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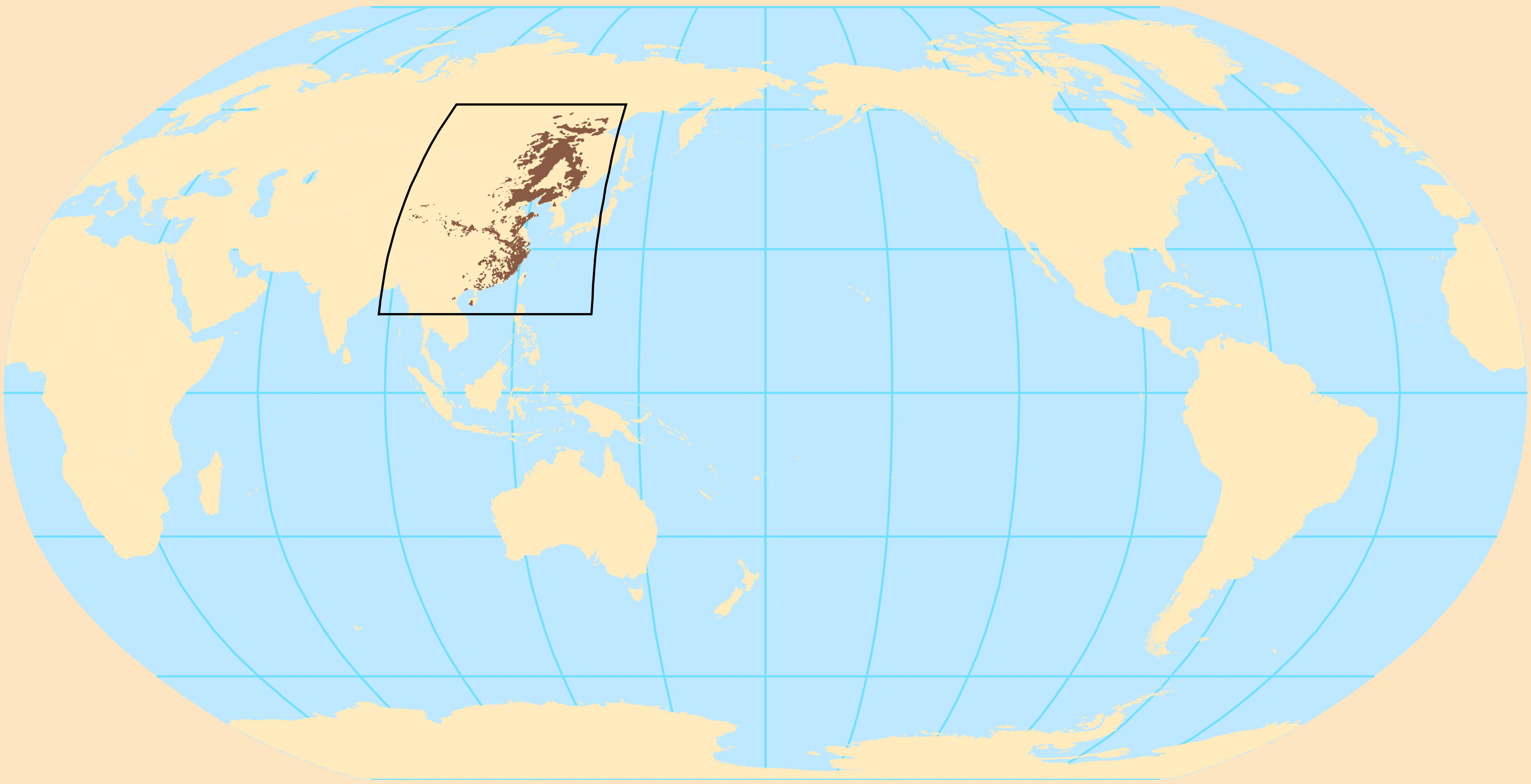
Global Mineral Resource Assessment

Porphyry Copper Assessment of the Mesozoic of East Asia—China, Vietnam, North Korea, Mongolia, and Russia



Prepared in cooperation with the Russian Academy of Sciences, China Geological Survey, Chinese Academy of Geological Sciences, the Coordinating Committee for Geoscience Programs in East and Southeast Asia, and XDM Geological Consultants, Inc.

Scientific Investigations Report 2010–5090–G

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

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By Steve Ludington, Mark J. Mihalasky, Jane M. Hammarstrom, Gilpin R. Robinson, Jr., Thomas P. Frost, Kathleen D. Gans, Thomas D. Light, Robert J. Miller, and Dmitriy Alexeiev; based on contributions of Yan Guangsheng, Lian Changyun, Mao Jingwen, Li Jinyi, Xiao Keyan, Qiu Ruizhao, Shao Jianbao, Zhai Gangyi, Du Yuliang, Arthur A. Bookstrom, and Andre Panteleyev

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Acronyms and Abbreviations Used in this report

ANOVA	analysis of variance
CIS	Commonwealth of Independent States
CCOP	Coordinating Committee for Geoscience Programs
CGS	China Geological Survey
GIS	Geographic Information Systems
kt	thousand metric tons
MASH	melt, assimilation, storage, and homogenization
Ma	million of years before the present
Mt	million metric tons
REE	rare-earth elements
SCLM	subcontinental lithospheric mantle
SHRIMP	sensitive high resolution ion microprobe
SSIB	small-scale digital internal boundaries
USGS	U.S. Geological Survey

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	4,047	square meter (m^2)
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 (T) (2,000 lb)	0.9072	megagram (Mg)
ton, short (T) (2,000 lb)	907.18474	kilogram (kg)
ton, short (T) (2,000 lb)	0.90718474	metric tons (t)

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
square centimeter (cm^2)	0.001076	square foot (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
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)

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Porphyry Copper Assessment of the Mesozoic of East Asia—China, Vietnam, North Korea, Mongolia, and Russia

By Steve Ludington[1], Mark J. Mihalasky[2], Jane M. Hammarstrom[3], Gilpin R. Robinson, Jr.[3], Thomas P. Frost[2], Kathleen D. Gans[1], Thomas D. Light[2], Robert J. Miller[1], and Dmitriy Alexeiev[4]; based on contributions of Yan Guangsheng[5], Lian Changyun[5], Mao Jingwen[6], Li Jinyi[5], Xiao Keyan[5], Qiu Ruizhao[5], Shao Jianbao[5], Zhai Gangyi[5], and Du Yuliang[5], Arthur A. Bookstrom[2], and Andre Panteleyev[7]

Abstract

The U.S. Geological Survey (USGS) collaborated with the China Geological Survey (CGS) to conduct a mineral resource assessment of Mesozoic porphyry copper deposits in East Asia. This area hosts several very large porphyry deposits, exemplified by the Dexing deposit in eastern China that contains more than 8,000,000 metric tons of copper. In addition, large parts of the area are undergoing active exploration and are likely to contain undiscovered porphyry copper deposits.

Three tracts were delineated to be permissive for Mesozoic porphyry copper deposits in East Asia: the Manchuride, Coastal Pacific, and East Qinling tracts, all Jurassic through Cretaceous in age. The tracts are based on mapped and inferred subsurface distributions of igneous rocks that define areas where the occurrence of porphyry copper deposits is possible. These tracts range in area from about 170,000 to about 1,400,000 km^2. Although maps at a variety of scales were used in the assessment, the final tract boundaries are intended for use at a scale of 1:1,000,000.

These Mesozoic deposits in East Asia all formed in post-subduction environments, environments newly recognized as permissive for the occurrence of porphyry copper deposits. Based on the grade, tonnage, and geologic characteristics of the known deposits, two tracts, Manchuride and Coastal Pacific, were evaluated using the general (Cu-Mo-Au) porphyry copper grade and tonnage model. The East Qinling tract was evaluated using the molybdenum-rich (Cu-Mo) model. Assessment participants estimated numbers of undiscovered deposits at different levels of confidence for each permissive tract. These estimates were then combined with the selected grade and tonnage models using Monte Carlo simulation to generate quantitative probabilistic estimates of undiscovered resources. Resources in future extensions of deposits with identified resources were not specifically evaluated.

Assessment results, presented in tables and graphs, show mean amounts of metal and rock in undiscovered deposits at different quantile levels, as well as the arithmetic mean for each tract. This assessment estimated a mean total of about 44 undiscovered porphyry copper deposits within the assessed permissive tracts in East Asia. This represents nearly 4 times the 12 known deposits. Predicted mean (arithmetic) resources that could be associated with these undiscovered deposits are about 198,000,000 metric tons (t) of copper and about 3,900 t of gold, as well as byproduct molybdenum and silver. The reported identified resources for those 12 known deposits total about 23,000,000 t of copper and about 850 t of gold. The assessment area is estimated to contain nearly nine times as much copper in undiscovered porphyry copper deposits as has been identified to date.

This report includes an overview of the assessment results and summary tables. Descriptions of each tract are included in appendixes, with estimates of numbers of undiscovered deposits, and probabilistic estimates of amounts of copper, molybdenum, gold, and silver that could be contained in undiscovered deposits for each permissive tract. A geographic information system that accompanies the report includes tract boundaries and a database of known porphyry copper deposits and prospects.

Introduction

Mesozoic porphyry copper deposits in eastern China, Mongolia, and Russia are part of an important copper

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province, one that provides much of China's copper. The area hosts Dexing, which contains more than 8,000,000 metric tons (t) of copper (Cu) and is China's largest operating copper mine. In addition, the study area hosts five more large porphyry copper deposits with more than 1,000,000 t of copper: Wunugetushan, Chengmenshan, and Zijinshan in China and Shakhtama and Bystrinskoe in Russia. Six other porphyry copper deposits have been reported (table 1), and there are numerous prospects in the assessed region (fig. 1).

Dexing has been in operation since at least the 1970s, and copper has been mined from high-grade vein and skarn deposits in eastern China for thousands of years. Most of the deposits in this region contain important amounts of molybdenum (Mo), gold (Au), and silver (Ag), all of which will be important byproducts in undiscovered deposits there.

The U.S. Geological Survey (USGS) conducted a probabilistic mineral-resource assessment of undiscovered resources in Mesozoic porphyry copper deposits in East Asia as part of a global mineral resource assessment. The purpose of the assessment was to (1) compile a database of known porphyry copper deposits and significant prospects, (2) delineate permissive areas (tracts) for undiscovered porphyry copper deposits at a scale of 1:1,000,000, (3) estimate numbers of undiscovered deposits within those permissive tracts, and (4) provide probabilistic estimates of the amounts of copper (Cu), molybdenum (Mo), gold (Au), and silver (Ag) that could be contained in those undiscovered deposits. The study was conducted in part in cooperation with the China Geological Survey (CGS) between 2002 and 2010. This document describes permissive areas for deposits of Mesozoic age within a geographic region (fig. 1) that includes much of eastern China, a small part of eastern Mongolia, and small areas in adjacent Russia, Korea, and Vietnam.

This assessment report includes an overview of the results, and summary tables. Detailed descriptions of each tract are included in appendixes, which include estimates of numbers of undiscovered deposits, and probabilistic estimates of amounts of copper, molybdenum, gold, and silver that could be contained in undiscovered deposits for each permissive tract. A database and map prepared using the geographic information system accompany the report, and include tract boundaries and a database of known porphyry copper deposits and significant prospects.

The assessment was conducted using the three-part form of mineral-resource assessment based on established mineral deposit models (Singer 1993, 2007a, b; Singer and Berger, 2007; Singer and Menzie, 2010). In the three-part form of mineral-resource assessment, geographic areas (permissive tracts) are delineated using geologic, geochemical, mineral occurrence, and geophysical data to identify areas with features typical of the type of deposit under consideration. In this study, three permissive tracts were defined: the northernmost Manchuride permissive tract (142pCu8509) in northern China, western Mongolia, North Korea, and Russia; the East Qinling permissive tract (142pCu8705) in central China; and the Coastal Pacific permissive tract (142pCu8704) in coastal southeastern China and Vietnem (fig. 1). Secondly, the amount of metal in undiscovered deposits is estimated using grade and tonnage models derived from information about known deposits. Probabilistic estimates of numbers of undiscovered deposits are consistent with the known deposits that define grade and tonnage models (Singer, 2007a). And thirdly, estimates are made at different confidence levels using a variety of estimation strategies to express the degree of belief that some fixed but unknown number of deposits exists within the permissive tract. These estimates are measures of the favorability of the tract and of the estimator's uncertainty about what may exist (Singer, 2007a).

Eastern Asia is an area of active mineral exploration, by both Chinese and international companies. This report reflects the status of porphyry copper exploration projects known to the authors as of August 2011. The supply of copper is important for Chinese industry, and continued exploration for and development of porphyry copper deposits is likely. Exploration in China, as elsewhere in the world, is presently focused on precious-metal deposits, due to current elevated prices, but porphyry copper systems may be associated with some precious-metal deposits and may be present in other parts of large exploration concessions under study for precious metals.

Terminology

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

•*Mineral deposit*—An occurrence of a valuable commodity or mineral that is of sufficient size and grade that it might, under the most favorable of circumstances, be considered to have potential for economic development.

•*Undiscovered mineral deposit*—A mineral deposit that is believed to exist or an incompletely explored mineral occurrence or prospect that could have sufficient size and grade to be classified as a deposit.

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

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

•*Permissive tract*—The surface projection of a volume of rock whose geologic characteristics permit the existence of a mineral deposit of a specified type. The probability that deposits of the type being studied occur outside the boundary

Table 1. Summary of identified resources in Mesozoic porphyry copper deposits of East Asia.

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

Tract	Tract name	Deposit name	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)	Contained Mo (t)	Contained Au (t)
142pCu8509	Manchuride	Shakhtama	153	1,100	0.26	0.06	0.09	n.d.	2,860,000	660,000	99
		Zhireken	158	130	0.1	0.099	n.d.	n.d.	130,000	129,000	n.d.
		Bystrinskoe	Jurassic	349	0.7	n.d.	0.81	3.63	2,440,000	n.d.	283
		Xiaosigou	106	18	0.73	0.086	n.d.	n.d.	131,000	15,500	n.d.
		Wunugetushan	184	558	0.4	0.05	n.d.	n.d.	2,230,000	279,000	n.d.
142pCu8704	Coastal Pacific	Tongchankou	143	45	0.94	0.04	n.d.	n.d.	419,000	17,800	n.d.
		Fengshandong	144	105	0.38	0.05	0.37	20	399,000	52,500	39
		Chengmenshan	144	409	0.75	0.047	0.24	9.9	3,070,000	192,000	98
		Dexing	171	1,825	0.459	0.016	0.12	1.9	8,380,000	292,000	219
		Yinshan	178	83	0.52	n.d.	0.8	n.d.	432,000	n.d.	66
		Zijinshan	105	356	0.49	n.d.	0.14	6	1,740,000	n.d.	50
142pCu8705	East Qinling	Jinduicheng	138	1,400	0.028	0.091	n.d.	n.d.	390,000	1,270,000	n.d.
						Total			22,600,000	2,910,000	854

of the tract is negligible. In this report, the term is commonly abbreviated to "tract."

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

•*Identified resources*—Resources whose location, grade, quality, and quantity are known or can be estimated from specific geologic evidence. For this assessment, identified resources are those in the porphyry copper deposits included in the grade and tonnage models used in the assessment (which can include measured, indicated, and inferred mineral resources at the lowest available cut-off grade). In addition, deposits that are not included in the models used for the assessment are considered to contain identified resources if they are characterized well enough to meet commonly used reporting guidelines.

•*S-type granite*—Granite in which geochemical and isotopic characteristics are primarily inherited through partial melting of a crustal sedimentary source.

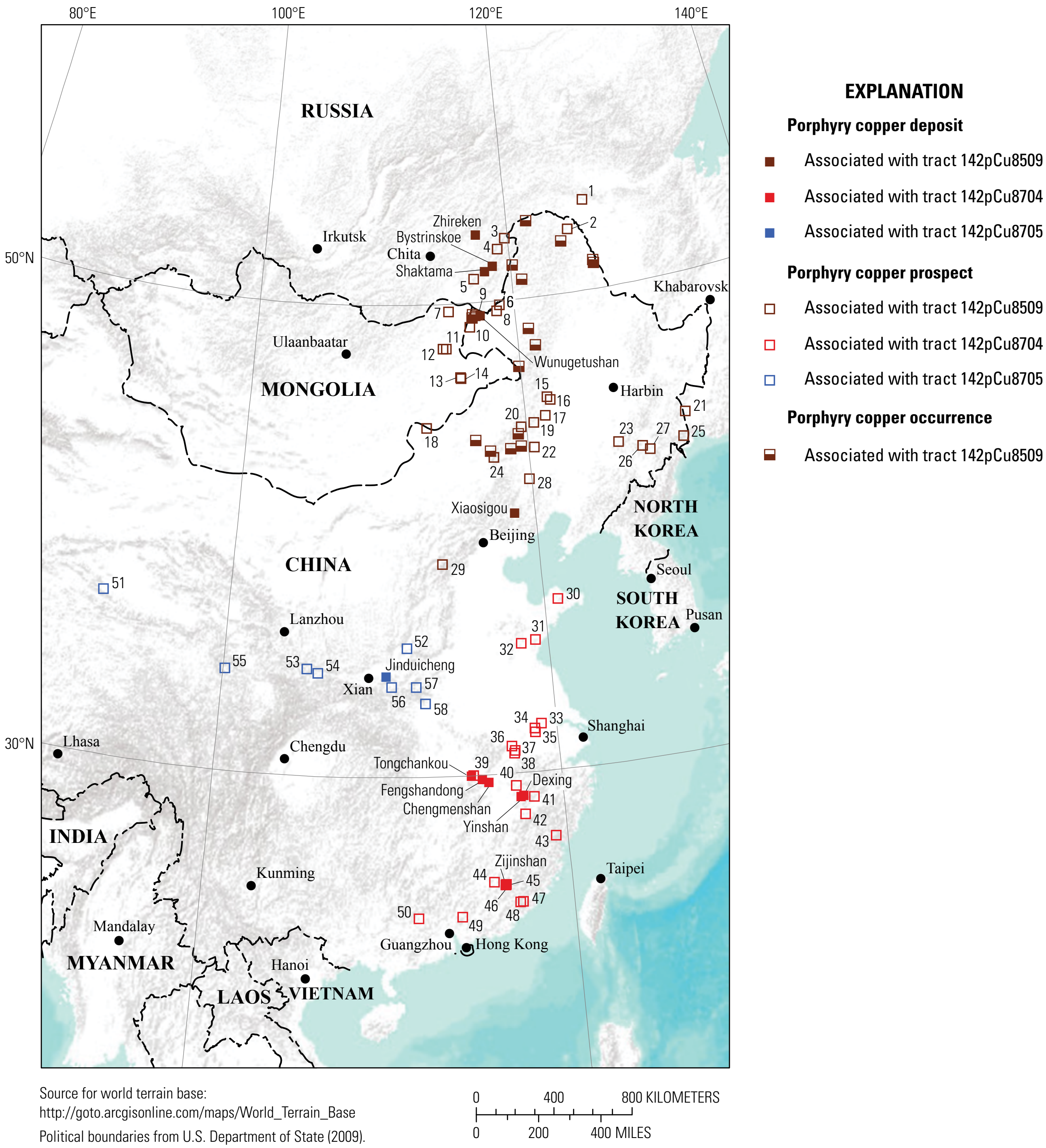
Report Format

This report begins with a discussion of descriptive and grade and tonnage models of porphyry copper deposits. This is followed by a discussion of the Mesozoic tectonic history of the region and how that history has influenced the emplacement of magmatic rocks and the formation of porphyry copper deposits. The next section consists of comments about the nature and quality of the data that was gathered for the assessment, followed by a brief discussion of the exploration history. Next, the processes used to delineate permissive tracts are described, and a brief description of the three tracts analyzed in this study is presented. The last section of the report describes the assessment process, including a description of how estimates of numbers of undiscovered deposits are made and a discussion of the assessment results and their significance.

There are six appendixes to the report. Assessment results for the three permissive tracts, Manchuride, Coastal Pacific, and East Qinling, are presented in tabular form in appendixes A, B, and C, respectively, along with brief descriptions of the deposits and prospects in the tracts, and references for that information. Detailed information about the porphyry copper deposits and prospects in the area is presented in tabular form in appendix D. Tract boundaries and point locations of significant deposits and prospects are included in a geographic information system (GIS) described in appendix E. Appendix F identifies the members of the assessment team.

Political Boundaries

The political boundaries used in this report are, in accord with U.S. Government policy, the small-scale digital international boundaries (SSIB) provided by the U.S. Department of State (U.S. Department of State, 2009). In various parts of the world, some political boundaries are in dispute. The use of the boundaries certified by the U.S. Department of State does not imply that the U.S. Geological Survey advocates or has an interest in the outcome of any international boundary disputes.



Source for world terrain base:
http://goto.arcgisonline.com/maps/World_Terrain_Base
Political boundaries from U.S. Department of State (2009).
Asia North Albers Equal Area Conic Projection.
Central meridian, 110° E., latitude of origin, 30° N.

Figure 1. Mesozoic porphyry copper deposits and prospects of East Asia. Sites are color coded by assessment tract: Brown, Manchuride (142pCu8509); Red, Coastal Pacific (142pCu8704); Blue, East Qinling (142pCu8705). Deposits are named on the map, prospects are numbered. Prospect names: 1, Borgulikan; 2, Twenty-one Station; 3, Lugokanskaya; 4, Kultuminskaya; 5, Kurunzulaiskaya; 6, Badaguan; 7, Advartolgoi; 8, Babayi; 9, Changling; 10, Group 6 and 7; 11, Bayantumen; 12, Davhar Uul; 13, Suul Tsagaan; 14, Zuun Matad; 15, Naoniushan; 16, Lianhuashan; 17, Budunhua; 18, Ulandler; 19, Aolonhua; 20, Aonaodaba; 21, Baikal; 22, Haoliabao; 23, Daheishan; 24, Yangchang; 25, Xiaoxinancha; 26, Shibadougou; 27, Xinhe; 28, Yajishan; 29, Houyu; 30, Shangjiazhuang; 31, Qibaoshan; 32, Duijinshan; 33, Anjishan; 34, Guli; 35, Taipingshan; 36, Shaxi; 37, Jingbian; 38, Bamaoshan; 39, Baiyunshan; 40, Dingjiashan; 41, Heishanling; 42, Yongping; 43, Wangjiazhuang; 44, Hongshan; 45, Zhongliao; 46, Luoboling; 47, Jinxi; 48, Zhongteng; 49, Guifeng; 50, Yuanzhuding; 51, Yemaquan; 52, Jiangligou; 53, Wenquan; 54, Taiyangshan; 55, Deemi; 56, Dan Feng; 57, Luocun; 58, Qiushuwan.

Considerations for Users of this Assessment

Ideally, assessments are done on a recurring basis, at a variety of scales, because available data change over time. This product represents a synthesis of current, readily available information as of August 2011. The assessment is based on the descriptive and grade-tonnage data contained in published mineral deposit models. Data in the grade and tonnage models represent the most reliable average grades available for each commodity of possible economic interest; the tonnages are based on the total of production, reserves, and resources at the lowest cutoff grade for which data were available when the model was constructed.

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

The mineral industry explores for extensions of identified resources, as well as for undiscovered deposits. Extensions of identified resources are not estimated in this assessment, although they are commonly a substantial part of newly discovered copper resources each year.

This assessment considers the potential for both exposed deposits and concealed deposits within 1 kilometer (km) of the surface. Very high grade deposits may be exploited at greater depths; however, it is not common. Exploration for and possible exploitation of these deeper deposits may be so expensive that they may not be discovered in the near term. If they are discovered, the cost to mine a deeply buried porphyry deposit may easily prohibit its development into a mine, 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. The tracts were constructed at a scale of 1:1,000,000 and are not intended for use at larger scales.

Porphyry Copper Deposit Models

Porphyry copper deposits typically form in subduction-related, compressional tectonic settings, during active subduction of oceanic or continental crust (Sillitoe, 2010; John and others, 2010). These deposits are associated with shallowly emplaced calc-alkaline plutons. The Andes range of South America is the classic province for continental arc magmatism (Kay and others, 1999; Richards and others, 2001). Magma associated with these deposits is typically hydrous, oxidized, and rich in sulfur and has likely undergone complex processes of differentiation and evolution at the crust/mantle boundary (Richards, 2003; John and others, 2010). Island arcs in the southwest Pacific Ocean are the archetypes of island arc magmatism (Garwin and others, 2005). Magma associated with island arc porphyry copper deposits is similar to that associated with continental arcs, but diorite, quartz diorite, and other more mafic rocks are somewhat more abundant (Kesler and others, 1975).

In recent years, evidence has accumulated for the existence of a family of porphyry copper deposits that formed in a significantly different tectonic setting: extensional or transpressional regimes that form within cratons after active subduction has ceased (Richards, 2009; Hou and others, 2011). The porphyry copper deposits on the Tibetan Plateau are the classic and original examples of this family (Hou and others, 2009), but similar deposits are found in comparable settings in Mesozoic rocks in eastern China, in the western United States, and in other parts of the world. The geology and mineralization style characteristic of these deposits are broadly similar to those of classic porphyry copper deposits; however, the magmas that form them originated from processes that are, as yet, poorly understood.

Richards (2009) presents a model that is based on the remelting of previously subducted arc lithosphere triggered by postsubduction lithospheric thickening, lithospheric extension, or mantle lithosphere delamination. Such previously subducted lithosphere would contain small amounts of chalcophile and siderophile element-rich sulfide minerals, and would be a fertile source for hydrous, oxidized, gold-rich (but comparatively sulfur-poor) magmas. In his view, the remelting is triggered by postsubduction lithospheric thickening, lithospheric extension, or mantle lithosphere delamination (fig. 2).

More recently, Hou and others (2011) have promulgated a model that involves partial melting of thickened juvenile mafic lower crust or delaminated lower crust, and that includes asthenospheric mantle components (fig. 3). The fertility of these magmas depends on the contribution of copper and gold from the mantle, thickened lower crust that has been metasomatized due to previous underplating, and the inclusion of crustal components (especially molybdenum) during crustal melting and magma ascent. They suggest that the formation of these magmas is triggered by asthenospheric upwelling, lithospheric delamination, and (or) large-scale translithospheric strike-slip faults or orogeny-transverse normal faults.

Both Richards (2009) and Hou and others (2011) stress that most magmas associated with postsubduction porphyry copper-gold deposits are mildly alkaline (shoshonitic), rather than calc-alkaline, and that they may form isolated complexes and (or) broad magmatic fields, in contrast to linear magmatic arcs. At this time, there is no evidence that these deposits in postsubduction environments have different grade/tonnage relationships from other porphyry copper deposits and there is no basis to create a grade and tonnage model specific to these deposits.

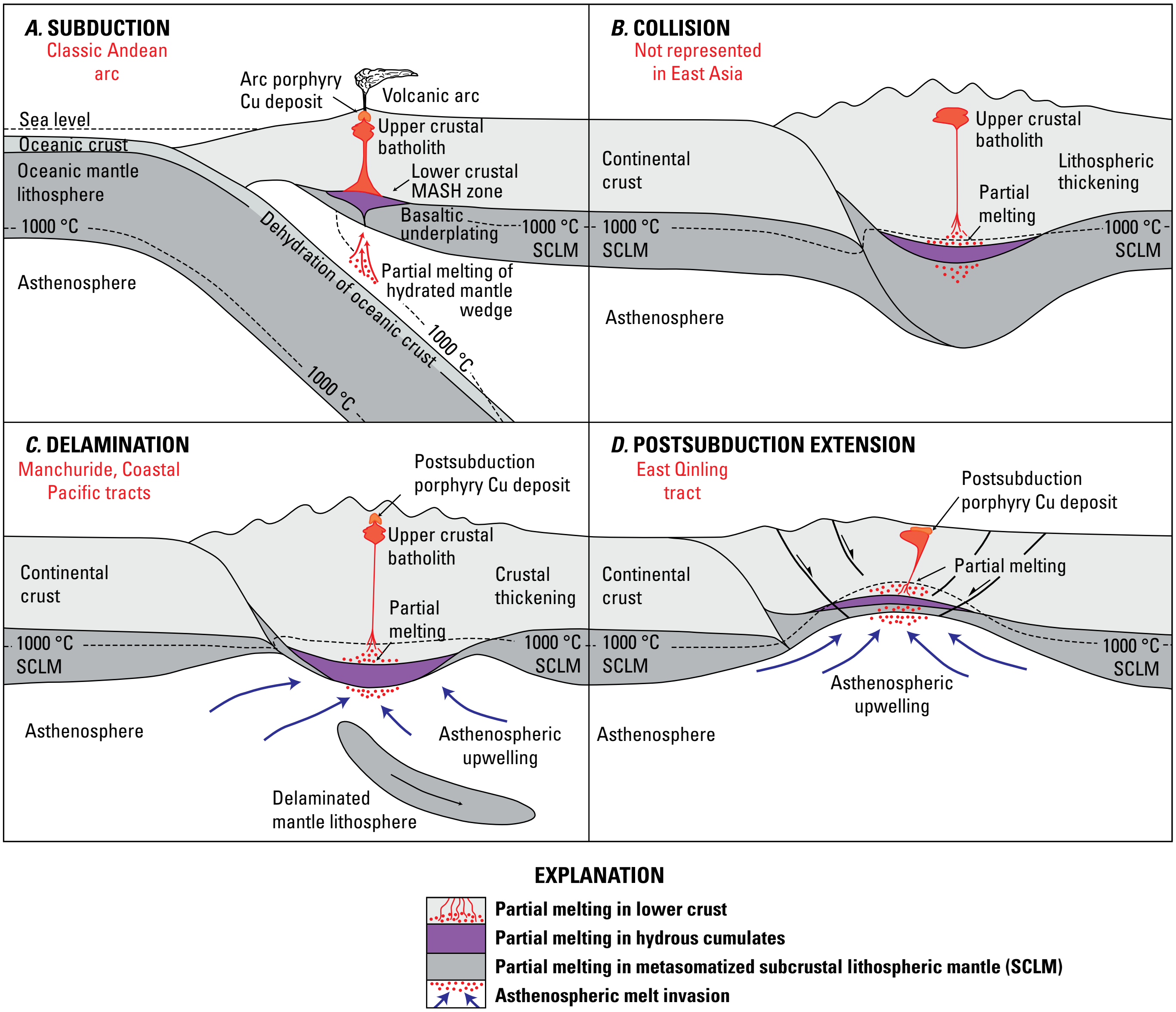


Figure 2. Subduction and postsubduction models for porphyry copper generation (after Richards, 2009). *A*, Normal arc magmatism. *B*, Collisional (compressive environment). *C*, Postcollisional mantle delamination (Manchuride and Coastal Pacific tracts). *D*, Postsubduction extension (East Qinling tract). MASH—melting, assimilation, storage, and homogenization. SCLM—subcontinental lithospheric mantle. In all cases, high Sr/Y magmas may be generated by residual or fractionating hornblende (±garnet, titanite).

Occurrence Models

Mineral deposit models used for this assessment include the porphyry copper models of Singer and others (2008), Cox (1986 a, b, c), and John and others (2010). The recent review of salient features of porphyry copper deposits by Sillitoe (2010) is also pertinent. The global porphyry copper database of Singer and others (2008) contains tabulated descriptive information along with grade and tonnage data. Discussions of porphyry copper deposits related to the special postsubduction setting of the East Asian deposits are given by Richards (2009) and Hou and others (2011).

Grade and Tonnage Models

The grade and tonnage models of Singer and others (2008) were used in this assessment. In addition to the global porphyry Cu-Mo-Au model that is based on data from 422 deposits, they identified two subtypes of porphyry copper deposit, Cu-Mo and Cu-Au, each with distinct grade and tonnage models. If sufficient reliable grade and tonnage data are available, the known deposits in a tract can be tested against the global models using statistical tests (t-test and (or) analysis of variance [ANOVA]). The Manchuride tract (142pCu8509)

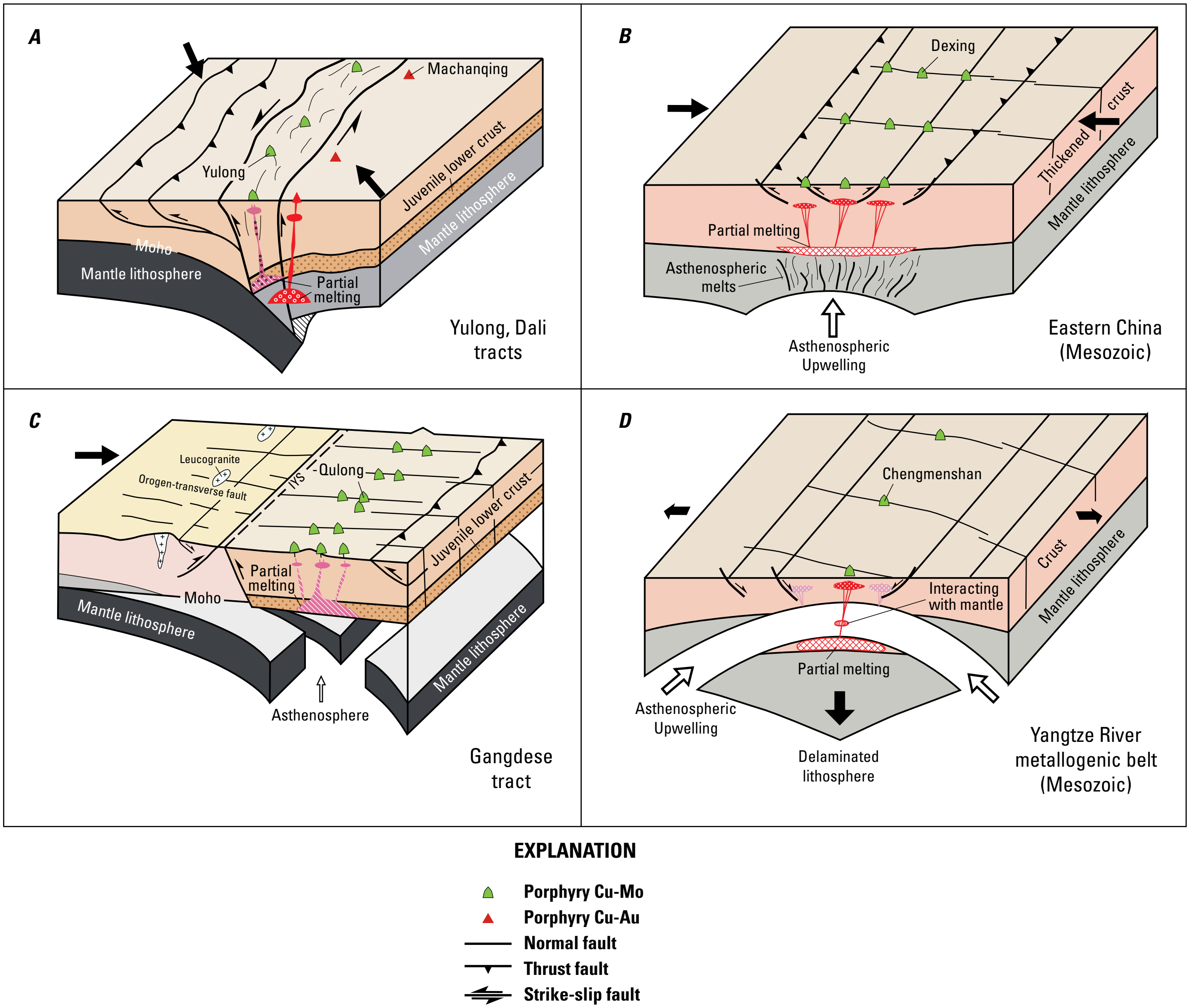


Figure 3. Models for porphyry copper deposits in nonarc settings (after Hou and others, 2011). *A*, Melting of lower crust triggered by translithospheric strike-slip faults in a late-collision, transpressional setting. *B*, Melting of thickened crust triggered by upwelling of asthenosphere in a postcollision, extensional setting. *C*, Melting of thickened, mafic lower crust, triggered by delamination of lithospheric root and upwelling of asthenosphere in an intracontinental, extensional setting. *D*, Melting of a delaminated lithospheric root and upwelling of asthenosphere in an anorogenic, extensional setting. The Yulong, Dali, and Gangdese tracts are described in a porphyry copper assessment of the Tibetan Plateau (Ludington and others, 2012). IYS, Indus-Yarlung-Tsangpo suture.

contains five sites that are considered deposits (table 1). Two of the deposits (Shaktama and Zhiriken) have extremely low (<0.3 percent) copper grades, whereas three of the five do not have a reported gold grade, and cutoff grades are not reported for any of the deposits. There is also conflicting information about grades for some of these deposits.

The Coastal Pacific tract (142pCu8704) contains seven known deposits, but only six with grade and tonnage data (table 1). Once again, the cutoff grades are not reported. A further complication in this tract is that several of the deposits contain substantial amounts of skarn ore, which is likely to have higher gold grades. The Zijinshan deposit, which has no reported molybdenum grade, has been called a high-sulfidation epithermal copper deposit.

The East Qinling tract contains only one deposit (Jinduicheng, table 1); it is primarily a molybdenum deposit and may be atypical of undiscovered deposits there. None of the identified prospects in the tract contain significant amounts of gold, but many Mesozoic porphyry molybdenum deposits occur, some with and some without important amounts of copper.

Statistical tests on the grade and tonnage data indicated that, taken as a whole, the deposits have too much molybdenum to be part of the global (Cu-Mo-Au) population or the copper-gold submodel and too much gold to be part of the copper-molybdenum submodel. These results are largely a result of varied (but unknown) cutoff grades, uncertainties regarding deposit classification, and incompletely characterized deposits. These uncertainties mean that the existing data are unreliable as indicators of the deposits likely to be discovered in this area. Accordingly, the global (Cu-Mo-Au) porphyry copper grade and tonnage model was used to assess the Manchuride and Coastal Pacific tracts and the porphyry copper-molybdenum submodel was used to assess the East Qinling tract. The available data suggest that the overall size distribution of the known Mesozoic deposits in East Asia is comparable (fig. 4) to that in the global model of Singer and others (2008).

Tectonic Setting

The porphyry copper deposits in East Asia described here formed after the amalgamation of the Asian continent, primarily in postsubduction settings. The magmatism associated with these deposits occurred during the Yanshanian orogeny, mostly during the Jurassic and Cretaceous periods. In the Chinese literature, this orogeny refers to Mesozoic events that are younger than the Indosinian orogeny.

The Indosinian orogeny refers to the East Asian collisional tectonic events associated with the closure of the eastern parts of the Paleo-Tethys Ocean and the formation of the Asian continent. Collisions occurred between the Sino-Korean Craton (North China) and the Yangtze Craton (South China) (fig. 5), and Indochina and Sibumasu[8] in southeast Asia. These collisions are essentially contemporaneous with the closure of the Solonker Suture, which marked the disappearance of the Paleo-Asian Ocean (Windley and others, 2007, 2010; Wilhelm and others, 2012). Controversy abounds regarding the usage of the Indosinian, but the important point is that by Late Triassic time, north-directed subduction of the Paleo-Tethys Ocean had ceased, the Paleo-Asian Ocean had been consumed, and the evolution of the Central Asian Orogenic Belt came to an end.

Before 1990, the Yanshanian igneous rocks in southeast China (Coastal Pacific tract) were commonly thought to have been derived from a typical continental-margin arc. But subsequently, Li (2000) and Xu and others (2002) proposed that many of these rocks, particularly the Cretaceous ones, formed primarily in a postsubduction, extensional tectonic regime. Numerous later papers support this idea. Extensive petrologic studies have led to a model that calls on partial melting of delaminated lower crust, unrelated to active subduction, to form these igneous rocks (for example, Xu and others, 2002; Wang and others, 2006; Windley and others, 2010). Subduction of the Pacific Plate remains a plausible origin and may well apply to the Jurassic rocks (Wang and others, 2011). Unfortunately, available geologic maps did not permit separation of Jurassic from Cretaceous rocks.

Northeast China (Manchuride tract) presents a similar story. Although a postsubduction origin for the Cretaceous igneous rocks is widely accepted (Deng and others, 2007; Zhai and others, 2007; Windley and others, 2010), strong arguments for a Pacific Plate subduction origin for the Jurassic rocks can be made (Zhang and others, 2011; Zeng and others, 2012). The distribution of the Yanshanian igneous rocks coincides generally with a large area of thinned crust and lithosphere. Most of the rocks are within and east of a major north-south gravity lineament that separates thick crust with few Yanshanian plutons on the west from thinner crust punctuated by numerous intrusions on the east (Windley and others, 2010).

The origin of the East Qinling magmatic belt, which is superimposed on and generally coincides with the Indosinian Qinling-Dabie collisional orogen, is problematic because the igneous rocks extend far inland, well to the west of the magmatic fields to the north and south (fig. 5). In the East Qinling molybdenum belt (fig. 5), the ages of the important porphyry deposits indicate two major mineralization events—one about 148 to 138 Ma and a second about 131 to 112 Ma (Mao and others, 2008). They also have strontium isotopic ratios that suggest the involvement of considerably more continental crust. Mao and others (2008) and Zhang and others (2009) call on mantle upwelling after lithospheric delamination for most of these rocks but allow that the subducted Paleopacific Plate could play a role in magmatism. The long (>2,000 km) linear shape of this magmatic belt indicates that the faults of the older Qinling-Dabie orogen were reactivated in Yanshanian time and played a

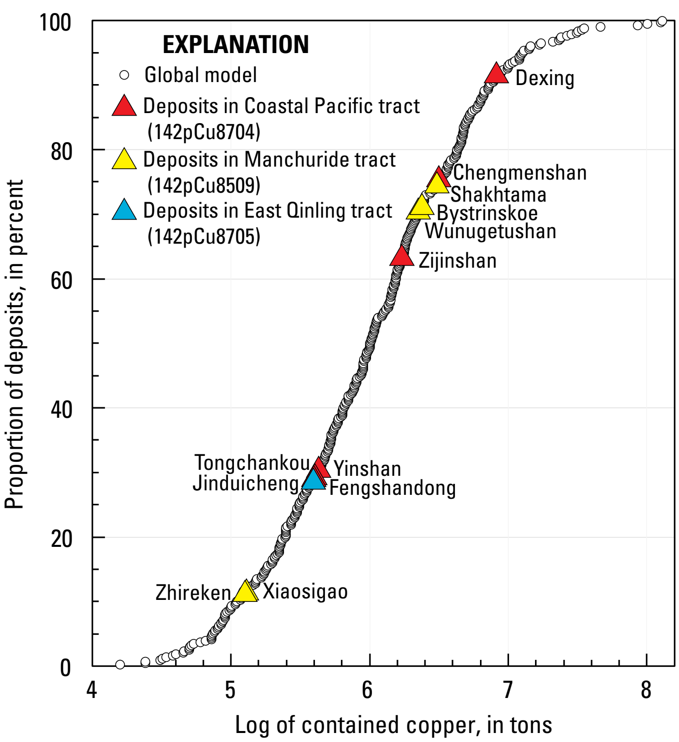
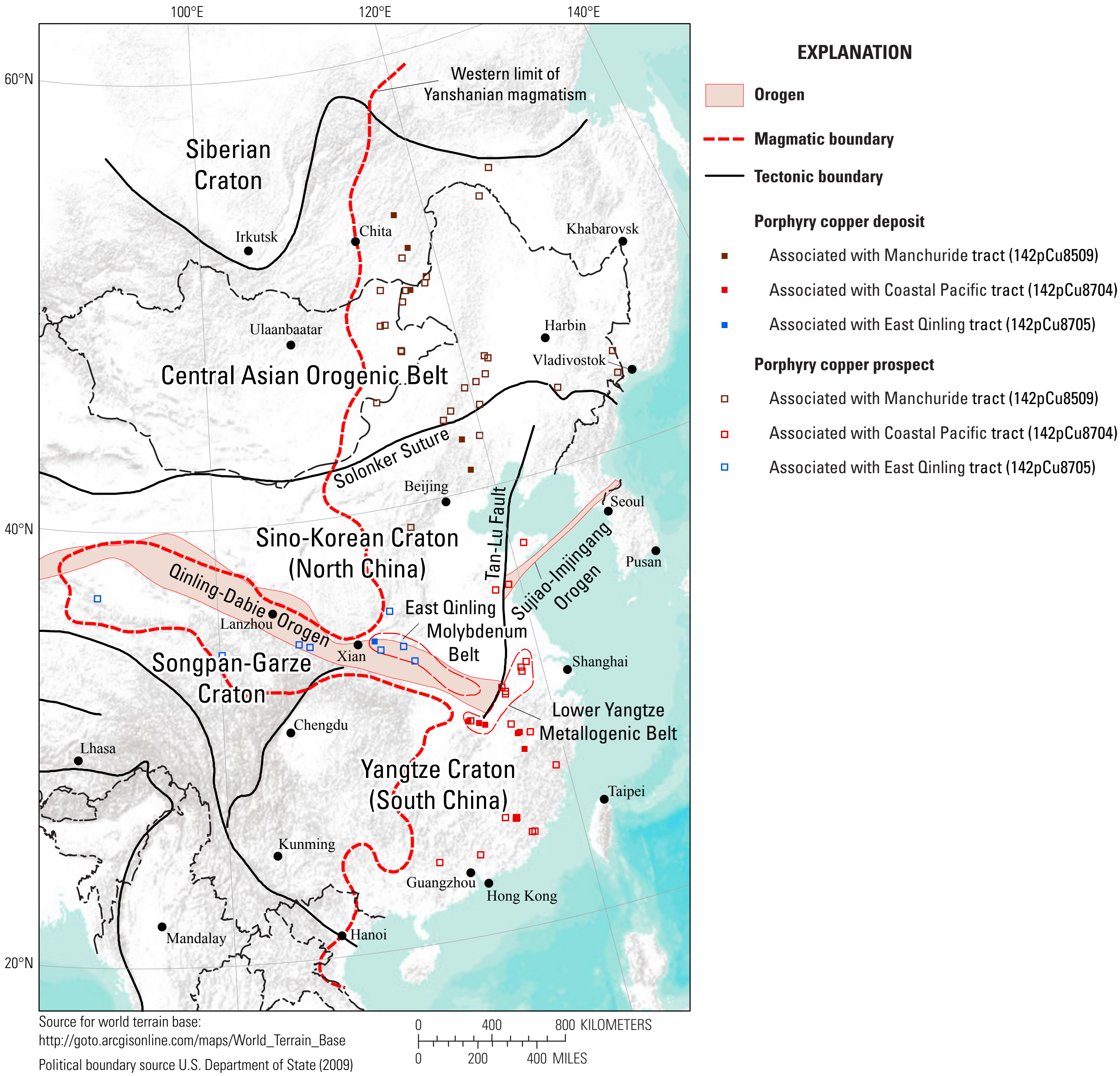


Figure 4. Cumulative frequency plot showing tonnages of East Asia Mesozoic porphyry copper deposits compared to global deposits from the grade-tonnage model of Singer and others (2008).

[8]A name for a continental basement block including parts of Siam, Burma, Malaya, and Sumatra.

role in providing access through the crust for the melts, whatever their origin.

The key evidence for a nonsubduction origin for the Yanshanian rocks is the width of the magmatic zones, the lack of synmagmatic compressional structures, and the thickness of the lower crust and lithospheric mantle. The width of the magmatic zones (>1,000 km) is greater than that observed (50–200 km) in most continental-margin arcs (Li, 2000; Li and Li, 2007; Hu and Zhou, 2012; Mao and others, 2012). Compressional structures that affect the plutons and volcanic rocks are lacking; in general, the plutons often cut preexisting structures. Finally, geophysical evidence (gravity and tomography) indicates that a large amount of lower crust and lithospheric mantle that was likely present beneath the area at the end of the Indosinian orogeny has been subsequently removed (Zhai and others, 2007; Windley and others, 2010), although the exact timing of the delamination is not determined. The area resembles the Cenozoic Basin and Range Province of western North America, where abundant postsubduction magmatism is associated with a wide variety of metallic mineral deposits.



Source for world terrain base:
http://goto.arcgisonline.com/maps/World_Terrain_Base

Political boundary source U.S. Department of State (2009)
Projection: Asia North Albers Equal Area Conic;
Central meridian; 95° E; Latitude of origin; 30° N

Figure 5. Simplified tectonic sketch map of East Asia.

Composition of magmatic rocks of Yanshanian age in the area range from gabbro and basalt to granite and rhyolite (Pirajno and others, 2009; Hu and Zhou, 2012; Mao and others, 2012). The majority of the granitoids are I-type, but S- and A-types are also prominent in some regions at some times. The widespread occurrence of Yanshanian tungsten and tin granite-related deposits in southeast China suggests that many of those plutons are reduced ilmenite-type granitoids (Ishihara, 2007). In northeast China, numerous molybdenum-rich porphyry deposits of both Jurassic and Cretaceous age are primarily associated with high-K calc-alkaline granodiorite, monzogranite, and granite (Zeng and others, 2012).

Both Hu and Zhou (2012) and Mao and others (2012) present similar metallogenic schemes that indicate systematic variation in petrochemistry, tectonic setting, and the resultant metallogeny throughout Yanshanian time. When these schemes can be incorporated into the attribution of available digital geologic maps, it will be feasible to considerably refine the boundaries of the permissive tracts in East Asia.

Lower Yangtze River Metallogenic Belt

The valley of the lower Yangtze River has been the site of repeated emplacement of porphyry copper and related deposits. This metallogenic belt (fig. 5) has been an important mining area in China for centuries and is the site of hundreds of Cu, Cu-Au, and Cu-iron (Fe) mineral deposits (Pan and Dong, 1999; Zhao and others, 1999). It contains three of the porphyry copper deposits in the Coastal Pacific tract (Tongshankou, Fengshandong, and Chenmengshan). Most of the deposits in the belt are made up of massive skarn and replacement ores, but all are related to granitoid rocks (mostly granodiorites and monzodiorites) emplaced in this belt from Late Jurassic to Early Cretaceous time (approximately 150 to 120 million years before the present (Ma); Li and others, 2010; Mao and others, 2006). The origin of the igneous rocks of the belt is a contentious issue, but it is generally accepted, based on strontium and neodymium isotopic data, that they are of mantle origin, but with a substantial continental crustal component (Pan and Dong, 1999). Arguments about why so many Yanshanian deposits are localized here focus on the juncture between the preexisting (Permo-Triassic) Qinling-Dabie orogen and the contemporaneous Tan-Lu Fault.

The Adakite Issue

Adakite is a term that is commonly used in the Chinese literature to mean igneous rocks with trace-element compositions that suggest an origin by melting of metabasaltic crust at pressures high enough to stabilize garnet, probably at depths of as much as 100 km (Xiao and Clemens, 2007). The most diagnostic parameters are high (> 20) strontium/yttrium (Sr/Y) and steep chondrite-normalized REE patterns (lanthanum/ytterbium (La/Yb) >20). Although the original definition (Defant and Drummond, 1990) was closely linked to an origin by direct melting of a subducting oceanic slab, the term "adakite" has been subsequently applied to rocks from other petrotectonic settings. Indeed, in a comprehensive review that documents the history of the evolution of the meaning of the term, Castillo (2006) pointed out that there is no single model for the origin of the rocks defined by these geochemical criteria.

Most of the rocks associated with the East Asian porphyry copper deposits have been classified in the literature as adakites, and a correlation between porphyry copper deposits and adakitic compositions has been noted in many parts of the world (Thiéblemont and others, 1997; Mungall, 2003). Direct melting of the slab, however, has been shown to be unsatisfactory as a unique factor in the genesis of porphyry copper deposits (Richards and Kerrich, 2007). Although the idea that plutons that give rise to porphyry copper deposits commonly have high Sr/Y and La/Yb seems valid, we avoid the use of the term "adakite" whenever possible in this assessment.

Assessment Data

Principal sources of information used by the assessment team for delineation of the tracts and compilation of deposits and prospects are listed in table 2.

Geologic Maps

Geologic maps at a variety of scales were used for tract delineation during the assessment. For China, unpublished digital versions of geological maps of the Chinese provinces that were published as part of a collection of Geologic Memoirs by the Chinese Ministry of Geology and Mineral Resources from 1984 through 1993 were used. In addition, the digital geologic map of China, based on the 1:2,500,000 scale map by the China Geological Survey (2004a), was consulted. Although this map is at a smaller scale than those in the geologic memoirs, it incorporates significant new petrologic and radiometric age data gathered in the 1990s. For Mongolia, a digital version of the 1:1,000,000 scale geologic map of Mongolia compiled by Tomurtogoo and others (1999) was used; this is a compilation based on mapping at various scales. For Russia, a digital version of the 1:2,500,000 scale map of Russia and the CIS Countries[9] published by the A.P. Karpinsky All-Russia Geological Research Institute (Petrov and Streinikov, 2008) was used.

The digital geologic maps do not always reflect the most recent radiometric age determinations or petrologic studies on the rocks in the tract; in many cases, ages of the igneous rocks are not accurately known. Many of the small plutons that host porphyry copper deposits in the region are too small to be depicted on the source maps, and the locations of some additional plutons were digitized based on available small-scale schematic maps.

[9]Commonwealth of Independent States (11 former U.S.S.R. republics).

Table 2. Principal sources of information used for assessment of Mesozoic porphyry copper in East Asia.

[NA, not applicable]

Theme	Name or Title	Scale	Citation
Geology	Regional Geology of Anhui Province	1:500,000	Bureau of Geology and Mineral Resources of the Anhui Province (1987)
	Regional Geology of Fujian Province	1:500,000	Bureau of Geology and Mineral Resources of the Fujian Province (1985)
	Regional Geology of Gansu Province	1:1,000,000	Bureau of Geology and Mineral Resources of the Gansu Province (1989)
	Regional Geology of Guandong Province	1:1,000,000	Bureau of Geology and Mineral Resources of the Guangdong Province (1988)
	Regional Geology of the Guangxi Zhuang Autonomous Region	1:1,000,000	Bureau of Geology and Mineral Resources of the Guangxi Zhuang Autonomous Region (1985)
	Regional Geology of Hebei Province	1:500,000	Bureau of Geology and Mineral Resources of the Hebei Province (1989)
	Regional Geology of Heilongjiang Province	1:1,000,000	Bureau of Geology and Mineral Resources of the Heilongjiang Province (1993)
	Regional Geology of Henan Province	1:500,000	Bureau of Geology and Mineral Resources of the Henan Province (1989)
	Regional Geology of Hubei Province	1:500,000	Bureau of Geology and Mineral Resources of the Hubei Province (1990)
	Regional Geology of Hunan Province	1:500,000	Bureau of Geology and Mineral Resources of the Hunan Province (1988)
	Regional Geology of Jiangsu Province	1:500,000	Bureau of Geology and Mineral Resources of the Jiangsu Province (1984)
	Regional Geology of Jianxi Province	1:500,000	Bureau of Geology and Mineral Resources of the Jiangxi Province (1984)
	Regional Geology of Jilin Province	1:500,000	Bureau of Geology and Mineral Resources of the Jilan Province (1989)
	Regional Geology of Liaoning Province	1:500,000	Bureau of Geology and Mineral Resources of the Liaoning Province (1989)
	Regional Geology of Nei Mongol (Inner Mongolia) Autonomous Region	1:1,500,000	Bureau of Geology and Mineral Resources of the Nei Mongol Autonomous Region (1991)
	Regional Geology of Qinghai Province	1:1,000,000	Bureau of Geology and Mineral Resources of the Qinghai Province (1991)
	Regional Geology of Shaanxi Province	1:500,000	Bureau of Geology and Mineral Resources of the Shaanxi Province (1989)
	Regional Geology of Shandong Province	1:500,000	Bureau of Geology and Mineral Resources of the Shandong Province (1991)
	Regional Geology of Shanxi Province	1:500,000	Bureau of Geology and Mineral Resources of the Shanxi Province (1987)
	Regional Geology of Sichuan Province	1:1,000,000	Bureau of Geology and Mineral Resources of the Sichuan Province (1991)
	Regional Geology of Xinjiang Uygur Autonomous Region	1:1,500,000	Bureau of Geology and Mineral Resources of the Xinjiang Uygur Autonomous Region (1993)
	Regional Geology of Zhejiang Province	1:500,000	Bureau of Geology and Mineral Resources of the Zhejiang Province (1989)
	Geological Map of Russia and CIS Countries	1:2,500,000	Petrov and Streinikov (2008)
	Geological Map of Mongolia	1:1,000,000	Tomurtogoo and others (1999)
	Geological map of the People's Republic of China	1:2,500,000	China Geological Survey (2004a)
Mineral occurrences	Porphyry copper deposits of the world: database, map, and grade and tonnage models	NA	Singer and others (2008)
	World Minerals Geoscience database	NA	Natural Resources Canada (2010); Kirkham and Dunne (2000)
	Mineral Resources Data System	NA	U.S. Geological Survey (2005)
	Mineral Resources Map of East Asia	NA	Kamitani and others (2007)
Stream-sediment geochemistry	Copper geochemical map	1: 12,000,000	National Geological Archives of China (2010a)
	Bismuth geochemical map	1: 12,000,000	National Geological Archives of China (2010b)
Aeromagnetics	Magnetic anomaly map of the (delta T)$_a$ field of the USSR territory and some adjacent water areas	1: 10,000,000	Ministry of Geology of the USSR All-union Order of Lenin Geological Research Institutue (VSEDGD) (1978)
	EMAG2-Earth Magnetic Anomaly Grid	2 arc-minute resolution	National Geophysical Data Center (2009)
	Magnetic anomaly map of the People's Republic of China and its adjacent waters	1: 5,000,000	China Geological Survey (2004b)

Mineral Occurrence Data

A global database of porphyry copper deposits and prospects published by Singer and others (2008) was supplemented with other global and regional mineral occurrence databases, including that of the Geological Survey of Canada (Natural Resources Canada, 2010; Kirkham and Dunne, 2000) and databases prepared by the Geological Survey of Japan (Kamitani and others, 2007). In addition, commercially available databases (InfoMine, Intierra, Metals Economic Group), technical reports, company websites, and geologic literature were consulted. The U.S. Geological Survey Mineral Resources Data System (MRDS), an online searchable database, also includes information on mines, prospects, and mineral occurrences worldwide (U.S. Geological Survey, 2005).

Sites were classified as deposits (grade and tonnage well delineated) or prospects (incompletely characterized with respect to grade and tonnage) on the basis of recent published literature. The deposit-type classification of some sites is ambiguous because of insufficient information. Deposits and prospects that could be classified with some certainty as porphyry copper or porphyry-copper-related are included in the database for this report (appendix D). Some sites, for which minimal information was available, are termed occurrences in appendix D and are not plotted on maps. Distributions of gold placers, copper- and copper-gold skarns, and epithermal precious-metal deposits, as well as unclassified copper and gold occurrences, were considered during the assessment, but those deposits are generally not included in the database. Some skarns were included if an associated porphyry system could plausibly be inferred.

Geochemical Data

Stream-sediment geochemistry has been very important for mineral exploration in China. Beginning in 1978, the Regional Geochemistry-National Reconnaissance project covered more than 6,000,000 km^2 of the territory of China, and it has been directly responsible for the discovery of hundreds of mineral deposits, including several porphyry copper deposits (Xie and others, 2008). Although the data themselves are not available to the public, the China Geological Survey has made numerous national maps for specified elements available on the internet. Maps (National Geological Archives of China, 2010a, b) that show the distribution of copper and bismuth were used to help refine the tracts defined in this study.

Other Data

Global magnetic anomaly data cover most of southern and eastern Asia (National Geophysical Data Center, 2009). The data are at 2-arc-minute resolution and display primarily broad, relatively deep magnetic features; however, because they do not correlate well with mapped outcrops of permissive rocks, they were of limited use. The 1:5,000,000-scale aeromagnetic map of China (China Geological Survey, 2004b) and the magnetic anomaly map of the USSR (Ministry of Geology of the USSR All-Union Order of Lenin Geological Research Institute, 1978; Racey and others, 1996) were similarly of limited use.

Exploration History

In many parts of the world, porphyry copper exploration has been cyclic, in response to changing global economic trends and the evolution of local infrastructure. Exploration for porphyry copper deposits in East Asia is in its initial cycle. The porphyry copper deposit model was not well known in China until the 1960s, when scientific and industrial activity was renewed after a long period of warfare and internal turmoil. Subsequently, basic geologic mapping as well as detailed geochemical and geophysical surveys have been completed, resulting in the discovery of numerous porphyry copper deposits and prospects (Wang and others, 2004; Xie and others, 2008).

A few non-Chinese international companies have operated in the region since about 1990, but most exploration activity has been conducted by State entitities; little information is publically available and the work is not well documented in the English language literature. In Russia and Mongolia, many of the prominent exposed porphyry systems were discovered prior to 1991 and information developed at that time is difficult to access. Recent private-sector exploration using modern methods is expected to result in new discoveries, as exemplified by the discovery in the late 1990s of the giant Oyu Tolgoi porphyry copper deposit in Mongolia (Perelló and others, 2001).

The Assessment Process

A workshop attended by USGS and CGS scientists was held in Kunming, China, in September of 2005. At this meeting, preliminary tracts were delineated using nondigital methods. The CGS published the outlines of these tracts along with an associated quantitative resource assessment based on them (Yan and others, 2007). Meanwhile, assessment technology continued to evolve, and in 2009, the USGS decided to standardize procedures for the global mineral resource assessment, and updated the assessment using those procedures. Preliminary versions of this assessment were presented at the Coordinating Committee for Geoscience Programs in East and Southeast Asia (CCOP) workshop in Busan, South Korea, in the spring of 2010. The assessment was further refined in 2011, after internal USGS review.

Three-Part Assessment

This assessment was conducted using methods, procedures, and models that support what have come to be known as three-part assessments. The three parts that are integrated to create the assessment are: (1) delineation of permissive tracts, according to the type of mineral deposits permitted by geology, (2) estimation of the amount of metal in typical deposits by using grade-tonnage models, and (3) probabilistic estimation of the number of undiscovered deposits by subjective methods (Singer, 2007a; Singer and Menzie, 2010).

A permissive tract for porphyry copper deposits is delineated as a geographic area that includes intrusive and volcanic rocks of specified ranges of composition and age that are part of a magmatic arc. These arcs have been traditionally related to convergent plate margins, but the Yanshanian-age rocks related to porphyry copper deposits in East Asia formed after subduction ceased. A tract generally is bounded by the outline of the magmatic arc, as depicted at the scale of the maps available for tract delineation, and may include areas covered by younger or structurally overlying materials that are less than 1 km thick. For these tracts in East Asia, many of the igneous rocks most closely associated with porphyry copper formation are not depicted on available geologic maps; instead, their locations come from the scientific literature.

Frequency distributions of premining tonnages and average grades of thoroughly explored deposits are used as models for grades and tonnages of undiscovered deposits (Singer, 1993). Models are constructed from average grades and tonnages (including both measured and inferred resources) based on the total production, reserves, and resources at the lowest possible cutoff grade, as described by Singer and others (2008).

Numbers of undiscovered deposits at various quantiles (degrees of belief) are estimated by an assessment team of experts using a variety of strategies, such as counting the number and ranking the favorability of significant prospects, and comparing the spatial density of known deposits and expected undiscovered deposits to that of known deposits in similar, well-explored regions (Singer, 2007b). Probable amounts of undiscovered resources are then estimated by combining estimates of numbers of undiscovered deposits with grade and tonnage models, using a Monte Carlo simulation process (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012).

Tract Delineation

The geology-based strategy used for porphyry copper tract delineation in the USGS global mineral resources assessment is described here. See appendixes A, B, and C for details on individual tracts. Digital geologic data were processed in a GIS (appendix E) using ArcMap software, as follows:

- Regional-scale maps and geologic literature were used to identify the fundamental units for tract delineation: magmatic arcs or belts of igneous rocks of a given age range.
- Digital geologic maps were then used to select map units to define preliminary tracts permissive for porphyry copper deposits. Igneous map units were subdivided by age groups and classified as permissive or nonpermissive based on lithology. Permissive rocks include calc-alkaline and alkaline plutonic and volcanic rocks. Nonpermissive rocks include, for example, ultramafic assemblages, ophiolites, highly evolved granites, peraluminous granites, and pillow basalts.
- Typically, a 10-, 15-, or 20-km buffer was then applied to plutonic rock polygons and a 2-km buffer to volcanic rock polygons; this generally expanded the area of the tract to include all porphyry copper deposits and significant associated prospects. The buffer accounts for uncertainties in the cartographic position of mapped boundaries, as well as possible unexposed or unmapped permissive rocks.
- After buffering, available data on mineral deposits and occurrences, locations of dated igneous rock samples, and geophysical and geochemical information were examined to identify previously unrecognized evidence of unmapped permissive rocks or hydrothermal systems.
- An aggregation and smoothing routine was applied to the resulting polygons, and the tracts were edited by hand in accord with postmineral fault boundaries. In some cases, more detailed geologic maps were used to resolve tract boundary issues or available schematic map illustrations from the literature were incorporated to augment the existing digital maps.
- Areas where postmineral volcanic centers, depositional basins, and other forms of cover were judged to exceed 1 km in thickness were excluded from the tracts. Intrusions younger than the designated tract age were also excluded. Volcanic rocks younger than the designated tract age but inferred to be less than 1 km thick were included within permissive areas.
- Resulting tract boundaries were truncated at shorelines to eliminate undersea areas using a global GIS dataset adopted for the project (U.S. Department of State, 2009).

Permissive Tracts for Mesozoic Porphyry Copper Deposits in East Asia

Three tracts permissive for porphyry copper deposits were delineated (table 3, fig. 6). Brief summaries of the tracts are included here, but the detailed rationale for tract delineation is in appendixes A, B, and C. The ages and resources in known porphyry copper deposits for each of these tracts are presented in table 1. Descriptions of deposits and prospects are in appendix D; tract boundaries and the deposits and prospects database are included in the GIS (appendix E).

Table 3. Permissive tracts for Mesozoic porphyry copper deposits in East Asia.

Tract	Tract name	Countries	Area (km^2)	Geologic feature assessed
142pCu8509	Manchuride	China, North Korea, Mongolia, Russia	1,170,920	An assemblage of Yanshanian (Jurassic and Cretaceous) igneous rocks that formed in a postcollision, postsubduction environment after the collision of North and South China
142pCu8704	Coastal Pacific	China, Vietnam	604,570	An assemblage of Yanshanian (Jurassic and Cretaceous) igneous rocks that formed in a postcollision, postsubduction environment after the collision of North and South China
142pCu8705	East Qinling	China	171,100	A linear belt of Yanshanian (Jurassic and Cretaceous) mainly plutonic rocks that formed by the melting of primarily continental crust after the collision of North and South China

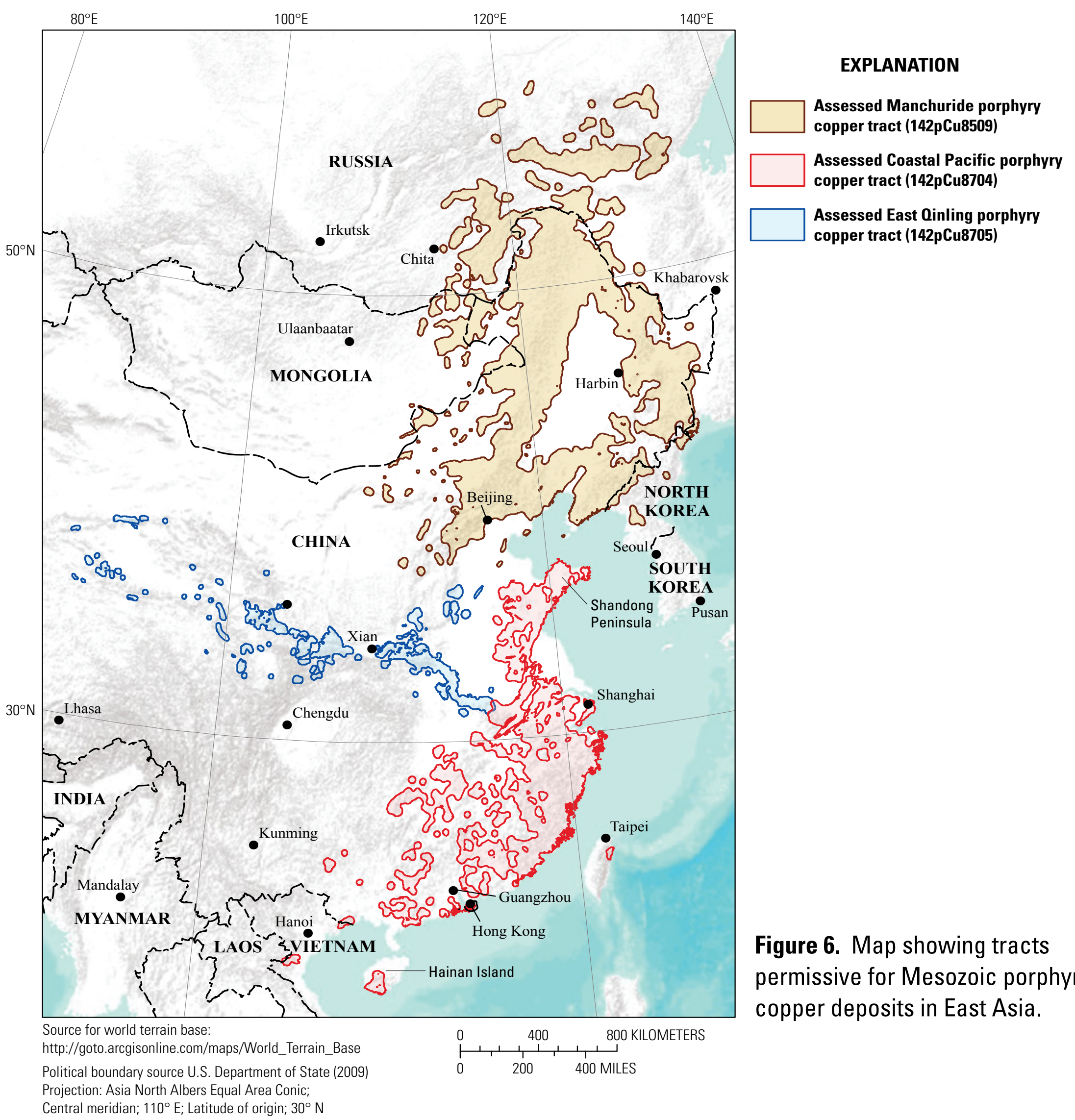


Figure 6. Map showing tracts permissive for Mesozoic porphyry copper deposits in East Asia.

Manchuride Tract

The Manchuride tract (142pCu8509), with an area of about 1,170,000 km^2, is defined by a large group of Jurassic and Cretaceous (Yanshanian) igneous rocks formed after the final assembly of the Asian continent. These rocks have a wide range of compositions and extend about 2,800 km from the vicinity of Beijing into far eastern Russia, including part of eastern Mongolia and small areas in North Korea. They formed in a post-subduction, postcollision environment, apparently as a result of melting of continental crust and previously subducted oceanic crust due to mantle upwelling after thinning and delamination of the lithosphere. The tract includes at least five known porphyry copper deposits (table 1), Zhiriken, Bystrinskoe, and Shakhtama in Russia and Xiaosigou and Wunugetushan in China. In addition, there are 15 significant prospects and at least 14 additional sites that could represent porphyry copper style mineralization (appendixes A, D).

Coastal Pacific Tract

The Coastal Pacific tract (142pCu8704), with an area of about 600,000 km^2, is defined by a large group of Jurassic and Cretaceous (Yanshanian) igneous rocks formed after the final assembly of the Asian continent. They have a wide range of compositions and extend about 2,500 km from northern Vietnam and Hainan Island to the tip of the Shandong Peninsula (fig. 6). They formed in a postsubduction, postcollision environment, apparently as a result of melting of continental crust and previously subducted oceanic crust due to mantle upwelling after thinning and delamination of the lithosphere. The tract includes six known porphyry copper deposits (table 1), including Dexing, China's leading copper producer. There are at least 12 significant porphyry copper prospects and 9 additional sites that could represent porphyry copper style mineralization (appendixes B, D). In addition, many more skarn and replacement Cu and Cu-Au deposits could be indicative of porphyry copper style mineralization. The Lower Yangtze metallogenic belt (fig. 5) contains hundreds of porphyry-related skarn and replacement deposits.

East Qinling Tract

The East Qinling tract (142pCu8705), with an area of about 170,000 km^2, is defined by a linear chain of primarily small plutons that formed in Jurassic and Cretaceous time along the suture between the North and South China paleocontinents. They are essentially bimodal in composition; the felsic rocks range from granodiorites to granite. The chain is about 2,300 km long in an east-west direction and varies in width from about 100 to 500 km. The rocks formed primarily by the melting of continental crust, heated by mantle upwelling after collision and subsequent thinning and delamination of the lithosphere. Most of the large mineral deposits in this tract are porphyry molybdenum deposits, including Jinduicheng (table 1). Some of the porphyry molybdenum deposits contain important quantities of copper. In addition, there are six significant porphyry copper prospects, including several large porphyry-related copper skarn deposits, and two other sites that could represent porphyry copper style mineralization (appendixes C, D).

Estimating 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. Estimates are expressed in terms of levels of certainty. Estimators were asked for the smallest number of deposits consistent with the porphyry copper model that they believed could be present at three specified levels of certainty (90 percent, 50 percent, and 10 percent). For example, on the basis of all available data, a team member might estimate that there is a 90-percent chance of 1 or more; a 50-percent chance of 5 or more; and a 10-percent chance of 10 or more undiscovered deposits in a permissive tract. The differences between individual estimates were discussed and evaluated before a single team estimate was agreed upon for each tract.

The estimates were converted to an expected (mean) number of deposits and standard deviation using an algorithm developed by Root and others (1992). This algorithm can be described by the following general equations (Singer and Menzie, 2005), which are used to calculate a mean number of deposits (λ) and a standard deviation (s_x) based on estimates of numbers of undiscovered deposits predicted at specified quantile levels[10] (N_{90} = 90 percent level, N_{50} = 50 percent level, for example):

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

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

For the example given above ($N_{90} = 1$; $N_{50} = 5$; $N_{10} = 10$), $\lambda = 5.2$ and $s_x = 3.2$.

Another useful parameter for reporting uncertainty associated with an estimate is the coefficient of variation (C_v), defined as:

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

The coefficient of variation is often reported as percent relative variation ($100 \times C_v$).

The final set of undiscovered deposit estimates reflects both the uncertainty in what may exist and the favorability of the tract (Singer, 1993). The estimates were combined with appropriate grade and tonnage models in a Monte Carlo simulation using the EMINERS computer program (Bawiec and Spanski, 2012; Duval, 2012), based on the original Mark 3

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

computer program described by Root and others (1992), to provide a probabilistic estimate of amounts of resources that could be associated with undiscovered deposits.

The rationales for individual tract estimates are discussed in appendixes A, B, and C. Recent published literature, company websites, and technical reports for exploration projects were examined for descriptions of geology, mineralogy, deposit type, rock alteration, and sampling results to evaluate the likelihood that a prospect is associated with a porphyry copper system. In some cases, the number of significant porphyry copper prospects within a tract was counted as an important factor in estimation. Particular weight was given to prospects described as porphyry copper-related in published literature and recent exploration reports.

In addition, the distributions of reported copper and gold occurrences of unknown type and of placer gold workings are relevant. The level of exploration was also a factor in making estimates. In less well explored areas and areas with poor documentation of mineral occurrences, we were unable to use such methods effectively, and the spread in estimates and the associated relatively high coefficients of variation reflects the uncertainty associated with the estimates.

Final team estimates of undiscovered deposits are summarized in table 4, along with statistics that describe the 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 assessment predicts a mean total of about 44 undiscovered porphyry copper deposits in all three tracts, many more than the 12 that have already been discovered.

Probabilistic Assessment Results

The Monte Carlo simulation yields estimates for the mean and median copper and gold contained in undiscovered deposits (table 5). Identified resources in the table refer to metal contained in well delineated porphyry copper deposits only; the resource data are based on total production, plus measured, indicated, and inferred reserves and resources at the lowest cutoff grade reported. Identified resources may include substantial amounts of metal that have already been produced, for example in the case of the porphyry copper deposits in the Lower Yangtze metallogenic belt.

All three permissive tracts contain identified resources, although those in the Coastal Pacific tract constitute nearly 75 percent of the total and those in the East Qinling tract are only about 2 percent. All tracts also contain porphyry copper systems that have been partially explored, but for which no reliable grade and tonnage estimates are yet available. Resources in deposits like these that have not been comprehensively drilled out are not included in the data for identified resources. These deposits were considered to be significant prospects with a high probability of representing deposits like those in the grade and tonnage models. An example is the Shaxi deposit, where a resource of nearly 500,000 t of copper (Lan and others, 2009) has been identified, but details are not known, and the deposit is still being readied for exploitation.

Simulation results are reported at selected quantiles, along with the mean expected amount of metal, the probability of the mean, and the probability of no metal (tables A5, B5, C5). The amount of metal reported at each quantile represents the least amount of metal expected. The quantile estimates are linked to each tract simulation and, therefore, should not be added. Mean estimates, however, can be added to obtain total amounts of metal and mineralized rock that can be compared between tracts.

Discussion

This probabilistic assessment of resources in undiscovered Mesozoic porphyry copper deposits in East Asia indicates that significant amounts of additional resources may be present (table 5). The mean estimate of undiscovered copper resources in the study area (about 198,000,000 t) is nearly nine times the amount of copper present in identified resources (about 23,000,000 t). This is entirely plausible for an area that is in

Table 4. Estimates of numbers of undiscovered Mesozoic porphyry copper deposits in East Asia.

[N_{XX}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; *s*, standard deviation; C_v%, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; tract area, area of permissive tract in square kilometers; N_{total}/100k km^2, deposit density reported as the total number of deposits per 100,000 km^2. N_{und}, *s*, and C_v% are calculated using a regression equation (Singer and Menzie, 2005)]

Tract	Tract name	Consensus undiscovered deposit estimates					Summary statistics					Tract area (km^2)	Deposit density (N_{total}/100k km^2)
		N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	*s*	C_v%	N_{known}	N_{total}		
142pCu8509	Manchuride	2	8	60	60	60	21.7	22.0	100	5	26.7	1,170,918	2.3
142pCu8704	Coastal Pacific	2	12	40	40	40	17.3	13.7	79	7	24.3	604,560	4.0
142pCu8705	East Qinling	1	3	12	12	12	5.0	4.2	83	1	6.0	171,104	3.5

Table 5. Summary of simulations of undiscovered resources in porphyry copper deposits and comparison with identified copper and gold resources in Mesozoic porphyry copper deposits in East Asia.

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

Tract	Tract name	Known resources		Median estimate of		Mean estimate of				
		Copper (t)	Gold (t)	Undiscovered copper resources (t)	Undiscovered gold resources (t)	Undiscovered copper resources (t)	Undiscovered gold resources (t)	Undiscovered molybdenum resources (t)	Undiscovered silver resources (t)	Rock (Mt)
142pCu8509	Manchuride	7,800,000	382	37,000,000	900	81,000,000	2,100	2,200,000	27,000	17,000
142pCu8704	Coastal Pacific	14,400,000	472	42,000,000	1,100	65,000,000	1,700	1,800,000	21,000	13,000
142pCu8705	East Qinling	392,000	0	19,000,000	360	52,000,000	130	2,400,000	22,000	9,300
Total		22,600,000	854	n.a.	n.a.	198,000,000	3,930	6,400,000	70,000	39,300

the early stage of exploration. In 2006, China's reserve base was reported to be 30,700,000 t of copper and the identified copper resources were 70,500,000 t, contained in more than 1,000 identified mines, many of them small (Li, 2008). At the same time, annual consumption was nearly 5,000,000 t and growing rapidly. Thus, the undiscovered resources in East Asia may play an important role in meeting China's copper supply needs in the short and medium term.

However, a significant part of these resources, if they are present, may be inaccessible or uneconomic. Results should be interpreted with due caution, as no economic filters have been applied to these results to evaluate what portion of the estimated undiscovered resources might be economic under various conditions. For each tract, identified resources are compared with mean and median estimates of undiscovered copper resources in figure 7.

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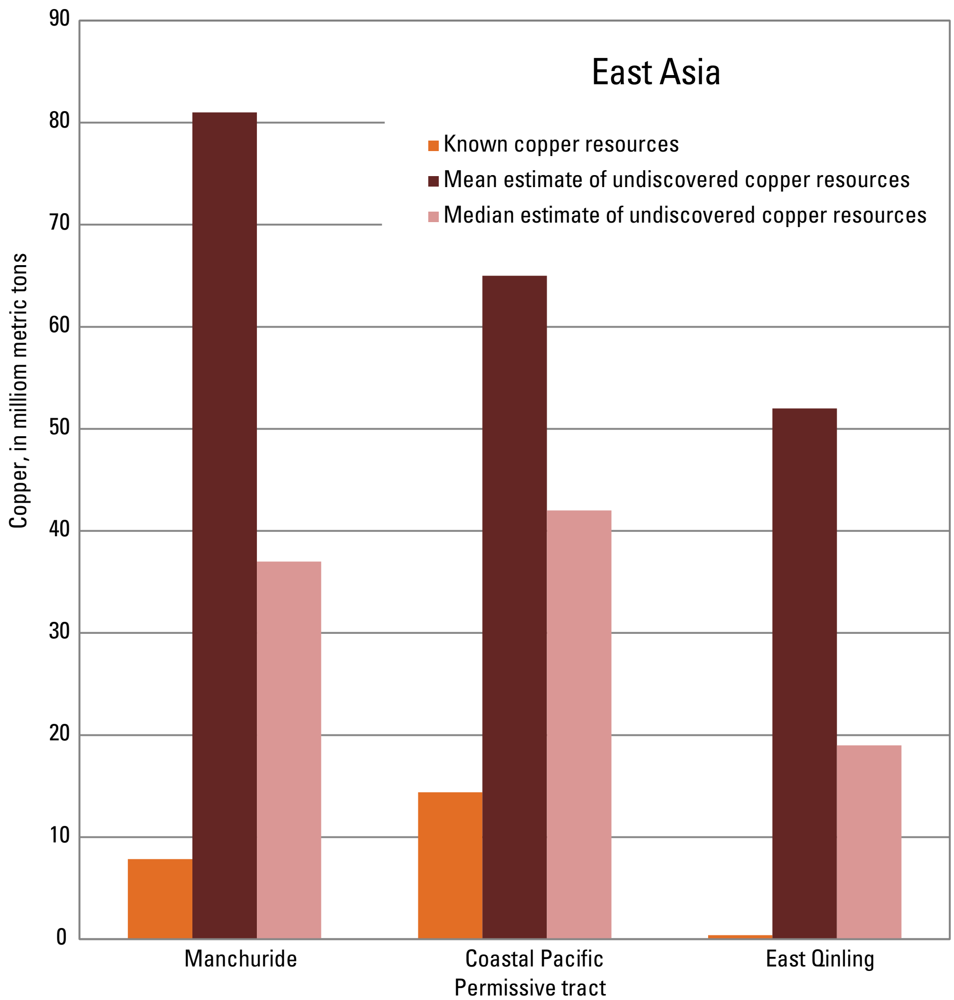

Figure 7. Chart showing identified and undiscovered copper resources for Mesozoic permissive tracts in East Asia.

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Appendixes A–F

Appendix A. Porphyry Copper Assessment for Tract 142pCu8509, Manchuride—China, Mongolia, North Korea, and Russia

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Deposit Type Assessed: Porphyry Copper

Deposit type: Porphyry copper
Descriptive model: Porphyry copper (Cox, 1986; John and others, 2010)
Grade and tonnage model: General porphyry copper (Singer and others, 2008)
Table A1 summarizes selected assessment results.

Table A1. Summary of selected resource assessment results for tract 142pCu8509, Manchuride—China, Mongolia, North Korea, and Russia.

[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)
2011	1	1,170,920	7,800,000	81,000,000	37,000,000

Location

The tract extends for nearly 3,000 km from Hebei and Shanxi provinces in China north into Russia, including part of eastern and northeastern Mongolia and a small area in North Korea along the Chinese border (fig. A1). The tract is as much as 1,500 km wide, extending from the Gobi Desert in China and Mongolia to the shores of the Yellow Sea and the Sea of Japan.

Geologic Feature Assessed

An assemblage of Yanshanian age (Jurassic and Cretaceous) volcanic and intrusive rocks that were formed by a variety of processes, including active subduction of the Paleopacific oceanic plate beneath the Sino-Korean (North China) craton, the Central Asian Orogenic Belt, and the Siberian craton (fig. 5), and mantle-induced melting after lithospheric delamination in an extensional tectonic regime.

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[3]U.S. Geological Survey, Reston, Virginia, United States.
[4]Russian Academy of Sciences, Moscow, Russia.
[5]China Geological Survey, Beijing, China.
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[7]XDM Geological Consultants, Inc., Victoria, Canada.

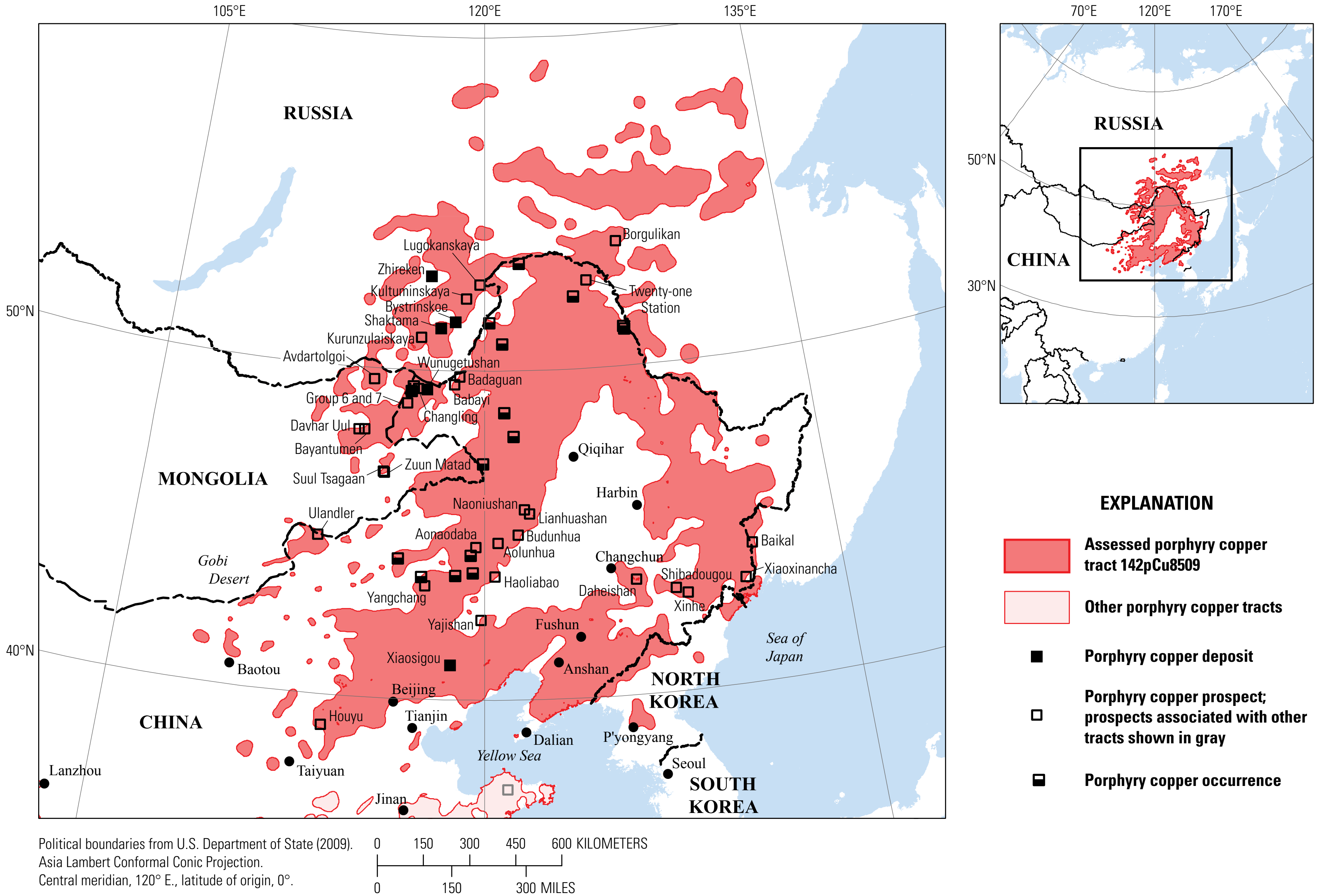

Figure A1. Map showing tract location, known porphyry copper deposits, and porphyry copper prospects for tract 142pCu8509, Manchuride—China, Mongolia, North Korea, and Russia.

Delineation of the Permissive Tract

Geologic Criteria

The tract outlines a field of intermediate to felsic Mesozoic intrusive and volcanic rocks that are widely regarded as posttectonic, related to lithospheric delamination instead of active subduction (Richards, 2009; Hou and others, 2011). This Mesozoic igneous activity occurred in concert with widespread crustal and lithospheric thinning during Yanshanian time (Windley and others, 2010; Zhai and others, 2007; Deng and others, 2007).

Because the maps used to delineate the permissive tract do not separate Triassic from Yanshanian age rocks, it was impossible to exclude the Triassic rocks, even though none of the porphyry copper deposits or prospects in the tract are Triassic in age. The tract was delineated using only intermediate-composition igneous rocks. Plutonic rocks include diorite, quartz diorite, granodiorite, monzonite, and syenite. Volcanic rocks include primarily andesite, with lesser amounts of dacite, trachyte, latite, and some pyroclastic rocks of unspecified composition. Granites, silicic ignimbrites, ultramafic rocks, and strongly peraluminous rocks were excluded.

Known Deposits

Zhireken (130,000 metric tons (t) Cu; Berzina and others, 2011), Shakhtama (2,860,000 t Cu; Berzina and others, 2011), Bystrinskoe (2,440,000 t Cu; Seltmann and others, 2010), Xiaosigou (131,000 t Cu; Yan and others, 2007), and Wunugetushan (2,230,000 t Cu; Wang and Qin, 1988) are the five known porphyry copper deposits in the tract (table A2, appendix D).

Zhireken, discovered in 1945 (Berzina and others, 2007), Bystrinskoe, and Shakhtama are in the northern part of the tract in Russia. Zhiriken and Shakhtama have relatively low copper grades and high molybdenum grades and both are being mined. Wunugetushan is a large deposit in northern China, near the boundaries of Russia and Mongolia. Xiaosigou is a very small deposit in the southern part of the tract, about 200 km northeast of Beijing.

Prospects, Mineral Occurrences, and Related Deposit Types

There are at least 30 identified porphyry copper prospects in the tract, mostly in China (appendix D, fig. A1). The 15 most significant prospects are listed in table A3; details on all sites are in appendix D.

The Xiaoxinancha Cu-Au deposit (Sun and others, 2009) is an operating mine (although the deposit is not yet fully delineated) in the eastern part of the tract, near the border with North Korea. It may be related to Pacific Plate subduction, as at 111 Ma, it is one of the youngest deposits in the tract (Ren and others, 2010). The delineated resource of 30 t of gold and 140,000 t of copper (Zhang and others, 2007) may be present largely in veins, but porphyry-style mineralization is also present.

Sources of Information

Government geological institutions in China, Russia, and Mongolia do not publicly distribute detailed earth science information. Thus, we are reliant primarily on generalized large-scale compilations that do not include needed information, and on academic papers in the scientific literature and promotional material from the websites of mineral exploration companies. Also, the understanding of the plate-tectonic history of the region is still evolving, which makes it difficult to use as a context for deposit occurrence. A list of the sources used in this assessment is in table 2 in the main body of this report.

Grade and Tonnage Model Selection

Incomplete, unreliable, and conflicting information about grades, tonnages, and cutoff grades means that existing data are unlikely to be reliable guides to undiscovered deposits.

Table A2. Porphyry copper deposits in tract 142pCu8509, Manchuride—China, Mongolia, North Korea, and Russia.

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

Name	Latitude	Longitude	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)
Shakhtama	51.28	117.88	153	1,100	0.26	0.06	0.09	n.d.	2,860,000
Zhireken	52.84	117.36	158	130	0.1	0.099	n.d.	n.d.	130,000
Bystrinskoe	51.48	118.57	Jurassic	349	0.7	n.d.	0.81	3.63	2,440,000
Xiaosigou	41.05	118.60	106	18	0.73	0.086	n.d.	n.d.	131,000
Wunugetushan	49.42	117.30	184	558	0.4	0.05	n.d.	n.d.	2,230,000

Table A3. Significant prospects in tract 142pCu8509, Manchuride—China, Mongolia, North Korea, and Russia.

[Ma, million years; t, metric ton; Mt, million metric tons; kt, thousand metric tons; %, percent; g/t, grams per metric ton]

Name	Latitude	Longitude	Age (Ma)	Comments (grade and tonnage data, if available)
Borgulikan	53.75	126.62	123	Grades up to 1% Cu, up to 3.3 g/t Au, up to 0.3–16.0 g/t Ag, up to 0.6% Mo.
Lugokanskaya	52.61	119.74	Jurassic	Resource of 713,000 t Cu, 0.14 t Au, 1.63 t Ag, at unknown grade
Kultuminskaya	52.19	119.10	Jurassic	Resource of 587,000 t Cu, 0.12 t Au, 0.95 t Ag, at unknown grade
Naoniushan	45.78	121.71	128	Copper grades from 0.3 to 0.98%
Lianhuashan	45.65	121.93	162	Average Cu grade 0.78%
Budunhua	45.00	121.43	166	Average Cu grade 0.40%
Ulandler	44.81	112.85	134	51 kt of Mo at 0.0934%; 1,300 t of Cu (no grade)
Aolunhua	44.76	120.56	131	Average Cu grade 0.29%
Aonaodaba	44.63	119.60	148	Copper grades from 0.3 to 1.0%; contains substantial Sn, Ag
Daheishan	43.49	126.32	175	May be primarily a Mo deposit
Yangchang	43.45	117.49	139	Ore in breccia
Xiaoxinancha	43.21	130.88	111	Grades of 0.63 to 0.8% Cu, 3.64 to 3.8 g/t Au, and 6.8 to 16.8 g/t Ag; mining in enriched chalcocite blanket; tonnage not available
Shibadougou	43.14	127.94	Yanshanian	Discovered in 2006 through stream-sediment geochemistry
Yajishan	42.42	119.83	151	Cu grade to 0.85%; 10.5 kt of Mo at 0.089%
Houyu	39.08	113.62	Yanshanian	Yan and others (2007) report an unsubstantiated resource of about 110 Mt at 0.037 Cu

Although several of the deposits in the tract have substantial molybdenum grades (table A2), the general porphyry copper model was used for the estimation of undiscovered resources in the Manchuride tract.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Our knowledge of the geology and mineral deposits of this part of the world can best be termed incomplete. In general, it is not possible to access critical geologic data from government earth science organizations through those institutions' websites. There are five known deposits in the tract and several significant prospects that have partially delineated resources and more than 30 other prospects.

Based on the relative proportions of volcanic and intrusive rock mapped, as well as the widespread prospects and mineral occurrences, much of the area appears to be exposed at an appropriate erosion level to preserve porphyry deposits. The largely postsubduction granitoid rocks in this tract are somewhat more silica-rich than many of the intrusions related to porphyry copper deposits worldwide, and several of the deposits and prospects (Zhiriken, for example) are related to high-silica granites, so in this area, the silica-rich granites are not necessarily negative evidence.

In this area, the rate of exploration success since the year 2000 appears to be rising rather than falling as it is in most of the world, suggesting that the area is relatively underexplored. The eastern part of the tract is heavily forested. Copper deposits have been mined in China for more than 1,000 years, but prospecting for porphyry copper deposits based on their geologic characteristics began only in the 1960s. The tract is quite large, covering an area of nearly 1,400,000 km^2. The large number of porphyry copper prospects, many of them discovered during the last decade, suggests that the tract may be as productive as a typical continental margin arc.

The assessment team estimated a 90 percent chance of 2 or more undiscovered deposits in the tract, a 50 percent chance of 8 or more deposits, and a 10 percent chance of 60 or more deposits (table A4). A number of the significant prospects in this tract have partially delineated resources and this guided the estimate for the 90 percent confidence level of 2 or more deposits.

The huge area of the tract is largely responsible for the estimate of 60 or more deposits at the 10 percent confidence level.

Because of the subjective nature of the tract delineation, it could be misleading to place great credence in a calculated deposit density for this tract, but the team's estimate is entirely consistent with worldwide deposit density estimates (Singer, 2008; Singer and others, 2005).

A previous assessment (Yan and others, 2007) covered large parts of this tract (their tracts I-1, I-2, II-1, II-2, II-3, II-4, III-1, III-2, III-3, IV-1, IV-2, IV-3, and IV-4). The mean of their estimate was about 45 undiscovered deposits, compared with the present team's estimate of about 22 (table A4). Their estimate, however, includes deposits of Paleozoic age, so should not be compared directly with this one.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining the team's estimate for numbers of undiscovered porphyry copper deposits with the general porphyry copper model of Singer and others (2008) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012). Selected simulation results are reported in table A5. Results of the Monte Carlo simulation are presented as a cumulative frequency plot (fig. A2), which shows the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

Table A4. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 142pCu8509, Manchuride—China, Mongolia, North Korea, and Russia.

[N_{XX}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; s, standard deviation; $C_v\%$, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; 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 $C_v\%$ 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)
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	s	$C_v\%$	N_{known}	N_{total}		
2	8	60	60	60	22.0	22.0	100	5	27	1,170,920	0.000023

Table A5. Results of Monte Carlo simulations of undiscovered resources for tract 142pCu8509, Manchuride—China, Mongolia, North Korea, and Russia.

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

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	260,000	2,000,000	37,000,000	220,000,000	280,000,000	81,000,000	0.37	0.04
Mo (t)	0	8,500	820,000	6,100,000	8,400,000	2,200,000	0.34	0.08
Au (t)	0	20	900	5,600	7,100	2,100	0.37	0.07
Ag (t)	0	0	9,700	73,000	100,000	27,000	0.33	0.12
Rock (Mt)	59	490	7,700	46,000	55,000	17,000	0.38	0.04

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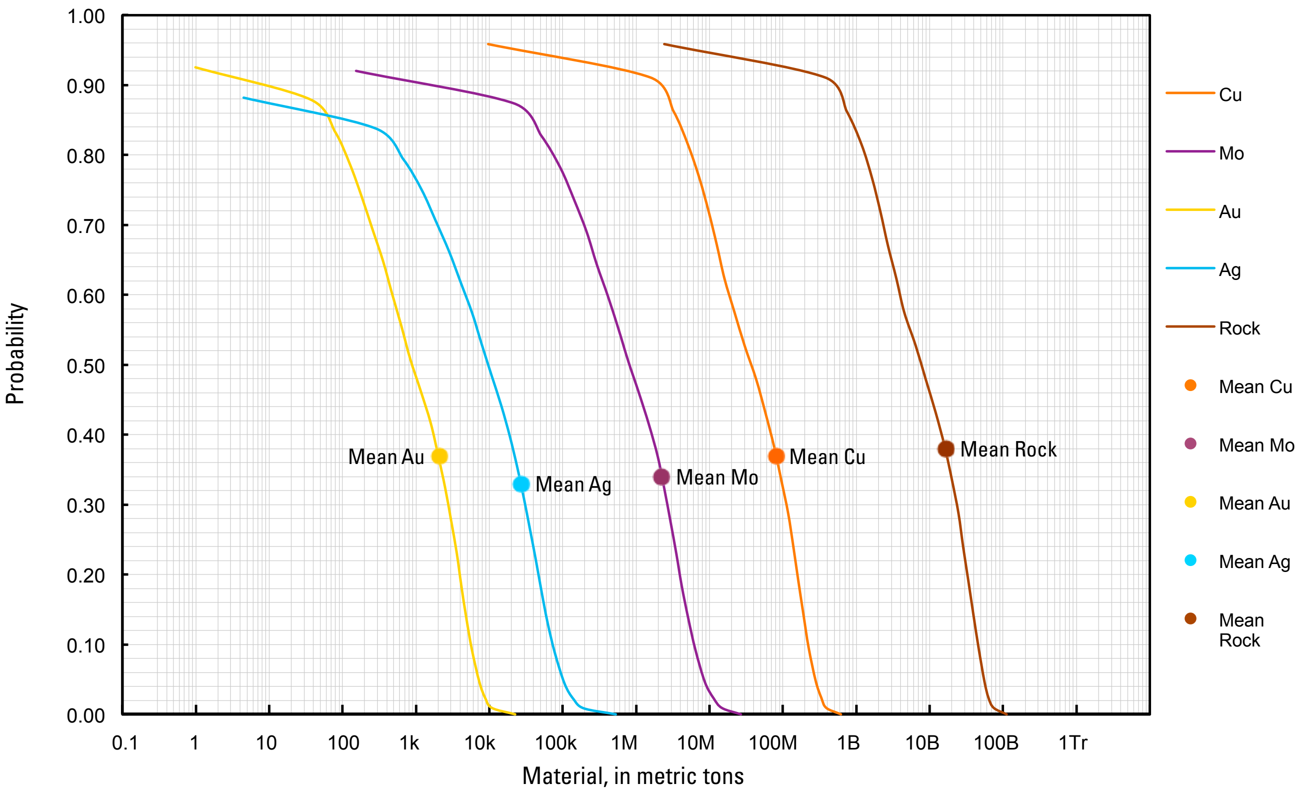

Figure A2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources for tract 142pCu8509, Manchuride—China, Mongolia, North Korea, and Russia. k, thousand; M, million; B, billion; Tr, trillion.

Appendix B. Porphyry Copper Assessment for Tract 142pCu8704, Coastal Pacific—China and Vietnam

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Deposit Type Assessed: Porphyry Copper

Deposit type: Porphyry copper
Descriptive model: Porphyry copper (Cox, 1986; John and others, 2010)
Grade and tonnage model: General porphyry copper (Singer and others, 2008)
Table B1 summarizes selected assessment results

Table B1. Summary of selected resource assessment results for tract 142pCu8704, Coastal Pacific—China and Vietnam.

[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)
2010	1	604,570	14,400,000	65,000,000	42,000,000

Location

The tract extends for about 2,500 km from northern Vietnam and Hainan Island in the south to the tip of the Shandong Peninsula in the north. A small area on Taiwan is also included. The tract is bordered on the east by the Pacific Ocean (Yellow Sea, East China Sea, and South China Sea) and extends as much as 800 km inland.

Geologic Feature Assessed

An assemblage of Yanshanian age (Jurassic and Cretaceous) volcanic and intrusive rocks that were formed by a variety of processes, including active subduction of the Paleopacific oceanic plate beneath the Yangtze (South China) Craton (fig. 5) and mantle-induced melting after lithospheric delamination in an extensional tectonic regime

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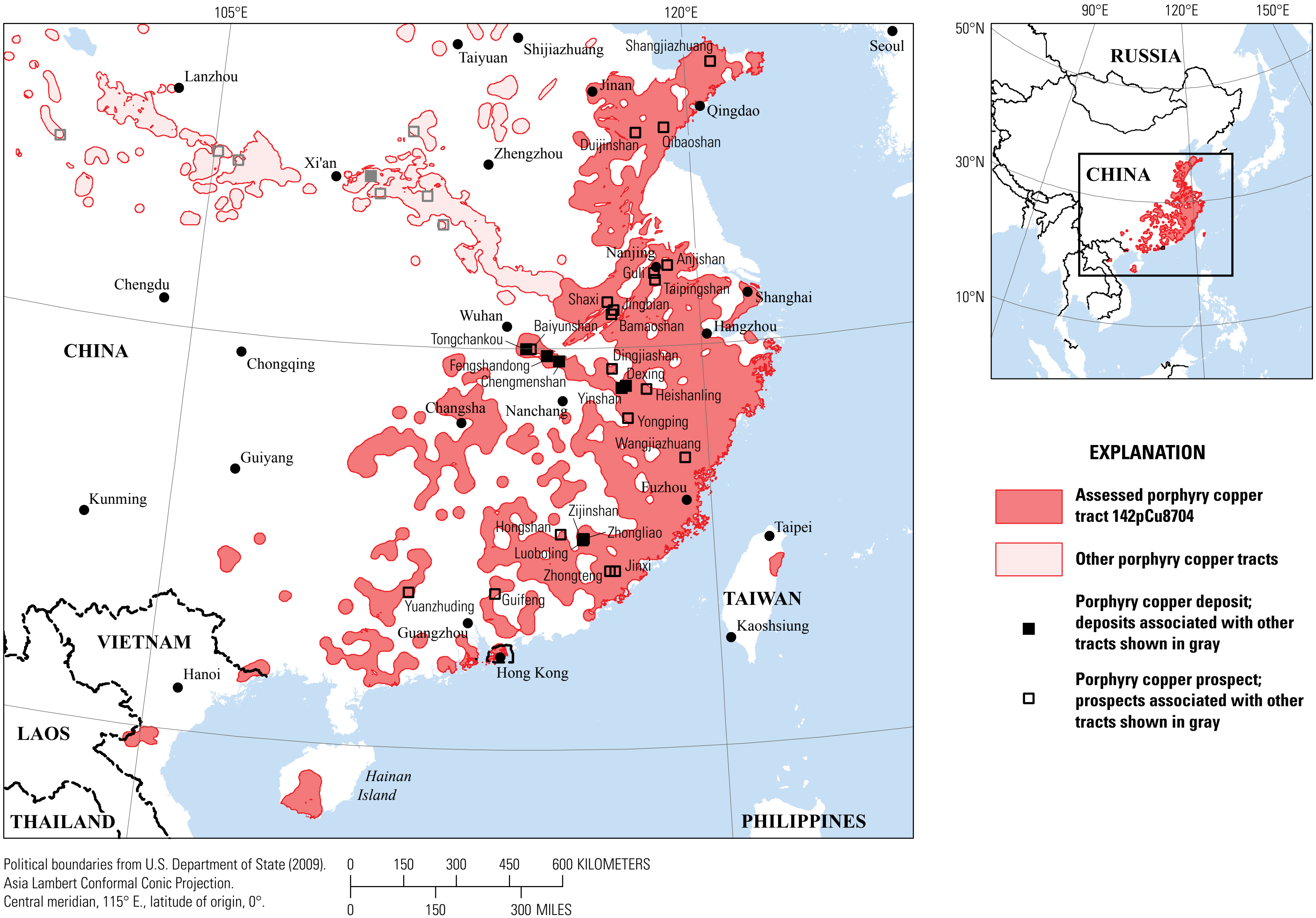

Figure B1. Map showing tract location, known porphyry copper deposits, and porphyry copper prospects for tract 142pCu8704, Coastal Pacific—China and Vietnam.

Delineation of the Permissive Tract

Geologic Criteria

The tract outlines a field of intermediate to felsic Mesozoic intrusive and volcanic rocks that are widely regarded as posttectonic, related to lithospheric delamination instead of active subduction (Richards, 2009; Hou and others, 2011). Li and Li (2007) and Li, Li, Wang, and others (2010) suggest a Late Permian and Triassic continental arc was followed by Jurassic and Cretaceous postorogenic magmatism related to mantle upwelling. Neodymium and strontium isotopic evidence shows that the postsubduction melts have a primarily mantle source, with varying crustal contributions (Xu and others, 2002). Some Chinese geologists ascribe all the Mesozoic igneous activity to subduction of the Paleopacific Plate beneath South China (Lan and others, 2009).

The Lower Yangtze metallogenic belt (Pan and Dong, 1999; Zhao and others, 1999) forms the heart of this tract and contains not only three of the known porphyry copper deposits, but also hundreds of Cu, Cu-Au, and Cu-Fe skarn and replacement deposits (fig. 5). The igneous rocks (150–120 Ma) are primarily granodiorites and monzodiorites (Mao and others, 2006; Li, Li, Wang, and others, 2010) that have a similar isotopic signature to many others throughout the tract, one of primary mantle origin with varying, but often significant, amounts of continental crustal involvement.

Because the maps used to delineate the permissive tract do not separate Triassic from Yanshanian age rocks, it was impossible to exclude the Triassic rocks, even though none of the porphyry copper deposits or prospects in the tract is Triassic in age. The tract was delineated using only intermediate-composition igneous rocks. Plutonic rocks include diorite, quartz diorite, granodiorite, monzonite, and syenite; granites were excluded. Volcanic rocks include primarily andesite, with lesser amounts of dacite, trachyte, latite, and some pyroclastic rocks of unspecified composition; the large exposures of silicic ignimbrite along the Pacific coast of eastern China were excluded, as were ultramafic rocks and known strongly peraluminous rocks. More detailed maps would likely allow the representation of this tract as multiple tracts with somewhat different histories.

Known Deposits

Tongchankou (419,000 metric tons (t) Cu; Li and others, 2008), Fengshandong (399,000 t Cu; Xie and others, 2007), and Chengmenshan (3,070,000 t Cu; Pan and Dong, 1999) are in the Yangtze River metallogenic belt. All are Late Jurassic in age (145–140 Ma) and all are being actively mined (table B2, appendix D).

Further east, Dexing (8,380,000 t Cu; Wang and others, 2006), is the largest porphyry copper deposit in China, and has been known since the 1950s (Li and Sasaki, 2007). Dexing is Middle Jurassic in age (approximately 171 Ma). Nearby deposits that are being actively mined include Yinshan (Jiuqiu) (432,000 t Cu), and Yongping (resource unknown). Yongping has been called a "Climax-type" porphyry Cu-Mo deposit (Li, Hu, and Wei, 2010), but there may be two deposits co-located, one copper-rich and one molybdenum-rich, and both with nearly the same Jurassic age. Because no grade and tonnage are available, Yongping was treated as a prospect during the assessment.

In the south, Zijinshan (1,740,000 t Cu) has been called a high-sulfidation epithermal copper deposit (Zhang and others, 1994; So and others, 1998), because of abundant alunite, but lower parts of the system exhibit classic potassic alteration assemblages.

Prospects, Mineral Occurrences, and Related Deposit Types

There are 21 known porphyry copper prospects in the tract (appendix D, fig. B1). Shaxi (Lan and others, 2009; Yang and others, 2007) is a buried porphyry copper system in the Yangtze River metallogenic belt that is being developed for eventual production. The final grade and tonnage are unknown, but it contains at least 500,000 t of copper. The 12 most significant prospects are listed in table B3; details on all sites are in appendix D.

Sources of Information

Government geological institutions in China, Russia, and Mongolia do not publicly distribute detailed earth science information. Thus, we are reliant primarily on generalized large-scale compilations that do not include needed information, and on academic papers in the scientific literature and promotional material from the websites of mineral exploration companies. Also, the understanding of the plate-tectonic history of the region is still evolving, which makes it difficult to use as a context for deposit occurrence. A list of the sources used in this assessment is in table 2 in the main body of this report.

Grade and Tonnage Model Selection

Incomplete, unreliable, and conflicting information about grades, tonnages, and cutoff grades means that existing data are unlikely to be reliable guides to undiscovered deposits. The general porphyry copper model was used.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Our knowledge of the geology and mineral deposits of this part of the world can best be termed incomplete. In

Table B2. Porphyry copper deposits in tract 142pCu8704, Coastal Pacific—China and Vietnam.

[Ma, million years; Mt, million metric tons; t, metric ton; g/t, gram per metric ton; n.d., no data. Contained Cu in metric tons is computed as tonnage (Mt × 1,000,000) × Cu grade (percent)]

Name	Latitude	Longitude	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)
Tongchankou	30.00	114.84	143	44.6	0.94	0.04	n.d.	n.d.	419,000
Fengshandong	29.82	115.45	144	105	0.38	0.05	0.37	20	399,000
Chengmenshan	29.68	115.81	144	409	0.75	0.047	0.24	9.9	3,070,000
Dexing	29.02	177.73	171	1,825	0.459	0.016	0.12	1.9	8,380,000
Yinshan	28.97	117.60	178	83	0.52	n.d.	0.8	n.d.	432,000
Zijinshan	25.18	116.40	105	356	0.49	n.d.	0.14	6	1,740,000

general, it is not possible to access critical geologic data from government earth science organizations through those institutions' websites.

There are six porphyry copper deposits in the tract (Chengmenshan, Dexing, Fengshandong, Tongchankou, Yinshan, and Zijinshan) and another porphyry deposit (Yongping) that is being mined, but for which we do not have grade and tonnage information. There are 21 prospects (probably more) as well as hundreds of Cu and Cu-Au skarn deposits and prospects. Two of the prospects (Hongshan and Shaxi) are judged to be particularly significant because they contain partially delineated resources. There are also numerous epithermal precious-metal deposits.

Based on the relative proportions of volcanic and intrusive rock mapped, as well as the widespread prospects and mineral occurrences, much of the area appears to be exposed at an appropriate erosion level to preserve porphyry deposits.

In China, the rate of exploration success since the year 2000 appears to be rising rather than falling as it is in most of the world, suggesting that the area is relatively underexplored. Copper deposits have been mined in China for more than 1,000 years, but prospecting for porphyry copper deposits

Table B3. Significant prospects and occurrences in tract 142pCu8704, Coastal Pacific—China and Vietnam.

[Ma, million years; Mt, million metric tons; kt, thousand metric tons; g/t, grams per metric ton; %, percent)]

Name	Latitude	Longitude	Age (Ma)	Comments (grade and tonnage data, if available)
Shangjiazhuang	37.29	120.86	Yanshanian	Yan and others (2007) report unsubstantiated resource of about 71 Mt at 0.047% Cu
Duijinshan	35.54	118.32	Yanshanian	Small resource at 0.21% Cu
Anjishan	32.07	119.10	108	Intermediate resources grading 0.76% Cu, 10.5 g/t Ag, 0.05 g/t Au
Taipingshan	31.70	118.70	Yanshanian	Yan and others report a small (44 kt) resource of copper at 0.48%
Shaxi	31.18	117.27	124	Tonnage and copper grade (49 Mt at 0.4% Cu and ~3.5 g/t Au) estimated on base of data of Yang and others (2002) and Yang and Lee (2005)
Jingbian	30.97	117.44	Yanshanian	Both vein and stockwork mineralization
Baiyunshan	30.00	114.97	Yanshanian	122 kt of Cu at 0.78%
Yongping	28.20	117.76	157	Two prospects; one is porphyry copper and one is classified as Climax-type molybdenum; formed during transition from compressional to extensional tectonic regime
Wangjiazhuang	27.15	119.33	Yanshanian	Small (46 kt) resource of copper at 1.01%; high grade suggests substantial skarn
Hongshan	25.30	115.80	98	8 orebodies with grades > 0.4% Cu
Zhongteng	24.37	117.12	Yanshanian	In breccia within Zhongteng caldera
Yuanzhuding	23.80	111.69	156	Resources of >600 Mt of ore; 980,000 t Cu and 260,000 t Mo

based on their geologic characteristics began only in the 1960s. The tract is quite large, covering an area of more than 600,000 km^2.

The assessment team estimated a 90 percent chance of 2 or more undiscovered deposits in the tract, a 50 percent chance of 12 or more deposits, and a 10 percent chance of 40 or more deposits (table B4). Although several porphyry copper deposits have been discovered, the short exploration history and the heavily populated and vegetated nature of the tract suggest that it should be considered underexplored. Physical exploration of the surface in some parts of the tract has been quite extensive and it is probable that most outcropping deposits have been found; thus the estimate for 2 or more undiscovered deposits at the 90 percent confidence level. However, drilling beneath known skarn and replacement deposits is likely to encounter porphyry deposits and this belief guided the estimates at the 50 and 10 percent confidence levels (table B4).

Because of the subjective nature of the tract delineation, it could be misleading to place great credence in a calculated deposit density for this tract, but the team's estimate is entirely consistent with worldwide deposit density estimates (Singer, 2008; Singer and others, 2005).

A previous assessment (Yan and others, 2007) covered about half the most favorable parts of this tract with 6 tracts (VI-1, VI-2, VII-1, VII-2, VII-3, and VII-5) and estimated about 17 mean undiscovered deposits, compared with the present team's estimate of about 18 (table B4).

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining the team's estimate for numbers of undiscovered porphyry copper deposits with the porphyry copper-gold model of Singer and others (2008) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012). Selected simulation results are reported in table B5. Results of the Monte Carlo simulation are presented as a cumulative frequency plot (fig. B2), which shows the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

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Table B4. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 142pCu8704, Coastal Pacific—China and Vietnam.

[N_{XX}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; s, standard deviation; C_v%, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; 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 C_v% 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)
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	s	C_v%	N_{known}	N_{total}		
2	12	40	40	40	17.3	13.7	79	7	24	604,570	0.00004

Table B5. Results of Monte Carlo simulations of undiscovered resources for tract 142pCu8704, Coastal Pacific—China and Vietnam.

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

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	250,000	2,500,000	42,000,000	160,000,000	200,000,000	65,000,000	0.39	0.04
Mo (t)	0	14,000	960,000	4,500,000	6,300,000	1,800,000	0.34	0.07
Au (t)	0	32	1,100	4,000	5,300	1,700	0.37	0.07
Ag (t)	0	39	11,000	53,000	76,000	21,000	0.33	0.10
Rock (Mt)	69	580	9,100	32,000	40,000	13,000	0.40	0.04

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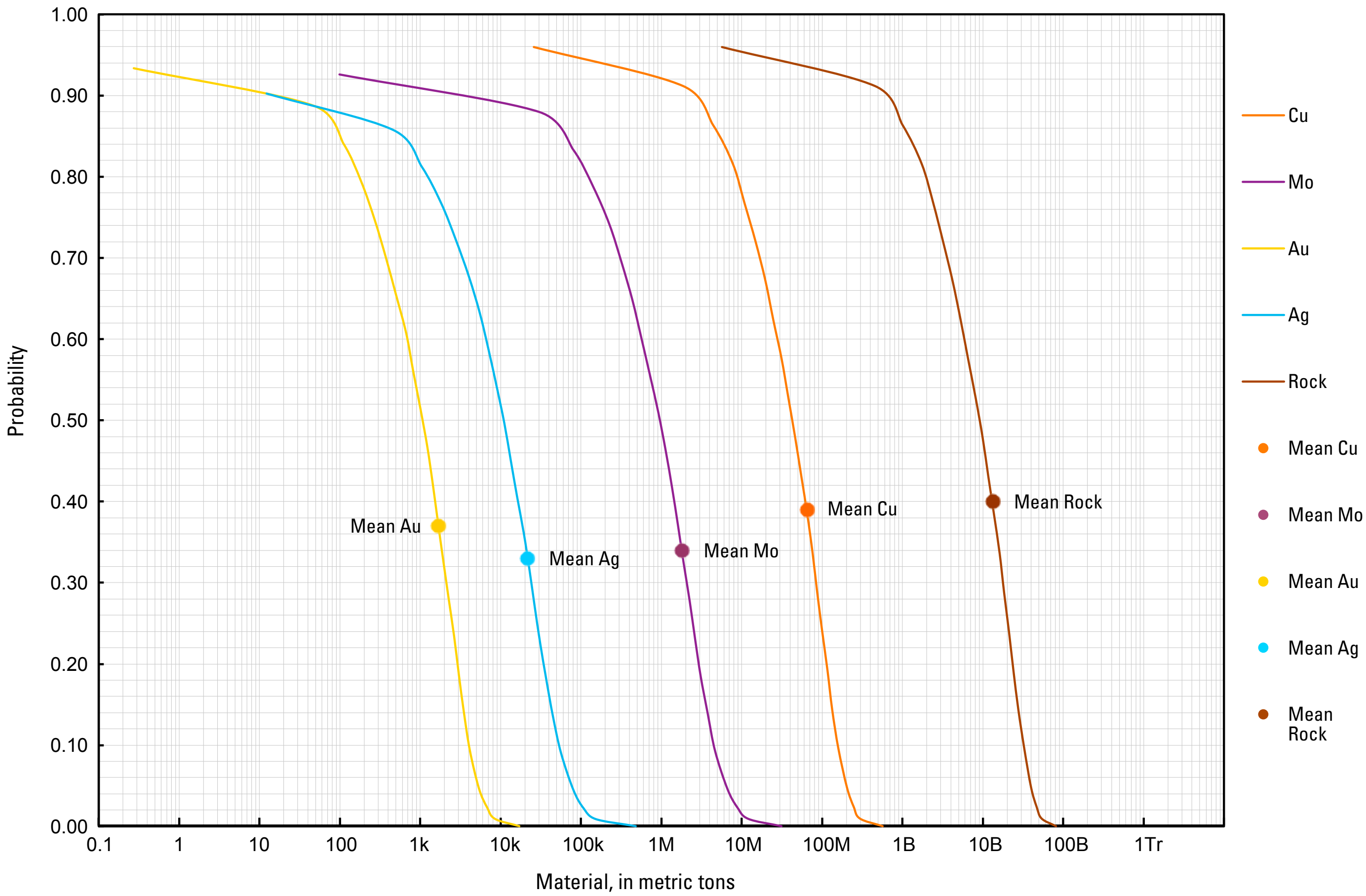

Figure B2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources for tract 142pCu8704, Coastal Pacific—China and Vietnam. k, thousand; M, million; B, billion; Tr, trillion.

Appendix C. Porphyry Copper Assessment for Tract 142pCu8705, East Qinling—China

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Deposit Type Assessed: Porphyry Copper

Deposit type: Porphyry copper
Descriptive model: Porphyry copper (Cox, 1986; John and others, 2010)
Grade and tonnage model: Porphyry copper-molybdenum (Singer and others, 2008)
Table C1 summarizes selected assessment results

Table C1. Summary of selected resource assessment results for tract 142pCu8705, East Qinling—China.

[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)
2010	1	171,100	392,000	52,000,000	19,000,000

Location

The tract extends for about 2,300 km from Anhui Province in eastern China westward into Xinjiang Autonomous Region (fig. C1). The tract ranges from 50 to 400 km in width.

Geologic Feature Assessed

A linear belt of primarily small Yanshanian (Jurassic and Cretaceous) plutons that were formed by a variety of processes, including active subduction, but primarily by mantle-induced melting that includes significant amounts of crustal material after lithospheric delamination in an extensional tectonic regime.

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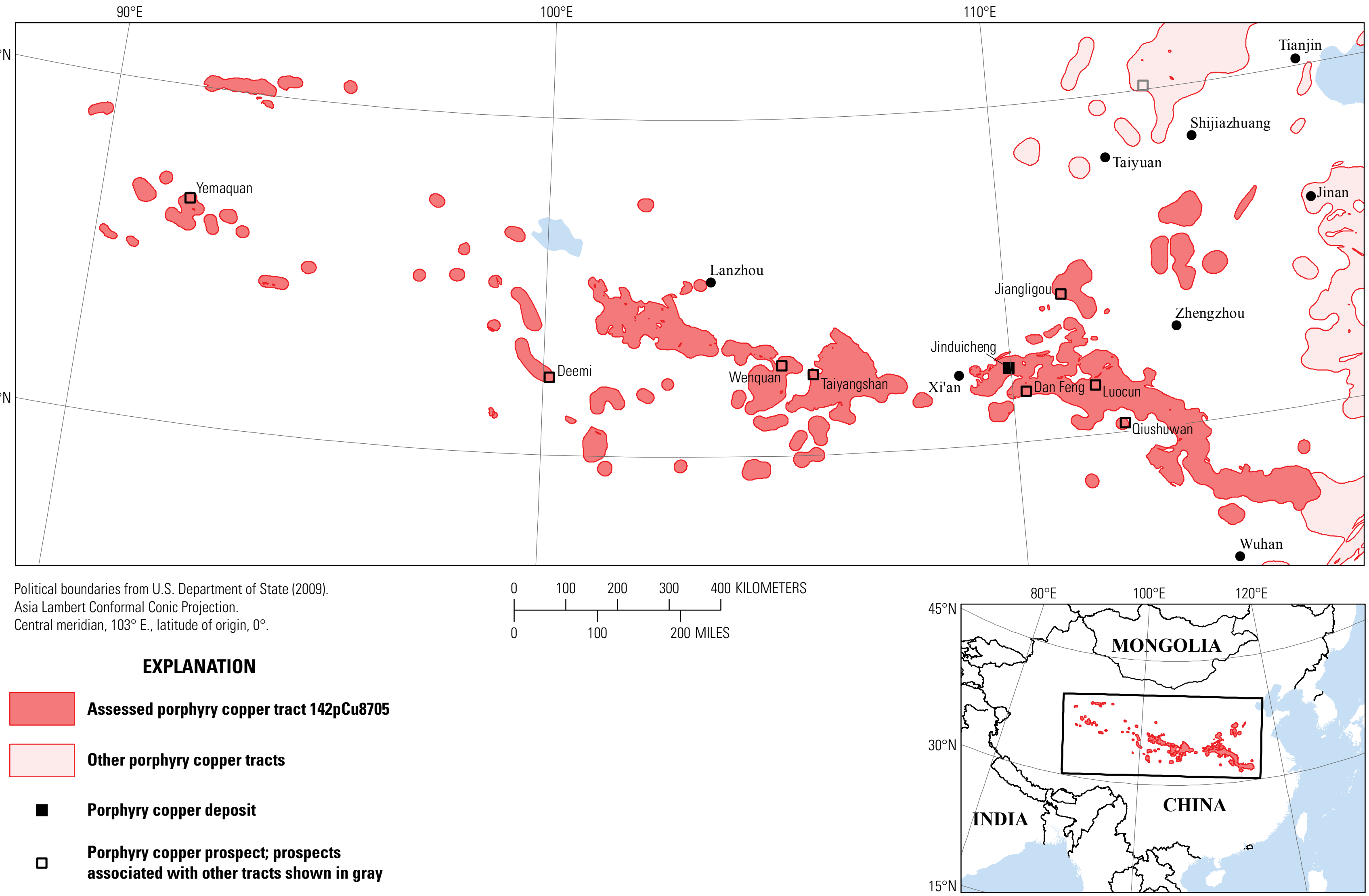

Figure C1. Map showing tract location, known porphyry copper deposits, and porphyry copper prospects for tract 142pCu8705, East Qinling—China.

Delineation of the Permissive Tract

Geologic Criteria

The tract outlines a field of intermediate to felsic Mesozoic intrusive and volcanic rocks that are widely regarded as post-tectonic, related to lithospheric delamination instead of active subduction. This magmatic belt is largely coincident with the preexisting Qinling-Dabie orogen (Ratsbacher and others, 2003), formed in Paleozoic through Triassic time, and the emplacement of the rocks was guided by extensional faults related to reactivation of older structures. Strontium and neodymium isotopic evidence indicates that the rocks formed from differentiated mantle-derived melts that incorporated large amounts of lower crustal material (Zhang and others, 2009; Mao and others, 2008).

The tract was delineated using only intermediate-composition igneous rocks. Plutonic rocks include diorite, quartz diorite, granodiorite, monzonite, and syenite; granites were excluded. Volcanic rocks include primarily andesite, with lesser amounts of dacite, trachyte, latite, and some pyroclastic rocks of unspecified composition. Many of the intrusive rocks associated with the numerous molybdenum deposits in the tract are granites, with more than 70 percent silica.

Known Deposits

The most important porphyry-style ore deposit in the tract is Jinduicheng (Huang and others, 1988; Zhang and others, 2009; Zhu and others, 2010), which is the largest molybdenum-producing mine in China. Although most authors refer to the deposit as a porphyry molybdenum deposit, and the deposit is quite large (1,400,000,000 metric tons (t)), the molybdenum grade is relatively low (0.091 percent Mo) and the copper grade is 0.028 percent, as reported by Zhang and others (2009). Many, but not all, of the known geologic characteristics of the deposit suggest it should be considered a porphyry molybdenum deposit, but the copper grade is quite atypical. It is included here as a deposit because of its importance, recognizing that there is disagreement about the classification of porphyry deposits with molybdenum and/or copper grades less than or equal to 0.1 percent. Jinduicheng was dated by Stein and others (1997), using Re-Os methods at about 138 Ma (Early Cretaceous) (table C2, appendix D).

The East Qinling molybdenum belt contains nearly half the known molybdenum resources of China (Zhang and others, 2009). Stretching east-west across much of southern Henan Province and eastern Shaanxi, the area contains nearly 20 molybdenum-bearing deposits (skarn, porphyry, and vein) and prospects, as well as the Jinduicheng deposit. Details of these deposits, including copper grades, are poorly known and their classification is uncertain.

Prospects, Mineral Occurrences, and Related Deposit Types

In addition to the numerous porphyry molybdenum deposits in the East Qinling molybdenum belt (Mao and others, 2008), we identified eight prospects that appear to be related to porphyry copper style mineralization (appendix D, fig. C1). Several of these prospects appear to be primarily skarns. The Qiushuwan prospect (Zhang and others, 2008) appears to be zoned, with a copper-rich part above a deeper molybdenum-rich part. The six most significant prospects are listed in table C3; details on all sites are in appendix D.

Sources of Information

Government geological institutions in China, Russia, and Mongolia do not publicly distribute detailed earth science information. Thus, we are reliant primarily on generalized large-scale compilations that do not include needed information, and on academic papers in the scientific literature and promotional material from the websites of mineral exploration companies. Also, the understanding of the plate-tectonic history of the region is still evolving, which makes it difficult to use as a context for deposit occurrence. A list of the sources used in this assessment is in table 2 in the main body of this report.

Grade and Tonnage Model Selection

Incomplete, unreliable, and conflicting information about grades, tonnages, and cutoff grades means that existing data are unlikely to be a reliable guide to undiscovered deposits. Because of the large number of contemporary molybdenum porphyry deposits in the belt, the porphyry copper-molybdenum model was used for assessment.

Table C2. Porphyry copper deposits in tract 142pCu8705, East Qinling—China.

[Ma, million years; Mt, million metric tons; t, metric ton; g/t, gram per metric ton; n.d., no data. Contained Cu in metric tons is computed as tonnage (Mt × 1,000,000) × Cu grade (percent)]

Name	Latitude	Longitude	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)
Jinduicheng	34.33	109.95	138	1400	0.028	0.091	n.d.	n.d.	390,000

Table C3. Significant prospects and occurrences in tract 142pCu8705, East Qinling—China.

[Ma, million years; kt, thousand metric tons; %, percent]

Name	Latitude	Longitude	Age (Ma)	Comments (grade and tonnage data, if available)
Qiushuwan	33.16	112.29	147	Resource of 500 kt Cu at 0.8%; 100 kt Mo at 0.12%
Dan Feng	33.90	110.28	Yanshanian	Claimed as Cu-Mo porphyry target; contains much skarn
Taiyangshan	34.43	105.78	Yanshanian	Small (8 kt) resource at 0.52% Cu
Wenquan	34.60	105.11	214	Cu grade to 0.05%
Deemi	34.38	100.13	Yanshanian	Indicated as a large copper deposit; probably a skarn (?)
Yemaquan	37.00	91.98	Yanshanian	Indicated as a medium copper deposit; probably a skarn (?)

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Most of the porphyry deposits in this tract are molybdenum porphyries; the East Qinling metallogenic belt is probably the most important molybdenum province in the world, with reserves of more than 8,000,000 t of molybdenum (Mao and others, 2011). We considered and assessed for only those deposits and prospects for which there was direct evidence of substantial copper content.

The largest molybdenum deposit in the tract, Jinduicheng, is difficult to classify, but it contains more copper (about 400,000 t) than many porphyry copper deposits. The breccia deposit at Qiushuwan (fig. C1) has a partially delineated resource of 500,000 t of copper. There are seven other prospects about which less is known; three of them may be skarn deposits.

Based on the relative proportions of volcanic and intrusive rock mapped, as well as the widespread prospects and mineral occurrences, much of the area appears to be exposed at an appropriate erosion level to preserve porphyry deposits. Some of the largely postsubduction granitoid rocks in this tract are somewhat more silica-rich than many of the intrusions related to porphyry copper deposits worldwide, but several of the deposits and prospects are related to high-silica granites, so in this area, the silica-rich granites are not necessarily negative evidence.

In China, the rate of exploration success since the year 2000 appears to be rising, rather than falling as it is in most of the world, suggesting that the area is relatively underexplored. For example, a recently announced resource for the Shapinggou deposit (China Mining, 2011), in the eastern part of the tract, of more than 2,000,000 t of molybdenum metal makes it the second-largest molybdenum deposit in the world, although it does not appear to contain important copper resources. Copper deposits have been mined in China for more than 1,000 years, but prospecting for porphyry copper deposits based on their geologic characteristics began only in the 1960s.

Despite these uncertainties, the team estimated a 90 percent chance of 1 or more undiscovered deposits in the tract, a 50 percent chance of 3 or more deposits, and a 10 percent chance of 12 or more deposits (table C4). It is probable that most outcropping deposits have been found. Qiushuwan may well be a porphyry copper deposit, and the presence of large Cu-Au skarn deposits is prospective; thus the estimate for undiscovered deposits at the 90th percentile confidence level was 1 or more.

Because of the subjective nature of the tract delineation, it could be misleading to place great credence in a calculated deposit density for this tract, but the team's estimate is entirely consistent with worldwide deposit density estimates (Singer, 2008; Singer and others, 2005).

Table C4. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 142pCu8705, East Qinling—China.

[N_{XX}, estimated number of deposits associated with the xxth percentile; N_{und}, expected number of undiscovered deposits; s, standard deviation; C_v%, coefficient of variance; N_{known}, number of known deposits in the tract that are included in the grade and tonnage model; N_{total}, total of expected number of deposits plus known deposits; 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 C_v% 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)
N_{90}	N_{50}	N_{10}	N_{05}	N_{01}	N_{und}	s	C_v%	N_{known}	N_{total}		
1	3	12	12	12	5.0	4.2	83	1	6	171,100	0.00004

A previous assessment (Yan and others, 2007) covered about half the tract (Qinling molybdenum belt, tract X-7). They estimated 0.3 mean undiscovered deposits, compared with the present team's estimate of about 5 deposits (table C4). Our estimate is meant to account for substantial copper resources in what are widely regarded as molybdenum deposits.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining the team's estimate for numbers of undiscovered porphyry copper deposits with the porphyry copper-gold model of Singer and others (2008) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012). Selected simulation results are reported in table C5. Results of the Monte Carlo simulation are presented as a cumulative frequency plot (fig. C2), which shows the estimated resource amounts associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

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Table C5. Results of Monte Carlo simulations of undiscovered resources for tract 142pCu8705, East Qinling—China.

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

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu (t)	0	410,000	19,000,000	150,000,000	200,000,000	52,000,000	0.31	0.07
Mo (t)	0	33,000	990,000	6,800,000	9,400,000	2,400,000	0.32	0.07
Au (t)	0	0	50	360	540	130	0.30	0.14
Ag (t)	0	0	6,900	62,000	110,000	22,000	0.28	0.15
Rock (Mt)	0	110	4,000	26,000	33,000	9,300	0.33	0.07

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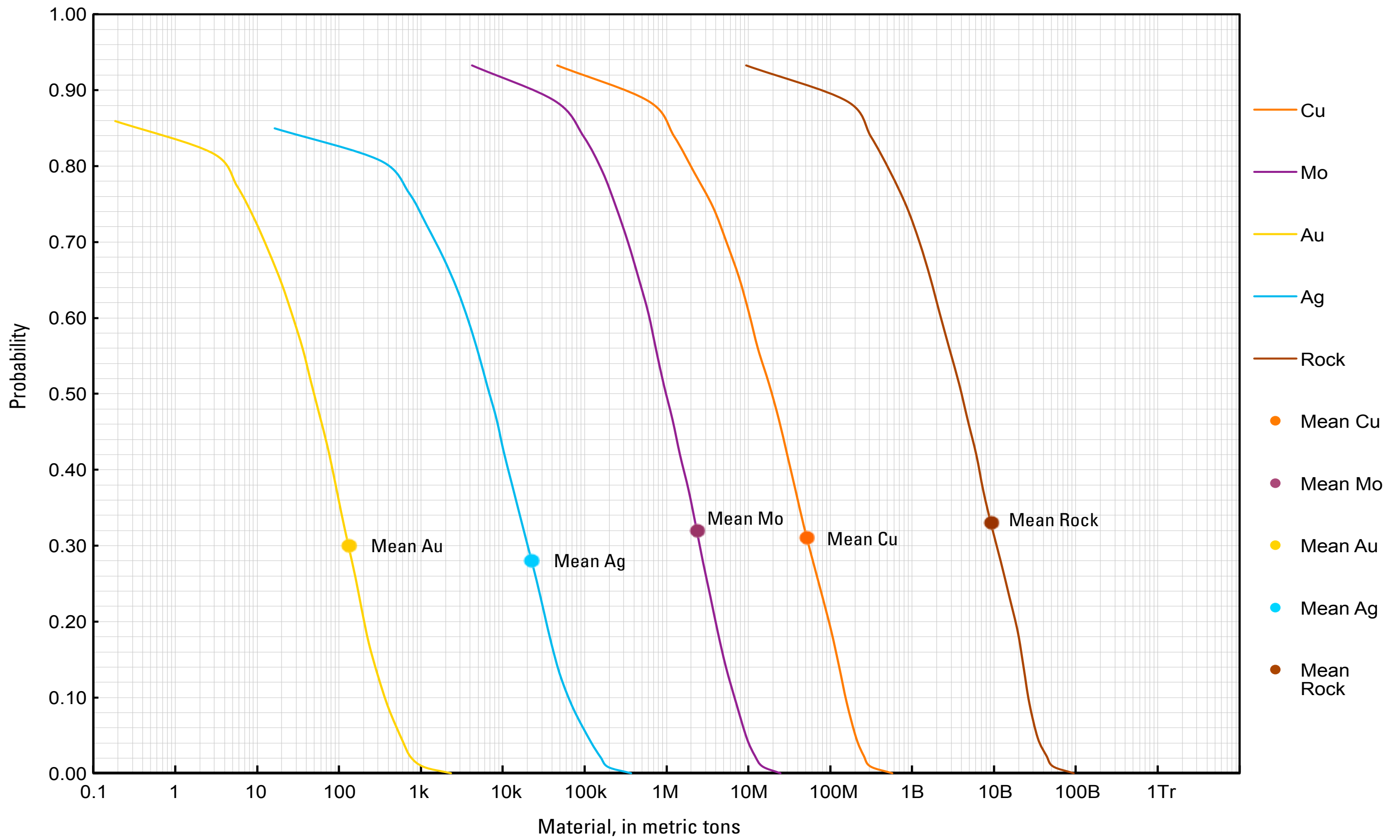

Figure C2. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources for tract 142pCu8705, East Qinling—China. k, thousand; M, million; B, billion; Tr, trillion.

Appendix D. Porphyry Copper Deposits, Prospects, and Occurrences in the Mesozoic of East Asia

This appendix consists of a table and an Excel workbook that contain detailed information about the porphyry copper deposits, prospects, and occurrences in the study area. Table D1 is an index of the deposits, prospects, and occurrences included in the Excel workbook, sorted by tract, site status, and rank. The workbook *EAM_DEPPROS.xls* includes four worksheets. The first contains descriptive information for each site listed in table D1. The remaining three worksheets include references for each site, organized by tract.

Table D1. Porphyry copper deposits, prospects, and occurrences in the Mesozoic of East Asia.

Deposit name	Country	Latitude	Longitude	Site status	Rank	ID on fig. 1
			Manchuride tract			
Zhireken	Russia	52.8430	117.3600	Deposit		
Bystrinskoe	Russia	51.4800	118.5700	Deposit		
Shaktama	Russia	51.2830	117.8830	Deposit		
Wunugetushan	China	49.4239	117.3010	Deposit		
Xiaosigou	China	41.0500	118.6010	Deposit		
Borgulikan	Russia	53.7909	126.6351	Prospect	Significant	1
Lugokanskaya	Russia	52.6140	119.7446	Prospect	Significant	3
Kultuminskaya	Russia	52.1851	119.0959	Prospect	Significant	4
Naoniushan	China	45.7800	121.7090	Prospect	Significant	15
Lianhuashan	China	45.6508	121.9260	Prospect	Significant	16
Budunhua	China	44.9991	121.4260	Prospect	Significant	17
Ulandler	China	44.8150	112.8520	Prospect	Significant	18
Aolunhua	China	44.7603	120.5560	Prospect	Significant	19
Aonaodaba	China	44.6331	119.6030	Prospect	Significant	20
Daheishan	China	43.4891	126.3240	Prospect	Significant	23
Yangchang	China	43.4477	117.4930	Prospect	Significant	24
Xiaoxinancha	China	43.2133	130.8850	Prospect	Significant	25
Shibadougou	China	43.1380	127.9420	Prospect	Significant	26
Yajishan	China	42.4202	119.8300	Prospect	Significant	28
Houyu	China	39.0768	113.6160	Prospect	Significant	29
Twenty-one Station	China	52.6641	125.0110	Prospect		2
Kurunzulaiskaya	Russia	50.9857	116.9645	Prospect		5
Badaguan	China	49.8232	118.8250	Prospect		6
Avdartolgoi	Mongolia	49.6721	114.8402	Prospect		7
Babayi	China	49.5821	118.5710	Prospect		8
Changling	China	49.4422	116.8960	Prospect		9

Table D1.—Continued

Deposit name	Country	Latitude	Longitude	Site status	Rank	ID on fig. 1
Group 6 and 7	China	48.9833	116.4330	Prospect		10
Bayantumen	Mongolia	48.1258	114.5395	Prospect		11
Davhar Uul	Mongolia	48.1167	114.2653	Prospect		12
Suul Tsagaan	Mongolia	46.8833	115.4889	Prospect		13
Zuun Matad	Mongolia	46.8389	115.5333	Prospect		14
Baikal	China	44.2190	131.3338	Prospect		21
Haoliabao	China	43.7461	120.4090	Prospect		22
Xinhe	China	42.9500	128.4170	Prospect		27
Name unknown	China	53.2438	121.6999	Occurrence		
Name unknown	China	52.1993	124.3408	Occurrence		
Name unknown	China	51.4521	120.1996	Occurrence		
Name unknown	China	51.2027	126.6660	Occurrence		
Name unknown	China	51.1189	126.7135	Occurrence		
Name unknown	China	50.8050	120.8169	Occurrence		
Name unknown	China	49.4918	116.6704	Occurrence		
Name unknown	China	49.3553	116.5891	Occurrence		
Name unknown	China	48.7169	120.8925	Occurrence		
Name unknown	China	47.9931	121.3002	Occurrence		
Name unknown	China	47.1660	119.9176	Occurrence		
Name unknown	China	44.3808	119.3842	Occurrence		
Name unknown	China	44.2410	116.3213	Occurrence		
Name unknown	China	43.8474	119.4940	Occurrence		
Name unknown	China	43.7701	118.7588	Occurrence		
Name unknown	China	43.7171	117.3225	Occurrence		
Coastal Pacific tract						
Tongchankou	China	29.9987	114.8390	Deposit		
Fengshandong	China	29.8189	115.4490	Deposit		
Chengmenshan	China	29.6813	115.8050	Deposit		
Dexing	China	29.0189	117.7300	Deposit		
Yinshan	China	28.9718	117.5960	Deposit		
Zijinshan	China	25.1801	116.4010	Deposit		
Shangjiazhuang	China	37.2917	120.8590	Prospect	Significant	30
Duijinshan	China	35.5420	118.3180	Prospect	Significant	32
Anjishan	China	32.0667	119.1000	Prospect	Significant	33
Taipingshan	China	31.6969	118.7065	Prospect	Significant	35
Shaxi	China	31.1833	117.2670	Prospect	Significant	36
Jingbian	China	30.9684	117.4450	Prospect	Significant	37
Baiyunshan	China	29.9965	114.9730	Prospect	Significant	39

Table D1.—Continued

Deposit name	Country	Latitude	Longitude	Site status	Rank	ID on fig. 1
Yongping	China	28.1983	117.7620	Prospect	Significant	42
Wangjiazhuang	China	27.1493	119.3270	Prospect	Significant	43
Hongshan	China	25.3000	115.8000	Prospect	Significant	44
Zhongteng	China	24.3700	117.1230	Prospect	Significant	48
Yuanzhuding	China	23.8040	111.6880	Prospect	Significant	50
Qibaoshan	China	35.6471	119.2200	Prospect		31
Guli	China	31.8800	118.7000	Prospect		34
Bamaoshan	China	30.8540	117.3800	Prospect		38
Dingjiashan	China	29.4650	117.3360	Prospect		40
Heishanling	China	28.9200	118.3170	Prospect		41
Zhongliao	China	25.1836	116.4350	Prospect		45
Luoboling	China	25.1465	116.4020	Prospect		46
Jinxi	China	24.3700	117.2670	Prospect		47
Guifeng	China	23.8200	114.0170	Prospect		49
East Qinling tract						
Jinduicheng	China	34.3323	109.9540	Deposit		
Yemaquan	China	36.9964	91.9758	Prospect	Significant	51
Wenquan	China	34.6010	105.1130	Prospect	Significant	53
Taiyangshan	China	34.4259	105.7790	Prospect	Significant	54
Deemi	China	34.3793	100.1300	Prospect	Significant	55
Dan Feng	China	33.8986	110.2830	Prospect	Significant	56
Qiushuwan	China	33.1599	112.2920	Prospect	Significant	58
Jiangligou	China	35.5500	111.2300	Prospect		52
Luocun	China	33.8810	111.7540	Prospect		57

Appendix E. Description of Geographic Information System (GIS) files

An Environmental Sciences Research Institute (ESRI) geodatabase file (*EASIA_pCu.gdb*) containing three feature classes and an ESRI map document (EASIA *_GIS.mxd*) are included with this report. These may be downloaded from the USGS website as zipped file *GIS_SIR5090G_appendix_E.zip*, which also contains the data in shapefile format.

The feature classes (and shapefiles) are as follows:

EASIA_pCu_Tracts is a vector (polygon) feature class that represents the three 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 files.

EASIA _pCu_ Deposits_prospects is a vector (point) feature class that represents the locations for known deposits (identified resources that have well-defined tonnage and copper grade) and prospects. The deposits and prospects are listed in tables in appendixes A, B, C, and D of this report. 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 files.

EASIA _political_boundaries is a vector (polygon) feature class that represents the political boundaries in and adjacent to the study area. The data were extracted from the country and shoreline boundaries maintained by the U.S. Department of State (2009).

The files can be viewed with an included ESRI map document (version 9.3) named *EASIA_GIS.mxd*.

Reference Cited

U.S. Department of State, 2009, Small-scale digital international land boundaries (SSIB)—Lines, edition 10, and polygons, beta edition 1, *in* Boundaries and sovereignty encyclopedia (B.A.S.E.): U.S. Department of State, Office of the Geographer and Global Issues.

Appendix F. Assessment Team Member Information

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

Mark J. Mihalasky is a research geologist with the USGS in Spokane, Washington. He received a B.S. in geology in 1984 from Stockton State College, an M.S. in geology in 1988 from Eastern Washington University, and a Ph.D. in earth sciences in 1999 from the University of Ottawa. He has worked as an exploration geologist and GIS consultant, Assistant Professor of Earth and Marine Geology and Coastal Research Center Director of Research at The Richard Stockton College of New Jersey, and, since joining the USGS in 2008, a geospatial analyst and resource assessment scientist. He has experience in economic geology, mineral and interdisciplinary natural resource assessment, and quantitative analysis and modeling of geospatial data. He has been involved with metallic mineral resource assessments (gold, silver, copper) in Nevada, China, Afghanistan, and western Asia (eastern Russia, Mongolia, northern China, Kazakhstan), diamond resources in Mali and Central African Republic, and interdisciplinary natural resource assessments in Madagascar, Gabon, and the United States.

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

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

Thomas P. Frost is a research geologist with the USGS in Spokane, Washington. He completed his B.A. in geology in 1975 at U.C. Santa Barbara and his Ph.D. at Stanford in 1987. He has experience as a marine geologist working on environmental hazards associated with oil leasing in the Gulf of Alaska and Cook Inlet, a petrologist working on rheologic modeling of mafic and felsic magma interaction in granitic plutons in the Sierra Nevada, and a geochemist doing geochemical surveys and geologic mapping. Recent work includes the Interior Columbia Basin Ecosystem Management Project, which was charged with assessing forest-landscape-aquatic-social-economic conditions in the Columbia River Basin and developing adaptive management plans for Federal lands in the basin. He has participated in porphyry copper mineral resource assessments of Russia, Mongolia, northern China, and Kazakhstan.

Thomas D. Light was a research geologist with the USGS in Spokane, Washington, where he retired in 2011. Tom received his B.S. in geology from Bowling Green State University in 1969. He worked as a mineral exploration geologist/geophysicist in northern Ontario and Wyoming, and as a geophysicist for the Naval Oceanographic Office before receiving his M.S. in geology from Northern Arizona University in 1975. Subsequently, Tom worked for the U.S. Bureau of Mines doing mineral resource assessments in the western U.S. In 1981 he joined the USGS, where he did geochemical and mineral resource studies of numerous Alaska Mineral Resource Assessment Program (AMRAP) quadrangles in Alaska, was the Associate Branch Chief for the Branch of Alaskan Geology, and was the coordinator for the Alaskan portion of the 1998 USGS National Mineral Resource Assessment. After 21 years in Alaska, Tom transferred to Spokane, Washington, where he spent 3 years working on the Global Mineral Resource Assessment Project.

Dmitriy Alexeiev is a senior scientist with the Geological Institute of the Russian Academy of Sciences (RAS) in Moscow, Russia. He received MA and Ph.D. degrees in geology from Moscow State University in 1985 and 1993 respectively. He worked as a mapping geologist in the Karatau area of southern Kazakhstan between 1985 and 1993. From 1993 to 2005 he was with RAS Institute of Oceanology, and has been with RAS Geological Institute from 2006 to the present. His studies focus on the tectonic evolution of the Paleozoic Kazakhstan –Tian-Shan region and the Mesozoic to Cenozoic Russian Far East. His work with the USGS has included regional tectonic syntheses, terrane models, and the evolution of arc systems through time for Kazakhstan, Central Asia, and the western Circum-Pacific.

Arthur A. Bookstrom is a research geologist with the USGS in Spokane, Washington. He received a B.A. in geology from Dartmouth College (1961), an M.S. in geology from the University of Colorado (1964), and a Ph.D. in geology from Stanford University (1975). He worked as a mine geologist at the Climax molybdenum mine in Colorado, El Romeral magnetite mine in Chile, and the Rochester silver mine in Nevada. He has done exploration-project work at sites in Colorado, Nevada, and Montana, as well as regional exploration for molybdenum in Colorado and regional exploration for gold in Nevada, Montana, and Saudi Arabia. His work with the USGS has included regional geologic studies, metallogenic studies, mineral-environmental studies, and mineral-resource assessments.

Andre Panteleyev is an economic geologist, formerly with the British Columbia Department of Mines of the British Columbia Geological Survey. He received his B.Sc. (Honours, 1964), M.Sc. (1969), and Ph.D. (1976) from the University of British Columbia. He specialized in economic geology studies at Queen’s University from 1967 to 1969, and is registered as a Professional Engineer (P.Eng.) with the Association of Professional Engineers and Geoscientists of British Columbia. He specializes in intrusion-related and subvolcanic mineralized environments, conceptual mineral deposit modeling, the genetic interrelationships of mineral deposits, regional metallogeny, methodologies and applications of regional mineral potential assessments, and multisector land use negotiations. His work experience includes nine field seasons in the Canadian Cordillera with Kennco Explorations (Western) Ltd (a Canadian subsidiary of Kennecott Copper Corporation) doing porphyry copper exploration. He has worked and lectured extensively in Canada, Mongolia, China, Argentina, Bolivia, Chile, and Perú, as well as the United States, El Salvador, Fiji, Mexico, and Sweden. He is currently with XDM Geological Consultants, Inc., in Victoria, Canada.

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