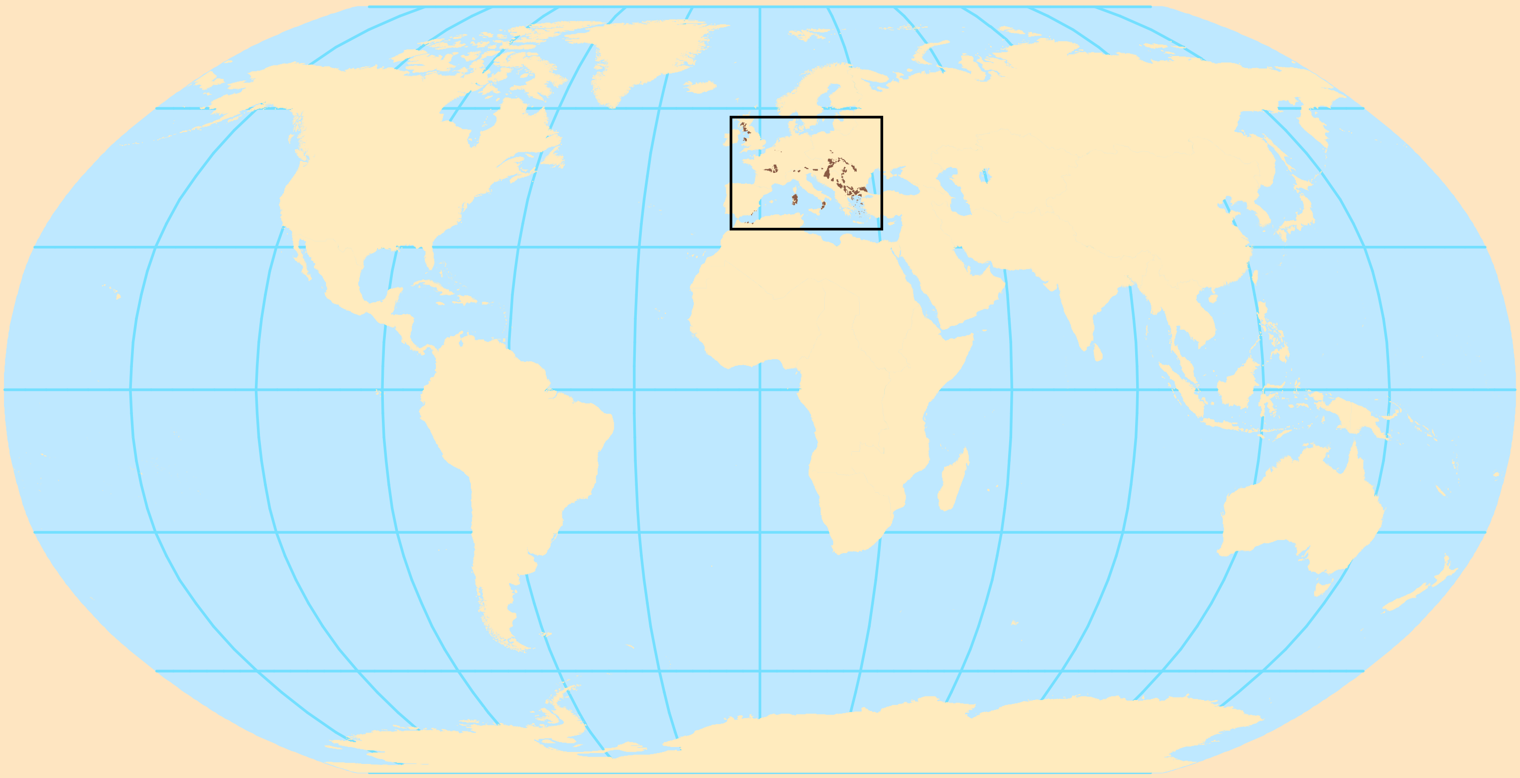
Global Mineral Resource Assessment

Porphyry Copper Assessment of Europe, Exclusive of the Fennoscandian Shield



Prepared in cooperation with the Bureau de Recheres Géologiques et Minières (BRGM), the Geological Institute of Romania, Charles University, and Dr. Duncan E. Large, Ph.D.

Scientific Investigations Report 2010–5090–K

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

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By David M. Sutphin, Jane M. Hammarstrom, Lawrence J. Drew, Duncan E. Large, Byron R. Berger, Connie L. Dicken, and Michael W. DeMarr *with contributions from* Mario Billa, Joseph A. Briskey, Daniel Cassard, Andor Lips, Zdeněk Pertold, and Emilian Roşu

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Acronyms and Abbreviations Used

ANOVA	Analysis of variance
GIS	Geographic Information System
g/t	grams per metric ton
kt	thousand metric tons
Ma	million of years before the present
Mt	million metric tons
PGE	platinum-group elements
REE	rare-earth elements
SHRIMP	sensitive high resolution ion microprobe
SSIB	small-scale digital international boundaries
t	metric ton (tonne) or megagram (Mg)
USGS	United States Geological Survey

Conversion Factors

Inch/Pound to SI

	Multiply by	To obtain
Length		
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
Area		
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
Mass		
ounce, troy (troy oz)	31.015	gram (g)
ounce, troy (troy oz)	32150.75	megagram (Mg)
ton, short (T) (2,000 lb)	0.9072	megagram (Mg)

SI to Inch/Pound

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

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Porphyry Copper Assessment of Europe, Exclusive of the Fennoscandian Shield

By David M. Sutphin[1], Jane M. Hammarstrom[1], Lawrence J. Drew[1], Duncan E. Large[2], Byron R. Berger[3], Connie L. Dicken[1], and Michael W. DeMarr[1], with contributions from Mario Billa[4], Joseph Briskey[1], Daniel Cassard[4], Andor Lips[4], Zdeněk Pertold[5], and Emilian Roşu[6]

Abstract

The U.S. Geological Survey (USGS) collaborated with European geologists to assess resources in porphyry copper deposits in Europe, exclusive of Scandinavia[7] and Russia. Porphyry copper deposits in Europe are Paleozoic and Late Cretaceous to Miocene in age. A number of the 31 known Phanerozoic deposits contain more than 1 million metric tons of contained copper, including the Majdanpek deposit, Serbia; Assarel, Bulgaria; Skouries, Greece; and Rosia Poeni, Romania. Five geographic areas were delineated as permissive tracts for post-Paleozoic porphyry copper deposits. Two additional tracts were delineated to show the extent of permissive igneous rocks associated with porphyry copper mineralization related to the Paleozoic Caledonian and Variscan orogenies. The tracts are based on mapped and inferred subsurface distributions of igneous rocks of specific age ranges that define areas where the occurrence of porphyry copper deposits within 1 kilometer of the Earth's surface is possible. These tracts range in area from about 4,000 to 93,000 square kilometers. Although maps at a variety of different scales were used in the assessment, the final tract boundaries are intended for use at a scale of 1:1,000,000.

The post-Paleozoic deposits in Europe all formed in conjunction with the tectonic evolution of southern Europe as the former Tethyan Ocean closed by convergence of the African and Arabian Plates with Europe, accompanied by accretion of microcontinents to the southern Eurasian Plate and development and demise of magmatic arcs and ocean basins. Many of the deposits formed in extensional or post-collisional settings; these tectonic environments are increasingly being recognized as environments where porphyry copper deposits occur.

Probabilistic estimates of undiscovered porphyry copper deposits were made for four Phanerozoic permissive tracts; the other tracts are discussed qualitatively. Assessment participants estimated numbers of undiscovered deposits at different levels of confidence for the four tracts. These estimates were then combined with grade and tonnage models using Monte Carlo simulation to generate probabilistic estimates of amounts of in-place undiscovered resources. Additional resources that may be present in extensions of known deposits were not evaluated. Assessment results are reported in tables and graphs as expected amounts of metal and rock in undiscovered deposits at different quantile levels, as well as the arithmetic mean for each commodity for each tract.

This assessment estimated a mean of 14 undiscovered porphyry copper deposits within the four permissive tracts for which estimates were made. On the basis of global grade and tonnage models, mean (arithmetic) estimated resources that could be associated with undiscovered deposits are about 46 million metric tons of copper and about 2,600 metric tons of gold, as well as byproduct molybdenum and silver. Reliable reported identified resources for the 27 deposits in the assessed areas total about 44 million metric tons of copper and about 2,300 metric tons of gold. Exploration for gold-rich porphyry systems is ongoing in some parts of historical copper mining districts in central Europe and in northwesternmost (European) Turkey. Political and social conflicts, environmental concerns associated with historical mining, and the global economic situation have had negative effects on exploration, development, and mining in Europe for many years.

The assessment includes an overview with summary tables. Detailed descriptions of each tract, including the rationales for delineation and assessment, are given in appendixes A-G. Appendix H describes a geographic information system (GIS) that includes tract boundaries and point locations of known porphyry copper deposits and significant prospects.

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[7]Sweden, Denmark, Norway, and Finland.

Introduction

The U.S. Geological Survey (USGS) led a probabilistic mineral resource assessment of undiscovered resources in porphyry copper deposits in Europe as part of a global mineral resource assessment. The purpose of the study was to (1) delineate permissive areas (tracts) for undiscovered porphyry copper deposits at a scale of 1:1,000,000; (2) compile a database of known porphyry copper deposits and significant prospects; (3) estimate numbers of undiscovered deposits within those permissive tracts, where data permit; 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 countries of Europe covered by this report include Albania, Andorra, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, France, Germany, Greece, Guernsey, Hungary, Ireland, Italy, Jersey, Kosovo, Liechtenstein, Luxembourg, Macedonia, Isle of Man, Malta, Monaco, Montenegro, Netherlands, Poland, Portugal, Romania, San Marino, Serbia, Slovakia, Slovenia, Spain, Switzerland, Turkey, Ukraine, and the United Kingdom (fig. 1). A small area of European affinity in northeastern Morocco also is included. Physiographic features mentioned in this study are shown on figure 1. The assessment was done by the U.S. Geological Survey in cooperation with European colleagues. In particular, the French Bureau de Recherches Géologiques et Minières (BRGM) hosted several workshops and provided data for the assessment.

Porphyry copper deposits are the most important large tonnage low-grade sources of global copper supply. The principal ore mineral in porphyry copper deposits is chalcopyrite, $CuFeS_2$, distributed in stockwork veinlets and disseminations in hydrothermally altered porphyry and adjacent rock. Molybdenum, silver, and gold are important byproducts in many deposits. Gold-rich porphyry copper deposits are especially attractive exploration targets due to the high gold prices that have characterized the beginning of the 21st century.

Total world mine production of copper in 2009 was about 16.2 Mt,[8] led by production from Chile (5.39 Mt), Peru (1.28 Mt), the United States (1.18 Mt), and China (0.995 Mt) as reported by Edelstein (2011). The countries of Europe, including Turkey, contributed about 858,000 metric tons (t) of copper ore production, which represented about 5 percent of world production (Edelstein, 2011). Poland produced about 56 percent (444,000 t) of European copper, primarily from sediment-hosted deposits, followed by Bulgaria, Portugal, Turkey, Sweden, Macedonia, Spain, Serbia, Finland, and Romania (Edelstein, 2011). Copper also is produced in Europe from porphyry copper deposits, polymetallic veins, volcanogenic- and ophiolite-associated massive sulfide deposits, ultramafic magmatic complexes, and skarns. Europe is not a leader in production of copper on a global scale; however, Europe hosts several world-class[9] porphyry copper deposits such as the Recsk deposit in Hungary (fig. 1*A*) and the Majdanpek deposit in Serbia (fig. 1*B*).

[8]Mt, million metric tons.

[9]Porphyry copper deposits that contain more than 2 million metric tons of copper.

Terminology

The terminology used in this report follows that used in the 1998 assessment of undiscovered deposits of gold, silver, copper, lead, and zinc in the United States (U.S. Geological Survey National Mineral Resource Assessment Team, 2000; U.S. Bureau of Mines and U.S. Geological Survey, 1976; Bates and Jackson, 1997). The terms used here represent standard definitions and general usage by the minerals industry and the resource-assessment community. Some countries, however, recently have adopted more rigorous definitions of terms for estimating mineral resources and mineral reserves and for reporting exploration information to comply with legal mandates (Committee for Mineral Reserves International Reporting Standards, 2006).

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

- *Undiscovered mineral deposit*—A mineral deposit believed to exist, or an incompletely explored mineral occurrence or prospect that could have sufficient size and grade to be classified as a deposit. For the global porphyry copper assessment, a depth limit of 1 km (kilometer) to the top of a mineralized porphyry system was adopted because of the difficulties of acquiring global-scale data to constrain the vertical extent of permissive rocks. However, more deeply buried porphyry systems are known, such as the Resolution deposit in Arizona.

- *Mineral prospect*—(a) An area that is a potential site of mineral deposits, based on mineral exploration (Bates and Jackson, 1987). (b) In some instances, an area that has been explored in a preliminary way but has not given evidence of economic value (Bates and Jackson, 1987). (c) An area to be searched by some investigative technique, for example, geophysical prospecting (Jackson and Bates, 1997). (d) A geologic or geophysical anomaly, especially one recommended for additional exploration (Bates and Jackson, 1987). (e) A mineral property whose value has not been proved by exploration (Bureau of Land Management, 1999).

- *Mineral occurrence*—(a) A concentration of a mineral that is considered valuable by someone somewhere, or that is of scientific or technical interest (Cox and Singer, 1986). (b) Any ore or economic mineral in any concentration found in bedrock or as float; especially a valuable mineral in concentration sufficient to suggest further exploration (Bates and Jackson, 1987).

- *Descriptive mineral deposit model*—A set of data in a convenient, standardized form that describes a group of mineral deposits having similar characteristics.

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

- *Grade and tonnage model*—Frequency distributions of the grades and sizes of well-explored, and(or) completely mined out, individual mineral deposits that are classified by a descriptive mineral deposit model. Model data represent average reported grades and tonnages based on total production, reserves, and identified resources at the lowest reported cutoff grade. For porphyry copper deposits, a spatial rule is used to aggregate tonnage and grade information for deposits. All mineralized rock or alteration within 2 kilometers is combined as one deposit (Singer and others, 2008).

- *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, and quantity are known or can be estimated from specific geologic evidence. For this assessment, identified resources are the deposits that constitute the grade and tonnage models used in the assessment (which can include measured, indicated, and inferred mineral resources at the lowest available cutoff grade). In addition, deposits that are not included in the models used for the assessment may be considered as identified resources if they are characterized well enough by deposit type, grade, and tonnage to meet U.S. Securities and Exchange Commission or CRIRSCO[10] reporting guidelines.

- *Undiscovered resources*—Resources in undiscovered mineral deposits whose existence is postulated on the basis of indirect geologic evidence. These include undiscovered resources in known types of mineral deposits postulated to exist in permissive geologic settings. Undiscovered resources may include active mines if the resource is delineated incompletely. For example, a deposit that is explored only partially and reported as "open to the west or open at depth" could be counted as an undiscovered deposit. Undiscovered resources in extensions to identified resources are not addressed explicitly in the USGS assessment process.

- *Calc-alkaline, calc-alkalic; alkaline, alkalic*—These terms are used in a general, non-rigorous manner to refer to plutonic igneous rocks of granitoid composition (calc-alkaline or calc-alkalic) and of syenitoid through dioritoid to gabbroid composition (alkaline or alkalic), and their volcanic equivalents (see Le Maitre and others, 2002, provisional field classifications, figures 2.10 and 2.19). In the literature on igneous rocks, the terms "-alkaline" and "-alkalic" are defined and used in multiple and inconsistent ways (see Arculus, 2003). For this assessment, the terms calc-alkalic and alkalic are used synonymously for calc-alkaline and alkaline, as well as for their associated porphyry copper deposit subtypes.

- *Ga*—Giga-annum, 1 billion (10^9) years.

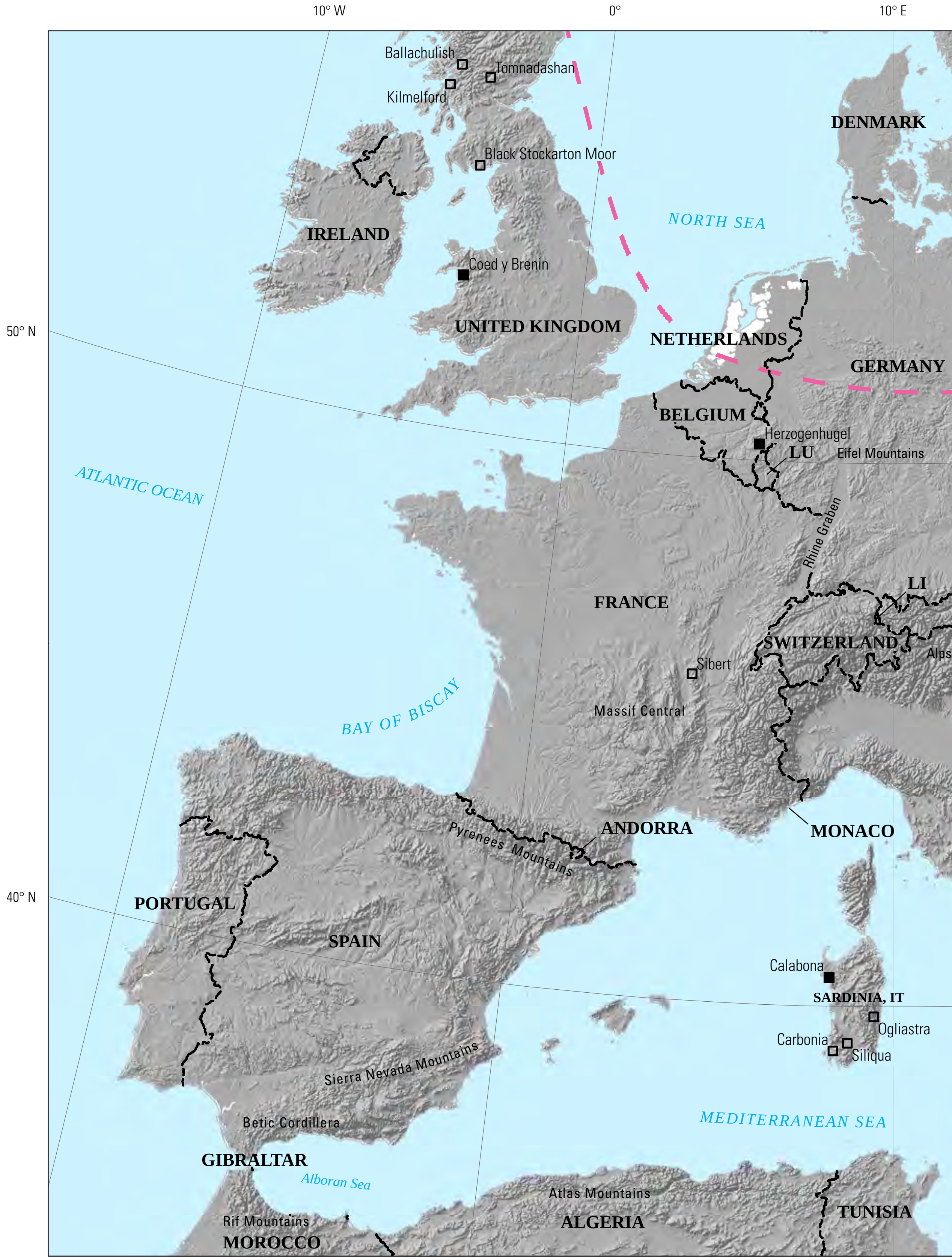
- *Ma*—Milli-annum, 1 million (10^6) years.

Considerations for Users of this Assessment

Global mineral resource assessment products represent a synthesis of current, available information. Ideally, assessments are done on a recurring basis, at a variety of scales, because available data change over time. This assessment is based on the descriptive and grade-tonnage data contained in published mineral deposit models. Data in the models represent average grades of each commodity of possible economic interest, and tonnages based on the total of production, reserves, and resources at the lowest cutoff grade for which data were available when the model was constructed. The economic viability of the deposits used to construct the models varies widely, so care must be exercised when using the results of this assessment to answer questions that involve economics. Estimates are of numbers of deposits that are likely to exist, not necessarily those likely to be discovered (Singer, 2007a,b). Only a percentage, perhaps on the order of 50 percent of the undiscovered resources, are likely to be economically viable depending on a number of factors such as metal prices, capital costs, mining methods, and depth (see for example, Drew and others' 1999b application of engineering cost models for porphyry copper deposits in Alaska, USA and British Columbia, Canada).

The assessment team may be aware of prospects, revealed by past or current exploration efforts, that are believed to be significant deposits, but that do not yet have a citable grade and tonnage. These probable deposits are treated here as undiscovered deposits, albeit ones with a high degree of certainty of existence. The mineral industry explores for extensions of identified resources, as well for greenfields projects (that is, exploration targets away from known deposits). Extensions to identified resources are not considered in this assessment, although they typically represent a substantial part of newly discovered copper resources each year. This assessment considers the potential for concealed deposits within 1 km of the surface. The mineral industry does consider deeper deposits for development in some parts of the world. Exploration and development of deeply buried deposits may be so

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



Base from European Environment Agency (2011).
Hillshade of DEM with grid spacing of 1 km.
Political boundaries from U.S. Department of State (2009).
Europe Albers Equal Area Conic Projection.
Central meridian 10° E., latitude of origin 45° N.

0 500 1,000 KILOMETERS

0 250 500 MILES

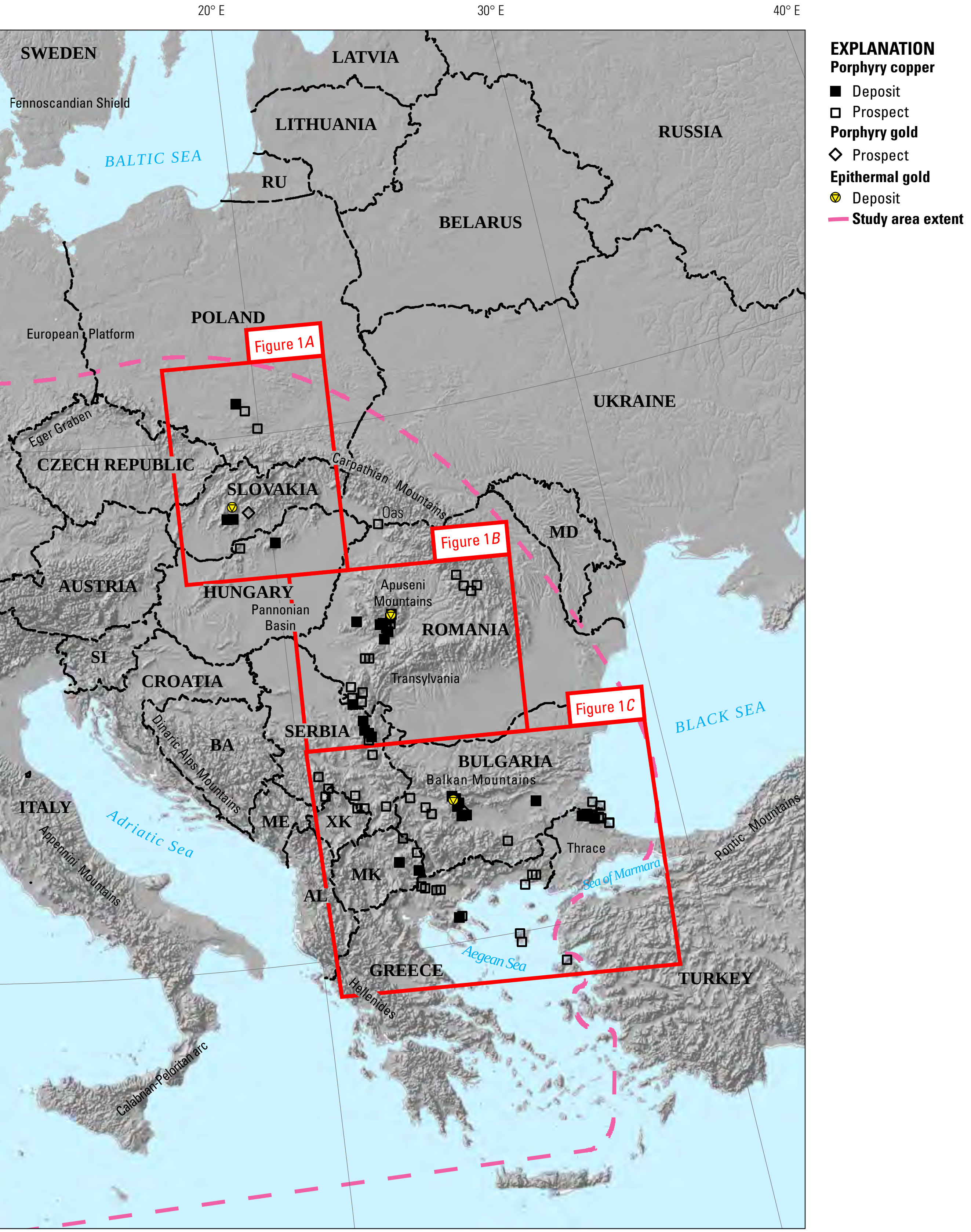


Figure 1. Map of the assessment area. Porphyry copper deposits (named), significant prospects, and physiographic features of Europe are shown. Country abbreviations (ISO 2-letter codes): AL, Albania; BA, Bosnia-Herzegovina; CH, Switzerland; MD, Moldova; ME, Montenegro; MK, Macedonia; SI, Slovenia; XK, Kosovo. *A,* Study area showing named deposits and significant prospects in northern Hungary, Slovakia, and southern Poland. Dashed line marks northern border of study area. *B,* Deposits (named) and prospects in Romania and eastern. Serbia *C,* Deposits (named) and prospects in Bulgaria, southern Serbia, Macedonia, Greece, and northwestern Turkey. See tables and figures in appendixes and GIS for prospect names and details on deposits and prospects.

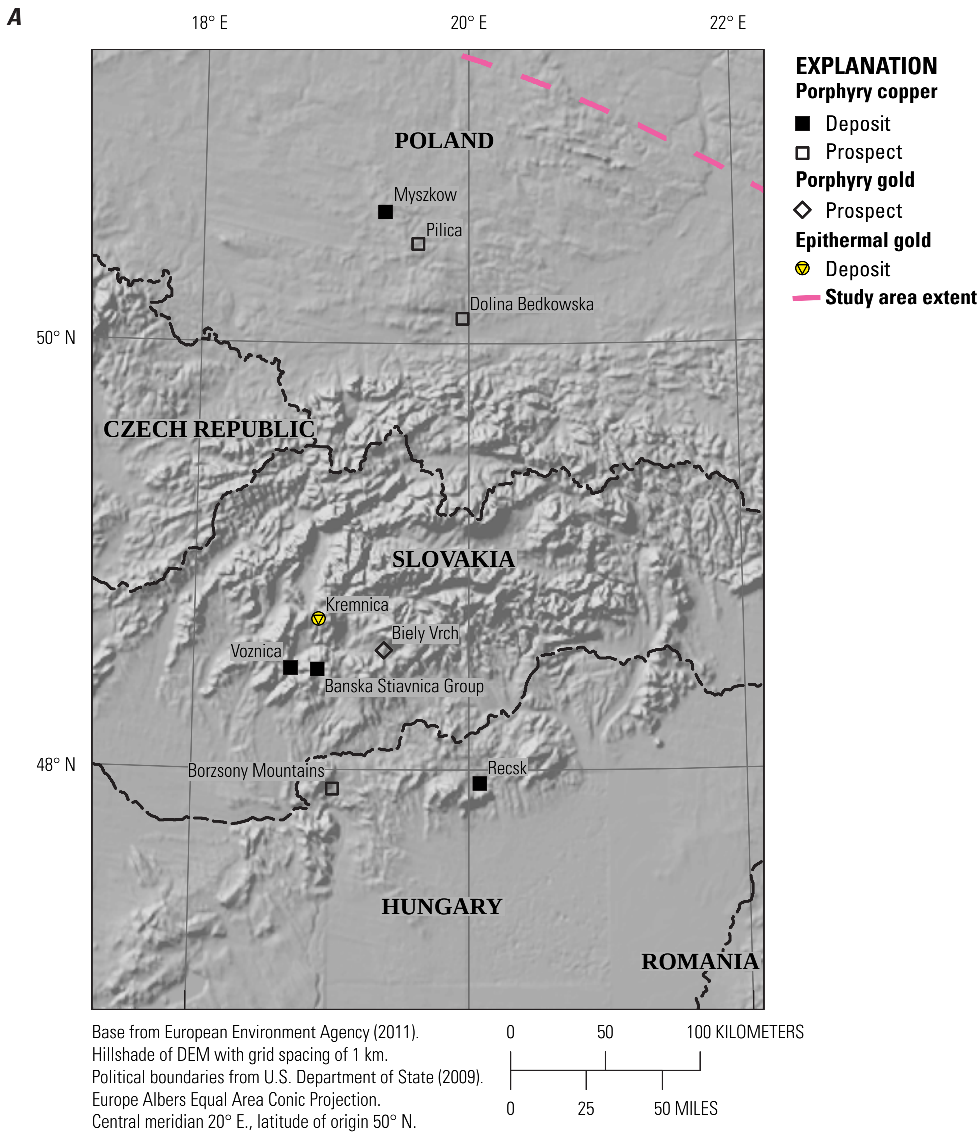


Figure 1.—Continued

B

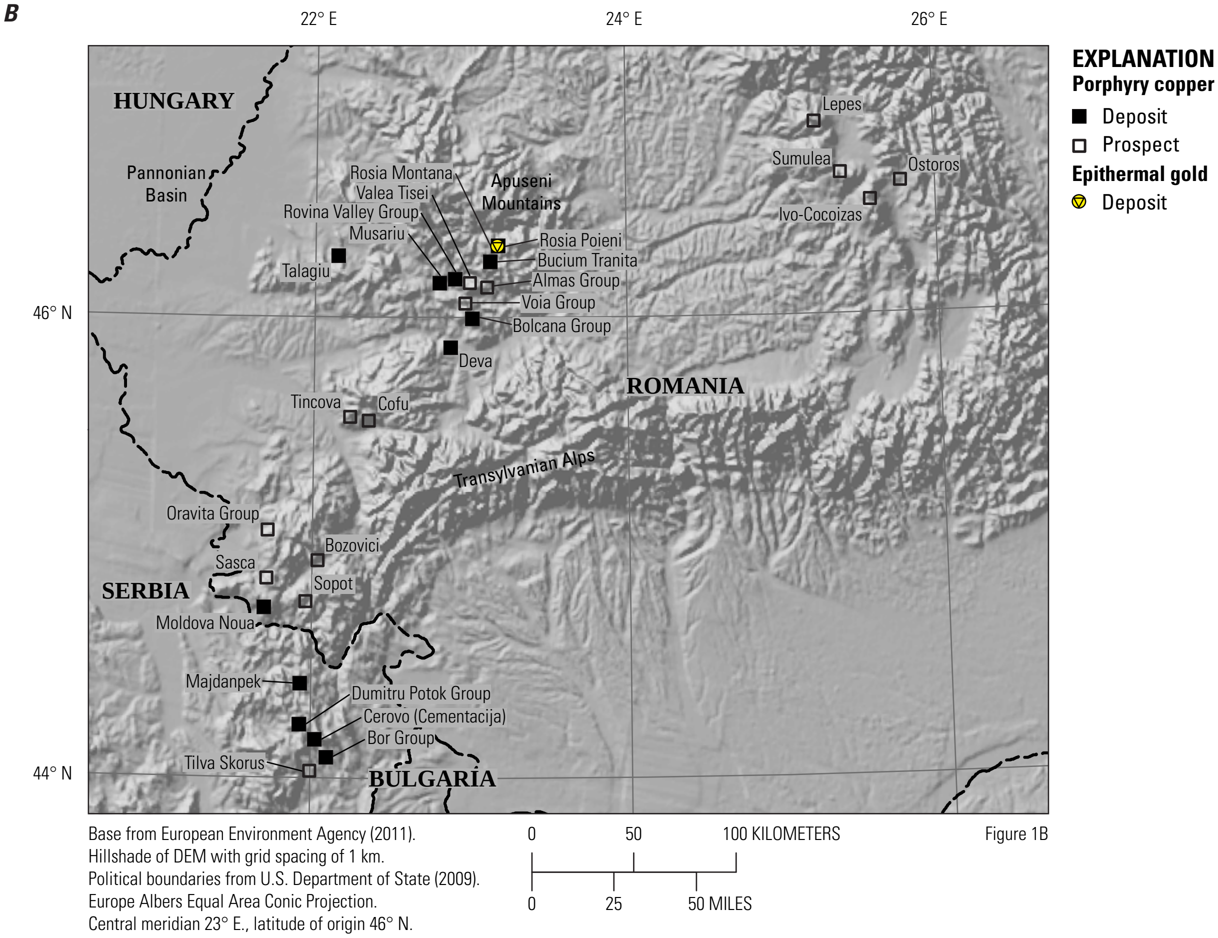
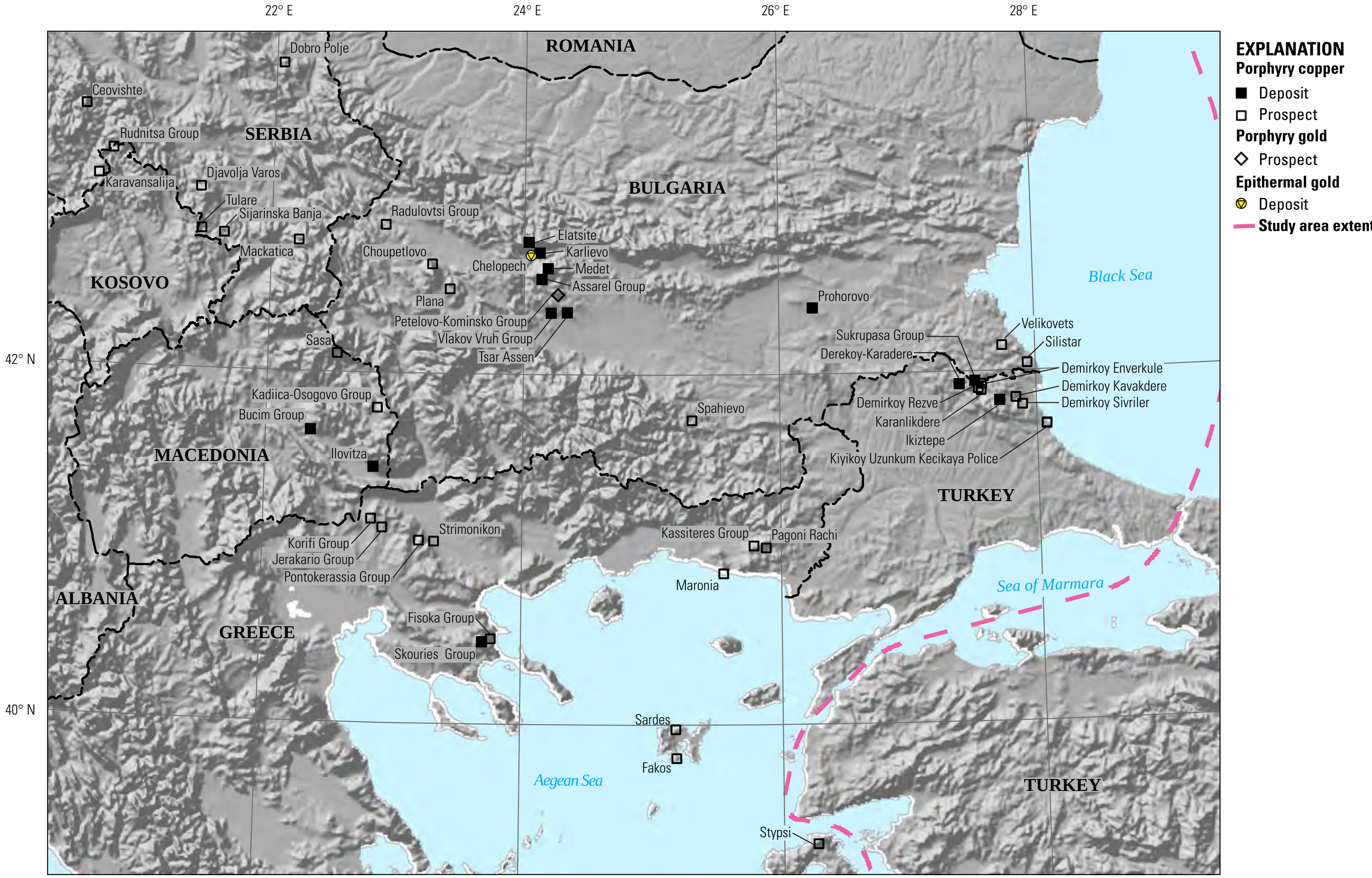


Figure 1.—Continued

C



Base from European Environment Agency (2011).
Hillshade of DEM with grid spacing of 1 km.
Political boundaries from U.S. Department of State (2009).
Europe Albers Equal Area Conic Projection.
Central meridian 25° E., latitude of origin 42° N.

0 100 200 KILOMETERS

0 50 100 MILES

Figure 1C

Figure 1.—Continued

expensive, however, that deposits may not be discovered in the near term. If they are discovered, the costs and logistics of development could be prohibitive, depending on metal prices and applicable mining technology.

The delineation of permissive tracts is based on geology, irrespective of political boundaries. Therefore, tracts may cross country boundaries or may include lands that have already been developed for other uses or been withdrawn from mineral development as protected areas. The tracts are presented at a scale of 1:1,000,000 and their boundaries are not intended for use at larger scales. Permissive tracts are assigned unique coded identifiers based on the U.N. region (150 for Europe), deposit type (pCu for porphyry copper), and a 4-digit number (for example 6001) as well as informal tract identifiers (EU01PC) and names based on a prominent geographic feature or an age range. Commodity terms are spelled out in the text, but abbreviated in the tables and in reference to porphyry deposit subtypes: Cu, copper; Mo, molybdenum; Au, gold; and Ag, silver.

Porphyry Copper Deposit Models

Porphyry copper deposits typically form along subduction-related convergent plate margins associated with island arcs and continental arcs or in extensional back-arc or postsubduction settings (John and others, 2010; Richards, 2009, 2011). The deposits are associated with calc-alkalic to alkalic, typically oxidized, multi-phase intrusive complexes emplaced within the upper 4 km of the crust. Porphyry copper systems may be associated with root zones of stratovolcanoes. Postsubduction settings include both extensional and contractional tectonic environments, which produce gold-rich porphyry and epithermal systems associated with alkalic and high-K calc-alkalic to shoshonitic igneous rocks, respectively (Richards, 2009).

Porphyry copper deposits in Europe are associated with subduction-related continental and oceanic arc systems, as well as with postcollisional tectonic settings. Most of the arcs and magmatic belts that host porphyry copper deposits in central and southern Europe are broadly related to the Phanerozoic closure of the Neotethys Ocean as the African Plate collided with Eurasia, and the ensuing Alpine orogeny.

Globally, porphyry copper deposits range in age from Archean (3.2 Ga) to Pleistocene (1 Ma), although 90 percent of the known deposits are of Carboniferous age or younger (<340 Ma), based on the compilation of Singer and others (2008). Most European porphyry copper deposits are of Cretaceous or younger age (<144 Ma) (fig. 2).The oldest identified porphyry copper deposits in Europe are the Proterozoic deposits in the Fennoscandian Shield (fig. 3) area of northern Europe (Sweden, Finland, Norway). The possible Paleoproterozoic porphyry copper deposits and prospects in Scandinavia are so modified by metamorphic and tectonic processes, however, that their porphyry-copper origins are uncertain. These Precambrian deposits are not considered further in this study.

Descriptive porphyry copper deposit models used for the assessment include the global models of Singer and others (2008), Cox (1986 a,b), Berger and others (2008), and John and others (2010). Drew (2003, 2006) developed a structural-tectonic model for the spatial occurrence of porphyry copper deposits and associated high-sulfidation and polymetallic vein systems, and demonstrated its applicability in southeastern Europe. The model provides a structural context for the emplacement of stocks and entrapment of hydrothermal fluids in fault systems associated with far-field stress release of tectonic strain on strike-slip faults developed above subducting plates. The model was applied in regional-scale mineral resource assessments of Late Cretaceous deposits in Hungary, Romania, Serbia, and Bulgaria (Drew and others, 1999a; Drew and Berger, 2001, 2002).

Fundamental Basis for Porphyry Copper Assessment

The fundamental geologic feature critical to delineation of a permissive tract for porphyry copper deposits is defined as a subduction-related magmatic arc or a postsubduction or postcollisional magmatic belt of a given age. Porphyry copper deposits form in hydrothermal systems that are spatially and temporally associated with apical, generally porphyro-aphanitic parts of felsic to intermediate stocks that were emplaced at shallow depths, typically less than 4 kilometers in depth.

Permissive tracts for porphyry copper deposits are delineated as geographic areas that include volcanic and intrusive rocks of a specified age range that typically can be related to a particular tectonic setting (such as a subduction-boundary zone). Tracts are based primarily on geologic map units that define the magmatic arc or belt. As a framework for the description of permissive tracts identified for the assessment of Europe, we briefly describe the tectonic setting of the major magmatic arcs and belts of the region.

Geologic Setting and Tectonic Framework for Phanerozoic Porphyry Copper Deposits in Europe

Present-day Europe is a collage of terranes that record a complex history of repeated continental accretion and breakup that extends back to the Archean. Most of the crust of Europe was assembled by the end of the Paleozoic (Oczlon, 2006). The post-Paleozoic geodynamics of southern Europe involved repeated opening and closing of ocean basins with associated development and accretion of continental arcs, island

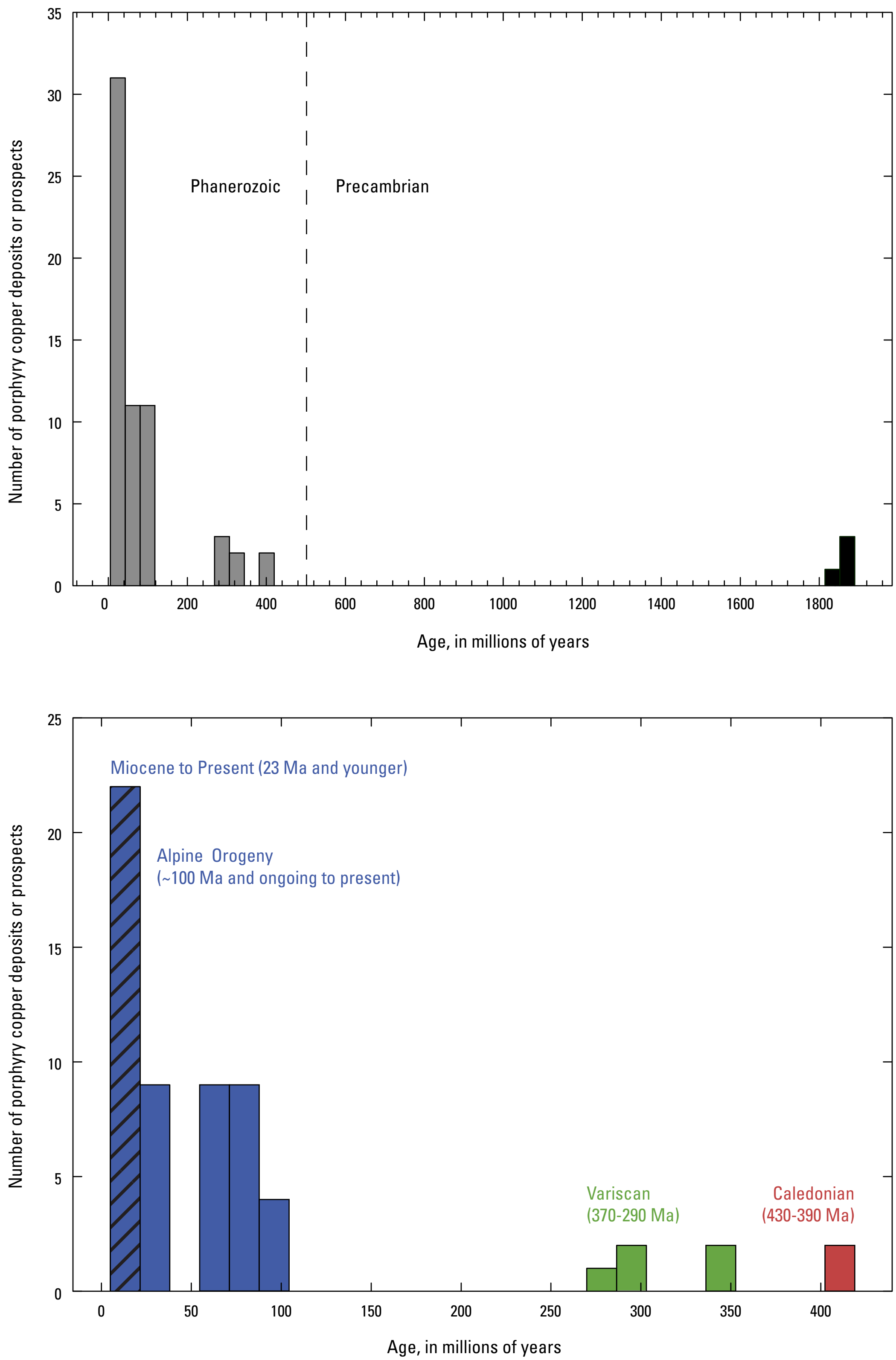


Figure 2. Age distributions of porphyry copper deposits in Europe. *A*, Age range. *B*, Phanerozoic deposits and prospects.

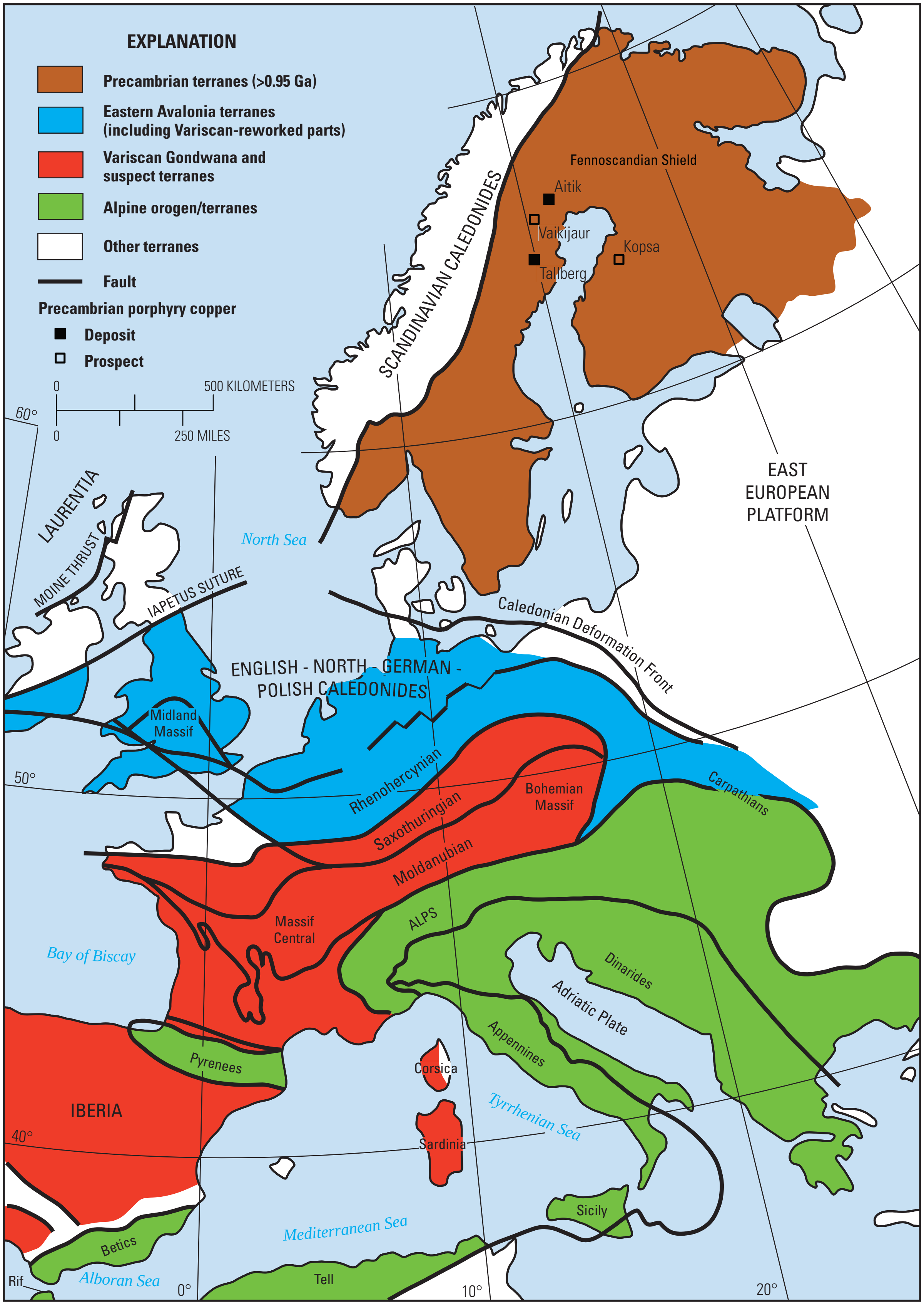


Figure 3. Major tectonic terranes of Europe (based on fig. 2-3 of Berthelsen, 1992).

arcs, and magmatic belts formed in postsubduction settings. The supercontinent/ancient continent sources of European terranes (Baltica, Gondwana, Laurentia, Laurussia) and the times of their assembly and accretion, as well as the location of post-Paleozoic sutures that mark the demise of ocean basins that developed within accreted terranes in southern Europe, are illustrated on a terrane map of Europe by Oczlon (2006).[11] The following synopsis of the tectonic history of Europe, with emphasis on the orogenies that host porphyry copper deposits, is based on an overview of the geological and tectonic history of Europe by Plant and others (2005), the two-volume geology of Central Europe (McCann, 2008a,b), and on seminal papers on metallogenic belts that host porphyry copper deposits in Europe (Ciobanu and others, 2002; Heinrich and Neubauer, 2002; Herrington and others, 2003; Janković, 1997; Marchev and others, 2005; Neubauer and others, 2005; Roşu and others, 2004a,b; von Quadt and others, 2005) and in northwestern Turkey (Yigit, 2009).

The distribution of the major tectonic units of Precambrian and Phanerozoic Europe (based on fig. 2–3 of Berthelsen, 1992) is shown in figure 3. In general, the terranes that preserve the major orogenic events that shaped modern Europe decrease in age from north to south. The evolution of what is now Europe from Early Cambrian time (fig. 4*A*) through the Middle Ordovician (fig. 4*B*) and Late Devonian (fig. 4*C*) to the Early Permian (fig. 4*D*), was reconstructed by Nance and Linneman (2008).

The Precambrian of Europe

By the end of the Proterozoic, Europe had drifted towards high southern latitudes, where the Gondwana continent (fig. 4*A*) was being assembled. Large areas of Gondwana-derived rocks of Archean age (pre-2,500 Ma) are present in the Fennoscandian Shield (fig. 3). These Archean rocks are all extensively deformed and metamorphosed and are not known to preserve any porphyry copper deposits.

Similarly, large areas in the Fennoscandian Shield are made up of Paleoproterozoic and Mesoproterozoic (2,500–1,000 Ma) igneous rocks. At least two deposits and two prospects that may be classified as porphyry copper deposits are preserved in Sweden and in Finland (fig. 3). Nevertheless, the Proterozoic rocks are, in general, deeply eroded and preserve an environment below which porphyry copper deposits are emplaced.

The Cadomian Orogeny

The late Precambrian (~750 to 540–530 Ma) Cadomian orogeny represents a cordilleran-type active plate margin that formed peripheral to the Gondwana supercontinent. The igneous rocks of the orogen are preserved in fragments that represent early felsic island arcs, continental magmatic arcs, a magmatic pulse at 580–570 Ma that may have been related to post-collisional slab breakoff, and a final anatectic magmatic pulse associated with arc and terrane amalgamation (Linnemann and others, 2008). Possible calc-alkaline arc rocks of this age range mainly are recognized in western France, southwestern Spain, and in several areas in the Carpathian chain, from the Czech Republic through Romania, Macedonia, and Greece (fig. 5). These rocks are poorly known, are commonly interspersed with Variscan rocks and highly deformed. Many of the Cadomian igneous rocks represent peraluminous crustal melts and migmatite zones, so lithologies are not permissive for porphyry systems. No porphyry copper deposits or prospects of Cadomian age are known.

[11]Available online at: http://www.searchanddiscovery.com/abstracts/pdf/2010/kiev/abstracts/ndx_Oczlon02.pdf.

The Paleozoic of Europe

The Caledonian Orogeny

The Caledonian orogeny refers to deformation that accompanied the collision of Baltica, Laurentia (now Greenland and much of North America), and Avalonia (now the east coast of North America, much of the British Isles and parts of Germany and the Netherlands; see fig. 3), and the closure of the Iapetus Ocean (fig. 4*B*). Deformation occurred at different times in different places, but the Caledonian period is roughly 430–390 Ma. Igneous rocks related to this event are found in the United Kingdom, in western France and Spain, and in Portugal (fig. 5). Most calc-alkaline igneous rocks of Caledonian age in Europe are deep-seated plutons that lack coeval volcanic rocks. Former magmatic arcs or belts are tectonically disrupted and, in some areas, highly metamorphosed. Most Caledonian terranes are deeply eroded to depths below those at which porphyry copper deposits typically are preserved. In addition, exposed permissive rocks that have indications of porphyry-style mineralization have been explored; however, no Caledonian deposits have been developed. European porphyry copper deposits and prospects of Caledonian age are described, but no probabilistic assessment was done. Available data indicate that deposits and prospects typically are low-grade (≤ 0.3 percent copper).

Caledonian Porphyry Copper Deposit and Prospects

Coed Y Brenin, Wales

Coed Y Brenin (fig. 1) in North Wales may be the largest porphyry copper deposit in the British Isles, with an estimated 200 Mt of mineralized material containing 0.3 percent copper and minor amounts of gold (Rice and Sharp, 1976; Bevins, 1994; Armstrong and others, 2003). The deposit was discovered in 1968; 110 holes were drilled to a depth of 300 m to define the resource (Colman and Cooper, 2000).

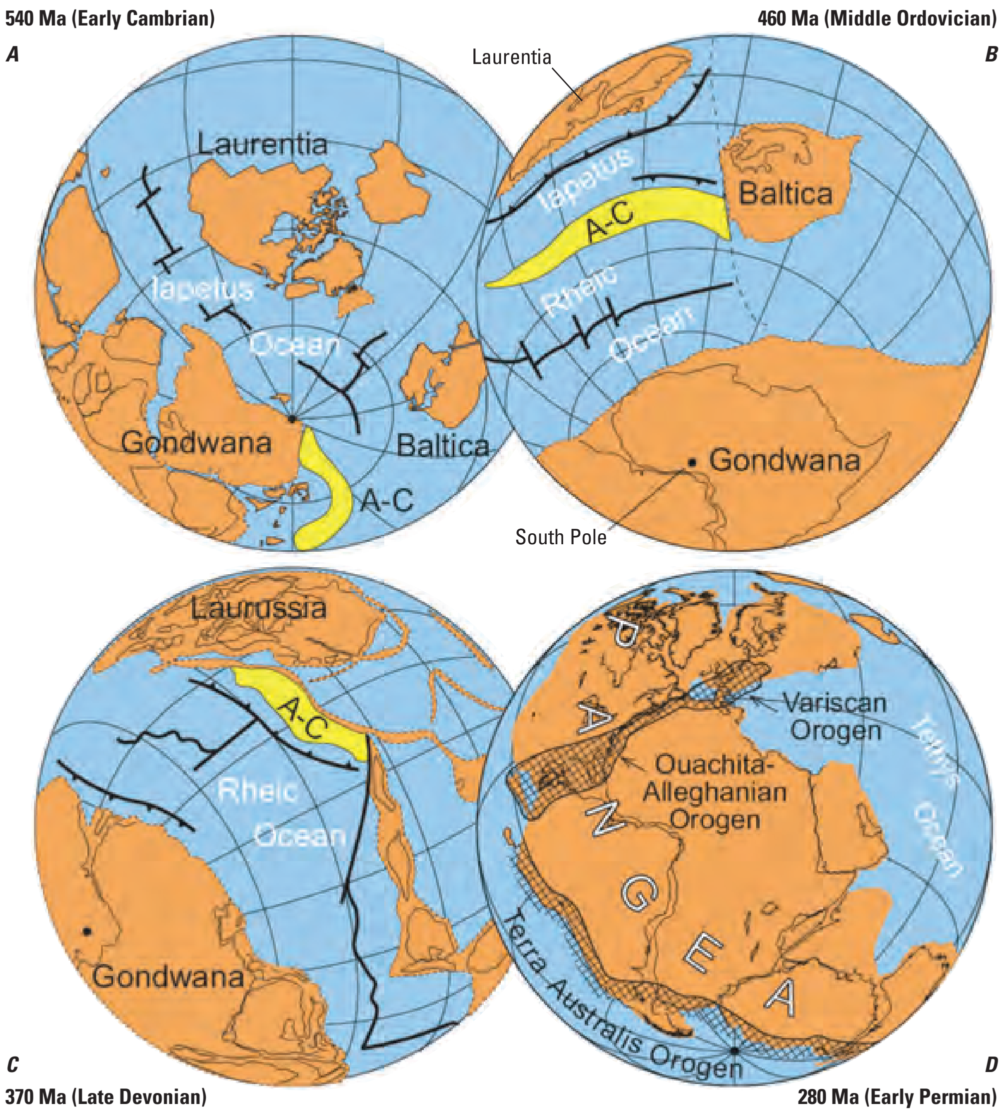
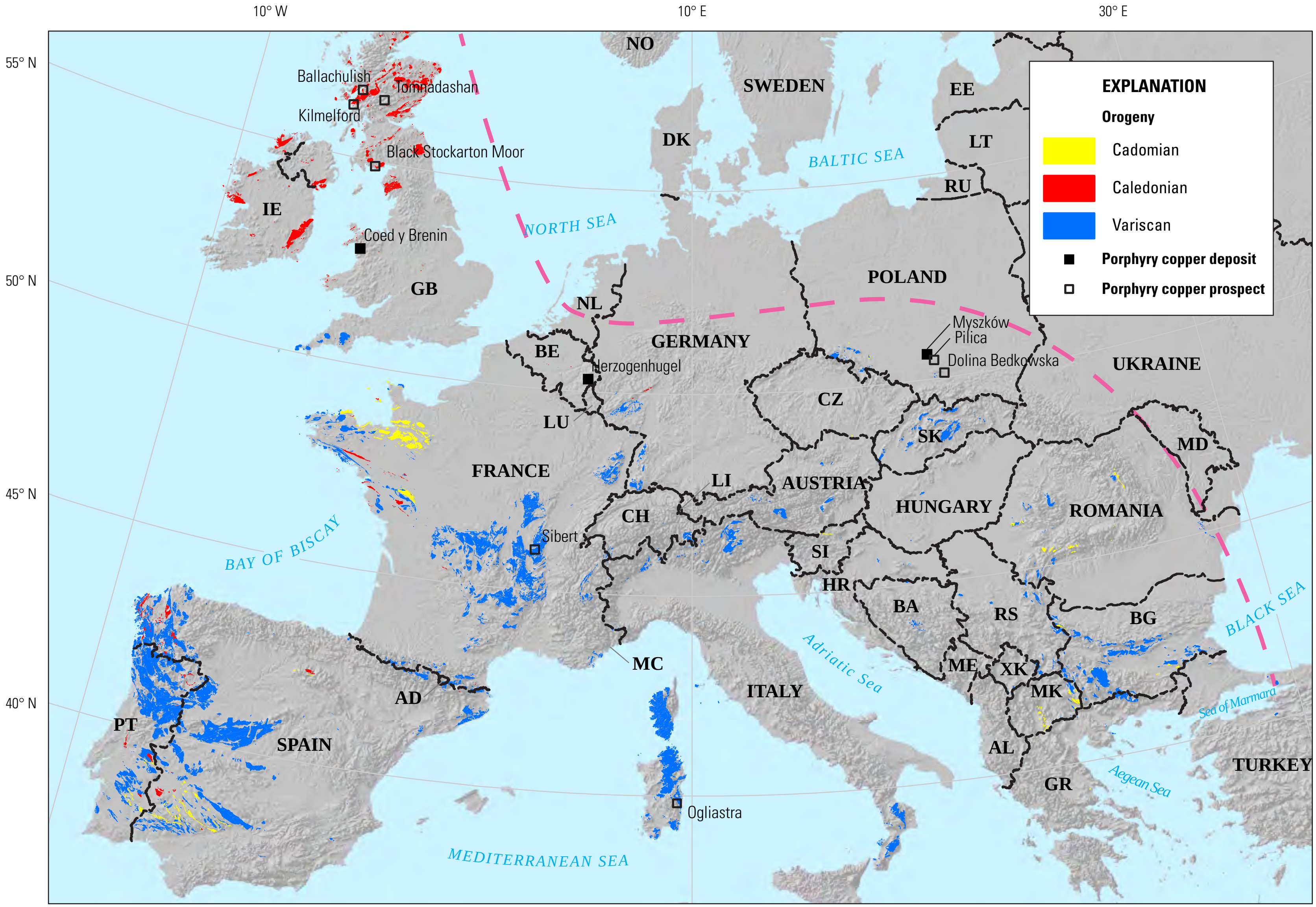


Figure 4. Paleozoic global reconstructions. *A*, By 540 Ma, the Iapetus Ocean had formed between Laurentia and Gondwana. Avalonia-Carolina (A-C) was still attached to Gondwana. *B*, By 460 Ma, Avalonia-Carolina (A-C) had separated from Gondwana, creating the Rheic Ocean. *C*, By 370 Ma [Late Devonian], Laurentia, Baltica, and Avalonia-Carolina had collided to form Laurussia, and the Rheic Ocean began to contract. *D*, The Rheic Ocean closed by 280 Ma [early Permian] to form Pangea, Hachured areas show position of orogens. (Nance and Linnemann, 2008, p. 5; modified from Murphy and Nance, 2008). Reproduced by permission of Geological Society of America.



Base from European Environment Agency (2011).
Hillshade of DEM with grid spacing of 1 km.
Europe Albers Equal Area Conic Projection.
Central meridian, 10° E., latitude of origin, 30° N.

0 500 1,000 KILOMETERS
0 250 500 MILES

Figure 5. Distribution of Cadomian, Caledonian, and Variscan igneous rocks based on work by Cassard and others (2006). Caledonian and Variscan age deposits and prospects classified as porphyry copper-type are also plotted. Dashed line marks northern border of study area. Country abbreviations (ISO 2-letter codes): AD, Andorra; AL, Albania; BA, Bosnia-Herzegovina; BE, Belgium; BG, Bulgaria; CH, Switzerland; CZ, Czech Republic; DK, Denmark; EE, Estonia; GB, Great Britain; GR, Greece; HR, Croatia; IE, Ireland; LI, Liechtenstein; LT, Lithuania; MC, Monaco; MD, Moldova; ME, Montenegro; MK, Macedonia; NO, Norway; PT, Portugal; RU, Russian Federation; SI, Slovenia; XK, Kosovo.

At Coed y Brenin, Middle to Late Cambrian sedimentary rocks are intruded by intermediate to basic igneous rocks of Late Cambrian to Early Ordovician age. Propylitic and phyllic alteration zones form an alteration halo around the deposit (Armstrong and others, 2003). Chalcopyrite, chalcocite, tennantite, and enargite are the principal copper minerals, with native copper, chalcopyrite, malachite, azurite, covellite, bornite, tetrahedrite, and molybdenite (Rice and Sharp, 1976; Bevins, 1994; Armstrong and others, 2003). The deposit is almost totally covered by overburden, lies within a protected forest, and is of interest for field excursions and mineralogy rather than as a potentially economic resource.

Herzogenhugel, Belgium

The Herzogenhugel porphyry copper deposit in Belgium (fig. 1) consists of disseminations, quartz stockworks, veinlets, and veins of pyrite, chalcopyrite, molybdenite, and other hypogene and supergene minerals in the southeast-dipping (30 degrees) sill-shaped Helle intrusion. This intrusive body has an outcrop area of roughly 0.85 km^2, a maximum thickness of about 100 m, and is composed of calc-alkaline-series quartz diorite (tonalite and trondhjemite) and granodiorite. These rocks, together with subordinate amounts of diorite, monzodiorite, and quartz granodiorite, intrude Cambrian siliciclastic rocks. Thermal metamorphism of the country rocks by the intrusion formed a zone of hornfels less than a meter wide and a halo of spotted schists hundreds of meters wide. Uranium-lead isotopic studies of zircons indicate magma emplacement during Silurian-Devonian time, with a minimum emplacement age of about 381±16 Ma (Middle Devonian) (Kramm and Buhl, 1985; Dejonghe, 2003). Exploration by Union Miniére S.A. in 1976–1977 included four drill holes that reached a maximum vertical depth of about 160 m. The deposit size is estimated to be approximately 20 Mt of 0.17 percent copper (range 0.01–0.45 percent) and 0.02 percent molybdenum (range 0.001–0.097 percent) (Dejonghe, 1986, 2003). On the basis of the small size and low copper- and molybdenum grades of the deposit, it is considered to be of little interest for development (Dejonghe, 2003).

The Variscan Orogeny

The Variscan orogeny (also called Hercynian) represents the most significant middle to late Paleozoic tectonometamorphic event in Central Europe (Kroner and others, 2008). The Variscan orogeny refers to deformation caused by the collision of Laurussia (Baltica, Laurentia, and Avalonia) with Gondwana to form the supercontinent of Pangea (fig. 4*C,D*). The Variscan of Europe (fig. 3) is part of a larger deformed belt that extends into the center of North America and into North Africa; the earliest structures termed Variscan are Late Devonian (about 370 Ma) and the amalgamation process was complete by Early Permian time (about 290 Ma) (Matte, 1991, 2001). The Variscan collisional orogen was built on pre-Variscan basement blocks derived from the Gondwana continental margin that were affected by post-Variscan Alpine imbrication and by large-scale strike-slip faulting and nappe deformation (von Raumer and others, 2003).

The continent-continent collisions resulted in crustal thickening and burial of crustal rocks to deep levels where melting formed peraluminous magmas, and peraluminous granites typify large parts of Variscan European terranes. Collision also terminated the subduction of oceanic slabs beneath these continental margins. Subducted oceanic slabs stagnated and eventually detached, and sank into the mantle, which facilitated emplacement of mafic magmas into the cores of deformed zones and emplacement of hybrid magmas into the upper crust. Outward spreading of the thickened and uplifted crust produced major thrust faults and associated foreland basins in the Late Carboniferous. Continued collapse of the hot, weak orogen led to the formation of Early Permian basins (Hancock and Skinner, 2000).

Variscan igneous rocks (fig. 5) comprise five magmatic pulses, characterized by distinct geochemical signatures (Finger and others, 1997; McCann and others, 2008): (1) Late Devonian to Early Carboniferous cordilleran I-type tonalites and granodiorites that form plutonic massifs, (2) Early Carboniferous deformed S-type granite/migmatite complexes, (3) Late Visean and early Namurian (~340–310 Ma) S-type and high-K I-type granitoids, (4) Late Carboniferous-Early Permian (~310–290 Ma) post-collisional, epizonal I-type granodiorites and tonalites, and (5) Late Carboniferous-Permian (~300–250 Ma) leucogranites with similarities to A-type and fractionated S-type granites. As noted by Bonin (2008), small volume A-type igneous complexes occur within Variscan-Alpine Europe in postcollisional (post-orogenic) provinces emplaced during the last stages of supercontinent amalgamation and in anorogenic settings concurrent with continental break-up. A- and S-type igneous complexes (groups 2, 3, and 5) are not permissive for porphyry copper deposits.

Many of the Variscan deposits that have been classified as porphyry copper deposits are ambiguous. The permissive rocks are dispersed over a wide area and, due to tectonism, it is not possible to delineate magmatic arcs or belts that control their distributions. Many of the Variscan igneous rocks are chemically unlikely to produce porphyry copper deposits, being peraluminous and mostly of crustal derivation (Massif Central of France, most Iberian granitoids) or strongly alkaline and peralkaline (Corsica, Sardinia). And, like the Caledonian, most Variscan terranes have been deeply eroded to depths below those at which porphyry copper deposits generally are preserved. European porphyry copper deposits and prospects of Variscan age are described; however, no probabilistic assessment was done.

Variscan Porphyry Copper Deposits and Prospects

Variscan porphyry copper deposits and prospects have been identified in France, southern Poland, and Sardinia. None of these have gone into production to date.

Sibert, France

In the Massif Central of central France, the Sibert porphyry copper prospect (fig. 5) consists of veins, veinlets, and disseminations of chalcopyrite and molybdenite in areas of fracture-controlled propylitic and potassic hydrothermal alteration (Icart and others, 1980; Beaufort and Meunier, 1983). Variscan magmatism in the Massif Central ranges in age from at least 366–270 Ma (Late Devonian to Early Permian). Variscan igneous rocks include calc-alkaline to subalkaline and alkaline rocks formed in subduction-related environments that included arc, back-arc-basin, and arc-continent-collision settings (for example, Pin and Duthou, 1990; Pin and Paquette, 1997; Lardeaux and others, 2001; and Bouchot and others, 2005).

The non-economic Sibert porphyry copper-molybdenum prospect in the northeastern part of the Massif Central is associated with subalkaline microgranites (Icart and others, 1980). The prospect consists of an intrusive complex of variably altered porphyritic granites that occur as small bodies or dikes intruding welded volcanic tuffs; hydrothermal alteration extends over an area of 1 by 2 km (Beaufort and Meunier, 1983). The prospect, drilled to a depth of 600 m, has never been developed, but has been the focus of mineralogical studies of the pervasive potassic alteration and superimposed phyllic alteration (Beaufort and Meunier, 1983; Davies and Whitehead, 2010). Veins and stockworks of chalcopyrite and molybdenite are associated with the granites, but Sibert is the only known porphyry prospect (Stussi, 1989).

Myszków, Poland

Hypabyssal granodiorites in Poland host porphyry copper prospects formed in an interplate structural setting variably referred to as the Cracow-Silesian orogenic belt, Kraków mobile belt, or Kraków-Lubliniec tectonic zone (Chaffee and others, 1994, 1997; Unrug and others, 1999; Markowiak and others, 2001; Buła and Markowiak, 2001; and Wolska, 2001). All known porphyry-like copper prospects in Poland occur in this 30 km to 50 km-wide orogenic belt, which was probably a Paleozoic boundary between Baltica and Gondwanaland (Chaffee and others, 1994).

Porphyry copper mineralization was identified in the Myszków area (fig. 5) of southwestern Poland in the late 1960s by the Polish Geological Institute. The Myszków deposit is the largest and best known example and is closely associated in time and space with a hypabyssal biotite granodiorite porphyry stock from which 11 biotites gave a K-Ar age of 312±17 Ma (Carboniferous) (Chaffee and others, 1994, 1997). $^{40}Ar/^{39}Ar$ dates (290–305 Ma) on alteration minerals associated with the formation of Myszków indicate that the prospect was mineralized in Late Carboniferous to Early Permian time (Chaffee and others, 1997; Markowiak and others, 2001). The most recent resource information is an inferred resource of 726 Mt at 0.121 percent copper, 0.617 percent molybdenum, 0.0404 percent tungsten, and 2.2 g/t silver, based on a cutoff of 0.085 percent molybdenum equivalent (Strezelcki Metals Ltd., 2011). The advanced exploration project is described as a Mo-W-Cu porphyry system with low concentrations of gold, mercury, arsenic, and antimony (Strezelcki Metals Ltd., 2011).

Porphyry copper prospects are associated with a subsurface granodiorite intrusion at Pilica and with hydrothermally altered rhyodacite porphyry dikes beneath 70 m of sedimentary cover at Dolina Bedkowska (fig. 5) (Haranczyk, 1980). The polymetallic vein assemblages, presence of tungsten, and lack of real stockworks suggest that deposits such as Myszków may represent deep parts of what may have been porphyry systems.

Ogliastra, Sardinia (Italy)

The Ogliastra prospect (fig. 5) is at the southern end of the large Variscan granitoid batholith that makes up much of northern Sardinia (Fiori and others, 1984). At Ogliastra, shallow tonalite and hornblende-biotite granodiorites were emplaced in a nappe structure (Secchi and others, 2001). Disseminations and veins of sphalerite, chalcopyrite, pyrite, magnetite, and minor galena and molybdenite were described and classified as porphyry-type copper occurrences (Fiori and others, 1984; Marcello and others, 2004; and Singer and others, 2008). Fiori and others (1984) referred to the Ogliastra as a group of “aborted” porphyry copper deposits consisting of iron, zinc, copper, and molybdenum mineralization in small bodies scattered in Hercynian plutons.

Occurrences and prospects that contain molybdenite, sphalerite, galena, pyrite, chalcopyrite, pyrrhotite, and arsenopyrite extend the length of the Calabrian-Peloritan Arc through Italy and Sicily (fig. 1); these have been referred to as Variscan porphyry copper-molybdenum systems (Bonardi and others, 1982; Atzori and others, 1984).

The Mesozoic of Europe

In Late Permian time, rifts began to form in the newly assembled Pangea, and large sedimentary basins developed in Europe (Plant and others, 2005). By the Late Triassic, major transgression of the Neotethyan Sea began to inundate large parts of Europe. In the Jurassic, breakup of Pangea began along the Central Atlantic axis (fig. 6*A*). Extension of the rift that would become the Atlantic Ocean became the dominant tectonic environment in Europe (Plant and others, 2005). During the Middle and Late Jurassic, the Neotethys Ocean and its branches opened in the Mediterranean area (fig. 6*A*). By Cretaceous time, though Europe had been part of Pangea (fig. 4*D*) since the Early Permian, the Neotethyan Ocean had separated Gondwana from Europe.

The Late Cretaceous and Cenozoic of Europe

Most of the known porphyry copper deposits and prospects in Europe are associated with the Alpine orogeny and the associated tectonism and magmatism that formed modern Europe. Late Cretaceous-Cenozoic magmatic belts in Central and Eastern Europe host historically significant mineral districts that produced copper from porphyry deposits and continue to be explored for base- and precious metals.

The Alpine Orogeny

The Alpine orogeny began in Late Cretaceous time, as Africa impinged on Eurasia and Neotethyan oceanic crust was subducting northward beneath eastern Europe. This orogeny, which continues to the present, has shaped the geographic face of modern Europe. At least two major periods of deformation, one in the Cretaceous and another in Eocene and Oligocene time, formed the modern mountain ranges such as the Pyrenees, and the various ranges of the Carpathian Mountains (fig. 1*A*). Figure 6 illustrates the changes in plate orientation and closure of the Neothethys Ocean from the Cretaceous (fig. 6*A*) to Eocene (fig. 6*B*) time. Intervals of extension occurred in the Tertiary; nevertheless, Africa is still underthrusting Europe, and the Alps continue to be uplifted a few millimeters per year. Figure 3 shows the extent of terranes that formed during the Alpine orogeny.

Intrusive rocks related to the Alpine orogeny are relatively rare, and of limited extent, perhaps because erosion has not yet exposed them, especially in the main Alpine range. Volcanic rocks of Alpine age are more widespread, and found in most European countries. Numerous microplates, both continental and oceanic, are involved in the complex tectonic history of the Alpine orogeny. The following discussion is organized by discrete geographic areas that contain, or may contain, porphyry copper deposits related to the Alpine orogeny. Western segments of the Tethyan Eurasian Metallogenic Belt (TEMB) host the most extensive belt of porphyry copper, high-sulfidation epithermal copper-gold, skarn, and polymetallic vein deposits in Europe, including deposits in the Carpathians, the Bor District, and the Srednogorie Zone (fig. 7).

Southeastern Europe and the Aegean

The Hellenides (fig. 1) of southeastern Europe form parts of the Alpine orogenic system, between the Dinarides to the northwest and the Tauride-Anatolide Platform to the southeast (fig. 8). The Hellenides form an arcuate orogen comprising a series of subparallel tectonostratigraphic terranes, and represent an accretionary collage of amalgamated terranes formed by the closure of various branches of the Neotethys Ocean (fig. 6 *A*,*B*; Himmerkus and others, 2007). These terranes, the remnants of microcontinents and ocean basins that existed within the Tethyan belt (Papanikolaou, 2009), are separated by large-scale faults. Ophiolite belts within terranes generally are interpreted as relict sutures marking closures of arms of the Neotethys Ocean, although some studies suggest that the ophiolites are obducted. The External Hellenides (Ionian-Gavrovo and Pindos zones on fig. 8) are composed of supracrustal platform carbonate and clastic rocks of the Apulian Plate which were separated from the Pelagonian microplate by the Pindos Ocean (fig. 6*A*) during the Triassic and Jurassic (Faupl and others, 1998); the carbonate rocks are interpreted as part of a passive continental Tethyan margin (Himmerkus and others, 2007). In contrast, the Internal Hellenides include, from west to east, the Pelagonian Zone, the Vardar Zone, the Serbo-Macedonian Massif, and the Rhodope Massif (fig. 8). The Vardar Zone is interpreted as the suture marking closure of the Vardar arm of the Neotethys Ocean (fig. 6*A*) following collisions between the Adriatic/Apulian and Eurasian Plates in the Late Cretaceous (Tremblay and others, 2010; Zelic and others, 2010). The Adriatic Plate represented a fragment of continental crust that separated from Africa in the Cretaceous.

Pre-Late Cretaceous arc-related and anorogenic igneous rocks are present within the Hellenides; these rocks have been deformed and metamorphosed. Although these older igneous rocks may be spatially associated with porphyry copper deposits, they are not known to host any deposits. Metallogenic belts associated with Late Cretaceous to Miocene igneous rocks transect oceanic and continental tectonostratigraphic terranes in Serbia, Bulgaria, Macedonia, Greece, and western Turkey (fig. 9). The Vardar Zone, for example, includes mid-Paleozoic continental basement and Late Jurassic arc rocks as well as syn- to postcollisional magmatic rocks that range from Late Cretaceous to Miocene (Anders and others, 2005). Geodynamic models and geochemical interpretations of Late Cretaceous and Tertiary magmatism associated with convergence of Africa and Eurasia in the Alpine Mediterranean area are controversial and complex due to the entrapment of multiple continental and oceanic microplates between the two major continents. Debates continue about the numbers and timing of closure of ocean basins and the relative roles of advancing and retreating subduction, extension, and mantle plumes (Heinrich and Neubauer, 2002; Harangi and Lenkey, 2007; Kovács and others, 2007).

Western segments of the Tethyan Eurasian Metallogenic Belt (fig. 7, TEMB) host the most extensive belt of porphyry copper, high-sulfidation epithermal copper-gold, skarn, and polymetallic vein deposits in Europe. Within this area, a number of magmatic and metallogenic belts are defined.

Three major porphyry copper belts transect the Hellenides (fig. 8) in a region known as the Alpine-Balkan-Carpathian-Dinaride (ABCD) region (fig. 9): (1) the Late Cretaceous Banatite Belt,[12] which extends from Transylvania to the Balkans, as the westernmost part of the Tethyan arc; (2) the Oligocene-early Miocene Serbomacedonian-Rhodope-Western Anatolia belt; and (3) the Tertiary Inner Carpathian Alpine belt (Heinrich and Neubauer, 2002). In contrast, the Alpine-West Carpathian part of the ABCD, which was metamorphosed and deformed in the Late Cretaceous, hosts deposit types associated with exhumed metamorphic core complexes (Neubauer, 2002), including orogenic gold deposits (fig. 9).

[12]Also referred to as the Apuseni-Banat-Timok-Srednogorie (ABTS) belt.

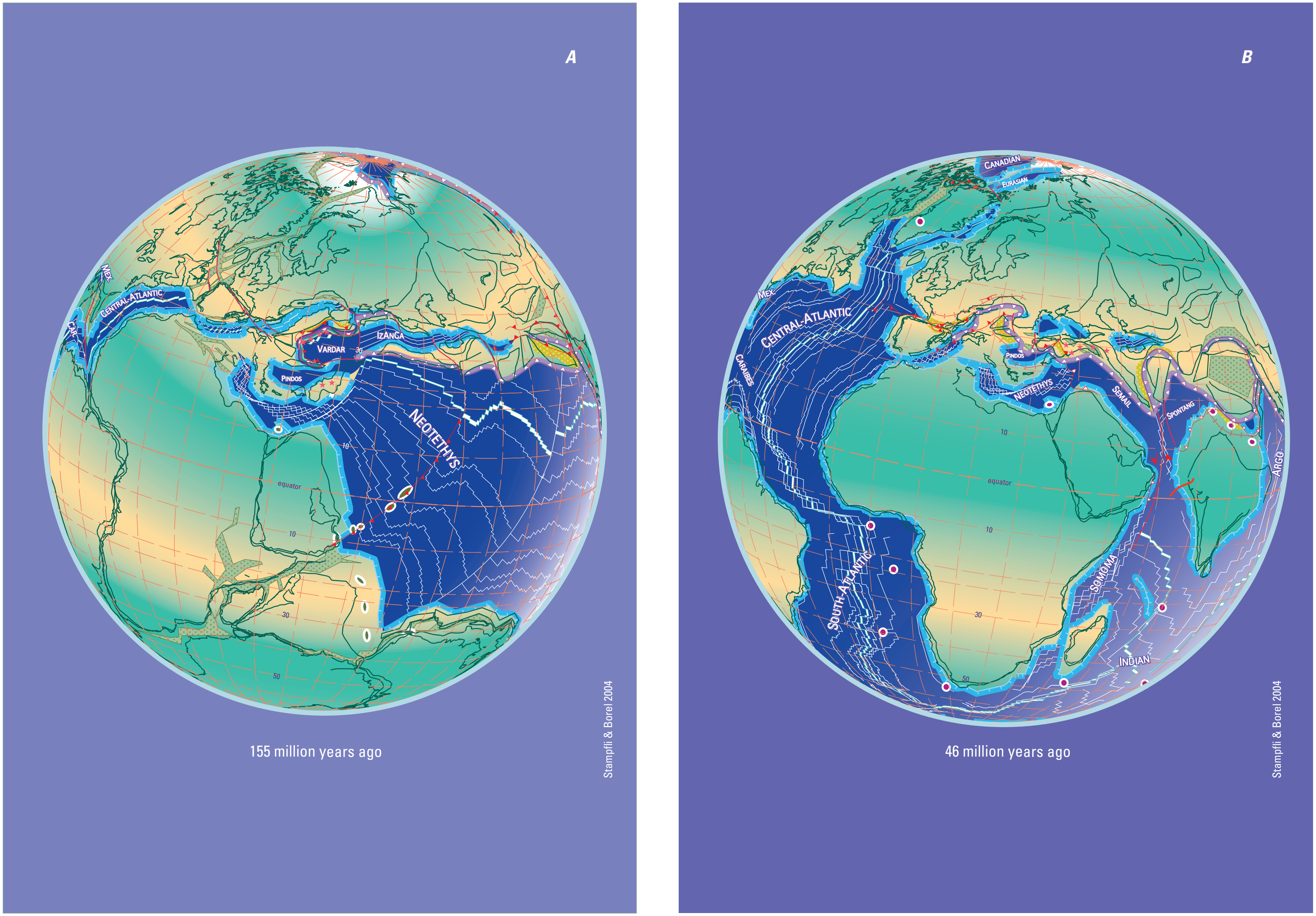


Figure 6. Mesozoic and Cenozoic geodynamic reconstructions. A, By Late Jurassic time (~155 Ma), several branches of the Neotethys were in existence, including the Pindos and Vardar seas. B, By the Eocene (~46 Ma) the Neotethys had narrowed, and various branches of it had narrowed or closed completely. Modified slightly and reproduced by permission of G. Stampfli.

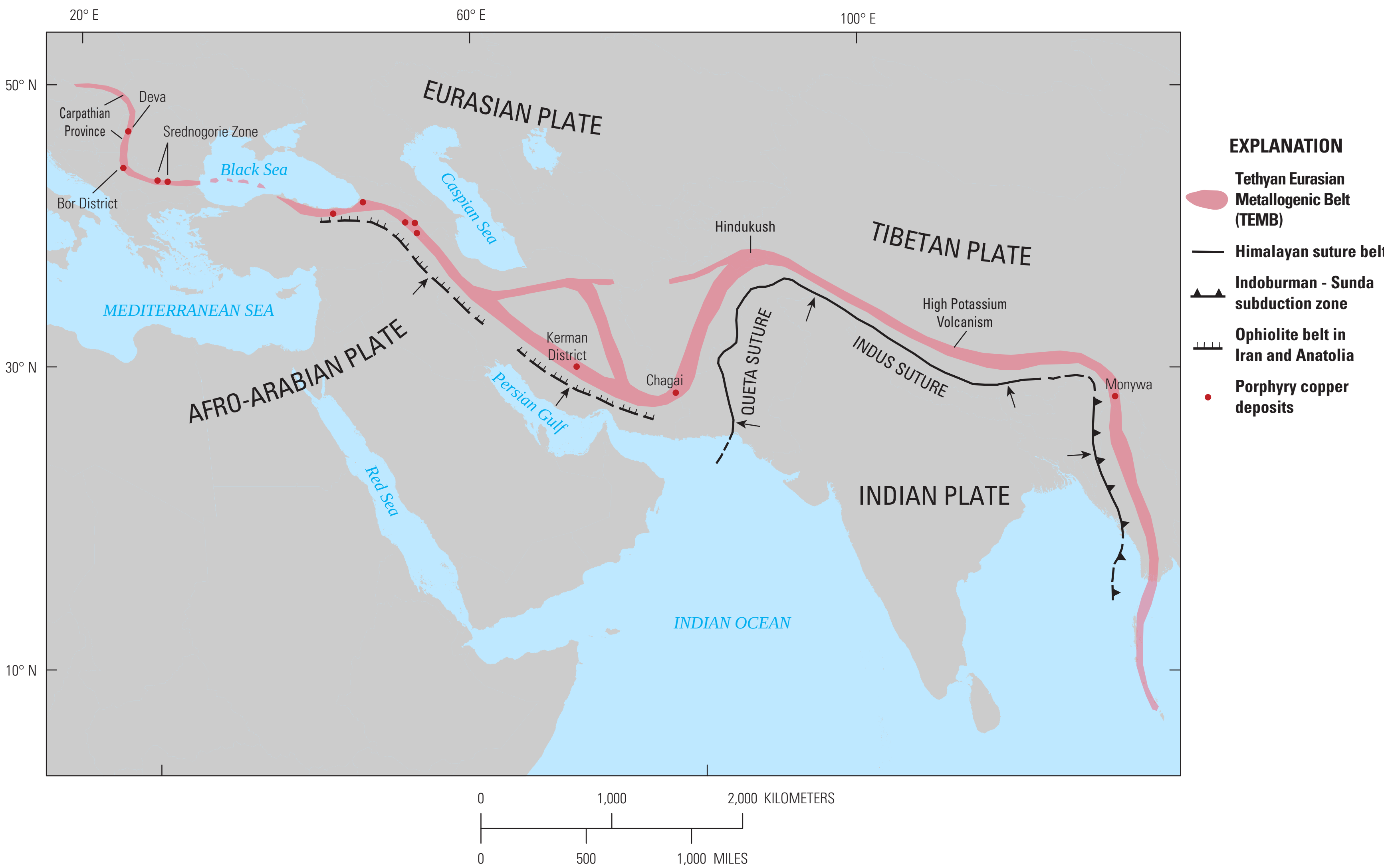


Figure 7. Map of the Tethyan Eurasian Metallogenic Belt (modified from Jankoviĉ, 1977).

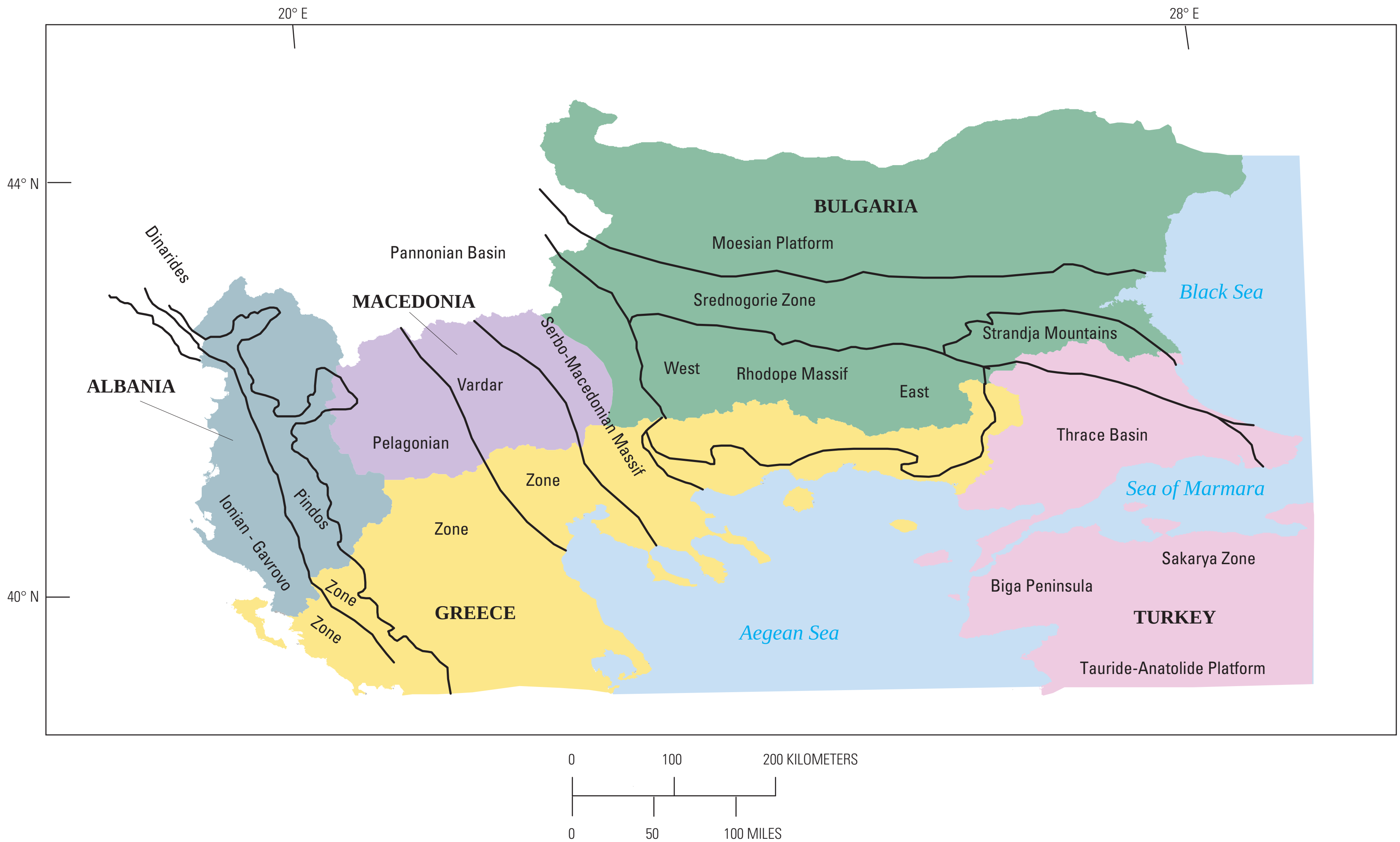


Figure 8. Tectonostratigraphic zones of the Hellenides (after Burchfiel and others, 2008). Tectonostratigraphic zones are bounded by black lines. Colors represent countries: Bulgaria (green), Macedonia (purple), Albania (blue-gray), Greece (yellow), Turkey (pink).

The distribution of mapped Late Cretaceous and Tertiary igneous rocks that could be associated with porphyry copper deposits is shown on figure 9, along with locations of porphyry copper deposits and prospects and approximate outlines of the metallogenic belts, as defined by Heinrich and Neubauer (2002). Permissive rocks extend into western Turkey, south of the Sea of Marmara. Those rocks are included in a porphyry copper assessment of the Central Tethys region (pink dashed line on fig. 9 marks the boundary between the Europe and Central Tethys assessment areas).

Late Cretaceous Banatite Belt (Apuseni-Banat-Timok-Srednogorie)

The L-shaped Banatite belt of Late Cretaceous volcano-plutonic complexes extends from the Transylvanian region, through the Apuseni Mountains and Banat area in Romania and Serbia, to the Srednogorie zone of Bulgaria (fig. 9). The belt is termed the Banatite magmatic and metallogenic belt by some workers, based on the petrographic name given to some diorites in the Banat area by von Cotta (1864); Strashimirov and Popov (2000) used the term Apuseni-Banat-Timok-Srednogorie belt (ABTS) for the same area. Late Cretaceous intrusive complexes in the belt host 15 porphyry copper deposits (table 1).

On the basis of a detailed analysis of large-scale maps for the structurally complex ABTS region, Drew (2006) developed a structural-tectonic model for Late Cretaceous porphyry copper and polymetallic vein mineralization associated with northward subduction of the Vardar Ocean under the Tisza and Dacia continental blocks in Central Europe (fig. 10). The internally deformed crystalline basements of the Tisza and Dacia blocks have been amalgamated since the early Tertiary, and share a common Late Cretaceous and Paleocene sedimentary cover (Márton and others, 2007). Note that figure 9 shows the modern alignment of the mineralized segments of the Banatite (ABTS) belt; figure 10 shows the alignment interpreted for Late Cretaceous time (80–70 Ma). In contrast to a continental rift model formerly proposed for extensional features within the ABTS region (Antonijević and others, 1974; Popov, 1987), the Drew model ascribes the development of the extensional features (that is, grabens that host magmatic complexes) to transpression within a major strike-slip fault system related to oblique northward subduction of the Vardar Ocean and Late Cretaceous docking with the Rhodope (Bulgaria) and Dacia (Albania, Slovenia, Croatia, Bosnia, Macedonia, Greece) tectonic blocks (fig. 10). Note that the alignment of these mineral districts changed from predominantly east-west in Late Cretaceous time (fig. 10) to the present northwest-southeast orientation shown in figure 9.

The porphyry deposits in the belt typically are associated with subvolcanic bodies and porphyry dikes intruded into calc-alkaline granitoid complexes (von Quadt and others, 2002). Deep-seated transverse structures may have controlled emplacement of porphyry systems in the most productive segments of the arc, the Timok area of Serbia and the Panagyurishte district in the Srednogorie tectonic zone of Bulgaria (fig. 10) (Heinrich and Neubauer, 2002). Post-ore block faulting and subsidence caused differential uplift and erosion throughout the belt, which resulted in exposure of mid-crustal plutons in the south. Dupont and others (2002) attributed variations in the nature of the ore deposits in the Romanian part of the belt to four factors: (1) differences in origins and compositions of subduction-related magmas, (2) depth of erosion, (3) host-rock types, and (4) deposit-scale zoning. For example, calc-alkaline to high-K calc-alkalic intrusions are associated with economic copper and molybdenum mineralization whereas shoshonitic rocks appear to be barren. Large, coarse-grained intrusions emplaced at mid-crustal depths are associated with skarns, whereas small shallow dikes and subvolcanic intrusions with fine- to medium-grained textures are associated with porphyry-style mineralization.

Calc-alkaline to high-K calc-alkaline magmatism occurred over a 30-million-year period, from 90 to 60 Ma. Geochemical characteristics of the igneous complexes indicate a mantle, or juvenile crustal, magma source with variable amounts of crustal contamination; $^{87}Sr/^{86}Sr$ ranges from 0.704 to 0.707, and ε_{Nd} varies from +3.9 to -3 (Dupont and others 2002; von Quadt and others, 2002, 2005). Figure 11 shows that the range of isotopic compositions for Late Cretaceous intrusions from porphyry-associated intrusions in the Banat area of Romania and in the Panagyurishte district of Bulgaria are relatively restricted and juvenile in composition compared with generalized fields of granitic rocks associated with porphyry copper deposits in other parts of the world (Ayuso, 2010; Dupont and others, 2002; von Quadt and others, 2005; Kouzmanov and others, 2009).

North-to-south increases in ε_{Nd} and decreases in $^{87}Sr/^{86}Sr$ within the Banatite (ABTS) belt are attributed to decreasing thickness of continental crust southward (von Quadt and others, 2005). On geochemical trace element discrimination diagrams (niobium-yttrium; rubidium-hafnium-tantalum), both Cretaceous and Variscan igneous rocks from the belt plot in VAG (volcanic arc granite) and VAG + syn-COLG (collision granite) fields (von Quadt and others, 2005). Spatial trends in strontium, neodymium, and lead isotope compositions of Cretaceous magmatic rocks document decreasing amounts of crustal contamination of mantle magmas as age of magmatism decreases from north to south (von Quadt and others, 2005). Slab rollback and extension resulted in crustal thinning in the arc to back-arc geodynamic environment that prevailed in Late Cretaceous time; shallow, medium-size porphyry-and epithermal copper-gold deposits are preserved.

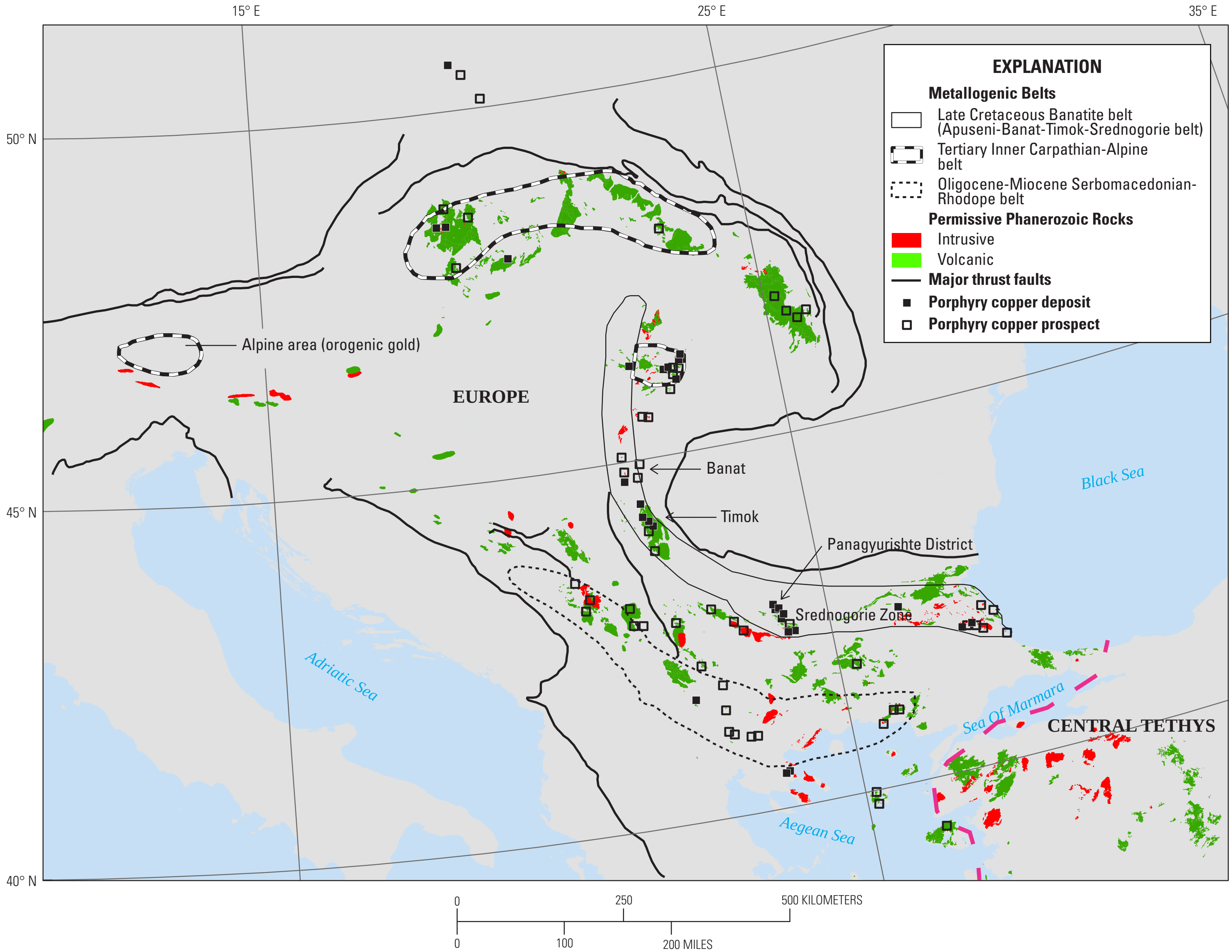


Figure 9. Late Cretaceous and Tertiary metallogenic belts. Belts are shown as defined by Heinrich and Neubauer (2002) within the Alpine-Balkan-Carpathian-Dinaride (ABCD) geodynamic province, along with the distribution of Phanerozoic igneous rocks permissive for porphyry copper deposits, and known deposits and prospects. Geology based on digital geologic map of Europe (Bureau de Recherches Géologiques et Minières (BRGM), 2004) and additional sources listed in table 2.

Table 1. Porphyry copper deposits of Europe.

[Mt, million metric tons; t, metric ton; %, percent; g/t, grams per metric ton; n.d., no data. Deposits and prospects within ~4 km of each other are grouped (groups shown in boldface). Contained copper and gold reported to 2 significant figures. See figure 1 for locations.]

Name	Country	Tonnage (Mt)	Copper (%)	Molybdenum (%)	Gold (g/t)	Silver (g/t)	Contained copper (t)	Contained gold (t)
Transylvanian-Balkan Mountains tract 150pCu6001 (EU01PC) [Late Cretaceous]								
Bor Group	Serbia	2,141	0.64	0.002	0.24	0.53	14,000,000	510
Majdanpek	Serbia	1000	0.60	0.005	0.35	1.0	6,000,000	350
Moldova Nouă	Romania	500	0.35	n.d.	n.d.	n.d.	1,800,000	n.d.
Assarel Group	Bulgaria	390	0.43	n.d.	0.19	n.d.	1,700,000	74
Elatsite	Bulgaria	350	0.39	n.d.	0.26	0.2	1,400,000	91
Cerovo (Cementacija)	Serbia	316	0.32	n.d.	0.10	n.d.	1,000,000	32
Dumitru Potok Group	Serbia	337	0.23	0.001	0.20	0.1	780,000	67
Prohorovo	Bulgaria	249	0.25	0.005	n.d.	n.d.	620,000	n.d.
Medet	Bulgaria	244	0.37	0.010	0.10	n.d.	900,000	24
Derekoy-Karadere	Turkey	270.5	0.28	0.003	n.d.	n.d.	760,000	n.d.
Ikiztepeler	Turkey	236.7	0.29	0.004	n.d.	n.d.	690,000	n.d.
Vlakov Vruh Group	Bulgaria	85	0.23	n.d.	n.d.	n.d.	200,000	n.d.
Karlievo	Bulgaria	61	0.21	0.005	0.05	n.d.	130,000	3
Sukrupasa Group	Turkey	8	0.41	0.003	0.08	n.d.	33,000	1
Tsar Assen	Bulgaria	6.6	0.47	n.d.	n.d.	n.d.	31,000	n.d.
Tract total							30,000,000	1,200
Dinaride-Aegean tract 150pCu6002 (EU02PC) [Paleocene-Miocene]								
Skouries Group	Greece	362	0.41	n.d.	0.53	n.d.	1,500,000	200
Bucim Group	Macedonia	150	0.30	n.d.	0.35	n.d.	450,000	53
Ilovitza	Macedonia	303	0.23	0.005	0.32	n.d.	700,000	96
Recsk	Hungary	700	0.66	0.005	0.28	n.d.	4,600,000	200
Tract total							7,300,000	550

Table 1. Porphyry copper deposits of Europe.—Continued

[Mt, million metric tons; t, metric ton; %, percent; g/t, grams per metric ton; n.d., no data. Deposits and prospects within ~4 km of each other are grouped (groups shown in boldface). Contained copper and gold reported to 2 significant figures. See figure 1 for locations.]

Name	Country	Tonnage (Mt)	Copper (%)	Molybdenum (%)	Gold (g/t)	Silver (g/t)	Contained copper (t)	Contained gold (t)
Apuseni Mountains tract 150pCu6003 (EU03PC) [Miocene]								
Rosia Poieni	Romania	431	0.55	n.d.	0.25	n.d.	2,400,000	110
Bucium Tarnita	Romania	335	0.50	n.d.	0.36	n.d.	1,700,000	120
Talagiu	Romania	150	0.35	n.d.	0.60	n.d.	520,000	90
Rovina Valley Group	Romania	370	0.17	n.d.	0.58	n.d.	650,000	226
Bolcana Group	Romania	90	0.30	n.d.	0.03	n.d.	270,000	3
Deva	Romania	20	0.70	n.d.	0.50	n.d.	140,000	10
Musariu	Romania	12	0.20	n.d.	0.30	n.d.	24,000	4
Tract total							5,700,000	560
Northern Carpathians tract 150pCu6004 (EU04PC) [Miocene]								
Ŝtiavnica Group	Slovakia	210	0.35	0.001	0.23	9.5	740,000	48
Tract total							740,000	48
Western Peri-Mediterranean Region tract 150pCu6005 (EU05PC) [Late Eocene - early Miocene]								
Calabona	Italy	189	0.07	n.d.	n.d.	0.5	130,000	n.d.
Southern and Central European Variscan tract 150pCu6065 (EU06PC) [Late Devonian - Early Permian]								
Myszków	Poland	726	0.121	0.062	n.d.	2.22	880,000	n.d.
Western European Caledonian tract 150pCu6007 (EU07PC) [Late Cambrian - Early Devonian]								
Herzogenhugel	Belgium	20	0.17	0.020	n.d.	n.d.	34,000	n.d.
Coed y Brenin	United Kingdom	200	0.3	n.d.	n.d.	n.d.	600,000	n.d.

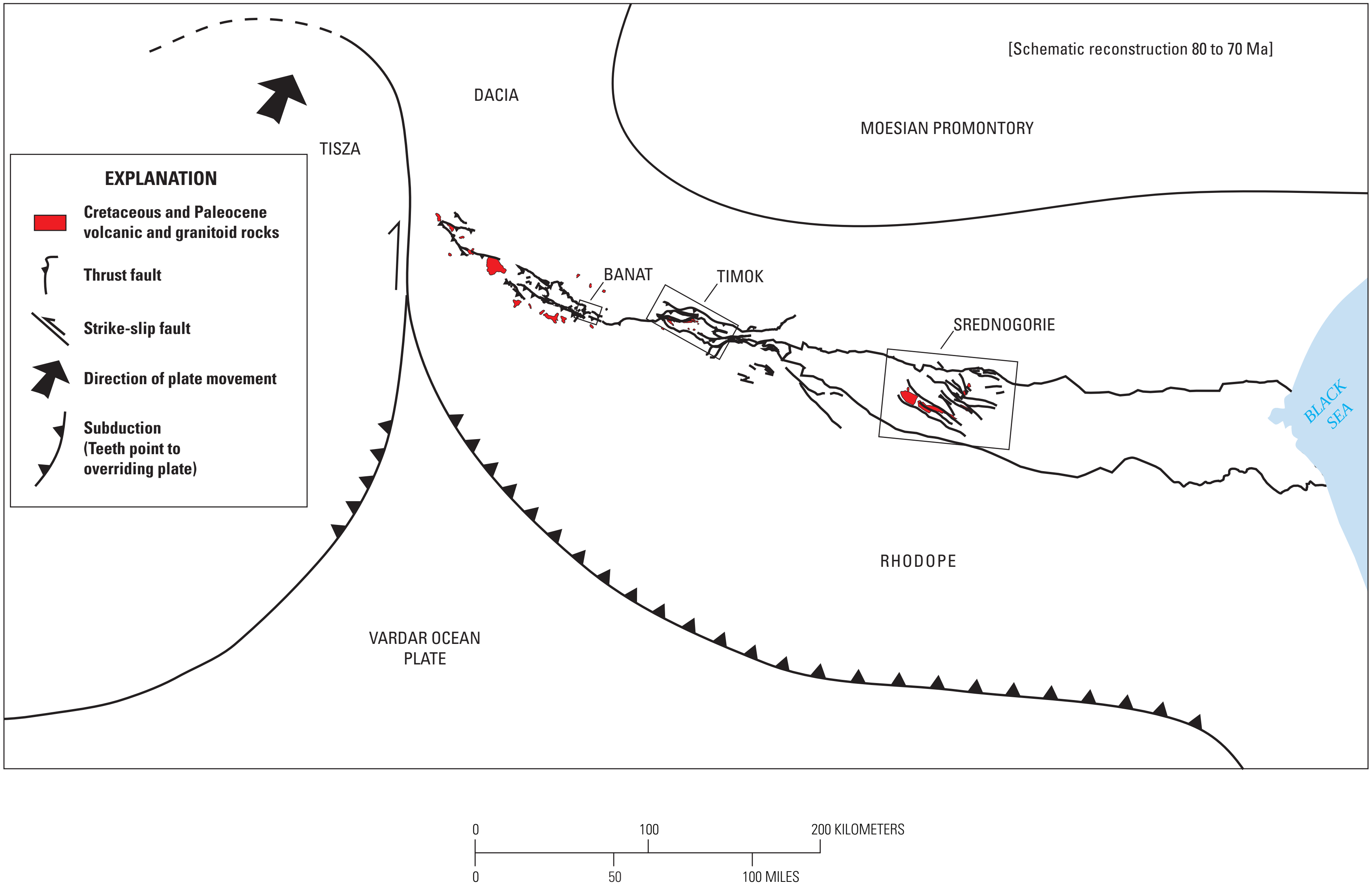


Figure 10. Schematic reconstruction of Late Cretaceous Vardar Ocean subduction showing the relative positions of the Banat, Timok, and Srednogorie mineral districts. Modified from figure 20 of Drew (2006).

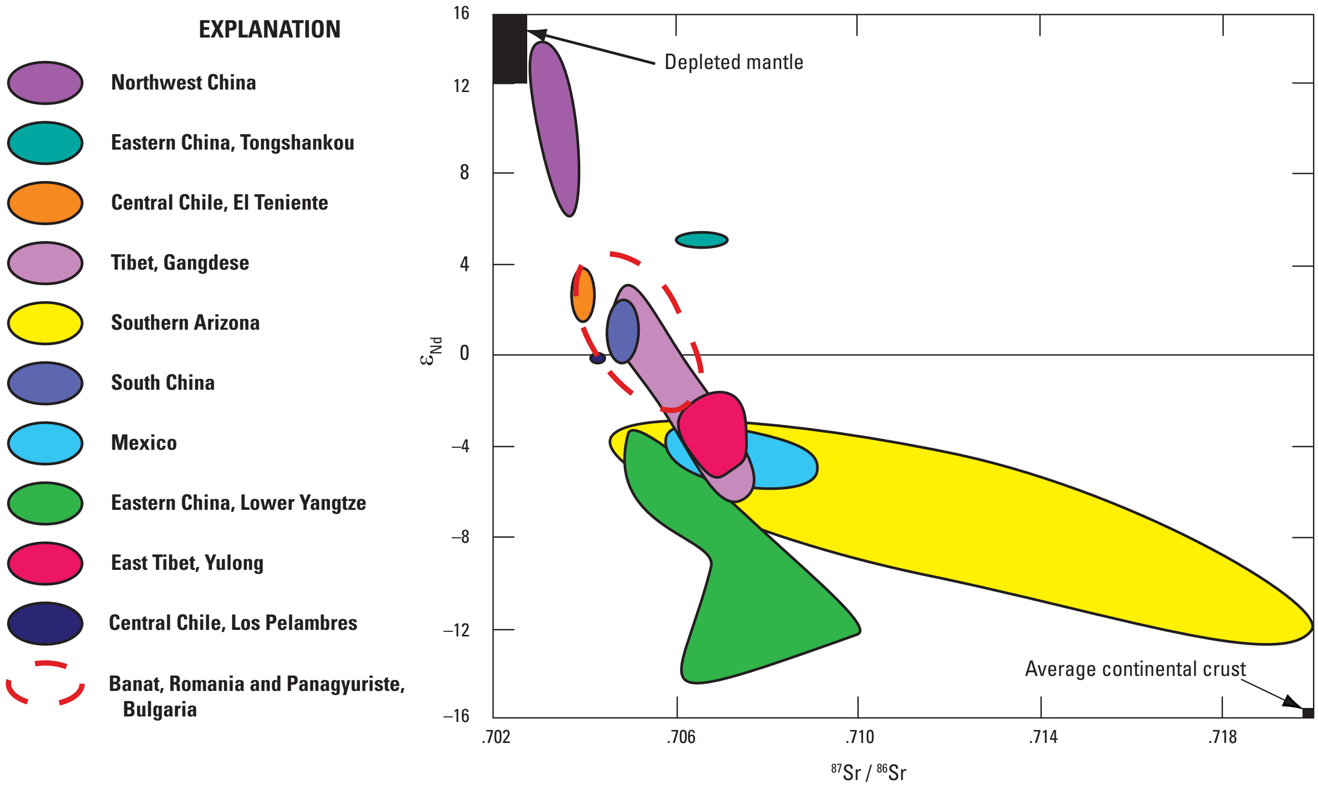


Figure 11. Generalized fields of neodymium (Nd) – strontium (Sr) isotopic compositions of granitic rocks associated with porphyry copper deposits (Ayuso, figure N6 in John and others, 2010). Data sources: Banat, Romania (Dupont and others, 2002); Panagyurishte District, Bulgaria (Kouzmanov and others, 2009); northwest China (Zhang and others, 2006); eastern China (Li and others, 2008;Ling and others, 2009); south China (Wang and others, 2006); Chile (Nystrom and others, 1993;Stern and Skewes, 1995; Kay and Kurtz, 2005);Tibet (Hou and others, 2004, 2005); southern Arizona (Farmer and Depaolo, 1984; Anthony and Titley, 1988; Lang and Titley, 1998); Mexico (Valencia-Moreno and others, 2001); average crust (Hoffmann, 1997; Rudnick and Gao, 2003).

Banat Region, Romania

In the Banat region (fig. 9), Late Cretaceous to Paleocene granitoid stocks and dikes are preserved along a narrow, north-trending belt along the western edge of a nappe structure. Drew (2006) interpreted the one known porphyry copper deposit in the area, the 500 Mt Moldova Nouă deposit and associated skarns, as emplaced in a extensional duplex following orogenic collapse. In contrast to the Timok and Srednogorie regions to the south (fig. 9), which host most of the known porphyry copper deposits in the ABTS belt, the extent of duplex development in the Banat region is much less and no extensional sedimentary basins formed (Drew, 2006).

Srednogorie Zone, Bulgaria

The Srednogorie zone is a 80–100-km-wide, east-west tectonic zone in Bulgaria (fig. 9). The Srednogorie zone hosts the Panagyurishte district (fig. 9), a north-northwest belt (that is, oblique to the Srednogorie zone orientation) of Late Cretaceous porphyry copper deposits, high-sulfidation epithermal copper-gold deposits, and polymetallic vein deposits and occurrences (Moritz and others, 2004; Zartova and others, 2004). The district may be localized by pre-existing north-northwest basement structures (von Quadt and others, 2005). The three major porphyry copper-gold deposits in the Panagyurishte district of the Central Srednogorie zone, Elatsite, Medet, and Assarel (fig. 1*C*), formed in a Late Cretaceous island arc to back-arc setting (Kamenov and others, 2007; von Quadt and others, 2005). Magmatism within the Srednogorie zone decreases in age from north to south; each ore deposit is closely related to a particular magmatic center (Lilov and Chipchakova, 1999; Heinrich and Neubauer, 2002; Kamenov and others, 2007; Zartova and others, 2004). Von Quadt and others (2005) proposed a model of oblique (northwest-directed) subduction accompanying closure of the Vardar Ocean arm of the Neotethys along the southern continental margin of Europe, followed by southward slab retreat and slab rollback, crustal thinning, and back-arc development to explain the north (older, ~92 Ma) to south (younger, ~78 Ma) age progression of magmatism associated with porphyry copper deposits in the Panagyurishte district of the Srednogorie zone.

Drew (2006) demonstrated the close spatial relation between the larger porphyry copper deposits and inferred strike-slip fault duplexes in the Srednogorie zone by analyzing structural features on large-scale geologic maps and satellite imagery. Figure 12*A* shows the relation of porphyry copper deposits and occurrences to geology, strike-slip faults, and the Iskar-Yavoritsa shear zone, a regional dextral strike-slip fault that can be traced for 80–90 km southeast of Sofia. Some of the Late Cretaceous intrusions were emplaced along, and deformed by, the shear zone; undeformed sills of the 75 Ma Gustal pluton intrude shear zone mylonites (Georgiev and others, 2009). Figure 12*B* shows the relationship of the deposits to strike-slip fault duplexes. The three major porphyry copper-gold deposits are hosted in, or near, small granodiorite-quartz monzodiorite stocks that were emplaced in extensional fracture zones; Assarel was emplaced in a strato-volcano whereas Medet and Elatsite were emplaced at deeper levels (Strashimirov and others, 2002; Drew, 2006). Smaller porphyry copper deposits associated with larger, elongated and deformed plutons tend to occur along or near the boundary faults that define the margins of the duplexes (fig. 12*A, B*). Structural interpretations of stress fields associated with duplex formation led Drew (2006) to conclude that areas of lower mean stress at corners and edges of duplexes facilitate maximum fluid flow rates and therefore are favorable for the repeated cycles of emplacement of magma pulses, fracturing, and ore deposition that result in large deposits (see inset on fig. 12*B*). Similar detailed analyses of large-scale maps and structural interpretations provided an explanation for porphyry distributions in the Banat and Timok areas (see appendix A).

Thrace Region, Turkey

In extreme northwestern Turkey, the area of European Turkey known as Thrace (fig. 1), the Tethyan Eurasian Metallogeniuc Belt (TEMB) is represented by intermediate and felsic igneous rocks that comprise the westernmost part of the Late Cretaceous Pontides magmatic arc. The 82 Ma Sukrupasa, 75 Ma Ikiztepeler, and Paleocene Derekoy-Karadere porphyry copper deposits near the Turkey-Bulgarian border (fig.1*C*) are associated with subduction-related Late Cretaceous magmatism that ended at about 71 Ma (Ohta and others, 1988).

Cenozoic Magmatism

The complex geodynamics of southeastern Europe (fig. 13) include subduction of oceanic plates, continent/micro-continent collisions, and opening of extensional basins that produced a wide spectrum of Tertiary to Quaternary magmas. Calc-alkaline and shoshonitic pulses of magmatism are ascribed to a variety of models, including subduction, subduction slab breakoff, delamination of lithospheric mantle due to gravitational collapse, convective removal of lower lithosphere, and upwelling of lithospheric mantle variably contaminated with crustal components (Haranghi and others, 2006). Figure 14 illustrates distributions of Paleogene to Holocene magmatic pulses in the Alpine-Mediterranean region in terms of age ranges and geochemical associations, based on data compiled by Harangi and others (2006). Porphyry copper deposits are associated with calc-alkaline and shoshonititic magmatism; where absent, Cenozoic intrusions may be too deeply eroded to preserve porphyry copper deposits, volcanic cover may be too thick, or the igneous complexes may simply be barren. Note that in most cases, alkaline (anorogenic) magmatism overlaps or postdates calc-alkaline magmatic pulses (fig. 14).

A

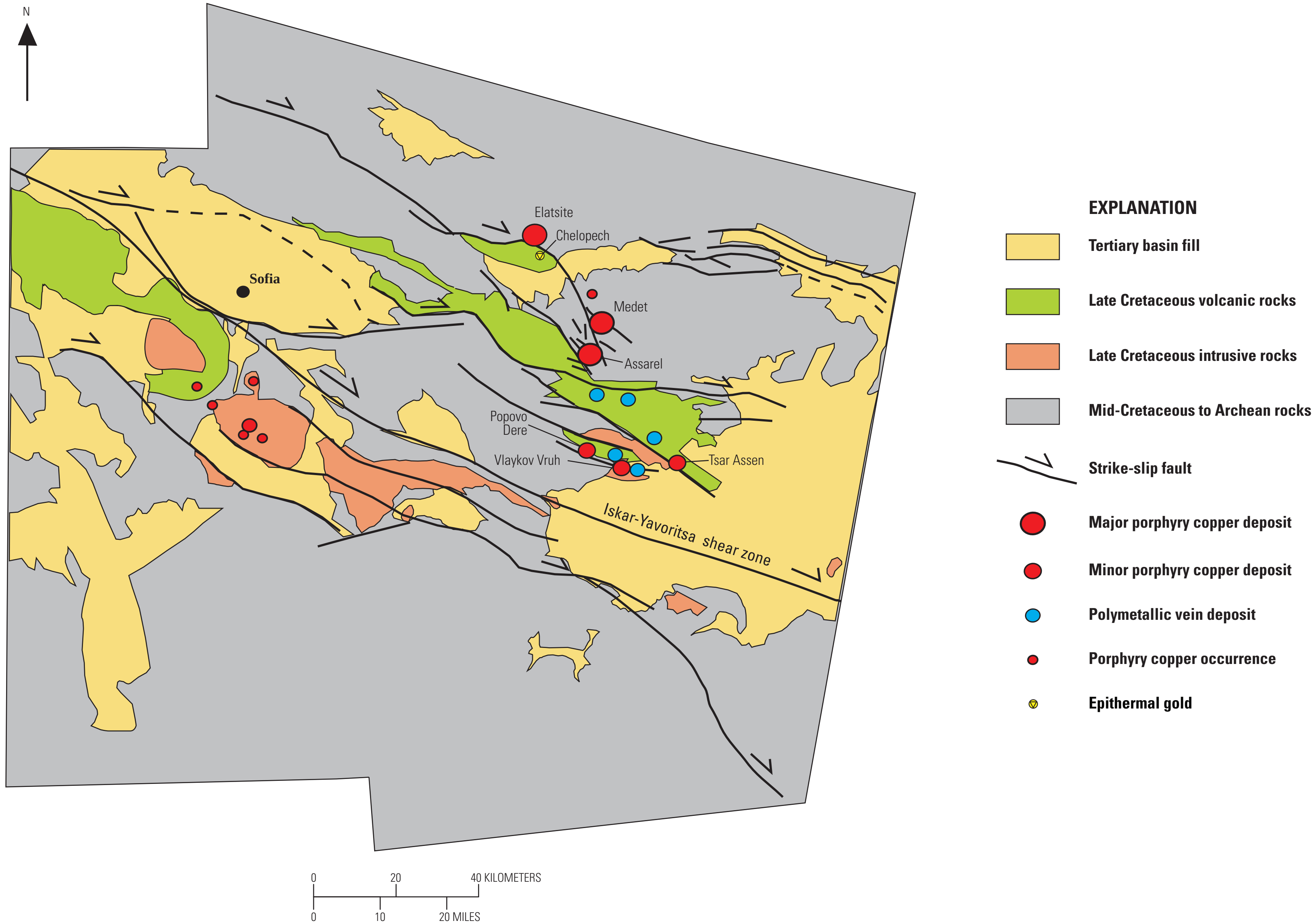


Figure 12. Central Srednogorie region, Bulgaria. See figure 10 for location of the Srednogorie region. Schematic illustrations of the relationships of mineral deposits to structure. *A*, Geology, known porphyry copper deposits and polymetallic vein deposits and occurrences, and strike-slip faults. Modified from Drew (2006, fig. 25); based on Bulgarian Academy of Sciences (1973), Bogdanov (1983), Bayraktarov (1994,) Ivanov and others (2002) and Strashimirov and others (2002). *B*, Strike-slip fault duplexes (gray) and their spatial association with porphyry copper deposits. Inset shows relative probabilities of occurrence of porphyry copper deposits in relation to proximity to shear zone. From Drew (2006, fig. 26). See tables A3 and A4 in appendix A for locations of deposits and prospects.

B

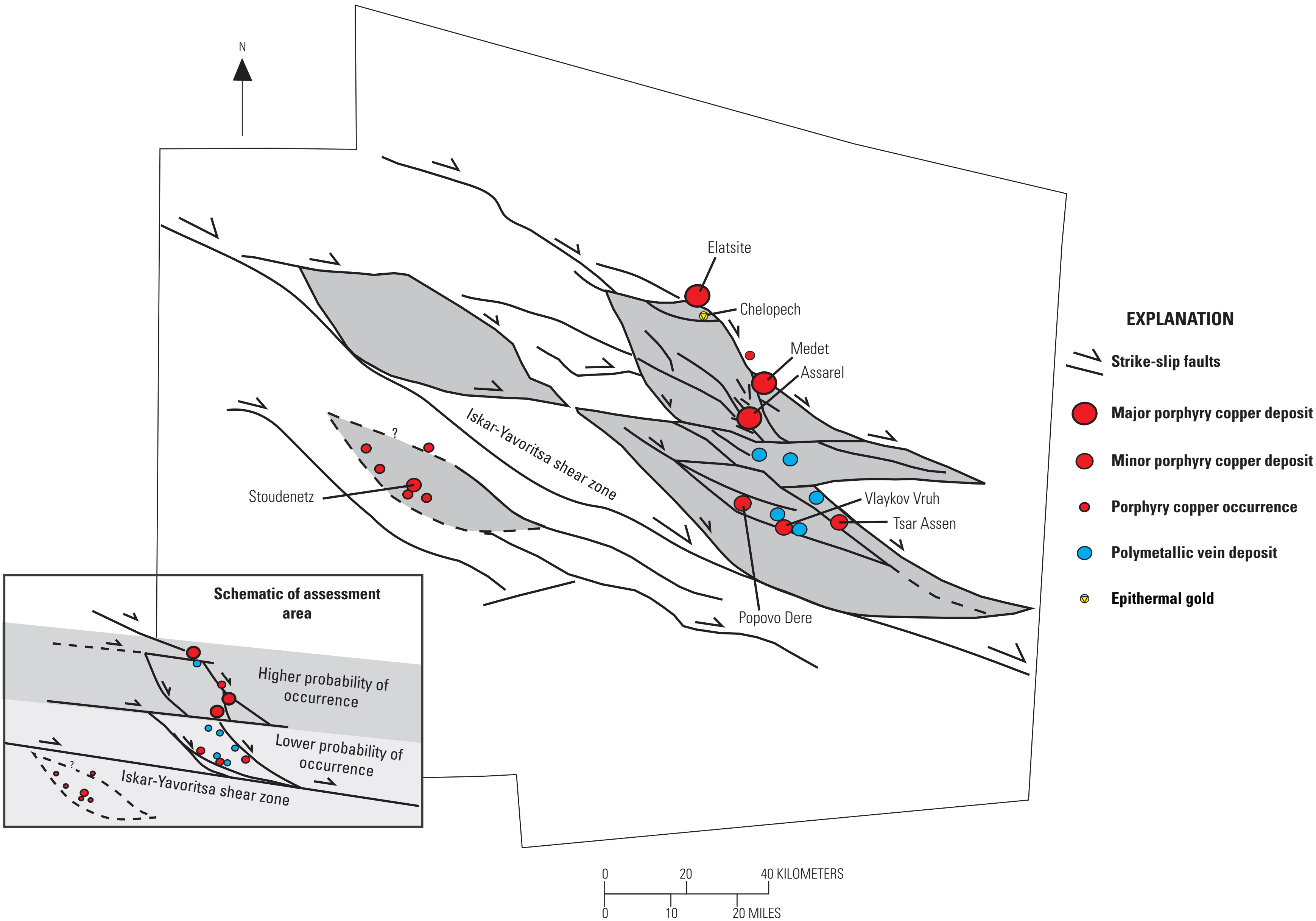


Figure 12..—Continued

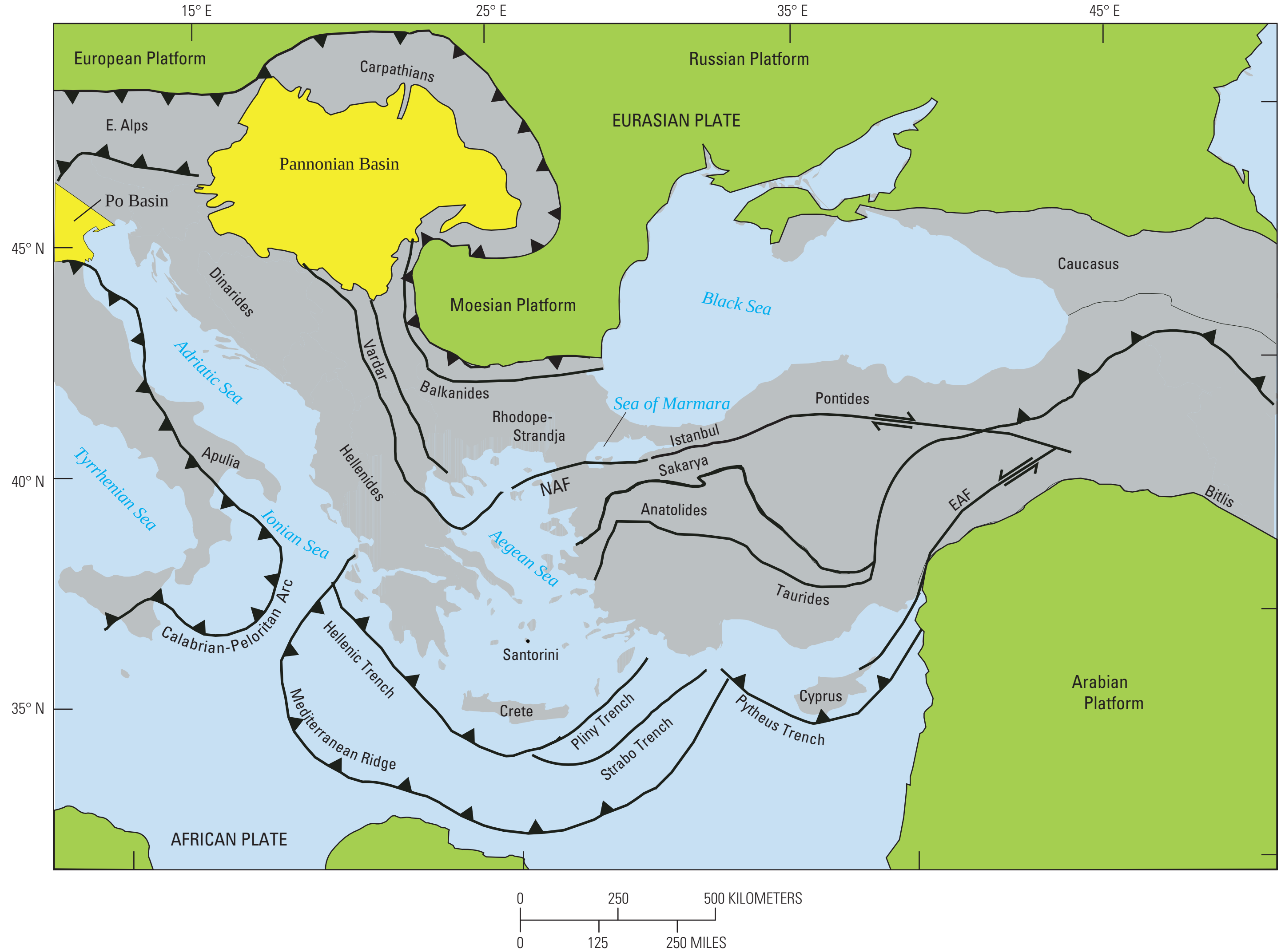


Figure 13. Modern regional geodynamic setting of the Dinaride-Hellenide-Anatolide region relative to the African and Eurasian Plates, and the Arabian Platform. Based on Pe-Piper and Piper (2007, fig. 1), Dinter (1998) and Robertson (1998). NAF, North Anatolia fault; EAF, East Anatolia fault.

Paleogene Dinaride-Rhodope-North Aegean Belt

A belt of late Eocene-Miocene calc-alkaline to high-K calc-alkaline to shoshonitic intrusions and volcanic rocks extends from the Dinaride Mountains in easternmost Bosnia and Herzegovina through Serbia, Macedonia, along the east coast and Aegean islands of Greece, and into southern Bulgaria and European Turkey (Marchev and others, 2005; Dumurdzanov and others, 2005; Pe-Piper and Piper, 2006). This ~500 km long by 150 km wide arcuate belt, referred to as the Macedonian-Rhodope-North Aegean magmatic belt, transects the main tectonostratigraphic terranes of southeastern Europe, including the Vardar zone (fig. 13) (Harkovska and others, 1989; Marchev and others, 2005). Cenozoic calc-alkaline magmatism in the Rhodope zone of Greece may be related to subduction of the Intra-Pontide Ocean (present-day Sea of Marmara region) that closed in Eocene or Oligocene time and separated Eurasia from the Sakarya microcontinent to the south (fig. 13). A review of the Paleogene-early Miocene igneous rocks of the Alpine-Carpathian-Dinaric region by Kovács and others (2007) suggested a possible extension of the belt to the north, where three linear zones of subduction-related, geochemically similar calc-alkaline rocks that parallel major faults were identified (fig. 15): (1) the mid-Hungarian zone (MHZ) of late Eocene-early Oligocene plutons and andesitic volcanic rocks, (2) the Sava-Vardar zone (SVZ) that parallels the Main Balkan and Vardar Faults, and (3) the Periadriatic zone (PZ) of late Eocene-early Oligocene plutons along the Periadriatic Fault. Paleogene magmatism in the MHZ and SVZ may be related to subduction of the Budva-Pindos Ocean, whereas the Paleogene-early Miocene magmatism in the PZ likely is related to southward Penninic Ocean subduction; sutures mark closure of these oceans (fig 15).

Paleogene porphyry copper deposits are known in the mid-Hungarian and Sava-Vardar zones; exposed Paleogene intrusions in the Periadriatic zone, such as the Adamello batholith (fig. 15) preserve depths of emplacement on the

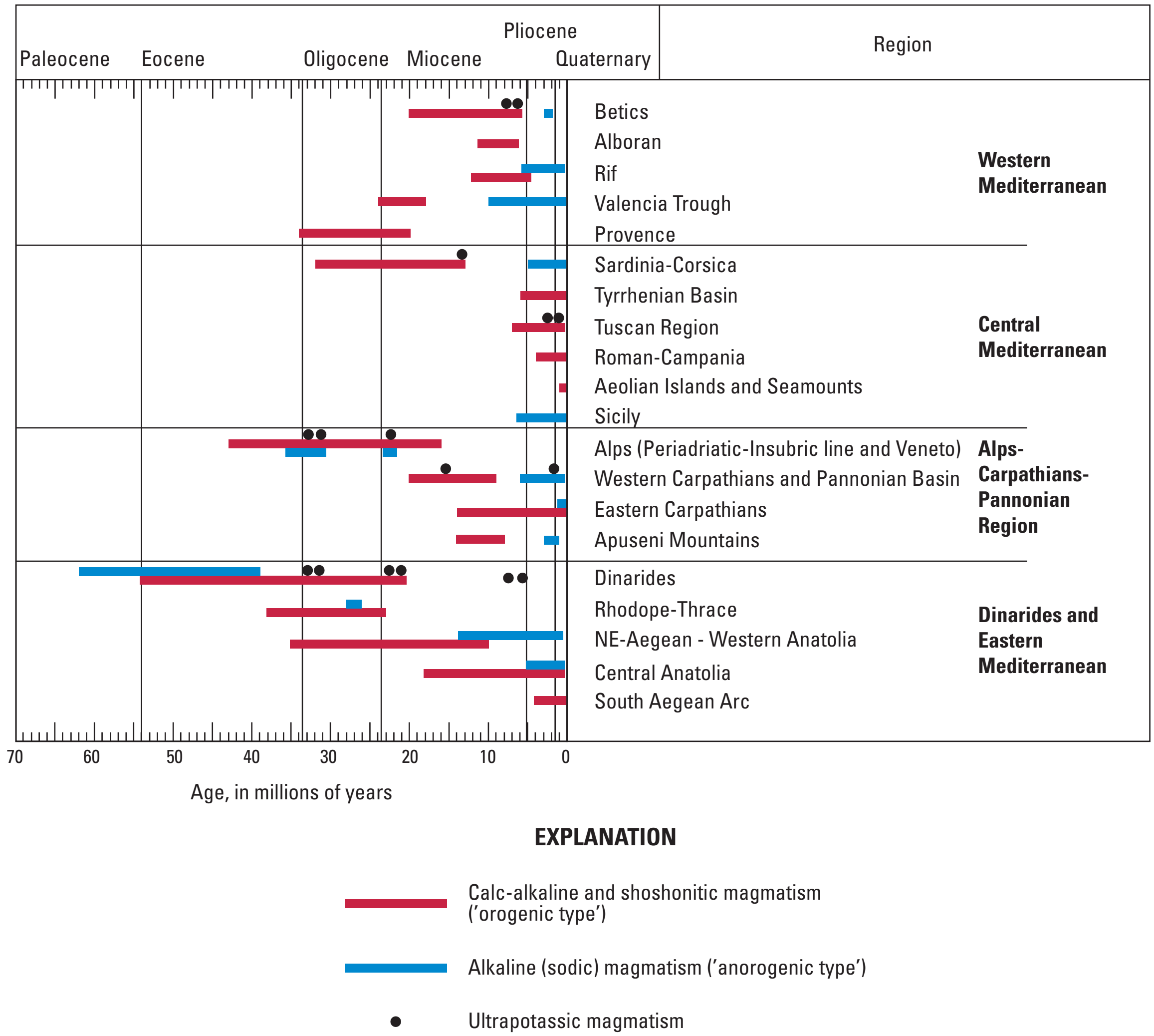


Figure 14. Distributions of age and geochemical affinity of Paleogene to Holocene magmatic rocks in the Alpine-Mediterranean region (based on figure 5 of Harangi and others 2006 and references therein).

order of 9–12 km, so any porphyry systems emplaced in the upper 4 km of the crust would have been eroded. These Paleogene-early Miocene rocks may have been part of a single, 1,200-km long subduction-related magmatic arc that was disrupted by Miocene tectonism.

The Recsk Mountains form part of the NE-striking Mid-Hungarian zone (fig. 15) of Paleogene-early Miocene igneous rocks, which is overlapped by middle to late Miocene volcanic rocks (Kovács and others, 2007). At Recsk, breccia-hosted high-sulfidation epithermal copper-gold ore bodies in an andesitic stratovolcano overlie a 36 Ma porphyry copper-gold deposit, with associated copper and zinc skarns.

A number of porphyry copper prospects coincide with the Sava-Vardar zone (fig. 15) and southeast-striking Serbomacedonian-Rhodope metallogenic belt (fig. 9). This area also hosts the 23 Ma Bucim (Buchim) deposit (450,000 t contained copper) in Macedonia, the 18 Ma Skouries deposit (~1.5 Mt contained copper) in Greece, and numerous porphyry copper prospects (fig. 1*C*).

In the central Aegean Sea west of the Anatolian peninsula, the Greek islands (Cyclades) are a southward extension of the Oligocene-Miocene Greek porphyry belt. The Fakos and Sardes porphyry copper-molybdenum prospects and the Stypsi molybdenum prospect of the Cyclades islands of Limnos and Lesvos (fig. 1*C*) were discovered in areas previously known to be prospective for epithermal-style mineralization (Voudouris and Alfieris, 2005). Although postcollisional porphyry systems tend to be gold-rich, crustal contamination of magmas derived from enriched lithospheric mantle may explain the elevated molybdenum contents in some of the deposits.

Africa is actively colliding with Europe in the western part of the Mediterranean, parts of the eastern Mediterranean are in a state of diachronous collision, and areas farther to the east are in a postcollisional phase (Robertson, 1998). Analysis of seismic data by Robertson (1998) showed that the present-day northern boundary of the African Plate in the eastern Mediterranean lies south of Cyprus, near the Pytheus Trench, and continues as an east-west boundary to the south of the Mediterranean Ridge (fig. 13). The Mediterranean

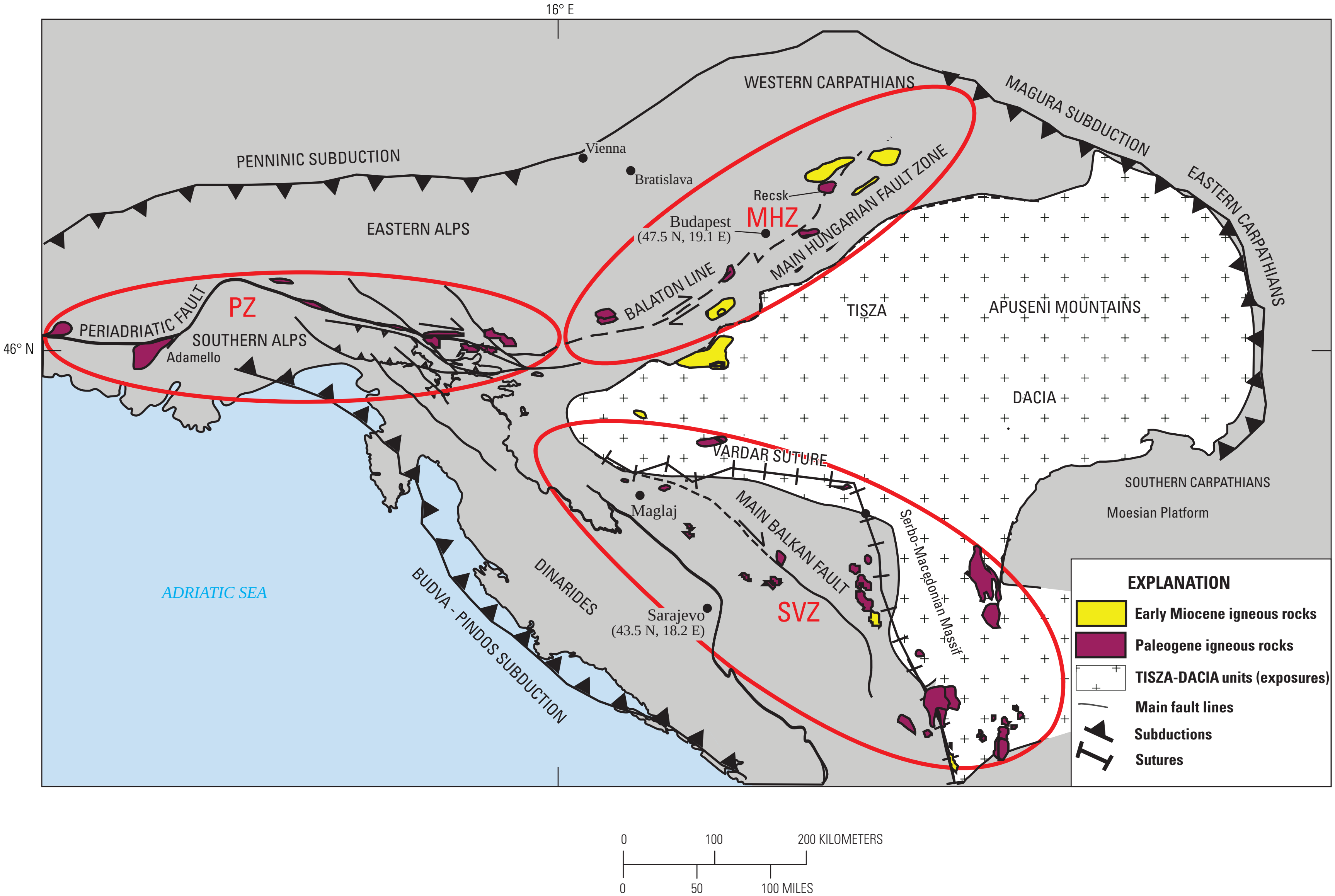


Figure 15. Paleogene-early Miocene igneous rocks in the Alpine-Carpathian-Pannonian-Dinaride (ALCAPA) region (modified from Kovács and others, 2007). Major volcanic provinces: MHZ, Mid-Hungarian zone; SVZ-Sava-Vardar zone; PZ, Periadriatic zone. Sutures represent proposed positions of former oceans.

Ridge is a 1,200-km-long by 150 to 300-km-wide large accretionary complex related to subduction of the African Plate beneath the European Plate and the Aegean microplate; the Hellenic Trench (fig. 13) bounds the Ridge on the north (Mascle and Chaumillon, 1998). The Hellenic Trench is an oceanic depression interpreted as part of a fore-arc basin, not a subduction zone, along the southern border of an inactive, outer arc through Crete. The active, inner South Aegean Arc hosts recently dormant and active volcanoes, such as Santorini (fig. 13). Rollback of the Hellenic subduction slab has caused the Hellenic Trench to retreat to the south as the Aegean Sea formed an extensional back-arc basin to the South Aegean volcanic arc, or alternatively, a basin formed by within-plate transtension and crustal thinning (Pe-Piper and Piper, 2002).

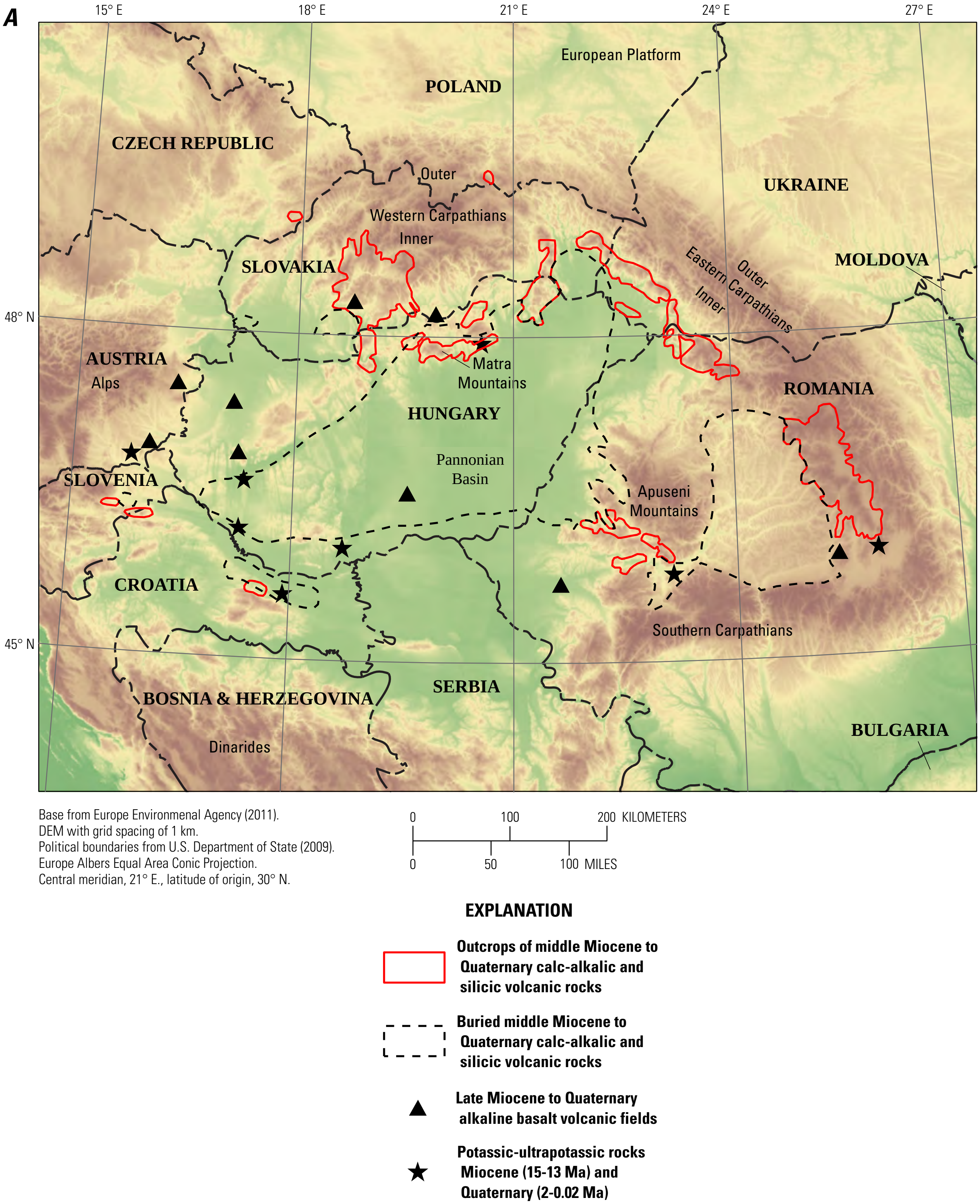
Carpathian Mountains

The Carpathians form a 1,300-km-long arcuate belt of mountain ranges that wrap around the Neogene Pannonian Basin (fig. 16*A*). The Carpathians extend eastward from the eastern Alps as part of the Alpine-Balkan-Carpathian-Dinaride orogen. Pre-Neogene inner orogenic zones and Paleogene-Miocene magmatic complexes make up the western and eastern Inner Carpathians; the eastern and western Outer Carpathians are a deformed flysch belt bordering the European Platform (fig. 16*A*). The Inner Carpathians are part of the Tertiary Alpine-Carpathian orocline that formed by subduction and collision processes related to closure of Neotethyan ocean basins (Neubauer and others, 2005).

Three mineral districts in the Inner Carpathians host porphyry copper and related deposit types: (1) the Recsk Mountains in Hungary, (2) the Central Slovakia volcanic district, and (3) the South Apuseni Mountains district of Romania (also referred to as the “Golden Quadrilateral”). The mineralization in the Recsk Mountains may be a northern part of the Paleogene-early Miocene Serbomacedonian-Rhodope Belt based on the 36 Ma age for the Recsk deposit and the extent of Paleogene-early Miocene dated permissive rocks delineated by Kovács and others (2007). However, younger Miocene back-arc extension, lithospheric thinning, and asthenospheric upwelling produced varied magmatic suites throughout the Carpathian-Pannonian region (Harangi, 2009).The Central Slovakia volcanic district (fig. 16*B*) is centered around middle Miocene andesitic stratovolcanoes and associated calc-alkaline granodiorite and diorite intrusions ranging from ~17–11.5 Ma (Neubauer and others, 2005). Normal faults representing releasing steps in a wrench fault system provided structural controls on magma emplacement and hydrothermal fluid flow paths for mineralization (12–11 Ma). Low-sulfidation epithermal vein-, porphyry-, and skarn deposits (Banská Ŝtiavnica Group on figure 1*A*) are associated with the Banská Ŝtiavnica stratovolcano.

The Apuseni Mountains of northwestern Romania are characterized by medium- to high-potassium calc-alkaline Miocene volcanism that produced andesitic stratovolcanoes, as well as differentiated rocks, subvolcanic intrusions, rare late-stage rhyolite, and epithermal mineralization (Plant and others, 2005). The opening of extensional basins and the emplacement of andesitic volcanic rocks and associated granitoid rocks in the Apuseni Mountains were coupled with the eastward tectonic escape of the Carpathian-Pannonian region during the Miocene and northeastward motion of a microcontinent from the south that formed the orocline (fig. 16*B*) (Royden and others, 1983; Drew, 2006; Heinrich and Neubauer, 2002). The Apuseni Mountains are informally referred to as “the Golden Quadrilateral” because of the cluster of low-sulfidation epithermal gold-telluride veins and associated small to medium- size porphyry copper-gold deposits. Porphyry copper-gold deposits include Bucium Tarnita (335 Mt at 0.5 percent copper, 0.36 g/t gold) and Rosia Poieni (fig. 1*B*). The Bucium Tarnita deposit, located immediately south of the Rosia Montana epithermal gold-silver deposit, was under exploration in 2011 (Gabriel Resources, 2011). Rosia Poieni was mined until 1999 (431 Mt at 0.55 percent copper, 0.25 g/t gold).

Porphyry copper deposits are associated with the Miocene calc-alkaline rocks in the Carpathian-Pannonian region, with the exception of the Paleogene Recsk deposit. The Miocene porphyry copper mineralization in the Banská Ŝtiavnica area may represent a postsubduction geodynamic setting. On the basis of geochemistry and geochronology, Harangi and Lenkey (2007) defined four groups of magmatic rocks in the region: (1) Miocene (21–13 Ma) silicic pyroclastic rocks, (2) middle Miocene to Quaternary (16.5–2 Ma) calc-alkaline volcanic rocks, (3) Miocene (15–13 Ma) and Quaternary (2–0.2 Ma) potassic and ultrapotassic rocks, and (4) late Miocene to Quaternary (11–0.2 Ma) alkalic sodic volcanic rocks. Figure 16*A* shows the distributions of exposed and buried calc-alkaline (group 2) rocks, as well as point locations for volcanic centers for groups 3 and 4. For the porphyry-associated group 2 rocks, both subduction and postcollisional origins have been proposed. Subduction is supported by the alignment of calc-alkaline andesite-dacite complexes parallel to the Carpathian Mountains and subduction-related trace-element signatures (Mason and others, 1996). Alternatively, postcollisional magma genesis, possibly related to slab break-off by melting of metasomatized lithospheric mantle contaminated by crustal material during peak extension, is compatible with gradual changes in geochemical signatures with time (decreasing La/Nb, Th/Nb, $^{87}Sr/^{86}Sr$; increasing $^{143}Nd/^{144}Nd$ and $^{206}Pb/^{204}Pb$). This geochemical signature likely reflects decreasing crustal contamination and(or) increasing material from enriched asthenospheric mantle in magma sources (Harangi, 2009; Harangi and others, 2006; Harangi and Lenkey, 2007). The extensional model is also supported by the observation of thin lithosphere and crust, and the presence of almandine garnet xenoliths in the early-stage 2 andesites and dacites suggesting rapid ascent from lower crustal depths (Harangi, 2009). In the eastern Carpathians, middle Miocene to Pleistocene arc volcanism produced mostly basaltic andesite, andesite stratovolcanoes, and/or small subvolcanic intrusions with rare differentiated rocks (Plant and others, 2005).



Base from Europe Environmenal Agency (2011).
DEM with grid spacing of 1 km.
Political boundaries from U.S. Department of State (2009).
Europe Albers Equal Area Conic Projection.
Central meridian, 21° E., latitude of origin, 30° N.

Figure 16. Carpathian-Pannonian region. *A*, Digital elevation model of the Carpathian orocline surrounding the Pannonian Basin, showing locations of outcropping Neogene to Quaternary volcanic rocks (Harangi, 2009). *B*, Schematic illustration of Miocene tectonic transport direction. See A for present-day location of the Mátra and Apuseni Mountains, Modified from figure 32 of Drew (2006) based on data from Csontos and others (1992) and Rumpler and Horvath (1988). CSVF, Central Slovakian Volcanic Field; MM, Mátra Mountains; AM, Apuseni Mountains.

B

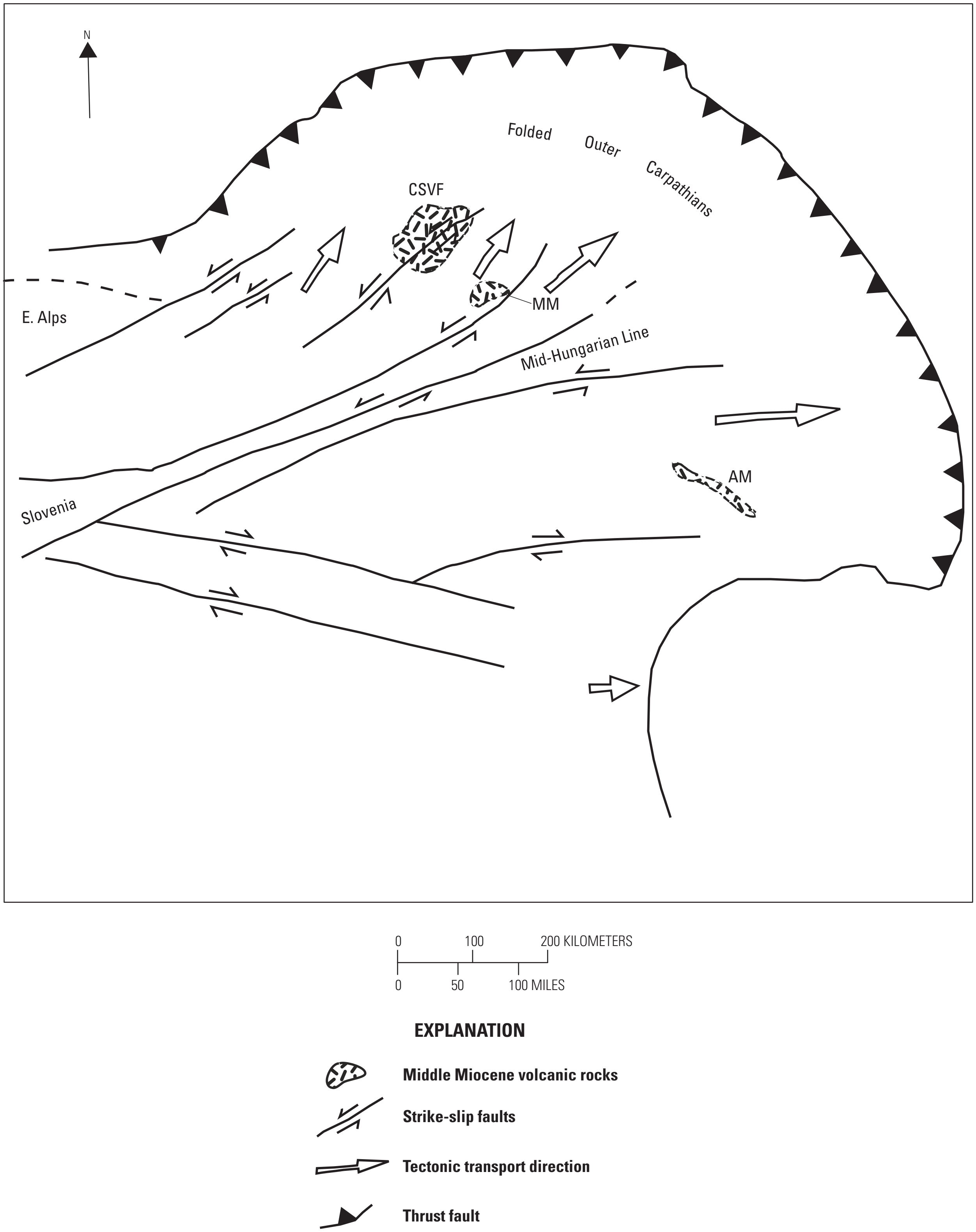


Figure 16.—Continued.

The Pannonian Basin (fig. 16*A*) formed late in the Alpine orogenic cycle, with extension starting ~20 Ma in the western part of the region and continuing until about 11 Ma. Thicknesses of Neogene and Quaternary basin sediments exceed 4 km or more in deeper parts of the basin (Plant and others, 2005). Calc-alkaline igneous rocks have been identified at depth in the Pannonian Basin by oil and gas exploration (Harangi and Lenkey, 2007). Detailed geophysics and analysis of basin structures could reveal unidentified mineralized systems, but no buried porphyry copper systems have been identified within 1 km of the surface. Since the late Pliocene, the basin has undergone tectonic inversion.

Western Europe

Sardinia. During the Alpine orogeny, Sardinia and Corsica were detached from Europe and rotated counterclockwise as part of the African Plate was subducted beneath Europe (Frezotti and others, 1992; Stefanini and Williams-Jones, 1996; Dumurdzanov and others, 2005). A system of grabens formed during late Oligocene to early Miocene extension related to westward subduction of submarine continental crust beneath Corsica and Sardinia and development of the volcanic arc seen on Sardinia (Casula and others, 2001). The subduction-related volcanic arc, which is well-exposed in the western part of Sardinia, hosts the low-grade Calabona (fig. 1*A*) porphyry copper deposit and several prospects (Casula and others, 2001; Stefanini and Williams-Jones,1996). The Calabona deposit has not been developed due to proximity of the deposit to a town, the depth to mineralization, and the low grade (0.07 percent copper) of the deposit (Fadda and others, 1998).

Spain and Morocco. The Betic-Rif mountain belt (fig. 1) of southern Spain and northern Africa represents the westernmost volcanic arc related to the Alpine orogeny (fig. 3). The mountain belt was formed by nappe tectonics during a series of Upper Cretaceous to early Miocene Alpine compressional episodes (Lonergan and White, 1997; Doblas and Oyarzun, 1989). The Neogene structure of the Betic-Rif mountain belt results from the westward rollback of a short east-dipping subduction zone as Africa and Europe converged (Platt and others, 2006). With plate rollback, post-compressional Neogene extension tectonics produced calc-alkaline, shoshonitic, and lamproitic volcanic rocks (Doblas and Oyarzun, 1989). The calc-alkaline volcanic rocks in southern Spain host pluton-related polymetallic mineralization and alunite-bearing advanced argillic alteration and are therefore permissive for porphyry copper deposits, although no porphyry copper deposits or prospects are known in the area (Arribas and others, 1995). Coeval andesites and a granodiorite pluton crop out in the Rif terrane of northeastern Morocco; the only mineral deposit known to be associated with the Moroccan rocks is a 7 Ma iron skarn (El Rhazi and Hayashi, 2002). Alpine-related Miocene igneous rocks that crop out in the eastern part of the Rif terrane along the Mediterranean in northeastern Algeria are peraluminous rare-metal granites and rhyolites, and therefore are not permissive for porphyry copper deposits (Council for Geoscience, South Africa (CGS) and Commission for the Geological Map of the World, France (CGMW), 2003; Bouabsa and others, 2010).

France, Belgium, Germany, Czech Republic. The Tertiary to Quaternary volcanism of the European Rift System, which includes the Massif Central and Auvergne region in France, the Rhine Graben and Eifel Mountains in western Germany and eastern Belgium, and the Eger Graben in the Czech Republic (fig. 1), is characterized by mostly volcanic fields of tephrite, basanite, alkali basalt and/or hawaiite lava flows, scoria cones, maars, and diatremes, with rare trachyte, phonolite extrusive domes, and tholeiitic basalt stratovolcanoes (Plant and others, 2005). Volcanic activity in the British Volcanic Province is related to rifting and the opening of the northern Atlantic (Plant and others, 2005). There are no known porphyry copper deposits related to either of these rift systems.

Assessment Data

Geology

Geologic maps of Europe at various scales, including both digital maps and paper maps that were scanned and georectified, were used in the assessment. Small-scale maps, such as the 1:5 million-scale map of Europe and adjacent areas (Asch, 2005), were consulted for regional framework; larger scale maps were used to develop permissive tracts. The primary map source was a proprietary version of a digital geologic map of western and central Europe at scale of 1:1,500,000 provided by the BRGM for the assessment, based on data compiled in GIS Central Europe (Cassard and others, 2004, 2006; Bureau de Recherches Géologiques et Minières, 2004). GIS Central Europe is a proprietary GIS package that users can explore to obtain information on geology, mineral resources, geochronology, heat flow, and other types of data. GIS Central Europe includes geologic maps at scales ranging from 1:25,000 to 1:500,000.

Geologic maps used for the assessment, including the source maps used in the digital geologic map provided by Bureau de Recherches Géologiques et Minières and other digital geologic compilations used for the assessment, are listed in table 2.

Table 2. Geologic maps used for the assessment of porphyry copper deposits in Europe.

[na, not available]

Country or continent	Scale	Reference
Africa	1:5,000,000	Veselinovic-Williams, M., and Frost-Killian, S., 2003 [2007], Digital international metallogenic map of Africa: Council for Geoscience, South Africa and Commission for the Geologic Map of the World, scale 1:5,000,000, CD-ROM
Albania	1:200,000	Instituti i Studimeve dhe i Prokektimeve të Gjeologjisë, 1983, Harta gjeologjike e RPS të Shqipërisë: Tiranë, Instituti i Studimeve dhe i Prokektimeve të Gjeologjisë, Instituti Gjeologjik i Naftës, 1 map on 3 sheets, scale 1:200,000.
Austria	1:1,000,000	Beck-Mannagetta, P. , 1963, Geologische übersichtskarte der Republik Österreich [General geological map of the Republic of Austria]: Wien, Österreichische Akademie der Wissenschaften [Austrian Academy of Sciences] Österreich-Atlas II/3, scale 1:1,000,000.
Bulgaria	1:1,000,000	Bulgarian Institute of Academy of Sciences, 1973, Geologic map of Bulgaria: Bulgarian Institute of Academy of Sciences, sheet 24–25, scale 1:1,000,000.
Bulgaria	1:500,000	Cheshitev, G., and Kâncev, I., eds., 1989, Geological map of P.R. Bulgaria: [Sofia], Committee of Geology, Department of Geophysical Prospecting and Geological Mapping, 1 map on 2 sheets, scale 1:500,000.
Carpathian-Balkan Region	1:1,000,000	Bogdanov and others, 1977, Map of Mineral Formations of the Carpathian-Balkan Region, in Egel, L., ed., Council For Mutual Economic Assistance, Delegation of the USSR to the CMEA Standing Commission on Geology, 9 sheets, scale 1:1,000,000.
Czechoslovakia (former)	1:1,000,000	Biely, A., Buday, T., Dudek, A., Fusán, O., Chlupáč, I., Kaiser, T., Kodym, O., Kopecký, L., Kuthan, M., Malecha, A., Malkovský, M., Matějka, A., Pešek, J., Seneš, J., Soukup, J., Svoboda, J., Tásler, R., and Zoubek, V., comps., 1966, Geological map of Czechoslovakia (superficial deposits omitted): Ustredni Ustav Geologicky, scale 1:1,000,000.
Czechoslovakia (former)	1:500,000	Fusan, O., Kodym, O., Matějka, A. and Urbánek, L., 1967, Geological map of Czechoslovakia: Ustredni Ustav Geologicky, 2 sheets, scale 1:500,000.
Europe	1:1,500,000	Cassard D., Lips A.L.W., Leistel J.-M. and Stein G., coordinators, 2006, Metallogenic map of Central and Southeastern Europe—An extract from GIS Europe: BRGM Report BRGM/RP-54703-FR.
Europe	1:5,000,000	Asch, Kristine, comp., 2005, The 1:5 million international geologic map of Europe and adjacent areas – IGME 5000: Bundesanstalt für Geowissenshaften und Rohstoffe [BGR], 1 sheet, scale 1:5,000,000.

Table 2. Geologic maps used for the assessment of porphyry copper deposits in Europe.—Continued

[na, not available]

Country or continent	Scale	Reference
France	1:1,000,000	Chantraine, Jean, Autran, Albert, Cavelier, Claude, Alabouvette, Bruno, Barféty, Jean-Claude, Cecca, Fabrizio, Clozier, Léopold, Debrand-Passard, Serge, Dubreuilh, Jacques, Feybesse, Jean-Louis, Guennoc, Pol, Ledru, Patrick, Rossi, Philippe, and Ternet, Yves, 2003, Carte géologique de la France à l'échelle du millionième, sixième édition révisée [Geological map of France at a scale of one million, sixth revised edition]: Bureau de Recherches Géologiques et Minières [BRGM], Service Géologique National, 2 sheets, scale 1:1,000,000.
Greece	1:500,000	Bornovas, John, and Rondogianni-Tsiambaou, Th., eds., 1983, ΓΕΩΛΟΓΙΚΟΣ ΧΑΡΤΗΣ ΤΗΣ ΕΛΛΑΔΑΣ [Geological map of Greece, second edition]: Athens, Institute of Geology and Mineral Exploration, 2 sheets, scale 1:500,000 [in Greek and English].
Hungary	1:500,000	Fülöp, Jósef, ed., 1984, Geological map of Hungary: Hungarian Geological Institute, Geological Atlas of Hungary, [sheet] 1, scale 1:500,000.
Italy	1:1,000,000	Compagnoni, Bruno, and Galluzzo, Fabrizio, eds., 2008, Carta geologica d' Italia [Geological map of Italy]: Servizio Geologico d' Italia [Geological Survey of Italy], 1 sheet, scale 1:1,000,000. [In Italian and English.]
Morrocco	1:1,000,000	Service Géologique du Maroc, 1985, Carte geologique du Maroc: Service Géologique du Maroc, Notes et Mémoire no. 260, 2 sheets, scale 1:1,000,000.
Poland	1:500,000	Rühle, Edward, comp., 1986, Geological map of Poland: [Warsaw], Geological Institute, Wydawnictwa Geologiczne, 1 map on 4 sheets, scale 1:500,000.
Poland, Ukraine, Slovakia (Carpathians)	1;200,000	Jankowski, Leszek, Kopciowski, Robert, and Ryłko, Wojciech, eds., 2004, Geological map of the outer Carpathians - Borderlands of Poland, Ukraine and Slovakia: Polish Geological Institute, 1 sheet, scale 1:200,000.
Romania	1:1,000,000	Săndulescu, Mircea, Kräutner, Hans, Borcoş, Mircea, Năstăseanu, Sergiu, Patrulius, Dan, Ştefănescu, Mihai, Ghenea, Constantin, Lupu, Marcel, Savu, Haralambie, Bercea, Iosif, and Marinescu, Florian, 1978, Republica Socialistă România - Harta geologică 1:1,000,000 [Socialist Republic of Romania - geological map 1:1,000,000] in Geographical Institute of the Romanian Academy of Sciences, 1974-1979: Institutul de Geologie şi Geofizică Atlasul Republicii Socialiste România [Institute of Geology and Geophysics Atlas for the Socialist Republics of Romania] II-1, 1 sheet (front and back), scale 1:1,000,000 [in Romanian, French, Cyrillic, and English].
Serbia		Monthel J., Vadala P., Leistel J.M., Cottard F., Ilic, M., Strumberger A., Tosovic R., Stepanovic A., 2002, Mineral deposits and mining districts of Serbia - compilation map and GIS databases: BRGM/RC-51448-FR, 69 p. 1 plate, CD-ROM.
Slovak Republic	1:500,000	Biely, Anton, ed., 1996, Geologická mapa Slovenskej Republiky [Geological map of Slovak Republic]: Bratislava, Geological Survey of Slovak Republic, scale 1:500,000. [Includes pamphlet: Geologická mapa Slovenska, 12 p.]
Spain	1:1,000,000	Instituto Técnológico Geominero de España, 1994, Mapa geológico de la Península Ibérica, Baleares y Canarias [Geologic map of the Iberian Peninsula, Baleares and the Canary Islands]: Instituto Tecnológico Geominero de España [IGME], scale 1:1,000,000.

Table 2. Geologic maps used for the assessment of porphyry copper deposits in Europe.—Continued

[na, not available]

Country or continent	Scale	Reference
Turkey	1:2,000,000	Bingöl, Ergüzer, comp., 1989, Türkiye jeoloji haritasi [Geological map of Turkey]: Ankara, General Directorate of Mineral Research and Exploration, 1 sheet, scale 1:2,000,000. [In Turkish and English.]
Turkey	1:500,000	General Directorate of Mineral Research and Exploration (MTA), 2000, Geological map of Turkey: Ankara, General Directorate of Mineral Research and Exploration, 1:500,000, 18 sheets. Digital version in vector format.
United Kingdom	1:625,000	British Geological Survey, 2007, Bedrock geology theme: British Geological Survey Digital geologic map of Great Britain [DiGMapGB].
United Kingdom	1:1,500,000	Colman, T.B., Scrivener, R.C., Morris, J.H., Long, C.B., O'Connor, P.J., Stanley, G., and Legg, I.C., comps., 1996, Metallogenic map of Britain and Ireland: British Geological Survey 1: 1,500,000 Series, 1 sheet, scale 1:1,500,000.
Ukraine	1:1,000,000	Perelshteyn, V.S., Belous, A.F., and Romanovskaya, N.L., 1977, [State geological map of the USSR, new series, sheet M-(35),36 Kiev, Map of the pre-Quaternary rocks]: Leningrad, Ministry of Geology of the USSR, VSEGEI, scale 1:1,000,000. [In Russian.]
Ukraine	1:1,000,000	Rastochinskaya, N.S., Nikulina, T.V., and Mironenkova, V.M., 1978, [Geological map of the USSR, new series, sheet M-(34),(35) Lvov, Map of pre-Quaternary rocks]: Leningrad, Ministry of Geology of the USSR, VSEGEI, scale 1:1,000,000. [In Russian.]
Ukraine	na	Center for Russian and Central Asian Mineral Studies, Department of Mineralogy, Natural History Museum, 2006, Ukraine GIS map: London, Natural History Museum, Center for Russian and Central Asian Mineral Studies, CD-ROM.
Yugoslavia (former)	1:500,000	Institute for Geological and Mining Exploration and Investigation of Nuclear and other Mineral Raw Materials, Belgrade, Serbia, [Institut za geološko-rudarska istraživanja i ispitivanja nuklearnih i drugih mineralnih sirovina Belgrade, Serbia], 1970, Geologic Map of Yugoslavia: Institute for Geological and Mining Exploration and Investigation of Nuclear and other Mineral Raw Materials, Belgrade, Serbia, 6 sheets, scale 1:500,000.

Known Deposits, Significant Prospects, and Mineral Occurrences

The global porphyry copper database of Singer and others (2008) was the primary data source for known deposits and for significant porphyry copper prospects in Europe. The 1:1,000,000-scale mineral resource map of Romania and accompanying texts provided information about prospect locations and deposit types (Borcos and others, 1983, 1984). Mineral-deposit maps and databases are available for Serbia (Ministry of Mining and Energy, 2010; Monthel and others, 2002), as well as compilations on porphyry copper deposits for Bulgaria (Bogdanov, 1983), and compilations for a variety of deposit types for Turkey (Yigit, 2006, 2009) and Central Europe (Dill and others, 2008). The comprehensive country-by-country explanatory memoir that accompanies the 1:2,500,000 metallogenic map of Europe and neighboring countries was also consulted (UNESCO, 1984).

Other data sources included mineral-occurrence data compiled in support of the GEODE[13] project (2006), including GIS Central Europe[14] (Bureau de Recherches Géologiques et Minières, 2004; Cassard and others, 2004, 2006), a review of non-ferrous mineral deposits in Europe (Lips and others, 2006), and a database produced by the Geological Survey of Canada (Dunne and Kirkham, 2003). In addition, commercially available databases (InfoMine,[15] Intierra,[16] Metals Economic Group[17]), metallogenic maps, technical reports, company web sites, publications and web sites of geological surveys, and the general geologic literature were consulted. The U.S. Geological Survey On-Line Mineral Resources Data System (MRDS)[18] includes information on mines, prospects, and mineral occurrences worldwide.

The assessment team classified sites as deposits, prospects, or mineral occurrences. Due to insufficient information, some prospects reported in data sources could not be classified unambiguously. Information about deposits and prospects that the team could classify as porphyry copper or porphyry-copper-related are included in tables in appendixes A through G and in the GIS database for this report (appendix H). Placer gold, skarn, and epithermal deposits, as well as unclassified copper and gold occurrences, were considered during the assessment but generally are not included in the database. Skarns and epithermal deposits may be included if the assessment team considered it likely that a porphyry system could be associated with them.

[13]Geodynamics and Ore Deposit Evolution project (GEODE), a program of the European Science Foundation that ran from 1998 to 2003.

[14]For information, see http://giseurope.brgm.fr/.

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

[16]http://www.intierra.com/Homepage.aspx.

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

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

Spatial Rules for Grouping Deposits and Prospects

Spatial rules are used to define the sampling unit that represents a deposit to ensure consistency in defining deposits as geologic entities for mineral resource assessment (Singer and Menzie, 2010). For porphyry copper deposits, two operational rules were applied in constructing the grade and tonnage models: (1) all mineralized or altered rock within 2 km is combined as a single deposit, and (2) grade and tonnage data are compiled for these single deposits based on total production, reserves, and resources at the lowest reported cutoff grade. Figure 17 illustrates an application of these rules. Site locations were verified using GoogleEarth™, georectified page-size maps from geologic reports, and locations reported in databases. For sites with visible surface disturbance, such as open pits, the locations are defined at the center of pit. Locations for many prospects are less exact. Using GIS tools, a 2 km buffer was drawn around each deposit and prospect to define closely spaced groups of deposits and prospects that are likely to represent parts of a single deposit or prospect. In the example shown in figure 17, the Skouries Group covers an area of 29 km^2 and includes the Skouries deposit as well as the Katsoures and Tsikara prospects; the 28 km^2 Fisoka Group includes Fisoka and 5 other prospects. Kockel and others (1975) reported the size of a strong alteration halo associated with the prospects included in the Fisoka Group as 9.3 km^2 and the size of the alteration halo associated with the Tsikara prospect (Skouries Group) as 15.2 km^2. In cases where deposits are grouped, the total tonnage and weighted average commodity grades are reported for the group (table 1).

Berger and others (2008) compiled data on extent of altered rock associated with 69 known, globally-distributed porphyry copper deposits as reported in Singer and others (2008). Altered areas in their compilation ranged from <1 to 82 km^2, with a mean of 12 km^2. Therefore, the grouped areas represent reasonable approximations of extents of altered areas associated with porphyry copper deposits. Prospects (open squares on fig. 17) within a group that contains a known deposit (filled squares on fig. 17) may represent extensions of identified resources, whereas groups of closely spaced prospects away from known deposits may represent manifestations of undiscovered greenfields deposits. The distance between the 2 km buffers around Skouries and Fisoka is about 2.5 km. We did not combine these two closely spaced groups because aeromagnetic data for the area suggests that the Skouries-Tsikara and the Fisoka areas are not connected in the shallow subsurface (European Goldfields, 2011). In other cases, where we do not have such data, closely spaced groups may be combined, such as the Rovina Valley Group in Romania (fig. 1*B*), which includes the Rovina, Colnic, and Valea Morii deposits as well as the Cainel Ciresata, and Valea Arsuli prospects. Groups are listed in tables and plotted on maps throughout this report. Individual site records are included in the GIS (appendix H).

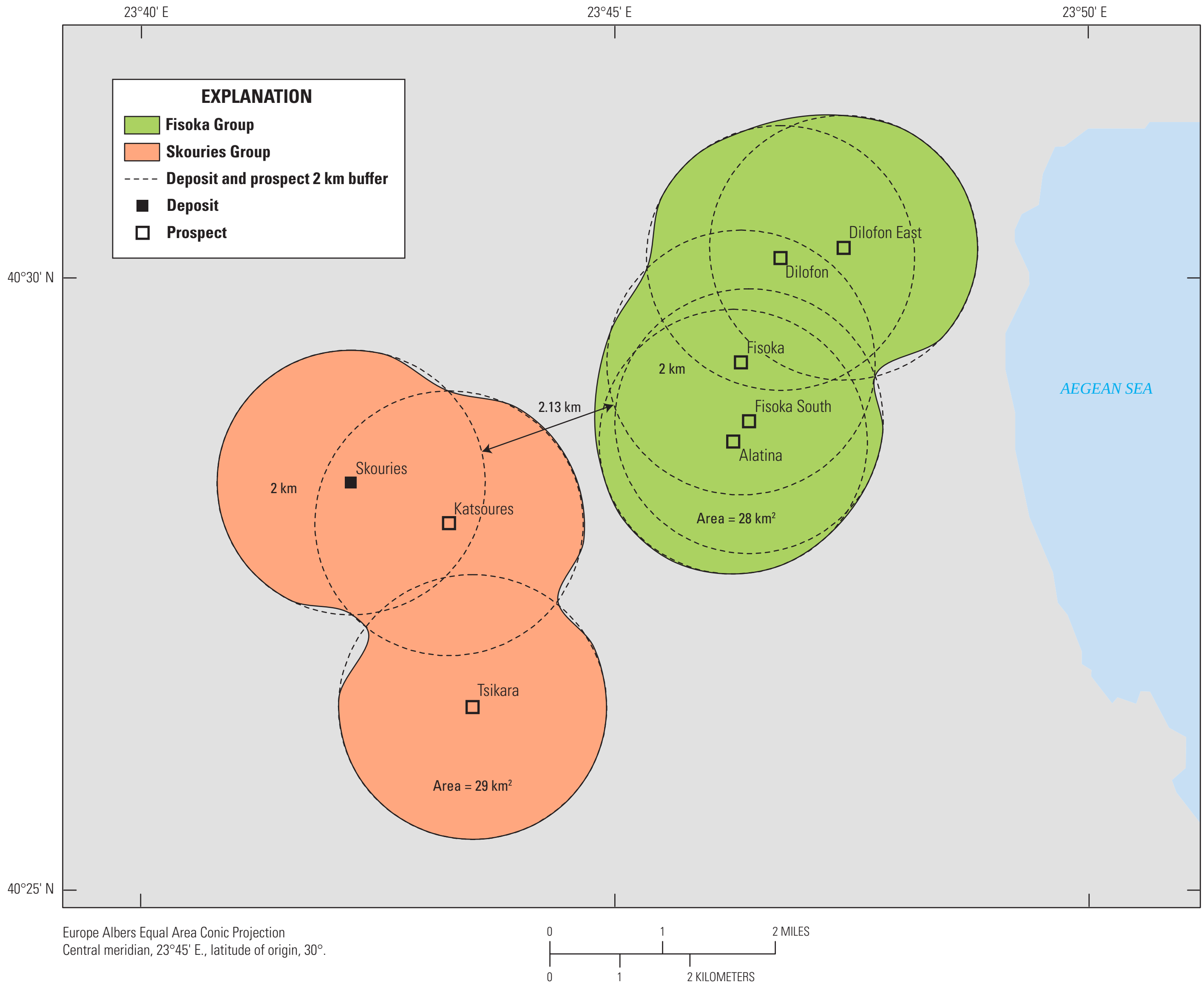


Figure 17. Example of spatial rule for grouping porphyry copper deposits and prospects.

Based on these rules, there are 28 post-Paleozoic Phanerozoic porphyry copper deposits having published grade and tonnage figures in Europe (table 1). The three Paleozoic (Variscan and Caledonian) deposits that have been classified as porphyry copper deposits have reported tonnages and grades (table 1), but may reflect other, or hybrid deposit types: (1) the Lower Ordovician Coed y Brenin deposit in Wales, (2) the Variscan Myszków prospect in Poland, and (3) the Caledonian Herzogenhugel deposit in Belgium. Numerous prospects, where grade, tonnage, or other missing data preclude classification as a deposit, provide evidence of processes associated with porphyry copper mineralization that was considered in the assessment of undiscovered resources. Information and references for porphyry copper deposits and significant prospects are discussed in detail in the appendixes, and included as attributes for deposit and prospect point locations in the GIS.

Related Deposit Types

Base- and precious-metal skarns, replacement-, and epithermal deposits typically form in magmatic-hydrothermal systems that include porphyry copper deposits (Sillitoe, 2010); however, they may also be unrelated to porphyry systems. Low-sulfidation epithermal deposits commonly are associated with postcollisional magmas whereas high-sulfidation epithermal deposits are common in subduction-related arc settings (Richards, 2009). Distributions of copper and gold prospects and occurrences were considered in the assessment, particularly if the occurrence could be linked to a possible porphyry-related deposit type. Skarn occurrences typically indicate the presence of an igneous intrusion, so the distribution of skarns may locate permissive rocks that do not appear on available geologic maps. Placer gold deposits may reflect gold-rich porphyry systems in an area if other deposit types, such as orogenic gold, can be ruled out.

Mining and Exploration Status

Mining has played a major role in shaping the Europe's history (Lynch, 2004). Many of the porphyry copper deposits discussed in this report, especially those in southern Europe, were mined millennia ago by the Romans, who developed large-scale mining methods, such as using aqueducts to bring large volumes of water to mine sites. Each region of Europe has a distinct mining and exploration history. Present-day attitudes and policies towards mining vary widely. Because of the long history of mining and industrial processing on the continent, environmental concerns and reclamation are significant issues.

Recent global trends in copper and gold exploration, and percentages of exploration in Europe by commodity, are illustrated in figure 18, based on Wilburn (2011). Gold exploration in Europe (fig. 18*A*) started increasing in 2001 relative to the previous few years; copper exploration (fig. 18*B*) increased during the 1999–2002 period, and then decreased as the exploration focus in Europe shifted to gold (fig. 18*C*).

The Frasier Institute conducts an annual survey of mining industry executives and exploration managers on the attractiveness of various global jurisdictions for exploration investment. The survey results are analyzed to develop a composite policy potential index.[19] Only a few European countries are included in the 2010–2011 Fraser Institute survey of mining companies in 79 jurisdictions around the world (McMahon and Cervantes, 2011). The latest rankings for the European countries considered in this porphyry copper assessment range from 32nd out of 79 for Bulgaria to 58th out of 79 for Turkey. Although subjective, and independent of deposit types, these rankings indicate that globally, the listed European countries that host porphyry copper deposits rank in the middle of the range.

The exploration histories, present-day attitudes, and policies towards mining for countries that host porphyry copper deposits are briefly described below, in alphabetical order by country.

[19]Country (PPI), where PPI = policy potential index rated from 1 (least) to 100 (most) favorable for exploration investment. Bulgaria (56), Finland (86), Ireland (73), Norway (67), Romania (38), Spain (53), Sweden (82), Turkey (35). PPI values for the 79 countries included are ranked; for example, Bulgaria with a PPI of 56 ranked 32 out of 79.

Bulgaria

Copper was produced at Medet, Assarel, Prohorovo, Tsar Assen, and Vlaykov Vruh (fig. 1*C*). The Assarel deposit was discovered in 1967 and mined by open pit from 1976 until 2000. The mine produced 100 Mt at 0.53 percent copper; resources remaining are estimated at 254 Mt averaging 0.43 percent copper.

France

No porphyry copper deposits are known in France; however, prospects are known in Variscan rocks, such as the Sibert prospect in the Massif Central (fig. 1) described by Icart and others (1980) and Beaufort and Meunier (1983). The Massif Central has never been the focus of porphyry copper exploration; the focus fas been directed mainly towards discovery of tin and tungsten deposits. Major known copper prospects have been evaluated for their potential as massive sulfide deposits by drilling. Most of the exposed permissive host rocks for porphyry copper deposits have been prospected at the surface, and most exposed copper occurrences have been located and field checked, mainly in 1980 by Société Nationale Elf Aquitaine Production (SNEAP). With the exception of medieval workings, major copper prospects have not been subjected to repeated exploration and evaluation. Although geochemical and geophysical exploration has been done over most of the permissive rocks in the massif, copper was not always part of the geochemical surveys and the geophysical surveys tended to be site-specific efforts at target identification for deposit types other than porphyry copper. Airborne geophysical and soil geochemical surveys followed by reconnaissance field checking were conducted as part of exploration activities in 1980. Subsurface exploration has not been conducted for unexposed deposits or their plutonic host rocks beneath areas of post-mineralization-age cover rocks or at depth in older pre-mineralization-age country rocks.

In 1995, the French government passed a law expediting the granting of surveying and mining licenses to encourage exploration (Newman, 1996). Since about 1999, however, France has declined as a domestic mineral producer (Perez, 2011).

Hungary

Hungary, best known for its bauxite resources, also hosts the Recsk porphyry copper deposit (fig. 1*A*). Recsk, in the Mátra Mountains of northern Hungary, was explored (1,200 drill holes) in the 1970s (Tóth and Bobok, 2007). As preparation for mining was being completed, the price of copper collapsed, Recsk was abandoned, and the workings were flooded (Tóth and Bobok, 2007). Recent geothermal surveys have determined that the Recsk area has substantial geothermal potential (Tóth and Bobok, 2007).

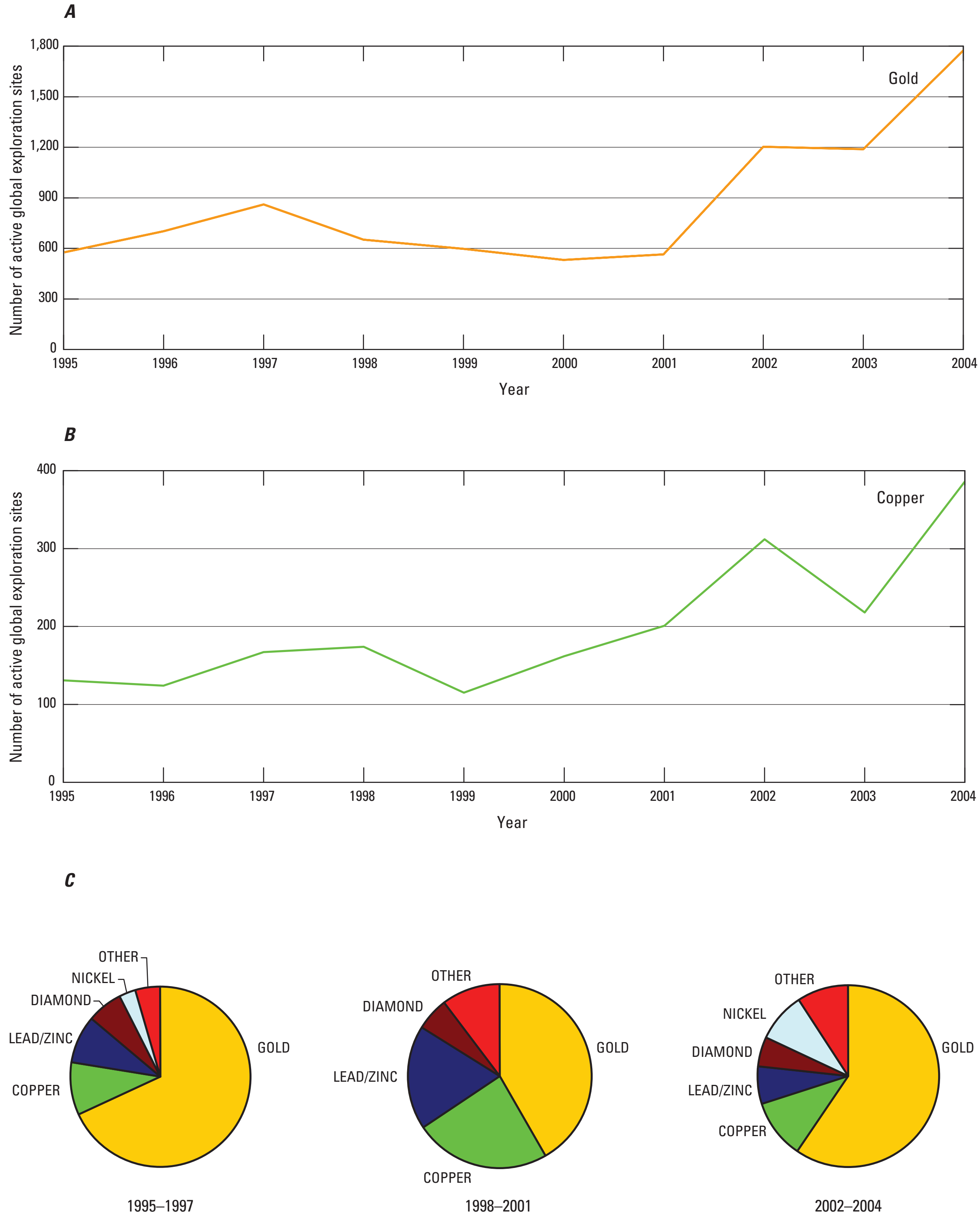


Figure 18. Charts of mineral exploration trends, 1995–2004. Global exploration trends for (*A*) gold and (*B*) copper. *C*, European nonfuel mineral commodity exploration targets by 3-year period based on numbers of active exploration projects by commodity for each year. Modified from Wilburn (2011).

Macedonia

Historical mining in Macedonia produced copper, nickel, chromium, lead, zinc, silver, and gold back to the time of the Romans (Hoodless Brennan, 2006). Recently, the Macedonian government has encouraged foreign investment in mining and a new mining law was passed in 1999 (Hoodless Brennan, 2006). Under the improved regulatory environment, previous state operations are being privatized and new projects are being tendered.

The Bucim porphyry copper-gold deposit in the Bucim Group (fig. 1*C*), the country's sole copper producer, was discovered in 1955 and production began in 1979 (Serafimovski and others, 1996). Recent rising copper prices have prompted interest in expanding reserves at Bucim (MINA,[20] 2011). For the period 2006–2010, Bucim produced about 4 Mt of copper ore each year (Brininstool, 2011a).

In 2010–2011, drilling continued at Ilovitza (fig. 1*C*), which had inferred resources of 790,000 metric tons of contained copper (Euromax Resources Limited, 2011) as of 2008. The latest drilling demonstrated that the deposit remains open to the east; an updated NI43-101 report was planned for 2012. Euromax Resources Ltd. formally applied for an exploitation permit in 2011 .

In 2006, Sirius Exploration explored prospects at Kadiica and Osogovo (fig. 1*C*). At that time, the Osogovo porphyry copper prospect was deemed too low grade to be economic and Kadiica was thought to be too small (Hoodless Brennan, 2006).

Poland

Porphyry copper-like deposits in the Variscan of Poland were first encountered through deep drilling in the 1950s (Haranczyk, 1979, 1980). They were first referred to as porphyry copper deposits by Gorecka (1973). Myszków (fig. 1*A*), the best known prospect, is an advanced exploration project (Strezelcki Metals Ltd., 2011).

Romania

Mine workings dating from Roman and Ottoman times are known in Romania. In the Banat area (fig. 9) of west Romania, gold, silver, and copper were first mined with rudimentary technology; in the 18th century, when the Banat area became part of the Austrian Empire, a mining industry developed. Mines associated with the Oravita and Sasca porphyry copper systems are mentioned in mineralogy research papers of the late 1700s (Nicolescu, 1998). See figure 1*B* for locations of deposits and prospects mentioned.

In the 1960s and 1970s, local geological, geochemical, and geophysical research programs resulted in discovery of the Rosa Poieni deposit in the South Apuseni Mountains (Milu and others, 2004). More recently, the Government of Romania developed policies aimed at reforming the industrial sector to raise competitiveness in preparation for privatization (Steblez, 2004). The Government planned to eliminate subsidies for lignite and metals mining by 2007, close unprofitable mines, and privatize mines that had the potential to operate economically (Brininstool, 2011b). In January 2007, Romania joined the EU, and many facilities have been closed to modernize to meet EU standards (Brininstool, 2011b). In 2006, exploration by Carpathian Gold, Inc., defined the Colnic porphyry deposit and discovered a significant gold component to the known copper mineralization at the Rovina porphyry (Marketwire, 2010). In 2008, more than 71 km of diamond drilling led to Carpathian Gold, Inc.'s discovery of the Ciresata concealed porphyry gold-copper deposit near the Rovina and Colnic deposits in the Apuseni Mountains of west-central Romania (Benzinga Staff, 2010). In 2010, Carpathian Gold, Inc., reinitiated diamond drilling at Ciresata (Marketwire, 2010). Rovina, Colnic, and Ciresata were all under exploration in 2011 as part of Carpathian Gold, Inc.'s Rovina Valley project (Carpathian Gold, 2011). The three closely-spaced sites are plotted as the Rovina Valley Group (fig. 1*B*).

In 2009, Romania produced 27,000 metric tons of copper ore (concentrate) from 9 mines, including the Rosia Poieni and Moldova Nouă porphyry deposits (Brininstool, 2011b).

Serbia

Exploitation of porphyry copper deposits in Serbia began in ancient times, as evidenced by discovery of 2000-year old workings at Majdanpek (Starostin, 1970) and more than 130 pits and shafts in the Rudnitsa prospect area (Carter, 2008). Deposits and prospects in Serbia are shown on figures 1*B* and 1*C*.

Bor was discovered in the late 1800s and worked by the French starting in the early 1900s (Starostin, 1970). By 1914, Bor had produced 10 Mt of ore averaging 6 percent copper along with significant amounts of precious metals (Starostin, 1970). In 1961, Majdanpek underwent a revival following an analysis of the primary ores and construction of a modern mining and beneficiating facility (Starostin, 1970).

Valja Strz is one of five separate porphyry centers in the 8 by 6 km^2 Coka Kuruga concession area explored by Dundee Precious Metals (2008) and currently is held by Avala Resources (2011). Valja Strz was drilled and trenched in 2008; it is included in the Dumitru Potak Group. In 2011, Serbia was being explored primarily for precious metals. Targets include porphyry copper deposits along with skarn and epithermal deposits. Avala Resources drilled prospects associated with the Timok Magmatic Complex, including the Kuruga deep porphyry targets (650 m or deeper?) below a 5 km^2 lithocap associated with high-sulfidation epithermal gold (Avala Resources, 2011).

[20]Macedonian International News Agency.

Slovakia

The Central Slovakian Volcanic Field has produced gold and copper for centuries from porphyry-, skarn-, and epithermal systems associated with eroded stratovolcanoes, such as at Banská Štiavnica and Kremnica (fig. 1*A*) in central Slovakia (Jeleň and others, 2003). Most of the historical gold and silver production in the Slovak Republic came from epithermal veins in these two mining districts. The main copper deposits, no longer in production, are associated with Banská Štiavnica, the largest stratovolcano in the volcanic field. Recently, EMED Mining (2010) drilled the Zlatno and Sementlov prospects at Banská Štiavnica as porphyry gold targets, which were subsequently rejected for further exploration based on negative results (intercepts for 6 holes ranged from 0.01–0.16 g/t gold; 0.013–0.05 percent copper).

The Javorie stratovolcano region was initially explored for sulfur in the 18th century. Drilling into a diorite porphyry in the 1970s identified an altered stock with weak porphyry alteration and prompted detailed mapping and topical studies in the central part of the volcano, which identified high-temperature porphyry-type mineralization with copper, molybdenum, lead, and zinc and a lower-temperature second phase of mineralization characterized by enargite, pyrite, and sphalerite (Hanes and others, 2010 and references therein). The 1999 discovery of gold in altered (advanced argillic) rocks in a silica quarry associated with explosive breccias led to the recognition of high-sulfidation epithermal systems and an exploration focus on epithermal-porphyry gold targets that continues to the present (Štohl and others, 1999; Hanes and others, 2010).

Discovery of the Biely Vrch gold deposit (fig. 1*A*) in 2006, a vertical, pipe-like body of quartz-pyrite stockwork veins in an andesitic (diorite) intrusion within a caldera-graben complex of the middle Miocene Javorie stratovolcano, and subsequent exploration led to a scoping study for development of an open pit gold mine. Indicated resources are 17.7 Mt averaging 0.81 g/t gold and inferred sources of 24.0 Mt averaging 0.77 g/t gold; copper averages 0.01 percent in the deposit (Fletcher and Bennett, 2010). The Biely Vrych deposit may be associated with a porphyry copper-gold system at depth (Fletcher and Bennett, 2010; Korděra and others, 2010).

United Kingdom

Exploration for a variety of commodities occurred in Britain from 1965 to 2000, as summarized by the British Geological Survey (BGS) (Colman and Cooper, 2000). The 1973–1997 Mineral Reconnaissance Programme of the BGS included studies on the geology, geochemistry, and geophysics of a number of porphyry copper prospect areas (Haslam and Kimball, 1981; Brown and others, 1979; Ellis and others, 1977; Beer and Kimble, 1989).

A major exploration program conducted from 1965 to 1973 by Rio Tinto Finance and Exploration Ltd. (RioFinEx) led to the discovery of the Coed y Brenin porphyry copper deposit in Wales. The Coed y Brenin discovery prompted exploration for porphyry copper deposits in the Scottish Caledonides that led to the 1971 discovery of porphyry style prospects in the Kilmelford region of western Scotland at Lagalochen. Ellis and others (1977) report the results of a geochemical-drainage survey that delineated strong copper and molybdenum anomalies associated with the porphyritic part of the 430 Ma Lagalochan (Kilmelford) calc-alkaline subvolcanic complex. Drilling by the British Geological Survey in 1976 showed the prospect to be very low-grade (<0.1 percent copper) and of limited extent. An adjacent area was explored by BP Minerals in the 1980s for gold in highly altered and brecciated zones associated with a shear zone. The prospect, presently inactive, is interpreted as a vented diatreme complex with early copper-molybdenum-gold veinlets in a core zone of breccia and diorite-granodiorite intrusions followed by polymetallic shear zone mineralization and lead-zinc-silver carbonate veins (British Geological Survey, 1999). The site was inactive as of 2000 (Colman and Cooper, 2000). Regional stream-sediment surveys were done throughout the Scottish Caledonides by industry in the 1970s; some further exploration was conducted but no discoveries were reported. A number of hydrothermally altered high-level Caledonian intrusive complexes contain low-grade, disseminated porphyry-style copper mineralization. These include a diorite at Tomnadashan, the ~410 Ma Ballachulish igneous complex, and the Black Stockarton Moor and Foreburn igneous complexes in southern Scotland (fig. 1).

No recent porphyry-related exploration activity has occurred, although exploration has continued and discoveries have been made since 1965 for other deposit types including mesothermal gold deposits, SEDEX barite, and tungsten-tin related to Variscan granites (Colman and Cooper, 2000). Based on previous discoveries and mineral deposit models, the BGS identified a variety of types of potentially economic mineral deposit types that could be discovered in Britain; porphyry copper deposits are not included (British Geological Survey, 2011).

Northwestern Turkey

European Turkey, known as Thrace (fig. 1), has long been known as a copper province. In the 1970s, the Turkish Geological Survey undertook a massive stream-sampling program that delineated several new metal-rich zones. In the 1980s, a joint undertaking between Turkish and Japanese agencies drilled 25 holes totaling about 8,800 m and confirmed the presence of the low grade Derekoy (fig. 1*C*) porphyry copper deposit (Ohta and others, 1988). Also in the 1980s, a local company identified several prospects with high potential, including the small Ikiztepeler porphyry/skarn Cu-Mo deposit (fig. 1*C*), which had been the site of extensive historical copper mining. Exploration continues in Turkey, in part due to the success of the Kisladag porphyry gold deposit and the search for similar deposits.

Summary

Relative to undeveloped areas of the world, Europe is relatively well-explored for copper. The countries are mapped at detailed scales, mineral-occurrence databases are available, and many areas have been covered by geochemical surveys and site-specific geological investigations. Nevertheless, recent applications of geophysical exploration tools are identifying new targets for drilling and may reveal new deposits under cover. High-sulfidation epithermal systems have not been explored at depth to look for underlying porphyry systems.

Based on thorough exploration in the United Kingdom and Massif Central, porphyry copper deposits are unlikely to be an exploration focus in the future. Most of the Caledonian and Variscan igneous rocks in Europe are unlikely future exploration targets for porphyry copper deposits because the older rocks are too dissected, too metamorphosed, too eroded, or of the wrong composition.

The known porphyry-mineralized belts associated with the Alpine orogeny are more likely to continue to be of interest for porphyry copper exploration. Much of Europe may be off limits to exploration due to population density, urban development, private landholdings, environmental protection, and social opposition to mineral development.

The Assessment Process

The assessment was done using a three-part form of mineral resource assessment based on mineral deposit models (Singer 1993, 2007a, b; Singer and Menzie, 2010; Drew and others, 1999b). In applying the three-part form of mineral resource assessment, geographic areas (permissive tracts) are delineated using available data on geologic, geochemical, and geophysical features typically associated with the type of deposit under consideration, as reported in descriptive mineral deposit models. Grade and tonnage models describe the size and quality (commodity grades) of thoroughly explored deposits that fit the characteristics of the descriptive mineral deposit models. The amount of metal contained in undiscovered deposits is estimated by using grade and tonnage models combined with probabilistic estimates of numbers of undiscovered deposits, based on the assumption that the undiscovered deposits will be similar to the deposits described in the model selected. Statistical tests are performed using data from the known deposits in a study area to ensure the appropriate grade and tonnage models are used (Singer, 2007a). In cases where existing global models are inappropriate, new models may be developed. 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 tract; these estimates represent a measure of the favorability of the tract and uncertainty about what may exist (Singer, 2007a).

Details of the three-part (mineral deposit models, permissive tracts, estimates of numbers of undiscovered deposits) form of mineral resources assessment are discussed by Singer and Menzie (2010). Root and others (1992) explained the use of Monte Carlo methods to combine estimates of numbers of undiscovered deposit from three-part assessments with grade and tonnage models to produce a probabilistic estimate of undiscovered resources. The probabilistic assessment for Europe focused on parts of the study area where the team considered undiscovered deposits likely to be present with the tops of porphyry systems within 1 km of the surface.

The assessment data and results for each permissive tract are presented in a standardized format in appendixes A through G. Permissive tract boundaries and point locations of significant deposits and prospects are included in a geographic information system (GIS) that accompanies this report (appendix H). The GIS attribute table for porphyry copper deposits and significant prospects includes locations, descriptive information, permissive tract designations, and references. Appendix I provides a brief biography of assessment team members. Selected attributes and references for each deposit and prospect are included in the tables in the appendixes. The political boundaries used are the small-scale international boundary files (SSIB) maintained by the U.S. Department of State (2009).

The Bureau de Recherches Géologiques et Minières (BRGM) hosted an initial workshop focused on western Europe in 2006 in Orléans, France that included geologists from the USGS, BRGM, Charles University, and the Geological Institute of Romania. The final assessment, completed at a USGS workshop in July 2010 included USGS participants and Dr. Duncan Large, an independent consultant in economic geology with expertise in Europe. USGS team members compiled existing data, evaluated deposit models, and prepared preliminary permissive tracts prior to assessment meetings where the probabilistic assessment was completed. Assessment results subsequently were evaluated by an internal USGS assessment review committee and modified prior to preparation of the final report. Team expertise included regional geology, porphyry copper deposits, mineral deposits and mineral exploration of Europe, and mineral-assessment methodology (see appendix I for brief biographies of participants).

Permissive Tracts

Tract Delineation

A geology-based strategy was used to delineate the permissive tracts in this assessment. The appendixes contain detailed descriptions for individual tracts. Digital geologic data were processed in a geographic information system (GIS) using ESRI ArcGIS software. The strategy includes the following steps:

1. Regional-scale geologic maps were examined and geologic literature was reviewed to identify fundamental units for tract delineation, which were defined as magmatic arcs, arc segments, or belts of igneous rocks, of a given age range.

2. Digital geologic maps at scales ranging from 1:200,000 to 1:1,000,000 were used to select map units to define preliminary permissive tracts for porphyry copper deposits. Digital geologic maps of Europe, Turkey, the United Kingdom, and Africa were used, and selected additional areas were digitized from large-scale maps to provide an enhanced digital database of igneous rocks of Europe. Igneous map units were separated by age groups and classified as permissive or nonpermissive based on lithology. Permissive rocks include calc-alkaline and alkalic plutonic and volcanic rocks. Other igneous rocks, such as ultramafic rocks, highly evolved granites, peraluminous granites, and pillow basalts were excluded from tract delineation as they are unlikely to be associated with porphyry copper deposits. Age group ranges were evaluated and map units were assigned to permissive tracts.

3. GIS tools were used to apply buffers to the polygons that represent these permissive rocks. A 10-km buffer was 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 known porphyry copper deposits and significant associated prospects.

4. An aggregation and smoothing routine was applied to the resulting polygons. GIS processing details are documented in the metadata that accompanies the permissive tract shapefile.

5. After aggregation, available data on mineral deposits and occurrences were examined along with locations of dated igneous rock samples, and geophysical and geochemical information, to ensure that the tract included any other evidence of unmapped permissive rocks or hydrothermal systems. Georectified large-scale, page-size maps from the geologic literature provided information on location and age of permissive igneous rocks to supplement the digital geologic maps. Paleogene and younger intrusive igneous rocks were excluded from older tracts using GIS tools; this results in apparent holes in some tracts.

6. Volcanic rocks younger than the designated tract age, but inferred to be less than 1 kilometer thick, may be present as cover over permissive areas. Pyroclastic rocks distal to volcanoplutonic centers generally were excluded.

7. Extensional basins and horst and graben structures characterize much of central Europe. Sedimentary basins may contain buried porphyry systems; however, many of the basins in Europe, such as the Pannonian Basin, are known to contain great thicknesses (>7 km) of Neogene sedimentary and volcanic rocks, so these areas are excluded except where proximal to exposed permissive igneous rocks.

8. Aeromagnetic data from a global data set (National Geophysical Data Center, 2009) were processed by a reduction-to-pole technique and brought into GIS; this data set, at 2-arc-minute resolution, captures broad, relatively deep features in the central Europe region and did not correlate well with mapped exposures of permissive rocks to aid in tracing permissive areas under cover.

9. Resulting tract boundaries were clipped to shorelines to eliminate undersea areas using small-scale digital international land boundary polygon files from the U.S. Department of State (2009),[21] which incorporate high tide coastline data from the U.S. National Geospatial Intelligence Agency's World Vector Shoreline[22] dataset.

Permissive Tracts for Porphyry Copper Deposits in Europe

Seven permissive tracts for porphyry copper deposits were delineated within Europe, exclusive of the Fennoscandian Shield area of northern Europe (table 3). Four tracts that describe Late Cretaceous to Miocene igneous rocks related to the Alpine orogeny host 27 known porphyry copper deposits (fig. 19*A*). Sufficient data were available for the assessment team to make a probabilistic assessment of undiscovered porphyry copper deposits for these four tracts. Three other tracts were assessed qualitatively (fig. 19*B*). These include the Alpine-orogeny-related Late Eocene to early Miocene Western Peri-Mediterranean tract 150pCu6005 and two tracts that delineate permissive rocks associated with Paleozoic magmatism associated with the Late Devonian to Permian Variscan (Hercynian) orogeny and the Late Cambrian to Devonian Caledonian orogeny (table 3, tracts 150pCu6006 and 150pCu6007). The team concluded that evidence for porphyry copper systems in the Western Peri-Mediterranean that would be consistent with global models was lacking. Paleozoic permissive rocks are widely scattered across Europe, and

[21]The political boundaries used in this report are, in accordance 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.

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

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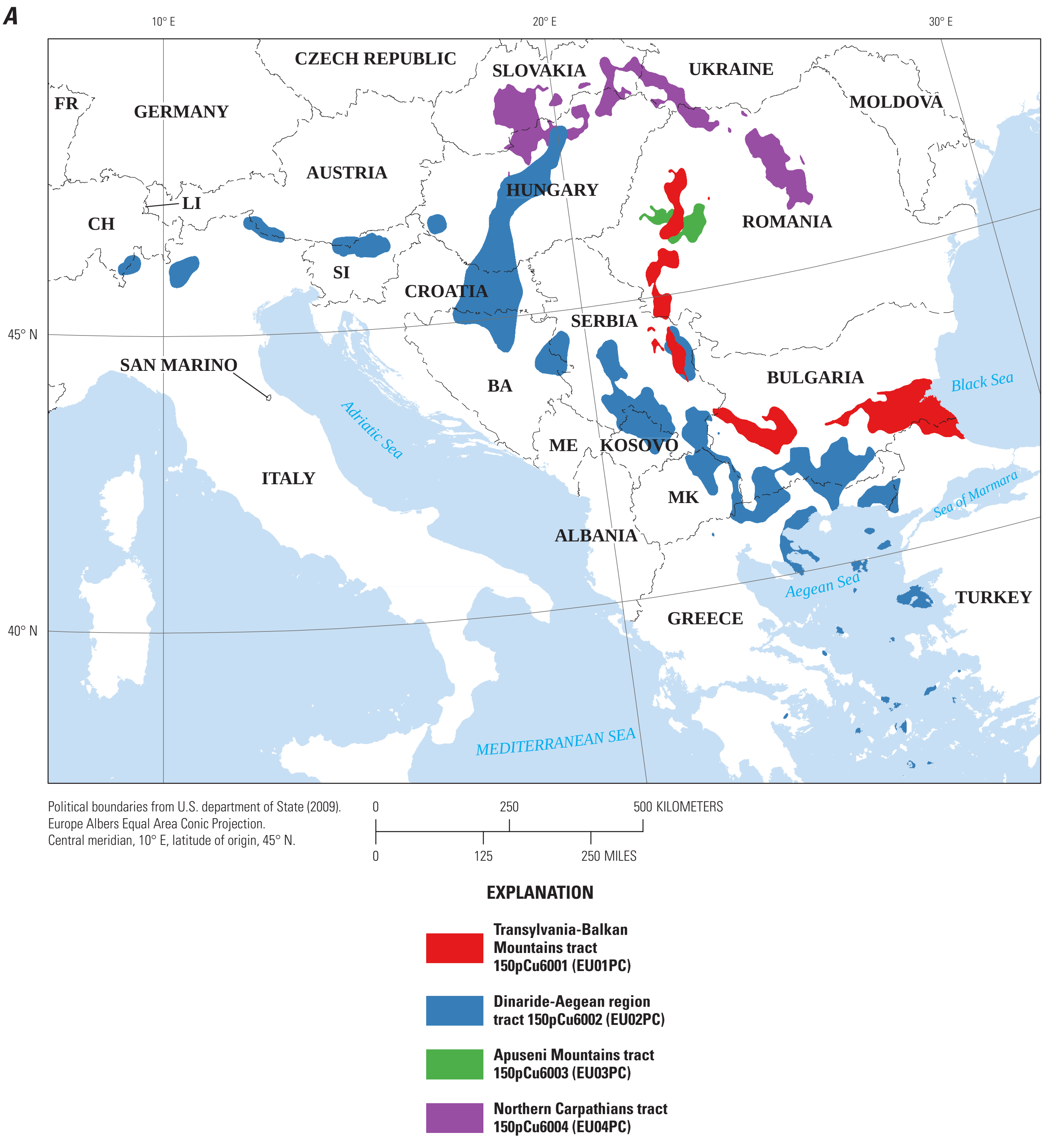
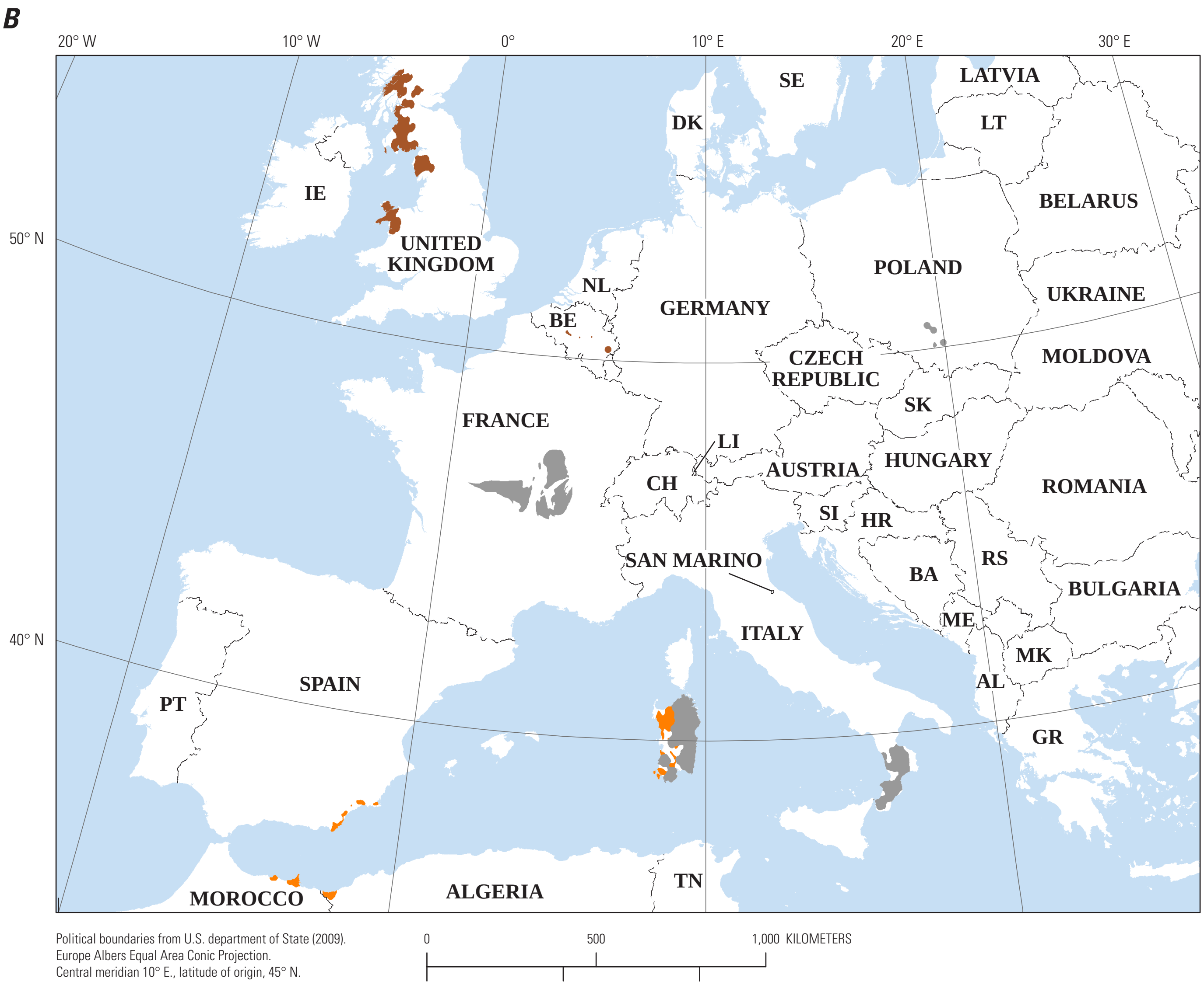


Figure 19. Permissive tracts for porphyry copper deposits in Europe. *A*, Tracts assessed quantitatively, 150pCu6001–150pCu6004. *B*, Tracts assessed qualitatively, 150pCu6005–150pCu6008. Country abbreviations (ISO 2-letter codes): AL, Albania; BA, Bosnia and Herzegovina; BE, Belgium; CH, Switzerland; DK, Denmark; FR, France; GR, Greece; HR, Croatia; IR, Ireland;LI, Liechtenstein; LT, Lithuania; LU, Luxembourg; ME, Montenegro; MK, Macedonia; NL, Netherlands; PT, Portugal; RS, Serbia; RU, Russia; SE, Sweden; SK, Slovakia; SI, Slovenia; TN, Tunisia; XK, Kosovo.



EXPLANATION

Western PeriMediterranean tract 150pCu6005 (EU05PC)

Variscan tract 150pCu6006 (EU06PC)

Caledonian tract 150pCu6007 (EU07PC)

Figure 19.—Continued

Table 3. Permissive tracts for porphyry copper deposits in Europe.

[km^2, square kilometers.]

Coded_ID	Tract name	Tract_ID	Countries	Age	Geologic Feature Assessed	Tract area (km^2)	Appendix
150pCu6001	Transylvania-Balkan Mountains	EU01PC	Southern Romania, Serbia, Bulgaria, and European Turkey	Late Cretaceous	Tethyan Eurasian Metallogenic Belt, including the Banatitic magmatic and metallogenic belt	28,500	A
150pCu6002	Dinaride-Aegean	EU02PC	Bosnia and Herzegovina, Serbia, Kosovo, Macedonia, Bulgaria, Greece, Turkey	Paleocene-Miocene	Late Eocene-Miocene Macedonian-Rhodope-North Aegean Magmatic Belt and its continuation in western Turkey	92,700	B
150pCu6003	Apuseni Mountains	EU03PC	Romania	Miocene	Miocene intrusive and volcanic intermediate and acidic rocks of the “Golden Quadrilateral” and surrounding areas in the Apuseni Mountains of southern Romania.	4,160	C
150pCu6004	Northern Carpathian	EU04PC	Romania, Ukraine, Hungary, and Slovakia	Miocene	Miocene felsitic plutonic and volcanic rocks in the Carpathian Mountains	28,850	D
150pCu6005	Western Peri-Mediterranean Region	EU05PC	Italy (Sardinia), Spain, northern Morocco	Late Eocene - early Miocene	Late Oligocene to Early Miocene volcanic arc	7,670	E
150pCu6006	Southern and Central European Variscan	EU06PC	France, Poland, Italy (Sardinia)	Late Devonian - Early Permian	Granitoids and volcanic rocks related to the Variscan orogeny	37,000	F
150pCu6007	Western Euopean Caledonian	EU07PC	United Kingdom, Belgium	Late Cambrian - Early Devonian	Granitoids and volcanic rocks related to the Caledonian orogeny	17,500	G

have been explored locally. Given the difficulties in identifying and tracing magmatic arcs and belts of this age due to post-emplacement tectonic disruption and the fact that known deposits and prospects have been explored and proved to be uneconomic, the assessment team declined to make a probabilistic assessment of undiscovered resources.

Late Cretaceous-Miocene Tracts

The Transylvania-Balkan Mountains tract, 150pCu6001 (EU01PC), with an area of about 29,000 km^2, is defined by the mapped extent of Late Cretaceous plutonic and volcanic rocks that form a curvilinear belt about 1,100 km long that stretches from western Romania through eastern Serbia, Bulgaria and western Turkey (fig. 19*A*). The tract covers the westernmost part of the Tethyan Eurasian Metallogenic Belt (fig. 7), as defined by Janković (1977), and includes the Banatite magmatic belt. The rocks that define the tract were emplaced about 90–60 Ma as a continental-margin volcanic arc formed as Tethyan oceanic crust (Vardar Plate) subducted northward beneath the Tisza, Dacia, and Rhodope blocks (fig. 10). Subsequent Tertiary deformation led to curved shape of the arc (Drew, 2006). The tract contains 15 porphyry copper deposits, including the deposits at Bor (14 Mt contained copper) and Majdanpek (6 Mt contained copper) in Serbia (fig. 1*B*, table 1). The tract contains 21 porphyry copper prospects, six of which have been partially explored by trenching or drilling and have indications of alteration and metallogeny consistent with porphyry copper models.

The Dinaride-Aegean tract, 150pCu6002 (EU02PC), outlines the late Eocene-early Miocene igneous rocks that form a Y-shaped magmatic field that extends from the Periadriatic area of the southern Alps and mid-Hungarian area in the north, through the Serbomacedonian-Aegean magmatic belt on the Balkan Peninsula and its continuation on the Greek Cyclades islands in the Aegean Sea, south to northwestern Turkey. The ~93,000 km^2 tract area hosts four porphyry copper-gold deposits, including the ~36 Ma Recsk deposit (fig. 1*A*) in Hungary (4.6 Mt contained copper) and the 19 Ma Skouries deposit (fig. 1*C*) in Greece (1.5 Mt contained copper). There are 20 variably explored prospects in the tract, including recently active exploration license areas in Macedonia, Serbia, Greece and Turkey.

The 4,200 km^2 Apuseni Mountains tract, 150pCu6003, is based on the distribution of Miocene intrusive and volcanic intermediate and felsic rocks of the "Golden Quadrilateral" area in the Apuseni Mountains in western Romania. The tract hosts seven 15–8 Ma porphyry copper-gold deposits, the largest of which is the 9 Ma Rosia Poieni deposit (fig. 1*B*) with 2.4 Mt contained copper. Three prospect areas were identified within the tract.

The ~29,000 km^2 Northern Carpathians tract, 150pCu6004 (EU04PC), includes middle Miocene calc-alkaline rocks of the Central Slovakian Volcanic Province in the Western and Eastern Carpathian Mountains of Hungary, Romania, Slovakia, and Ukraine, exclusive of the Apuseni Mountains. The Banska Ŝtiavnica Group (fig. 1*A*) of porphyry copper-gold deposits, which contain about 735,000 t of copper, are associated with the middle Miocene Ŝtiavnica stratovolcano complex which evolved in stages from about 16.2–10.5 Ma (Korděra and others, 2010). The tract includes eight prospects.

Permissive rocks that host scattered porphyry copper occurrences in Neogene rocks of southern Europe are included in the Western Peri-Mediterranean tract (fig. 19*B*), 150pCu6005 (EU05PC). The tract includes Neogene igneous rocks in western Sardinia that host the low-grade Calabona deposit (fig. 1) and scattered areas of permissive rocks along the Betic Cordillera of southern Spain and the Rif Mountains of northeastern Morocco.

Paleozoic Tracts

Extensive belts of igneous rocks associated with the Caledonian and Variscan orogenies in Europe include some rocks that are permissive for porphyry copper deposits and many that are not, such as S-type granitoids, A-type granitoids, or highly deformed and metamorphosed igneous rocks. These rocks exhibit a wide range of compositions and origins, and many of them are the result of continental collision tectonics. The ~17,000 km^2 Caledonian tract 150pCu6007 (EU07) is based on the distribution of Late Cambrian to Early Devonian granitoids and volcanic rocks in the United Kingdom and Belgium, which host the Coed y Brenin and Herzogenhugel porphyry copper deposits (fig. 1), respectively. The 37,000 km^2 Variscan tract 150pCu6006 (EU06PC) delineates Late Devonian to Early Permian plutonic and volcanic rocks that crop out in southern Poland, central France, and eastern Sardinia. The only Variscan porphyry copper deposit in Europe that is undergoing active exploration is the Myszków Mo-W-Cu deposit in Poland (fig. 1*A*). Permissive tracts for Caledonian and Variscan porphyry copper deposits are shown in figure 19*B*.

Map unit attributes for these older rocks typically indicate a broad range of possible ages and(or) report generalized or undifferentiated lithologies (for example, granitoid); compilations of geochronology and larger-scale geology for all of Europe were beyond the scope of this study. Owing to these uncertainties, the fact that Europe has been explored for centuries, and the complex tectonic history that included extensive deformation caused by younger orogenic events and segmentation of what may have been fragments of continuous magmatic arcs, no estimate of numbers of undiscovered porphyry copper deposits was made.

Selection of Grade and Tonnage Models

The global grade and tonnage models for porphyry copper deposits from Singer and others (2008) were evaluated for use in the simulation of undiscovered resources in Europe. Available models include a global porphyry copper-gold-molybdenum (Cu-Au-Mo) model based on 422 deposits, a copper-gold (Cu-Au) subtype model based on 115 deposits, and a copper-molybdenum (Cu-Mo) subtype model based on 51 deposits. Grades and tonnages of deposits within the tracts were tested against global models using statistical tests (*t*-test or analysis of variance (ANOVA)).

The tracts that were selected for probabilistic assessment contain 27 porphyry copper deposits. Tonnage and grade information are based on Singer and others (2008) and updates to that compilation (table 1). Data for deposits within 2 km of each other were grouped for evaluation of grade and tonnage models, in accordance with the spatial rules by Singer and others (2008) to construct models for porphyry copper deposits. Those 27 deposits range in size from the very small Tsar Assen (6.6 Mt) and Vlaykov Vruh (9.8 Mt) deposits in Bulgaria to the very large Bor Group (>2,000 Mt) and Majdanpek (1,000 Mt) deposits in Serbia (fig. 20*A*). Visual inspection of the copper grades for the European deposits (20*B*) shows that although some of the copper grades are distributed above and below the median for the model (0.44 percent copper), the European deposits are all lower in grade than the 90th percentile of the grade model (0.75 percent copper) and none of the deposits is as large as largest 6 percent of the deposits in the global tonnage model. Average copper grades for the European deposits in assessed tracts range from 0.19–0.70 percent copper (table 1); 20 of the 27 deposits have copper grades <0.44 percent. The apparent lower grades may be explained by the fact that many deposits are eroded and that supergene enrichment is virtually lacking.

For many deposits in Europe, only tonnage and copper are reported; molybdenum and silver are infrequently reported, and gold grades are sometimes missing, although the literature may describe the deposits as porphyry copper-gold types. Statistical test results (table 4) indicated that none of the tracts fails either the general Cu-Au-Mo model or the Cu-Au subtype model for tonnage or copper grade at the 1 percent screening level adopted for the assessment. The Transylvanian-Balkan Mountains tract 150pCu6001 (EU01PC) fails the *t*-tests based on both models for silver and fails for the Cu-Au subtype model for gold. Lack of data for silver and molybdenum preclude reliable statistical test results for the Dinaride-Aegean tract, 150pCu6002 (EU02PC) and for the Apuseni Mountains tract, 150pCu6003 (EU03PC).

The general model porphyry copper model was selected for the assessment of the Late Cretaceous Transylvania-Balkan Mountains tract 150pCu6001(EU01PC); the Cu-Au subtype model was selected for the three younger tracts (Periadriatic-Aegean, Apuseni Mountains, and Northern Carpathians). Taken as a group, the European deposits contain less copper than the global model (fig. 21). The lower contained copper contents reflect the overall lower average copper grades for the European deposits (table 1) compared to the grades in the global model. The team discussed the existing models, but concluded that a new model was not warranted because the tonnages and copper grades did not actually fail the tests adopted for the global assessment. However, future research should be conducted to evaluate characteristics of the Phanerozoic porphyry copper deposits in the complex tectonic setting that accompanied the closure of the Neotethys relative to deposits in other tectonic settings, such as the continental arcs of the Andes.

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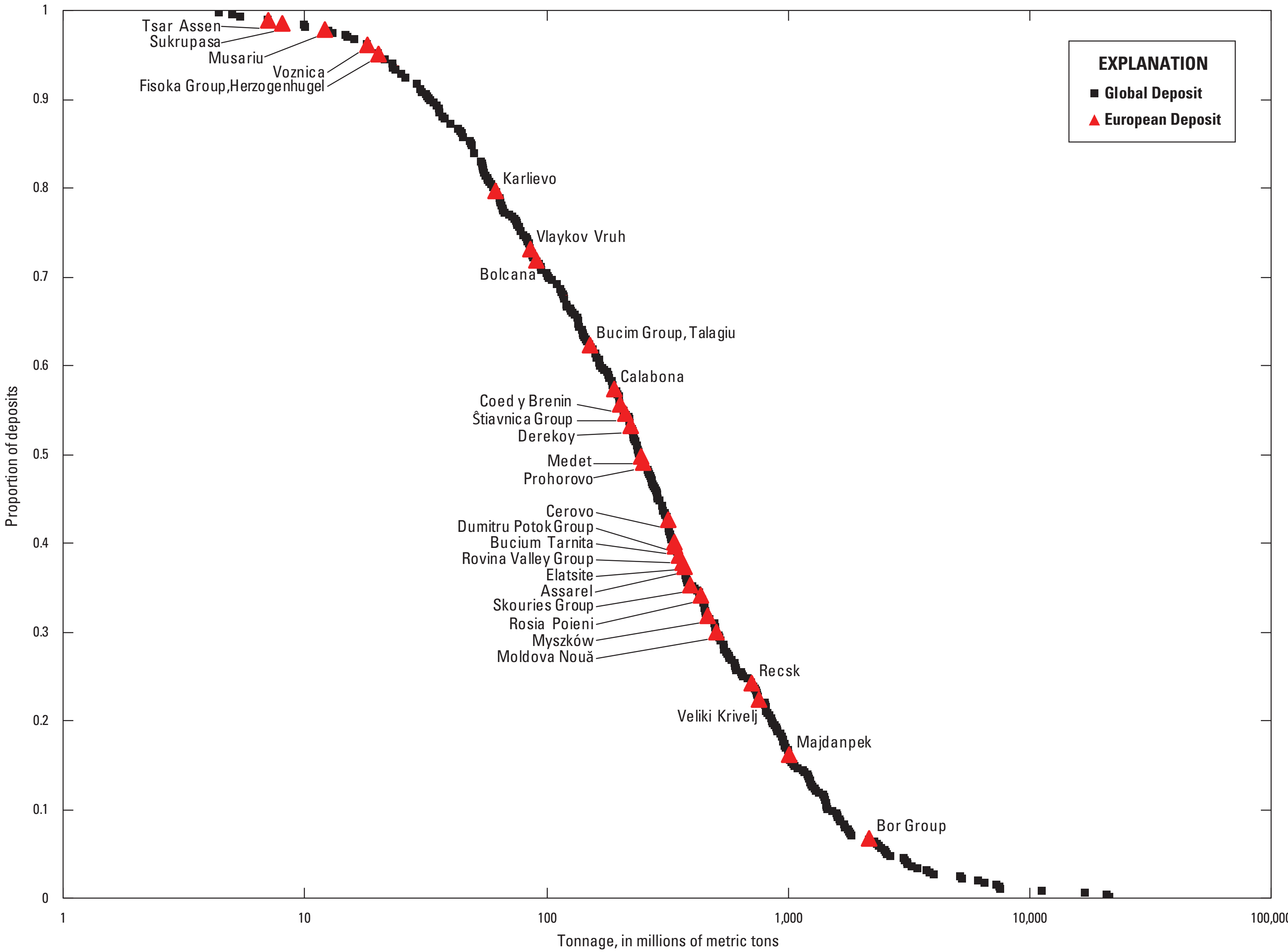


Figure 20. Tonnage and copper grades for porphyry copper deposits in Europe compared with the global porphyry copper data of Singer and others (2008). *A*, tonnage. *B*, copper grade.

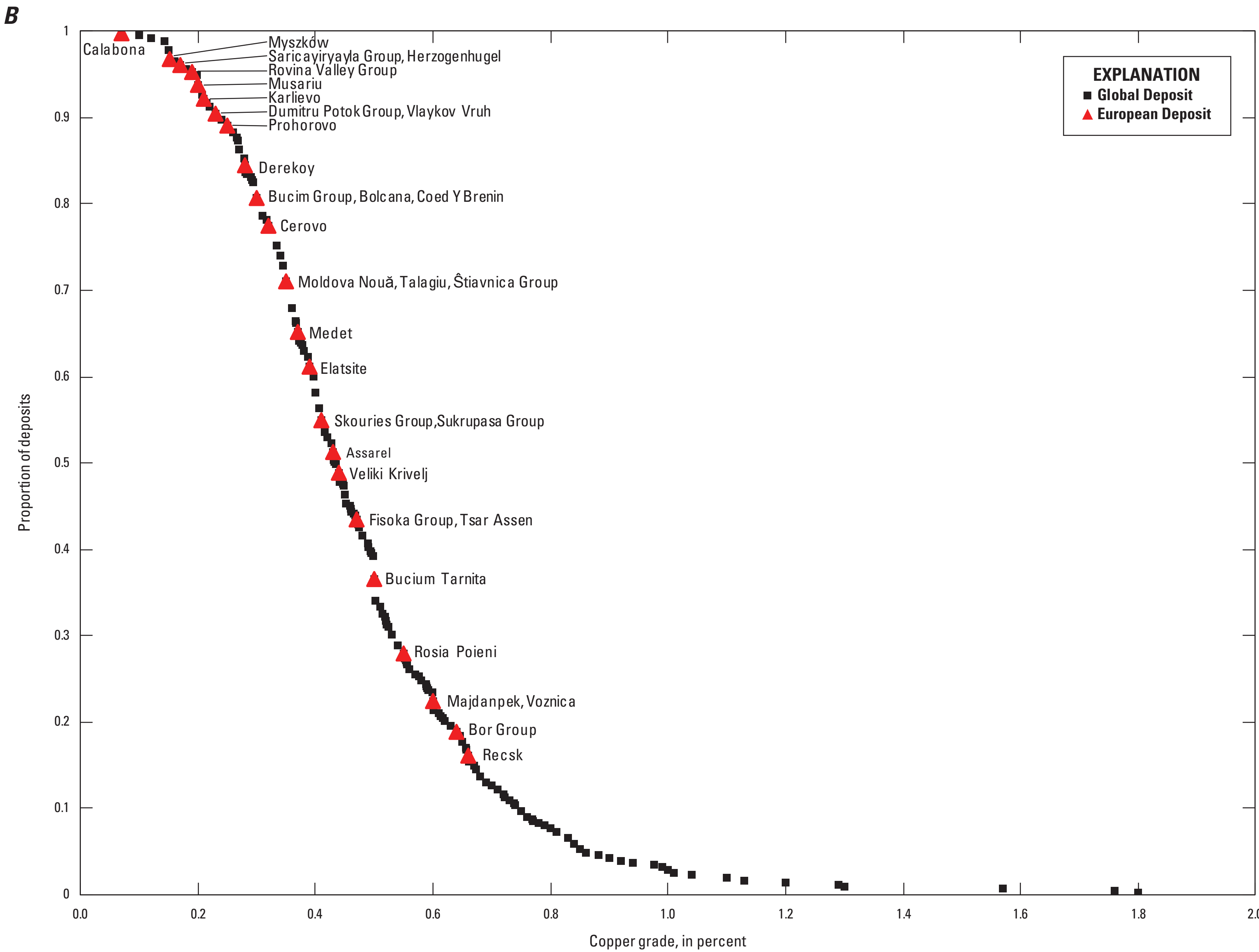


Figure 20.—Continued

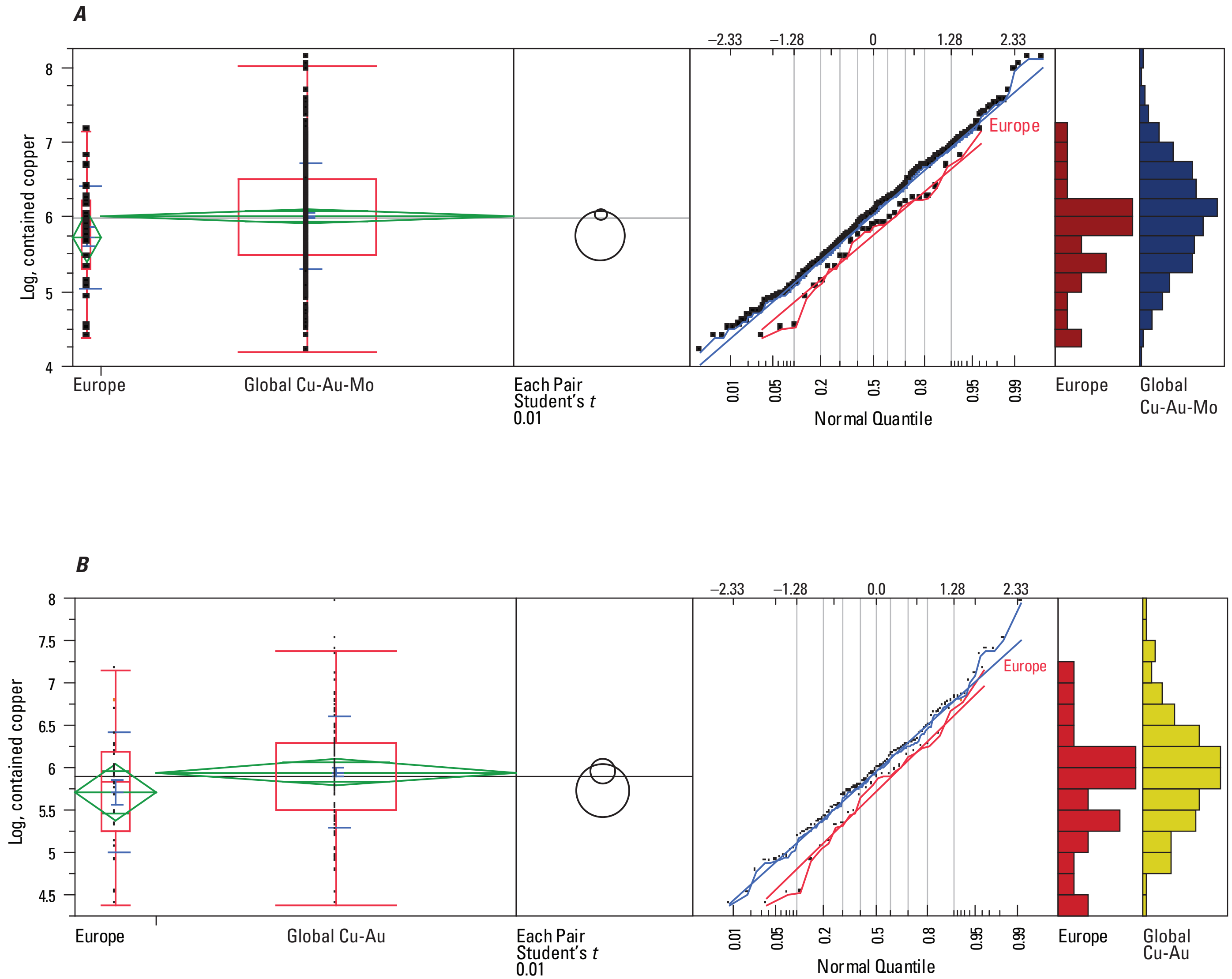
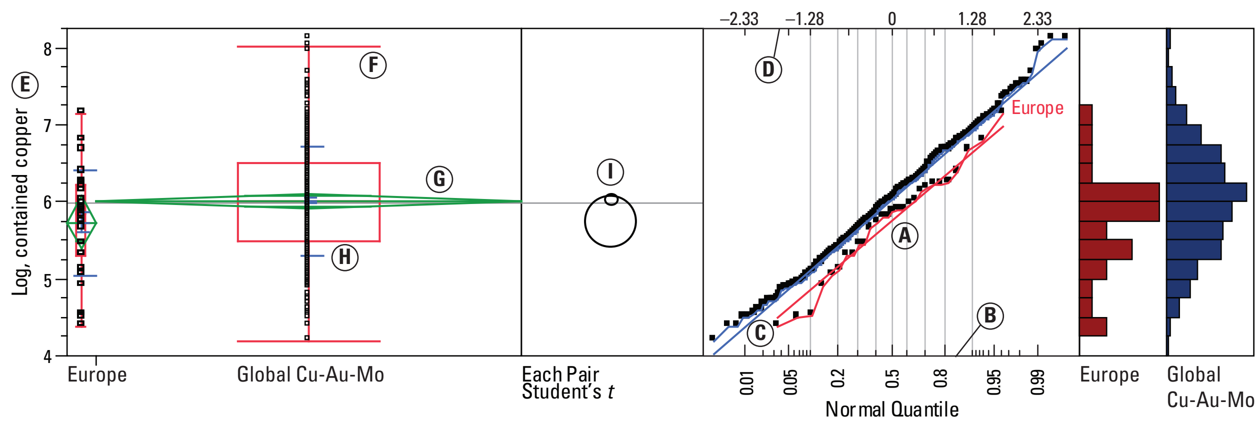


Figure 21. Statistics of contained copper distributions in European and global porphyry copper deposits. *A*, Box and whisker plot, *t*-test, probability plot, and histograms comparing contained copper in European porphyry copper deposits (n=27) with other porphyry Cu-Au-Mo deposits (Singer and others, 2008). *B*, Box and whisker plot, *t*-test, probability plot, and histograms comparing contained copper in European porphyry copper deposits (n=27) with other porphyry Cu-Au deposits (Singer and others, 2008). *C*, Explanation of the plots in *A*, *B*.

C



A. **Mean is intersection of line with normal quantile score = zero**

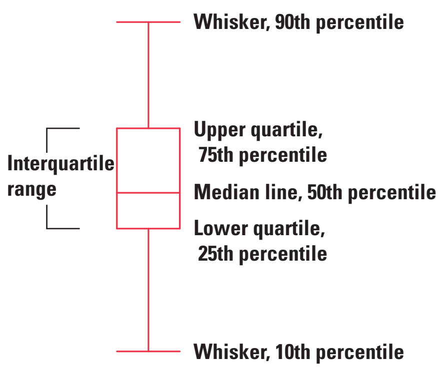
B. **Probability score**

C. **Slope is standard deviation**

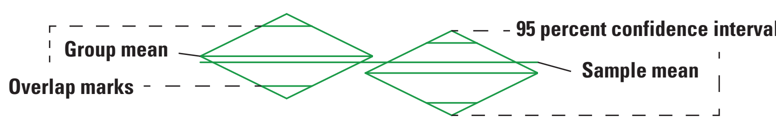
D. **Normal quantile score**

E. **Data values**

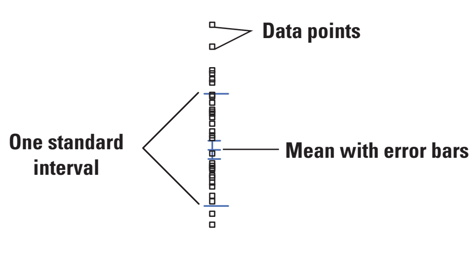
F. **Box plots are schematics that illustrate how data are distributed as measured by percentiles.**



G. **The means diamonds are a graphical illustration of the *t* test. If the overlap marks do not vertically separate the groups, the groups are probably not significantly different. The groups appear separated if there is vertical space between the top overlap mark of one diamond and the bottom overlap of the other.**



H. **Graph that illustrates how data are distributed using estimates of the measured standard deviation.**



I. **Comparison circles are a graphical technique that illustrate significant separation among means in terms of how circles intersect.**

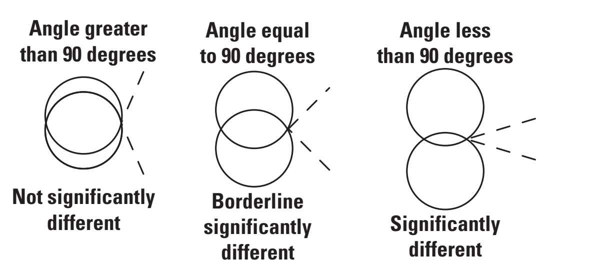


Figure 21.—Continued

Table 4. Statistical test results, porphyry copper assessment, Europe.

[Pooled *t*-test results assuming equal variances; p>0.01 indicates that the deposits in the tract are not significantly different from those in the model in terms of tonnage and commodity grades at the 1-percent level; p<0.01 indicates that the deposits in the tract are significantly different from those in the model at the 1-percent level and therefore, the tract fails the selected test (as indicated by the *) and the model is inappropriate for the assessment. See table 1 for data used in tests against models of Singer and others (2008). N_{known}, number of known deposits in the tract; n.d., no data. Cu, copper; Mo, molybdenum; Ag, silver; Au, gold]

Tract name	Coded_ID	Tract_ID	N_{known}	Global porphyry Cu-Au-Mo model					
				Tonnage	Cu	Mo	Ag	Au	Contained Cu
Transylvania-Balkan Mountains	150pCu6001	EU01PC	15	0.59	0.06	0.0003*	<0.001*	0.9	0.3
Dinaride-Aegean Region	150pCu6002	EU02PC	4	0.66	0.59	0.27	n.d.	0.21	0.8
Apuseni Mountains	150pCu6003	EU03PC	7	0.26	0.17	n.d.	n.d.	0.43	0.15
Northern Carpathians	150pCu6004	EU04PC	1	0.21	0.86	0.01	0.07	0.35	0.26

Table 4. Statistical test results, porphyry copper assessment, Europe.—Continued

[Pooled *t*-test results assuming equal variances; p>0.01 indicates that the deposits in the tract are not significantly different from those in the model in terms of tonnage and commodity grades at the 1-percent level; p<0.01 indicates that the deposits in the tract are significantly different from those in the model at the 1-percent level and therefore, the tract fails the selected test (as indicated by the *) and the model is inappropriate for the assessment. See table 1 for data used in tests against models of Singer and others (2008). N_{known}, number of known deposits in the tract; n.d., no data. Cu, copper; Mo, molybdenum; Ag, silver; Au, gold]

Tract name	Coded_ID	Tract_ID	Global porphyry Cu-Au subtype model						Model selected	Basis for selection
			Tonnage	Cu	Mo	Ag	Au	Contained Cu		
Transylvania-Balkan Mountains	150pCu6001	EU01PC	0.96	0.07	0.99	<0.001*	<0.001*	0.54	Cu-Au-Mo	Of the 15 deposits: 4 are classified as Cu-Au subtype; 9 report Au; 4 report Ag; 8 report Mo. General Cu-Au-Mo selected as a default; Cu-Au subtype model fails test on Au grade. Insuficient Ag data for test.
Dinaride-Aegean Region	150pCu6002	EU02PC	0.48	0.56	0.51	n.d.	0.68	0.64	Cu-Au	The 4 deposits can be classified as Cu-Au subtype based on average Au grade; Mo data reported for 2 of the 4 deposits.
Apuseni Mountains	150pCu6003	EU03PC	0.34	0.15	n.d.	n.d.	0.04	0.18	Cu-Au	Of the 6 deposits, 5 are classified as Cu-Au subtype based on average Au grades. No Mo data are reported.
Northern Carpathians	150pCu6004	EU04PC	0.24	0.89	0.17	0.1	0.92	0.29	Cu-Au	Both deposits fit the criteria for Cu-Au deposits based on average Au grades.

Estimates of Numbers of Undiscovered Deposits

The assessment team evaluated the available data and made individual, subjective estimates of the numbers of undiscovered porphyry copper deposits. Estimates are expressed in terms of different levels of certainty. Estimators were asked for the least number of deposits of a given type that they believe could be present at three specified levels of certainty (90-percent, 50-percent, and 10-percent). For example, on the basis of all the available data, a team member might estimate that there was a 90-percent chance (or better) of at least 1; a 50-percent chance of at least 3; and a 10-percent chance of at least 5 undiscovered porphyry copper deposits in a permissive tract. Individual estimators use different strategies to arrive at estimates. Some estimators start with their expected number of deposits in mind and look for a distribution that captures that mean and uncertainty. Others consider the tract area and analogies with distributions of deposits in other settings with which they are familiar. Another strategy is to consider the number of prospects and exploration history of the tract, and the likelihood of prospects becoming deposits, if fully explored.

The individual estimates were recorded and then discussed as a group, and estimators were asked to elaborate on their rationale for their numbers. After discussion, a single team estimate was agreed upon for each tract. The estimates are converted to a mean number of deposits and standard deviation based on an algorithm developed by Singer and Menzie (2005). The algorithm can be described by the following general equations to calculate an expected (mean) number of deposits (λ) and a standard deviation (s_x) based on estimates of numbers of undiscovered deposits predicted at different quantile levels[23] (N_{90} = 90 percent level, N_{50} = 50 percent level, etc.):

$$\lambda = 0.233\,N_{90} + 0.4\,N_{50} + 0.225\,N_{10} + 0.045\,N_{05} + 0.04\,N_{01} \quad (1)$$

$$s_x = 0.121 - 0.237\,N_{90} - 0.93\,N_{50} + 0.183\,N_{10} + 0.073\,N_{05} + 0.123\,N_{01} \quad (2)$$

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

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

The coefficient of variation is often reported as percent (%) relative variation:

$$\%C_v = 100 \text{ x } C_v \quad (4)$$

Team estimates reflect both the uncertainty in what may exist and the favorability of the tract (Singer, 1993). The estimates are combined with appropriate grade and tonnage models in a Monte Carlo simulation using the EMINERS computer program (Duval, 2012; Bawiec and Spanski, 2012). EMINERS is based on the original Mark3 computer program that was developed to provide a probabilistic estimate of amounts of resources that could be contained in undiscovered deposits (Root and others, 1992). No economic filters are applied, so results must be viewed with the realization that deposits, if discovered, might not be developed.

The rationales for individual tract estimates are discussed in the appendixes. In some cases, the number of significant porphyry copper prospects within a tract served as the primary basis for estimates at the 90th and 50th quantiles. Particular weight was given to prospects classified as porphyry copper-related in published literature and recent exploration reports. The location, number, deposit type, and relative importance of other prospects were also considered. Recent literature, company Web sites, and technical reports for exploration projects were checked 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 similar to those in the grade and tonnage models. In some cases, team members provided information about prospects based on personal observations from site visits. The distributions of porphyry-associated deposit types as well as reported copper and gold occurrences of unknown type and placer gold workings were considered in making estimates.

Consensus estimates of undiscovered deposits are summarized in table 5, along with statistics that describe mean numbers of undiscovered deposits, the standard deviation and coefficient of variation associated with the estimate, the number of known deposits, and the implied deposit density for each tract. The assessment predicts a mean total of 14 undiscovered porphyry copper deposits in the four tracts that were assessed, which is about half the number of known deposits (27) in the four assessed tracts. Selected Monte Carlo simulation estimates are reported in table 6. Mean and median copper and gold contained in undiscovered deposits are compared with identified resources in table 6 and figure 22. Identified resources may include substantial amounts of metal that already have been produced.

[23]To use the equation in cases where three non-zero 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}.

Summary of Probabilistic Assessment Results

Numbers of known deposits exceed the mean estimated numbers of undiscovered deposits for all tracts except the Northern Carpathians, where we estimated 2.6 deposits compared to 1 known deposit (table 5). This probabilistic assessment of the metal resources associated with undiscovered porphyry copper deposits in Europe indicates that additional resources may be present (table 6). The mean estimate of undiscovered copper resources in 14 undiscovered deposits (~46 Mt) is comparable to the amount of copper present in identified resources (~44 Mt) in 27 known deposits in those four tracts. However, these resources, if present, may be either inaccessible or uneconomic to develop. Results should be interpreted with due caution pending application of economic filters to evaluate what portion of the estimated undiscovered resources might be economic under various conditions such as mining method, metal prices, capital development costs, and so forth. Identified resources are compared with mean, and median estimates of undiscovered copper and gold resources by tract in figures 22*A* and 22*B*, respectively.

The mean estimated copper resources in undiscovered porphyry copper deposits in the Transylvania-Balkan Mountains tract (150pCu6001) represent about half of the identified resources (table 6). The mean estimated copper for the other three tracts exceeds the identified resources (table 6). Mean estimated gold resources also exceed identified resources for the three younger tracts. Assessment results indicate a mean of 615,000 metric tons of molybdenum and 15,000 metric tons of silver in undiscovered porphyry copper deposits (table 6). These estimates are difficult to compare with identified resources because these commodities infrequently are reported for the European deposits. Given the long mining history in Europe, all historical production from these deposits may not be reflected in available information.

Discussion

Operating mines producing copper from porphyry copper deposits in Europe, as of 2007–2009, included Assarel, Medet, Elatsite, and Tsar Asen in Bulgaria (Brininstool, 2010a); Rosia Poeni, and Moldova Nouă in Romania (Brininstool, 2011b). Copper also was produced from the high sulfidation epithermal deposit at Chelopech in Bulgaria (primarily a gold mine) and at the Rosia Montana low- to intermediate sulfidation state epithermal gold-silver deposit in Romania (1*C*). Production at the Bucim mine in Macedonia was expected to resume in 2011 (Brininstool, 2010b). Active exploration (drilling and geophysical surveys) at a number of properties, including partially-delineated deposits, such as Ilovitza in Macedonia, may lead to development.

Primary copper (and other) metal mining production in the 25 countries of the European Union represents a very small percentage of global production; mining here has declined over the past 100 years as the industry focused on deposits in other parts of the world (Lips and BioMinE Consortium, 2006). Present average metal consumption in Europe, however, is about double metallurgical production, which in turn is about double the amount of primary metal production (Lips and BioMinE Consortium, 2006). To plan for future needs, a large technical and economic evaluation project was done in 2004 to 2008 to review European metal deposits for the development of biohydrometallurgy as a way to recover metals, minimize negative environmental and social impacts, and provide a means of sustainable exploitation of non-ferrous metal resources (Morin and others, 2008). The project's initial screening of potential target sites for the BioMinE project identified copper, zinc, and refractory gold deposits including active and inactive mines, projects under development, and prospects and occurrences as candidates for this technology. The final list of deposits identified as potential targets for this technology (Lips and BioMinE Consortium, 2006) includes many of the porphyry copper deposits mentioned in this assessment, such as in Bulgaria (Assarel, Elatsite, Prohorovo), Greece (Skouries, Fisoka), Serbia (Cerovo, Majdanpek, Dumitru Potok), and Romania (Bucim-Tarnita, Rosia Poeni).

World production of copper (all deposit types) in 2010 was estimated at 16.2 Mt (Edelstein, 2011). Identified copper resources in European porphyry copper deposits (~44 Mt), many of which are mined out or no longer in operation, represent about two and a half years of global production; the mean estimated undiscovered copper resources (~46 Mt) represent closer to three years global production (table 6). None of the countries included in this assessment are among the top 12 global copper producers.

World production of gold in 2010 was estimated to be 2,500 t. The total identified gold resources in European porphyry copper deposits (~2,300 t) represents less than the annual global gold production from all mineral deposit types (George, 2011); mean estimated gold in undiscovered porphyry copper deposits in Europe represents about a year of global gold production from all mineral deposit types.

This assessment predicts that fewer deposits (~14) remain to be found than have already been discovered (27) within the quantitatively assessed tracts in the study area. Those 14 undiscovered deposits are estimated to contain about the same amount of copper and gold as the amounts reported for known deposits. This conclusion raises a number of issues for future consideration, such as:

- Given the long history of production in some parts of Europe, are the reported grade and tonnage data for known deposits in Europe reliable?

Table 5. Summary of estimates of numbers of undiscovered deposits, numbers of known deposits, tract areas, and deposit densities for the porphyry copper assesment of Europe.

[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; km^2, area of permissive tract in square kilometers; N_{total}/km^2, deposit density reported as the total number of deposits per km^2; 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). NA, not applicable.]

Tract name	Coded_ID	Tract_ID	Consensus estimates of numbers of undiscovered deposits			Summary statistics					Area (km^2)	Deposit density (N_{total}/100k km^2)
			N_{90}	N_{50}	N_{10}	N_{und}	s	C_v%	N_{known}	N_{total}		
Transylvania-Balkan Mountains	150pCu6001	EU01PC	2	3	8	4.1	2.4	59	15	19	28,500	67
Dinaride-Aegean Region	150pCu6002	EU02PC	0	2	4	2	1.4	73	4	6	92,700	6
Apuseni Mountains	150pCu6003	EU03PC	1	3	6	3.2	1.88	58	7	10	4,160	245
Northern Carpathians	150pCu6004	EU04PC	0	2	6	2.6	2.2	85	1	4	28,850	12
Total			NA	NA	NA	13.7	NA	NA	27	38.9	154,210	NA

Table 6. Summary of simulations of undiscovered resources in porphyry copper deposits and comparison with identified copper and gold resources in porphyry copper deposits within each permissive tract, Europe.

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

Tract Name	Coded_Id	Tract_Id	Identified copper resources (t)	Mean estimate of undiscovered copper resources (t)	Mean/ Identified copper	Median estimate of undiscovered copper resources (t)	Identified gold resources (t)	Mean estimate of undiscovered gold resources (t)	Mean/ Identified gold	Median estimate of undiscovered gold resources (t)	Mean estimate of undiscovered molybdenum resources (t)	Mean estimate of undiscovered silver resources (t)	Mean estimate of rock (Mt)
Transylvania-Balkan Mountains	150pCu6001	EU01PC	30,000,000	16,000,000	0.5	8,200,000	1,200	390	0.3	170	440,000	5,100	3,200
Dinaride-Aegean	150pCu6002	EU02PC	7,300,000	12,000,000	1.6	5,700,000	540	880	1.6	480	67,000	3,900	2,400
Apuseni Mountains	150pCu6003	EU03PC	5,700,000	10,000,000	1.9	4,600,000	490	730	1.5	390	57,000	3,300	2,000
Northern Carpathians	150pCu6004	EU04PC	740,000	7,900,000	11	2,900,000	48	580	12	250	46,000	2,600	1,600
Total			44,000,000	46,000,000	1.1	NA	2,300	2,600	1.1	NA	610,000	13,000	9,200

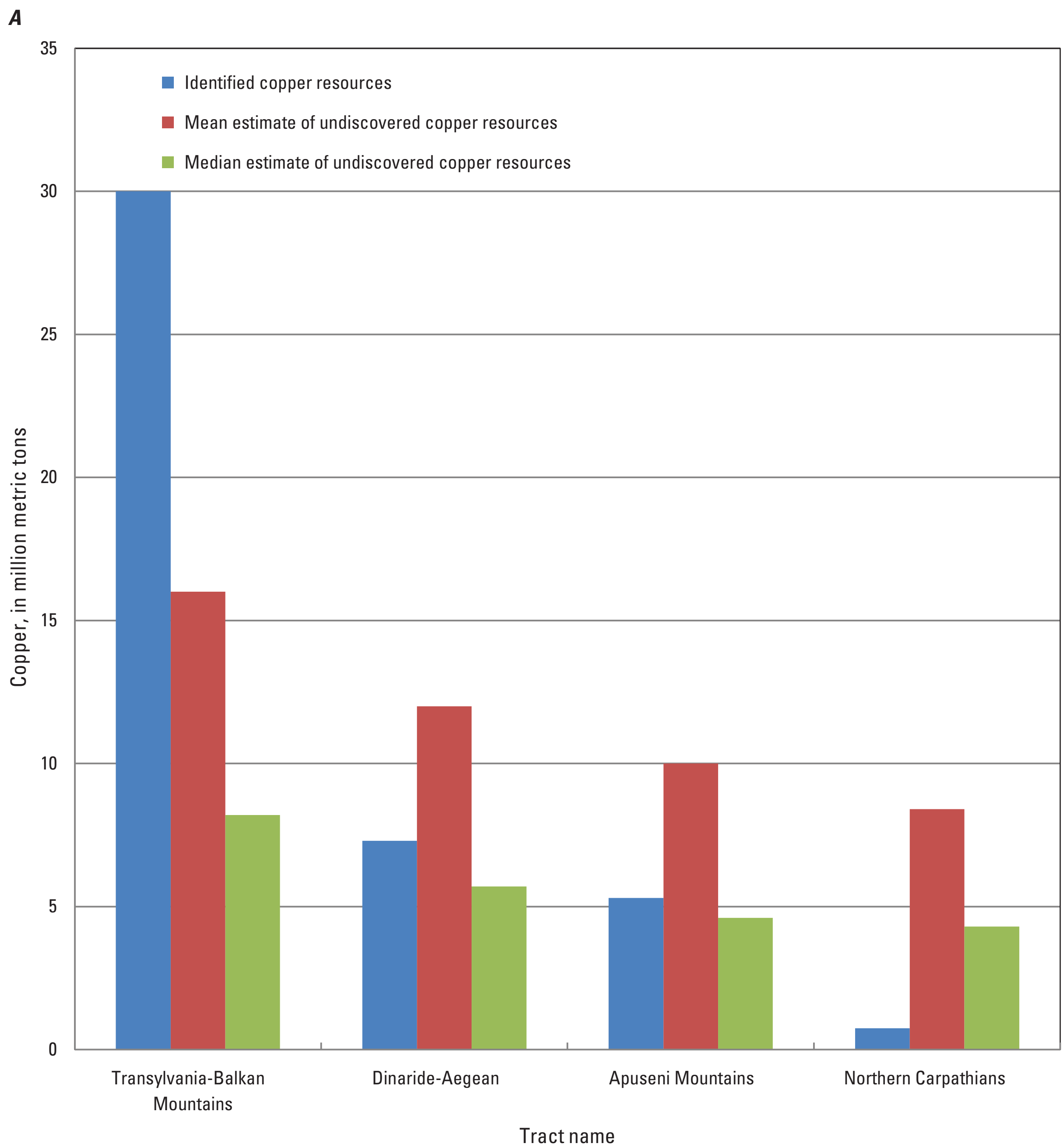


Figure 22. Bar charts of probabilistic assessment results. Comparison of identified resources with mean and median estimated resources in undiscovered porphyry copper deposits in Europe on a tract by tract basis. *A*, Copper. *B*, Gold.

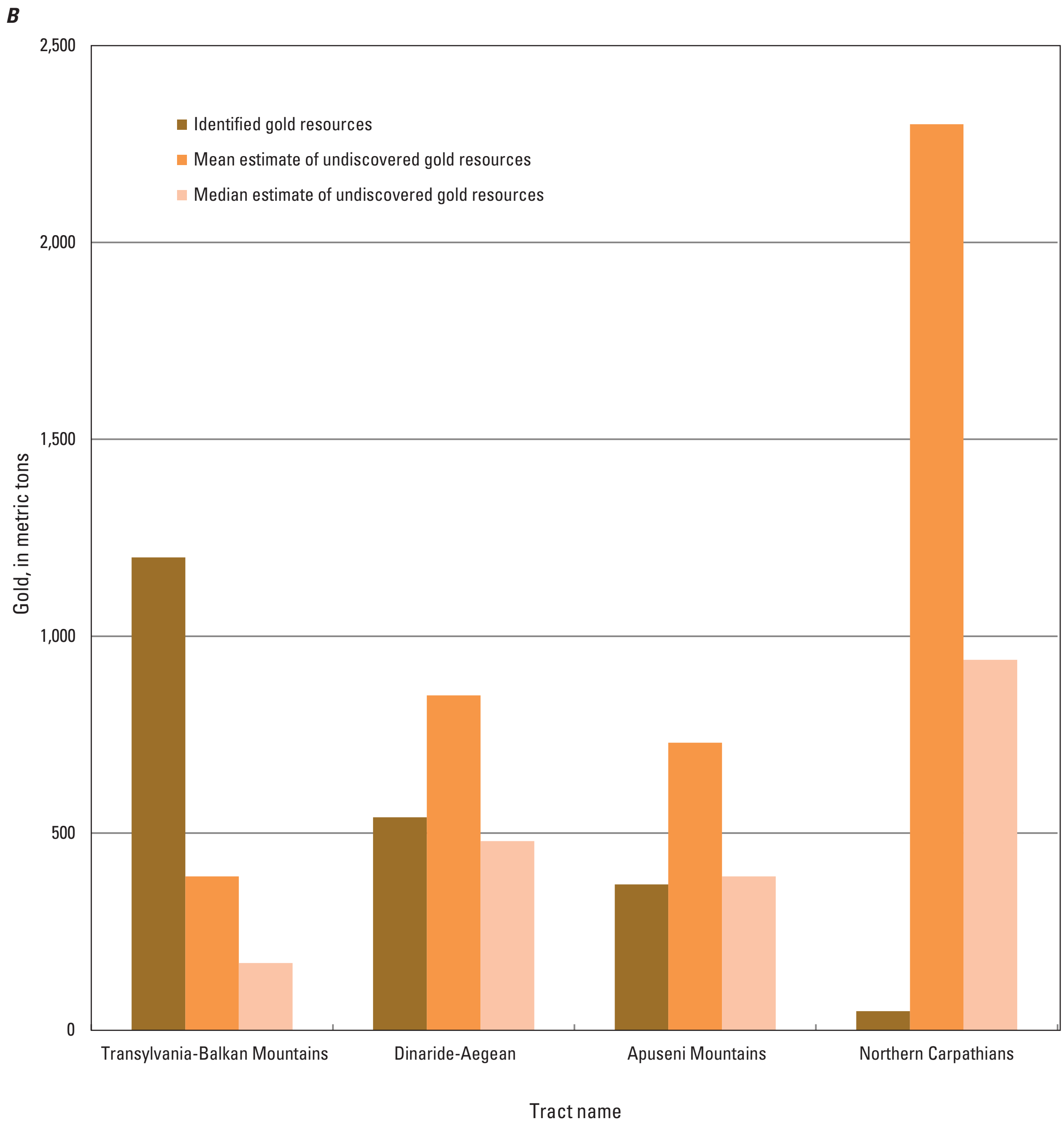


Figure 22. Bar charts of probabilistic assessment results. Comparison of identified resources with mean and median estimated resources in undiscovered porphyry copper deposits in Europe on a tract by tract basis. *A*, Copper. *B*, Gold.

- Are there geologic reasons for the apparent lower contained copper content of the European deposits relative to porphyry copper deposits in many other regions of the world, such as lack of development of supergene enrichment?

- The Transylvanian-Balkan and Northern Carpathian tracts are comparable in size (~29,000 km^2). The Translvanian-Balkan tract hosts 15 known deposits whereas the Northern Carpathian tract hosts one known porphyry copper system associated with the Štiavnaca volcano. Do underexplored porphyry systems underlie some of the epithermal gold deposits and(or) some of the volcanos in Europe?

Because the assessment is probabilistic, median (50 percent) and other reported quantile values, as well as the mean, should be considered by users. Quantiles represent ranked data from the simulation results; therefore, only means are additive in the aggregation of assessment results unless specific assumptions about dependencies and correlations are applicable. Details of simulation results for each tract, as reported in the appendixes, show that the probabilities associated with the mean are on the order of 30 percent; the amounts of resources associated with some probabilities of occurrence may be zero (see tables and cumulative frequency graphs in appendixes A–D).

Some parts of Europe have been but little explored for porphyry copper deposits for many years due to political turmoil, years of war and social conflicts, environmental concerns, low copper prices, and local opposition to mineral development. Upward trends in gold and copper prices in recent years have resulted in renewed interest in exploration and development in mineralized areas in central Europe and western Turkey, with a focus on epithermal gold and gold-rich parts of porphyry systems. Therefore, although Europe has the longest history of mineral exploration of any area of the world, the area cannot be considered completely explored by modern techniques that could reveal additional deposits in old districts, under cover in basin areas, and in greenfields projects in frontier areas such as western Turkey. Increasing recognition of the association of epithermal gold systems with porphyry systems may prompt exploration to deeper levels, and adjacent to epithermal deposits.

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Appendix A. Porphyry Copper Assessment for Tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains— Western Romania, Serbia, Bulgaria, and Western Turkey

By David M. Sutphin[1], Lawrence J. Drew[1], Duncan E. Large[2], Byron R. Berger[3], and Jane M. Hammarstrom[1]

Deposit Type Assessed: Porphyry Copper

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

Table A1. Summary of selected resource assessment results for tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains—Western Romania, Serbia, Bulgaria, and European Turkey.

[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	28,500	30,000,000	16,000,000	8,200,000

Location

The ~950-km long arcuate tract extends from the Apuseni Mountains and Transylvania region (fig. 1[4]) of western Romania through the Balkan Mountains into Serbia, Bulgaria, and northwestern Turkey to the Black Sea (fig. A1). The tract is about 125 km wide at its widest point.

Geologic Feature Assessed

An assemblage of Late Cretaceous calc-alkaline volcanic and intrusive rocks formed by the subduction of the Tethyan Ocean beneath the European continent margin in the Late Cretaceous Banatite belt in the westernmost part of the Tethyan Eurasian Metallogenic Belt (fig. 7).

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[2]Independent consulting geologist, Branschweig, Germany and London, United Kingdom.

[3]U.S. Geological Survey, Denver, Colorado, United States.

[4]Refers to figures and tables in the main report.

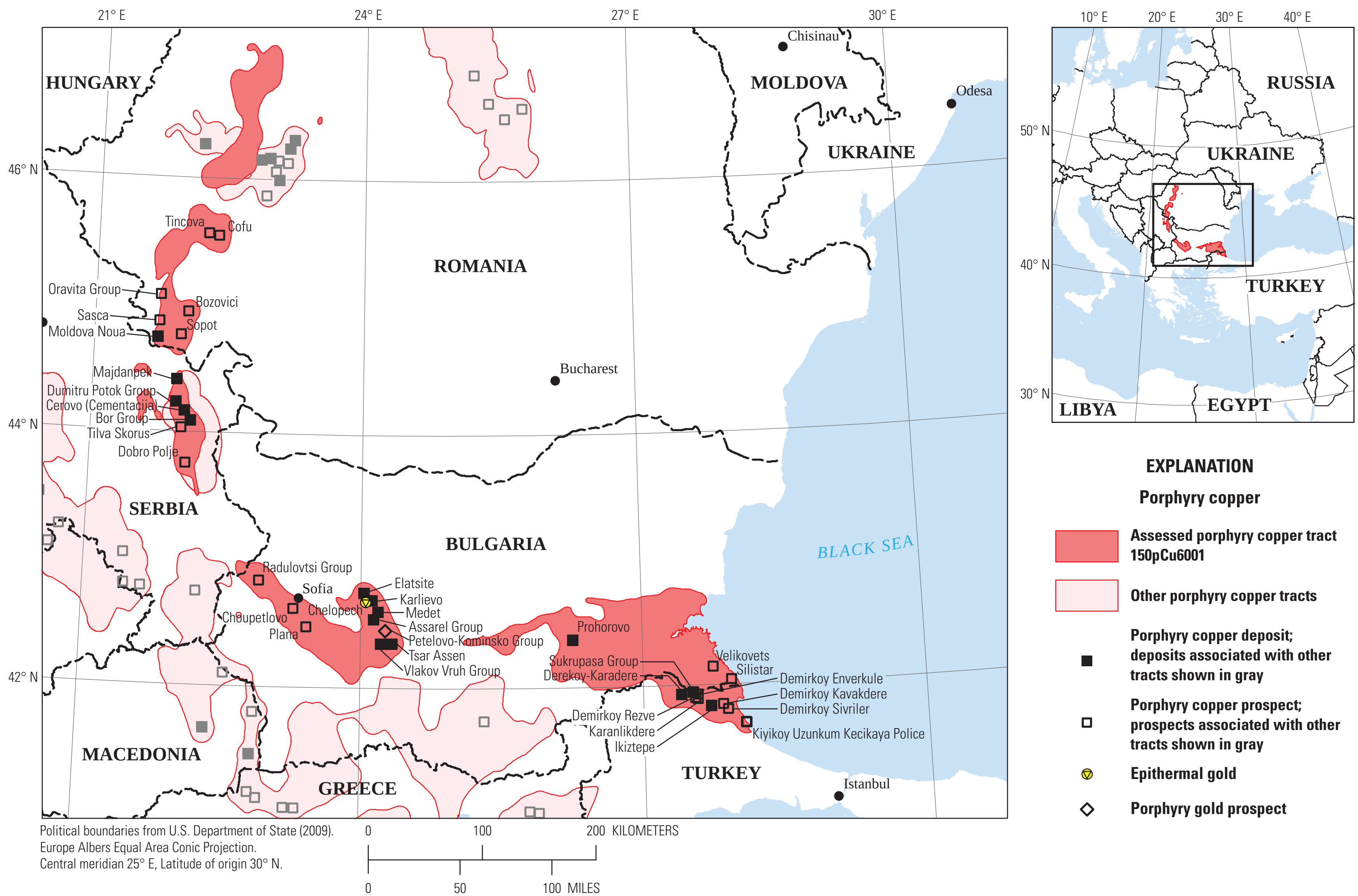

Figure A1. Map showing location, known deposits, and significant prospects and occurrences for permissive tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains—Western Romania, Serbia, Bulgaria, and Western Turkey.

Delineation of the Permissive Tract

Tectonic Setting

The tract outlines volcanic and intrusive rocks of the Late Cretaceous Banatite belt (also known as the Apuseni-Banat-Timok-Srednogorie belt or ABTS, as shown on figure 9 in eastern Europe (von Quadt and others, 2005a). The belt formed by Late Cretaceous subduction beneath the continental margin of Europe during the final stages of collision between Africa and Europe in the Alpine-Himalayan orogeny (von Quadt and others, 2005a). The L-shaped belt defines the major ore-bearing calc-alkaline magmatic arc linked to closure of the Tethys Ocean (Ciobanu and others, 2002) and includes calc-alkaline rocks that host the most productive porphyry copper deposits and associated high-sulfidation epithermal deposits of Europe.

Calc-alkaline to high-K calc-alkaline magmatism occurred over a 30-million-year period from about 90–60 Ma. The porphyry deposits in the belt typically are associated with subvolcanic bodies and porphyry dikes intruded into calc-alkaline granitoid plutons that have island-arc geochemical signatures (von Quadt and others, 2002). Deep-seated transverse structures may have controlled emplacement of porphyry systems in the most productive segments of the arc, the Timok area of Serbia (fig. A2) and the Panagyurishte area of Bulgaria (Heinrich and Neubauer, 2002).

Geologic Criteria

The tract is defined by Late Cretaceous intrusive and volcanic rocks (fig. A2), as depicted on geologic maps for the countries that cover the western Tethyan Arc. Preliminary tracts were identified by outlining areas of interest on printed paper maps. The final tract was constructed by processing geologic data from the enhanced digital geologic map of permissive igneous rocks prepared for the study (Cassard and others, 2006), as follows:

- Permissive igneous lithologies in map units attributed as Late Cretaceous, or including rocks as young as Late Cretaceous, were selected from the 1:1,500,000-scale enhanced digital geologic map of Europe.
- A prototract was developed by placing a 10-km-wide buffer around permissive intrusive rocks and a 2-km buffer around permissive volcanic rocks. This expanded the area of the tract to include most porphyry copper deposits and significant associated prospects and accounts for possible unexposed or unmapped adjacent permissive rocks.
- After buffering, aggregation and smoothing routines were applied to the resulting polygons, and the tract was edited manually to honor fault boundaries and exclude any nonpermissive rocks and areas where the thickness of cover is known to be >1 km.
- The tract was edited to follow the trend of the faults a short distance west of the Oravita Group of prospects, Sasca and Moldova Nouă; the northern part of the polygon containing Majdanpek and Bor was edited on both the east and west sides to follow bounding faults.
- Locations of Late Cretaceous porphyry copper deposits and prospects were examined. In many cases, the igneous rock associated with a deposit or prospect may not be represented at the available map scales; scanned and rectified page-size illustrations from the literature were incorporated in the GIS to check locations and refine permissive rock boundaries.
- Finally, any areas that are intruded by post-Late Cretaceous intrusions were excluded and the tract polygons were clipped to the shoreline to eliminate undersea areas (U.S. Department of State, 2009).

The final tract consists of a series of discrete polygons, as shown in figure A1. Permissive units are shown in figure A2; map units and source maps are listed in table A2. Permissive rocks include volcanic and intrusive rocks shown on the Beograd map sheet of the geologic map of Yugoslavia (Institute for Geological and Mining Exploration and Investigation of Nuclear and other Mineral Raw Materials, 1970), similar rocks on the geologic map of Bulgaria (Cheshitev and Kăncev, 1989) east to the Black Sea, and extending a short distance into northern part of European Turkey (Istanbul sheet, General Directorate of Mineral Research and Exploration (MTA), 2000).

In the Banat area of Romania (fig. A2), permissive rocks include Late Cretaceous granitoids that occur in a narrow, north-trending zone that contains known porphyry copper and polymetallic vein deposits associated with small stocks and dikes (Drew, 2006). The southern end of the Banat area contains the Moldova Nouă porphyry copper deposit (fig. A1). The tract area includes limestone wallrocks that have been altered to discontinuous pods of skarn (Drew, 2006). The Banat area is bounded in part on the west by right-lateral strike-slip faults and on the east by nappe-type thrust faults related to Vardar subduction (Drew, 2006). Other rocks mapped as Late Cretaceous to Paleocene granitoids in southern Romania are not in the same tectonic setting as Banat and do not have known porphyry copper mineralization. In the Timok magmatic zone of Serbia (fig. A2), the tract outlines Cretaceous volcanic rocks and intrusive rocks as shown on the Beograd map sheet (Institute for Geological and Mining Exploration and Investigation of Nuclear and other Mineral Raw Materials, 1970). Details of the local geology and structure for the Timok and Banat areas are shown in figures A3 and A4, respectively.

Farther east, in the Srednogorie area of west-central Bulgaria (fig. A2), the tract is based on Cretaceous volcanic

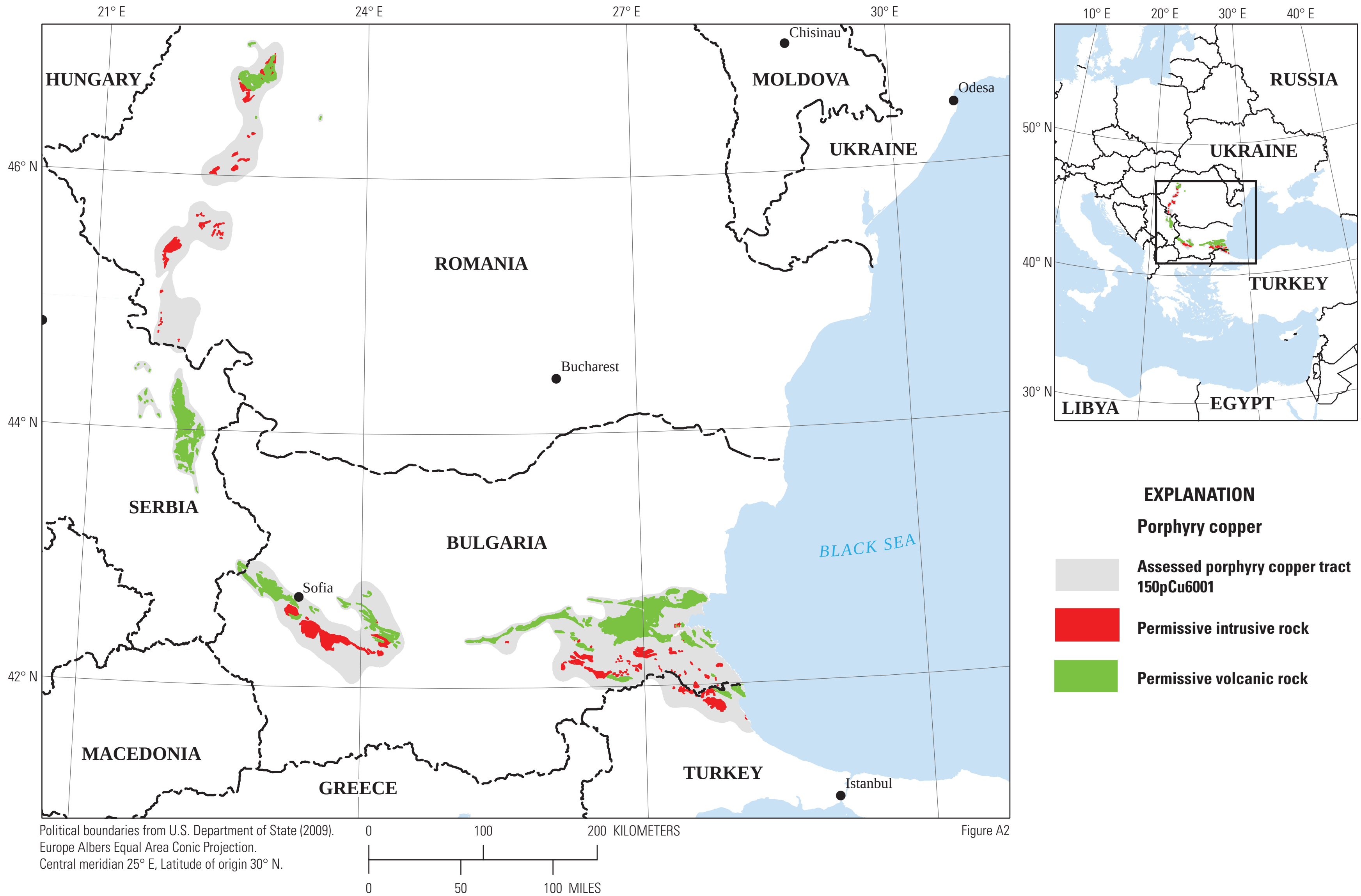

Figure A2. Map showing the distribution of permissive igneous rocks for tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains—Western Romania, Serbia, Bulgaria, and Western Turkey.

Table A2. Map units that define tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains—Western Romania, Serbia, Bulgaria, and European Turkey.

[Map unit, age range, and principal lithologies are based on Cassard and others (2006) 1:1,500,000 digital geologic map and scanned and rectified paper maps at larger scales]

Map symbol	Lithology	Age range	Source map
		Intrusive rocks	
22-23	Diorite, monzonite, intermediate plutonic complex	Triassic-Oligocene 230–23.5 Ma	Cassard and others (2006)
22-23	Granitoid (granite, leucogranite, granodiorite, etc.)	Triassic-Oligocene 230–23.5 Ma	Cassard and others (2006)
γγd	Granite (gamma’), granodiorite (gamma delta’)	Late Cretaceous	Sandulescu and others (1978)
δK2	Porphyritic granitoids	Cretaceous	Cheshitev and Kâncev (1989)
θK22,3	Intrusive rocks	Cretaceous	Beograd map sheet (Institute for Geological and Mining Exploration and Investigation of Nuclear and other Mineral Raw Materials, 1970)
K1, K2	Granitoid	Late Cretaceous to Paleocene	Cassard and others (2006)
γK2	Volcanic and volcanogenic-sedimentary rocks and granitoids	Cretaceous	Cheshitev and Kâncev (1989)
Y5	Granitoid	Late Cretaceous 96–65 Ma	General Directorate of Mineral Research and Exploration (2000)
		Volcanic rocks	
5K2cn-st	Volcanogenic-sedimentary formation in Panagjuriste strip & Celopec Formation in the syncline of same name volcanics, andesite, dacite, andesite-basalts in extrusive explosive and subvolcanic facies, rare sediments, sandstone, siltstone, marls, limestone	Late Cretaceous 96–65 Ma	Cheshitev and Kâncev (1989)
8K2cp	Volcanogenic-sedimentary formation in Stara Zagora strip tuffs and tephroidal rocks interbedded with sedimentary rocks; andesites	Late Cretaceous 96–65 Ma	Cheshitev and Kâncev (1989)
9K2cp	Volcanogenic-sedimentary formation in West Srednogorie--andesites, trachyandesites, andesite-basalts	Late Cretaceous 96–65 Ma	Cheshitev and Kâncev (1989)
c2va	Dominantly volcanic and volcano-plutonic acidic rocks	Late Cretaceous 96–65 Ma	Cassard and others (2006)
c2vi	Dominantly intermediate pyroclastic rocks	Late Cretaceous 96–65 Ma	Cassard and others (2006)
jcva	Dominantly acidic pyroclastic rocks and volcanic and volcano-plutonic acidic rocks	Jurassic-Cretaceous 203–65 Ma	Cassard and others (2006)

Table A2. Map units that define tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains—Western Romania, Serbia, Bulgaria, and European Turkey.—Continued

[Map unit, age range, and principal lithologies are based on Cassard and others (2006) 1:1,500,000 digital geologic map and scanned and rectified paper maps at larger scales]

Map symbol	Lithology	Age range	Source map
k2s_volcanic	Volcanic and sedimentary rocks	Late Cretaceous 96–65 Ma	General Directorate of Mineral Research and Exploration (2000)
αK32	Volcanic rocks	Cretaceous	Beograd map sheet (Institute for Geological and Mining Exploration and Investigation of Nuclear and other Mineral Raw Materials, 1970)
θK32	Pyroclastites with effusions andesites	Late Cretaceous 96–65 Ma	Institute for Geological and Mining Exploration and Investigation of Nuclear and other Mineral Raw Materials (1970)
v	Extrusive (larger bodies of andesites, andesitobasalts, dacites, trachytes)	Late Cretaceous 96–65 Ma	Cheshitev and Kâncev (1989)

and volcanogenic-sedimentary rocks and granitoids. In eastern Bulgaria, the east end of the tract delineates a broad zone volcanic and intrusive rocks intermixed with large areas of sedimentary rocks; intrusive rocks include granitoids and porphyritic granitoids (Cheshitev and Kăncev, 1989). Near the Turkish border, Paleozoic granitoids (γPz2) are included in the tract because they have been intruded in several places by Cretaceous granitoids (gK2). The northeastern border of the Turkish tract segment is a thrust fault.

Known Deposits

The tract contains 15 porphyry copper deposits (table A3). The known deposits cluster in districts. The major districts from north to south are: Banat, Timok (Bor), and the Central and Eastern parts of the Srednogorie zone (fig. A2). The largest deposits in the tract are in Serbia: the 90 Ma Bor group, which includes Bor and the nearby Borska Reka, and Veliki Krivelj, contains about 14 Mt of copper and the 84 Ma Majdanpek porphyry copper-gold deposit contains at least 6 Mt of copper (fig. A1). Most of the major porphyry copper deposits in the tract are associated with small, Late Cretaceous intrusive stocks associated with inferred strike-slip fault duplexes; smaller porphyry copper deposits and occurrences are associated with larger intrusive complexes (Drew, 2006).

The Banat-Timok-Srednogorie porphyry copper deposits generally are located at the corners, and occasionally along the edges, of strike-slip fault duplexes; polymetallic vein deposits identified are located in the interiors of duplexes (Drew, 2006). The structural styles vary within the tract. In the Banat region, the extent of duplex development is much less than in the areas to the south (fig. A3). No sedimentary basins formed in the Banat area, possibly as a consequence of reversal of strike-slip movements associated with “escape” tectonics as continental blocks move laterally away from the orogen during orogen-parallel extension (Drew, 2006). The Timok area is a strike-slip duplex where Late Cretaceous to Miocene andesitic to dacitic tuffs, volcanoclastic rocks, and sediments filled a graben-syncline and are intruded by monzonite and diorite of similar ages (fig. A4). Unaltered andesite of the same ages occurs mainly in the northern half of the area. The Timok magmatic zone extensional strike-slip fault duplex is on an upper block several kilometers west of a thrust. The Majdanpek porphyry copper deposit (fig. A4), at the northern tip of the Timok magmatic zone, is emplaced in a positive flower structure within the principal deformation zone of a master strike-slip fault (Drew, 2006). In the central Srednogorie zone of Bulgaria, the Medet deposit occurs in the northern corner of a duplex, the Elatsite deposit occurs in the northeastern corner of another duplex, and the Assarel deposit occurs in the southeastern corner of that same duplex (fig. 12). Each of these porphyry copper deposits contains ~1 million metric tons or more of copper and is within or near granodiorite-quartz monzodiorite stocks in associated volcanic rocks (Strashimirov and others, 2002; Drew, 2006). Strike-slip faulting and thrust faults are less prevalent in the eastern part of the Srednogorie zone along the Bulgarian-Turkey border. Known deposits in the tract are described by area, from north to south, and listed in table A3 in alphabetical order.

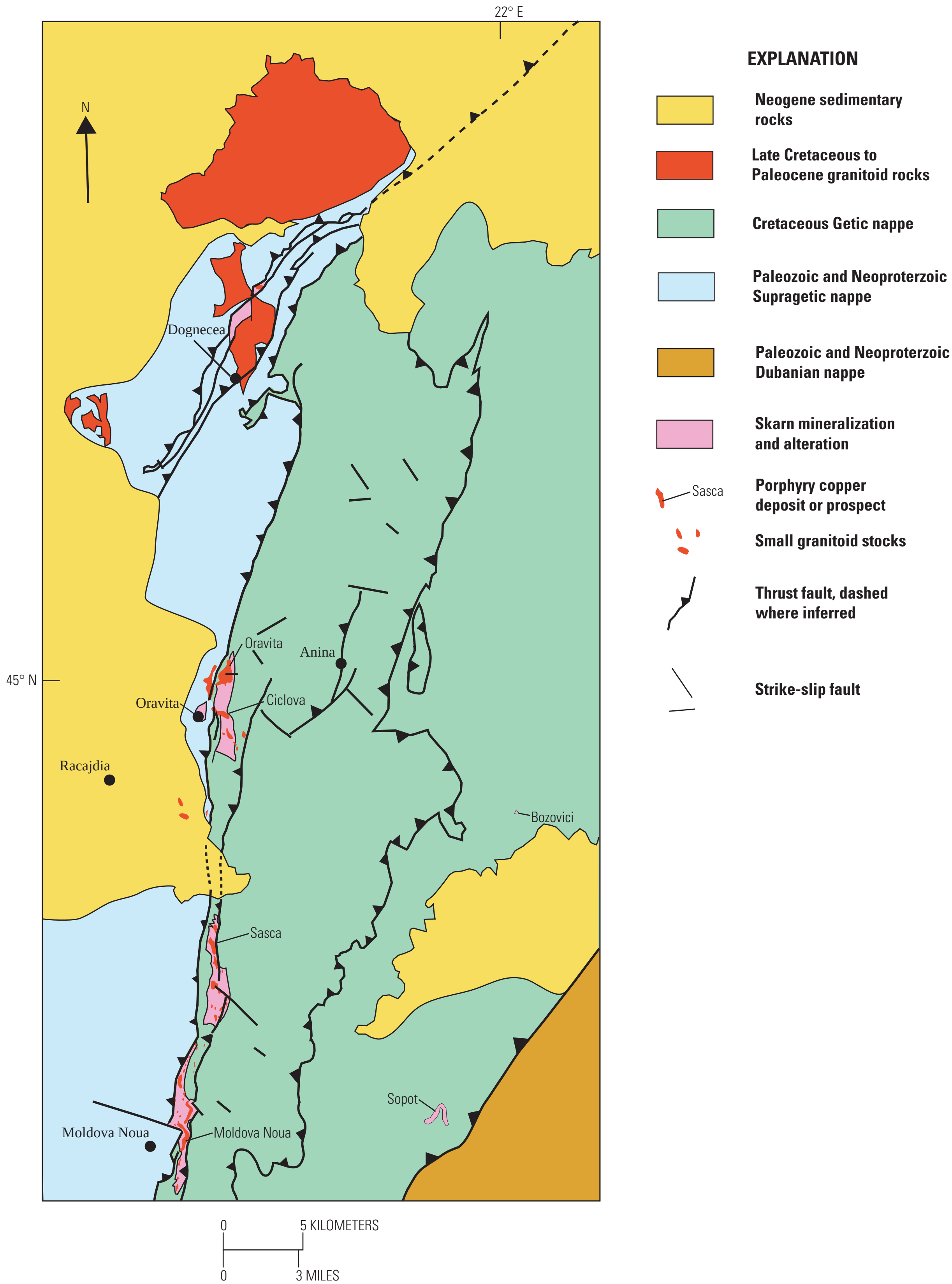

Figure A3. The Banat region, Romania. After Drew (2005). Modified from Codarcea (1967), Codarcea and Dimitrescu (1967), Codarcea and Raileanu (1968), Nastaseanu and Maier (1972), Maier and others (1973), and Nastaseanu and others (1975). See tables A3 and A4 for locations of deposits and prospects.

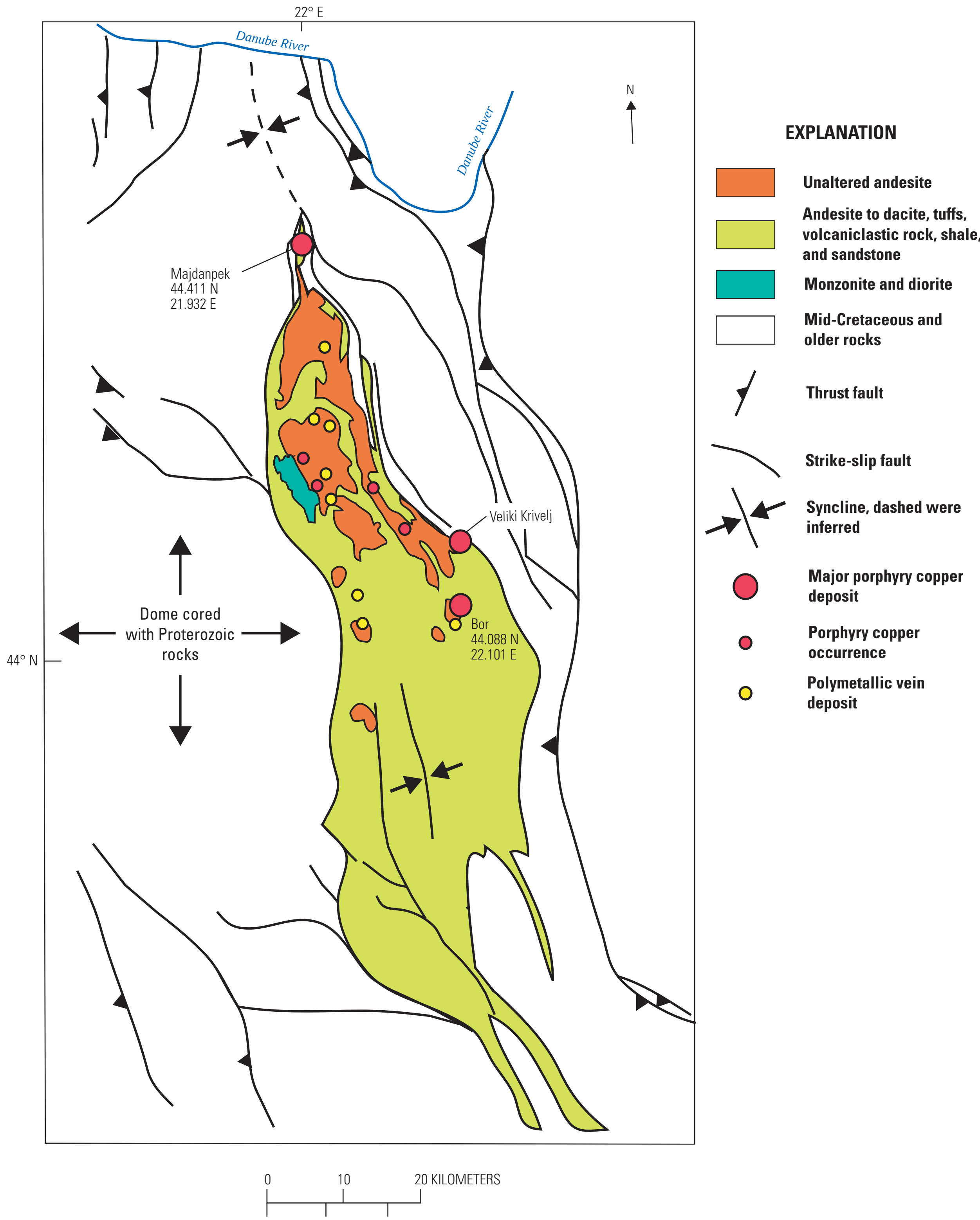

Figure A4. Schematic illustration of the relationship of porphyry copper and polymetallic veins deposits in the Timok magmatic zone (a strike-slip fault duplex) in Serbia to structure and geology. After Drew (2005) and Drew and others (2003). Modified from Yugoslavia Federal Geological Institute (1970), Janković (1990), and Karamata and others (1997). Porphyry copper and vein deposit locations from Kozelj and Jelenkovic (2001).

Table A3. Porphyry copper deposits in tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains—Western Romania, Serbia, Bulgaria, and European Turkey.

[Group names in boldface. Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; n.d., no data; NA, Not applicable. Cu-Au subtype, deposits that have Au/Mo ratios >30 or average Au grades >0.2 g/t. See appendix H (GIS) for individual site records.]

Name	Includes	Country	Latitude	Longitude	Subtype	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)	Reference
Assarel Group	Assarel, Orlovo Gnezdo	Bulgaria	42.544	24.137	NA	90	390	0.43	n.d.	0.19	n.d.	1,700,000	Angelkov and Parvanov (1980), Biomine (2006), Bogdanov (1982, 1983), Eliopoulos and others (1995), Herrington and others (2003), Kamenov and others (2007), Lips and others (2006), Nakov and others (2002), Petrunov and others (1990), Peytcheva and others (2007), Popov and others (1996), Singer and others (2008), Tarkian and Stribny (1999), von Quadt and others (2005b), Zartova and others (2004)
Bor Group	Bor, Borska Reka, Veliki Krivelj	Serbia	44.088	22.101	Cu-Au	85	2,141	0.64	0.002	0.24	0.5	14,000,000	Anonymous (1973a), Armstrong and others (2005), Clark (1993), Clark and Ulrich (2004), Herrington and others (1998, 2003), Janković (1982, 1990), Janković and others (1980), Kachalovskaya and others (1975), Kozelj and Jelenković (2001), Lerouge and others (2005), Lips and others (2006), Ministry of Mining and Energy (2010), Monthel and others (2002), Pavicevic and others (1995), Porter Geoconsultancy (2008), Tarkian and Stribrny (1999), Singer and others (2008)
Cerovo (Cementacija)	NA	Serbia	44.165	22.029	NA	Late Cretaceous	316	0.32	n.d.	0.10	n.d.	1,000,000	Jelenković and others (2007), Karamata and others (1997), Knežević and others (1995), Lips and others (2006)
Derekoy-Karadere	NA	Turkey	41.911	27.317	NA	71	270.5	0.28	0.003	n.d.	n.d.	760,000	Anatolia Minerals Development Ltd. (2005), Cloudbreak Resources Ltd. (2007), Engin (2002), Erdem (2008), Leaman and Staude (2003), Ohta and others (1988), Slim (2006), Taner and Çağatay (1983), Yigit (2006, 2009), Young (2010)

Table A3. Porphyry copper deposits in tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains—Western Romania, Serbia, Bulgaria, and European Turkey.—Continued

[Group names in boldface. Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; n.d., no data; NA, Not applicable. Cu-Au subtype, deposits that have Au/Mo ratios >30 or average Au grades >0.2 g/t. See appendix H (GIS) for individual site records.]

Name	Includes	Country	Latitude	Longitude	Subtype	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)	Reference
Dumitru Potok Group	Dumitru Potok, Valja Strz	Serbia	44.232	21.932	Cu-Au	Late Cretaceous	337	0.23	0.001	0.20	0.1	780,000	Dundee Precious Metals, Inc. (2008), Karmata and others (1997), Lips and others (2006), Mazzoni and others (2010), Ministry of Mining and Energy (2010), Monthel and others (2002), Porter Geoconsultancy (2011)
Elatsite	NA	Bulgaria	42.755	24.033	Cu-Au	92	350	0.39	n.d.	0.26	0.2	1,400,000	Bogdanov (1983), Bogdanov (1986), Dragov (1996), Eliopoulos and others (1995), Fanger and others (2001), Georgiev (2008), Herrington and others (2003), Kamenov and others (2007), Petrunov and others (1992), Strashimirov and Popov (2000), Strashimirov and others (2002)
Ikiztepeler	NA	Turkey	41.833	27.713	NA	75	237	0.29	0	n.d.	n.d.	690,000	Anatolia Mineals Development Ltd. (2005), Cloudbreak Resources Ltd. (2006, 2007), Engin (2002), Marketwire (2007), New Blaze (2007), Ohta and others (1988), Slim (2006), Taner and Çağatay (1983), Yigit (2009), Young (2010)
Karlievo	NA	Bulgaria	42.694	24.121	NA		61	0.21	0.005	0.05	n.d.	130,000	Georgiev (2008), Lips and others (2006), Nakov and others (2002)
Majdanpek	NA	Serbia	44.411	21.932	Cu-Au	84	1,000	0.60	0.005	0.35	1.0	6,000,000	Anonymous (1973b), Armstrong and others (2005), Clark (1993), Clark and Ulrich (2004), Drew (2005), Herrington and others (1998, 2003), Jankovič (1982), Jankovič and others (1980), Lips and others (2006), Monthel and others (2002), Starostin (1970), Tarkian and Stribrny (1999)

Table A3. Porphyry copper deposits in tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains—Western Romania, Serbia, Bulgaria, and European Turkey.—Continued

[Group names in boldface. Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; n.d., no data; NA, Not applicable. Cu-Au subtype, deposits that have Au/Mo ratios >30 or average Au grades >0.2 g/t. See appendix H (GIS) for individual site records.]

Name	Includes	Country	Latitude	Longitude	Subtype	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)	Reference
Medet	NA	Bulgaria	42.605	24.187	NA	90	244	0.37	0.010	0.10	n.d.	900,000	Bogdanov (1982, 1983, 1986), Clark (1993), Economou-Eliopoulos and others (2007), Eliopoulos and others (1995), Herrington and others (2003), Kamenov and others (2007), Peytcheva and others (2007), Popov and others (1996), Strashimirov and others (2002), Tarkian and Stribrny (1999), von Quadt and others (2005b)
Moldova Nouă	NA	Romania	44.738	21.703	NA	65	500	0.35	n.d.	n.d.	n.d.	1,800,000	Berza and others (1998), Bestinescu (1984), Borcos and others (1984), Cioflica and Vlad (1980), Cioflica and others (1995), Folea and Berbeleac (1987), Ianovici and Borcos (1982), Ianovici and others (1977, 1990), Karamata and others (1997), Nastaseanu and Maier (1972)
Prohorovo	NA	Bulgaria	42.378	26.263	NA	81	249	0.25	0.005	n.d.	n.d.	620,000	Bogdanov (1983, 1986), Eliopoulos and others (1995), Tarkian and Stribrny (1999), Lips and others (2006), Nakov and others (2002)
Sukrupasa Group	Sukrupasa, Byrdtseto	Turkey	41.938	27.506	NA	82	8	0.41	0.003	0.08	n.d.	33,000	Bogdanov (1983, 1986), Bonev and others (1989), Gultekin (1999), Nedialkov and others (2009), Ohta and others (1988),Yigit (2006, 2009)
Tsar Assen	NA	Bulgaria	42.355	24.339	NA	90	6.6	0.47	n.d.	n.d.	n.d.	31,000	Bogdanov (1983, 1986), Ciobanu and others (2002), Eliopoulos and others (1995), Ignatovski (1996), Strashimirov and others (2002), Strashimirov and Popov (2000), Tarkian and Stribrny (1999), von Quadt and others (2005b)
Vlakov Vruh Group	Vlakov Vruh, Popovo Dere	Bulgaria	42.353	24.214	NA	86	85	0.23	n.d.	n.d.	n.d.	200,000	Bogdanov and others (1997), Ciobanu and others (2002), Lips and others (2006), Nakov and others (2002), Peytcheva and others (2003), Strashimirov and others (2002), Strashimirov and Popov (2000), von Quadt and others (2005b)

Banat

Moldova Nouă, Romania

Porphyry copper deposits and prospects in the Banat area are associated with Late Cretaceous to Paleocene granitoid stocks, many of which are surrounded by skarn and hydrothermal alteration. Levels of exposure range from plutonic (deeper) in the North Banat area to subvolcanic to plutonic (shallower) in the South Banat area (Dupont and others, 2002). Map patterns for skarns in the district are consistent with extensional duplexes with a left-lateral sense of shear, whereas the regional sense of shear associated with the closure of the Vardar Ocean recorded in the Srednogorie and Timok regions is right-lateral (Drew, 2006). Late Cretaceous transpression in a left-lateral extensional strike-slip fault duplex accommodated emplacement of the 65 Ma Moldova Nouă copper-molybdenum deposit in the South Banat district, which is associated with a quartz diorite stock (fig. A3). In 2011, the Moldova Nouă mine, formerly operated by the State, was for sale.

Timok (Bor) District, Serbia

The Timok district in northeastern Serbia is approximately 80 km long and up to 20 km wide. The district contains an estimated 15.4 Mt of copper, 630 t of gold, 3,900 t of silver, 116,000 t of lead-zinc, and 150,000 t of molybdenum in porphyry copper- and related deposits, including high-sulfidation epithermal massive-enargite (gold) sulfide deposits and low-sulfidation epi- to mesothermal polymetallic veins (Republic of Serbia, undated). Janković and others (1980) and Janković (1990) describe the Timok district as a graben-syncline associated with a paleorift that has been filled by andesite, dacite, tuffs, and other volcaniclastic rocks, shale, and sandstone. In the Late Cretaceous, these rocks were intruded by small calc-alkaline igneous stocks ranging in composition from gabbro to granodiorite, but most commonly monzonite. Structural data interpreted from detailed maps and remote sensing data showed that the Timok magmatic zone is an extensional strike-slip duplex with a right-lateral, right-step sense of movement (fig. A4) and that the intrusions were emplaced during the reactivation of preexisting fractures (Drew and others, 2003; Drew, 2006).

Mineralization is related to strongly hydrothermally altered volcanic rocks of Late Cretaceous to Paleocene age that were intruded by granodiorite stocks and dykes. Magmatism in the Timok district occurred over a period of about 11 million years, from about 89–78 Ma, based on recent zircon studies (Moll and others, 2009). The youngest ages are found in the eastern part of the Timok Complex around Valja Strz. Duration of mineralization at individual centers of porphyry copper mineralization may have been much shorter, such as at Veliki Krivelj, where the ore-associated magmatism lasted less than a million years (Moll and others, 2009).

Mining of the Timok district started in the early 20th century, and for almost half a century it was at the center of the Yugoslav copper industry. The cumulative production is estimated at about 6 Mt of copper, 300 t of gold, and about 1,200 t of silver (Republic of Serbia, undated).

Majdanpek, Serbia

The 1,000 Mt Majdanpek porphyry Cu-Au deposit is associated with replacement deposits (skarn, manto) and high-sulfidation epithermal massive-enargite (gold) sulfide deposits (GEODE, 2006). The deposit was mined for massive pyrite and limonite until 1962, but since then the large porphyry copper deposit has been developed as an open pit with an annual production of 12 to 14 Mt of copper ore (Jelenković and others, 2007). The highest copper grades occur in a highly silicified core of the ore body associated with small intrusive stocks (Drew, 2006).

The main mineralization stage at Majdanpek occurred at 83.6–84.0 ± 0.6 Ma, coinciding with the later stages of the first cycle of high-potassium calc-alkaline andesitic volcanism in the district (Clark and Ulrich, 2004). The Majdanpek porphyry copper deposit in Late Cretaceous andesite is part of a positive flower structure within the northern extension of a north-trending strike-slip fault duplex (fig. A4).

Dumitru Potok Group, Serbia

The Valja Strz and Dumitru Potok deposits are adjacent to the Late Cretaceous to early Tertiary Crni Vrh plutonic complex which was emplaced along a regional fracture zone on the western margin of the Timok Magmatic Complex (Porter Geoconsultancy, 2011). The Timok Magmatic Complex intruded Late Cretaceous andesites and clay-rich sediments. The plutons are generally potassic with isotopic signatures indicative of a mantle source contaminated with continental material. The margins and central parts of the plutonic complex are extensively altered along a zone that extends for 8 km or more. Alteration is typically propylitic, dominated by chlorite and epidote with silicification and pyritization (Porter Geoconsultancy, 2011). Epithermal mineralization developed at the margins of these bodies (Porter Geoconsultancy, 2011). Numerous other targets have been identified in the 5 by 4 km mining concession (Dundee Precious Metals, Inc., 2008).

Cerovo, Serbia

The Cerovo porphyry copper deposit is about 10 km northwest of Bor and is likely similar in age to, and associated with, the arc magmatism that formed the district (Clark and Ulrich, 2004). The geology in the area of the deposit consists of Early Cretaceous sediments, hydrothermally altered volcanic-sedimentary, Late Cretaceous intrusive rocks, and alluvial sediments (Jelenković and others, 2007). The dominant alteration is silicification; chloritization, sulfidation, chloritization, kaolinization, sericitization and locally feldspathic alteration are observed (Jelenković and others, 2007). The deposit is zoned horizontally and vertically, and includes some supergene enrichment. The Cerovo ore zone includes numerous cross-cut and diagonal faults consistent with its position within a larger fault duplex. The main copper minerals are chalcopyrite, chalcocite, malachite, and azurite (Knežević and others, 1995). The Cerovo copper mine is slated for rejuvenation, and once that is completed, it will likely be the most modern copper mine in Europe (Serbia Business, 2011).

Bor Group, Serbia

The Bor group includes Bor, Borska Reka, Veliki Krivelj (fig. A1, A4) and contains about 14 Mt of copper (table A3). The Bor deposit alone contains 29 known ore bodies such as Coka Dulkan, Mika, and Tilva Ros. At the start of the 20th century, high sulfidation mineralization was discovered at Bor, and mining began in 1903. Alunite from the high-sulfidation copper-gold deposit at Bor has oxygen and sulfur isotopes indicative of a magmatic-hydrothermal origin (Lerouge and others, 2005).The principal copper minerals at Bor are chalcocite, covellite and enargite, with associated marcasite, chalcopyrite, tetrahedrite and sylvanite (Porter Geoconsultancy, 2008).

Central Srednogorie Zone (Panagyurishte District), Bulgaria

Porphyry copper deposits in the Panagyurishte district of the Central Srednogorie zone of southern Bulgaria (fig. A2) are associated with small subvolcanic intrusions that are discordant to volcanic edifices or intruded in pre-Mesozoic basement rocks (Kouzmanov and others, 2009). The magmatism in the district has been interpreted to be related to a Late Cretaceous island arc system (Dabovski and others, 1991). The district contains the Elatsite deposit in the north, Assarel and Medet deposits, and Petelovo prospect in the center, and the Vlaykov Vruh and Tsar Assen deposits in the south (fig. A1). The deposits in the northern and central parts of the district formed in extensional fracture zones, along the edges of a strike-slip fault duplex (fig. 10; Drew, 2006). The district also hosts epithermal high-sulfidation copper-gold deposits that are genetically linked to the porphyry copper-gold systems. Chelopech, the largest of these epithermal deposits, is in the northern part of the district, whereas the southern part of the district hosts only small, subeconomic epithermal deposits (Kouzmanov and others, 2009). The Panagyurishte district shows progressively younger magmatism from about 92 Ma in the north (in the area of Elatsite) to about 78 Ma in the south (including the Tsar Assen and Vlaykov Vruh deposits). This trend of decreasing age of magmatism from north to south coincides with a north-south decrease in crustal contributions to mantle-derived magmas (von Quadt and others, 2005b). This change in magma composition may reflect slab roll-back or hinge retreat during oblique subduction. This trend is confirmed in the lead-isotope signatures of the sulfide minerals increasing toward the north (Kouzmanov and others, 2009). The thickness of the Earth's crust has been observed to become thinner from the north in the Elatsite area to the area near Elshitsa in the south part of the Panagyurishte district. This variation in crustal thickness may have influenced the differences in magma chemistry observed in the district. One of the characteristics of the porphyry copper deposits in the district is the occurrence of cobalt, nickel, and platinum-group element minerals, which are interpreted as a reflection of a mantle signature (Lips, 2002; Augé and others, 2005). The deeper erosional level in the southernmost part of the district, which may lack economic mineralization, has probably additionally reduced the crustal thickness in the district (Kouzmanov and others, 2009) and could influence the prospectivity of this area of the tract.

Elatsite, Bulgaria

The Elatsite porphyry copper-gold deposit is one of the largest operating porphyry copper mines in eastern Europe (Kamenov and others, 2007). The deposit is associated with Late Cretaceous subvolcanic bodies and porphyry dikes intruded into Cambrian metamorphic rocks and into Carboniferous granodiorites (von Quadt and others 2002; Kamenov and others, 2007). The Elatsite ore body covers an area of about 1 km^2 in the northeast corner of a strike-slip fault duplex where it was emplaced at a somewhat deeper level than Assarel (Strashimirov and others, 2002; Drew, 2006). The deposit is hosted by Late Cretaceous monzonitic-monzodioritic porphyry stocks that have been emplaced into Precambrian to Cambrian phyllites (Tarkian and others, 2003). Quartz monzonite porphyries (~92 Ma) are the earliest and volumetrically most significant ore-related rocks; a second generation of dikes consists of granodiorite porphyries and needle-like amphiboles (von Quadt and others 2002). Narrow potassium feldspar-rich aplite dikes represent a late-stage third generation of ore-related dikes (von Quadt and others 2002). The ore occurs as veins and disseminations that form a large stockwork (Georgiev, 2008). The magnetite-bornite-chalcopyrite ore assemblage, which is preserved mainly in the central potassic-alteration core, contains a suite of platinum-group minerals (Augé and others, 2005) and Au-Ag-Te-Se minerals (Kamenov and others, 2007). Mining began in 1981 (Kouzmanov and others, 2009). Copper is the primary product, with secondary gold and molybdenum (Georgiev, 2008).

Karlievo, Bulgaria

The 61 Mt Late Cretaceous Karlievo porphyry copper deposit is in the southern part of the Elatsite-Chelopech mineralized area, about 10 km southeast of Elatsite and 3 km east-southeast of Chelopech (Tarkian and others, 2003). At Karlievo, a small intrusive body and some dikes intrude Precambrian metamorphic rocks along a system of radial–concentric faults (Tarkian and others, 2003).

Assarel-Medet, Bulgaria

The Assarel porphyry copper deposit is situated in the central part of the Srednogorie zone, roughly halfway between Elshitsa 25 km to the south and Elatsite 25 km to the north; Medet is about 8 km to the northeast (Zartova and others, 2004; Kamenov and others, 2007). At the Assarel deposit, the Paleozoic basement rocks are biotite or two-mica gneisses, granodiorites, granites, pegmatites and aplites (Zartova and others, 2004). The deposit, in the southeast corner of a strike-slip fault duplex, was emplaced at a shallow crustal level in a stock intruded into the superstructure of a volcano (Drew, 2006).

In the mid-1950s, Medet became the first porphyry copper deposit discovered in Europe, and later its first producing porphyry copper mine (Strashimirov and others, 2002). The pluton hosting the deposit is a small, stock-like body. Magnetic studies suggest that the pluton is located in and above a larger and deeper intrusion at the intersection of a north-northwest trending deep-seated fault zone (Kamenov and others, 2007). The host pluton consists of three ore-producing phases: quartz-monzodiorites, granodiorites, and porphyry quartz-monzonites as dikes and small intrusions quartz-monzonites (Kamenov and others, 2007). The Medet deposit occurs in the north corner of a strike-slip fault duplex where it was emplaced at a somewhat deeper level than Assarel (Strashimirov and others, 2002; Drew, 2006).

The deposits at Assarel and Medet were privatized in December, 1998. In the 2000s, operations were modernized and environmental issues were addressed; the deposits currently operate as the Assarel-Medet JSC (joint-stock company) Mining and Processing Complex, which processes about 13 Mt of ore annually (Assarel-Medet JSC, 2011). The undeveloped Orlovo Gnezdo deposit (36 Mt of resources with an average grade of 0.36 percent copper and 0.14 g/t gold) lies within 2 km of Assarel and is included as part of the Assarel Group.

Vlaykov Vruh Group, Bulgaria

The Vlaykov Vruh Group includes the Vlakov Vruh and Popovo Dere deposits. These are small porphyry copper deposits that occur along the edges of a strike-slip fault duplex within a larger duplex fault system to the south of the duplex that contains the Assarel, Elatsite, and Medet porphyry copper deposits (fig. 12). Vlaykov Vruh produced copper and gold 1962–1979 and closed in 1980 (Ciobanu and others, 2002). The deposit occurs near (paired with) the Elshitsa low-sulfidation epithermal massive sulfide deposit (Ciobanu and others, 2002). These deposits were formed along the southwest flank of the Elshitsa volcano-intrusive complex and are spatially associated with northwest-southeast-trending hypabyssal and sub-volcanic bodies of granodioritic composition (Kouzmanov and others, 2009). The intrusion at Vlaykov Vruh is granodiorite with potassic alteration; both the granodiorite and alteration were dated as Late Cretaceous (86–85 Ma) by Ciobanu and others (2002). More recent Re-Os ages on four samples of coarse molybdenite in vuggy quartz yielded ages ranging from 86.77±0.5 to 87.70 ±0.5 Ma (Zimmerman and others, 2008). The ore mineral is chalcopyrite in disseminations, veins, and veinlets with related pyrite veins (Ciobanu and others, 2002). Popovo Dere is a small, unworked subeconomic deposit with 75 Mt of known resources.

Tsar Assen, Bulgaria

The Tsar Assen porphyry copper deposit (fig. 12*A*) is a small, past producer of copper and gold hosted in an argillically altered granodiorite pluton with chalcopyrite and pyrite; the deposit was mined out between 1962 and 1979 (Ciobanu and others, 2002). The intrusion and alteration have been dated as Late Cretaceous, 88–86 Ma. The nearby Radka intermediate-sulfidation epithermal massive deposit is considered a related deposit.

Eastern Srednogorie Zone

In the European part of northwestern Turkey (Thrace) adjoining the Bulgarian border, the southeasternmost part of the tract delineates intermediate composition volcanic rocks that represent a Late Cretaceous Andean-type continental arc. Around 71 Ma, igneous activity in northwestern Turkey ended, probably because of the closing of the Neotethys Ocean (Ohta and others, 1988).

Prohorovo, Bulgaria

The Prohorovo porphyry copper deposit is composed of chalcopyrite veinlets with minor pyrite, magnetite, and rutile associated with sericitic and propylitic alteration (Tarkian and Stribrny, 1999). Unlike many other deposits in the district included in a study of PGE in 33 porphyry copper deposits from around the world, ore concentrates from Prohorovo lack detectable platinum or palladium (Tarkian and Stribrny, 1999).

Derekoy-Karadere,Turkey

In the 1970s, the Turkish Geological Survey conducted a massive stream-sediment sampling program in the Thrace region (fig. 1) that delineated several prospective metal anomalies. Follow-up research discovered the Derekoy low-grade porphyry copper-molybdenum deposit (Slim, 2006). At Derekoy, magnetite series I-type granitoid stocks intrude Triassic to Jurassic metasedimentary rocks along the axis of a pre-Cretaceous northwest-trending anticline (Otha and others, 1988; Yigit, 2009). The metasedimentary rocks are partly covered by Late Cretaceous volcano-sedimentary rocks (Taner and Çağatay, 1983). The stocks and deposits are aligned with the regional folds (Ohta and others, 1988). At Derekoy, Cu-Mo mineralization is closely related to tonalite porphyry. Numerous skarn and hydrothermal minerals have been identified, including pyrite, magnetite, chalcopyrite, sphalerite, galena, enargite, and native gold, silver, molybdenite, scheelite, hematite, rutile, anatase, ilmenite, ilmeno-magnetite, bornite, marcasite, malachite, azurite, limonite, and others (Taner and

Çağatay, 1983). Drilling at Derekoy produced intercepts with a return of 173.3 m at 0.33 percent copper, 0.0054 percent molybdenum and 0.046 g/t gold, including 16.1 m at 0.54 percent copper, 0.0047 percent molybdenum and 0.071g/t gold.

At the Karadere porphyry copper-molybdenum and skarn deposit, greenschist facies regionally metamorphosed limestones and schists are cut by Late Cretaceous quartz diorite intrusive rocks; ore minerals typically developed at the intrusive contact. (Taner and Çağatay, 1983; General Directorate of Mineral Research and Exploration, 2000). Total reserves for Karadere are 500,000 t at 0.43 percent copper (General Directorate of Mineral Research and Exploration, 2000).

Average weighted reported resources for Derekoy and the nearby Karadere area are 270.5 Mt at 0.28 percent copper and 0.003 percent molybdenum. Although the deposit area is still incompletely explored, an economic risk analysis indicated a 95 percent chance of a positive net present value based on the estimated proven reserves of 210 Mt and an average grade of 0.244 percent copper for the southeastern part of the Derekoy deposit (Erdem, 2008).

Ikiztepeler (Ikiztepe-Sarp, Demirköy), Turkey

Ikiztepeler (Ikiztepe Hill) is the site of several copper-molybdenum-gold skarn-porphyry-type mineral occurrences. Cu-Mo-W mineralization is associated with granodioritic to quartz monzonitic granitoids (Ohta and others, 1988). Where the granitoids encountered calcic rocks such as dolomitic limestone, skarns formed (Taner and Çağatay, 1983). Mineral suites consistent with both skarn deposits (diopside, actinolite, biotite, garnet, titanite, and tremolite) and porphyry deposits (chalcocite, molybdenite, and chalcopyrite) are present (Taner and Çağatay, 1983). Tungsten mineralization occurs as scheelite and wolframite (Taner and Çağatay, 1983). The occurrence of tungsten at both Ikiztepe and Sukrupasa is evidence of the reaction of the parent magma with the basement monzonitic gneiss (Ohta and others, 1988). Ikiztepeler is one of the most important ore deposits in the Thrace region; historically, it was worked for copper, molybdenum and tungsten (Taner and Çağatay, 1983). From the 1970s to the early 1990s, exploration focused on part of the known skarn deposit at Ikiztepe where drilling delineated several mineralized areas (Slim, 2006). In 1978, Granges International Mining calculated a resource of 2.2 Mt at 1.17 percent copper and 0.07 percent molybdenum in the skarn and 13.5 Mt at 0.52 percent copper and 0.05 percent molybdenum of disseminated porphyry-style mineralization (News Blaze, 2007). The deposit was part of Cloudbreak Resources Ltd.’s 286 km^2 Ikiztepe-Sarp project site (Slim, 2006), as is Derekoy. In 2008, Cloudbreak Resources Ltd. of Canada withdrew options on the Ikiztepe-Sarp property; no further exploration or development has ensued because of the international economic downturn in recent years (Mobbs, 2011).

Sukrupasa Group, Turkey

At the 82 Ma Sukrupasa deposit, granodiorite porphyry intruded partly dolomitic beds, limestones, and calcic schists (News Blaze, 2007). The porphyry deposit consists of disseminated and stockwork ore (Taner and Çağatay, 1983). Drilling identified several mineralized intercepts with significant copper and molybdenum values; resources are reported as 8 Mt at 0.41 percent copper. Silicate skarn minerals are present, including wollastonite, scapolite, and corundum (Taner and Çağatay, 1983).

Prospects, Mineral Occurrences, and Related Deposit Types

The tract contains 21 porphyry copper prospects and possible porphyry-related skarns and occurrences (fig. A1). Table A4 lists in the sites in alphabetical order. Figures A3 and A4 show the relationship of porphyry, skarn, and polymetallic veins deposits to known deposits in the Banat and Timok areas, respectively. The most significant prospects are those that have been partially explored using modern exploration techniques such as Demirkoy Kavakdere in Turkey and prospects associated with the Silistar Intrusive Complex in Bulgaria.

Exploration History

Areas adjacent to thoroughly explored deposits continue to be explored in the northern parts of the tract, especially along structural trends. The southern parts of the tract are relatively underexplored because of a lower degree of erosion and more extensive cover. Modern mineral exploration techniques and concepts of ore geology started to be applied in Turkey only in the 1980s (Yigit, 2006). The government of Turkey has taken steps to improve the regulatory environment to attract foreign investors. In northwestern Turkey, porphyry and/or skarn mineralization related to Late Cretaceous magnetite series I-type granitoids were explored for porphyry Cu-Mo-Au potential, as well as epithermal gold potential, by several mining companies as of 2009 (Yigit, 2009).

Valhalla Resources Ltd. explored the Sarp property that includes the Derekoy and Ikiztepeler copper-molybdenum targets located near the Turkish-Bulgarian border. As of April 2010, the Ikiztepe-Derekoy Project was undergoing a feasibility study (Young, 2010).

Sources of Information

Principal sources of information used by the assessment team for the Transylvania-Balkan Mountains tract 150pCu6001 (EU01PC) are listed in table A5.

Table A4. Significant prospects and occurrences in tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains—Western Romania, Serbia, Bulgaria, and European Turkey.

[%, percent; g/t, grams per metric ton; Mt, million metric tons; Ma, million years; NA, not applicable; n.d., no data; See appendix H (GIS) for individual site records.]

Name	Includes	Country	Latitude	Longitude	Age (Ma)	Comments	Reference
Armutveren Karanlik-dere	NA	Turkey	41.892	27.573	n.d.	Copper prospect (Pb, Zn, Mo) associated with Late Cretaceous granodiorite. Thrace area, NW Turkey.	General Directorate of Mineral Research and Exploration (MTA) (2000), Taner and Çağatay (1983)
Bozovici	NA	Romania	44.945	22.036	65	Porphyry Cu-Au prospect. Host-rock is hypabyssal quartz monzonite porphyry in crystalline schist.	Berbeleac and others (1995), Ianovici and others (1977), Ciobanu and others (2002)
Choupetlovo	NA	Bulgaria	42.624	23.272	n.d.	Porphyry copper prospect associated with the hydrothermally-altered, Late Cretaceous Silistar Intrusive Complex in the eastern Srednogorie Zone.	Nakov and others (2002)
Cofu	NA	Romania	45.550	22.350	65	Occurs as cylindrical hypabyssal quartz diorite porphyry intruding marls.	Berbeleac and others (1995), Ianovici and others (1977)
Demirkoy Enverkule	NA	Turkey	41.927	27.576	n.d.	Late Cretaceous porphyry Cu-Mo skarn prospect.	General Directorate of Mineral Research and Exploration (MTA) (2000)
Demirkoy Kavakdere	NA	Turkey	41.846	27.841	n.d.	Resource: 500,000 metric tons at 0.43% Cu. Classified as a prospect (<20,000 t contained copper)	Erdem (2008); General Directorate of Mineral Research and Exploration (MTA) (2000)
Demirkoy Rezve	NA	Turkey	41.903	27.549	n.d.	Late Cretaceous porphyry copper-related (?) skarn prospect	General Directorate of Mineral Research and Exploration (MTA) (2000)
Demirkoy Sivriler	NA	Turkey	41.806	27.891	n.d.	Late Cretaceous porphyry copper-related (?) skarn prospect	General Directorate of Mineral Research and Exploration (MTA) (2000)
Dobro Polje	NA	Serbia	43.754	22.056	n.d.	Prospect in Late Cretaceous andesitic volcanic rocks and volcaniclastics with conglomerate, sandstone, siltstone, limestone at N end of a NNE structural zone (based on geophysics, soil geochemistry). Diorite to granodiorite intrudes andesitic volcanics. K-alteration, phyllic, argillic, propylitic. structurally-controlled advanced argillic alteration along ridges. 12 trenches, 3 short drill holes (2007): Low grade Au associated with quartz-oxide-chrysocolla/malachite stockworks. Peak assays trenched, 0.24 g/t Au, 862 ppm Cu; peak assays drilled in pyrite stockworks veinlets 0.37 g/t Au, 1071 ppm Cu.	Mazzoni and others (2010)

Table A4. Significant prospects and occurrences in tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains—Western Romania, Serbia, Bulgaria, and European Turkey.—Continued

[%, percent; g/t, grams per metric ton; Mt, million metric tons; Ma, million years; NA, not applicable; n.d., no data; See appendix H (GIS) for individual site records.]

Name	Includes	Country	Latitude	Longitude	Age (Ma)	Comments	Reference
Kiyikoy Uzunkum Kecikaya Police	NA	Turkey	41.691	28.078	n.d.	Porphyry copper prospect associated with the hydrothermally-altered , Late Cretaceous Silistar Intrusive Complex in the eastern Srednogorie Zone.	Nakov and others (2002)
Oravita Group	Oravita, Ciclova	Romania	45.073	21.717	65	Group location given for Oravita prospect; includes Ciclova prospect.Cu skarns with porphyry features. 2005 drilling at Oravita: 105 m at 0.3% Cu including 30 m at 0.54% Cu. Hypabyssal quartz diorite intruding carbonate rocks. 2005 drilling 105 m at 0.3% Cu including 30 m at 0.54% Cu.	Carpathian Gold Inc. (2006, 2009), Ciobanu and others (2002), Cioflica and Vlad (1980), Ianovici and Borcos (1982), Ianovici and others (1977), Karamata and others (1997), Nastaseanu and others (1975)
Petelovo-Kominsko Group	Petelovo, Kominsko	Bulgaria	42.455	24.264	n.d.	Location given for Petelovo; Kominsko Mountain prospect lies ~3 km NW. There are 2 total prospects. Porphyry copper prospect associated with the hydrothermally-altered, Late Cretaceous Silistar Intrusive Complex in the eastern Srednogorie Zone. May be transitional to high sulfidation epithermal system (Pesovets epithermal system in another fold 3 km S). Trenched by Euromax in 2005 (up to 75 m at 3.98 g/t Au using 0.5 g/t Au cutoff); drilling halted pending EIS.	Bogdanov (1983), Menzies (2006), Nakov and others (2002), Hikov (2004)
Plana	NA	Bulgaria	42.483	23.417	76	Sofia district, Bulgaria. Dikes of granodiorite and monzodiorite porphyry intersect the Plana pluton, which intrudes Late Cretaceous volcanic rocks. Chalcopyrite and pyrite with inclusions of bornite, tennantite, molybdenite, and cobaltite.	Bogdanov (1983, 1986), Singer and others (2008)
Radulovtsi Group	Radulovtsi, Bratoushkovo, Dragotintsi, Gourgoulyatski kamuk	Bulgaria	42.843	22.900	n.d.	Group location given for Radulovtsi prospect. Group of 4 closely spaced porphyry copper prospects associated with the hydrothermally-altered , Late Cretaceous Silistar Intrusive Complex in the eastern Srednogorie Zone.	Nakov and others (2002)

Table A4. Significant prospects and occurrences in tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains—Western Romania, Serbia, Bulgaria, and European Turkey.—Continued

[%, percent; g/t, grams per metric ton; Mt, million metric tons; Ma, million years; NA, not applicable; n.d., no data; See appendix H (GIS) for individual site records.]

Name	Includes	Country	Latitude	Longitude	Age (Ma)	Comments	Reference
Sasca	NA	Romania	44.867	21.717	65	Occurs in a series of shallow intrusions of monzodiorite and diorite to granodiorite. Cu, (Mo) are reported metals.	Cioflica and Vlad (1980), Karamata and others (1997), Vlad (1997), Singer and others (2008)
Silistar	NA	Bulgaria	42.041	27.935	n.d.	Porphyry copper prospect associated with the hydrothermally-altered, Late Cretaceous Silistar Intrusive Complex in the eastern Srednogorie Zone.	Nakov and others (2002)
Sopot	NA	Romania	44.765	21.962	65	Porphyry Cu prospect with gold	Cioflica and Vlad (1980), Ianovici and others (1977), Ciobanu and others (2002)
Tilva Skorus	NA	Bulgaria	44.031	22.000	n.d.	Prospect in the Malko-Turnovo district, Bulgaria.	Mazzoni and others (2010)
Tincova	NA	Romania	45.567	22.233	65	Host rock is quartz-diorite porphyry that penetrates crystalline schists. The setting was subvolcanic.	Cioflica and Vlad (1980), Ianovici and others (1977), Karamata and others (1997)
Uzunkum	NA	Turkey	41.695	28.076		Cu-Mo-W porphyry copper- skarn prospect. 0.015% Cu and 0.0003% Mo	General Directorate of Mineral Research and Exploration (MTA) (2000)
Velikovets	NA	Bulgaria	42.145	27.743	n.d.	Prospect in the Malko-Turnovo district, Bulgaria.	Bogdanov (1983)

Table A5. Principal sources of information used for tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains—Western Romania, Serbia, Bulgaria, and European Turkey.

[NA, not applicable]

Theme	Name or title	Scale	Citation
Geology	Geological map of Yugoslavia	1:500,000	Institute for Geological and Mining Exploration and Investigation of Nuclear and Other Mineral Raw Materials (1970)
	Geological map of Turkey, Istanbul sheet (in digital vector format)	1:500,000	General Directorate of Mineral Research and Exploration (2000)
	Geological map of Romania	1:1,000,000	Sandulescu and others (1978)
	Digitial geologic map of Europe	1:1,500,000	Cassard and others (2006)
	Mineral formations of the Carpathia-Balkan region	1:1,000,000	Bogdanov and others (1977)
	Geologic quadrangle maps of Romania	1:50,000	Maier and others (1973)
	Geologic quadrangle maps of Romania (Deva, Resita, Timişoara)	1:200,000	Cordarcea (1967), Cordacea and Dimitrescu (1967), Cordacea and Răileanu (1968)
	Geological Map of P.R. Bulgaria	1:500,000	Cheshitev and Kâncev (1989)
Mineral occurrences	Porphyry copper deposits of the world—Database, map, and grade and tonnage models	NA	Singer and others (2008)
	Mineral and energy resources of Central Europe	1;2,500,000	Dill and Saschsenhofer (2008)
	Geologic literature	NA	See references in tables A3 and A4.
	World distribution of porphyry, porphyry-related skarn, and bulk-mineable epithermal deposits	NA	Dunne and Kirkham (2003)
	Mineral Resources Data System (MRDS)	NA	U.S. Geological Survey (2009)
	Mineral deposits of Serbia—ore deposit database	NA	Ministry of Mining and Energy (2010)
	Mineral occurrences of Turkey	NA	General Directorate of Mineral Research and Exploration (2000)
	Mineral deposits of Serbia—ore deposit database	NA	Monthel and others (2002)
Geophysics	Eastern Europe (reduced to pole aeromagnetics)	NA	National Geophysical Data Center (2009; J. Philipps (written commum., 2010)

Grade and Tonnage Model Selection

Four of the 15 known porphyry copper deposits in tract are classified as porphyry copper-gold subtype based on average gold grades of 0.2 g/t or more. Five deposits have reported average gold grades <0.2 g/t and no gold grades are reported for the others (table A3). Statistical tests (*t*-tests) of the tonnages and grades for the 14 deposits compared with the general Cu-Au-Mo and Cu-Au subtype models of Singer and others (2008) showed that the general model could be applied for tonnage and copper- and gold grades (table 4). The Cu-Au subtype model failed the *t*-test for gold and silver at 1-percent screening level. Test results indicate weak significance (that is, p values <0.1) for copper grade compared with global models (table 4). The general Cu-Au-Mo grade-tonnage model was adopted for the simulation of undiscovered resources, with the recognition that the known deposits in the tract tend to be lower in copper grade than the deposits in global models.

Rationale for the Estimate

Estimates of numbers of undiscovered deposits were made at a workshop in July 2010. Individual estimates were made privately, recorded, and then discussed to arrive at a consensus estimate (table A6). Positive factors for additional deposits included the fact that although the area has a long history of exploration, modern exploration concepts have not been applied everywhere. In addition, there are large deposits and 21 known prospects, including five prospects with preliminary reported grades or tonnage information from past drilling or trenching (table A4). Complex structural geology, which may have localized hydrothermal fluids, characterizes the tract. Negative factors include: (1) many prospects are inadequately characterized and may simply represent “manifestation of ore”, (2) poor outcrop, (3) uncertain quality of historical data, and (4) social and environmental constraints that have limited exploration and development.

Low individual estimates reflected the belief that with 15 known deposits in the tract, the probability of additional deposits was greatly reduced. High individual estimates were based on consideration of the number of the porphyry prospects (table A4) that could, if fully explored, represent deposits like those already discovered. In addition, possible related deposit types (skarns), historical small-scale mining, and favorable structural setting were considered in arriving at estimates.

Table A6 shows the individual and team estimates for undiscovered porphyry copper deposits in tract EU01PC at the 90, 50, 10 probability levels and summary statistics. The mean numbers of undiscovered deposits calculated from the probabilistic estimates ranged from 3.0 to 8.5 deposits. The consensus team estimate of 2, 3, and 8 undiscovered deposits for the 90-, 50-, and 10-percent probability levels results in a mean of 4.1 undiscovered deposits.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered porphyry copper deposits with the general porphyry Cu-Mo-Au grade and tonnage model (Singer and others, 2008) using the EMINERS program (Root and others, 1992; Duval, 2012; Bawiec and Spanski, 2012). Selected output parameters are reported in table A7. Results of the Monte Carlo simulation are presented as a cumulative frequency plot (fig. A5). The cumulative frequency plots show the estimated resource volumes associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock. The mean copper associated with undiscovered deposits, 16 Mt, represents about half of the 31 Mt of identified copper resources in the tract.

Table A6. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains—Western Romania, Serbia, Bulgaria, and European Turkey.

[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; km^2, area of permissive tract in square kilometers; N_{total}/km^2, deposit density reported as the total number of deposits per km^2; $N_{total}/100k\ km^2$, 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).]

Assessor	Consensus undiscovered deposit estimates			Summary statistics					Tract area (km^2)	Deposit density (N_{total}/100k km^2)
	N_{90}	N_{50}	N_{10}	N_{und}	s	C_v%	N_{known}	N_{total}		
A	3	8	14	8.1	4.0	49	15	23.1	28,500	81
B	2	3	9	4.4	2.8	64	15	19.4	28,500	68
C	0	3	6	3	2.1	71	15	18	28,500	63
D	2	2	7	3.4	2.1	63	15	18.4	28,500	65
E	2	8	16	8.5	5.0	59	15	23.5	28,500	82
Consensus	2	3	8	4.1	2.4	59	15	19.1	28,500	67

Table A7. Results of Monte Carlo simulations of undiscovered resources for tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains—Western Romania, Serbia, Bulgaria, and European Turkey.

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

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu	250,000	950,000	8,200,000	36,000,000	57,000,000	16,000,000	0.29	0.04
Mo	0	0	130,000	1,000,000	1,800,000	440,000	0.24	0.13
Au	0	0	170	990	1,400	390	0.29	0.11
Ag	0	0	1,400	11,000	21,000	5,100	0.24	0.21
Rock	69	230	1,800	7,400	11,000	3,200	0.3	0.04

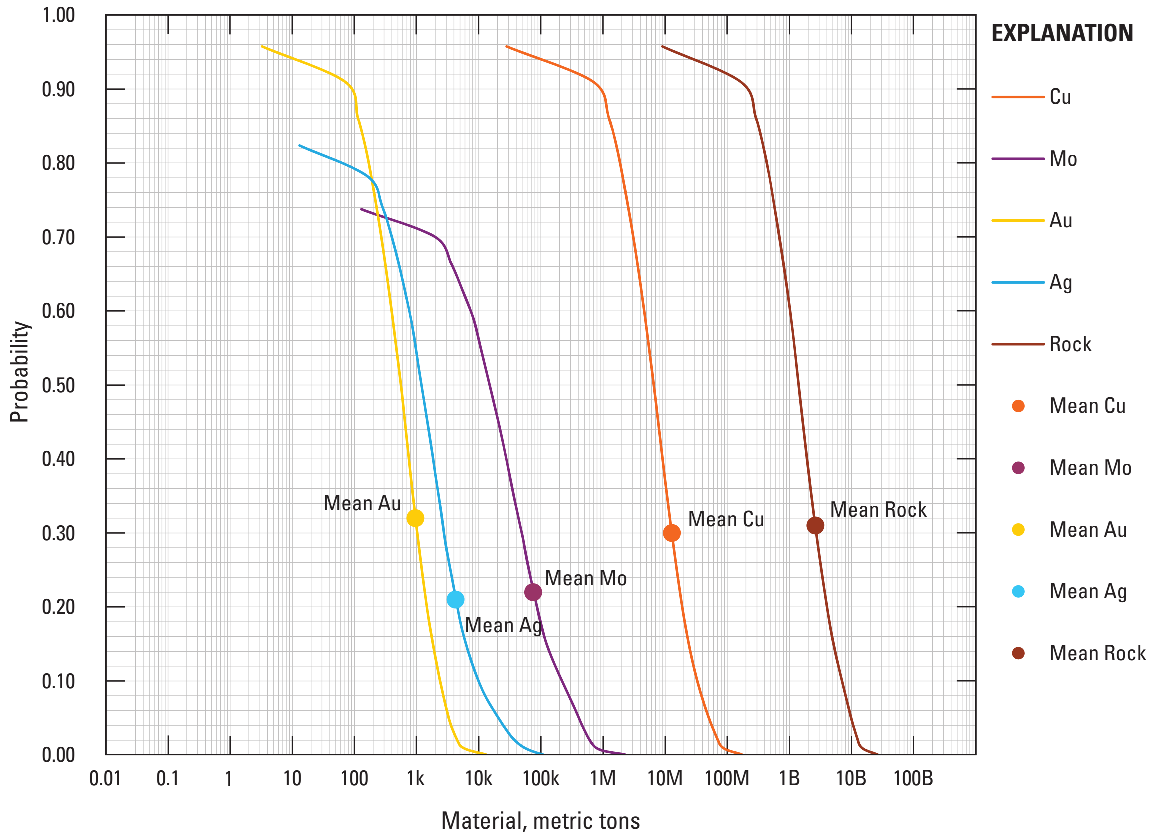

Figure A5. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in porphyry copper deposits in tract 150pCu6001 (EU01PC), Transylvania-Balkan Mountains—Western Romania, Serbia, Bulgaria, and Western Turkey. k, thousand; M, million; B, billion.

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Appendix B. Porphyry Copper Assessment for Tract 150pCu6002 (EU02PC), Dinaride-Aegean Region—Italy, Slovenia, Croatia, Hungary, Bosnia and Herzegovina, Serbia, Kosovo, Macedonia, Bulgaria, Greece, and Turkey

By David M. Sutphin[1], Lawrence J. Drew[1], Duncan E. Large[2], Byron R. Berger[3], and Jane M. Hammarstrom[1]

Deposit Type Assessed: Porphyry Copper, Copper-Gold Subtype

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

Table B1. Summary of selected resource assessment results for tract 150pCu6002 (EU02PC), Dinaride-Aegean Region—Italy, Slovenia, Croatia, Hungary, Bosnia and Herzegovina, Serbia, Kosovo, Macedonia, Bulgaria, Greece, and Turkey.

[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	92,700	7,251,100	12,000,000	5,700,000

Location

The tract extends over a distance of about 1,000 km from northern Italy and Switzerland eastward across Slovenia to Hungary, and southward across Serbia, Macedonia, through Greece and the Greek islands in the Aegean Sea (fig. B1).

Geologic Feature Assessed

An assemblage of Paleocene to Miocene calc-alkaline volcanic and intrusive rocks that formed in a postsubduction environment; includes the Serbomacedonian-Rhodope metallogenic belt.

[1]U.S. Geological Survey, Reston, Virginia, United States.
[2]Independent consulting geologist, Braunschweig, Germany and London, United Kingdom.
[3]U.S. Geological Survey, Denver, Colorado, United States.

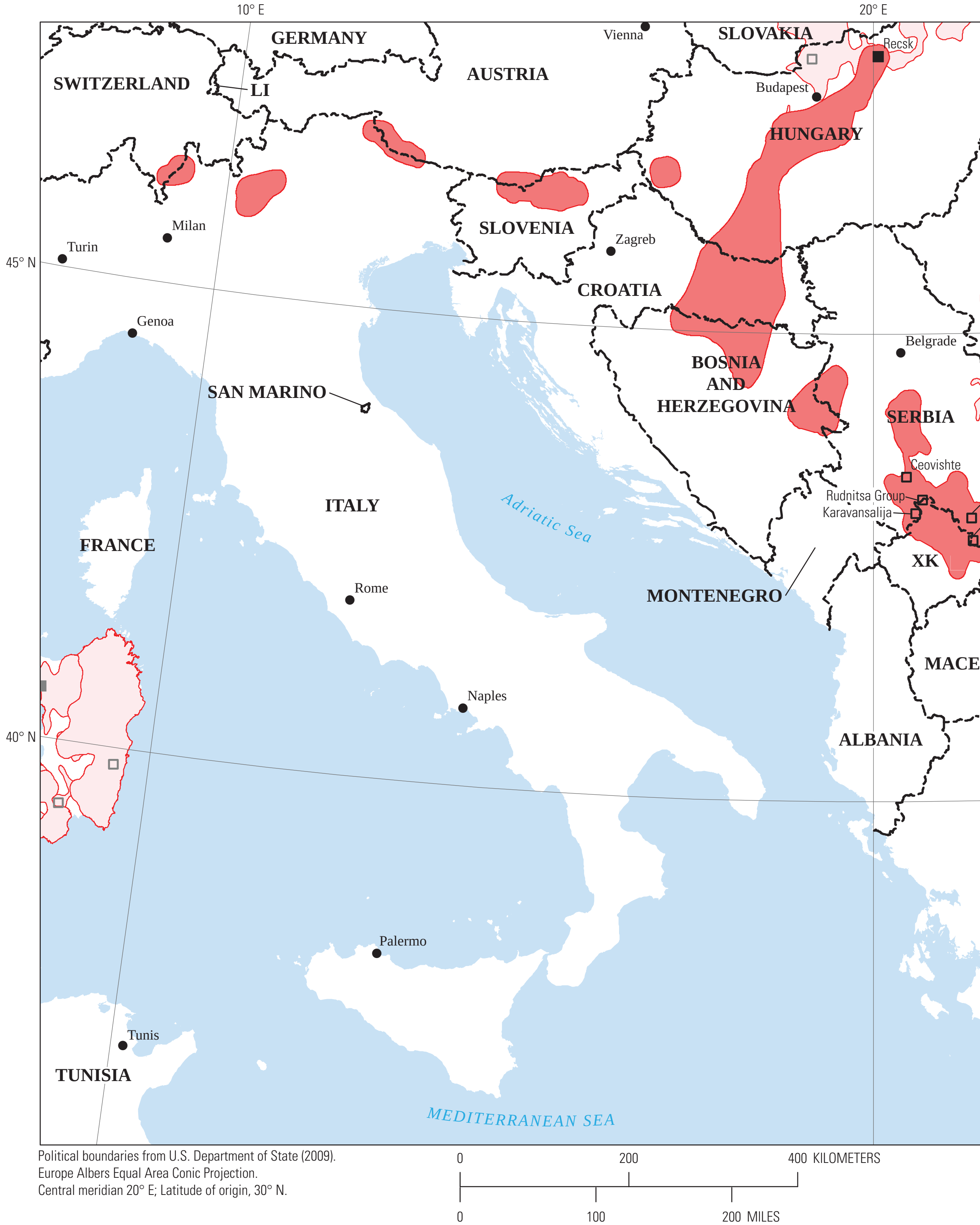
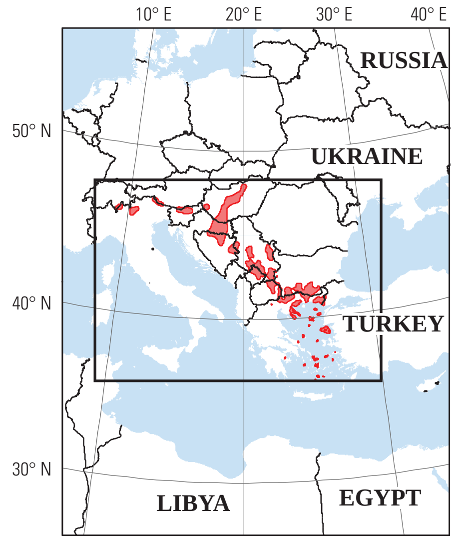


Figure B1. Map showing the location, known deposits, and significant prospects and occurrences for permissive tract 150pCu6002 (EU02PC), Dinaride-Aegean Region—Italy, Slovenia, Croatia, Hungary, Bosnia and Herzegovina, Serbia, Kosovo, Macedonia, Bulgaria, Greece, and Turkey.



EXPLANATION

Porphyry copper

Assessed porphyry copper tract 150pCu6002

Other porphyry copper tracts

■ **Porphyry copper deposit; deposits associated with other tracts shown in gray**

□ **Porphyry copper prospect; prospects associated with other tracts shown in gray**

Delineation of the Permissive Tract

Tectonic Setting

The tract delineates permissive Paleocene to early Miocene igneous rocks that extend from northern Italy through the Dinaric Alps (fig. 1[4]) in Slovenia, Hungary, Croatia, Bosnia and Herzegovina, and cut across the Internal Hellenides of Serbia, Bulgaria, Macedonia, and Greece. The tract crosses the Internal Hellenides part of the Alpine-Himalayan orogenic belt, which includes the following tectonostratigraphic zones, from west to east: the Pelagonian Zone, the Vardar Zone, the Serbo-Macedonian Massif, and the Rhodope Massif (fig. 8). The Vardar Zone consists of an assemblage of oceanic and continental rocks and syn- to post-collisional magmatic rocks that range from Late Cretaceous to Miocene (Zelic and others, 2010). The Vardar Zone is interpreted as the suture marking the closure of the Neotethys Ocean following collisions between the Adriatic and Eurasian Plates in the Late Cretaceous (Tremblay and others, 2010; Zelic and others, 2010).

The tract is defined by Eocene, Oligocene, and Miocene felsic and intermediate intrusions and volcanic rocks (fig. B2) that formed in a postcollisional or extensional setting. The northernmost, east-west part of the belt from Switzerland and Italy east to Hungary is based on the occurrence of permissive rocks dated as Paleogene, as compiled by Kovács and others (2007). The southern part of the belt corresponds to the Serbomacedonian-Rhodope metallogenic belt (see fig. 9), which trends southeasterly from Serbia through eastern Macedonia and western Bulgaria and Greece to the Aegean Sea and to western Turkey (Heinrich and Neubauer, 2002; Janković and others, 1980; Dumurdzanov and others, 2005). These magmatic arcs and the Pliocene to Holocene active arc are related to the retreating subduction zone to the south and west of the Aegean Sea and related areas of back-arc extension (Dumurdzanov and others, 2005).

Geologic Criteria

Preliminary tracts were identified by outlining areas of interest on printed paper maps. The final tract was constructed by processing geologic data from the enhanced digital geologic map of permissive igneous rocks prepared for the study (Cassard and others, 2006), as follows:

- Permissive igneous lithologies in map units attributed as Paleocene, Eocene, Oligocene, and Miocene, or including rocks as young as Miocene were selected from the 1:1,500,000-scale enhanced digital geologic map of Europe (Cassard and others, 2006). Additional permissive map units were digitized from maps listed in table B2.
- A prototract was developed by placing a 10-km-wide buffer around permissive intrusive rocks and a 2-km buffer around permissive volcanic rocks. This expanded the area of the tract to include most porphyry copper deposits and significant associated prospects.
- Aggregation and smoothing routines were applied to the resulting polygons, and the tract was edited manually to honor fault boundaries and exclude any non-permissive rocks and areas where the thickness of cover is known to be >1 km.
- Locations of Paleocene to early Miocene porphyry copper deposits and prospects were examined. In cases where a deposit or prospect fell outside of the tract, the tract was extended to include the deposit or prospect area. In many cases, the igneous rocks associated with a deposit or prospect may not be represented at the available map scales; scanned and rectified page-size illustrations from the literature were incorporated into the GIS to check locations and refine permissive rock boundaries.
- Ground magnetic data reported on Web sites for some exploration projects, such as Ilovitza in Macedonia (Euromax Resources Limited, 2011) and Skouries and Fisoka in Greece (European Goldfields, 2011) help define shallow buried intrusions and the subsurface extent of mapped permissive rocks.

Finally, any areas that are intruded by late Miocene and younger intrusions were excluded and the final tract polygons were clipped to the shoreline to eliminate undersea areas (U.S. Department of State, 2009). The final tract consists of a series of discrete polygons, as shown in figure B1. Permissive units and source maps are listed in table B2.

Known Deposits

The Dinaride-Aegean tract 150pCu6002 (EUPC02) contains four known porphyry copper deposits (fig. B1, table B2). Deposits within the tract are described from north to south. See references listed in table B3 for more detailed information about each deposit.

Recsk, Hungary

The Recsk (Lahóca) porphyry and epithermal ore complex in the Mátra Mountains of the Inner Carpathians in Hungary was recognized as a mineralized area early as 1763, and mined intermittently until 1979 (Seres-Hartai, 1998; Tóth and Bobok, 2007). The economic value of the gold in the deposit was not recognized until production ceased, which led to exploration and drilling focused on the epithermal parts of the system in the 1990s (Földessy and others, 2004).

[4]Refers to figures and tables in the main report.

The late Eocene Recsk porphyry underlies the Lahóca high-sulfidation epithermal copper-gold deposit. The porphyry parts of the complex are in diorite porphyry, part of a post-syncollisional Eocene arc localized along the Periadriatic-Balaton Lineament (fig. 15), a major tectonic zone. The Balaton Line, north of the Mid-Hungarian Line, represents an eastward continuation of the Periadriatic Line, a structurally significant Alpine fault zone. Like the Periadriatic Fault (Line), the Balaton strike-slip zone was accompanied by multiple stages of Paleogene calc-alkaline magmatism (Benedek, 2002), including in the Recsk region, where Eocene magmas intruded along a pre-existing shear zone in an older horst block (Földessy and others, 2004).

High grade copper-gold skarn overprints porphyry mineralization in propylitically altered zones; molybdenite is present in silica-anhydrite veins in peripheral parts of the ore body (Seres-Hartai, 1998). Gold occurs in both epithermal (breccias, andesite pipes, quartz-adularia veins, distal sediment-hosted mineralization in shale) and mesothermal (porphyry copper, copper skarn, zinc skarn) deposits within the Recsk ore system (Földessy and others, 2004).

Bucim Group, Macedonia

Bucim is a producing copper-gold porphyry deposit in the Radovis district of east Macedonia in the Serbo-Macedonian metallogenic province. At Bucim, chalcopyrite, gold, pyrite, bornite, covellite, chalcocite, and native copper are present as disseminated ore and as mineralized stockworks associated with an andesite stock in basement gneiss (Serafimovski and Tasev, 2006). Alteration types include potassic, sericitization, neobiotitization, and silicification.

The deposit was discovered in 1955 and went into production in 1979. At the end of 2008, Russian mine owners temporarily closed the Bucim mine because of the low price of copper (Brininstool, 2010). A new SX-EW project was slated to produce cathode copper from stockpiled overburden and oxidized ore (average 0.2–0.3 percent copper) in 2011 (Solway Group, 2011).

Ilovitza, Macedonia

Ilovitza is the site of historical mining of silica-iron and silica-alunite bodies for base metals and gold adjacent to a pervasively altered intrusive complex. The deposit was drilled in 2004 through 2006 and in 2008, which led to delineations of CIM-compliant inferred mineral resources of 303 Mt of sulfide resources at 0.23 percent copper, 0.32 g/t gold, and 0.005 percent molybdenum (Euromax Resources Limited, 2011). The following description of the Ilovitza project area is based on a technical report prepared for Euromax Resources Limited (Carter, 2008).

The deposit is located between north-northwest-striking Tertiary magmatic-related mineral belts. The deposit occurs in a roughly circular, altered and mineralized, medium-grained granodiorite intrusion and intrusive breccia complex of probable Tertiary age intruded into lower Paleozoic granite. The grain-size of the intrusion grades vertically from coarse (granodiorite) to fine (dacite), and an intrusive breccia is cut by numerous dacite-granodiorite dikes. Porphyry copper-gold-molybdenum mineralization is recognized at the surface by a limonitic leached stockwork with anomalous gold, copper, and molybdenum values; advanced argillic alteration is present, and high-sulfidation breccias and veins occur in association with the porphyry system. Coarse molybdenite occurs in quartz veinlets. Although magnetite is uncommon at the surface, the subsurface ore body is expressed as a magnetic high. A 9–70 m-thick supergene zone (0.25–0.69 percent copper as chalcocite and covellite) separates the leached cap and the sulfide ore body.

Skouries Group, Greece

At the Skouries porphyry copper-gold deposit, a 19 Ma porphyritic, calc-alkaline stock intruded amphibolite, mica schist, and two-mica gneiss (Eliopoulos and Economou-Eliopoulos, 1991). Four or more hypabyssal, pipe-like, shoshonitic monzonite porphyry intrusive phases are cut by barren late-stage monzonite dikes (Kroll and others, 2002). The rocks have undergone silicification, but potassic alteration predominates; phyllic and propylitic alteration types are less common (Eliopoulos and Economou-Eliopoulos, 1991). Azurite and malachite indicated copper mineralization, but chalcopyrite, bornite, and chalcocite are the main economic minerals in veins, stockworks, and disseminations (Kockel and others, 1975). Gold and electrum are present as inclusions in chalcopyrite (Eliopoulos and Economou-Eliopoulos, 1991). Platinum group elements are significantly enriched at Skouries. The deposit is estimated to contain 10 t palladium and 2.2 t platinum which possibly were contributed by assimilation of the mafic and ultramafic country rocks at depth prior to emplacement (Economou-Eliopoulos and others, 2001). As of 2007, Skouries was being developed to produce a Cu-Au concentrate and doré (gold bullion bars) over a 22-year mine life (Beare and others, 2007).

Skouries shares characteristics with other porphyry copper-gold deposits (Kroll and others, 2002; Sillitoe, 1979), including well-developed potassic (highest gold) and phyllic alteration zones, indications of oxidized magmas (anhydrite and magnetite), and association with alkaline magmas. Two prospects are spatially associated with the Skouries deposit, Tsikara and Katsoures. Because of their proximity to Skouries, they are included as part of the Skouries Group.

Prospects, Occurrences, and Related Deposit Types

Information on 20 porphyry copper prospects, occurrences, and related deposit types is listed in table B4; locations are plotted on figure B1. The most significant porphyry copper prospects are the active (2011) exploration projects at Fisoka, Greece; the Kadiica-Osogovo area in Macedonia; and Rudnitsa and Tulare in Serbia. The Mackatica molybdenum

Figure B2. Map showing the distribution of permissive intrusive and volcanic rocks used to delineate tract 150pCu6002 (EU02PC), Dinaride-Aegean Region—Italy, Slovenia, Croatia, Hungary, Bosnia and Herzegovina, Serbia, Kosovo, Macedonia, Bulgaria, Greece, and Turkey. See table B2 for data sources.

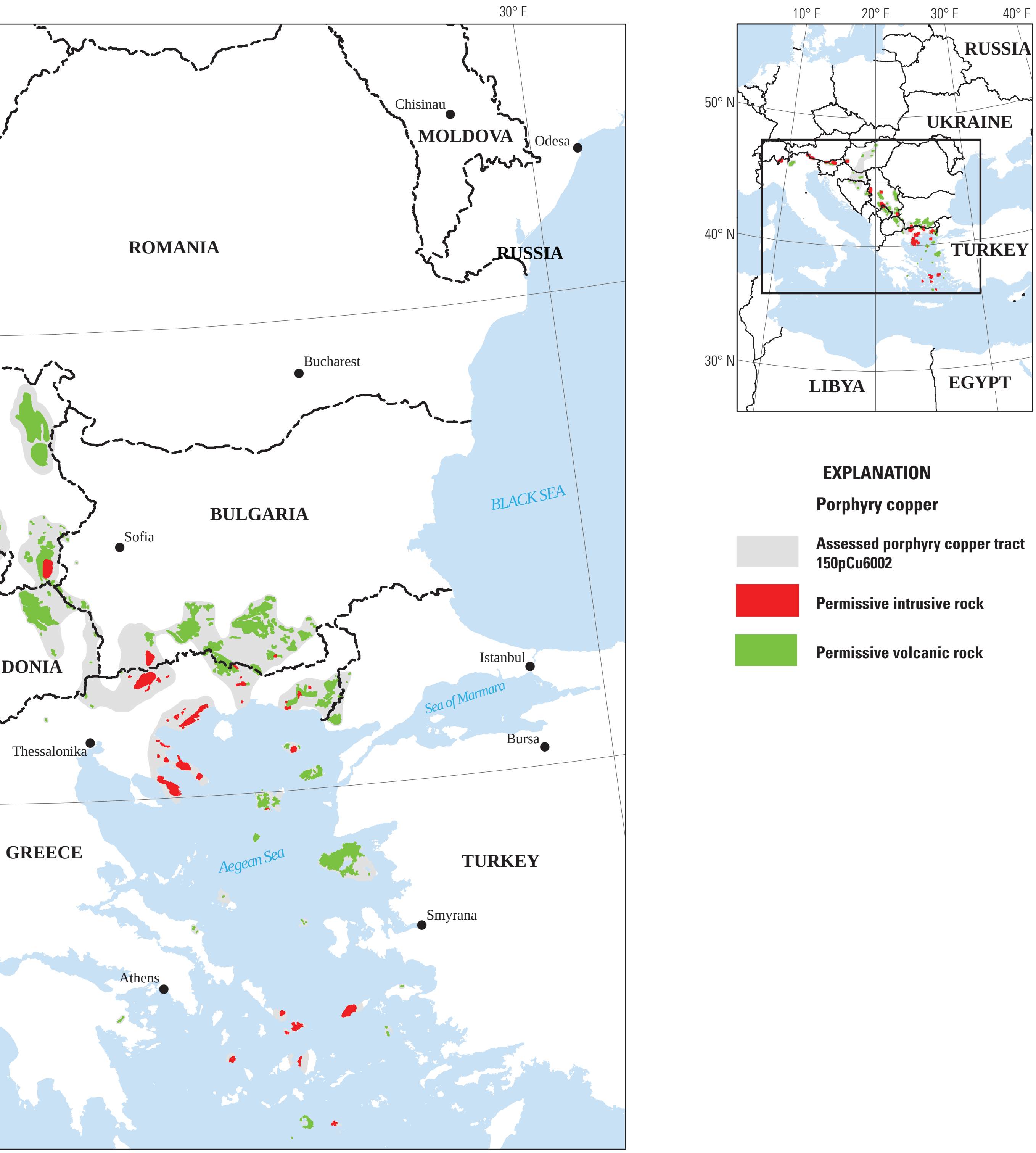

30° E
ROMANIA
MOLDOVA
Chisinau
Odesa
RUSSIA
Bucharest
BULGARIA
Sofia
BLACK SEA
DONIA
Istanbul
Sea of Marmara
Bursa
Thessalonika
GREECE
Aegean Sea
TURKEY
Smyrana
Athens
10° E
20° E
30° E
40° E
50° N
40° N
30° N
RUSSIA
UKRAINE
TURKEY
LIBYA
EGYPT
EXPLANATION
Porphyry copper
Assessed porphyry copper tract 150pCu6002
Permissive intrusive rock
Permissive volcanic rock

Table B2. Map units that define tract 150pCu6002 (EU02PC), Dinaride-Aegean Region—Italy, Slovenia, Croatia, Hungary, Bosnia and Herzegovina, Serbia, Kosovo, Macedonia, Bulgaria, Greece, and Turkey.

[Map unit, age range, and principal lithologies are based on Cassard and others (2006) 1:1,500,000 digital geologic map units and scanned and rectified paper maps at larger scales. Ma, million years.]

Map symbol	Lithology	Age range	Source map
		Intrusive rocks	
23, 22-23	Granitoid (granite, leucogranite, granodiorite, etc.)	Oligocene 33.5–23.5 Ma	Cassard and others (2006)
γ3	Granites, granodiorites, monzonites	Various ages from Paleocene-Miocene 65–23.5 Ma	Bornovas and Rondogianni-Tsiambaou, (1983)
		Volcanic rocks	
αα qN	Dacite, andesite	Neogene	Institute for Geological and Mining Exploration and Investigation of Nuclear and other Mineral Raw Materials (1970); Skopje sheet
epvi	Dominantly intermediate pyroclastic rocks	Paleogene 65–33.7 Ma	Cassard and others (2006)
ev1	Dominantly volcanic and volcano-plutonic intermediate rocks	Paleogene 65–33.7 Ma	Cassard and others (2006)
ev2	Dominantly intermediate pyroclastic rocks	Paleogene 65–33.7 Ma	Cassard and others (2006)
gmva	Dominantly acidic pyroclastic rocks	Oligocene 33.5–23.5 Ma	Cassard and others (2006)
gmvi	Dominantly volcanic and volcano-plutonic intermediate rocks	Oligocene 33.5–23.5 Ma	Cassard and others (2006)
mp	Dominantly volcanic and volcano-plutonic acidic rocks	Miocene-Pliocene 23.5–1.75 Ma	Cassard and others (2006)
mpv	Dominantly acidic pyroclastic rocks	Miocene-Pliocene 23.5–1.75 Ma	Cassard and others (2006)
mpvi	Dominantly volcanic and volcano-plutonic intermediate rocks	Miocene-Pliocene 23.5–1.75 Ma	Cassard and others (2006)
mv	Dominantly pyroclastic rocks and volcanic and volcano-plutonic rocks	Miocene 23.5–5.3 Ma	Cassard and others (2006)
mva	Dominantly volcanic and volcano-plutonic acidic rocks	Miocene 23.5–5.3 Ma	Cassard and others (2006)
mvi	Dominantly volcanic and volcano-plutonic intermediate rocks	Miocene 23.5–5.3 Ma	Cassard and others (2006)
pqva	Dominantly pyroclastic rocks	Pliocene-Quaternary 5.3–0 Ma	Cassard and others (2006)
pqva	Dominantly volcanic and volcano-plutonic acidic rocks	Pliocene–Quaternary 5.3–0 Ma	Cassard and others (2006)
ρ1, τ1	Tuffs, ignimbrites	Eocene-Oligocene	Bornovas and Rondogianni-Tsiambaou, (1983)
ρ2, τ2	Rhyolites, rhyodacites, dacites, andesites, trachyandesites, trachytes	Miocene-Pliocene 23.5–1.75 Ma	Bornovas and Rondogianni-Tsiambaou, (1983)

Table B3. Porphyry copper deposits in tract 150pCu6002 (EU02PC), Dinaride-Aegean Region—Italy, Slovenia, Croatia, Hungary, Bosnia and Herzegovina, Serbia, Kosovo, Macedonia, Bulgaria, Greece, and Turkey.

[Group names in boldface. Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; n.d., no data. Cu-Au subtype, deposits that have Au/Mo ratios >30 or average Au grades >0.2 g/t; no data for silver]

Name	Includes	Country	Latitude	Longitude	Subtype	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Contained Cu (t)	Reference
Bucim Group	Bucim deposit; Damjan prospect	Macedonia	41.667	22.349	Cu-Au	23	150	0.30	n.d.	0.35	450,000	Bogdanov (1983, 1986), Bonev and others (1989), Serafimovski and others (1996), Serafimovski and Cifliganec, 2006), Serafimovski and Tasev, 2006), Solway Group (2011),Volkov and others (2010)
Ilovitza	NA	Macedonia	41.462	22.843	Cu-Au	Tertiary	303	0.23	0.005	0.32	700,000	Canby and others (2007), Carter (2008), Euromax Resources Ltd. (2011)
Recsk	NA	Hungary	47.939	20.078	Cu-Au	36	700	0.66	0.005	0.28	4,600,000	Baksa and others (1980), Földessy and others (2004), Gatter and others (1999), Herrington and others (2003), Hungarian Geological Survey (2002), Magyar Mining Plc. (2007), Molnár (2007), Morvai (1982), Seres-Hartai (1998)

Table B3. Porphyry copper deposits in tract 150pCu6002 (EU02PC), Dinaride-Aegean Region—Italy, Slovenia, Croatia, Hungary, Bosnia and Herzegovina, Serbia, Kosovo, Macedonia, Bulgaria, Greece, and Turkey.—Continued

[Group names in boldface. Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; n.d., no data. Cu-Au subtype, deposits that have Au/Mo ratios >30 or average Au grades >0.2 g/t; no data for silver]

Name	Includes	Country	Latitude	Longitude	Subtype	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Contained Cu (t)	Reference
Skouries Group	Skouries deposit; 2 prospects: Tsikara, Katsoures	Greece	40.472	23.704	Cu-Au	19	362	0.41	n.d.	0.53	1,500,000	Anonymous (1997), Eliopoulos and Economou-Eliopoulos (1991), Economou-Eliopoulos and others (2001), Economou-Eliopoulos and Eliopoulos (2005), European Goldfields (2011), Frei (1995), Gilg and Frei (1994), Kockel and others (1974), Koloceropoulus and others (1989), Kroll and others (2002), Lips and others (2006), Pe-Piper and Piper (2002), Tarkian and Stribrny (1999)

Table B4. Significant prospects and occurrences in tract 150pCu6002 (EU02PC), Dinaride-Aegean Region—Italy, Slovenia, Croatia, Hungary, Bosnia and Herzegovina, Serbia, Kosovo, Macedonia, Bulgaria, Greece, and Turkey.

[Group names in boldface. Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; ppm, parts per million (=g/t); ppb, parts per billion; n.d., no data.]

Name	Includes	Country	Latitude	Longitude	Age (Ma)	Comments	Reference
Ceovishte	NA	Serbia	43.478	20.485	n.d.	Large areas of intense hydrothermal alteration have been mapped in the 48 km^2 license area and three base and precious metal prospects have been identified.	Euromax Resources Limited (2008)
Djavolja Varos	NA	Serbia	43.034	21.425	Neogene	Gold mineralization at Djavolija Varos is found in veins and silicified breccia of the adularia-sericite.	Monthel and others (2002)
Fakos	NA	Greece	39.812	25.192	21	Chip samples contain as much as 11 g/t Au, 11.3 g/t Ag, 780 ppm Cu, 3500 ppm Pb, 256 ppm Zn, 4630 ppm As, 83 ppm Mo.	Voudouris (2006), Voudouris and Alferis (2005)
Fisoka Group	Fisoka, Fisoka South, Dilofon, Dilofan East, Alatina	Greece	40.489	23.772	23	Tonnage (20 Mt) and grade (0.47% Cu, 0.16 g/t Au) reported as reserves for Fisoka by Lips and others (2006). However, only supergene zone has been drilled; deposit is open; 2011 exploration by European Goldfields on magnetic targets. At Fisoka, several bodies within 1,000 by 600 m, strong alteration, fissures with iron oxides and gossan; max 3,400 ppm Cu in hard-rock samples; max 3,200 ppm Cu in soil samples. Alteration, dikes, anomalous Cu in soil and rock samples. K-Ar age for diorite porphyry.	Anonymous (1997d), Eliopoulos and Economou-Eliopoulos (1991), Economou-Eliopoulos and Eliopoulos (2000, 2005), Economou-Eliopoulos and others (2001), European Goldfields (2011), Frei (1995), Gilg and Frei (1994), Kockel and others (1975), Koloceropoulus and others (1989), Kroll and others (2002), Tarkian and Stribrny (1999), Lips and others (2006), Pe-Piper and Piper (2002)
Jerakario Group	Jerakario, Vathi, Divounon	Greece	41.117	22.922	18	Group location given for Jerakario prospect; 2 adjacent prospects. U-Pb zircon age on Vathi quartz monzonite 18±2 Ma.	Kockel and others (1975), Reeves and others (1986)
Kadiica-Osogovo Group	Kadiica, Osogovo	Macedonia	41.800	22.867	23	Location given for Kadiica prospect; Osogova prospect lies ~3 km to the west. Kadiica-Bukovic: 9 km^2 hydrothermal alteration associated with dacite dome, intrusion breccia, granodiorite porphyry dikes. Intersections of the well-developed supergene blanket: 52.3 m at 0.4% Cu; 21 m at 0.77% Cu; 116 m at 0.27% Cu. Explored by the State for copper 1984–1985 (mapping, soil, IP, no drilling). PD sampling of Kadiica intrusive complex, soils, and stream sediments in 2001–2002. Drilling by Sirius Exploration 2005. Osogova: Weak supergene zone. Prominent intersections: 16.4 m at 1.7% Cu, 20 g/t Ag; 31.5 m at 0.32% Cu.	Canby and others (2003, 2007), Sirius Exploration Plc (2005), Volkov and others (2008)

Table B4. Significant prospects and occurrences in tract 150pCu6002 (EU02PC), Dinaride-Aegean Region—Italy, Slovenia, Croatia, Hungary, Bosnia and Herzegovina, Serbia, Kosovo, Macedonia, Bulgaria, Greece, and Turkey.—Continued

[Group names in boldface. Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; ppm, parts per million (=g/t); ppb, parts per billion; n.d., no data.]

Name	Includes	Country	Latitude	Longitude	Age (Ma)	Comments	Reference
Karavansalija	NA	Serbia	43.088	20.612	n.d.	Skarn outcrop around unexposed intrusion; may be porphyry system at depth.	Carter (2008)
Kassiteres Group	Kassiteres, Koryfes Hill, St. Demetrios	Greece	41.023	25.788	24	Group location given for Kassiteres prospect. Series of HS-IS epithermal -porphyry prospects. Includes St. Demetrios, St. Barbara. Calc-alkalic to high-K calc-alkalic andesitic to dacitic volcanics, porphyry. Silicic, argillic, sericitic alteration. Telluride-rich minerals; epithermal-porphyry transitional setting.	Voudouris (1993, 1997, 2006), Voudouris and others (2003, 2006), Voudouris and Alfieris (2005)
Korifi Group	Korifi, Akritas, Doirani, Drosaton, Gavra, Monolith I, II, and III	Greece	41.164	22.833	Tertiary	Group location given for Korifi Prospect. There are 8 prospects in a 10-km long east-west group. Variably altered areas with anomalous Cu in soil and rock.	Kockel and others (1975)
Mackatica (Surdulica)	NA	Serbia	42.747	22.217	n.d.	Porphyry molybdenum deposit in Dunav Resources Ltd's. Surdulica project. Rhenium-rich molybdenite. Indicated and inferred resources: 383 Mt at 0.03% Mo; minor chalcopyrite present but no Cu resources reported.	Corley and others (2010), Monthel and others (2002)
Maronia	NA	Greece	40.867	25.555	29	Chip samples: 7,600 ppm Mo, 5,460 ppm Cu; drill hole intersection 10 m at 12 g/t Au, 17 g/t Ag, 2.0% Cu. Rhenium in molybdenite 0.12 to 4.12%. The prospect is hosted in Tertiary porphyritic microgranite. Three hydrothermal alteration zones have been recognized in the porphyritic microgranite--argillic, phyllic, and propylitic.	Melfos and others (2002), Voudouris and others (2003)
Pagoni Rachi	NA	Greece	41.011	25.884	n.d.	Porphyry type Cu-Mo prospect. Quartz stockworks overprinted by quartz-carbonate polymetallic veins with tellurides in calc-alkalic dacite andesite porphyry. Early K-Na-silicate and propylitic alteration with magnetite, bornite, chalcopyrite, molybdenite, pyrite, quartz, biotite, sericite; late sericite-chlorite. Molybdenite contains up to 4.21% Re.	Voudouris and others (2006)
Pontokerassia Group	Koukouta Lofos, Didimi Lofi, Pontokerassia	Greece	41.044	23.208	32	Reported grades: 0.2–0.6% Cu, 10 ppb Pt, 60 ppb Au for Pontokerassia. Location at Pontokerassia; 2 other prospects along a SE trend at intrusive bodies with weak to moderate alteration. Oligocene and early Miocene magmatism	Economou-Eliopoulos and Eliopoulos (2000), Jankovič and others (1980), Kockel and others (1974)

Table B4. Significant prospects and occurrences in tract 150pCu6002 (EU02PC), Dinaride-Aegean Region—Italy, Slovenia, Croatia, Hungary, Bosnia and Herzegovina, Serbia, Kosovo, Macedonia, Bulgaria, Greece, and Turkey.—Continued

[Group names in boldface. Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; ppm, parts per million (=g/t); ppb, parts per billion; n.d., no data.]

Name	Includes	Country	Latitude	Longitude	Age (Ma)	Comments	Reference
Rudnitsa Group	Rudnitsa (Rudnitza), Plavkovo	Serbia	43.233	20.717	14	Location for Rudnitsa prospect. Rudnitsa: Porphyry Cu intersections: 144 m of sulfide ore at 0.4% Cu and 0.38 g/t Au; 88 m at 0.26% Cu and 0.44 g/t Au. Pb-Zn-Ag intersections: 8 m at 7.11% Pb, 3.37% Zn, 108.0 g/t Ag; 4 m at 9.21% Pb, 11.19% Zn, 229 g/t Ag. Exposed. The property has the potential to host a large porphyry Cu-Au deposit (Euromax Resources, 2007). Plavkovo: Au-Cu prospect in Vardar Zone, adjacent to Rudnitsa porphyry Cu-Au prospect. 150-m-wide zone of sulfide-quartz veins in structurally-controlled zone of argillically altered andesites. Outcrop chip and 4 trenches sampled: trench results 16.2 m of 0.21% Cu; 14m of 0.49% Cu; up to 1.41 ppm Au.	Euromax Resources Ltd. (2007), Kozelj and others (2007), Reservoir Capital (2011)
Sardes	NA	Greece	39.975	25.186	n.d.	Au grades reach 1.1 ppm, Cu 200 ppm, Pb 200 ppm, Zn 130 ppm, and As 1,400 ppm	Voudouris and Alfieris (2005)
Sasa	NA	Macedonia	42.107	22.543	n.d.	A Pb-Zn skarn mine adjacent to the Osogovo porphyry Cu prospect	Hoodless Brennan (2006)
Sijarinska Banja	NA	Serbia	42.776	21.623	n.d.	Au mineralization at Sijarinska Banja is found in veins and silicified breccia of the adularia-sericite type, developed in hydrothermally altered andesite and pyroclastic rock.	Monthel and others (2002)
Spahievo	NA	Bulgaria	41.739	25.314	33	Anomalous contents: 800 ppm Cu, 370 ppm Mo. 60% covered by Neogene-Quaternary sediments.	Georgiev and others (1996), Marchev and Singer (1999), Singer and Marchev (2000), Yosifov and others (1990)
Strimonikon	NA	Greece	41.042	23.325	n.d.	A 400 by 200 m body having strong alteration and no alteration halo, 13 hard-rock samples yielded a max of 180 ppm Cu; 26 soil samples had a max of 55 ppm Cu	Kockel and others (1975)
Stypsi	NA	Greece	39.318	26.256	n.d.	A Mo-enriched porphyry system, with quartz stockwork that contains molybdenite, bismuthinite, galena, and sphalerite.	Voudouris and Alfieris (2005)
Tulare	NA	Serbia	42.795	21.443	23	Kiseljak prospect, Tulare porphyry cluster ,within Lece Volcanic Complex. Active exploration project (Dunav Resources, 2011). Hosted in andesitic volcanic rocks and at least two phases of diorite porphyry. Exposed over 800 by 300 m area; locally to 450 m depth. Stockwork quartz-pyrite-chalcopyrite veins, small veinlets and disseminations. Historical (non-compliant with current standards) Soviet-C2 resource reported as 155 Mt at 0.27% Cu, 0.35 g/t Au, 1 g/t Ag, and 23 ppm Mo.	Dunav Resources Ltd. (2011), Mazzoni and Smith (2010), Monthel and others (2002)

porphyry (Surdulica project) is included for reference; no copper is reported there. In addition to porphyry copper prospects, the Oligocene-Miocene Serbo-Macedonian metallogenic belt (fig. 9) hosts epithermal to mesothermal Pb-Zn (-Ag-Au) vein and carbonate replacement deposits. The Lece volcanic complex, Serbia (mapped as **mpvi),** the remnant of a stratovolcano, for example, is dominated by lead-zinc deposits but also includes the Tulare porphyry copper prospect on its southern end.

Fisoka Group, Greece

The Fisoka area, about five kilometers east of Skouries along the same structural trend, includes several ore bodies within an area of about 1,000 by 600 m. Several prospects are characterized by strong alteration, fissures with iron oxides and gossan, with anomalous copper in rock and soil samples. Singer and others (2008) reported Fisoka as part of the Skouries deposits. European Goldfields (2011) described 3 porphyry copper-gold targets at Fisoka based on magnetic data and noted that only the supergene zone has been drilled to date. On the basis of the spatial separation between Skouries and Fisoka, and the reported data, Fisoka is considered a prospect that may represent a separate deposit from that at Skouries. Diorite porphyry ages, 23.0±1.2 (K-Ar on sericite and 24.5±1.2 (K-Ar whole rock), at Fisoka suggest that the system is slightly older than Skouries.

Mackatica Porphyry Molybdenum Deposit, Serbia

The Mackatica molybdenum deposit in the Osogovo-Blagodat district of Serbia is an Oligocene to early Miocene molybdenum porphyry deposit formed as a stockwork of stringers or veinlets on the perimeter of a Tertiary granodiorite complex (Ministry of Mining and Energy, 2010a, b). The deposit produced molybdenum from underground workings in the 1940s, and intermittently in the 1960s (Corley and others, 2010). Mineralization at Mackatica is mostly rhenium-rich molybdenite with some pyrite; hematite, minor chalcopyrite, sphalerite, galena, scheelite, and hübnerite are also present (Ministry of Mining and Energy, 2010b). The ore minerals are associated with a stockwork of quartz veinlets that cuts the intrusion and the mica schist country rock. Hydrothermal alteration types observed are silicification and sericitization of the host rock between the veinlets (Ministry of Mining and Energy, 2010b). The deposit is part of Dunav Resources Ltd.'s Surdulica project, acquired from Dundee Precious Metals Ltd. in 2011 (Dunav Resources Ltd., 2011). Indicated resources are reported as 43 Mt at 349 ppm molybdenum, 0.10 ppm rhenium; inferred resources are 340 Mt at 297 ppm molybdenum and 0.09 ppm rhenium (Corley and others, 2010). No copper resources are reported.

Exploration History

Since 2000, a number of companies have been exploring within the tract area in Serbia, Macedonia, and Greece. In Greece, gold is the focus of exploration and development at Skouries and at the epithermal systems in the Kassiteres-Sappes-St. Demetrios areas (Newman, 2011). The northern parts of the tract that fall outside of recognized metallogenic belts, where exposures of permissive rocks are less continuous, have not been thoroughly explored for porphyry copper deposits.

Sources of Information

Principal sources of information used for the assessment of delineation of the tract are listed in table B5.

Grade and Tonnage Model Selection

The four known porphyry copper deposits in the tract (table B3) are classified as the Cu-Au subtype. Although statistical analysis using a two-sample *t*-test shows that they are described by either the global porphyry Cu-Au Mo or global Cu-Au porphyry subtype model using a 1-percent screening level (table 5), the global Cu-Au subtype model was used, based on the geological characteristics of the metallogenic belt.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

Considerations for the assessment included the fact that the level of exploration in the tract area is immature to moderate and deposits are still being discovered; deposits that have been evaluated are mostly low-grade in copper and recent exploration interest largely is for gold. The tract contains four deposits and 20 prospect areas, some of which have been drilled.

Previously, the presence of the 36 Ma Recsk deposit in the midst of younger Miocene rocks had been considered an anomaly. Based on Kovács and others (2007) documentation of a broader belt of Paleocene to early Miocene rocks (see main report for a discussion), the tract was drawn to encompass all permissive rocks of this age range. The distribution of volcanic and intrusive rocks in the northern parts of the tract suggest that erosion levels may be appropriate for preservation of porphyry systems, although Recsk is the only known deposit of that age in the region, and known porphyry copper prospects do not extend north of Serbia (fig. B1). Within the southern parts of the tract (Serbia through Greece), porphyry prospects are uniformly distributed.

Table B5. Principal sources of information used for tract 150pCu6002 (EU02PC), Dinaride-Aegean Region—Italy, Slovenia, Croatia, Hungary, Bosnia and Herzegovina, Serbia, Kosovo, Macedonia, Bulgaria, Greece, and Turkey.

[NA, not applicable]

Theme	Name or Title	Scale	Citation
Geology	Geological map of Yugoslavia	1:500,000	Institute for Geological and Mining Exploration and Investigation of Nuclear and Other Mineral Raw Materials (1970)
	Map of mineral formations of the Carpathian-Balkan region	1:1,000,000	Bogdanov and others (1977)
	Geological map of Greece	1:500,000	Bornovas and Rondogianni-Tsiambaou (1983)
	Geological map of Europe	1:1,000,000	Cassard and others (2006)
	Geological map of Romania		Sandulescu and others (1978)
	Geological map of P.R. Bulgaria	1:500,000	Cheshitev and Kâncev (1989)
Mineral occurrences	Porphyry copper deposits of the world: database, map, and grade and tonnage models	NA	Singer and others (2008)
	Mineral occurrences of Turkey	NA	General Directorate of Mineral Research and Exploration (2000)
	Mineral and energy resources of Central Europe	1;2,500,000	Dill and Saschsenhofer (2008)
	World distribution of porphyry, porphyry-related skarn, and bulk-mineable epithermal deposits	NA	Dunne and Kirkham (2003)
	Mineral Resources Data System (MRDS)	NA	U.S. Geological Survey (2009)
	Company Web sites; geologic literature	NA	See references in tables B3 and B4
	Mineral deposits of Serbia—Ore deposit database	NA	Ministry of Mining and Energy (2010a,b)
Geophysics	Eastern Europe reduced to pole aeromagnetics	NA	J. Phillips (unpublished)

Estimates of undiscovered porphyry Cu-Au deposits in the tract by individuals and the team consensus at the 90-, 50-, 10-percent probability levels and summary statistics are shown in table B6. Estimates at the 90- and 50-percent levels reflected team members' belief that some of the significant prospects may represent deposits once they are fully evaluated. Estimator E (table B6) was much more optimistic about the prospectivity of the tract than the other team members; the consensus mean estimate, reached after discussion of the relative significance of prospects, was two or more undiscovered deposits, in accord with the estimates of the four other team members.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered porphyry copper deposits with the porphyry copper-gold grade and tonnage model (Singer and others, 2008) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012). Selected output parameters are reported in table B7. Results of the Monte Carlo simulation are presented on a cumulative frequency plot (fig. B3). The cumulative frequency plot shows the estimated resource volumes associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock. The mean estimated copper in undiscovered resources, 12 Mt, exceeds the ~7 Mt of identified copper resources (table B1).

Table B6. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 150pCu6002 (EU02PC), Dinaride-Aegean Region—Italy, Slovenia, Croatia, Hungary, Bosnia and Herzegovina, Serbia, Kosovo, Macedonia, Bulgaria, Greece, and Turkey.

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

Assessor	Consensus undiscovered deposit estimates			Summary statistics					Tract area (km²)	Deposit density (N_{total}/ km²)	Deposit density (Ntotal/100k km2)
	N_{90}	N_{50}	N_{10}	N_{und}	s	C_v%	N_{known}	N_{total}			
A	1	2	5	2.5	1.6	63	4	6.5	92,700	7	7
B	1	2	4	2.2	1.2	54	4	6.2	92,700	7	7
C	0	2	4	2	1.4	73	4	6	92,700	6	6
D	0	2	4	2	1.4	73	4	6	92,700	6	6
E	1	10	20	10.2	6.5	64	4	14.2	92,700	15	15
Consensus	0	2	4	2	1.4	73	4	6	92,700	6	6

Table B7. Results of Monte Carlo simulations of undiscovered resources for tract 150pCu6002 (EU02PC), Dinaride-Aegean Region—Italy, Slovenia, Croatia, Hungary, Bosnia and Herzegovina, Serbia, Kosovo, Macedonia, Bulgaria, Greece, and Turkey.

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

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu	0	320,000	5,700,000	32,000,000	48,000,000	12,000,000	0.30	0.07
Mo	0	0	12,000	180,000	360,000	67,000	0.23	0.32
Au	0	32	480	2,200	3,300	880	0.32	0.07
Ag	0	0	1,100	8,500	17,000	3,900	0.22	0.24
Rock	0	77	1,200	6,500	9,500	2,400	0.31	0.07

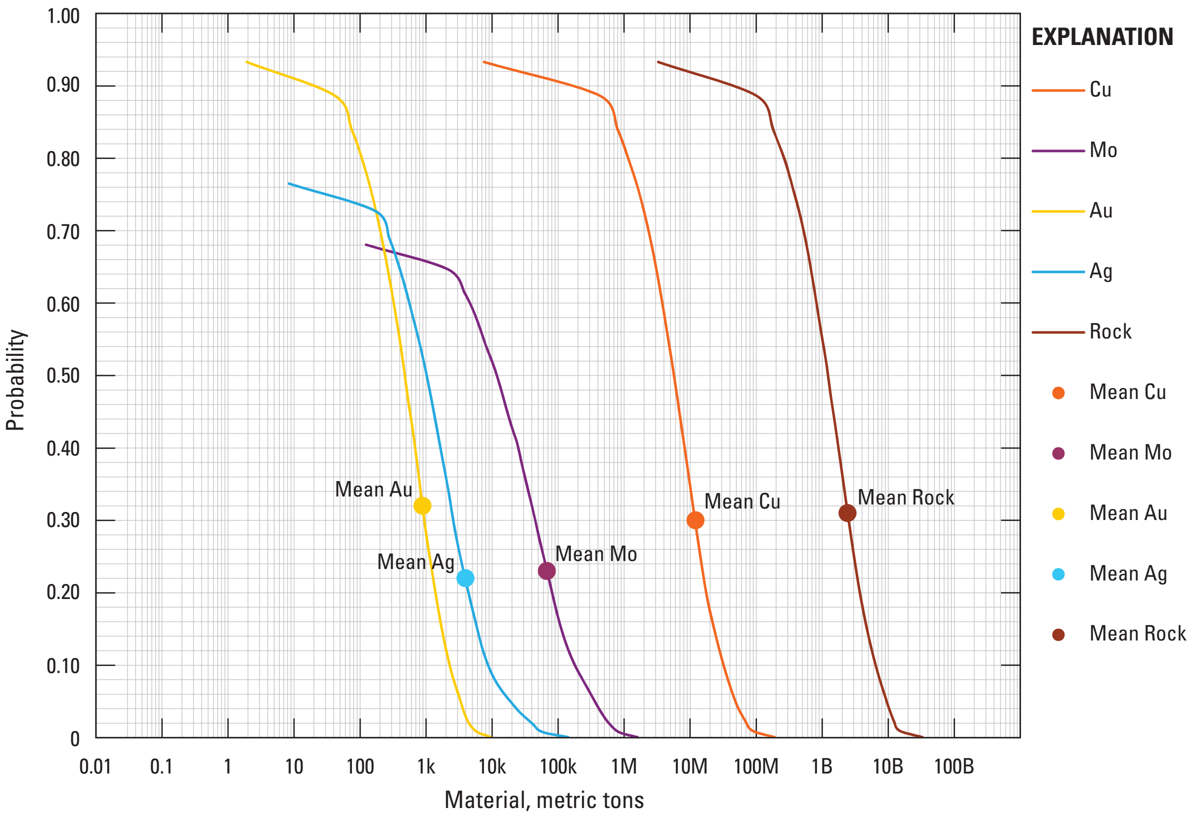


Figure B3. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in porphyry copper-gold deposits in tract 150pCu6002 (EU02PC), Dinaride-Aegean Region—Italy, Slovenia, Croatia, Hungary, Bosnia and Herzegovina, Serbia, Kosovo, Macedonia, Bulgaria, Greece, and Turkey. k, thousand; M, million; B, billion.

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Appendix C. Porphyry Copper Assessment for Tract 150pCu6003 (EU03PC), Apuseni Mountains—Western Romania

By David M. Sutphin[1], Lawrence J. Drew[1], Duncan E. Large[2], Byron R. Berger[3], and Jane M. Hammarstrom[1]

Deposit Type Assessed: Porphyry copper, copper-gold subtype

Descriptive model: Porphyry copper, copper-gold subtype (Cox, 1986; Berger and others, 2008; John and others, 2010)
Grade and tonnage model: Porphyry copper, copper-gold subtype (Singer and others, 2008)
Table C1 summarizes selected assessment results.

Table C1. Summary of selected resource assessment results for tract 150pCu6003 (EU03PC), Apuseni Mountains—Western Romania.

[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	4,160	5,600,000	10,000,000	4,600,000

Location

The tract encompasses a small area (about 100-km-wide) in the Apuseni Mountains of western Romania (fig. C1).

Geologic Feature Assessed

An assemblage of Miocene calc-alkaline volcanic and intrusive rocks, primarily andesitic in composition, that formed in a postsubduction setting due to mantle upwelling at the base of the crust.

[1]U.S. Geological Survey, Reston, Virginia, United States.

[2]Independent consulting geologist, Branschweig, Germany and London, United Kingdom.

[3]U.S. Geological Survey, Denver, Colorado, United States.

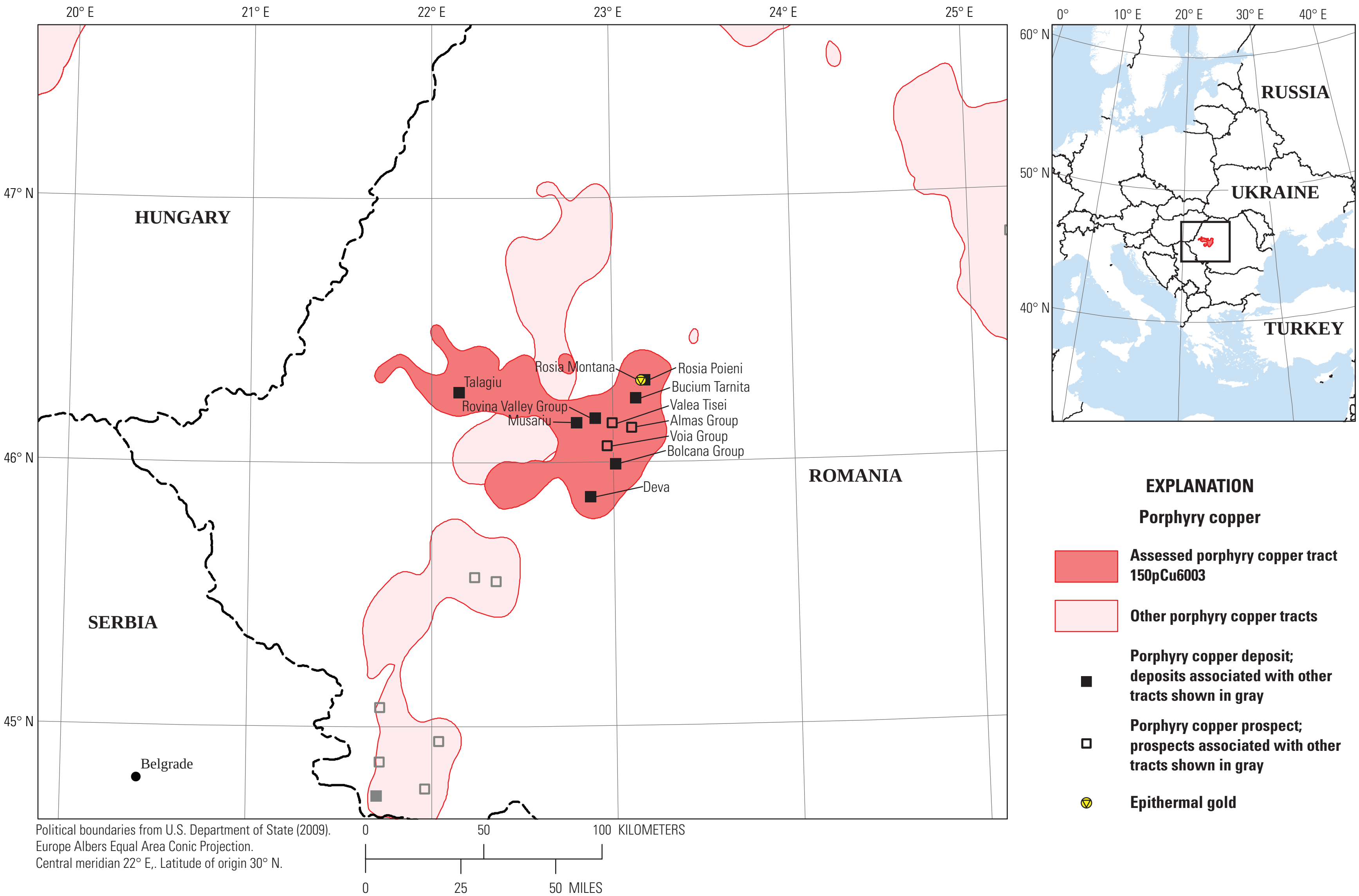


Figure C1. Map showing the location, known deposits, and significant prospects and occurrences for permissive tract 150pCu6003 (EU03PC), Apuseni Mountains—Western Romania.

Delineation of the Permissive Tract

The Apuseni Mountains (fig. 1[4]) represent an unusual concentration of ore-forming processes restricted in time and space that produced some of the largest porphyry copper-gold and epithermal gold deposits in Europe (Roşu and others, 2004). Although the tract area is very small (4,160 km^2), it was delineated as a separate tract rather than included with other Miocene tracts because of its unique character and location relative to the main Carpathian Arc (Carpathian Mountains on fig. 1).

Tectonic Setting and Magmatism

The Apuseni Mountains formed in a complex geodynamic setting that was not associated with a plate boundary zone. The Apuseni Mountains, situated in the eastern Pannonian Basin (fig. 1), are part of the Tisza-Dacia lithospheric block (fig. 15) that was translated eastward from Cretaceous to Miocene time (fig. 16*B*). As the whole block underwent a 20^o clockwise rotation, the Apuseni Mountains area experienced an additional 60^o clockwise rotation and transtension during Miocene time that resulted in horst and graben formation (Seghedi and others, 1998). According to Neubauer and others (2005), the Apuseni Mountains reflect an unusual rotated transtensional/extensional setting near the termination of a graben system. In that setting, fluid flow probably was localized by fault propagation at the inner tip of the graben system. The opening of extensional duplexes (basins) and the emplacement of andesitic volcanic and associated granitoid rocks in the Apuseni Mountains were coupled with the eastward tectonic escape of (and extension within) the Carpathian-Pannonian region during the Miocene (Drew, 2006). From 17–15 Ma, the geodynamic setting of the region was characterized by extension and basin development (Fodor and others, 1999). Preexisting anisotropy that had been introduced into this region by thrusting during the Jurassic likely facilitated development of the 100-km-long Brad-Zarand-Zlatna Basin (fig. C2). This anisotropy not only determined the configurations of the basins, but also controlled the positioning of the fault duplexes (fig. C3) within the basins when the far-field stress regime evolved from local rift-like tectonics to strike-slip tectonics (Drew, 2005).

Variations in Miocene magmatism in the Apuseni Mountains have been interpreted in terms of the geodynamic evolution of the area (Roşu and others, 2004). As magmatism shifted eastward from about 13–11 Ma, the predominantly andesitic volcanic rocks evolved from normal calc-alkaline to adakite-like calc-alkaline to alkaline; trace-element and isotopic signatures show general trends with decreasing age of magmatism (decreasing $^{87}Sr/^{86}Sr$, increasing $^{144}Nd/^{143}Nd$, increasing Sr/Y). These trends are compatible with a transition to a more primitive upwelling asthenospheric mantle magma source as the region underwent extension following rotation (Roşu and others, 2004). The youngest volcanism in the Apuseni Mountains, 1.6 Ma trachyandesite in the Uroi area (fig. C2), represents an alkalic (shoshonitic) pulse of asthenosphere-sourced magmatism that formed in a late extensional event. A tomographic cross-section showing the crust and upper mantle to a depth of more than 800 km from the Eastern Alps, through the Apuseni Mountains, to the Eastern Carpathians shows that a west-dipping subducted plate broke off beneath the Apuseni Mountains allowing hot asthenosphere to approach the surface thereby triggering Neogene magmatism and subsequent mineralization (Neubauer and others, 2005).

Roşu and others' (2004) compilation of age and geochemical data for the Miocene igneous rocks in the Apuseni Mountains mainly included andesite, with a few samples of microdiorite, and in the eastern part of the area, samples of trachyandesite. The analyzed rocks, which include samples associated with porphyry copper deposits and prospects, range from 56–62 weight percent SiO_2 and exhibit a wide range of Sr/Y ratios (fig. C4). The locations of analyzed samples, coded by Sr/Y range and labeled with age, are shown in figure C2. Elevated Sr/Y ratios (≥35) characterize the samples from the eastern part of the Apuseni Mountains, where most of the porphyry copper deposits occur. This observation is consistent with Loucks' (2011) evaluation of a global petrochemical database of Cenozoic copper-ore productive igneous suites; that study showed that igneous suites having Sr/Y>35–40 (at SiO_2 > 57 weight percent) may be copper-prospective relative to average Late Cenozoic arc volcanic rocks and arc suites that are known to be unprospective for copper (fig. C4). Loucks' (2011) data also include analyses for rocks associated with porphyry copper deposits in other tracts described in this report: Elatsite and Moldova Nouă in tract 150pCu6001 (appendix A), Skouries in tract 150pCu6002 (appendix B), and at Zlatno, part of the Štiavnica Group in tract 150pCu6004 (appendix D). These analyses all fall within, or near the boundaries for copper and(or) copper-gold productive intrusions (fig. C4).

[4]Refers to figures and tables in the main report.

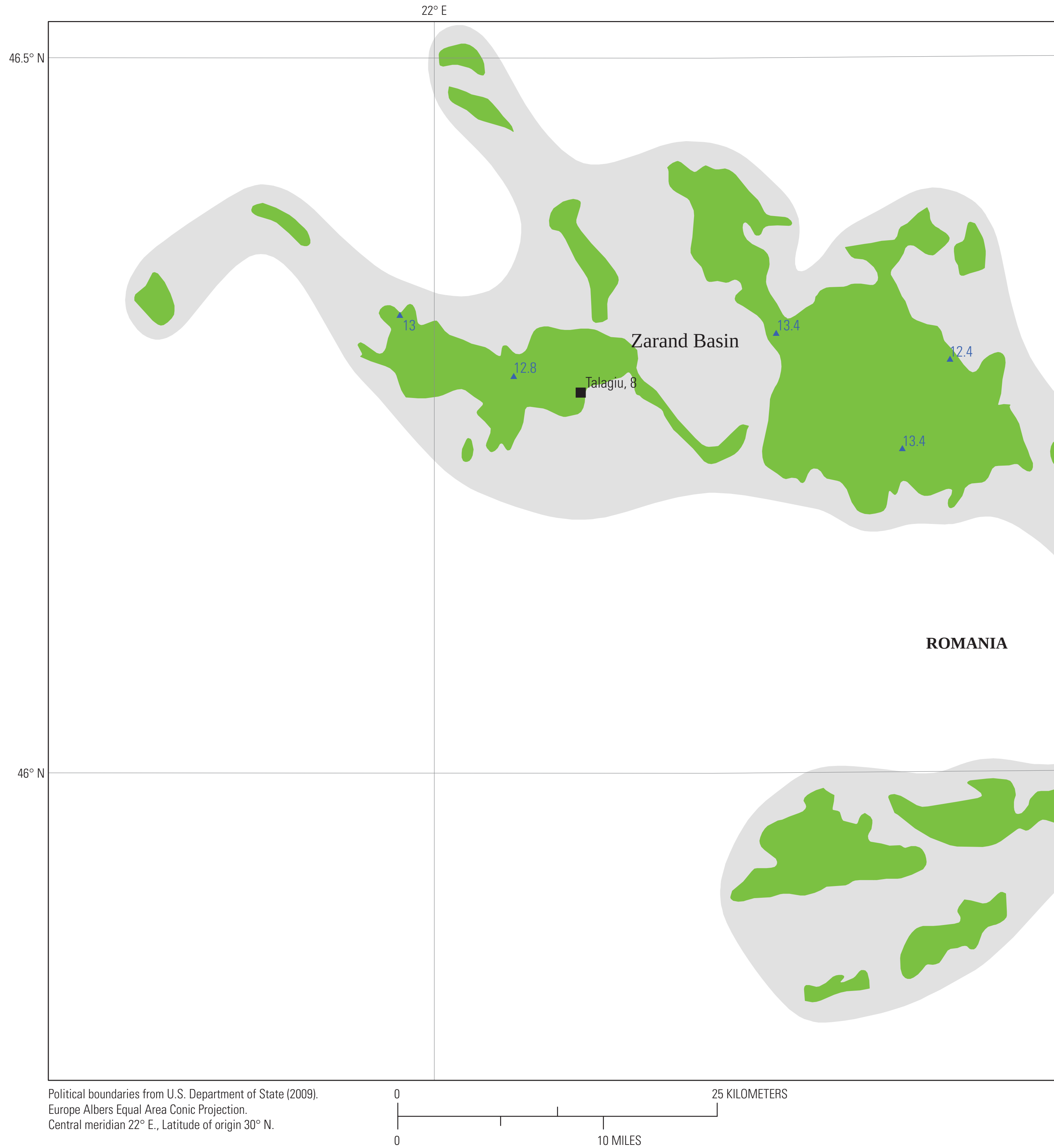
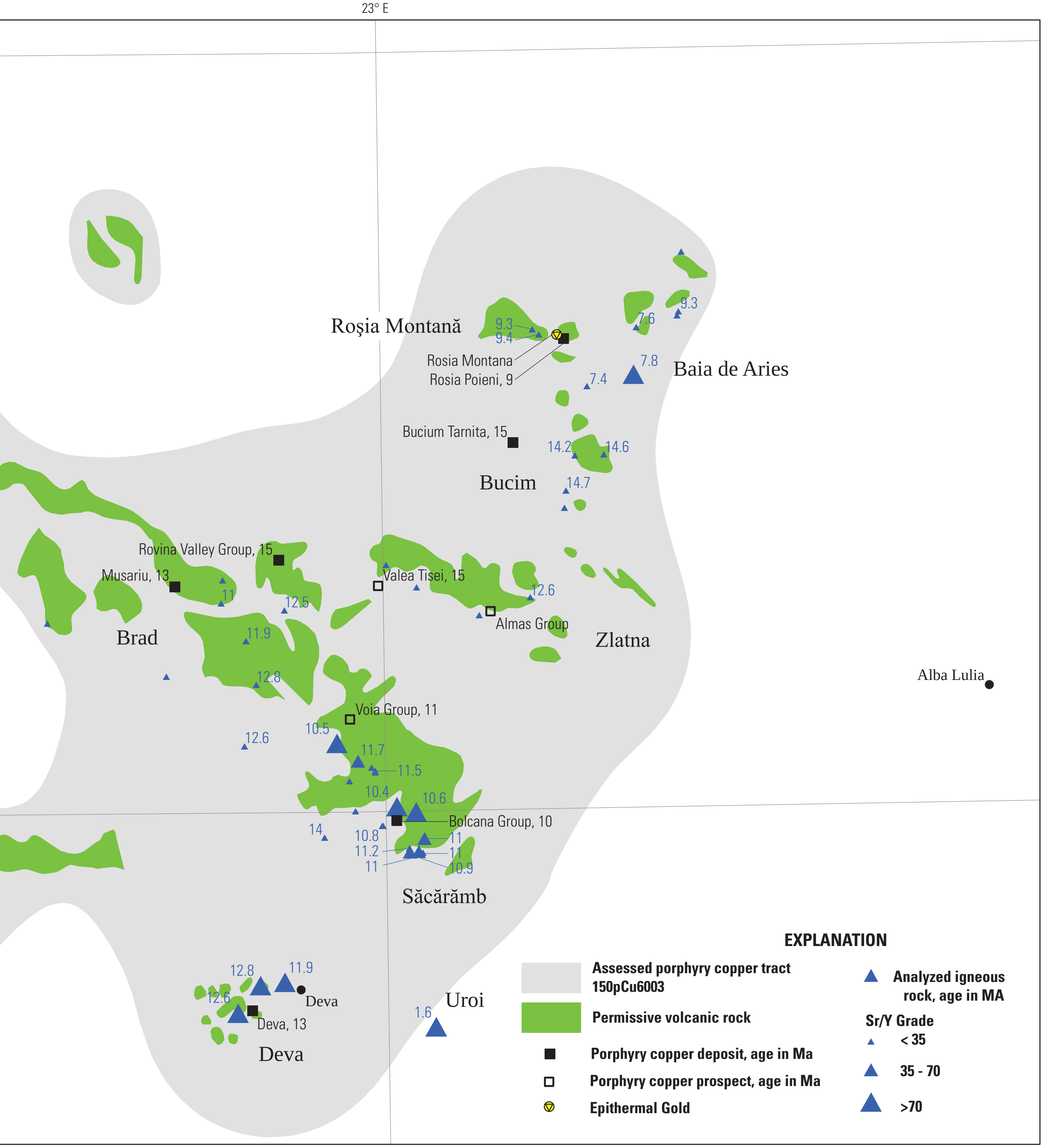


Figure C2. Map showing distribution of permissive rocks used to define tract 150pCu6003 (EU03PC), Apuseni Mountains—Western Romania. Tria
of Sr/Y ratios. Age reported in Ma (millions of years).



angles, sample locations for igneous rocks analyzed by Roşu and others (2004). Symbol sizes for igneous rock samples represent ranges

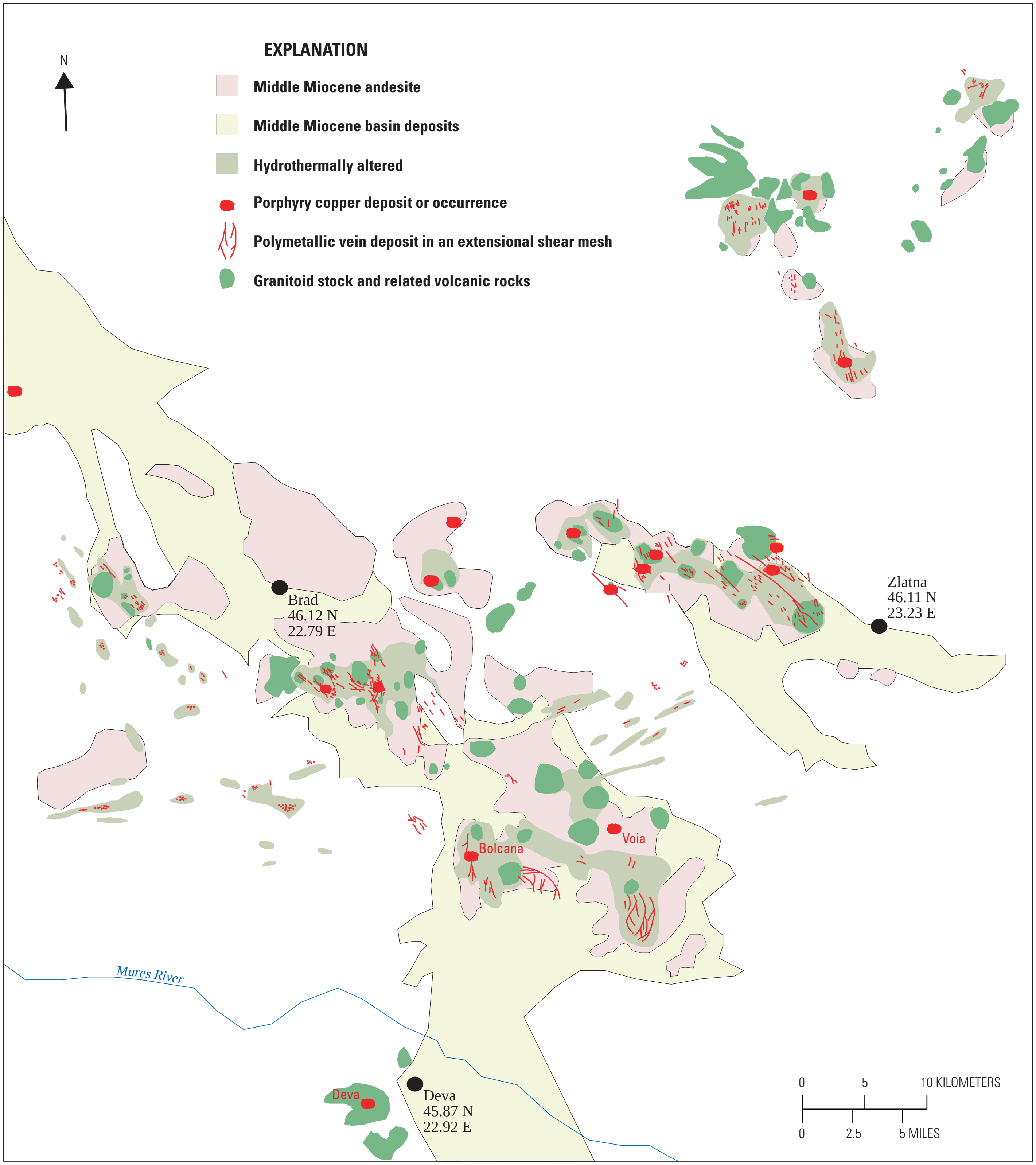


Figure C3. Porphyry copper and polymetallic vein deposits, andesitic volcanic rocks, granitoid stocks, alteration, and Tertiary sediments in the Brad-Sacaramb and Zlatna basins, Apuseni Mountains, Romania. After Drew (2006). (Modified from Ghitulescu and Socolescu,1941; Borcos, 1994; Berberleac and others, 1995).

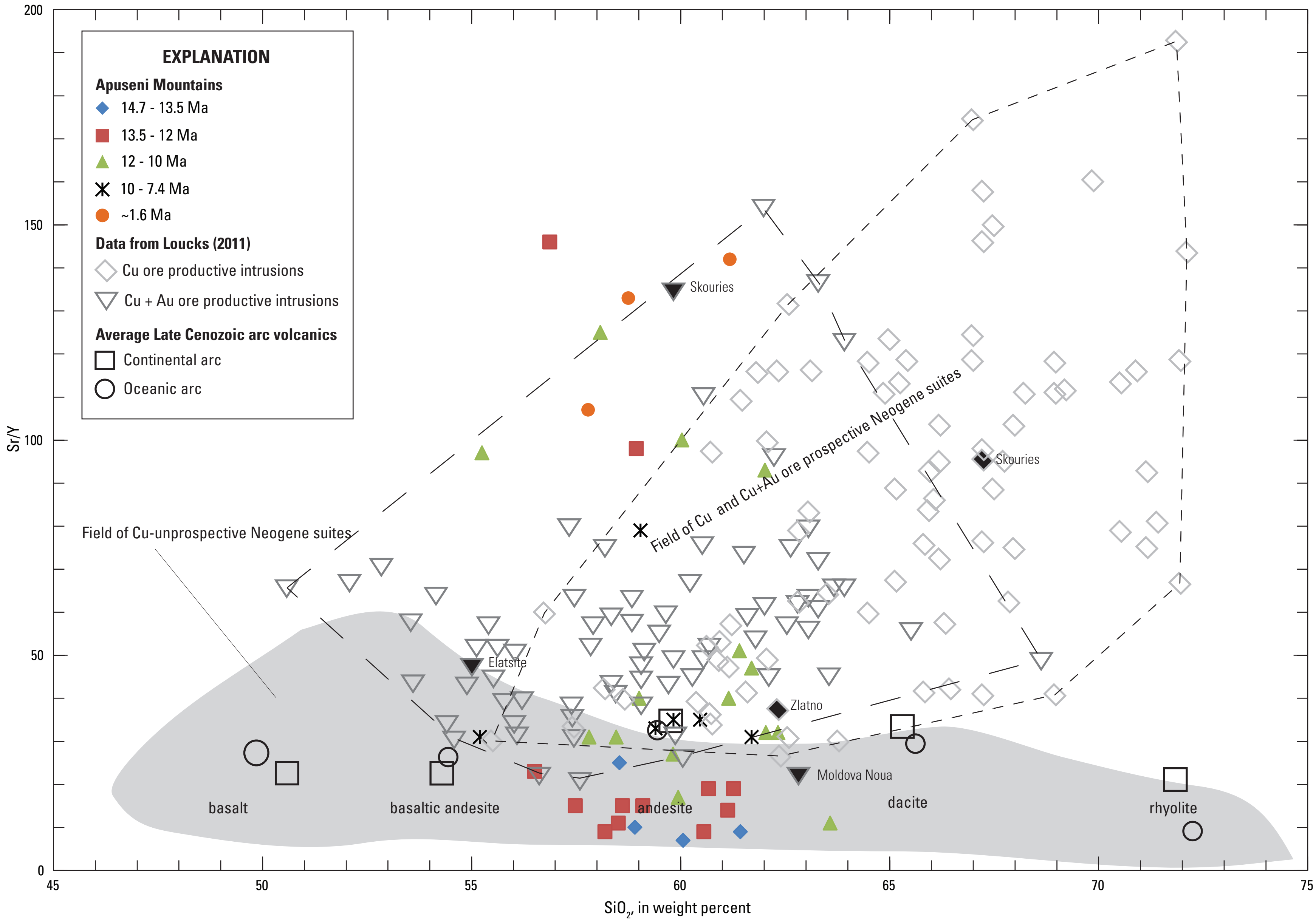


Figure C4. Sr/Y ratios as a function of SiO_2 content for Miocene igneous rocks in the Apuseni Mountains (Korděra and others, 2010) and average Late Cenozoic arc compositions and fields of copper-prospective, and copper-unprospective Neogene suites based on Loucks (2011). Samples associated with porphyry systems in Europe are shown as solid black symbols and labeled. Louck's data are based on his global petrochemical database. See figure C2 for Apuseni Mountains sample locations from Korděra and others (2010).

Geologic Criteria

The Neogene rocks in the Apuseni Mountains tract mainly include volcanic andesites, intermediate pyroclastic rocks, and volcanic and volcano-plutonic intermediate rocks (table C2), as shown on maps by Sandelescu and others (1978), Ghitulescu and Socolescu (1941), and Cassard and others (2006). The tract is delineated by Miocene intrusive and volcanic rocks, as depicted on geologic map of Romania for the Apuseni Mountains and adjacent areas (Sandulescu and others, 1978). Permissive rocks used to delineate the tract are listed in table C2. Preliminary tracts were identified by outlining areas of interest on printed paper maps. Figure C2 shows the extent of mapped permissive volcanic rocks as well as point locations of andesites, microdiorites, and trachyandesites reported by Roşu and others (2004); their 1.6 Ma trachyandesite at Uroi, which lies just outside of the tract boundary, is related to a younger extensional event than those that formed the porphyry copper systems in the area.

The final tract was constructed by processing geologic data from the enhanced digital geologic map of permissive igneous rocks prepared for the study (Cassard and others, 2006), as follows:

- Permissive igneous lithologies in map units attributed as Miocene, Miocene-Pliocene, or Neogene were selected from the 1:1,500,000-scale enhanced digital geologic map of Europe (Cassard and others, 2006).

- A prototract was developed by placing a 10-km-wide buffer around permissive intrusive rocks and a 2-km buffer around permissive volcanic rocks. This expanded the area of the tract to include most porphyry copper deposits and significant associated prospects and accounts for possible unexposed or unmapped adjacent permissive rocks.

- Aggregation and smoothing routines were applied to the resulting polygons.

- Locations of Neogene porphyry copper deposits and prospects and point locations of permissive rocks reported by Roşu and others (2004) were checked to ensure that they were included within the tract.

- The final tract consists of two discrete polygons as shown in figure C1. In three areas, the tract overlaps with the Transylvania-Balkan Mountains tract, which represents Cretaceous rocks. The younger volcanic rocks may represent cover on the older igneous rocks.

Known Deposits

Table C3 lists seven deposits that have identified copper resources. The largest deposit in the Apuseni Mountains is the 431 Mt Rosia Poieni deposit. Copper grades for all deposits range from 0.20–0.7 percent copper (table C3); the deposits are gold-rich (>0.2 g/t gold) with the exception of Bolcana (0.03 g/t gold).

Talagiu, Romania

The 150 Mt Talagiu porphyry copper-gold deposit and associated epithermal gold prospect occurs in volcanic rocks in the western part of the tract in the Zarand Mountains (fig. C2). Hydrothermal alteration at the Talagiu volcano resulted in large-scale pyrophyllite deposits of potential economic value (Ianovici and others, 1984; Sinyakovskaya and others 2005).

Talagiu was a blind porphyry target; mineralization lies at a depth of 400 m. Initial exploration conducted on behalf of European Goldfields during 2003 utilized photogeological and remote sensing to identify 17 generally circular surface anomalies in the Talagiu region (European Goldfields Ltd., 2004). The anomalies included topographic depressions possibly related to areas of less resistant, hydrothermally-altered rocks as well as topographic highs associated with known and possible dacite and andesite porphyry intrusions (European Goldfields Ltd., 2004).

Table C2. Map units that define tract 150pCu6003 (EU03PC), Apuseni Mountains—Western Romania.

[Map unit, age range, and principal lithologies are based on Cassard and others (2006) 1:1,500,000 digtial geologic and scanned and rectified paper maps at larger scales. Ma, million years.]

Map symbol	Lithology	Age range	Source map
	Volcanic rocks		
α	Andesites	Neogene	Sandulescu and others (1978)
mpvi	Dominantly intermediate pyroclastic rocks volcanic and volcano-plutonic intermediate rocks	Miocene-Pliocene 23.5–1.75 Ma	Cassard and others (2006)
mvi	Dominantly intermediate pyroclastic rocks	Miocene 23.5–5.3 Ma	Cassard and others (2006)

Table C3. Porphyry copper deposits in tract 150pCu6003 (EU03PC), Apuseni Mountains—Western Romania.

[Group names in boldface. Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; n.d., no data. Cu-Au subtype, deposits that have Au/Mo ratios >30 or average Au grades >0.2 g/t.]

Name	Includes	Latitude	Longitude	Subtype	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)	Reference
Bolcana Group	Bolcana deposit; Magura prospect	45.994	23.010	NA	10	90	0.30	n.d.	0.03	n.d.	270,000	Berbeleac and others (1995a,b), Cardon and others (2006), Drew and Berger (2001), European Goldfields, Ltd. (2004), Ianovici and others (1977), Milu and others (2003)
Bucium Tarnita	NA	46.242	23.127	Cu-Au	15	335	0.50	n.d.	0.36	n.d.	1,700,000	Berbeleac and others (1995a,b), Gabrielle Resources (2010), Ianovici and Borcos (1982), Ianovici and others (1977), Kouzmanov and others (2005)
Deva	NA	45.870	22.870	Cu-Au	13	20	0.70	n.d.	0.50	n.d.	140,000	Ianovici and Borcos (1982), Ianovici and others (1977), Ivascanu and others (2003), Sillitoe (1980), Lips and others (2006)
Musariu	NA	46.150	22.800	Cu-Au	13	12	0.20	n.d.	0.30	n.d.	24,000	Berbeleac and others (1995a,b), Ciobanu and others (2007), Ianovici and others (1977), Vlad (2007)
Rosia Poieni	NA	46.310	23.177	Cu-Au	9	431	0.55	n.d.	0.25	n.d.	2,400,000	Berbeleac and others (1995a,b), Berza and others (1998), Bestinescu (1984), Borcos and others (1984), Damman and others (1996), Folea and Berbeleac (1987), Herrington and others (2003), Ianovici and Borcos (1982), Ianovici and others (1977), Kouzmanov and others (2005, 2007), Marcoux and others (2002), Milu and others (2004)
Rovina Valley Group	Deposits: Rovina, Colnic, Valea Morii Prospects: Ciresata, Valea Arsului	46.167	22.900	Cu-Au	15	370	0.17	n.d.	0.58	n.d.	650,000	Berbeleac and others (1995a,b), Carpathian Gold Inc. (2006, 2007, 2010, 2011), Cumming (2007), Ianovici and others (1977), Benzinga Staff (2010), Marketwire (2008, 2010), Lips and others (2006), Proactiveinvestors (2011), Gratian and others (undated), Drew and Berger (2001), Kouzmanov and others (2003, 2007), Marcoux and others (2002), Vlad and Orlandea (2008)
Talagiu	NA	46.267	22.150	Cu-Au	8	150	0.35	n.d.	0.60	n.d.	530,000	Berbeleac and others (1992;1995a,b), Ianovici and others (1984), Vlad (2007)

Musariu (Barza-Musariu), Romania

Musariu, like Bolcana to the southeast, is a subvolcanic Neogene porphyry copper prospect. Musariu is located at the north end of the northwest-trending Brad-Sacaramb Basin (fig. C2), where a quartz andesite pluton intruded volcanic rocks in the second cycle of Miocene volcanic activity in the Apuseni Mountains (Ianovici and others, 1977). The prospect is cylindrical in shape, characterized by potassic- and argillic alteration, and contains chalcopyrite and bornite in stockworks, with pyrite gangue (Ianovici and others, 1977).

Rovina Valley Group, Romania

The approximate centers of the Rovina and Colnic deposits are 2.8 km apart, about 5 km north of the Ciresata prospect, along a 7.5 km northeast trend (Marketwire, 2010). On the basis of the spatial rules adopted for this study, several deposits and prospects are grouped (table C3). Although discovered separately, Rovina and Colnic probably are parts of the same porphyry system. Both will be mined by conventional open-pit mining methods (Benzinga Staff, 2010).

The exposed Rovina and Colnic copper-gold deposits are hosted in an altered porphyritic microdiorite intrusion (Carpathian Gold, Inc., 2011). Ore is associated with magnetite veinlets and as disseminated granular agglomerates with secondary biotite, consistent with potassic alteration at the core of a gold-rich porphyry hydrothermal system; the alteration is cut by quartz-chalcopyrite-pyrite stockwork veinlets, and large halos of phyllic alteration surround the deposits (Carpathian Gold Inc., 2011).

The Ciresata porphyry copper prospect is the most southerly of the north-south trending Rovina-Colnic-Ciresata line of deposits discovered in recent years. Ciresata is a blind deposit with no apparent surface manifestations. It also has the highest gold grade of the three porphyries (Benzinga Staff, 2010). As of 2008, the first six diamond-drill holes at Ciresata had intersected gold and copper mineralization over an approximately 300 by 300 m area. Results from this early drilling program indicate that mineralization occurs 50 to 120 m beneath a magnetite-altered cover of andesite (Marketwire, 2008). The Ciresata deposit lies within an interpreted 3-km long, northeast-trending structural corridor where additional exploration targets have been identified (Marketwire, 2008). The mining plan is to focus on higher-grade core zones within the deposit to maximize the early return on the project. Ciresata is to be mined by bulk-underground methods and ore processing utilizes an industry-standard flotation that does not require cyanide (Benzinga Staff, 2010).

Rosia Poieni, Romania

Rosia Poieni is the largest of the porphyry copper-gold-molybdenum deposits in the Apuseni Mountains. It was discovered through local geological, geochemical, and geophysical research carried out in the 1960s and 1970s (Milu and others, 2004). Open-pit mining began in 1986 after exploratory adits were driven, and further drilling defined the resources (Borcos and others, 1998; Milu and others, 2004). The subvolcanic Fundoaia microdiorite stock was intruded into andesites that have been altered only in the immediate contact zone with the intrusion. The mineralization consists mainly of fine disseminations, nests, and veinlets of pyrite, chalcopyrite, and magnetite; the chalcopyrite and pyrite carry gold. Other ore minerals include bornite, covellite, chalcocite, galena, molybdenite, germanite, malachite, and azurite.

Milu and others (2004) distinguished four types of hydrothermal alteration at Rosia Poieni: potassic, phyllic, advanced argillic, and propylitic. The potassic alteration assemblage consists mainly of Mg-biotite and K-feldspar accompanied by ubiquitous quartz; chlorite, and anhydrite are also present (Milu and others, 2004). Magnetite, pyrite, chalcopyrite, and minor bornite are associated with the potassic alteration (Milu and others, 2004). Kouzmanov and others (2005) recognized that Rosia Poieni is a porphyry copper system with a high-sulfidation epithermal overprint.

Bucium Tarnita, Romania

The Bucium Tarnita porphyry copper-gold-molybdenum deposit is in the Montana-Bucium extensional basin, one of several subparallel northwest-southeast basins forming well-delimited volcano-plutonic structures (Wallier and others, 2006). Bucium Tarnita is genetically related to porphyritic, subvolcanic andesite-microdiorite bodies (Wallier and others, 2006). Bucium Tarnita is cut by epithermal veins; the high sulfidation epithermal overprint is dated at 14.87 to 14.60 Ma (Kouzmanov and others, 2005).

Bolcana Group, Romania

The Bolcana copper-gold porphyry deposit is in the Brad-Sacaramb district (figs. C2 and 3) in southern part of the Apuseni Mountains of Romania. Basement rocks consist of Middle Jurassic to Early Cretaceous ophiolites and Early Cretaceous rhyolites overlain by Paleocene sedimentary rocks (Borcos and others, 1984; Cardon and others, 2008). The oldest Neogene igneous rocks in the Bolcana area are middle Miocene andesite flows, intrusions, and pyroclastic units (Cardon and others, 2008). The Bolcana intrusion that hosts the ore deposit is one of several microdiorite bodies that intrude andesites. The intrusion is exposed over a small area in the center of the Neogene volcanic rocks and is the only mineralized intrusion in the area (Cardon and others, 2008). Early alteration was potassic in the center of the intrusion and grades into propylitic alteration towards the edge of the intrusion and the surrounding andesite (Cardon and others, 2008). A Re-Os study on ubiquitous pyrite (because no molybdenite was found in the sample) determined that Bolcana was mineralized about 11.8 (+0.51/-2.8) Ma (Cardon and others, 2008), in good agreement with a K-Ar age of 10.77 ±0.64 on amphibole from a nearby andesite (Roşu and others, 2001). In 2002, the Bolcana porphyry reportedly returned promising drill intercepts (European Goldfields Ltd., 2004). The Hondol and Magira prospects lie within 2 km of the Bolcana deposit.

Deva, Romania

The Deva area was mined by the Romanian state at an indicated gold grade of 0.5 g/t gold and 0.7 percent copper. The Deva porphyry historically produced about 20 Mt at 0.8 percent copper; gold grade is not recorded (European Goldfields Ltd., 2010). Potassium-argon dating demonstrated that three subvolcanic andesite bodies were emplaced at Deva within a relatively short period of 12.8–11.8 Ma (Ivascanu and others, 2003). A northeast-southwest through-going cross-section shows a vertical, 500 m diameter, cylindrical breccia-hosted subvolcanic stock of amphibole andesites and breccia-ringed amphibole-biotite andesites intruded into low-grade metamorphic greenschists (Kouzmanov and others, 2005). Mineralization consists of bornite-chalcopyrite-magnetite stringers (Kouzmanov and others, 2005). Native gold at Deva is associated with copper minerals and magnetite (Gratian and others, undated). European Goldfields Ltd. holds a concession that covers some 137 km² and includes the Deva copper-gold porphyry and the Muncel-Vetel massive sulfide deposits.

Prospects, Mineral Occurrences, and Related Deposit Types

Table C4 lists three porphyry copper prospect areas within the tract. Skarns, high-sulfidation epithermal deposits, replacements, and copper- and polymetallic veins are the major types of magmatic-hydrothermal deposits in the Apuseni Mountains, and may or may not be related to porphyry copper deposits. Figure C3 shows the associations of middle Miocene andesite, porphyry copper occurrences, hydrothermal alteration, and polymetallic veins in extensional shear meshes in the eastern part of the tract area (Drew, 2006).

Exploration History

The Apuseni Mountains of western Romania, arguably one of the most highly mineralized areas on Earth, host the richest concentration of gold in Romania. The shape of the cluster of epithermal and gold-rich porphyry copper and related deposits led to the name “Golden Quadrilateral”, based on the outline of the intensely mineralized area. Gold and other metals have been found and mined for millennia in the Apuseni Mountains. Historical gold production from epithermal deposits is estimated at about 1,600 metric tons—about 25 percent produced by the Romans, 25 percent in the Middle Ages, and the remainder in modern times (Gratian and others, undated).

In the 1960s and 1970s, local geological, geochemical, and geophysical research programs resulted in discovery of the Rosa Poieni deposit in the South Apuseni Mountains (Milu and others, 2004). In 2006, exploration by Carpathian Gold, Inc., defined the Colnic porphyry deposit and discovered a significant gold component to the known copper mineralization at the Rovina porphyry (Marketwire, 2010). In 2008, more than 71 km of diamond drilling led to discovery by Carpathian Gold, Inc., of a “blind” third porphyry gold-copper deposit, Ciresata, proximal to the Rovina and Colnic deposits in west-central Romania (Benzinga Staff, 2010). As of 2010, Carpathian Gold, Inc., had again begun diamond drilling at the Ciresata gold-copper porphyry (Marketwire, 2010). The area has been extensively explored for gold veins; it was gold exploration that encountered the porphyry copper deposits.

Sources of Information

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

Table C4. Significant prospects and occurrences in tract 150pCu6003 (EU03PC), Apuseni Mountains—Western Romania.

[%, percent; g/t, grams per metric ton; Mt, million metric tons; Ma, million years; NA, not applicable; n.d., no data]

Name	Includes	Latitude	Longitude	Age (Ma)	Comments	Reference
Almas Group	Almas, Baba-Babuta, Breaza, Hanes-Large, Muncaceasca East, Munca-ceasca West, Trimpoiele	46.131	23.103	Neogene	Group location given for Almas, 7 total prospects in group. Almas, surface sampling by European Goldfields returned one intercept of 63.15 g/t Au over 2 meters. Nine other samples returned gold values greater than 0.8 g/t Au.	Cook and Ciobanu (2004), European Goldfields, Ltd. (2004), Gratian and others (undated), Levine and others (2004), Milu and others (2004), Popa and Popa (2005), Singer and others (2008), Vlad and Orlandea (2008)
Valea Tisei	NA	46.149	22.995	15	Beginning in 2001, Valea Tisei was drilled for Au, Ag, Cu, Pb, and Zn by European Goldfield Ltd. Along with the porphyry Cu-Au mineral-ization, they noted a potential for near-surface epithermal deposits. The deposit is a disseminated Au-Cu porphyry system with higher grade gold mineralization in veins associated with enhanced base metal grades.	Milu and others (2004), Vlad and Orlandea (2008), European Gold-fields, Ltd. (2004)
Voia Group	Voia, Draica	46.061	22.967	11	Location for Voia prospect. The Voia porphyry copper prospect is hosted in a Neogene andesitic plug. During the 1970s and 1980, Voia was an exploration target. In the early 2000s, European Goldfields did geologic mapping and soil geochemical surveys on the Voia porphyry system. The Draica pros-pect lies ~3 km along strike to the northwest of the Stogu prospect; epithermal-style veining, contained within the same extensive zone of argillic alteration.	Berbelac (2003), Berbeleac and others (1995a,b; 2005), Drew and Berger (2001), Ianovici and others (1977), European Goldfields, Ltd. (2004)

Table C5. Principal sources of information used for tract 150pCu6003 (EU03PC), Apuseni Mountains—Western Romania.

[NA, not applicable]

Theme	Name or Title	Scale	Citation
Geology	Geological map of Romania	1:1,000,000	Sandulescu and others (1978)
	Digitial geologic map of Europe	1:1,500,000	Cassard and others (2006)
	Geologic map of the Metalliferes Mountains	1:75,000	Ghitulescu and Socolescu (1941)
	Geological map of South Apuseni Mountains	1:225,000	Roşu (2001)
	A tectonic model for the spatial occurrence of porphyry copper and polymetallic vein deposits—Applications to Central Europe	NA	Drew (2006)
Mineral occurrences	Mineral deposits of Europe	NA	Lips and others (2006)
	Geologic literature	NA	See references in tables C3 and C4
	Mineral and energy resources of Central Europe	1;2,500,000	Dill and Saschsenhofer (2008)
	Mineral Resources Data System (MRDS)	NA	U.S. Geological Survey (2009)
	Porphyry copper deposits of the world—Database, map, and grade and tonnage models	NA	Singer and others (2008)

Grade and Tonnage Model Selection

Six of the seven known porphyry copper deposits in the tract have reported gold values greater than 0.2 g/t copper (table C3). On the basis of these values, and the *t*-tests, the global Cu-Au subtype model of Singer and others (2008) was selected for the simulation of undiscovered resources.

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

The very small Apuseni Mountains tract (~4,200 km^2) lies within the most gold-mineralized area in Europe, an area referred to as the “Golden Quadrilateral”. Though well-explored for gold veins, the geology is complex and not thoroughly understood. The porphyry copper deposits that have been discovered are small, but the team concluded that some of the prospect areas could represent additional deposits. Further exploration along mineralized structural corridors may yield new prospects, and increased use of modern geophysical techniques may reveal buried deposits within the highly mineralized tract area. At times in recent years, permitting for mining was on hold, and environmental and bureaucratic issues were detriments to modern exploration.

Table C6 shows the individual and team estimates for undiscovered porphyry copper deposits in the Apuseni Mountains tract at the 90, 50, 10 probability levels and summary statistics. The team estimate was 1, 3, and 6 deposits at the 90, 50, and 10 probability levels, respectively, with a mean of 3.2 undiscovered deposits.

Probabilistic Assessment Simulation Results

Undiscovered resources for the tract were estimated by combining consensus estimates for numbers of undiscovered porphyry copper deposits with the porphyry copper-gold grade and tonnage model (Singer and others, 2008) using the EMINERS program (Root and others, 1992; Bawiec and Spanski, 2012; Duval, 2012). Selected output parameters are reported in table C7. Results of the Monte Carlo simulation are presented as a cumulative frequency plot (figure C5). The cumulative frequency plot shows the estimated resource volumes associated with cumulative probabilities of occurrence, as well as the mean, for each commodity and for total mineralized rock.

Table C6. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 150pCu6003 (EU03PC), Apuseni Mountains—Western Romania.

[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; Ntotal, total of expected number of deposits plus known deposits; km^2, area of permissive tract in square kilometers; N_{total}/km^2, deposit density reported as the total number of deposits per km^2; 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)]

Assessor	Consensus undiscovered deposit estimates			Summary statistics					Tract Area (km^2)	Deposit density (N_{total}/100k km^2)
	N_{90}	N_{50}	N_{10}	N_{und}	*s*	C_v%	N_{known}	N_{total}		
A	2	3	6	3.5	1.6	47	7	10.5	4,156	252
B	1	4	6	3.6	1.8	49	7	10.6	4,156	255
C	1	2	7	3.1	2.4	75	7	10.1	4,156	243
D	1	3	5	2.9	1.9	51	7	9.9	4,156	238
E	0	2	5	2.3	1.8	80	7	9.3	4,156	224
Consensus	1	3	6	3.2	1.9	58	7	10.2	4,156	245

Table C7. Results of Monte Carlo simulations of undiscovered resources for tract 150pCu6003 (EU03PC), Apuseni Mountains—Western Romania.

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

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu	0	270,000	4,600,000	26,000,000	43,000,000	10,000,000	0.27	0.07
Mo	0	0	8,500	140,000	330,000	57,000	0.21	0.33
Au	0	31	390	1,900	2,800	730	0.31	0.07
Ag	0	0	760	6,700	16,000	3,300	0.19	0.24
Rock	0	67	1,000	5,300	8,700	2,000	0.29	0.07

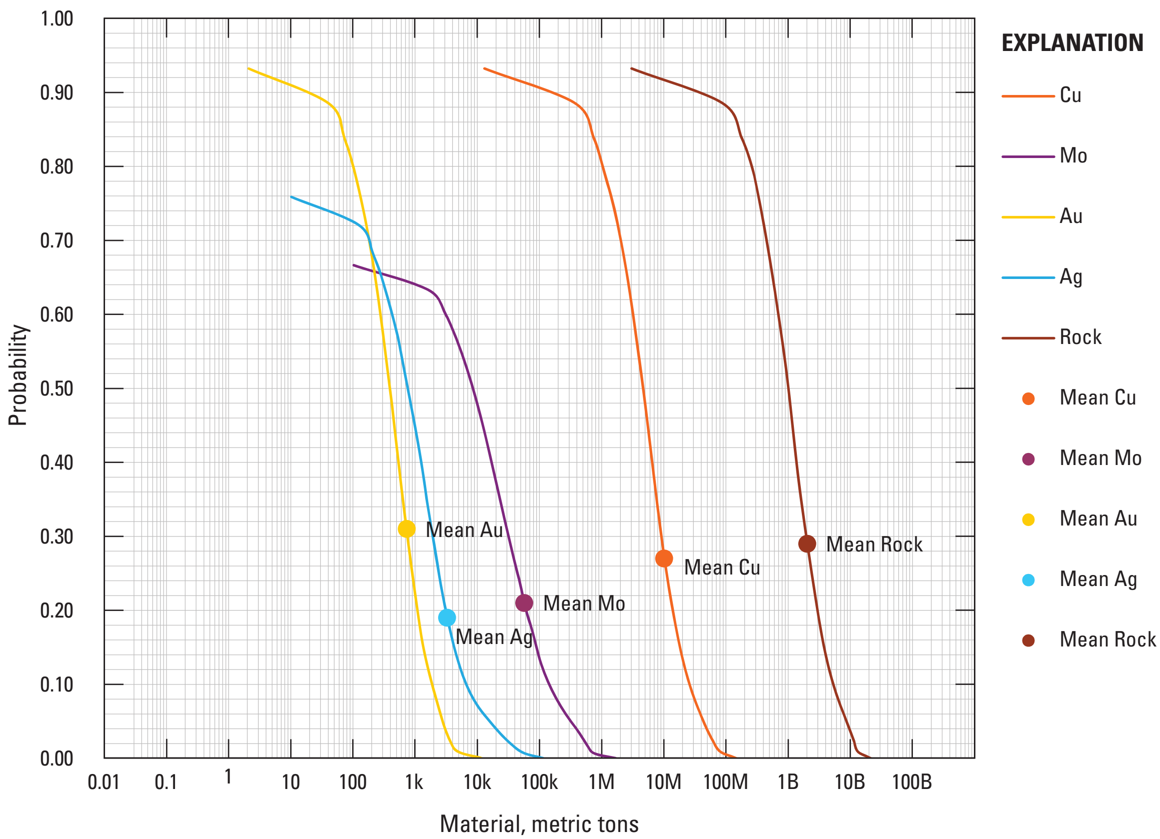


Figure C5. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in porphyry copper-gold deposits in tract 150pCu6003 (EU03PC), Apuseni Mountains—Western Romania. k, thousand; M, million; B, billion.

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Appendix D. Porphyry Copper Assessment for Tract 150pCu6004 (EU04PC), Northern Carpathians—Hungary, Romania, Slovakia, and Ukraine

By David M. Sutphin[1], Lawrence J. Drew[1], Duncan E. Large[2], Byron R. Berger[3], and Jane M. Hammarstrom[1]

Deposit Type Assessed: Porphyry copper

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

Table D1. Summary of selected resource assessment results for tract 150pCu6004 (EU04PC), Northern Carpathians—Romania, Ukraine, Hungary, and Slovakia.

[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	28,850	740,000	7,900,000	2,900,000

Location

The tract is a 700 km-long arcuate belt that encompasses much of the northern Carpathian Mountains stretching from Hungary and Slovakia, through southwestern Ukraine into central Romania (fig. 1*A*[4], fig. D1).

Geologic Feature Assessed

An arcuate belt of calc-alkaline volcanic and intrusive rocks that formed in a postsubduction setting due to extension, lithospheric thinning, and mantle upwelling (Inner Carpathian magmatic arc).

[1]U.S. Geological Survey, Reston, Virginia, United States.

[2]Independent consulting geologist, Branschweig, Germany and London, United Kingdom.

[3]U.S. Geological Survey, Denver, Colorado, United States.

[4]Refers to figures and tables in the main report.

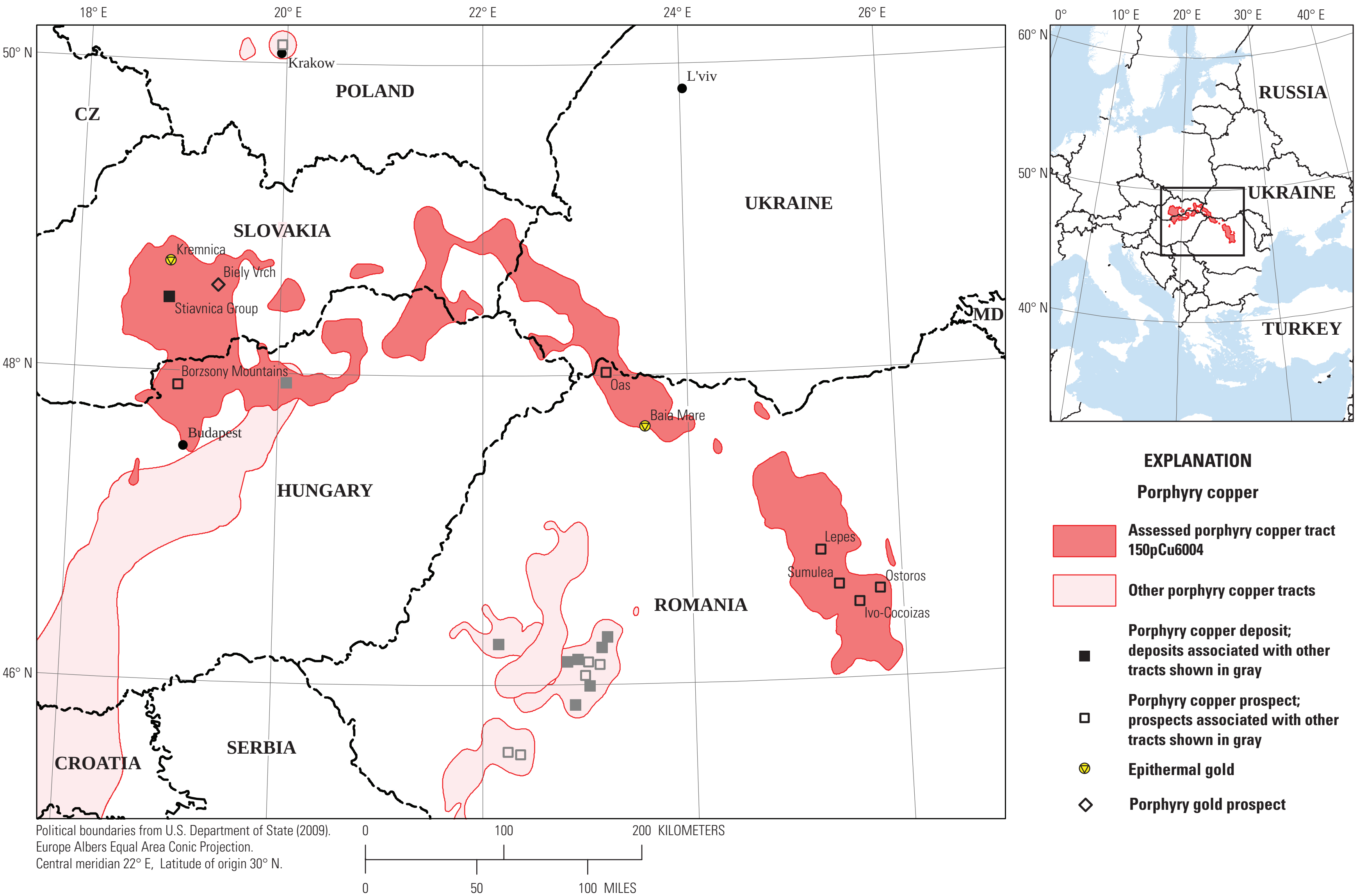

Figure D1. Map showing the location, known deposits, and significant prospects and occurrences for permissive tract 150pCu6004 (EU04PC), Northern Carpathians—Romania, Ukraine, Hungary, and Slovakia.

Delineation of the Permissive Tract

Tectonic Setting

The tract is defined by the Inner Carpathian magmatic arc (fig. 16*A*), where Miocene to Pliocene calc-alkaline volcanism was related to subduction of a small ocean basin (Mason and others, 1996). Calc-alkaline magmatism resulted from an interplay between plate roll-back and lithospheric detachment and breakoff of a subducted plate in a postcollisional setting Seghedi and others (1998). The geodynamic evolution and development of structural features resulted in hydrothermal fluid channeling within transtensional settings developed during periods of extension related to block rotation (Neubauer and others, 2005).

The Inner Carpathians contain several discrete Neogene mineral districts; porphyry and epithermal vein deposits are associated with volcanic and subvolcanic rocks (Neubauer and others, 2005; Vágó and Binelly, 2006). There are 18 major volcanic centers in the region; some of the Neogene volcanic centers are barren. The ages of volcanic activity in the Carpathians generally range from 20–11 Ma in the Central Slovakian Volcanic Field (fig. D2) in the westernmost Inner Carpathians to 14–9 Ma in the central part of the region, to 9–0.2 Ma in Călimani-Harghita Mountains (fig. D2) (Lang, 1979; Seghedi and others, 1998).

The western part of the tract includes the Neogene (16.5–8.5 Ma) Central Slovakian Volcanic Field (CSVF); historically, this area produced precious- and base metals from a variety of mineral deposit types, including porphyry copper-gold and related epithermal and replacement deposits (Konečny and others, 1999; Lexa, 1999a; Jelen and others, 2003). Andesitic volcanism in the CSVF is associated with development of horst and graben structures. Horst and graben orientation changed over time owing to a change in the regional principal stress axis as the Alpine-Carpathian-Pannonian crustal block collided with the European Platform (Konečny and others, 1999). Northwest-southeast-trending faults controlled early graben structures; subsequent grabens were controlled by north and north-northeast-trending faults. Marginal graben faults localized volcanic centers. Multiple phases of caldera collapse, volcanotectonic subsidence, and as much as 3 km of horst uplift led to exposure of basement and subvolcanic intrusions at Štiavnica and elsewhere in the CSVF.

Epithermal gold- and base-metal deposits occur in the Eastern Carpathian Mountains in western Ukraine, but no porphyry copper deposits or prospects are recognized there. In the Călimani-Harghita Mountains (fig. D2), the low- to-medium- to high-K calc-alkaline andesites and dacites were generated through partial melting of the subducted slab followed by gradual break-off of the subducted plate along its north-south strike (Mason and others, 1996; Seghedi and others, 1998).

Geologic Criteria

The Northern Carpathians tract is defined by Tertiary plutonic and coeval volcanic rocks in the Carpathian Mountains of Hungary, Romania, Slovakia, and Ukraine (excluding the Apuseni Mountains) (fig. D2). Table D2 lists the plutonic and volcanic, volcano-sedimentary, and pyroclastic geologic map units from the enhanced geologic map of Europe (Cassard and others, 2006) that were selected as permissive for the occurrence of porphyry copper deposits.

The permissive intrusive rocks are intermediate granitoids mapped as Oligocene; these include undifferentiated diorite and monzonite to granite, granodiorite, and leucogranite. Intrusive rocks make up only a small percentage of the tract; dominantly felsic and intermediate volcanic rocks make up the majority of the tract. One included map unit, **jpva**, covers an age range from Jurassic to the Pliocene (203–1.75 Ma), although the major volcanism in the Carpathians began at about 20 Ma (Lang, 1979; Seghedi and others, 1998). In general, late Miocene high-K volcanic rocks characterize the western parts of the tract whereas medium-K volcanic rocks are predominant in the east (Herrington and others, 2003.

Preliminary tracts were identified by outlining areas of interest on printed paper maps, such as the geologic map of Romania. The final tract was constructed by processing geologic data from the enhanced digital geologic map of permissive igneous rocks prepared for the study (Cassard and others, 2006), as follows:

- Permissive igneous lithologies in map units in the Carpathian Mountains and attributed as Tertiary or extending into the Tertiary were selected from the 1:1,500,000-scale enhanced digital geologic map of Europe. These included rocks with age ranges of Jurassic-Pliocene, Paleogene, Oligocene, Miocene, and Miocene-Pliocene (table D2).
- A prototract was developed by placing a 10-km-wide buffer around permissive intrusive rocks and a 2-km buffer around permissive volcanic rocks. This expanded the area of the tract to include most porphyry copper deposits and significant associated prospects and accounts for possible unexposed or unmapped adjacent permissive rocks.
- After buffering, aggregation and smoothing routines were applied to the resulting polygons.
- Locations of Tertiary porphyry copper deposits and prospects were examined to ensure that were included in the map-based tract.

The final tract consists of nine discrete polygons, three relatively large elongate shapes and six smaller less complexly shaped bodies, as shown in figure D1. Permissive units and source maps are listed in table D2.

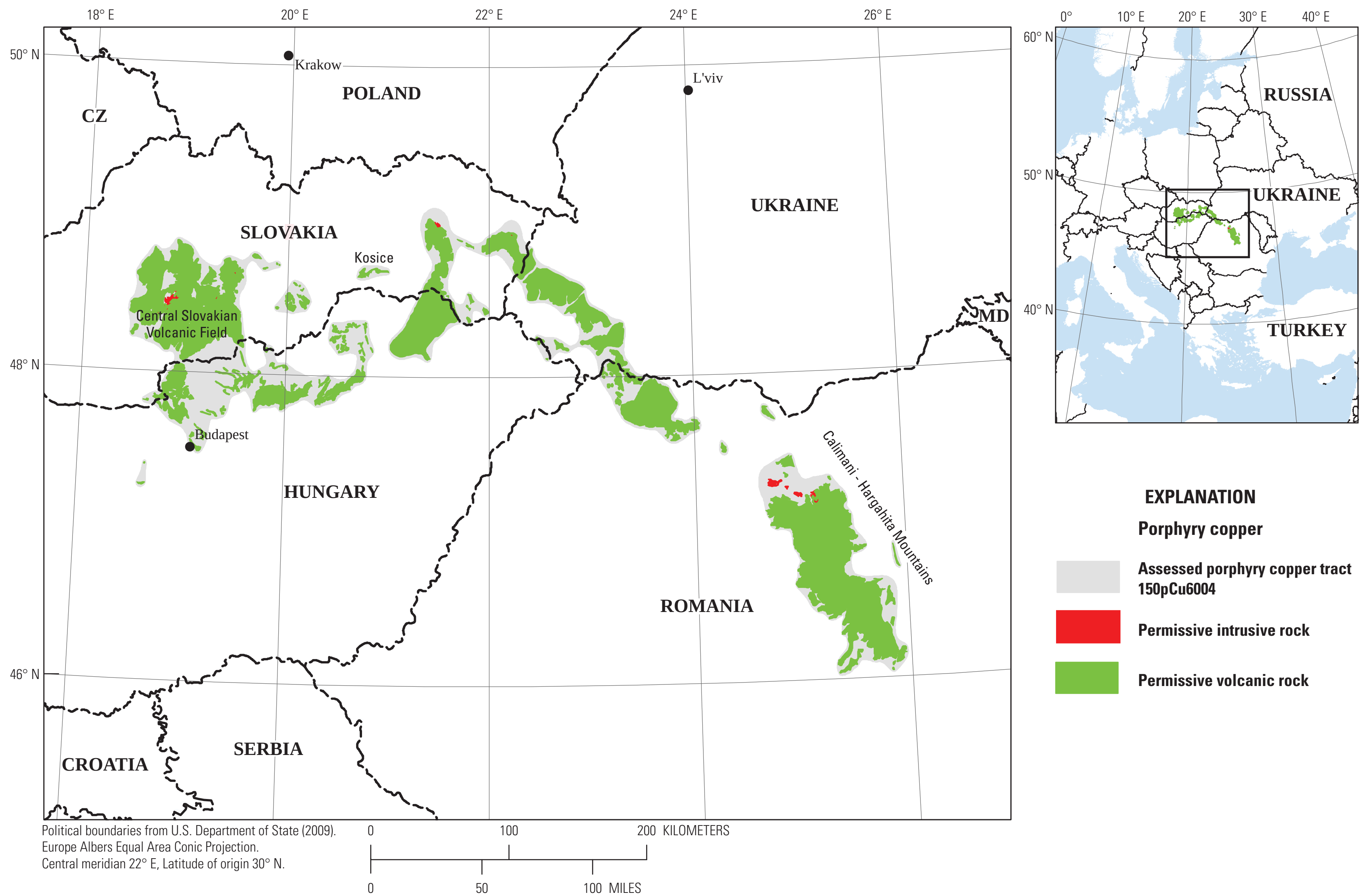

Figure D2. Map showing permissive rocks used to delineate tract 150pCu6004 (EU04PC), Northern Carpathians—Romania, Ukraine, Hungary, and Slovakia.

Table D2. Map units that define tract 150pCu6004 (EU04PC), Northern Carpathians—Romania, Ukraine, Hungary, and Slovakia.

[Map unit, age range, and principal lithologies are based on Cassard and others (2006) 1:1,500,000 digtial geologic map units; scanned and rectified paper maps at larger scales checked for inclusion in the tract (see table D5)]

Map symbol	Lithology	Age range	Source map
	Intrusive rocks		
24	Diorite, monzonite, intermediate plutonic complex and granitoid (granite, leucogranite, granodiorite, etc.)	Oligocene 33.5–23.5 Ma	Cassard and others, 2006
	Volcanic rocks		
jpva	Dominantly volcanic and volcano-plutonic acidic rocks	Jurassic-Pliocene 203–1.75 Ma	Cassard and others, 2006
m	Dominantly volcano-sedimentary rocks	Miocene 23.5–5.3 Ma	Cassard and others, 2006
mp	Dominantly volcanic and volcano-plutonic acidic rocks	Miocene-Pliocene 23.5–1.75 Ma	Cassard and others, 2006
mpv	Dominantly acidic pyroclastic rocks and volcano-sedimentary rocks	Miocene-Pliocene 23.5–1.75 Ma	Cassard and others, 2006
mv	Dominantly pyroclastic rocks and volcanic and volcano-plutonic rocks	Miocene 23.5–5.3 Ma	Cassard and others, 2006
mva	Dominantly acidic pyroclastic rocks and volcanic and volcano-plutonic acidic rocks	Miocene 23.5–5.3 Ma	Cassard and others, 2006
mvi	Dominantly intermediate pyroclastic rocks and volcanic and volcano-plutonic intermediate rocks	Miocene 23.5–5.3 Ma	Cassard and others, 2006

Known Deposits

Vysoká-Zlatno (Štiavnica Group)

Mineral deposits associated with Štiavnica (table D3), the largest andesitic volcano in the CSVF, historically produced precious- and base metals from epithermal and base-metal vein deposits (Jelen and others, 2003). The middle Miocene Štiavnica volcano, with a diameter of ~50 km and a 20-km-wide caldera (fig. D3), developed in several stages from 16.2–10.5 Ma, which were accompanied by different styles of mineralization (Koděra and others, 2010):

- 16.2–15.8 Ma Pre-caldera andesitic stratovolcano; no mineralization
- 15.5–14.5 Ma Denudation of the volcano and subvolcanic intrusion stage (quartz diorite to granodiorite porphyry pluton, stocks, and dikes); early barren advanced-argillic lithocap skarn and porphyry copper-gold-molybdenum systems
- 14.5–14.0 Ma Caldera subsidence stage with andesite-dacite volcanism and emplacement of quartz diorite porphyry dikes and sills at depth; low-sulfidation epithermal gold in caldera center and hot-spring alteration of caldera infill
- 14.0–12.5 Ma Post-caldera andesitic volcanism; no mineralization
- 12.5–10.5 Ma Resurgent horst uplift associated with rhyolitic volcanism; asymmetric uplift and subsequent erosion exposed a subvolcanic intrusive complex and basement; intermediate to low-sulfidation base- and precious metal veins.

Deep drilling (900–1,500 m) in the 1970s led to the discovery of the Vysoká-Zlatno copper-gold skarn-porphyry deposit and the first recognition of skarn-porphyry mineralization associated with the volcano (Koděra and others, 2010). Subsequent exploration identified medium-size skarn-porphyry prospects at Sementlov and Sklenne Teplice and other small prospects (fig. D3). The 13.4 Mt Vysoká-Zlatno deposit, with an average grade of 0.52 percent copper, is the largest porphyry system identified to date. At Zlatno, a granodiorite porphyry stock hosts an extensive stockwork of veinlets at a depth of 700 and 1,000 m. During the Soviet era, Zlatno was extensively explored for copper but not for gold and drilling delineated a low-grade porphyry copper/skarn at depth (EMED Mining, 2010a,b). In late 2007, Allied Gold Resources had three drill rigs on site at Zlatno to begin a 15-hole borehole drilling and coring exploration program for gold and silver (Allied Gold Resources, 2008). In the 1980s, the Slovakian Geological Survey reported exploration results for Sementlov, including 1-m drilling intervals with grades of 30 g/t gold and 19.5 g/t silver, respectively and a 350 by 500 m soil geochemical anomaly (>20 ppb gold coincident with >100 ppm copper) (Cunneen, 2009a).

All of the skarn-porphyry prospects are associated with quartz diorite to granodiorite porphyry stocks and dike

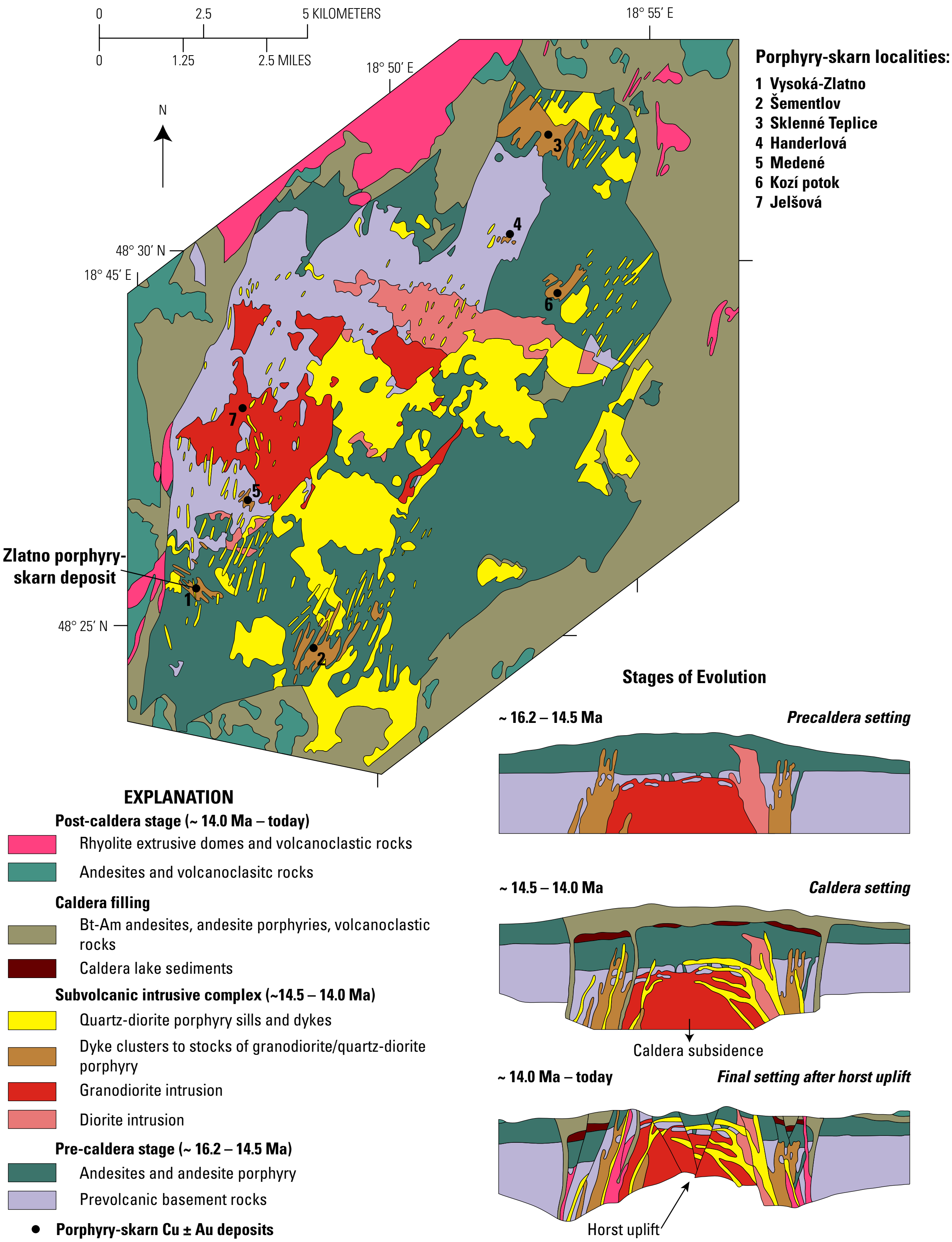

Figure D3. Simplified geologic map of the central zone of the Štiavnica volcano, Slovakia, showing the subvolcanic intrusive complex and skarn-porphyry localities (modified from Koděra and others, 2010). Bt-Am, biotite-amphibole.

clusters around an older granodiorite pluton (fig. D3). Individual localities have estimated resources of millions to tens of millions of metric tons of ore at grades considered to be uneconomic: up to 0.4 percent copper, 10 ppm molybdenum, and 1 g/t gold (Lexa and others, 1999b). On the basis of the close spatial association of all the prospects with the Štiavnica volcano, we consider the system as one deposit; further, and deeper, exploration may extend the identified resources at Vysoká-Zlatno or identify additional deposits. The weighted average of available data for the Štiavnica Group, which includes Banska Štiavnica, Sementlov, and Zlatno is 210 Mt at 0.35 percent copper (table D3).

Prospects, Mineral Occurrences, and Related Deposit Types

Table D4 lists six porphyry copper prospects in the tract; four prospects are located in the Călimani-Harghita Mountains of eastern Romania (fig. D2). Most of the prospects are in hydrothermally altered volcanic rocks associated with uplifted and eroded volcanic centers and have not been thoroughly explored.

Biely Vrch, Slovakia

The Slovak Geological Survey detected anomalous gold at Biely Vrch during rock-chip sampling, but it was not until advanced argillic alteration was recognized in 2005 that the prospect was considered as a potential porphyry copper deposit (Cuneen, 2009b). The prospect is centered on the western side of a mineralized hornblende andesite porphyry; gold is confined to quartz stockwork veinlets associated with early potassic alteration of the andesite porphyry Cuneen (2009b).

In October 2006, EMED Mining announced a gold discovery at Biely Vrch (Detva exploration license area) in Slovakia. Drilling had intercepted 108 m of rock averaging 1.26 g/t gold from the surface; further drilling had intercepted 252 m of mineralized rock averaging 1.21 g/t gold from the surface (Cuneen, 2009b). Biely Vrch is currently considered to be a porphyry gold deposit in a caldera-graben complex in the center of an andesitic stratovolcano; initial JORC-compliant indicated and inferred resources are 17.7 Mt at 0.81 g/t gold (Fletcher and Bennett, 2010). Only gold and silver are economic in the near-surface deposit; copper averages 0.01 percent with a maximum of 0.33 percent. The gold deposit may represent the upper parts of a gold-copper system at depth (Fletcher and Bennett, 2010).

Mining and Exploration History

Mine workings dating from Roman and Ottoman times are still apparent in the Carpathian Mountains. During medieval times, about 80 percent of Europe's gold production originated in the Carpathians (Molnár and others, 1999). From the 12th to the 15th centuries, Hungarian Kingdom precious-metals production reached 2.5 t gold and 10 t silver annually (Molnár and others, 1999). Most of the silver used in Renaissance Europe originated in Slovakia (EMED Mining, 2010a). Agricola's (1556) monumental treatise on mining is based on his experiences in Carpathian mining districts (Molnár and others, 1999).

Decades of environmentally unsound practices and the January 2000 retaining wall failure and cyanide release at the Baia Mare epithermal mine (fig. D1) and processing plant in Romania have affected societal attitudes toward mining in Central Europe (Argeseanu, 2004). In 2006, the Romanian Government stated that companies that exceeded the European Union (EU) target pollution rate and that had not been approved for special transition periods in which to reduce emissions would either be shut down or would face substantial fines. As a result of the new environmental policy, funding was suspended for 20 mines beginning in January 2007 (Rompres, 2006, 2007; Brininstool, 2011). On January 1, 2007, Romania joined the EU, which led some facilities to modernize or close (Brininstool, 2011). EMED Mining holds a number of exploration licenses in the Banská Štiavnica area, including the Biely Vrch porphyry gold deposit (EMED Mining, 2010). Both the Zlatno and Sementlov prospects were explored for copper during the Soviet era, but not for gold; the drill-delineated low-grade porphyry copper/skarn deposit at Zlatno was deemed uneconomic at the time (Fletcher and Bennett, 2010). Some former prospect areas in the Central Slovakian Volcanic Field (Sklené Teplice, fig. D3) have been sterilized due to land restrictions (Cunneen, 2009a) .

The Eastern Carpathian Mountains may be underexplored for porphyry copper deposits. Some areas, however, are moderately well-explored for gold deposits. In Slovakia, Rio Tinto conducted a geochemical exploration project in the Kosice area (fig. D2). All of the recent exploration focus is on gold; porphyry copper systems, if present, may be too deep and(or) too low-grade to warrant development in the foreseeable future.

Sources of Information

Principal sources of information used for delineation of the Northern Carpathians tract 150pCu6004 (EU04PC) are listed in table D5.

Grade and Tonnage Model Selection

The Štiavnica porphyry system is classified as Cu-Au subtype based on average gold contents (>0.2 g/t gold) and negligible molybdenum content. Porphyry gold and epithermal prospects associated with the tract area also suggest that any undiscovered deposits are likely to be gold-rich. Therefore, the global porphyry Cu-Au subtype model of Singer and others (2008) was used for the simulation of undiscovered resources.

Table D3. Porphyry copper deposits in tract 150pCu6004 (EU04PC), Northern Carpathians—Romania, Ukraine, Hungary, and Slovakia.

[Group names in boldface. Ma, million years; Mt, million metric tons; t, metric ton; %, percent; g/t, gram per metric ton; n.d., no data. Cu-Au subtype, deposits that have Au/Mo ratios >30 or average Au grades >0.2 g/t.

Name	Includes	Country	Latitude	Longitude	Sub-type	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)	Reference
Ŝtiavnica Group	Vysoka-Zlatno, Sementlov, Banska Štiavnica	Slovakia	48.471	18.899	Cu-Au	~11	210	0.35	0.001	0.23	9.5	740,000	Allied Gold Resources (2008), Bohmer (1980), Burian and Smolka (1982), Cunneen (2009a), EMED Mining (2010a,b; 2011), Grula and others (1997), Jelen and others (2003), Koděra and others (2010), Kusik (1992), Lips and others (2006)

Table D4. Significant prospects and occurrences in tract 150pCu6004 (EU04PC), Northern Carpathians—Romania, Ukraine, Hungary, and Slovakia.

[Ma, million years; n.d., no data]

Name	Country	Latitude	Longitude	Age (Ma)	Comments	Reference
Biely Vrch	Slovakia	48.561	19.380	Miocene?	Gold porphyry deposit in Miocene Javorie stratovolcano. Initital resource estimates 42 Mt at 0.8 g/t Au. Gold-pyrite in quartz vein stockworks in hydrothermally altered diorite intrusion; coeval andesitic volcanic rocks. May overlie porphyry Au-Cu system at depth, but gold and silver are the only potentially economic commodities determined to date.	Cunneen (2009b), EMED Mining (2007), Fletcher and Bennett (2010), Hanes and others (2010), Kordĕra and others (2010b)
Borzsony Mountains	Hungary	47.910	19.014	14	0.1 to 0.2% Cu.	Csillagne Teplansky and others (1983), Korpas (1998), Paar and others (1997)
Ivo-Cocoizas	Romania	46.491	25.582	5	Hydrothermally altered stratovolcano in the Călimani-Gurghiu-Hargahita volcanic chain	Mason and others (1995), Mason and others (1996), Szakăcs and Seghedi (1995)
Kremnica	Slovakia	48.712	18.902	~16	Described as a porphyry- and porphyry-related deposit in an old mining district. No data on past production. Cu, Au, Mo, Sn, and Ag reportedly present, but no Cu grades cited. Kremnica gold project JORC-compliant resources are 17.4 Mt, 1.68 g/t Au, 13.3 g/t Ag for gold associated with sheeted quartz vein.	Lips and others (2006), Cunneen (2009a), Ortac Resources (2011)
Lepes	Romania	46.834	25.232	8	Advanced argillic alteration around vuggy silica associated with a Fancel Lapusna caldera in the Lepes-Eseniu area; calc-alkalic to high-K calc-alkalic volcanism in the Călimani, Gurghiu and Harghita Mountains of Romania. Zoned hydrothermal alteration consistent with porphyry system; andesitic domes, microdiorite bodies at 500 m depth. Rock chemistry compatible with porphyry; high sulfidation epithermal system.	Mason and others (1995), Popa and others (2002)

Table D4. Significant prospects and occurrences in tract 150pCu6004 (EU04PC), Northern Carpathians—Romania, Ukraine, Hungary, and Slovakia.—Continued

[Ma, million years; n.d., no data]

Name	Country	Latitude	Longitude	Age (Ma)	Comments	Reference
Oas	Romania	48.020	23.208	Miocene?	In the Eastern Carpathians subprovince, the Oas metallogenic zone contains base metal deposits accompanied locally by Au, Ag and Hg mineralization.	Janković (1997), Gratian and others (undated), Gunzburg (2004)
Ostoros	Romania	46.571	25.782	5	Minera Andes 1999 exploraton license area; preliminary mapping, geophysical studies, and sampling by Romanian-owned companies and institutes indicated areas of intense hydrothermal alteration and localized base-metal and gold occurrences.	Brown and others (1999) Mason and others (1995), Popa and others (2002), Szakács and Seghedi (1995), Minera Andes (2000)
Sumulea	Romania	46.611	25.394	8	Hydtothermally altered stratovolcano in the Călimani-Gurghiu-Hargahita volcanic chain	Mason and others (1995), Minera Andes Inc. (1999), Mason and others (1996)

Estimate of the Number of Undiscovered Deposits

Rationale for the Estimate

The assessment team noted that although the tract area is moderately well-explored for gold in recent years, it has not been thoroughly explored with modern techniques for porphyry copper deposits. Favorable features are that there are many young volcanoes, epithermal-gold, skarn, and polymetallic vein occurrences. Parts of the tracts are structurally complex; strike-slip faults provide structural traps for emplacement of igneous stocks at strike-slip stepover structures. Pessimistic features for undiscovered deposits are the low copper grades, the lack of extensive mineralization in Neogene volcanic rocks, and the small size of the prospects. One team member speculated that the hydrothermal fluids that accompanied the Neogene volcanism were not contained within the rocks and vented to the atmosphere negating the potential for the formation of porphyry copper deposits.

In 1997, an assessment team from the U.S. Geological Survey and the Hungarian Geological Survey applied a tectonic model to assess the probability of undiscovered porphyry copper and polymetallic vein deposits in the Mátra Mountains in northern Hungary in the central part of the tract (Drew and others, 1999; Drew and Berger, 2001, 2002; Drew, 2003). The 1997 team concluded that although no porphyry copper deposits have been discovered in the Mátra Mountains, mapped silicified areas and polymetallic veins could represent manifestations of a porphyry copper system. They estimated no deposits at the 90- and 50-percent probability levels, 1 deposit at the 10-percent level, and 2 deposits at the 1-percent level, which resulted in a mean of less than 1 undiscovered deposit.

The 2010 estimate for the larger Northern Carpathians tract 150pCu6004 (~30,000 km^2), which includes the Mátra Mountains, was 0, 2, and 6 at the 90-, 50-, and 10- percent probability levels (table D6). This distribution produces a mean of 2.6 undiscovered porphyry copper deposits.

Probabilistic Assessment Simulation Results

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

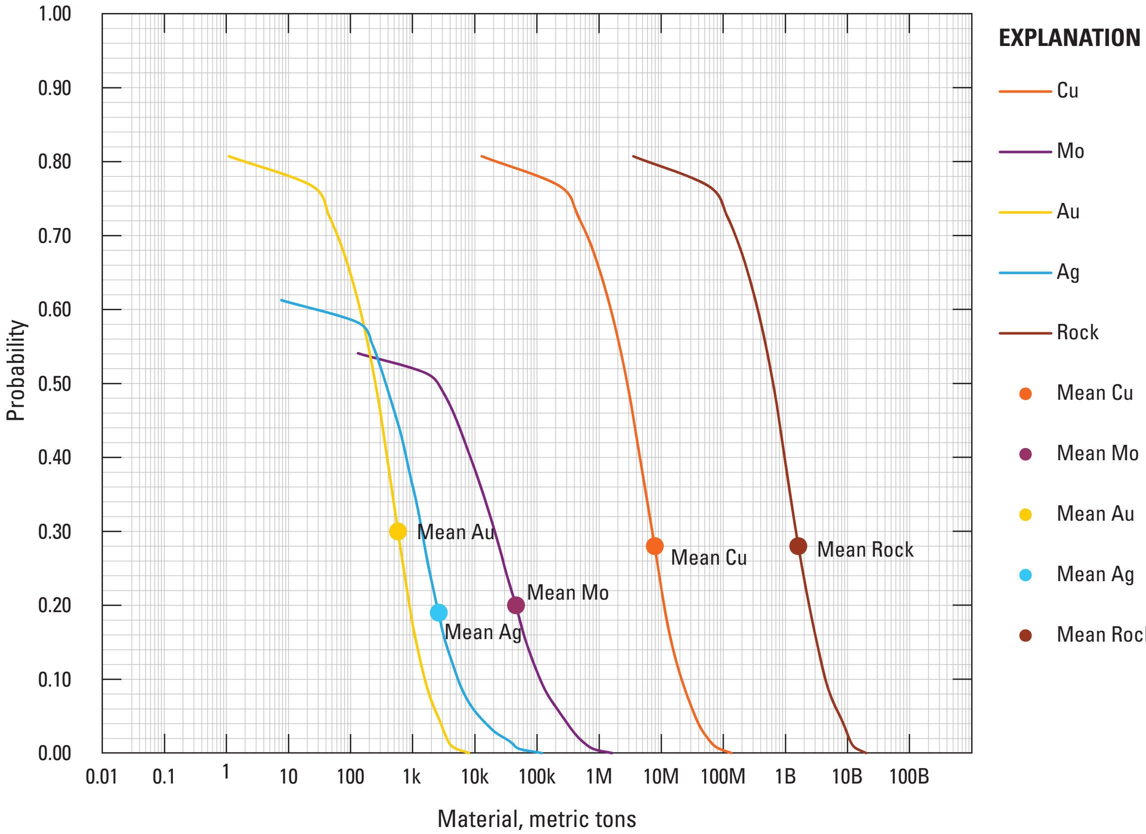

Figure D4. Cumulative frequency plot showing the results of Monte Carlo computer simulation of undiscovered resources in porphyry copper deposits in tract 150pCu6004 (EU04PC), Northern Carpathians—Romania, Ukraine, Hungary, and Slovakia. k, thousand; M, million; B, billion.

Table D5. Principal sources of information used for tract 150pCu6004 (EU04PC),Northern Carpathians—Romania, Ukraine, Hungary, and Slovakia.

[NA, not applicable]

Theme	Name or Title	Scale	Citation
Geology	Digital geologic map of Europe	1:1,000,000	Cassard and others (2006)
	Geological map of Romania	1:1,000,000	Sandulescu and others (1978)
Mineral occurrences	Mineral and energy resources of Central Europe	1;2,500,000	Dill and Saschsenhofer (2008)
	Mineral Resources Data System (MRDS)	NA	U.S. Geological Survey (2009)
	Hungary (Mineral deposits of Europe)	NA	Morvai (1982)
	Porphyry copper deposits of the world—Database, map, and grade and tonnage models	NA	Singer and others (2008)
Metallogeny	Map of mineral formations of the Carpathian-Balkan Region	1:1,000,000	Bogdanov and others (1977)

Table D6. Undiscovered deposit estimates, deposit numbers, tract area, and deposit density for tract 150pCu6004 (EU04PC), Northern Carpathians—Romania, Ukraine, Hungary, and Slovakia.

[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; km^2, area of permissive tract in square kilometers; N_{total}/km^2, deposit density reported as the total number of deposits per 100,000 km^2. Nund, s, and C_v% are calculated using a regression equation (Singer and Menzie, 2005)]

Assessor	Consensus undiscovered deposit estimates				Summary statistics				Tract Area (km^2)	Deposit density (N_{total}/100k km^2)
	N_{90}	N_{50}	N_{10}	N_{und}	s	C_v%	N_{known}	N_{total}		
A	1	2	3	1.9	0.8	43	1	2.9	28,850	14
B	0	2	5	2.3	1.8	80	1	3.3	28,850	14
C	0	1	8	2.8	3.1	109	1	3.8	28,850	17
D	0	2	4	2	1.5	73	1	3	28,850	14
E	0	2	8	3.2	3.0	93	1	4.2	28,850	17
Consensus	0	2	6	2.6	2.2	85	1	3.6	28,850	17

Table D7. Results of Monte Carlo simulations of undiscovered resources for tract 150pCu6004 (EU04PC), Northern Carpathians—Romania, Ukraine, Hungary, and Slovakia.

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

Material	Probability of at least the indicated amount						Probability of	
	0.95	0.9	0.5	0.1	0.05	Mean	Mean or greater	None
Cu	0	0	2,900,000	21,000,000	34,000,000	7,900,000	0.28	0.19
Mo	0	0	2,300	110,000	250,000	46,000	0.2	0.46
Au	0	0	250	1,600	2,500	580	0.3	0.19
Ag	0	0	370	5,400	11,000	2,600	0.19	0.39
Rock	0	0	640	4,400	7,800	1,600	0.28	0.19

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Appendix E. Porphyry Copper Assessment for Tract 150pCu6005 (EU05PC), Western Peri-Mediterranean Region—Italy (Sardinia), Spain, and Northern Morocco

By David M. Sutphin[1], Lawrence J. Drew[1], Duncan E. Large[2], Byron R. Berger[3], and Jane M. Hammarstrom[1]

Deposit Type Assessed: Porphyry copper

Descriptive model: Porphyry copper (Cox, 1986; Berger and others, 2008; John and others, 2010)
Although the tract is broadly permissive (0.001 percent, or 1 in 100,000 chance or more) for porphyry copper deposits, the assessment team concluded that a probabilistic estimate of undiscovered deposits was not warranted based on available data. Summary information is listed in table E1.

Location

Table E1. Summary information for tract 150pCu6005 (EU05PC), Western Peri-Mediterranean Region—Italy (Sardinia), Spain, and Northern Morocco.

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

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (t)
2010	1	6,450	130,000

The tract includes the western half of the Italian island of Sardinia and the Betic-Rif Cordillera of southeastern Spain and northeastern Morocco (fig. E1).

Geologic Feature Assessed

The tract assesses fragments of Neogene postcollisional volcanic belts related to the Alpine orogeny in the western peri-Mediterranen area.

[1]U.S. Geological Survey, Reston, Virginia, United States.

[2]Independent consulting geologist, Branschweig, Germany and London, United Kingdom.

[3]U.S. Geological Survey, Denver, Colorado, United States.

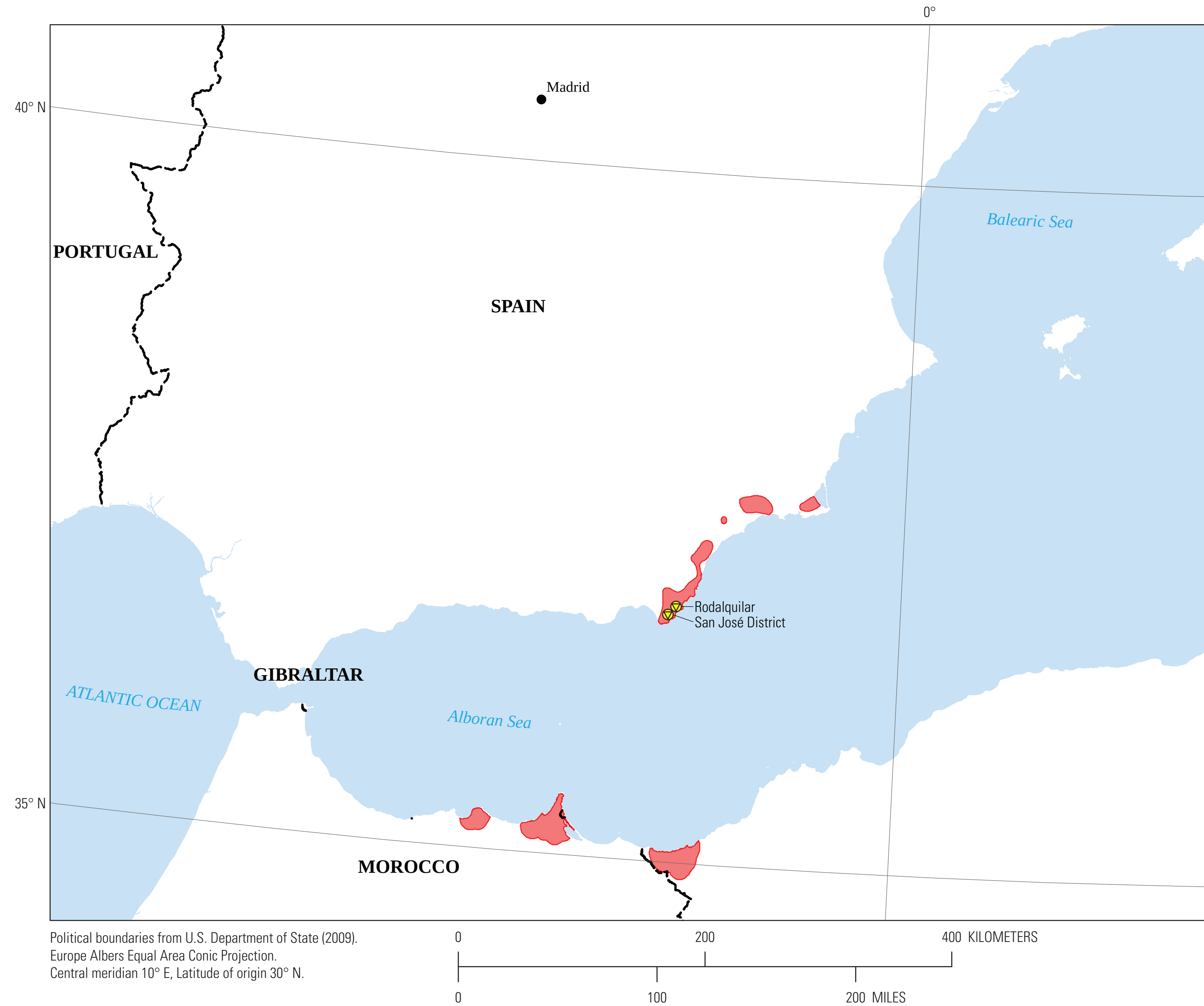
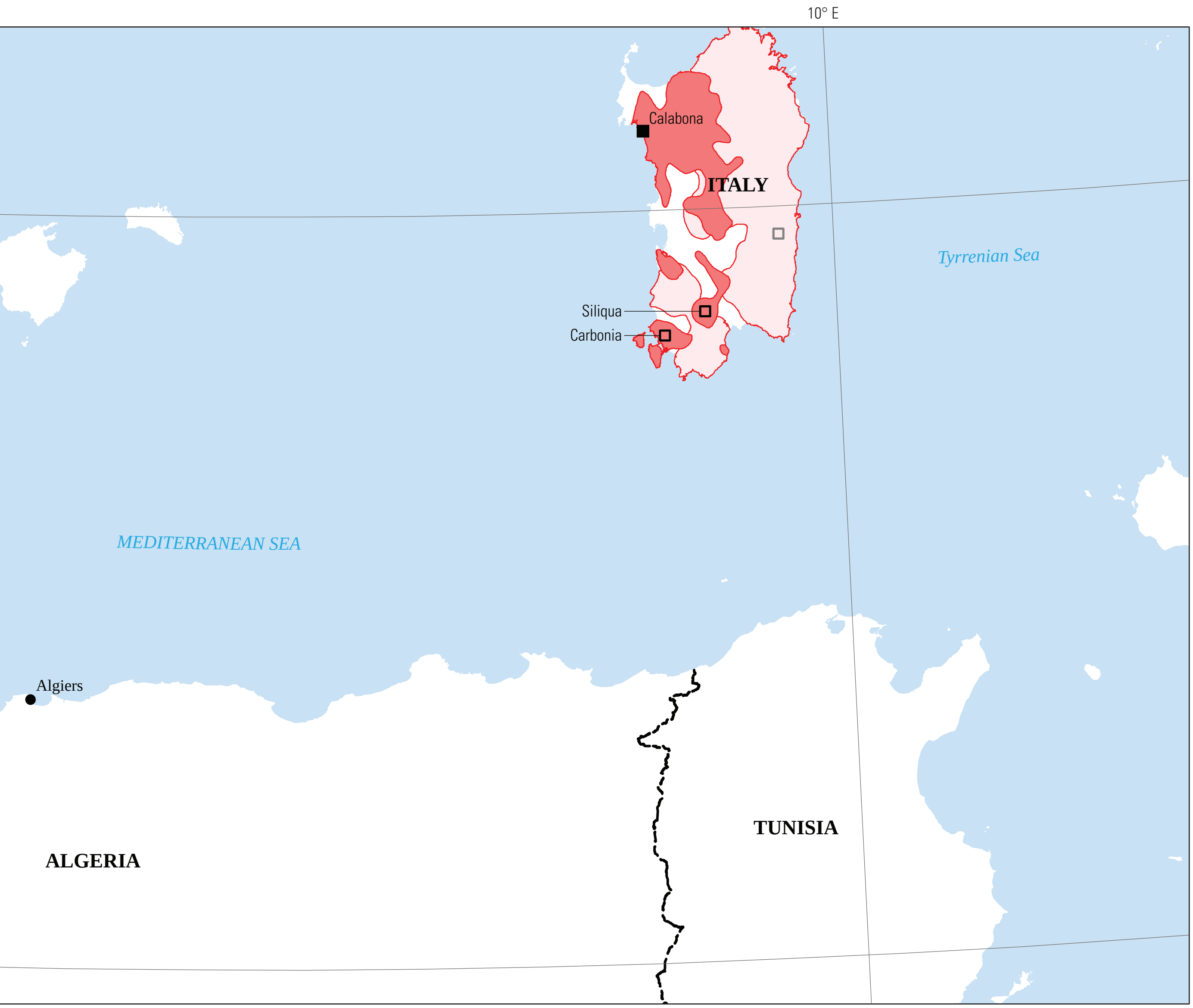


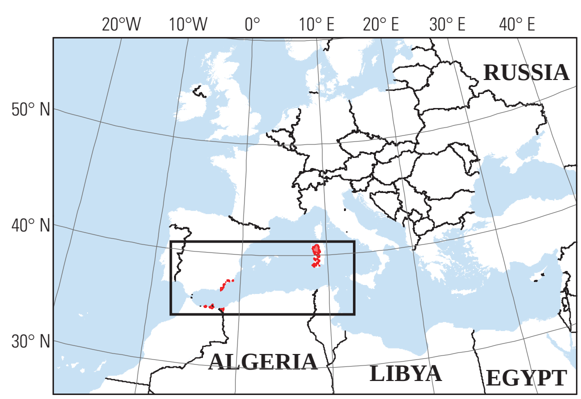
Figure E1. Map showing the location, known deposits, and significant prospects and occurrences for tract 150pCu6005 (EU05PC), Western Peri-Mediterranean Region—Italy (Sardinia), Spain, and northern Morocco.



EXPLANATION

Porphyry copper

- **Assessed porphyry copper tract Coded_ID 150pCu6005**
- **Other porphyry copper tracts**
- **Porphyry copper deposit; deposits associated with other tracts shown in gray**
- **Porphyry copper prospect; prospects associated with other tracts shown in gray**
- **Epithermal gold**



Delineation of the Permissive Tract

Tectonic Setting

The Western Peri-Mediterranean tract 150pCu6005 (EU05PC) is defined by locally preserved disparate belts of late Alpine Neogene magmatism in Sardinia and southeastern Spain-northeastern Morocco. During the Alpine orogeny, both the European and African plate margins converged from north and south, respectively (Platt and others, 2006). Sardinia and Corsica were detached from Europe and were rotated counterclockwise as part of the African Plate was subducted beneath Europe (Frezotti and others, 1992; Stefanini and Williams-Jones, 1996; Dumurdzanov and others 2005). A late Oligocene to early Miocene volcanic arc is well exposed in Sardinia, where a system of grabens formed during late Oligocene to early Miocene extension that resulted from westward subduction of submarine crust beneath Corsica and Sardinia (Casula and others, 2001). The Oligocene to Miocene calc-alkaline volcanism on the islands and the 32.3±0.5 Ma porphyritic dacite stock that intrudes into Hercynian metasedimentary rocks at the Calabona prospect in Sardinia are products of that subduction (Stefanini and Williams-Jones, 1996). The permissive rocks host three known Tertiary porphyry copper deposits and prospects on the island—the 285 Ma Oligiastra porphyry copper prospect is Variscan (Fiori and others, 1984).

The origins of the westernmost part of the peri-Mediterranean region, the Betic-Rif orocline and intervening Alboran Sea extensional basin (see figure 3[4]), are not well understood. Proposed models to explain the coeval extension in the Alboran Basin and compression-related orogenic systems to the north (Betic Cordillera of Spain) and south (Rif Mountains of northern Morocco) include rollback of a short east-dipping subduction zone as Africa and Europe converged (Platt and others, 2006; Royden, 1993; Lonergan and White, 1997) or delamination of a lithospheric root and asthenospheric upwelling that resulted in uplift and extension (for example, Garcia-Duenas and others, 1992). Recent tomography supports either a delaminated lithosphere or subducted slab (rollback) model (Calvert and others, 2000). In either case, the geodynamic setting accommodated calc-alkaline to shoshonitic and lamproitic magmatism (Doblas and Oyarzun, 1989).

The Betic-Rif volcanic arc represents the westernmost part of the Alpine orogeny. The mountain belt was formed by nappe tectonics during a series of Late Cretaceous to early Miocene Alpine compressional episodes (Lonergan and White, 1997; Doblas and Oyarzun, 1989). Middle to late Miocene igneous rocks in the eastern Betic Range include 15–18 Ma rhyolites and basalts, 11–8 Ma granitoid plutons, and K-rich ignimbrites. In the Rif Mountains (fig. E2), calc-alkaline volcanic centers are preserved in several areas along the Alboran Sea coast including the 13.0–12.4 Ma Ras Tarf volcano, the 9.8 Ma Trois Fourches Cape volcanic complex, the 9–4.6 Ma Gourougou stratavolcano and a granodiorite with associated dikes and a 7.3 Ma sill at Beni Bou (Brahim and Choton, 1990). Magmatism in both areas was localized along a pre-existing NE-SW shear zone which may have formed from tectonic inversion of Hercynian thrusts (Savelli, 2002). The calc-alkaline volcanic rocks in southern Spain host pluton-related polymetallic mineralization and alunite-bearing advanced argillic alteration; these rocks are permissive for porphyry copper deposits, although studies such as Arribas and others (1995) do not identify any such prospects in the region. A magnetite skarn is associated with microgranodiorite at Beni Bou Ifrour in the Rif Mountains of Morocco (El Rhazi and Hayashi, 2002); no copper mineralization or indications of any porphyry systems are known to be associated with the Rif magmatism.

[4]Refers to figures and tables in the main report.

Geologic Criteria

The rocks in the tract include late Oligocene to early Miocene andesites, rhyolites, and calc-alkaline rhyodacites on the western half of the Island of Sardinia, calc-alkaline to high-K to shoshonitic rocks in the Cabo de Gata-Cartagena belt of southeastern Spain, and andesitic volcanic centers and granodioritic intrusions in the Rif area of northeastern Morocco.

The tract outlines Oligocene to Miocene volcanic rocks as depicted on the geologic maps of Italy (Compagnoni and Galluzzo, 2008), Spain (Instituto Técnológico Geominero de España, 1994), Europe (Cassard and others, 2006), and Africa (Service Géologique du Maroc, 1985). The tract was constructed by processing geologic data from the enhanced digital geologic map of permissive igneous rocks prepared for the study, as follows:

Permissive igneous lithologies in map units occurring in Sardinia and Spain and attributed as Oligocene to Miocene were selected from the 1:1,500,000-scale enhanced digital geologic map of Europe (table E2). The volcanic rocks in Sardinia that host porphyry copper occurrences are mostly silicic rhyolites and rhyodacites. Figure E2 shows the extent of permissive rocks included in the tract.

- A prototract was developed by placing a 2-km buffer around the permissive volcanic rocks. This expanded the area of the tract to include most porphyry copper deposits and significant associated prospects and possible unexposed or unmapped adjacent permissive rocks.
- Finally, tract outlines were aggregated and smoothed, and clipped to the shoreline to eliminate undersea areas (U.S. Department of State, 2009).
- The final tract consists of several polygons, some of which represent small islands off the southwest coast of Sardinia, as shown in figure E1. Permissive units and source maps are listed in table E2.

Known Deposits

Calabona

The Calabona district has been recognized as a mineralized zone since the pre-Etruscan (pre-700 BC) age (Frezzotti and others, 1992). As recently as World War II, zinc, copper, and iron minerals were mined in the district from replacement bodies of massive pyrite in limestone (Frezzotti and others, 1992). In the 1960s, exploration detected copper anomalies that led to the discovery of the Calabona porphyry system (Jaffé, 1975; Frezzotti and others, 1992).

The Calabona porphyry system (table E3) is described as a barren, or poorly mineralized, example of a well formed porphyry copper system (Stefanini and Williams-Jones, 1996). It has many of the same general characteristics as well-mineralized porphyry copper deposits, including a central calc-alkaline porphyry stock with zones of hydrothermal alteration; however, copper grades at Calabona fall far short of economic values (Stefanini and Williams-Jones, 1996). The lack of significant copper mineralization is mainly a consequence of the relatively deep level of emplacement of the intrusion and its dacitic composition. These factors are interpreted by Stefanini and Williams-Jones (1996) to have combined to retard melt saturation with alkali chloride-enriched fluids until late stages of crystallization, which restricted the amount of fluid and copper produced by the melt. The proximity of the deposit to a town, the depth to mineralization, and the low grade of the deposit have discouraged further development (Fadda and others, 1998).

Prospects

Table E4 lists two known porphyry copper prospects in the tract. No porphyry copper prospects or occurrences are known in the Betic Cordillera.

Carbonia, Italy

The Carbonia prospect was discovered by geologic reconnaissance and a geochemical survey of the southwestern part of Sardinia (Frezzotti and others, 1992; Maccioni and others, 1992). Field observations of weak hydrothermal alteration and pyrite mineralization led to petrographic studies and geochemical prospecting (Maccioni and others, 1992).

Siliqua, Italy

Siliqua is characterized as a “diorite model” Cu-Au-Mo porphyry-type system in southern Sardinia (Fiori and others, 2000). The prospect consists of stock-like porphyritic bodies of andesitic composition with a potassic alteration zone in which gold values may exceed 2 ppm. Alteration is characterized by biotite replacement after amphibole, with magnetite, minor pyrite, chalcopyrite and molybdenite (Fadda and others, 1998).

Related (?) Deposit Types

Miocene epithermal deposits in the Betics of southeastern Spain include the abandoned Rodalquilar gold-alunite deposit, a shallow high-sulfidation system associated with the Rodalquilar andesitic volcano and deeper, fracture-controlled low-sulfidation polymetallic vein systems in the San José district to the south (Arribas and others, 1995; Carrillo Rosúa and others, 2003). These epithermal districts are shown on figure E1 for reference, but are not necessarily indicative of any association with porphyry systems at depth.

Exploration History

Modern mineral exploration has not been extensive on Sardinia. Since the early 1990s, however, porphyry and epithermal occurrences associated with Oligocene-Miocene calc-alkaline volcanism have been discovered (Fiori and others, 2000). In 1992, geochemical and petrological studies were done on some of the subvolcanic andesitic bodies in extensional structures in southwest Sardinia (Maccioni and others, 1992). The prospecting was initiated based on the presence of weak alteration and pyrite disseminations (Maccioni and others, 1992). This effort led to discovery of the Carbonia porphyry copper prospect. Stream-sediment data for Sardinia was acquired in the 1990s to produce baseline geochemical maps as references for monitoring land use change; copper showed isolated highs, including an area south of the Calabona porphyry copper deposit, but generally correlated with cobalt, nickel, and chromium concentrated in Paleozoic nappes and Ordovician porphyroids (DeVivo and others, 1997). In 2004, the volcanic rocks of Sardinia were being newly investigated because it was recognized that the island’s Oligocene-Miocene calc-alkaline magmatism had produced mineralization in the form of porphyry copper-gold deposits linked to subvolcanic bodies at Calabona (Frezzotti and others, 1992) and Siliqua (Maccioni and others, 1992; Fiori and others, 2003; Marcello and others, 2004).

Spain is known for volcanic-hosted massive sulfide (VMS) deposits in the Iberian Pyrite Belt of southern Spain and not for porphyry copper deposits. The Betic area of southeastern Spain has been extensively explored for gold-silver epithermal deposits.

The only mineral deposit associated with Neogene magmatism in the Rif area of northeastern Morocco is the 7 Ma Beni Bou Ifrour magnetite skarn with estimated reserves of 48 Mt of ore at a grade of 45–60 percent iron (El Rhazi and Hayashi, 2002). The deposit was discovered in 1905 and subsequently developed. No recent exploration is known to be occurring in the area.

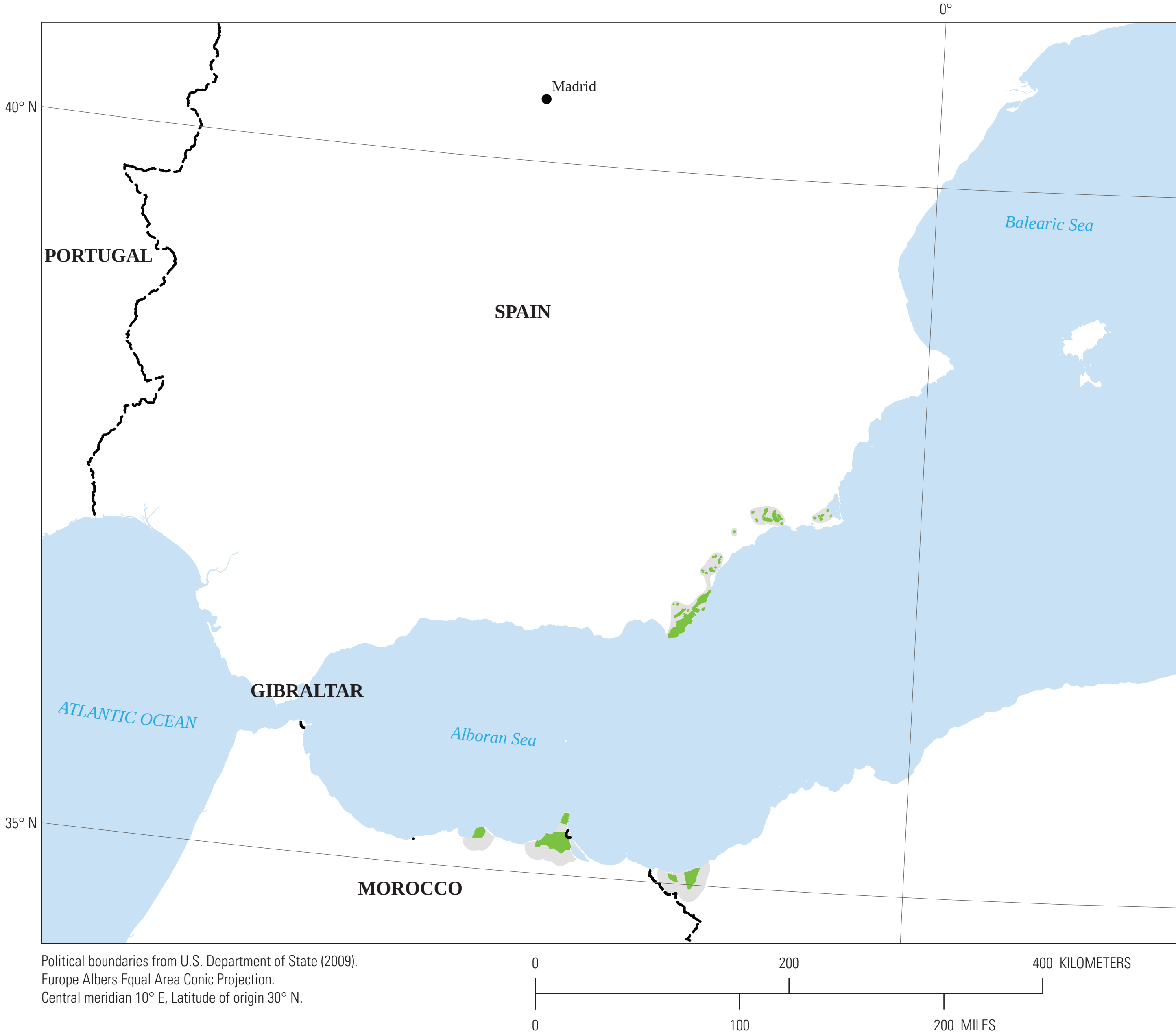
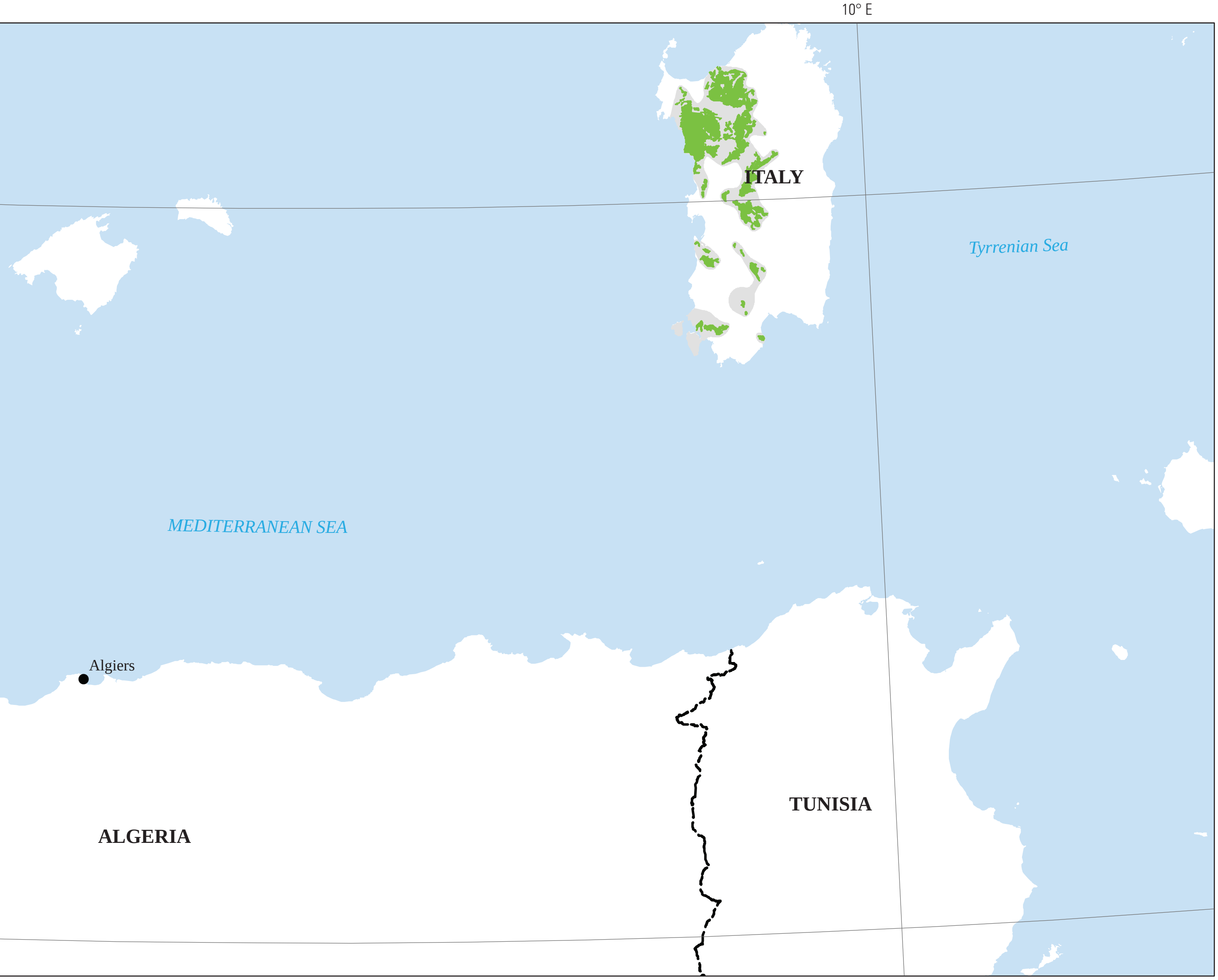


Figure E2. Map showing the distribution of permissive intrusive and volcanic rocks used to delineate tract 150pCu6005 (EU05PC), Western Peri-Mediterranean Region—Italy (Sardinia), Spain, and northern Morocco. Locations of epithermal districts in southeastern Spain are shown for reference.



EXPLANATION

Porphyry copper

Assessed porphyry copper tract 150pCu6005

Permissive volcanic rock

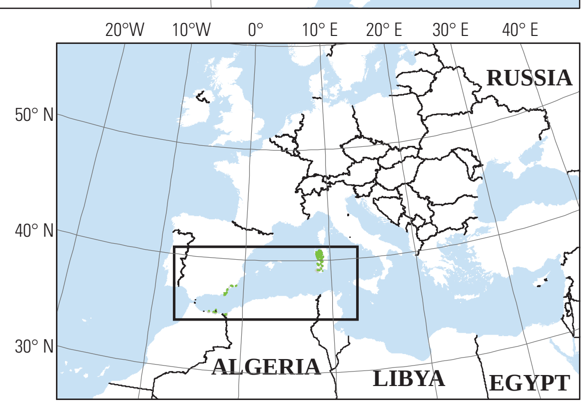


Table E2. Map units that define tract 150pCu6005 (EU05PC), Western Peri-Mediterranean Region—Italy (Sardinia), Spain, and Northern Morocco.

[Map unit, age range, and principal lithologies are based on source maps cited]

Map symbol	Lithology	Age range	Source map
		Volcanic rocks	
gm2v	Sardinia:andesites, rhyolites, and calc-alkaline rhyodacites	Oligocene-Miocene 33.7–11 Ma	Cassard and others (2006)
NA	Morocco	Mapped as Neogene basalts on 1:5M map; shown to be andesites based on 1:1M-scale map and literature	Veselinovic-Williams and Frost-Killian (2003); Service Géologique du Maroc (1985)
m2-3v	Spain: calc-alkaline volcanics	16–5.3 Ma	Cassard and others (2006)

Table E3. Porphyry copper deposits in tract 150pCu6005 (EU05PC), Western Peri-Mediterranean Region—Italy (Sardinia), Spain, and Northern Morocco.

[Ma, million years; Mt, million metric tons; t, metric ton; g/t, gram per metric ton; NA, subtype not applicable; n.d., no data]

Name	Latitude	Longitude	Subtype	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)	Reference
Calabona	40.532	8.365	NA	34–27	189	0.07	n.d.	n.d.	0.5	130,000	Fadda and others (2007), Frezotti and others (1992), Jaffé (1975), Stefanini and Williams-Jones (1996)

Table E4. Significant prospects and occurrences in tract 150pCu6005 (EU05PC), Western Peri-Mediterranean Region—Italy (Sardinia), Spain, and Northern Morocco.

[Ma, million years]

Name	Latitude	Longitude	Age (Ma)	Comments	Reference
Carbonia	39.171	8.496	30	Weak alteration and pyrite disseminations in subvolcanic andesite bodies led to a geochemical survey and the discovery.	Maccioni and others (1992)
Siliqua	39.320	8.850	Oligocene-Miocene	In 2000, this was speculated to be a porphyry Cu-Au-Mo system. The area has acid drainage from the unmined deposit; surface waters and soils have indicated high heavy metal concentrations.	Fiori and others (1998, 2000)

Sources of Information

Principal sources of information used by the for delineation of the Western Peri-Mediterranean tract are listed in table E5.

Qualitative Assessment

The Calabona deposit is included in the global grade and tonnage models for Cu-Mo-Au deposit. Although the calc-alkaline volcanic rocks of the Betic Cordillera are permissive for porphyry copper deposits, all of the known mineralization in the region is epithermal. The team had no data on the depth of volcanic cover, although caldera structures and volcanic domes suggest that the volcanic pile may be thick, and we had no specific indication of porphyry-related systems at depth. Deep drilling, below or adjacent to, epithermal systems might change this analysis, but the assessment team was unaware of any existing drill data or geophysical targets for porphyry systems. Although the igneous Rif rocks are permissive, the andesitic volcanic rocks may be too thick and the exposed skarn may represent too deep a level of exposure for porphyry copper deposits, if they ever formed, to be present within 1 km of the surface.

Based on the small tract area and low grade of the identified resources in Sardinia, and the lack of any reported copper occurrences or alteration suggestive of porphyry systems in the Betic-Rif belt of Spain and northeastern Morocco, the team concluded that no probabilistic estimate was warranted.

Table E5. Principal sources of information used for tract 150pCu6005 (EU05PC), Western Peri-Mediterranean Region—Italy (Sardinia), Spain, and Northern Morocco.

[NA, not applicable]

Theme	Name or Title	Scale	Citation
Geology	Geological map of Italy	1:1,000,000	Compagnoni and Galluzzo (2008)
	Geologic map of the Iberian Peninsula	1:1,000,000	Instituto Técnológico Geominero de España (1994)
	Carte geologique du Maroc	1:1,000,000	Service Géologique du Maroc (1985)
	Metallogenic map of Africa	1:5,000,000	Veselinovic-Williams and Frost-Killian (2003)
	Digital geologic map of Europe	1:1,000,000	Cassard and others (2006)
Mineral occurrences	Mineral and energy resources of Central Europe	1;2,500,000	Dill and Saschsenhofer (2008)
	Metallogeny in Sardinia	NA	Marcello and others (2004)
	World distribution of porphyry, porphyry-related skarn, and bulk-mineable epithermal deposits	NA	Dunne and Kirkham (2003)
	Metallogenic map of Europe (and notes)	1:2,500,000	UNESCO (1984)
	Mineral Resources Data System (MRDS)	NA	U.S. Geological Survey (2009)
	Porphyry copper deposits of the world—Database, map, and grade and tonnage models	NA	Singer and others (2008)

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Appendix F. Porphyry Copper Assessment for Tract 150pCu6006 (EU06PC), Southern and Central European Variscan—France, Italy, and Poland

By David M. Sutphin[1] and Jane M. Hammarstrom[1]

Deposit Type Assessed: Porphyry copper

Descriptive model: Porphyry copper (Cox, 1986; Berger and others, 2008; John and others, 2010)
Although the tract is broadly permissive (0.001 percent, or 1 in 100,000 chance or more) for porphyry copper deposits, the assessment team concluded that a probabilistic estimate of undiscovered deposits was not warranted based on available data. Summary information is listed in table F1.

Table F1. Summary of selected resource assessment results for tract 150pCu6006 (EU06PC), Southern and Central European Variscan—France, Italy, and Poland.

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

Date of assessment	Assessment depth (km)	Tract area (km²)	Known copper resources (t)
2010	1	46,000	880,000

Location

The tract is located in central France, southern Italy, and southwestern Poland (fig. F1).

Geologic Feature Assessed

The tract is defined by discrete areas of intrusive and volcanic rocks of Variscan age in Europe, where some evidence of porphyry-style hydrothermal activity is preserved.

[1]U.S. Geological Survey, Reston, Virginia, United States.

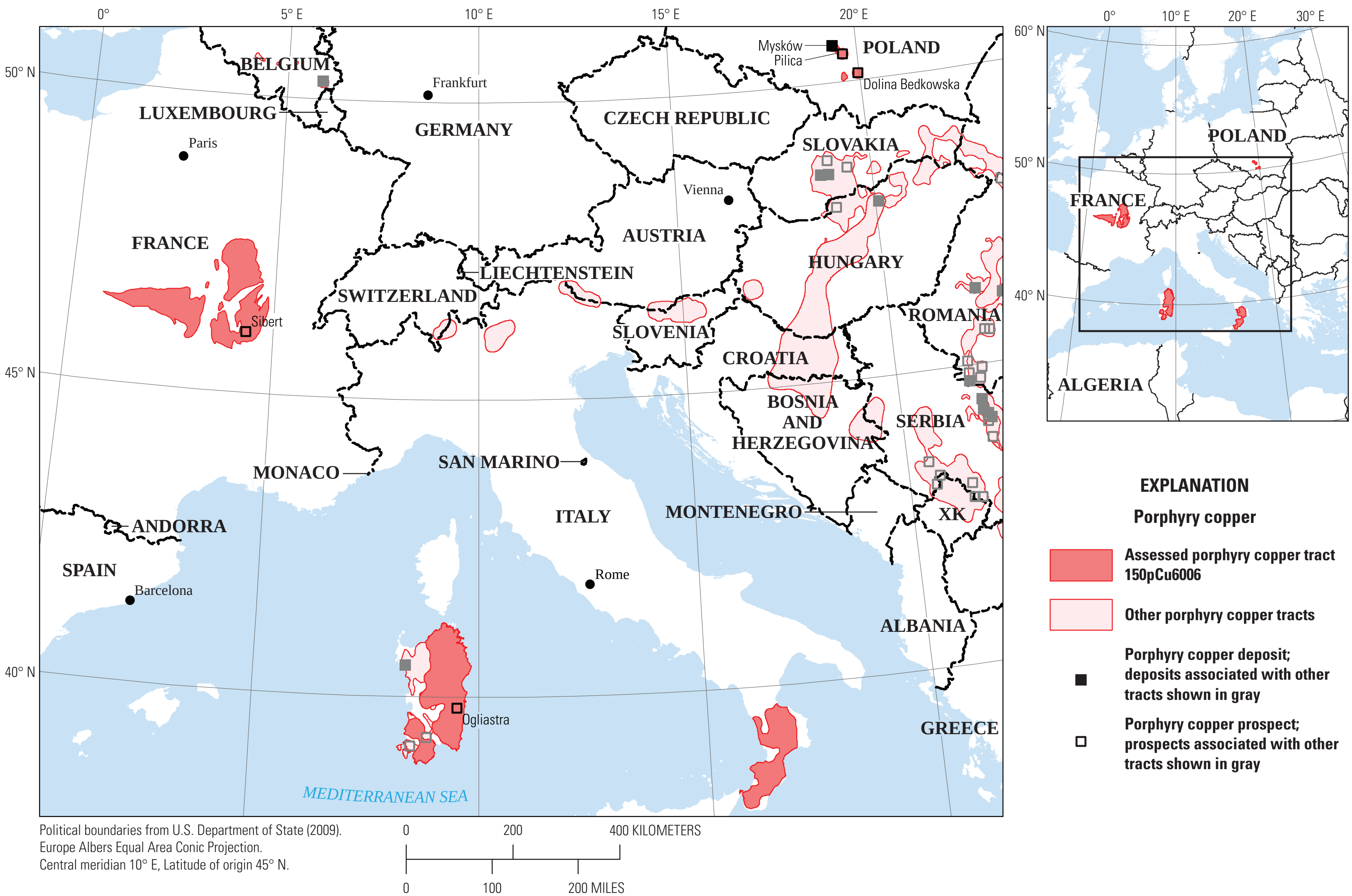

Figure F1. Map showing the location, known deposits, and significant prospects and occurrences for tract 150pCu6006 (EU06PC), Southern and Central European Variscan— France, Italy(Sardinia), and Poland.

Delineation of the Permissive Tract

Tectonic Setting

The Late Paleozoic Variscan orogeny was caused by north-south continent-continent collision that formed the supercontinent Pangea (Franke, 1989; Plant and others, 2005). During the Variscan orogeny, subparallel east-west, northward- and southward-dipping subduction zones formed as oceans closed, continents and microcontinents collided, the crust thickened along the suture zones, and collisional mountains rose across what is now Southern and Central Europe (Franke, 1989). The end of the orogeny largely is characterized by the emplacement of voluminous granites into hot migmatitic crust. Figure 5[2] shows the distribution of Variscan basement rocks in Europe.

The tectonics of the Variscan orogeny of southern Europe were similar to those of the Tertiary Alpine orogeny of Southern Europe that produced the numerous porphyry copper deposits cited in this report. During both of these orogenies, high-latitude continent and micro-continents collided with a low-latitude continent closing a proto-ocean, and subduction of ocean floor beneath the European continent generated widespread magmatism (Franke, 1989).

Five genetic groups of Variscan granitoids in Central Europe, as defined by Finger and others (1997), are as follows: (1) Late Devonian to early Carboniferous (370–340 Ma) Cordilleran I-type granitoids that form plutonic massifs, mainly tonalite and granodiorites, in the Saxothuringian Zone and Bohemian Massif (fig. 3), (2) Early Carboniferous (~340 Ma) S-type granites and migmatites, (3) Late Visean and early Namurian (~340–310 Ma) S-type and high-K I-type postcollisional granitoids, along the central axis if the Variscan orogen in the Moldanubian Zone (fig. 3), (4) Postcollisional, epizonal I-type granodiorites and tonalities (~310–290 Ma), mainly in the Alps (fig. 3), and (5) Late Carboniferous to Permian (~300–250 Ma) leucogranites similar to subalkaline A-type granites. Bonin (2008) noted that A-type granites, emplaced as discrete events in Variscan-Alpine Europe, are markers of postcollisional (post-orogenic) and anorogenic geodynamic settings. Detailed analyses of large-scale maps, geochronologic, and other topical studies necessary to subdivide the map units that we used were beyond the scope of this study. Note, however, that much of the Variscan magmatism (S-, A-type) is not permissive for porphyry copper deposits. Therefore, the tract is restricted to areas where the permissive rocks and some indications of porphyry-style mineralization are known to be present. The tract includes Variscan granitoids that crop out as part of the complex Calabrian-Peloritan arc (fig. 1) in southern Italy (Atorzi and others, 1984).

[2]Refers to figures and tables in the main report.

Geologic Criteria

The tract is defined by Variscan intrusive and volcanic rocks, as depicted on geologic maps for the countries within the study area. Preliminary tracts were identified by outlining areas of interest on printed paper maps. The tract was constructed by processing geologic data from the enhanced digital geologic map of permissive igneous rocks prepared for the study, as follows:

- Areas of Europe that contain Variscan igneous rocks that host known porphyry copper occurrences were identified on the basis of mineral-occurrence databases and geologic literature.

- For those areas, permissive igneous lithologies in map units attributed as having ages that extend into the Variscan (380–280 Ma) were selected from the enhanced digital geologic map of Europe (Cassard and others, 2006). Map units having an upper age of 500 Ma and a lower age of 275 Ma, which could be Caledonian or Variscan, were assigned to the Variscan orogeny unless there was evidence to the contrary. Map units with extreme ranges of possible age, such as from 500 Ma to 65 Ma, were not used.

- For the areas in Italy and Poland, a prototract was developed by placing a 10-km-wide concentric buffer around permissive intrusive rocks and a 2-km concentric buffer around permissive volcanic rocks. After buffering, aggregation and smoothing routines were applied to the resulting polygons.

- For the Massif Central of France, tract segments were delineated during a workshop in Orléans using the digital geologic base map of Cassard and others (2006) and the 1:1,000,000-scale geologic map of France (Chantraine and others, 2003). The tract is based on the distribution of Variscan calc-alkaline to subalkaline plutons and volcanic rocks, and cover rocks within or beneath which such plutons are expected to occur within 1 km of the surface. The tract segments include the maximum extent of exposed Hercynian igneous rocks in the Massif Central of France and some inliers of Permian sedimentary rocks of unknown thickness. Clearly defined Permian-upper Carboniferous pull-apart basins are excluded, as is the Limagne graben. Tract boundaries closely follow the steep margin of the Rhone graben to the east, but are projected basinward beneath the younger cover rocks of the gently dipping Paris basin to the north; in many areas the tract segments are fault-bounded. Parts of the tract are covered by younger rocks and sediments, mostly from sedimentation in the Paris basin.

- Locations of Variscan porphyry copper deposits and prospects were examined. In cases in which a deposit or prospect fell outside of the tract, the deposit or prospect was buffered (10 km) and the tract was extended to include the deposit or prospect area. In some cases, the igneous rocks associated with a deposit or prospects may not be represented at the available map scales. For example, the Sibert porphyry prospect in the Massif Central, France, is associated with small bodies of porphyritic granites and dikes in a 1 by 2 km area of hydrothermal alteration (Beaufort and Meunier, 1983); these rocks are not shown on the 1:1,500,000-scale map used to delineate the tract (fig. F3).

- Finally, we excluded any areas that are intruded by post-Variscan intrusions and clipped the resulting shapefile to the shoreline to eliminate undersea areas (U.S. Department of State, 2009).

The final tract consists of a series of discrete polygons, as shown in figure F1. Permissive units and source maps are listed in table F2.

Permissive rocks include 11 map units for plutonic rocks from the digital geologic map of Europe (Cassard and others, 2006), which include Variscan felsic to intermediate granitoid rocks among their constituents. Map unit 21v from the same map contains both alkaline granites, acidic volcanic rocks. The volcanic map units were selected because the attributes include acidic to intermediate volcanic rocks that may be permissive for the occurrence of porphyry copper deposits.

Known Deposits

The only porphyry copper deposit with identified resources is at Myszków, Poland which is reported to contain about 900,000 t of copper (table F3). Singer and others (2008) classify it as a Cu-Mo porphyry copper deposit.

Central Europe

Myszków, Poland

Located in southwest Poland, mineralization in the Myszków area was identified in the late 1960s by the Polish Geological Institute, and further drilling confirmed the presence of a Mo-Cu-W deposit (Strzelecki Metals Limited, 2010). Myszków is one of several porphyry copper-type deposits in central Europe that occur within the buried Paleozoic Cracow-Silesian orogenic belt, a zone in which continental or island arc volcanic activity probably occurred in the vicinity of convergent plate boundaries (Chaffee and others, 1994). It is the only example of porphyry copper mineralization of this age known in Europe (Strzelecki Metals Limited, 2010). Geochemical characteristics, mineralogy, and vein morphology at Myszków are typical of calc-alkaline porphyry copper deposits elsewhere (Strzelecki Metals Limited, 2010).

The Myszków prospect is closely associated in time and space with a hypabyssal biotite granodiorite porphyry stock from which 11 biotites gave a K-Ar age of 312±17 Ma (Carboniferous) (Chaffee and others, 1994 and 1997). $^{40}Ar/^{39}Ar$ dates (290–305 Ma) on alteration minerals associated with the formation of Myszków indicate that the prospect was mineralized in Late Carboniferous to Early Permian time (Chaffee and others, 1997; Markowiak and others, 2001). A range of estimated tonnages and grades have been reported for Myszków: 460–800 Mt; 0.088–0.152 percent copper; 0.044–0.048 percent molybdenum; and 0.025–0.041 percent tungsten (Podemski, 2001; Singer and others, 2008). The latest information reports an inferred resource of 726 Mt at 0.121 percent copper, 0.062 percent molybdenum, 0.0404 percent tungsten, and 2.2 g/t silver, based on a cutoff of 0.085 percent molybdenum equivalent (Strezelcki Metals Ltd., 2010). The advanced exploration project is described as a Mo-W-Cu porphyry system with low concentrations of gold, mercury, arsenic, and antimony (Strezelcki Metals Ltd., 2010).

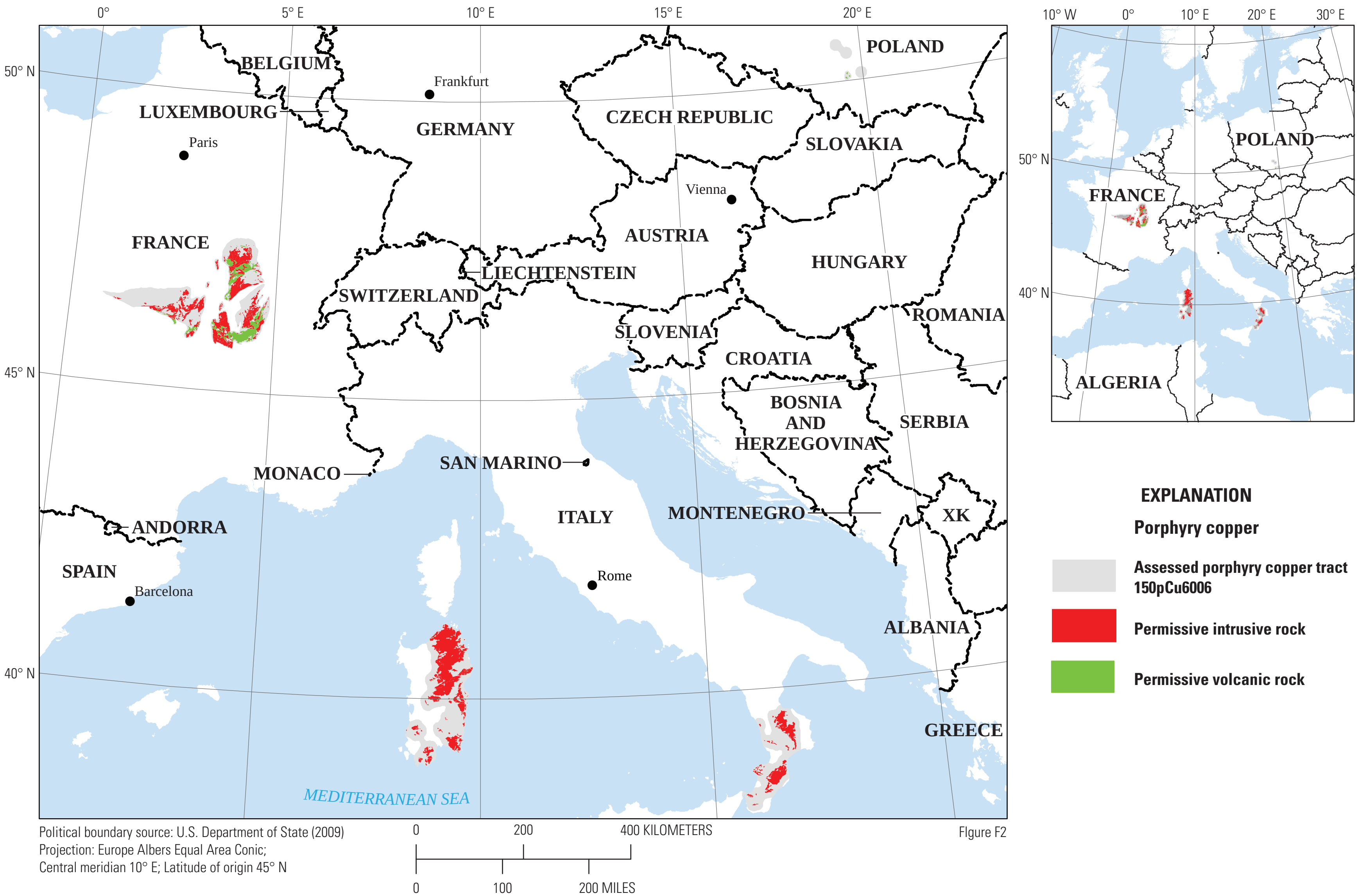

Figure F2. Map showing the distribution of permissive intrusive and volcanic rocks used to delineate tract 150pCu6006 (EU06 PC), Southern and Central European Variscan—France, Italy (Sardinia), and Poland.

Table F2. Map units that define Central European Variscan tract 150pCu6006 (EU06PC)—France, Italy, and Poland.

[Map unit, age range, and principal lithologies are based on Cassard and others (2006) 1:1,500,000 digital geologic map. Ma, million years.]

Map symbol	Lithology	Age range (Ma)
	Intrusive rocks	
13	monzogranites, granodiorites	390–295
14	granitoids undifferentiated, granodiorites, quartz diorites, monzogranites; tonalites, diorites, gabbros	390–355
15	granitoids undifferentiated, monzogranites, granodiorites, tonalites, quartz diorites; microgranites, apli-granites, leucogranites, trondhjemites; tonalites, diorites, gabbros	355–335
16	granitoids undifferentiated, granodiorites, tonalites, quartzdiorites, monzogranites, metagranites	355–305
17	granitoids undifferentiated, monzogranites, granodiorites; microgranites, apligranites, metagranites; tonal-ites, quartzdiorites, diorites	335–305
18	complexe acide à basic undifferentiated, granite synorogenic, granodiorites; biotite granites; two-mica granites; alkaline granites; microgranites, apligranites; monzogranites, metagranites; roches intermedi-aires à basic; tonalites	335–295
19	alkaline granites, granitoids undifferentiated, leucogranites sodic-potassic; micrograntes, granophyres; monzogranites, granodiorites	335–295
20	granites; muscovite granites; granitoid (granite, leucogranite, granodiorite, etc.); microgranites, rhyoda-cites; monzogranites, granodiorites; quartz diorite	305–275
21	intrusion alpine undifferentiated, syenite	305–277
20–22	granites, granodiorites, monzonites	305–175
d3	quartz diorites, trondhjemites	375–355
21v	alkaline granites, volcanics acidic	295–250
	Volcanic rocks	
d2hv	volcanics indifferenciees	385–295
d3hva	rhyodacites, tuffs acidic, ignimbrites	375–295
d3vb	andesito-basaltes, tuffs basic, green schists	375–355
dva	ignimbrite tuffs	410–355
dvi	andesites, basaltic lavas and tuffs	410–355
h1v	andesito-basaltes, spilites, tuffs basic; rhyodacites, andesites, ignimbrites, tuffs acidic, bi-modal volcanics	355–335
h2va	rhyodacites, andesites, ignimbrites, acidic tuffs	335–305
h3rv	andesites, tuffs, trachytes; andesito-basaltes, trachy-andesites; rhyodacites, granophyres, ignimbrites	305–250
h3v	andesitic basalts, trachy-andesites; rhyodacites, tuffs acidic, ignimbrites	305–295
r	dominantly volcano-sedimentary rocks	295–250
rtv	dominantly volcanic and volcano-plutonic acidic rocks	295–203
rv	andesito-basaltes, spilites, tuffs basic; rhyodacites, granophyres, ignimbrites, acidic tuffs; undifferentiated volcanic rocks	295–250
rva	dominantly volcanic and volcano-plutonic acidic rocks	295–250
rva-alc	volcanics acidic alcalines	295–250
rvb	dominantly volcanic and volcano-plutonic mafic rocks	295–250

Table F3. Porphyry copper deposits in Central European Variscan tract 150pCu6006 (EU06PC)—France, Italy, and Poland.

[Ma, million years; Mt, million metric tons; t, metric ton; g/t, gram per metric ton;%, percent. Cu-Mo subtype, deposits that have Au/Mo ratios <3 or average Mo grades >0.03%; n.d., no data]

Name	Country	Latitude	Longitude	Subtype	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)	Reference
Myszków	Poland	50.617	19.367	Cu-Mo	305–290	726	0.121	0.062	n.d.	2.22	880,000	Badera (2001), Chaffee and others (1994), Chaffee and others (1997), Haranczyk (1980), Markowiak and others (2001), Podemski (2001), Rusinov (2002), Strzelecki Metals Limited (2010)

Prospects, Mineral Occurrences, and Related Deposit Types

Table F4 lists four porphyry copper prospects in the tract.

Southern Europe

In addition to the prospects described below, occurrences of molybdenite and chalcopyrite associated with mesoaluminous granitoids in the Calabrian-Peloritan Arc (fig. 13) of southern Italy have been attributed to a Variscan porphyry copper-molybdenum system (Bonardi and others, 1982; Atorzi and others, 1984).

Sibert, France

The uneconomic Sibert porphyry copper-molybdenum prospect is located in the northeast part of the Massif Central and is associated with subalkaline microgranites (Icart and others, 1980). The prospect consists of an intrusive complex of variably altered porphyritic granites that occur as small bodies or dikes intruding welded volcanic tuffs; hydrothermal alteration extends over an area of 1 by 2 km (Beaufort and Meunier, 1983). The prospect, drilled to a depth of 600 m, has never been developed, but has been the focus of mineralogical studies of the pervasive potassic alteration and superimposed phyllic alteration (Beaufort and Meunier, 1983; Davies and Whitehead, 2010). Veins and stockworks of chalcopyrite and molybdenite are associated with the granites, but Sibert is the only known porphyry prospect (Stussi, 1989).

Ogliastra, Sardinia (Italy)

The Ogliastra prospect occurs along the central part of the east coast of Sardinia at the southern end of the large Variscan granitoid batholith that makes up much of northern Sardinia (Fiori and others, 1984). At Ogliastra, shallow tonalite and hornblende-biotite granodiorites were emplaced in a nappe structure (Secchi and others, 2001). Fiori and others (1984) referred to the Ogliastra as a group of “aborted” porphyry copper deposits consisting of iron, zinc, copper, and molybdenum mineralization in small bodies scattered in Hercynian plutons.

Central Europe

Pilica, Poland

Three areas of Variscan age mineralization have been distinguished at Pilica, including a skarn, a subsurface granodiorite intrusion with hydrothermal alteration, and porphyry-type mineralization (Haranczyk, 1980). Vein deposits with fine grained pyrrhotite, magnetite, and wolframite also are present, as well as scheelite and silver telluride minerals (Haranczyk, 1980; Chaffee and others, 1994; Dill, 1994).

Dolina Bedkowska, Poland

Located 17 km northwest of Cracow beneath 70 m of Mesozoic sedimentary rocks, the Dolina Bedkowska prospect consists of rhyodacite porphyry dikes intruded into Lower Cambrian slates (Haranczyk, 1980). Mineralization is a stockwork with numerous veins and veinlets with subordinate disseminated mineralization. Concentric zoning is evident. Potassic feldspathization and sericitization of the wallrock accompany disseminated pyrite and chalcopyrite. Ore minerals include silver tellurides (Dill, 1994).

Exploration History

The Massif Central has never been the focus of porphyry copper exploration; historically, exploration was directed to the discovery of tin and tungsten deposits. Major known copper prospects have been evaluated for their potential as massive sulfide deposits, including the drilling of 1or 2 holes in some prospects. Incidental to past exploration, most of the exposed permissive host rocks for porphyry copper deposits have been prospected at the surface. Most exposed copper occurrences have been located and field checked, mainly in

1980 by Société Nationale Elf Aquitaine Production (SNEAP). With the exception of medieval workings, major copper prospects have not been subjected to repeated exploration and evaluation. Although geochemical and geophysical exploration has been conducted over most of the permissive rocks in the massif, copper was not always part of the geochemical surveys and the geophysical surveys tended to be site-specific efforts at target identification for deposit types other than porphyry copper. Airborne geophysical and soil geochemical surveys followed by reconnaissance field checking were conducted as part of the exploration activities done in 1980. Subsurface exploration for unexposed deposits or their plutonic host rocks beneath areas of post-mineralization-age cover rocks or at depth in older pre-mineralization-age country rocks has been done.

Porphyry deposits in Poland were first recognized in a deep drilling program that targeted the Cracow-Silesian orogenic belt in the 1950s (Haranczyk, 1980; Chaffee and others, 1994). The Polish Geological Institute identified the Myszków deposit in the late 1960s; subsequent drilling identified other prospects (Strzelecki Metal Limited, 2010). Myszków is currently (2011) considered to be an open, advanced exploration project.

Because most Variscan igneous rocks are either deeply eroded or petrochemically unsuitable for porphyry copper association, they have in general not been considered as potential porphyry copper exploration targets.

Sources of Information

Principal sources of information used for delineation of the Southern and Central European Variscan tract are listed in table F5.

Qualitative Assessment

Pluton-related copper deposits of Variscan age are widely scattered throughout Europe. Post-mineralization structural disruption makes it difficult to delineate coherent magmatic arcs or belts. Most of the permissive Variscan rocks crop out as intrusions in uplifted massifs (fig. F2). Coeval volcanic rocks typically are absent, and the level of erosion is such that porphyry copper deposits that may have formed in association with Variscan rocks have probably been lost to erosion unless preserved under younger cover or in down-dropped basins. The wide range of compositions of the pre-, syn- and late-collisional granitoids include some peraluminous transitional I-S type granitoids and S-type rocks such as the late-collisional granites along the northern margin of the Bohemian Massif (fig. 3) in Germany, which are associated with tin, tungsten, and uranium deposits (Förster and others, 1999). The western European Variscan belt exposed in the Massif Central of France hosts high-temperature, granite-related tungsten deposits, rare-metal granites, shear-zone gold and antimony ores, and uranium (Marignac and Cuney, 1999). Deep erosion has removed nearly all of the subvolcanic environments in which porphyry copper deposits form in parts of the Massif Central. In summary, porphyry copper deposits are not significant deposit types in Variscan metallogeny and the team concluded that estimation of undiscovered deposits in this tract was not warranted.

Table F4. Significant prospects and occurrences in Cenral European Variscan tract 150pCu6006 (EU06PC)—France, Italy, and Poland.

[Ma, million years]

Name	Country	Latitude	Longitude	Age (Ma)	Comments	Reference
Dolina Bedkowska	Poland	50.117	19.950	Middle or Late Paleozoic	One of three Late Paleozoic Cu-Mo-W porphyry occurrences known in Poland	Chaffee and others (1994), Haranczyk (1980), Podemski (2002)
Ogliastra	Italy (Sardinia)	39.817	9.516	285	The prospect is in Variscan basement, consisting of granodiorites, tonalites and granites that have been exposed by Tertiary rifting. Sphalerite, chalcopyrite, magnetite, galena, and molybdenite are present in uneconomic concentrations in this “aborted” porphyry system	Fiori and others (1984), Helbing and others (2006)
Pilica	Poland	50.467	19.617	Middle or Late Paleozoic	Granodiorite drilled and dated at 370 Ma. Pyrite, chalcopyrite, pyrrhotite, hematite, molybdenite, wolframite, and cassiterite are found in alteration zones	Chaffee and others (1994), Haranczyk (1980), Wolska (2001)
Sibert	France	46.333	3.950	Perm-Carboniferous (Hercynian)	A porphyry Cu-Mo showing, related to a swarm of post-Visean subalkaline microgranites. An area 1 km by 2 km has been hydrothermally altered. Sibert was explored using 10 drill holes, 2 as deep as 600 m.	Icart and others (1980), Beaufort and Meunier (1983)

Table F5. Principal sources of information used for Central European Variscan tract 150pCu6006 (EU06PC)—France, Italy, and Poland.

[NA, not applicable]

Theme	Name or title	Scale	Citation
Geology	Digitial geologic map of Europe	1:1,500,000	Cassard and others (2006)
Mineral occurrences	Mineral and energy resources of Central Europe	1;2,500,000	Dill and Saschsenhofer (2008)
	Geologic literature	NA	See references in tables B3 and B4.
	World distribution of porphyry, porphyry-related skarn, and bulk-mineable epithermal deposits	NA	Dunne and Kirkham (2003)
	Mineral Resources Data System (MRDS)	NA	U.S. Geological Survey (2009)
	Porphyry copper deposits of the world—Database, map, and grade and tonnage models	NA	Singer and others (2008)

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Appendix G. Porphyry Copper Assessment for Tract 150pCu6007 (EU07PC), Western European Caledonian—Belgium and United Kingdom

By David M. Sutphin[1], Jane M. Hammarstrom[1], and Michael Demarr[1]

Deposit Type Assessed: Porphyry copper

Descriptive model: Porphyry copper (Cox, 1986; Berger and others, 2008; John and others, 2010)
Although the tract is broadly permissive (0.001 percent, or 1 in 100,000 chance or more) for porphyry copper deposits, the assessment team concluded that a probabilistic estimate of undiscovered deposits was not warranted based on available data. Summary information is listed in table G1.

Table G1. Summary of selected resource assessment results for tract 150pCu6007 (EU07PC), Western European Caledonian—United Kingdom and Belgium.

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

Date of assessment	Assessment depth (km)	Tract area (km^2)	Known copper resources (t)
2010	1	17,500	630,000

Location

The tract is located in western parts of the United Kingdom in Wales and Scotland and in Belgium (fig. G1).

Geologic Feature Assessed

Fragments of a Caledonian continental-margin arc.

[1]U.S. Geological Survey, Reston, Virginia, United States.

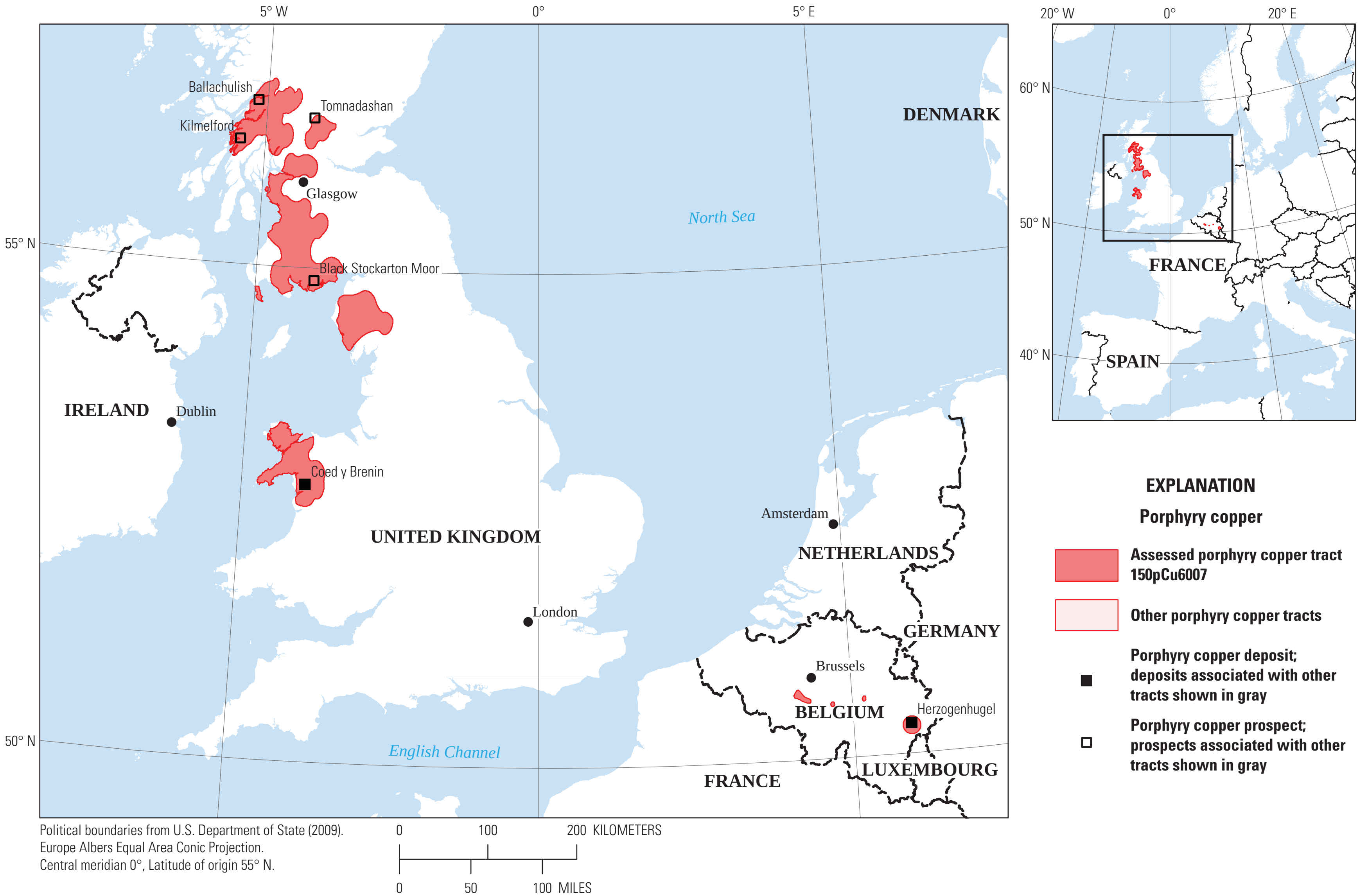

Figure G1. Map showing the location, known deposits, and significant prospects and occurrences for permissive tract 150pCu6007 (EU07PC), Western European Caledonian—United Kingdom and Belgium.

Delineation of the Permissive Tract

Tectonic Setting

The tract is defined by Caledonian (Late Cambrian to earliest Devonian, 490–390 Ma) felsic to intermediate volcanic and plutonic rocks in Europe where some evidence of porphyry-style hydrothermal activity is preserved. Caledonian igneous rocks mainly occur on the western coast of the continent from Scandinavia to Scotland and Ireland to France, Spain, and Portugal (see fig. 5[2]). The rocks formed prior to and during assembly of the supercontinent Pangea, in the orogeny related to closing of the proto-Atlantic Ocean. Caledonian rocks have been eroded, deformed, buried, metamorphosed, and glaciated. These processes probably destroyed most high-level porphyry copper deposits associated with Caledonian magmatism and buried others.

Geologic Criteria

The tract is defined by intrusive and volcanic rocks of Caledonian age in areas of western Europe where some evidence for porphyry copper mineralization is present. Preliminary tracts were identified by selecting rocks where the attributed age range included all or part of the Caledonian orogeny. The tract was constructed by processing geologic data from the digital geologic maps of permissive igneous rocks prepared for the study, as follows:

- Areas that contain Caledonian igneous rocks that host known porphyry copper occurrences were identified based on mineral-occurrence databases and geologic literature.
- In those areas, permissive igneous lithologies in map units attributed as Caledonian, or including rocks as coinciding with the Caledonian, were selected from the digital geologic bedrock map of Great Britain and from the 1:1,500,000-scale enhanced digital geologic map of Europe (Cassard and others, 2006). The 1:1,500,000-scale metallogenic map of the United Kingdom was georectified for GIS use to locate some prospect areas.
- A prototract was developed by placing a 10-km-wide concentric buffer around permissive intrusive rocks and a 2-km concentric buffer around permissive volcanic rocks. After buffering, aggregation and smoothing routines were applied to the resulting polygons. The northern boundary of the tract in Scotland was truncated at the Great Glen Fault.
- Locations of Caledonian porphyry copper deposits and prospects were checked to ensure that they fell within the geology-based tract. Finally, any areas that are intruded by post-Caledonian intrusions were excluded and tract boundaries were clipped to shorelines to eliminate undersea areas (U.S. Department of State, 2009).
- The final tract consists of a series of discrete polygons, as shown in figure G1. Permissive units and source maps are listed in table G2 and shown on figure G2.The intrusive rocks generally are granitoids such as granites, granodiorites, monzogranites, alkaline granites, microgranites, and leucogranites; and the volcanic rocks range from various combinations of rhyodacites and trachyandesites to andesites as ignimbrites, tuffs, lavas, and volcano-sedimentary rocks.

Known Deposits

The tract contains two porphyry copper deposits that have reported identified resources (table G3): (1) the 200 Mt Coed y Brenin porphyry copper deposit in Wales, which contains an estimated 600,000 t of copper (Rice and Sharp, 1976), and (2) the 20 Mt Herzogenhugel deposit in Belgium.

Coed y Brenin, United Kingdom

Coed y Brenin is located in Wales, where Middle to Late Cambrian sedimentary rocks are intruded by intermediate to basic Late Cambrian to Early Ordovician igneous rock. Propylitic and phyllic alteration zones form an alteration halo around the porphyry copper deposit (Armstrong and others, 2003). The deposit lies along the somewhat younger Afon Wen Fault, which may have provided a conduit by which fluids traversed the porphyry system during post-Cambrian movements and removed much of the mineralization as evidenced by the paucity of disseminated pyrite in the fault-zone (Mason, undated). The deposit was discovered in 1968; 110 holes were drilled to a depth of 300 m to define the resource (Colman and Cooper, 2000). Ore minerals include chalcopyrite, chalcocite, tennantite, and enargites, with native copper, chalcopyrite, malachite, azurite, covellite, bornite, tetrahedrite, and molybdenite (Rice and Sharp, 1976; Bevins, 1994; Mason, undated; Armstrong and others, 2003). Coed y Brenin contains an estimated 200 Mt of mineralized material containing 0.3 percent copper (Rice and Sharp, 1976; Bevins, 1994; Armstrong and others, 2003).

The Coed y Brenin ore-zone is almost totally covered by overburden. The deposit lies within a protected forest and is of interest for field excursions and mineralogy, rather than as a potentially economic resource.

[2]Refers to figures and tables in the main report.

Table G2. Map units that define tract 150pCu6007 (EU07PC), Western European Caledonian—United Kingdom and Belgium.

[Map unit, age range, and principal lithologies are based on Cassard and others (2006) 1:1,500,000]

Map symbol	Lithology	Age range	Source map
	Intrusive rocks		
8	monzogranites, granodiorites, apligranites, metagranites, monzogranites; acid and basic alkali complex; alkaline granites	500–455 Ma	Cassard and others (2006)
10	granitoid (granite, leucogranite, granodiorite, etc.)	455–435 Ma	Cassard and others (2006)
12	microgranites, granophyres	500–295 Ma	Cassard and others (2006)
	Volcanic rocks		
kov	trachyandesites, microdiorites	540–435 Ma	Cassard and others (2006)
o2v	rhyodacites, tuffites acides, and metavolcanic rocks	465–455 Ma	Cassard and others (2006)
od1v	rhyodacites, tuffs, porphyroids, and ignimbrites	500–385 Ma	Cassard and others (2006)
osv	acidic volcanic rocks, acidic tuffs; porphyroids; tuffs, mainly andesitic	500–410 Ma	Cassard and others (2006)
osvi	andesitic lavas and tuffs, undifferentiated	500–410 Ma	Cassard and others (2006)
ova	rhyodacites, ignimbrites	500–435 Ma	Cassard and others (2006)
sdv	undifferentiated volcano-sedimentary rocks	435–410 Ma	Cassard and others (2006)
sv	acidic volcanic rocks, acidic tuffs	435–410 Ma	Cassard and others (2006)

Herzogenhugel, Belgium

At Herzogenhugel, a southeast-dipping sill-shaped intrusion hosts disseminations, quartz stockworks, veinlets, and veins of pyrite, chalcopyrite, molybdenite, and other hypogene and supergene minerals. This calc-alkaline quartz diorite (tonalite and trondhjemite) and granodiorite body crops out over an area of about 0.85 km^2, is less than 100 m thick, and intrudes Cambrian siliciclastic rocks. Thermal metamorphism of the country rocks formed a zone of hornfels less than a meter wide and a halo of spotted schists hundreds of meters wide. Uranium-lead isotopic studies of zircons indicate magma emplacement sometime during Silurian-Devonian time, with a minimum emplacement age of about 381±16 Ma (middle Devonian) (Kramm and Buhl, 1985; and Dejonghe, 2003). Exploration by Union Miniére S.A. in 1976–1977 included four drill holes that reached a maximum vertical depth of about 160 m. The deposit size is estimated to be approximately 20 Mt of 0.17 percent copper (range 0.01–0.45 percent) and 0.02 percent molybdenum (range 0.001–0.097 percent) (Dejonghe, 1986, 2003).

Prospects, Mineral Occurrences, and Related Deposit Types

Four porphyry copper prospect areas are recognized in Scotland (table G4), none of which have proved to be economic to develop. A geochemical-drainage survey delineated anomalous copper and molybdenum associated with the porphyritic part of the 430 Ma Lagalochan (Kilmelford) calc-alkaline subvolcanic complex that led to the discovery of the Kilmelford prospect (Ellis and others, 1977). Drilling by the British Geological Survey in 1976 showed the prospect to be very low-grade (<0.1 percent copper) and of limited extent. An adjacent area was explored by BP Minerals in the 1980s for gold in highly altered and brecciated zones associated with a shear zone. The prospect, presently inactive, is interpreted as a vented diatreme complex with early copper-molybdenum-gold veinlets in a core zone of breccia and diorite-granodiorite intrusions followed by polymetallic shear zone mineralization and lead-zinc-silver carbonate veins (British Geological Survey, 1999). The site was inactive as of 2000 (Colman and Cooper, 2000). Other porphyry copper prospects that were investigated by the British Geological Survey and in topical studies include Tomnadashan, the ~410 Ma Ballachulish igneous complex, and the Black Stockarton Moor and Foreburn igneous complexes in southern Scotland (fig. G1, table G4).

Exploration History

Regional stream-sediment surveys were done throughout the Scottish Caledonides by industry in the 1970s; some further exploration was conducted but no discoveries were reported. A number of hydrothermally altered high-level Caledonian intrusive complexes contain evidence of low-grade, disseminated porphyry-style copper mineralization. The British Geological Survey's 1973–1997 Mineral Reconnaissance Programme included studies on the geology, geochemistry, and geophysics of a number of porphyry copper prospect areas (Haslam and Kimball, 1981; Brown and others, 1979; Ellis and others, 1977; Beer and Kimbell, 1989).

A major exploration program conducted from 1965 to 1973 by Rio Tinto Finance and Exploration Ltd. (RioFinEx) led to the discovery of the Coed y Brenin porphyry copper

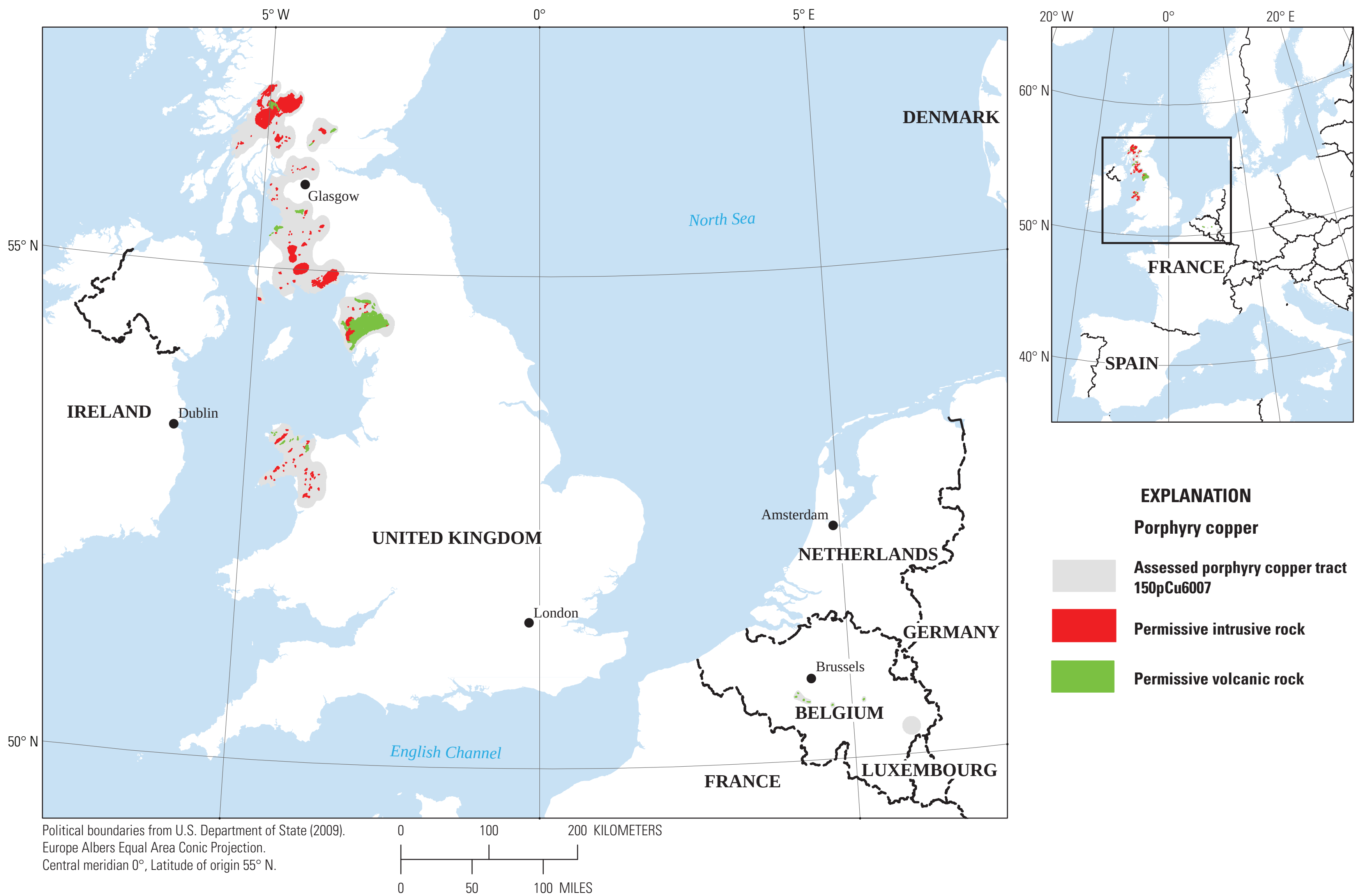

Figure G2. Map showing the distribution permissive intrusive and volcanic rocks used to delineate tract 150pCu6007 (EU07PC), Western European Caledonian—United Kingdom and Belgium.

Table G3. Porphyry copper deposits in tract 150pCu6007 (EU07PC), Western European Caledonian—United Kingdom and Belgium.

[Ma, million years; Mt, million metric tons; t, metric ton; %, percent;g/t, gram per metric ton; NA, subtype not applicable. Contained Cu in metric tons is computed as tonnage (Mt×1,000,000) × Cu grade (%). n.d., no data]

Name	Country	Latitude	Longitude	Subtype	Age (Ma)	Tonnage (Mt)	Cu (%)	Mo (%)	Au (g/t)	Ag (g/t)	Contained Cu (t)	Reference
Coed y Brenin	United Kingdom (Wales)	52.814	–3.932	NA	Lower Ordovcian	200	0.3	n.d.	n.d.	n.d.	600,000	Mason (undated), Rice and Sharp (1976), Shepherd and Allen (1985)
Herzogenhugel	Belgium	50.283	5.917	NA	Paleozoic	20	0.17	0.02	n.d.	n.d.	34,000	Dejonghe (1986), Van Wambeke (1955a), Van Wambeke (1955b), Weis and others (1980)

Table G4. Significant prospects and occurrences in tract 150pCu6007 (EU07PC), Western European Caledonian—United Kingdom and Belgium.

Name	Country	Latitude	Longitude	Age	Comments	Reference
Kilmelford	Scotland	56.263	–5.466	418 Ma	Exploration since 1970 included stream-sediment sampling, drilling, bedrock sampling, geophysics.	Zhou (1988), Bowie (1977), SGS Group (1998), Burley and others (1978)
Ballachulish	Scotland	56.665	–5.179	Caledonian	Sporadic mineralization over an 1800 by 800 m area in adamellite and microadamellite of the Balluchulish igneous complex. Explored by the British Geological Survey in the 1970s by IP, core, and outcrop sampling. Subeconomic.	Colman and others (1996), Haslam and Kimball (1981,
Tomnadashan	Scotland	56.514	–4.128	Caledonian	Copper minerals associated with granite lenses intruded into a Caledonian diorite; mined in the 1800s for gold and copper. Site of “killer rabbit” scene in Monty Python movie.	Colman and others (1996), Pattrick (1984)
Black Stockarton Moor	Scotland	54.874	–3.976	Caledonian	Anomalous copper (<140 to 5,500 ppm) in a soil survey associated with the Caledonian Black Stockarton Moor composite subvolcanic complex led to mineralogical and chemical evaluation in the 1970s.	Brown and others (1979), Colman and others (1996)

deposit in Wales. The Coed Y Brenin discovery prompted exploration for porphyry copper deposits in the Scottish Caledonides that led to the 1971 discovery of porphyry-style prospects in the Kilmelford region of western Scotland at Lagalochen. No recent porphyry-related exploration activity has occurred.

The Herzogenhugel deposit was drilled in 1976–77 by Union Miniere. The Kilmelford region of Scotland has been subjected to numerous phases of exploration, such as stream sediment-sampling and diamond drilling, since 1970 (SGS Group, 1998). Ellis and others (1977) report the results of a geochemical drainage survey begun in 1975 that delineated a strong copper and molybdenum anomaly associated with the porphyritic part of the calc-alkaline intrusive complex. Diamond drilling during the following two years confirmed the presence of low-grade copper mineralization associated with strong hydrothermal alteration (Ellis and others, 1977). In 1981, British Petroleum (BP) started a geochemical bedrock sampling program at Kilmelford using jackhammers to penetrate glacial till.

Sources of Information

Principal sources of information used for delineation of the Western European Caledonian tract 150pCu6007 (EU07PC) are listed in table G5.

Qualitative Assessment

The two known Caledonian porphyry copper deposits and the single prospect in the tract are associated with felsic intrusions; none have ever been mined. The known Caledonian porphyry copper occurrences are widely scattered throughout Europe. Post-mineralization tectonic disruption precludes delineation of coherent magmatic arcs or belts. Caledonian deposits and prospects in Europe that have been investigated have not proven to represent significant resources. Porphyry copper deposits of Caledonian age are present in other parts of the world, such as the Cadia Hill/Ridgeway deposits (~3.9 Mt contained copper) in the Macquarie Arc of eastern Australia, and the Boshchekul deposits (~6.7 Mt contained copper) in Kazakhstan (Singer and others, 2008). However, based on the available data and the past exploration results at known prospects, the team concluded that a probabilistic assessment for undiscovered Caledonian porphyry copper deposits within 1 km of the surface was not warranted. Any future interest in porphyry copper within the tract rocks is likely to focus on extensions of identified resources.

Table G5. Principal sources of information used for tract 150pCu6007 (EU07PC), Western European Caledonian—United Kingdom and Belgium.

[NA, not applicable]

Theme	Name or Title	Scale	Citation
Geology	Digitial geologic map of Europe	1:1,500,000	Cassard and others (2006)
	Geological map of Italy	1:1,000,000	Compagnoni and others (2008)
	Bedrock geology theme: British Geological Survey digital geologic map of Great Britain	1:625,000	British Geological Survey (2007)
	Metallogenic map of Britain and Ireland	1:1,500,000	Colman and others (1996)
Mineral occurrences	Metallogenic map of Britain and Ireland	1:1,500,000	Colman and others (1996)
	Minerals in Britain	NA	British Geological Survey (1999)
	Mineral potential (Britain)	NA	British Geological Survey (2011)
	Mineral Resources Data System (MRDS)	NA	U.S. Geological Survey (2009)
	Porphyry copper deposits of the world—Database, map, and grade and tonnage models	NA	Singer and others (2008)

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Appendix H. Description of GIS Files

Three ESRI shapefiles (.shp), a file geodatabase (.gdb), and an ESRI map document (.mxd) are included with this report. The file geodatabase contains three feature classes and two data tables. These may be downloaded from the USGS Web site as zipped file **GIS_SIR5090-K.zip**.

The file geodatabase is **Europe_pCu** and contains the following three feature classes and two data tables:

Europe_pCu_Deposits_prospects—point locations for known deposits (identified resources that have well-defined tonnage and copper grade) and prospects. Feature class 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 feature class. Note that attributes for tonnages and commodities listed as "-9999" represent no data available.

Europe_pCu_Tracts—a polygon feature class that represents porphyry copper permissive tracts for Europe. 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 feature class.

Europe_political_boundaries—polygon feature class showing countries within and adjacent to the study area. The feature class is extracted from the country and shoreline boundaries maintained by the U.S. Department of State (2009).

Means data table—shows the mean amount for each commodity by tract in Europe.

Quantiles data table—shows the probabilistic assessment results as quantiles for commodity by tract.

Three shapefiles are included (**Europe_pCu_Tracts.shp, Europe _pCu_Deposits_prospects.shp, Europe _political_boundaries.shp)**. The shapefiles have been created from the feature classes. They represent an exact copy of the feature class in shapefile format.

These three feature classes are included in an ESRI map document (version 10 Service Pack 5): **Europe_pCu.mxd**. Probabilistic assessment results are included in two "relate" tables in the GIS package; Excel versions of these tables also are provided. Mean, shows the mean amount for each commodity by tract. Quantiles, shows probabilistic assessment results as quantiles for commodity by tract.

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Appendix I. Assessment Team

Byron R. Berger is a research geologist with the USGS in Denver, Colorado. He has expertise on porphyry copper deposits, mineral-resource assessment, and porphyry- and related mineral deposits of Central Europe. He has conducted field work in Central Europe focused on structural settings of porphyry- and polymetallic vein deposits, published a number of papers on that subject with Lawrence Drew, and participated in the 2010 assessment workshop at the USGS.

Mario Billa is an economic geologist with the Bureau de Recherches Géologiques et Minières, Orléans, Cedex 2, France. He participated in the Orléans assessment workshop.

Joseph A. Briskey is a retired economic geologist who spent more than 30 years at the USGS. Prior to his retirement, he was a Co-chief of the USGS Global Mineral Resource Assessment project. He assembled the team for the Orléans assessment workshop and led that meeting.

Daniel Cassard is an economic geologist with the Bureau de Recherches Géologiques et Minières, Orléans, Cedex 2, France. He is a principal author of GIS Central Europe and arranged and participated in the Orléans assessment workshop.

Michael W. DeMarr is a graduate student at George Mason University in Fairfax, Virginia. He participated in the project as a GIS specialist and research assistant at the USGS in Reston, Virginia.

Connie L. Dicken is a GIS specialist with the USGS in Reston, Virginia. She is the GIS task leader for the USGS Global Mineral Resource Assessment Project and oversaw the GIS activities of the project.

Lawrence J. Drew is a senior mineral economist with the USGS in Reston, Virginia, an expert on mineral resource assessment, and author of studies on the structural setting of porphyry copper and associated deposits of Central Europe. Drew conducted field work in Central Europe focused on structural settings of porphyry- and polymetallic vein deposits and published a number of papers on that subject with Byron Berger. He participated in the 2010 assessment workshop at the USGS .

Jane M. Hammarstrom is a research geologist with the USGS in Reston, Virginia. She is Co-chief of the USGS Global Mineral Resource Assessment project, the task leader for the porphyry copper assessment, and author of several porphyry copper assessments. She has more than 30 years of research experience in igneous petrology, mineralogy, geochemistry, economic geology, and mineral resource assessment. She participated in the 2010 USGS workshop and edited the final report.

Duncan E. Large is a Europe-based, independent consulting geologist with over 30 years of experience in the mineral exploration and mining industry. Prior to becoming a consultant in 1981, he spent 5 years with the Rio Tinto group (mostly in Indonesia and Europe) and 4 years as a Research Scientist working at the TU Braunschweig on projects funded by the German Federal Institute of Geosciences. He participated in the 2010 assessment workshop at the USGS.

Andor L.W. Lips is an economic geologist formerly at the Bureau de Recherches Géologiques et Minières, Orléans, Cedex 2, France. He is a principal author of databases and GIS Central Europe and participated in the assessment workshop held in Orléans in 2006.

Zdeněk Pertold is a professor on the faculty of the Institute of Geochemistry, Mineralogy, and Mineral resources at Charles University in Prague. He specialized in studies of the mineral deposits of the Bohemian Massif. Dr. Pertold participated in an assessment workshop held in Orléans in 2006.

Emilian Roşu is an economic geologist and an expert on Romanian geology at the Geological Institute of Romania, Bucharest. Dr. Roşu participated in an assessment workshop held in Orléans in 2006.

David M. Sutphin is a geologist at the USGS in Reston, Virginia. Dave has been with the USGS for more than 30 years, during which time he served as graphite commodity geologist and resource analyst for quantitative mineral-resource assessments, including the Roswell and Mimbres BLM areas in New Mexico, sand and gravel resources of parts of New Hampshire, Global Mineral Resources Assessment Project assessments of Europe and South America, and assessments of various mineral commodities in Madagascar and Afghanistan. He has visited some of the deposits in Central Europe and he compiled the material for the 2010 assessment workshop, participated in that meeting, and prepared the draft report.

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