-Laramide arc break north of the TMVB at the Eocene/Oligocene age boundary at 33.9 Ma (U.S. Geological Survey Geologic Names Committee, 2007). This age break was used to differentiate the Laramide tracts MX-L1, MX-L2, and MX-L3 from the MX-T2 Tertiary tract. In this area the Tertiary arc tracts are predominately mid-Tertiary in age. South of the TMVB, Laramide-age igneous rocks have been grouped with the younger Tertiary igneous rocks into the Tertiary arc, as subduction and subduction-related magmatism continued without interruption across the Upper Cretaceous-Tertiary boundary at 65.5 Ma (U.S. Geological Survey Geologic Names Committee, 2007) in this area.

[13]In a recent model, Hildebrand (2009) linked porphyry copper deposits in Sonora to Late Cretaceous-Early Tertiary failure of a westerly-directed slab subducting North America beneath a ribbon continent (Rubia) that preceded development of easterly-dipping subduction and arc magmatism in Tertiary time.

Within the Laramide arc porphyry copper belt, deposits generally decrease in age from north to south, and from west to east, both in Mexico and the United States. West to east progressions in age and composition of arc-associated rocks have been interpreted in terms of arc migration through time as the locus of magmatism moved farther and farther eastward from the paleotrench (Damon and others, 1983). Laramide igneous rocks in the western part of the Cordillera arc (within 500 km of the paleotrench) are calcalkalic, whereas those farther inland (700 to 1,000 km) tend to be alkalic (Damon and others, 1983). The conventional model ascribes the eastward shift of the locus of arc magmatism to flattening of the dip angle of the subducting Farallon plate. Beginning in Late Eocene time, as active subduction ceased, the slab collapsed through the asthenosphere, and steepened due to slab rollback. Subduction-induced compression gave way to extensional tectonics, and post-subduction magmatism retreated westward back towards the Pacific margin (Ferrari and others, 2007). Huge volumes of ignimbrites (>3.0 x 10^5 km^3) were erupted in the Sierra Madre Occidental (fig. 3) during the Oligocene and Early Miocene (~38 to 15 Ma), forming a large silicic, primarily alkali-calcic, igneous province prior to the opening of the Gulf of California around 12 to 15 Ma (Ferrari and others, 2007). At approximately 23 Ma, the Farallon plate was subdivided into the Cocos and Juan de Fuca plates (fig. 4) by the impingement of the spreading ridge/transform on the trench and subsequent creation of two migrating triple junctions.

The Sierra Madre Occidental volcanic province dominates the landscape of northern Mexico (fig. 3). The pre-Oligocene (pre-extension) deformation history of the area is not well constrained due to lack of outcrops, intense weathering, and normal faulting. Most of the porphyry copper deposits in the western part of the Sierra Madre Occidental (in Sonora and Sinaloa) were emplaced in highly fractured rocks during the Paleocene to Eocene (Ferrari and others, 2007). Deposits are apparently associated with ENE-WSW extensional structures that represent the last phase of Laramide compressional tectonics (Horner and Enriquez, 1999) or a transitional phase of deformation between the Laramide compression and Oligocene through Pliocene extension (Ferrari and others, 2007). Differential amounts and directions of Cenozoic extension characterize the southern parts of the Sierra Madre Occidental volcanic province, between about 20 and 25 degrees latitude north, and define the modern physiographic provinces (fig. 3). Major north-trending fault systems form the boundaries between the Sierra Madre Occidental, Mesa Central, and Sierra Madre Oriental physiographic provinces (Nieto-Samaniego and others, 2007). These three physiographic provinces are interpreted as crustal blocks that record different styles and timing of Cenozoic volcanism and deformation based on differences in stratigraphy, structure, topography, and crustal thickness (Nieto-Samaniego and others, 2007). Porphyry copper deposits are notably absent from the Mesa Central (excepting the 40 Ma Concepcion del Oro porphyry stock and related skarn), although much of it is covered by alluvium. This is an elevated plateau that exposes mostly

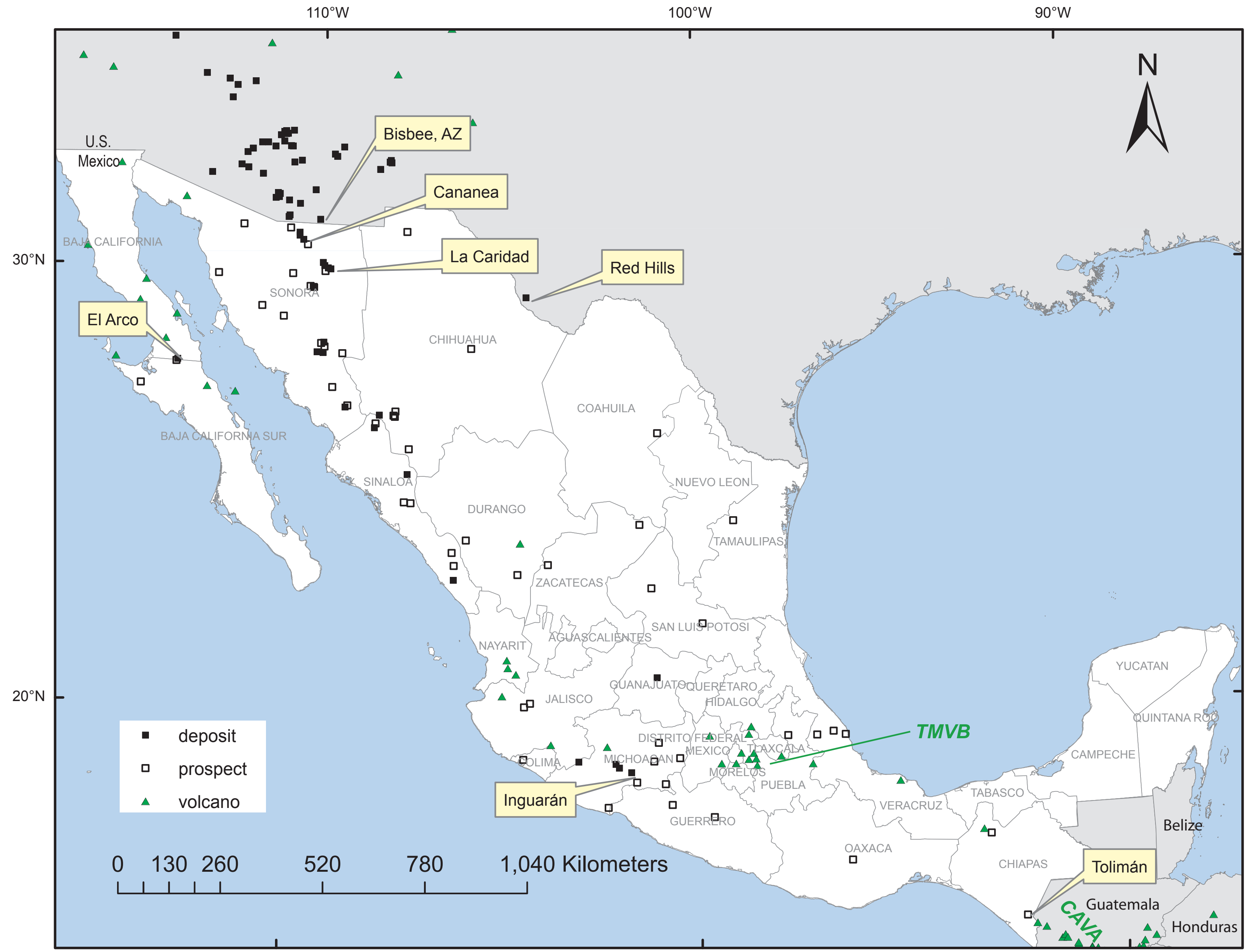


Figure 1. Porphyry copper deposits and significant porphyry copper prospects in Mexico and adjacent areas (Singer and others, 2008; this study). See text for discussion of named deposits. Holocene and historic volcanoes (global volcanism data compiled in Hearn and others, 2003). TMVB, Trans-Mexican Volcanic Belt. CAVA, northern end of the Central American Volcanic Arc in Guatemala.

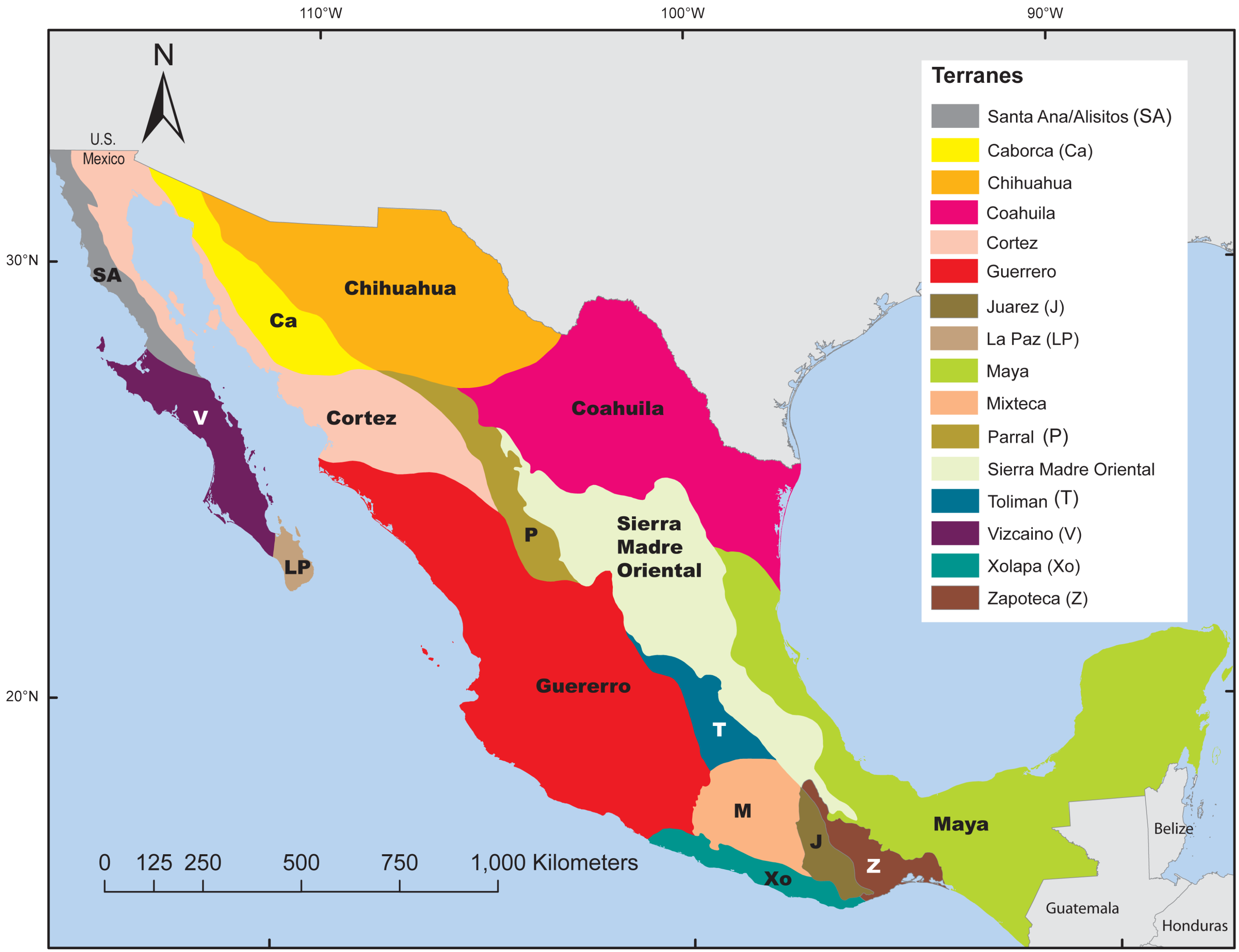


Figure 2. Simplified tectonostratigraphic terrane map of Mexico, based on Coney and Campa (1987).

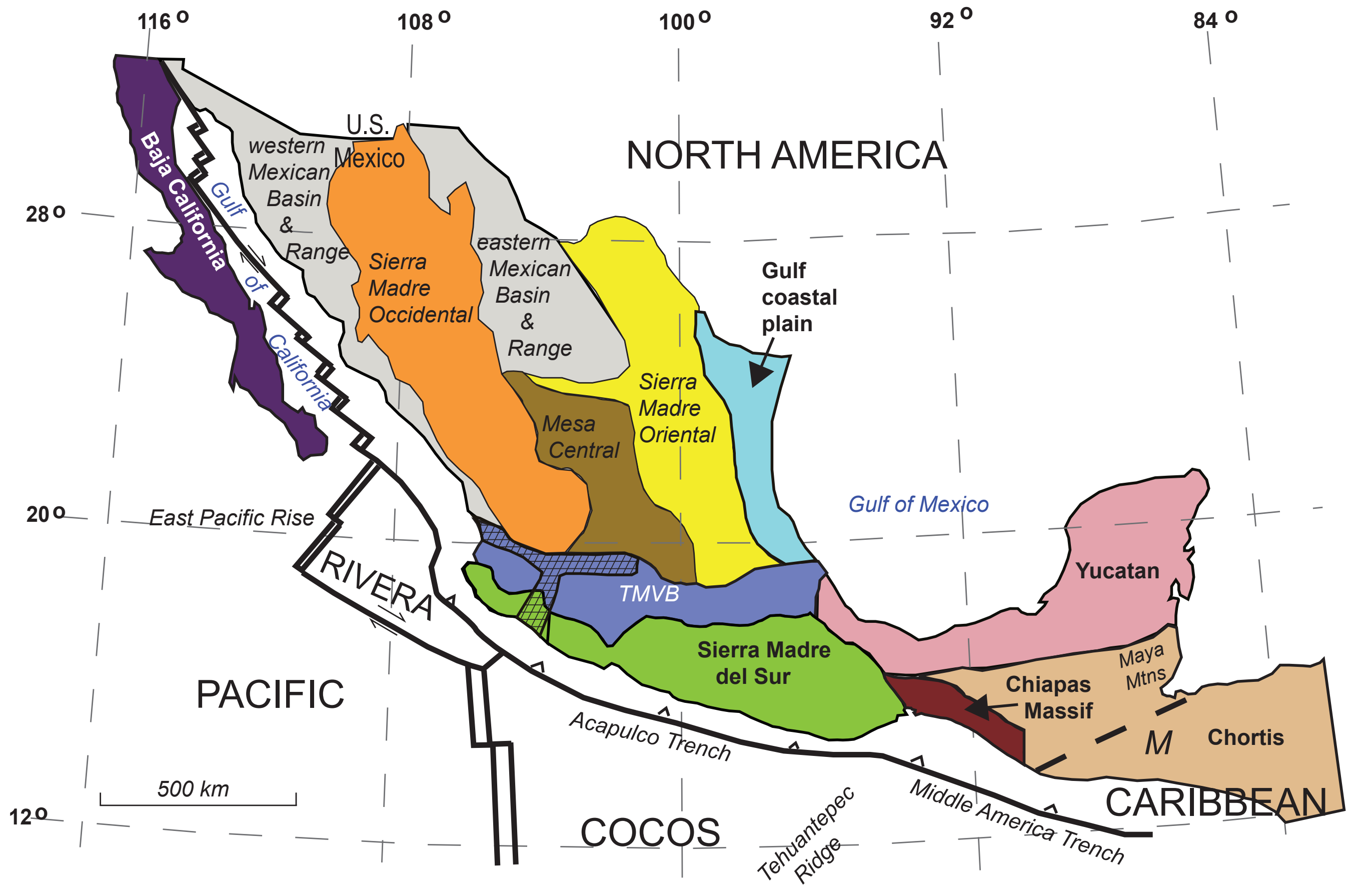


Figure 3. Major geologic and physiographic provinces of Mexico (modified from Sedlock and others, 1993). TMVB, Trans-Mexican Volcanic Belt. M, Motagua fault. Hachured area in southwestern Mexico shows the location of the Zacoalco (west), Colima (south), and Chapala (east) grabens.

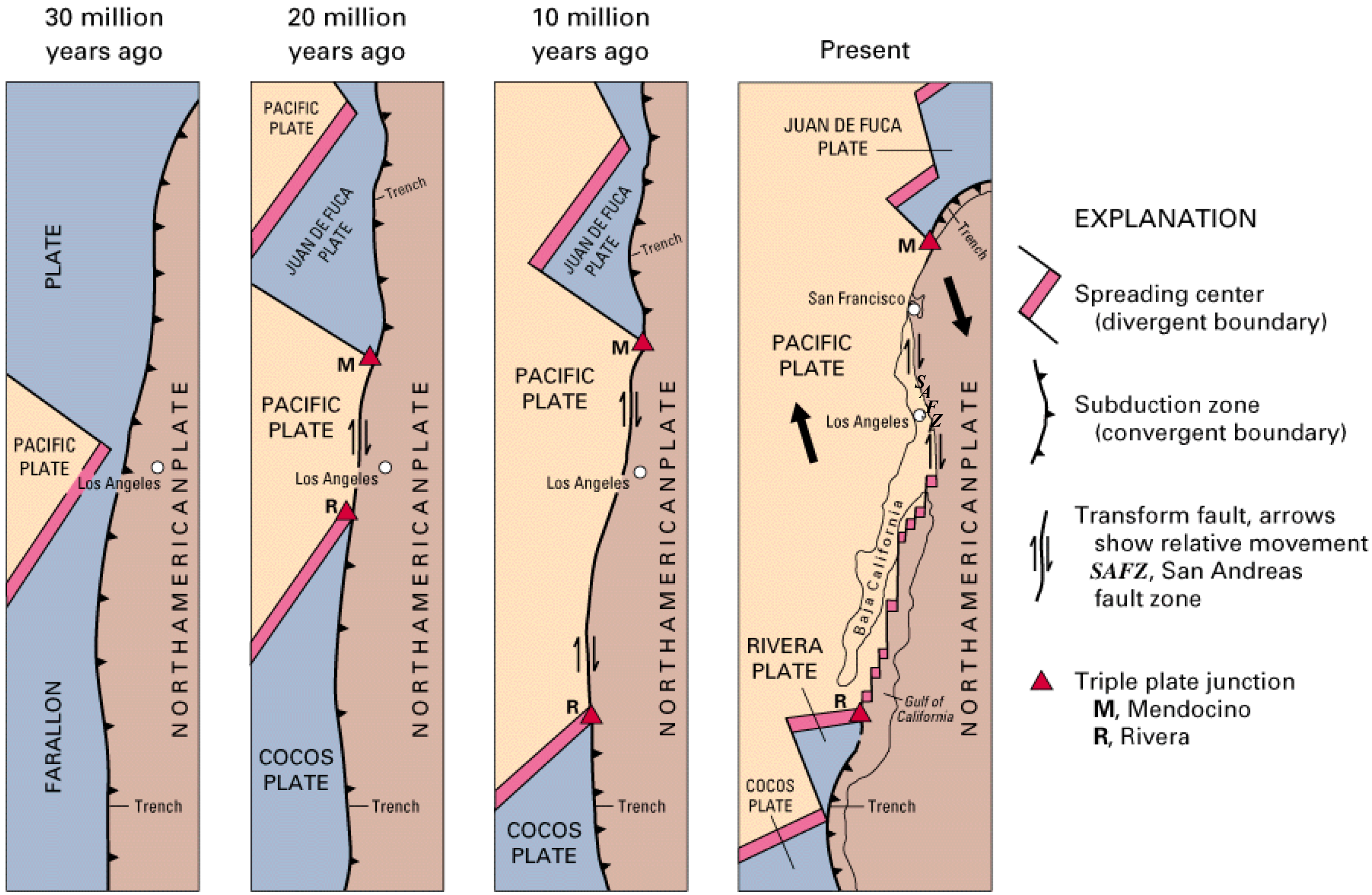


Figure 4. Plate tectonic evolution of western Mexico. The Farallon Plate was progressively consumed beneath the North American and Caribbean Plates, leaving the present-day Juan de Fuca, Rivera, and Cocos Plates as small remnants. Large solid arrows show the present-day sense of relative movement between the Pacific and North American Plates. (From Kious and Tilling, 1996).

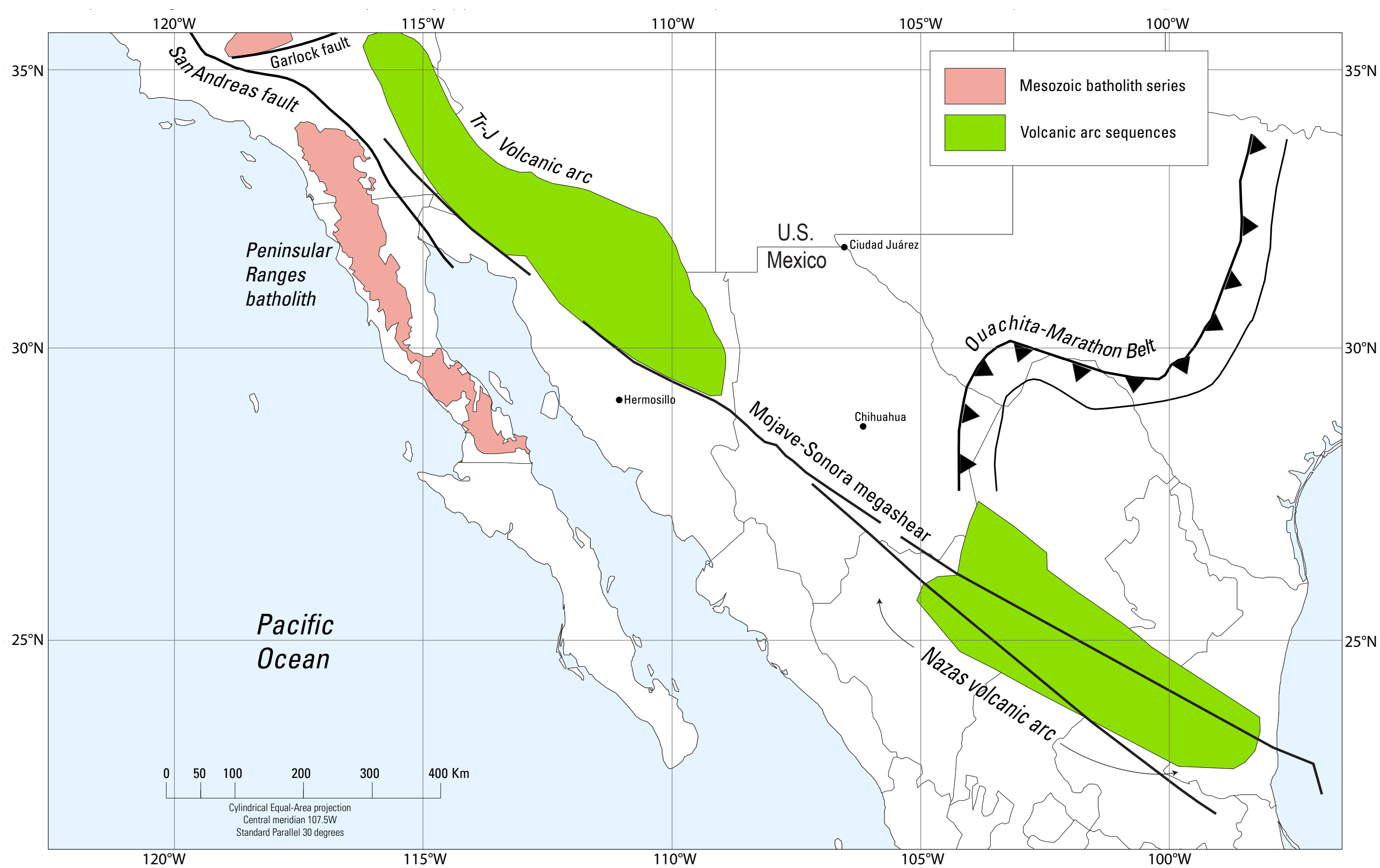


Figure 5. Triassic-Jurassic (Tr-J) volcanic arcs and tectonic elements in the Mohave-Sonora megashear of north-central Mexico and southwestern U.S. (Modified from Molina-Garza and Iriondo, 2007).

Mesozoic marine rocks, unconformably overlain by Cenozoic continental rocks, Oligocene topaz rhyolites, and Miocene to Quaternary alkaline basalt. The Mesa Central hosts significant low-sulfidation epithermal, iron-oxide copper-gold (IOCG), and carbonate replacement mineral deposits, as well as skarns along border areas (Nieto-Samaniego and others, 2007).

Present-day Mexico is a complex patchwork of pre-Laramide tectonostratigraphic terranes of varying age and provenance (Gondwana, Pangea, and Pacific) that were accreted to the North American and Middle American-Amazon cratons. Campa and Coney (1983) first applied terrane analysis to describe the tectonic evolution and mineral resource distributions of Mexico. We include a simplified version of Coney and Campa's 1987 oft-cited terrane map as figure 2 to facilitate discussion. Campa and Coney (1983) related observed distributions of gold and silver deposits to Mesozoic accreted terranes, and distributions of lead and zinc deposits to terranes underlain by Precambrian basement, but did not address the distribution of porphyry copper deposits. Sedlock and others (1993) and Keppie (2004) modified terrane boundaries and introduced new names; they also discussed plate tectonic reconstructions of Mexico, which continue to evolve and generate debate as new data become available. Terrane nomenclature is embedded within the literature on porphyry copper deposits of Mexico. However, only in a few cases did terrane boundaries influence delineation of permissive tracts.

Recognition of a Permo-Triassic continental arc suggests that an east-dipping subduction zone formed along the western border of Pangea during this time in the tectonic evolution of what was to become Mexico (Torres and others, 1999). Traces of this arc are indicated by a series of granitoid rocks that extends from Chihuahua to Chiapas in eastern Mexico and mark a boundary between terranes to the east that were amalgamated to Pangea prior to the Permian arc formation and the Mesozoic terranes to the west (Guerrero, Cortez, Caborca, fig. 2). Fragments of pre-Laramide island arcs and continental arcs are preserved in Mexico and southwestern U.S. (fig. 5). No pre-Jurassic porphyry copper deposits have been recognized to date anywhere in Mexico.

The Neogene-to-Holocene TMVB (fig. 3) is a 1,000-km-long by 90- to 230-km-wide province where volcanism began in Middle to Late Miocene time, possibly as a consequence of slab detachment that propagated from the southern Gulf of California to central Mexico (Ferrari, 2004). Farther east, in central Mexico, the TMVB remained the locus of bimodal volcanism as the arc migrated away from the trench in a northeasterly direction (west to east arc progression). Magma compositions varied over time and include volcanic rocks with both subduction and intraplate geochemical affinities (Ferrari and others, 1999). The relative roles of mantle plumes and subduction in the genesis of the TMVB have been debated for many years. The TMVB is the locus of modern stratovolcanoes and small shield volcanoes (fig. 1), but no porphyry copper deposits or epithermal deposits are recognized. We postulate that no permissive tract is related to the TMVB, although pre-Miocene hydrothermal systems may be present under the TMVB.

South of the TMVB, volcanic arc rocks of Laramide age reappear, but the tectonic evolution there cannot be related to low-angle subduction because arc magmatism has remained proximal to the inferred paleotrench throughout the life of the arc, even as the locus of the magmatism has migrated southeast (Morán-Zentano and others, 2007). Extensional tectonics (NW-SE and E-W strike-slip faults) developed in southwestern Mexico by late Eocene time**,** but total extension is much less than in the north; as the present width of the arc is everywhere less than 200 km. Detachment and displacement of the Chortis block of present-day Guatemala and Honduras (1,100 km of strike-slip displacement), along with migration of a trench-trench-transform triple junction, is one of the explanations for the truncation of the continental margin, shear-zone development, and southeastward migration of magmatism in southwestern Mexico. Many conflicting interpretations for the pre-Tertiary location and path of the Chortis block of northern Central America, a key tectonic element in unraveling Caribbean plate tectonics, have been published. The Chortis block has been interpreted as being autochthonous, allocthonous and adjacent to Mexico, and lying outboard of Mexico in the Pacific (Rogers and others, 2007; Pindell and others, 2006; Silva-Roma, 2008). Differential uplift in the Miocene resulted in exposure of older arc plutons along the coast, including some areas that are too deeply exhumed to preserve porphyry copper deposits (that is, Xolopa terrane on fig. 2). In contrast, Cretaceous and Cenozoic volcanic, sedimentary, and volcano-sedimentary rocks are exposed farther inland.

The kinematics of the change in subducted slab geometry that shifted arc magmatism from the Sierra del Sur of southwestern Mexico (fig. 3) in Eocene-Oligocene time to the Trans-Mexico Volcanic Belt in Miocene time may be related to Chortis block tectonics, although the tectonics of this area are the subject of ongoing studies and debate and linked to interpretations of Caribbean tectonics (Morán-Zentano and others, 2007).

Miocene subduction of the Cocos plate formed the ancestral Chiapanecan arc that is represented by uplift of the Paleozoic Chiapas Massif and emplacement of an intrusive belt along the Pacific Coast (fig. 3). The modern subduction zone extends from Mexico to Panama in segments that represent variations in the angle and depth of the subducting plate that resulted in different arc orientations. Manea and Manea (2006) proposed that, between 25 and 17 Ma, a fairly continuous volcanic arc extended from Central Mexico through Chiapas and Guatemala. In middle Miocene time (~17 to 12 Ma), the Central Mexican volcanic belt moved inland as the subducting slab flattened; but in the southern part of the arc, the dip angle on the subducting plate was preserved, and the arc remained parallel to the trench to form the Central America Volcanic Arc (CAVA), a chain of volcanoes along the Pacific coast of Central America that extends from Guatemala (fig. 1) to Panama. Between 17 and 12 Ma, slab flattening continued to the southeast, a hot mantle wedge developed, and the CAVA segment migrated to the southeast. Between 9 and 3 Ma, the ancestral arc parallel to the coast in Mexico was abandoned. Inflow of a hot mantle wedge from northwest to southeast led to development of the modern Chiapanecan arc, a 150-km-long roughly NW-trending belt of volcanic domes that lies between the TMVB and the CAVA in a complex tectonic zone at the juncture of the North America, Cocos, and Caribbean plates. Although all of the Upper Miocene to recent volcanism in Mexico and Central America is dominantly andesitic and presumably related to Cocos plate subduction, the modern Chiapanecan arc is characterized by small volcanic domes and associated pyroclastic flows, whereas the TMVB and CAVA host large stratovolcanoes (Mora and others, 2007). The modern Chiapanecan arc lies 300-350 km from the Middle America trench (fig. 3) at an oblique angle to the trench. Significant porphyry copper prospects associated with the evolution of the modern arc include Ixhuatán (3 Ma) and Tolimán (5.8 Ma). Subduction and serpentinization of the Tehuantepec ridge (fig. 3) beneath the modern Chiapanecan arc may have released water into the overlying mantle wedge, thereby promoting melting. The unusual alkaline composition of the El Chichón volcano, situated in a zone of strike-slip faults at the northwestern end of the modern Chiapanecan arc, is geochemically and isotopically distinct from the calcalkaline rocks of the TMVB (García-Palomo and others, 2004).

Deposit Characteristics

Throughout most of recorded history, Mexico has been famous for its silver production from epithermal, polymetallic vein, and polymetallic replacement deposits. However, copper has been produced on a small scale for hundreds of years. The Cananea district was discovered in 1760, followed by mining development of skarns in the Cuenca Capote. La Colorada Veta first went into production in 1899. The Los Pilares breccia pipe in the Nacozari district went into production in the early 1900s, and the adjacent La Caridad porphyry was discovered in 1961. Extensive exploration and development of porphyry copper deposits began in the 1960s.

Summary studies of porphyry copper deposits in Mexico published during the last 30 years provided background and the initial framework for this assessment. References are noted here, along with information salient to this assessment. Sillitoe (1976) described characteristics of 29 examples of porphyry copper-type mineralization in a reconnaissance of the Mexican porphyry copper belt in which he noted that hydrothermal breccias are important components of the Mexican deposits and, in some cases, copper mineralization is apparently restricted to breccias. Clark and de la Fuente (1978) described the spatial relationship of Laramide porphyry copper deposits to the paleosubduction zone in northern Mexico. Damon and others (1983) reported K-Ar ages for 41 porphyry-deposit-related intrusions in Mexico and documented spatial trends in age and composition of associated igneous rocks. Their study demonstrated that 85 percent of the dated deposits were emplaced during eastward progression of the Laramide arc during the middle Cretaceous through Eocene. Barton and others (1995) described 103 porphyry copper and other intrusion-related districts in Mexico, noted the spatial and temporal association of porphyry copper deposits with Laramide intrusive centers in northern Mexico and with mid-Tertiary intrusions in southern Mexico, and discussed metallogenic patterns in terms of process controls, preservation, and lithospheric province. They also noted the association of porphyry copper deposits with breccia pipes as well as with numerous small copper skarns in the states of Sonora, Guerrero, and Michoacán.

In the Sierra Madre del Sur of southwestern Mexico, Solano-Rico (1995) recognized a poorly-mineralized coastal trend of coarse-grained Cretaceous intrusives and an inland belt of multiphase intrusions of probable Laramide age associated with mineralized porphyry systems. In addition to summarizing characteristics of 11 porphyry copper-related occurrences in the area, Solano-Rico (1995) noted that the known deposits tend to be small (27 to 74 Mt); structurally controlled along zones of weakness; formed along borders of intrusions, or as tubular bodies and breccias; and typically lack supergene enrichment. The porphyry-type occurrences in the Sierra Madre del Sur of southwestern Mexico are hosted by rocks of the Guerrero terrane, and few deposits have been thoroughly explored or developed (Miranda-Gasca, 2000). The Guerrero Gold Belt hosts Goldcorp's 7 M-oz Los-Filos-Bermejal-Nukay deposit that includes skarn, epithermal, and porphyry gold (?) styles of mineralization (Goldcorp, 2009). Riverside Resources Inc.'s Cerro Azul property in the Guerrero Gold Belt includes at least two porphyry copper targets (Riverside Resources Inc., 2009).

Staude and Barton (2001) presented a palinspastic reconstruction of northwestern Mexico that showed that removal of postmineralization extension narrows the presently exposed area of the Laramide arc by as much as 50 percent, thus bringing its width more in line with typical copper-bearing volcanic arcs elsewhere. They also suggested that there could be hundreds of Laramide-age porphyry deposits under the younger mid- to late-Tertiary volcanic cover of the Sierra Madre Occidental, basing this suggestion on analogy with the abundance of known deposits in southern Arizona and northern Sonora. Staude and Barton (2001) conclude that similar unexposed plutonic rocks and mineral deposits likely extend beneath the Sierra Madre Occidental, based on observations of porphyry systems exposed in windows and along stream channels eroded into the ignimbrites of the Sierra Madre Occidental.

In a synthesis of the regional geology and ore-deposit studies of the U.S.-Mexico transborder region, Titley and Zürcher (2008) suggest that the area is highly prospective for future ore discoveries. In particular, they noted that new Jurassic porphyry deposits could possibly be found in previously unidentified Jurassic rocks or under basin cover, and that future Laramide porphyry and skarn targets in both Arizona and Sonora could be concealed under cover of younger rocks or tectonically disrupted by Basin and Range faulting.

In a review of geological and metallogenetic characteristics of the porphyry copper deposits of Mexico, Valencia-Moreno and others (2007) tabulated the most recent age determinations and other characteristics for 61 porphyry and related deposits and considered the role of different basement domains on observed metal distributions and Laramide magma compositions. They noted that the Cu-Mo-W deposits in Sonora correlate with the northern and central parts of the Laramide porphyry belt where basement is composed of Proterozoic crystalline rocks of the North American craton and the overlying reduced sedimentary assemblage of the Triassic Barranca Group. Cu-Au and Au porphyry deposits are found farther south in the Laramide arc of Mexico where basement is composed of Mesozoic rocks of the Guerrero terrane.

Assessment Process

The assessment team for the porphyry assessment of Mexico was composed of geologists from the headquarters and regional offices of the SGM, the University of Sonora, the Geologic Institute of the Universidad Nacional Autónoma de México, the University of Arizona, and the USGS. Team expertise included regional geology, porphyry copper deposits, mineral deposits of Mexico, Mexico mineral exploration, GIS, and mineral-assessment methodology. The SGM provided 1:500,000 scale geologic map data for Mexico, mineral-deposits databases, and stream-sediment geochemical data to the assessment team. In addition, SGM hosted two assessment workshops in Hermosillo, Sonora. The team compiled existing data and reviewed the geology of Mexico and appropriate deposit models. The USGS team members prepared preliminary permissive tracts, presented their findings to the entire team, and completed the probabilistic mineral resource assessment with input from all team members.

Assessment Data

The assessment team utilized geologic maps at a variety of scales, mineral-occurrence databases, technical reports on prospects, topical data and maps, geological-mining monographs for Mexican states, mining company Websites, and published geologic literature. Geologic maps and other data are available online from the SGM at http://www.coremisgm.gob.mx/.

Geology

The SGM published a revised 1:2,000,000 scale geologic map of Mexico in 2007. Recent (post-2000) geologic maps of individual states or groups of states that contain both geology and minerals information (Carta geólogico-minera map series) are available at a scale of 1:500,000. Digital geology at a scale of 1:500,000 was provided for this study. In addition, 1:250,000-scale quadrangle maps were rectified and consulted during the assessment. The 2007 Geological Society of America Special Paper on the Geology of México (Alaniz-Álvarez and Nieto-Samaniego, 2007) was used as a principal source of information. Tectonostratigraphic terrane maps and studies were consulted as an aid to understanding the tectonic evolution and extent of magmatic arcs in Mexico (Campa and Coney, 1983; Coney and Campa, 1987; Sedlock and others, 1993; Keppie, 2004).

Derivative geologic map layers for the assessment.—The geologic map contains more than 600 map units. We created a derivative map for analysis by grouping map units of similar age and lithology, using information coded in the map-unit designations, in order to define the magmatic arcs that form the fundamental units for defining permissive tracts for porphyry copper deposits. The map units were grouped into 20 categories (table 1) that allowed us to use GIS tools to select intrusive and volcanic rocks by age. The three main lithologies associated with each map unit were defined in a GIS database so that the subsets of map units could be evaluated for those rock types likely or unlikely to be associated with porphyry copper deposits. This allowed us to distinguish, for example, volcanic units of a given age that are more likely to be associated with porphyry copper systems, such as andesite, from units that are less likely to be associated with porphyry copper systems, such as basalt or rhyolite.

Figure 6*A* shows the distribution of exposed igneous rocks in Mexico that formed the basis for delineation of permissive tracts. Note the west to east age progressions and the distribution of exposed intrusive (darker colors) versus extrusive rocks (lighter colors). Quaternary volcanics, shown in black (fig. 6*A*) were excluded from permissive tracts. In some areas, intrusions may be too deeply eroded to preserve any associated porphyry copper deposits.

Known Deposits, Significant Prospects, and Mineral Occurrences

The global porphyry copper database of Singer and others (2008) was used as the primary data source for known deposits (identified resources)[14] and for significant porphyry copper prospects in Mexico. We used spatial rules for defining deposits and grade-tonnage models reported in Singer and others (2008). Some locations were added or modified, and some grade-tonnage data were modified based on more recent information.

The SGM provided a digital database of more than 8,000 site records with information on site names, commodities present, and status, as well as a list of sites identified as porphyry copper deposits and prospects. The assessment team also accessed a digital compilation of geologic and mineral resource information prepared by a University of Arizona-U.S. Geological Survey-Industry Consortium project completed in 1999, which contained a database of approximately 7,000

[14]Resources whose location, grade, quality, and quantity are known or can be estimated from specific geologic evidence. Identified resources are the deposits included in the grade and tonnage models used in the assessment; additional deposits may be considered as identified resources if they are well enough characterized by deposit type, grade, and tonnage to meet reporting guidelines of the U.S. Securities and Exchange Commission or Committee for Mineral Reserves International Reporting Standards (2006).

site records provisionally classified by deposit type. Many of the sites were updated from USGS Mineral Resource Data System (MRDS) records by editing, checking locations, and in some cases, supplementing previous information with observations based on site visits. The Consortium GIS project also contained a radiometric-age database, igneous geochemistry, and other geologic and cultural data layers. Additional data sources included a database of Mexico mineral occurrences (Fitch, 2000), MRDS (U.S. Geological Survey, 2005), tables in summary publications on porphyry copper deposits in Mexico (Sillitoe, 1976; Damon and others, 1983; Barton and others, 1995; Solano-Rico, 1995; Valencia-Moreno and others, 2007; Camprubi, 2009), other global databases (Kirkham and Dunne, 2000a,b), age compilations (Iriondo and others, 2003; NAVDAT database, 2008) and Web searches.

The team compiled data from these various sources; examined the distribution of mines, prospects, and occurrences using a GIS; and made a qualitative evaluation of the relative importance of prospects as indicators of undiscovered porphyry copper deposits. Deposits and significant prospects are listed in table 2 and plotted in figures 1 and 6*B* (by age group). See permissive tract descriptions in the appendixes for locations, more detailed information, and references.

Related Deposit Types

In many cases, high-sulfidation epithermal systems overlie, or are spatially associated with porphyry copper deposits (Arribas and others, 1995). Although most of the epithermal deposits in Mexico are low to intermediate in sulfidation state, a few high-sulfidation epithermal deposits have been recognized in Sonora near the Cananea and La Caridad porphyry copper deposits, as well as in Chihuahua (Camprubí and Albinson, 2007; Valencia and others, 2008).

Copper skarns may or may not be associated with porphyry copper deposits. The occurrence of skarns depends on the presence of carbonate wallrock. In southwestern North America, porphyry copper stocks that intruded carbonate-rich sedimentary rocks typically developed skarns; these porphyry-related skarns tend to have higher hypogene copper grades than stocks intruded into noncarbonate rocks (Einaudi, 1982).

Exploration History

State-by-state monographs prepared by the Consejo de Recursos Minerales[15] document exploration concessions and activities. A Web-based unofficial directory of mining companies in Mexico was consulted for 1996-2005 exploration activities, as well as Mexican government compilations of exploration projects. Company Web sites and SEDAR[16] reports were examined for additional information on deposit types, exploration data, and resource estimates. In some cases, locations and resource estimates described in the global porphyry copper database of Singer and others (2008) were updated based on more recent data. In addition, assessment team members contributed personal knowledge of exploration activities and observations based on field trips and site visits.

[15]The Consejo de Recursos Minerales became the Servicio Geológico Mexicano in 1995.

[16]Canadian Securities Administrators System for Electronic Document Analysis and Retrieval.

Table 1. Generalized geologic units, porphyry copper assessment, Mexico.

[Based on 1:500,000 scale geologic maps of Mexico]

Units
Quaternary unconsolidated deposits
Quaternary sedimentary rocks
Quaternary volcanic rocks
Tertiary sedimentary rocks
Tertiary volcanic rocks
Tertiary intrusive rocks
Cretaceous intrusive rocks
Cretaceous volcanic rocks
Jurassic intrusive rocks
Jurassic volcanic rocks
Triassic intrusive rocks
Triassic volcanic rocks
Mesozoic metamorphic rocks
Mesozoic sedimentary rocks
Paleozoic intrusive rocks
Paleozoic metamorphic rocks
Paleozoic sedimentary rocks
Paleozoic volcanic rocks
Precambrian intrusive rocks
Precambrian metamorphic rocks

Geophysical Data

The North American magnetic anomaly map (North America Magnetic Anomaly Group, 2002), compiled from multiple aeromagnetic datasets with variable resolution, was used to aid interpretations of possible pluton locations. A reduction-to-pole transformation, a standard geophysical technique used to center anomalies over their sources, was applied to the portion of the North American magnetic anomaly map that overlies Mexico (Baranov and Naudy, 1964; Blakely, 1995). The 1:10,000,000 scale magnetic anomaly map was used in conjunction with the digital geology to compare magnetic highs with mapped intrusions and look for possible subsurface expressions of extensions of mapped intrusions under cover.

Aeromagnetic anomalies reflect spatial variations of total magnetization, the vector sum of induced and remanent magnetizations. Induced magnetization, an instantaneous property, is proportional to magnetic susceptibility and has the same direction as the present-day ambient field. Remanent magnetization is a long-lived property, is related to a rock's formation and geologic history, and may be directed in a different direction than the induced magnetization. Large-magnitude components of remanent magnetization are common in volcanic rocks, but rare in the silicic- and intermediate-composition plutons characteristic of magmatic arcs (Clark, 1999).

Porphyry copper deposits are normally associated with subduction-related plutons. These plutons typically can be classified as I-type (Chappell and White, 1974), or magnetite-series (Ishihara, 1977) in composition. This association is important because these plutons are frequently important sources of positive aeromagnetic anomalies (Maniar and Piccoli, 1989; Clark, 1999). Therefore, aeromagnetic surveys may be used to search for plutons that may be related to porphyry copper deposits (Clark and others, 1992; Gunn and Dentith, 1997).

Aeromagnetic anomalies were interpreted to reflect possible shallow (<1 km) plutons when they had certain characteristics. First, plutons that are parts of magmatic arcs should produce aeromagnetic highs (for example, positive anomalies), since they generally display little magnetic remanence. Second, the aeromagnetic highs should in a rough sense be round or elliptical in extent, reflecting the common shapes of plutons in map view. Finally, the magnetic highs should have relatively short wavelengths. This criterion is related to the fact that deeper magnetic sources produce broader anomalies

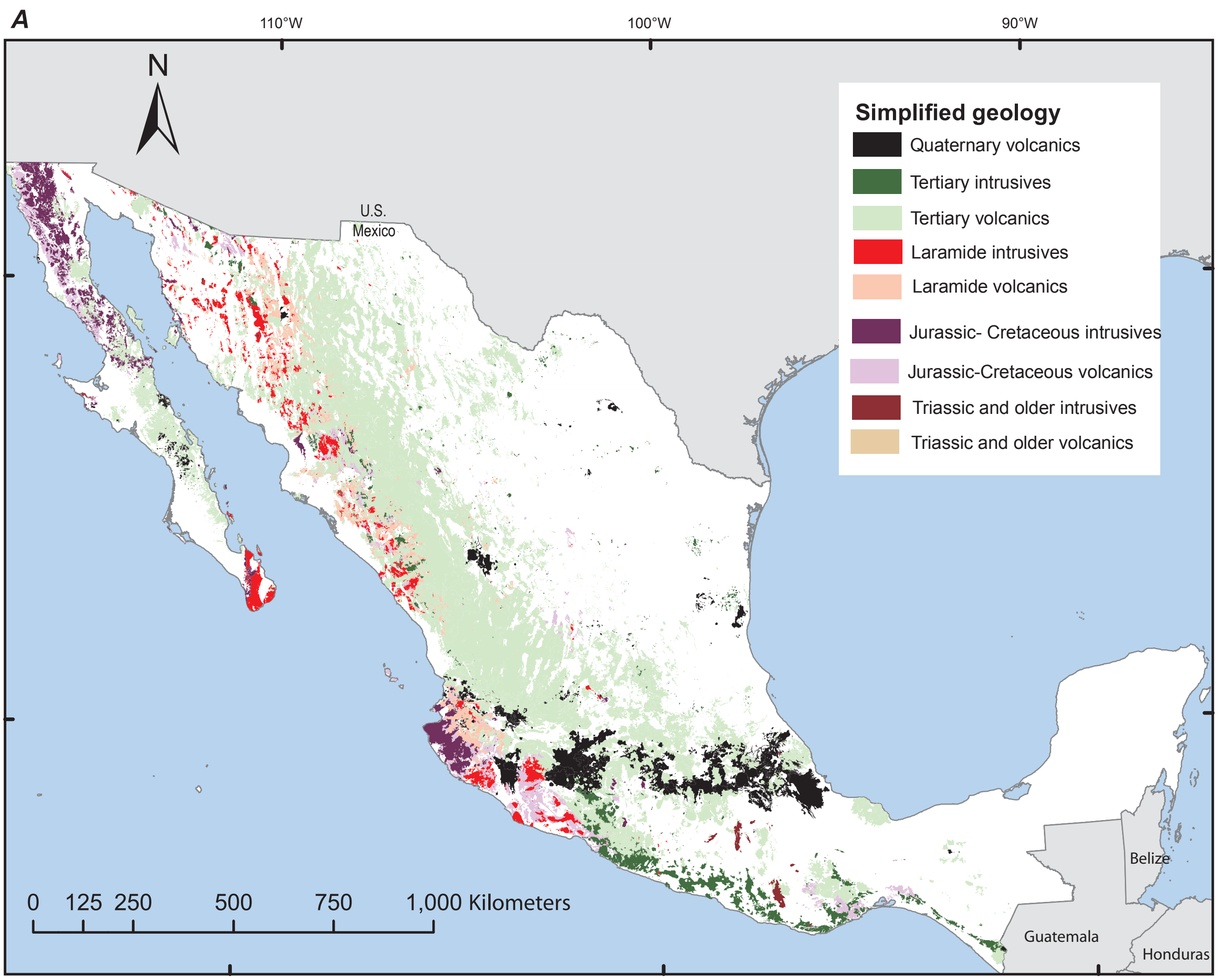


Figure 6. Age distributions. *A*, Simplified geologic map of Mexico showing igneous rocks by age group. *B*, Porphyry copper deposits and significant prospects plotted by age group (data as in figure 1). Numbers shown are radiometric ages of individual porphyry copper deposits.

than do shallow sources. Together, these characteristics were used to identify possible shallow plutons for comparison with surface geology. The analysis of the distribution of short-wavelength magnetic highs was done after the permissive tracts were delineated on the basis of geology. The analysis identified ~1,500 anomalies that could reflect shallow sources. Of these, 18 percent of the magnetic anomalies fall within our geology-based tracts, 46 percent represent areas that are excluded from our permissive tracts based on geology (for example, wrong rock composition, depth of erosion, known thickness of cover), and the rest are unaccounted for. These unaccounted for anomalies may represent shallow intrusions associated with porphyry copper deposits. However, we did not extend tract boundaries to include these for several reasons: (1) no geologic rationale for extending the tract; (2) lack of correlation between magnetic anomalies and exposed igneous rocks that do define the tracts, with the exception of western Baja California; (3) uncertainties about depth; (4) uncertainties about the nature of the geologic source of the anomaly; and (5) uncertainties about age represented by the anomaly, especially in areas of tract overlap. In addition, the volcanic rocks tend to be associated with "noisy" areas of short-wavelength features. Magnetite-destructive alteration associated with a porphyry copper deposit could negate the significance of a magnetic-high anomaly. The scale and flight spacing of the data also preclude detailed interpretations.

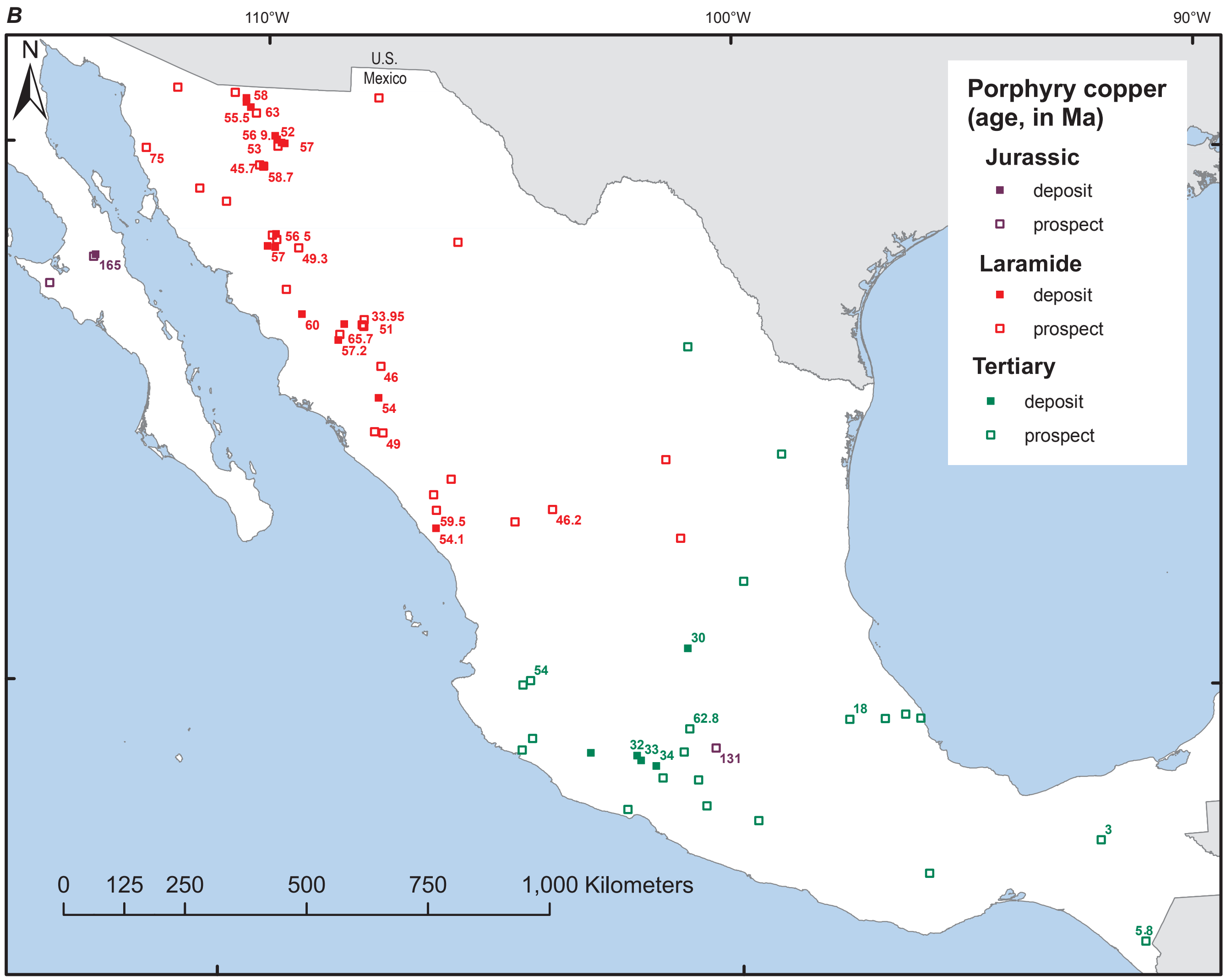


Figure 6.—Continued

Stream-Sediment Geochemical Data

As an additional tool in the mineral-resource assessment process, we used the national-scale stream-sediment database of the SGM to identify geochemically anomalous areas that may contain porphyry copper deposits in Mexico. The SGM database contains nearly 47 thousand sediment samples collected and analyzed by 1 by 2 degree quadrangle. Most quadrangles contain 400 to 600 sediment sample sites. The data were processed by the USGS to produce a stream-sediment geochemistry map for use in the porphyry copper assessment.

Classified Stream-Sediment Geochemistry Map.—To remove analytical stream-sediment data drift generated by different laboratory analysis and methods, the geochemical data were normalized on a quadrangle basis. A log-centering approach was used to adjust the mean value for each element for each quadrangle to be similar to the mean value for the entire database. Raster data layers for each element were created by inverse distance-weighting interpolation of the leveled geochemistry sample site data using a 2-kilometer cell size, similar in scale to typical porphyry deposit sizes.

The Cu, Pb, Zn, Mo, W, As, and Au sediment data layers were evaluated relative to locations of known porphyry copper deposits in Mexico. Using the ArcSDM extension for ArcMap (Sawatzky and others, 2004), Weights of Evidence (Bonham-Carter and others, 1989; Bonham-Carter, 1994) parameters for the geochemical datasets were calculated for each element to define threshold concentrations outlining target areas containing the porphyry deposits. The effectiveness of the geochemical data in targeting porphyry copper deposits was evaluated from relations between the overall rates of targeted deposits against the areas of the identified targets (deposit density). The identified threshold concentrations (T2 and/or T1) for each geochemical element raster are listed in table 3. Map areas where the sediment geochemical values for each element listed in table 3 exceed the T2 and/or T1 thresholds are the areas where the known porphyry copper deposits and prospects occur with the highest density.

Logistic regression (Menard, 2002; Hosmer and Lemeshow, 2000) was used to combine data from all of the classified single-element maps in an analysis to measure the association between the classified geochemical raster maps and porphyry deposits. Copper and molybdenum were found to have the strongest spatial correspondence to porphyry copper deposits, followed by gold and arsenic. Lead, zinc, and tungsten were found to have no significant relationship with porphyry copper deposits in the multiple-element evaluation results**;** these elements have many natural or anthropogenic sources throughout Mexico that are unrelated to porphyry deposits. The results of the logistic-regression model using the Cu, Mo, Au, and As geochemical data were classified into high, medium, and low classes (fig. 7). Porphyry copper deposit occurrence is approximately 100 times more likely to occur in the high-density category of the geochemistry model than in the low-density category. Although the model results probably reflect some degree of influence from copper, molybdenum, and other metals released into the environment from earlier porphyry copper mining operations, the sediment sampling in small drainage areas was designed to avoid obviously contaminated sites, and the geochemical classification thresholds were set at relatively low levels to minimize the influence of contaminated sites in the model. In the porphyry copper tract areas defined independently for Mexico, the classified geochemistry map identifies 56 percent of deposits and significant prospects in 3 percent of the area (high class); 80 percent of deposits and significant prospects in 25 percent of the area (high and medium classes), and highlights other areas that may contain undiscovered deposits.

Alteration

We also used the rock-alteration types shown on the 1:250,000 scale 1 by 2 degree quadrangle SGM geologica-minera map series as a guide for assessment. The geologic maps were rectified, and the mapped rock-alteration areas were digitized and classified by alteration type. The mapped rock-alteration categories shown on these maps include combinations of the following types: silicification (silicification and jasperite subtypes), oxidation (oxidation and hematite subtypes), sulfidation (sulfidic and pyritic subtypes), carbonatization (carbonate, dolomite, and aragonite subtypes), potassic alteration, granitization, argillic alteration (argillic and kaolinite subtypes), propylitic alteration, and various distinctive alteration minerals, such as alunite, adularia, biotite, chlorite, sericite, serpentine, epidote, tourmaline, and zeolites.

The rock-alteration areas were evaluated relative to the locations of porphyry copper deposits and significant prospects, considering both alteration types and proximity of these deposits to areas of rock alteration. Using the ArcSDM extension for ArcMap (Sawatzky and others, 2004), Weights of Evidence parameters for the rock alteration areas and a series of 2-km buffers around the mapped rock-alteration areas were calculated. The effectiveness of proximity to rock-alteration areas in targeting porphyry copper deposits was evaluated from relations between the overall rates of targeted deposits against the areas of the identified targets (deposit density) (fig. 8*A*,*B*). Porphyry copper deposits occur with the highest density in the mapped rock alteration areas (fig. 8*A*, class 3), and the observed density of deposits decreases with increasing distance from the mapped alteration areas (fig. 8*A*). The 2-km-buffer distance interval categories shown in figure 8*A* have been grouped into four general classes that show a logarithmic trend with deposit density (fig. 8*B*). Porphyry copper deposits and significant prospects were generally within and near the mapped argillic-, propylitic-, pyritic-, and alunite-types of alteration. Buffer distances of 6 and 10 km around these rock-alteration types were good indicators of where porphyry copper deposits are likely to occur (fig. 8*A*).

In the porphyry copper tracts defined for Mexico, the classified rock-alteration map (fig. 8*C*) targets 25 percent of deposits and significant porphyry copper prospects in the mapped rock-alteration areas (occupying less than 0.5 percent of the tract areas) and 54 percent of deposits and significant prospects in 7 percent of the tract areas. Porphyry copper deposits are more than 100 times more likely to occur in the identified rock-alteration categories (fig. 8*B*, class 3) than outside of these areas in the permissive tracts (fig. 8*B*, class 0).

Permissive Tracts in Mexico

The assessment team delineated 12 permissive tracts, grouped into three periods of magmatic-arc activity that gave rise to porphyry copper deposits in Mexico: Jurassic-Early Cretaceous, Laramide (90 to 34 Ma), and Tertiary (<34 Ma). Tract MX-T3 overlaps the Laramide and Tertiary periods of magmatic arc activity with igneous intrusions ranging in age from Paleocene to Miocene. Table 4 lists the tract identifier codes, tract names, a brief description of the fundamental unit for tract delineation, tract area, and amount of younger cover. Tracts are shown by age group in figures 9*A-C*. Tracts MX-J2 and MX-T4 are shown in figure 9 for reference, but they are not included in the probabilistic assessment because major portions of these tracts lie beyond the Mexican border. The geology that defines some other tracts extends across country borders, but the tracts lie mainly in Mexico. The Mexican portion of MX-J2 is described in the appendix. MX-T4 represents only the northernmost part of the tract; MX-T4 and cross-border extensions are considered in other regional reports (in press,).

Magmatic-arc activity in Mexico includes both island arcs and continental arcs that span a wide range in space and time. Unlike the narrow, well-exposed, relatively continuous magmatic arcs of the Andes of South America, the numbers, extent, and ages of magmatic arcs in parts of Mexico are less well-defined, more dismembered, migrated through time (Clark and others, 1982), and probably formed as a result of long-lived or episodic subduction. Some arc fragments were accreted to the mainland and form parts of composite tectonostratgraphic terranes. An arc affinity for some of the younger igneous complexes that are permissive for porphyry systems in eastern Mexico is not well-established.

Tract Delineation

The first step in delineating permissive tracts is to identify and select the geologic map units that define the intrusive- and volcanic-rock components of a magmatic arc, grouped by the temporal limits that define the duration of arc magmatism for individual arc features. Detailed age and lithologic information from the geologic map-unit attributes are crucial to this step. In order to delineate the boundaries of the permissive tract, we include all areas that might contain intrusive-rock systems of the appropriate age and composition to host porphyry copper deposits and include an area surrounding these units to accommodate unexposed porphyry copper deposits up to a depth of 1 km from the Earth's surface. Geologic evidence for porphyry-copper intrusive-rock systems includes (1) mapped intrusive rocks of suitable chemistry, age, and tectonic setting to host porphyry copper deposits (Berger and others, 2008) and (2) related volcanic-rock domains that may contain or conceal the intrusive rocks in category 1. The mapped intrusive rocks considered to be related to porphyry copper deposits include granite, quartz monzonite, monzonite, granodiorite, tonalite, and diorite for the general porphyry copper deposit model, and syenite in addition to the preceding rock types for the Cu-Au porphyry copper deposit subtype. Isolated bodies of gabbro and peraluminous granites are not included because they are unlikely to be related to porphyry copper deposits. The mapped volcanic rocks considered to be associated with intrusive systems related to porphyry copper deposits include pre-Quaternary andesite, dacite, rhyodacite, trachyte, latite, and rhyolite associated with other intermediate volcanics. Thick rhyolitic ignimbrite deposits were not included as these high-silica volcanics are unlikely to be from igneous sources related to porphyry copper deposits, and their thickness in the Sierra Madre Occidental (fig. 3) often exceeds 1 km. In addition, rhyolite, rhyolite tuffs, and basalts associated with bimodal basalt-rhyolite volcanic fields were excluded because they are unlikely to be related to porphyry copper deposits.

Mineral deposits and prospects of types that are related to porphyry copper intrusive-rock systems that are external to, but nearby, these permissive igneous-rock units may indicate partially to completely concealed intrusions, uncertainty in deposit and map- unit contact locations, or misidentification of rock units during geologic mapping due to pervasive rock alteration or other features associated with mineralization. Because we are assessing for undiscovered deposits buried as deeply as 1 km, extending the boundaries of the permissive areas defined by the selected geologic map units allows for inclusion of permissive rocks that are covered by younger materials or have older rocks structurally superimposed. Because the thickness of cover is not well defined over much of the magmatic-arc areas in Mexico, we used a GIS to create buffers around the permissive map-unit polygons. We use a 10-km buffer around permissive intrusive units and a 2-km buffer for permissive volcanic units, reasoning that plutons have irregular subsurface contacts and may extend far beyond their surface outcrops at 1 km depth. We consider these buffer distances to be reasonable, based on the size of porphyry copper mineral systems[17] and allowing for unmapped or shallow, unexposed porphyry stocks. The volcanic map units (generally excluding pyroclastic rocks and bimodal basalt-rhyolite fields) are defined with a narrower 2-km buffer. The 2-km buffer distance is used because any included and concealed intrusions within those map units are likely to be much smaller, and there is some uncertainty in the actual location of contacts at a 1:500,000 map scale. These buffers were generated in a GIS, but the final tract boundaries were hand-digitized using the buffers as a guide. This allowed us to make subjective decisions about including areas that were spatially coherent (within approximately 5 km), but failed to close using our strict digital-proximity criteria. Some tracts

[17]Singer and others (2008) showed that ore areas for porphyry copper deposits range from <1 to 11 km^2 and associated altered areas range from <1 to >30 km^2 , based on a global database and assuming an elliptical plan view.

Table 2. Deposits and significant porphyry copper prospects, porphyry copper assessment, Mexico.

[Listed in alphabetical order. Identified resources are listed for known deposits; prospects that are primarily skarn are listed in italics; grade and tonnages in parentheses are considered prospects for this assessment, see tract descriptions for references and additional information; Ma, mega-annum; Mt, million metric tons; %, percent; g/t, grams per metric ton; n.d., no data]

Name	Tract	State	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained copper (Mt)
Arco Sur	MX-J1	Baja South	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Aurora	MX-L2	Sonora	~52	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Bahuerachi	MX-L2	Chihuahua	65.7	605	0.39	0.008	0.032	3.91	24
Batacosa	MX-L1	Sonora	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Bismark	MX-L3	Chihuahua	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Caballo Blanco	MX-T1	Veracruz	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cananea	MX-L2	Sonora	55.5	7,140	0.42	0.01	0.012	0.6	300
Carol	MX-L1	Sonora	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cerro Azul	MX-T3	Guererro	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cerro Chileno	MX-L2	Sinaloa	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cerro Colorado	MX-L2	Chihuahua	46	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cerro Colorado (Batopilas)	MX-L2	Chihuahua	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cerro del Gallo (San Antón)[1]	MX-T2	Guanajuato	30	(627)	(0.11)	n.d.	(0.23)	(10.0)	(7)
Charcas (San Sebastian)	MX-L3	San Luis Potosi	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cobre Grande	MX-T3	Oaxaca	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

[1]Total weighted average resource estimate based on 350 drill holes; open in 3 directions (Stewart, 2008).

Table 2. Deposits and significant porphyry copper prospects, porphyry copper assessment, Mexico.—Continued

Name	Tract	State	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained copper (Mt)
Cobre Rico	MX-L2	Sonora	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Concepcion Del Oro	MX-L3	Zacatecas	~39	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Corral De Piedra - SGM	MX-L3	Durango	36?	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Corralitos (Batopilas)	MX-L2	Chihuahua	45	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cuatro Hermanos	MX-L2	Sonora	56.5	764	0.18	0.02	n.d.-	1.2	14
Cumobabi	MX-L2	Sonora	58.7	67	0.27	0.10	n.d.	n.d.	2
Dos Naciones	MX-L2	Sonora	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Dos Amigos	MX-T1	Coahuila	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
El Alacran	MX-L2	Sonora	60.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
El Arco	MX-J1	Baja South	165	1016	0.52	n.d.-	0.12	n.d.	53
El Batamote	MX-L2	Sonora	57	4.4	0.36	n.d.	n.d.	n.d.	0.2
El Datilon	MX-J5	Baja South	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Table 2. Deposits and significant porphyry copper prospects, porphyry copper assessment, Mexico.—Continued

Name	Tract	State	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained copper (Mt)
El Pilar	MX-L2	Sonora	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
El Pulpo (Jocquistes)	MX-L2	Sinaloa	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Gallo De Oro	MX-T1	Veracruz	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Inguarán	MX-T3	Michoacán	34	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Ixhuatán (Santa Fe)	MX-T4	Chiapas	3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
La Azulita	MX-L2	Sinaloa	59.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
La Balsa	MX-T3	Michoacán	n.d.-	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
La Bella Esperanza	MX-L2	Sonora	56.9	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
La Caridad	MX-L2	Sonora	53.7	1,800	0.45	0.02	n.d.	n.d.	81.4
La Chereca	MX-T3	Colima	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
La Chora	MX-T1	San Luis Potosi	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
La Desencantada	MX-L2	Sinaloa	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Table 2. Deposits and significant porphyry copper prospects, porphyry copper assessment, Mexico.—Continued

Name	Tract	State	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained copper (Mt)
La Florida	MX-L2	Sonora	52	135	0.33	n.d.	n.d.	n.d.	4.5
La Fortuna	MX-L1	Sonora	75	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
La Sierrita/La Cobriza	MX-L1	Sonora	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
La Tortuga Property	MX-T3	Jalisco	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
La Verde	MX-T3	Michoacán	32	110	0.70		0.088	2.5	7.7
Las Higueras	MX-L2	Sinaloa	49	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Los Cimientos	MX-T3	Michoacán	62.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Los Humos	MX-L1	Sonora	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Los Verdes[2]	MX-L2	Sonora	49.3	(17.5)	(0.34)	(0.10)	n.d.	n.d.	n.d.
Luz del Cobre (San Antonio de la Huerta)	MX-L2	Sonora	n.d.	14.7	0.74	n.d.	n.d.	n.d.	1.1
Magistral	MX-T3	Jalisco	54	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

[2]Weighted average of measured, indicated and inferred resources for oxide and non oxide mineralization based on 171 drillholes; no reserves; for Cu-Mo breccia parts of system (Virgin Metals, Inc., 2008).

Table 2. Deposits and significant porphyry copper prospects, porphyry copper assessment, Mexico.—Continued

Name	Tract	State	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained copper (Mt)
Malpica	MX-L2	Sinaloa	54.1	29	0.51	n.d.	0.400	n.d.	1.5
Mariquita	MX-L2	Sonora	63	100	0.48	n.d.	n.d.	n.d.	4.8
Milpillas	MX-L2	Sonora	58	230	0.85	n.d.	n.d.	n.d.	19.6
Nukay	MX-T3	Guerrero	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Picacho	MX-L1	Sonora	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Piedra Lipe	MX-T3	Guerrero	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Piedras Verdes	MX-L1	Sonora	60	288	0.37	n.d.	n.d.	n.d.	1.0
Pilares	MX-L2	Sonora	53	147	1.04	n.d.	n.d.	n.d.	15.3
Rodeo	MX-T3	Michoacán	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
San Antonio	MX-T2	Chihuahua	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
San Antonio- SGM prospect	MX-T3	Michoacán	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
San Carlos	MX-T1	Tamaulipas	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Table 2. Deposits and significant porphyry copper prospects, porphyry copper assessment, Mexico.—Continued

Name	Tract	State	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained copper (Mt)
San Diego	MX-T3	Michoacán	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
San Isidro	MX-T3	Michoacán	33	81.0	0.35	n.d.	n.d.	n.d.	2.8
San Javier project	MX-L2	Sonora	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
San Martin	MX-L3	Zacatecas	46.2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Santo Tomas	MX-L2	Sinaloa	57.2	274	0.50	n.d.	0.050	n.d.	13.6
Satevo (Batopilas)	MX-L2	Chihuahua	51	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Suaqui Verde	MX-L2	Sonora	57	87	0.43	n.d.	n.d.	n.d.	3.7
Tahonas (Corralitos Batopilas)	MX-L2	Chihuahua	45	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Tameapa	MX-L2	Sinaloa	54	50	0.40	n.d.	n.d.	n.d.	2.0
Tango	MX-L2	Sinaola	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Tatatila	MX-T2	Veracruz	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Tepal	MX-T3	Michoacán	n.d.	80	0.23	n.d.	0.448	n.d.	1.9

Table 2. Deposits and significant porphyry copper prospects, porphyry copper assessment, Mexico.—Continued

Name	Tract	State	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained copper (Mt)
Tiámaro	MX-J4	Michoacán	131	500	0.60	n.d.	0.100	n.d.	30.0
Tolimán	MX-T4	Chiapas	5.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Tuligtic	MX-T2	Puebla	18	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Washington	MX-L2	Sonora	45.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

Table 3. Stream-sediment chemistry thresholds, porphyry copper assessment, Mexico.

[mg/Kg, millgrams per kilogram; µg/Kg, micrograms per kilogram; <, less than]

Feature	Units	Minimum	T1	T2	Maximum
Cu_raster	mg/Kg	1	25	40	3,279
Pb_raster	mg/Kg	2	25	40	31,268
Au_raster	µg/Kg	<0.5	8	14	3,100
As_raster	mg/Kg	<0.5	9	14	2,873
Mo_raster	mg/Kg	<0.5	4		867
W_raster	mg/Kg	2	8		737

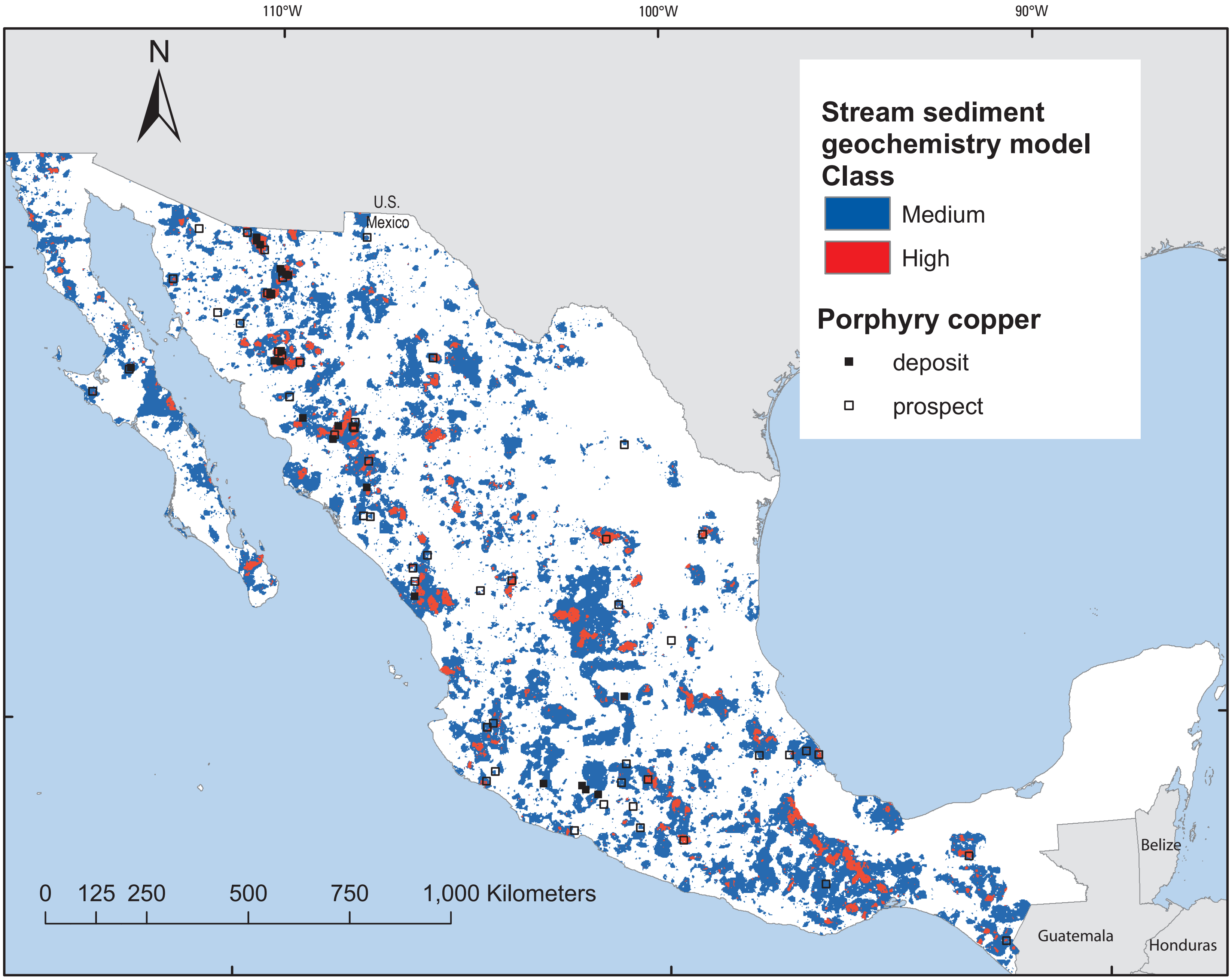


Figure 7. Stream sediment geochemistry model. See text for details and development of classes.

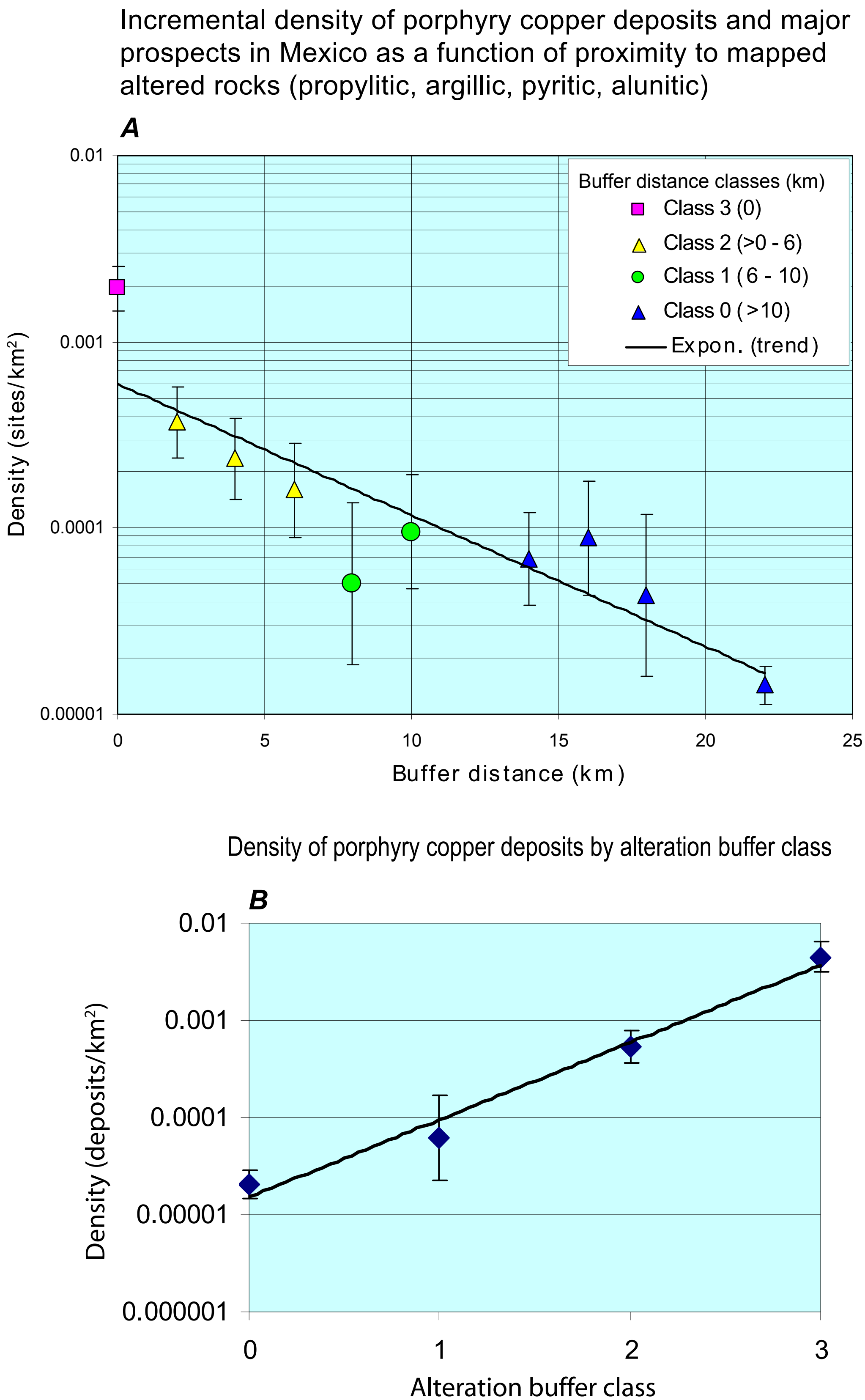


Figure 8. Alteration model. *A*, Observed porphyry copper mineralization density as a function of proximity to mapped alteration. See text for details. *B*, Density of porphyry copper deposit by alteration buffer class. See text for details. *C*, Alteration model map. See text for details.

C

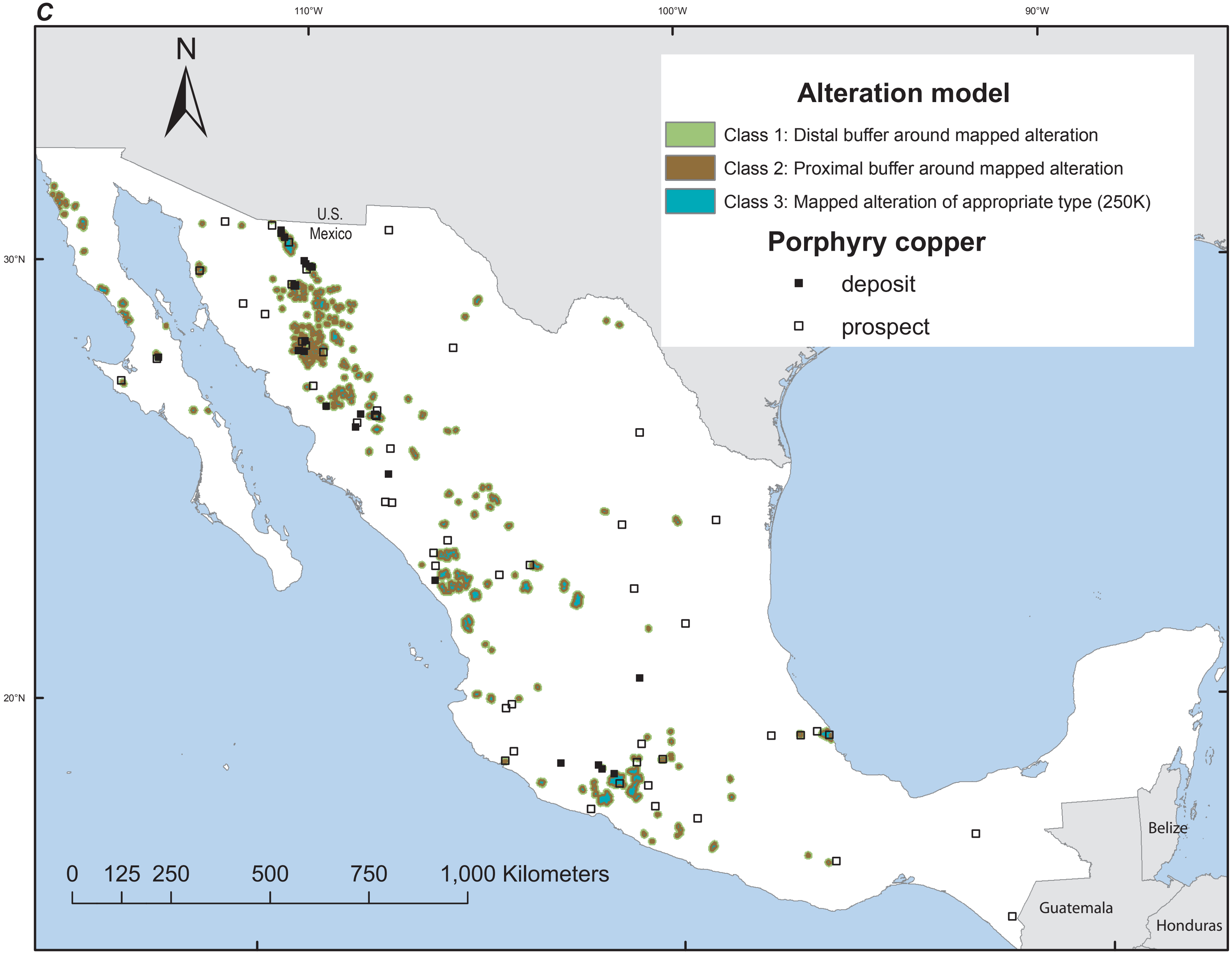


Figure 8. Alteration model.—Continued

Table 4. Permissive tracts, porphyry copper assessment, Mexico.

[**, Mexican part of the tract is shown on figure 9 for reference only; km², square kilometers]

Tract ID	Tract name	Coded ID	Tract area (km²)	Cover (percent)	Fundamental unit for the tract
MX-J1	Baja California	003pCu3001	30,260	40	Jurassic-Early Cretaceous island arc(s) of western Baja California, including the western part of the Cretaceous Peninsular Ranges batholith and associated volcanic rocks
MX-J2	Sonoran Desert	003pCu3003	19,002	77	Triassic-Jurassic continental magmatic arc in northern Mexico and Arizona
MX-J3	Guanajuato	003pCu3004	26,080	81	Jurassic Nazas magmatic arc rocks in central Mexico
MX-J4	Balsas	003pCu3005	11,810	29	Jurassic-Early Cretaceous Teloloapan volcanic arc in the Guerrero terrane of southwestern Mexico
MX-J5	Coastal Baja California	003pCu3002	2,910	47	Jurassic-Upper Cretaceous magmatic arc rocks (San Andres-Cedros Complex) along the Pacific coast of Baja California Sur, Mexico
MX-L1	Western Mexican Basin and Range	003pCu3006	74,140	76	Late Cretaceous to middle Eocene island arc(s)-related calcalkaline magmatic rocks lying along the western margin of Mexico
MX-L2	Sierra Madre Occidental (W)	003pCu3007	115,110	57	Late Cretaceous to middle Eocene (Laramide) magmatic arc rocks in the Sierra Madre Occidental of northern Mexico
MX-L3	Laramide Central Plateau	003pCu3008	58,720	65	Belt of Late Cretaceous to middle Eocene (Laramide) magmatic arc rocks in the eastern part of the Sierra Madre Occidental, eastern Mexican Basin and Range, and the Mesa Central of northern Mexico
MX-T1	Eastern Alkaline Province	003pCu3010	56,839	24	Tertiary back-arc and extension-related alkaline magmatic rocks in eastern Mexico
MX-T2	Tertiary Central Plateau	003pCu3009	183,520	66	Belt of Middle Tertiary (Oligocene to Miocene) granitic to intermediate intrusive rocks and volcanics associated with the post-Laramide stage of magmatism in northern Mexico
MX-T3	SW Mexico	003pCu3011	156,650	19	Paleocene to Miocene continental magmatic arc rocks along the Pacific coast of Mexico, from the state of Nayarit southeast to Oaxaca
MX-T4	Chiapas Arc	003pCu3012	17,649**	27**	Miocene and younger volcanic arcs of the Chiapas area (Miocene Sierra Madre arc-modern Chiapanecan volcanic arc-Central American volcanic arc)

were further refined by using the aeromagnetic map (North American Magnetic Anomaly Group, 2002) to include some adjacent areas (within approximately 5 km) that appear to have a shallow magnetic source, where the anomaly appears to be continuous with mapped igneous rock used to define the tract.

In addition, any map units or areas that are deemed as nonpermissive for porphyry copper deposits are removed. For example, areas that are deeply eroded (eroded below the level where porphyry copper deposits are formed, about 3 to 7 km) were removed. Ignimbrites were removed where their thicknesses is likely greater than 1 km. In other cases, rocks may spatially and temporally coincide with permissive rocks, but have origins not directly related to the arc. For example, peraluminous granites that formed primarily by melting of continental crust and that are related to crustal extension and metamorphism are not included. Bimodal basalt-rhyolite fields and high-silica rhyolite tuff deposits were excluded from the permissive volcanic rocks.

Stream-sediment geochemistry and alteration are not used as criteria for tract delineation. These data are discussed in the individual tract descriptions and are used in evaluating the likelihood of occurrence of undiscovered deposits. In general, the areas identified by these methods were already included in the permissive tracts derived from the geology-based methods described above.

All of our porphyry copper deposits and significant prospects fell within our permissive-tract boundaries. In situations when this does not occur, the geologic source information would be examined for quality and appropriateness of scale as additional geologic features or criteria may be needed to define appropriate permissive tract boundaries. Areas where there is no evidence for magmatic-arc rocks that could host porphyry copper and related deposits in the near surface environment were excluded from permissive tracts.

Some tracts, such as MX-J1, are comprised of only a few discrete polygons, whereas others, such as MX-L3 and MX-T2, are comprised of more than 100 discrete polygons. The present distribution of map units that define the arcs reflects post-arc tectonics (extension), differential uplift across Mexico, and deposition of younger cover.

Cover

The permissive-tract boundaries may extend beyond map-unit boundaries. We determined the percentage of each final tract area that is covered by younger rocks. Each map unit was coded with respect to its role as a cover rock for a particular tract and the results of this exercise were analyzed using GIS tools to determine the percentage of each tract that is covered (table 4).

Jurassic-Early Cretaceous Tracts (fig. 9*A*)

The Jurassic-Early Cretaceous tracts represent: (1) two discrete oceanic arcs in Baja California and Coastal Baja California (MX-J1 and MX-J5); (2) parts of the tectonically disrupted Nazas continental volcanic arc in the Sonoran Desert and Guanajuato tracts (MX-J2, MX-J3); and (3) rocks associated with the Teloloapan volcanic arc in the Balsas tract (MX-J4) preserved in the Guerrero terrane in south-central Mexico.

Tract MX-J1 outlines the well-defined western part of the Peninsular Ranges batholith. The only known porphyry copper deposit in MX-J1 is the 165 Ma El Arco (Valencia and others, 2006). The extent of the Santa Ana/Alisitos terrane (fig. 2) in Baja California was used in delineation of tract MX-J1, in addition to mapped units and geophysics and other data that define the boundary between the western, and more deeply eroded eastern parts of the Peninsular Ranges batholith. Although the area of MX-J1 has been explored for porphyry copper deposits in the past, most of the recent interest is in IOCG deposits.

MX-J2 is the southern extension of the arc that includes the Bisbee deposit in southern Arizona, as well as other Jurassic porphyry copper deposits farther north. Tract MX-J3 may represent a segment of MX-J2 that was displaced to the southeast along the Mojave-Sonora megashear (fig. 5), or other structures. No deposits have been discovered within the segments of the Nazas arc in Mexico. Bartolini and others (2003) described the Nazas arc as a belt of Late Triassic to Middle Jurassic volcanic, sedimentary, and granitic plutonic rocks that extends from the southwestern United States to Guatemala. The arc is expressed as a discontinuous, southeast -trending belt (fig. 5) through the states of Chihuahua, Coahuila, Durango, Zacatecas, and San Luis Potosí. Most of the arc is deeply buried by 5 to 7 km of sedimentary rocks, and isotopic intrusion ages commonly were reset by the Laramide orogeny (Bartolini and others, 2003). Prior to recent radiometric-age studies, both Tiámaro and El Arco were thought to be younger. As more age data become available, especially studies that combine zircon and Re-Os dating of ore minerals and Ar/Ar studies that document cooling history, Jurassic-Early Cretaceous arc rocks in Mexico may prove to be more widespread and more prospective for porphyry copper deposits than previously thought.

Within tract MX-J4 in the Guerrero terrane of mainland Mexico, the only known porphyry copper is the 131 Ma Tiámaro deposit, which previously was assumed to be Eocene-Oligocene (Garza-González and others, 2006; Miranda-Gasca, 2000). MX-J5, the smallest tract, outlines island-arc rocks that intruded through Triassic ophiolite basement in the Vizcaino terrane (fig. 2), west of the Peninsular Ranges batholith.

Camprubi (2009) included San Juan Mazatlán, Oaxaca, as a porphyry copper prospect in his compilation of dated mineral deposits in Mexico. He based this on Damon and others' (1983) reported K-Ar ages of ~191 Ma for biotite from quartz monzonite porphyry and diorite stocks with disseminated and fissure forms of mineralization. The wallrocks are redbeds of the Triassic Todos Santos Formation. We did not include this area in any tract because of limited information about the occurrence and our assumption that the area is likely to be too deeply eroded to preserve a deposit.

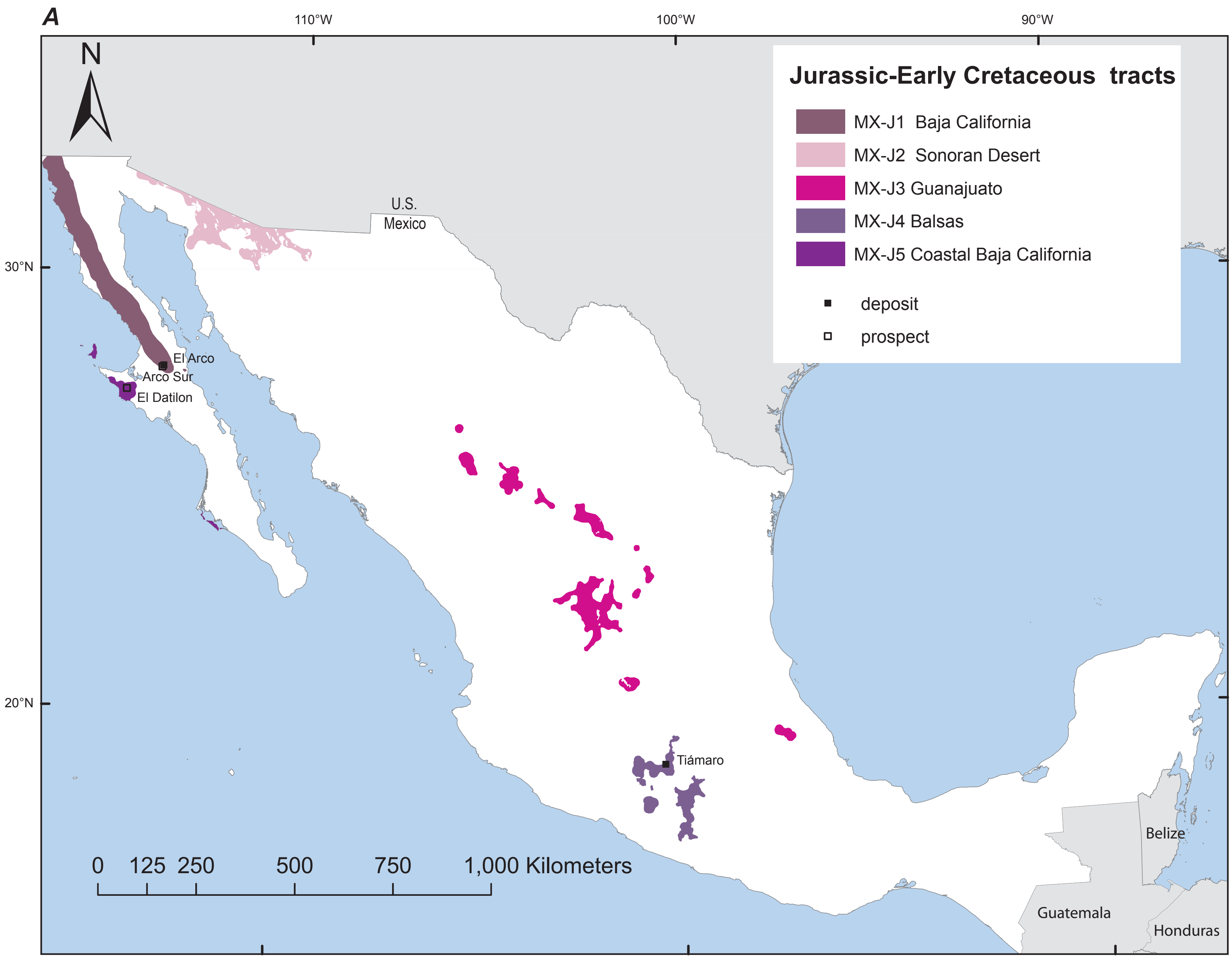


Figure 9. Permissive tracts for porphyry copper deposits in Mexico. Deposit names are shown on each view. *A*, Jurassic-Early Cretaceous tracts. *B*, Laramide tracts. *C*, Tertiary tracts.

B

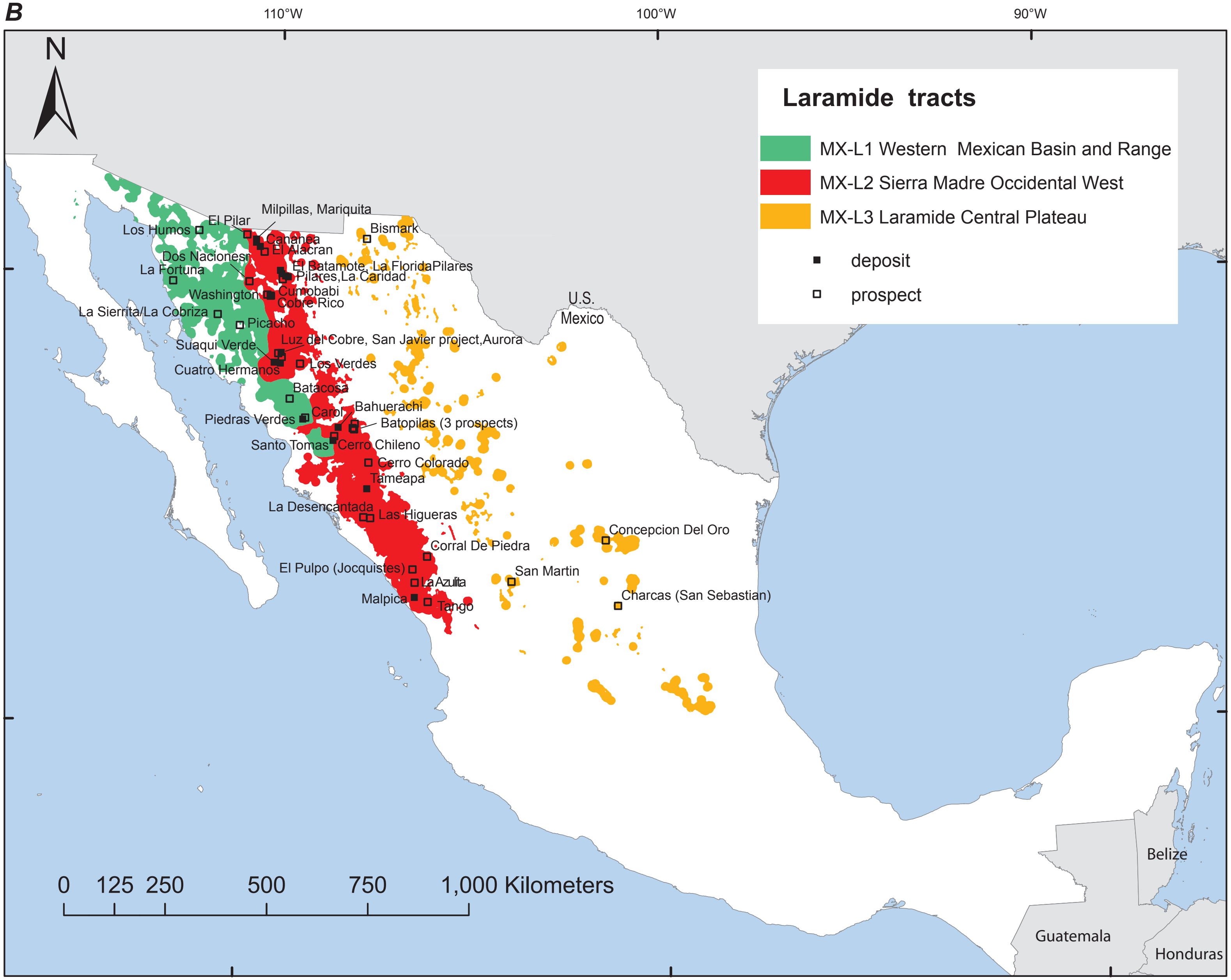


Figure 9. Permissive tracts for porphyry copper deposits in Mexico.—Continued

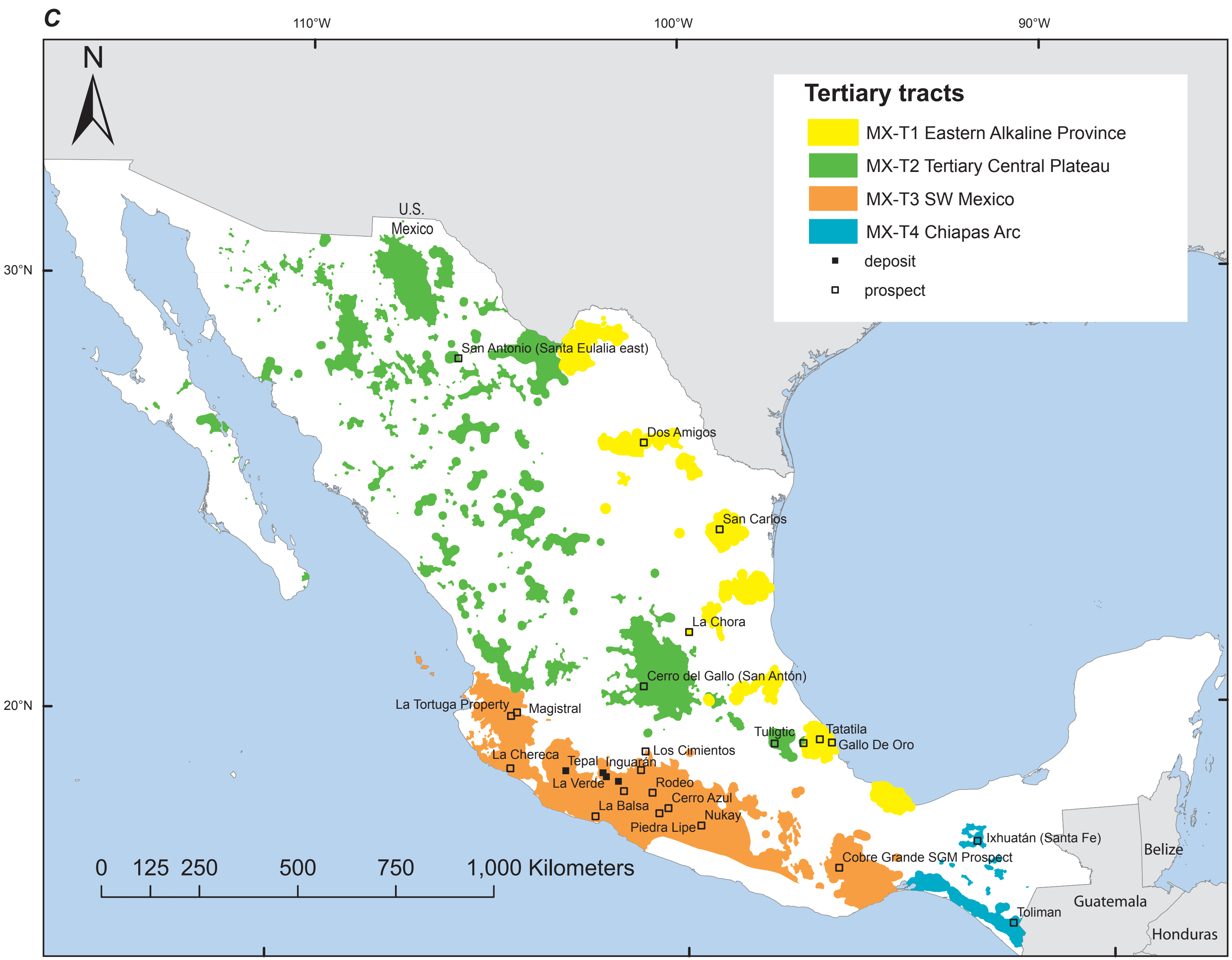


Figure 9. Permissive tracts for porphyry copper deposits in Mexico.—Continued

Laramide Tracts (fig. 9*B*)

The Laramide porphyry copper deposits of southwestern U.S. and northern Mexico are one of the great concentrations of porphyry deposits, rivaling the Tertiary age deposits in the southern Andes or the Philippine Islands. The Laramide porphyry copper belt is interpreted as being a result of an Andean-type arc that evolved as high-angle subduction of the Farallon oceanic plate under the North American continental block flattened at the end of the Cretaceous, possibly due to an increase in the rate of plate convergence, as suggested by Valencia-Moreno and others (2007).

Within the preserved Laramide arc, the relative apparent depth of erosion forms the basis for distinguishing tracts MX-L1, MX-L2, and MX-L3. Laramide volcanic rocks are rare to absent in the area of the most deeply eroded tract, MX-L1. Piedras Verdes is the only known porphyry copper deposit in MX-L1, although several porphyry-type prospects are documented. The less-deeply eroded Tract MX-L2, which includes Cananea, La Caridad, and many of the other known porphyry copper and prospects deposits in Mexico, preserves both plutonic and volcanic rocks. Recent uplift of this area has resulted in thinner and less extensive volcanic and post-mineralization cover in this tract than in Tract MX-L1. Tract MX-L3 was delineated as a separate tract where the arc rocks are largely covered by a thick accumulation of post-mineralization volcanic rocks. Prospects in MX-L3 are skarns; the 63 Ma Red Hills porphyry copper deposit in western Texas (fig. 1) falls within the arc, just east of the Mexican border.

Tertiary Tracts (fig. 9*C*)

The distinctions between the waning stages of the Laramide arc and the onset of younger arc activity, as well as the plate tectonic setting of the younger arc rocks in Mexico, are ambiguous. There is little hint of the late Eocene to early Oligocene hiatus in magmatism that is well-recognized in the U.S. cordillera. We delineated four post-Laramide tracts as Tertiary tracts based on age and lithology. The assessment for tract MX-T4 is not included in this report because most of the tract lies south of Mexico in an area included in an assessment of Central America and the Caribbean area (in press,).

Tract MX-T1 delineates Oligocene to Pleistocene alkaline rocks of the Eastern Alkalic Province, a distinctive belt of alkaline rocks at the extreme eastern margin of the North American cordillera that extends from northern Montana to southern Veracruz state in Mexico (McLemore, 1996; Kelley and Ludington, 2001; Robin, 1976, 1982). In contrast with the subduction-related compressional setting that characterized most of the Laramide-arc evolution, these rocks likely formed in Tertiary back-arc and extensional environments. In the southern part of the tract, a 700-km-long positive magnetic anomaly suggests a large dike-like mafic intrusive body that could indicate a late Tertiary failed rift. The lithologic descriptions encoded in geologic map unit names were used, along with Tertiary ages, to select the alkalic map units that compose the tract. The tract consists of 16 discrete areas along the eastern coast of Mexico. Ages generally decrease from late Eocene in the north to Pleistocene in the south. The area has been underexplored for copper porphyry deposits; however, copper skarns and stockworks occur throughout the tract area, and exploration for high-sulfidation epithermal prospects at Caballo Blanco is associated with an underlying porphyry copper exploration target.

Tract MX-T2 defines a dispersed belt of Oligocene to Miocene granitic to intermediate igneous rocks associated with post-Laramide magmatism in northern Mexico. These rocks overlap in age with the beginning of basin-and-range extension (~30 Ma), but predate the extension that led to the opening of the Gulf of California. As a group, these rocks are more silicic and more potassic than the Laramide rocks; they are thought to be related to post-subduction collapse or rollback of the Farallon plate (Humphreys, 1995). Bimodal assemblage volcanic rocks that can be ascribed to late Tertiary extension have been excluded from the tract. The Cerro del Gallo prospect, an unusual reduced-facies Cu-Au porphyry system, was recently recognized within the tract (Stewart, 2008). Tuligtic and Tatatila (Almaden Minerals Ltd., 2008; Chesapeake Gold Corporation, 2007) represent significant porphyry prospects. A number of epithermal deposits throughout the tract appear to be related to porphyritic intrusive rocks and Cu-bearing skarn deposits.

Tract MX-T3 encompasses continental Paleocene to Late Miocene continental-arc rocks within the Guerrero terrane in the Sierra Madre del Sur in southwestern Mexico (fig. 3). Arc magmatism was largely restricted to a 200-km-wide belt near the inferred paleotrench, and the age of igneous activity appears to young to the southeast along the arc. The ages of igneous rocks in the tract overlap in age with the igneous rocks in the Laramide arc to the north, but the area is differentiated from the Laramide arc because this area has not been significantly affected by the mid-Tertiary extension that defines the cessation of the Laramide arc. Post-Laramide age (Oligocene and Miocene) igneous rocks in tract MX-T3 show a clear association with subduction that continued without apparent interruption in this area into the late-Tertiary. Known porphyry copper deposits include Tepal, Inguarán, La Verde, and San Isidro. Exploration and development of high-grade zones of apparent porphyry systems are, as of this writing, underway at La Balsa and Magistral. Intrusive rocks in the Xolapa terrane (fig. 2), which borders the onshore southern boundary of tract MX-T3, were excluded from the permissive tract in southwestern Mexico because exhumation of Paleocene to Eocene plutonic rocks there was so deep that any porphyry copper deposits would have been eroded.

Tract MX-T4 represents the northernmost (in Chiapas, Mexico) part of a late-Tertiary magmatic arc along the North America-Caribbean-Cocos plate boundaries. This magmatism is related to subduction along the Middle America trench that continues to the present day, with active volcanism and compression resulting in rapid uplift and erosion of the magmatic arc (Mora and others, 2007). As a result of this rapid uplift and erosion, the youngest porphyry copper prospects in Mexico, Ixhuatán (3 Ma) and Tolimán (5.8 Ma) lie within the tract.

Grade and Tonnage Models

Grades and tonnages for known deposits in Mexico were compared with the global porphyry copper models of Singer and others (2008), as shown in figure 10. For the permissive tracts that contain identified resources, grades and tonnages of deposits within the tracts were tested against the global model to determine its applicability. At the 1 percent screening level adopted for this study, we determined that the global porphyry Cu-Mo-Au model was acceptable for all of the tracts that contain one or more known deposits (table 5). For permissive tracts that lack identified resources for statistical tests, the global porphyry Cu-Mo-Au model was used, except for MX-T1 and MX-T2. For these two tracts, we used the Cu-Au subtype model. Porphyry copper deposits associated with alkaline source rocks (MX-T1) typically are relatively enriched in gold (Barr and others, 1976; Mutschler and others, 1985, 1991; McMillan and Pantaleyev, 1988; Sillitoe, 2002). Not all gold-rich porphyry copper deposits are alkaline; however, nearly all alkaline porphyry copper deposits are gold rich. It seems likely that any porphyry copper deposits discovered in tract MX-T1 (the Eastern Alkaline Province) will be relatively rich in gold. For tract MX-T2, geologic characteristics, tectonic setting, and gold grades reported for active exploration projects suggested that the Cu-Au subtype is the appropriate model for MX-T2 (Humphreys, 1995; Richards, 2009).

Estimates of Numbers of Undiscovered Deposits

The assessment team evaluated the available data and made individual, subjective estimates of the numbers of undiscovered porphyry copper deposits by using expert judgment. The individual estimates were discussed as a group, and a consensus estimate was agreed upon for each tract. The rationales for the estimates for each tract are discussed in the appendixes. In some cases, we counted the number of significant porphyry copper prospects within a tract as 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. We also considered the location, number, deposit type, and relative importance of other prospects as well as the presence of appropriate alteration or stream sediment geochemical anomalies within the tract. The absence of mapped alteration or favorable geochemistry was not considered to be a negative factor because gaps in data coverage occur, and many undiscovered deposits may be covered. Therefore, geochemical anomalies or rock alteration may not be exposed at the surface. Recent literature and technical reports for exploration projects in NI43-101-compliant reports (Committee for Mineral Reserves International Reporting Standards, 2006) were checked for descriptions of geology, mineralogy, deposit type, rock alteration, and sampling results to evaluate the likelihood that the prospect is associated with a porphyry copper system like those in the grade and tonnage models. In addition, some team members provided information about prospects based on personal observations from site visits.

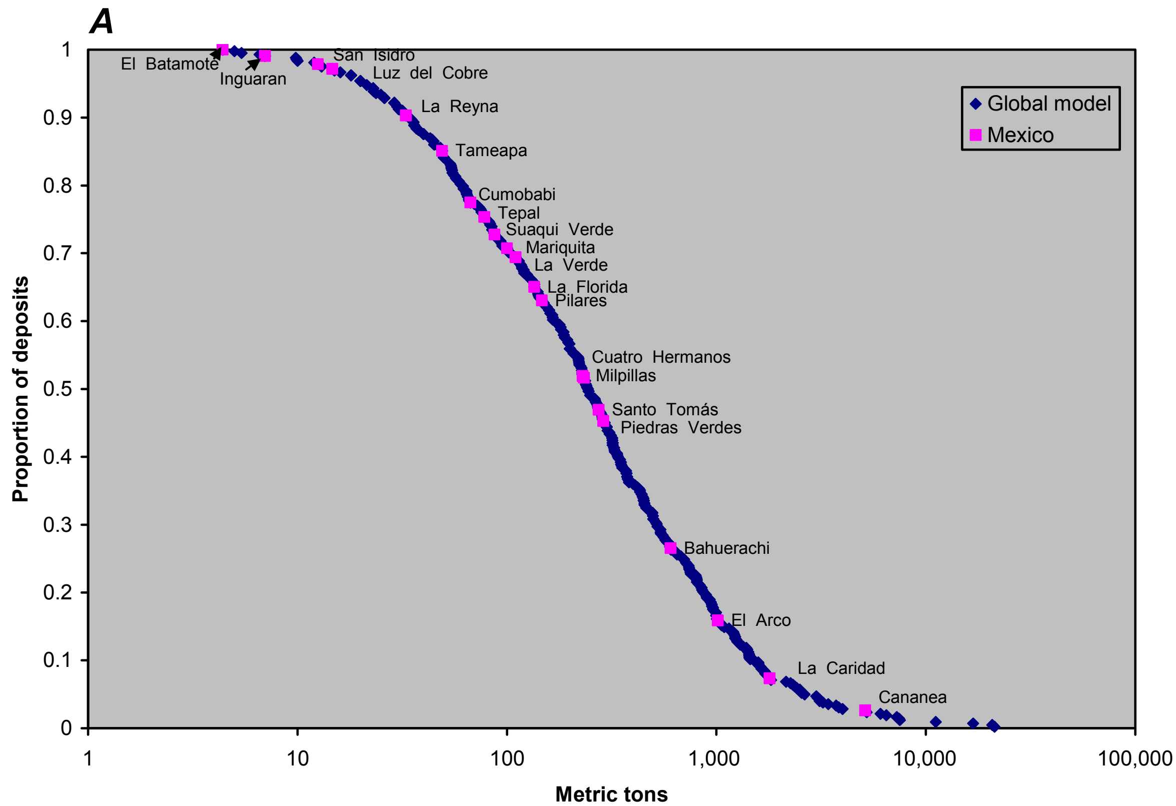
Consensus estimates of undiscovered deposits are summarized in table 6, along with statistics that describe mean expected numbers of undiscovered deposits, the standard deviation and coefficient of variation associated with the estimate, the number of known deposits, and the implied deposit density for each tract. The team estimated a mean expected total of 39 undiscovered porphyry copper deposits in all tracts, or about 1.8 times as many deposits as have already been discovered and well-delineated (21 known deposits). Note that tract areas range over two orders of magnitude. Although all the Jurassic tracts have relatively low estimates of numbers of undiscovered deposits (<1 mean expected deposit), as previously discussed, apparent deposit densities are strongly affected by tract area. Also, the uncertainties associated with estimates for the Jurassic-Early Cretaceous tracts, as shown by the coefficients of variation (table 6), are much higher than those associated with younger tracts.

Deposit density models (Singer and others, 2005; Singer, 2008) were not used in the estimation process. After final tract boundaries and consensus estimates of numbers of undiscovered deposits were agreed upon, tract areas were computed. Comparison of deposit densities based on expert judgment with those predicted by the model (fig. 11) shows that our estimates predict a lower deposit density for most tracts than the model would predict, with the exception of tract MX-L2, which plots at a higher deposit density than the model predicts. Post-mineralization extension may affect the apparent deposit density for all the Laramide and older tracts.

Summary of Probabilistic Assessment Results

Simulation results for each tract are listed in tables in the individual tract descriptions (appendixes). Results are reported at selected quantile levels, along with the mean expected amount of metal, the probability of the mean, and the probability of no metal. The amount of metal reported at each quantile represents the least amount of metal expected. The quantile results represent ranked data from the 4,999 Monte Carlo simulations. The quantiles are linked to each tract simulation and, therefore, are not additive. Mean estimates, however, can be added to obtain total amounts of metal and mineralized rock in undiscovered deposits. Mean results for each tract are listed in table 7. The probability of occurrence associated with the mean typically is on the order of a 20- to 30-percent chance.

Identified resources in known deposits within each tract are listed in table 8, on the basis of data reported for individual deposits in table 2. Note that these identified resources include substantial amounts of metal that have already been



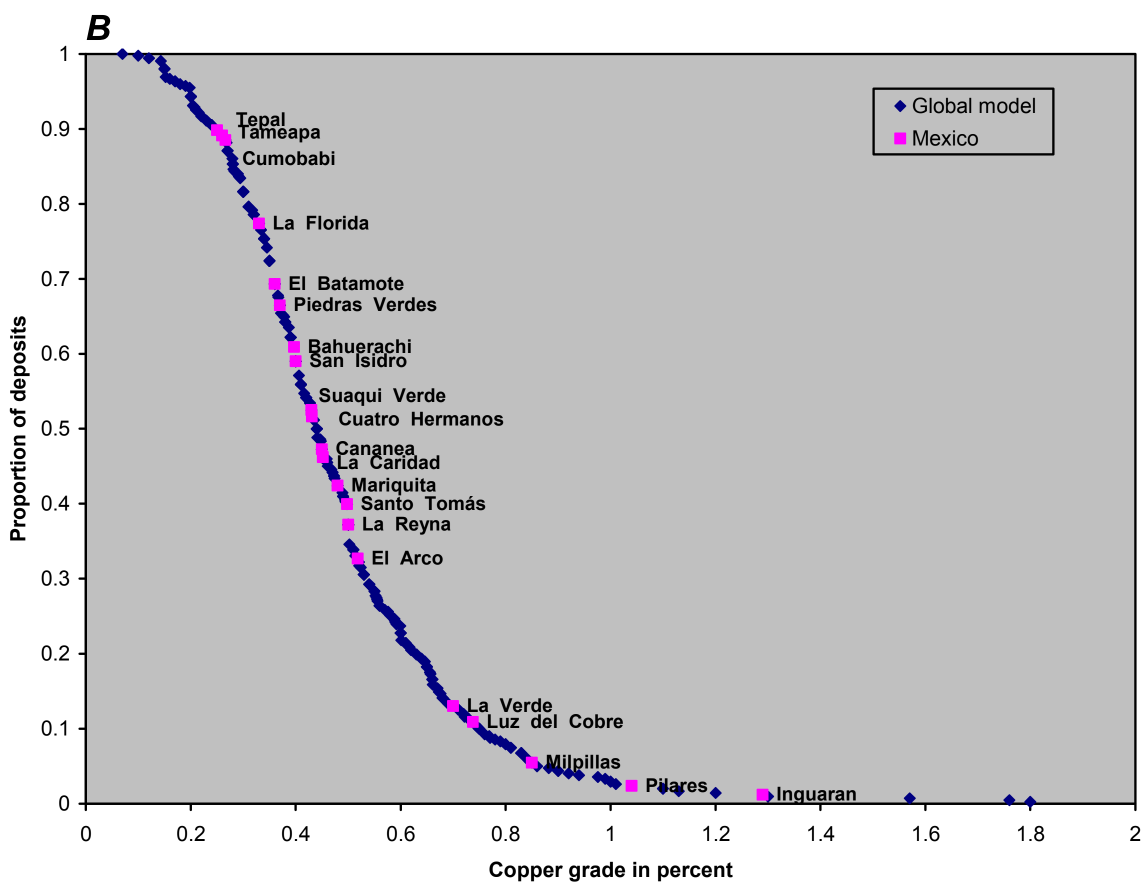


Figure 10. Global tonnage and copper grade models used for the Mexico porphyry copper assessment. Global data from Singer and others (2008); deposits in Mexico are labeled by name. *A*, Global tonnage model. *B*, Global copper grade model.

produced. Reported resources are based on total production, if any, and published data for measured, indicated, and inferred reserves and resources at the lowest cutoff grade reported. Tracts MX-J1, MX-J4, and MX-L1 each contain one known deposit. Tract MX-L2 contains 15 known deposits and tract MX-T3 contains 3 known deposits. Some other tracts contain significant prospects that are the focus of recent exploration, such as La Balsa in tract MX-T3 and Caballo Blanco in tract MX-T1. Although parts of these porphyry copper systems have been explored, no reliable grade and tonnage estimates are yet available.

How much copper is present in undiscovered porphyry copper deposits in Mexico? Based on the mean estimates from the Monte Carlo simulation, undiscovered porphyry copper deposits in the areas assessed may contain at least 144 million metric tons of copper, 4 million metric tons of molybdenum, ~4,000 metric tons of gold, and ~48,000 metric tons of silver beyond that known in identified resources. Approximately 52 million metric tons of copper are identified in known porphyry copper deposits.

Resource estimates for undiscovered porphyry copper deposits are compared with identified resources in table 9. This assessment predicts that undiscovered deposits may contain ~2.7 times as much copper as has already been identified in porphyry copper deposits in Mexico. For tracts that contain identified resources, the ratios of undiscovered to identified resources indicate that:

- The Jurassic-Early Cretaceous tracts MX-J1 and MX-J2 contain fewer estimated undiscovered copper resources (ratios <1) than the identified resources documented in table 8.
- Laramide tract MX-L1 may contain significantly more copper than has been identified.
- Laramide tract MX-L2, the tract that contains most of the known deposits in Mexico, including the world-class deposits at Cananea and La Caridad, may contain about as much copper, molybdenum, and silver in undiscovered deposits and more gold than has been identified.
- Tertiary tracts MX-T1 and MX-T2, where no porphyry copper deposits are known, may contain undiscovered deposits.
- Tertiary tract MX-T3 may contain about three times more copper than has been identified.
- Byproduct metal estimates relative to identified resources (molybdenum, gold, and silver) are not defined for most tracts because no data are available for identified resources (table 8).
- Permissive tracts with no known deposits (MX-J3, MX-J5, MX-L3, MX-T1, MX-T2) contain approximately 30 percent of the total estimated undiscovered copper resources.

Global Perspective

In 2008, Mexico produced 270,000 metric tons of copper, making it the 12th largest copper producer in the world (Edelstein, 2009). The largest production came from the deposits at Cananea and La Caridad (Perez, 2009). Mexican copper reserves (all deposit types), as of 2008, amount to 38 million metric tons (Edelstein, 2009). U.S. and world copper reserves are on the order of 35 and 550 million metric tons, respectively.

As part of the global mineral-resource assessment, an assessment of undiscovered porphyry copper resources in the Andes region of South America, including all of Chile, was done (Cunningham and others, 2008). Chile is the world's largest copper producer (5.6 million metric tons in 2008) and has the world's largest reported reserves (160 million metric tons). The Andes assessment estimated that about 145 undiscovered deposits remain, or about twice as many as the 69 deposits that have already been found.

The porphyry copper assessment for Mexico suggests that about 39 deposits remain to be found, or nearly twice as many as the 21 known deposits. Until recent years, most porphyry copper exploration in Mexico focused on the exposed northern parts of the Laramide arc. Our assessment suggests that the exposed and shallowly buried (<1 km) parts of the Laramide and Tertiary arcs delineated as permissive tracts are more likely to contain undiscovered deposits than older (Jurassic-Early Cretaceous) arc segments. Interest in gold has prompted exploration of historical precious-metal prospects and small mines in Mexico, some of which may represent high-sulfidation epithermal systems overlying or adjacent to porphyry copper systems. Mineralized breccia pipes and copper-gold skarns may also represent exposed expressions of porphyry copper systems that warrant further exploration.

Considerations for Users of this Assessment

Global Mineral Resource Assessment products represent a synthesis of current, readily available information. Ideally, assessments are done on a recurring basis, at a variety of scales, because available data change over time. This assessment is based on the descriptive and grade-tonnage data contained in published mineral deposit models. Data in the models represent average grades of each commodity of possible economic interest and tonnages 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 present-day economic viability of the deposits used to construct the models varies widely, 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

Table 5. Statistical test results, porphyry copper assessment, Mexico.

[ANOVA tests used for tracts with a single deposit; 2-sample t-test used for other tracts. n.d., no data; p>0.01 indicates that the deposits in the tract are not significantly different from those in the global model at the 1-percent level]

User_ID	Tract name	Coded_ID	No. known deposits	Tons	Cu	Mo	Au	Ag
				Probability (p) that known deposits are not significantly different from the global porphyry copper model of Singer and others (2008)				
MX-J1	Baja California	003pCu3001	1	0.33	0.70	n.d.	0.85	n.d.
MX-J4	Balsas	003pCu3005	1	0.62	0.48	n.d.	0.78	n.d.
MX-L1	Western Mexican Basin and Range	003pCu3006	1	0.98	0.66	n.d.	n.d.	n.d.
MX-L2	Sierra Madre Occidental (W)	003pCu3007	15	0.10	0.98	0.12	0.20	0.82
MX-T3	SW Mexico	003pCu3011	3	0.03	0.41	n.d.	0.74	0.83

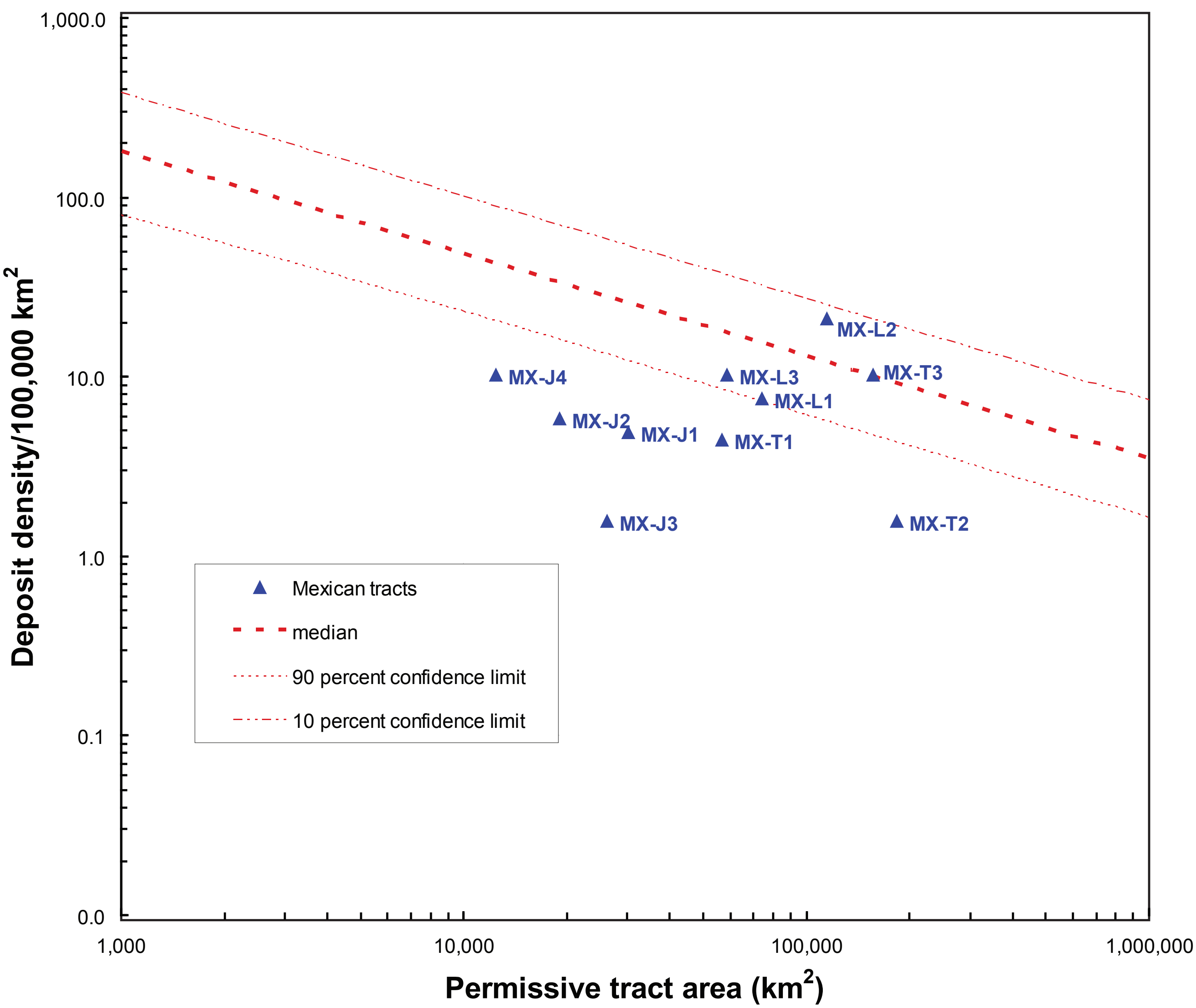


Figure 11. Comparison of permissive tract areas and deposit densities estimated for Mexico (table 6) from this assessment with the deposit density model (regression line) of Singer (2008).

Table 6. Estimates of numbers of undiscovered deposits, porphyry copper assessment, Mexico.

[Nxx, estimated number of deposits associated with the xxth percentile; N_{und} , expected number of undiscovered deposits; s, standard deviation; Cv%, coefficient of variance, in percent; N_{known}, number of known deposits that have identified resources within the tract; N_{total}, total of expected number of deposits plus known deposits; tract area, area of permissive tract in square kilometers; deposit density, reported as the total number of deposits per 100,000 square kilometer; N_{und}, s, and Cv% are calculated using a regression equation (Singer and Menzie, 2005); n.d., no data; *, deposit densities are not reported for tract areas <10,000 km^2]

User_ID	Tract name	Coded_ID	Consensus undiscovered deposit estimates					Summary statistics					Tract area, in km^2	Deposit density
			N90	N50	N10	N05	N01	N_{und}	s	Cv%	N_{known}	N_{total}		
MX-J1	Baja California	003pCu3001	0	0	1	3	4	0.48	1	210	1	1.5	30,260	5
MX-J3	Guanajuato	003pCu3004	0	0	1	2	3	0.41	0.82	200	0	0.41	26,080	2
MX-J4	Balsas	003pCu3005	0	0	1	1	2	0.33	0.62	190	1	1.3	11,810	11
MX-J5	Coastal Baja California	003pCu3002	0	0	1	2	3	0.41	0.82	200	0	0.41	2,910	*
MX-L1	Western Mexican Basin and Range	003pCu3006	2	4	7	n.d.	n.d.	4.2	1.9	46	1	5.2	74,140	7
MX-L2	Sierra Madre Occidental (W)	003pCu3007	7	13	19	n.d.	n.d.	13	4.5	36	15	28	115,110	25
MX-L3	Laramide Central Plateau	003pCu3008	2	5	10	n.d.	n.d.	5.5	3	54	0	5.5	58,720	9
MX-T1	Eastern Alkaline Province	003pCu3010	1	2	4	n.d.	n.d.	2.2	1.2	54	0	2.2	56,839	4
MX-T2	Tertiary Central Plateau	003pCu3009	1	2	5	n.d.	n.d.	2.5	1.6	63	0	2.5	183,520	1
MX-T3	SW Mexico	003pCu3011	6	10	14	n.d.	n.d.	9.6	3.1	32	3	13	156,650	8
		Total						39			21			

Table 7. Summary of Monte Carlo simulations of undiscovered resources in each tract, porphyry copper assessment, Mexico.

[t metric tons; Mt; megatonne or one million tons; Mean, arithmetic mean of simulation results]

User_ID	Tract name	Coded_ID	Mean expected amounts of metal and rock				
			Cu (t)	Mo (t)	Au (t)	Ag (t)	Rock (Mt)
MX-J1	Baja California	003pCu3001	2,100,000	58,000	48	660	410
MX-J3	Guanajuato	003pCu3004	1,500,000	40,000	41	520	310
MX-J4	Balsas	003pCu3005	1,200,000	35,000	30	400	240
MX-J5	Coastal Baja California	003pCu3002	1,500,000	42,000	41	550	320
MX-L1	Western Mexican Basin and Range	003pCu3006	16,000,000	460,000	400	5,600	3,300
MX-L2	Sierra Madre Occidental (W)	003pCu3007	48,000,000	1,300,000	1,200	16,000	9,900
MX-L3	Laramide Central Plateau	003pCu3008	20,000,000	560,000	510	6,500	4,100
MX-T1	Eastern Alkaline Province	003pCu3010	6,700,000	39,000	490	2,200	1,300
MX-T2	Tertiary Central Plateau	003pCu3009	9,600,000	260,000	250	3,100	1,900
MX-T3	SW Mexico	003pCu3011	37,000,000	1,000,000	940	12,000	7,500
		Total	143,600,000	3,794,000	3,950	47,530	29,280

those likely to be discovered (Singer, 2007b). In some cases, assessment teams were aware of prospects, revealed by past or current exploration efforts, that are believed to be significant deposits but that do not yet have a citable grade and tonnage. These probable deposits are treated here as undiscovered deposits, albeit ones 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 estimated in this assessment, although they are commonly a substantial part of newly discovered copper resources each year, both in Mexico and globally. This assessment considers the potential for concealed deposits within 1 km of the surface. However, exploration for and exploitation of such deposits may be so expensive that deposits, if present, may not be discovered in the near term. If they are discovered, the costs and logistics related to mining a deeply buried porphyry deposit might prohibit their development into mines given current or near-term metal prices and technology.

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. Many of the permissive tracts described in this report are continuous into the U.S. to the north. However, the descriptions and estimates in this report pertain only to the Mexico portions of the tracts and will ultimately be combined with revised tracts from the 1996 National Assessment of the United States (U.S. Geological Survey National Mineral Resource Assessment Team, 2000;

Table 8. Identified resources by tract, porphyry copper assessment, Mexico.

[t metric tons; Mt; megatonne or one million tons; n.d., no data]

User_ID	Tract name	Deposit	Contained Cu (t)	Contained Mo (t)	Contained Au (t)	Contained Ag (t)	Tonnage (Mt)
MX-J1	Baja California	El Arco	5,262,900	n.d.	122	n.d.	1,016
MX-J4	Balsas	Tiámaro	3,000,000	n.d.	50	n.d.	500
MX-L1	Western Mexican Basin and Range	Piedras Verdes	1,065,000	n.d.	n.d.	n.d.	288
MX-L2	Sierra Madre Occidental (W)	La Caridad	8,136,000	444,600	n.d.	n.d.	1,800
MX-L2	Sierra Madre Occidental (W)	Bahuerachi	2,401,000	48,400	19	2,364	605
MX-L2	Sierra Madre Occidental (W)	Santo Tomás	1,365,000	n.d.	14	n.d.	274
MX-L2	Sierra Madre Occidental (W)	Cuatro Hermanos	1,383,000	168,100	n.d.	924	764
MX-L2	Sierra Madre Occidental (W)	Milpillas	1,955,000	n.d.	n.d.	n.d.	230
MX-L2	Sierra Madre Occidental (W)	Pilares	1,529,000	n.d.	n.d.	n.d.	147
MX-L2	Sierra Madre Occidental (W)	La Florida	445,500	n.d.	n.d.	n.d.	135
MX-L2	Sierra Madre Occidental (W)	Mariquita	480,000	n.d.	n.d.	n.d.	100
MX-L2	Sierra Madre Occidental (W)	Suaqui Verde	375,000	n.d.	n.d.	n. d.	87
MX-L2	Sierra Madre Occidental (W)	Cumobabi	178,200	66,300	n.d.	n.d.	67
MX-L2	Sierra Madre Occidental (W)	Tameapa	127,400	14,700	n.d.	n.d.	49
MX-L2	Sierra Madre Occidental (W)	Malpica	147,900	n.d.	12	n.d.	29
MX-L2	Sierra Madre Occidental (W)	Luz del Cobre	108,500	n.d.	n.d.	n.d.	15
MX-L2	Sierra Madre Occidental (W)	El Batamote	15,840	n.d.	n.d.	n.d.	4
MX-L2	Sierra Madre Occidental (W)	Cananea	23,135,000	102,800	180	13,418	5,140
MX-T3	SW Mexico	La Verde	770,000	n.d.	10	275	110
MX-T3	SW Mexico	Tepal	195,000	n.d.	39	n.d.	78
MX-T3	SW Mexico	San Isidro	283,500	n.d.	n.d.	n.d.	81
		Total	52,357,000	844,100	445	17,000	11,500

Table 9. Identified resources and resource ratios (undiscovered/identified), porphyry copper assessment, Mexico.

[Mean estimated undiscovered resources from table 7; n.d., no data]

Area	Cu	Mo	Au	Ag	Rock
Identified resources					
MX-J1	5,262,880	n.d.	122	n.d.	1,016
MX-J4	3,000,000	n.d.	50	n.d.	500
MX-L1	857,500	n.d.	n.d.	n.d.	245
MX-L2	41,780,625	844,906	224	16,707	9,447
MX-T3	1,338,800	n.d.	49	275	276
Total	52,447,305	844,906	445	16,982	11,527
Ratio of undiscovered to identified resources					
MX-J1	0.4	n.d.	0.4	n.d.	0.4
MX-J4	0.4	n.d.	0.4	n.d.	0.5
MX-L1	15	n.d.	n.d.	n.d.	12
MX-L2	1.1	1.5	5.3	1.0	1.0
MX-T3	28	n.d.	19	44	27
Total	2.7	4.5	8.9	2.8	3

Schruben, 2002). In addition, permissive tracts in southern Mexico that continue into Guatemala will be described in the assessment of Central American countries.

The tracts are constructed at a scale of 1:1,000,000 and are not intended for use at larger scales.

Acknowledgments

The authors are grateful to the Servicio Geologico Mexicana (SGM), the University of Arizona, the Departamento de Geologia, Universidad de Sonora, and the Estacion Regional del Noroeste, Instituto de Geologia, Universidad Nacional Autonoma de Mexico (UNAM) for their participation in this assessment. SGM provided expertise and data and hosted two assessment meetings at theHermosillo regional office. Thanks to Francisco Cendejas Cruz and his staff in Hermosillo for hosting these meetings. Enrique Gomez de la Rosa, Juan Carlos Salinas, Julio Velez Lopez, and Hector Alba Infante facilitated SGM's involvement on the project and provided data early on.

Mukul Sonwalker, Boris Barrios, and Paul Schruben assisted with graphics. USGS colleagues Art Bookstrom, David John, Larry Drew, and Michael Zientek served as the assessment oversight committee to review preliminary results. USGS colleagues Alan Wallace and Tom Frost provided helpful and timely technical reviews of the final report. Larry Drew provided information on assessment methods. Connie Dicken provided GIS expertise and she and Pam Dunlap provided data management support.

References Cited

Alaniz-Álvarez, S.A., and Nieto-Samaniego, Á.F., eds., 2007, Geology of México, celebrating the centenary of the Geological Society of México: Geological Society of America Special Paper 422, p. 433-458.

Almaden Minerals, 2008, Tuligtic project, Puebla State [Mexico]: Almaden Minerals Ltd. Web page accessed March 20, 2008, at http://www.almadenminerals.com/Projects/tuligtic.html.

Arribas, Antonio, Jr., Hedenquist, J.W., Itaya, Tetsumaru, Okado, Toshinori, Concepción, R.A., and Garcia, J.S., Jr., 1995, Contemporaneous formation of adjacent porphyry and epithermal Cu-Au deposits over 300 ka in northern Luzon, Philippines: Geology, v. 23, no. 4, p. 337-340.

Baranov, V., and Naudy, H., 1964, Numerical calculation of the formula of reduction to the magnetic pole: Geophysics, v. 29, p. 67-79.

Barr, D.A., Fox, P.E., Northcote, K.E., and Preto, V.A., 1976, The alkaline suite porphyry deposits—A summary: Special volume of the Canadian Institution for Mining and Metallurgy, v. 15, p. 359-367.

Bartolini, C., Lang, H., and Spell, T., 2003, Geochronology, geochemistry, and tectonic setting of the Mesozoic Nazas arc in north-central Mexico, and its continuation to northern South America, *in* Bartolini, C., Buffler, R.T., and Blickwede, J., eds., The Circum-Gulf of Mexico and the Caribbean—Hydrocarbon habitats, basin formation, and plate tectonics: American Association of Petroleum Geologists Memoir 79, p. 79-82.

Barton, M.D., Staude, J.-M.G., Zürcher, L., and Megaw, P.K.M., 1995, Porphyry copper and other intrusion-related mineralization in Mexico, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Tucson, Arizona Geological Society Digest, v. 20, p. 487-524.

Bawiec, W.J., and Spanski, G.T., in press, EMINERS—Economic Mineral Resource Simulator, version 3.0: U.S. Geological Survey Open-File Report 2009-1057, program files and 29-p. Quick-Start Guide.

Berger, B.R., Ayuso, R.A., Wynn, J.C., and Seal, R.R., 2008, Preliminary model of porphyry copper deposits: U.S. Geological Survey Open-File Report 2008-1321, 55 p., accessed May 15, 2009, at http://pubs.usgs.gov/of/2008/1321.

Blakely, R.J., 1995, Potential theory in gravity and magnetic applications: Cambridge University Press, 441 p.

Bonham-Carter, G. F., 1994, Geographic information systems for geoscientists—Modeling in GIS: New York, Elsevier Science, 398 p.

Bonham-Carter, G.F., Agterberg, F.P. and Wright, D.F., 1989, Weights of evidence modeling— A new approach to mapping mineral potential, *in* Agterberg, F.P. and Bonham-Carter, G.F., eds., Statistical applications in the earth sciences: Geological Survey of Canada Paper 89-9, p. 171-183.

Campa, M.F., and Coney, P.J., 1983, Tectono-stratigraphic terranes and mineral resource distributions in Mexico: Canadian Journal of Earth Sciences, v. 20, p. 1040-1051.

Camprubi, A., 2009, Major metallogenic provinces and epochs of Mexico: SGA News, no. 25, p. 1-20. (Also available online at http://www.e-sga.org.)

Camprubi, A. and Albinson, T., 2007, Epithermal deposits in Mexico–Update of current knowledge, and an empirical reclassification, *in* Alaniz-Alvarez, S.A. and Nieto-Samaniego, A.F., eds., Geology of Mexico, celebrating the centenary of the Geological Society of Mexico: Geological Society of America Special Paper 422, p. 377-415.

Chappell, B.W., and White, A.J.R., 1974, Two contrasting granite types: Pacific Geology, v. 8, p. 173-174.

Chesapeake Gold, 2007, Chesapeake consolidates a new significant mining district in Veracruz, Mexico: Chesapeake Gold Corp. Web page accessed January 15, 2008, at http://www.chesapeakegold.com/downloads/ChesapeakeGold_2007_10_10_40.pdf.

Clark, D.A., 1999, Magnetic petrology of igneous intrusions—Implications for exploration and magnetic interpretation: Exploration Geophysics, v. 30, p. 5-26.

Clark, D.A., French, D.H., Lackie, M.A., and Schmidt, P.W., 1992, Magnetic petrology— Application of integrated rock magnetic and petrological techniques to geological interpretation of magnetic surveys: Exploration Geophysics, v. 23, p. 65-68.

Clark, K.F., and de la Fuente L., F.E., 1978, Distribution of mineralization in time and space in Chihuahua, Mexico: Mineralium Deposita, v. 13, p. 27-49.

Clark, K.F., Foster, C.T., and Damon, P.E., 1982, Cenozoic mineral deposits and subduction-related magmatic arcs in Mexico: Geological Society of America Bulletin, v. 93, p. 533-544.

Committee for Mineral Reserves International Reporting Standards, 2006, International reporting template for the reporting of exploration results, mineral resources, and mineral reserves: Committee for Mineral Reserves International Reporting Standards, 53 p., accessed January 15, 2008, at http://www.crirsco.com/crirsco_template_first_ed_0806.pdf.

Coney, P.J., and Campa, M.F., 1987, Lithotectonic terrane map of Mexico (West of the 91st Meridian): U.S. Geological Survey Miscellaneous Field Studies Map MF-1874-D, scale 1:2,500,000, 1 sheet.

Cox, D.P., 1986, Descriptive model of porphyry Cu (Model 17), *in* Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 76. (Also available online at http://pubs.usgs.gov/bul/b1693/.)

Cunningham, C.G., Zappettini, E.O., Vivallo S.,Waldo, Celada, Carlos Mario, Quispe, Jorge, Singer, D.A., Briskey, J.A., Sutphin, D.M., Gajardo M., Mariano, Diaz, Alejandro, Portigliati, Carlos, Berger, V.I., Carrasco, Rodrigo, and Schulz, K.J., 2008, Quantitative mineral resource assessment of copper, molybdenum, gold, and silver in undiscovered porphyry copper deposits in the Andes Mountains of South America: U.S. Geological Survey Open File Report 2008-1253, prepared and published jointly by the geological surveys of Argentina, Chile, Colombia, Peru, and the United States, accessed October 15, 2008, at http://pubs.usgs.gov/of/2008/1253.

Damon, P.E., Shafiqullah, M., and Clark, K.F., 1983, Geochronology of the porphyry copper deposits and related mineralization of Mexico: Canadian Journal of Earth Sciences, v. 20, p. 1052-1071.

Edelstein, D.L., 2009, Copper, *in* Metals and minerals: U.S. Geological Survey Mineral Yearbook 2007, v. I, p. 20.-20.28, accessed online March 15, 2010, at http://minerals.usgs.gov/minerals/pubs/commodity/copper/myb1-2007-coppe.pdf.

Einaudi, M.T., 1982, Descriptions of skarns associated with porphyry copper plutons, southwestern North America, *in* Titley, S.R., ed., Advances in geology of the porphyry copper deposits, southwestern North America: Tucson, University of Arizona Press, p. 139-184.

Ferrari, Luca, 2004, Slab detachment control on mafic volcanic pulse and mantle heterogeneity in central Mexico: Geology, v. 32, no. 1, p. 77-80.

Ferrari, L., Lopez-Martinez, M., Aguirre-Díaz, G., and Carrasco-Núñez, G., 1999, Space-time patterns of Cenozoic arc volcanism in central Mexico—From the Sierra Madre Occidental to the Mexican Volcanic Belt: Geology, v. 27, p. 303-306.

Ferrari, L., Valencia-Moreno, M., and Bryan, S., 2007, Magmatism and tectonics of the Sierra Madre Occidental and its relation with the evolution of the western margin of North America, *in* Alaniz-Alvarez, S.A. and Nieto-Samaniego, A.F., eds., Geology of Mexico, celebrating the centenary of the Geological Society of Mexico: Geological Society of America Special Paper 422, p. 1- 40.

Fitch, D.C., 2000, Mexico mineral occurrences, map and GIS database, 3,722 selected mineral occurrences from CRM Monograph data with USGS selected data: Copyrighted database available from David C. Fitch, Geologist, P.O. Box 70547, Reno, NV 89570, USA igeologist.com, CD-ROM.

García-Palomo, A., Macias, J.L., and Espindola, J.M., 2004, Strike-slip faults and K-alkaline volcanism at El Chich´on volcano, southeastern Mexico: Journal of Volcanology and Geothermal Research, v. 136, p. 247-268.

Garza-González, Carlos, Camprubí, Antoni, González-Partida, Eduardo, Arriaga-García, Germán, and Rosique-Naranjo, Fernando, 2006, Hydrothermal alteration and fluid inclusion study of the Lower Cretaceous porphyry Cu-Au deposit of Tiámaro, Michoacán, Mexico: Journal of Geochemical Exploration, v. 889, p. 124-128.

Goldcorp, 2009, Los Filos: Goldcorp Web page, accessed June 30, 2009, at http://www.goldcorp.com/operations/los_filos/.

Gunn, P.J., and Dentith, M.C., 1997, Magnetic responses associated with mineral deposits: AGSO Journal of Australian Geology and Geophysics, v. 17, p. 145-158.

Hearn, P., Jr., Hare, T., Schruben, P., Sherrill, D., LaMar, C., and Tsushima, P., 2003, Global GIS database—Digital atlas of the Earth: U.S. Geological Survey Digital Data Series DDS-62-H, DVD-ROM.

Hildebrand, R.S., 2009, Did westward subduction cause Cretaceous-Tertiary orogeny in the North America Cordillera?: Geological Society of America Special Paper 457, 71 p.

Horner, J.T., and Enriquez, E., 1999, Epithermal precious metal mineralization in a strike-slip corridor —The San Dimas district, Durango, Mexico: Economic Geology, v. 94, p. 1375-1380.

Hosmer, D.W., and Lemeshow, S., 2000, Applied logistic regression (2d ed.): New York, Wiley, 397 p.

Humphreys, E., 1995, Post-Laramide removal of the Farallon slab, western United States: Geology, v. 23, p. 987-990.

Iriondo, A., Kunk, M.J., Wininck, J.A., 2003, ^{40}Ar- ^{39}Ar Dating studies of minerals and rocks in various areas in Mexico—USGS/CRM scientific collaboration (Part I): U.S. Geological Survey Open-File Report 03-020, 79 p. (Also available online at http://pubs.usgs.gov/of/2003/ofr-03-020/.)

Ishihara, S., 1977, The magnetite-series and ilmenite-series granitic rocks: Mining Geology, v. 27, p. 293-305.

Kelley, K.D., and Ludington, Steve, 2001, Cripple Creek and other alkaline related gold deposits in the southern Rocky Mountains, USA—Influence of regional tectonics: Mineralium Deposita, v. 37, p. 38-60.

Keppie, J.D., 2004, Terranes of Mexico revisited—A 1.3 billion year odyssey: International Geology Review, v. 46, p. 765-794.

Kious, W.J., and Tilling, R.I., 1996, This dynamic Earth—The story of plate tectonics: U.S.Geological Survey, accessed January 15, 2008, at http://pubs.usgs.gov/gip/dynamic/dynamic.html.

Kirkham, R.V., and Dunne, K.P.E., 2000a, World distribution of porphyry, porphyry-associated skarn, and bulk tonnage epithermal deposits and occurrences: Geological Survey of Canada, Open File Report 3792a, 26 p.

Kirkham, R.V., and Dunne, K.P.E., 2000b, World distribution of porphyry, porphyry-associated skarn, and bulk tonnage epithermal deposits and occurrences: Geological Survey of Canada, Open File Report 3792b, scale 1:35,000,000, 1 sheet.

Maniar, P.D., and Piccoli, P.M., 1989, Tectonic discrimination of granitoids: Geological Society of America Bulletin, v. 101, p. 635-643.

Manea, V.C., and Manea, Marina, 2006, Origin of the modern Chiapanecan volcanic arc in southern Mexico inferred from thermal models, in Rose, W.I., Bluth, G.J.S., Carr, M.J., Ewert, J.W., Patino, L.C., and Vallance, J.W., Volcanic hazards in Central America: Geological Society of America Special Paper 412, p. 27-38.

McLemore, V.T., 1996, Great Plains margin (alkaline-related) gold deposits in New Mexico, in Coyner, A.R., and Fahey, P.L.,eds., Geology and ore deposits of the American Cordillera: Symposium Proceedings of the Geological Society of Nevada, Reno, p. 935-950.

McMillan, W.J., and Pantaleyev, A., 1988, Porphyry copper deposits, in Roberts, R.G., and Sheahan, P.A., eds., Ore deposit models: Geoscience Canada Reprint Series 3, p. 45-58.

Menard, S., 2002, Applied logistic regression analysis: Thousand Oaks, California, Sage Publications, Inc., 130 p.

Mining Companies in Mexico, 2006, Unofficial directory: Imdex, Inc. Web page accessed January 15, 2008, at http://www.imdex.com/toc/c_tocl.htm/.

Miranda-Gasca, M.A., 2000, The metallic ore-deposits of the Guerrero Terrane, western Mexico—An overview: Journal of South American Earth Sciences, v. 13, p. 403-413.

Molina-Garza, R.S., and Iriondo, A., 2007, The Mojave-Sonora megashear— The hypothesis, the controversy, and the current state of knowledge, *in* Alaniz-Álvarez, S.A.

and Nieto-Samaniego, A.F., eds., Geology of México, celebrating the centenary of the Geological Society of México: Geological Society of America, Special Paper 422, p. 233-259.

Mora, J.C., Jaimes-Viera, M.C., Garduño-Munroy, V.H., Layer, P.W., Pompa-Mera, V., and Godinez, M.L., 2007, Geology and geochemistry characteristics of the Chiapan ecan volcanic arc (Central area), Chiapas Mexico: Journal of Volcanology and Geothermal Research, v. 162, no. 1-2, p. 43-72.

Morán-Zenteno, D.J., Cerca, M., and Kepple, J.D., 2007, The Cenozoic tectonic and magmatic evolution of southwestern Mexico—Advances and problems of interpretation, *in* Alaniz-Álvarez, S.A. and Nieto-Samaniego, A.F., eds., Geology of México, celebrating the centenary of the Geological Society of México: Geological Society of America, Special Paper 422, p. 71-91.

Mutschler, F.E., Griffen, M.E., Stevens, D.S., and Shannon, S.S., Jr., 1985, Precious metal deposits related to alkaline rocks in the North American Cordillera; an interpretive review: Transactions of the Geological Society of South Africa, v. 88, p. 355-377.

Mutschler, F.E., Mooney, T.C., and Johnson, D.C., 1991, Precious metal deposits related to alkaline igneous rocks—A space-time trip through the Cordillera: Mining Engineering, v. 43, no. 3, p. 304-309.

NAVDAT, 2008, The western North America volcanic and intrusive rock database: NAVDAT database, accessed January 15, 2008, at http://www.navdat.org.

North American Magnetic Anomaly Group, 2002, Magnetic anomaly map of North America, U. S. Geological Survey Special Map, 1:10,000,000, accessed January 15, 2008, at http://pubs.usgs.gov/sm/mag_map/index.html.

Nieto-Samaniego, A., Alaniz-Alvarez, S.A., and Camprubri, A., 2007, Mesa Central of México—Stratigraphy, structure, and Cenozoic tectonic evolution, *in* Alaniz-Álvarez, S.A. and Nieto-Samaniego, A.F., eds., Geology of México, celebrating the centenary of the Geological Society of México: Geological Society of America, Special Paper 422, p. 41-70.

Perez, A.A., 2009, The mineral industry of Mexico, *in* Area Reports–International–Latin America and Canada: U.S. Geological Survey Mineral Yearbook 2007, v. III, p. 13.1-13.14, accessed online March 14, 2010, at http://minerals.usgs.gov/minerals/pubs/country/2007/myb3-2007-mx.pdf.

Pindell, J., Kennan, L., Stranek, K.P., Maresch, W.V., and Draper, G., 2006, Foundations of Gulf of Mexico and Caribbean evolution—Eight controversies resolved: Geologica Acta, v. 4, p. 303-341.

Richards, J.P., 2009, Postsubduction porphyry Cu-Au and epithermal Au deposits—Products of remelting subduction-modified lithosphere: Geology, v. 37, no. 3, p. 247-250.

Riverside Resources Inc., 2009, Projects: Riverside Resources Inc. Web page, accessed May 15, 2009, at http://www.rivres.com/s/Home.asp/.

Robin, C., 1976, Présence simultanée de magmatismes de significations tectoniques opposées dans l'Est du Mexique: Bulletin de la Société Géologique de France, 18, p. 1637-1645.

Robin, C., 1982. Relations volcanologie–magmatologie-geodynamique; application au passage entre volcanismes alcalin et andesitique dans le sud Mexicain (Axe Trans-mexicain et Province Alcaline Oriental): Ph.D. thesis, Annales Scientifiques de l'Université de Clermont-Ferrand II France, 503 p.

Rogers, R.D., Mann, P., and Emmet, P.A., 2007, Tectonic terranes of the Chortis block based on integration of regional aeromagnetic and geologic data, *in* Mann, P., ed., Geologic and tectonic development of the Caribbean plate in northern Central America: Geological Society of America Special Paper 428, p. 65-88.

Root, D.H., Menzie, W.D., III, and Scott, W.A., 1992, Computer Monte Carlo simulation in quantitative resource assessment: Nonrenewable Resources, v. 1, no. 2, p. 125-138.

Sawatzky, D.L., Raines, G.L., Bonham-Carter, G.F., and Looney, C.G., 2004, ArcSDM2—ArcMap extension for spatial data modeling using weights of evidence, logistic regression, fuzzy logic and neural network analysis: Geotechnologies Research Group, accessed May 15, 2009, at http://www.ige.unicamp.br/sdm/default_e.htm.

Scott, M. and Dimitrakopoulos, R., 2001, Quantitative analysis of mineral resources for strategic planning—implications for Australian geological surveys: Nonrenewable Resources, v.10, no. 3, p. 159-177.

Schruben, Paul, (recompiler), 2002, Assessment of undiscovered deposits of gold, silver, copper, lead, and zinc in the United States—A portable document format (pdf) recompilation of USGS OFR 96-96 and Circular 1178, by the National Mineral Resource Assessment Team: U.S. Geological Survey Open-File Report 02-198, one CD-ROM. (Also available online at http://pubs.usgs.gov/of/2002/of02-198/.)

Sedlock, R.L., 2003, Geology and tectonics of the Baja California peninsula and adjacent areas, *in* Johnson, S.E., Paterson, S.R., Fletcher, J.M., Girty, G.H., Kimbrough, D.L., and Martín-Barajas, Arturo, eds., Tectonic evolution of northwestern México and the southwestern USA: Geological Society of America Special Paper 374, p. 1- 42.

Sedlock, R.L., Ortega-Gutiérrez, F., and Speed, R.C., 1993, Tectonostratigraphic terranes and tectonic evolution of Mexico: Geological Society of America Special Paper 278, 153 p.

Servicio Geológico Mexicano, 2007a, Carta geológica de la República Mexicana: Servicio Geológico Mexicano, scale 1:2,000,000, 1 sheet. (Also available online at http://www.coremisgm.gob.mx/.)

Servicio Geológico Mexicano, 2007b, Base de datos de Mineral de Cobre de la Cartografìa Geològico Minera, 1:250,000: Subdirección de Geociencia Digital y Docu mentación Tècnica. (Also available online at http://www.coremisgm.gob.mx/.)

Sillitoe, R.H., 1976, A reconnaissance of the Mexican porphyry copper belt: Transactions of the Institution of Mining and Metallurgy, Section B, p. B170-B189.

Sillitoe, R.H., 2002, Some metallogenic features of gold and copper deposits related to alkaline rocks and consequences for exploration: Mineralium Deposita, v. 37, p. 4-13.

Silva-Romo, G., 2008, Guayape-Papalutla fault system—A continuous Cretaceous structure from southern Mexico to the Chortís block? Tectonic implications: Geology, v. 36, no.1, p. 75-78.

Singer, D.A., 1993, Basic concepts in three-part quantitative assessments of undiscovered mineral resources: Nonrenewable Resources, v. 2, no. 2, p. 69-81.

Singer, D.A., 2007a, Short course introduction to quantitative mineral resource assessments: U.S. Geological Survey Open-File Report 2007-1434, accessed May 15, 2009, at http://pubs.usgs.gov/of/2007/1434/.

Singer, D.A., 2007b, Estimating amounts of undiscovered resources, *in* Briskey, J.A., and Schulz, K.J., eds., Proceedings for a workshop on deposit modeling, mineral resource assessment, and their role in sustainable development, 31st International Geological Congress, Rio de Janeiro, Brazil, August 18-19, 2000: U.S. Geological Survey Circular 1294, p. 79-84. (Also available online at http://pubs.usgs.gov/circ/2007/1294/.)

Singer, D.A., 2008, Mineral deposit densities for estimating mineral resources: Mathematical Geosciences, v. 40, no. 1, p. 33-46.

Singer, D.A., and Berger, V.I., 2007, Deposit models and their application in mineral resource assessments, *in* Briskey, J.A., and Schulz, K.J., eds., Proceedings for a Workshop on Deposit Modeling, Mineral Resources Assessment, and Their Role in Sustainable Development, 31st International Geological Congress, Rio de Janeiro, Brazil, August 18-19, 2000: U.S. Geological Survey Circular 1294, p. 71-78. (Also available online at http://pubs.usgs.gov/circ/2007/1294/.)

Singer, D.A., Berger, V.I., Menzie, W.D., and Berger, B.R., 2005, Porphyry copper density: Economic Geology, v. 100, no. 3, p. 491-514.

Singer, D.A., Berger, V.I., and Moring, B.C., 2008, Porphyry copper deposits of the world: database, map, and grade and tonnage models, 2008: U.S. Geological Survey Open-File Report 2008-1155, 45 p., accessed January 15, 2009, at http://pubs.usgs.gov/of/2008/1155/.

Solano-Rico, B., 1995, Some geologic and exploration characteristics of porphyry copper deposits in the Sierra Madre del Sur province, Mexico, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Tucson, Arizona Geological Society Digest, v. 20, p. 545-550.

Staude, J.M., and Barton, M.D., 2001, Jurassic to Holocene tectonics, magmatism, and metallogeny of northwestern Mexico: Geological Society of America Bulletin v. 113, no. 10, p. 1357-1374.

Stewart, Robert, 2008, Technical report on the Cerro del Gallo deposit within the San Antón property Mexico: San Anton Resource Corporation Inc. Web page accessed Feb. 6, 2009, at http://www.sanantonresourcecorp.com/vm/newvisual/attachments/719/Media/SanAntonNI43101ReportJuly2008.pdf.

Titley, S.R. and Zürcher, Lukas, 2008, Regional geology and ore-deposit styles of the trans-border region, southwestern North America, *in* Spencer, J.E. and Titley, S.R.,eds., Ores and orogenesis—Circum-Pacific tectonics, geologic evolution, and ore deposits: Arizona Geological Society Digest 22, p. 275-294.

Torres, Ricardo, Ruiz, Joaquin, Patchett, P.J., and Grajales, J.M., 1999, Permo-Triassic continental arc in eastern Mexico—Tectonic implications for reconstructions of southern North America, *in* Bartolini, C., Wilson, J.L., and Lawton, T.F., eds., Mesozoic sedimentary and tectonic history of north-central Mexico: Geological Society of America Special Paper 340, p. 191-196.

U.S. Geological Survey National Mineral Resource Assessment Team, 2000, 1998 assessment of deposits of gold, silver, copper, lead, and zinc in the United States: U.S. Geological Survey Circular 1178, 21 p.

U.S. Geological Survey Geologic Names Committee, 2007, Divisions of geologic time—Major chronostratigraphic and geochronologic units: U.S. Geological Survey Fact Sheet 2007-3015, 2 p.

U.S. Geological Survey, 2005, Mineral Resources Data System: U.S. Geological Survey, Reston, Virginia, accessed December 15, 2007, at http://tin.er.usgs.gov/mrds/.

Valencia, V.A., Barra, F., Weber, B., Ruiz, J., Gehrels, G., Chesley, J., and Lopez-Martinez, M., 2006, Re/Os and U/Pb geochronology of the El Arco porphyry copper deposit, Baja California Mexico —Implications for the Jurassic tectonic setting: Journal of South America Earth Sciences, v. 22, p. 39-51.

Valencia, V.A., Eastoe, C., Ruiz, J., Ochoa-Landin, L., Gehrels, G., González-Leon, C., Barra, F., and Espinoza, E., 2008, Hydrothermal evolution of the porphyry copper deposit at La Caridad, Sonora, Mexico, and the relationship with a neighboring high-sulfidation epithermal deposit: Economic Geology, v. 103, p. 473-491.

Valencia-Moreno, M., Ochoa-Landín, L., Noguez-Alcántara, B., Ruiz, J., Pérez-Segura, E., M., 2007, Geological and metallogenetic characteristics of the porphyry copper deposits of México and their situation in the world context, *in* Alaniz-Álvarez, S.A., and Nieto-Samaniego, Á.F., eds., Geology of México, celebrating the centenary of the Geological Society of México: Geological Society of America Special Paper 422, p. 433-458.

Virgin Metals, Inc., 2008, Technical Report Los Verdes Project, Sonora México: NI 43-101 Report, 105 p. (Also available online at http://www.virginmetals.com/assets/content/LosVerdes%2043-101.pdf).

Appendixes A–L

Appendix A. Porphyry Copper Assessment for Tract 003pCu3001 (MX-J1), Baja California, Mexico

By Jane M. Hammarstrom[1], Francisco Cendejas-Cruz[2], Enrique Espinosa[2], Floyd Gray[1], Steve Ludington[1], Gilpin R. Robinson, Jr.[1], Efrén Pérez-Segura[3], Martín Valencia-Moreno[4], José Luis Rodríguez-Castañeda[4], Rigoberto Vásquez-Mendoza[2], and Lukas Zürcher[5]

Deposit Type Assessed: Porphyry copper

Descriptive model: Porphyry copper (Cox, 1986; Berger and others, 2008)
Grade and tonnage model: Porphyry copper (Singer and others, 2008)
(Table A1 summarizes selected assessment results)

Location

The tract extends from the U.S. border in California, through the western part of the Mexican state of Baja California, to an area ~30 km south of the border between the states of Baja California and Baja California Sur (fig. A1).

Geologic Feature Assessed

Jurassic-Early Cretaceous island arc(s) of western Baja California, including the western part of the Cretaceous Peninsular Ranges batholith and associated volcanic rocks.

Table A1. Summary of selected resource assessment results for tract 003pCu3001 (MX-J1), Baja California, Mexico.

[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)
May 2008	1	30,260	5,262,880	2,100,000	0

[1]U.S. Geological Survey.
[2]Servicio Geológico Mexicano.
[3]Departamento de Geologia, Iniversidad de Sonora
[4]Estacion Regional del Noroeste, Instituto de Geología, Universidad Nacional Autonoma de Mexico.
[5]University of Arizona.

Delineation of the Permissive Tract

Geologic Criteria

Tract 003pCu3001 includes Jurassic and Early Cretaceous intrusive and volcanic rocks on the western side of the Baja Peninsula (fig. A1). The tract includes exposed plutons in the western zone of the Peninsular Ranges batholith of Baja California, Mexico. Distinct differences in age, composition, and emplacement depth characterize the western and eastern parts of the 800-km-long batholith. The western plutons (140 to 105 Ma) intruded Early Cretaceous volcanic and sedimentary rocks at shallow depths and have relatively primitive island arc geochemical signatures (Gastil and others, 1975; Gastil and others, 1990; Langenheim and Jachens, 2003; Silver and Chappell, 1988; Todd and others, 2003). The eastern zone plutons (La Posta type) are younger, were emplaced at greater depths, and were rapidly exhumed after emplacement. The eastern part of the batholith is not considered to be permissive for porphyry copper deposits because any associated porphyry systems would have been eroded. The western Jurassic-Cretaceous island arc rocks were sutured against North America prior to, or coeval with the emplacement of the eastern part of the batholith between about 120 and 90 Ma (Langenheim and Jachens, 2003).

The tract extends from the U.S.-Mexico border to the southern limit of Jurassic Cretaceous intrusive and volcanic rocks depicted on the 1:500,000 scale maps of Baja California and Baja California Sur (Teràn-Ortega and Maraver-Romero, 2005, 2007). The tract coincides with Terreno Guerrero on these maps, which largely coincides with the Santa Ana terrane of Coney and Campa (1987) or Alisitos terrane of Campa and Coney (1983). This area is shown as SA in western Baja on the terrane map (fig. 2). The southern boundary extends approximately 30 km south of the Baja California Sur border to the area near the El Arco porphyry copper deposit (fig. A1). The tract extends from the Pacific coast on the west to the eastern edge of the terrane boundary, which is essentially coincident with a discontinuity between the western and eastern parts of the Peninsular Ranges batholith. The boundary marks the eastern limit of large gabbro intrusions, separates variably deformed magnetite-bearing plutons on the west from undeformed ilmenite-bearing plutons on the east (Gastil and others, 1975, 1990), and coincides with geochemical and isotopic discontinuities and local shear zones (Silver and Chappell, 1988; Thomson and Girty, 1994; Todd and others, 1988). The west-east discontinuities are less distinct in the southern part of the batholith (Sedlock, 2003). The tract (and terrane) boundary generally corresponds to the eastern limit of a belt of magnetic highs, as depicted on the 1:10,000,000 scale magnetic anomaly map of North America (North American Magnetic Anomaly Group, 2002). Langenheim and Jachens (2003) showed that the 70-km-wide belt of magnetic highs that extends for 1200 km from southern California to the tip of Baja California is associated with the mafic western belt of the Peninsular Ranges batholith, which is well-exposed along the northern 800 km of the belt. Their modeling showed that the anomaly source extends to mid- to lower-crustal levels.

The tectonic setting of the Baja Peninsula has been the subject of extensive debate for more than 30 years. This composite Guerrero terrane includes the Alisitos and Yuma terranes, as defined by Sedlock and others (1993) and Sedlock (2003). The Alisitos terrane consists of Early Cretaceous island arc volcanic and volcaniclastic rocks (mainly the Alisitos Formation) separated from the Mesozoic basin sediments and volcanic arc rocks of the Yuma terrane (Santiago Peak Volcanics) to the north by the NW-trending Agua Blanca fault zone (fig. A2).

Proposed models for the east-west variations across the Peninsular Ranges batholith include a model of a single arc that migrated across an older lithospheric boundary that separated oceanic and continental crust versus composite arc models that call for accretion of fringing or exotic island arcs to the western edge of North America along a suture zone (Sedlock, 2003). Although there is general agreement that the batholith was uplifted and eroded from about 100 to 75 Ma, no consensus has been reached on the processes that led to uplift or the existence and nature of proposed northward transport relative to North America sometime after the mid-Cretaceous and prior to the Cenozoic opening of the Gulf of California (Sedlock, 2003).

The tract was constructed by analyzing a 1:500,000-scale preliminary digital geologic of Mexico (Servicio Geológico Mexicano, written commun., 2007) in ArcGIS, as follows.

Map units were classified into generalized units by age and lithologic class (igneous volcanic, igneous plutonic, sedimentary, metamorphic, unconsolidated) based on principal lithologies associated with each map unit. From this enhanced geology map database, all igneous rocks whose potential age spans include the Jurassic and Early Cretaceous were selected. Areas of potentially permissive rocks of appropriate age under shallow cover (<1 km thick) were considered by creating a 10-km concentric buffer around Jurassic and Early Cretaceous intrusive igneous rocks and a 2-km concentric buffer around Cretaceous volcanic rocks. A preliminary tract was digitized by hand from the buffered permissive rock units. Larger-scale (1:250,000) geologic maps and literature were consulted and used to check map-unit boundaries, ages, and structures. The tract was extended to the west of the buffered, mapped igneous rocks to include the area of Terreno Guerrero, as well as a highly magnetic area, shown on the aeromagnetic map (North American Magnetic Anomaly Group, 2002). The magnetic high anomaly extends to the west of the mapped intrusives; some of the mapped intrusive overlie areas of relative aeromagnetic lows.

Table A2 lists map units selected as the basis for tract 003pCu3001.The tract includes diorite (KsD), granodiorite and tonalite of the western part of the Peninsular Ranges batholith (KsGd-Tn), as well as andesite, volcanic breccia, and dacite of the Santiago Peak Volcanics (KnapA-BvA-Da) and Alisitos Group (KapaA-BvA). All of the mapped Cretaceous volcanic rocks of Baja California lie within the tract. Plutonic and volcanic rocks of known and suspected Jurassic age are exposed in the immediate area of the El Arco porphyry copper deposit. The tract includes the El Arco porphyry (KsPGr) and all younger rocks within a 10-km-wide buffer zone drawn around it, which could conceal deposits at shallow depths (<1 km).

Alteration mapped on the 1:250,000-scale quadrangle maps within the tract includes oxidation, propylitization, and silicification mainly in the southern part of the tract, and argillic alteration and oxidation in areas north and south of the El Socorro prospect (fig. A2).

Stream-sediment geochemical data from the national database (Servicio Geológico Mexicano, written commun., 2007) were adjusted for analytical drift and interpreted. The resulting map (fig. 7) indicates a number of areas within the tract that have a geochemical signature suggestive of porphyry copper deposits.

El Arco was long considered to be an Early Cretaceous pluton associated with the Peninsular Ranges batholith intruded into Cretaceous volcanic, volcaniclastic, and sedimentary rocks of the Alisitos Formation. Recent geochronologic and isotopic studies demonstrate that the age of the porphyritic stock and associated porphyry copper mineralization at El Arco is about 165 Ma, based on Re-Os on molybdenite and U-Pb ages on zircon (Valencia and others, 2006). Previously reported younger K-Ar ages (93 to 138 Ma) reflect an Early Cretaceous greenschist facies thermal overprint related to the intrusion of the Peninsular Ranges batholith (Valencia and others, 2006; Weber and Lopez-Martinez, 2006).

Valencia and others (2006) suggested that the volcanic and plutonic rocks of the El Arco-Calmalli area represent an extension of a Middle to Late Jurassic oceanic-arc system and the Late Triassic ophiolites of the Vizcaino Peninsula and Cedros Island along the west coast of Baja. However, we have designated the Triassic to Jurassic oceanic arc system identified in the Cedros-Vizcaino region (Weber and Lopez-Martinez, 2006) along the coast as a separate tract (003pCu3002). The two tracts are separated by about 60 km of thick unconsolidated Quaternary deposits.

Known Deposits

El Arco (table A3) is the only known Jurassic porphyry copper deposit in Mexico. El Arco is a 1,016 Mt deposit with an average grade of 0.52 percent copper and 0.12 g/t gold (Singer and others, 2008). No copper production is reported, although gold was produced before 1940. The deposit has been thoroughly explored. As of 2007, Grupo Mexico planned to put the deposit into production in 2012 with a goal of producing 190,000 tonnes of copper per year (Daniel, 2007). Subsequently, the property was acquired by Southern Copper Corporation, who announced in 2008 that they are in the process of identifying water sources for a leaching operation; they report indicated resources of 846 Mt of sulfide ore with an average grade of 0.51 percent copper and 0.14 g/t gold and 170 Mt of leachable material with an average grade of 0.56 percent copper (Southern Copper Corporation, 2008).

El Arco is considered to be a classic example of a diorite-type porphyry Cu-Au deposit based on its affinity with an oceanic island arc, granodioritic to monzodioritic composition, and lack of phyllic alteration (Valencia-Moreno and others, 2006). The deposit is centered on a small, hypabyssal monzodioritic to quartz monzodioritic stock that intruded andesite (Coolbaugh and others, 1995; Weber and Lopez-Martinez, 2006; Valencia and others, 2006). Disseminated and vein chalcopyrite is present with bornite, molybdenite, native gold, and magnetite in the potassically-altered core of the stock. Alteration is zoned with outer zones of sodic-calcic and propylitic alteration; sericitic and argillic alteration are absent (Valencia and others, 2006). The deposit is oxidized to a depth of about 50 m.

Geochemical and isotopic data (Sr, Nd, Pb) indicate that the El Arco area rocks record a mantle signature and formed in an oceanic-arc environment without significant contributions from continental crust (Weber and Lopez-Martinez, 2006). These features, as well as the age, distinguish El Arco from the Laramide porphyries of southwest U.S. and mainland Mexico, and from continental Jurassic arc rocks to the east in Sonora.

The El Arco porphyry copper deposit lies within the Calmalli-El Arco mining district. The district appears to be localized by the intersection of regional northwest- and northeast-trending structures (Coolbaugh and others, 1995). Before 1950, gold was produced from small mines and surface workings, mainly by dry methods due to the scarcity of water in the area. El Arco was discovered in 1969 by ASARCO Mexicana, after geological reconnaissance exploration prompted drilling.

Prospects, Mineral Occurrences, and Related Deposit Types

The Arco Sur Au-Cu-Mo prospect is about 5 km southwest of El Arco along the northern edge of a diorite pluton (table A4, figs. A1 and A2). Several other Au-Cu prospects of unknown deposit type are localized along structures within the tract in this area, as shown on the 1:250,000-scale H-12-10 Isla San Esteban geologic map (Romero-Rojas and others, 1998).

Three copper skarn prospects are associated with the tract (fig. A2): (1) San Antonio Del Mar Cu-Au-Fe skarn prospect, (2) Fe-Cu skarns in roof pendants at the San Fernando prospect, where drilling intercepted chalcopyrite, hematite, and magnetite and late tectonic breccias carry elevated gold (Barton and others, 1995; Salas, 1975), and (3) the Evolución prospect in the Santa Ursala area of IOCG and iron skarn prospects of probable Jurassic or Early Cretaceous age. Other copper prospects that may be associated with porphyry copper deposits include Alborada, Esmeralda, and Luciana (fig. A2). Alborada is a small iron, copper, gold occurrence in an area of Cretaceous andesitic volcanics and diorite associated with alteration (Gastélum-Corral and others, 2003; Menchaca De

La Fuente Moises, 1985). Esmeralda, a prospect within an area mapped as Cretaceous granodiorite-tonalite, produced a small amount of copper in the past (Guild, 1981; Salas, 1975). The tract contains more than 50 copper prospects and occurrences, most of which are copper-gold or copper-iron occurrences of uncertain or unknown deposit type (fig. A2). Known deposit types within the tract include iron skarn, iron-oxide-copper-gold (IOCG) deposits, veins, breccias, and porphyry systems. Descriptions of mineralized areas on the 1:250,000-scale maps and deposit type classifications in databases consulted (U.S. Geological Survey, 2005; unpublished University of Arizona-Industry-USGS Mexico Consortium, March 1999 Release Notes) indicate that magmatic, replacement, and contact metasomatic deposits of iron, copper, gold, and silver are possible within the tract.

Exploration History

The tract covers an area that is currently (2008) the focus of extensive exploration and target identification for iron oxide-copper-gold (IOCG) deposits. The area was explored for iron ore deposits by the United Nations in the 1950s, and subsequently explored by the Consejo de Recursos Minerales. Mining districts were described and evaluated in a Geological-mining monograph report for the state of Baja California (Martín-Barajas and Delgado-Argote, 1995). The El Arco porphyry copper deposit was delineated by a drilling program conducted by ASARCO in the 1970s. Reconnaissance geophysical surveys for porphyry copper deposits were conducted in the area in the 1990s, prior to widespread recognition of IOCG deposit characteristics.

Table A2. Map units that define tract 003pCu3001 (MX-J1), Baja California, Mexico.

[Map unit, age range, and principal lithologies from a 1:500,000 scale preliminary digital geologic map of Mexico (Servicio Geológico Mexicana, written commun., 2007); n.d., no data]

Map unit	Maximum age	Minimum age	Lithology1	Lithology2
		Intrusive rocks		
KsGd-Tn	Cretaceous, Late	Cretaceous, Late	granodiorite	tonalite
KsD	Cretaceous, Late	Cretaceous, Late	diorite	n.d.
KsPGr	Cretaceous, Late	Cretaceous, Late	porphyritic granite	n.d.
		Volcanic rocks		
KnapA-BvA-Da	Cretaceous	Cretaceous	andesite	volcanic breccia
KapaA-BvA	Cretaceous	Cretaceous	andesite	volcanic breccia

Table A3. Known porphyry copper deposits in tract 003pCu3001 (MX-J1), Baja California, Mexico.

[Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; Cu-Mo subtype, deposits that have Au/Mo ratios <3 or average Mo grades >0.03 percent; Cu-Au subtype, deposits that have Au/Mo ratios > 30 or average Au grades >0.2 g/t; NA, not applicable; n.d., no data. Contained Cu in metric tons is computed as tonnage (Mt*1,000,000) * Cu grade (%).

Name	Latitude	Longitude	Subtype	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)	Reference
El Arco	28.033	-113.396	NA	165	1,016	0.518	n.d.	0.12	n.d.	5,262,880	Singer and others (2008)

Table A4. Significant prospects and occurrences in tract 003pCu3001 (MX-J1), Baja California, Mexico.

Name	Latitude	Longitude	Age (Ma)	Comments (grade and tonnage data, if available)	Reference
Arco Sur	27.993	-113.428	Jurassic(?)	Porphyry copper prospect reported by SGM	SGM (written commun., 2007), Romero-Rojas and others (1997)

Since that time, IOCG deposits have been the focus of exploration efforts. In 2001-2003, Cardero Resources Corp. identified several IOCG targets in west-central Baja California that lie within the tract, including the Main Alisitos and La Encantada properties located about 30 km northwest of the Esmeralda prospect (fig. A2). The 2003 exploration program included regional geochemistry, geophysics, mapping, and remote sensing which led to identification of 31 IOCG-type target areas for further exploration (Cardero Resources Corp., 2008)

Sources of Information

Principal sources of information used by the assessment team for delineation of tract 003pCu3001 are listed in table A5.

Grade and Tonnage Model Selection

The porphyry copper model of Singer and others (2008) was selected for the assessment based on geologic characteristics of the El Arco deposit and the results of an ANOVA test comparing $\log_{10}$ tonnage, copper grade, and gold grade for El Arco against the global model containing 421 other deposits. The statistical tests showed that El Arco is not significantly different from the global model at the 1-percent level. No molybdenum or silver grades are reported for El Arco, so the applicability of the global model for those commodities could not be tested.

Although El Arco has been described as a Cu-Au deposit (Valencia-Moreno and others, 2007), the reported average gold grade of 0.12 g/t is less than the arbitrary gold-grade criteria (>0.2 g/t or Au/Mo>30) used by Singer and others (2008) to

Table A5. Principal sources of information used by the assessment team for tract 003pCu3001 (MX-J1), Baja California, Mexico.

[NA, not available or not applicable]

Theme	Name or title	Scale	Citation
Geology	Preliminary digital geologic map of the Republic of Mexico	1:500,000	Servicio Geológico Mexicano (written commun., 2007)
	Carta geológica de la República Mexicana	1:2,000,000	Servicio Geológico Mexicano (2007a)
	Carta geólogico-minera, Estado de Baja	1:500,000	Teràn-Ortega and Maraver-Romero (2005)
	Carta geólogico-minera, Estado de Baja California Sur	1:500,000	Teràn-Ortega and Maraver-Romero (2007)
Mineral occurrences	SGM Minas database	NA	Servicio Geológico Mexicano (written commun., 2007b)
	MRDS database	NA	U.S. Geological Survey (2005)
	University of Arizona-Industry-USGS Mexico Consortium	NA	University of Arizona-Industry-USGS Mexico Consortium, March 1999 Release Notes (unpublished)
	Porphyry copper deposits of the world: database, map, and grade and tonnage models	NA	Singer and others (2008)
	Carta y provincias metalogeneticas de la Republica Mexican	NA	Salas (1975)
	Geological and metallogenetic characteristics of the porphyry copper deposits of México and their situation in the world context	NA	Valencia-Moreno and others (2007)
Geochemistry	SGM stream-sediment database	NA	Servicio Geológico Mexicano (written commun., 2007)
Geophysics	North American magnetic map	1:10,000,000	North American Magnetic Anomaly Group (2002)
Exploration	Company Web sites for exploration in Baja; published reports mentioned in the text	NA	Cardero Resources Corp. (2008)

classify deposits as Cu-Au subtype. Therefore, the team concluded that the porphyry copper grade-tonnage model, which includes Cu-Au and Cu-Mo subtypes, was most appropriate for the probabilistic assessment of undiscovered deposits in the tract.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

The team noted that both volcanic and plutonic rocks of Early Cretaceous age occur within the tract. Thus, the area may neither be too deeply eroded nor too deeply buried by volcanic cover to preclude the potential for porphyry copper deposits within 1 km of the surface. The team also considered the possibility that additional Jurassic-age porphyry systems such as El Arco could occur within the western half of the Peninsular Ranges batholith. The fact that the area is currently of interest for IOCG deposits rather than porphyry deposits does not preclude the possibility of undiscovered porphyry deposits. Although fluid sources may be distinct for IOCG mineralization, Williams and others (2005) noted that dioritic Au-rich porphyry copper deposits and associated iron and copper skarns represent deposit types that warrant consideration with respect to genesis of IOCG deposits.

The team attached a level of importance to each copper prospect that might be associated with porphyry copper deposits based on available information. Five potential porphyry-type prospects in the tract ranked low to moderate on the subjective scale. Insufficient data exist to classify the deposit type for many of the 63 other copper prospects within the tract. Alteration styles and stream-sediment geochemical anomalies are consistent with, but not necessarily indicative of, mineralization processes associated with porphyry copper deposits.

The assessment team considered the idea that the northern part of the tract might be better considered permissive for IOCG deposits instead of porphyry copper deposits, but a lack of detailed information about most of the prospects led us to not make that determination.

Approximately 40 percent of the tract area is covered by younger rocks. The team did not use deposit density models (Singer and others, 2005; Singer, 2008) in estimating deposits. Post-assessment comparisons show that our mean estimate of deposit density of 4.9 x 10^{-5} /km^2 (table A6) is relatively low with respect to expected deposits predicted from worldwide porphyry copper tracts using deposit density models. The more conservative consensus estimate by the team reflects the fact that the area has been moderately well-explored during the past 30 years and the uncertainty of deposit-type associations for the many copper prospects in the area.

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 copper model of Singer and others (2008) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, in press,). Selected simulation results are reported in table A7. Results of the Monte Carlo simulation are presented as a cumulative frequency plot (fig. A3). 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. The mean expected amount of copper contained in undiscovered porphyry copper deposits within the tract (2.1 Mt) represents about 38 percent of the identified copper resources in the El Arco deposit.

Table A6. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 003pCu3001 (MX-J1), Baja California, Mexico.

[NXX, estimated number of deposits associated with the xxth percentile; Nund, expected number of undiscovered deposits; s, standard deviation; Cv%, coefficient of variance; Nknown, number of known deposits in the tract that are included in the grade and tonnage model; Ntotal, total of expected number of deposits plus known deposits; area, area of permissive tract in square kilometers; density, deposit density reported as the total number of deposits per km^2. Nund, s, and Cv% are calculated using a regression equation (Singer and Menzie, 2005).]

Consensus undiscovered deposit estimates					Summary statistics					Tract area (km^2)	Deposit density (N_{total}/km^2)
N90	N50	N10	N05	N01	N_{und}	s	Cv%	N_{known}	N_{total}		
0	0	1	3	4	0.48	1	210	1	1.5	30,260	0.000049

Table A7. Results of Monte Carlo simulations of undiscovered resources for tract 003pCu3001 (MX-J1), Baja California, Mexico.

[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	0	0	0	4,200,000	9,100,000	2,100,000	0.14	0.70
Mo	0	0	0	63,000	200,000	58,000	0.11	0.81
Au	0	0	0	84	250	48	0.13	0.79
Ag	0	0	0	630	2,400	660	0.10	0.84
Rock	0	0	0	890	1,900	410	0.15	0.70

References Cited

Barton, M.D., Staude, J.-M.G., Zürcher, L., and Megaw, P.K.M., 1995, Porphyry copper and other intrusion-related mineralization in Mexico, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Tucson, Arizona Geological Society Digest, v. 20, p. 487-524.

Bawiec, W.J., and Spanski, G.T., in press, EMINERS—Economic Mineral Resource Simulator, version 3.0: U.S. Geological Survey Open-File Report 2009-1057, program files and 29-p. Quick-Start Guide.

Berger, B.R., Ayuso, R.A., Wynn, J.C., and Seal, R.R., 2008, Preliminary model of porphyry copper deposits: U.S. Geological Survey Open-File Report 2008-1321, 55 p., accessed May 15, 2009, at http://pubs.usgs.gov/of/2008/1321.

Campa, M.F., and Coney, P.J., 1983, Tectono-stratigraphic terranes and mineral resource distributions in Mexico: Canadian Journal of Earth Sciences, v. 20, p. 1040-1051.

Cardero Resources Corp., 2008, Properties: Cardero Resources Corp Web page accessed May 15, 2009, at http://www.cardero.com/s/Home.asp.

Coney, P.J., and Campa, M.F., 1987, Lithotectonic terrane map of Mexico (West of the 91st Meridian): U.S. Geological Survey Miscellaneous Field Studies Map MF-1874-D, scale 1:2,500,000, 1 sheet.

Coolbaugh, D.F., Hernandez, A.O., Perez, A.E., and Muller, R.M., 1995, El Arco porphyry copper deposit, Baja California, Mexico, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Tucson, Arizona Geological Society Digest 20, p. 525-534.

Cox, D.P., 1986, Descriptive model of porphyry Cu (Model 17), *in* Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 76. (Also available online at http://pubs.usgs.gov/bul/b1693/.)

Daniel, F.J., 2007, UPDATE 3-Major new Grupo Mexico mine to begin output in 2012: Reuters website, accessed August 22, 2008, at http://www.reuters.com/article/bondsNews/idUSN0640844420070606.

Gastélum-Corral, Ramón, Guzmán-Espinoza, J.B., Zamora-Tovar, Eduardo and Ruíz-Romo, Toribio, 2003, Carta geológico-minera, Ensenada H11-2, Baja California [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, scale 1:250,000.

Gastil, R.G., Phillips, R.P., and Allison, E.C., 1975, Reconnaissance geology of the state of Baja California: Geological Society of America Memoir 140, 170 p.

Gastil, R.G., Diamond, J., Knaack, C., Walawander, M., Marshall, M., Boyles, C., Chadwick, B., and Erskine, B., 1990, The problem of the magnetite-ilmenite boundary in southern and Baja California, *in* Anderson, J.J., ed., Geological Society of America Memoir 174, p. 19-32.

Guild, P.W., 1981, Preliminary metallogenic map of North America—Listing of Deposits: U.S. Geological Survey Circular 858-A, 93 p.

Langenheim, V.E., and Jachens, R.C., 2003, Crustal structure of the Peninsular Ranges batholith from magnetic data—Implication for Gulf of California rifting: Geophysical Research Letters v. 30, no. 11, p. 51-1-51-4.

Martín-Barajas, A., and Delgado-Argote, L.A., 1995, Monografía Geológico-Minera de Baja California, 107 p.

Menchaca De La Fuente Moises, J., 1985, Analisis Metalogenetico Regional De La Peninsula De Baja California: Masters Thesis, Universidad Nacional Autónoma, Mexico Facultad De Ingeniera, Mexico City, 158 p.

North American Magnetic Anomaly Group, 2002, Magnetic anomaly map of North America: U.S. Geological Survey Special Map, scale 1:10,000,000, accessed January 15, 2008, at http://pubs.usgs.gov/sm.mag_map/.

Romero-Rojas, S.A., Maraver-Romero, D.A., and de la O-Burrola, Francisco, 1998, Carta geológico-minera, Isla San Esteban H12-10, Baja California y Sonora [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Root, D.H., Menzie, W.D., and Scott, W.A., 1992, Computer Monte Carlo simulation in quantitative resource estimation: Natural Resources Research, v. 1, no. 2, p. 125-138.

Salas, G.P., 1975, Carta y provincias metalogeneticas de la Republica Mexicana: Consejo de Recursos Minerales, publicación 21E, 242 p.

Sedlock, R.L., Ortega-Gutiérrez, F., and Speed, R.C., 1993, Tectonostratigraphic terranes and tectonic evolution of Mexico: Geological Society of America Special Paper 278, 153 p.

Sedlock, R.L., 2003, Geology and tectonics of the Baja California peninsula and adjacent areas, *in* Johnson, S.E., Paterson, S.R., Fletcher, J.M., Girty, G.H., Kimbrough, D.L., and Martín-Barajas, Arturo, eds., Tectonic evolution of northwestern México and the southwestern USA: Geological Society of America Special Paper 374, p. 1-42.

Servicio Geológico Mexicano, 2007a, Carta geológica de la República Mexicana: Servicio Geológico Mexicano, scale 1:2,000,000. (Also available online at http://www.coremisgm.gob.mx/.)

Servicio Geológico Mexicano, 2007b, Base de datos de mineral de cobre de la cartografìa geològico minera, 1:250,000: Subdirección de Geociencia Digital y Documentación Tècnica. (Also available online at http://www.coremisgm.gob.mx/.)

Silver, L.T., and Chappell, B.W., 1988, The Peninsular Ranges batholith—an insight into the evolution of the Cordilleran batholiths of southwestern North America: Transactions of the Royal Society of Edinburgh, Earth Sciences, v. 79, p. 105-121.

Singer, D.A., 2008, Mineral deposit densities for estimating mineral resources: Mathematical Geosciences v. 40, p. 33-36.

Singer, D.A., Berger, V.I., Menzie, W.D., and Berger, B.R., 2005, Porphyry copper density: Economic Geology, v. 100, no. 3, p. 491-514.

Singer, D.A., Berger, V.I., and Moring, B.C., 2008, Porphyry copper deposits of the world—Database, map, and grade and tonnage models, 2008: U.S. Geological Survey Open-File Report 2008-1155, 45 p., accessed January 15, 2009, at http://pubs.usgs.gov/of/2008/1155/.

Singer, D.A., and Menzie, W.D., 2005, Statistical guides to estimating the number of undiscovered mineral deposits—An example with porphyry copper deposits, *in* Cheng, Qiuming, and Bonham-Carter, Graeme, eds., Proceedings of IAMG, The annual conference of the International Association for Mathematical Geology: Geomatics Research Laboratory, York University, Toronto, Canada, p. 1028-1033.

Southern Copper Corporation, 2008, Operations: Southern Copper Corporation Web site accessed April 28, 2008, at http://www.southernperu.com/AboutSCC/Operations/Exploration/tabid/224/Default.aspx.

Teràn-Ortega, L.A., and Maraver-Romero, D.A., compilers, 2005, Carta geólogico-minera, Estado de Baja California: Servicio Geológico Mexicano, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/california.pdf).

Teràn-Ortega, L.A., and Maraver-Romero, David, compilers, 2007, Carta geólogico-minera, Estado de Baja California Sur: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000 (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/california_sur.pdf).

Thomson, C.N., and Girty, G.H., 1994, Early Cretaceous intra-arc ductile strain in Triassic-Jurassic and Cretaceous continental margin rocks, Peninsular Ranges, California: Tectonics, v. 13, no. 5, p. 1108-1119.

Todd, V.R., Erskine, B.G., and Morton, D.G., 1988, Metamorphic and tectonic evolution of the northern Peninsular Ranges batholith, *in* Ernst, W.G., ed., Metamorphism and crustal evolution of the western United States: Rubey Volume VII, Englewood Cliffs, New Jersey. Prentice-Hall, p. 849-937.

Todd, V.R., Shaw S.S., and Hammarstrom, J.M., 2003, Cretaceous plutons of the Peninsular Ranges batholith, San Diego and westernmost Imperial Counties, California—Intrusion across a Late Jurassic continental margin, *in* Johnson, S.E., Paterson, S.R., Fletcher, J.M., Girty, G.H., Kimbrough, D.L., and Martín-Barajas, Arturo, eds., Tectonic evolution of northwestern México and the southwestern USA: Geological Society of America Special Paper 374, p. 185-235.

U.S. Geological Survey, 2005, Mineral Resources Data System: U.S. Geological Survey, Reston, Virginia, accessed December 15, 2007, at http://tin.er.usgs.gov/mrds/.

Valencia-Moreno, M., Ochoa-Landín, L., Noguez-Alcántara, B., Ruiz, J., Pérez-Segura, E., M., 2007, Geological and metallogenetic characteristics of the porphyry copper deposits of México and their situation in the world context, *in* Alaniz-Álvarez, S.A., and Nieto-Samaniego, Á.F., eds., Geology of México—Celebrating the centenary of the Geological Society of México: Geological Society of America Special Paper 422, p. 433-458.

Valencia, V.A., Barra, F., Weber, B., Ruiz, J., Gehrels, G., Chesley, J., and Lopez-Martinez, M., 2006, Re/Os and U/Pb geochronology of the El Arco porphyry copper deposits, Baja California Mexico—Implications for the Jurassic tectonic setting: Journal of South America Earth Sciences, v. 22, p. 39-51.

Weber, Bodo, and Lopez-Martinez, M., 2006, Pb, Sr, and Nd isotopic and chemical evidence for a primitive island arc emplacement of the El Arco porphyry copper deposit (Baja California, Mexico): Mineralium Deposita, v. 40, p. 707-725.

Williams, P.J., Barton, M.D., Johnson, D.A., Fontboté, L., de Haller, A., Mark, G., Oliver, N.H.S., and Marchik, R., 2005, Iron oxide copper-gold deposits—Geology, space-time distribution, and possible modes of origin, *in* Hedenquist, J.W., Thompson, J.F.H., Goldfarb, R.J., and Richards, J.R., eds., Economic Geology, 100th Anniversary Volume: Littleton, Colorado, Society of Economic Geologists, Inc., p.371- 405.

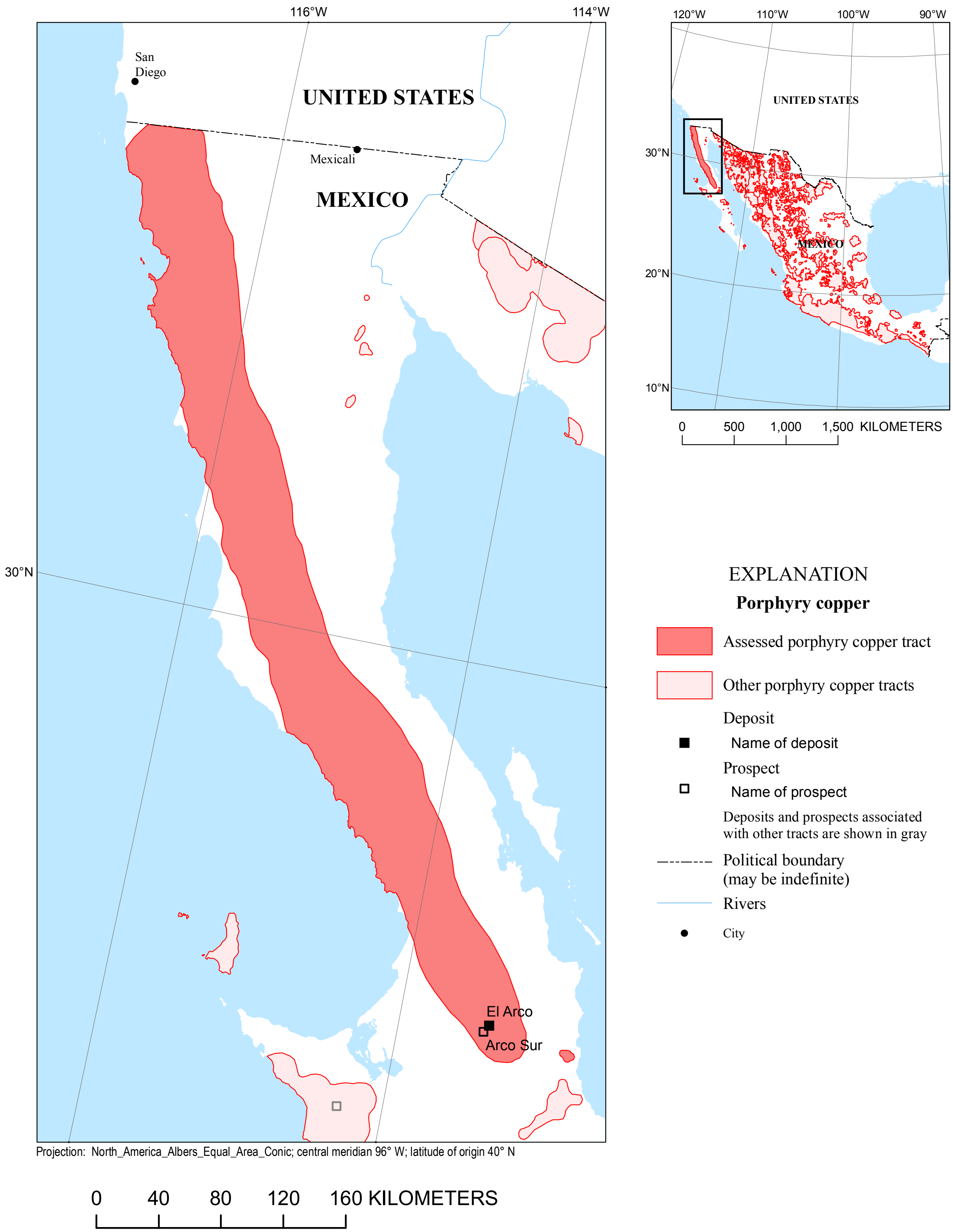


Figure A1. Map showing tract location, known porphyry copper deposits, and significant porphyry copper prospects for tract 003pCu3001 (MX-J1), Baja California, Mexico.

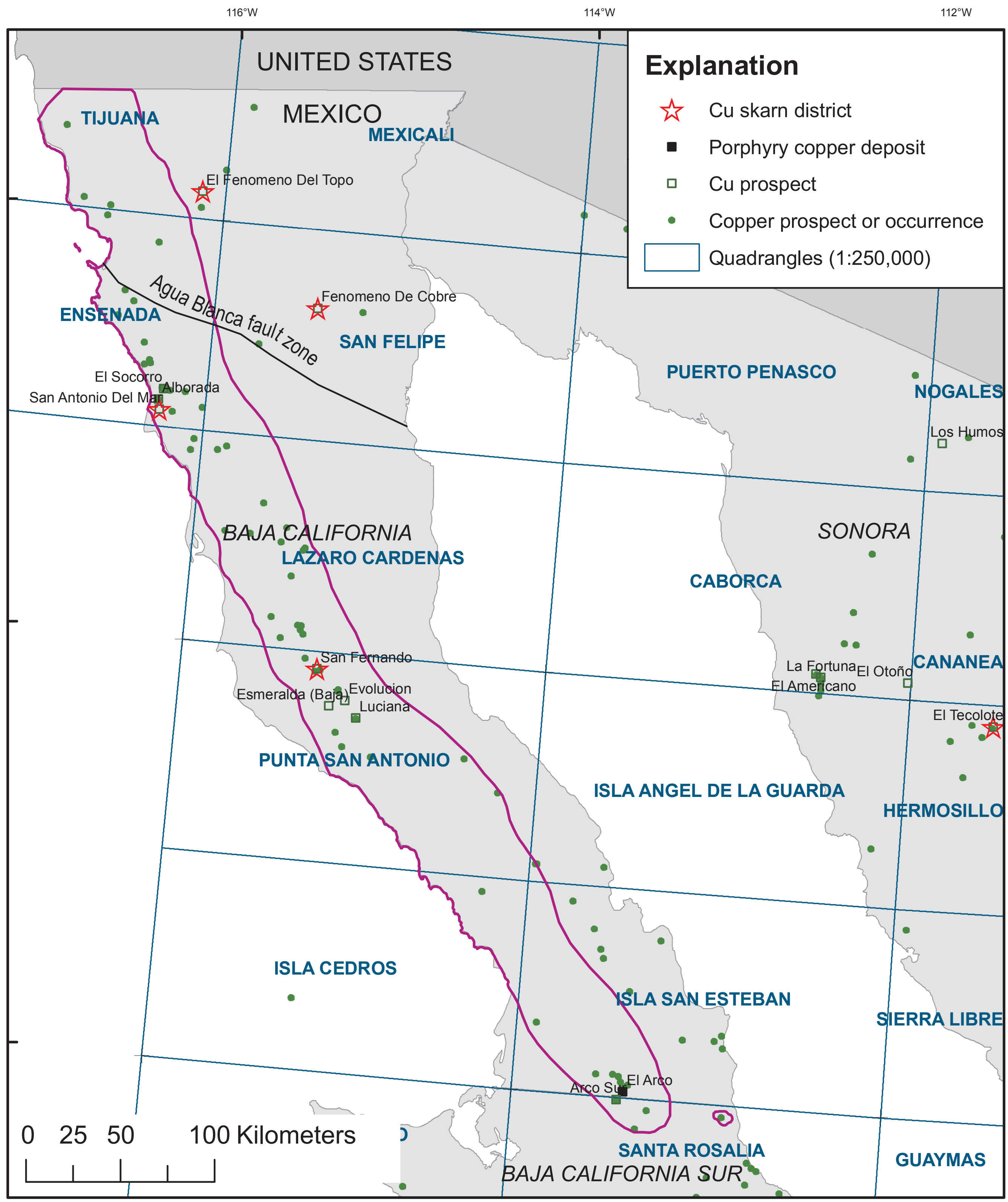


Figure A2. Map showing copper skarn districts, copper prospects and occurrences (all types, ages unknown), and outlines and names of 1:250,000-scale geologic quadrangle maps relative to permissive tract 003pCu3001 (MX-J1), Baja California, Mexico.

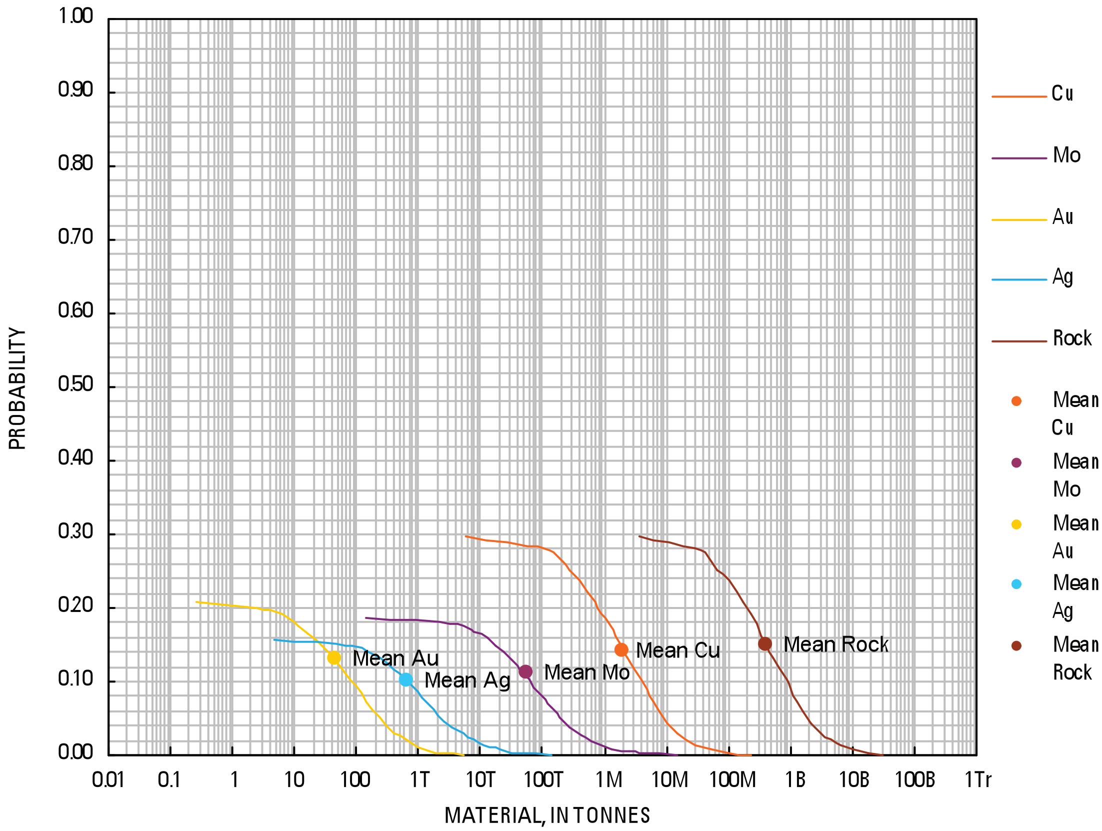


Figure A3. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in tract 003pCu3001 (MX-J1), Baja California, Mexico. T, thousands; M, millions; B, billions; Tr, trillions.

Appendix B. Porphyry Copper Assessment for Tract 003pCu3003 (MX-J2), Sonoran Desert, Mexico

By Jane M. Hammarstrom[1], Francisco Cendejas-Cruz[2], Enrique Espinosa[2], Floyd Gray[1], Steve Ludington[1], Gilpin R. Robinson, Jr.[1], Efrén Pérez-Segura[3], Martín Valencia-Moreno[4], José Luis Rodríguez-Castañeda[4], Rigoberto Vásquez-Mendoza[2], and Lukas Zürcher[5]

Deposit Type Assessed: Porphyry copper

Descriptive model: Porphyry copper (Cox, 1986; Berger and others, 2008)
Grade and tonnage model: Not applicable
(Table B1 summarizes selected assessment results)

Location[6]

The tract is located in the northernmost part of the Sierra Madre Occidental in the state of Sonora (fig. B1).

Geologic Feature Assessed

Mexican part of a Triassic-Jurassic continental magmatic arc in northern Mexico and Arizona.

Table B1. Summary of selected resource assessment results for tract 003pCu3003 (MX-J2), Sonoran Desert, Mexico.

[km, kilometers; km², square kilometers; t, metric tons; n.d., no data]

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)
May 2008	1	19,000	n.d.	n.d.	n.d.

[1]U.S. Geological Survey.
[2]Servicio Geológico Mexicano.
[3]University of Sonora.
[4]Geologic Institute, Universidad Nacional Autónoma de México.
[5]University of Arizona.

[6]MX-J2 is the southern extension of the arc that includes the Bisbee deposit in southern Arizona, as well as other Jurassic porphyry copper deposits farther north. This report outlines criteria for delineation of the tract within Mexico. No probabilistic estimate is included (to be included with U.S. part of the tract).

Table B2. Map units that define tract 003pCu3003 (MX-J2), Sonoran Desert, Mexico.

[Map unit, age range, and principal lithologies from a 1:500,000 scale preliminary digital geologic map of Mexico (Servicio Geológico Mexicana, written commun., 2007); n.d., no data]

Map unit	Maximum age	Minimum age	Lithology 1	Lithology 2
		Intrusive rocks		
TRsGr	Triassic, Late	Triassic, Late	granite	n.d.
JmsGr	Jurassic, Middle	Jurassic, Late	granite	n.d.
		Volcanic rocks		
JimR-Ar-A	Jurassic, Early	Jurassic, Middle	rhyolite	sandstone, andesite

Delineation of the Permissive Tract

Geologic Criteria

Tract 003pCu3003 includes Triassic and Jurassic volcanic and plutonic continental-arc rocks in northern Mexico (fig. B1, table B2). Exposed rocks represent remnants of an arc that extended from the Sonoran desert area of southern California, southern Arizona and northern to central Mexico. The arc has been interpreted as a continental margin magmatic arc that formed along the truncated margin of North America as a result of oblique subduction of the oceanic Kula or Farallon plates beneath the North American craton (Tosdal and others, 1989). The arc setting is largely within Proterozoic North American continental basement. The tract delineates the northwestern part of the mid-Mesozoic arc, mainly northeast of the Mojave-Sonora megashear (fig. 5). The igneous rocks that crop out within the tract in Mexico include Triassic plutons (TRsGr) in northwestern Sonora, as well as Jurassic intrusive (JmsGr) and rhyolitic and andesitic volcanic rocks (JimR-Ar-A). The Middle to Upper Jurassic volcanic rocks and coeval plutons of northern Sonora represent an extension of the Jurassic arc of the western U.S. (fig. 5). The Jurassic arc rocks overlie Paleozoic sedimentary rocks and Mesoproterozoic granitoids (~1.4 to 1.0 Ga) that intruded Paleoproterozoic continental basement. Arc rocks crop out in mountains north of Caborca and Santa Ana in Mexico and in the Sonoran desert of Arizona. The Jurassic arc rocks were deformed and metamorphosed in the Late Cretaceous and Mid-Tertiary and are locally affected by Late Jurassic NW-SE faults that parallel the Mojave-Sonora megashear and form a basin filled by Lower Cretaceous syntectonic and marine sediments (Molina-Garza and Iriondo, 2007).

The eastern and western margins of the tract are defined by eastern and western limits of Triassic and Jurassic plutons and volcanic rocks, as depicted on the 1:500,000-scale digital geology of Mexico and 1:2,000,000-scale geologic map (Servicio Geológico Mexicano, 2007). The tract is truncated at the border for this preliminary report; however, the northern limit of the tract corresponds to the northern limit of Jurassic igneous rocks in the western U.S. The geology is continuous into the western U.S., where a permissive tract for all igneous rocks of Jurassic or younger age was previously delineated in the assessment of the United States (Schruben, 2002). The southern limit of the tract is the southern limit of exposed Jurassic plutons in northwestern Mexico.

In the Cananea district, the Triassic-Jurassic rocks of the Elenita and Henrietta Formations include rhyolitic flows and tuffs interbedded with andesites and sedimentary rocks overlain by 1,500 m of Laramide andesite and dacite (Valencia-Moreno and others, 2007). The Triassic-Jurassic rocks are correlated with the 220-192 Ma Wrightson and Fresnal Canyon Formations of southern Arizona. Jurassic volcanic rocks in Fresnal Canyon in Sonora were dated at 160 to 180 Ma (U-Pb zircon, Stewart and others, 1986). Tosdal and others (1989) described the heterogeneous Jurassic plutonic and hypabyssal rocks of northern Sonora as the Ko Yaya superunit, and noted their close association with coeval volcanic rocks.

The tract includes three small bodies mapped as Middle to Upper Jurassic granite (JmsGr) that lie south of the Mojave-Sonora megashear, which has been interpreted in the past as the truncation of the Jurassic continental arc and a major boundary separating two Precambrian provinces (Silver and Anderson, 1974; Anderson and Schmidt, 1983). Recent studies however, document occurrences of Jurassic volcanic rocks (andesites, rhyolites) and porphyry south of the megashear and challenge the geotectonic significance of the megashear (Molina-Garza and Iriondo, 2007).

The tract was constructed by analyzing the 1:500,000 digital geologic of Mexico (Servicio Geológico Mexicano, written commun., 2007) in ArcGIS, as follows.

Map units were classified into generalized units by age and lithologic class (igneous volcanic, igneous plutonic, sedimentary, metamorphic, unconsolidated) based on principal lithologies associated with each map unit. From this enhanced geology map database, all igneous rocks whose potential age span includes the Triassic and Jurassic were selected.

Areas of potentially permissive rocks under shallow cover (<1 km thick) were considered by creating a 10-km

Table B3. Principal sources of information used by the assessment team for tract 003pCu3003 (MX-J2), Sonoran Desert, Mexico.

[NA, not available or not applicable]

Theme	Name or title	Scale	Citation
Geology	Preliminary digital geologic map of the Republic of Mexico	1:500,000	Servicio Geológico Mexicano (written commun., 2007)
	Carta geológica de la República Mexicana	1:2,000,000	Servicio Geológico Mexicano (2007)
	Carta geólogico-minera, Estado de Sonora	1:500,000	Arriaga-Meléndez and others (2004)
Mineral occurrences	SGM Minas database	NA	Servicio Geológico Mexicano (written commun., 2007)
	MRDS database	NA	U.S. Geological Survey (2005)
	Carta y provincias metalogeneticas de la Republica Mexican	NA	Salas (1975)
	Carta y provincias metalogeneticas de la Republica Mexican	NA	Salas (1975)
	Porphyry copper deposits of the world: database, map, and grade and tonnage models	NA	Singer and others (2008)
	Geological and metallogenetic characteristics of the porphyry copper deposits of México and their situation in the world context	NA	Valencia-Moreno and others (2007)
Geochemistry	SGM stream-sediment database	NA	Servicio Geológico Mexicano (written commun., 2007)
Geophysics	North American magnetic map	1:10,000,000	North American Magnetic Anomaly Group (2002)
Exploration	Geological-mining monograph of the state of Sonora	1:500,000	Consejo de Recursos Minerales (1994)

concentric buffer around igneous rocks and a 2-km concentric buffer around volcanic rocks of appropriate age. A preliminary tract was digitized by hand from the buffered permissive rock units. Plutonic rocks that are younger than Jurassic were displayed. The preliminary tract was edited to exclude (slightly generalized) Cretaceous and Tertiary intrusives, including what appears as a large embayment on the south side of the tract to exclude a large area of Laramide and younger rocks.

Larger-scale (1:250,000) geologic maps and literature were consulted and used to check map unit boundaries, ages, and structures. Tract boundaries delineated on the basis of geology show no apparent correlations with features on the 1:10,000,000-scale aeromagnetic map (North American Magnetic Anomaly Group, 2002). Most parts of the tract are overlapped by Laramide tracts; observed hydrothermal alteration and stream-sediment geochemical anomalies are most likely associated post-Jurassic events.

Known Deposits

There are no known deposits of appropriate age within the tract in Mexico. However, the Jurassic Bisbee porphyry copper deposit in the Warren mining district of southern Arizona occurs within the same Jurassic continental magmatic arc. A number of Jurassic porphyry copper deposits are present in Nevada (for example, Yerington, Ely, Ann Mason, MacArthur, and Contact). We include information about Bisbee in this discussion, because its existence confirms the permissive nature of this arc.

The orebodies at Bisbee are in quartz porphyry, breccia, skarn, and limestone replacements associated with the Sacramento stock intrusive complex (Bryant and Metz, 1966). Damon and others (1983) cite an age of 178 Ma for the Bisbee deposit. From 1956 to 1975, open pit and underground mining produced 96.3 Mt of ore at 1.14 percent copper, 0.057 g/t gold, and 1.63 g/t silver. In 2004, heap leach resources of 250.3 Mt at 0.47 percent copper were reported (Singer and others, 2008).

The undeveloped Cochise deposit, located immediately north of the Lavender pit, contains an estimated 190 Mt of rock containing 0.4 percent acid-soluble copper.

Prospects, Mineral Occurrences, and Related Deposit Types

Many copper, gold, silver, and polymetallic prospects occur within the tract. However, most areas of the tract are coincident with permissive areas and mineral deposits of Laramide age. None of the prospects in the tract can be shown definitively to be Triassic or Jurassic in age.

Exploration History

Most of the area of tract 003pCu3003 is overlapped by the Laramide Western Mexican Basin and Range tract (003pCu3006). The easternmost part of the tract is overlapped by the Laramide Sierra Madre Occidental West tract (003pCu3007), which includes the Cananea mining district. The geographic area is well-explored because of the numerous known Laramide porphyry copper deposits. A summary of the exploration history of the area can be found in the descriptions for those tracts. No pre-Laramide porphyry systems have been identified within the tract area in Mexico. Within the U.S., Entree Gold Inc. announced an agreement with Empirical Discovery LLC in March of 2008 to explore for concealed porphyry copper-gold targets along north-northeast structures in an area north of Bisbee under Cretaceous cover (Entrée Gold, 2008).

The Consejo de Recursos Minerales, precursor to the Servicio Geológico Mexicano, conducted detailed studies of mining districts throughout Mexico on a state-by-state basis. These studies resulted in monographs for each state that include descriptions of the geology, prospects, mining history, sampling results, and potential of mining districts.

Sources of Information

Principal sources of information used by the assessment team for delineation of 003pCu3003 are listed in table B3.

References Cited

Anderson, T.H., and Schmidt, V.A., 1983, The evolution of Middle America and the Gulf of Mexico-Caribbean Sea during Mesozoic time: Geological Society of America Bulletin, v. 94, p. 941-961.

Arriaga-Meléndez, Hilario, López-Escalona, J.J., López-Reyes, J.E., Terán-Ortega, L.A., Castro-Escarrega, J.J., Espinoza-Beltrán, C.C., and Vázquez-Mendoza, Rigoberto, compilers, 2004, Carta Géologico-Minera, Estado de Sonora: Servicio Geológico Mexicano, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/sonora.pdf.)

Berger, B.R., Ayuso, R.A., Wynn, J.C., and Seal, R.R., 2008, Preliminary model of porphyry copper deposits: U.S. Geological Survey Open-File Report 2008-1321, 55 p., accessed May 15, 2009, at http://pubs.usgs.gov/of/2008/1321.

Bryant, D.G., and Metz, H.E., 1966, Geology and ore deposits of the Warren mining district, *in* Titley, S.R., and Hicks, C.L., eds., Geology of the porphyry copper deposits, southwestern North America: Tucson, University of Arizona Press, p. 189–203.

Consejo de Recursos Minerales, 1994, Monografia geologico-minera del estado de Sonora: Consejo de Recursos Minerales Publication M-8e, Pachuca, Hgo., Mexico, 220 p.

Cox, D.P., 1986, Descriptive model of porphyry Cu (Model 17), *in* Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 76. (Also available online at http://pubs.usgs.gov/bul/b1693/.)

Damon, P.E., Shafiqullah, M., and Clark, K.F., 1983, Geochronology of the porphyry copper deposits and related mineralization of Mexico: Canadian Journal of Earth Sciences, v. 20 p. 1052-1071.

Entrée Gold, Inc., 2008, Properties: Entrée Gold, Inc. Web site accessed April 4, 2010 at http://www.entreegold.com/properties/united_states/.

Molina-Garza, R.S., and Iriondo, A., 2007, The Mojave-Sonora megashear— The hypothesis, the controversy, and the current state of knowledge, *in* Alaniz-Álvarez, S.A. and Nieto-Samaniego, A.F., eds., Geology of México—Celebrating the centenary of the Geological Society of México: Geological Society of America Special Paper 422, p. 233-259.

North American Magnetic Anomaly Group, 2002, Magnetic anomaly map of North America: U.S. Geological Survey Special Map, scale 1:10,000,000, accessed January 15, 2008, at http://pubs.usgs.gov/sm.mag_map/.

Salas, G.P., 1975, Carta y provincias metalogeneticas de la Republica Mexicana: Consejo de Recursos Minerales, publicación 21E, 242 p.

Schruben, Paul, (recompiler), 2002, Assessment of undiscovered deposits of gold, silver, copper, lead, and zinc in the United States—A portable document format (pdf) recompilation of USGS OFR 96-96 and Circular 1178, by the National Mineral Resource Assessment Team: U.S. Geological Survey Open-File Report 02-198, one CD-ROM. (Also available online at http://pubs.usgs.gov/of/2002/of02-198/.)

Servicio Geológico Mexicano, 2007, Carta geológica de la República Mexicana: Servicio Geológico Mexicano, scale 1:2,000,000. (Also available online at http://www.coremisgm.gob.mx/.)

Silver, L.T., and Anderson, T.H., 1974, Possible left-lateral early to middle Mesozoic disruption of the southwestern North America craton margin: Geological Society of America Abstracts with Programs, v. 6, no. 7, p. 955-956.

Singer, D.A., Berger, V.I., and Moring, B.C., 2008, Porphyry copper deposits of the world—Database, map, and grade and tonnage models, 2008: U.S. Geological Survey Open-File Report 2008-1155, 45 p., accessed January 15, 2009, at http://pubs.usgs.gov/of/2008/1155/.

Stewart, J.H., Anderson, T.H., Haxel, G.B., Silver, L.T., and Wright, J.E., 1986, Late Triassic paleogeography of the southern Cordillera—The problem of a source for voluminous volcanic detritus in the Chinle Formation of the Colorado Plateau region: Geology, v. 14, p. 567-570.

Tosdal, R.M., Haxel, G.B., and Wright, J.E., 1989, Jurassic geology of the Sonoran Desert region, southern, Arizona, southeastern California, and northernmost Sonora—Construction of a continental-margin magmatic arc, *in* Jenney, J.P., and Reynolds, S.J., eds., Geologic evolution of Arizona: Arizona Geological Society Digest, v. 17, p. 397-434.

U.S. Geological Survey, 2005, Mineral Resources Data System: U.S. Geological Survey, Reston, Virginia, accessed December 15, 2007, at http://tin.er.usgs.gov/mrds/.

Valencia-Moreno, M., Ochoa-Landín, L., Noguez-Alcántara, B., Ruiz, J., Pérez-Segura, E., M., 2007, Geological and metallogenetic characteristics of the porphyry copper deposits of México and their situation in the world context, *in* Alaniz-Álvarez, S.A., and Nieto-Samaniego, Á.F., eds., Geology of México—Celebrating the centenary of the Geological Society of México: Geological Society of America Special Paper 422, p. 433-458.

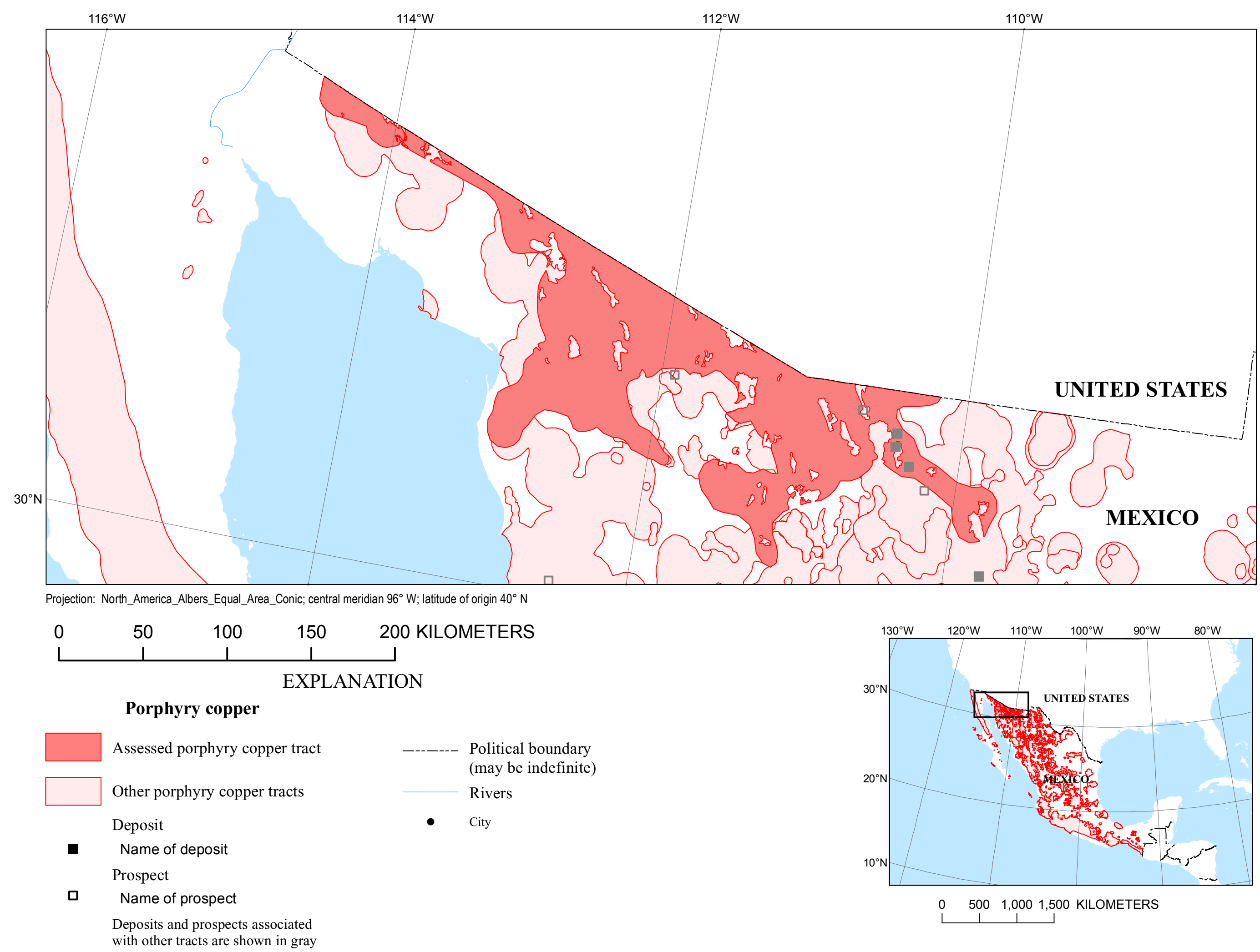


Figure B1. Map showing the location of permissive tract 003pCu3003 (MX-J2), Sonoran Desert, Mexico.

Appendix C. Porphyry Copper Assessment for Tract 003pCu3004 (MX-J3), Guanajuato, Mexico

By Jane M. Hammarstrom[1], Francisco Cendejas-Cruz[2], Enrique Espinosa[2], Floyd Gray[1], Steve Ludington[1], Gilpin R. Robinson, Jr.[1], Efrén Pérez-Segura[3], Martín Valencia-Moreno[4], José Luis Rodríguez-Castañeda[4], Rigoberto Vásquez-Mendoza[2], and Lukas Zürcher[5]

Deposit Type Assessed: Porphyry copper

Descriptive model: Porphyry copper (Cox, 1986; Berger and others, 2008)
Grade and tonnage model: General porphyry copper (Singer and others, 2008)
(Table C1 summarizes selected assessment results)

Location

The tract is along the western margin of the Sierra Madre Oriental on the Mesa Central in southern Chihuahua, eastern Durango, southern Coahuila, Zacatecas, San Luis Potosí, Aguascalientes, Guanajuato, and Puebla in central Mexico (fig. C1).

Geologic Feature Assessed

Late Triassic-Jurassic(?) Nazas magmatic arc rocks in central Mexico.

Table C1. Summary of selected resource assessment results for tract 003pCu3004 (MX-J3), Guanajuato, Mexico.
[km, kilometers; km^2, square kilometers; t, metric tons; n.d., no data]

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)
May 2008	1	26,080	n.d.	1,500,000	0

Delineation of the Permissive Tract

Geologic Criteria

Tract 003pCu3004 (fig. C1) includes a northwest-southeast trend of exposures of Jurassic to Early Cretaceous intrusive and volcanic rocks that may represent remnants of one or more magmatic arcs (fig. 5), tentatively identified as the Nazas arc

[1]U.S. Geological Survey.
[2]Servicio Geológico Mexicano.
[3]University of Sonora.
[4]Geologic Institute, Universidad Nacional Autónoma de México.
[5]University of Arizona.

(Jones and others, 1995; Bartolini and others, 2003). Magmatic arc associations for pre-Tertiary igneous rocks in Mexico are difficult to establish because of the extent of Laramide and Tertiary arc magmatism and Neogene basin and range extension. Subaerial volcanic rocks and associated redbeds in Durango, Zacatecas, San Luis Potosí and areas to the east of those states have been proposed as remnants of a Late Triassic(?) to Middle Jurassic volcanic arc along the active continental margin of western North America that was related to subduction of the Kula Plate (Barboza-Gudino and others, 1998; Campa and Coney, 1983; Dickinson and Lawton, 2001; Bartolini and others, 2003). The arc is delineated by Jurassic volcanic rocks in northeastern Mexico, mainly the Nazas Formation and equivalents (Jones and others, 1995). Jurassic volcanic rocks include pyroclastic flows and lava flows, mainly composed of andesite, rhyolite, and dacite. The Caopas Formation, a porphyritic rhyolite interpreted as a cogenetic subvolcanic pluton within volcanics, was dated by a U-Pb zircon age of 157 $\pm$ 4Ma (Jones and others, 1995). The volcanic rocks in northern Zacatecas represent the most extensive part of the arc identified to date. These Jurassic volcanic rocks may be autochthonous, or more likely, were transported southeastward by left-lateral faulting along the proposed Mojave-Sonora megashear or along other faults, such as the Cohuila-Tamaulipas transform (Jones and others, 1995; Dickinson and Lawton, 2001; Cross, 2007). The megashear zone forms the boundary between the Caborca and Chihuahua terranes (see fig. 2). In the case of displacement, the Jurassic tracts delineated as 003pCu3004 represent a transported segment of, and may be correlative with, permissive tract 003pCu3003 (MX-J2) in northern Sonora and southern Arizona. Bartolini and others (2003) noted that the volcanic, sedimentary, and granitic plutons that comprise the Nazas arc are discontinuously exposed in a southeast-trending belt across north-central Mexico; isotopic ages were reset by the Laramide orogeny, and the arc underwent two phases of subsidence that resulted in thick sedimentary deposits (5- to 7-km thick) over much of the arc area.

The northernmost segments of the tract lie within the Parral terrane (fig. 2), as defined by Campa and Coney (1983); most of the other segments are within the Sierra Madre Oriental and Guerrero-Altiplano terranes.

The 11 polygons that comprise the tract are based on exposed Jurassic plutons and volcanic rocks identified on the geologic map of Mexico. These include Jurassic quartz monzonite (JiqMz) in Chihuahua, granite (JsGr-D) in Durango, Jurassic andesite, rhyolite and polymictic conglomerate of the Nazas-Rodeo Formation (JimA-R-Cgp) in Durango, andesite and andesitic tuff of the Chilitos Formation (JtKa(?)A-TA) in Zacatecas and western San Luis Potosí, the Cerro Pelon tonalite (JsTn) in Guanajuato, and Jurassic granite (JcGr-D) in Puebla.

The tract was constructed by analyzing the 1:500,000 digital geologic of Mexico (Servicio Geológico Mexicano, written commun., 2007) in ArcGIS, as follows.

Map units were classified into generalized units by age and lithologic class (igneous volcanic, igneous plutonic, sedimentary, metamorphic, unconsolidated) based on principal lithologies associated with each map unit.

From this enhanced geology map database, all igneous rocks whose potential age span includes the Jurassic and Early Cretaceous were selected. The enhanced geology file was sorted by the first and second lithologies associated with the mapped units to remove areas of non-permissive rocks. A group of andesite-limestone-sandstone map units in Durango, Sinaloa, Chihuahua, and Sonora were excluded because they are believed to represent ocean-floor volcanism with no associated plutonic activity.

Table C2 lists map units selected as the basis for tract 003pCu3004. Areas of potentially permissive Jurassic rocks under shallow cover (<1 km thick) were considered by creating a 10-km concentric buffer around Jurassic plutonic rocks and a 2-km concentric buffer around Jurassic-Cretaceous volcanic rocks.

A preliminary tract was digitized by hand from the buffered permissive rock units. Plutonic rocks that are younger than Jurassic were displayed. The preliminary tract was edited to exclude most plutonic rocks younger than Jurassic and to include some upper Cretaceous rocks (table C2).

Larger-scale (1:250,000) geologic maps and literature were consulted and used to check map-unit boundaries, ages, and structures. Tract boundaries delineated on the basis of geology show no apparent correlations with features on the 1:10,000,000-scale aeromagnetic map (North American Magnetic Anomaly Group, 2002). The tract polygons follow the northwesterly trend of the Late Triassic-Middle Jurassic arc outlined by Bartolini and Mickus (2001), based on interpretation of geologic information, drill-hole data, and isostatic gravity anomalies. Their study indicated that the present-day width of the magmatic arc is greater than 150 km (affected by younger tectonism). They also noted that Cretaceous carbonate rocks and Tertiary volcanic rocks cover most of the arc, and, locally, 3 to 4 km of Upper Jurassic to Upper Cretaceous strata cover the Triassic-Jurassic arc rocks.

We also examined 1:250,000 scale geologic maps published by the Servicio Geológico Mexicano for the areas included in the tract to be sure that we had included any mapped areas of hydrothermal alteration that might be indicative of porphyry copper deposits (fig. 8*C*). Two areas so depicted are associated with the northwestern part of the tract that overlaps the borders of the states of Zacatecas, San Luis Potosí, and Aguas Calientes.

Stream-sediment geochemical data from the national database (Servicio Geológico Mexicano, written commun., 2007) indicates number of areas within and adjacent to the tract with a geochemical signature compatible with porphyry copper deposits (fig. 7).

Many parts of the tract are overlapped by Laramide or Tertiary tracts; observed hydrothermal alteration and stream-sediment geochemical anomalies are likely associated post-Jurassic events. The reported thickness (>2,500 m) and an intra-arc basin setting for the deposition of the volcanic and pyroclastic rocks of the Nazas Formation that define the arc suggest that permissive rocks for porphyry copper deposits in the arc may be deeply buried.

Table C2. Map units that define tract 003pCu3004 (MX-J3), Guanajuato, Mexico.

[Map unit, age range, and principal lithologies from a 1:500,000 scale preliminary digital geologic map of Mexico (Servicio Geológico Mexicana, written commun., 2007); n.d., no data]

Map unit	Maximum age	Minimum age	Lithology 1	Lithology 2
		Intrusive rocks		
JiqMz	Jurassic, Early	Jurassic, Early	quartz monzonite	n.d.
JsGr-D	Jurassic, Late	Jurassic, Late	granite	n.d.
KsGr	Cretaceous, Late	Cretaceous, Late	granite	n.d.
JsTn	Jurassic, Late	Jurassic, Late	tonalite	n.d.
KapaD	Cretaceous	Cretaceous	diorite	n.d.
JcGr-D	Jurassic	Jurassic	granite	n.d.
KvGd	Cretaceous	Cretaceous	granodiorite	n.d.
		Volcanic rocks		
JimA-R-Cgp	Jurassic, Early	Jurassic, Middle	andesite	rhyolite
JtKaA-Ar-Cz	Jurassic	Cretaceous	andesite	sandstone
KmR	Cretaceous, Middle	Cretaceous, Middle	rhyolite	n.d.
JtKa(?)A-TA	Jurassic	Cretaceous?	andesite	andesite tuff
JsB	Jurassic, Late	Jurassic, Late	basalt	n.d.

Known Deposits

There are no deposits of the appropriate age in this part of Mexico.

Prospects, Mineral Occurrences, and Related Deposit Types

Most of the tract is at least partly coincident with, or adjacent to, Laramide or Tertiary tracts. No copper prospects in the area can unequivocally be related to Jurassic igneous activity, although some occurrences of epithermal Pb-Zn veins and Cu-Fe skarns are spatially associated with the tract in areas that do not overlap younger tracts. The tract area includes more than 200 prospects and occurrences of a variety of deposit types, mainly polymetallic Ag-Pb-Zn veins, carbonate hosted veins and skarns, volcanic-hosted epithermal Au-Ag veins, polymetallic veins, including antimony- and tin-bearing varieties. None of these are correlated with Jurassic porphyry systems.

Exploration History

The Consejo de Recursos Minerales, precursor to the Servicio Geológico Mexicano, conducted detailed studies of mining districts throughout Mexico on a state-by-state basis. These studies resulted in monographs for each state that include descriptions of the geology, prospects, mining history, sampling results, and potential of mining districts. The Jurassic tracts are partly coincident with some well-explored mining districts where exploration and mine development historically focused on silver-rich deposits associated with younger rocks; however, we know of no exploration conducted with the aim of identifying Jurassic porphyry copper systems.

Sources of Information

Principal sources of information used by the assessment team are listed in table C3.

Grade and Tonnage Model Selection

The porphyry copper model of Singer and others (2008) was selected for the assessment. No statistical tests were performed because there are no identified porphyry copper deposits of this age within the tract.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

The tract area consists of 11 discrete areas that may represent dissected parts of a single arc. No porphyry copper deposits are known within the tract. Intrusive rocks of appropriate age are not well exposed. The area is covered by volcanics and younger Cretaceous miogeoclinal rocks. Alteration in the tract can be ascribed to Tertiary events and does not appear to be intimately associated with Jurassic rocks.

A favorable indicator for porphyry copper deposits is that the igneous compositions and the presence of both volcanic

Table C3. Principal sources of information used by the assessment team for tract 003pCu3004 (MX-J3), Guanajuato, Mexico.

[NA, not available or not applicable]

Theme	Name or title	Scale	Citation
Geology	Preliminary digital geologic map of the Republic of Mexico	1:500,000	Servicio Geológico Mexicano (written commun., 2007)
	Carta geológica de la República Mexicana	1:2,000,000	Servicio Geológico Mexicano (2007a)
	Carta geólogico-minera, Estado de Durango	1:500,000	López-Escalona and others (2006)
	Carta geólogico-minera, Estado de Chihuahua	1:500,000	Salinas-Prieto and others (2004)
	Carta geólogico-minera, Estado de San Luis Potosí	1:500,000	Maldonado-Lee and others (2007)
	Carta geólogico-minera, Estado de Aguascalientes y Zacatecas	1:500,000	López-Escalona and others (2007)
	Carta geólogico-minera, Estados de Guanajuato	1:500,000	López-Reyes and others (2007)
	Carta geólogico-minera, Estados de Puebla	1:500,000	Montiel-Escobar and others (2007)
Mineral occurrences	SGM Minas database	NA	Servicio Geológico Mexicano (written commun., 2007b)
	MRDS database	NA	U.S. Geological Survey (2005)
	University of Arizona-Industry-USGS Mexico Consortium	NA	University of Arizona-Industry-USGS Mexico Consortium, March 1999 Release Notes (unpublished)
	Porphyry copper deposits of the world: database, map, and grade and tonnage models	NA	Singer and others (2008)
	Carta y provincias metalogeneticas de la Republica Mexican	NA	Salas (1975)
	Geological and metallogenetic characteristics of the porphyry copper deposits of México and their situation in the world context	NA	Valencia-Moreno and others (2007)
Geology, mineral occurrences and exploration	Geological-mining monograph of the state of Zacatecas	1:500,000	Consejo de Recursos Minerales (1992)
	Geological-mining monograph of the state of Durango	1:500,000	Consejo de Recursos Minerales (1993)
	Geological-mining monograph of the state of Puebla	1:500,000	Consejo de Recursos Minerales (1995)
	Geological-mining monograph of the state of Guanajuato	1:500,000	Consejo de Recursos Minerales (1992b)
	Geological-mining monograph of the state of San Luis Potosí	1:500,000	Consejo de Recursos Minerales (1992c)
Geochemistry	SGM stream-sediment database	NA	Servicio Geológico Mexicano (written commun., 2007)
Geophysics	North American magnetic map	1:10,000,000	North American Magnetic Anomaly Group (2002)
	Gravity data for northeast-central Mexico	NA	Bartolini and Mickus (2001)

Table C4. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 003pCu3004 (MX-J3), Guanajuato, Mexico.

[NXX, estimated number of deposits associated with the xxth percentile; Nund, expected number of undiscovered deposits; s, standard deviation; Cv%, coefficient of variance; Nknown, number of known deposits in the tract that are included in the grade and tonnage model; Ntotal, total of expected number of deposits plus known deposits; area, area of permissive tract in square kilometers; density, deposit density reported as the total number of deposits per km^2. Nund, s, and Cv% are calculated using a regression equation (Singer and Menzie, 2005).]

Consensus undiscovered deposit estimates					Summary statistics					Tract area (km^2)	Deposit density (N_{total}/km^2)
N90	N50	N10	N05	N01	N_{und}	s	Cv%	N_{known}	N_{total}		
0	0	1	2	3	0.41	0.82	200	0	0.41	26,080	0.000016

Table C5. Results of Monte Carlo simulations of undiscovered resources in 003pCu3004, Mexico.

[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	0	0	0	3,200,000	7,000,000	1,500,000	0.16	0.69
Mo	0	0	0	52,000	160,000	40,000	0.11	0.81
Au	0	0	0	74	210	41	0.13	0.80
Ag	0	0	0	420	1,800	520	0.09	0.85
Rock	0	0	0	710	1,500	300	0.17	0.69

rocks and plutons demonstrate that, at least in some areas, an appropriate level of exposure for porphyry deposits is preserved. Volcanics are known to be >2,500-m thick in some places, thin in others. Plutons include granodiorite, tonalite, and granite. The team concluded that the tract area is permissive for undiscovered porphyry systems of Jurassic age, but that there was, at most, a 10-percent chance of 1 or more undiscovered deposits (table C4). Our estimate (1.6 x 10^{-5}deposits/km^2) is low with respect to worldwide porphyry copper tracts of similar areal extent (fig. 11) based on deposit density models (Singer and others, 2005; Singer, 2008).

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 copper model of Singer and others (2008) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, in press). Selected simulation results are reported in table C5. Results of the Monte Carlo simulation are presented as cumulative frequency plots (fig. C2). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

References Cited

Barboza-Gudino, J.R., Tristán-González, Margarito, and Torres-Hernández, J.R., 1998, The Late Triassic-Early Jurassic active continental margin of western North America in northeastern Mexico: Geofisica Internacional, v. 37, no. 4, p. 238-292.

Bartolini, Claudio, and Mickus, Kevin, 2001, Tectonic blocks, magmatic arcs, and oceanic terrains—A preliminary interpretation based on gravity, outcrop, and subsurface data, northeast-central Mexico, *in* Bartolini, C., Buffler, R.T., Blickwede, J., and Cantú-Chapa, eds., The western Gulf of Mexico Basin—Tectonics, sedimentary basins, and petroleum systems: American Association of Petroleum Geologists Memoir 75, p. 29-43.

Bartolini, C., Lanf, H., and Spell, T., 2003, Geochronology, geochemistry, and tectonic setting of the Mesozoic Nazas arc in north-central Mexico, and its continuation to northern South America, *in* Bartolini, C., Buffler, R.T., Blickwede, J., eds., The circum-Gulf of Mexico and the Caribbean—Hydrocarbon habitats, basin formation, and plate tectonics: American Association of Petroleum Geologists Memoir 79, p. 427-461.

Bawiec, W.J., and Spanski, G.T., in press, EMINERS—Economic Mineral Resource Simulator, version 3.0: U.S. Geological Survey Open-File Report 2009-1057, program files and 29-p. Quick-Start Guide.

Berger, B.R., Ayuso, R.A., Wynn, J.C., and Seal, R.R., 2008, Preliminary model of porphyry copper deposits: U.S. Geological Survey Open-File Report 2008-1321, 55 p., accessed May 15, 2009, at http://pubs.usgs.gov/of/2008/1321.

Campa, M.F., and Coney, P.J., 1983, Tectono-stratigraphic terranes and mineral resource distributions in Mexico: Canadian Journal of Earth Sciences, v. 20, p. 1040-1051.

Consejo de Recursos Minerales, 1992a, Geological-mining monograph of the State of Zacatecas: Consejo de Recursos Minerales Publication M-2e, Pachuca, Hgo., Mexico, 154 p.

Consejo de Recursos Minerales, 1992b, Geological-mining monograph of the State of Guanajuato: Consejo de Recursos Minerales Publication M-6e, Pachuca, Hgo., Mexico, 136 p.

Consejo de Recursos Minerales, 1992c, Geological-mining monograph of the State of San Luis Potosí: Consejo de Recursos Minerales Publication M-7e, Pachuca, Hgo., Mexico, 281 p.

Consejo de Recursos Minerales, 1993, Monografia Geologico-Minera del estado de Durango: Consejo de Recursos Minerales Publication M-10e, Pachuca, Hgo., Mexico, 204 p.

Consejo de Recursos Minerales, 1995, Monografia Geologico-Minera del estado de Puebla: Consejo de Recursos Minerales Publication M-16e, Pachuca, Hgo., Mexico, 139 p.

Cox, D.P., 1986, Descriptive model of porphyry Cu (Model 17), *in* Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 76. (Also available online at http://pubs.usgs.gov/bul/b1693/.)

Cross, G.E., 2007, Testing the Mojave-Sonora megashear hypothesis in northeastern and north-central Mexico using the spatial distribution of Late Triassic-Middle Jurassic volcanic arc rocks, accessed April 29, 2008 at http:www.geo.utexas.edu/courses/371c/project/2007_Fall/Cross/Cross.htm/.

Dickinson, W.R., and Lawton, T.F., 2001, Carboniferous to Cretaceous assembly and fragmentation of Mexico: Geological Society of America Bulletin 113, p. 1142-1160.

Entrée Gold, Inc., 2008, Entrée Gold, Inc.Web page accessed December 15, 2008, at http://www.entreegold.com/properties/united_states/.

Jones, N.W., McKee, J.W., Anderson, T.H., and Silver, L.T., 1995, Jurassic volcanic rocks in northeastern Mexico—A possible remnant of a Cordilleran magmatic arc, *in* Jacques-Ayala, C., González-León, C.M., and Roldán-Quintana, J., eds., Studies on the Mesozoic of Sonora and Adjacent Areas: Geological Society of America Special Paper 301, p. 179-190.

López-Escalona, Juan, Espinoza-Beltrán, Carlos, Díaz-Salgado, C.C., and Castro-Escárrega, J.J., compilers, 2006, Carta geólogico-minera, Estado de Durango: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/durango.pdf.)

López-Escalona, Juan, Montiel-Escobar, J.E., Dorantes-Salgado, Enrique, Jiménez-Gonzaga, J.A., and Diaz-Salgado, C.C., compilers, 2007, Carta geólogico-minera, Estado de Aguascalientes y Zacatecas: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/zacatecas.pdf.)

López-Reyes, J.E. and de la Calleja-Moctezuma, Alfredo, compilers, 2007, Carta geólogico-minera, Estados de Guanajuato y Querétaro: Servicio Geológico Mexicano, sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/gto_queretaro.pdf.)

Maldonado-Lee, J.M., Reyes-Reyes, N.A., de la Calleja-Moctezuma, Alfredo, Barajas-Nigoche, L.D., and Montiel-Escobar, J.J., compilers, 2007, Carta geólogico-minera, Estado de San Luis Potosí: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/slp.pdf.)

Molina-Garza, R.S., and Iriondo, A., 2007, The Mojave-Sonora megashear— The hypothesis, the controversy, and the current state of knowledge, *in* Alaniz-Álvarez, S.A., and Nieto-Samaniego, A.F., eds.,Geology of México—Celebrating the centenary of the Geological Society of México: Geological Society of America Special Paper 422, p. 233–259.

Montiel-Escobar, José, López-Reyes, Julian, de la Calleja-Moctezuma, Alfredo, Ney-Aranda, José, and Bastida-Jimenez, Raymundo, compilers, 2007, Carta geólogico-minera, Estados de Puebla y Tlaxcala: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/puebla_tlxa.pdf.)

Niemuth, N.J., 1994, The primary copper industry of Arizona, 1992: Arizona Department of Mines and Mineral Resources SR-20, 58 p.

North American Magnetic Anomaly Group, 2002, Magnetic anomaly map of North America: U.S. Geological Survey Special Map, scale 1:10,000,000, accessed January 15, 2008, at http://pubs.usgs.gov/sm.mag_map/.

Root, D.H., Menzie, W.D., and Scott, W.A., 1992, Computer Monte Carlo simulation in quantitative resource estimation: Natural Resources Research, v. 1, no. 2, p. 125-138.

Salas, G.P., 1975, Carta y provincias metalogeneticas de la Republica Mexicana: Consejo de Recursos Minerales, publicación 21E, 242 p.

Salinas-Prieto, J.C., Arriaga-Meléndez, Hiliaro, López-Reyes, J.E., Montiel-Escobar, J.E., Terán-Ortego, L.A., Lebrado-Flores, José, and Amezcua-Torres, Natalia, compilers, 2004, Carta Geólogico-Minera, Estado de Chihuahua: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/chihuahua.pdf.)

Servicio Geológico Mexicano, 2007a, Carta geológica de la República Mexicana: Servicio Geológico Mexicano, scale 1:2,000,000. (Also available online at http://www.coremisgm.gob.mx/.)

Singer, D.A., 2008, Mineral deposit densities for estimating mineral resources: Mathematical Geosciences, v. 40, no. 1, p. 33-46.

Singer, D.A., Berger, V.I., Menzie, W.D., and Berger, B.R., 2005, Porphyry copper density: Economic Geology, v. 100, no. 3, p. 491-514.

Singer, D.A., Berger, V.I., and Moring, B.C., 2008, Porphyry copper deposits of the world—Database, map, and grade and tonnage models, 2008: U.S. Geological Survey Open-File Report 2008-1155, 45 p., accessed January 15, 2009, at http://pubs.usgs.gov/of/2008/1155/.

Singer, D.A., and Menzie, W.D., 2005, Statistical guides to estimating the number of undiscovered mineral deposits—An example with porphyry copper deposits, *in* Cheng, Qiuming, and Bonham-Carter, Graeme, eds., Proceedings of IAMG, The annual conference of the International Association for Mathematical Geology: Geomatics Research Laboratory, York University, Toronto, Canada, p. 1028-1033.

U.S. Geological Survey, 2005, Mineral Resources Data System: U.S. Geological Survey, Reston, Virginia, accessed December 15, 2007, at http://tin.er.usgs.gov/mrds/.

Valencia-Moreno, M., Ochoa-Landín, L., Noguez-Alcántara, B., Ruiz, J., Pérez-Segura, E., M., 2007, Geological and metallogenetic characteristics of the porphyry copper deposits of México and their situation in the world context, *in* Alaniz-Álvarez, S.A., and Nieto-Samaniego, Á.F., eds., Geology of México—Celebrating the centenary of the Geological Society of México: Geological Society of America Special Paper 422, p. 433-458.

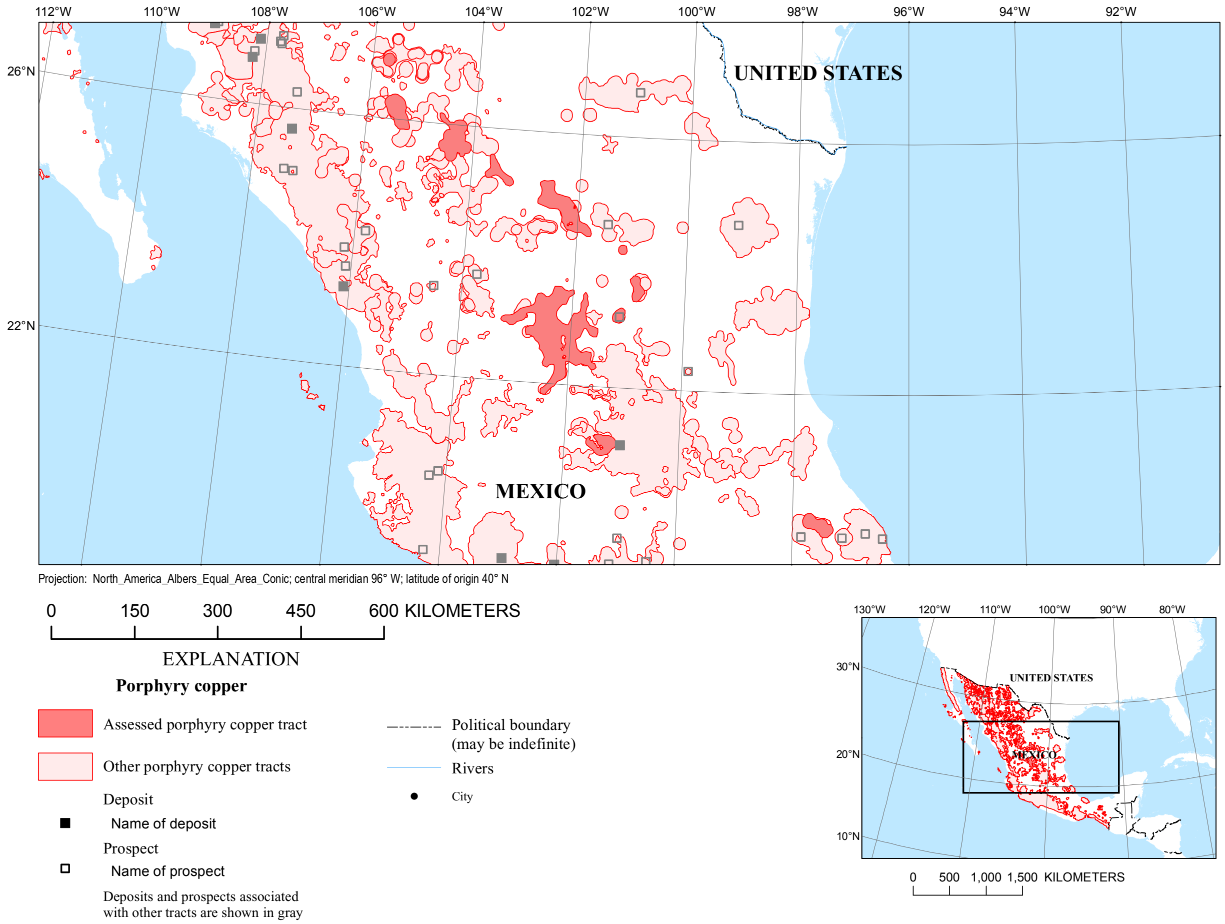


Figure C1. Map showing the location of permissive tract 003pCu3004 (MX-J3), Guanajuato, Mexico. No known deposits or significant porphyry copper prospects are associated with the tract.

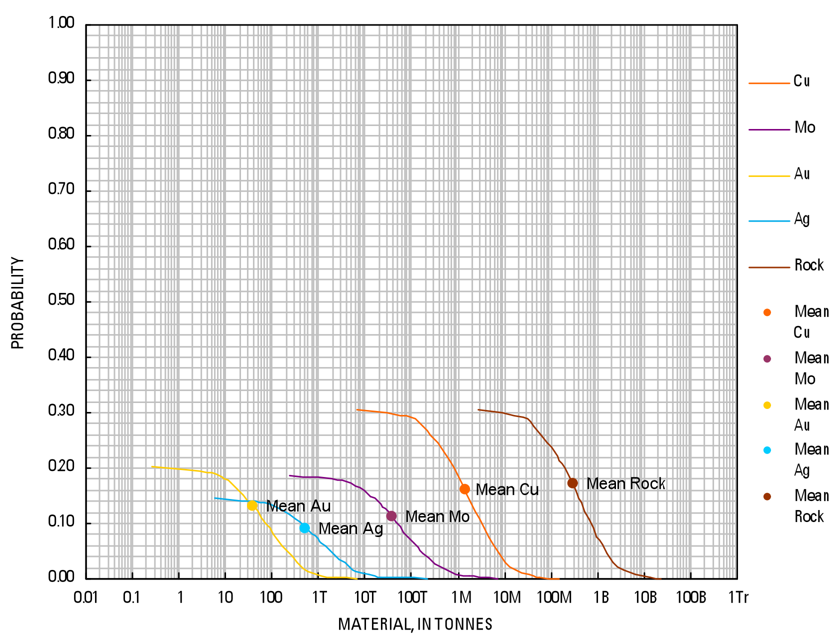


Figure C2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in tract 003pCu3004 (MX-J3), Guanajuato, Mexico. T, thousands; M, millions; B, billions; Tr, trillions.

Appendix D. Porphyry Copper Assessment for Tract 003pCu3005 (MX-J4), Balsas, Mexico

By Jane M. Hammarstrom[1], Francisco Cendejas-Cruz[2], Enrique Espinosa[2], Floyd Gray[1], Steve Ludington[1], Gilpin R. Robinson, Jr.[1], Efrén Pérez-Segura[3], Martín Valencia-Moreno[4], José Luis Rodríguez-Castañeda[4], Rigoberto Vásquez-Mendoza[2], and Lukas Zürcher[5]

Deposit Type Assessed: Porphyry copper

Descriptive model: Porphyry copper (Cox, 1986; Berger and others, 2008)
Grade and tonnage model: General porphyry copper (Singer and others, 2008)
(Table D1 summarizes selected assessment results)

Location

The tract is in the Sierra Madre del Sur in southwestern Mexico. It includes substantial parts of the Balsas River Basin, and parts of the states of Michoacán, México, Guerrero, Oaxaca, and Puebla (fig. D1).

Geologic Feature Assessed

Jurassic-Early Cretaceous Teloloapan volcanic arc in the Guerrero terrane of southwestern Mexico.

Delineation of the Permissive Tract

Table D1. Summary of selected resource assessment results for tract 003pCu3005 (MX-J4), Balsas, Mexico.

[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)
May 2008	11,810	12,440	3,000,000	1,200,000	0

Geologic Criteria

Tract 003pCu3005 includes Jurassic and Cretaceous plutons and volcanic rocks in the Sierra Madre del Sur, south of the Trans-Mexican Volcanic Belt (fig. 3, fig. D1). This tract lies primarily within the southern part of the Guerrero terrane and partly

[1]U.S. Geological Survey.
[2]Servicio Geológico Mexicano.
[3]University of Sonora.
[4]Geologic Institute, Universidad Nacional Autónoma de México.
[5]University of Arizona.

in the Mixteca Este terrane (fig. 2). The Guerrero terrane is a complex, poorly understood amalgamation of subterranes that likely represent a series of arcs that were accreted to the continent in Laramide time. The southern Guerrero and Mixteca arc assemblages are coeval with the Alisitos arc in Baja California.

Most of the porphyry copper deposits and prospects in the Sierra Madre del Sur are associated with post-90 Ma calcalkaline Laramide intrusions that parallel the subducting plate margin along the coast and along a parallel belt ~120 km inland (Solano-Rico, 1995; Miranda-Gasca, 2000). Pre-Laramide magmatic activity in the area is not well constrained**.** However, the recent documentation of a Lower Cretaceous age (140 to 131 Ma) for a porphyritic pluton associated with the Tiámaro porphyry copper prospect in Michoacán confirms that pre-Laramide rocks host this type of mineral deposit in southwestern Mexico (Garza-Gonzalez and others, 2006).

The tract consists of four discrete polygons (fig. D1). Three areas in the western part of the tract are based on intrusive rocks (KsGr-Gd). Just to the east, the north-south-trending segment of the tract in central Guerrero is based on buffered areas around outcrops of formations of cover rocks on the Teloloapan volcanic arc that include meta-andesites (KnapMA-Ar) (Salinas-Prieto, 2007). These rocks are termed the Villa de Ayala Formation (coeval with the arc) and the Acapetlahuaye Formation (sedimentary cover on the arc). The tectonic interpretation of the calcalkalic rocks and exact location of the Jurassic-Cretaceous arc(s) are uncertain; the area has been affected by Late Cretaceous to Paleogene thrust faulting (Cabral-Cano and others, 2000). The Teloloapan subterrane of the Guerrero terrane is a 100-km-wide by 300-km-long, north-south- trending belt of rocks interpreted as an evolved, intra-oceanic arc that includes a high-K calcalkaline magmatic suite (Mendoza and Suastegui, 2000). The tectonic evolution of the Teloloapan arc and the adjacent oceanic arcs subterranes that constitute the Guerrero composite terrane are not well established. During the Late Mesozoic, a complex arc-trench system analogous to the modern eastern Pacific is envisioned for the area based on constraints on provenance from recent detrital zircon studies on Upper Jurassic-Cretaceous volcano-sedimentary rocks (Talavera-Mendoza and others, 2007). The tract was constructed by analyzing the 1:500,000-scale digital geologic of Mexico (Servicio Geológico Mexicano, 2007) in ArcGIS, as follows.

Map units were classified into generalized units by age and lithologic class (igneous volcanic, igneous plutonic, sedimentary, metamorphic, unconsolidated) based on principal lithologies associated with each map unit. From this enhanced geology map database, all igneous rocks whose potential age span includes the Jurassic and Early Cretaceous were selected. Areas of potentially permissive Jurassic-Cretaceous rocks under shallow cover (<1 km thick) were considered by creating a 10-km concentric buffer around Jurassic igneous rocks and a 2-km concentric buffer around Jurassic volcanic rocks. A preliminary tract was digitized by hand from the buffered permissive rock units.

Plutonic rocks that are younger than Jurassic were displayed. The preliminary tract was edited to exclude (slightly generalized) Laramide intrusive rocks. Map units included in the tract are listed in table D2.

Larger-scale (1:250,000) geologic maps and literature were consulted and used to check map unit boundaries, ages, and structures. Tract boundaries delineated on the basis of geology show no apparent correlations with features on the 1:10,000,000-scale aeromagnetic map (North American Magnetic Anomaly Group, 2002); some polygons enclose or partly overlie magnetic highs.

Stream-sediment geochemical data from the national database (Servicio Geológico Mexicano, written commun., 2007) indicates a number of areas within the three largest tract polygons that have a geochemical signature indicative of porphyry copper deposits (fig. 7).

We also examined 1:250,000 scale geologic maps published by the Servicio Geológico Mexicano (SGM) of the areas included in the tract to be sure that we had included any mapped areas of hydrothermal alteration that might be indicative of porphyry copper deposits (fig. 8*C*). Several areas so depicted are contained within the northernmost tract polygon as delineated.

Known Deposits

The Tiámaro Cu-Au porphyry deposit is one of a number of quartz monzonitic and granodioritic porphyry-type deposits hosted by metasedimentary rocks and andesites in the Guerrero Terrane (Miranda-Gasca, 2000). Porphyry-type mineralization in south-Central Mexico was assumed to be Eocene-Oligocene in age until recent studies documented a Lower Cretaceous age of 140 to 131 Ma (U-Pb zircon) for hypabyssal tonalite at Tiámaro and a $^{40}Ar/^{39}Ar$ age of 140±5 Ma on sericite from a nearby zone of phyllic alteration in microgranite at the El Rey mine (Garza-González and others, 2006). Tiámaro consists of stockworks in tonalite, adamellite, granite-tonalite overprinted by propylitic, phyllic, and argillic alteration. Garza-González and others (2006) noted that most of the copper ore is associated with phyllic alteration as stockworks of pyrite-chlacopyrite± bornite correlated with fluid inclusions temperatures in the range 300 to 350 degrees Celsius. They suggested that studied parts of the deposit may represent the uppermost, lower temperature portions of a larger system. Red conglomerates cap the volcanoplutonic complex, which has trace-element geochemical affinities to primitive tholeiites typical of an island arc setting. The porphyritic andesite, subvolcanic breccias, agglomerates, and dacite flows overlain by red conglomerates form a volcano-plutonic complex intruded by the Tuzantla batholith (quartz monzonite to granodiorite with calcalkaline affinity). Modern drilling focused on an area between the abandoned El Rey and El Cuervo mines (active in 19th century). Garza-González and others (2006) reported a resource estimate of

Table D2. Map units that define tract 003pCu3005 (MX-J4), Balsas, Mexico.

[Map unit, age range, and principal lithologies from a 1:500,000 scale preliminary digital geologic map of Mexico (Servicio Geológico Mexicana, written commun., 2007); n.d., no data]

Map unit	Maximum age	Minimum age	Lithology 1	Lithology 2
Intrusive rocks				
KhD	Cretaceous	Cretaceous	diorite	n.d.
KsGr-Gd	Cretaceous, Late	Cretaceous, Late	granite	granodiorite
J(?)D	Jurassic?	Jurassic?	diorite	n.d.
JiGr	Jurassic, Early	Jurassic, Early	granite	n.d.
Volcanic rocks				
KnapMA-Ar	Cretaceous	Cretaceous	metaandesite	sandstone
KnapA-BvA	Cretaceous	Cretaceous	andesite	volcanic breccia
KbevA-Cgo	Cretaceous	Cretaceous	andesite	oligomictic conglomerate

Table D3. Known porphyry copper deposits in tract 003pCu3005 (MX-J4), Balsas, Mexico.

[Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; Cu-Mo subtype, deposits that have Au/Mo ratios <3 or average Mo grades >0.03 percent; Cu-Au subtype, deposits that have Au/Mo ratios >30 or average Au grades >0.2 g/t; NA, not applicable; n.d., no data. Contained Cu in metric tons is computed as tonnage (Mt*1,000,000) * Cu grade (%).]

Name	Latitude	Longitude	Subtype	Age (Ma)	Tonnage (Mt)	Grade				Contained Cu (t)	Reference
						Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)		
Tiámaro	19.217	-100.483	NA	131	500	0.60	n.d.	0.1	n.d.	3,000,000	Garza-González and others (2006)

500 Mt with average grade of 0.60 percent copper and 0.1 g/t gold for Tiámaro, and noted that the perspective on the richest ore zones is likely to change as deeper zones of the deposit are drilled (table D3).

Prospects, Mineral Occurrences, and Related Deposit Types

Most of the areas included in the tract are also included within Tertiary tract 003pCu3001 (southwest Mexico). The ages of many of the rocks in the overlap area are not well known, and the ages of the mineral deposits and prospects are even less well known. A few prospects (El Cabrigo I and II, San Francisco) included in the SGM database and described by Montiel-Escobar and others (1998) occur in zones of mapped alteration within 2 km of Tiámaro and likely represent parts of the same mineralized system. Middle Jurassic to Early Cretaceous VMS deposits border the easternmost tract area; geochemical signatures of VMS deposits in this part of the Guerrero terrane suggest that they formed in a back-arc or mixed-arc setting (Mortensen and others, 2008).

Exploration History

The Consejo de Recursos Minerales, precursor to the SGM, conducted detailed studies of mining districts throughout Mexico on a state-by-state basis. These studies resulted in monographs for each state that include descriptions of the geology, prospects, mining history, sampling results, and potential of mining districts. The tract area covers parts of the states of Michoacán, Guerrero, and an area along the Puebla-Oaxaca border. The monographs describe exploration by the Consejo, as well as exploration by private companies up to the mid-1990s. The identification of Tiámaro as a Cretaceous deposit will likely spur renewed exploration for porphyry deposits in the area. Soltoro Ltd. (2008) reported an application for the 1,371 hectare Margarita claim at the Tiámaro property with mention of a September 2008 sampling plan; no results were available to the assessment team.

Table D4. Principal sources of information used by the assessment team for tract 003pCu3005 (MX-J4), Balsas, Mexico.

[NA, not available or not applicable]

Theme	Name or title	Scale	Citation
Geology	Preliminary digital geologic map of the Republic of Mexico	1:500,000	Servicio Geológico Mexicano (written commun., 2007)
	Carta geológica de la República Mexicana	1:2,000,000	Servicio Geológico Mexicano (2007a)
	Carta geólogico-Minera, Distrito Federal, Estados de México y Morelos	1:500,000	Montiel-Escobar and others (2007a)
	Carta geólogico-minera, Distrito Federal, Estados de Michoacán	1:500,000	Montiel-Escobar and others (2007b)
	Carta geólogico-minera, Estados de Guerrero	1:500,000	Montiel-Escobar and others (2007c)
	Carta geólogico-minera, Estado de Oaxaca	1:500,000	Montiel-Escobar and others (2007d)
	Carta geólogico-minera, Estados de Puebla y Tlaxcala	1:500,000	Montiel-Escobar and others (2007e)
Mineral occurrences	SGM Minas database	NA	Servicio Geológico Mexicano (written commun., 2007b)
	MRDS database	NA	U.S. Geological Survey (2005)
	University of Arizona-Industry-USGS Mexico Consortium	NA	University of Arizona-Industry-USGS Mexico Consortium, March 1999 Release Notes (unpublished)
	Porphyry copper deposits of the world: database, map, and grade and tonnage models	NA	Singer and others (2008)
	Carta y provincias metalogeneticas de la Republica Mexican	NA	Salas (1975)
	Geological and metallogenetic characteristics of the porphyry copper deposits of México and their situation in the world context	NA	Valencia-Moreno and others (2007)
Geochemistry	SGM stream-sediment database	NA	Servicio Geológico Mexicano (written commun., 2007)
Geophysics	North American magnetic map	1:10,000,000	North American Magnetic Anomaly Group (2002)
Exploration	Geological-mining monograph of the state of Michoacán	1:500,000	Consejo de Recursos Minerales (1995a)
	Geological-mining monograph of the state of Guererro	1:500,000	Consejo de Recursos Minerales (1999)
	Geological-mining monograph of the state of Puebla	1:500,000	Consejo de Recursos Minerales (1995b)
	Proyectos de Compañias Extranjeras por Estado	NA	Dirección General de Promoción Minera (2005)

Table D5. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 003pCu3005 (MX-J4), Balsas, Mexico.

[NXX, estimated number of deposits associated with the xxth percentile; Nund, expected number of undiscovered deposits; s, standard deviation; Cv%, coefficient of variance; Nknown, number of known deposits in the tract that are included in the grade and tonnage model; Ntotal, total of expected number of deposits plus known deposits; area, area of permissive tract in square kilometers; density, deposit density reported as the total number of deposits per km². Nund, s, and Cv% are calculated using a regression equation (Singer and Menzie, 2005).]

Consensus undiscovered deposit estimates					Summary statistics					Tract Area (km²)	Deposit density (N_{total}/km²)
N90	N50	N10	N05	N01	N_{und}	s	Cv%	N_{known}	N_{total}		
0	0	1	1	2	0.33	0.62	190	1	1.3	11,810	0.00011

Table D6. Results of Monte Carlo simulations of undiscovered resources in tract 003pCu3005 (MX-J4), Balsas, Mexico.

[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	0	0	0	2,400,000	5,300,000	1,200,000	0.15	0.71
Mo	0	0	0	32,000	120,000	35,000	0.10	0.83
Au	0	0	0	49	140	30	0.12	0.82
Ag	0	0	0	280	1,300	400	0.09	0.88
Rock	0	0	0	530	1,100	240	0.16	0.71

Sources of Information

Principal sources of information used by the assessment team for delineation of 003pCu3005 are listed in table D4.

Grade and Tonnage Model Selection

The porphyry copper model of Singer and others (2008) was selected for the assessment. Tiámaro is open at depth and is not included in the deposit compilation of Singer and others (2008). Partial resource estimates for the Tiámaro prospect based on drilling suggest that the porphyry copper model is appropriate based on ANOVA tests. The tonnage reported is 500 Mt and the copper grade is 0.60 percent. The average gold grade reported for Tiámaro is <0.2 g/t gold, and no molybdenum is reported.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

The tract consists of four discrete areas that outline intrusive and(or) volcanic or volcaniclastic rocks of appropriate age. Although parts of the tract are associated with mapped areas of alteration typical of porphyry-copper deposits, as well as areas of stream-sediment geochemistry that exhibit medium and high correlations with porphyry-type systems, it is more likely that most of these features are associated with mineralization processes of Tertiary age. Tertiary permissive tract 003pCu3011 (Southwest Mexico) largely overlaps the Jurassic-Lower Cretaceous tract. The recent determination of a Lower Cretaceous age at Tiámaro, however, suggests that the deposits of this age may be present in this part of Mexico. The complex tectonics, thick sequences of volcanics and sediments, occurrences of Kuroko-type VMS deposits in the Teloloapan and adjacent subterranes (Miranda-Gasca, 2000), and paucity of exposed plutons are pessimistic factors for porphyry copper deposits. The team estimated at most a 10-percent chance for 1 undiscovered deposit (table D5). The low estimate and high uncertainty reflect the lack of good indicators of porphyry copper mineralization of this age within 1 km of the surface on the basis of available data.

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 copper model of Singer and others (2008) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, in press). Selected simulation results are reported in table D6. Results of the Monte Carlo simulation are presented as cumulative frequency plots (fig. D2). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

References Cited

Bawiec, W.J., and Spanski, G.T., in press, EMINERS—Economic Mineral Resource Simulator, version 3.0: U.S. Geological Survey Open-File Report 2009-1057, program files and 29-p. Quick-Start Guide.

Berger, B.R., Ayuso, R.A., Wynn, J.C., and Seal, R.R., 2008, Preliminary model of porphyry copper deposits: U.S. Geological Survey Open-File Report 2008-1321, 55 p., accessed May 15, 2009, at http://pubs.usgs.gov/of/2008/1321.

Cabral-Cano, E., Lang, H.R., and Harrison, C.G.A., 2000, Stratigraphic assessment of the Arcelia-Teloloapan area, southern Mexico—Implications for southern Mexico's post-Neocomian tectonic evolution: Journal of South America Earth Sciences, v. 13, p. 443-457.

Consejo de Recursos Minerales, 1995a, Geological-mining monograph of the State of Michoacán: Consejo de Recursos Minerales Publication M-15e, Pachuca, Hgo., Mexico, 176 p.

Consejo de Recursos Minerales, 1995b, Geological-mining monograph of the State of Puebla: Consejo de Recursos Minerales Publication M-16e, Pachuca, Hgo., Mexico, 139 p.

Consejo de Recursos Minerales, 1999, Geological-mining monograph of the State of Guerrero: Consejo de Recursos Minerales Publication M-19a, Pachuca, Hgo., Mexico, 281 p.

Cox, D.P., 1986, Descriptive model of porphyry Cu (Model 17), *in* Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 76. (Also available online at http://pubs.usgs.gov/bul/b1693/.)

Dirección General de Promoción Minera, 2005, Proyectos de Compañias Extranjeras por Estado: Dirección General de Promoción Minera, Ministry of the Economy [Mexico] Web site, accessed January 15, 2008, at http://www.economia.gob.mx/?P=1537.

Garza-González, Carlos, Camprubí, Antoni, González-Partida, Eduardo, Arriaga-García, Germán, and Rosique-Naranjo, Fernando, 2006, Hydrothermal alteration and fluid inclusion study of the Lower Cretaceous porphyry Cu-Au deposit of Tiámaro, Michoacán, Mexico: Journal of Geochemical Exploration, v. 889, p. 124-128.

Mendoza, O.T., and Suastegui, M.G., 2000, Geochemistry and isotopic composition of the Guerrero Terrane (western Mexico)—Implications for the tectono-magmatic evolution of southwestern North America during the Late Mesozoic: Journal of South American Earth Sciences, v. 13, p. 297-324.

Miranda-Gasca, M.A., 2000, The metallic ore-deposits of the Guerrero Terrane, western Mexico—An overview: Journal of South American Earth Sciences, v. 13, p. 403-413.

Montiel-Escobar, José, Librado-Flores, José, Salazar-Reyes, Joaquín, Bustamante-García, Jorge, and Sánchez-Garrido, Eduardo, 1998, Carta geológico-minera, Morelia E14-1, Guanajuato, Michoacán, and Estado de Mexico [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Montiel-Escobar, J.E., Bastida-Jiménez, Raymundo, and Aranda-Osorio, J.N., compilers, 2007a, Carta geólogico-minera, Distrito Federal, Estados de México y Morelos: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/df_mex_morelos.pdf.)

Montiel-Escobar, J.E., Aranda-Osorio, J.N. and Bastida-Jiménez, Raymundo, compilers, 2007b, Carta géologico-minera, Estado de Michoacán: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/michoacan.pdf.)

Montiel-Escobar, J.E., Aranda-Osorio, J.N. and Bastida-Jiménez, Raymundo, compilers, 2007c, Carta géologico-minera, Estados de Guerrero: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/guerrero.pdf.)

Montiel-Escobar, J.E., Bastida-Jiménez, Raymundo, Aranda-Osorio, J.N., and Dorantes-Salgado, Enrique, compilers, 2007d, Carta geólogico-minera, Estado de Oaxaca: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/oaxaca.pdf.)

Montiel-Escobar, José, López-Reyes, Julian, de la Calleja-Moctezuma, Alfredo, Ney-Aranda, José, and Bastida-Jimenez, Raymundo, compilers, 2007e, Carta geólogico-minera, Estados de Puebla y Tlaxcala: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/puebla_tlxa.pdf.)

Mortensen, J. K., Hall, B.V., Bissig, T., Freidman, R.M., Danielson, T., Oliver, J., Rhys, D.A., Ross, K.V., and Gabites, J.E., 2008, Age and paleotectonic setting of volcanogenic massive sulfide deposits in the Guerrero terrane of central

Mexico—Constraints from U-Pb and Pb isotope studies: Economic Geology, v. 103, p. 117-140.

North American Magnetic Anomaly Group, 2002, Magnetic anomaly map of North America: U.S. Geological Survey Special Map, scale 1:10,000,000, accessed January 15, 2008, at http://pubs.usgs.gov/sm.mag_map/.

Root, D.H., Menzie, W.D., and Scott, W.A., 1992, Computer Monte Carlo simulation in quantitative resource estimation: Natural Resources Research, v. 1, no. 2, p. 125-138.

Salas, G.P., 1975, Carta y provincias metalogeneticas de la Republica Mexicana: Consejo de Recursos Minerales, publicación 21E, 242 p.

Salinas-Prieto, Juan Carlos, 2007, Análisis de la deformación dúctil en la región Norte del estado de Guerrero: Revista del Servicio Geológico Mexicano, Ano 1, no. 2, p. 5-25.

Servicio Geológico Mexicano, 2007a, Carta geológica de la República Mexicana: Servicio Geológico Mexicano, scale 1:2,000,000. (Also available online at http://www.coremisgm.gob.mx/.)

Singer, D.A., Berger, V.I., Menzie, W.D., and Berger, B.R., 2005, Porphyry copper density: Economic Geology, v. 100, no. 3, p. 491-514.

Singer, D.A., Berger, V.I., and Moring, B.C., 2008, Porphyry copper deposits of the world—Database, map, and grade and tonnage models, 2008: U.S. Geological Survey Open-File Report 2008-1155, 45 p., accessed January 15, 2009, at http://pubs.usgs.gov/of/2008/1155/.

Singer, D.A., and Menzie, W.D., 2005, Statistical guides to estimating the number of undiscovered mineral deposits—An example with porphyry copper deposits, *in* Cheng, Qiuming, and Bonham-Carter, Graeme, eds., Proceedings of IAMG, The annual conference of the International Association for Mathematical Geology: Geomatics Research Laboratory, York University, Toronto, Canada, p. 1028-1033.

Solano-Rico, B., 1995, Some geologic and exploration characteristics of porphyry copper deposits in the Sierra Madre del Sur province, Mexico, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Tucson, Arizona Geological Society Digest, v. 20, p. 545-550.

Soltoro Ltd., 2008, Management discussion and analysis: Soltoro Ltd. Web page accessed January 15, 2009, at http://www.soltoro.com/pdf/MDASEP08.pdf.

Talavera-Mendoza, Oscar, Ruiz, J., Gehrels, G.E., Valencia, V.A., and Centano-García, E., 2007, Detrital zircon U/Pb geochronology of southern Guerrero and western Mixteca arc successions (southern Mexico)—New insights for the tectonic evolution of southwestern North America during the late Mesozoic: Bulletin of the Geological Society of America, v. 199, no. 9-10, p. 1052-1065.

U.S. Geological Survey, 2005, Mineral Resources Data System: U.S. Geological Survey, Reston, Virginia, accessed December 15, 2007, at http://tin.er.usgs.gov/mrds/.

Valencia-Moreno, M., Ochoa-Landín, L., Noguez-Alcántara, B., Ruiz, J., Pérez-Segura, E., M., 2007, Geological and metallogenetic characteristics of the porphyry copper deposits of México and their situation in the world context, *in* Alaniz-Álvarez, S.A., and Nieto-Samaniego, Á.F., eds., Geology of México—Celebrating the centenary of the Geological Society of México: Geological Society of America Special Paper 422, p. 433-458.

Yañez, P., Ruiz, J., Patchett, P.J., Ortega-Gutierrez, F., and Gehrels, G.E., 1991, Isotopic studies of the Acatlan complex, southern Mexico—Implications for Paleozoic North American tectonics: Bulletin of the Geological Society of America, v. 103, p. 817-828.

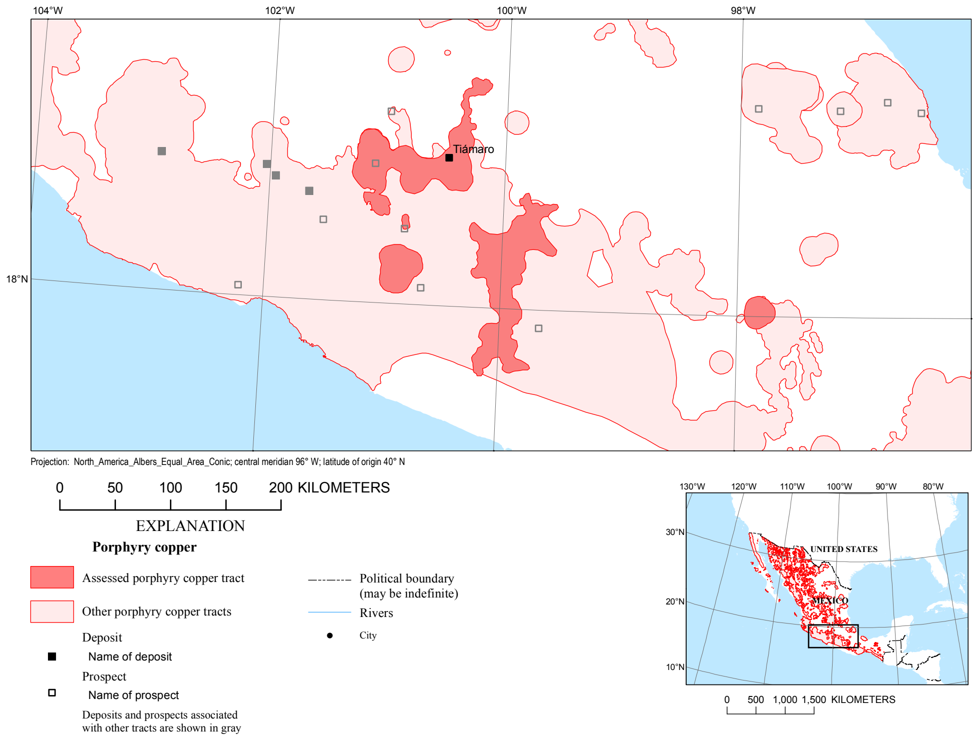


Figure D1. Map showing the location of permissive tract 003pCu3005 (MX-J4), Balsas, Mexico, the Tiámaro deposit, and significant porphyry copper prospects in adjacent tracts.

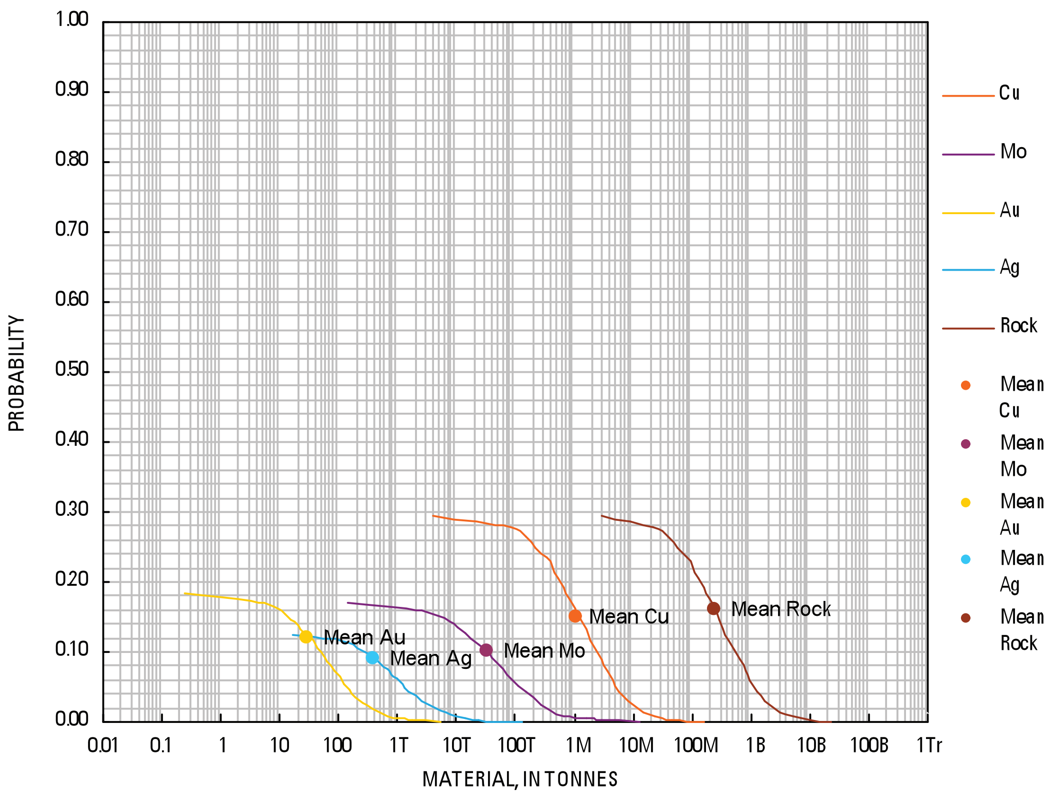


Figure D2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in tract 003pCu3005 (MX-J4), Balsas, Mexico. T, thousands; M, millions; B, billions; Tr, trillions.

Appendix E. Porphyry Copper Assessment for Tract 003pCu3002 (MX-J5), Coastal Baja California, Mexico

By Jane M. Hammarstrom[1], Francisco Cendejas-Cruz[2], Enrique Espinosa[2], Floyd Gray[1], Steve Ludington[1], Gilpin R. Robinson, Jr.[1], Efrén Pérez-Segura[3], Martín Valencia-Moreno[4], José Luis Rodríguez-Castañeda[4], Rigoberto Vásquez-Mendoza[2], and Lukas Zürcher[5]

Deposit Type Assessed: Porphyry copper

Descriptive model: Porphyry copper (Cox, 1986; Berger and others, 2008)
Grade and tonnage model: General porphyry copper (Singer and others, 2008)
(Table E1 summarizes selected assessment results)

Location

The tract includes the Vizcaino Peninsula, Cedros Island, and San Benitos Islands along the Pacific Coast of western Baja California, Mexico (fig. E1).

Geologic Feature Assessed

Jurassic-Upper Cretaceous magmatic arc rocks (San Andres-Cedros Complex) along the Pacific coast of Baja California Sur, Mexico.

Table E1. Summary of selected resource assessment results for tract 003pCu3002 (MX-J5), Coastal Baja California, Mexico.

[km, kilometers; km^2, square kilometers; t, metric tons; n.d., no data]

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)
May 2008	1	2,910	n.d.	1,500,000	0

Delineation of the Permissive Tract

Geologic Criteria

Tract 003pCu3002 (fig. E1) delineates Jurassic-Cretaceous island arc rocks that intruded through Triassic ophiolite basement exposed west of the Peninsular Ranges along the Pacific Coast of Baja California Sur. The tract lies within the composite

[1]U.S. Geological Survey.
[2]Servicio Geológico Mexicano.
[3]University of Sonora.
[4]Geologic Institute, Universidad Nacional Autónoma de México.
[5]University of Arizona.

Vizcaino terrane (fig. 2) of Coney and Campa (1987). The 10 polygons (some very small) that constitute the tract include Jurassic-Cretaceous granodiorite-tonalite plutons, Jurassic granite plutons, Jurassic diorite plutons, and Jurassic andesitic volcanics of the Gran Cañon-Choyal formation (JimA-TA-BvA) on the Vizcaino Peninsula, the northern half of Cedros Island, and San Benitos Islands (table E2). The Middle Jurassic to Early Cretaceous (165 – 135 Ma) arc plutons are dominantly metaluminous to peraluminous, calcic, I-type tonalite and granodiorite, with primitive initial strontium isotopic signatures ($^{87}Sr/^{86}Sr$ = 0.704 to 0.706) and Rb/Y+Nb signatures that plot in the volcanic arc granitoid field on a Pearce diagram (Kimbrough and Moore, 2003). Plutons on the Vizcaino Peninsula range from small stocks and dikes to 40 km^2 bodies emplaced at shallow levels, based on observations of miarolitic cavities and narrow contact aureoles (Kimbrough and Moore, 2003).

Valencia and others (2006) suggested that the volcanic and plutonic rocks of the El Arco-Calmalli area (tract MX-J1) represent an extension of the Middle to Late Jurassic oceanic arc system represented by tract MX-J5.

Tract MX-J5 was constructed by analyzing the 1:500,000 digital geologic of Mexico (Servicio Geológico Mexicano, written commun., 2007) in ArcGIS, as follows.

Map units were classified into generalized units by age and lithologic class (igneous volcanic, igneous plutonic, sedimentary, metamorphic, unconsolidated) based on principal lithologies associated with each map unit. From this enhanced geology map database, all igneous rocks whose potential age span includes the Jurassic were selected.

A 10-km concentric buffer around Jurassic igneous rocks and a 2-km concentric buffer around Jurassic volcanic rocks were used as the starting point for tract delineation. A preliminary tract was digitized by hand from the buffered permissive rock units. Larger-scale (1:250,000) geologic maps and literature were consulted and used to check map unit boundaries, ages, and structures.

The Vizcaino Peninsula and Cedros Island parts of the tract overlie magnetic highs, as shown on the 1:10,000,000 scale aeromagnetic map (North American Magnetic Anomaly Group map, 2002).

Stream-sediment geochemical data from the national database (Servicio Geológico Mexicano, written commun., 2007) indicate areas within the defined tract that have a geochemical signatures that could be indicative of porphyry copper deposits (fig. 7).

We also examined 1:250,000-scale geologic maps published by the Servicio Geológico Mexicano (SGM) of the areas included in the tract to be sure that we had included any mapped areas of hydrothermal alteration that might be indicative of porphyry copper deposits. One such area is observed around the El Datilón prospect (fig. E1; fig. 8*C*).

Known Deposits

There are no known deposits of the appropriate age within the tract area.

Prospects, Mineral Occurrences, and Related Deposit Types

The El Datilón copper prospect on the Vizcaino Peninsula (fig. E1) has characteristics of a porphyry copper deposit (E. Perez-Segura, oral commun., 2008). Malachite and exploration holes were noted in 2006 (T. Moore, oral commun., 2008). The El Datilón prospect and the Campo Los Cocos prospect (~ 5 km to the south) are adjacent to granodiorite and tonalite plutons (Aparicio-Cordero and Zermeño-Ávalos, 1997; Chavez, 1985). Six other copper prospects and occurrences of uncertain deposit type occur within this part of the tract. Copper (average grade 0.5 to 2.0 percent) and gold were produced intermittently since the late 1800s from hydrothermally altered volcanic rock at Punta Norte on the northern tip

Table E2. Map units that define tract 003pCu3002 (MX-J5), Coastal Baja California, Mexico.

[Map unit, age range, and principal lithologies from a 1:500,000 scale preliminary digital geologic map of Mexico (Servicio Geológico Mexicana, written commun., 2007); n.d., no data]

Map unit	Maximum age	Minimum age	Lithology 1	Lithology 2
		Intrusive rocks		
JsKnGd-Tn	Jurassic, Late	Cretaceous	granodiorite	tonalite
JsGr	Jurassic, Late	Jurassic, Late	granite	n.d.
JiD-Ga	Jurassic, Early	Jurassic, Early	diorite	n.d.
		Volcanic rocks		
JimA-TA-BvA	Jurassic, Early	Jurassic, Middle	andesite	andesite tuff
JisA-TA-BvA	Jurassic, Late	Jurassic, Late	andesite	andesite tuff

Table E3. Significant prospects and occurrences in tract 003pCu3002 (MX-J5), Coastal Baja California, Mexico.

Name	Latitude	Longitude	Age (Ma)	Comments (grade and tonnage data, if available)	Reference
El Datilón (La Rinconada)	27.433	-114.300	Jurassic (?)	Included as a porphyry copper prospect by Fitch; described as a past copper producer associated with Jurassic andesite	Aparicio-Cordero and Zermeño-Ávalos (1997), Fitch (2000), U.S. Geological Survey (2005)

of Cedros Island, where shallow granitic rocks that intrude volcanic arc rocks of the Choyal Formation are exposed in canyons.

Exploration History

The Consejo de Recursos Minerales, precursor to the SGM, conducted detailed studies of mining districts throughout Mexico on a state-by-state basis. These studies resulted in monographs for each state that include descriptions of the geology, prospects, mining history, sampling results, and potential of mining districts. The tract area in the state of Baja California Sur is covered by the monograph for this state (Bustamante-García, 1999). This monograph describes exploration by the Consejo, as well as exploration by private companies up to the mid-1990s.

Table E4. Principal sources of information used by the assessment team for tract 003pCu3002 (MX-J5), Coastal Baja California, Mexico.

[NA, not available or not applicable]

Theme	Name or title	Scale	Citation
Geology	Preliminary digital geologic map of the Republic of Mexico	1:500,000	Servicio Geológico Mexicano (written commun., 2007)
	Carta geológica de la República Mexicana	1:2,000,000	Servicio Geológico Mexicano (2007a)
	Carta geólogico-minera, Estado de Baja California Sur	1:500,000	Teràn-Ortega and Maraver-Romero (2007)
Mineral occurrences	SGM Minas database	NA	Servicio Geológico Mexicano (written commun., 2007b)
	MRDS database	NA	U.S. Geological Survey (2005)
	University of Arizona-Industry-USGS Mexico Consortium	NA	University of Arizona-Industry-USGS Mexico Consortium, March 1999 Release Notes (unpublished)
	Porphyry copper deposits of the world: database, map, and grade and tonnage models	NA	Singer and others (2008)
	Carta y provincias metalogeneticas de la Republica Mexican	NA	Salas (1975)
	Geological and metallogenetic characteristics of the porphyry copper deposits of México and their situation in the world context	NA	Valencia-Moreno and others (2007)
Geochemistry	SGM stream-sediment database	NA	Servicio Geológico Mexicano (written commun., 2007)
Geophysics	North American magnetic map	1:10,000,000	North American Magnetic Anomaly Group (2002)
Exploration	Geological -mining monograph of the state of Baja California Sur	1:500,000	Bustamante-García (1999)

Sources of Information

Principal sources of information used by the assessment team for delineation of 003pCu3002 are listed in table E4.

Grade and Tonnage Model Selection

The porphyry copper model of Singer and others (2008) was selected for the assessment. No statistical tests were performed because there are no identified porphyry copper deposits of this age within the tract.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Based on the intrusive and volcanic igneous rocks of appropriate age and composition, mapped alteration characteristic of porphyry copper deposits, at least one porphyry prospect, and anomalous copper in stream sediments within the tract, the team arrived at a consensus estimate of a 10-percent chance of one or more undiscovered porphyry copper deposits within the tract. The 1-percent estimate (3 deposits) represents the maximum number of sites within the tract that the team felt could contain a deposit. In addition, the team considered that the tract may be related to tract 003pCu3001 that hosts the El Arco deposit. The two tracts are separated by an area with thick cover. Approximately 47 percent of the entire tract is covered by younger rocks or alluvium.

Tract 003pCu3002 is the smallest tract delineated in this assessment, and permissive rocks may extend offshore (not considered in this assessment). The high coefficient of variation reflects the team's uncertainty based on available information for the tract area.

Table E5. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 003pCu3002 (MX-J5), Coastal Baja California, Mexico.

[NXX, estimated number of deposits associated with the xxth percentile; Nund, expected number of undiscovered deposits; s, standard deviation; Cv%, coefficient of variance; Nknown, number of known deposits in the tract that are included in the grade and tonnage model; Ntotal, total of expected number of deposits plus known deposits; tract area, area of permissive tract in square kilometers; deposit density, reported as the total number of deposits per km^2; *, deposit densities are not reported for tract areas <10,000 km^2; N_{und}, s, and Cv% are calculated using a regression equation (Singer and Menzie, 2005).]

Consensus undiscovered deposit estimates					Summary statistics					Tract area (km^2)	Deposit density (N_{total}/km^2)
N90	N50	N10	N05	N01	N_{und}	s	Cv%	N_{known}	N_{total}		
0	0	1	2	3	0.41	0.82	200	0	0.41	2,910	*

Table E6. Results of Monte Carlo simulations of undiscovered resources in tract 003pCu3002 (MX-J5), Coastal Baja California, Mexico.

[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	0	0	0	2,900,000	6,500,000	1,500,000	0.15	0.70
Mo	0	0	0	47,000	150,000	42,000	0.10	0.82
Au	0	0	0	74	210	41	0.13	0.80
Ag	0	0	0	360	1,800	550	0.09	0.86
Rock	0	0	0	710	1,400	320	0.16	0.70

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 copper model of Singer and others (2008) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, in press). Selected simulation results are reported in table E6. Results of the Monte Carlo simulation are presented as cumulative frequency plots (fig. E2). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

References Cited

Aparicio-Cordero, Eleuterio, Zermeño-Ávalos, Arnulfo, 1997, Carta geológico-minera, Guerrero Negro G11-3, Baja California Sur [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Bawiec, W.J., and Spanski, G.T., in press, EMINERS—Economic Mineral Resource Simulator, version 3.0: U.S. Geological Survey Open-File Report 2009-1057, program files and 29-p. Quick-Start Guide.

Berger, B.R., Ayuso, R.A., Wynn, J.C., and Seal, R.R., 2008, Preliminary model of porphyry copper deposits: U.S. Geological Survey Open-File Report 2008-1321, 55 p., accessed May 15, 2009, at http://pubs.usgs.gov/of/2008/1321.

Bustamente-García, J., 1999, Monografía geológico-minera de Baja California Sur: Consejo de Recursos Minerales, Pachuca, Hgo., México, 237 p.

Chavez, O.R., 1985, Analisis metalogenetico regional de la peninsula de Baja California: Baja Mexico.

Coney, P.J., and Campa, M.F., 1987, Lithotectonic terrane map of Mexico (west of the 91st Meridian): U.S. Geological Survey Miscellaneous Field Studies Map MF-1874-D, scale 1:2,500,000, 1 sheet.

Cox, D.P., 1986, Descriptive model of porphyry Cu (Model 17), *in* Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 76. (Also available online at http://pubs.usgs.gov/bul/b1693/.)

Fitch, D.C., 2000, Mexico mineral occurrences, map and GIS database, 3,722 selected mineral occurrences from CRM Monograph data w/USGS selected data: Copyrighted database available from David C. Fitch, Geologist, P.O. Box 70547, Reno, NV 89570, USA, igeologist.com, CD-ROM.

Kimbrough, D.L., and Moore, T.E., 2003, Ophiolite and volcanic arc assemblages on the Vizcaíno Peninsula and Cedros Island, Baja California Sur, México—Mesozoic forearc lithosphere of the Cordilleran magmatic arc, *in* Johnson, S.E., Paterson, S.R., Fletcher, J.M., Girty, G.H., Kimbrough, D.I., and Martín-Barajas, A., eds., Tectonic evolution of northwestern México and southwestern USA: Geological Society of America Special Paper 374, p. 43-71.

North American Magnetic Anomaly Group, 2002, Magnetic anomaly map of North America: U.S. Geological Survey Special Map, scale 1:10,000,000, accessed January 15, 2008, at http://pubs.usgs.gov/sm.mag_map/.

Root, D.H., Menzie, W.D., and Scott, W.A., 1992, Computer Monte Carlo simulation in quantitative resource estimation: Natural Resources Research, v. 1, no. 2, p. 125-138.

Salas, G.P., 1975, Carta y provincias metalogeneticas de la Republica Mexicana: Consejo de Recursos Minerales, publicación 21E, 242 p.

Servicio Geológico Mexicano, 2007, Carta geológica de la República Mexicana: Servicio Geológico Mexicano, scale 1:2,000,000, 1 sheet. (Also available online at http://www.coremisgm.gob.mx/.)

Singer, D.A., 2008, Mineral deposit densities for estimating mineral resources: Mathematical Geosciences, v. 40, no. 1, p. 33-46.

Singer, D.A., Berger, V.I., and Moring, B.C., 2008, Porphyry copper deposits of the world—Database, map, and grade and tonnage models, 2008: U.S. Geological Survey Open-File Report 2008-1155, 45 p., accessed January 15, 2009, at http://pubs.usgs.gov/of/2008/1155/.

Singer, D.A., Berger, V.I., Menzie, W.D., and Berger, B.R., 2005, Porphyry copper density: Economic Geology, v. 100, no. 3, p. 491-514.

Singer, D.A., and Menzie, W.D., 2005, Statistical guides to estimating the number of undiscovered mineral deposits—An example with porphyry copper deposits, *in* Cheng, Qiuming, and Bonham-Carter, Graeme, eds., Proceedings of IAMG, The annual conference of the International Association for Mathematical Geology: Geomatics Research Laboratory, York University, Toronto, Canada, p. 1028-1033.

Teràn-Ortega, L.A., and Maraver-Romero, David, compilers, 2007, Carta geólogico-minera, Estado de Baja California Sur: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/california_sur.pdf.)

U.S. Geological Survey, 2005, Mineral Resources Data System: U.S. Geological Survey, Reston, Virginia, accessed December 15, 2007, at http://tin.er.usgs.gov/mrds/.

Valencia, V.A., Barra, F., Weber, B., Ruiz, J., Gehrels, G., Chesley, J., and Lopez-Martinez, M., 2006, Re/Os and U/

Pb geochronology of the El Arco porphyry copper deposits, Baja California Mexico —Implications for the Jurassic tectonic setting: Journal of South American Earth Sciences, v. 22, p. 39-51.

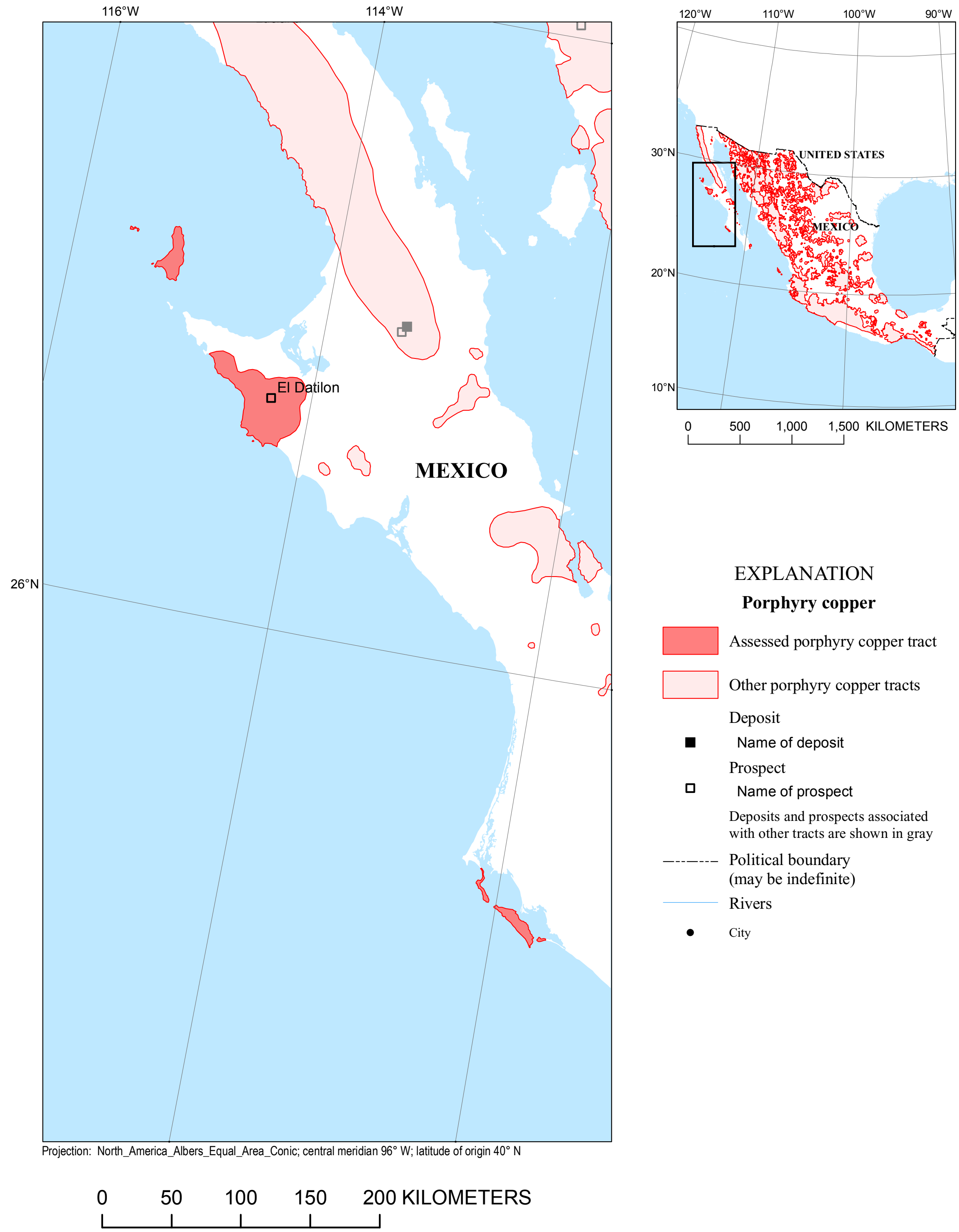


Figure E1. Map showing the location of tract 003pCu3002 (MX-J5), Coastal Baja California, Mexico and deposits and significant prospects and occurrences in adjacent areas.

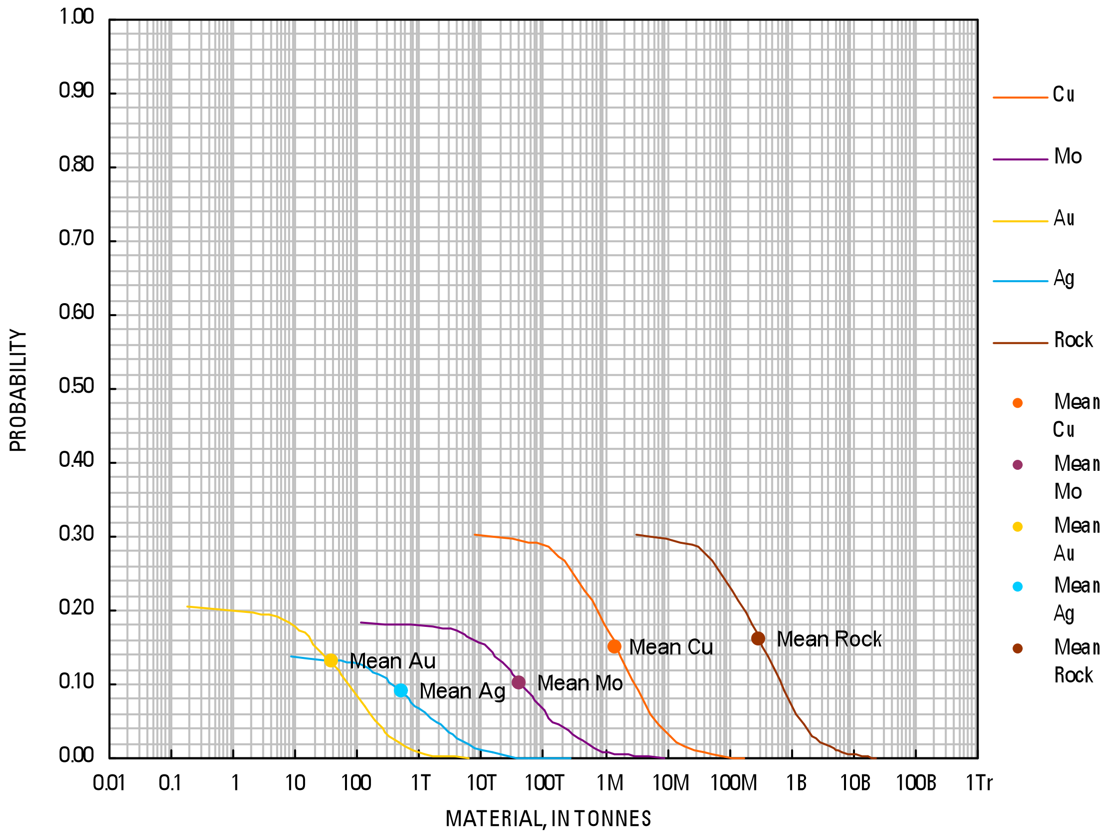


Figure E2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in tract 003pCu3002 (MX-J5), Coastal Baja California, Mexico. T, thousands; M, millions; B, billions; Tr, trillions.

Appendix F. Porphyry Copper Assessment for Tract 003pCu3006 (MX-L1), Western Mexican Basin and Range, Mexico

By Floyd Gray[1], Francisco Cendejas-Cruz[2], Enrique Espinosa[2], Jane M. Hammarstrom[1], Steve Ludington[1], Gilpin R. Robinson, Jr.[1], Efrén Pérez-Segura[3], Martín Valencia-Moreno[4], José Luis Rodríguez-Castañeda[4], Rigoberto Vásquez-Mendoza[2], and Lukas Zürcher[5]

Deposit Type Assessed: Porphyry copper

Descriptive model: Porphyry copper (Cox, 1986; Berger and others, 2008)
Grade and tonnage model: Porphyry copper (Singer and others, 2008)
(Table F1 summarizes selected assessment results)

Location

The tract extends from the U.S. border in Arizona in western Sonora in the Basin and Range province to the northern border of Sinaloa along the eastern edge of the sea of Cortez (fig. F1).

Geologic Feature Assessed

Late Cretaceous to middle Eocene (Laramide) island arc(s)-related calcalkaline magmatic rocks along the western margin of Mexico.

Table F1. Summary of selected resource assessment results for tract 003pCu3006 (MX-L1), Western Mexican Basin and Range, Mexico.

[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)
May 2008	1	74,140	1,065,000	16,000,000	8,900,000

[1]U.S. Geological Survey.
[2]Servicio Geológico Mexicano.
[3]University of Sonora.
[4]Geologic Institute, Universidad Nacional Autónoma de México.
[5]University of Arizona.

Delineation of the Permissive Tract

Geologic Criteria

This tract includes Late Cretaceous to middle Eocene island arc(s)-related calc-alkaline magmatic rocks lying along the western margin of Mexico. These rocks form one of several subparallel metallogenic belts occurring inboard from late Mesozoic to Paleogene subduction of the Farallon plate beneath the North American continent (Coney and Reynolds, 1977). The arc has been widened beyond its original dimensions by post-emplacement Tertiary basin and range extension.

Tract 003pCu3006 (fig. F1) includes Late Cretaceous to Paleocene (Laramide) intrusives along the northwest-trending Cordilleran magmatic belt (Cordilleran arc) characterized by the Sonora and Sinaloa batholiths that run along the Pacific coast of Mexico. The 900-km-long tract consists of Laramide (90 to 45 Ma) igneous centers that are largely calcalkaline and intermediate in composition, with lesser amounts of felsic rocks and a marked absence of coeval volcanic and volcano-sedimentary strata (for example, Damon and others, 1983; Clark and others, 1988; Mead and others, 1988; Barton and others, 1995; Staude and Barton, 2001). The absence of associated volcanic-arc rocks indicates that in northwestern Mexico, in the region of tract 003pCu3006, the western part of the Laramide arc is more deeply eroded than its eastern part (Valencia-Moreno and others, 2003). New $^{40}Ar/^{39}Ar$ and U-Pb zircon dates on plutonic rocks from the region underlying the tract show that the intrusive rocks were emplaced predominantly between 80 and 70 Ma; this is older than recorded Laramide plutonic activity to the east (Valencia-Moreno and others, 2007). Granite to granodiorite (KsTpaGr-Gd) compositions are the most abundant intrusive rocks; lesser granodiorite (TeGd-D) and granodiorite-tonalite (KsGd-Tn (Ki) are present in scattered mountain ranges. Within the tract, Laramide intrusives commonly were emplaced into Proterozoic igneous rocks, Triassic to Jurassic igneous and metamorphic complexes, and rarer Paleozoic sediments. On the western edge of the area, the intrusives are in contact with minor Laramide age andesite (KsTpaA-Ar), andesite and andesitic tuff (KsTpaA-Ta), and minor rhyolite (KsTpaR-Tr).

The tract extends from the U.S.-Mexico border to the northern part of Sinaloa along the Pacific coast. To the south, Laramide rocks are covered by young volcanic rocks of the Trans-Mexican Volcanic Belt. The eastern boundary is defined by the western limit of coeval volcanic rocks, indicating that plutonic rocks within the tract (west of the boundary) were eroded to greater depths. Within the tract the presence of molybdenum and tungsten skarns indicate a level of exposure generally below the horizon most commonly associated with porphyry copper emplacement.

The distribution of the different lithotectonic terranes into which the Laramide intrusives were emplaced, and potential terrane effects on the size and metallogenic character of porphyry systems, have been the subject of an ongoing debate. Although the composition of the main granitic plutons in the Laramide arc is diverse and exhibits no systematic regional control, geochemical and isotopic evidence suggests that basement domains modified the compositions of the magmas and affected the metallogeny of the porphyry copper systems (Campa and Coney, 1983; Valencia-Moreno, 1998; Valencia-Moreno and others, 2001, 2003).

Three basement domains underlie this tract and the adjoining Laramide tracts as proposed by Gastil and others (1991). They are: (1) a northern domain (ND) characterized by the Proterozoic basement of North America and its sedimentary Neoproterozoic and Paleozoic cover in north and northeastern Sonora (Chihuahua-West terrane) and a of sequence plutonic and amphibolite facies metamorphic rocks in western Sonora (Caborca terrane); (2) a central domain (CD) composed of deep-water Paleozoic marine rocks underlain by rocks of the North American craton in southern Sonora and northern Sinaloa (Cortez terrane); and (3) a southern domain (SD) characterized by rocks of the Guerrero terrane, where North American cratonal rocks are unknown. Valencia-Moreno and others (2007) indicate that initial strontium and neodymium ratios change systematically from north to south across these terrane boundaries and indicate progressively less contamination by North American cratonal rocks. These relationships show that the composition of Laramide magmas was significantly modified by crustal contamination.

Porphyry copper mineralization occurred across the tract from about 77.6 to 60 Ma. Although many prospects remain undated in Sonora, and Sinaloa, there is a general trend of younging to the south (Barra and others, 2005) and from west to east across northwestern Mexico (Valencia-Moreno and others, 2007).

Tract 003pCu3006 was constructed by analyzing the 1:500,000-scale digital geologic of Mexico in ArcGIS, as follows.

Map units were classified into generalized units by age and lithologic class (igneous volcanic, igneous plutonic, sedimentary, metamorphic, unconsolidated) based on principal lithologies associated with each map unit. From this enhanced geology file, all igneous rocks whose potential age span includes the Laramide (Late Cretaceous, Paleocene, and Eocene) were selected (table F2). Eocene basalts were omitted from the tract.

The tracts were digitized by hand using a 10-km buffer around plutonic rocks and a 2-km buffer around volcanic rocks. Plutonic rocks that are younger than Laramide were then displayed, and slightly generalized exclusions based on these were digitized by hand. Some internal polygons that are more than 10 (or 2) km from permissive rocks were removed; these areas were then clipped out of the tracts.

Known deposits and prospects were plotted and the preliminary tract was edited to include known or suspected Laramide porphyry copper deposits and prospects. Larger-scale (1:250,000) geologic maps and literature were consulted and used to check map-unit boundaries, ages, and structures.

Table F2. Map units in tract 003pCu3006 (MX-L1), Western Mexican Basin and Range, Mexico.

[Map unit, age range, and principal lithologies from a 1:500,000 scale preliminary digital geologic map of Mexico (Servicio Geológico Mexicana, written commun., 2007); n.d., no data]

Map unit	Maximum age	Minimum age	Lithology 1	Lithology 2
Intrusive rocks				
KsTpaGr-Gd	Cretaceous	Paleocene	granite	granodiorite
TeGd-D	Eocene	Eocene	granodiorite	diorite
TpaePMz-PqMz	Paleocene	Eocene	porphyritic monzonite	porphyritic quartz monzonite
Volcanic rocks				
TpaeA	Paleocene	Eocene	andesite	n.d.
KsTpaA-TA	Cretaceous	Paleocene	andesite	andesite tuff
TpaeA-TA	Paleocene	Eocene	andesite	andesite tuff
KsTpaA-Ar	Cretaceous	Paleocene	andesite	sandstone

The tract was then further refined using the aeromagnetic map (North American Magnetic Anomaly Group, 2002) to include some adjacent areas that appear to have shallow magnetic sources.

Stream-sediment geochemical data from the national database (Servicio Geológico Mexicano, written commun., 2007) indicate a number of areas within the tract that have a geochemical signature indicative of porphyry copper deposits (fig. 7).

We also examined 1:250,000-scale geologic maps published by the Servicio Geológico Mexicano (SGM) for areas included in the tract to be sure that we had included any mapped areas of hydrothermal alteration that might be indicative of porphyry copper deposits (fig. 8*C*).

Known Deposits

The Piedras Verdes mine, the only deposit in tract 003pCu3006, is located 21 km north-northwest of the town of Alamos in the state of Sonora (table F3). The town of Alamos (population 9,000) is approximately 370 km to the southeast of Hermosillo. Estimated resources for this deposit include ~290 Mt of ore, averaging 0.37 percent copper (Espinosa-Perea, 1999). The deposit consists of a stockwork of pyrite, chalcopyrite, and molybdenite, with 0.15-0.3 percent copper and values of molybdenum relatively greater in the interior of the system, decreasing to <0.1 percent copper and almost no molybdenum outward. This deposit includes a zone of secondary enrichment from a primary low-grade ore composed of pyrite and chalcopyrite. The mineralization of Piedras Verdes is hosted in a sequence of deformed deep-marine sediments, which may correlate with a similar sequence exposed in northern Sinaloa (Mullan, 1978; Gastil and others, 1991; Dreier and Braun, 1995). These rocks were intruded by a Laramide granodiorite and a sequence of porphyries associated with the mineralization, which was dated by Re-Os in molybdenite to be ~60 Ma (Espinosa-Perea, 1999).

Prospects, Mineral Occurrences, and Related Deposit Types

The tract contains approximately 11 copper prospects and occurrences, most of which are porphyry copper type, evenly distributed between copper, copper-gold, and copper-molybdenum occurrences. Several of the occurrences are tungsten-bearing polymetallic skarns. Known deposits of other types within the tract include W-skarn, Au-Quartz vein, and Tertiary shear-zone gold. Table F4 lists several prospects that may be associated with porphyry copper deposits. The significant prospects that occur in tract 003pCu3006 are described here. The descriptions are discussed from north to south by the three basement domains and by their association in mineral districts.

Los Humos (Northern Domain)

Current exploration data indicates that the defined orebody contains approximately 271 million tons of ore at 0.31 percent copper.

La Sierrita/La Cobriza (Northern Domain)

The La Sierrita/La Cobriza and El Picacho prospects are located 45 km northwest of Hermosillo and are part of a cluster of prospects around the La Verde Grande skarn. The area is underlain by a thick sequence of metamorphosed limestones that are intruded by granite and quartz monzonite porphyries, dikes, and mineralized aplite dikes (Yale Resources Ltd., 2008). Mineralization consists of structurally-controlled skarn bodies and fault/breccia zones. The La Sierrita porphyry crops out northwest of the prospect area and is believed to be the source of mineralizing fluids that produced the Cu-Zn-W-Mo-bearing skarn and stockwork occurrences.

El Picacho (Northern Domain)

The El Picacho prospect (fig. F1) occurs as a northwest-striking belt of discontinuous tactite outcrops surrounded by metamorphosed limestone and hornfels, probably underlain by granite. Granite crops out 200 m west of the limestone, separated from it by silicified volcanic breccia in contact with limestone along a pre-intrusive fault. Copper oxide mineralization is exposed throughout the workings and predominately occurs within a series of breccias. Irregularly spaced chip channel sampling from within the main working returned an average of 1.27 percent copper, 13.4 g/t silver and 0.67 percent zinc (Yale Resources, 2008).

Batacosa (Central Domain)

The Batacosa prospect is located 250 km southeast of Hermosillo and is underlain by granitic rocks. Reported mineralization includes epithermal gold-silver and porphyry copper-gold molybdenum.

Carol (Central Domain)

The Carol Property is located approximately 5 km north of the Piedras Verdes porphyry copper deposit and has a reported reserve of 191 million tons of ore grading 0.36 percent copper. The occurrence includes two skarn zones that yield high grades of copper, zinc, silver, and gold.

Exploration History

This tract contains territory extensively explored for precious-metal deposits. The current focus of exploration in the tract, as typified by exploration in the central and southern portions of the tract area, is for Laramide precious-metal and polymetallic vein deposits, epigenetic skarn, and gold on flat faults. Some scattered exploration for copper was initiated due to surging metals prices; however, this mainly centered on high-grade skarn systems with molybdenum, gold, and tungsten as byproduct metals.

The Consejo de Recursos Minerales, precursor to the SGM, conducted detailed studies of mining districts throughout Mexico on a state-by-state basis. These studies resulted in monographs for each state that include descriptions of the geology, prospects, mining history, sampling results, and potential of mining districts (Consejo de Recursos Minerales, 1992, 1994).

Grade and Tonnage Model Selection

The porphyry copper model of Singer and others (2008) was selected for the assessment based on geologic characteristics of the known deposit in the tract and the results of an ANOVA test comparing tonnage and copper grade against the global model containing 421 other deposits. The statistical test showed that the Piedras Verdes deposit is not significantly different from the global model.

Sources of Information

Principal sources of information used by the assessment team for delineation of 003pCu3006 are listed in table F5.

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, the occurrence of 1 known deposit, with ~11 copper prospects and anomalous copper in stream sediments within the tract, the team arrived at a consensus estimate of 2 undiscovered deposits at a 90-percent confidence level, 4 undiscovered deposits at a 50-percent confidence level, and 7 undiscovered deposits at 10-percent confidence level (table F6). These estimates reflect the number of current exploration targets in play, copper skarn occurrences not associated with deposits, and the extent of geochemical anomalies and altered areas in the tract. Specifically, the apparent mature development status of the Los Humos, Carol, and Picacho prospects influenced the confidence level of the team's estimate. It was noted that occurrences in the northern and central domains that are underlain by continental crust, are characterized by Cu-Mo-W systems (Valencia-Moreno and others, 2007). Deposits in the southern domain of the tract are underlain by oceanic basement and seem to be characterized by Cu-Au mineralization, and undiscovered deposits there may be smaller.

Optimistic aspects of the tract for undiscovered deposits include the fact that the high degree of extension in the tract likely exposed different levels of the crust, one deposit is known, and the Los Humos prospect was recently drilled. Negative factors include the greater abundance of plutons relative to volcanic rocks, which suggests that much of the tract may be too deeply eroded to preserve deposits and the fact that northern Mexico has been relatively well explored.

We did not directly use the deposit density models of Singer and others (2005) and Singer (2008). Our estimate (~7 deposits/100,000 km^2) is congruent with respect to worldwide porphyry copper distributions (fig. 11).

Table F3. Known porphyry copper deposits in tract 003pCu3006 (MX-L1), Western Mexican Basin and Range, Mexico.

[Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; Cu-Mo subtype, deposits that have Au/Mo ratios <3 or average Mo grades >0.03 percent; Cu-Au subtype, deposits that have Au/Mo ratios >30 or average Au grades >0.2 g/t; NA, not applicable; n.d., no data. Contained Cu in metric tons is computed as tonnage (Mt*1,000,000) * Cu grade (%).]

Name	Latitude	Longitude	Subtype	Age (Ma)	Tonnage (Mt)	Grade				Contained Cu (t)	Reference
						Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)		
Piedras Verdes	27.164	-109.002	NA	60	288	0.37	n.d.	n.d.	n.d.	1,065,000	Barton and others (1995), Dreier and Braun (1995), Sillitoe (1976), Minjárez-Sosa and others (2002)

Table F4. Significant prospects and occurrences in tract 003pCu3006 (MX-L1), Western Mexican Basin and Range, Mexico.

[Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; km, kilometer]

Name	Latitude	Longitude	Type	Age (Ma)	Comments (grade and tonnage data, if available)	References
Carol	27.189	-108.854	Skarn	?	Skarn 4 km NE of Piedras Verdes porphyry copper deposit	Yale Resources Ltd. (2009)
Batacosa	27.607	-109.366	Porphyry Cu	?	Located on 500K state map (prospect on 1:250K map is named Los Cusis); explored by Phelps-Dodge in the past.	Minjárez-Sosa and others (2002), Fitch (2000)
Picacho	29.183	-110.723	Porphyry Cu	?	Part of Yale Resources 2,620-hectare La Verde Project on 6 contiguous exploration concessions (Yale Resource Ltd., 2008). Tentatively classified as a porphyry system based on geology (L. Zürcher, oral commun., 2008). Epidote-garnet tactite with scheelite, powellite, and oxide copper minerals. Development: W-bearing tactite discovered in the district in 1943. Three claims recorded: El Nublado, El Picacho, and La Florencia. Minor development (shallow pit), but no tungsten ore mined; gold produced at El Picacho and La Florencia. Geology: NW-striking belt of discontinuous tactite outcrop surrounded by metalimestone and hornfels, probably underlain by granite. Granite crops out 200 m W of the limestone, separated by silicified volcanic breccia in contact with limestone along a pre-intrusive fault.	Yale Resources Ltd. (2008), Peña-Leal and others (1999), University of Arizona-Industry-USGS Mexico Consortium, March 1999 Release Notes (unpublished)

Table F4. Significant prospects and occurrences in tract 003pCu3006 (MX-L1), Western Mexican Basin and Range, Mexico.—Continued

[Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; km, kilometer]

La Sierrita/La Cobriza	29.395	-111.302	Porphyry Cu	?	La Cobriza and La Sierrita porphyry target (Cu, Zn, W, Mo) are part of Yale Resources 2,620-hectare La Verde Project that cover 6 contiguous exploration concessions (Yale Resource Ltd., 2008). Cluster of prospects; near La Verde skarn. Exploration by the Consejo de Recursos Minerales (1982) showed irregular distribution of skarn; chemistry on chip samples from historic workings: 0.28 to 5.45% Cu, 0.16 to 8.6% Zn, 4.9 to 578 g/t Ag, 0.1 to 11.1 g/t Au.	Yale Resources Ltd. (2008), Peña-Leal and others (1999)
Los Humos	31.231	-111.917	Porphyry Cu	?	Location uncertain; plotted in Sierra El Humos area in SW corner of Nogales 1:250,000-scale map. Los Humos porphyry copper exploration project of Pecobre Mining Company (joint venture between Codelco and Industria Peñoles de Mexico); described as 300 Mt of 0.3% Cu in leachable ore resources.	Ingeneiro Andino (2003)
La Fortuna	30.078	-112.494	Porphyry Cu-Mo	70?	Porphyry Cu-Mo prospect; located ~ 3 km from El Americano prospect; both prospects surrounded by alteration (no overlap).	Cortéz-García and others (2002)

Table F5. Principal sources of information used by the assessment team for tract 003pCu3006 (MX-L1), Western Mexican Basin and Range, Mexico.

[NA, not available or not applicable]

Theme	Name or title	Scale	Citation
Geology	Preliminary digital geologic map of the Republic of Mexico	1:500,000	Servicio Geológico Mexicano (written commun., 2007)
	Carta geológica de la República Mexicana	1:2,000,000	Servicio Geológico Mexicano (2007)
	Carta geólogico-minera, Estado de Sonora	1:500,000	Arriaga-Meléndez and others (2004)
	Carta geólogico-minera, Estados de Sinaloa	1:500,000	Castro-Escárrega and others (2007)
Mineral occurrences	SGM Minas database	NA	Servicio Geológico Mexicano (written commun., 2007)
	MRDS database	NA	U.S. Geological Survey (2005)
	University of Arizona-Industry-USGS Mexico Consortium	NA	University of Arizona-Industry-USGS Mexico Consortium, March 1999 Release Notes (unpublished)
	Porphyry copper deposits of the world: database, map, and grade and tonnage models	NA	Singer and others (2008)
	Geological and metallogenetic characteristics of the porphyry copper deposits of México and their situation in the world context	NA	Valencia-Moreno and others (2007)
	Carta y provincias metalogeneticas de la Republica Mexicana	NA	Salas (1975)
Geochemistry	SGM stream-sediment database	NA	Servicio Geológico Mexicano (written commun., 2007)
Geophysics	North American magnetic map	1:10,000,000	North American Magnetic Anomaly Group (2002)
Exploration	Proyectos de Compañias Extranjeras por Estado	NA	Dirección General de Promoción Minera (2005)
	Geological-mining monograph of the state of Sonora	1:500,000	Consejo de Recursos Minerales, 1994
	Geological-mining monograph of the state of Sinaloa	1:500,000	Consejo de Recursos Minerales, 1992
	Company Web sites	NA	See tables and text

Table F6. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 003pCu3006 (MX-L1), Western Mexican Basin and Range, Mexico.

[NXX, estimated number of deposits associated with the xxth percentile; Nund, expected number of undiscovered deposits; s, standard deviation; Cv%, coefficient of variance; Nknown, number of known deposits in the tract that are included in the grade and tonnage model; Ntotal, total of expected number of deposits plus known deposits; area, area of permissive tract in square kilometers; density, deposit density reported as the total number of deposits per km2. Nund, s, and Cv% are calculated using a regression equation (Singer and Menzie, 2005).]

Consensus undiscovered deposit estimates			Summary statistics					Tract area (km^2)	Deposit density (N_{total}/km^2)
N90	N50	N10	N_{und}	s	Cv%	N_{known}	N_{total}		
2	4	7	4.2	1.9	46	1	5.2	74,140	0.00007

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, in press). Selected output parameters are reported in table F7. Results of the Monte Carlo simulation are presented as cumulative frequency plots (fig. F2). The cumulative frequency plots show the estimated resource volumes associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock. The median expected amount of copper within the tract is 8.1 million tons, and the mean expected amount is 15 million tons. Both numbers represent a significant increase in the original resource in known deposits of about 1.06 million tons (table F1).

References Cited

Arriaga-Meléndez, Hilario, López-Escalona, J.J., López-Reyes, J.E., Terán-Ortega, L.A., Castro-Escarrega, J.J., Espinoza-Beltrán, C.C., and Vázquez-Mendoza, Rigoberto, compilers, 2004, Carta geólogico-minera, Estado de Sonora: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/sonora.pdf.)

Barra, F., Ruiz, J., Valencia, V.A., Ochoa-Landín, L., Chesley, J.T., and Zürcher, L., 2005, Laramide porphyry Cu-Mo mineralization in northern Mexico—Constraints from Re-Os geochronology in molybdenite: Economic Geology, v. 100, p. 1605–1616.

Barton, M.D., Staude, J.-M.G., Zürcher, L., and Megaw, P.K.M., 1995, Porphyry copper and other intrusion-related mineralization in Mexico, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Tucson, Arizona Geological Society Digest, v. 20, p. 487-524.

Bawiec, W.J., and Spanski, G.T., in press, EMINERS—Economic Mineral Resource Simulator, version 3.0: U.S. Geological Survey Open-File Report 2009-1057, program files and 29-p. Quick-Start Guide.

Berger, B.R., Ayuso, R.A., Wynn, J.C., and Seal, R.R., 2008, Preliminary model of porphyry copper deposits: U.S. Geological Survey Open-File Report 2008-1321, 55 p., accessed May 15, 2009, at http://pubs.usgs.gov/of/2008/1321.

Campa, M.F., and Coney, P.J., 1983, Tectono-stratigraphic terranes and mineral resource distributions in Mexico: Canadian Journal of Earth Sciences, v. 20, p. 1040-1051.

Castro-Escárrega, J.J., López-Escalona, Juan, Díaz-Salgado, Ciro, and Espinoza-Beltrán, Carlos, compilers, 2007, Carta geólogico-minera, Estado de Sinaloa: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/sinaloa.pdf.)

Clark, K.A, Damon, P.E., and Saffiqullah, M., 1988, Metallization epoch in relation to late Mesozoic and Cenozoic igneous activity, Sinaloa, Mexico, *in* Clark, K.F., Goodell, P.C., and Hoffer, J.M., eds., Stratigraphy, tectonics and resources of parts of Sierra Madre Occidental province, Mexico: El Paso Geological Society, Guidebook for the 1988 Field Conference, p. 343-362.

Coney, P.J., and Reynolds, S.J., 1977, Cordilleran Benioff zones: Nature, v. 270. p. 403-406.

Consejo de Recursos Minerales, 1992, Monografía geologico-minero del Estado de Sinaloa: Consejo de Recursos Minerales, Pachuca, Hgo., Mexico, Publicación M1-e, 159 p.

Table F7. Results of Monte Carlo simulations of undiscovered resources in tract 003pCu3006 (MX-L1), Western Mexican Basin and Range, Mexico.

[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	290,000	1,200,000	8,900,000	36,000,000	60,000,000	16,000,000	0.28	0.04
Mo	0	0	150,000	1,000,000	1,900,000	460,000	0.23	0.12
Au	0	5	190	970	1,500	400	0.29	0.09
Ag	0	0	1,600	13,000	23,000	5,600	0.23	0.19
Rock	63	280	1,900	7,600	13,000	3,300	0.30	0.04

Consejo de Recursos Minerales, 1994, Monografía geologico-minero del Estado de Sonora: Consejo de Recursos Minerales, Pachuca, Hgo., Mexico, Publicación M8-e, 220 p.

Cortéz-García, J.A., Terán-Martínez, Guillermo, and Zamora-Tovar, Eduardo, 2002, Carta geológico-minera, Caborca H12-4, Sonora [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Cox, D.P., 1986, Descriptive model of porphyry Cu (Model 17), *in* Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 76. (Also available online at http://pubs.usgs.gov/bul/b1693/.)

Damon, P.E., Shafiqullah, M., and Clark, K.F., 1983, Geochronology of the porphyry copper deposits and related mineralization of Mexico: Canadian Journal of Earth Sciences, v. 20, p. 1052-1071.

Dirección General de Promoción Minera, 2005, Proyectos de Compañias Extranjeras por Estado: Dirección General de Promoción Minera, Ministry of the Economy [Mexico] Web site, accessed January 15, 2008, at http://www.economia.gob.mx/?P=1537.

Dreier, J.E., and Braun, Eric, 1995, Piedras Verdes, Sonora, Mexico—A structurally controlled porphyry copper deposit: Arizona Geological Survey Digest, v. 20, p. 535-543.

Espinosa-Perea, V.J., 1999, Magmatic evolution and geochemistry of the Piedras Verdes Deposit, Sonora, Mexico: The University of Arizona, Tucson, Arizona, master's thesis, 114 p.

Ferrari, L., Tagami, T., Eguchi, M., Orozco-Esquivel, M.T., Petrone, C.M., Jacobo-Albarrán, J., and López-Martínez, M., 2005, Geology, geochronology, and tectonic setting of late Cenozoic volcanism along the southwestern Gulf of Mexico—The Eastern Alkaline Province revisited: Journal of Volcanology and Geothermal Research, v. 146, p. 284-306.

Fitch, D.C., 2000, Mexico mineral occurrences, map and GIS database, 3,722 selected mineral occurrences from Consejo de Recursos Minerales Monograph data w/USGS selected data: Copyrighted database available from David C. Fitch, Geologist, P.O. Box 70547, Reno, NV 89570, USA igeologist.com, CD-ROM.

Gastil, R.G., Miller, R.H., Anderson, P., Crocker, J., Campbell, M., Buch, P., Lothringer, C., Leier-Engeldardt, P., DeLattre, M., Hoobs, J., and Roldán-Quintana, J., 1991, The relation between the Paleozoic strata on opposite sides of the Gulf of California, *in* Perez- Segura, E., and Jacques-Ayala, C., eds., Studies of Sonoran geology: Geological Society of America Special Paper 254, p. 7-16.

Ingeneiro Andino, 2003, Mexico (Projects and engineering in Chile, Peru, Bolivia, and Argentina), no. 602, accessed May 15, 2009, at http://www.editec.cl/IngAndino/historico/ingles/IA602ing.pdf.

Iriondo, A., Kunk, M.J., Wininck, J.A., 2003, ^{40}Ar-^{39}Ar Dating studies of minerals and rocks in various areas in Mexico—USGS/CRM scientific collaboration (Part I): U.S. Geological Survey Open-File Report 03-020, 79 p. (Also available online at http://pubs.usgs.gov/of/2003/ofr-03-020/OFR-03-020-508eng.pdf.)

Mead, R.D., Kesler, S.E., Foland, K.A., and Jones, L.M., 1988, Relationship of Sonoran tungsten mineralization to the metallogenic evolution of Mexico: Economic Geology, v. 83, p. 1943-1965.

Minjárez-Sosa, Ismael, Montño-Jiménez, T.R., Ochoa-Granillo, José, Grijalva-Noriega, F.J., Ochoa-Landín, L.H., Urbina-Herrera, Saúl, Guzmán-Espinosa, J.B., and Mancilla-Gutiérrez, A.A., 2002, Carta geológico-minera, Ciudad Obregón G12-3, Sonora, Chihuahua, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Mullan, H.S., 1978, Evolution of part of the Nevadan orogen in northwestern Mexico: Geological Society of America Bulletin, v. 89, p 1175-1188.

NAVDAT, 2008, The western North America volcanic and intrusive rock database: NAVDAT database, accessed January 15, 2008, at http://www.navdat.org.

North American Magnetic Anomaly Group, 2002, Magnetic anomaly map of North America: U.S. Geological Survey Special Map, scale 1:10,000,000, accessed January 15, 2008, at http://pubs.usgs.gov/sm.mag_map/.

Peña-Leal, J.L., Zamora-Tovar, R.E., Núñez-Othón, Aristeo, and Orantes-Contreras, Vladimir, 1999, Carta geológico-minera, Hermosillo H12-8, Sonora [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Ramírez-Fernández, J. A., and Keller, J., 1997, The Sierra de Tamaulipas in NE Mexico—Transition from subduction related to intraplate Tertiary magmatism including carbonatites: EUG 9, Strasbourg, Terra Nova, 9/Abstr. Supp. l, 38.

Robin, C., 1982, Relations volcanologie–magmatologie-geodynamique—Application au passage entre volcanismes alcalin et andesitique dans le sud Mexicain (Axe Trans-mexicain et Province Alcaline Oriental), Ph.D. thesis, Annales Scientifiques de l'Université de Clermont-Ferrand II France, 503 p.

Root, D.H., Menzie, W.D., and Scott, W.A., 1992, Computer Monte Carlo simulation in quantitative resource estimation: Natural Resources Research, v. 1, no. 2, p. 125-138.

Salas, G.P., 1975, Carta y provincias metalogeneticas de la Republica Mexicana: Consejo de Recursos Minerales, publicación 21E, 242 p.

Servicio Geológico Mexicano, 2007, Carta geológica de la República Mexicana, Texto explicativo. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/cartas250/geologia/Texto_explicativo.pdf.)

Sillitoe, R.H., 1976, A reconnaissance of the Mexican porphyry copper belt: Transactions of the Institution of Mining and Metallurgy, Section B, p. B170-B189.

Singer, D.A., 2008, Mineral deposit densities for estimating mineral resources: Mathematical Geosciences, v. 40, no. 1, p. 33-46.

Singer, D.A., Berger, V.I., Menzie, W.D., and Berger, B.R., 2005, Porphyry copper density: Economic Geology, v. 100, no. 3, p. 491-514.

Singer, D.A., Berger, V.I., and Moring, B.C., 2008, Porphyry copper deposits of the world—Database, map, and grade and tonnage models, 2008: U.S. Geological Survey Open-File Report 2008-1155, 45 p., accessed January 15, 2009, at http://pubs.usgs.gov/of/2008/1155/.

Singer, D.A., and Menzie, W.D., 2005, Statistical guides to estimating the number of undiscovered mineral deposits—An example with porphyry copper deposits, *in* Cheng, Qiuming, and Bonham-Carter, Graeme, eds., Proceedings of IAMG, The annual conference of the International Association for Mathematical Geology: Geomatics Research Laboratory, York University, Toronto, Canada, p. 1028-1033.

Staude, J.M., and Barton, M.D., 2001, Jurassic to Holocene tectonics, magmatism, and metallogeny of northwestern Mexico: Geological Society of America Bulletin, v. 113, p. 1357–1374,

U.S. Geological Survey, 2005, Mineral Resources Data System: U.S. Geological Survey, Reston, Virginia, accessed December 15, 2007, at http://tin.er.usgs.gov/mrds/.

Valencia-Moreno, M., 1998, Geochemistry of Laramide granitoids and associated porphyry copper mineralization in NW Mexico: Tucson, The University of Arizona, Ph. D. thesis, 164 p.

Valencia-Moreno, M., Ruiz, J., Barton, MD., Patchett, P.J., Zürcher, L., Hodkinson, D., and Roldán-Quintana, J., 2001, A chemical and isotopic study of the Laramide granitic belt of northwestern Mexico—Identification of the southern edge of the North American Precambrian basement: Geological Society of America Bulletin, v.113, p.1409-1422.

Valencia-Moreno, M., Ruiz, J., Ochoa-Landín, L., Martínez-Serrano, R., and Vargas-Navarro, P., 2003, Geochemistry of the coastal Sonora batholith, northwestern Mexico: Canadian Journal of Earth Sciences, v. 40, p. 819-831.

Valencia-Moreno, M., Ochoa-Landín, Lucas, Noguez-Alcántara, Benito, Ruiz, Joaquin, Pérez-Segura, Efrén, 2007, Geological and metallogenic characteristics of the porphyry copper deposits of México and their situation in the world context: Geological Society of America Special Paper 422, p. 433-458.

Yale Resources Ltd., 2008, La Verde Project: Yale Resources Ltd.Web page accessed December 29, 2008, at http://www.yaleresources.com/s/LaVerde.asp.

Yale Resources Ltd., 2009, The Carol Project: Yale Resources Ltd.Web page accessed October 23, 2009, at http://www.yaleresources.com/s/Carol.asp.

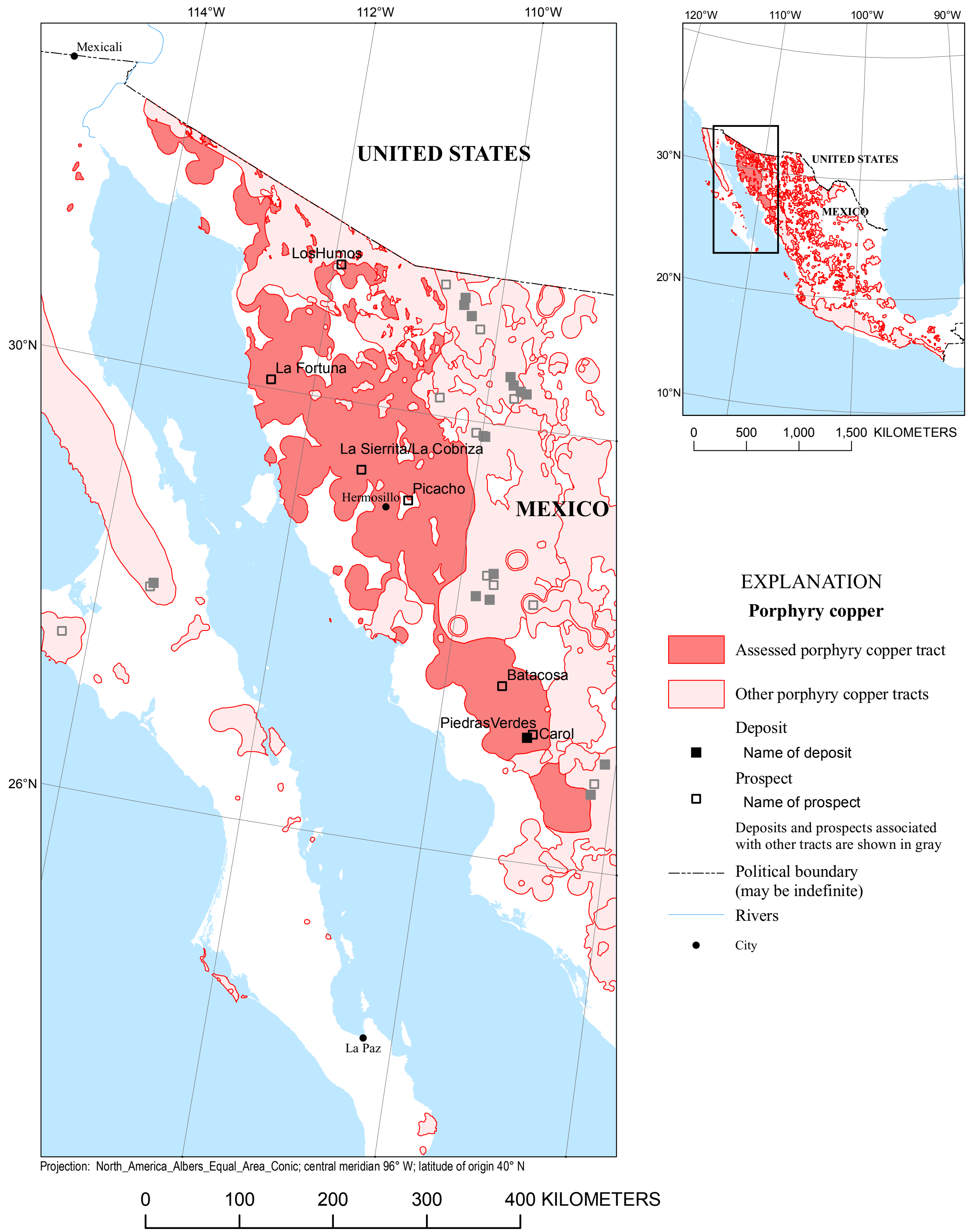


Figure F1. Map showing the location, known deposits, and significant prospects and occurrences for tract 003pCu3006 (MX-L1), Western Mexican Basin and Range, Mexico.

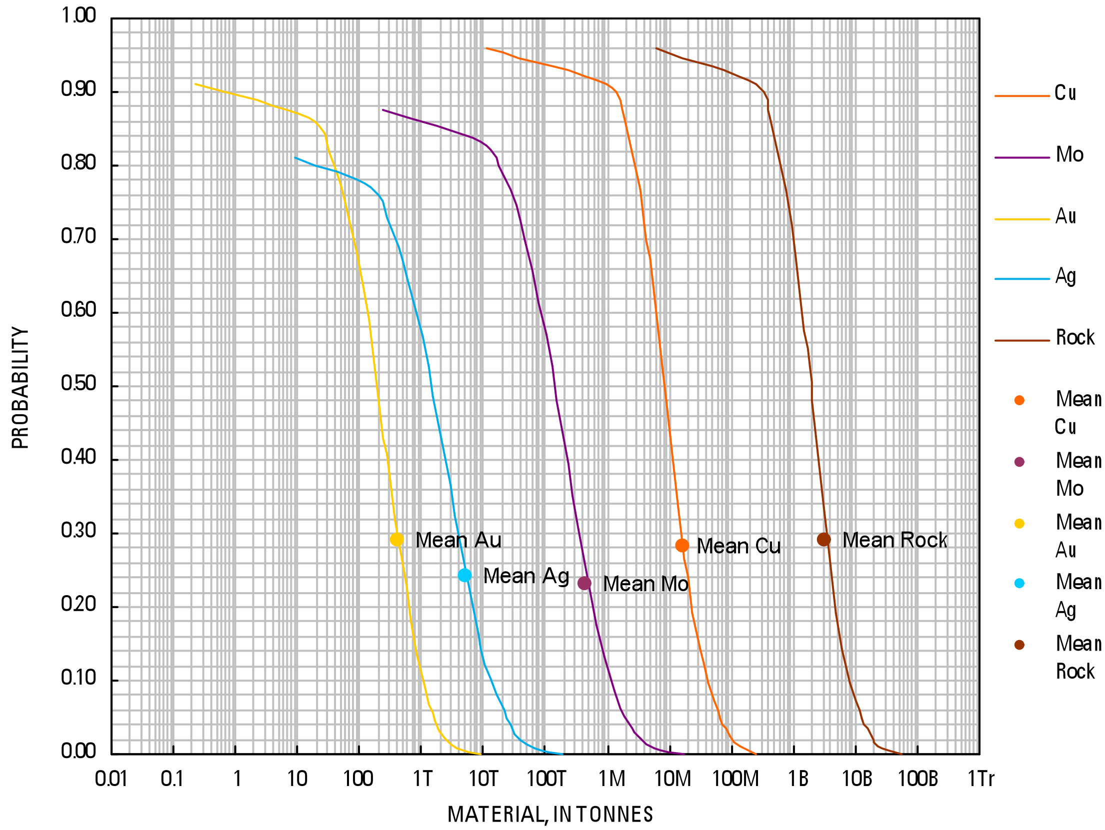


Figure F2. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in tract 003pCu3006 (MX-L1), Western Mexican Basin and Range, Mexico. T, thousands; M, millions; B, billions; Tr, trillions.

Appendix G. Porphyry Copper Assessment for Tract 003pCu3007 (MX-L2), Sierra Madre Occidental West, Mexico

By Floyd Gray[1], Francisco Cendejas-Cruz[2], Enrique Espinosa[2], Jane M. Hammarstrom[1], Steve Ludington[1], Gilpin R. Robinson, Jr.[1], Efrén Pérez-Segura[3], Martín Valencia-Moreno[4], José Luis Rodríguez-Castañeda[4], Rigoberto Vásquez-Mendoza[2], and Lukas Zürcher[5]

Deposit Type Assessed: Porphyry copper

Descriptive model: General porphyry copper (Cox, 1986; Berger and others, 2008)
Grade and tonnage model: General porphyry copper (Singer and others, 2008)
(Table G1 summarizes selected assessment results)

Location

The tract extends from the U.S. border through Sonora, southwestern Chihuahua, Sinaloa, and western Durango to just beyond the northern border of Nayarit (fig. G1).

Geologic Feature Assessed

Late Cretaceous to middle Eocene (Laramide) magmatic arc rocks in the Sierra Madre Occidental of northern Mexico.

Table G1. Summary of selected resource assessment results for tract 003pCu3007 (MX-L2), Sierra Madre Occidental West, Mexico.

[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)
May 2008	1	115,110	49,000,000	48,000,000	36,000,000

---

[1]U.S. Geological Survey.
[2]Servicio Geológico Mexicano.
[3]University of Sonora.
[4]Geologic Institute, Universidad Nacional Autónoma de México.
[5]University of Arizona.

Delineation of the Permissive Tract

Geologic Criteria

Tract 003pCu3007 (figs. G1, G2) includes Late Cretaceous to Paleocene (Laramide) intrusive and volcano-sedimentary rocks along the northwest-trending Cordilleran magmatic belt subparallel to the Pacific coast of Mexico. The 2,800-km-long tract contains abundant Laramide (90 to 45 Ma) igneous centers that are roughly coeval with associated volcanic rocks and are largely calcalkaline and intermediate in composition, along with lesser amounts of more felsic rocks (for example, Damon and others, 1983a; Clark and others, 1988; Mead and others, 1988; Barton and others, 1995; Staude and Barton, 2001). The age of mineralization within many of the porphyry systems is constrained between about 61 and 50 Ma (Barra and others, 2005). Hornblende-(pyroxene- and biotite-) bearing quartz diorites and granodiorites (map units KiGd-Tn and TeGd-D) are the most abundant intrusive rocks; lesser granite (KsTpaGr-Gd, TpaGr-Gd), diorite, monzonite, quartz monzonite (TpaePMz-PqMz), and subvolcanic porphyritic dacite are also reported (see table G2). Andesite (KsTpaA-Ar, KsTpA-TA, KsTpA-Tq, and TpaeA-TA) and minor dacite (TePDa) are the primary coeval volcanic rocks in the area (Barton and others, 1995). Minor late-stage rhyolite and quartz-feldspar porphyry occur in many of the intrusive centers, but areas of only rhyolitic volcanic rocks were not used to define the tract.

The tract extends from the U.S.-Mexico border to the southern limit of exposed Laramide volcanic and intrusive rocks. To the south, Laramide rocks are covered by young volcanic rocks of the Trans-Mexican Volcanic Belt. West of the boundary, in tract MX-L1, volcanic rocks are rare to absent and the presence of molybdenum and tungsten skarns indicates a level of exposure generally below the horizon most commonly associated with porphyry copper emplacement. The eastern boundary of this tract is defined by thick (>1 km) mid-Tertiary (Oligocene) ignimbrite volcanic rocks of the Sierra Madre Occidental where exposures of Laramide intrusions are rare (McDowell and Clabaugh, 1979; Ferrari and others, 2005).

The distribution of the different lithotectonic terranes into which Laramide intrusives were emplaced, and potential terrane effects on the size and metallogenic character of porphyry systems, have been the subject of an ongoing debate. Although the lithologic composition of the main granitic plutons in the Laramide arc is diverse and exhibits no systematic regional control, geochemical and isotopic evidence suggests that basement domains modified the compositions of the magmas and affected the metallogeny of the porphyry copper systems (Campa and Coney, 1983; Valencia-Moreno, 1998; Valencia-Moreno and others, 2001, 2003).

Three basement domains underlie the tract: (1) a northern domain (ND) characterized by the Proterozoic basement of North America and its sedimentary Neoproterozoic and Paleozoic cover in north and northeastern Sonora (Chihuahua-West terrane) and a sequence of plutonic and amphibolite facies metamorphic rocks in western Sonora (Caborca terrane); (2) a central domain (CD) composed of deep-water Paleozoic marine rocks underlain by rocks of the North American craton in southern Sonora and northern Sinaloa (Cortez terrane); and (3) a southern domain (SD) characterized by rocks of the Guerrero terrane, where North American cratonal rocks are unknown.

Valencia-Moreno and others (2007) indicate that initial strontium and neodymium ratios change systematically from north to south across these terrane boundaries and indicate progressively less contamination by North American cratonal rocks. These relationships show that the composition of Laramide magmas was significantly modified by crustal contamination.

Porphyry copper mineralization occurred across the tract from about 60 to 50 Ma. Although many prospects remain undated in Sonora, Sinaloa, and western Durango, there is a general trend of younging to the south (Barra and others, 2005).

The tract, which consists of 25 discrete polygons, was constructed by analyzing the 1:500,000-scale digital geologic map of Mexico in ArcGIS, as follows.

Map units were classified into generalized units by age and lithologic class (igneous volcanic, igneous plutonic, sedimentary, metamorphic, unconsolidated) based on principal lithologies associated with each map unit. From this enhanced geology map database, all igneous rocks whose potential age span includes the Laramide were selected. Areas of potentially permissive rocks of appropriate age under shallow cover (<1 km thick) were considered by creating a 10-km concentric buffer around Laramide intrusive igneous rocks and a 2-km concentric buffer around Laramide volcanic rocks. A preliminary tract was digitized by hand from these buffered permissive rock units. This was then inspected and extended in some cases to include additional areas that included known or suspected Laramide porphyry copper deposits and prospects. Plutonic rocks younger than Laramide were displayed, and the tract was edited to exclude (slightly generalized) post-Eocene Tertiary intrusive rocks.Larger-scale (1:250,000) geologic maps and literature were consulted and used to check map unit boundaries, ages, and structures.

The tract was then further refined using the aeromagnetic map (North American Magnetic Anomaly Group, 2002) to include some adjacent areas that appear to have shallow magnetic sources. Stream-sediment geochemical data from the national database (Servicio Geológico Mexicano, written commun., 2007) were adjusted for analytical drift and were interpreted. The resulting map (fig. 7) indicates a number of areas within the tract that have a geochemical signature indicative of porphyry copper deposits.

We also examined 1:250,000-scale geologic maps, published by the Servicio Geológico Mexicano (SGM) of

Table G2. Map units in tract 003pCu3007 (MX-L2), Sierra Madre Occidental West, Mexico.

[Map unit, age range, and principal lithologies from a 1:500,000 scale preliminary digital geologic map of Mexico (Servicio Geológico Mexicana, written commun., 2007); n.d., no data]

Map unit	Maximum age	Minimum age	Lithology 1	Lithology 2
Intrusive rocks				
TpaGr-Gd	Paleocene	Paleocene	granite	granodiorite
KiGd-Tn	Cretaceous, Early	Cretaceous, Early	granodiorite	tonalite
Volcanic rocks				
KsTpaA-Tq	Cretaceous	Paleocene	andesite	trachyte
TePDa	Eocene	Eocene	dacite	n.d.

the areas included in the tract to be sure that we had included any mapped areas of hydrothermal alteration that might be indicative of porphyry copper deposits.

Known Deposits

Fifteen known deposits occur in tract 003pCu3007 and are described here and in table G3. The descriptions are organized by the three basement domains and by their association in mineral districts.

Northern Domain

Cananea constitutes the principal mining district of Mexico, and it is one of the foremost porphyry copper districts in the world. The deposits of this district, along with La Caridad, are part of “the great cluster” of porphyry copper deposits of Arizona, Sonora, and New Mexico which contain an estimated resource of 240 Mt of copper (Keith and Swan, 1996). Approximately 95 percent of the total copper production in México is derived from mines in this region. The Cananea district includes the deposits of Cananea, Mariquita, and Milpillas (table G3). The main copper production in the Cananea Mine is derived from open-pit mining of a >500-m-thick chalcocite blanket (Meinert, 1982; Wodzicki, 2001). However, the highest ore grades are associated with breccia pipes that were mined previously and continue to be of economic significance (Bushnell, 1988). The total resources of Cananea include 7,140 Mt of ore at 0.42 percent copper, 0.008 percent molybdenum, 0.58g/t silver, and 0.012 g/t gold (Singer, and others, 2008), which represents ~30 Mt of metallic copper.

The basement in the Cananea district consists of Paleozoic sedimentary rocks overlying Proterozoic granite (Anderson and Silver, 1977). Above this, Mesozoic volcanic rocks are overlain by a 1,500-m-thick sequence of andesite and dacite flows with lesser volcanosedimentary sequences of Laramide age (Blodgett and others, 2002; Gray and others, 2004; Page and others, 2003). These volcanic rocks were intruded by a number of intermediate composition plutons with ages ranging from about 70 to 55 Ma.

Recently published Re-Os molybdenite ages suggest that the mineralization episode at Cananea (~59 to 61 Ma) represents one of several distinctive ‘pulses’ of magmatism recognized in northern Mexico; the second episode is represented by La Caridad, El Crestón, and Malpica occurring at ~54 Ma (Barra and others, 2005). A possible older regional mineralization episode (~63 to 64 Ma), initially proposed by McCandless and Ruiz (1993), may be tentatively documented at the Milpillas deposit.

Milpillas and Mariquita are located ~14 km to the northwest of the Cananea mine, and they are separated from each other by 5 km. The Milpillas deposit contains 30 Mt of ore at 2.5 percent copper, while Mariquita has resources of 35 Mt of ore at 0.4 to 0.6 percent copper. These deposits have a geological framework similar to that at Cananea. The Milpillas deposit consists of high-grade chalcocite blankets that are entirely covered by Tertiary-Quaternary alluvial sediments commonly 50- to 250-m thick (de la Garza and others, 2003). At least three cycles of secondary enrichment that have been recognized in the deposit resulted in at least six ‘blankets’ that occur at a depth of 150 to 750 m below the surface. The Milpillas deposit is the oldest porphyry in the Cananea District at about 63 Ma (Valencia and others, 2006).

The Nacozari district, located southeast of Cananea, is the second largest porphyry copper district in Mexico. The district includes the La Caridad, Pilares, La Florida-Barrigón, and El Batamote deposits. La Caridad is the most important and best- documented deposit in the district, containing >1,800 Mt of ore at 0.452 percent copper and 0.0247 percent molybdenum, representing a resource of 8.14 Mt of metallic copper (Echávarri-Pérez, 1971; Livingston, 1973, 1974; Seagart and others, 1974; Berchenbritter, 1976; Singer and others, 2008). The geology of the district consists of Early Cretaceous sedimentary rocks of the Bisbee Group, which are overlain by Laramide intermediate-composition volcanic rocks. The mineralization was associated with a quartz monzonite intrusive dated between 54 and 55 Ma

(Damon and others, 1983a). This age corresponds with slightly younger molybdenite Re-Os dates of 53.6 and 53.8 Ma (Valencia and others, 2004) on the deposit itself.

The Cumobabi district, located ~150 km northeast of Hermosillo, was inactive up to several years ago, but recent exploration has again focused interest on the district, which includes the San Judas, Transvaal, Cobre Rico, and Washington mines (Barton and others, 1995; Carten and others, 1993; Damon and others, 1983a; Sherkenbach and others, 1985). An early producer of molybdenum in Mexico, the district contains 2.9 Mt of ore at 0.245 percent molybdenum and 0.165 percent copper (Consejos de Recursos Minerales, 1992a). The district is underlain by phyllites, metavolcanics, gneissic granite, and younger andesite and dacite host rocks intruded by monzonite which yielded a biotite K-Ar age of 63.1±1.7 Ma (Sherkenbach and others, 1985). A granodiorite exposed near the Washington mine, about 25 km west of San Judas, yielded a biotite K-Ar age of 56.4±1.2 Ma, which is thought to represent a pre-mineral event age constraint in the district (Damon and others, 1983a). Two recent Re-Os dates in molybdenite indicate a concordant age of 58.7±0.2 Ma (Barra and others, 2005). Numerous breccias (quartz-tourmaline-sulfide) host mineralization associated with overlapping potassic and sericitic alteration.

Central Domain

The Suaqui Grande district, located ~150 km southeast of Hermosillo in east-central Sonora, includes the Suaqui Verde, Cuatro Hermanos, and Luz del Cobre (also known as San Antonio de la Huerta) deposits (table G3). The geology of the district is different than that of the northern domain because of the lack of Proterozoic crystalline basement. The oldest exposed rocks in the area are deformed Paleozoic sedimentary rocks unconformably overlain by Late Triassic clastic-continental and lesser marine sedimentary rocks. These rocks are covered by Laramide flows and tuffs of intermediate composition. The volcanic sequence appears to be more voluminous in this region of Sonora possibly due to less tectonic uplift and erosion (Valencia-Moreno and others, 2001). The district lies in a region dominated by the structural trend of the rift-related Late Triassic Barranca Group basin (Stewart and Roldán-Qunintana, 1991) and, as such, an east-west orientation and distribution shown by the various deposits and occurrences in this zone suggests that the deep-seated structures that bound the basin could serve as important structural controls for the circulation of mineralizing fluids (Valencia-Moreno and others, 2007). Intrusive rocks of quartz-diorite to granite composition yielded K-Ar ages between 49.6±1.2 and 63.3±0.3 Ma (Damon and others, 1983a, 1983b). Alteration minerals yield K-Ar ages of between 53 and 59 Ma. In the Cuatro Hermanos deposit, mineralization was associated with granodiorites and granite porphyry stocks (Zürcher, 2002) characterized by mineralized breccias with pyrite, chalcopyrite, and molybdenite, with zones of supergene enrichment and the potential for associated exotic copper. The supergene blanket, which hosts the chief target of the current exploration project, contains grades of approximately 0.5 percent copper with molybdenum. Recent molybdenite Re-Os dates from this deposit yielded an age of 55.7±0.3 Ma (Barra and others, 2005). The Suaqui Verde deposit is similar to the Cuatro Hermanos deposit but in addition has a ferricrete that covers the ore body, also suggesting the potential development of exotic copper deposits. Recent Re-Os dates on molybdenites from the deposit define the age of the mineralizing event as ranging from 56.8±0.2 to 57.0±0.3 Ma (Barra and others, 2005). Mineralization at Luz del Cobre is associated with breccias with molybdenite, chalcopyrite, chalcocite, covellite, and digenite, also including roughly 207 tons of U_3O_8 (Barton and others, 1995; Perez-Segura, 1985).

Southern Domain

The southernmost basement domain contains four known deposits: (1)Bahuerachi and (2) Santo Tomás in the Choix district in northern Sinaloa and southwestern Chihuahua; (3)Tameapa (Tameapa district) in eastern Sinaloa, northeast of Culiacán; and (4) Malpica, in southern Sinaloa near Mazatlán (table G3, figs. G1, G2).

Santo Tomás is associated with a quartz monzonite porphyry hosted in Cretaceous limestone and metamorphosed andesite (Bustamante-Yáñez, 1986; Clark and others, 1988). A K-Ar date on sericite yielded an age of 57.2±1.2 Ma (Damon and others, 1983a). Nearby replacement deposits in Cretaceous limestone are associated with granodiorite and granite porphyry yielding ages of 59 to 60 Ma (Damon and others, 1983a; Clark and others, 1988).

The Bahuerachi deposit lies approximately 35 km northeast of the Santo Tomás deposit and is appreciably larger (table G3). The geology of the deposit consists of Triassic-Cretaceous age volcano-sedimentary units at the base, locally overlain by Laramide andesitic, pyroclastic and ignimbrite flows intruded by rocks ranging in composition from diorite to rhyolite. Numerous peripheral base and precious metal epithermal systems have also been identified in the area.

The Tameapa district (fig. G2) includes the Tameapa deposit and several small prospects. Mineralization at the deposit consists of stockwork and breccias associated with a quartz-monzonite pluton that was dated at 54.1±0.1 Ma from a K-Ar age on biotite (Damon and others, 1983a). New ages from Re-Os geochronology on molybdenite separates indicate that mineralization occurred in two principal pulses at 57 and 53 Ma.

At Malpica, the mineralization is hosted in two breccia structures cemented by tourmaline that were emplaced in a granodiorite stock crosscut by a later porphyry phase of similar composition which yielded biotite and hornblende K-Ar ages of 57.3±0.6 Ma and 54.2±1.2 Ma, respectively

(Damon and others, 1983a; Bustamante-Yáñez, 1986). Mineralization occurs as breccia filling, stockwork, and small zones of supergene enrichment; the age of mineralization based on Re-Os dates on molybdenites was determined to be 54.3±0.3 Ma (Barra and others, 2005).

Prospects, Mineral Occurrences, and Related Deposit Types

Significant prospects and occurrences are listed in table G4 and shown in figures G1 and G2. Selected prospects are described in this section in geographic order, from north to south, which generally corresponds as well to their age order from Early Paleocene to late Eocene.

El Pilar (ND)

The El Pilar prospect is located 15 km southeast of Nogales, Arizona, and the international boundary. The inferred mineral resource currently consists of 180 Mt of 0.365 percent copper (Stingray Copper Inc., 2009). This inferred resource is primarily in the form of oxide mineralization in a conglomerate. Copper oxide mineralization at El Pilar is hosted by a conglomerate containing clasts of equigranular and porphyritic intrusive, as well as highly silicified rock. The mineralization is interpreted to have been derived from a pre-existing porphyry copper deposit and related structurally controlled mineralization. Reconstruction of events suggests that a mineralized bedrock source was mechanically weathered and eroded, transported, and deposited in a channel and alluvial-fan sequence overlying a conglomerate unit that was derived from rock that was originally overlying the mineralized bedrock source. The other significant copper occurrence is at El Pilar de Arriba, where a sericite altered fault zone contains erratic copper prospects over a 2-km strike length; however, no significant mineralization to date has been found.

El Alacrán (ND)

The El Alacrán deposit, ~17 km southeast of the Cananea mine, is a small prospect with inferred resources of 0.7 Mt at 0.5 percent copper (Consejo de Recursos Minerales, 1992a) hosted in a 700-m-thick volcanic sequence. K-Ar ages on biotite from potassic alteration yielded an age of 56.7± .2 Ma for the hydrothermal alteration (Damon and others, 1983a). Recent Re-Os molybdenite ages date the mineralization at El Alacrán at 60.9±0.2 and 60.8±0.2 Ma (Barra and others, 2005).

Dos Naciones (ND)

The Dos Naciones porphyry prospect, about 160 km northeast of Hermosillo, is defined in part by peripheral skarn bodies outlining the edge of a regional magnetic anomaly that is approximately 2 km in diameter. Trench sampling over the skarn yields average grades of greater than 0.5 percent copper (Yale Resources Ltd., 2009).

La Bella Esperanza (ND)

The Bella Esperanza prospect, like other occurrences in the Nacozari district, is underlain by Early Cretaceous sedimentary rocks equivalent to the Bisbee Group rocks of SE Arizona. Laramide flows and tuffaceous rocks were intruded by numerous subvolcanic stocks. Mineralization at Bella Esperanza consists of a zone of stockwork and breccia associated with a quartz-monzonite stock dated by K-Ar method at 55.9±1.2 Ma on biotite (Damon and others, 1983a). The deposit features a well-developed oxide zone.

Washington (ND)

Andesite and dacite volcanic rocks were intruded by a granodioritic pluton in the area of the Washington prospect within the Cumobabi district. The intrusive is dated at 56.4±1.2 Ma on biotite (Damon and others, 1983a). The prospect area contains breccias dominated by pyrite, chalcopyrite, molybdenite, and scheelite associated with phyllic and potassic alteration (Simmons and Sawkins, 1983).

San Javier (CD)

The San Javier Copper Project is located approximately 140 km east-southeast of Hermosillo on the western flank of the Sierra Madre Occidental. A preliminary resource estimate for the site has been reported as being between 81 to 96 Mt of ore at 0.28 to 0.35 percent copper (Constellation Copper Corp., 2007). Small-scale underground mining of silver, copper, and gold took place at the site but is poorly documented. Ages of 73 and 70 Ma, and 90 and 89 Ma have been obtained from U-Pb age dating (McDowell and others, 2001). Copper mineralization is hosted primarily within hydrothermal-tectonic breccias and associated stockwork. The prospect has also been described as IOCG-type.

Los Verdes (CD)

The Los Verdes prospect is ~150 km southeast of Hermosillo and some 45 km east of the Cuatro Hermanos deposit in east-central Sonora. A resource calculation of 10.5 Mt at grades of 0.12 percent molybdenum and 0.46 percent copper has been reported (Virgin Metals, 2008). The prospect is in exposures of weakly porphyritic monzonite that intruded into older andesitic and dacitic volcanic rocks. Numerous breccia zones traverse the pluton and also occur around its margins. The breccias consist of granodiorite clasts of varying size in an iron-rich tourmaline quartz matrix. Molybdenite occurs in the matrix along with chalcopyrite, pyrite and minor scheelite. Recent drilling has shown

Table G3. Known porphyry copper deposits in tract 003pCu3007 (MX-L2), Sierra Madre Occidental West, Mexico.

[Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; Cu-Mo subtype, deposits that have Au/Mo ratios <3 or average Mo grades >0.03 percent; Cu-Au subtype, deposits that have Au/Mo ratios > 30 or average Au grades >0.2 g/t; NA, not applicable; n.d., no data. Contained Cu in metric tons is computed as tonnage (Mt*1,000,000) * Cu grade (%).]

Name	Latitude	Longitude	Subtype	Age (Ma)	Tonnage (Mt)	Grade				Contained Cu (t)	Reference
						Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)		
Milpillas	31.113	-110.427	NA	58	230	0.85	n.d.	n.d.	n.d.	1,955,000	Fitch (2000), Castro-Escárrega and others (2000)
Mariquita	31.044	-110.426	NA	63	100	0.45	n.d.	n.d.	n.d.	450,000	Leonard (1989), Sillitoe (1976), Castro-Escárrega and others (2004)
Cananea	30.954	-110.322	NA	55.5	7140	0.42	0.008	0.012	0.58	29,988,000	Anderson and Silver (1977), Barton and others (1995), Bushnell (1988), Casaceli (1992), Einaudi (1982), Meinert, 1982, Long (1995), Terán-Martínez and others (1999)
El Batamote	30.449	-109.771	NA	57	4.4	0.36	n.d.	n.d.	n.d.	15,840	Singer and others (2005) and references therein, Damon and others (1983a,b), Palafox-Reyes and others (1998), Valencia-Moreno and others (2007)
La Florida-Barrigón	30.379	-109.725	NA	52	135	0.33	n.d.	n.d.	n.d.	445,500	Damon and others (1983a,b), Sillitoe (1976), Theodore and de Witt (1978), Terán-Martínez and others (1999), Palafox-Reyes and others (1998)
Pilares	30.330	-109.629	NA	53	147	1.04	n.d.	n.d.	n.d.	1,528,800	Gilmour (1982), Leonard (1989), Long (1995), Palafox-Reyes and others (1998)
La Caridad	30.315	-109.559	NA	51	1800	0.452	0.0247	n.d.	n.d.	8,136,000	Damon and others (1983a), Long (1995), Palafox-Reyes and others (1998)
Cumobabi	29.870	-109.961	Cu-Mo	51.5	67	0.266	0.099	n.d.	n.d.	178,220	Barton and others (1995), Carten and others (1993), Damon and others (1983a),

Table G3. Known porphyry copper deposits in tract 003pCu3007 (MX-L2), Sierra Madre Occidental West, Mexico.—Continued

[Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; Cu-Mo subtype, deposits that have Au/Mo ratios <3 or average Mo grades >0.03 percent; Cu-Au subtype, deposits that have Au/Mo ratios > 30 or average Au grades >0.2 g/t; NA, not applicable; n.d., no data. Contained Cu in metric tons is computed as tonnage (Mt*1,000,000) * Cu grade (%).]

						Grade					
											Sherkenbach and others (1985)
Luz del Cobre	28.627	-109.642	NA		14.7	0.74	n.d.	n.d.	n.d.	108,486	Valencia-Moreno and others (2007), Zaruma Resources (2008)
Suaqui Verde	28.399	-109.802	NA	57	87.2	0.43	n.d.	n.d.	n.d.	374,960	Barton and others (1995), Damon and others (1983a), Leonard (1989), García-Cortez and others (2000), Flores-Vásquez and others (2004)
Cuarto Hermanos	28.388	-109.644	NA	56.5	764	0.18	0.02	n.d.	1.2	1,382,840	Virgin Metals Inc. (2008), Barton and others (1995), Fitch (2000), Sillitoe (1976), García-Cortez and others (2000), Preismeyer and Leroux (2006)
Bahuerachi	27.015	-108.121	NA	65.7	604.7	0.393	0.008	0.032	3.91	2,376,471	Jutras and McCandlish (2006), Minjárez-Sosa and others (2002), Independent Mining Consultants (2007)
Santo Tomas	27.014	-108.121	NA	57.2	274	0.50	n.d.	0.05	n.d.	1,364,520	Valencia-Moreno and others (2007)
Tameapa	25.668	-107.351	NA	54	50	0.40	n.d.	n.d.	n.d.	200,000	Barton and others (1995), Damon and others (1983a), Sillitoe (1976), Saldaña-Saucedo and others (1999)
Malpica/ La Reyna	23.269	-106.100	Cu-Au	54-1	33	0.5	n.d.	0.4	n.d.	165,000	Torres-Escamilla and other (1999); Singer and others (2008)

mineralization is disseminated within, and in veinlets cutting, the unbrecciated granodiorite; this mineralization forms a flat-lying envelope in the upper regions of the granodiorite body (Virgin Metals, 2008). Exploration results suggest that the deposit has a number of features that can be characterized as a molybdenum-bearing breccia pipe related to a large porphyry copper-molybdenum system. Similar deposit relationships occur at Cananea (La Colorado pipe), Nacozari (Pilares pipe), and at Cumobabi (El Transvaal breccia) among others. A ~100-m-thick supergene zone constitutes the bulk of the resource.

La Guadalupana (SD)

La Guadalupana is located some 70 km south-southeast of the Bahuerachi deposits in southwestern Chihuahua near the border with Sinaloa where copper-, molybdenum-, and tungsten-mineralized veins cut a granodiorite intrusive with a biotite K-Ar age of 59.4±1.2 Ma (Damon and others, 1983a). Values of 20-30 percent copper, 32 oz silver, and 2.65g/t gold were derived from bulk samples of veins.

Cerro Colorado (Batopilas District) (SD)

The Cerro Colorado prospect is in the Batopilas District in southwestern Chihuahua, near the Sonora-Sinaloa-Chihuahua state boundaries, in the region of the town of Batopilas. Preliminary estimated resources include ~3 Mt of ore with 0.3 percent copper and 0.4 g/t gold (Barton and others, 1995). At Batopilas, altered andesite was intruded by coeval granodiorite and quartz-diorite (Bagby and others, 1981). Mineralization is associated with a dome-shaped granodiorite intrusive and is mainly found as a quartz-pyrite stockwork with copper and gold. The porphyry copper style mineralization pre-dated the silver mineralization in the Batopilas area and formed a cluster of prospects (Cerro Colorado, Tahonas, Satevo, and Corallitos), currently under evaluation.

Tahonas (Batopilas District) (SD)

The Tahonas prospect, approximately 2.5 km southwest of Batopilas, occurs as part of an oxidized surface called the Corralitos gossan. The Corralitos prospect also is within the area of the gossan which overlies the Tahonas granodiorite and the Pastrana dacite. A deeply incised portion of the gossan reveals an area containing sericite alteration, chalcanthite efflorescent minerals, pyrite veinlets and disseminations, and quartz stockwork veins (Wilkerson and others, 1988).

Satevo (Batopilas District) (SD)

The Satevo area, located 5 km southeast of the Tahonas copper prospect, consists of strong quartz-alunite alteration surrounding several volcanic structures and may be related to the Corralitos porphyry system. The alteration assemblages are similar to those exposed at the nearby El Sauzal deposit and precious-metal values have been identified in surface sampling. Peñoles previously drilled in the area. The prospect has gold anomalies within an oxidation surface related to a micro-quartz –diorite with a biotite K-Ar age of 51.6±1.1 Ma (Wilkerson and others, 1988). Resource estimates for the area were determined to be 4 Mt of ore with 4 percent copper and 2 Mt of ore with 2-3 g/t gold with variable copper values in the oxidation surface (Barton and others, 1995).

El Pulpo (SD)

The El Pulpo prospect is 125 km northeast of Mazatlan in Sinaloa. High-grade porphyry-related gold, silver, and copper mineralization has been identified discontinuously over a surface area of ~12 km^2. Initial sampling in several target areas within the claim has yielded values of 1.43 percent copper, 0.13 g/t gold and 52.4 g/t silver (El Bagre) and from a nearby zone, 0.29 percent to 0.79 percent copper and up to 0.8 g/t gold (Ross River Minerals, 2009).

Corral de Piedra (SD)

Mineralization at the Corral de Piedra prospect took place in Tertiary rhyolite and granodiorite in the core of a domal structure whose long axis trends northeast. Alteration in the area displays concentric zoning of K-feldspar, quartz, sericite, and propylitic alteration enveloping middle Cretaceous to Miocene age metavolcanics and fossiliferous carbonates and molybdenite-pyrite-chalcopyrite-bearing stockwork veins (Randall, 1974). Minor cassiterite and tungsten are reported in the veinlets. Geochemical sampling has defined an anomalous zone, based on molybdenum threshold values, approximately 2 km by 400 m. K-Ar ages on the granodiorite stock range from about 36 million years to 50-90 million years in the southern part of Sinaloa, suggesting a Laramide age affinity (Henry and Fredrikson, 1972). Surface alteration has produced some secondary enrichment in copper which assayed at 0.15 percent copper.

Tango (SD)

The Tango property is a 17,457-ha exploration project of Minera Camarga (2009) in southern Sinaloa. The property was explored for gold and silver by the Consejo de Recursos Minerales (SGM) in the 1980s as the Viva Zapata concession. In the 1990s, exploration by various concession holders focused on veins, soil, and channel sampling, and in 2000, regional mapping and stream-sediment sampling. The property is promoted as a porphyry gold-copper project and encompasses more than 100 historical workings. No resources have been announced.

Exploration History

This tract contains some of the most explored territory in all of Mexico. In the northern part of the tract, extensive prospecting has taken place to extend the Cananea and La Caridad districts to their present reaches. The current focus of exploration in the tract, as typified by exploration in the central and southern portions of the tract area, is for Laramide precious and polymetallic vein deposits, epigenetic skarn, and underlying or structurally uplifted porphyry copper deposits. Much of the current exploration is focused on known porphyry copper districts by using geophysical techniques to estimate extensions of shallow buried intrusives and subsequent targeted geochemistry to locate surface mineralization. A number of targets in the southern portion of the tract are being evaluated as oxidized zones with broader mineralization potential in underlying strata.

A number of precious-metal skarn prospects, potentially associated with porphyry-type mineralization, are currently undergoing further exploration and development.

The Consejo de Recursos Minerales, precursor to the SGM, conducted detailed studies of mining districts throughout Mexico on a state-by-state basis. These studies resulted in monographs for each state that include descriptions of the geology, prospects, mining history, sampling results, and mineral potential.

Sources of Information

Principal sources of information used by the assessment team for delineation of Tract 003pCu3007 are listed in table G5.

Grade and Tonnage Model Selection

The porphyry copper model of Singer and others (2008) was selected for the assessment based on geologic characteristics of the 15 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 containing 407 other deposits. The statistical tests showed that the deposits are not significantly different from the global model at the 1-percent level.

Although some deposits in the tract have been described as Cu-Mo or Cu-Au deposits (Valencia-Moreno and others, 2007), the gold grades of known deposits in the tract are less than the arbitrary gold grade criteria (>0.2 g/t or Au/Mo>30) used in this study to classify deposits as Cu-Au subtype. Therefore, the team concluded that the porphyry copper grade-tonnage models, which includes Cu-Au and Cu-Mo subtypes, was most appropriate for the probabilistic assessment of undiscovered deposits in the tract.

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, the occurrence of 15 known deposits with ~90 copper prospects, and anomalous copper in stream sediments within the tract, the team arrived at a consensus estimate of 7 undiscovered deposits at a 90-percent confidence level, 13 undiscovered deposits at a 50-percent confidence level, and 19 undiscovered deposits at 10-percent confidence level (table G6). These estimates reflect the number of current exploration targets in play (many of which have published grade-tonnage numbers), copper skarn occurrences not associated with deposits, and the extent of geochemical anomalies and altered areas in the tract. There was considerable discussion about the possibility of dividing the tract because of basement control of deposit size, however the observed effects on deposit size and grade are not conclusive, and the team chose not to subdivide the tract. It was noted that deposits in the northern and central domains that are underlain by continental crust are characterized by Cu-Mo-W deposits and include the large deposits of Cananea and La Caridad (Valencia-Moreno and others, 2007). Deposits in the southern domain of the tract are underlain by oceanic basement and seem to be characterized by Cu-Au mineralization, and undiscovered deposits there may be smaller.

We did not use the deposit density models of Singer and others (2005) directly. Our mean estimate of 13 undiscovered deposits (24 deposits/100,000 km^2) is higher than predicted by the density model (fig. 11).

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, in press). Selected output parameters are reported in table G7. Results of the Monte Carlo simulation are presented as cumulative frequency plots (fig. G3).The cumulative frequency plots show the estimated resource volumes associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock. The median expected amount of copper within the tract is 36 Mt, and the mean expected amount is 48 Mt. The mean expected copper in undiscovered deposits is comparable to the identified resources of about 49 Mt (table G1).

Table G4. Significant prospects and occurrences in tract 003pCu3007 (MX-L2), Sierra Madre Occidental West, Mexico.

[t, metric tons; Mt, megatonne or one million tons; n.d., no data]

Name	Latitude	Longitude	Type	Age (Ma)	Comments (grade and tonnage data, if available)	Reference
El Pilar	31.206	-110.673	Porphyry Cu	n.d.	Noranda Exploration	Castro-Escárrega and others (2007)
El Alacran	30.845	-110.200	Porphyry Cu	60.9	Potential resources: 3,100 t Cu; Resource: 700,000 t 0.5% Cu, 2.4 Mt 0.35% Cu. Potassic alteration dated at 55.9 Ma; (55.4±1.2 Ma andesite, 56.7±1.2 Ma biotite). High-level Laramide porphyry copper deposit occupying elongate area of 2.7 by 6.0 km. Supergene copper enriched "blanket" underlying a leached cap characterized by a chalcocite zone which grades downward into a bornite-digenite-covellite zone and then into lower-grade material. Geology: Late Cretaceous- Early Tertiary andesitic volcaniclastic rocks with local quartz latite intruded by a small quartz latite porphyry stock.	Dean and Guilbert (1981), Pérez-Segura (1985), Terán-Martínez and others (1999)
Dos Naciones	30.172	-110.537	Skarn	n.d.	Skarn associated with potential porphyry-style target based on skarn proximity to regional aeromagnetic high associated with an altered intrusive.	Yale Resources (2009)
La Bella Esperanza	30.256	-109.698	Porphyry Cu	55.9± 1.2 Ma	Age based on dated granodiorite within 0.5 km of prospect.	Damon and others (1983a), Pérez-Segura (1985), Palafox-Reyes and others (1998)
Washington	29.895	-110.067	Porphyry Cu	45.7	Oval-shaped deposit, vertically plunging collapse breccia ~60 m in diameter. NNW trending faults form contacts at the surface and crosscut breccia at depth. Plunge of orebody changes to ~60SW at 200 m depth. Total resources (1985): 1.2 Mt, 1.8% Cu, 0.14% WO_3, 0.106% Mo, 15.8 g/t Ag, 0.172 g/t Au	Sherkenbach and others (1985), Simmons and Sawkins (1983)
Cobre Rico	29.876	-109.985	Porphyry Cu	n.d.	Cumobabi area: Molybdenite and chalcopyrite in collapse breccia within volcanics; in alteration	Sherkenbach and others (1985), Pérez-Segura

Table G4. Significant prospects and occurrences in tract 003pCu3007 (MX-L2), Sierra Madre Occidental West, Mexico.—Continued

[t, metric tons; Mt, megatonne or one million tons; n.d., no data]

Name	Latitude	Longitude	Type	Age (Ma)	Comments (grade and tonnage data, if available)	Reference
					zone (sericitic, propylitic). Historical mining in the area.	(1985), Cendejas and Barcenas (1978), Guzmán-Espinosa and others (1999), Valencia-Moreno and others (2007)
San Javier Project	28.604	-109.714	Porphyry Cu	n.d.	Copper mineralization is hosted by the Tarahumara Formation (andesitic volcanic breccias, flows volcaniclastic sandstone, conglomerate. In 2007, Cerro Verde was at an early stage of development (inferred resources of 81.0 Mt of 0.35% Cu); the other 2 areas are exploration targets.	Constellation Copper Corp. (2007), García-Cortez and others (2000)
Aurora	28.526	-109.621	Porphyry Cu	~54	Copper along E-W trending breccia zone, in zone of mapped alteration (oxidation, silicification). Sulfides (tetrahedrite) in vein systems. Gold discovered as placer and vein deposits in 1889. Aurora is along the SE contact of a 5km body of KsTpaGr-Gd that also hosts the Labra Au prospect.	García-Cortez and others (2000), Panczner (1987), Pérez-Segura (1985)
Los Verdes	28.394	-109.149	Porphyry Cu	49.3	Resource: minimum estimate 10,000,000 t 0.25% Mo, 0.2% Cu, 0.2% WO_3 (Perez Segura, 1985)	Pérez-Segura (1985), García-Cortez and others (2000), Virgin Metals (2008)
Cerro Colorado (Batopilas)	27.110	-107.710	Porphyry Cu	51.6 + 1.1 Ma	Cerro Colorado area is part of Exmin Resources, Inc. 43,000 hectare Batopilas 2006-2007 exploration project. Resource estimate (without drilling) from Barton and others (1995): >3 Mt, 0.3% Cu, 0.4 g/t Au. Location is for the Cerro Colorado Au prospect (Sanjuanito 1:250,000 map) which is located ~ 2 km east a north-south-trending mapped alteration zone.	Wilkerson and others (1988), Barton and others (1995), Damon and others (1983a) , Goodell (1995), Maldano-Lee and others (2000), Valencia-Moreno and others (2007)
Tahonas (Corralitos Batopilas)	27.013	-107.734	Porphyry Cu	33.95	Well developed mineralogical zonation in district is concentric around the deposit. Preliminary fluid inclusion homogenization temperatures 217 to 434 ^{o}C. Location is that of Corralitos gossan (oxidized surface expression of the Tahonas porphyry copper deposit).	Wilkerson (1983), Wilkerson and others (1988), Maldano-Lee and others (2000)
Satevo	26.987	-107.719	Porphyry	51	Resources: 4 Mt at 0.4% Cu and 2-3 g/t Au. Lies 5 km	Barton and others (1995),

Table G4. Significant prospects and occurrences in tract 003pCu3007 (MX-L2), Sierra Madre Occidental West, Mexico.—Continued

[t, metric tons; Mt, megatonne or one million tons; n.d., no data]

Name	Latitude	Longitude	Type	Age (Ma)	Comments (grade and tonnage data, if available)	Reference
(Batopilas)			Cu		southeast of the Tahonas prospect.	Goodell (1995), Wilkerson and others (1988), Librado-Flores and others (1999)
Cerro Chileno	26.817	-108.208	Porphyry Cu	n.d.	Skarns of the Choix district surround the SGM porphyry prospect (stockwork).	Escamilla-Torres and others (2000), SGM (written commun., 2007)
Cerro Colorado	26.254	-107.332	Porphyry Cu	46	Described as porphyry Cu-Mo deposit with breccia and disseminated ore associated with granodiorite porphyry (Valencia-Moreno and others, 2007, Table 1, #32). This is the location for Alt. Cerro Colorado on the SGM maps, dated by Damon and others (1983a). This site is distinct from Cerro Colorado in the Batopilas district to the north.	Damon and others (1983a), Librado-Flores and others (1999), Singer and others (2008), Valencia-Moreno and others (2007)
La Desencantada	25.027	-107.410	Porphyry Cu	n.d.	SGM porphyry copper prospect. La Desencantada, Guadalupe, Las Guasimas, and La Espanola prospects are all within 3 km of each other.	SGM (written commun., 2007), Saldaña-Saucedo and others (1999)
Las Higueras	25.013	-107.238	Porphyry Cu	49	Cu-Mo porphyry copper prospect (hydrothermal, sulfides, vein). Las Higueras and Cabo Canaveral prospects are within 5 km in the same pluton. Molybdenite and chalcopyrite associated with quartz veins and disseminated in granodiorite (54.9 Ma biotite; 49.0 Ma sericite from mineralized zone)	SGM (written commun., 2007), Saldaña-Saucedo and others (1999), Valencia-Moreno and others (2007), Damon and others (1983a)
Corral de Piedra	24.192	-105.816	Porphyry Cu	~36?	Geochemical survey carried out. Porphyry Mo-Cu-W, topaz rhyolite? (Similar to Climax) Piaxtla Granodiorite Batholith. Pre-mineral NE rhyodacite dikes and post-mineral NW andesite dikes.	Múngia-Rojas and others (2000), Randall (1974)
El Pulpo (Jocquistes)	23.896	-106.161	Porphyry Cu	n.d.	Cu-Au porphyry target. Mineralized outcrops along creek banks and canyon walls; disseminated copper and Cu-Mo-tourmaline breccia. Grab samples of 10 outcrops: 0.37% Cu, 14.66 ppm Mo, 0.11 g/t Au, and 16 g/t Ag. No resources or reserves.	Reeves (2005), Ross River Mineral Inc. (2008), Torres-Escamilla and others (1999)
La Azulita	23.600	-106.100	Porphyry Cu	59.5	Valencia-Moreno and others (2007) report 0.5 Mt @ 1.2% Cu, 0.01% Mo. Hydrothermal breccias (possible porphyry Mo-Cu?) associated with Cretaceous	Salas (1975), Torres-Escamilla and other (1999), Geoinformatics

Table G4. Significant prospects and occurrences in tract 003pCu3007 (MX-L2), Sierra Madre Occidental West, Mexico.—Continued

[t, metric tons; Mt, megatonne or one million tons; n.d., no data]

Name	Latitude	Longitude	Type	Age (Ma)	Comments (grade and tonnage data, if available)	Reference
					granodiorite and monzonite. La Noria concession has 5 prospective areas (166.5 km^2 area): Azulitas, N Azulitas, Las Minas, Cerro Colorado, La Verde, Inferred resources announced for polymetallic breccias/fracture zones open at depth: 5.63 Mt of 0.54% Cu, 12.2g/t Ag, 0.08 g/t Au, and 0.04% Mo.	Exploration Inc (2008), SRK Consulting (2006), Valencia-Moreno and others (2007)
Tango	23.178	-105.772	Porphyry Cu	n.d.	Gold veins peripheral to a Tertiary intrusive complex with potential for porphyry Cu-Au deposits. Multiple porphyritic intrusions (granodiorite, granite, monzonite), alteration (potassic, phyllic, propylitic), geochemical footprint anomalies over 41 km^2, tourmaline breccias.	Minera Camarga (2009)

Table G5. Principal sources of information used by the assessment team for tract 003pCu3007 (MX-L2), Sierra Madre Occidental West, Mexico.

[NA, not available or not applicable]

Theme	Name or title	Scale	Citation
Geology	Preliminary digital geologic map of the Republic of Mexico	1:500,000	Servicio Geológico Mexicano (written commun., 2007)
	Carta geólogico-minera, Estado de Durango	1:500,000	López-Escalona and others (2006)
	Carta geólogico-minera, Estados de Sinaloa	1:500,000	Castro-Escárrega and others (2007)
	Carta geólogico-minera, Estado de Sonora	1:500,000	Arriaga-Meléndez and others (2004)
	Carta geólogico-minera, Estado de Chihuahua	1:500,000	Salinas-Prieto and others (2004)
	Carta geólogico-minera, Estado de Nayarit	1:500,000	Terán-Ortega and others (2007)
Mineral occurrences	SGM Minas database	NA	Servicio Geológico Mexicano (written commun., 2007)
	Porphyry copper deposits of the world: database, map, and grade and tonnage models	NA	Singer and others (2008)
	University of Arizona-Industry-USGS Mexico Consortium	NA	University of Arizona-Industry-USGS Mexico Consortium, March 1999 Release Notes (unpublished)
	Geological and metallogenetic characteristics of the porphyry copper deposits of México and their situation in the world context	NA	Valencia-Moreno and others (2007)
	MRDS database	NA	U.S. Geological Survey (2005)
Geochemistry	SGM stream-sediment database	NA	Servicio Geológico Mexicano (written commun., 2007)
Geophysics	North American magnetic map	1:10,000,000	North American Magnetic Anomaly Group (2002)
Exploration	Geological-mining monograph of the state of Sonora	1:500,000	Consejo de Recursos Minerales (1992a)
	Geological-mining monograph of the state of Chihuahua	1:500,000	Consejo de Recursos Minerales (1994a)
	Geological-mining monograph of the state of Sinaloa	1:500,000	Consejo de Recursos Minerales (1992b)
	Geological-mining monograph of the state of Durango	1:500,000	Consejo de Recursos Minerales (1993)
	Geological-mining monograph of the state of Nayarit	1:500,000	Consejo de Recursos Minerales (1994b)
	Company Web pages	NA	See tables and text

Table G6. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 003pCu3007 (MX-L2), Sierra Madre Occidental West, Mexico.

[NXX, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; s, standard deviation; Cv%, 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; area, area of permissive tract in square kilometers; density, deposit density reported as the total number of deposits per km^2. N_{und}, s, and Cv% are calculated using a regression equation (Singer and Menzie, 2005).]

Consensus undiscovered deposit estimates			Summary statistics					Tract area (km^2)	Deposit density (N_{total}/km^2)
N90	N50	N10	N_{und}	s	Cv%	N_{known}	N_{total}		
7	13	19	13	4.5	36	15	28	115,110	0.00024

Table G7. Results of Monte Carlo simulations of undiscovered resources in tract 003pCu3007 (MX-L2), Sierra Madre Occidental West, Mexico.

[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	5,500,000	11,000,000	36,000,000	100,000,000	140,000,000	48,000,000	0.34	0.01
Mo	48,000	130,000	740,000	3,100,000	4,600,000	1,300,000	0.30	0.02
Au	84	190	880	2,600	3,500	1,200	0.36	0.02
Ag	350	1,200	8,600	36,000	53,000	16,000	0.29	0.03
Rock	1,300	2,300	7,700	22,000	27,000	9,900	0.36	0.01

References Cited

Anderson, T.H., and Silver, L.T., 1977, U-Pb isotope ages of granitic plutons near Cananea, Sonora: Economic Geology, v. 72, p. 827-836.

Arriaga-Meléndez, Hilario, López-Escalona, J.J., López-Reyes, J.E., Terán-Ortega, L.A., Castro-Escarrega, J.J., Espinoza-Beltrán, C.C., and Vázquez-Mendoza, Rigoberto, compilers, 2004, Carta geólogico-minera, Estado de Sonora: Servicio Geológico Mexicano, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/sonora.pdf.).

Bagby, W.C., Cameron, K.L., and Cameron, M., 1981, Contrasting evolution of calc-alkalic volcanic and plutonic rocks of western Chihuahua, Mexico: Journal of Geophysical Research, v. 86, p. 10,420-10,410.

Barra, F., Ruiz, J., Valencia, V.A., Ochoa-Landín, L., Chesley, J.T., and Zürcher, L., 2005, Laramide porphyry Cu-Mo mineralization in northern Mexico—Age constraints from Re-Os geochronology in molybdenite: Economic Geology, v. 100, p. 1605-1616.

Barton, M.D., Staude, J.M., Zürcher, L., and Megaw, P.K.M., 1995, Porphyry copper and other intrusion-related mineralization in Mexico, *in* Pierce, F.W., and Bonn, J.G., eds., Porphyry copper deposits of the American Cordillera: Arizona Geological Society Digest, v. 20, p. 487-524.

Bawiec, W.J., and Spanski, G.T., in press, EMINERS—Economic Mineral Resource Simulator, version 3.0: U.S. Geological Survey Open-File Report 2009-1057, program files and 29-p. Quick-Start Guide.

Berchenbritter, D.K., 1976, The geology of La Caridad fault, Sonora, Mexico: Iowa City, University of Iowa, master's thesis, 127 p.

Berger, B.R., Ayuso, R.A., Wynn, J.C., and Seal, R.R., 2008, Preliminary model of porphyry copper deposits: U.S. Geological Survey Open-File Report 2008-1321, 55 p., accessed May 15, 2009, at http://pubs.usgs.gov/of/2008/1321.

Blodgett, Robert B., Moore, Thomas E., and Gray, Floyd, 2002, Stratigraphy and Paleontology of Lower Permian rocks north of Cananea, Northern Sonora, Mexico: Journal of South American Earth Science, vol. 15, p. 481- 495.

Bushnell, S.E., 1988, Mineralization at Cananea, Sonora, Mexico,-and paragenesis and zoning of breccia pipes in quartzofeldspathic rock: Economic Geology, v. 83, p.1760-1781.

Bustamante-Yáñez, M.A., 1986, Recursos mineros en el Estado de Sinaloa: Geomimet, v 142, p. 81-102.

Campa, M.F., and Coney, P.J., 1983, Tectono-stratigraphic terranes and mineral resource distribution in Mexico: Canadian Journal of Earth Sciences, v. 20, p. 1040–1051.

Carten, R.B., White, W.H., and Stein, H.J., 1993, High-grade granite-related molybdenum systems—Classification and origin, *in* Kirkham, R.V., Sinclair, W.D., Thorpe, R.I., and Duke, J.M., eds., Mineral deposit modeling: Geological Association of Canada Special Paper 40, p. 521–554.

Casaceli, R.J., 1992, Mexico exploration and mining activity, *in* Randol at Minexpo '92: Golden, Colorado, Randol International Ltd., p. 11-27.

Castro-Escarrega, J.J., Espinoza-Beltrán, C.C., and Vázquez-Mendoza, Rigoberto, compilers, 2004, Carta geólogico-minera, Estado de Sonora: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/sonora.pdf.)

Castro-Escárrega, J.J., López-Escalona, Juan, Díaz-Salgado, Ciro, and Espinoza-Beltrán, Carlos, compilers, 2007, Carta geólogico-minera, Estado de Sinaloa: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/sinaloa.pdf.)

Cendejas F.C., and Barcenas, R.A., 1978, Geologia de la region cuprifera del Transvaal, Municipio de Cumpas, Sonora: Primero Simposio Sobre La Geologia Y Potencial Minero Del Estado De Sonora, Resumenes 1, Hermosillo, Mexico, p. 27-29.

Clark, K.A., Damon, P.E., and Saffiqullah, M., 1988, Metallization epoch in relation to late Mesozoic and Cenozoic igneous activity, Sinaloa, Mexico, *in* Clark, K.F., Goodell, P.C., and Hoffer, J.M., eds., Stratigraphy, tectonics and resources of parts of Sierra Madre Occidental province, Mexico: El Paso Geological Society, Guidebook for the 1988 Field Conference, p. 343-362.

Consejo de Recursos Minerales, 1991, Monografía geologico-minero del Estado de Sinaloa: Consejo de Recursos Minerales, Pachuca, Hgo., Mexico, Publicación M1-e, 159 p.

Consejo de Recursos Minerales, 1992a, Monografía geologico-minero del Estado de Sonora: Consejo de Recursos Minerales, Pachuca, Hgo., Mexico, Publicación M8-e, 220 p.

Consejo de Recursos Minerales, 1992b, Monografía geologico-minero del Estado de Sinaloa: Consejo de Recursos Minerales, Pachuca, Hgo., Mexico, Publicación M1-e, 159 p.

Consejo de Recursos Minerales, 1993, Monografía geologico-minero del Estado de Durango: Consejo de Recursos Minerales, Pachuca, Hgo., Mexico, Publicación M10-e, 204 p.

Consejo de Recursos Minerales, 1994a, Monografía geologico-minero del Estado de Chihuahua: Consejo de Recursos Minerales, Pachuca, Hgo., Mexico, Publicación M14-e, 297 p.

Consejo de Recursos Minerales, 1994b, Monografía geologico-minero del Estado de Nayarit: Consejo de Recursos Minerales, Pachuca, Hgo., Mexico, Publicación M12-e, 171 p.

Constellation Copper Corporation, 2007, NI 43-101 Technical Report, Constellation Copper Corp. San Javier Copper Project, San Javier, Sonora, Mexico: Report prepared by SRK Consulting, 85 p., accessed online Feb. 26, 2008, at http://www.constellationcopper.com/art/san-javier/43-101_007.pdf.

Cox, D.P., 1986, Descriptive model of porphyry Cu (Model 17), *in* Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 76. (Also available online at http://pubs.usgs.gov/bul/b1693/.)

Damon, P.E., Clark, K.C., and Shafiqullah, M., 1983a, Geochronology of the porphyry copper deposits and related mineralization of Mexico: Canadian Journal of Earth Science, v 20, p.1052-1071.

Damon, P.E., Shafiqullah, M., Roldán-Quintana, J., and Cochemé, J.J., 1983b, El batolito Laramide (90–40 Ma) de Sonora, Memorias de la XV Convención Nacional de la AIMMGM, Guadalajara, Jalisco: Asociación de Ingenieros de Minas, Metalurgistas y Geólogos de México (AIMMGM), p. 63-95.

de la Garza, V., Noguez, B., Carreón-Pallares, N., 2003, Geology, mineralization and emplacement of the Milpillas secondary-enriched porphyry copper deposit, Sonora, Mexico, *in* XX Convención Internacional de Minería, Acapulco, Guerrero, v. I: Mexico, Asociación de Ingenieros de Minas, Metalurgistas y Geólogos de México (AIMMGM).

Dean, D.A., And Guilbert, J.M., 1981, El Alacran—A high level porphyry copper deposit, Sonora, Mexico: Geological Society of America Abstracts with Programs, v. 13, no. 2, p. 51.

Echávarri-Pérez, A., 1971, Petrografía y alteración del depósito La Caridad, Nacozari, Sonora, México, Memorias de la IX Convención Nacional de la AIMMGM, Hermosillo, Sonora, México: Asociación de Ingenieros de Minas, Metalurgistas y Geólogos de México (AIMMGM), p. 1–33.

Echávarri-Pérez, A., 1978, Metallogenetic map of Sonora, Mexico: Arizona Geological Society Digest, v. XI, p.145-154.

Einaudi, M.,1982, Description of skarns associated with porphyry copper plutons, southwestern North America, *in* Titley, S.R., ed., Advances in geology of the porphyry copper deposits: Tucson, The University of Arizona Press, p.139-135.

Escamilla-Torres, Tonatiuh, Saldaña-Saucedo, Gutberto, Polanco-Salas, Alfredo, Quevedo-León, Alberto, and

Moreno-López, M.H., 2000, Carta geológico-minera, Huatabampo G12-6, Sonora, Sinaloa and Chihuahua [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Ferrari, L., Tagami, T., Eguchi, M., Orozco-Esquivel, M.T., Petrone, C.M., Jacobo-Albarrán, J., and López-Martínez, M., 2005, Geology, geochronology, and tectonic setting of late Cenozoic volcanism along the southwestern Gulf of Mexico—The Eastern Alkaline Province revisited: Journal of Volcanology and Geothermal Research, v. 146, p. 284-306.

Fitch, D.C., 2000, Mexico mineral occurrences, Map and GIS Database, 3,722 selected mineral occurrences from Consejo de Recursos Minerales Monograph data w/USGS selected data: Copyrighted database available from David C. Fitch, Geologist, P.O. Box 70547, Reno, NV 89570, USA igeologist.com, CD-ROM.

Flores-Vázquez, I., Ochoa-Landín, L., Valencia-Moreno, M., Valencia, V, and Del Rio-Sales, R, 2004, Emplacement depths of porphyry copper-related plutons in the Suaqui Verde deposit, east-central Sonora, Mexico: IV Reunion Nacional de Ciencias de la Tierra, Sociedad Geológica Mexicana, p.190.

García-Cortez, J.A., Guzmán-Espinoza, J.B., Mancillas-Gutiérrez, A.A., García-Duarte, Rodolfo, and Siqueiros-López, Christian, 2000, Carta geológico-minera, Tecoripa H12-12, Sonora and Chihuahua. [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Geoinformatics Exploration Inc., 2008, News release: Geoinformatics Exploration Inc. Web page accessed May 15, 2009, at http://www.geoinformex.com/i/pdf/2008-02-13_NR.pdf.

Gilmour, P., 1982, Grades and tonnages of porphyry copper deposits, *in* Titley, S.R., ed., Advances in geology of the porphyry copper deposits, southwestern North America: Tucson, University of Arizona Press, p. 7-35.

Goodell, P.C., 1995, Porphyry deposits along the Batopilas lineament, Chihuahua, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Tucson, Arizona Geological Society Digest 20, p. 544.

Gray, Floyd, Page, W.R., Wynn, J.C., Callegary, James, Maldonado, Florián, Poole, Don, Miller, R.J., Villaseñor, Félix, and Norman, Laura, 2004, Integration of multispectral imagery with aeromagnetic and geologic map data to understand the tectonic framework of the San Pedro River Headwaters, Sonora, Mexico: VI Seminario Minero International, Sonora, October 19 –23, 2004, Hermosillo, Sonora, Libro de Resúmenes, p. 20-21.

Guzmán-Espinosa, J.B., García-Cortés, J.A., Gutiérrez-Macillas, A.A., García-Duarte, Rodolfo, and Salazar-Velázquez, Ramón, 1999, Carta geológico-minera, Madrera H12-9, Sonora and Chihuahua [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Henry, C.D., and Fredrikson, Goran, 1972, Edades de intrusions, Sinaloa, Mexico: Soc. Geol. Mex. 2nd Annual meeting abstracts, Mazatlán, p. 189-190.

Independent Mining Consultants, Inc., 2007, Bahuerachi Project - Preliminary Economic Assessment report, Chihuahua, Mexico dated November 8, 2007: Tyler Resources Web page accessed Feb. 15, 2008, at http://www.tylerresources.com/pdf/Bahuerachi_Project_Preliminary_Economic_Assessment_Report%20and%20Consents.pdf.

Iriondo, A., Kunk, M.J., Wininck, J.A., 2003, 40Ar- 39Ar Dating studies of minerals and rocks in various areas in Mexico—USGS/CRM scientific collaboration (Part I): U.S. Geological Survey Open-File Report 03-020, 79 p. (Also available online at http://pubs.usgs.gov/of/2003/ofr-03-020/OFR-03-020-508eng.pdf.)

Jutras, J.P. and McCandlish, Keith, 2006, Resource estimate: Tyler Resources Inc., Bahuerachi deposit, Chihuahua State, Mexico: Report prepared for Tyler Resources Inc., Calgary, Alberta, 117 p.

Keith, S.B., and Swan, M.M., 1996, The great Laramide porphyry copper cluster of Arizona, Sonora, and New Mexico—The tectonic setting, petrology and genesis of the world class metal cluster, *in* Coyner, A.R., and Fahey, P.L., eds., Geology and ore deposits of the American cordillera: Geological Society of Nevada Symposium Proceedings, Reno-Sparks, Nevada, p. 1667–1747.

Leonard, K.R., 1989, Preliminary deposit–type map of northwestern Mexico: U.S. Geological Survey Open-File Report 89–158, 350 p.

Librado-Flores, José, Salazar-Reyes, Joaquín, Pérez-De La Cruz, J.A., Miranda-Huerta, Alfonso, Maldonado-Sánchez, Guadalupe, Torreblanca, Teresita, and Prian, Jean, 1999, Carta geológico-minera, Guachochi G13-4, Chihuahua, Sinaloa and Durango [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Livingston, D.E., 1973, Geology, K-Ar ages and Sr isotropy at La Caridad, Nacozari district, Sonora, Mexico: Tucson, The University of Arizona, master's thesis, 31 p.

Livingston, D.E., 1974, K-Ar ages and isotropy of La Caridad, Sonora, compared to other porphyry copper deposits of the southern Basin and Range province: Geological Society of America Abstract with Programs, v. 6, no 3, p. 208.

Long, K.R., 1995, Production and reserves of Cordilleran (Alaska to Chile) porphyry copper deposits, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Tucson, Arizona Geological Society Digest 20, p. 35-68.

López-Escalona, Juan, Espinoza-Beltrán, Carlos, Díaz-Salgado, C.C., and Castro-Escárrega, J.J., compilers, 2006, Carta geológico-minera, Estado de Durango: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000.

Maldano-Lee, J.M., García-Palacios, Raúl, Larrañaga-Obregón, Gerardo, Sánchez-Bermeo, Gilberto, Aguilar-

Carrizales, Alfredo, and Pierre-Prian, Jean, 2000, Carta geológico-minera, San Juanito G13-1, Chihuahua [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

McCandless, T.E., and Ruiz, J., 1993, Rhenium-osmium evidence for regional mineralization in southwestern North America: Science, v. 261, p. 1282–1286.

McDowell, F.W., and Clabaugh, S.E., 1979, Ignimbrites of the Sierra Madre Occidental and their relation to the tectonic history of western Mexico, *in* Chapin, C.E., Elston, W.E., eds., Ash-flow tuff: Geological Society of America Special Paper 180, p. 113– 124.

McDowell, F.W., Roldán-Quintana, J., and Connelly, J.N., 2001, Duration of Late Cretaceous-early Tertiary magmatism in east-central Sonora, Mexico: Geological Society of America Bulletin, v. 113, p. 521-524.

Mead, R.D., Kesler, S.E., Foland, K.A., and Jones, L.M., 1988, Relationship of Sonoran tungsten mineralization to the metallogenic evolution of Mexico: Economic Geology, v. 83, p. 1943-1965.

Meinert, L.D., 1982, Skarn, manto, and breccia pipe formation in sedimentary rocks of the Cananea mining district, Sonora, Mexico: Economic Geology, v. 77, p. 919-949.

Minera Camargo, 2009, Mineral Camargo S.A. de C.V website: Minera Carmago Web page accessed August 15, 2009, at http://www.mineracamargo.com/projects/tango.html.

Minjárez-Sosa, Ismael, Montaño-Jiménez, T.R., Ochoa-Granillo, José, Grijalva-Noriega, F.J., Ochoa-Landín, L.H., Urbina-Herrera, Saúl, Guzmán-Espinosa, J.B., and Mancilla-Gutiérrez, A.A., 2002, Carta geológico-minera, Ciudad Obregón G12-3, Sonora, Chihuahua, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Múngia-Rojas, Pedro, García-Padilla, J.L., Armenta-Román, Roberto, and Manuel-Camacho, Juan, 2000, Carta geológico-minera, Santiago Papasquiaro G13-8, Durango [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

North American Magnetic Anomaly Group, 2002, Magnetic anomaly map of North America: U.S. Geological Survey Special Map, scale 1:10,000,000, accessed January 15, 2008, at http://pubs.usgs.gov/sm.mag_map/.

Page, William R., Gray, Floyd, Blodgett, Robert B., Maldonado, Florian, Miller, Robert J., and Jamie-Ruiz, Rafael, 2003, Mesozoic-Cenozoic tectonic evolution of the Northern Sierra Los Ajos, Sonora, México: Abstracts with Programs, Geological Society of America, Cordilleran Section, April 1-3, Puerto Vallarta, Mexico, v. 35, no. 4, p. 70.

Palafox-Reyes, J.J., Minjarez-Sosa, Ismael, Saavedra-Monreal, Rogelio, Alamazán-Vázquez, Emelio, Morales-Montaño, Mariano, Ochoa-Landin-L.H., Rodríguez-Torres, Rafael, Rivera-Enriquez, Braulio, Castro-Escarrega, J.J., and Zamora-Tovar, R.E., 1998, Carta geológico-minera, Nacozari H12-6, Sonara [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Panczner, William D., 1987, Minerals of Mexico: New York, Van Nostrand Reinhold Co., 459 p.

Pérez-Segura, E., 1985, Carta Metalogenética de Sonora 1:250,000—Una interpretación de la metalogenia de Sonora: Gobierno del Estado de Sonora Publicación 7, 64 p.

Preismeyer, S.T. and Leroux, D.C., 2006, Technical report on the Cuatro Hermanos copper-molybdenum project, Sonora State (for Virgin Metals, Inc.): A.C.A. Howe International Ltd. Report #894.

Randall, J.A., 1974, The Corral de Piedra molybdenite stockwork, Durango, Mexico, *in* Elliot, I.L., and Fletcher, W.K., eds., Geochemical Exploration 1974, Association of Exploration Geochemists, Special Publication No. 2.

Reeves, J.R., 2005, Technical Report on the El Pulpo project (El Pulpo property), San Ignacio municipality, State of Sinaloa-Mexico for Ross River Minerals, Inc., 75 p.

Root, D.H., Menzie, W.D., and Scott, W.A., 1992, Computer Monte Carlo simulation in quantitative resource estimation: Natural Resources Research, v. 1, no. 2, p. 125-138.

Ross River Minerals, Inc., 2008, El Pulpo, Sinaloa [Mexico]: Ross River Minerals, Inc. Web page accessed May 15, 2009, at http://www.rossriverminerals.com/el_pulpo.html.

Salas, G.P., 1975, Mapa Metallogenetico de la Republica Mexicana: Consejo De Recursos Naturales No Renovables, Publicación 21E, Mexico D.F., 188 p.

Saldaña-Saucedo, Gutberto, Polanco-Salas, Alfredo, Bataz-Manríquez, Gabriel, and Moreno-López, M.H., 1999, Carta geológico-minera, Pericos G13-7, Sinaloa, Durango, and Chihuahua [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Salinas-Prieto, J.C., Arriaga-Meléndez, Hiliaro, López-Reyes, J.E., Montiel-Escobar, J.E., Terán-Ortego, L.A., Lebrado-Flores, José, and Amezcua-Torres, Natalia, compilers, 2004, Carta Geólogico-Minera, Estado de Chihuahua: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/chihuahua.pdf.)

Seagart, W.E., Sell, J.D., and Kilpatrick, B.E., 1974, Geology and mineralization of La Caridad porphyry copper deposit, Sonora, Mexico: Economic Geology, v. 67, p. 1069-1077.

Servicio Geológico Mexicano, 2007, Carta geológica de la República Mexicana, Texto explicativo. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/cartas250/geologia/Texto_explicativo.pdf.)

Sherkenbach, D.A., Sawkins, F.J., and Seyfried, W.E., Jr., 1985, Geologic, fluid inclusion, and geochemical stud ies of the mineralized breccias at Cumobabi, Sonora, Mexico: Economic Geology, v. 80, p. 1566-1592.

Sillitoe, R.H., 1976, A reconnaissance of the Mexican porphyry copper belt: Transactions of the Institution of Mining and Metallurgy, Section B, p. B170-B189.

Simmons, S.F., and Sawkins, F.J., 1983, Mineralogic and fluid inclusion studies of the Washington Cu-Mo-W-bearing breccia pipe, Sonora, México: Economic Geology, v. 78, p. 521-526.

Singer, D.A., Berger, V.I., Menzie, W.D., and Berger, B.R., 2005, Porphyry copper density: Economic Geology, v. 100, no. 3, p. 491-514.

Singer, D.A., Berger, V.I., and Moring, B.C., 2008, Porphyry copper deposits of the world—Database, map, and grade and tonnage models, 2008: U.S. Geological Survey Open-File Report 2008-1155, 45 p., accessed January 15, 2009, at http://pubs.usgs.gov/of/2008/1155/.

SRK Consulting, 2006, Technical report on the La Noria exploration concession, Sinaloa, Mexico: Report prepared for GeoInformatics Exploration Inc., 110 p.

Staude, J.M., and Barton, M.D., 2001, Jurassic to Holocene tectonics, magmatism, and metallogeny of northwestern Mexico: Geological Society of America Bulletin, v. 113, p. 1357–1374.

Stewart, J.H., and Roldán-Quintana, J., 1991, Late Triassic Barranca Group—nonmarine and shallow marine rift basin deposits of northwestern Mexico, *in* Pérez-Segura, E., and Jaques-Ayala, C., eds., Studies of Sonoran geology: Geological Society of America Special Paper 254, p. 19-36.

Stingray Copper, Inc., 2009, Stingray Copper, Inc. home page accessed November 29, 2009 at http://www.stingraycopper.com/.

Terán-Martínez, G.E., Cerecero-Luna, Miguel, Mendoza-Romero, Macario, Castro-Escárrega, J.J., and García-Cortez, J.A., 1999, Carta geológico-minera, Cananea H12-5, Sonora [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Terán-Ortega, L.A., Maraver-Romero, D.A., Montiel-Escober, J.E., Jiménez-Gonzaga, Alejandro, and Dorantes-Salgado, Enrique, compilers, 2007, Carta Geólogico-Minera, Estado de Nayarit: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/nayarit.pdf.)

Theodore, T. G., and Priego De Wit, M., 1978, Porphyry type metallization and alteration at La Florida de Nacozari, Sonora, Mexico: U.S. Geological Survey Journal of Research, v. 6, p. 59-72.

Titley, S.R., editor, 1982, Advances in geology of the porphyry copper deposits, southwestern North America: Tucson, University of Arizona Press, 560 p.

Torres-Escamilla, Tonatiuh, Bataz-Manríquez, Gabriel, Moreno-López, M.H. Fernando, 1999, Carta geológico-minera, Mazatlán F13-1, Sinaloa [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

U.S. Geological Survey, 2005, Mineral Resources Data System: U.S. Geological Survey, Reston, Virginia, accessed December 15, 2007, at http://tin.er.usgs.gov/mrds/.

Valencia, V., Ruiz, J., Eastoe, C., Gehrels, G., and Barra, F., 2004, Evolución del Pórfi do cuprífero de La Caridad, Sonora, México—Basado en análisis de inclusiones fluidas, isótopos de S, O, H, U-Pb y Re-Os: IV Reunión Nacional de Ciencias de la Tierra, Sociedad Geológica Mexicana, p. 189.

Valencia, V.A., Noguez-Alcántara, B., Barra, F., Ruiz, J., Gehrels, G., Quintanar, F., and Valencia-Moreno, M., 2006, Re-Os molybdenite and LA-ICPMS-MC U-Pb zircon geochronology for the Milpillas porphyry copper deposits—Insights for the timing of mineralization in the Cananea District, Sonora, Mexico: Revista Mexicana de Ciencias Geológicas, v.23, no. 1, p. 39-53.

Valencia-Moreno, M., 1998, Geochemistry of Laramide granitoids and associated porphyry copper mineralization in NW Mexico: Tucson, The University of Arizona, Ph. D. thesis, 164 p.

Valencia-Moreno, M., Ruiz, J., and Roldán-Quintana, J., 1999, Geochemistry of Laramide granite rocks across the southern margin of the Paleozoic North American continent, Central Sonora, Mexico: International Geology Review, v. 41, p. 845-857.

Valencia-Moreno, M., Ruiz, J., Barton, M.D., Patchett, P.J., Zürcher, L., Hodkinson, D., and Roldán-Quintana, J., 2001, A chemical and isotopic study of the Laramide granitic belt of northwestern Mexico—Identification of the southern edge of the North American Precambrian basement: Geological Society of America Bulletin, v. 113, p .1409-1422.

Valencia-Moreno, M., Ruiz, J., Ochoa-Landín, L., Martínez-Serrano, R., and Vargas-Navarro, P., 2003, Geochemistry of the coastal Sonora batholith, northwestern Mexico: Canadian Journal of Earth Sciences, v. 40, p. 819-831.

Valencia-Moreno, M., Ochoa-Landín, Lucas, Noguez-Alcántara, Benito, Ruiz, Joaquin, Pérez-Segura, Efrén, 2007, Geological and metallogenic characteristics of the porphyry copper deposits of México and their situation in the world context: Geological Society of America Special Paper 422, p. 433-458.

Virgin Metals, Inc., 2008, Los Verdes Project, Sonora México, NI 43-101 Report, 105 p., accessed May 15, 2009 at http://www.virginmetals.com/assets/content/Los-Verdes%2043-101.pdf .

Wilkerson, G., 1983, The Batopilas mining district, Chihuahua, México: University of Texas, El Paso, Ph. D. thesis, 642 p.

Wilkerson, G., Quingping, D., Llavona, R., and Goodell, P., 1988, Batopilas mining district, Mexico: Economic Geology, v. 83, p. 1721-1736.

Wodzicki, W.A., 2001, The evolution of magmatism and mineralization in the Cananea district, Sonora, Mexico: Society of Economic Geologists Special Publication 8, p. 243-263.

Yale Resources, Ltd., 2009, Yale Resources Ltd. Home page accessed November 29, 2009 at http://www.yaleresources.com/ .

Zaruma Resources, Inc., 2008, Luz del Cobre Project: Zaruma Resources, Inc. Web page accessed June 8, 2008 at http://www.zaruma.com.

Zürcher, L., 2002, Regional setting and magmatic evolution of Laramide porphyry copper systems in western Mexico: Tucson, The University of Arizona, Ph. D. thesis, 427 p.

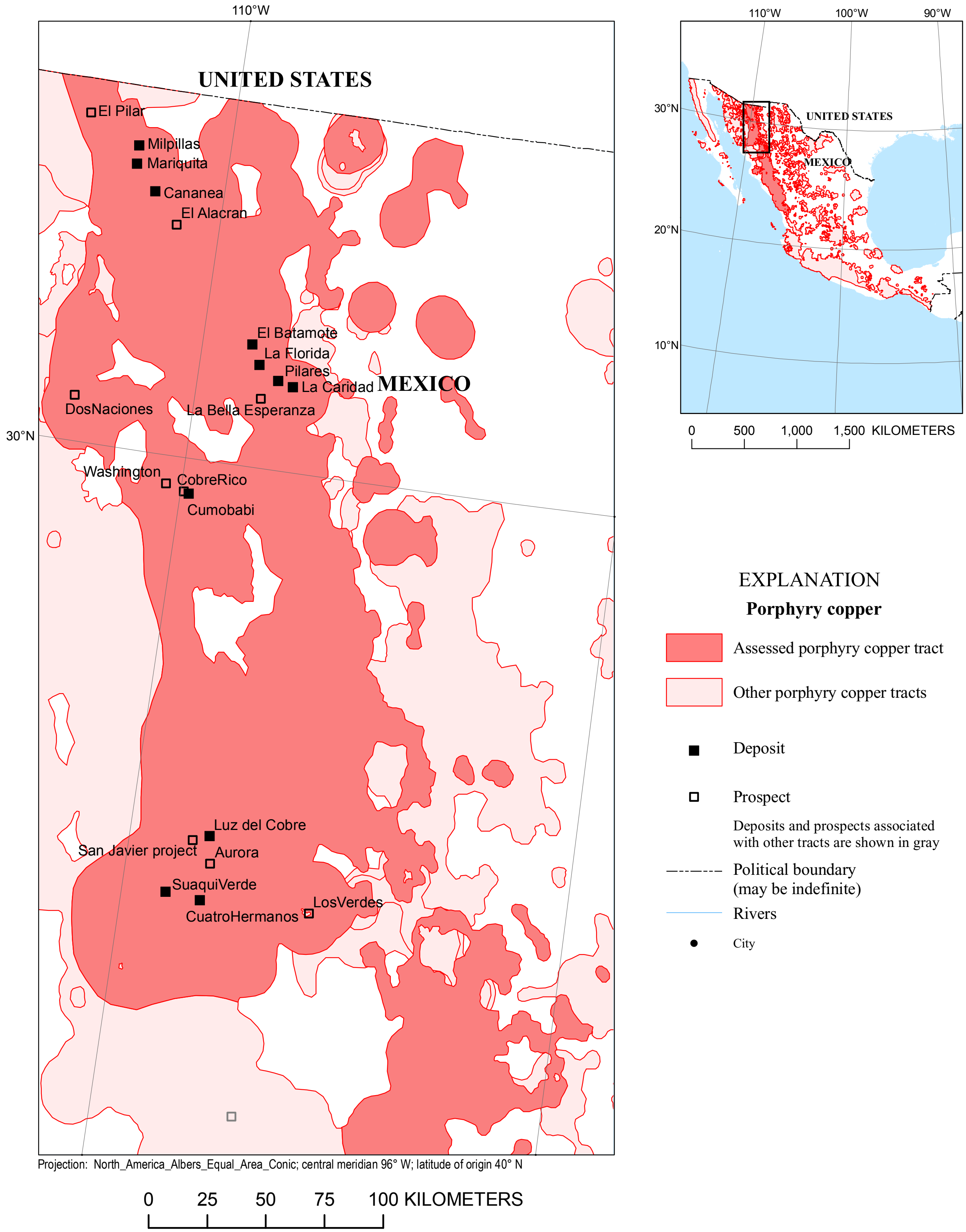


Figure G1. Map showing the location, known deposits, and significant prospects and occurrences in the Northern and Central Domains of tract 003pCu3007 (MX-L2), Sierra Madre Occidental West, Mexico.

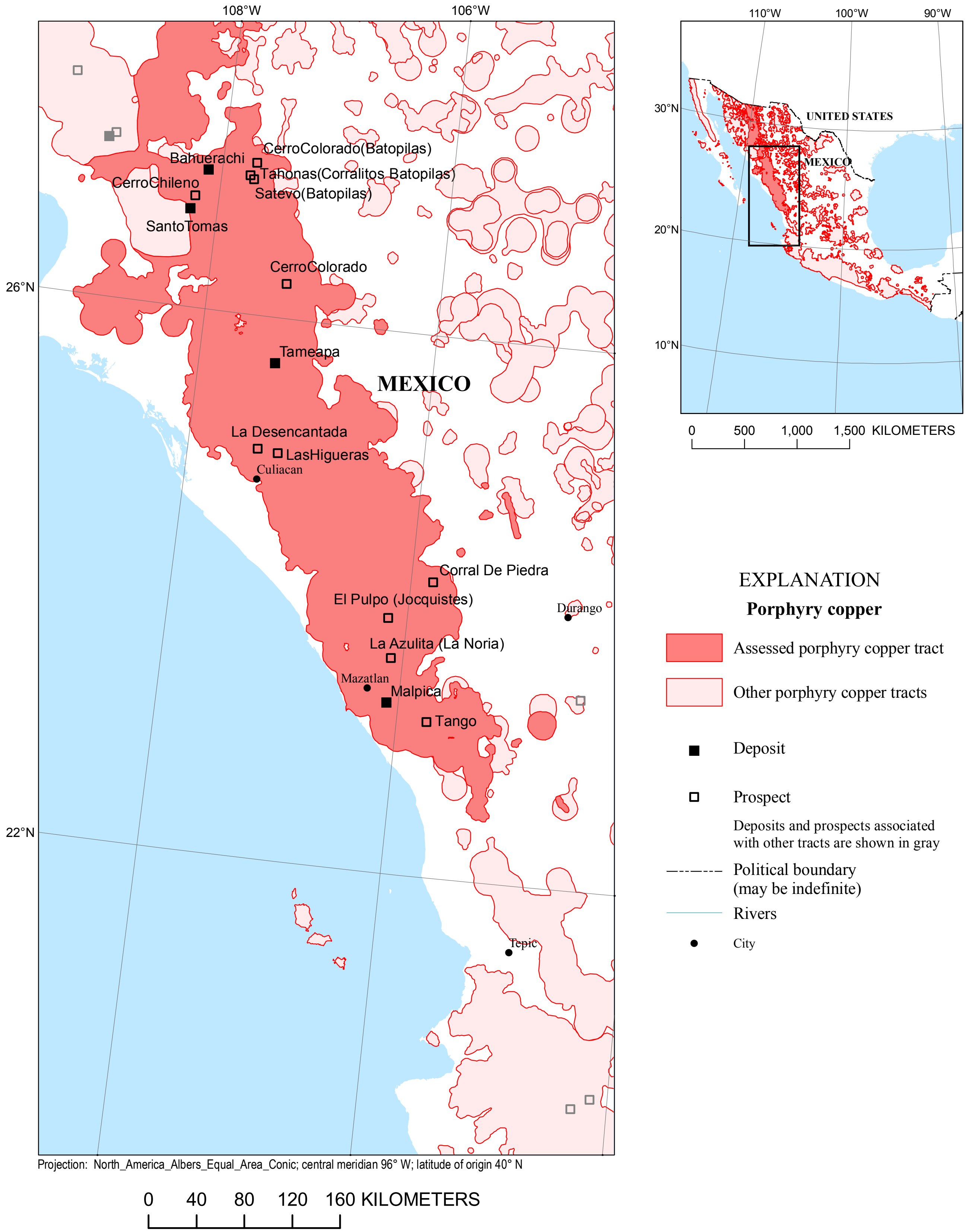


Figure G2. Map showing the location, known deposits, and significant prospects and occurrences in the Southern Domain of tract 003pCu3007 (MX-L2), Sierra Madre Occidental West, Mexico.

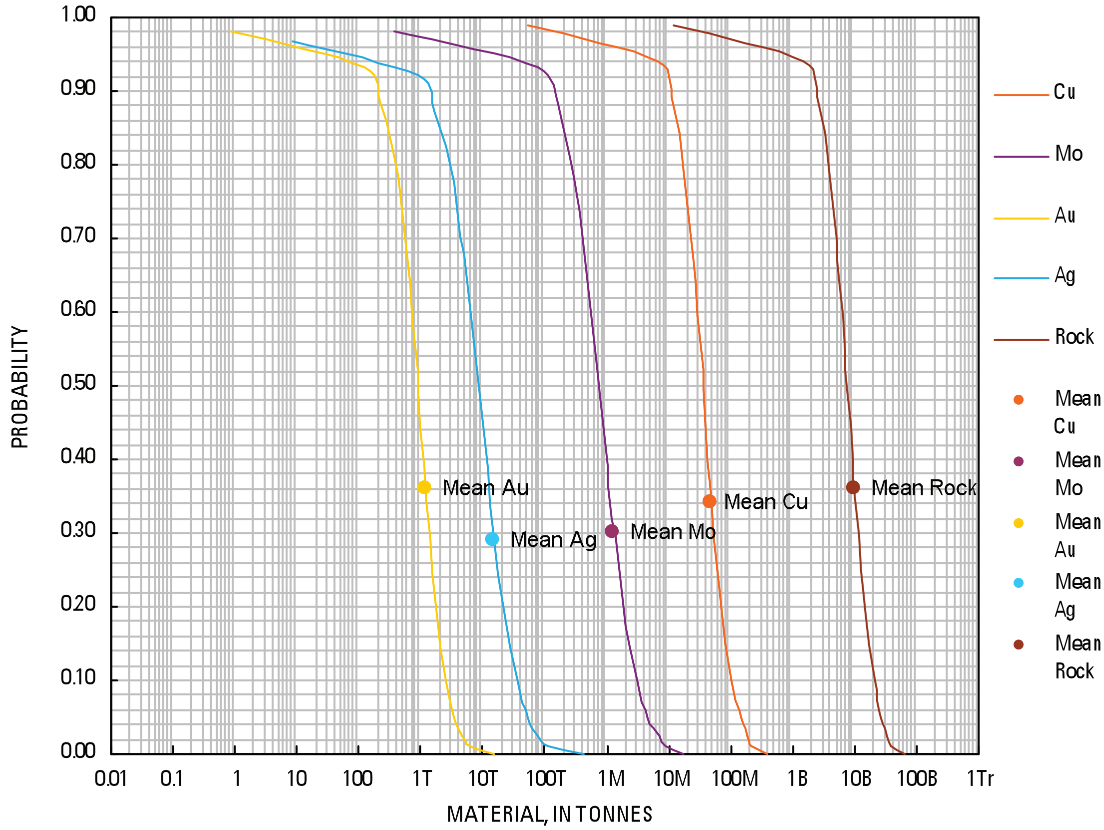


Figure G3. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in tract 003pCu3007 (MX-L2), Sierra Madre Occidental West, Mexico. T, thousands; M, millions; B, billions; Tr, trillions.

Appendix H. Porphyry Copper Assessment for Tract 003pCu3008 (MX-L3), Laramide Central Plateau, Mexico

By Floyd Gray[1], Francisco Cendejas-Cruz[2], Enrique Espinosa[2], Jane M. Hammarstrom[1], Steve Ludington[1], Gilpin R. Robinson, Jr.[1], Efrén Pérez-Segura[3], Martín Valencia-Moreno[4], José Luis Rodríguez-Castañeda[4], Rigoberto Vásquez-Mendoza[2], and Lukas Zürcher[5]

Deposit Type Assessed: Porphyry copper

Descriptive model: Porphyry copper (Cox, 1986; Berger and others, 2008)
Grade and tonnage model: Porphyry copper (Singer and others, 2008)
(Table H1 summary is selected assessment results)

Location

The tract extends from the U.S. border through the states of Chihuahua, Durango, Guanajuato, Sinaloa, San Luis Potosi, and Zacatecas, north of the Trans-Mexican Volcanic Belt (fig. H1).

Geologic Feature Assessed

Belt of Late Cretaceous to middle Eocene (Laramide) magmatic arc rocks in the eastern part of the Sierra Madre Occidental, eastern Mexican Basin and Range, and the Mesa Central of northern Mexico.

Table H1. Summary of selected resource assessment results for tract 003pCu3008-1 (MX-L3), Central Laramide Plateau, Mexico.

[km, kilometers; km^2, square kilometers; t, metric tons; n.d., no data]

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)
May 2008	1	58,720	n.d.	20,000,000	12,000,000

[1]U.S. Geological Survey.
[2]Servicio Geológico Mexicano.
[3]University of Sonora.
[4]Geologic Institute, Universidad Nacional Autónoma de México.
[5]University of Arizona.

Delineation of the Permissive Tract

Geologic Criteria

Tract 003pCu3008 (MX-L3) outlines early Tertiary (48-34 Ma) intermediate to felsic intrusive and volcanic rocks that appear discontinuously in and along the eastern edge of the Oligocene-Miocene Sierra Madre Occidental ignimbrite province and through the Eastern Mexican Basin and Range, Central Mesa, and Sierra Madre Oriental provinces. These mainly Eocene magmas, part of Laramide subduction-related magmatism that began in western Sonora and southern Baja California, were emplaced across northern Mexico into central Chihuahua, western Durango, San Luis Potosi, and Zacatecas (McDowell and Clabaugh, 1979; Aguirre Díaz and McDowell, 1991; Barton and others, 1995; Staude and Barton, 2001). These and similar rocks extend into adjacent areas of the U.S. and may represent magmatism formed inboard of a convergent plate boundary associated with latest Laramide age subduction along the western coast of this part of North America.

The tract lies within or near the margin of the Mexican thrust belt, which is composed of thick Jurassic to Cretaceous basinal successions deformed during the Laramide Orogeny (Campa, 1985). The host tectonostratigraphic terranes are floored by Paleozoic or older crust along, or irregularly outcropping near, the eastern edge of the mid-Tertiary ignimbrite fields and its eastern outliers. Several major tectonostratigraphic basement terranes (fig. 2) underlying the tract include the Caborca, Chihuahua, Coahuila, Sierra Madre, and Maya terranes that are underlain by Paleozoic or older continental crust (Ruiz and others, 1988). A thick succession of Mesozoic sedimentary rocks deposited during progressive flooding of the basement terranes by a Jurassic-Cretaceous sea created a depositional succession consisting of basal continental red beds with evaporites subsequently followed by a series of shale and carbonate facies (Lopez-Ramos, 1979; Smith, 1981; Megaw and others, 1988). The carbonate rocks in these successions may exceed 3,000 m in thickness and typically host the mineralization in this tract. Mineralization in the area was strongly controlled by Laramide-age deformation with resulting structures acting as controls. The resulting structures include broad domal features to tight isoclinal, overturned, and thrusted folds, which were accompanied by axial brecciation, faulting, fracturing, and fissuring. These structural elements were overprinted locally by the emplacement of Tertiary intrusions.

The plutonic rocks that crop out within the tract include diorite, porphyritic diorite, granodiorite, granite, quartz monzonite, porphyritic andesite (quartz latite), and syenite of

Table H2. Map units in tract 003pCu3008-1 (MX-L3), Central Laramide Plateau, Mexico.

[Map unit, age range, and principal lithologies from a 1:500,000 scale preliminary digital geologic map of Mexico (Servicio Geológico Mexicana, written commun., 2007); n.d., no data]

Map unit	Maximum age	Minimum age	Lithology 1	Lithology 2
		Intrusive rocks		
TeMz-qMz	Eocene	Eocene	monzonite	quartz monzonite
TeqMz	Eocene	Eocene	quartz monzonite	n.d.
KcSi	Cretaceous	Cretaceous	syenite	n.d.
TeD	Eocene	Eocene	diorite	n.d.
TpaPA	Paleocene	Paleocene	porphyritic andesite	n.d.
TeGd	Eocene	Eocene	granodiorite	n.d.
TeGr	Eocene	Eocene	granite	n.d.
TpaPD	Paleocene	Paleocene	porphyritic diorite	n.d.
TpaeGr	Paleocene	Eocene	granite	n.d.
Tpa(?)qMz	Paleocene?	Paleocene?	quartz monzonite	n.d.
TeoGd-Mz*	Eocene	Oligocene	granodiorite	n.d.
		Volcanic rocks		
TeA	Eocene	Eocene	andesite	n.d.
TeBvp	Eocene	Eocene	polymictic volcanic breccia	n.d.
TeB	Eocene	Eocene	basalt	n.d.
TeA-BvA	Eocene	Eocene	andesite	volcanic breccia
TePA	Eocene	Eocene	porphyritic andesite	n.d.
TeA-B-Ig	Eocene	Eocene	andesite	basalt
TeA-B	Eocene	Eocene	andesite	basalt

* Tract MX-L3 includes one small area of this Eocene or Oligocene map unit, most of which crops out south of the Trans-Mexican Volcanic Belt and is included in MX-T2.

Cretaceous to Eocene age (table H2). The chemistry of these rocks ranges from primarily high-K, calcalkaline to alkaline igneous rocks. Textures of intrusives range from equigranular to porphyritic to aphanitic. The exposed occurrences of intrusives with host rocks and skarn-type mineralization may include a wide range of types including large, composite stocks and multiple dike clusters and sills.

The volcanic rocks in the tract include andesite, porphyritic andesite, volcanic breccia, and basalt. Bimodal rhyolite-basalt sequences and associated tuffs that are primarily within basaltic suites have been excluded from the tract as these volcanic systems are unlikely to host porphyry copper deposits. Thick volcanic rock sequences that constitute the ignimbrite plateau of the Sierra Madre Occidental are also excluded from the tract as their thickness generally covers any underlying mineralized intrusive rocks by a km or more. The eastern margin of the tract is defined by the Gulf coastal plain. The northern limit of the tract borders the U.S.; however, it should be noted that comparable-age igneous rocks clearly extend into southeastern Arizona, western New Mexico, and west Texas. The southern limit of the tract is the northern border of the Trans-Mexican Volcanic Belt that covers Early to Middle Tertiary rocks and defines a tectonic transition above a Tertiary to recent subduction zone of the Cocos Plate to the south of Mexico (fig. 3).

The tract was delineated using a 10-km buffer around the intrusive map units described above and a 2-km buffer around the volcanic units. It was then further refined using the aeromagnetic map (North American Magnetic Anomaly Group, 2002) to include some areas that appear to have shallow magnetic sources. Larger-scale (1:250,000) geologic maps and literature were consulted and used to check map-unit boundaries, ages, and structures.

Known Deposits

There are no known porphyry copper deposits in the tract.

Prospects, Mineral Occurrences, and Related Deposit Types

Abundant precious-metal, base-metal polymetallic vein, skarn, and replacement deposits occur within tract 003pCu3008 (MX-L3); several of the deposits are compatible with porphyry copper-style mineralization lateral to, or at depth from, presently exploited areas. As such, many areas of the tract are coincident with permissive areas and mineral deposits assigned to the waning stages of the Laramide exposed underneath and east of the Tertiary ignimbrite cover of the Sierra Madre Occidental. Although there has been some relatively recent dating of mineral deposits within the tract, and because much of the area contains both Laramide and younger intrusions, many of the prospects could belong to either tract age group (see Megaw and others, 1988; Barton and others, 1995; Camprubi and others, 2003). Mineral occurrences in the tract, including known deposits of other types, were evaluated for certain criteria we believed permissive for the presence of porphyry copper-type mineralization and therefore have one or more of the following features: (1) identified stockwork and(or) disseminated vein mineralization distal to skarn or replacement systems; (2) presence of exposed intrusive rock and near-intrusion skarn (Megaw and others, 1988); and (3) and presence of significant copper mineralization. In addition to the six significant prospects listed in table H3, more than 12 additional copper-bearing vein, replacement and skarn prospects were identified that may be related to porphyry systems in the tract.

A number of copper, gold, silver, and polymetallic prospects occur within the tract. However, many of the outlined areas of the tract are coincident with permissive areas and mineralization systems of Middle Tertiary age (48- 34 Ma). Some of the prospects within Tract 003pCu3008 (MX-L3) cannot be assigned to Laramide-age intrusions with confidence because of the lack of unequivocal age constraints.

Bismark

The Bismark deposit (8.5 Mt at 8 percent zinc, 0.5 percent lead, 0.2 percent copper, and 50 g/t silver) is hosted by massive sulfide within altered limestone adjacent to the multiphase quartz monzonite stock (~42 Ma) and the Bismark fault. Alteration concurrently developed in both intrusion and adjacent limestone. The equigranular to porphyritic-textured Bismark quartz monzonite contains early-stage potassic alteration which was overprinted by kaolinite-rich veins, and later by quartz, sericite, and pyrite alteration with sulfide ore minerals (Baker and Lang, 2003). Exoskarn alteration in the limestone consists of green andradite and diopside with transitional skarn composed of red-brown andradite, hedenbergite and accessory calcite, vesuvianite, fluorite, and quartz. The hydrothermal system developed synchronously with faulting and is concentrated in both the hanging wall and footwall of the Bismark fault. Mineralization was classified as being compatible with a continuum of deposit types including contact skarn (limestone replacement), epithermal vein, massive sulfide, and porphyry. Upper-level hanging wall and footwall ores are Zn-Pb-Ag with low copper grades (<0.3 percent); however, with increasing depth ores there become zinc-rich, with accompanying low grades of silver and lead, and markedly higher copper grades that may reach 1.5 percent. The outer margin of the Bismark stock may host disseminated and fracture-controlled mineralization.

Providencia/Concepcion del Oro

The Providencia/Concepcion del Oro area, the largest copper-producing district in Mexico, at least until the early 1960s, is underlain by Jurassic to Cretaceous limestones, siltstones, and shales intruded by Tertiary intrusive rocks. The area is currently being explored for porphyry copper-style mineralization. Historical mining from iron oxide and skarn deposits produced an estimated 3 Mt averaging 0.8 percent copper, or approximately 53 million pounds of copper. A recent preliminary indicated resource estimate on both skarn and porphyry-style mineralization yielded 25.6 Mt of ore at 1.02 percent copper for 591, 924,000 pounds of contained copper. An additional inferred resource was estimated at ~8.8 Mt of ore at 0.81 percent copper yielding 156,248,000 lbs of copper (Aura Minerals, Inc., 2008). The principal composite stock is differentiated with zones ranging from a hornblende diorite to biotite-rich granodiorite, and it was intruded into a northwest-trending fault zone with smaller northeast-oriented cross faults during or shortly after folding of the sedimentary rocks. Ages for the intrusion range from 44 Ma to 34.5 Ma (Buseck, 1966; Ohmoto and others, 1966). The hydrothermal system evolved from early near-contact iron rich skarns to main stage copper-gold skarns to later stage zinc-silver skarns with minor molybdenum. Mineralized skarn occurs adjacent to portions of the intrusive complex with intense stockwork veining of quartz and sericite in the Arroyos Azules area. Biotite-bearing phases of the quartz monzonite to granodiorite were the most important hosts for porphyry style copper mineralization and copper-gold skarn formation in the Arranzazu and Arroyos Azules areas. Alteration in the intrusive is quartz, secondary biotite, sericite, and pyrite occurring as veins and flooding. Skarn alteration is principally garnet with magnetite, pyrite, chalcopyrite and chalcocite (Aura Minerals, Inc., 2008).

San Martín

The San Martín skarn and associated prospect area was formed by a multistage hydrothermal system associated with the intrusion of the 46 Ma Cerro de la Gloria quartz monzonite stock into middle Cretaceous limestone. The San Martín mine yielded Cu-Zn-Ag ore from veins and replacement bodies hosted by skarn, and the nearby Sabinas mine hosts Zn-Pb-Ag (±Au) ore from veins hosted by skarn and recrystallized limestone (Rubin and Kyle, 1988). Local quartz stockwork occurs near intrusive contacts. Early high-temperature mineralization was overprinted by lower-temperature mineralization during the late stages of hydrothermal activity. Chalcopyrite, molybdenite, and pyrite were deposited in the altered intrusive rock and predated the formation of the main orebodies. Total reserves are listed as approximately 30.5 Mt with average ore grades of 1.0 percent copper, 5.0 percent zinc, 150 ppm silver, and 0.5 percent lead (Rubin and Kyle, 1988; Olivares, 1991).

Charcas (San Sebastian)

The principal mineralization in the Charcas district consists of fault-controlled vein systems (district-wide) as well as skarn and replacement bodies localized in the contact zone adjacent to an exposed body of granite to granodiorite. Skarn and replacement type mineralization also are present several km from the exposed intrusive. Stockwork veining and pervasive alteration suggest that the district is permissive for porphyry copper mineralization. Past production totals approximately 22 Mt of ore that varied in grade over time ranging from 3.45 to 0.3 percent lead, 0.42 to 0.3 percent copper, 6.60 to 5.0 percent zinc, and 22 to 60 g/t silver. Reserves have been estimated at 21.6 Mt of ore yielding 0.36 percent lead, 0.26 percent copper, 5.12 percent zinc and 73 g/t silver throughout the district (Consejo de Recursos Minerales, 1993).

Exploration History

The tract has been extensively explored for precious-metal deposits and polymetallic vein and replacement deposits. Several of the deposits found have produced large tonnages of base metals, including copper, and one deposit, Providencia/ Concepcion del Oro, was a principal copper producer of Mexico through the early 1960s. Economically important precious-metal epithermal deposits such as Sombrerete, Zacatecas, Velardeña, and Zimapan occur in the general area of the tract and several known epithermal deposits and prospects in the tract are under exploration for porphyry copper-styled mineralization in previously unexplored sectors of these districts (Charcas, San Martin, and Bismark). These epithermal precious-metal and polymetallic deposits are all Tertiary in age, most are Paleocene to Eocene, and their space and time distribution follows the extension of Laramide-age magmatism exposed east of and beneath the mid- Tertiary ignimbrite province of the Sierra Madre Occidental. Many of the deposits are exposed in erosional windows within a belt that marks the termination toward the east of the Cenozoic volcano-plutonic arc and the beginning of the Mesozoic inner-arc thrust belt west of the Mesa Central (Albinson, 1988).

Although no identified porphyry copper deposits are know in the tract, a number of new prospects are under evaluation.

Table H3. Significant prospects and occurrences in tract 003pCu3008-1 (MX-L3), Central Laramide Plateau, Mexico.

Name	Latitude	Longitude	Type	Age (Ma)	Comments (grade and tonnage data, if available)	Reference
Bismark	31.236	-107.584	Skarn	42 to 42.5±1.1 Ma	8.5 Mt at 8% Zn, 0.5% Pb, 0.2% Cu, and 50 g/t Ag. Noranda Exploration site; Old Bismark mine is located 0.75 km southeast of the current mine. The old Bismark mine described in earlier reports as precious metal-bearing contact metasomatic deposit consisting of pockets of Fe-, Mn-, and Cu-oxides carrying Au-Ag values in quartz matrix; in limestone along contact with rhyolite dike trending N47E. The new Bismark deposit is a steeply dipping, tabular zone with one major splay and consists of 5 ore bodies of irregular shape.	Castro-Escárrega and others (2007), Baker and Lang (2003), Starr (2003)
Providencia/Concepcion del Oro	24.656	-101.484	Skarn	40± 0.2 to 38±1.2 Ma	District localized in Sierra de la Caja anticline with NW-SE Laramide age folding. 27.7 Mt at 1.22% Cu, 0.29 g/t Au, and 12 g/t Ag. Near contact with Concepion del Oro stock. Skarn and porphyry (L. Zürcher, oral commun., 2008).	Hayes and Kesler (1988), Buseck (1966), Ohmoto and others (1966), Valencia-Moreno and others (2007), Aura Minerals, Inc. (2008)
San Martin	23.664	-103.746	Skarn	46.2	Alteration mapped (argillic and oxidation) about 6 km away. Mineralization overprinted by lower temperature mineralization during late stages of hydrothermal activity. Between 1959 and 1987 ASARCO mined approx. 10.5 Mt of ore	Rubin and Kyle (1988), Olivares (1991), Sánchez-González and others (1998)
Charcas (San Sebastian)	23.134	-101.155	Skarn	46.6	Significant polymetallic skarn and replacement district; historical production recorded at 22 Mt of ore yielding 0.3% Pb, 0.3% Cu, 5.0 % Zn, and 60 g/t Ag (1991);other prospects and mines located ~2.5 km SW of this locality. Near Tegd (Laramide intrusion)	Consejo de Recursos Minerales (1993)

Sources of Information

Principal sources of information used by the assessment team for delineation of table 003pCu3008-4.

Table H4. Principal sources of information used by the assessment team for tract 003pCu3008-1 (MX-L3), Central Laramide Plateau, Mexico.

[NA, not available or not applicable]

Theme	Name or title	Scale	Citation
Geology	Preliminary digital geologic map of the Republic of Mexico	1:500,000	Servicio Geológico Mexicano (written commun., 2007)
	Carta geólogico-minera, Estado de Aguascalientes y Zacatecas	1:500,000	López-Escalona and others (2007)
	Carta geólogico-minera, Estado de San Luis Potosí	1:500,000	Maldonado-Lee and others (2007)
	Carta geólogico-minera, Estado de Chihuahua	1:500,000	Salinas-Prieto and others (2004)
	Carta geólogico-minera, Estado de Durango	1:500,000	López-Escalona and others (2006)
	Carta geólogico-minera, Estados de Guanajuato y Querétaro	1:500,000	López-Reyes and others (2007)
	Carta geólogico-minera, Estado de Sinaloa	1:500,000	Castro-Escárrega and others (2007)
Mineral occurrences	SGM Minas database	NA	Servicio Geológico Mexicano (written commun., 2007)
	MRDS database	NA	U.S. Geological Survey (2005)
	University of Arizona-Industry-USGS Mexico Consortium	NA	University of Arizona-Industry-USGS Mexico Consortium, March 1999 Release Notes (unpublished)
Geochemistry	SGM stream-sediment database	NA	Servicio Geológico Mexicano (written commun., 2007)
Geophysics	North American magnetic map	1:10,000,000	North American Magnetic Anomaly Group (2002)
Exploration	Company Web sites; published reports	NA	See text and tables

Grade and Tonnage Model Selection

The general porphyry copper model of Singer and others (2008) was selected for the assessment based on geologic characteristics of the tract and because we do not have sufficient information to justify the use of a specialized subtype model to estimate undiscovered resources. Only one significant prospect of the six delineated, Concepcion del Oro, has reported gold grades >0.2 g/t. Therefore, the general porphyry copper grade-tonnage model, which includes Cu-Au and Cu-Mo subtypes, was selected to be most appropriate for the probabilistic assessment of undiscovered resources in the tract.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Despite the absence of fully delineated porphyry copper deposits in the tract with features like those found in the grade-tonnage models, abundant early Tertiary skarn, epithermal precious-metal and polymetallic vein deposits in the tract are closely associated in space and time with the extension of Laramide-age magmatism (Megaw and others, 1988;

Camprubi and Albinson, 2007). Many skarn and replacement deposits found in the region have exposed or near-surface contact relations with intrusive stocks or dikes and sills, and display a multiphase nature with overlapping, coeval alteration envelopes in both host and intrusive rocks. Significant copper production occurred in five of the districts, and porphyry style mineralization is observed in poorly explored sections. Many of the skarns display the characteristic mineralogy of those related to porphyry copper intrusive systems—they are copper enriched and contain an association of andraditic garnet and diopsidic clinopyroxene with near-subeconomic zinc concentrations near the marbleized contact (Einaudi, 1982). Therefore, the assessment team believes there is a potential for buried porphyry copper deposits in the region due to the typical close association in space and time between epithermal, polymetallic, and some skarn deposits and porphyry copper deposits (Drew and Menzie, 2006).

The apparent lack of known porphyry copper deposits in the tract may be accounted for by the extensive, thick (>2 km) cover of continental sedimentary rocks, mainly deep-water limestone deposited in the Pedregosa Basin, and large volumes of Tertiary ignimbrites found in the Sierra Madre Occidental (McKee, 1951; Pierce, 1976; Einaudi, 1982). Abrupt thinning of Paleozoic sedimentary rocks in southeastern Arizona, southwestern New Mexico, and west Texas to <1 to 2 km corresponds to a well-developed porphyry copper terrane in similar Laramide-age rocks in the United States. Tyrone, Morenci, the Safford district deposits, Red Hill, and Chino all occur in the U.S. extension of Mexican porphyry copper tract 003pCu3008 (MX-L3). A number of possible Late Cretaceous to early Tertiary porphyry deposits could be buried to a depth greater than 1 km. The extensive sedimentary and volcanic cover, therefore, reduces the probability that porphyry copper deposits are exposed or within 1 km of the surface.

Based on the presence of intrusive and volcanic igneous rocks typical of a subduction-related magmatic arc system of appropriate age and composition, mapped alteration characteristic of porphyry copper deposits, the occurrence of no known deposits with ~20 copper prospects, anomalous copper in stream sediments within the tract, and the occurrence of known deposits in the U.S. extension of the track, the team arrived at a consensus estimate of 2 undiscovered deposits at a 90-percent confidence level, 5 undiscovered deposits at a 50-percent confidence level, and 10 undiscovered deposits at 10-percent confidence level (table H5). These estimates reflect the number of copper skarn occurrences not associated with deposits and the extent of geochemical anomalies and altered areas in the tract. The estimate is low relative to the 11 deposits predicted by deposit density model of Singer and others (2005) based on permissive tract area (fig. 11).

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, in press). Selected output parameters are reported in table H6. Results of the Monte Carlo simulation are presented as cumulative frequency plots (fig. H3). The cumulative frequency plots show the estimated resource volumes associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

Table H5. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 003pCu3008-1 (MX-L3), Central Laramide Plateau, Mexico.

[NXX, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; s, standard deviation; Cv%, 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; area, area of permissive tract in square kilometers; density, deposit density reported as the total number of deposits per km^2. N_{und}, s, and Cv% are calculated using a regression equation (Singer and Menzie, 2005).]

Consensus undiscovered deposit estimates			Summary statistics					Tract area (km^2)	Deposit density (N_{total}/km^2)
N90	N50	N10	N_{und}	s	Cv%	N_{known}	N_{total}		
2	5	10	5.5	3	54	0	5.5	58,720	0.000093

Table H6. Results of Monte Carlo simulations of undiscovered resources in tract 003pCu3008-1 (MX-L3), Central Laramide Plateau, Mexico.

[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	280,000	1,500,000	12,000,000	47,000,000	73,000,000	20,000,000	0.31	0.04
Mo	0	990	220,000	1,300,000	2,200,000	560,000	0.26	0.10
Au	0	10	270	1,200	1,800	510	0.31	0.08
Ag	0	0	2,300	16,000	26,000	6,500	0.25	0.15
Rock	70	330	2,600	9,500	15,000	4,100	0.32	0.04

References Cited

Aguirre-Diaz, G.J., and McDowell, F.W., 1991, The volcanic section at Nazas, Durango, Mexico, and the possibility of widespread Eocene volcanism within the Sierra Madre occidental: Journal of Geophysical Research, v. 96, p. 13,373-13,338.

Albinson, T., 1988, Geologic reconstruction of paleosurfaces in the Sombrerete, Colorada, and Fresnillo district, Zacatecas state, Mexico: Economic Geology, v. 83 p. 1647-1667.

Arriaga-Meléndez, Hilario, López-Escalona, J.J., López-Reyes, J.E., Terán-Ortega, L.A., Castro-Escarrega, J.J., Espinoza-Beltrán, C.C., and Vázquez-Mendoza, Rigoberto, compilers, 2004, Carta geólogico-minera, Estado de Sonora: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/sonora.pdf.)

Aura Minerals Inc., 2008, NI 43-101 Technical report and audit of the preliminary resource estimate on the Aranzazu Property, Zacatecas State, Mexico: Aura Minerals Inc. Web page accessed May 15, 2009, at http:/auraminerals.comi/pdf/Reports/Technical_Report_Aranzazu-July_2008.pdf.

Baker, Timothy, and Lang, J.R., 2003, Reconciling fluid inclusion types, fluid processes, and fluid sources in skarns—An example from the Bismark Deposit, Mexico: Mineralium Deposita, v. 38, p. 474-495.

Barton, M.D., Staude, J.M., Zürcher, L., and Megaw, P.K.M., 1995, Porphyry copper and other intrusion-related mineralization in Mexico, *in* Pierce, F.W., and Bonn, J.G., eds., Porphyry copper deposits of the American Cordillera: Arizona Geological Society Digest, v. 20, p. 487-524.

Bawiec, W.J., and Spanski, G.T., in press, EMINERS—Economic Mineral Resource Simulator, version 3.0: U.S. Geological Survey Open-File Report 2009-1057, program files and 29-p. Quick-Start Guide.

Berger, B.R., Ayuso, R.A., Wynn, J.C., and Seal, R.R., 2008, Preliminary model of porphyry copper deposits: U.S. Geological Survey Open-File Report 2008-1321, 55 p., accessed May 15, 2009, at http://pubs.usgs.gov/of/2008/1321.

Buseck, Peter, 1966, Contact metasomatism and ore deposition—Concepcion del Oro, Mexico: Economic Geology, v. 61, p. 97-136.

Bustamante-Yáñez, M.A., 1986, Recursos mineros en el Estado de Sinaloa: Geomimet, v. 142, p. 81-102.

Campa, M. F., 1985, The Mexican thrust belt, *in* Howell, D.G., ed., Tectonstratigraphic terranes of the circum Pacific region: Houston, Texas, Circum Pacific Council Energy Mineral Resources, p. 299-313.

Camprubi, A., and Albinson, T., 2007, Epithermal deposits in Mexico—Update of current knowledge, and an empirical reclassification, *in* Alaniz-Alvarez, S.A., and Nieto-Samaniego, A.F., eds., Geology of Mexico—Celebrating the centenary of the Geological Society of Mexico: Geology Society of America Special Paper 422, p. 377-415.

Camprubi, A., Ferrari, L., Cosca, M., Cardellach, E., and Canals, A., 2003, Ages of epithermal deposits in Mexico—Significance and links with the evolution of tertiary volcanism: Economic Geology, v. 98, p. 1029-1037.

Castro-Escárrega, J.J., López-Escalona, Juan, Díaz-Salgado, Ciro, and Espinoza-Beltrán, Carlos, compilers, 2007, Carta Geólogico-Minera, Estado de Sinaloa: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/sinaloa.pdf.)

Clark, K.A, Damon, P.E., and Saffiqullah, M., 1988, Metallization epoch in relation to late Mesozoic and Cenozoic igneous activity, Sinaloa, Mexico, *in* Clark, K.F, Goodell, P.C., and Hoffer, J.M., eds., Stratigraphy, tectonics and resources of parts of Sierra Madre Occidental province, Mexico: El Paso Geological Society, Guidebook for the 1988 Field Conference, p. 343-362.

Coney, P.J., and Campa, M.F., 1987, Lithotectonic terrane map of Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1874D, scale 1:2,500,000.

Consejo de Recursos Minerales, 1993, Monografía Geológico-Minera del Estado de San Luís Potosí, Secretaria de Energía, Minas E Industria Paraestatal, Subsecretaria de Minas E Industria Básica, 218 p.

Cox, D.P., 1986, Descriptive model of porphyry Cu (Model 17), *in* Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 76. (Also available online at http://pubs.usgs.gov/bul/b1693/.)

Damon, P.E., Clark, K.C., and Shafiqullah, M., 1983, Geochronology of the porphyry copper deposits and related mineralization of Mexico: Canadian Journal of Earth Science, v. 20, p. 1052-1071.

de la Garza, V., Noguez, B., Carreón-Pallares, N., 2003, Geology, mineralization and emplacement of the Milpillas secondary-enriched porphyry copper deposit, Sonora, Mexico, in XX Convención Internacional de Minería, Acapulco, Guerrero, v. I: Mexico, Asociación de Ingenieros de Minas, Metalurgistas y Geólogos de México (AIMMGM).

Drew, L.J., and Menzie, W.D., 2006, Is there a metric for mineral deposit occurrence probabilities?: Natural Resources Research, 2, p. 92-105.

Echávarri-Pérez, A., 1978, Metallogenetic map of Sonora, Mexico: Arizona Geological Society Digest, v. XI, p. 145-154.

Einaudi, M.,1982, Description of skarns associated with porphyry copper plutons, southwestern North America, *in* Titley, S.R., ed., Advances in geology of the porphyry copper deposits: Tucson, The University of Arizona Press, p. 139-135.

Ferrari, L., Tagami, T., Eguchi, M., Orozco-Esquivel, M.T., Petrone, C.M., Jacobo-Albarrán, J., and López-Martínez, M., 2005, Geology, geochronology, and tectonic setting of late Cenozoic volcanism along the southwestern Gulf of Mexico—The Eastern Alkaline Province revisited: Journal of Volcanology and Geothermal Research, v. 146, p. 284–306.

García-Padilla, J.L., Manuel-Camacho, Juan, Islas-Tenorio, J.J., Ontiveros-Escobedo, Enrique, Guereca-Meza, Raúl, Armenta-Román, Roberto, and Ortiz-Jácome, Adriana, 2003, Carta geológico-minera, El Salto F13-2, Sinaloa, Durango, Zacatecas, and Nayarit [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Goodell, P.C., 1995, Porphyry deposits along the Batopilas lineament, Chihuahua, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Tucson, Arizona Geological Society Digest 20, p. 544.

Hayes, F.M., and Kesler, S.E., 1988, Compositions and sources of mineralizing fluids for chimney and manto limestone replacement ores in Mexico: Economic Geology, v. 83, p. 1985-1992.

Henry, C.D., and Fredrikson, G., 1972, Edades de intrusiones, Sinaloa, México (abstract): Mem.IIa. Convención Nacional de Sociedad Geológica Mexicana, Mazatlán, p. 155.

Hewitt, W.P., 1943, Geology and mineralization of the San Antonio Mine, Santa Eulalia District, Chihuahua, México: Geological Society of America Bulletin, v. 53, no. 2, p. 173-204.

Iriondo, A., Kunk, M.J., Wininck, J.A., 2003, ^{40}Ar- ^{39}Ar Dating studies of minerals and rocks in various areas in México—USGS/CRM scientific collaboration (Part I): U.S. Geological Survey Open-File Report 03-020, 79 p., (Also available online at http://pubs.usgs.gov/of/2003/ofr-03-020/OFR-03-020-508eng.pdf.)

Laznicka, P., 1999, Quantitative relationships among giant deposit of metals: Economic Geology, v. 94, p. 455-473.

López-Escalone, Juan, Espinoza-Beltrán, Carlos, Díaz-Salgado, C.C., and Castro-Escárrega, J.J., compilers, 2006, Carta geológico-Minera, Estado de Durango: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000 (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/durango.pdf).

López-Escalona, Juan, Montiel-Escobar, J.E., Dorantes-Salgado, Enrique, Jiménez-Gonzaga, J.A. and Diaz-Salgado, C.C., compilers, 2007, Carta Geólogico-Minera, Estado de Aguascalientes y Zacatecas: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/zacatecas.pdf.)

López-Ramos, E., 1979, Geologia de México, v. 2, 3rd ed.: México City, Ediciones Mexico, 453 p.

López-Reyes, Julían, De Los Santos-Montaño, José De Jesús, Cacho-Casillas, Sergio, and Sánchez-Bermeo, Gilberto, 1997, Carta geológico-minera, Pachuca F14-11, San Louis Potosí, Hidalgo, Estado De México, Veracruz and Puebla [México]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

López-Reyes, J.E. and de la Calleja-Moctezuma, Alfredo, compilers, 2007, Carta Geólogico-Minera, Estados de Guanajuato y Querétaro: Servicio Geológico Mexicano, sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/gto_queretaro.pdf.)

McKee, E.D., 1951, Sedimentary basins of Arizona and adjoining areas: Geological Society of America Bulletin, v. 62, p. 481-506.

Maldonado-Lee, J.M., Reyes-Reyes, N.A., de la Calleja-Moctezuma, Alfredo, Barajas-Nigoche, L.D., and Montiel-Escobar, J.J., compilers, 2007, Carta geólogico-minera, Estado de San Luis Potosí: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.

coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/slp.pdf.)

McDowell, F.W., and Clabaugh, S.E., 1979, Ignimbrites of the Sierra Madre Occidental and their relation to the tectonic history of western Mexico: Geological Society of America Special Paper 180, p. 113-124.

Megaw, P.K.M., Ruiz, Joaquin, and Titley, S.R., 1988, High-temperature, carbonate-hosted Ag-Pb-Zn(Cu) deposits of Northern Mexico: Economic Geology, v. 83, p. 1856-1885.

North American Magnetic Anomaly Group, 2002, Magnetic anomaly map of North America: U.S. Geological Survey Special Map, scale 1:10,000,000, accessed January 15, 2008, at http://pubs.usgs.gov/sm.mag_map/.

Ohmoto, H., Hart, S.R., and Holland, H.D., 1966, Studies in the Providencia area, Mexico, II, K-Ar and Rb-Sr ages of intrusive rocks and hydrothermal minerals: Economic Geology, v. 61, p. 1205-1213.

Olivares, R.P., 1991, Economic geology of the San Martin mining district, *in* Salas, G.P., ed., Economic geology, Mexico: Boulder, Colorado, Geological Society of America, The Geology of North America, v. P-3, p. 229-238.

Pierce, H.W., 1976, Elements of Paleozoic tectonics in Arizona: Arizona Geological Survey Digest X, p. 37-57.

Root, D.H., Menzie, W.D., and Scott, W.A., 1992, Computer Monte Carlo simulation in quantitative resource estimation: Natural Resources Research, v. 1, no. 2, p. 125-138.

Rubin, J.N., and Kyle, R.J., 1988, Mineralogy and geochemistry of the San Martin skarn deposit, Zacatecas, Mexico: Economic Geology, v. 83, p. 1782-1801.

Ruiz, J., Patchett, P.J., and Ortega G. F., 1988, Proterozoic and Phanerozoic basement terranes of Mexico from neodymium isotopic studies: Geological Society of America Bulletin, v. 100, p. 322-330.

Salinas-Prieto, J.C., Arriaga-Meléndez, Hiliaro, López-Reyes, J.E., Montiel-Escobar, J.E., Terán-Ortego, L.A., Lebrado-Flores, José, and Amezcua-Torres, Natalia, compilers, 2004, Carta Geólogico-Minera, Estado de Chihuahua: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/chihuahua.pdf.)

Sánchez-González, Antonio, Vázquez-Tortoledo, Rafael, Romo-Ramírez, Julio, De la Calleja-Moctezuma, Alfredo, and Guerro-Armenta, A.A., 1998, Carta geológico-minera, Fresnillo F13-3, Durango, Zacatecas, and San Luis Potosi [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Servicio Geológico Mexicano, 2007, Carta geológica de la República Mexicana, Texto explicativo. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/cartas250/geologia/Texto_explicativo.pdf.)

Singer, D.A., Berger, V.I., Menzie, W.D., and Berger, B.R., 2005, Porphyry copper density: Economic Geology, v. 100, no. 3, p. 491-514.

Singer, D.A., Berger, V.I., and Moring, B.C., 2008, Porphyry copper deposits of the world—Database, map, and grade and tonnage models, 2008: U.S. Geological Survey Open-File Report 2008-1155, 45 p., accessed January 15, 2009, at http://pubs.usgs.gov/of/2008/1155/.

Singer, D.A., and Menzie, W.D., 2005, Statistical guides to estimating the number of undiscovered mineral deposits—An example with porphyry copper deposits, *in* Cheng, Qiuming, and Bonham-Carter, Graeme, eds., Proceedings of IAMG, The annual conference of the International Association for Mathematical Geology: Geomatics Research Laboratory, York University, Toronto, Canada, p. 1028-1033.

Smith, C. I., 1981, Review of the geologic setting, stratigraphy and facies distribution of the Lower Cretaceous in northern Mexico: Geological Society of West Texas Guidebook Publication 81-74, p. 1-27.

Starr, Jesse R., 2003, Multiphase magmatism in the Bismark stock; relation to zinc skarn and porphyry zinc alteration in the Bismark Mine, Chihuahua, Mexico [abs.]: Geological Society of America, 99th Annual Cordilleran Section Meeting, April 1-3, 2003.

Staude, J.M., and Barton, M.D., 2001, Jurassic to Holocene tectonics, magmatism, and metallogeny of northwestern Mexico: Geological Society of America Bulletin, v. 113, p. 1357-1374.

Titley, S.R., ed., 1982, Advances in geology, of the porphyry copper deposits, southwestern North America: Tucson, University of Arizona Press, 560 p.

U.S. Geological Survey, 2005, Mineral Resources Data System: U.S. Geological Survey, Reston, Virginia, accessed December 15, 2007, at http://tin.er.usgs.gov/mrds/.

Valencia, V.A., Noguez-Alcántara, B., Barra, F., Ruiz, J., Gehrels, G., Quintanar, F., and Valencia-Moreno, M., 2006, Re-Os molybdenite and LA-ICPMS-MC U-Pb zircon geochronology for the Milpillas porphyry copper deposits—Insights for the timing of mineralization in the Cananea District, Sonora, Mexico: Revista Mexicana de Ciencias Geológicas, v.23, no. 1, p. 39-53.

Valencia-Moreno, M., Ruiz, J., and Roldán-Quintana, J., 1999, Geochemistry of Laramide granite rocks across the southern margin of the Paleozoic North American continent, Central Sonora, Mexico: International Geology Review, v. 41, p. 845-857.

Valencia-Moreno, M., Ruiz, J., Barton, MD., Patchett, P.J., Zürcher, L., Hodkinson, D., and Roldán-Quintana, J., 2001, A chemical and isotopic study of the Laramide granitic belt of northwestern Mexico—Identification of the southern edge of the North American Precambrian basement: Geological Society of America Bulletin, v. 113, p. 1409-1422.

Valencia-Moreno, M., Ruiz, J., Ochoa-Landín, L., Martínez-Serrano, R., and Vargas-Navarro, P., 2003, Geochemistry of the coastal Sonora batholith, northwestern Mexico: Canadian Journal of Earth Sciences, v. 40, p. 819-831.

Valencia-Moreno, M., Ochoa-Landìn, L., Noguez-Alcantara, B., Ruìz, J., Pèrez- Segura, E., 2006, Características metalogenéticas de los depósitos de tipo pórfido cuprífero en México y su situación en el contexto mundial: Boletín de la Sociedad Geológica Mexicana, Vol. Conmemorativo del

Centenarìo, Tomo. LVIII. Num.1, p. 1-26.

Valencia-Moreno, M., Ochoa-Landín, Lucas, Noguez-Alcántara, Benito, Ruiz, Joaquin, Pérez-Segura, Efrén, 2007, Geological and metallogenic characteristics of the porphyry copper deposits of México and their situation in the world context: Geological Society of America Special Paper 422, p. 433-458.

Valenzuela-Navarro, L.C., Valencia-Moreno, M., Iriondo, A., and Premo, W., 2003, The El Crestón granite—A new confirmed Paleo-proterozoic locality in the Opodepe area, North-Central Sonora, Mexico: Geological Society of America Abstracts with Programs, v. 35, no. 4, p. 83.

Vassallo, L.F., Solorio, J.G., Ortega-Rivera, M.A., Sousa, J.E., and Olalde, G., 2008, Paleogene magmatism and associated skarn-hydrothermal mineralization in the central part of Mexico: Universidad Nacional Autónoma de México Web page accessed May 15, 2009, at http://www.geociencias.unam.mx/~bole/eboletin/aVassallo0908.pdf.

Wilkerson, G., Quingping, D., Llavona, R., and Goodell, P., 1988, Batopilas mining district, Mexico: Economic Geology, v. 83, p. 1721-1736.

Wodzicki, W.A., 2001, The evolution of magmatism and mineralization in the Cananea district, Sonora, Mexico: Society of Economic Geologists Special Publication 8, p. 243-263.

Zürcher, L., 2002, Regional setting and magmatic evolution of Laramide porphyry copper systems in western Mexico: Tucson, University of Arizona, Ph. D. thesis, 427 p.

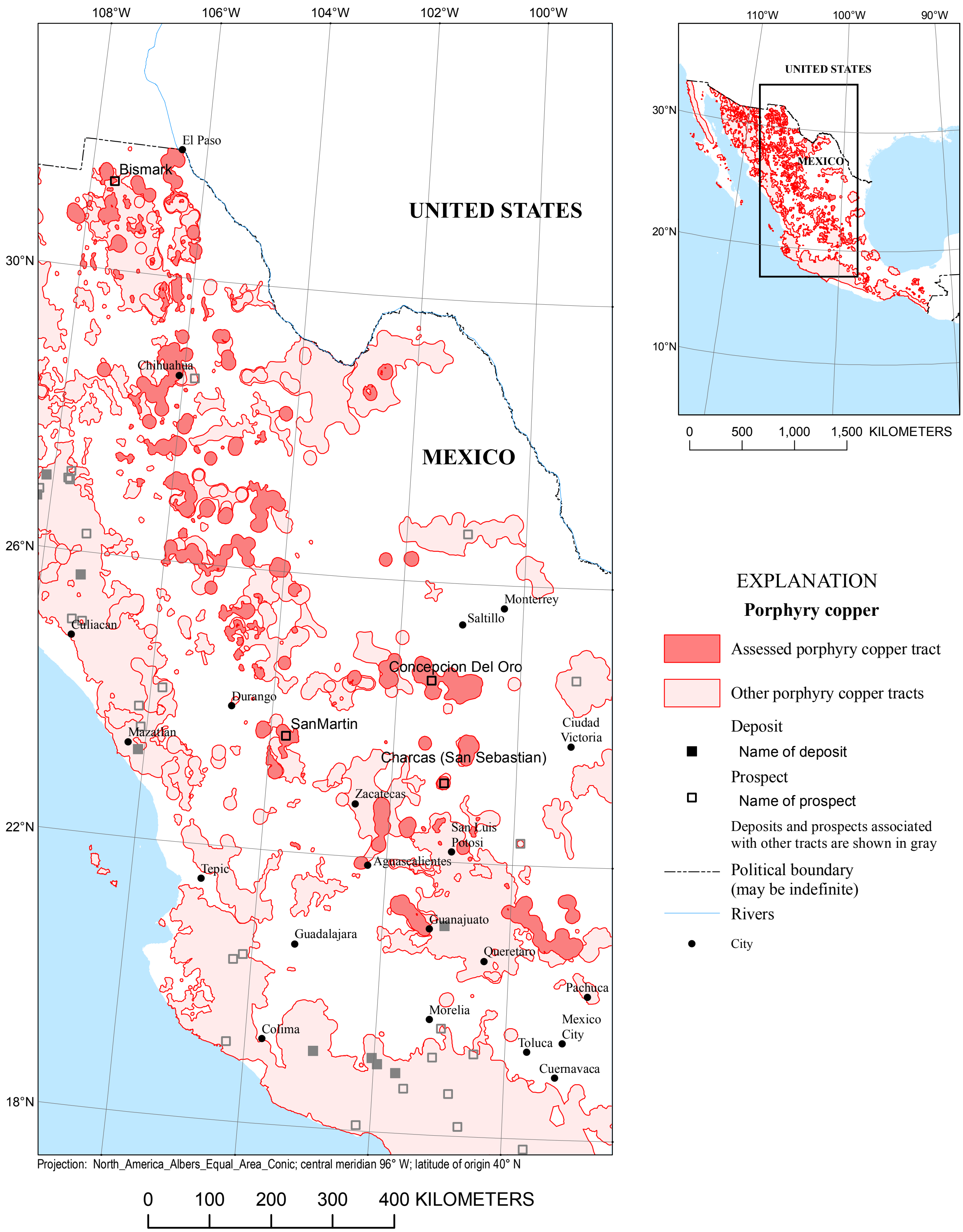


Figure H1. Map showing the location, known porphyry copper deposits, and significant porphyry copper prospects, tract 003pCu3008-1 (MX-L3), Central Laramide Plateau, Mexico.

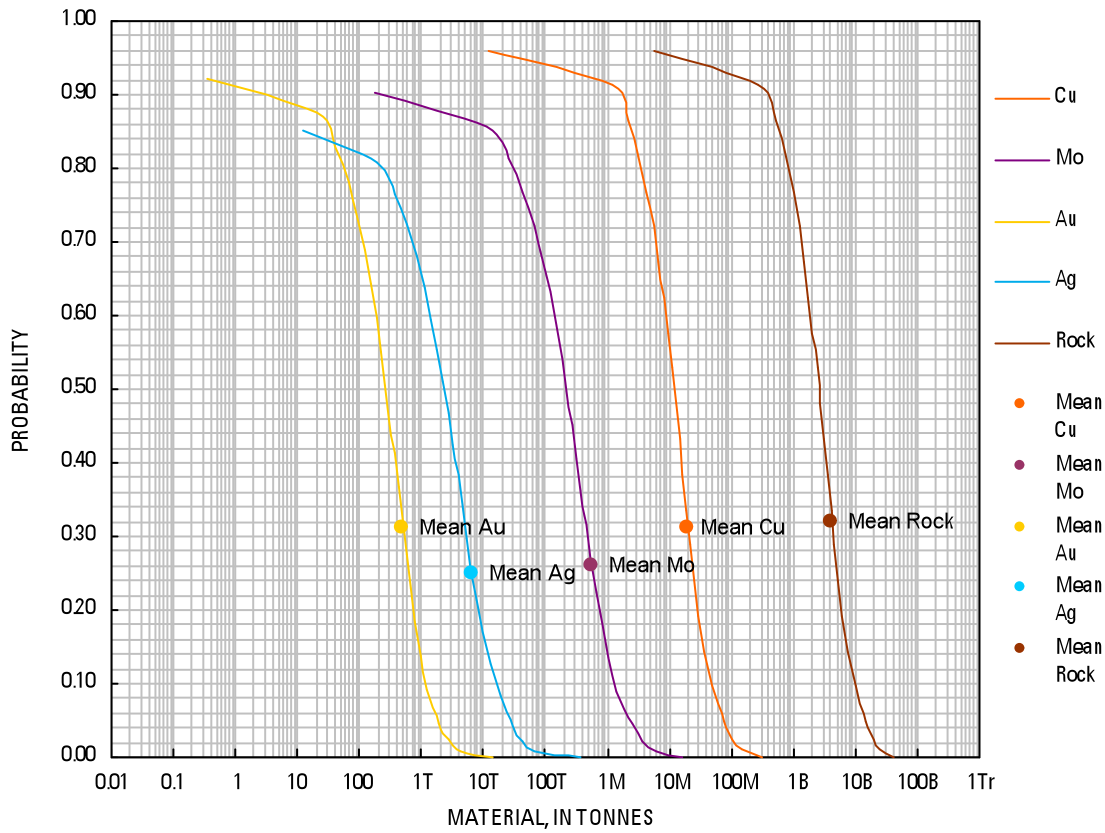


Figure H2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in tract 003pCu3008-1 (MX-L3), Central Laramide Plateau, Mexico. T, thousands; M, millions; B, billions; Tr, trillions.

Appendix I. Porphyry Copper Assessment for Tract 003pCu3010 (MX-T1), Eastern Alkaline Province, Mexico

By, Steve Ludington[1], Francisco Cendejas-Cruz[2], Enrique Espinosa[2], Floyd Gray[1], Jane M. Hammarstrom[1], Gilpin R. Robinson, Jr.[1], Efrén Pérez-Segura[3], Martín Valencia-Moreno[4], José Luis Rodríguez-Castañeda[4], Rigoberto Vásquez-Mendoza[2], and Lukas Zürcher[5]

Deposit Type Assessed: Porphyry copper, copper-gold subtype

Descriptive model: Porphyry copper-gold (Cox, 1986)
Grade and tonnage model: Porphyry copper, Cu-Au subtype (Singer and others, 2008)
(Table I1 summarizes selected assessment results)

Location

The tract consists of a number of discrete areas in the eastern part of Mexico, east of the Sierra Madre Occidental, and includes areas from adjacent to the U.S. border in the north, to the state of Veracruz in the south (fig. I1).

Geologic Feature Assessed

Tertiary back-arc and extension-related alkaline magmatic rocks in eastern Mexico.

Table I1. Summary of selected resource assessment results for tract 003pCu3010 (MX-T1), Eastern Alkaline Province, Mexico.

[km, kilometers; km^2, square kilometers; t, metric tons; n.d., no data]

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)
May 2008	1	56,839	n.d.	6,700,000	2,700,000

[1]U.S. Geological Survey.
[2]Servicio Geológico Mexicano.
[3]University of Sonora.
[4]Geologic Institute, Universidad Nacional Autónoma de México.
[5]University of Arizona.

Delineation of the Permissive Tract

Geologic Criteria

This tract (fig. I1) includes copper- and gold-bearing mineral deposits related to alkaline igneous rocks that range in age from Eocene to Pleistocene and have been described as the Eastern Alkaline Province by Robin (1976, 1982). Rocks of this province are found from the U.S. border, near Big Bend National Park, Texas, to the southeastern part of the state of Veracruz. The rocks are discriminated petrologically by lithologic descriptions provided by a 1:500,000-scale preliminary digital geologic of Mexico (Servicio Geológico Mexicano, written commun., 2007).

The Eastern Alkaline Province of Mexico is the southward continuation of a similar group of igneous rocks and related mineral deposits in the U.S. that extends from the Canadian border in central Montana to southern New Mexico and western Texas (Kelley and Ludington, 2001; Jensen and Barton, 2000; McLemore, 1996; Mutschler and Mooney, 1995). The mineral deposits associated with this group of rocks include both Au-rich copper deposits (porphyry and skarn) and epithermal gold deposits; this theme is consistent worldwide (Müller, 2002). The age of the rocks varies from Paleocene in the north to Pleistocene in the south, and the relationship of these rocks to subduction along the Pacific margin is a matter of some debate. The degree of mantle involvement and the role of rifting in the origin of the alkaline rocks in this belt have not been established. Nevertheless, these alkaline rocks have consistently formed at the eastern margin of the Cordilleran arc, and they have commonly formed late in the magmatic history of any given region.

First, map units were selected from the digital geologic map of Mexico on the basis of alkaline rock names; they are listed and described in table I2. These units define most of the rocks included by Robin (1982) and Ferrari and others (2005) in the Eastern Alkaline Province.

In addition, a few areas were added to the tract because of information we gained independent of the digital geologic map. In northern Coahuila, map units ToD (Oligocene diorite) and ToGr-D (Oligocene granite and diorite) were included because they are contemporaneous with alkaline rocks and field examination has shown at least part of them to be alkaline. In eastern Coahuila and western Nuevo León (the Monclova belt), the map unit TeGd-D (Eocene granodiorite and diorite) was included because studies by Morton-Bermea (1995) and Yousefpour (1980) indicate that many of these intrusions are alkaline. In southern Tamaulipas, the map units ToGa-D (Oligocene gabbro and diorite) and TmGa-Di (Oligocene gabbro and diorite) were included because they are part of the Sierra de Tamaulipas alkaline igneous complex and are, at least in part, alkaline (Ramírez-Fernández and Keller, 1997).

A study by Ferrari and others (2005) identified several regions near the Gulf of Mexico that contain alkaline volcanic rocks, and all of the mapped volcanic rocks in these areas were included. The volcanic fields included are the Tlanchinol-Tantima-Alamo (8-1 Ma), Chiconquiaco-Palma Sola (17-1 Ma), and Los Tuxtlas (8-1 Ma). The Palma Sola field contains the Caballo Blanco porphyry copper-gold prospect (Singer and others, 2008); although the digital geologic map shows only TmD-Tn (Miocene diorite and tonalite), the intrusive rocks there are described as magnetic monzonite and diorite (Poliquin, 2007).

A few areas in Sonora, Chihuahua, Sinaloa, Durango, Zacatecas, San Luís Potosí, Guanajuato, and Queretaro were then excluded from the selection, even though they contain some Oligocene through Pliocene trachyte, latite, and monzonite. These areas are scattered, are distinctly west of the axis of the Eastern Alkaline Province, and have no nearby porphyry copper-related prospects; they are included in tract 003pCu3009 (MX-T2).

The tract was delineated using a 10-km buffer around the intrusive map units described above and a 2-km buffer around the volcanic units. These buffers were generated in a GIS, but the final tract boundaries were hand-digitized, using the buffers as a guide. The tract was then further refined using the aeromagnetic map (North American Magnetic Anomaly Group, 2002) to include some adjacent areas that appear to have shallow magnetic sources.

We also examined 1:250,000-scale geologic maps published by the Servicio Geológico Mexicano (SGM) of the areas included in the tract to be sure that we had included any mapped areas of hydrothermal alteration that might be indicative of porphyry copper deposits. Three areas so depicted, in Coahuila, Nuevo León, and Veracruz, are contained within the tract as delineated.

Stream-sediment geochemical data from the national database (Servicio Geológico Mexicano, written commun., 2007) were adjusted for analytical drift and interpreted by the U.S. Geological Survey and Servicio Geológico Mexicano (2008). The resulting map indicates a number of areas within the tract that have a geochemical signature indicative of porphyry copper deposits.

The tract consists of 16 individual polygons that were assessed together (fig. I1).

Known Deposits

There are no known porphyry copper deposits in the tract. The Caballo Blanco and San Carlos prospects appear to be porphyry copper systems, but they have been incompletely explored and have no published grade and tonnage information.

Prospects, Mineral Occurrences, and Related Deposit Types

The prospects and occurrences described in this section are described in geographic order, from north to south, which generally corresponds as well to decreasing age order, from

Table I2. Map units that define tract 003pCu3010 (MX-T1), Eastern Alkaline Province, Mexico.

[Map unit, age range, and principal lithologies from a 1:500,000 scale preliminary digital geologic map of Mexico (Servicio Geológico Mexicana, written commun., 2007); n.d., no data]

Map unit	Maximum age	Minimum age	Lithology 1	Lithology 2
		Intrusive rocks		
ToGr-Si	Oligocene	Oligocene	granite	syenite
ToD	Oligocene	Oligocene	diorite	n.d.
ToGr-D	Oligocene	Oligocene	granite	n.d.
To(?)D	Oligocene?	Oligocene?	diorite	n.d.
ToGr-Mz	Oligocene	Oligocene	granite	monzonite
To(?)Si	Oligocene?	Oligocene?	syenite	n.d.
ToD-Si	Oligocene	Oligocene	diorite	syenite
To(?)Gd-Mz	Oligocene?	Oligocene?	granodiorite	monzonite
ToGd-Si	Oligocene	Oligocene	granodiorite	syenite
ToGa-D	Oligocene	Oligocene	gabbro	diorite
To(?)Ga-D	Oligocene?	Oligocene?	gabbro	diorite
ToMz	Oligocene	Oligocene	monzonite	n.d.
TmGa-Di	Miocene	Miocene	gabbro	diabase
TmD-Tn	Miocene	Miocene	diorite	tonalite
TmSi	Miocene	Miocene	syenite	n.d.
		Volcanic rocks		
ToA-TA	Oligocene	Oligocene	andesite	andesite tuff
ToPA	Oligocene	Oligocene	porphyritic andesite	n.d.
To(?)R	Oligocene?	Oligocene?	rhyolite	n.d.
ToPDa	Oligocene	Oligocene	porphyritic dacite	n.d.
ToDa	Oligocene	Oligocene	dacite	n.d.
TomA-B-TA	Oligocene	Miocene	andesite	basalt
TmA	Miocene	Miocene	andesite	n.d.

latest Eocene to Pliocene, or even possibly Pleistocene. The areas discussed below are shown on fig. I2 and summarized in table I3.

Encantada Area

This area is characterized by an east-trending alignment of Oligocene intrusive rocks and associated mineral deposits, the great majority of which are fluorspar deposits. The intrusive rocks are small stocks and plugs that are primarily silica-undersaturated, but range in composition from nepheline syenite to rhyolite (Shearer, 1985). The ages of these rocks range from Eocene (about 40 Ma) to as young as Early Oligocene (30 Ma, Iriondo and others, 2003). In the southwestern part of the area, silica-saturated plutons are associated with Pb-Zn-Ag mineralized rocks. An evolved rhyolite plug (El Pilote; Levresse and others, 2005; Kesler, 1977) is associated with fluorspar deposits and resembles the highly evolved intrusions that are associated with Climax-type molybdenite deposits.

Monclova Intrusive Belt

Near the city of Monclova, Coahuila, a 200-km-long belt of late Eocene to Oligocene intrusions hosts a number of Cu- and Au-bearing skarn and stockwork deposits. These rocks straddle the boundary between alkaline and subalkaline rocks and range in composition from quartz monzodiorite to syenite (Morton-Bermea, 1995).

Copper Skarns Near Monclova

The plutons to the south and west of Monclova host a number of Cu-and precious-metal-bearing skarns, most notably two abandoned mines at the western end of the intrusive belt, Aime y San Miguel and nearby Manto Rojo (SGM MINAS database).

Some of the plutons are also associated with Pb-Zn-Ag deposits and Fe-skarns.

Dos Amigos (Panuco)

Forty-five km southeast of Monclova, a distinctive mineral deposit in the Cerro Panuco pluton was exploited for copper and molybdenum (Price, 1944). Discovered around 1870, the mine was worked for copper until the Mexican Revolution, closing in 1912. An attempt was made to recover molybdenum as early as 1918, but this early attempt failed, largely due to the unsettled political situation in the country at that time. From 1925–30, the mine was again worked for copper, this time by leaching in place. The deposit consists of a pegmatite-like chimney of granitic composition that cuts the larger pluton, which is largely granodiorite to diorite. Granodiorite from the pluton was dated at 38.64 Ma by Iriondo and others (2003). Both molybdenite and chalcopyrite occur in this body, although copper in the upper part of the chimney was present primarily as copper sulphate. The copper and molybdenum grades of this material are unknown.

Sometime after World War II, the mine was operated for a number of years, and the molybdenite was used in the steel production process at the works in nearby Monclova. We have no information about when this activity ceased.

Candela Area

Several Au and Au-Cu skarn prospects are adjacent to a group of 6 granodiorite-granite stocks in the Sierras de El Carrizal that straddles the border between Coahuila and Nuevo León, about 120 km north of Monterrey. The rocks are not dated, but are likely Oligocene in age. They range in composition from granodiorite to granite and syenite. On the flanks of several of these stocks, Cu-Mo skarn deposits that contain elevated values of gold and silver are found (Yousefpour, 1980; Arias Guiterrez and Barranco, 1978).

South of Saltillo

Two small Tertiary stocks crop out south and east of Saltillo. The first is a diorite, presumably of Oligocene age (Servicio Geológico Mexicano, written commun., 2007) that has no known associated mineral deposits. The second is an Oligocene granite-monzonite stock about 100 km west of Saltillo, near the village of El Siete de Enero, near the border with the state of Zacatecas. This stock has a Cu-Au-Fe prospect (La Minita) adjacent to it, and 3 small abandoned Cu-Au-Fe mines nearby (La Lupita, Las Palmas, and El Cañon; SGM MINAS database). The geologic map of the Monterrey quadrangle (1:250,000) indicates that the stock is surrounded by an envelope of quartz-sericite alteration. No further information was found about this stock or prospect.

Sierra de San Carlos

The Sierra de San Carlos is made up of Cretaceous shale, limestone, and marl that was intruded by dozens of small Oligocene stocks of strongly alkaline diorite, granodiorite, monzonite, and syenite (Servicio Geológico Mexicano, written commun., 2007; Servicio Geológico Mexicano, 2007; Nick, 1988). These intrusions have ages between 31 and 28 Ma (Iriondo and others, 2003; Bloomfield and Cepeda-Davila, 1973). The most important of these intrusive rocks are the diorite porphyries described by Hubberten (1985) that make up the northern part of the massif. A chemical analysis of one of these rocks, reported by Kemp (1904), shows it to have a composition near the monzonite-monzodiorite boundary. Bastin (1937) reported aegerine-augite as a common mafic mineral in samples that are not strongly affected by hydrothermal alteration.

The area was under active exploration in 2008 (Almaden Minerals, Ltd., 2008a). Mineral deposits and prospects in this area include (1) Cu-skarns in the northern end of the main intrusive mass, about 13 km northwest of the town of San Carlos; (2) indications of skarn and porphyry-style mineralization at the south end of the main intrusive mass, about 11 km southwest of the town of San Carlos; (3) Pb-Ag veins that are distal to the intrusions, about 13 km northeast of the town of San Carlos, and (4) an area termed the El Jatero zone, about 5 km east of the town of San Carlos, that is characterized by gold anomalies in stream-sediment samples from streams that drain a pluton of diorite porphyry (SGM MINAS database, Almaden Minerals, Ltd., 2008a; Hubberten, 1985; Bastin, 1937; and Kemp, 1904; 1905).

The copper skarns northwest of San Carlos are the most important porphyry copper target in the area. They were exploited near the end of the 19th century and in the early years of the 20th century. They were described in some detail by Bastin (1937), who noted that, in the central part of the district, away from any skarns developed in calcareous wall rocks, chalcopyrite and molybdenite occur in endoskarn and quartz and quartz-magnetite veinlets that cut the intrusive. This was also noted by Kemp (1904), as well as by the senior author of this tract description, on a visit to the district in 1997. The area has many characteristics of a porphyry copper prospect.

Sierra de Tamaulipas

The Sierra de Tamaulipas is made up primarily of Early Miocene mafic alkaline volcanic and intrusive rocks (Ramírez-Fernández, 1996; Ramírez-Fernández and Keller, 1997), including some carbonatite intrusions. The massif is known primarily for the presence of rare-earth element occurrences, related to carbonatites at El Picacho (Elías-Herrera and others, 1990, 1991). The rocks are Late Oligocene to Early Miocene in age (Cantagrel and Robin, 1979; Robin, 1982).

In addition to the rare-earth element occurrences, there are two abandoned Zn-Pb-Ag mines and one abandoned Cu-Au-Ag mine (La Colmena) in the western part of the Sierra de Tamaulipas (SGM MINAS database). These sites are all near or within mafic to silicic alkaline plutons that intrude the volcanic rocks (Servicio Geológico Mexicano, written commun., 2007).

Table I3. Significant prospects and occurrences in tract 003pCu3010 (MX-T1), Eastern Alkaline Province, Mexico.

[Coordinates are referred to the NAD 83 datum]

Name	Latitude	Longitude	Age (Ma)	Comments	Reference
San José district, Sierra de San Carlos	24.68	-99.08	30-28	Production in early 19th century, being actively explored 2008. Cu skarn and stockwork deposits	Kemp (1905), Bastin (1937), Almaden Minerals, Ltd. (2008a)
Dos Amigos (Pánuco)	26.708	-100.986	39	Mo- and Cu-rich pegmatite. Mo was mined for use in the steel industry	Price (1944) personal visit
La Chora	22.317	-99.894	Miocene	Producing mine, associated with syenite pluton	SGM Minas database
Gallo de Oro	19.765	-96.744	Miocene?	Cu-Au prospect	SGM Minas database
Caballo Blanco	19.681	-96.453	Miocene or Pliocene	Active prospect of Almaden Minerals, Ltd.; porphyry Cu and high-sulfidation epithermal targets	Almaden Minerals, Ltd. (2008b)

To the southwest of Sierra de Tamaulipas, about 210 km due west of the city of Tampico, a small mine (La Chora) that produces Au, Ag, Pb, and Cu is adjacent to a small Miocene syenite stock (SGM MINAS database). No more information about this deposit could be found.

Tlanchinal-Tantina-Alamo Volcanic Field

This area, south and west of Tampico in the states of Veracruz, Hidalgo, and Puebla, is made up primarily of basaltic rocks, both lava flows and volcanic necks, that range in composition from basanite to hawaiite to phonotephrite. The age of these rocks ranges from about 9 to about 6 Ma (Ferrari and others, 2005).

The only metallic mineral deposits in this area are some small manganese deposits in the basalts in Mesozoic limestones adjacent to the volcanic rocks in the western part of the area.

Jalapa Area

Near the city of Jalapa, on the Gulf Coast, about 60 km north of the city of Veracruz, an east-trending chain of mountains, the Texiutlán massif, is uplifted along structures that divide the Tampico-Misantla Basin on the north from the Veracruz Basin on the south. This massif also marks the intersection of the Eastern Mexico Volcanic Province with the Transverse Mexican Volcanic Belt. Igneous rocks here can be divided into four groups: (1) Middle to Late Miocene mafic to intermediate intrusive rocks, (2) latest Miocene to Pliocene alkaline basalts,(3) latest Pliocene shoshonitic lava flows, and (4) Late Pliocene to Holocene basaltic lava flows and cinder cones (Ferrari and others, 2005).

Three mineralized areas are indicative of porphyry copper deposits, the Caballo Blanco prospect a few km from the Gulf Coast, the area around Gallo de Oro, and the Tatatila project area, about 80 km inland, at the west end of the permissive area.

Caballo Blanco Prospect

The prospect appears to be in a window through Pliocene alkaline volcanic rocks that exposes Miocene volcanic and plutonic rocks with ages as old as 17 Ma (Robin, 1982; Negendank and others, 1985). The prospect was under active exploration in 2008 and consists of a central zone of argillic hydrothermal alteration that overlies a postulated porphyry copper deposit, flanked by several high-sulfidation epithermal prospects that were also being actively explored. The porphyry copper target exhibits quartz-magnetite veins and potassium silicate alteration, but has not been explored at depth (Almaden Minerals, 2008b; Polinquin, 2007).

Gallo de Oro Area

The Gallo de Oro Au-Cu prospect (SGM MINAS database) is adjacent to a Miocene diorite to tonalite pluton that intruded Miocene basalt and andesite. Little else is known about this prospect, but its metallogenic and petrologic character are consistent with it being a porphyry copper prospect.

Table I4. Principal sources of information used by the assessment team for tract 003pCu3010 (MX-T1), Eastern Alkaline Province, Mexico.

[NA, not available or not applicable]

Theme	Name or title	Scale	Citation
Geology	Preliminary digital geologic map of the Republic of Mexico	1:500,000	Servicio Geológico Mexicano (written commun., 2007)
Mineral occurrences	SGM Minas database	NA	Servicio Geológico Mexicano (written commun., 2007)
	MRDS database	NA	U.S. Geological Survey (2005)
	University of Arizona-Industry-USGS Mexico Consortium	NA	University of Arizona-Industry-USGS Mexico Consortium, March 1999 Release Notes (unpublished)
	Porphyry copper deposits of the world: database, map, and grade and tonnage models	NA	Singer and others (2008)
	Geological and metallogenetic characteristics of the porphyry copper deposits of México and their situation in the world context	NA	Valencia-Moreno and others (2007)
Geochemistry	SGM stream-sediment database	NA	Servicio Geológico Mexicano (written commun., 2007)
Geophysics	North American magnetic map	1:10,000,000	North American Magnetic Anomaly Group (2002)
Exploration	Proyectos de Compañias Extranjeras por Estado	NA	Dirección General de Promoción Minera (2005)
	Company Web sites	NA	See tables and text

Sierra de los Tuxtlas

This area is an isolated mountain range on the Gulf Coast in the state of Veracruz, about 100 km southeast of the city of Veracruz. The rocks, mostly volcanic, in this area show a wide variety of compositions, but they are primarily mafic and alkaline. They range in age from Late Miocene to Holocene (Verma, 2006; Nelson and others, 1995). Part of the area, near the Gulf Coast, is protected from exploitation by the Los Tuxtlas Biosphere Reserve.

There has been relatively little mineral exploration in the area, although one silver deposit (La Morelense) was discovered and explored during the 1990s. It had to be abandoned because of the region's environmental sensitivity.

Exploration History

Exploration specifically for porphyry copper deposits in the Eastern Alkaline Province is a relatively new phenomenon, although the copper-bearing skarn deposits in the Sierra de San Carlos were exploited in the 19th century. The area is also prospective for gold deposits related to the alkaline magmatism. The Consejo de Recursos Minerales (now the SGM) explored the skarn deposits in the Sierras de El Carrizál in the 1980s, but development of a deposit was not possible. The Caballo Blanco prospect was discovered by Almaden Resources, Ltd., in 1994 on the basis of a literature review. Almaden, and companies working with them under option, has since explored both the epithermal gold and porphyry copper sectors of the prospect area by using soil and rock geochemical sampling, geophysical methods (induced polarization, ground magnetics), and diamond drilling.

Sources of Information

Principal sources of information used by the assessment team for delineation of 003pCu3010 are listed in table I4.

Grade and Tonnage Model Selection

The grade and tonnage model used in this assessment was the porphyry Cu-Au subtype described by Singer and

Table I5. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 003pCu3010 (MX-T1), Eastern Alkaline Province, Mexico.

[NXX, estimated number of deposits associated with the xxth percentile; Nund, expected number of undiscovered deposits; s, standard deviation; Cv%, coefficient of variance; Nknown, number of known deposits in the tract that are included in the grade and tonnage model; Ntotal, total of expected number of deposits plus known deposits; area, area of permissive tract in square kilometers; density, deposit density reported as the total number of deposits per km^2. N_{und}, s, and Cv% are calculated using a regression equation (Singer and Menzie, 2005).]

Consensus undiscovered deposit estimates			Summary statistics					Tract area (km^2)	Deposit density (N_{total}/km^2)
N90	N50	N10	N_{und}	s	Cv%	N_{known}	N_{total}		
1	2	4	2.2	1.2	54	0	2.2	56,839	0.000039

others (2008). The use of this subtype is not based on the nature of known deposits within the tract as there are none. The rationale is based on the idea that porphyry copper deposits associated with alkaline source rocks are relatively rich in gold. This idea apparently originated with Barr and others (1976) and has been further developed by Mutschler and others (1985, 1991), McMillan and Pantaleyev (1988), and Sillitoe (2002). Singer and others (2008) do not specifically classify deposits as alkaline or not, but the inclusion of associated rock types within their compilation allows the examination of the data for those deposits with alkaline rock names. Those data, along with the grade and tonnage information in Schroeter and others (1989) seem to confirm that, whereas not all gold-rich porphyry copper deposits are alkaline, nearly all alkaline porphyry copper deposits are gold-rich. Therefore, it seems likely that any porphyry copper deposits in the Eastern Alkaline Province will be relatively rich in gold.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

The Eastern Alkaline Province of Mexico is the southward continuation of a magmatic province in the U.S. that extends from the Canadian border in central Montana to southern New Mexico and western Texas (Kelley and Ludington, 2001; Jensen and Barton, 2000; McLemore, 1996; Mutschler and Mooney, 1995). Although no well-explored porphyry copper deposits are known within the tract, a number of prospects with at least some of the characteristics of porphyry copper deposits are found both within the tract and in the continuation of the province into southern New Mexico and western Texas (Kelley and Ludington, 2001).

Table I6. Results of Monte Carlo simulations of undiscovered resources in tract 003pCu3010 (MX-T1), Eastern Alkaline Province, Mexico.

[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	0	180,000	2,700,000	16,000,000	27,000,000	6,700,000	0.26	0.07
Mo	0	0	2,700	88,000	190,000	39,000	0.19	0.44
Au	0	20	240	1,200	2,000	490	0.29	0.07
Ag	0	0	400	4,200	9,100	2,200	0.19	0.33
Rock	0	46	600	3,300	5,900	1,300	0.26	0.07

Two prospect areas, San Carlos and Caballo Blanco, are reasonably likely to be porphyry copper prospects, and there is a significant probability that each area might contain a deposit. This judgment helped anchor our estimate of a 50-percent chance or more for two or more deposits. The permissive area is discontinuous and can be represented by only 16 discrete polygons. This observation helped limit our estimate of a 5-percent chance of four or more deposits. We believe the area has been underexplored in the past due to the relative scarcity of precious-metal deposits. On the other hand, exploration of a somewhat larger area to the north in the U.S. has failed to discover a viable porphyry copper deposit. In addition, post-mineral rocks and unconsolidated material cover only 24 percent of the tract, also arguing against large numbers of undiscovered deposits. We did not use the deposit density models of Singer and others (2008) directly, but we are comfortable that our estimate (3.9 deposits/100,000 km^2, table I5) is relatively low with respect to worldwide porphyry copper distributions (fig. 11).

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered porphyry copper-gold deposits with the porphyry Cu-Au subtype (Singer and others, 2008) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, in press). Selected simulation results are reported in table I6. Results of the Monte Carlo simulation are presented as a cumulative frequency plots (fig. I3). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock. Note that, although the mean expected amount of contained copper in the tract is 6,700,000 t, there is a 7-percent chance that there is none.

References Cited

Almaden Minerals Ltd., 2008a, San Carlos, Tamaulipas State [Mexico]: Almaden Minerals Ltd. Web page accessed May 15, 2009, at http://www.almadenminerals.com/Projects/SanCarlos.html.

Almaden Minerals Ltd., 2008b, Caballo Blanco, Veracruz State [Mexico]: Almaden Minerals Ltd. Web page accessed May 15, 2009, at http://www.almadenminerals.com/Projects/CaballoBlanco.html.

Arias Guiterrez, M.A., and Barranco, R.F., 1978, Zonas de trabajos y resultados obtenidos en la exploración geológico-minera del proyecto de Candela, Estado de Coahuila: Archivo Tecnico, Servicio Geológico de México, No. 050114, 27 p.

Barr, D.A., Fox, P.E., Northcote, K.E., and Preto, V.A., 1976, The alkaline suite porphyry deposits—A summary: Special volume of the Canadian Institution for Mining and Metallurgy, v. 15, p. 359–367.

Bastin, E.S., III, 1937, Ore deposits of the San Carlos Mountains, part 3 of The geology and biology of the San Carlos Mountains, Tamaulipas, Mexico: Michigan University Studies in Science Series, v. 12, p. 157-206.

Bawiec, W.J., and Spanski, G.T., in press, EMINERS—Economic Mineral Resource Simulator, version 3.0: U.S. Geological Survey Open-File Report 2009-1057, program files and 29-p. Quick-Start Guide.

Bloomfield, K., and Cepeda-Davila, L., 1973, Oligocene alkaline igneous activity in NE Mexico: Geological Magazine, v. 110, p. 551-555.

Cantagrel, J.M., and Robin, C., 1979, K-Ar Dating on Eastern Mexican Volcanic Rocks—Relations Between the Andesitic and the Alkaline Provinces: Journal of Volcanology and Geothermal Research, v. 5, p. 99-114.

Cox, D.P., 1986, Descriptive model of porphyry Cu-Au (Model 20c), *in* Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 110. (Also available online at http://pubs.usgs.gov/bul/b1693/.)

Elías-Herrera, Mariano, Rubinovich-Kogan, Raúl, Lozano-Santa Cruz, Rufino, Sanchez-Zavala, J.L., 1990, Parte 2. Petrología y mineralización de tierras raras del complejo ígneo El Picacho, Sierra de Tamaulipas, in Estudios sobre Tierras Raras de México: Universidad Nacional Autónoma de México Boletín 108, p. 25-97.

Elías-Herrera, M., Rubinovich-Kogan, R., Lozano-Santa Cruz, R., and Sanchez-Zavala, J.L., 1991, Nepheline-rich foidolites and rare-earth mineralization in the El Picacho Tertiary intrusive complex, Sierra de Tamaulipas, northeastern Mexico, Canadian Mineralogist, v. 29, p. 319-336.

Ferrari, L., Tagami, T., Eguchi, M., Orozco-Esquivel, M.T., Petrone, C.M., Jacobo-Albarrán, J., and López-Martínez, M., 2005, Geology, geochronology, and tectonic setting of late Cenozoic volcanism along the southwestern Gulf of Mexico—The Eastern Alkaline Province revisited: Journal of Volcanology and Geothermal Research, v. 146, p. 284-306.

Hubberten, H. W., 1985, The Sierra de San Carlos, Tamaulipas—An igneous complex of the eastern Mexican Alkaline Province: Zentralblatt für Geologie und Paleontologie Teil l, Heft 9/10, p. 1183-1191.

Iriondo, A., Kunk, M.J., Wininck, J.A., 2003, ^{40}Ar-^{39}Ar Dating studies of minerals and rocks in various areas in Mexico—USGS/CRM scientific collaboration (Part I): U.S. Geological Survey Open-File Report 03-020, 79 p. (Also available online at http://pubs.usgs.gov/of/2003/ofr-03-020/OFR-03-020-508eng.pdf.)

Jensen, E. P., and Barton, M.D., 2000, Gold deposits related to alkaline magmatism: Economic Geology Review, v. 13, p. 279-314.

Kelley K.D., and Ludington, S., 2001, Cripple Creek and other alkaline-related gold deposits in the southern Rocky Mountains, USA—Influence of regional tectonics: Mineralium Deposita, v. 37, p. 38-60.

Kemp, J.F., 1904, The copper deposits at San José, Tamaulipas, Mexico: Annals of the New York Academy of Sciences, v. xiv, p. 247-348.

Kemp, J.F., 1905, The copper deposits at San José, Tamaulipas, Mexico: Transactions of the Society of Mining Engineers of American Institute of Mining, Metallurgical and Petroleum Engineers, v. 36, p. 178-203.

Kesler, S.E., 1977, Geochemistry of manto fluorite deposits, northern Coahuila, Mexico, Economic Geology, v. 72, p. 204-218.

Levresse, G., Tritlla, J., Villareal, J., and Gonzalez-Partida, E., 2005, The "El Pilote" fluorite skarn—A crucial deposit in the understanding and interpretation of the origin and mobilization of F from northern Mexico deposits: Journal of Geochemical Exploration, v. 89, p. 205-209.

McLemore, V.T., 1996, Great Plains Margin (alkaline-related) gold deposits in New Mexico, *in* Coyner, A.R., and Fahey, P.L., eds., Geology and ore deposits of the American Cordillera: Geological Society of Nevada Symposium Proceedings, v. 2, p. 935-950.

McMillan, W.J., and Pantaleyev, A., 1988, Porphyry copper deposits, *in* Roberts, R.G., and Sheahan, P.A., eds., Ore deposit models: Geoscience Canada Reprint Series 3, p. 45-58.

Morton-Bermea, O., 1995, Petrologie, Mineralogie und Geochemie des Alkalikomplexes von Monclova-Candela (Mexiko): University of Hamburg, Germany, Ph.D. thesis, 100 p.

Mutschler, F.E., and Mooney, T.C. 1995, Precious metal deposits related to alkaline igneous rocks—Provisional classification, grade-tonnage data, and exploration frontiers: Geological Association of Canada Special Paper, IAGOD 1990 Symposium on ore deposit models, 22 p.

Mutschler, F.E., Griffen, M.E., Stevens, D.S., and Shannon, S.S., Jr., 1985, Precious metal deposits related to alkaline rocks in the North American Cordillera; an interpretive review: Transactions of the Geological Society of South Africa, v. 88, p. 355-377.

Mutschler, F.E., Mooney, T.C., and Johnson, D.C., 1991, Precious metal deposits related to alkaline igneous rocks—a space-time trip through the Cordillera: Mining Engineering, v. 43, no. 3, p. 304-309.

Müller, D., 2002, Gold–copper mineralization in alkaline rocks: Mineralium Deposita, v. 37, p. 1-3.

Negendank, J.F.W., Emmermann, R., Krawczyk, R., Mooser, F., Tobschall, H., and Welre, D., 1985, Geological and geochemical investigations on the eastern Trans Mexican volcanic belt: Geofisica Internacional, v. 24, p. 477-575.

Nelson, S.A., Gonzalez-Caver, E., and Kyser, T.K., 1995, Constraints on the origin of alkaline and calc-alkaline magmas from the Tuxtla Volcanic Field, Veracruz, Mexico: Contributions to Mineralogy and Petrology, v. 122, p. 191-211.

Nick, K., 1988, Mineralogische, geochemische und petrographische Untersuchungen in der Sierra de San Carlos (Mexiko): University of Karlsruhe, Germany, Ph.D. thesis, 167 p.

North American Magnetic Anomaly Group, 2002, Magnetic anomaly map of North America: U.S. Geological Survey Special Map, scale 1:10,000,000, accessed January 15, 2008, at http://pubs.usgs.gov/sm.mag_map/.

Poliquin, M., 2007, High-sulfidation epithermal quartz-alunite gold-silver deposits and the Caballo Blanco project, Mexico: Almaden Minerals Ltd. Web page, accessed May 15, 2009, at http://www.almadenminerals.com/Projects/Papers/Epithermal_CB.pdf.

Price, J.F., 1944, Preliminary report on the Panuco molybdenum mine, state of Coahuila, Mexico: Archivo Tecnico, Servicio Geológico de México, No. 050422, 14 p.

Ramírez Fernández J. A., 1996, Zur petrogenese des alkalikomplexes der Sierra de Tamaulipas, NE-Mexiko: Albert-Ludwigs-Universität, Freiburg, Germany, Doctoral thesis, 316 p.

Ramírez-Fernández, J.A., and Keller, J., 1997, The Sierra de Tamaulipas in NE Mexico—Transition from subduction related to intraplate Tertiary magmatism including carbonatites: EUG 9, Strasbourg, Terra Nova, 9/Abstr. Suppl. 1, 138.

Robin, C., 1976, Présence simultanée de magmatismes de significations tectoniques opposées dans l'Est du Mexique: Bulletin de la Société Géologique de France, v. 18, p. 1637-1645.

Robin, C., 1982, Relations volcanologie–magmatologie-geodynamique: application au passage entre volcanismes alcalin et andesitique dans le sud Mexicain (Axe Transmexicain et Province Alcaline Oriental):Annales Scientifiques de l'Université de Clermont-Ferrand II France, Ph.D. thesis, 503 p.

Root, D.H., Menzie, W.D., and Scott, W.A., 1992, Computer Monte Carlo simulation in quantitative resource estimation: Natural Resources Research, v. 1, no. 2, p. 125-138.

Schroeter, T.G., Lund, C., and Carter, G., 1989, Gold production and reserves in British Columbia: British Columbia Geological Survey Open-File Report 1989-22, 86 p.

Servicio Geológico Mexicano, 2007, Carta geológica de la República Mexicana, Texto explicativo. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/cartas250/geologia/Texto_explicativo.pdf.)

Shearer, C. D., 1985, Geology of the igneous intrusions of northern Valle Las Norias, Coahuila, Mexico [abs.]: Geological Society of America, Abstracts with Programs, v. 17(3), p. 191.

Sillitoe, R.H., 2002, Some metallogenic features of gold and copper deposits related to alkaline rocks and consequences for exploration: Mineralium Deposita, v. 37, p. 4-13.

Singer, D.A., 2008, Mineral deposit densities for estimating mineral resources: Mathematical Geosciences, v. 40, p. 33-36.

Singer, D.A., Berger, V.I., and Moring, B.C., 2008, Porphyry copper deposits of the world—Database, map, and grade and tonnage models, 2008: U.S. Geological Survey Open-File Report 2008-1155, 45 p., accessed January 15, 2009, at http://pubs.usgs.gov/of/2008/1155/.

Singer, D.A., Berger, V.I., Menzie, W.D., and Berger, B.R., 2005, Porphyry copper density: Economic Geology, v. 100, no. 3, p. 491-514.

Singer, D.A., and Menzie, W.D., 2005, Statistical guides to estimating the number of undiscovered mineral deposits—An example with porphyry copper deposits, *in* Cheng, Qiuming, and Bonham-Carter, Graeme, eds., Proceedings of IAMG, The annual conference of the International Association for Mathematical Geology: Geomatics Research Laboratory, York University, Toronto, Canada, p. 1028-1033.

U.S. Geological Survey, 2005, Mineral Resources Data System: U.S. Geological Survey, Reston, Virginia, accessed December 15, 2007, at http://tin.er.usgs.gov/mrds/.

U.S. Geological Survey and Servicio Geológico Mexicano, 2008, Mineral-resource assessment using large-scale digital stream-sediment geochemical data—porphyry copper deposits in Mexico: [abs] VIII Seminario Minero Internacional Sonora, Hermosillo, Mexico, 25-28 October, 2008.

Verma, S.P., 2006, Extension-related origin of magmas from a garnet-bearing source in the Los Tuxtlas volcanic field, Mexico: International Journal of Earth Sciences, v. 95, p. 871-901.

Yousefpour, M.V., 1980, Report on work with Consejo de Recursos Minerales, resulting from observation of skarn deposits in Candela, Coah.: Archivo Tecnico, Servicio Geológico de México, No. 050219, 28 p.

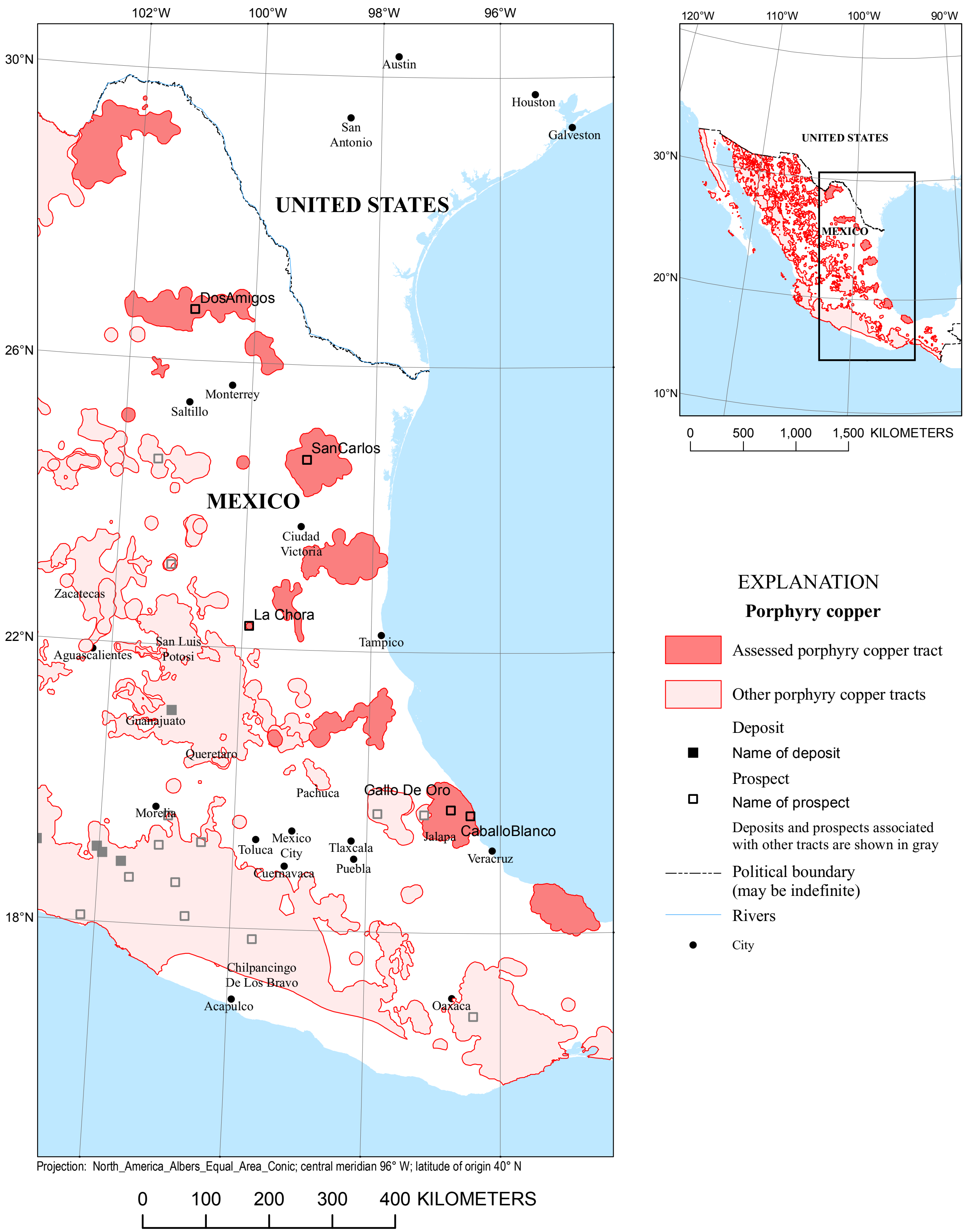


Figure I1. Map showing tract location and significant prospects for tract 003pCu3010 (MX-T1), Eastern Alkaline Province, Mexico.

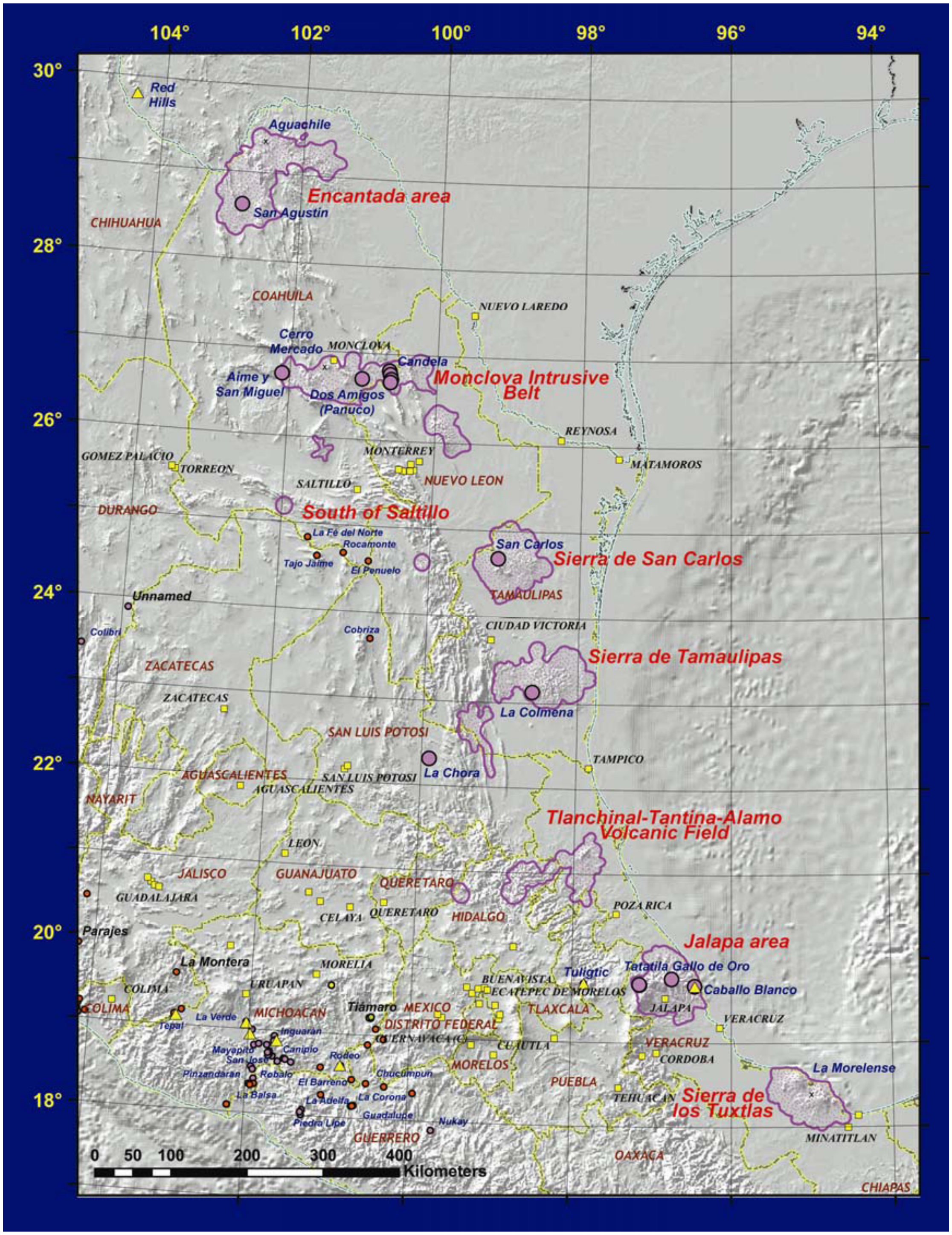


Figure I2. Map showing location of named areas (purple outlines) discussed under prospects and occurrences, tract 003pCu3010 (MX-T1), Eastern Alkaline Province, Mexico.

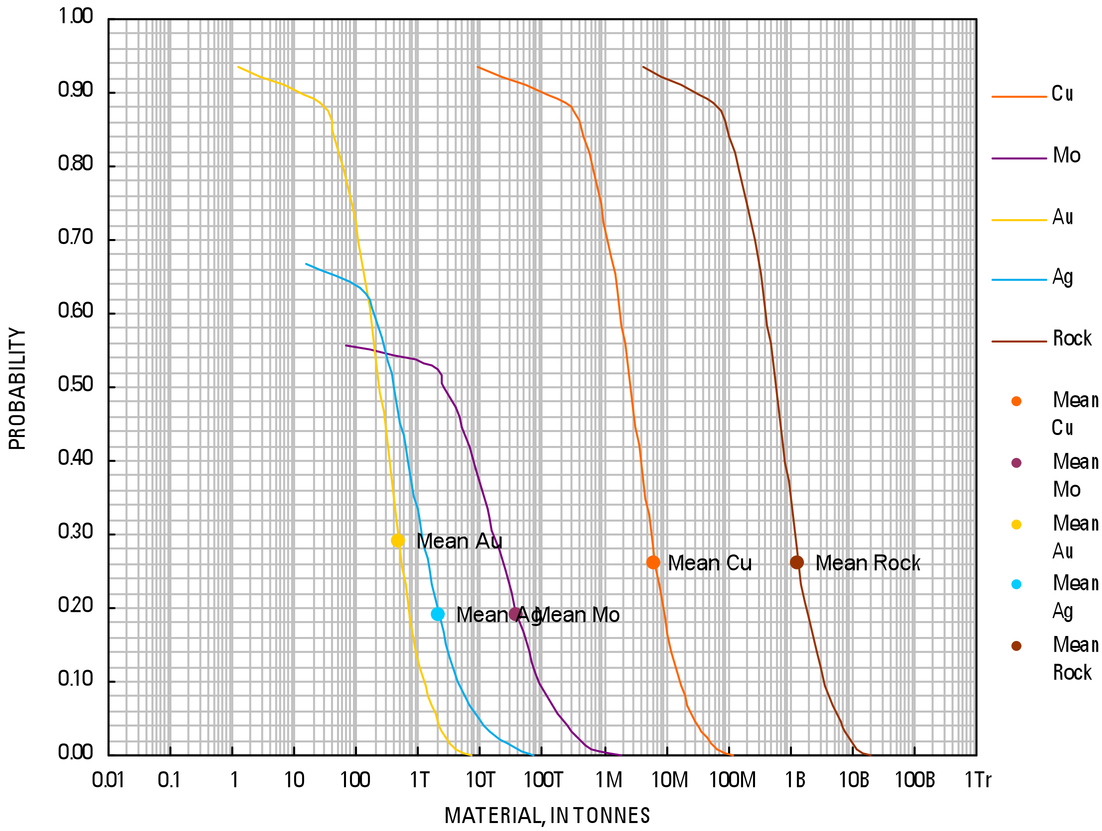


Figure I3. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in tract 003pCu3010 (MX-T1), Eastern Alkaline Province, Mexico. T, thousands; M, millions; B, billions; Tr, trillions.

Appendix J. Porphyry Copper Assessment for Tract 003pCu3009 (MX-T2), Tertiary Central Plateau, Northern Mexico

By Gilpin R. Robinson, Jr.[1], Francisco Cendejas-Cruz[2], Enrique Espinosa[2], Floyd Gray[1], Jane M. Hammarstrom[1], Steve Ludington[1], Efrén Pérez-Segura[3], Martín Valencia-Moreno[4], José Luis Rodríguez-Castañeda[4], Rigoberto Vásquez-Mendoza[2], and Lukas Zürcher[5]

Deposit Type Assessed: Porphyry copper, copper-gold subtype

Descriptive model: Porphyry copper-gold (Cox, 1986)
Grade and tonnage model: Porphyry copper Cu-Au subtype (Singer and others, 2008)
(Table J1 summarizes selected assessment results)

Location

The tract includes much of the mountainous part of northern Mexico, from the U.S. border south to the Trans-Mexican Volcanic Belt (fig. J1). The tract includes parts of the states of Baja California Sur, Chihuahua, Coahuila, Durango, Guanajuato, Hidalgo, Nayarit, Querétaro, San Luis Potosi, Sinaloa, Sonora, Veracruz, and Zacatecas.

Geologic Feature Assessed

A dispersed belt of Middle Tertiary (Oligocene to Miocene) granitic to intermediate-composition intrusive and volcanic rocks associated with post-Laramide stage of magmatism in northern Mexico.

Table J1. Summary of selected resource assessment results for tract 003pCu3009 (MX-T2), Tertiary Central Plateau, Northern Mexico.

[km, kilometers; km^2, square kilometers; t, metric tons; n.d., no data]

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)
May 2008	1	183,520	n.d.	7,800,000	3,100,000

[1]Servicio Geológico Mexicano.
[2]U.S. Geological Survey.
[3]University of Sonora.
[4]Geologic Institute, Universidad Nacional Autónoma de México.
[5]University of Arizona.

Delineation of the Permissive Tract

Geologic Criteria

Tract 003pCu3009 (MX-T2) includes mid- to late-Tertiary (Oligocene to Miocene) granitic to intermediate-composition plutons and associated volcanic rocks dispersed across northern Mexico (fig. J1). The belt overlaps in age with the initiation of basin-and-range style extension, but pre-dates the opening of the Gulf of California. Igneous rocks of similar age, chemistry, and setting occur in nearby areas of the U.S. (for example, Colorado, Bookstrom, 1990; and Nevada, Ryscamp and others, 2008) and represent magmatism formed inboard of a convergent plate boundary associated with late subduction to post-subduction tectonism along the western coast of this part of North America. The rocks in question were emplaced after Laramide deformation and overlapped in age with the initiation of basin-and-range style extension that began around 30 Ma (Ferrari and others, 2007), but were emplaced before the onset of widespread strike-slip faulting and east-west extension that led to the opening of the Gulf of California.

The relationship of these rocks to subduction on the Pacific margin is unclear (Ferrari and others, 2007), but their tectonic setting and their dispersed broad regional distribution during a narrow time interval represent the continuation of igneous activity in the broad crustal area previously heated by Laramide subduction magmatic-arc activity, reactivated by extension and crustal thinning. This unusual tectonic setting produced oxidized (magnetite series) and reduced (ilmenite series) mafic and intermediate-composition magmas with an arc-like chemical signature over a wide area far removed from the subduction trench. One hypothesis is that the dispersed arc-like magmatism was the result of a rollback of the subducted slab (Humphreys, 1995), and the tectonic setting for the porphyry copper deposits likely to occur in this tract may be analogous to the postsubduction porphyry copper-gold deposits described by Richards (2009). The ages of the rocks that define the tract are much the same as the ages of the voluminous Oligocene and Miocene ignimbrite eruptions that define the thick Upper Volcanic Supergroup of the Sierra Madre Occidental (McDowell and Keizer, 1977).

The plutonic rocks that crop out within the tract include numerous small bodies of granodiorite-diorite (some porphyritic), granite-granodiorite, and quartz monzonite (some porphyritic) of Oligocene to Miocene age (table J2). The chemistry of these rocks ranges from calc-alkalic to alkali-calcic (Ferrari and others, 2007), and they are transitional in chemistry between the calc-alkalic rocks to the west and the alkalic rocks typical of the Eastern Alkaline Province (Tract MX-T1) (McDowell and Clabaugh, 1979). As a group, these rocks are more silicic and more potassic than the Laramide rocks. The intrusive rocks in the tract may have mixed S- or I-type affinity depending on host rock composition (Zürcher, 2002). Middle Tertiary monzonitic and syenitic igneous rocks in eastern Mexico were assigned to the Eastern Alkaline Province tract (003pCu3010 (MX-T1)). S-type granites of the Formacion Granito Milonitico, and similar rocks, have been excluded from the tract as they are unlikely to host porphyry copper deposits based on their chemistry, extensional gneiss-dome tectonic setting, and likely depth of exhumation. The volcanic rocks in the tract include andesite flows and tuffs, dacite, latite, and trachyte (table J2). Bimodal rhyolite-basalt sequences and andesitic tuffs that are primarily within basaltic suites have been excluded from the tract as these volcanic systems are unlikely to host porphyry copper deposits. Thick volcanic rock sequences that constitute the ignimbrite plateau of the Sierra Madre Occidental are also excluded from the tract as their thickness is generally greater than a km. The eastern and western margins of the tract are defined by the eastern and western limits of middle Tertiary igneous rocks, as depicted on the geologic map of Mexico (Servicio Geológico Mexicano, 2007). The northern limit is the U.S. border, and the southern limit of the tract is the northern border of the Trans-Mexican Volcanic Belt that covers the Middle Tertiary rocks and defines a tectonic transition along a fracture zone to a Tertiary to recent subduction zone of the Cocos Plate to the south in Mexico (fig. 3).

Much of the tract is situated along the eastern flank of the Sierra Madre Occidental volcanic plateau where the thick Tertiary ignimbrite deposits were not as extensively developed and a higher percentage of mid- to late-Tertiary plutonic and older rocks are exposed by fault displacement and erosion.

Tract 003pCu3009 (MX-T2) was constructed using the 1:500,000-scale digital geologic of Mexico (Servicio Geológico Mexicano, written commun., 2007) in ArcGIS using a 10-km buffer around the intrusive map units described above and a 2-km buffer around the volcanic units. The tract consists of 193 polygons. The tract boundaries were further refined using the aeromagnetic map (North American Magnetic Anomaly Group, 2002) to include some areas that have magnetic sources interpreted to be caused by shallow buried intrusions. Larger-scale geologic maps and literature were consulted and used to check map unit boundaries, ages, and structures.

Known Deposits

There are no known porphyry copper deposits in the tract.

Prospects, Mineral Occurrences, and Related Deposit Types

Many copper, gold, silver, and polymetallic prospects occur within the tract and several of these are indicative of possible porphyry copper style mineralization. However, many areas of the tract are coincident with permissive areas and mineral deposits of Laramide age. There has been relatively little age dating of mineral deposits within the tract, and, because much of the area contains both Laramide and younger intrusions, many prospects could belong to either tract age group. Table J3 lists four important prospects that we can assign unequivocally to the later episode.

Cerrro del Gallo (San Anton)

At the Cerro del Gallo (San Anton) prospect, San Anton Resource Corp. has identified porphyry Cu-Au, skarn, and epithermal Ag-Au deposit targets. The relatively Cu-poor and Au-rich porphyry-system with bordering skarn and fringing epithermal vein deposits is classified as a reduced porphyry Cu-Au deposit by Rowins (2000). The mineralized area

Table J2. Map units that define tract 003pCu3009 (MX-T2), Tertiary Central Plateau, Northern Mexico.

[Map unit, age range, and principal lithologies from a 1:500,000 scale preliminary digital geologic map of Mexico (Servicio Geológico Mex cana, written commun., 2007); n.d., no data]

Map unit	Maximum age	Minimum age	Lithology 1	Lithology 2
		Intrusive rocks		
TeoGd-Mz	Eocene	Oligocene	granodiorite	n.d.
ToGd-D	Oligocene	Oligocene	granodiorite	n.d.
ToPD	Oligocene	Oligocene	porphyritic diorite	n.d.
ToGr-Gd	Oligocene	Oligocene	granite	granodiorite
ToGr	Oligocene	Oligocene	granite	n.d.
ToGd	Oligocene	Oligocene	granodiorite	n.d.
TomGr-Gd	Oligocene	Miocene	granite	granodiorite
ToPMz-PqMz	Oligocene	Oligocene	porphyritic monzonite	porphyritic quartz monzonite
ToMz-qMz	Oligocene	Oligocene	monzonite	porphyritic monzonite
ToMz-PMz	Oligocene	Oligocene	monzonite	porphyritic monzonite
ToPMz	Oligocene	Oligocene	porphyritic monzonite	n.d.
TomMz-qMz	Oligocene	Miocene	monzonite	quartz monzonite
TmGr	Miocene	Miocene	granite	n.d.
TmPqMz	Miocene	Miocene	porphyritic quartz monzonite	n.d.
TmPD	Miocene	Miocene	porphyritic diorite	n.d.
TmqMz	Miocene	Miocene	quartz monzonite	n.d.
TmTn	Miocene	Neogene	tonalite	n.d.
TmGd-PDa	Miocene	Miocene	granodiorite	n.d.
		Volcanic rocks		
ToA-TR	Oligocene	Oligocene	andesite	rhyolite tuff
ToA-B	Oligocene	Oligocene	andesite	basalt
ToRd	Oligocene	Oligocene	rhyodacite	n.d.
ToB-A	Oligocene	Oligocene	basalt	andesite
ToDa-Rd	Oligocene	Oligocene	dacite	rhyodacite
ToPRd-PTq	Oligocene	Oligocene	porphyritic rhyodacite	porphyritic trachyte
ToBvR	Oligocene	Oligocene	rhyolite breccia	n.d.
ToDa-A	Oligocene	Oligocene	dacite	andesite
ToB-TRd	Oligocene	Oligocene	basalt	rhyodacite tuff
TomPA	Oligocene	Miocene	porphyritic andesite	n.d.
TomA-TA	Oligocene	Miocene	andesite	andesite tuff
ToR-Da	Oligocene	Oligocene	rhyolite	dacite
ToTA-Da-BvA	Oligocene	Oligocene	andesite tuff	dacite
TomTDa-TRd	Oligocene	Miocene	dacite tuff	rhyodacite tuff
ToPDa-PA	Oligocene	Oligocene	porphyritic dacite	porphyritic andesite
ToplA-Da	Oligocene	Pliocene	andesite	dacite
ToTq	Oligocene	Oligocene	trachyte	n.d.
ToLa	Oligocene	Oligocene	latite	n.d.
ToTqA	Oligocene	Oligocene	trachyte	andesite
ToPLa	Oligocene	Oligocene	porphyritic latite	n.d.
ToA-Tq	Oligocene	Oligocene	andesite	trachyte
ToTq-A	Oligocene	Oligocene	trachyte	andesite
TmPRd	Miocene	Miocene	porphyritic rhyodacite	n.d.
TmplPRd	Miocene	Pliocene	porphyritic rhyodacite	n.d.
TmTq-B	Miocene	Miocene	trachyte	basalt
TmLa	Miocene	Miocene	latite	n.d.

formed where two small granodioritic and monzodioritic stocks have intruded into siliciclastic sediments (Stewart, 2008). Hydrothermal alteration is concentrically zoned around the stocks with a core of potassic alteration overprinted with propylitic alteration. The copper-gold-silver mineralized area is spatially associated with the stocks and two episodes of fracturing and veining (Stewart, 2008). The estimated age of mineralization is 30 Ma (Stewart, 2008).

Tatatila

The Tatatila project, Veracruz, consists of more than 30 gold, copper-gold, and iron skarns with associated polymetallic vein prospects in an area surrounding and including the formerly abandoned Boquillas and Cinco Senores Au-Cu mines (SGM-Minas database). Here Jurassic and Cretaceous limestone, siltstone, and shale are intruded by Tertiary granodiorite, quartz-diorite, and granite (Chesapeake Gold Corporation, 2007). Most of the skarns formed along the contact between intrusive and sedimentary rock, but endoskarns within the intrusion are also present.

Tuligtic

The Tuligtic prospect, a copper-gold porphyry system covering approximately 11,000 hectares of altered rocks, is located in the state of Puebla. Both porphyry copper and epithermal gold targets have been identified in the area (Almaden Minerals, 2008). The porphyry copper targets occur in potassically altered intrusive rocks that intruded deformed limestone, producing skarn-type mineralized areas along intrusive contacts. An IP geophysical survey indicates a much larger unexposed mineralized target, and soil sampling has returned anomalous copper, molybdenum, silver, and gold in soil samples over a large area (Almaden Minerals, 2008)

San Antonio (Santa Eulalia East Camp)

The stratigraphic section that hosts the San Antonio mine in the Santa Eulalia district consists of a series of Cretaceous carbonate and evaporite units unconformably overlain by Tertiary volcanics and volcaniclastic sediments. In the San Antonio mine, a large north-northeast-trending graben offset the Cretaceous carbonates and the lower part of the Tertiary volcanic section that strongly controlled the emplacement of a series of diabase sills and felsite dikes (Hewitt, 1943; Megaw, 1990). Mineralized areas in the San Antonio mine were spatially related to a series of en-echelon felsite dikes, 1- to10-m-wide, known collectively as the San Antonio dike. The felsites commonly contain disseminated pyrite and, less commonly, sphalerite, galena, and arsenopyrite in a banded texture. The margins of the felsite bodies are frequently highly altered and brecciated. The felsites are about 10 million years younger than the diabase sills, which have been dated at 37.5 Ma. A quartz-monzonite dike is present in the mine area. Silicate rocks locally grade into massive sulfide ores, but may show sharp outer contacts with limestone. Silicate bodies contain economic amounts of sphalerite, galena, and pyrite with minor amounts of chalcopyrite and arsenopyrite. Massive sulfide chimneys composed of sphalerite and pyrite, and mantos consisting of galena and pyrrhotite with sphalerite, both occur locally outside of the silicate zones. Several tin-chimneys and vein replacement lodes also occur on upper levels of the mine. Early production (prior to 1925) came from oxidized ores. Later mining exploited sulfide ores (Megaw and others, 1988; Walter, 1985). Production for the total district (E and W) is 40 Mt at 8.8 percent lead, 7.3 percent zinc, and 320 g/t silver. The east camp averages <0.3 percent copper, 0.1 g/t gold, <1.5 percent tin, and <5 percent vanadium.

Exploration History

The tract has been extensively explored for precious-metal deposits and polymetallic vein and replacement deposits. More recently, porphyry copper deposits have also been the subject of exploration. Economically important precious metal epithermal deposits in Mexico, such as Guanajuato, Fresnillo, and Zacatecas, occur in the general area of the tract (Camprubi and Albinson, 2007), and six epithermal deposits and prospects in the tract are under exploration for copper, including Charcas, San Antonio, La Reyna, and Naica (Zürcher, 2008, oral commun.). These epithermal precious and polymetallic epithermal deposits are all middle- to late- Tertiary in age, most are Oligocene to Miocene, and their space and time distribution follows the evolution of Tertiary magmatism in the region (Camprubi and Albinson, 2007). The current focus of exploration in the tract is for epithermal precious-metal and polymetallic-vein deposits, epigenetic skarn, and gold-bearing porphyry copper deposits.

Although no identified porphyry copper deposits are known in the tract, a number of prospects are under evaluation. The Tatatila project, Veracruz, consisting of more than 30 gold, copper-gold, and iron skarns with associated polymetallic-vein prospects, is under active exploration. Porphyry copper prospects are also found in the project area but are not the main target of exploration (Chesapeake Gold Corporation, 2007).

Exploration at the Cerro del Gallo prospect, evaluated by San Anton Resource Corp. as part of their San Anton property exploration, includes core drilling, rock, soil, and stream-sediment sampling, and ore metallurgy evaluation (Stewart, 2008). Total weighted-average tonnage and grade data based on NI43-101 compliant resource estimates (350 drill holes, 0.07 percent copper cut off grade) are reported as measured and indicated resources of 461 Mt at 0.11 percent copper, 0.27 g/t gold, 11 g/t silver; inferred resources of 166 Mt at 0.10 percent copper, 0.11 g/t gold, and 7 g/t silver (Stewart, 2008). Resources in the prospect are open to the southeast, northwest, and at depth.

In 2006, Almaden Minerals identified porphyry copper and epithermal gold targets at the Tuligtic prospect, a copper-gold porphyry system in the state of Puebla, Mexico (Almaden Minerals, 2008). The property was under further evaluation by Pinnacle Mines, Ltd. (Free Market News, 2006), but the option agreement was terminated in 2007 (Marketwire, 2007).

Table J3. Significant prospects and occurrences in tract 003pCu3009 (MX-T2), Tertiary Central Plateau, Northern Mexico.

[t, metric tons; Mt, megatonne or one million tons; n.d., no data]

Name	Latitude	Longitude	Age (Ma)	Comments (grade and tonnage data, if available)	Reference
Cerro del Gallo (San Antón)	21.074	-101.027	30	Evaluated by San Anton Resource Corp. as part of their San Anton property exploration (drilling, rock, soil, and stream-sediment sampling, metallurgy). Total weighted average tonnage and grade data based on NI43-101 compliant) resource estimate (350 drill holes. 0.07%Cu cut off grade): Measured and indicated resources of 461 Mt at 0.11% Cu, 0.27 g/t Au, 11 g/t Ag; Inferred resources of 166 Mt at 0.10% Cu, 0.11 g/t Au, and 7 g/t Ag (Stewart, 2008). Open to SE, NW, and at depth.	Stewart (2008) Rowins (2000)
Tatatila	19.691	-97.147	n.d.	Exploration of the 200 km^2 Tatatila project by Chesapeake Gold Corp. (2007) identified 25 skarn alteration zones; Cretaceous limestones and sedimentary rocks associated with multiphase Tertiary intrusives (granodiorites, quartz-diorites and granites).	Chesapeake Gold Corp. (2007), Martínez-Vergara and others (2002), Salas (1975)
Tuligtic	19.701	-97.850	18	Grab samples: up to 0.8% Cu, 6 g/t Au and 600 g/t Ag. Exposed. Breccia, quartz monzonite porphyry, skarn.	Almaden News Release (2001)
San Antonio (Santa Eulalia East Camp)	28.606	-105.806	26.6	Age for Santa Eulalia district. Polymetallic skarn (Pb-Zn-Ag-Cu-Au), chimney, and manto deposits. Quartz monzonite underlies mineralized areas.	Megaw and others (1988), Walter (1985), Barton and others (1995)

Sources of Information

Principal sources of information used by the assessment team are listed in table J4.

Table J4. Principal sources of information used by the assessment team for tract 003pCu3009 (MX-T2), Tertiary Central Plateau, Northern Mexico.

[NA, not available or not applicable]

Theme	Name or title	Scale	Citation
Geology	Preliminary digital geologic map of the Republic of Mexico	1:500,000	Servicio Geológico Mexicano (written commun., 2007)
	Carta geológica de la República Mexicana	1:2,000,000	Servicio Geológico Mexicano (2007a)
	Carta geólogico-minera, Estado de Baja California Sur	1:500,000	Teràn-Ortega and Maraver-Romero (2007)
	Carta geólogico-minera, Estado de Sonora	1:500,000	Arriaga-Meléndez and others (2004)
	Carta geólogico-minera, Estado de Chihuahua	1:500,000	Salinas-Prieto and others (2004)
	Carta geólogico-minera, Estado de Durango	1:500,000	López-Escalona and others (2006)
	Carta geólogico-minera, Estado de Aguascalientes y Zacatecas	1:500,000	López-Escalona and others (2007)
	Carta geólogico-minera, Estados de Guanajuato y Querétaro	1:500,000	López-Reyes and de la Calleja-Moctezuma (2007a)
	Carta geólogico-minera, Estado de Hidalgo	1:500,000	López-Reyes and de la Calleja-Moctezuma (2007b)
	Carta geólogico-minera, Estados de Puebla y Tlaxcala	1:500,000	Montiel-Escobar and others (2007a)
	Carta geólogico-minera, Distrito Federal, Estados de México y Morelos	1:500,000	Montiel-Escobar and others (2007b)
	Carta geólogico-minera, Estado de Nayarit	1:500	Teràn-Ortega and others (2007)
	Carta geólogico-minera, Estado de Sinaloa	1:500	Castro-Escárrega and others (2007)
Mineral occurrences	SGM Minas database	NA	Servicio Geológico Mexicano (written commun., 2007b)
	MRDS database	NA	U.S. Geological Survey (2005)
	University of Arizona-Industry-USGS Mexico Consortium	NA	University of Arizona-Industry-USGS Mexico Consortium, March 1999 Release Notes (unpublished)
	Porphyry copper deposits of the world: database, map, and grade and tonnage models	NA	Singer and others (2008)
	Carta y provincias metalogeneticas de la Republica Mexican	1:2,000,000	Salas (1975)
	Geological and metallogenetic characteristics of the porphyry copper deposits of México and their situation in the world context	NA	Valencia-Moreno and others (2007)
Geochemistry	SGM stream-sediment database	NA	Servicio Geológico Mexicano (written commun., 2007)

Table J4. Principal sources of information used by the assessment team for tract 003pCu3009 (MX-T2), Tertiary Central Plateau, Northern Mexico.—Continued
[NA, not available or not applicable]

Theme	Name or title	Scale	Citation
Geology, mineral occurrences and exploration	Geological-mining monograph of the state of Zacatecas	1:500,000	Consejo de Recursos Minerales (1992)
	Geological-mining monograph of the state of Durango	1:500,000	Consejo de Recursos Minerales (1993)
	Geological-mining monograph of the state of Puebla	1:500,000	Consejo de Recursos Minerales (1995)
	Geological-mining monograph of the state of Guanajuato	1:500,000	Consejo de Recursos Minerales (1992b)
	Geological-mining monograph of the state of San Luis Potosí	1:500,000	Consejo de Recursos Minerales (1992c)
	Geological-mining monograph of the state of Nayarit	1:500,000	Consejo de Recursos Minerales (1994a)
	Geological-mining monograph of the state of Sinaloa	1:500,000	Consejo de Recursos Minerales (1991)
	Geological-mining monograph of the state of Sonora	1:500,000	Consejo de Recursos Minerales (1992d)
	Geological-mining monograph of the state of Chihuahua	1:500,000	Consejo de Recursos Minerales (1994b)
	Geological-mining monograph of the state of Baja California Sur	1:500,000	Bustamante-García (1999)
Geophysics	North American magnetic map	1:10,000,000	North American Magnetic Anomaly Group (2002)
Exploration	Proyectos de Compañias Extranjeras por Estado	NA	Dirección General de Promoción Minera, 2005
	Company Web sites	NA	Almaden Minerals Ltd. (2001, 2008), Chesapeake Gold Corp. (2008), Exmin Resources Inc. (2008)

Grade and Tonnage Model Selection

The grade and tonnage model used in this assessment was the porphyry Cu-Au subtype described by Singer and others (2008), and the Cu-Au porphyry subgroup is the target of most current exploration for porphyry copper deposits in the tract. The Cerro de Gallo and Tuligtic prospect sites are incompletely explored and delineated, but have geologic characteristics and reported ore grades consistent with the porphyry Cu-Au subtype. The reported average gold grades of 0.27 g/t for Cerro de Gallo and 6 g/t for Tuligtic fit the gold grade criteria (>0.2 g/t or Au/Mo>30) used by Singer and others (2008) to classify deposits as Cu-Au subtype. The geologic features and tectonic setting of the tract are also consistent with the postsubduction tectonic model for porphyry Cu-Au deposits described by Richards (2009). Although there are identified resources reported for Cerro del Gallo, the property is open in several directions and the team was unaware of its existence when the tract was evaluated in May of 2008. Therefore, it is included as a prospect and included in the estimate of undiscovered resources. Although the tonnage and gold grades reported for Cerro del Gallo fit the Cu-Au subtype, the average reported copper grade is low and fails an ANOVA test when compared with the Cu-Au grade model.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Although no fully delineated porphyry copper deposits with characteristics like those in the grade-tonnage models are known in the tract, the numerous middle Tertiary epithermal precious-metal and polymetallic-vein deposits in the tract are associated in space and time with middle Tertiary magmatism (McKee and others, 1992; Enriquez and Riveria, 2001; Camprubi and Albinson, 2007). These vein systems typically are distal to, and shallower than, the source porphyry intrusions. Therefore, the assessment team believes there is potential for buried porphyry copper deposits in the region. Worldwide, there is often a close association in space and time between epithermal, polymetallic, and skarn deposits and porphyry copper deposits (Drew and Menzie, 2006).

A number of factors may account for the apparent paucity of porphyry copper deposits in the tract. The area is covered primarily by continental volcanic rocks, including a large volume of ignimbrites, and by continental sedimentary rocks. The ratio of exposed volcanic to plutonic rock of mid-Tertiary age in the tract is more than 60:1, much higher than the ratios of 1:1 that are more typical of areas that are highly prospective for porphyry copper deposits. The preservation of porphyry copper deposits depends on depth of burial, rate of erosion, and time available for erosion (Damon and others, 1983). There has been less time for erosion and fault disruption in these mid-Tertiary volcanic rocks than in the Laramide arc. Thus, a number of possible porphyry deposits could be buried to a depth greater than 1 km. These extensive sedimentary and volcanic deposits reduce the probability that porphyry copper deposits are exposed, or are within 1 km of the surface.

Like the situation in the western U.S. to the north, the mid-Tertiary igneous rocks in the tract include a high proportion of rhyolite and dacite, and lesser andesite. The rocks may represent a chemical transition between the primarily calc-alkalic Laramide rocks and the rocks of the Eastern Alkaline Province (Ferrari and others, 2007; McDowell and Clabough, 1979). Damon and others (1983) have also suggested that the primary copper content of the mid-Tertiary magmas was lower than those in the Laramide arc, thus decreasing the probability that copper can be enriched by hydrothermal and supergene processes to economic grades in the younger porphyry systems. Also, many of the volcanic centers are calderas that produced large ignimbrite sheets (Ferrari and others, 2007), and this eruption style may decrease the likelihood that porphyry-style mineralized rock is preserved in the roots of the volcanic systems (Damon and others, 1983).

The assessment team concluded that the tract is not representative of a typical subduction-related magmatic-arc system, but is consistent with a postsubduction porphyry Cu-Au deposit setting as described by Richards (2009). For all of the above reasons, the assessment team concluded that the deposit densities to be expected here should be low with respect to the worldwide porphyry copper-deposit densities (fig. 11) tabulated by Singer and others (2008).

Nevertheless, the team did believe that at least two of the three identified prospect areas have a significant probability to contain a deposit. This judgment helped anchor our estimate of a 50-percent chance or more for two deposits (table J5). Although much of the tract has been extensively explored for epithermal polymetallic and precious-metal deposits, large areas of barren volcanics in the tract have not been explored and may conceal buried porphyry Cu-Au deposits.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered porphyry copper deposits with the grade and tonnage model of Singer and others (2008) by using the EMINERS program (Root and others, 1992; Bawiec and Spanski, in press). Selected simulation results are reported in table J6. Results of the Monte Carlo simulation are presented as cumulative frequency plots (fig. J2). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

Table J5. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 003pCu3009 (MX-T2), Tertiary Central Plateau, Northern Mexico.

[NXX, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; s, standard deviation; Cv%, 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; area, area of permissive tract in square kilometers; density, deposit density reported as the total number of deposits per km^2. N_{und}, s, and Cv% are calculated using a regression equation (Singer and Menzie, 2005).]

Consensus undiscovered deposit estimates			Summary statistics					Tract area (km^2)	Deposit density (N_{total}/km^2)
N90	N50	N10	N_{und}	s	Cv%	N_{known}	N_{total}		
1	2	5	2.5	1.6	63	0	2.5	183,520	0.000014

Table J6. Results of Monte Carlo simulations of undiscovered resources in tract 003pCu3009 (MX-T2), Tertiary Central Plateau, Northern Mexico.

[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	0	170,000	3,100,000	20,000,000	33,000,000	7,800,000	0.26	0.07
Mo	0	0	3,600	110,000	240,000	46,000	0.20	0.42
Au	0	19	260	1,400	2,300	560	0.29	0.07
Ag	0	0	490	5,200	12,000	2,700	0.18	0.31
Rock	0	42	680	4,000	7,000	1,600	0.26	0.07

References Cited

Almaden News Release, 2001, March 6, 1998 to October 2, 2001: Almaden Minerals Ltd. Web page, accessed May 15, 2009, at http://www.almadenresources.com/releases/News.

Almaden Minerals, 2008, August 6, Tuligtic Project: Almaden Minerals Ltd. Web page, accessed May 15, 2009, at http://www.almadenminerals.com/Projects/tuligtic.html.

Arriaga-Meléndez, Hilario, López-Escalona, J.J., López-Reyes, J.E., Terán-Ortega, L.A., Castro-Escarrega, J.J., Espinoza-Beltrán, C.C., and Vázquez-Mendoza, Rigoberto, compilers, 2004, Carta geólogico-minera, Estado de Sonora: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/sonora.pdf.)

Barton, M.D., Staude, J.-M.G., Zürcher, L., and Megaw, P.K.M., 1995, Porphyry copper and other intrusion-related mineralization in Mexico, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Tucson, Arizona Geological Society Digest, v.20, p.487-524.

Bawiec, W.J., and Spanski, G.T., in press, EMINERS—Economic Mineral Resource Simulator, version 3.0: U.S. Geological Survey Open-File Report 2009-1057, program files and 29-p. Quick-Start Guide.

Berger, B.R., Ayuso, R.A., Wynn, J.C., and Seal, R.R., 2008, Preliminary model of porphyry copper deposits: U.S. Geological Survey Open-File Report 2008-1321, 55 p., accessed May 15, 2009, at http://pubs.usgs.gov/of/2008/1321.

Bookstrom, A. A., 1990, Igneous rocks and carbonate-hosted ore deposits of the central Colorado Mineral Belt, *in* Beaty, D. W., Landis, G. P., and Thompson, T. B., eds., Carbonate-hosted sulfide deposits of the central Colorado Mineral Belt: Economic Geology, Monograph 7, p. 45-65.

Bustamente-García, J., 1999, Monografía Geológico-Minera de Baja California Sur: Consejo de Recursos Minerales, Pachuca, Hgo., México, 237 p.

Camprubi, A. and Albinson, T., 2007, Epithermal deposits in Mexico – Update of current knowledge, and an empirical reclassification, *in* Alaniz-Alvarez, S.A., and Nieto-Samaniego, A.F., eds., Geology of Mexico—Celebrating the centenary of the Geological Society of Mexico: Geological Society of America Special Paper 422, p. 377-415.

Castro-Escárrega, J.J., López-Escalona, Juan, Díaz-Salgado, Ciro, and Espinoza-Beltrán, Carlos, compilers, 2007, Carta Geólogico-Minera, Estado de Sinaloa: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/sinaloa.pdf.)

Chesapeake Gold Corporation, 2007, Chesapeake consolidates a new significant mining district in Veracruz, Mexico: Chesapeake Gold Corporation Web page accessed May 15, 2009, at http://www.chesapeakegold.com/downloads/ChesapeakeGold_2007_10_10_40.pdf.

Consejo de Recursos Minerales, 1991, Monografia geologico-minera del estado de Sinaloa: Consejo de Recursos Minerales Publication M-1e, Pachuca, Hgo., Mexico, 159 p.

Consejo de Recursos Minerales, 1992a, Geological-mining monograph of the State of Zacatecas: Consejo de Recursos Minerales Publication M-2e, Pachuca, Hgo., Mexico, 154 p.

Consejo de Recursos Minerales, 1992b, Geological-mining monograph of the State of Guanajuato: Consejo de Recursos Minerales Publication M-6e, Pachuca, Hgo., Mexico, 136 p.

Consejo de Recursos Minerales, 1992c, Geological-mining monograph of the State of San Luis Potosí: Consejo de Recursos Minerales Publication M-7e, Pachuca, Hgo., Mexico, 281 p.

Consejo de Recursos Minerales, 1992d, Monografía geologico-minero del Estado de Sonora: Consejo de Recursos Minerales, Pachuca, Hgo., Mexico, Publicación M8-e, 220 p.

Consejo de Recursos Minerales, 1993, Monografia geologico-minera del estado de Durango: Consejo de Recursos Minerales Publication M-10e, Pachuca, Hgo., Mexico, 204 p.

Consejo de Recursos Minerales, 1994a, Monografia geologico-minera del estado de Nayarit: Consejo de Recursos Minerales Publication M-12e, Pachuca, Hgo., Mexico, 171 p.

Consejo de Recursos Minerales, 1994b, Monografia geologico-minera del estado de Chihuahua: Consejo de Recursos Minerales Publication M-14e, Pachuca, Hgo., Mexico, 297 p.

Consejo de Recursos Minerales, 1995 Monografia geologico-minera del estado de Puebla: Consejo de Recursos Minerales Publication M-16e, Pachuca, Hgo., Mexico, 139 p.

Cox, D.P., 1986, Descriptive model of porphyry Cu-Au (Model 20c), *in* Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 110. (Also available online at http://pubs.usgs.gov/bul/b1693/.)

Damon, P.E., Shafiqullah, M., and Clark, K.F., 1983, Geochronology of the porphyry copper deposits and related mineralization of Mexico: Canadian Journal of Earth Sciences, v. 20, p.1052-1071.

Dirección General de Promoción Minera, 2005, Proyectos de Compañias Extranjeras por Estado: Dirección General de Promoción Minera, Ministry of the Economy [Mexico] Web site, accessed January 15, 2008, at http://www.economia.gob.mx/?P=1537.

Drew, L.J., and Menzie, W.D., 2006, Is there a metric for mineral deposit occurrence probabilities?: Natural Resources Research, 2, p. 92-105.

Enriquez, E., and Rivera, R., 2001, Timing of magmatic and hydrothermal activity in the San Dimas district, Durango, Mexico: Society of Economic Geologists Special Publication Series, v. 8, p. 32-38.

Exmin Resources Inc., 2008, Exmin Resources Web site accessed December 17, 2008, at http://www.exmin.com/.

Ferrari, L., Valencia-Moreno, M., and Bryan, S., 2007, Magmatism and tectonics of the Sierra Madre Occidental and its relation with the evolution of the western margin of North America, *in* Alaniz-Alvarez, S.A., and Nieto-Samaniego, A.F., eds., Geology of Mexico—Celebrating the centenary of the Geological Society of Mexico: Geological Society of America Special Paper 422, p. 1- 40.

Free Market News, July 25, 2006, To purchase interest in Tugligtic copper-gold project in Mexico: Free Market News Web page accessed May 15, 2009, at http://www.freemarketnews.com/Press-Release.asp?nid=7469.

Gans, P.B., 1997, Large-magnitude Oligo-Miocene extension in southern Sonora—Implications for the tectonic evolution of northwest Mexico: Tectonics, v. 16, no. 3, p. 388-408.

García-Cortez, J.A., Morales-Morales, Heliodoro, and Mancillas-Gutiérrez, Ángel, 2003, Carta geológico-minera, Agua Prieta H12-3, Sonora and Chihuahua [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Goodell, P.C., 1995, Porphyry deposits along the Batopilas lineament, Chihuahua, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Tucson, Arizona Geological Society Digest 20, p. 544.

Henry, C.D., Price, J.G., and James, E.W., 1991, Mid-Cenozoic stress evolution and magmatism in the southern cordillera, Texas and Mexico—Transition from continental arc to intraplate extension: Journal of Geophysical Research, v. 96, p. 13545-13560.

Hewitt, W.P., 1943, Geology and mineralization of the San Antonio Mine, Santa Eulalia District, Chihuahua, México: Geological Society of America Bulletin, v. 53, no. 2, p. 173-204.

Humphreys, E., 1995, Post-Laramide removal of the Farallon slab, western United States: Geology, v. 23, p. 987-990.

Long, K.R., 1995, Production and reserves of Cordilleran (Alaska to Chile) porphyry copper deposits, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Tucson, Arizona Geological Society Digest 20, p. 35-68.

López-Escalona, Juan, Espinoza-Beltrán, Carlos, Díaz-Salgado, C.C., and Castro-Escárrega, J.J., compilers, 2006, Carta geólogico-minera, Estado de Durango: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/durango.pdf.)

López-Escalona, Juan, Montiel-Escobar, J.E., Dorantes-Salgado, Enrique, Jiménez-Gonzaga, J.A. and Diaz-Salgado, C.C., compilers, 2007, Carta géologico-minera, Estado de Aguascalientes y Zacatecas: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/zacatecas.pdf.)

López-Reyes, J.E., and de la Calleja-Moctezuma, Alfredo, compilers, 2007a, Carta geólogico-minera, Estados de Guanajuato y Querétaro: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/gto_queretaro.pdf.)

López-Reyes, J.E., and de la Calleja-Moctezuma, Alfredo, compilers, 2007b, Carta geólogico-minera, Estado de Hidalgo: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/hidalgo.pdf).

Maldano-Lee, J.M., García-Palacios, Raúl, Larrañaga-Obregón, Gerardo, Sánchez-Bermeo, Gilberto, Aguilar-Carrizales, Alfredo, and Pierre-Prian, Jean, 2000, Carta geológico-minera, San Juanito G13-1, Chihuahua [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Maldonado-Lee, J.M., Reyes-Reyes, N.A., de la Calleja-Moctezuma, Alfredo, Barajas-Nigoche, L.D., and Montiel-Escobar, J.J., compilers, 2007, Carta geólogico-minera, Estado de San Luis Potosí: Servicio Geológico Mexi cano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/slp.pdf.)

Marketwire, 2007, Article—Almaden terminates Tuligtic option: Marketwire, September 26, 2007 Web page accessed May 15, 2009, at http://www.highbeam.com/doc/1P2-13770483.html.

Martínez-Vergara, Alvaro, Zárate-López, Javier, De La Calleja, Alfredo, and Jiménez-Hernández, Acel, 2002, Carta geológico-minera, Veracruz E14-3, Veracruz, Puebla, and Tlaxcala [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

McDowell, F.W., and Clabaugh, S.E., 1979, Ignimbrites of the Sierra Madre Occidental and their relation to the tectonic history of western Mexico: Geological Society of America Special Paper 180, p. 113-124.

McDowell, F.W., and Keizer, R.P., 1977, Timing of mid-Tertiary volcanism in the Sierra Madre Occidental between Durango City and Mazatlán, Mexico: Geological Society of America Bulletin v. 88, p. 1479-1787.

McDowell, F.W., Roldán-Quintana, J., Amaya-Martínez, R., 1997, Interrelationship of sedimentary and volcanic deposits associated with Tertiary extension in Sonora, Mexico: Geological Society of America Bulletin, v. 109, p. 1349-1360.

McKee, E.H., Dreier, J.E., and Noble, D.C., 1992, Early Miocene hydrothermal activity at Pachuca-Real del Monte, Mexico: an example of space-time association of volcanism and epithermal Ag-Au mineralization: Economic Geology, v. 87, p. 1635-1637.

Megaw, P.K.M., 1990, Geology and geochemistry of the Santa Eulalia Mining District, Chihuahua, Mexico: Tucson, University of Arizona, Ph.D. dissertation, 461 p.

Megaw, P.K.M., Ruiz, Joaquin, and Titley, S.R., 1988, High-temperature, carbonate-hosted Ag-Pb-Zn(Cu) deposits of Northern Mexico: Economic Geology, vol. 83, p. 1856-1885.

Montiel, J.E., Amezcua-Torres, C.N., Reyes-Reyes, N.A., Maldonado-Lee, J.M., Aranda-Osorio, J.N., and Santiago-Carrasco, Brigido, compilers, 2005, Carta geólogico-minera, Estado de Coahuila: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/coahuila.pdf.)

Montiel-Escobar, J.E., Aranda-Osorio, J.N. and Bastida-Jiménez, Raymundo, compilers, 2007, Carta geólogico-minera, Estado de Michoacán: Servicio geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/michoacan.pdf.)

Montiel-Escobar, José, López-Reyes, Julian, de la Calleja-Moctezuma, Alfredo, Ney-Aranda, José, and Bastida-Jimenez, Raymundo, compilers, 2007a, Carta geólogico-minera, Estados de Puebla y Tlaxcala: Servicio Geológico
Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/puebla_tlxa.pdf.)

Montiel-Escobar, J.E., Bastida-Jiménez, Raymundo, and Aranda-Osorio, J.N., compilers, 2007b, Carta geólogico-minera, Distrito Federal, Estados de México y Morelos: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/df_mex_morelos.pdf.)

Múngia-Rojas, Pedro, García-Padilla, J.L., Armenta-Román, Roberto, and Manuel-Camacho, Juan, 2000, Carta geológico-minera, Santiago Papasquiaro G13-8, Durango [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

North American Magnetic Anomaly Group, 2002, Magnetic anomaly map of North America: U.S. Geological Survey Special Map, scale 1:10,000,000, accessed January 15, 2008, at http://pubs.usgs.gov/sm.mag_map/.

Randall, J.A., 1974, The Corral de Piedra Molybdenite Stockwork, Durango, Mexico, *in* Elliot, I.L., and Fletcher, W.K., eds., Geochemical Exploration 1974, Association of Exploration Geochemists, Special Publication No 2.

Richards, J.P., 2009, Postsubduction porphyry Cu-Au and epithermal Au deposits—Products of remelting of subduction-modified lithosphere: Geology, v. 37, no. 3, p. 247-250.

Root, D.H., Menzie, W.D., and Scott, W.A., 1992, Computer Monte Carlo simulation in quantitative resource estimation: Natural Resources Research, v. 1, no. 2, p. 125-138.

Rowins, S.M., 2000, A model for the genesis of "reduced" porphyry copper-gold deposits: The Gangue, v. 67, p. 1-7.

Ryscamp, E.B., Abbott, J.T., Christiansen, E.H., Keith, J.K., Vervoort, J.D., and Tingey, D.G., 2008, Age and petrogenesis of volcanic and intrusive rocks in the Sulphur Spring Range, central Nevada—Comparisons with ore-associated Eocene magma systems in the Great Basin: Geosphere, June 2008, v. 4, no. 3, p. 496-519.

Salas, G.P., 1975, Carta y provincias metalogeneticas de la Republica Mexicana: Consejo de Recursos Minerales, publicación 21E, 242 p.

Salinas-Prieto, J.C., Arriaga-Meléndez, Hiliaro, López-Reyes, J.E., Montiel-Escobar, J.E., Terán-Ortego, L.A., Lebrado-Flores, José, and Amezcua-Torres, Natalia, compilers, 2004, Carta Geólogico-Minera, Estado de Chihuahua: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/chihuahua.pdf.)

Servicio Geológico Mexicano, 2007, Carta geológica de la República Mexicana: Servicio Geológico Mexicano, scale 1:2,000,000, 1 sheet. (Also available online at http://www.coremisgm.gob.mx/.)

Singer, D.A., Berger, V.I., Menzie, W.D., and Berger, B.R., 2005, Porphyry copper density: Economic Geology, v. 100, no. 3, p. 491-514.

Singer, D.A., Berger, V.I., and Moring, B.C., 2008, Porphyry copper deposits of the world—Database, map, and grade and tonnage models, 2008: U.S. Geological Survey Open-File Report 2008-1155, 45 p., accessed January 15, 2009, at http://pubs.usgs.gov/of/2008/1155/.

Singer, D.A., and Menzie, W.D., 2005, Statistical guides to estimating the number of undiscovered mineral deposits—An example with porphyry copper deposits, *in* Cheng, Qiuming and Bonham-Carter, Graeme, eds., Proceedings of IAMG, The annual conference of the International Association for Mathematical Geology: Geomatics Research Laboratory, York University, Toronto, Canada, p. 1028-1033.

Stewart, Robert, 2008, Technical report on the Cerro del Gallo deposit within the San Antón property Mexico: Prepared by San Anton Resource Corporation Inc., Toronto, Canada, 130 p., accessed Feb. 6, 2009 at http://www.sanantonresourcecorp.com/vm/newvisual/attachments/719/Media/SanAntonNI43101ReportJuly2008.pdf.

Teràn-Ortega, L.A., and Maraver-Romero, David, compilers, 2007, Carta geólogico-minera, Estado de Baja California Sur: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/california_sur.pdf).

Terán-Ortega, L.A., Maraver-Romero, D.A., Montiel-Escobar, J.E., Jiménez-Gonzaga, J.A., and Dorantes-Salgado, Enrique, compilers, 2008, Carta Geólogico-Minera, Estados de Colima y Jalisco: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/colima_jalisco.pdf.)

Terán-Ortega, L.A., Maraver-Romero, D.A., Montiel-Escober, J.E., Jiménez-Gonzaga, Alejandro, and Dorantes-Salgado, Enrique, compilers, 2007, Carta Geólogico-Minera, Estado de Nayarit: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/nayarit.pdf.)

U.S. Geological Survey, 2005, Mineral Resources Data System: U.S. Geological Survey, Reston, Virginia, accessed December 15, 2007, at http://tin.er.usgs.gov/mrds/.

Valencia-Moreno, Martín, Iriondo, Alexander, and González-León, Carlos, 2006, Temporal constraints on the eastward migration of the Late Cretaceous–early Tertiary magmatic arc of NW Mexico based on new $^{40}Ar/^{39}Ar$ hornblende geochronology of granitic rocks: Journal of South American Earth Sciences, v. 22, p. 22-38.

Walter, T.G., 1985, Metals distribution at the San Antonio mine, Santa Eulalia mining district, Chihuahua, Mexico: Tucson, AZ, University of Arizona, master's thesis, 102 p.

Wilkerson, G., Quingping, D., Llavona, R., and Goodell, P., 1988, Batopilas mining district, Mexico: Economic Geology, v. 83, p. 1721-1736.

Zürcher, L., 2002, Regional setting and magmatic evolution of Laramide porphyry copper systems in western Mexico: Tucson, The University of Arizona, Ph. D. thesis, 427 p.

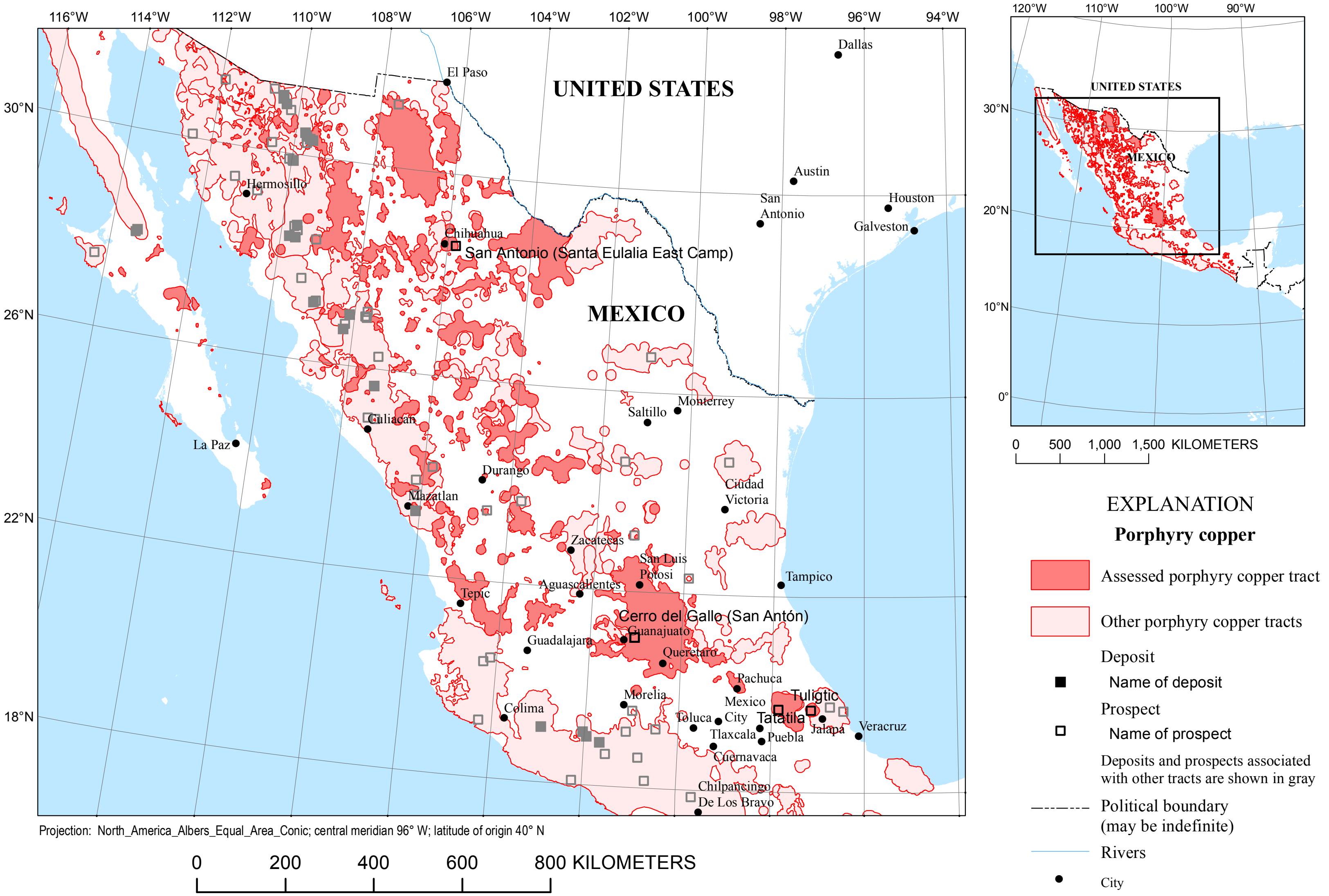


Figure J1. Map showing the tract location and significant prospects and occurrences in tract 003pCu3009 (MX-T2), Tertiary Central Plateau, Northern Mexico, and in adjacent areas.

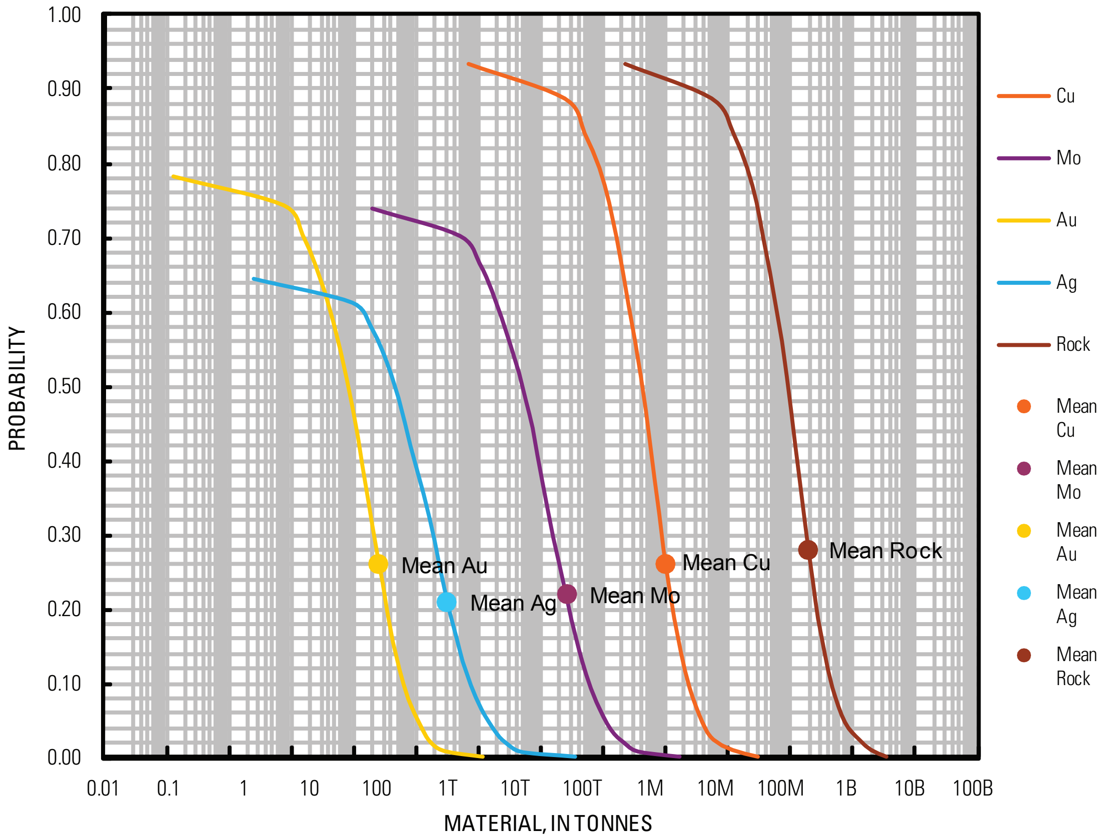


Figure J2. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in tract 003pCu3009 (MX-T2), Tertiary Central Plateau, Northern Mexico. T, thousands; M, millions; B, billions; Tr, trillions.

Appendix K. Porphyry Copper Assessment for Tract 003pCu3011 (MX-T3), Southwest Mexico

By Gilpin R. Robinson, Jr.[1], Francisco Cendejas-Cruz[2], Enrique Espinosa[2], Floyd Gray[1], Jane M. Hammarstrom[1], Steve Ludington[1], Efrén Pérez-Segura[3], Martín Valencia-Moreno[4], José Luis Rodríguez-Castañeda[4], Rigoberto Vásquez-Mendoza[2], and Lukas Zürcher[5]

Deposit Type Assessed: Porphyry copper

Descriptive model: Porphyry copper (Cox, 1986; Berger and others, 2008)
Grade and tonnage model: General porphyry copper (Singer and others, 2008)
(Table K1 summarizes selected assessment results)

Location

The tract is in west-central Mexico, generally coincident with the Sierra Madre del Sur, and is in the shape of a belt elongated parallel to the Pacific coast. It generally extends from the coast landward about 200 km, from the southernmost part of the Gulf of California to the Isthmus of Tehuantepec, and includes parts of the states of Nayarit, Jalisco, Colima, Michoacán, Guerrero, and Oaxaca (fig. K1).

Geologic Feature Assessed

Paleocene to Miocene continental magmatic-arc rocks along the Pacific coast of Mexico, from the state of Nayarit southeast to Oaxaca.

Table K1. Summary of selected resource assessment results for Tract 003pCu3011 (MX-T3), Southwest Mexico.
[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)
May 2008	1	156,650	1,015,000	37,000,000	26,000,000

[1]Servicio Geológico Mexicano.
[2]U.S. Geological Survey.
[3]University of Sonora.
[4]Geologic Institute, Universidad Nacional Autónoma de México.
[5]University of Arizona.

Delineation of the Permissive Tract

Geologic Criteria

Tract 003pCu3011 (MX-T3) outlines Paleocene to late Miocene granitic to intermediate-composition intrusive and associated volcanic rocks in southwestern Mexico. The tract is a continental-arc system that began activity in the Paleocene, coincident with Laramide intrusion and deformation with similar orientation in areas in northern Mexico (Morán-Zenteno and others, 2007a), with intrusion and volcanism continuing into the Oligocene and Miocene. In contrast to the Laramide arc to the north, magmatism in tract MX-T3 is largely restricted to a 200-km-wide belt near the inferred paleo-trench (Morán-Zenteno and others, 2007a), and the area has not been significantly affected by subsequent extension. The Paleocene to Miocene age range overlaps the Laramide and Tertiary metallogenic events that are used in this study to define tracts elsewhere in Mexico. The age of igneous activity appears to young to the southeast along the arc trend.

The plutonic rocks spatially related to porphyry mineralization are mostly porphyritic quartz-monzonites and granodiorites that intrude Proterozoic, Paleozoic, and Mesozoic rocks that constitute the Guerrero, Mixteca, Oaxaca, and Juarez tectonostratigraphic terranes (fig. 2; Campa and Coney, 1983; Coney and Campa, 1987; Morán-Zenteno and others, 2007a)

The plutonic rocks that crop out within the tract include granite, quartz monzonite, monzonite, granodiorite, tonalite, and diorite of Paleocene to Miocene age and the volcanic rocks in the tract include andesite, dacite, and rhyolite of Paleocene to Pliocene age (table K2). In the southeastern part of the tract, along the Pacific coast, evidence of compression, uplift, and exhumation (Morán-Zenteno and others, 2007; Ducea and others, 2004; de Cserna, 1989) is present in the Xolapa terrane (fig. 2). Plutonic rocks of Paleocene to Eocene age in the Xolapa terrane are highly tectonized and locally migmatitic and have been excluded from the tract as they are exposed at a level too deep to host porphyry copper deposits. In addition, two small isolated bodies of Miocene gabbro in the state of Nayarit and one body of Eocene to Oligocene gabbro in the state of Guerrero were excluded from the tract because they are unlikely to be related to porphyry copper deposits. Global studies of porphyry copper deposits show that isolated bodies of gabbroic rocks are not associated with these types of mineral deposits.

The northeastern boundary of the tract is defined by the extent of the plutonic and volcanic rocks described above. The southwestern boundary is the Pacific Coast, except for the excluded Xolapa terrane. The northwestern boundary is the Gulf of California, and the tract terminates on the southeast at the Isthmus of Tehuantepec. The isthmus is at the intersection of the Tehuantepec Ridge and the Middle America Trench, and it forms a magmatic gap between Miocene and older rocks north of the isthmus and younger rocks to the south (Barrier and others, 1998; Manea and others, 2005).

The tract was delineated using a 10-km buffer around the intrusive map units described above and a 2-km buffer around the volcanic units. It was then further refined using the aeromagnetic map (North American Magnetic Anomaly Group, 2002) to include some areas that appear to have shallow magnetic sources. Larger-scale (1:250,000) geologic maps and literature were consulted and used to check map unit boundaries, ages, and structures.

Known Deposits

Three porphyry copper deposits with defined resources exist in the tract: La Verde, San Isidro, and Tepal (table K3). La Verde, the largest deposit at 110 Mt at 0.7 percent copper, has not been brought into production, but has recently been acquired by a major copper-producing company. Both La Verde and San Isidro are Oligocene in age and contain important amounts of ore in breccias (Miranda-Gasca, 2000). Tepal is Paleocene or Eocene in age and appears to be a more typical stockwork deposit related to high-level tonalite intrusions (Priesmeyer, 2006). Tepal occurs along a line of small tonalite stocks exhibiting multiple brecciation phases (Northern Miner, 2008). A recent resource estimate for the Tepal project by Arian Silver reports 78 Mt of oxide ore grading 0.47 g/t gold and 0.25 percent copper (Priesmeier, 2006), based on 54 drill-hole intercepts from two distinct mineralized zones (Northern Miner, 2008).

Prospects, Mineral Occurrences, and Related Deposit Types

The tract is primarily in the Guerrero terrane (Campa and Coney, 1983) that hosts a wide variety of base and precious metal deposits, including Cretaceous volcanogenic massive sulfide (VMS) deposits and Tertiary epigenetic skarn, porphyry copper, and polymetallic vein deposits (Miranda-Gasca, 2000). Some of the Tertiary vein deposits were exploited by indigenous people and later by the Spanish. The Tertiary Fe-skarn deposits have been the source of much of the iron produced in Mexico (Miranda-Gasca, 2000).

The known porphyry deposits and prospects in the tract range in age from Paleocene to Oligocene (Damon and others, 1983; Miranda-Gasca, 2000). Propylitic and sericitic alteration is present in the known porphyry deposits and prospects (Miranda-Gasca, 2000). Most of the porphyry copper prospects in the tract have not been significantly explored or developed (Miranda-Gasca, 2000), although a number of the porphyry copper prospects appear to be in various stages of development and other prospects are receiving renewed exploration. A number of significant porphyry prospects occur in the tract, including La Balsa, Magistral, Nukay, Piedra Lipe, Rodeo, and La Chereca (table K4). In addition to the significant porphyry copper prospects listed in table K4, more than 40 additional copper-, vein-, and skarn prospects that may be related to porphyry systems occur in the tract.

Table K2. Map units that define Tract 003pCu3011 (MX-T3), Southwest Mexico.

[Map unit, age range, and principal lithologies from a 1:500,000 scale preliminary digital geologic map of Mexico (Servicio Geológico Mexicana, written commun., 2007); n.d., no data]

Map unit	Maximum age	Minimum age	Lithology 1	Lithology 2
Intrusive rocks				
TpgD	Paleogene	Paleogene	diorite	n.d.
TpaeGr-Gd	Paleocene	Eocene	granite	granodiorite
TpaD	Paleocene	Paleocene	diorite	n.d.
TpaTn	Paleocene	Paleocene	tonalite	n.d.
TpaMz	Paleocene	Paleocene	monzonite	n.d.
TpaGd	Paleocene	Paleocene	granodiorite	n.d.
TpaGd-Tn	Paleocene	Paleocene	granodiorite	tonalite
TeGr-Gd	Eocene	Eocene	granite	granodiorite
TeoGr	Eocene	Oligocene	granite	n.d.
TeoGr-Gd	Eocene	Oligocene	granite	granodiorite
ToTn	Oligocene	Oligocene	tonalite	n.d.
TomqMz-D	Oligocene	Miocene	quartz monzonite	diorite
Tom(?)Gr-Gd	Oligocene	Miocene?	granite	granodiorite
TmGd-Gr	Miocene	Miocene	granodiorite	n.d.
Volcanic rocks				
KapaA-Cz	Cretaceous	Cretaceous	andesite	limestone
KsTpaTR	Cretaceous	Paleocene	rhyolite tuff	n.d.
KapaA-Ar-Cgp	Cretaceous	Cretaceous	andesite	sandstone
TeoA	Eocene	Oligocene	andesite	n.d.
TeoA-Da	Eocene	Oligocene	andesite	dacite
TeoTA-A	Eocene	Oligocene	andesite tuff	andesite
TmTA-TR	Miocene	Miocene	andesite tuff	rhyolite tuff

The area now known as the Inguarán mine has been an important source for copper since at least 1533, and it seems likely that the mine was operated by indigenous people to obtain copper for agricultural implements before the Spanish conquest. The mine operated until at least 1787, when it passed out of the hands of the Spanish crown (Barrett, 1981). In the 1970s to 1980s, Asarco mined the Inguarán copper-silver-tungsten breccia pipe as an underground mine and produced more than 7 Mt of ore averaging 1.29 percent copper. An estimated reserve of 3 Mt of similar-grade material was identified at that time (Rome Resources Ltd., 2006). Additional exploration surrounding the Inguarán mine by Rome Resources Ltd. in 2003 and 2004 identified six additional geophysical and geochemical targets, primarily along a northwest trending fault bordering the mined deposit. A drilling program begun in late 2004 identified two target areas with core rock intervals averaging 1 percent copper (Rome Resources Ltd., 2006), so this deposit listed in Singer and others (2008) should be considered as open with additional tonnage likely. Inguarán is treated as a prospect with unknown resources in this assessment.

The large Fe-skarn deposits of El Encino and Pena Colorada, located along the Pacific coast, associated with Paleocene quartz-monzonites and andesites and the epithermal Ag-Au and mesothermal base metal deposits comprising the Fresnillo and Guanajuanto districts, formed from 31 to 29 Ma, share an affinity in age and source intrusions with the porphyry systems associated with porphyry copper deposits (Miranda-Gasca, 2000). Gold-copper skarn deposits with porphyry-copper deposit characteristics occur at Nukay (63 Ma) and El Bermejal (65 Ma) (Miranda-Gasca and Roldan-Martinez, 2003).

The La Balsa copper-gold porphyry prospect in Michoacán is being brought into production in 2009 by Bell Copper as a low-cost, high-grade mine. Initial production will come from three mineralized areas (La Virgen, Iguana Prieta, and Playa Azul) with an estimated combined resource of more than 190 million pounds of copper (Bell Copper, 2008).

Drilling at the Magistral claim has delineated high-grade copper mineralization in quartz-tourmaline breccia zones within a broader porphyry system with disseminated copper mineralization (Market Wire, 2006). The La Chereca prospect (includes the El Vidrio and Las Truchas prospects) incorporates a cluster of prospects aligned along a 5-km trend in the southern part of a large porphyritic stock with disseminated sulfides (Méndez-Alvarado and others, 2000).

Table K3. Known porphyry copper deposits in Tract 003pCu3011 (MX-T3), Southwest Mexico.

[Ma, million years; Mt, million metric tons; t, metric ton; g/t, gram per metric ton; Cu-Mo subtype, deposits that have Au/Mo rations <3 or average Mo grades >0.03%; Cu-Au subtype, deposits that have Au/Mo rations > 30 or average Au grades >0.2 g/t; NA, not applicable; n.d., no data. Contained Cu in metric tons is computed as tonnage (Mt*1,000,000) * Cu grade (%).]

Name	Latitude	Longitude	Subtype	Age (Ma)	Tonnage (Mt)	Grade				Contained Cu (t)	Reference
						Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)		
La Verde	19.083	-102.035	NA	32	110	0.7	n.d.	0.088	2.5	770,000	Barton and others (1995), Coochey and Eckman (1978), Damon and others (1983), Long (1995), Sillitoe (1976), Solano-Rico (1995), Rosas-Elguera and others (1999)
San Isidro	18.995	-101.952	NA	33	12.5	0.4	n.d.	n.d.	n.d.	50,000	Barton and others (1995), Damon and others (1983), Sillitoe (1976), Solano-Rico (1995), Montiel-Escobar and others (2003)
Tepal	19.083	-102.938	Cu-Au	n.d.	78	0.25	n.d.	0.47	n.d.	195,000	Solano-Rico (1995), Rosas-Elguera and others (1999), Priesmeyer and Leroux (2006), Northern Miner (2008)

Table K4. Significant prospects and occurrences in Tract 003pCu3011 (MX-T3), Southwest Mexico.

[Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; km, kilometer; n.d., no data]

Name	Latitude	Longitude	Age (Ma)	Comments (grade and tonnage data, if available)	Reference
Cerro Azul	18.259	-100.448	n.d.	Cerro Azul exploration property (260 km^2) includes several epithermal gold and 2 or more porphyry-copper type hydrothermal systems. Several intrusive phases intrude Cretaceous volcano-sedimentary rocks. Location noted is for NE corner of the property in area of mapped alteration (oxidation, chloritization) associated with map unit TeoGr .	Riverside Resources Inc. (2009)
Cobre Grande SGM Prospect	16.790	-96.395	n.d.	Cu-Mo-Zn-Ag skarn project explored by Linear Metals Corp. (2008). Inferred Mineral Resource estimate for skarn: 49.8 Mt of 0.50% Cu, 0.04% Mo, 0.22% Zn, 12.9 g/t Ag; open; associated with W-dipping silicified granodiorite porphyry dikes (Ross and Chamois, 2008) . Large hydrothermal system associated with quartz monzonite porphyry dikes. Zoned, from a core characterized by high molybdenum values (Cu:Mo = 1:1); Cu increases and Mo decrease out from the core until molybdenite disappears entirely as the system zones eastward out of quartz stockworked skarn into unveined Zn-rich skarn. The Main Zone (1,600-m strike length) is open for extension to the north.	Linear Metals Corporation (2008), Sánchez-Rojas and others (2000), Ross and Chamois (2008)
Inguarán	18.885	-101.660	34	Rome Resources Ltd. (2008) Inguarán Valley porphyry Cu-W Project surrounds the Inguarán copper mine; geochemistry, geophysics, and drilling indicate prospectivity for a 50 to 100 Mt low-grade porphyry copper deposit. Past production from breccia zones at the Inguarán copper mine operated by ASARCO in the 1970s and early 1980s: ~10 Mt at 1.29% Cu and 0.04% WO_3 was mined. Included as a deposit in Singer and others (2008); however, reported resources are for breccia zones which may overlie a larger porphyry system.	Montiel-Escobar and others (2003), Rome Resources Ltd. (2008), Singer and others (2008)
La Balsa	18.080	-102.212	n.d.	La Balsa previously known as La Virgen Cu-Oxide property. Potential for buried large-scale porphyry copper. Exploration focus on development (Dec.2008) of high-grade oxide/breccia ore. Qsp alteration in quartz monzonite porphyry. Total measured and indicated CIM 43-101 compliant resources at a cutoff grade 0.2% Cu for Iguana Prieta, La Virgen, and Playa Azul: 11.4 Mt at 0.77% Cu, inferred resource of 0.7 Mt of 0.66% Cu. Resources represent oxide, mixed, and sulfide ore in flat-lying copper oxide deposits, breccia zones in monzonite porphyry, and disseminated mineralized areas in monzonite. Deposits are only partially delineated.	Montiel-Escobar and others (2003), Solano-Rico and Deng (2008)
La Chereca	19.167	-104.284	n.d.	Porphyritic, sulfides, disseminated. A group of prospects cluster in the S part of a large stock, SW of a major fault system. El Vidrio, La Chereca, and Las Truchas prospects line up along a 5-m-long NE trend.	Méndez-Alvarado and others (2000)

Table K4. Significant prospects and occurrences in Tract 003pCu3011 (MX-T3), Southwest Mexico.—Continued

[Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; km, kilometer; n.d., no data]

La Tortuga Property	20.377	-104.286	n.d.	Exploration suggests potential for Cu-Au porphyry system and epithermal veins in a window of the Sierra Madre Occidental volcanic arc at the western end of the Trans-Mexican Volcanic Belt. Epithermal polymetallic Au-Cu-Ag vein systems and large areas of argillic alteration associated with outcropping mineralized, porphyritic intrusions.	Carter, 2006
Los Cimientos	19.572	-100.997	62.8	Approximate location from map (p. 546 of Solano-Rico, 1995) Location of town of same name used. Plots in Tertiary ignimbrites on 1:500K map.	Montiel-Escobar and others (1998), Solano-Rico (1995), Valencia-Moreno and others (2006)
Magistral	20.460	-104.141	54	Breccia-type deposit in Sierra Madre del Sur porphyry Cu belt. Subhorizontal fracture zones and crackle breccias near granodiorite cupola. Ore reserves: <1 Mt of 1.2% Cu. At N end of a 400-km-long belt (Solano-Rico, 1995). SGM database: Hydrothermal, sulfides, pipe. Noted as Magistral on 1:250K map, La Sorpresa Magistral in SGM database, La Sorpresa in Solano-Rico (same location).	López-Ojeda and Avila-Lugo (1993), Paizanni-Herrera and others (1999), Solano-Rico (1995)
Nukay	17.850	-99.667	n.d.	Cu-Fe-Au skarn (Fe>Cu) but potentially associated with a porphyry. Note that rocks in the tract are mapped as Oligocene on 1:500K map, but there are dated, dioritic porphyries within the tract. Jones and Jackson (1999) noted that andesite and granodiorite porphyry magmas at Nukay played a role in the formation of the Los Filos Au skarn. The area is considered part of the Guerrero gold skarn belt. Goldcorp started producing gold at Los Filos in January 2008 (Goldcorp, 2008).	Campa-Uranga and others (1998),Goldcorp (2008), Jones and Jackson (1999)
Piedra Lipe	18.143	-100.672	n.d.	Cluster of 3 copper prospects within 2 km of each other (Guadalupe, Piedra Lipe, La Corona) At contact with sediments (TpaeCgp-Lm)	Montiel-Escobar and others (2003)
Rodeo	18.619	-100.836	n.d.	Porphyry copper-molybdenum prospect, 4 km^2 , with possible secondary enrichment. Stockwork quartz veins, extensive biotite alteration, chalcopyrite and molybdenite in veinlets, and widespread occurrence of hematitic goethite. Drilling began in 2008.	Cox, D.P. (oral commun., 2007), Montiel-Escobar and others (2003), Cox (2009)
San Antonio-SGM Prospect (Michoacan)	18.661	-101.527	n.d.	SGM porphyry copper prospect area. Location near 3 prospect locations (La Reyna SGM, Begonia, and Santa Elena all within 2 km of each other) at N end of syenite-diorite stock at the Santa Elena location. La Gloria mineralized zone.	Montiel-Escobar and others (2003)
San Diego	19.143	-101.111	n.d.	Porphyry copper drill target based on Cu-Mo soil anomaly and hydrothermal alteration associated with quartz diorite porphyry. Mineralized porphyry exposed at low elevations near San Diego River - may be a buried target. Chalcopyrite and molybdenite phyllic alteration zone; potassically altered breccia zone. Ground mag, soil, and silt surveys. No drilling.	Woods (2004)

Exploration History

The tract has been explored before and during colonial times for precious-metal deposits and is currently the focus of exploration for volcanic massive sulfide, gold, and Tertiary epigenetic skarn, porphyry copper, and polymetallic vein deposits (Miranda-Gasca, 2000). Additional exploration around the Inguarán deposit has identified a number of new mineralized targets that are likely to expand the known resources listed in table K3 (Rome Resources Ltd., 2006). A number of significant porphyry prospects occur in the tract, including Tepal, La Balsa, Magistral, Piedra Lipe, Nukay, Rodeo, and La Chereca. A number of these porphyry copper prospects appear to be in various stages of development and other prospects are receiving renewed exploration.

Tepal, a stockwork copper-gold porphyry system in Michoacán state, was explored in the 1970s and 1990s by several companies, including Inco, Teck Cominco, and Hecla Mining (Northern Miner, 2008). A recent resource estimate for the Tepal project by Arian Silver reports 79 Mt of oxide ore grading 0.47 g/t gold and 0.24 percent copper, based on 54 drill-hole intercepts from two distinct mineralized zones (Northern Miner, 2008).

The La Balsa copper-gold porphyry prospect in Michoacán, Mexico is being brought into production in 2009 by Bell Copper, a privately-held merger company formed in 2008 by a merger between Bell Resources, Grandcru Resources, and Rogue River Resources Corporations. The company expects La Balsa to become a low-cost, high-grade mine, and initial production will come from three mineralized areas (La Virgen, Iguana Prieta, and Playa Azul) with a combined resource of more than 86,000 tonnes of copper (Bell Copper, 2008).

The Magistral claim and the adjacent La Sorpresa prospect are under advanced exploration and evaluation by Southern Silver Explorations and Fury Exploration corporations. Drilling has delineated high-grade copper-mineralized areas in quartz-tourmaline breccia zones within the broader porphyry system with disseminated copper mineralized areas. The exploration area covers 9,400 hectares and includes multiple geophysical and radiometric anomalies that were not completely explored in 2006 (Market Wire, 2006).

The previously undrilled San Diego porphyry copper-gold prospect in Michoacán state has been under exploration by Noranda and Terra Nova Gold since 2002, with exploration projected to continue into 2009 (Edgar Online, 2005). The exploration target was identified as a result of the sediment-sampling program conducted by the Mexican government (SGM) in 1998. Field studies have identified hydrothermal altered igneous rocks with copper, molybdenum, and gold anomalies; an airborne magnetic survey completed in 2004 outlines the intrusive complex hosting the probable porphyry copper system (Edgar Online, 2005).

A number of precious-metal skarn prospects, potentially associated with porphyry-type mineralized areas, are currently undergoing further exploration and development. The Nukay prospect, a copper-gold skarn with porphyry-copper deposit characteristics (Miranda-Gasca and Roldan-Martinez, 2003), is undergoing active exploration by Riverside Resources. El Bazatan, a small copper-skarn underground mine in Michoacán is producing copper ore with some molybdenum and tungsten at a rate of more than 200 tonnes per day (Fitch, 1999). Three copper-gold prospects are under exploration by Minuarum Gold (2008). The Aurena prospect in southwestern Oaxaca is the most advanced of the Minaurum Gold targets, with well-exposed skarn mineralized areas with visible gold in outcrop. El Porfido in Morelos state and Jackie in eastern Guerrero state show similarities to other major iron-gold skarn deposits and gram-plus gold values have been obtained in reconnaissance exploration of the El Porfido prospect (Minaurum Gold, 2008).

Sources of Information

Principal sources of information used by the assessment team for delineation of 003pCu3011 are listed in table K5.

Grade and Tonnage Model Selection

The geochemical characteristics of the magmatism in tract 003pCu3011 (MX-T3) generally indicate a low degree of assimilation of continental crust and a greater involvement of oceanic arc and sediment basement (Guerrero terrane) in magma generation (Moran-Zenteno and others, 2007a). The intrusive bodies typically associated with porphyry copper-mineralized areas in this tract share these characteristics (Damon and others, 1983). In Mexico, the copper metal grades do not show evidence of regional basement-type control. Higher molybdenum and tungsten grades and larger tonnage deposits typically occur in the northern areas of Mexico underlain by Proterozoic North American crystalline crust, whereas tract 003pCu3011 (MX-T3) in the southern Mexico is characterized by Cu-Au deposits with smaller tonnages (Valencia-Moreno and others, 2007).

ANOVA tests were conducted to compare log-transformed tonnage, copper, silver, and gold grade for the known deposits in the tract against the general porphyry copper and the Cu-Au porphyry copper deposit subtype models of Singer and others (2008). The statistical tests showed that log-transformed copper, silver, and gold grade and tonnage for the known deposits in the tract are not significantly different from either the general or Cu-Au models at the 1-percent level. No molybdenum grades are reported for the deposits in the tract, so the applicability of the global model for this commodity could not be tested. Although the reported tonnages for the deposits in the tract (table K3) pass the ANOVA test at the 1-percent confidence level, the reported tonnages are low compared to the average tonnage characteristics of both the general porphyry copper and the Cu-Au subtype models.

Table K5. Principal sources of information used by the assessment team for Tract 003pCu3011 (MX-T3), Southwest Mexico.

[NA, not available or not applicable]

Theme	Name or title	Scale	Citation
Geology	Preliminary digital geologic map of the Republic of Mexico	1:500,000	Servicio Geológico Mexicano (written commun., 2007)
	Carta geológica de la República Mexicana	1:2,000,000	Servicio Geológico Mexicano (2007)
	Carta geólogico-minera, Estados de Colima y Jalisco	1:500,000	Teràn-Ortega and others (2008)
	Carta geólogico-mineral, Estados de Guerrero	1:500,000	Montiel-Escobar and others (2007a)
	Carta geólogico-minera, Distrito Federal, Estados de Michoacán	1:500,000	Montiel-Escobar and others (2007b)
	Carta geólogico-minera, Estado de Nayarit	1:500,000	Teràn-Ortega and others (2007)
	Carta geólogico-minera, Estado de Oaxaca	1:500,000	Montiel-Escobar and others (2007c)
Mineral occurrences	SGM Minas database	NA	Servicio Geológico Mexicano (written commun., 2007b)
	MRDS database	NA	U.S. Geological Survey (2005)
	University of Arizona-Industry-USGS Mexico Consortium	NA	University of Arizona-Industry-USGS Mexico Consortium, March 1999 Release Notes (unpublished)
	Porphyry copper deposits of the world: database, map, and grade and tonnage models	NA	Singer and others (2008)
	Carta y provincias metalogeneticas de la Republica Mexican	1:2,000,000	Salas (1975)
	Geological and metallogenetic characteristics of the porphyry copper deposits of México and their situation in the world context	NA	Valencia-Moreno and others (2007)
Geochemistry	SGM stream-sediment database	NA	Servicio Geológico Mexicano (written commun., 2007)
Geology, mineral occurrences and exploration	Geological-mining monograph of the state of Colima	1:500,000	Consejo de Recursos Minerales (1994a)
	Geological-mining monograph of the state of Guerrero	1:500,000	Consejo de Recursos Minerales (1999)
	Geological-mining monograph of the state of Jalisco	1:500,000	Consejo de Recursos Minerales (1992)
	Geological-mining monograph of the state of Michoacán	1:500,000	Consejo de Recursos Minerales (1995)
	Geological-mining monograph of the state of Nayarit	1:500,000	Consejo de Recursos Minerales (1994b)
	Geological-mining monograph of the state of Oaxaca	1:500,000	Consejo de Recursos Minerales (1996)
Geophysics	North American magnetic map	1:10,000,000	North American Magnetic Anomaly Group (2002)
Exploration	Proyectos de Compañias Extranjeras por Estado	NA	Dirección General de Promoción Minera (2005)
	Company Web sites	NA	Almaden Minerals Ltd. (2009), Chesapeake Gold Corp. (2009), Exmin Resources Inc. (2008)

The general porphyry copper model of Singer and others (2008) was selected for the assessment based on the general geologic characteristics of the tract and because we do not have sufficient information to justify the use of a specialized subtype model, such as the Cu-Au deposit model, to estimate undiscovered resources. Only two deposits in the tract, Tepal and La Verde, have reported gold grades. The reported average gold grade of 0.5 g/t for Tepal is greater than the reported average gold grade of 0.09 g/t for La Verde and is less than the gold grade criteria (>0.2 g/t or Au/Mo>30) used in this study to classify deposits as Cu-Au subtype. Therefore, the general porphyry copper grade-tonnage model, which includes Cu-Au and Cu-Mo subtypes, was judged to be most appropriate for the probabilistic assessment of undiscovered resources in the tract.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

The team considered that porphyry copper deposits tend to occur in belts or clusters. The tract contains 3 known deposits with grade and tonnage information and numerous prospects and occurrences of copper, gold, and iron. The team attached a level of importance to porphyry-type and related prospects based on their belief that the prospect might be associated with deposits like those in the grade-tonnage models. Six prospects (Cobre Grande, La Balsa, La Cherca, Magistral, Piedra Lipe, and Nukay), many of which are undergoing exploration and development, are considered as likely to fit the deposit grade and tonnage models when fully explored. Four additional prospects (Ingurán, La Tortuga, Rodeo, and San Diego) are considered promising as potential porphyry copper deposits. In addition to the significant porphyry copper prospects listed in table K4, more than 40 additional copper prospect, vein, and skarn prospects in the tract are considered to have some potential as porphyry copper deposits. The tract also hosts more than 20 occurrences tentatively classified as epithermal copper veins, some of which may be related to subsurface porphyry systems. Exploration intensity over the tract is variable, with areas in the altiplano more extensively explored than the heavily vegetated coastal areas. Based on these considerations, the assessment team concluded that there is a 90-percent chance of a least 6 deposits, at least 10 porphyry copper deposits with grade-tonnage characteristics consistent with the general porphyry copper model at 50-percent confidence and that at least 14 porphyry copper deposits with grade-tonnage characteristics consistent with the general porphyry copper model are estimated at 10-percent confidence, respectively (table K6).

Table K6. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for Tract 003pCu3011 (MX-T3), Southwest Mexico.

[NXX, estimated number of deposits associated with the xxth percentile; Nund, expected number of undiscovered deposits; s, standard deviation; Cv%, coefficient of variance; Nknown, number of known deposits in the tract that are included in the grade and tonnage model; Ntotal, total of expected number of deposits plus known deposits; area, area of permissive tract in square kilometers; density, deposit density reported as the total number of deposits per km^2. N_{und}, s, and Cv% are calculated using a regression equation (Singer and Menzie, 2005).]

Consensus undiscovered deposit estimates			Summary statistics					Tract area (km^2)	Deposit density (N_{total}/km^2)
N90	N50	N10	N_{und}	s	Cv%	N_{known}	N_{total}		
6	10	14	9.6	3.1	32	3	13	156,650	0.00008

Table K7. Results of Monte Carlo simulations of undiscovered resources in tract 003pCu3011 (MX-T3), Southwest Mexico.

[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	3,400,000	7,300,000	26,000,000	80,000,000	110,000,000	37,000,000	0.33	0.02
Mo	19,000	74,000	540,000	2,400,000	3,600,000	1,000,000	0.28	0.03
Au	42	130	630	2,000	2,900	940	0.33	0.03
Ag	75	640	6,100	28,000	43,000	12,000	0.28	0.05
Rock	790	1,700	5,500	17,000	23,000	7,500	0.34	0.02

The assessment team considered the tract to be representative of typical subduction-arc systems and that the active uplift and erosion in much of the tract area has been sufficient to expose porphyry deposit systems of Paleocene to Miocene age. The team did not apply the deposit density models of Singer and others (2005) directly during the assessment; however, our estimate of 8.3 deposits/100,000 km^2 is similar to the worldwide porphyry copper-deposit density (fig. 11) reported by Singer and others (2005).

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, in press). Selected simulation results are reported in table K7. Results of the Monte Carlo simulation are presented as a cumulative frequency plots (fig. K2). The cumulative frequency plots show the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

References Cited

Almaden Minerals Ltd., 2009, Mexican Exploration, Almaden Minerals Ltd. Web page accessed November, 29, 2009, at http://www.almadenminerals.com/projects.html.

Barrett, E.M., 1981, The King's copper mine—Inguarán in New Spain: The Americas, v. 38, p. 1–29.

Barrier, E., Velasquillo, L., Chavez, M., and Gaulon, R., 1998, Neotectonic evolution of the Isthmus of Tehuantepec (southeastern Mexico): Tectonophysics, v. 287, no. 1-4, p. 77-98.

Barton, M.D., Staude, J.-M.G., Zürcher, L., and Megaw, P.K.M., 1995, Porphyry copper and other intrusion-related mineralization in Mexico, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Tucson, Arizona Geological Society Digest, v. 20, p. 487-524.

Bawiec, W.J., and Spanski, G.T., in press, EMINERS—Economic Mineral Resource Simulator, version 3.0: U.S. Geological Survey Open-File Report 2009-1057, program files and 29-p. Quick-Start Guide.

Bell Copper, 2008, La Balsa Prospects: Bell Copper web page accessed May 15, 1009, at http://www.bellcopper.net/s/La_Balsa.asp?ReportID=300371.

Berger, B.R., Ayuso, R.A., Wynn, J.C., and Seal, R.R., 2008, Preliminary model of porphyry copper deposits: U.S. Geological Survey Open-File Report 2008-1321, 55 p., accessed May 15, 2009, at http://pubs.usgs.gov/of/2008/1321.

Campa, M.F., and Coney, P.J., 1983, Tectono-stratigraphic terranes and mineral resource distributions in Mexico: Canadian Journal of Earth Sciences, v. 20, p. 1040-1051.

Campa-Uranga, María, García-Díaz, J.L., Bustamante-García, Javier, Torreblanca-Castro, Teresita de Jesús, Martínez-Aguilera, M.A., Vergana-Martínez, Alvaro, 1998, Carta geológico-minera, Chilpancingo E14-8, Guerrero, Oaxaca and Pueblo [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Carter, G.S., 2006, Technical report on the copper/gold/silver resources on the La Tortuga property, Jalisco state, Mexico on behalf of Soltoro Ltd., 43 p.

Chesapeake Gold Corporation, 2009, Properties in Mexico: Chesapeake Gold Corporation Web page accessed November, 29, 2009, at http://www.chesapeakegold.com/mexico.php.

Coney, P.J., and Campa, M.F., 1987, Lithotectonic terrane map of Mexico (West of the 91st Meridian): U.S. Geological Survey Miscellaneous Field Studies Map MF-1874-D, scale 1:2,500,000, 1 sheet.

Consejo de Recursos Minerales, 1992 Monografia geologico-minera del estado de Jalisco: Consejo de Recursos Minerales Publicación M-5e, Pachuca, Hgo., Mexico, 122 p.

Consejo de Recursos Minerales, 1994a, Monografia geologico-minera del estado de Colima: Consejo de Recursos Minerales Publicación M-11e, Pachuca, Hgo., Mexico, 90 p.

Consejo de Recursos Minerales, 1994b, Monografia geologico-minera del estado de Nayarit: Consejo de Recursos Minerales Publicación M-12e, Pachuca, Hgo., Mexico, 171 p.

Consejo de Recursos Minerales, 1995, Geological-mining monograph of the State of Michoacán: Consejo de Recursos Minerales Publicación M-15e, Pachuca, Hgo., Mexico, 176 p.

Consejo de Recursos Minerales, 1996, Monografia geologico-Minera del estado de Oaxaca: Consejo de Recursos Minerales Publicación M-17e, Pachuca, Hgo., Mexico, 280 p.

Consejo de Recursos Minerales, 1999, Geological-mining monograph of the State of Guerrero: Consejo de Recursos Minerales Publicación M-19a, Pachuca, Hgo., Mexico, 281 p.

Coochey, D.V., and Eckman, P., 1978, Geology of the La Verde copper deposits, Michoacan, Mexico, *in* Jenney, J.P., and Hauck, H.R., eds., Proceedings of the porphyry copper symposium: Arizona Geological Society Digest, v. 11, p. 129-137.

Cox, D.P., 1986, Descriptive model of porphyry Cu (Model 17), *in* Cox, D.P., and Singer, D.A., eds., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 76. (Also available online at http://pubs.usgs.gov/bul/b1693/.)

Cox, D.P., 2009, Web site: http://dpcox.com/DPresume.html.

Damon, P.E., Shafiqullah, M., and Clark, K.F., 1983, Geochronology of the porphyry copper deposits and related mineralization of Mexico: Canadian Journal of Earth Sciences, v. 20, p. 1,052-1,071.

de Cserna, Z., 1989, An outline of the geology of Mexico, *in* Bailey, A.W., and Palmer, A.R., eds., Geology of North

America—An overview: Geological Society of America, The Geology of North America, v. A, p. 233-264.

Ducea, M.N., Gehrels, G.E., Shoemaker, S., Ruiz, J., and V.A. Valencia, 2004, Geological evolution of the Xolapa Complex, Southern Mexico—Evidence from U-Pb zircon geochronology: Geological Society of America Bulletin, v. 116, no. 7/8, p. 1,016-1,025.

Einaudi, M.T., 1982, Description of skarns associated with porphyry copper plutons, *in* Titley, S.R., ed., Advances in geology of the porphyry copper deposits, southwestern North America: Tucson, University of Arizona Press, p. 139-183.

Edgar Online, 2005, Terra Nova Gold Corp: Securities and Exchange CommissionForm 6-K, accessed August 5, 2010, at http://msnmoney.brand.edgar-online.com/EFX_dll/EDGARpro.dll?FetchFilingHTML1?ID=3903305&SessionID=Ycl4HoPVNX9Prm9.

EXMIN Resources Inc., 2008, EXMIN Resources Inc. home page accessed May 15, 2009, at http://www.exmin.com/.

Fitch, D.C., 1999, Review of exploration in Mexico—Part 1—Copper, polymetallics, silver, VMS deposits: Mexico Mining, 1999 Randol Conference, Puerto Vallarta, Mexico, January 17-19, 1999.

Goldcorp, 2008, Los Filos: Goldcorp Web page accessed May 15, 2009, at http://www.goldcorp.com/operations/los_filos/.

Jones, D.M. and Jackson, P.R., 1999, Geologic setting of skarn-associated gold deposits of the Nukay District, Guerrero, Mexico: Association of Mining, Metallurgical, and Geological Engineers (AIMMGM, A.C), Memorias, p. 42-46.

Linear Metals Corporation, 2008, Cobre Grande Overview: Linear Metals Corporation Web page accessed June 10, 2008, at http://www.linearmetals.com/properties/Cobre_Grande_Overview.

Long, K.R., 1995, Production and reserves of Cordilleran (Alaska to Chile) porphyry copper deposits, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Tucson, Arizona Geological Society Digest 20, p. 35-68.

López-Ojeda, J.A., and Avila-Lugo, F., 1993, Exploracion por cobre en el area del "Magistral," Municipio de Ameca, Jalisco.

Manea, M., Manea, V.C., Ferrari, L., Kostoglodov, V., and Bandy, W.L., 2005, Tectonic evolution of the Tehuantepec Ridge: Earth and Planetary Science Letters, v. 238, p. 64-77.

Market Wire, July 2006, Fury options Magistral I to Southern Silver Exploration: http://findarticles.com/p/articles/mi_pwwi/is_200607/ai_n16537075.

Méndez-Alvarado, Héctor, Romo-Ramírez, Julio, Munguía-Rojas, Pedro and Vázquez-Tortoledo, Rafael, 2000, Carta geológico-minera, Manzanillo E13-2-5, Colima and Jalisco. [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Minaurum Gold, 2008, Fact Sheet: http://minaurumgold.com/fact_sheet2.pdf.

Miranda-Gasca, M.A., 2000, The metallic ore-deposits of the Guerrero Terrane, western Mexico—an Overview: Journal of South American Earth Sciences, v. 15, p. 403-413.

Miranda-Gasca, M.A. and Roldan-Martinez, J., 2003, Laramidic Cu-Au porphyry-style mineralization in Mochitlan, Guerrero, Mexico: Geological Society of America Abstracts with Program, Cordilleran Section, April 1-3, 2003, accessed May 15, 2009, at http://gsa.confex.com/gsa/2003CD/finalprogram/abstract_52398.htm.

Molina-Garza, R.S., and Ortega-Rivera, A., 2006, Chronostratigraphy and paleomagnetism of the Balsas Group in the Tuzantlan-Copalillo basin, northern Guerrero state, Mexico: Revista Mexicana de Ciencias Geologicas, v. 23, no. 2, p 215-232.

Montiel-Escobar, J.E., Aranda-Osorio, J.N. and Bastida-Jiménez, Raymundo, compilers, 2007a, Carta Geólogico-Mineral, Estados de Guerrero: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/guerrero.pdf.)

Montiel-Escobar, J.E., Aranda-Osorio, J.N. and Bastida-Jiménez, Raymundo, compilers, 2007b, Carta Geólogico-Minera, Estado de Michoacán: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/michoacan.pdf.)

Montiel-Escobar, J.E., Bastida-Jiménez, Raymundo, Aranda-Osorio, J.N., and Dorantes-Salgado, Enrique, compilers, 2007c, Carta Geólogico-Minera, Estado de Oaxaca: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/oaxaca.pdf.)

Montiel-Escobar, J.E., Segura-De La Teja, M.A., Estrada-Rodarte, Graciela, Cruz-Lopez, D.E, and Rosales-Franco, Enrique, 2003, Carta geológico-minera, Ciudad Altamirano E14-4, Michoacán, Guerrero and Edo. De Méx. [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Montiel-Escobar, José, Librado-Flores, José, Salazar-Reyes, Joaquín, Bustamante-García, Jorge, and Sánchez-Garrido, Eduardo, 1998, Carta geológico-minera, Morelia E14-1, Guanajuato, Michoacán, and Estado de Mexico [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Montiel-Escobar, J.E., Segura-De La Teja, M.A., Estrada-Rodarte, Graciela, Cruz-Lopez, D.E, and Rosales-Franco, Enrique, 2003, Carta geológico-minera, Ciudad Altamirano E14-4, Michoacán, Guerrero and Edo. De Méx. [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Moran-Zenteno, D.J.., Cerca, M., and Kepple, J.D., 2007, The Cenozoic tectonic and magmatic evolution of southwestern Mexico—Advances and problems of interpretation, *in* Alaniz-Álvarez, S.A., and Nieto-Samaniego, A.F., eds., Geology of México—Celebrating the centenary of the Geological Society of México: Geological Society of America, Special Paper 422, p. 71-91.

Moran-Zenteno, D.J.., Monter-Ramirez, A., Centeno-Garcia, E., Alba-Aldave, L.A. and Sole, J., 2007, Stratigraphy of the Balsas Group in the Amacuzac area, southern Mexico: relationship with Eocene volcanism and deformation of the Tilzapotla-Taxco sector: Revista Mexicana de Ciencias Geologicas, v. 24, no. 1, p. 68-80.

North American Magnetic Anomaly Group, 2002, Magnetic anomaly map of North America: U.S. Geological Survey Special Map, scale 1:10,000,000, accessed January 15, 2008, at http://pubs.usgs.gov/sm.mag_map/.

Northern Miner, 2008, Arian confirms gold, copper resource at Tepal: The Northern Miner, v. 94, no. 6, April 6, 2008.

Osoria, H.A., Loija, V.N., and Esquivel, R., 1991, Economic geology of the Inguaran mining district, Michoacán, *in* Salas, G.P., ed., Economic geology. Mexico: Boulder, Colorado, Geological Society of America. The geology of North America, v. P-3, p. 365-368.

Paizanni-Herrera, Felipe, Ramírez-Romo, Julio, Gamez-Ordaz, Vicente, and Ávila-Lugo, Fernando, 1999, Carta geológico-minera, Puerto Vallarta F13-11, Jalisco and Nayarit. [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Priesmeyer, S.T., 2006, Technical report on the Tepal project, Michoacán, Mexico: A.C.A. Howe International Limited, accessed May 15, 2009, at http://www.ariansilver.com/i/pdf/tepal-43101.pdf.

Priesmeyer, S.T. and Leroux, D.C., 2006, Technical report on the Cuatro Hermanos copper-molybdenum project, Sonora State (for Virgin Metals, Inc.): A.C.A. Howe International Ltd. Report #894.

Riverside Resources Inc., 2009, Cerro Azul property: Riverside Resources Inc. Web page accessed May 15, 2009, at http://www.rivres.com/s/CerroAzul.asp.

Rome Resources, Ltd., 2006, Mexican La Huavana porphyry copper Project (Inguaran porphyry copper property): Rome Resources, Ltd. Web page accessed May 15, 2009, at http://www.romermr.com/Exploration.html.

Rome Resources, Ltd., 2008, Inguaran- Michoacán, Mexico: Rome Resources, Ltd. Web page accessed June 11, 2008, at http://romemr.com/site/projects/mexican/.

Root, D.H., Menzie, W.D., and Scott, W.A., 1992, Computer Monte Carlo simulation in quantitative resource estimation: Natural Resources Research, v. 1, no. 2, p. 125-138.

Rosas-Elguera, José, Hernández-Berrera, David, Pérez-Rodríguez, Gerardo, Valladolid-Cacho, Rafael, Tortoledo-Vázques, Rafael, Ramírez-Romo, Julio, 1999, Carta geológico-minera, Colima E13-3, Colima, Jalisco, and Michoacán. [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Ross, D.A., and Chamois, Paul, 2008, Technical report on the Cobre Grande Project, Oaxaca State, Mexico; prepared for Linear Metals Corporation, NI 43-101 Report., 128 p.: Linear Metals Web page accessed May 15, 2009, at http://www.linearmetals.com/images/userfiles/File/Ross_2008_43-101_Cobre_Grande_Resource_Report_Final.pdf.

Salas, G.P., 1975, Mapa Metallogenetico de la Republica Mexicana; Consejo de Recursos Naturales No Renovables, Publicación 21E, Mexico D.F., 188 p.

Sánchez-Rojas, L.E., Aranda-Osorio, J.N., Zárate-López, Javier and Castro-Rodríguez, M.G., 2000, Carta geológico-minera, Zaachila E14-12, Oaxaca [Mexico]: Pachuca, Hidalgo, Servicio Geológico Mexicano, 1 sheet, scale 1:250,000.

Sawkins, F.J., 1979, Fluid inclusion studies of copper-bearing breccia pipes: Inguaran Mine, Michoacán, Mexico: Economic Geology, v. 74, p. 924-928.

Sillitoe, R.H., 1976, A reconnaissance of the Mexican porphyry copper belt: Transactions of the Institution of Mining and Metallurgy, Section B, p. B170–B189.

Singer, D.A., Berger, V.I., Menzie, W.D., and Berger, B.R., 2005, Porphyry copper density: Economic Geology, v. 100, no. 3, p. 491-514.

Singer, D.A., Berger, V.I., and Moring, B.C., 2008, Porphyry copper deposits of the world—Database, map, and grade and tonnage models, 2008: U.S. Geological Survey Open-File Report 2008-1155, 45 p., accessed January 15, 2009, at http://pubs.usgs.gov/of/2008/1155/.

Singer, D.A., and Menzie, W.D., 2005, Statistical guides to estimating the number of undiscovered mineral deposits—An example with porphyry copper deposits, *in* Cheng, Qiuming, and Bonham-Carter, Graeme, eds., Proceedings of IAMG, The annual conference of the International Association for Mathematical Geology: Geomatics Research Laboratory, York University, Toronto, Canada, p. 1028-1033.

Solano-Rico, B., 1995, Some geologic and exploration characteristics of porphyry copper deposits in the Sierra Madre del Sur province, Mexico, *in* Pierce, F.W., and Bolm, J.G., eds., Porphyry copper deposits of the American Cordillera: Tucson, Arizona Geological Society Digest, v. 20, p. 545-550.

Solano-Rico, Baltazar, and Deng, Qingping, 2008, Technical report, La Balsa copper project, Municipality of Lázaro Cárdenas, State of Michoacán, Mexico prepared by Behre Dolbear and Company (USA), Inc. for Rogue River Resources, accessed February 8, 2008 at http://www.nexvucapital.com/i/pdf/LaBalsa_NI43-101.pdf .

Tardy, M., Lapierre, H., Freydier, C., Coulon, C., Gill, J-B., Mercier de Lapinay, B., Beck, C., Martinez, J., Talavera, O., Ortiz, E., Stein, G., Bourdier, J-L. and Yta, M., 1994, The Guerrero suspect terrane (western Mexico) and coeval arc terranes (the Greater Antilles and the Western Cordillera of Columbia)—A late Mesozoic intra-oceanic arc accreted to cratonal America during the Cretaceous: Tectonophysics, v. 230, p. 49-73.

Terán-Ortega, L.A., Maraver-Romero, D.A., Montiel-Escober, J.E., Jiménez-Gonzaga, Alejandro, and Dorantes-Salgado, Enrique, compilers, 2007, Carta Géologico-Minera, Estado de Nayarit: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/nayarit.pdf.).

Terán-Ortega, L.A., Maraver-Romero, D.A., Montiel-Escobar, J.E. Jiménez-Gonzaga, J.A., and Dorantes-Salgado, Enrique, compilers, 2008, Carta Geólogico-Minera, Esta dos de Colima y Jalisco: Servicio Geológico Mexicano, 1 sheet, scale 1:500,000. (Also available online at http://www.coremisgm.gob.mx/productos/cartas/estados/geologia/pdf/colima_jalisco.pdf.)

U.S. Geological Survey, 2005, Mineral Resources Data System: U.S. Geological Survey, Reston, Virginia, accessed December 15, 2007, at http://tin.er.usgs.gov/mrds/.

Valencia-Moreno, M., Ochoa-Landìn, L., Noguez-Alcantara, B., Ruìz, J., Pèrez- Segura, E., 2006, Características metalogenéticas de los depósitos de tipo pórfido cuprífero en México y su situación en el contexto mundial: Boletín de la Sociedad Geológica Mexicana, Vol. Conmemorativo del Centenarìo, Tomo. LVIII. Num.1, p. 1-26.

Valencia-Moreno, M., Ochoa-Landin, L, Noguez-Aleantara, B., Ruiz, J., and Perez-Segura, E., 2007, Geological and metallogenic characteristics of the porphyry copper deposits of Mexico and their situation in the world context, *in* Alaniz-Álvarez, S.A., and Nieto-Samaniego, A.F., eds., Geology of México—Celebrating the centenary of the Geological Society of México: Geological Society of America, Special Paper 422, p. 233-259.

Woods, Gary, 2004, San Diego property, Michoacán State, Mexico, 43-101F1 Technical report prepared for Terra Nova Gold Corp., 41 p.

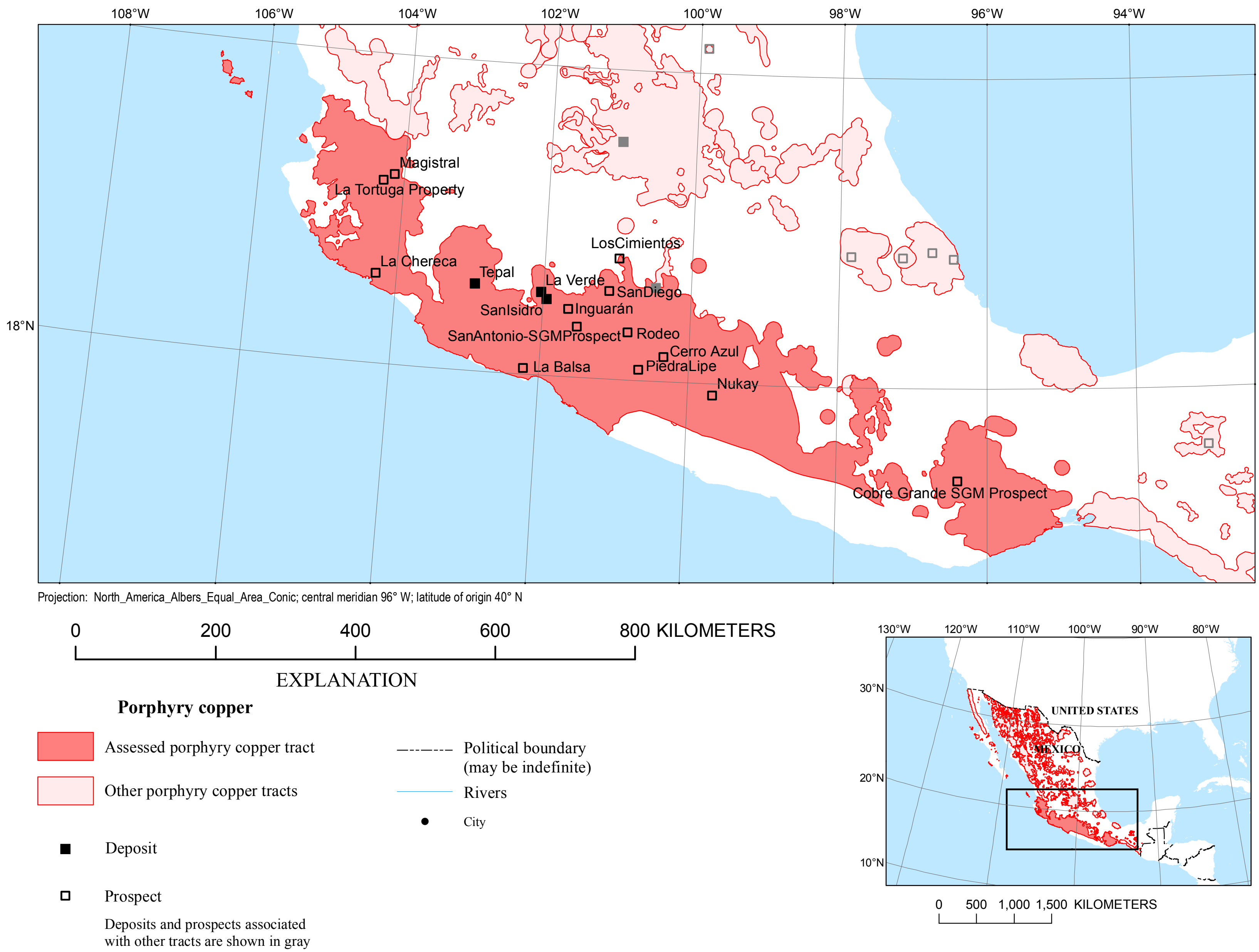


Figure K1. Map showing the location, known deposits, and significant prospects and occurrences for tract 003pCu3011 (MX-T3), Southwest Mexico.

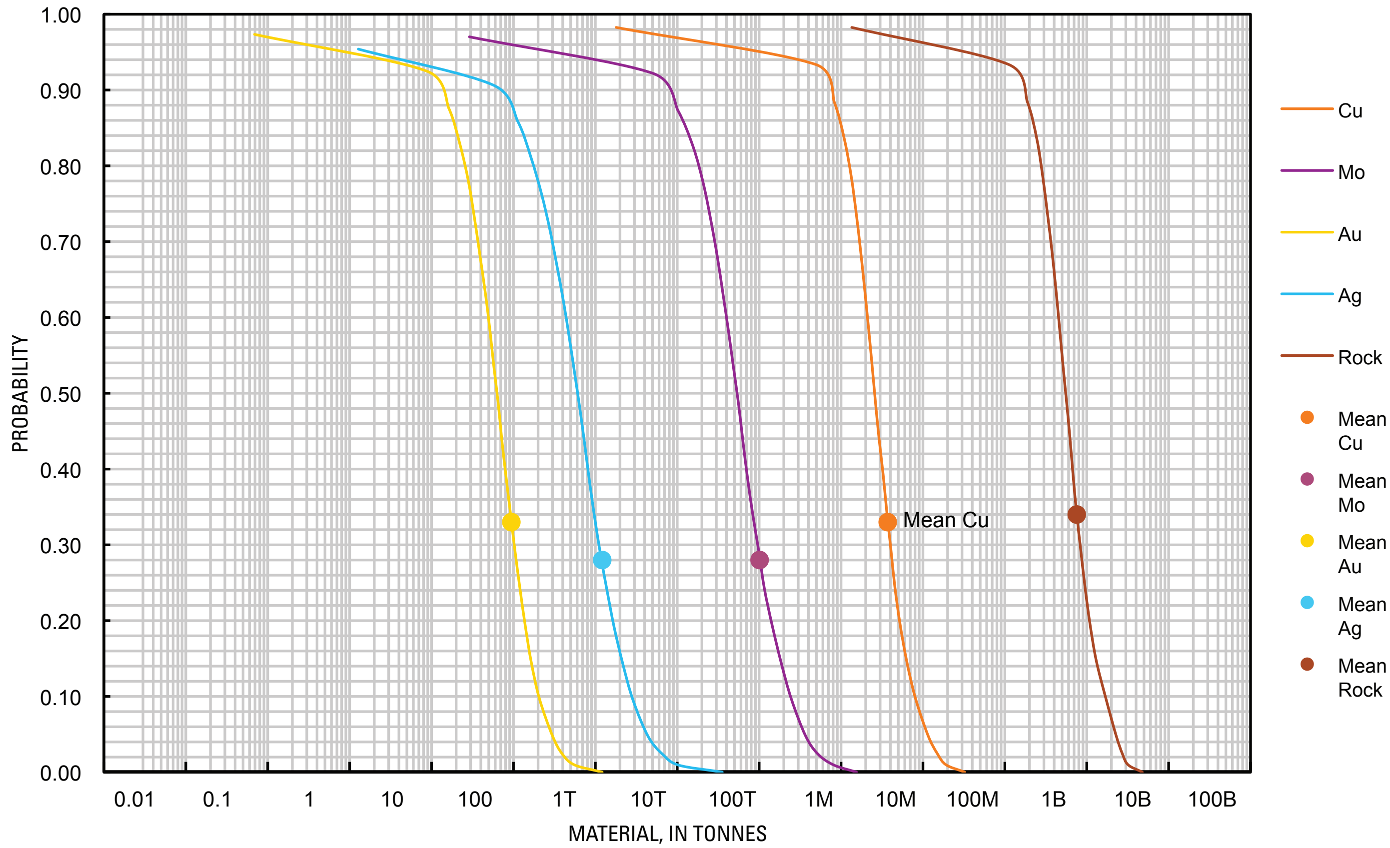


Figure K2. Cumulative frequency plot showing the results of a Monte Carlo computer simulation of undiscovered resources in tract 003pCu3011 (MX-T3), Southwest Mexico. T, thousands; M, millions; B, billions; Tr, trillions.

Appendix L. Description of GIS files

Three ESRI shapefiles (.shp) and an ESRI map document (.mxd) are included with this report. These may be downloaded from the USGS website as zipped file **sir2010-5090a_gis.zip**.

The shapefiles are as follows:

MX_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.

MX_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 and prospects are listed in table 3 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.

MX_political_boundaries.shp is a shapefile showing the outline of Mexico, the southern border of the U.S., and the outline of the countries that lie to the south of Mexico (Belize and Guatemala along the southern Mexican border; El Salvador and Honduras). The shapefile is extracted from the global GIS of Hearn and others (2003).

These three shapefiles are included in an ESRI map document (version 9.3): **GIS_SIR5090-A.mxd**.

References Cited

Hearn, P., Jr., Hare, T., Schruben, P., Sherrill, D., LaMar, C., and Tsushima, P., 2003, Global GIS database—Digital atlas of the Earth: U.S. Geological Survey Digital Data Series DDS-62-H, DVD-ROM.

Produced in the Western Region, Menlo Park, California
Manuscript approved for publication, February 2, 2010
Text edited by Tracey Suzuki and Peter H. Stauffer
Layout and design by Stephen L. Scott

USGS

Hammarstrom and others—**Global Mineral Resource Assessment—Porphyry Copper Assessment of Mexico**—Scientific Investigations Report 2010-5090–A