5.0 Deposits related to felsic to intermediate porphyritic igneous rocks

Mineral deposits related to felsic to intermediate porphyritic igneous rocks include porphyry copper and associated deposits, such as polymetallic skarns and veins (section 5.1) and gold-bearing parts of the same systems (section 5.2). A number of areas in Afghanistan contain occurrences and geologic features that show promise for future discovery and exploitation of these important deposits (Ludington and others, 2006).

5.1 Porphyry copper and associated deposits

Contributions by Stephen D. Ludington and Stephen G. Peters

About 200 igneous-related hydrothermal mineral deposits and occurrences in Afghanistan contain copper as a major commodity. The majority of these are classified as copper skarn (about 50 prospects) and polymetallic vein (about 70 prospects) deposits (Abdullah and others, 1977; Doebrich and Wall, 2006). These deposit types are typically associated with and occur in the same geologic environments as porphyry copper deposits (Drew and Menzie, 1993). Thus, their presence is direct evidence that the geologic environments permissive for porphyry copper deposits exist in Afghanistan. In addition, igneous rocks typical of geologic provinces that contain porphyry copper deposits are common in Afghanistan. Most of these prospects are associated with Cretaceous through Late Tertiary plutonic rocks that constitute a number of igneous belts that are part of Tethyan magmatic arcs. Most igneous-related copper prospects are located in western Afghanistan in the Band-e Bayan, Farah Rod, Helmand, Arghandab, Spin Boldak, and Chagai plutonic belts, northwest of the Chaman fault and south of the Herat fault (fig. 1.0-3).

Porphyry copper deposits are an extremely important source of copper worldwide, and are found in plutonic rocks in magmatic arcs in North and South America, Europe, Asia, and the southwestern Pacific Ocean. The Tethyan arcs, stretching from the Carpathian Mountains of south and east Europe through East Asia, are the setting for numerous important porphyry copper deposits both to the west (Sar Chesmeh, Iran), south (Reqo Diq, Pakistan), and east (Yulong, Tibet) of Afghanistan. Several of the known copper-bearing occurrences in Afghanistan have measured or estimated resources, including Gbarghey, about 70 km north-northeast of Kandahar; Kundalyan, about 125 km northeast of Kandahar; and Shaida, about 75 km southwest of Herat. Because relatively little is known about the specific characteristics of porphyry copper prospects in Afghanistan, we assessed this deposit type using the general porphyry copper model as described by Singer and others (2005).

In Afghanistan, copper skarn deposits are associated with intrusive `igneous rocks and these occurrences are numerous and widespread. They are present mainly as exocontact concentrations that are hosted in sedimentary carbonate and calcareous clastic rocks at the contacts with intrusions. Fifty-seven (57) skarn deposits and occurrences have copper as a major commodity. They are classified as copper, zinc-lead, tin, tungsten, and copper-gold skarns. In other parts of the world, large copper skarns associated with porphyry copper deposits may contain hundreds of millions of metric tons of ore. The copper skarns occur in carbonate rocks and calcareous siliciclastic rocks ranging in age from Cambrian to Cretaceous. Some important examples of copper skarns are Ahankashan in Badghis Province, Dehana in Herat Province, and Tourva in Zabul Province. Zinc-lead and iron skarns are also abundant, although their association with porphyry copper deposits is not as strong.

Copper-bearing polymetallic vein occurrences in shear zones, fractures and breccias also are widespread throughout much of Afghanistan. They are especially common in the Arghandab plutonic belt, in Gazni, Oruzgan, Zabul, and Kandahar Provinces.

5.1.1 Descriptive Models

Porphyry copper deposits are large, relatively low grade deposits that may also contain significant amounts of molybdenum and gold as byproducts. They generally require 100s of million dollars in capital investment and also require significant power and transportation infrastructure. Development from discovery to production may take up to 10 or more years. The deposits commonly are mined by large open pit mines, but especially rich deposits may also be mined by underground methods. Porphyry copper deposits are commonly spatially associated with a number of higher-grade deposit types such as skarns and polymetallic veins that are thought to be genetically related to a common hydrothermal system. These smaller but higher grade deposits often serve as exploration guides and their study may lead to the discovery of porphyry copper deposits. A summary and references to the appropriate occurrence and grade and tonnage models for all these deposit types are given in table 5.1-1.

Table 5.1-1. Median tonnage and grade for porphyry copper and associated deposit models.

Model	Median tonnage	Median grade	Reference
Porphyry copper (model 17)	220	0.44 Cu, 0.01 Mo, 1.2 Ag, 0.077 Au	Cox, 1986c; Singer and others, 2005
Porphyry copper-gold (model 20c)	220	0.44 Cu, 0.002 Mo, 1.4 Ag, 0.4 Au	Cox, 1986e; Singer and others, 2005
Porphyry copper-molybdenum (model 21a)	270	0.45 Cu, 0.028 Mo, 1.5 Ag, 0.012 Au	Cox, 1986f; Singer and others, 2005
Porphyry copper, skarn-related (model 18a)	80	0.98 Cu, 1 Ag	Cox, 1986d; Singer, 1986
Cu skarn (model 18b)	0.56	1.7 Cu	Cox and Theodore, 1986; Jones and Menzie, 1986
Zn-Pb skarn (model 18c)	1.4	5,9 Zn, 2.8 Pb, 0.09 Cu, 58 Ag	Cox, 1986g; Mosier, 1986
Fe skarn (model 18d)	7.2	50 Fe	Cox, 1986a; Mosier and Menzie, 1986
Polymetallic veins (model 22c)	nd	nd	Cox, 1986b; Bliss and Cox, 1986
Polymetallic replacement (model 19a)	1.8	5.2 Pb, 3.9 Zn, 0.094 Cu, 150 Ag, 0.19 Au	Morris, 1986; Mosier and others, 1986

All tonnage in millions of tones. Copper, molybdenum, lead, and zinc grades in weight percent element; silver and gold grades in grams/tonne. * Numbers refer to models in Cox and Singer (1986).

Porphyry copper deposits

Porphyry copper deposits are typified by chalcopyrite and bornite mineralization, either disseminated or more commonly in quartz veins in stockworks or breccias and generally are confined to intrusive rocks and their immediate wall rocks. If calcareous wall rocks are present, part of the deposit may occur as skarn.

Intrusive rocks in porphyry copper provinces are generally intermediate to felsic in composition, commonly granodiorite and quartz monzonite. They are almost invariably I-type and calc-alkaline, although some gold-rich deposits are associated with alkaline rocks. The deposits are found in both continental and oceanic magmatic arcs.

Large masses of rock have undergone hydrothermal alteration in porphyry copper deposits. The nature and zoning patterns of this alteration can serve as an important guide to ore, and thus have been studied intensively by geologists. The innermost alteration zone is usually termed potassic, and is characterized by secondary potassium feldspar and(or) biotite, either disseminated throughout the rock or in the copper sulfide-bearing veins and veinlets. Outward from the potassic zone, very large areas of phyllic alteration, also known as quartz-sericite-pyrite (QSP), are often present. Phyllic alteration is often so intense that no original minerals are left in the rock. Much of the QSP-altered rock may be outside the commercial copper ore. Distal to the phyllic zone, and often extending as much as several kilometers from the copper ore, is the propylitic zone characterized by chlorite, epidote, and pyrite.

Placer gold deposits occur downstream from some, but not all, porphyry copper deposits, and they have been used successfully as exploration guides in some areas.

Copper skarn deposits

Skarns are high temperature replacements of carbonate rocks at and closely adjacent to contacts with intrusive rocks; the deposits generally are irregular or tabular masses. Copper skarns typically contain chalcopyrite, pyrite, and hematite or magnetite in a calc-silicate gangue. Any combination of bornite, pyrrhotite, molybdenite, bismuthinite, sphalerite, galena, arsenopyrite, enargite, tennantite, and tetrahedrite may also be present. These sulfide and oxide minerals are generally interstitial to the silicate skarn assemblage, which has a granoblastic texture.

The skarn gangue assemblage is usually diopside and andradite in the hottest central zone, surrounded by wollastonite and tremolite; marble is often found on the periphery of the skarn. There may be retrograde alteration to actinolite, chlorite, and clays.

Skarn deposits often weather to an iron-rich gossan with residual silicate minerals and copper carbonate. Geochemical signatures may show a Cu–Au–Ag–rich inner zone that grades outward to Au–Ag zones with high Au:Ag ratios and finally to an outer Pb–Zn–Ag zone. Trace amounts of cobalt, arsenic, antimony, and bismuth are found in some deposits. If the skarn contains magnetite, a strong magnetic anomaly may be present.

Drew and Menzie (1993) point out that not all copper skarn deposits are associated with porphyry copper deposits. Nevertheless, many porphyry deposits do have associated skarn-style mineralization, and skarn occurrences serve as an important guide to undiscovered porphyry copper deposits.

Iron skarn deposits

Iron skarn deposits are not as clearly indicative of porphyry copper occurrence, as many of them are found in districts that have no important base-metal deposits. Nevertheless, in some districts, iron skarns are closely associated with porphyry copper deposits.

Iron skarn deposits contain magnetite, sometimes accompanied by chalcopyrite, pyrite, or pyrrhotite, in a calc-silicate gangue. They are found adjacent to intrusive rocks that vary in composition from gabbro to granite. The skarn gangue assemblage is often diopside-hedenbergite, grossular-andradite, and epidote, with late-stage amphibole and(or) chlorite.

In addition to iron, the deposits commonly are enriched in copper, cobalt, gold, and sometimes tin. Weathering of these deposits generally results in bold outcrops and abundant float of magnetite. A strong aeromagnetic anomaly is almost always present.

Zinc-lead skarn deposits

Zinc-lead skarns typically contain enargite, sphalerite, argentite, and tetrahedrite in a calc-silicate gangue. Any combination of digenite, chalcopyrite, bismuthinite, proustite, pyrargyrite, jamesonite, jordanite, bournonite, stephanite, and polybasite may also be present. These sulfide minerals are generally interstitial to the silicate skarn assemblage, which has a granoblastic texture.

The skarn gangue assemblage commonly contains hedenbergite, andradite or grossular or spessartine, bustamite, and rhodonite. Peripheral and(or) late-stage skarn minerals are actinolite, ilvaite, chlorite, dannemorite, and rhodocrosite.

Zinc-lead skarn deposits often weather to a manganese-rich gossan with residual silicate minerals and zinc and lead carbonates. Geochemical signatures may include Zn, Pb, Mn, Cu, Co, Au, Ag, As, W, Sn, and F.

Polymetallic Vein deposits

One of the most common deposit types associated with porphyry copper deposits is polymetallic veins. These deposits are characterized by sulfide minerals that contain the common base metals copper, lead, and zinc. The most common minerals are galena, sphalerite, chalcopyrite, and tetrahedrite-tennantite. Most polymetallic veins also contain important amounts of the precious metals gold and silver, usually found as electrum, and in argentiferous galena and silver-bearing sulfosalts. The veins may occur individually, in swarms, or commonly in a semi-radial pattern around associated epizonal or mesozonal intrusions. It is common to find several polymetallic vein deposits associated with a porphyry copper deposit. The gangue in the veins is most commonly quartz, but may include calcite, dolomite, ankerite, siderite, rhodocrosite, barite, fluorite, or rhodonite. Pyrite is nearly ubiquitous, and arsenopyrite is also common.

Hydrothermal alteration around polymetallic veins is normally characterized by narrow (less than a few meters) zones of sericitic and(or) argillic alteration, with much more widespread propylitic alteration. Placer gold deposits often form downstream from outcropping polymetallic vein deposits. If the hydrothermal fluids that form polymetallic veins encounter carbonate rocks, they commonly form polymetallic replacement deposits.

Polymetallic veins are present in most of the plutonic belts of Afghanistan, but are especially common in the Arghandab belt.

Polymetallic replacement deposits

In many parts of the world, polymetallic replacement deposits are common in carbonate rocks in areas where polymetallic veins are prevalent. No deposits or prospects in Afghanistan have been classified as polymetallic replacements. A few zinc-lead skarn deposits are known, and one area in the Band-E Bayan plutonic belt east of Herat contains a number of lead- and zinc-bearing deposits in carbonate rocks that we classify as possible sediment-hosted lead-zinc deposits. Why there are apparently no polymetallic replacement deposits is not known despite the abundance of suitable calc-alkaline intrusions into carbonate rocks.

5.1.2 Tract Descriptions

Because igneous rocks of the type that typically host porphyry copper deposits are common in Afghanistan and most of the country is part of the Tethyan geodynamic belt that contains important porphyry copper deposits from the Carpathian Mountains in south and east Europe to the Himalayas in Central Asia, twelve tracts permissive for the occurrence of porphyry copper deposits were delineated. Each tract is characterized by a combination of features that supports a separate delineation. Because relatively little is known about the specific characteristics of the prospects and occurrences of mineral deposit types associated with porphyry copper deposits in Afghanistan, and because there are no known porphyry copper deposits, we used the general porphyry copper deposit model described by Singer and others (2005). In some cases, the tracts also are permissive for copper skarn, as well as other skarn and polymetallic deposits, but we did not make separate estimates of numbers of undiscovered deposits for these types. Figure 5.1-1 shows the generalized location of all 12 tracts.

Quantitative estimates of the number of undiscovered porphyry copper deposits were made for 11 of the 12 tracts. Tracts ppycu02, ppycu05, and ppycu07 have the highest predicted deposit densities and they are recommended as the most attractive areas for exploration.

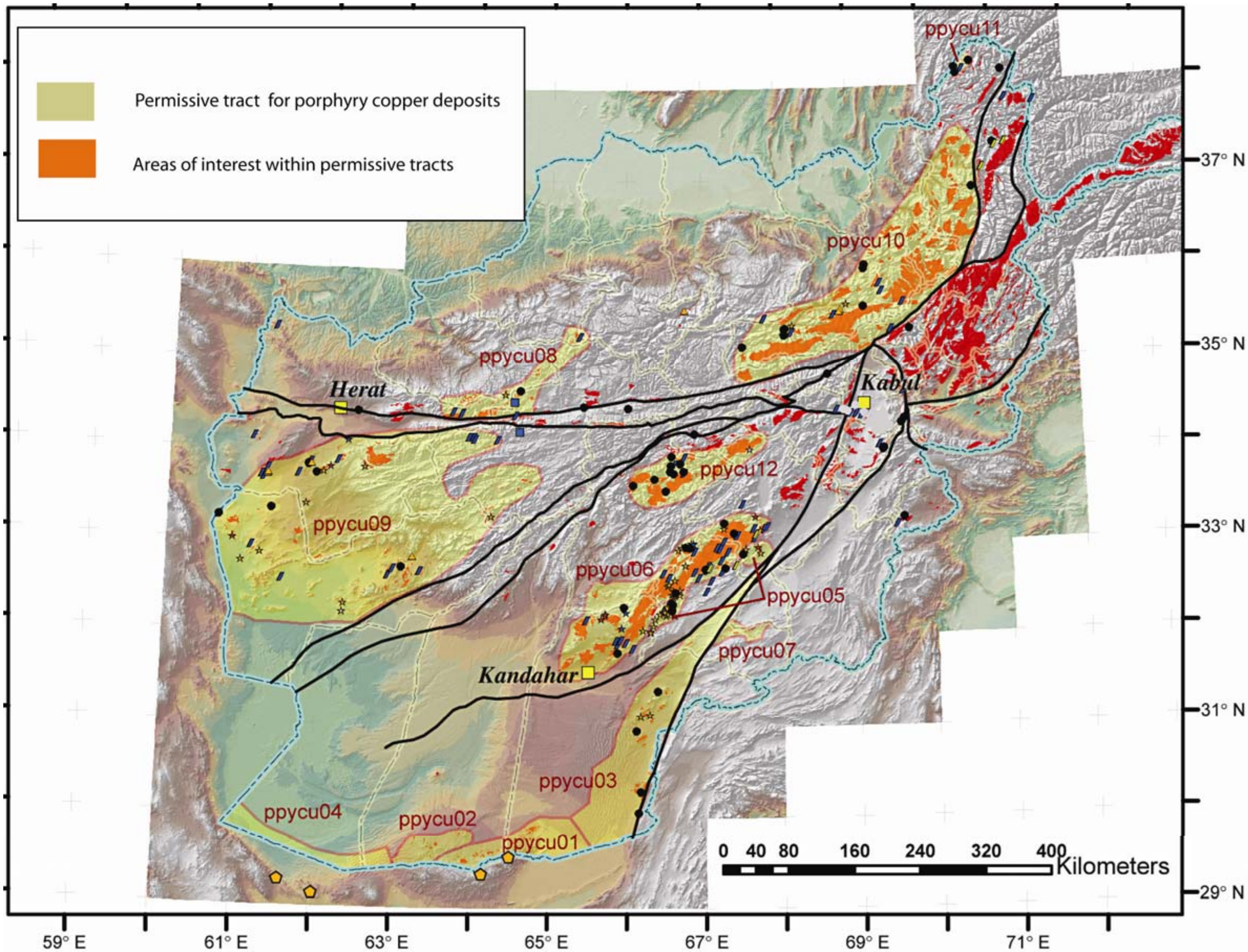

Figure 5.1-1. Map of Afghanistan, showing the location and identification of assessment tracts for porphyry copper deposits. Intrusive rocks are shown in dark red. Major faults are labeled on Figure 1.0-3. Symbols for mineral deposits and prospects are explained in Doebrich and Wahl (2006)

Chagai east tract (ppycu01)

This tract, found in the southern part of Afghanistan along the border with Pakistan, is permissive for porphyry copper deposits and for skarn copper deposits. No deposits are known within the tract, but five porphyry copper deposits and prospects are present a few kilometers south, in Pakistan (Dasht-e-Kain, Ziarat Pir Sultan, Saindak, Koh-i-Dalil, Reko Diq). The Dasht-e-Kain porphyry copper deposit (350 million metric tons at 0.3 percent copper) is a porphyry copper-gold deposit associated with Early Miocene (21 Ma) breccia and tonalite porphyry. The Saindak deposit (440 million metric tons at 0.41 percent copper and 0.5 g/t gold) is also dated at about 21 Ma. The largest deposit is Reqo Dik (807 million metric tons at 0.645 percent copper and 0.35 g/t gold). Rocks associated with these deposits include andesite, andesite agglomerate, diorite, granodiorite and granite (Ahmad, 1992; Ahmad and others, 1986; Ahmed and others, 1972; Breitzman and others, 1983; Kazmi and Qasim, 1997; Leaman and Staude, 2003; Sillitoe and Khan, 1977; Sillitoe, 1978; Spector and others, 1987).

The tract encompasses an east-northeast-trending belt of Oligocene (?) intrusive bodies (map unit P_3grg), that consist of granite, granite porphyry, granodiorite, quartz syenite, and granosyenite. These rocks have not been dated in Afghanistan, but, based on information about the ages of the porphyry copper deposits in nearby Pakistan, they are probably between about 22 and 12 Ma. These rocks intrude felsic and mafic volcanic rocks, flint, fine- and coarse-grained continental sedimentary rocks, marl, and limestone. The tract extends from the border with Pakistan north to where the rocks are estimated to be covered by more than a kilometer of Quaternary and Early Pliocene sedimentary and volcanic rocks (fig. 5.1-2). Where they are exposed, some of the plutonic and volcanic rocks exhibit areas of phyllic alteration mapped from ASTER imagery (Mars and Rowan, 2007). The tract boundary was refined using aeromagnetic data, as the intrusions are characterized by linear positive anomalies that trend east-west (Sweeney and others, 2006). The areas affected by phyllic alteration and upslope from lead-zinc geochemical halo anomalies (fig. 5.1-2) are favorable areas. The eastern boundary of the tract with the Spin Boldak tract (ppycu03) is arbitrary, as this area is entirely covered with younger deposits.

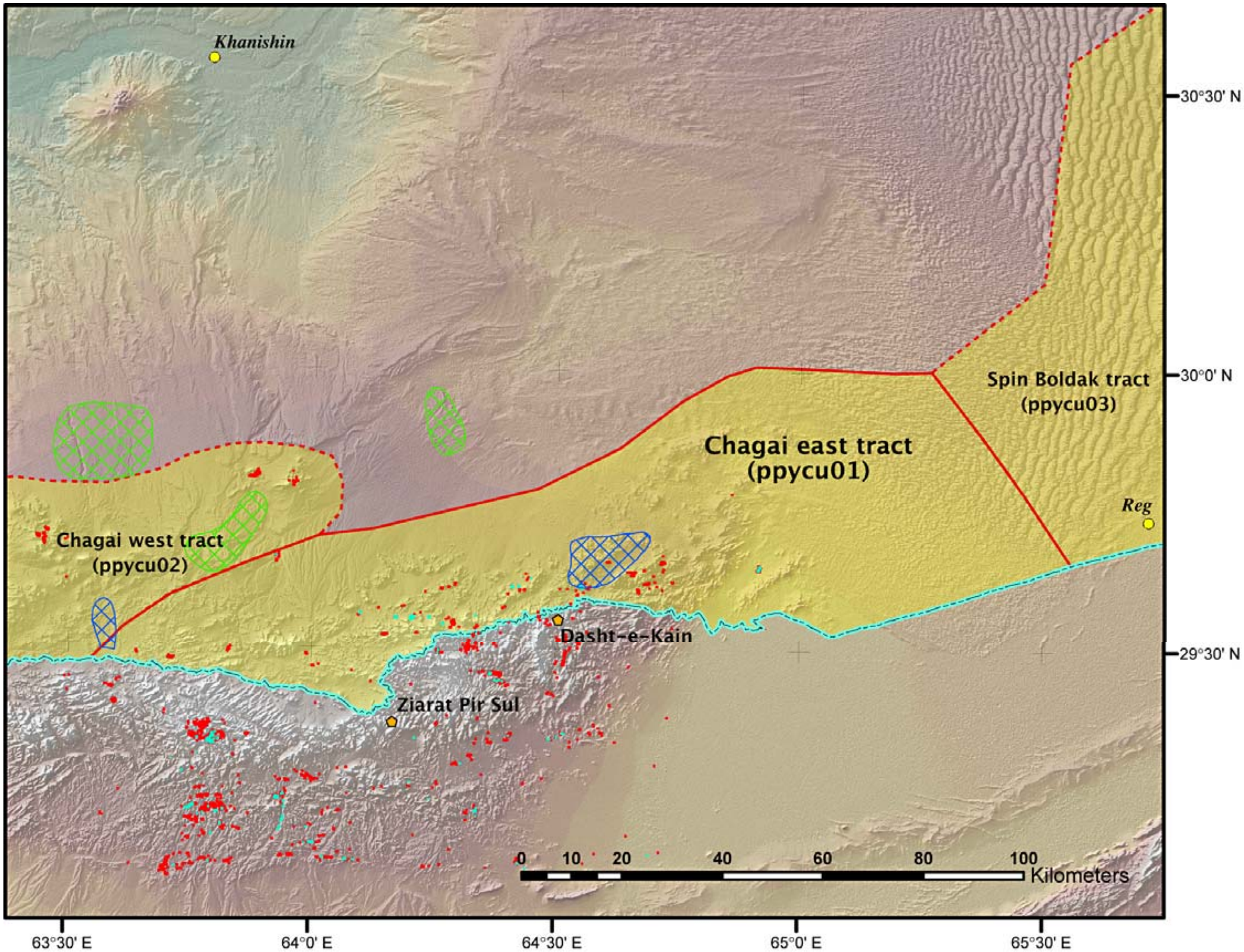

Figure 5.1-2. Map showing the Chagai east permissive tract (ppycu01) for undiscovered porphyry copper deposits and skarn copper deposits. The known porphyry copper deposits (Dash-e-Kain) and prospect (Ziarat Pir Sul) nearby in Pakistan are indicated as orange pentagons. Hydrothermal alteration from ASTER imagery is shown in red (phyllic) and turquoise (argillic). Blue crosshatch indicates lead-zinc mineral halos; green crosshatch indicates tin mineral halos.

Information used to delineate this tract included the geologic map, aeromagnetic map, ASTER and LANDSAT imagery, and the mineral deposit database (Doebrich and Wahl, 2006; Sweeney and others, 2006; Mars and Rowan, 2007; Orris and Bliss, 2002).

The presence of two well-explored porphyry copper prospects nearby in Pakistan, along with three other porphyry copper prospects, is a strong positive indication that undiscovered porphyry copper deposits may occur in the tract. The geologic environment of those deposits and prospects can be extrapolated into the Chagai east area. In addition, the aeromagnetic signature and presence of phyllic alteration are favorable factors. On the other hand, there are no known prospects in the tract. Based on satellite imagery, the area appears to be somewhat more deeply eroded than the area to the south.

There is no known past exploration in this part of Afghanistan, and the U.S. Geological Survey Assessment Team did not visit the area. The Dasht-e-Kain porphyry copper deposit in adjacent Pakistan was discovered in 1975, and this part of Pakistan has been extensively explored. The information most needed to make a better assessment in this area is intermediate-scale (1:25,000) geologic mapping, geophysical prospecting, and geochemical sampling, especially of the hydrothermally altered areas identified by ASTER imagery.

The assessment team estimated that there is a 90 percent chance of 0 or more undiscovered porphyry copper deposits, a 50 percent chance of 1 or more, and a 10 percent chance of 3 or more (figs. 5.1-3, 5.1-4, table 5.1-2). The amounts of contained metal that result from the Monte Carlo simulation based on this estimate and the combined grade and tonnage for porphyry copper deposits from Singer and others (2005) are illustrated in figures 5.1-3 and 5.1-4 and summarized in table 5.1-2.

Table 5.1-2. Table summarizing statistical parameters for the assessment of the Chagai east permissive tract (ppycu01). The mean number of expected deposits is 1.3.

quantile	Cu	Mo	Au	Ag	Rock
0.95	0	0	0	0	0
0.90	0	0	0	0	0
0.50	1,000,000	1,000	7	0	240,000,000
0.10	10,000,000	240,000	265	2,900	2,000,000,000
0.05	17,000,000	490,000	430	6,400	3,400,000,000
mean	4,200,000	110,000	98	1,400	820,000,000
Probability of mean	0.24	0.18	0.23	0.16	0.26
Probability of zero	0.30	0.49	0.46	0.60	0.30

The Mark3 index is 84 – Porphyry Cu New General 2005. Amounts are in metric tons.

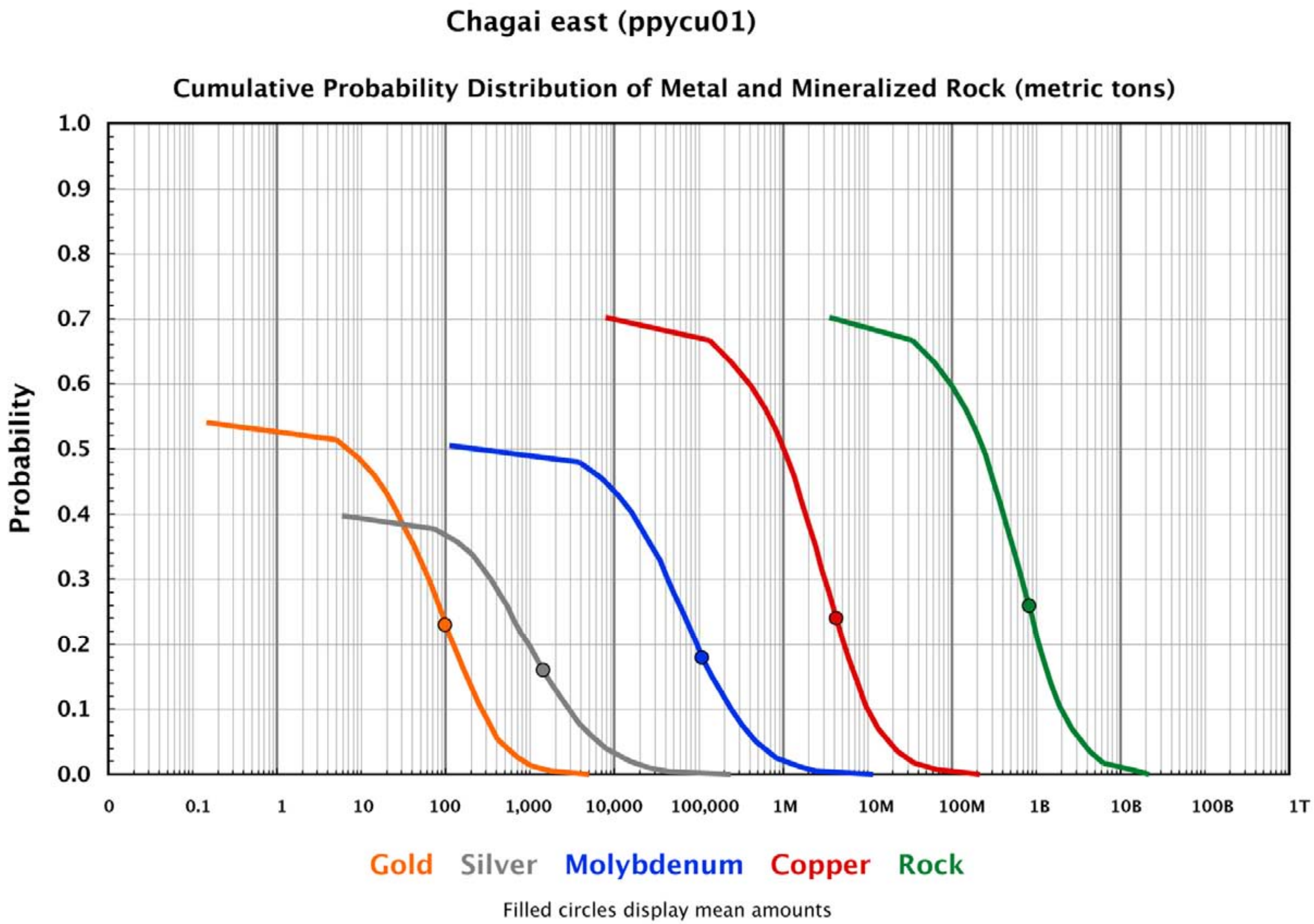

Figure 5.1-3. Cumulative distribution of estimated contained metal and mineralized rock in the Chagai east permissive tract (ppycu01).

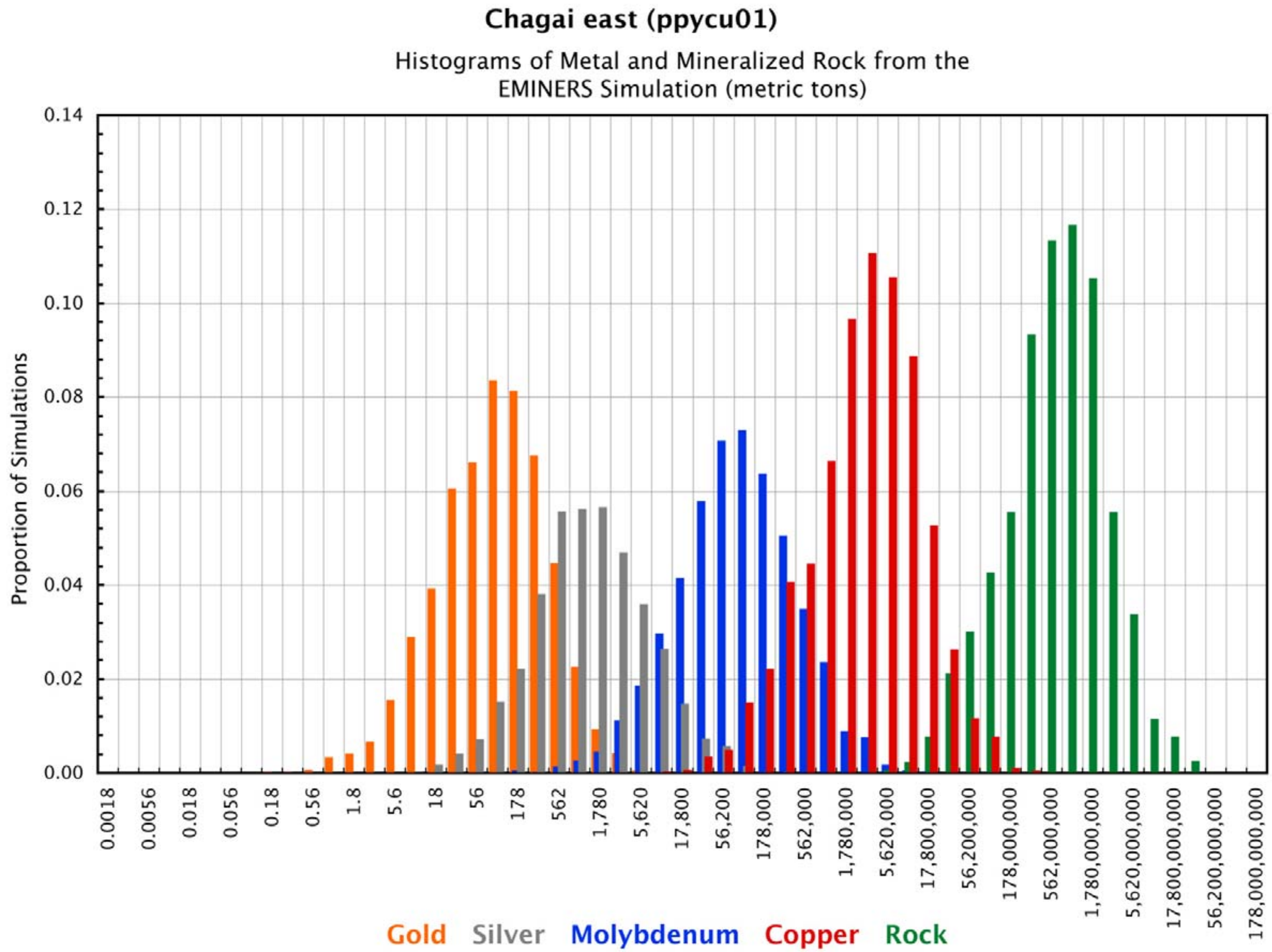

Figure 5.1-4. Histograms of estimated contained metal and mineralized rock in the Chagai east permissive tract (ppycu01).

Chagai west tract (ppycu02)

This tract is also in the southern part of Afghanistan along the border with Pakistan, and is permissive for porphyry copper deposits and for skarn copper deposits. The tract was delineated separately from ppycu01 in the west and ppy04 in the west on the basis of differences in geologic, geophysical and alteration features, No deposits are known within the tract, but five porphyry copper deposits and prospects are present a few kilometers south, in Pakistan (Dasht-e-Kain, Ziarat Pir Sultan, Saindak, Koh-i-Dalil, Reko Diq). The Dasht-e-Kain porphyry copper deposit (350 million metric tons at 0.3 percent copper) is a copper-gold porphyry deposit associated with Early Miocene (21 Ma) breccia and tonalite porphyry. The Saindak deposit (440 million metric tons at 0.41 percent copper and 0.5 g/t gold) is also dated at about 21 Ma. The largest deposit is Reqo Dik (807 million metric tons at 0.645 percent copper and 0.35 g/t gold). Rocks associated with these deposits include andesite, andesite agglomerate, diorite, granodiorite and granite (Ahmad, 1992; Ahmad and others, 1986; Ahmed and others, 1972; Breitzman and others, 1983; Kazmi and Qasim, 1997; Leaman and Staude, 2003; Sillitoe and Khan, 1977; Sillitoe, 1978; Spector and others, 1987).

The tract encompasses an east northeast-trending belt of late Tertiary or Quaternary subvolcanic bodies (map unit $\mathbf{Q_1rd}$), that consist of dacite and rhyolite. These rocks have not been dated in Afghanistan, but the porphyry copper deposits in nearby Pakistan have ages between about 22 and 12 Ma. These rocks intrude felsic and mafic volcanic rocks, flint, fine- and coarse-grained continental sedimentary rocks, marl, and limestone. The tract extends from the border with Pakistan north to where the rocks are estimated to be covered by more than a kilometer of Quaternary and Early Pliocene sedimentary and volcanic rocks (fig. 5.1-5). Where they are exposed, the permissive plutonic and volcanic rocks exhibit areas of phyllic alteration mapped from ASTER imagery (Mars and Rowan, 2007). The tract boundary was refined using aeromagnetic data, as the intrusions are characterized by linear positive anomalies that trend east-west (Sweeney and others, 2006). The areas that are affected by phyllic alteration and that are upslope from the anomalous lead-zinc geochemical mineral halos are favorable areas (fig. 5.1-5). The western boundary of the tract with the Saindak north tract (ppycu04) is arbitrary, as this area is entirely covered with younger deposits.

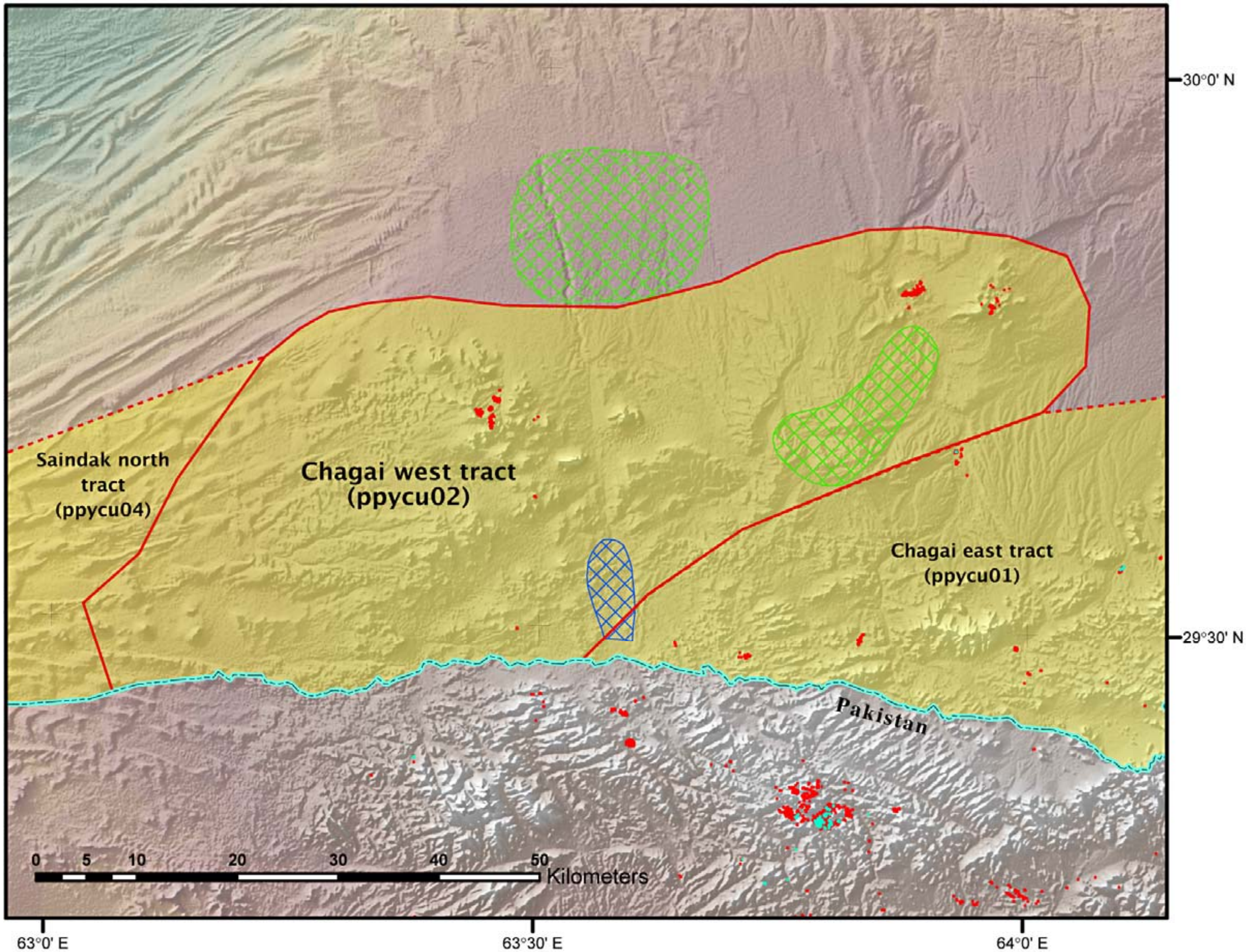

Figure 5.1-5. Map showing the Chagai west permissive tract (ppycu02) for undiscovered porphyry copper and skarn copper deposits. Hydrothermal alteration from ASTER imagery is shown in red (phyllic) and turquoise (argillic). Blue crosshatch indicates lead-zinc mineral halos; green crosshatch indicates tin mineral halos.

Information used to delineate this tract included the geologic map, aeromagnetic map, ASTER and LANDSAT imagery, and the mineral deposit database (Doebrich and Wahl, 2006; Sweeney and others, 2006; Mars and Rowan, 2007; Orris and Bliss, 2002).

The presence of two well-explored porphyry copper deposits (Saindak and Reko Diq) to the southwest in Pakistan, along with three other porphyry copper prospects, is a strong positive indication. The geologic environment of those deposits and prospects can be extrapolated into the Chagai west area. In addition, the aeromagnetic signature and presence of phyllic alteration are favorable factors. On the other hand, there are no known prospects in the tract.

There is no known past exploration in this part of Afghanistan, and the U.S. Geological Survey Assessment Team did not visit the area. A few aragonite occurrences are the only known mineral prospects. The Reko Diq porphyry deposit in adjacent Pakistan is presently being developed, and there is extensive exploration activity in Pakistan. The information most needed to make a better assessment in this area is intermediate-scale (1:25,000) geologic mapping and geochemical sampling, especially of the hydrothermally altered areas identified by ASTER imagery.

The assessment team estimated that there is a 90 percent chance of 0 or more undiscovered porphyry copper deposits, a 50 percent chance of 1 or more, and a 10 percent chance of 2 or more (table 5.1-3; figs. 5.1-6, 5.1-7). The amounts of contained metal that result from the Monte Carlo simulation based on this estimate are illustrated and summarized in table 5.1-3 and in figures 5.1-6 and 5.1-7.

Table 5.1-3. Table summarizing statistical parameters for the assessment of the Chagai west permissive tract (ppycu02). The mean number of expected deposits is 1.0.

quantile	Cu	Mo	Au	Ag	Rock
0.95	0	0	0	0	0
0.90	0	0	0	0	0
0.50	740,000	0	1	0	170,000,000
0.10	7,400,000	170,000	214	2,000	1,500,000,000
0.05	14,000,000	370,000	360	5,000	2,800,000,000
mean	3,300,000	85,000	82	1,100	660,000,000
Probability of mean	0.23	0.16	0.21	0.16	0.24
Probability of zero	0.30	0.54	0.50	0.64	0.30

The Mark3 index is 84 – Porphyry Cu New General 2005. Amounts are in metric tons.

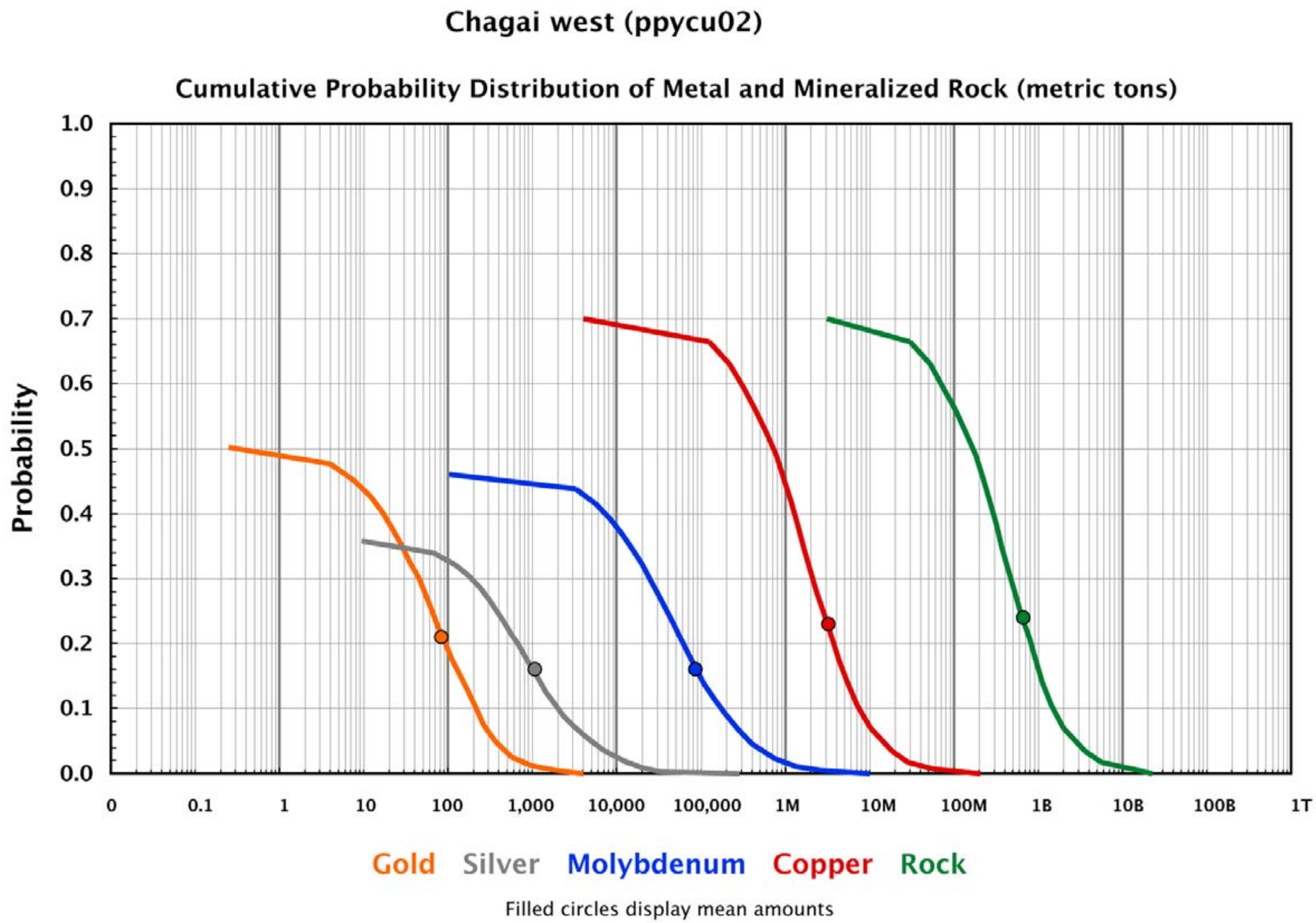

Figure 5.1-6. Cumulative distribution of estimated contained metal and mineralized rock in the Chagai west permissive tract (ppycu02).

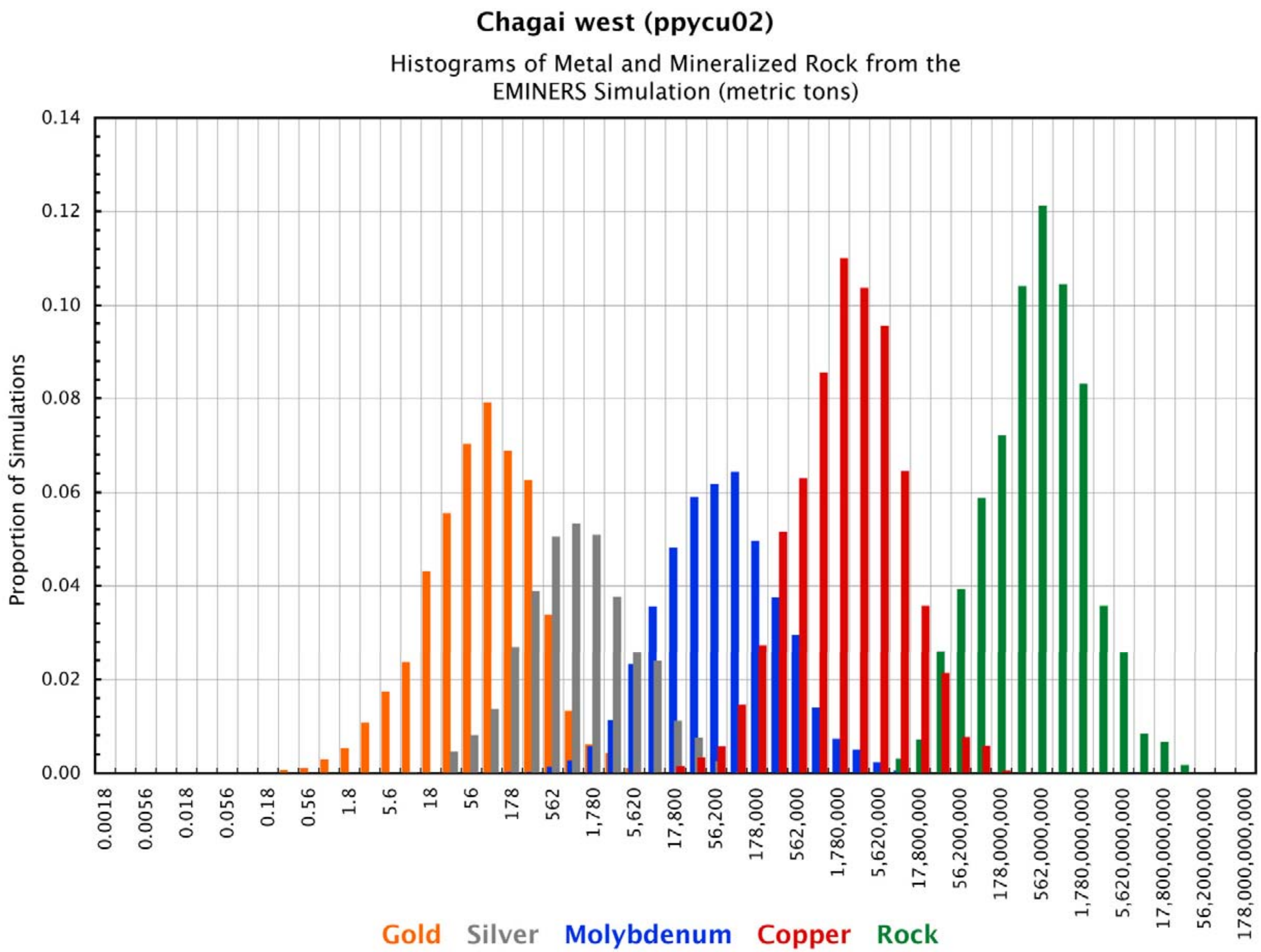

Figure 5.1-7. Histograms of estimated contained metal and mineralized rock in the Chagai west permissive tract (ppycu02).

Spin Boldak tract (ppycu03)

This tract, found in the southern part of Afghanistan along the border with Pakistan, is permissive for porphyry copper and skarn copper deposits. No porphyry copper deposits are known, but six (6) copper-bearing occurrences are present in the tract.

The tract encompasses a north-northeast-trending belt of Eocene and possibly Cretaceous subvolcanic and shallow plutonic bodies (map unit P_3grg) that are generally granitic in composition (Debon and others, 1987). These rocks intrude a complex assemblage of Cretaceous sedimentary and volcanic rocks (Montenat and others, 1986). The tract extends along the border with Pakistan west of the Chaman fault (fig. 1.2) and generally corresponds to the Spin Boldak plutonic belt (Debon and others, 1987) (fig. 5.1-8). Some of the exposed plutonic and volcanic rocks exhibit areas of phyllic alteration mapped from ASTER imagery (Mars and Rowan, 2007). Many areas are covered by young unconsolidated material, especially in the southern part of the tract. The tract boundary was refined using aeromagnetic data, as the intrusive bodies are characterized by northeast-trending positive anomalies (Sweeney and others, 2006). The areas near the known geochemical mineral occurrences and upslope from the copper and lead-zinc mineral halos (fig. 5.1-8) are favorable areas for undiscovered porphyry copper deposits.

There are two small skarn copper prospects in the hills northwest of the village of Spin Boldak, in the central part of the tract. These mineralized areas are up to 100 m long and 30 m wide, but generally are no wider than 3 m. Other unclassified copper occurrences in the tract are mineralized shear zones and zones of dissemination of base-metal sulfide minerals in altered limestone. Most are unnamed. In addition, there are aragonite and iron (Myen Boldak) occurrences in the tract (Douvgal and others, 1971; Koshelev and others, 1972; Abdullah and others, 1977; Orris and bliss, 2002).

There has been limited previous exploration in this part of Afghanistan, although occurrences in the central and southeastern part of the tract indicate some ground prospecting. Stream-sediment samples were taken prior to 1979. The U.S. Geological Survey team did not visit the area. The information most needed to make a better assessment in this area is intermediate-scale (1:25,000) geologic mapping and geochemical sampling, especially near the known mineral prospects, and the sparse hydrothermally altered areas identified by ASTER imagery (Mars and Rowan, 2007).

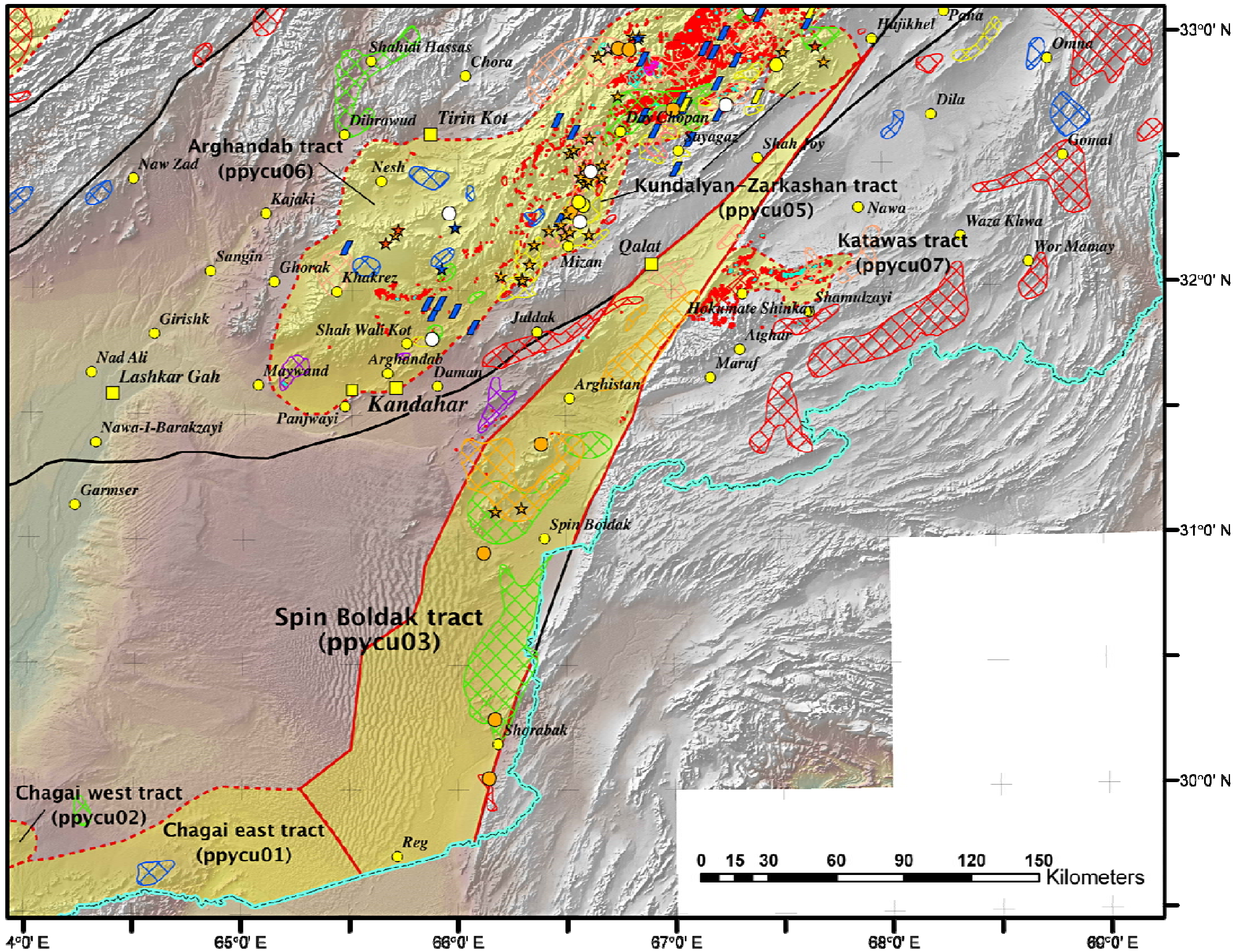

Figure 5.1-8. Map showing the Spin Boldak permissive tract (ppycu03) for undiscovered porphyry copper deposits and skarn copper deposits. Hydrothermal alteration from ASTER imagery is shown in red (phyllic) and turquoise (argillic). Crosshatch indicates mineral halos: blue – lead-zinc; red – mercury; orange – copper; yellow – gold; turquoise – bismuth; flesh – tungsten; green – tin. Mineral occurrence symbols drawn according to the legend of Doebrich and Wahl (2006) (see also legend for fig. 5.1-1).

Information used to delineate this tract included the geologic map, aeromagnetic map, ASTER and LANDSAT imagery, and the mineral deposit database (Doebrich and Wahl, 2006; Sweeney and others, 2006; Mars and Rowan, 2007; Orris and Bliss, 2002). The description of the Kandahar basin by Montenat and others (1986)

The presence of copper-bearing mineral prospects indicates that hydrothermal mineralizing processes have been active within the tract, and the intrusive rocks are of an appropriate age, composition, and level of exposure to host and generate porphyry copper deposits. There is, however, little evidence of widespread hydrothermal alteration near intrusive rock outcrops. Prospects and other signs of mineralization are not numerous or widespread, and many of the geochemical anomalies are tin or tungsten, rather than copper.

The assessment team estimated that there is a 90 percent chance of 0 or more undiscovered porphyry copper deposits, a 50 percent chance of 0 or more, and a 10 percent chance of 2 or more (fig. 5.1-4). The amounts of contained metal that result from the Monte Carlo simulation based on this estimate are illustrated and summarized in table 5.1-4 and figures 5.1-3 and 5.1-4.

Table 5.1-4. Table summarizing statistical parameters for the assessment of the Spin Boldak permissive tract (ppycu03). The mean number of expected deposits is 0.6.

quantile	Cu	Mo	Au	Ag	Rock
0.95	0	0	0	0	0
0.90	0	0	0	0	0
0.50	0	0	0	0	0
0.10	4,800,000	93,000	129	950	990,000,000
0.05	8,700,000	220,000	270	2,800	1,700,000,000
mean	2,100,000	47,000	54	640	400,000,000
Probability of mean	0.19	0.14	0.17	0.12	0.21
Probability of zero	0.60	0.73	0.71	0.79	0.60

The Mark3 index is 84 – Porphyry Cu New General 2005. Amounts are in metric tons.

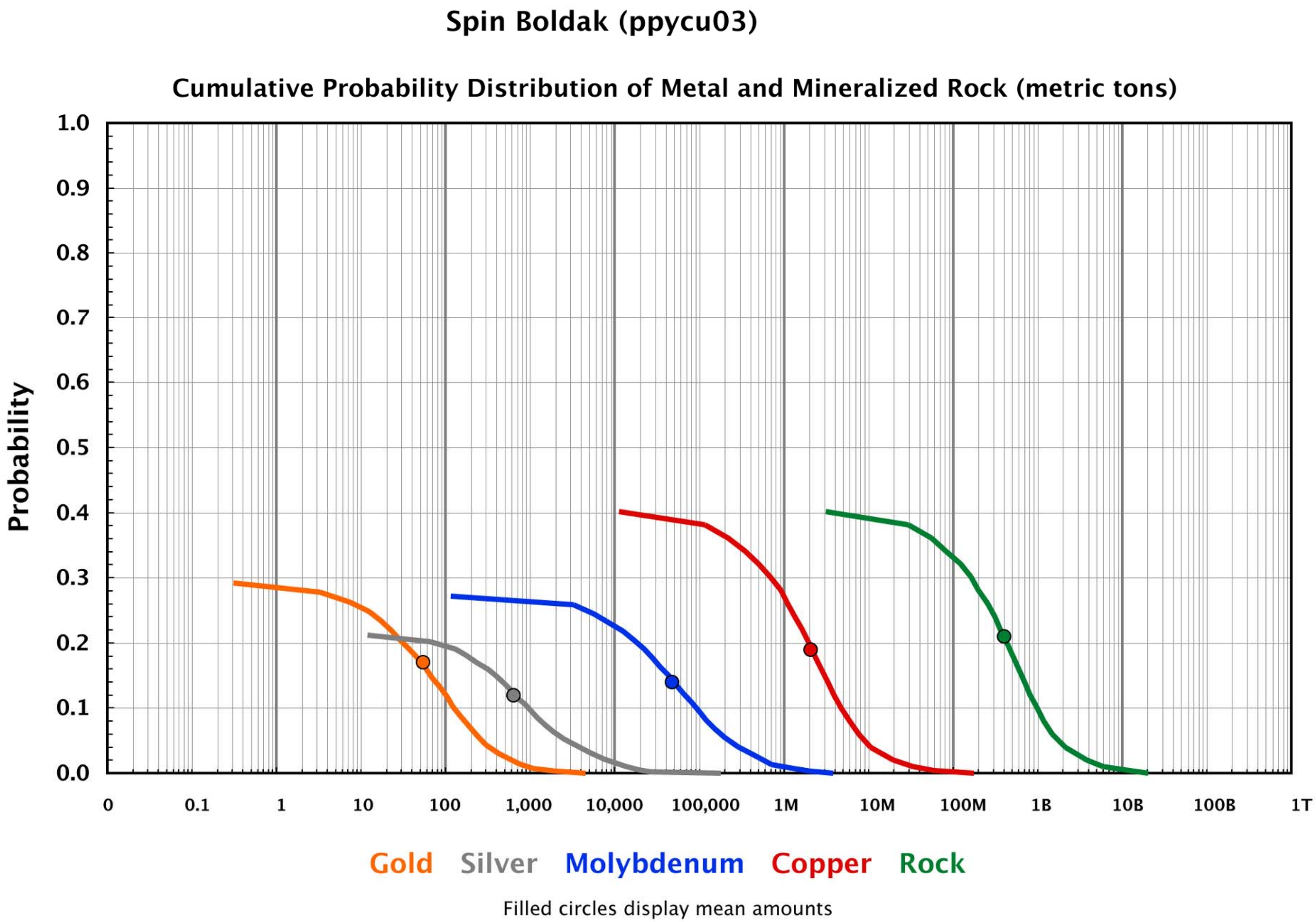

Figure 5.1-9 Cumulative distribution of estimated contained metal and mineralized rock in the Spin Boldak permissive tract (ppycu03).

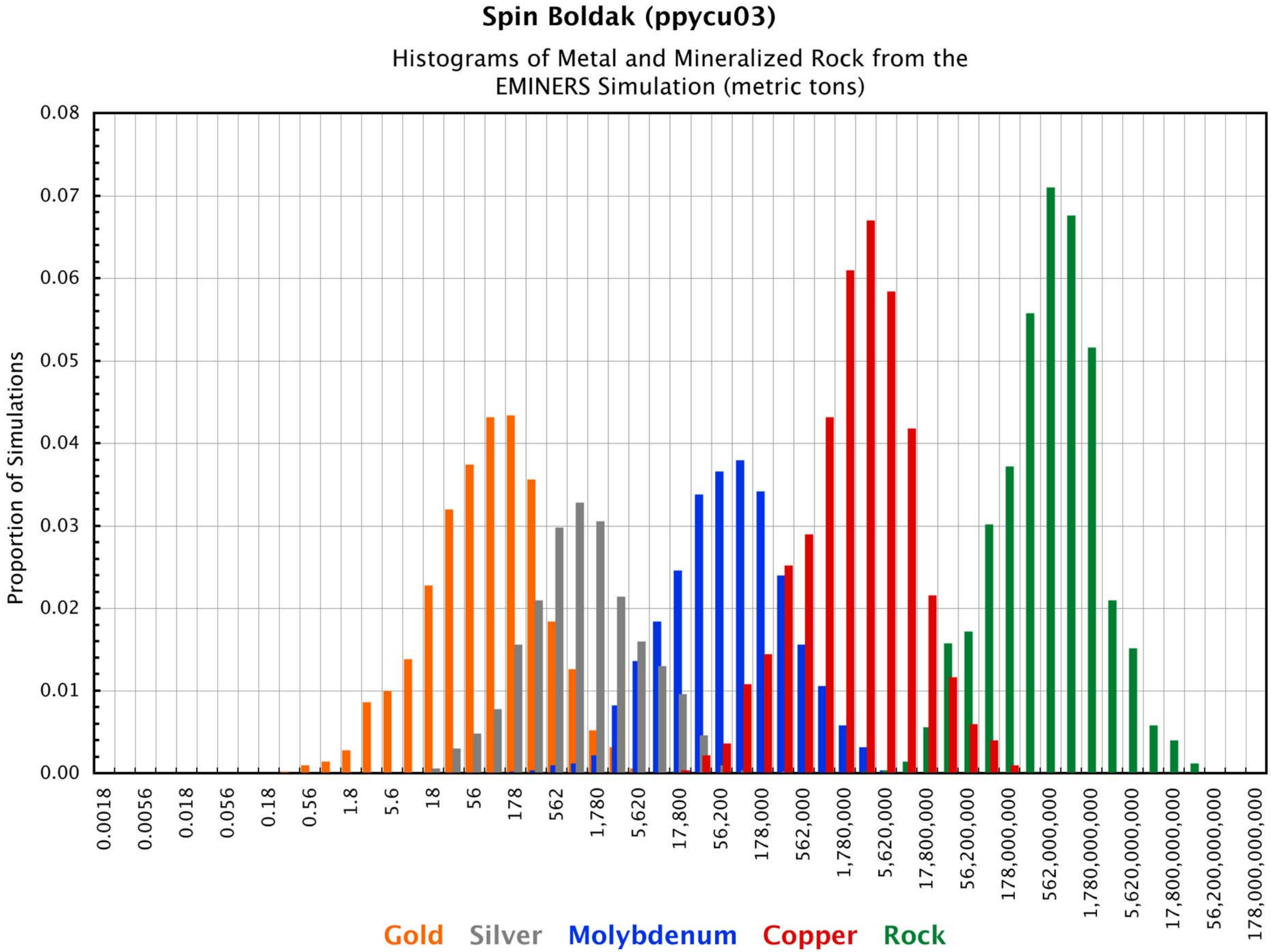

Figure 5.1-10. Histograms of estimated contained metal and mineralized rock in the Spin Boldak permissive tract (ppycu03).

Saindak north tract (ppycu04)

This tract, found in the southwestern corner of Afghanistan along the border with Pakistan, is permissive for porphyry copper and skarn copper deposits. There are no mineral deposits or prospects in the tract, however, the Saindak and Reko Diq porphyry copper deposits are located about 30 km to the south in Pakistan. The Saindak porphyry copper-gold deposit (440 million metric tons at 0.41 percent copper and 0.5 g/t gold) is an Early Miocene deposit associated with polymetallic veins and hosted in andesite porphyry, aplite, dacite, and diorite porphyry. Host rocks are andesite, agglomerate, limestone, mudstone, and sandstone. The largest deposit is Reqo Dik (807 million metric tons at 0.645 percent copper and 0.35 g/t gold), which is hosted in breccia, feldspar porphyry, and granodiorite porphyry. The Koh-i-Dalil prospect, adjacent to Reqo Dik, is apparently slightly younger (14.9 Ma) and was only recently discovered (Ahmad, 1992; Ahmad and others, 1986; Ahmed and others, 1972; Breitzman and others, 1983; Kazmi and Qasim, 1997; Leaman and Staude, 2003; Sillitoe and Khan, 1977; Sillitoe, 1978; Spector and others, 1987).

The tract is delineated entirely on the basis of the proximity of the known deposits in Pakistan and the presence of magnetic anomalies that indicate igneous rocks are present underneath the unconsolidated cover. More field investigation is needed to determine if the rocks associated with the magmatic arc in Pakistan extend north into Afghanistan. The location and limits of the tract are shown in figure 5.1-11.

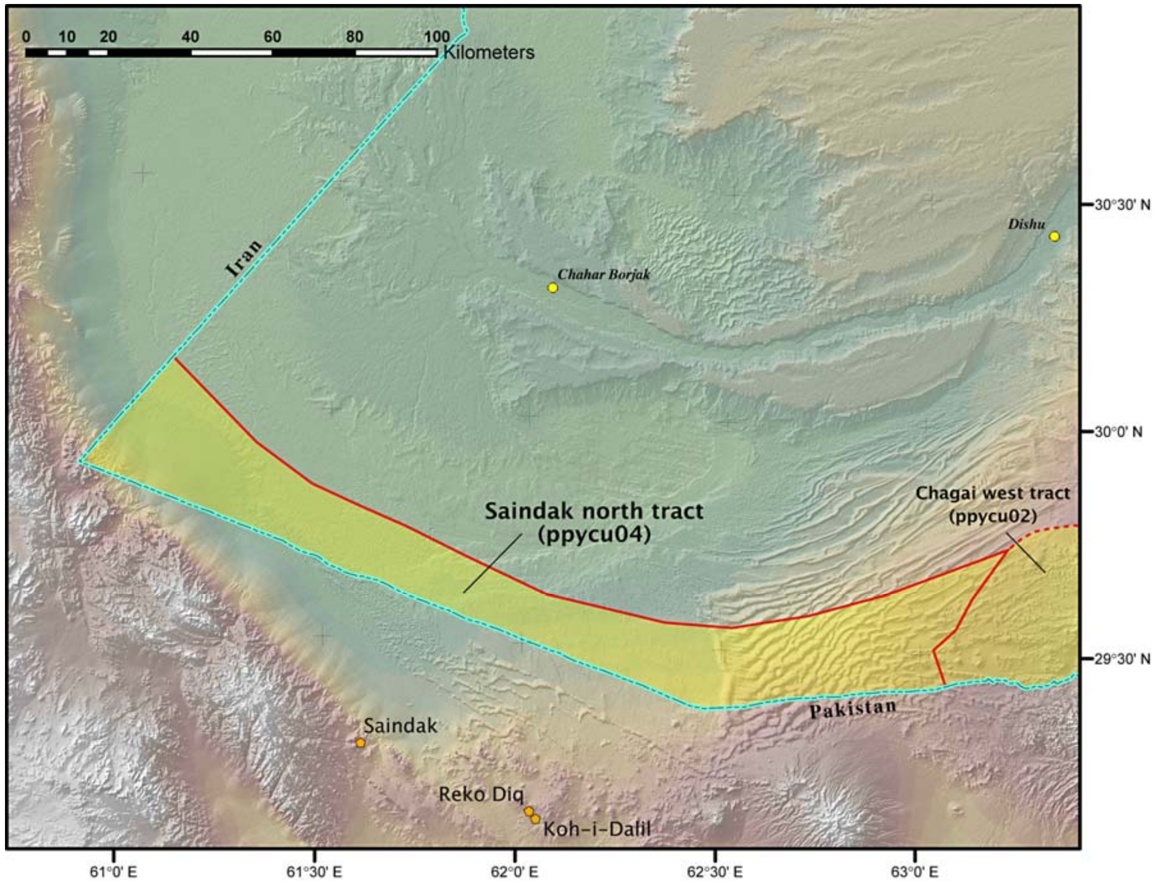

Figure 5.1-11. Map showing the Saindak north permissive tract (ppycu04) for undiscovered porphyry copper and skarn copper deposits. Nearby porphyry copper deposits and prospects in Pakistan shown as orange pentagons.

Information used to delineate this tract included the geologic map, aeromagnetic map, ASTER and LANDSAT imagery, and the mineral deposit database (Doebrich and Wahl, 2006; Sweeney and others, 2006; Mars and Rowan, 2007; Orris and Bliss, 2002).

The presence of two well-explored porphyry copper deposits nearby in Pakistan, along with three known porphyry copper prospects, is a strong positive indication. The geologic environment of those deposits and prospects can be extrapolated into the Saindak north area, although the tract area is completely covered by Quaternary deposits and bedrock is not exposed. In addition, the aeromagnetic signature is a favorable factor (Sweeney and others, 2006). However, there are no known prospects in the tract.

There is no known past exploration in this part of Afghanistan, and the U.S. Geological Survey Assessment Team did not visit the area. The area surrounding the Reqo Diq and Saindak deposits in Pakistan has been extensively explored since the 1970s. The information most needed to make a better assessment in this area is an additional processing and interpretation of the existing aeromagnetic data of Sweeney and others (2006). Any further exploration would require a site visit, detailed ground geophysical exploration, geochemical prospecting, and drilling.

The assessment team estimated that there is a 90 percent chance of 0 or more undiscovered porphyry copper deposits, a 50 percent chance of 0 or more, and a 10 percent chance of 3 or more (figs. 5.1-12, 5.1-13, and table 5.1-5). The amounts of contained metal that result from the Monte Carlo simulation based on this estimate are illustrated and summarized in table 5.1-5and figures 5.1-12 and 5.1-13 and summarized in table 5.1-5.

Table 5.1-5. Table summarizing statistical parameters for the assessment of the Saindak north permissive tract (ppycu04). The mean expected number of deposits is 0.9.

quantile	Cu	Mo	Au	Ag	Rock
0.95	0	0	0	0	0
0.90	0	0	0	0	0
0.50	0	0	0	0	0
0.10	7,700,000	170,000	180	1,800	1,500,000,000
0.05	16,000,000	350,000	360	4,600	3,000,000,000
mean	3,000,000	80,000	74	910	590,000,000
Probability of mean	0.22	0.16	0.18	0.14	0.23
Probability of zero	0.58	0.68	0.66	0.74	0.58

The Mark3 index is 84 – Porphyry Cu New General 2005. Amounts are in metric tons.

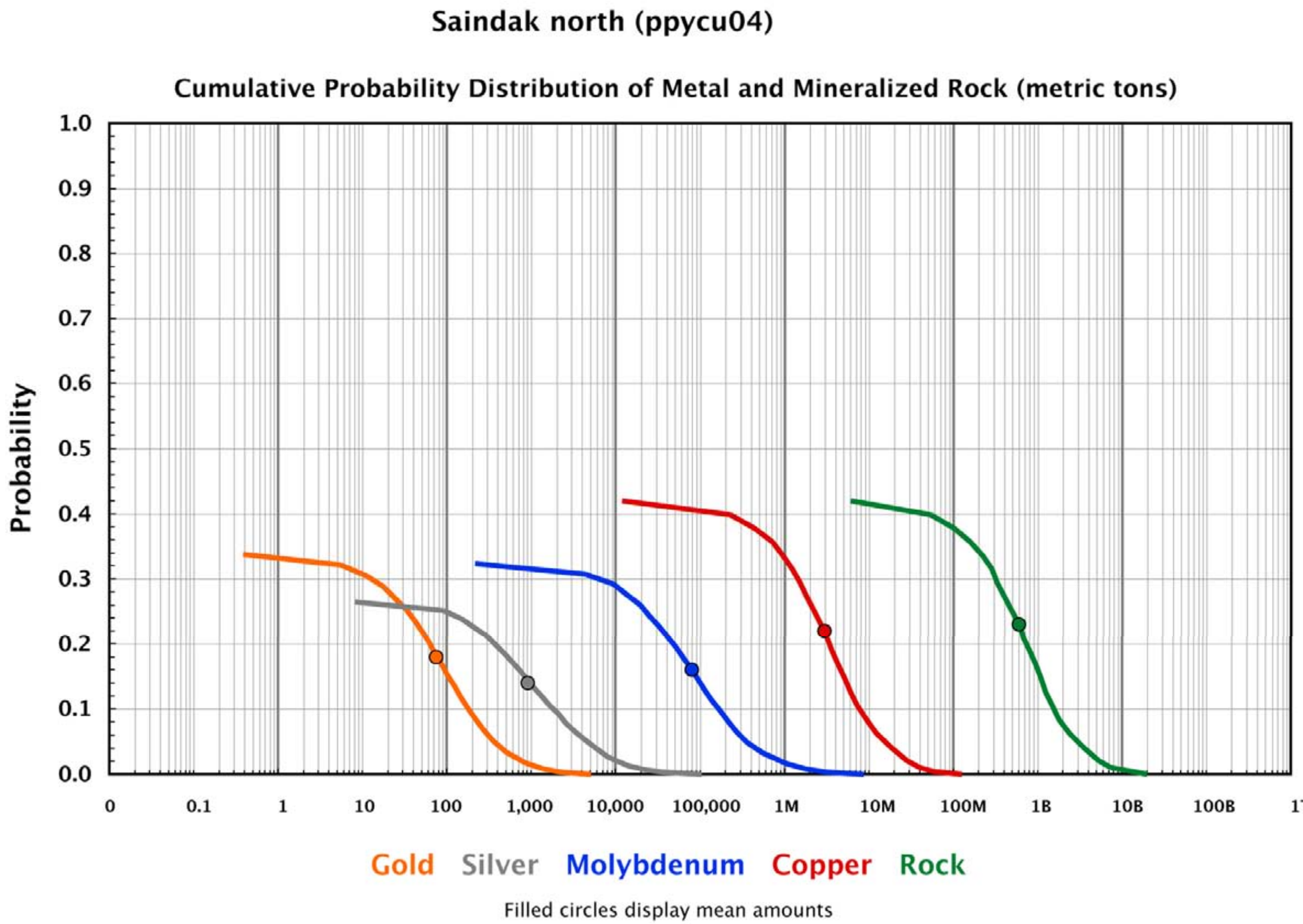

Figure 5.1-12. Cumulative distribution of estimated contained metal and mineralized rock in the Saindak north permissive tract (ppycu02).

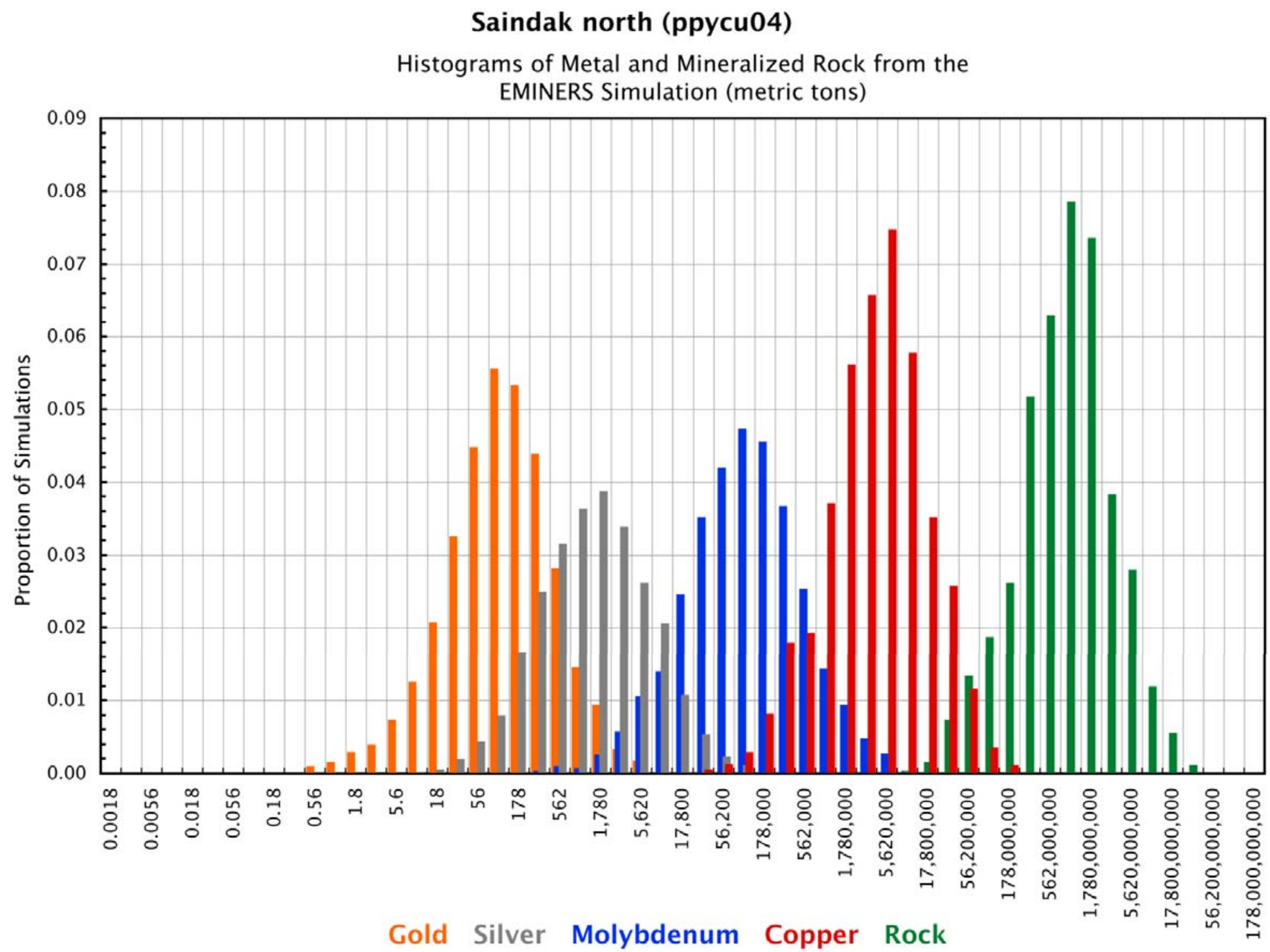

Figure 5.1-13. Histograms of estimated contained metal and mineralized rock in the Saindak north permissive tract (ppycu02).

Kundalyan-Zarkhashan tract (ppycu05)

This tract consists of two areas about 70 km apart along the southeast margin of the Arghandab plutonic belt (fig 1.0-3), where each area is centered on a group of extensively prospected gold- and copper-bearing skarn and vein occurrences. The tract is permissive for porphyry copper and skarn copper deposits. Although many of the plutons in the Arghandab plutonic belt appear to be Oligocene in age, the intrusive rocks in this tract are Cretaceous in age, and the mineral deposits also are assumed to be of that age.

The tract has two parts, the Zarkashan area to the north, and the Kundalyan area to the south (fig. 5.1-14). Their boundaries are based primarily on the distribution of map unit KP_1gbm (Doebrich and Wall, 2006), and the associated skarn copper and polymetallic vein prospects. The rocks of this map unit are alkaline, consisting of gabbro, monzonite, diorite, granite, granosyenite, and syenite. The rocks are also relatively oxidized, and the tract boundaries were refined using the aeromagnetic data of Sweeney and others (2006), which show strong positive magnetic anomalies over both intrusive complexes. The western boundary is the adjacent Tertiary-age permissive tract ppycu06. This adjacent tract has a different aeromagnetic signature and is dominated by younger (Oligocene?) intrusions.

Information used to delineate this tract included the geologic map, aeromagnetic map, ASTER and LANDSAT imagery, and the mineral deposit database (Doebrich and Wahl, 2006; Sweeney and others, 2006; Mars and Rowan, 2007; Orris and Bliss, 2002).

Favorable areas (see section 1.0) are identified in each of the tract areas. Two parts of the Zarkashan area are considered favorable (fig. 5.1-15). Both these areas contain known and partially explored prospects with potentially important gold contents (see section 5.2). Development of these gold deposits could be accomplished in a shorter time frame than porphyry copper prospects.

Along the west margin of the tract, a linear alignment of skarn copper and unclassified gold occurrences is associated with Cretaceous diorite dikes and small intrusive bodies. These deposits are all hosted in Upper Permian carbonate rocks. The skarn occurrences are gold-bearing and select samples contain as much as 35 g/t gold (Khasanov and others, 1967; Meshcheryakov and others, 1970; Douvgal and others, 1971). Gold-bearing veins also are present.

In the central part of the Zarkashan area, the Zarkashan gold-bearing skarn copper occurrence, and a number of other skarn occurrences form a north-trending band about 5 km wide along the west margin of the major pluton in the area (fig. 5.1-15). The host country rocks in this favorable area are Triassic carbonate rocks. The copper skarns (Zarkashan, Guyakhel, Sufi-Kademi) are all gold-bearing. Several other occurrences in the area (Kareztu tin, Mirzaka, Syaghar, and Maghn) are classified as tin skarn, and cassiterite is the most abundant ore mineral, but they have potentially important copper contents (Abdullah and others, 1977; Doebrich and Wall, 2006).

To the south, in the Kundalyan part of the tract, a large area surrounding the alkaline Cretaceous rocks is considered favorable (fig. 5.1-16). Here, as in the Zarkashan area, a prominent magnetic high underlies the plutonic complex, and known deposits and prospects are clustered near the plutonic rocks.

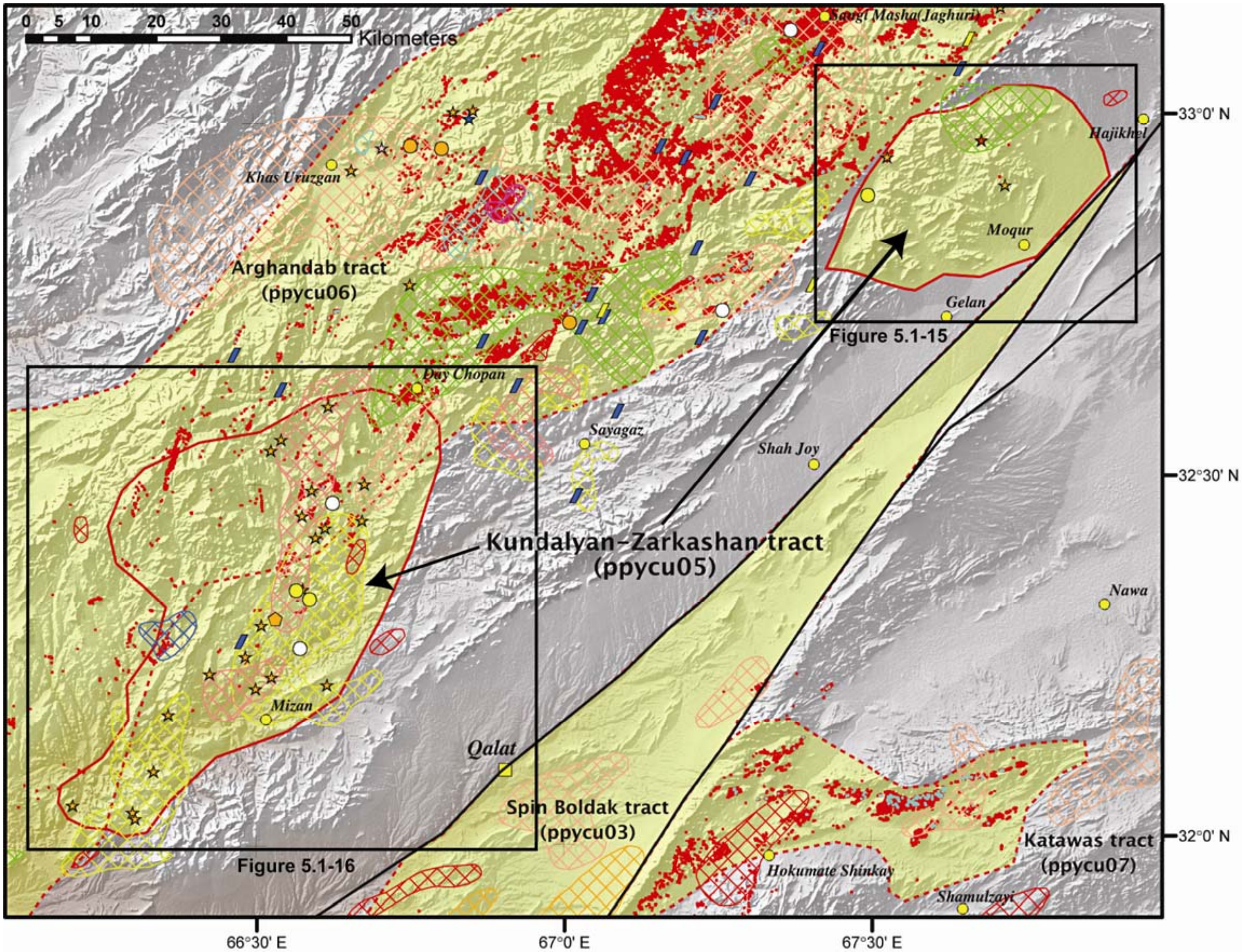

Figure 5.1-14. Map showing the Kundalyan-Zarkashan permissive tract (ppycu05) for undiscovered porphyry copper and skarn copper deposits. Hydrothermal alteration from ASTER imagery is shown in red (phyllic) and turquoise (argillic). Crosshatch indicates mineral halos: blue – lead-zinc; red – mercury; orange – copper; yellow – gold; turquoise – bismuth; flesh – tungsten; green – tin. Mineral occurrence symbols from Doebrich and Wahl (2006).

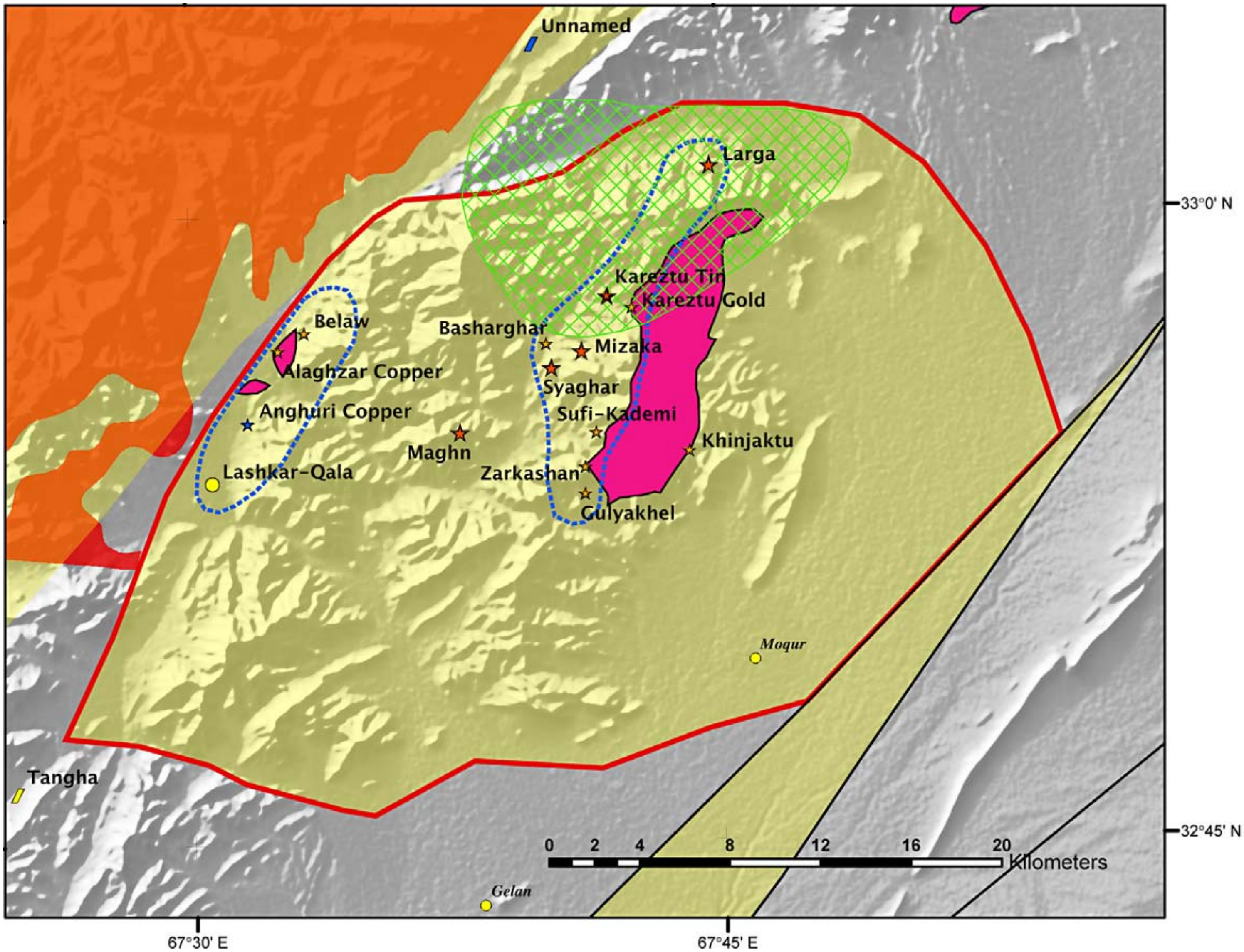

Figure 5.1-15. Map of the Zarkashan part of the Kundalyan-Zarkashan porphyry copper tract. Alkaline Cretaceous intrusive rocks are shown in pink (map unit KP_1gbm). Green crosshatch is a tin mineral halo. Blue dashed line outlines the most favorable part of the tract.

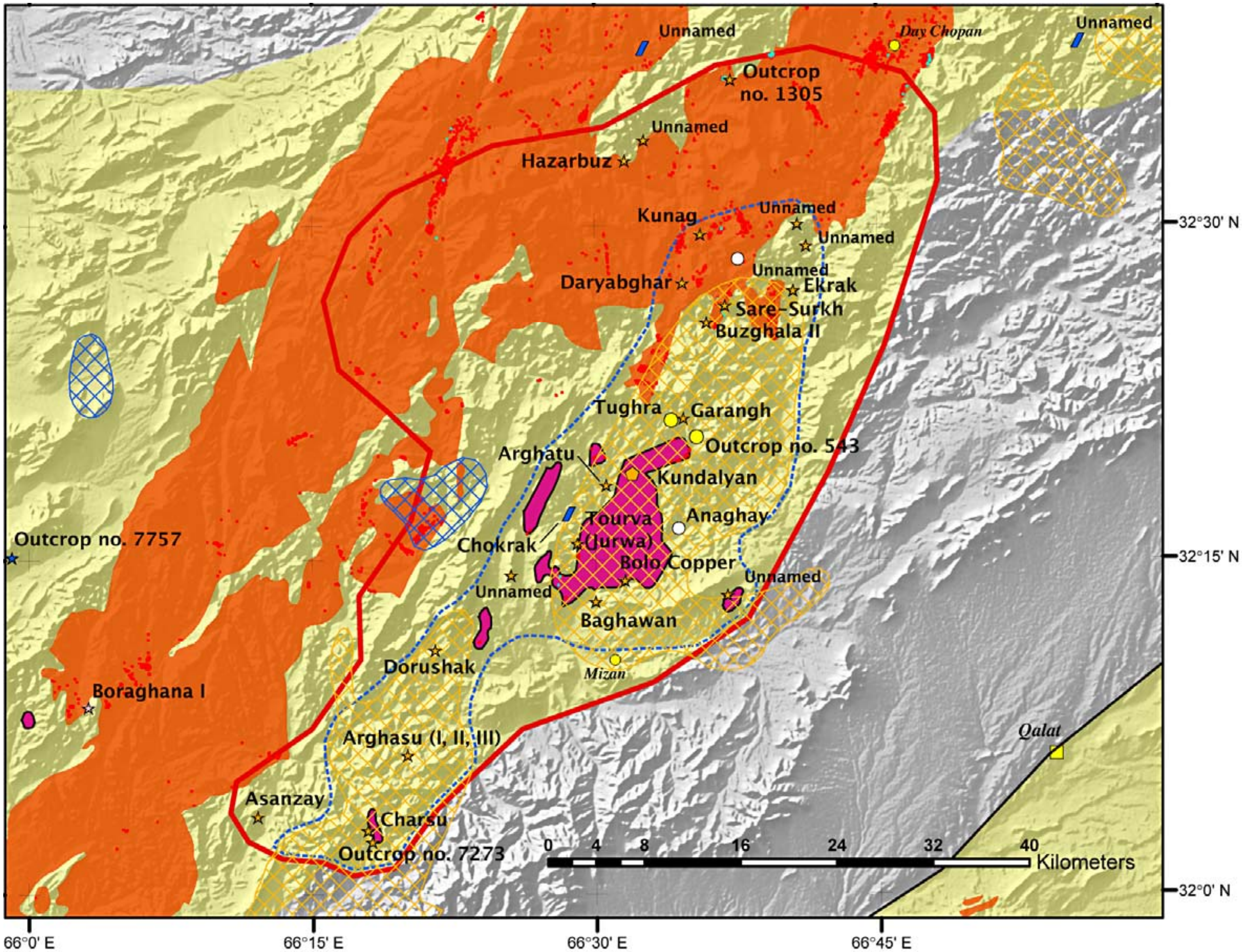

Figure 5.1-16. Map of the Kundalyan part of the Kundalyan-Zarkashan porphyry copper permissive tract. Exposed alkaline Cretaceous intrusive rocks are highlighted in pink (map unit KP_1gbm). Orange area contains rocks of the main Oligocene Arghandab Igneous belt. Blue crosshatch is a tin mineral halo; gold crosshatch is a gold mineral halo. Blue dashed line outlines the most favorable part of the tract.

In the central part of the area the Kundalyan prospect (fig. 5.1-16) (which includes sites known as Kaptarghor and Surkh-i-Shela) was classified as a porphyry copper prospect at least 30 years ago (Abdullah and others, 1977). There are measured resources, although they are mostly in skarn-type mineralized rock: 21,400 t Cu, 1.6 t Au, and 133.4 t Mo at average of 1.21% Cu (0.66 to 4.03%), 0.9 g/t Au (0.3 to 3.1 g/t), 0.14% Mo, up to 10 g/t Ag and 0.03% Bi (Singer and others, 2005). Outside the skarn areas, argillic hydrothermal alteration is reported (Abdullah and others, 1977).

Both northeast and southwest of Kundalyan, a number of gold-bearing copper skarn prospects as well as smaller outcrops of alkaline diorite help further define the favorable area. Much of the area also corresponds to a gold geochemical halo (fig. 5.1-16).

The Kundalyan and Zarkashan areas were explored by trenches, tunnels, and diamond drilling by Soviet and Afghanistan geologists. The U.S. Geological Survey Assessment Team paid a brief (10 minute) visit to one dump that contained chalcopyrite at Kundalyan and flew over the Zarkashan area (figs. 5.1-17, 5.1-18). Small past production of gold and base metals also are reported in the Garangh copper-gold skarn area (Douvgal and others, 1971). The Tughra gold (near Kundalyan) and Sufi Kademi (near Zarkashan) mineral occurrences are reported as ancient workings. Drilling has taken place at the Dynamitic gold occurrence (Abdullah and others, 1977).

Figure 5.1-17. Aerial view of Kundalyan area. Barren subdued slopes are map unit KP_1gbm.

Figure 5.1-18. Evidence of mineral exploration in the Kundalyan area. A sample from the dump in the foreground contains chalcopyrite.

The presence of relatively well explored gold-and copper-bearing prospects (Kundalyan and Zarkashan areas) is the most important positive indicator for this tract. The petrologic characteristics of the associated intrusive rocks and the available assays suggest that any porphyry copper deposits discovered here might be gold-bearing. On the other hand, the exploration conducted prior to 1979 did not reveal an unequivocal porphyry copper deposit.

This permissive tract requires field examination and detailed mapping to determine if there is porphyry-style mineralized rock in addition to the skarn deposits. At the same time, further exploration of the skarns could result in defining mineralization adequate for development of a viable mine. At least several man-months in each of the two parts of the tract would be needed. The magnetite-rich skarns would respond well to ground magnetometer surveys. In addition, the mineralization age should be determined, to confirm which mineralized systems are related to the Cretaceous plutons and which are related to Oligocene plutons exposed in the area.

For the permissive areas in the Kundalyan and Zarkashan tracts, the assessment team estimated that there is a 90 percent chance of 0 or more undiscovered porphyry copper deposits, a 50 percent chance of 1 or more, and a 10 percent chance of 2 or more (table 5.1-6; figs. 5.1-19, 5.1-20,). The amounts of contained metal that result from the Monte Carlo simulation based on this estimate are illustrated and summarized in table 5.1-6 and figures 5.1-19 and 5.1-20. This is a relatively optimistic estimate for a relatively small area.

Table 5.1-6. Table summarizing statistical parameters for the assessment of the Kundalyan-Zarkashan permissive tract (ppycu05). The mean expected number of deposits is 1.0.

quantile	Cu	Mo	Au	Ag	Rock
0.95	0	0	0	0	0
0.90	0	0	0	0	0
0.50	710,000	0	0	0	170,000,000
0.10	7,700,000	170,000	188	2,100	1,500,000,000
0.05	15,000,000	370,000	350	5,100	2,900,000,000
mean	3,300,000	79,000	80	1,100	650,000,000
Probability of mean	0.23	0.18	0.20	0.15	0.24
Probability of zero	0.31	0.55	0.52	0.65	0.31

The Mark3 index is 84 – Porphyry Cu New General 2005. Amounts are in metric tons.

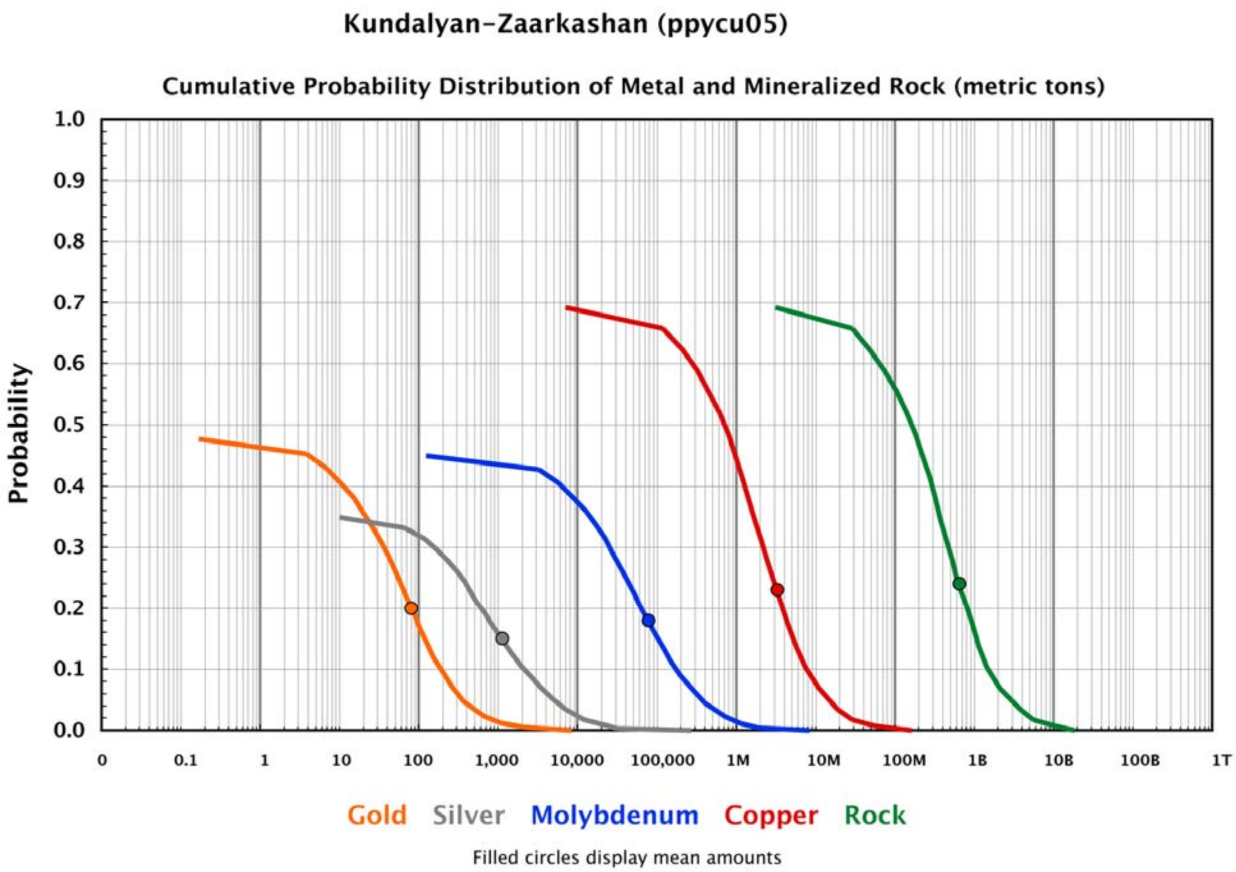

Figure 5.1-19. Cumulative distribution of estimated contained metal and mineralized rock in the Kundalyan-Zarkashan permissive tract (ppycu05).

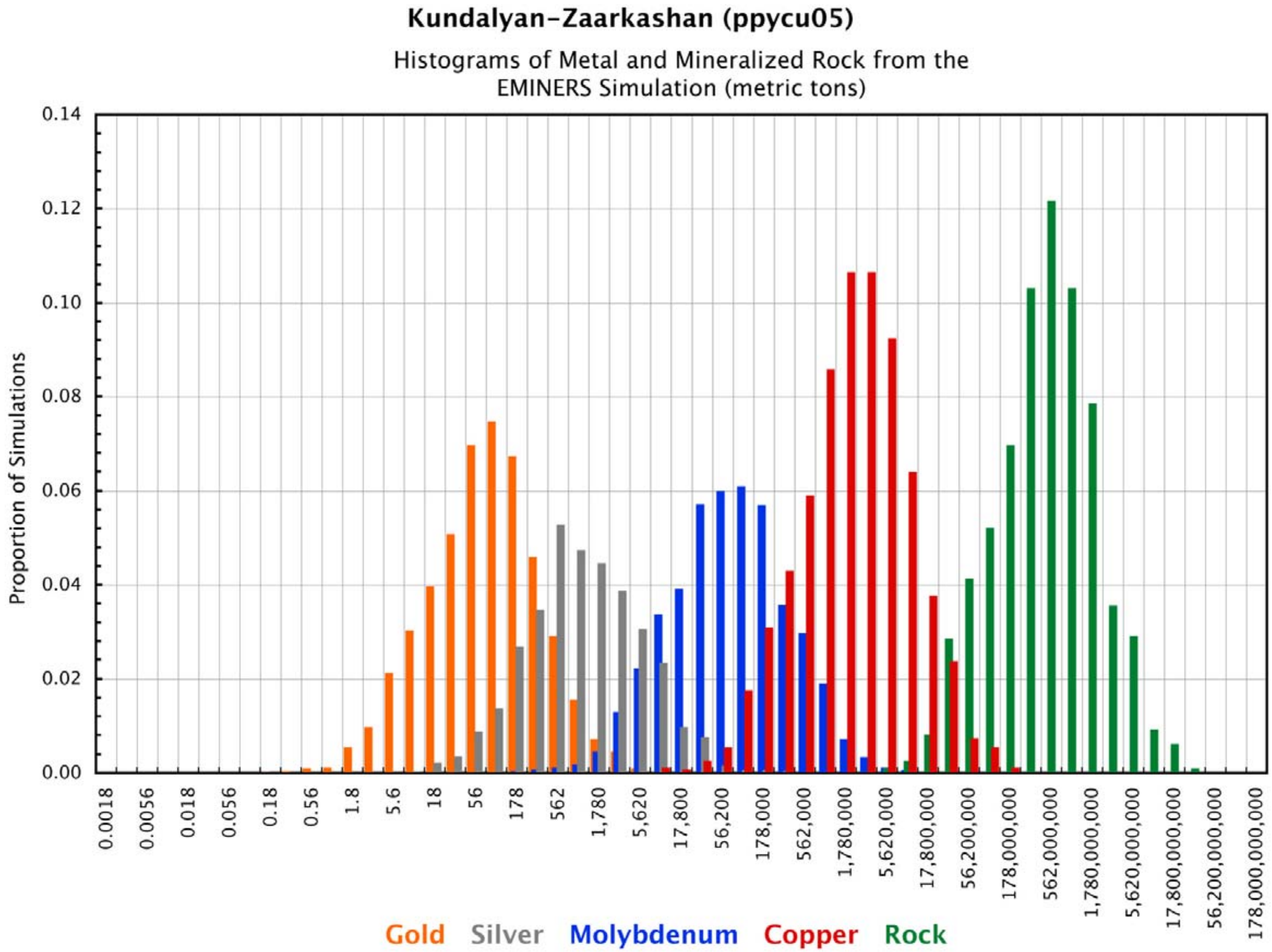

Figure 5.1-20. Histograms of estimated contained metal and mineralized rock in the Kundalyan-Zarkashan permissive tract (ppycu05).

Arghandab tract (ppycu06)

This tract is in the central mountains of Afghanistan and is permissive for undiscovered porphyry copper and skarn copper deposits. There are a large number of mineral occurrences and prospects within the area, which encompasses the Arghandab plutonic belt of Debon and others (1987). The most common mineral deposit type is polymetallic veins, but there are also numerous skarn occurrences of copper, zinc-lead, iron, and tungsten, as well as precious-metal-bearing vein occurrences.

The Arghandab plutonic belt is nominally Oligocene in age according to the map of Doebrich and Wall (2006) which is based on Chmyriov and Mirzad (1972). However, Debon and others (1987) reported numerous Cretaceous ages from the area, as well as at least one Jurassic age. They found that the majority of the plutonic rocks are intermediate to felsic in composition (mostly granodiorite, quartz monzonite, and granite) and are subalkaline to calc-alkaline. Most are metaluminous, with a few mildly peraluminous rocks. Preliminary aeromagnetic maps (Sweeney and others, 2006) indicate that the magnetic anomalies associated with these rocks are of lesser magnitude than those in the Kundalyan and Zarkashan areas (previous section) and those associated with late Tertiary rocks of southwesternmost Afghanistan, which are associated with porphyry copper deposits in Pakistan.

The tract is delineated on the basis of the outcrop area of this large composite batholith, combined with the distribution of the known mineral occurrences that are indicative of an environment suitable for porphyry copper deposits. Aeromagnetic data (Sweeney and others, 2006) help to indicate the extent of covered intrusive rocks and were used to refine the tract boundaries. Processed ASTER imagery for this area (Mars and Rowan, 2007) shows widespread areas of phyllic and argillic alteration. The northeastern boundary of the tract is bounded by a large Quaternary graben filled with young alkaline volcanic rocks of the Dacht-e Nawar field (Bordet and others, 1984). The location and limits of the tract are shown in figure 5.1-21. Lacking more detailed information, it is possible to suggest that areas exhibiting clustering of known prospects combined with evidence of hydrothermal alteration are the most favorable areas for undiscovered porphyry copper deposits in the tract. Another indicator of favorability is the distribution of mineral halos within the tract (fig. 5.1-21).

The southernmost area that shows these features is the coincidence of five polymetallic vein occurences that form a crude northwest-trending belt about 40 km north of Kandahar. The only named prospect is Zanda I, and it and the other unnamed prospects are small, but some do contain gold, and they are aligned with an adjacent arcuate belt of phyllic alteration. About 25 km to the north, both the Chinar and Darra-i-Nur skarn occurrences have had minor production in the past (Kabakov, 1973; Efimenko and others, 1973).

Farther northeast (about 130 km northeast of Kandahar), the Ludin polymetallic vein prospect has yielded gold values as high as 13 g/t gold (Plotnikov and others, 1968), and several copper-rich polymetallic veins are nearby.

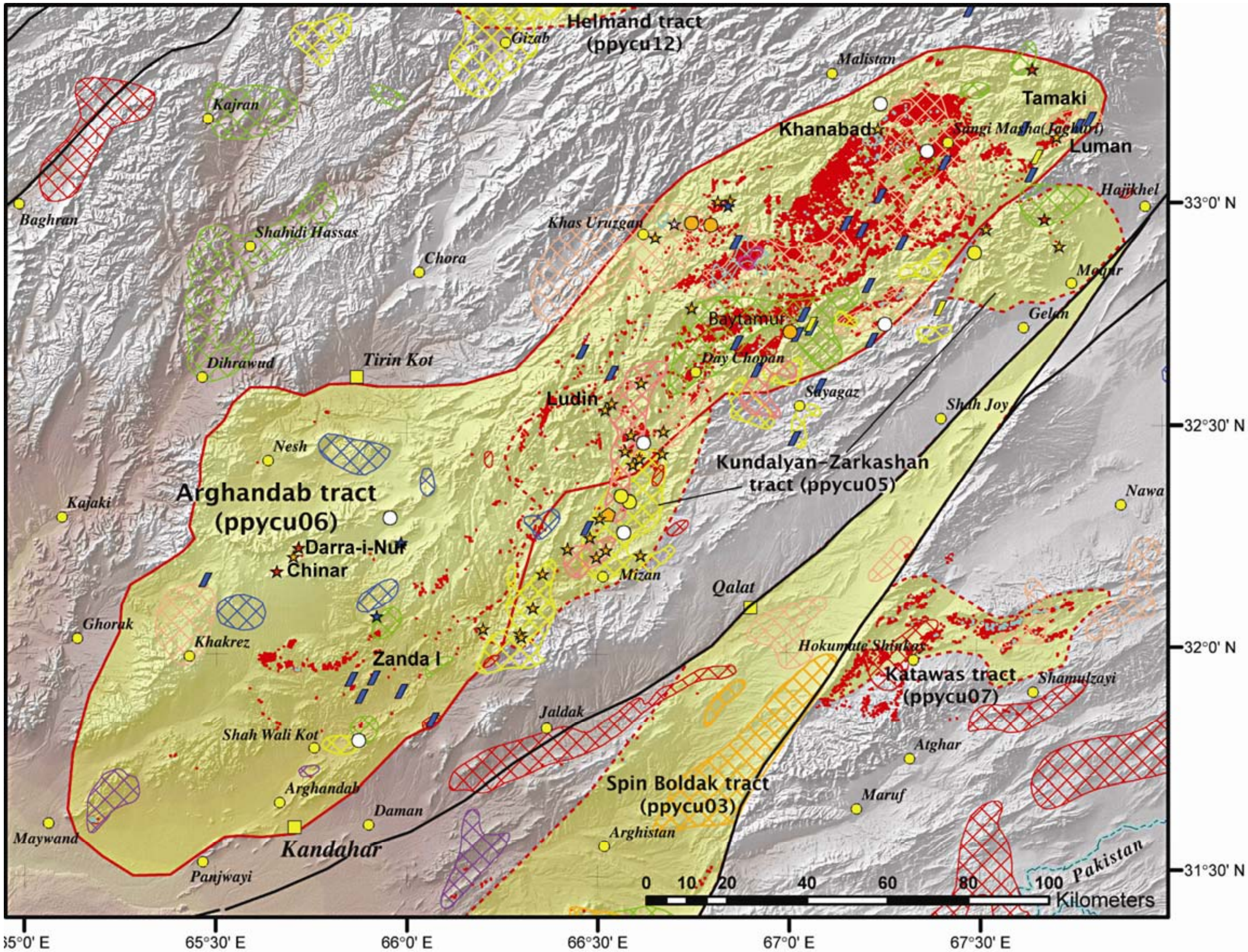

Figure 5.1-21. Map showing the Argandhab permissive tract (ppycu06) for undiscovered porphyry copper deposits and skarn copper deposits. Hydrothermal alteration from ASTER imagery is shown in red (phyllic) and turquoise (argillic). Crosshatch indicates mineral halos: blue – lead-zinc; red – mercury; orange – copper; yellow – gold; turquoise – bismuth; flesh – tungsten; green – tin; violet - chromium.

The northeastern half of the tract is characterized by much more widespread hydrothermal alteration than the southwestern half (fig. 5.1-20) and is probably the most favorable part of the tract. At the southwest end of this area of alteration, the Baytamur area has been described as being the possible site of an exposed large low-grade deposit of tungsten, beryllium, and possibly other rare metals (fig. 4.1.4). Some important mineral prospects in this northeastern favorable part of the tract include the Khanabad copper skarn (115 km west-southwest of Ghazni), which has yielded samples with 2–6 g/t gold (Abdullah and others, 1977), and the Tamaki and Luman gold occurrences (about 75 km west-southwest of Ghazni), polymetallic vein prospects with potentially significant gold contents (Douvgal and others, 1971; Abdullah and others, 1977.)

The information that is most needed to improve the assessment for this tract is intermediate-scale (1:100,000) geologic mapping, along with site visits and geochemical sampling of the major prospects.

The presence of a large number of mineral prospects and occurrences throughout the tract suggests that undiscovered porphyry copper deposits could exist here. The widespread hydrothermal alteration is also a positive factor, although the patterns of alteration suggest that much of it is related to regional fractures, rather than being closely correlated to the distribution of the mineral prospects. The composition of many of the rocks is not highly favorable. There are many peraluminous rocks, and a relative paucity of mafic-intermediate rocks (diorites). Both of these features are atypical of porphyry-bearing regions. Also, the relatively large size of individual plutons suggests that exposure levels are primarily mesozonal and that much of the area has been relatively deeply eroded. Much of the porphyry environment that could have been present may have been removed by erosion.

There has been only limited detailed exploration in the past. Many prospects and occurrences are documented, but few have been fully explored. Much of the area is remote and difficult to access. The U.S. Geological Survey team flew over part of this area, but was unable to visit any sites on the ground.

The assessment team estimated that there is a 90 percent chance of 0 or more undiscovered porphyry copper deposits, a 50 percent chance of 0 or more, and a 10 percent chance of 2 or more (figs. 5.1-22, 5.1-23, table 5.1-7). The amounts of contained metal that result from the Monte Carlo simulation based on this estimate are illustrated and summarized in table 5.1-7 and figures 5.1-22 and 5.1-23.

Table 5.1-7. Table summarizing statistical parameters for the assessment of the Argandhab permissive tract (ppycu06). The mean expected number of deposits is 0.6.

quantile	Cu	Mo	Au	Ag	Rock
0.95	0	0	0	0	0
0.90	0	0	0	0	0
0.50	0	0	0	0	0
0.10	5,100,000	94,000	118	1,000	1,000,000,000
0.05	10,000,000	230,000	250	3,000	1,900,000,000
mean	2,200,000	61,000	51	640	420,000,000
Probability of mean	0.18	0.13	0.16	0.12	0.20
Probability of zero	0.60	0.73	0.71	0.79	0.60

The Mark3 index is 84 – Porphyry Cu New General 2005. Amounts are in metric tons.

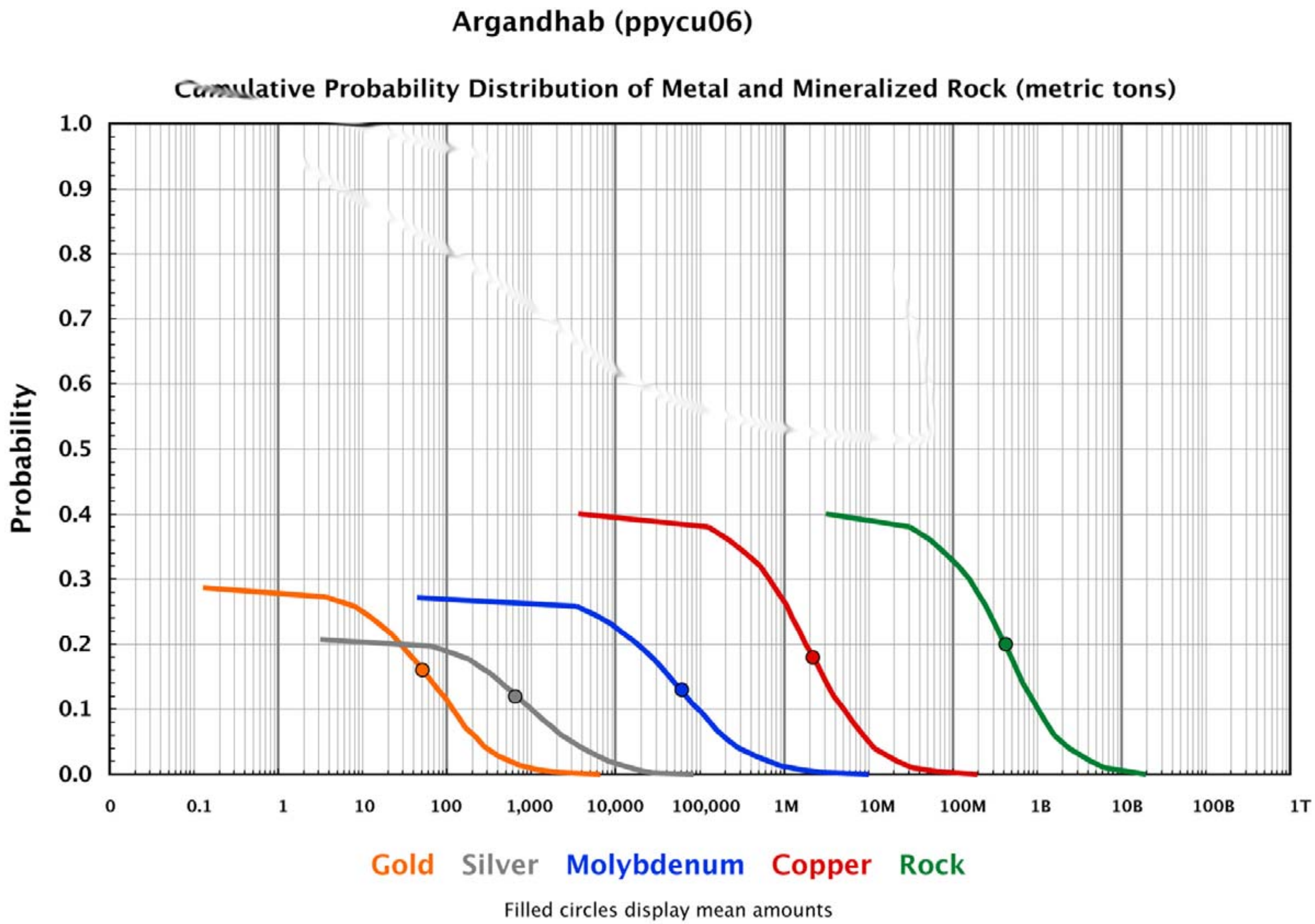

Figure 5.1-22. Cumulative distribution of estimated contained metal and mineralized rock in the Argandhab permissive tract (ppycu06).

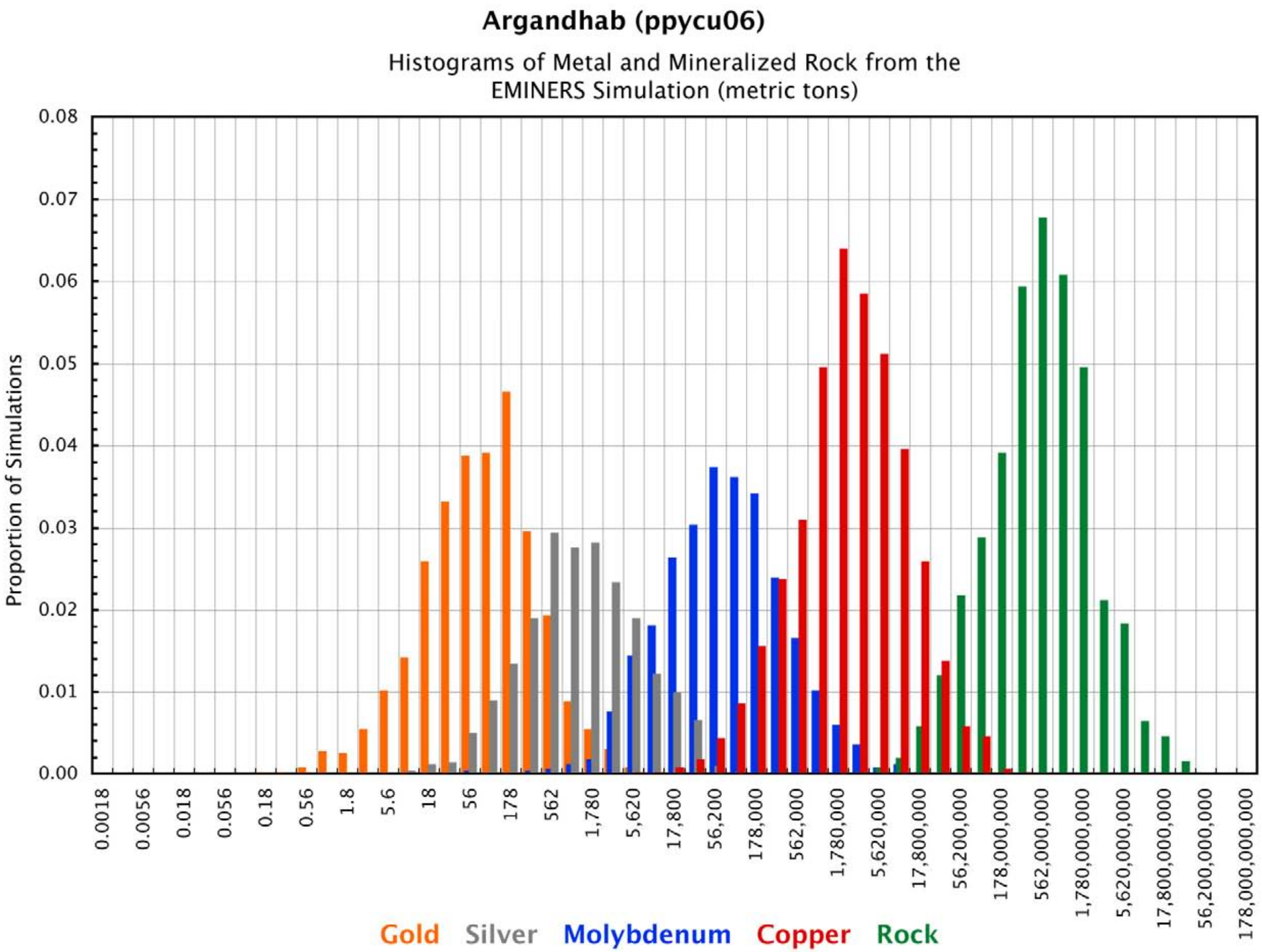

Figure 5.1-23. Histograms of estimated contained metal and mineralized rock in the Argandhab permissive tract (ppycu06).

Katawaz tract (ppycu07)

This tract is southeast of the central mountains of Afghanistan in the Belutchan tectonic domain and is permissive for undiscovered porphyry copper and skarn copper deposits. There are no known mineral deposits or prospects within the area; the area was not assigned to a plutonic belt by Debon and others (1987).

The map of Doebrich and Wall (2006), which is based on Chmyriov and Mirzad (1972), designates the intrusive rocks in this area as map unit N_1dig, which is Miocene in age, and is characterized by diorite, granodiorite, monzonite, syenite, and nepheline syenite.

The tract is delineated primarily on the basis of the outcrop area of these Miocene intrusive rocks, and also on the widespread phyllic and lesser argillic alteration mapped in this area by Mars and Rowan (2007). These alteration patterns are linear and correspond spatially with the distribution of the intrusive rocks (fig. 5.1-23). The intrusive rocks have no apparent magnetic signature (Sweeney and others, 2006) and may be ilmenite-series granitoids. The location and limits of the tract are shown in figure 5.1-24.

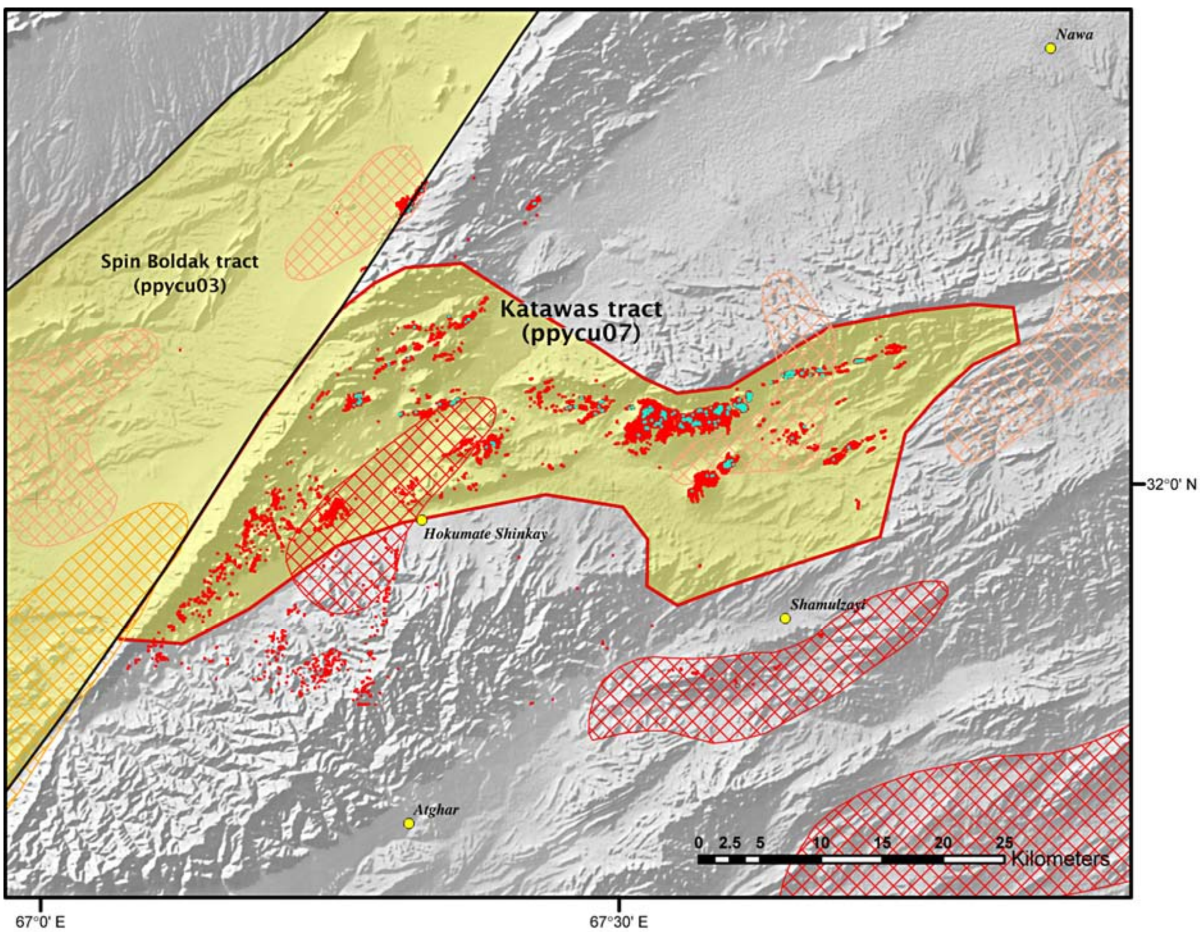

Figure 5.1-24. Map showing the Katawaz permissive tract (ppycu07) for undiscovered porphyry copper and skarn copper deposits. Hydrothermal alteration from ASTER imagery is shown in red (phyllic) and turquoise (argillic). Crosshatch indicates mineral halos: red – mercury; orange – copper; flesh – tungsten. Miocene intrusive rocks not shown; see fig. 6.1-17.

The information that is most needed to improve the assessment of this tract is intermediate-scale (1:100,000 and 1:25,000) geologic mapping and geochemical sampling in order to determine if metals are associated with the widespread hydrothermal alteration. Both would require site visits.

The areas of intense hydrothermal alteration indicated by the ASTER data are typical of regions that contain porphyry copper deposits. It is not known whether the lack of known mineral prospects is due to a lack of exploration. There is no known exploration and the U.S. Geological Survey assessment team did not visit the area.

The assessment team estimated that there is a 90 percent chance of 0 or more undiscovered porphyry copper deposits, a 50 percent chance of 0 or more, and a 10 percent chance of 2 or more (table 5.1-8; figs. 5.1-25, 5.1-26). The amounts of contained metal that result from the Monte Carlo simulation based on this estimate are illustrated and summarized in table 5.1-8 and figures 5.1-25 and 5.1-26.

Table 5.1-8. Table summarizing statistical parameters for the assessment of the Katawaz permissive tract (ppycu07). The mean expected number of deposits is 0.6.

quantile	Cu	Mo	Au	Ag	Rock
0.95	0	0	0	0	0
0.90	0	0	0	0	0
0.50	0	0	0	0	0
0.10	4,900,000	87,000	112	970	1,000,000,000
0.05	9,500,000	230,000	250	2,800	1,800,000,000
mean	2,000,000	53,000	48	590	390,000,000
Probability of mean	0.19	0.13	0.17	0.13	0.21
Probability of zero	0.60	0.73	0.71	0.79	0.60

The Mark3 index is 84 – Porphyry Cu New General 2005. Amounts are in metric tons.

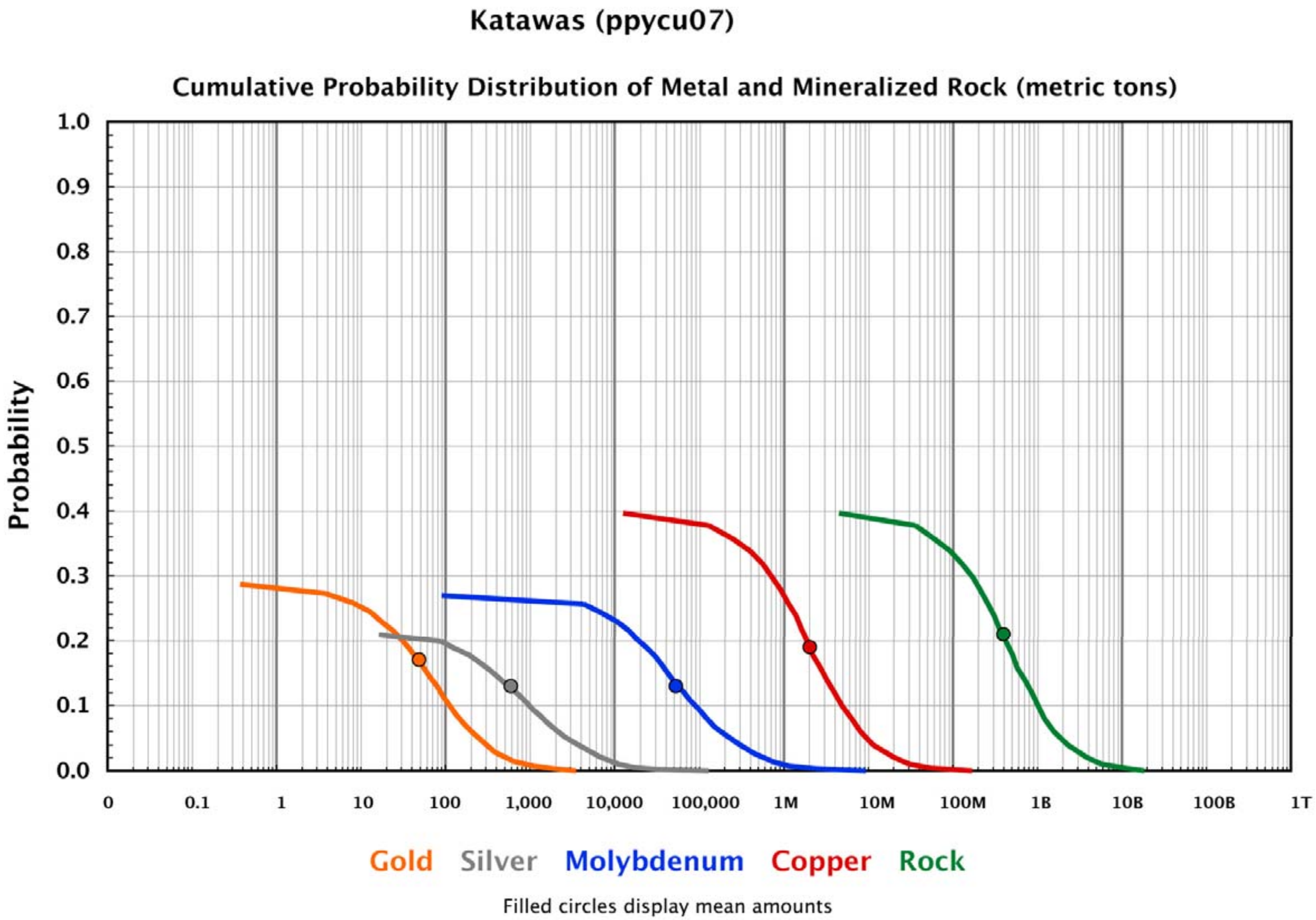

Figure 5.1-25. Cumulative distribution of estimated contained metal and mineralized rock in the Katawaz permissive tract (ppycu07).

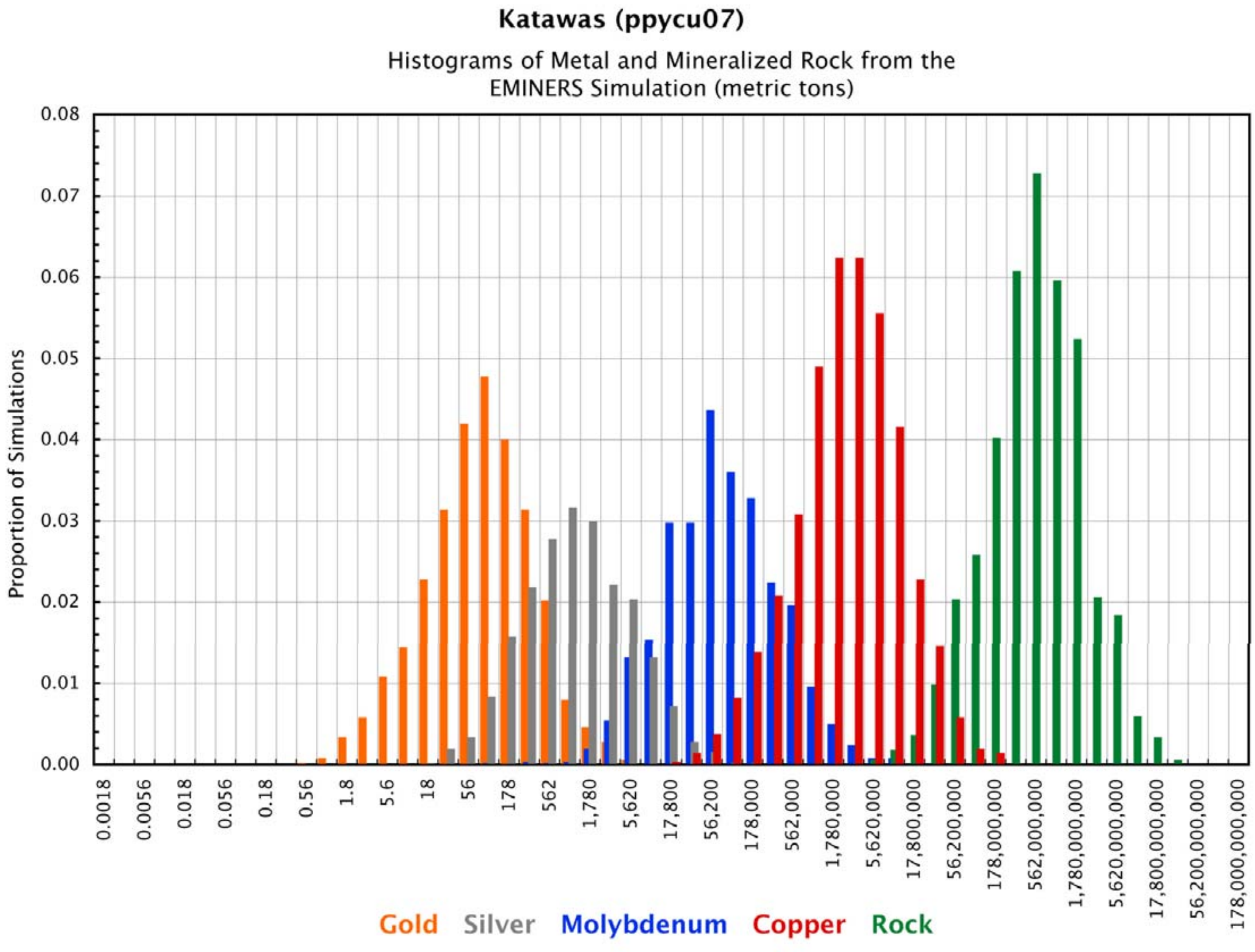

Figure 5.1-26. Histograms of estimated contained metal and mineralized rock in the Katawaz permissive tract (ppycu07).

Feroz Koh tract (ppycu08)

This tract is in the northern part of Afghanistan north of the Herat fault and is permissive for porphyry copper and skarn copper deposits. There are only a few mineral occurrences in the area, one of which is classified as a skarn copper occurrence. The intrusive rocks in this area were assigned to the Feroz Koh plutonic belt by Debon and others (1987).

The map of Doebrich and Wall (2006), which is based on Chmyriov and Mirzad (1972), designates the intrusive rocks in this area as the same map unit, N_1dig of Doebrich and Wahl (2006), as the intrusive rocks in the Katawaz tract (ppycu07). These rocks are designated to be Miocene in age, and consist of diorite, granodiorite, monzonite, syenite, and nepheline syenite. Of two radiometric dates for these rocks reported by Debon and others (1987), one is Miocene and one is Oligocene. The rocks primarily intrude Upper Cretaceous and younger sedimentary rocks.

The tract is delineated primarily on the basis of the outcrop area of the Miocene intrusive rocks, and includes the few mineral prospects nearby. No ASTER studies have been made in this area. The intrusive rocks have no apparent magnetic signature (Sweeney and others, 2006) and may be ilmenite-series granitoids. The location and limits of the tract are shown in figure 5.1-27.

The Ahankashan copper-gold skarn, near the center of the tract (fig. 5.1-27) is proximal to a granodiorite porphyry body that intrudes Lower Triassic and Upper Cretaceous calcareous sedimentary rocks producing magnetite-hematite and epidote-garnet-magnetite skarns. The mineralized areas are between 100 and 200 m long and 10 to 15 m wide, and contain disseminations of chalcopyrite, covellite, and chalcocite. Copper contents of as much as 3.6 wt. percent and gold contents of 0.2 to 0.5 g/t, with trace amounts of lead, zinc, and molybdenum, are reported by Shcherbina and others (1974).

At the northeast extremity of the tract, the Koh iron skarn and Seh-Koh copper-bearing polymetallic vein occurrences (fig. 5.1-27) are associated with another granodiorite porphyry body. The Seh-Koh occurrence extends over several hundred meters and contains hematite, magnetite, chalcopyrite and chalcocite, with copper contents as high as 1.44 wt. percent (Dronov and others, 1972).

The Okhankoshan copper-gold-molybdenum occurrence is reported on the website of the Afghanistan Geological Survey (*http://www.bgs.ac.uk/afghanminerals/docs/copper_A4.pdf*). It is described as a porphyry copper prospect and referenced to “Abdullah et al. 1980”, which we assume to be the same as Abdullah and others (1977). Part 1 of that work does mention Okhankashan as a porphyry copper prospect, but provides no location other than the “Central Afghanistan Median Mass” which is well to the south of this tract. It also mentions a second porphyry copper prospect called “Kaftaghar.” Neither of these names occurs in Part 2 of the same work, which is a detailed listing of mineral prospects. Neither name is in the U.S. Geological Survey database of mineral deposits and prospects. Further complicating this issue, the Afghanistan Geological Survey website plots Okhankoshan very near the location of the Seh-Koh polymetallic vein occurrence, not near the Ahankashan copper skarn.

The information that is most needed to improve the assessment of this tract is intermediate-scale (1:100,000) geologic mapping and geochemical sampling of the known prospects. Both would require site visits. ASTER studies of this area to identify hydrothermally altered rocks also would be quite useful. In addition, the uncertainty about names and locations of prospects should be cleared up. The U.S. Geological Survey assessment team did not visit this area.

The description of Ahankashan in Abdullah and others (1977) includes mention of stockwork and veinlet mineralization, and the skarn may be related to porphyry copper style mineralization. On the other hand, there are only a few known prospects in the tract.

The assessment team estimated that there is a 90 percent chance of 0 or more undiscovered porphyry copper deposits, a 50 percent chance of 0 or more, and a 10 percent chance of 2 or more (figs. 5.1-28, 5.1-29, table 5.1-9). The amounts of contained metal that result from the Monte Carlo simulation based on this estimate are illustrated in figures 5.1-28 and 5.1-29 and summarized in table 5.1-9.

Table 5.1-9. Table summarizing statistical parameters for the assessment of the Feroz Koh permissive tract (ppycu08). The mean expected number of deposits is 0.6.

quantile	Cu	Mo	Au	Ag	Rock
0.95	0	0	0	0	0
0.90	0	0	0	0	0
0.50	0	0	0	0	0
0.10	4,900,000	82,000	116	990	1,000,000,000
0.05	9,200,000	220,000	250	3,000	1,800,000,000
mean	2,000,000	50,000	48	670	400,000,000
Probability of mean	0.19	0.14	0.16	0.12	0.20
Probability of zero	0.60	0.74	0.72	0.80	0.60

The Mark3 index is 84 – Porphyry Cu New General 2005. Amounts are in metric tons.

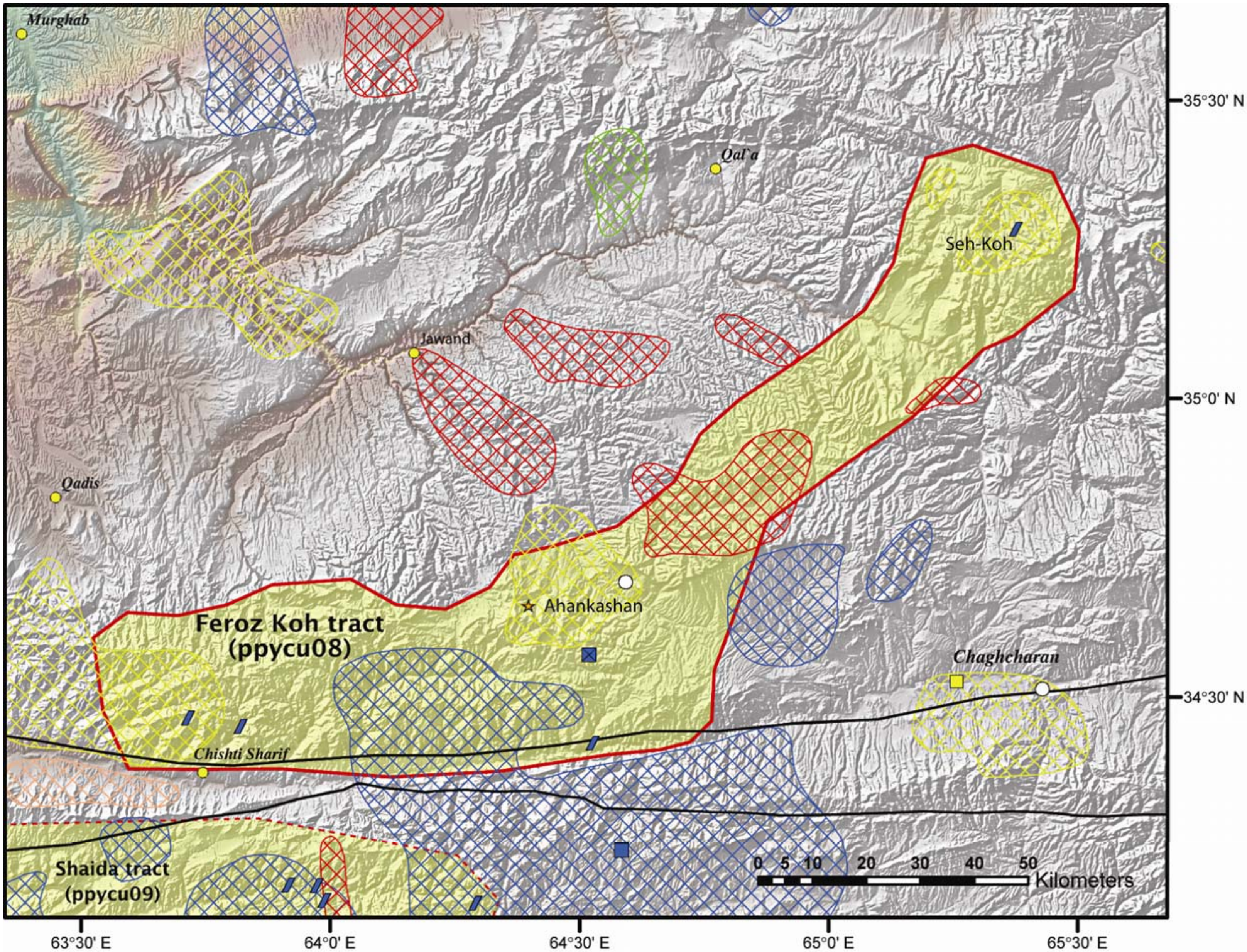

Figure 5.1-27. Map showing the Feroz Koh permissive tract (ppycu08) for undiscovered porphyry copper deposits and skarn copper deposits. Crosshatch indicates mineral halos: red – mercury; blue – lead-zinc; flesh – tungsten; green – tin; yellow - gold.

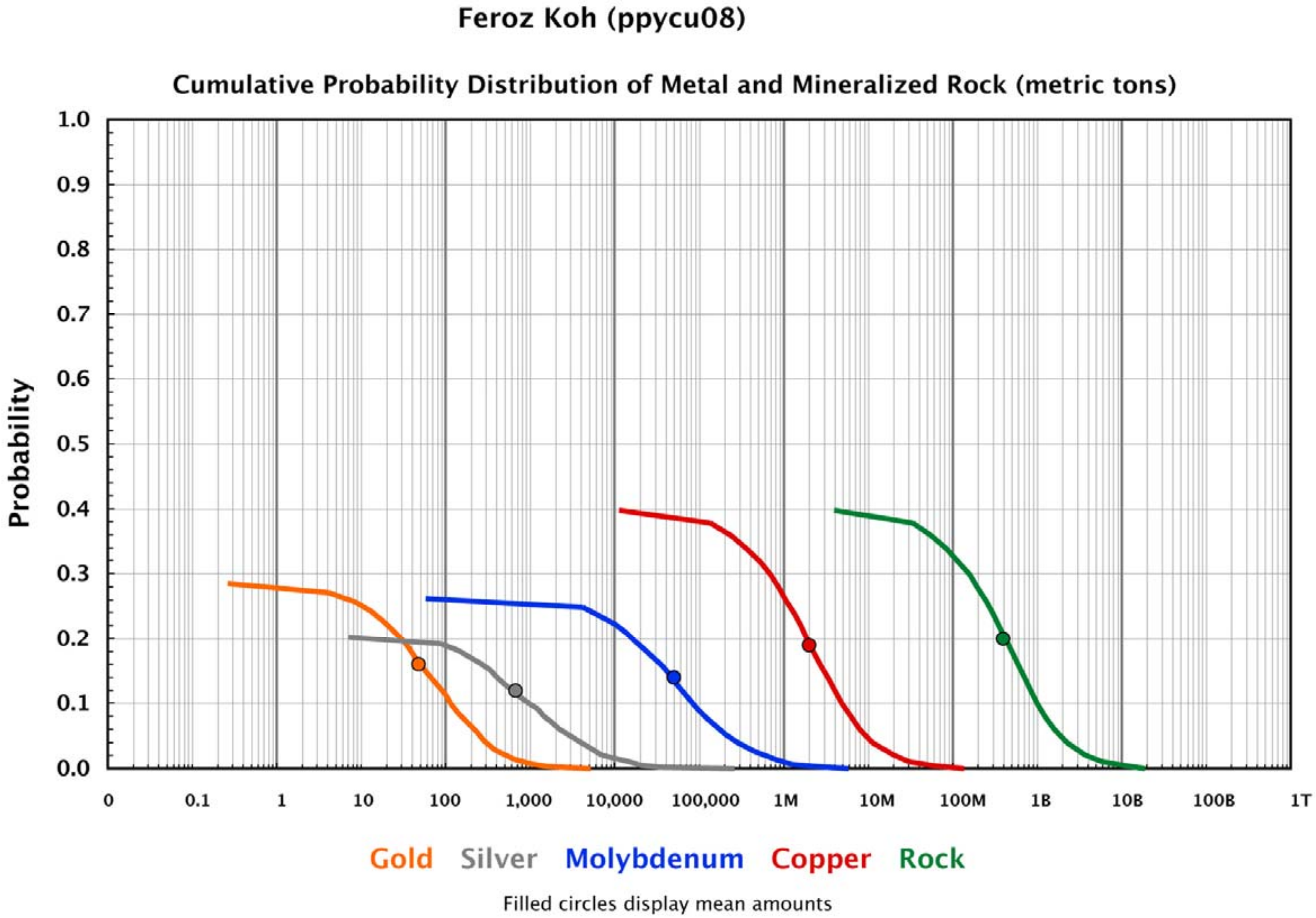

Figure 5.1-28. Cumulative distribution of estimated contained metal and mineralized rock in the Feroz Koh permissive tract (ppycu08).

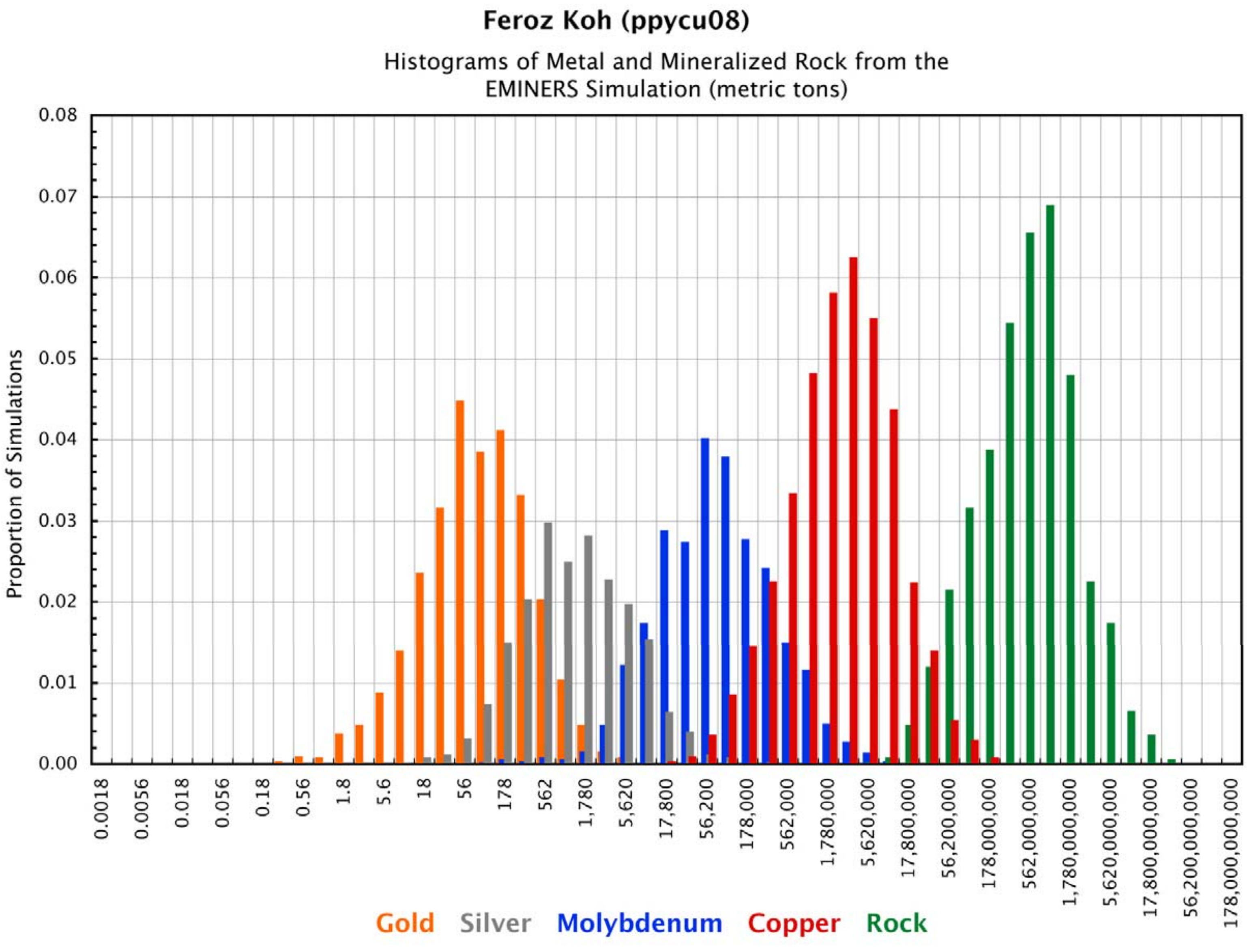

Figure 5.1-29. Histograms of estimated contained metal and mineralized rock in the Feroz Koh permissive tract (ppycu08).

Farah Rod tract (ppycu09)

This tract is in the far west of Afghanistan and is permissive for porphyry copper and skarn copper deposits. There are numerous mineral occurrences within the area, including a number of polymetallic veins and skarn copper occurrences. The tract coincides in large part with the Farah Rod plutonic belt of Debon and others (1987). The rocks in the plutonic belt range in age from Cretaceous to Oligocene and are primarily calc-alkaline and subalkaline.

The Shaida copper deposit, in the north-central part of the Farah Rod tract, has been described as a porphyry copper deposit (ESCAP, 1995; Daud Saba, pers. comm., 2005), although Soviet geologists did not classify it as such. The tract contains numerous mineral prospects and occurrences, including a number of polymetallic veins and skarn copper deposits. There also are several tin and tungsten occurrences, described in Chapter 4. A number of prospects associated with Jurassic volcanic rocks have also been classified as volcanogenic massive sulfide type (VMS) occurrences. Prospects adjacent to the Shaida deposit also share the name Shaida and are classified as VMS occurrences (see section 6.2).

The tract is delineated primarily on the basis of the outcrop area of map unit P_3grg (Doebrich and Wall, 2006), which consists of granite, granodiorite, quartz syenite, and granosyenite, and whose distribution corresponds to the Farah Rod plutonic belt mentioned above. Some volcanic rocks of equivalent age also are present. The tract was extended to include the mineral prospects that were suspected to be related to this same igneous event. The boundary was refined using aeromagnetic data in the south parts where high resolution data are available (Sweeney and others, 2006). The magnetic pattern is typical of volcanic terranes and shows many short wavelength anomalies. The location and limits of the tract are shown in figure 5.1-30.

The area surrounding the Shaida group of prospects is classified as favorable (fig. 5.1-30). These prospects are associated with a Late Jurassic to Lower Cretaceous quartz porphyry and Jurassic quartz keratophyre volcanic rocks that are intruded by Oligocene (?) granite porphyry forming silicified lenses that contain chalcopyrite and oxide minerals. Samples from the area contain 0.01 to 0.30 wt. percent copper with minor lead, zinc, tin, molybdenum and arsenic. A resource of 4.8 million metric tons of ore grading 1.1 wt. percent copper and 1.2 wt. percent zinc was established in the 1970s (Tarasenko and others, 1973; Abdullah and others, 1977; ESCAP, 1995). About 20 km to the southeast, but still within the favorable area, the Kalmurgh, Dahana, Misgaran and Mir-Ali occurrences also contain potentially significant amounts of copper. Other areas within the tract where known mineral occurrences are clustered can also be considered to be the more favorable parts of the tract (dotted line on fig. 5.1-30).

In the far west of the tract, the Gologha copper occurrence is a mineralized breccia in andesite flows that contains copper concentrations as high as 6.2 wt. percent. Small amounts of copper were produced here prior to 1979 (Abdullah and others, 1977).

The information that is most needed to improve the assessment of this tract is intermediate-scale (1:100,000) geologic mapping and geochemical sampling of the known prospects. Both would require site visits. ASTER studies of this area to identify hydrothermally altered rocks also would be quite useful. The U.S. Geological Survey assessment team did not visit this area.

The presence of at least one prospect (Shaida) that has been interpreted to be a porphyry copper prospect is a positive indication. The geologic environment is appropriate and the presence of associated volcanic rocks suggests that the level of exposure is favorable. Copper is prominent in the metallogenic signature of many of the deposits and prospects. Limestone is relatively scarce in the tract, meaning that skarn deposits are less likely than porphyry deposits.

The presence of numerous tin-bearing occurrences may be a negative factor. In other parts of the world, some types of tin-copper deposits exist, but tin is not known to be an important element in the geochemical signature of porphyry copper deposits. It has been suggested that Shaida is Cretaceous in age, and not related to the Oligocene (?) rocks used to delineate the tract. Shaida and a number of other occurrences in the tract have been interpreted to be a simple vein deposits or volcanogenic massive sulfide deposits. Indeed, the characteristics of many of the deposits in the tract have characteristics similar to volcanogenic massive sulfide deposits, rather than porphyry copper deposits.

The numerous identified prospects suggest that the amount of previous exploration was moderate, in this area. The U.S. Geological Survey assessment team did not visit the area.

The assessment team estimated that there is a 90 percent chance of 0 or more undiscovered porphyry copper deposits, a 50 percent chance of 1 or more, and a 10 percent chance of 3 or more (table 5.1-10; figs. 5.1-31, 5.1-32,). The amounts of contained metal that result from the Monte Carlo simulation based on this estimate are illustrated and summarized in table 5.1-10 and figures 5.1-31 and 5.1-32.

Table 5.1-10. Table summarizing statistical parameters for the assessment of the Farah Rod permissive tract (ppycu09). The mean expected number of deposits is 1.3.

quantile	Cu	Mo	Au	Ag	Rock
0.95	0	0	0	0	0
0.90	0	0	0	0	0
0.50	990,000	2,300	7	0	230,000,000
0.10	11,000,000	260,000	259	2,900	2,100,000,000
0.05	19,000,000	510,000	440	6,600	3,700,000,000
mean	4,300,000	110,000	99	1,400	840,000,000
Probability of mean	0.24	0.20	0.23	0.17	0.26
Probability of zero	0.30	0.49	0.46	0.59	0.30

The Mark3 index is 84 – Porphyry Cu New General 2005. Amounts are in metric tons.

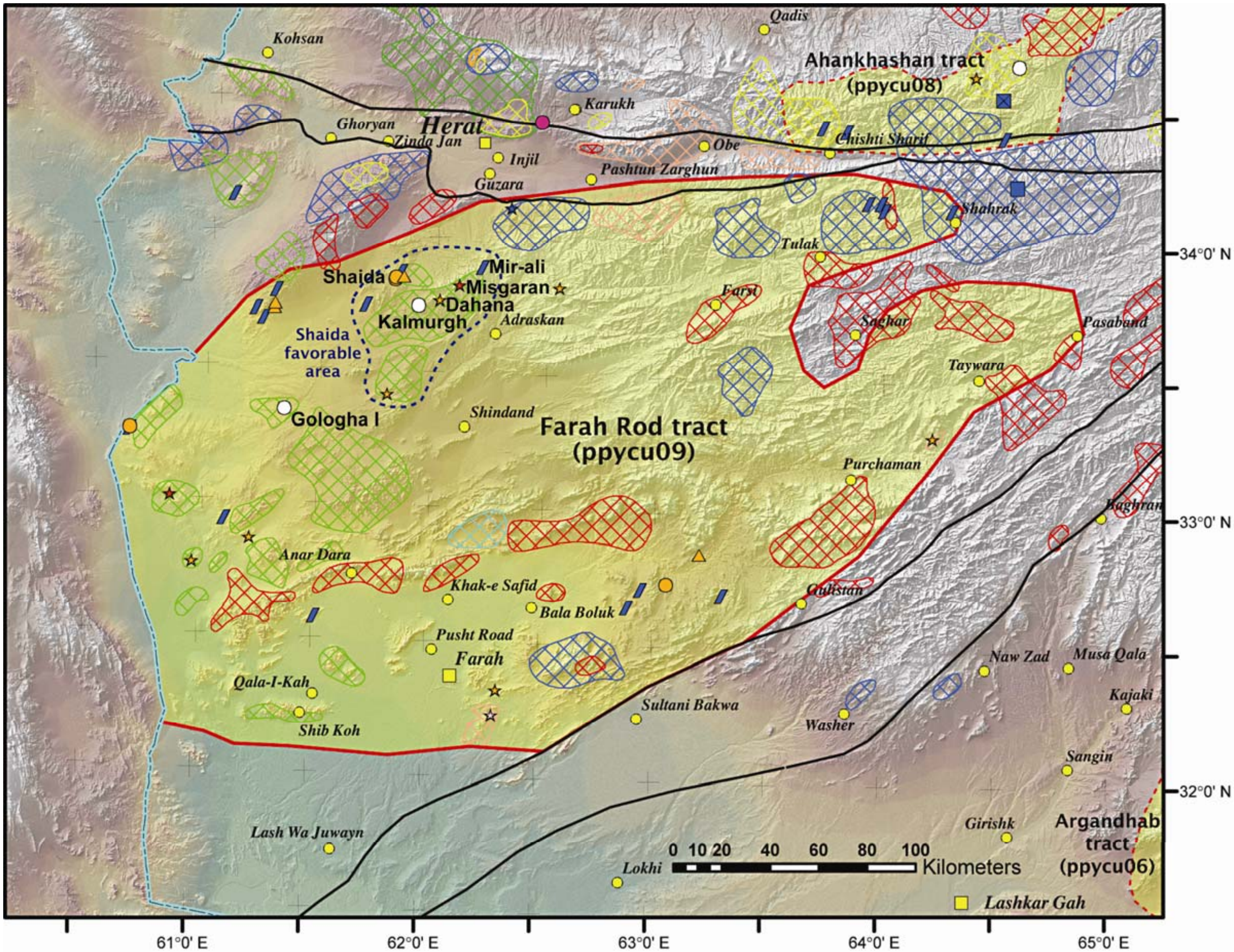

Figure 5.1-30. Map showing the Farah Rod permissive tract (ppycu09) for undiscovered porphyry copper deposits and skarn copper deposits. Crosshatch indicates mineral halos: red – mercury; orange – copper; yellow – gold; blue – lead-zinc; green – tin; turquoise – bismuth; flesh – tungsten. Shaida favorable area is indicated with the dotted blue line. Symbols of mineral occurrences are derived from Doebrich and Wahl (2006).

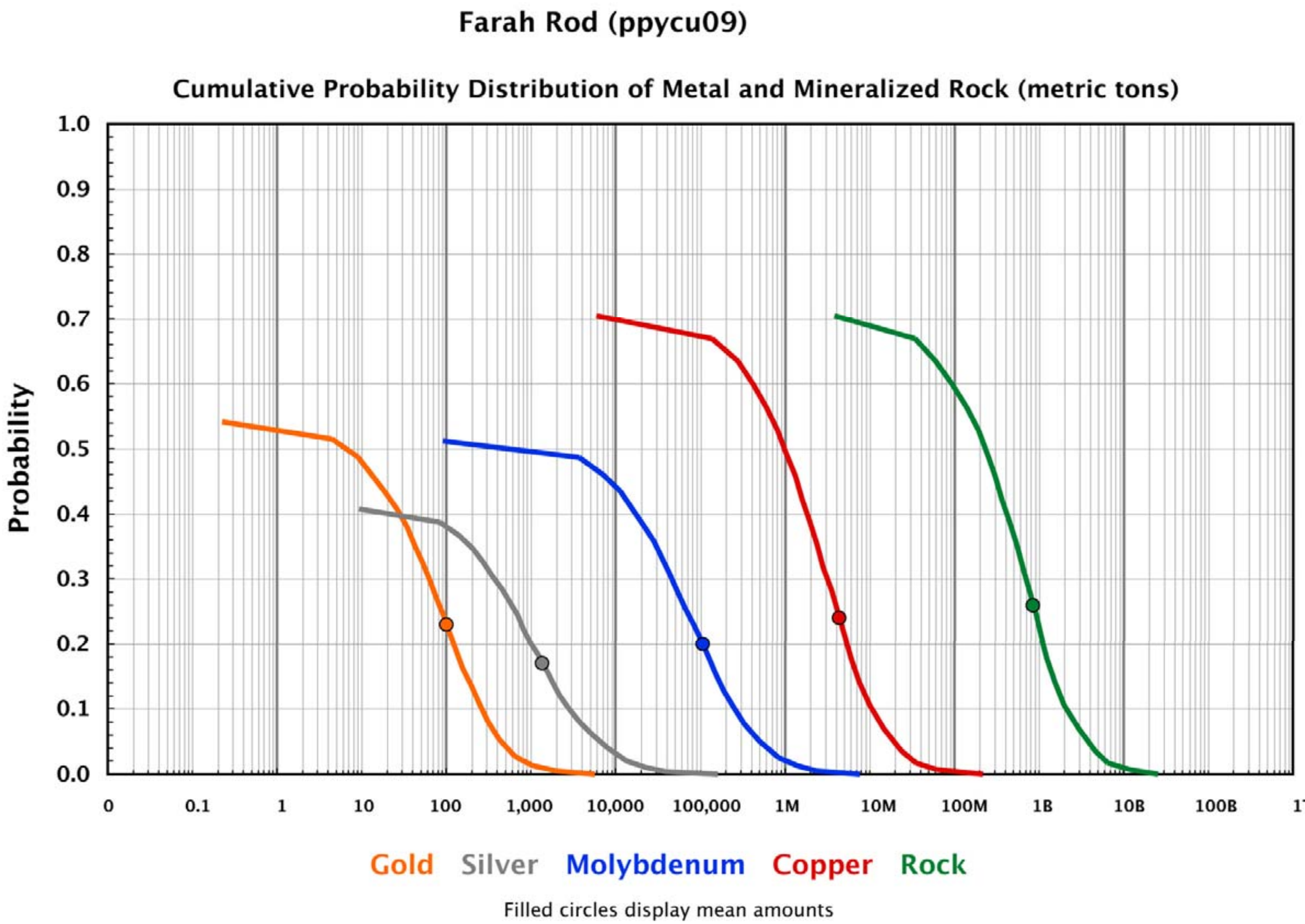

Figure 5.1-31. Cumulative distribution of estimated contained metal and mineralized rock in the Farah Rod permissive tract (ppycu09).

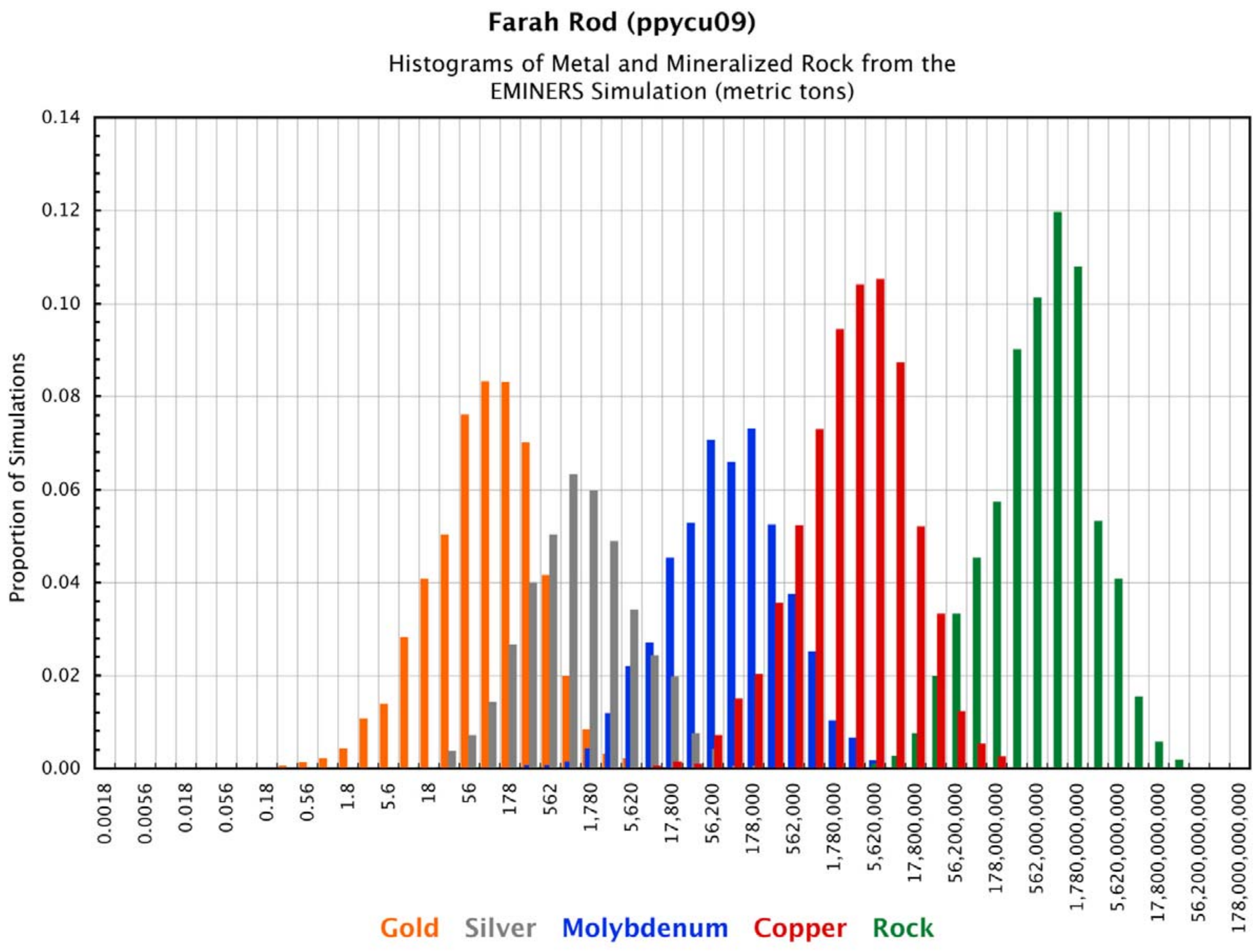

Figure 5.1-32. Histograms of estimated contained metal and mineralized rock in the Farah Rod permissive tract (ppycu09).

West Hindu Kush tract (ppycu10)

This large tract is in northeast Afghanistan and is permissive for undiscovered porphyry copper deposits and for skarn copper deposits. There are scattered mineral occurrences in the tract, including copper skarns (Darra Alasang, and Andarab copper) and a number of polymetallic vein occurrences. There are no known porphyry copper prospects. The tract coincides in large part with the Western Hindu Kush and Western Badakhshan plutonic belts of Debon and others (1987). The rocks in these plutonic belts, northwest of the Badakhshan fault, are almost entirely Triassic in age and are primarily calc-alkaline and subalkaline.

The tract is delineated primarily on the basis of the outcrop area of map unit T_1gdg (Doebrich and Wall, 2006), which consists of granodiorite and granite, and whose distribution corresponds to the Western Hindu Kush and Western Badakhshan plutonic belts mentioned above. The tract was extended to include the mineral prospects that were suspected to be related to this same igneous event. The location and limits of the tract are shown in figure 5.1-33.

Two areas in the southwest and central parts of the tract appear to be the most favorable, where a number of prospects cluster near the Darra Alasang and Andarab gold-bearing skarn copper deposits. The Darra-i-Alansang Cu-Pb-Zn-Sn-W-Au skarn is about 12 km south of the village of Tala Wa Barfak (fig. 5.1-33). The occurrence is in Late Triassic granite and Middle to Upper Triassic shale. Pyrrhotite, chalcopyrite, sphalerite, galena, scheelite, cassiterite and ilmenite occur in skarn zones up to 30 m wide and 200 m long near the contact between the intrusion and shale. Concentrations of between 0.01 and 5 wt. percent copper, of 0.01 to 1 wt. percent lead, and 0.01 to 3 wt. percent zinc are present in the mineralized zones, along with traces of silver and tin.

Farther east, the Andarab copper skarn occurrence and a number of copper-bearing polymetallic vein occurrences are located Andarab (Banu) and Khenjan villages (fig. 5.1-33). The Andarab occurrence is hosted in Lower Carboniferous volcanic rocks in a 200-m-long, 0.5– to 2.5–m-wide copper-rich silicified zone that contains quartz-calcite veinlets and copper concentrations up to 0.7 wt. percent (Kafarskiy and others, 1972). Polymetallic vein occurrences in the same general area are all copper-bearing and could be related to a single hydrothermal system (Kafarskiy and others, 1972).

Other areas within the tract where known mineral occurrences are clustered can also be considered to be the parts of the tract with the higher probability of discovery of undiscovered deposits..

The information that is most needed to improve the assessment of this tract is intermediate-scale (1:100,000) geologic mapping and geochemical sampling of the known prospects. In addition, visits to the known mineral prospects could clarify whether they are related to porphyry copper deposits. The U.S. Geological Survey assessment team did not visit this area.

The relatively small number of prospects and occurrences in the tract argues against the presence of numerous porphyry copper deposits. Nevertheless, the geologic environment is appropriate and the level of exposure is permissive. Copper is prominent in the metallogenic signature of many of the occurrences and prospects.

The area has received some attention in the past, as evidenced by the presence of identified prospects. The U.S. Geological Survey assessment team did not visit the area.

The assessment team estimated that there is a 90 percent chance of 0 or more undiscovered porphyry copper deposits, a 50 percent chance of 0 or more, and a 10 percent chance of 1 or more (table 5.1-11; figs. 5.1-34, 5.1-35). The amounts of contained metal that result from the Monte Carlo simulation based on this estimate are illustrated and summarized in table 5.1-11 and figures 5.1-34 and 5.1-35.

Table 5.1-11. Table summarizing statistical parameters for the assessment of the West Hindu Kush permissive tract (ppycu10). The mean expected number of deposits is 0.3.

quantile	Cu	Mo	Au	Ag	Rock
0.95	0	0	0	0	0
0.90	0	0	0	0	0
0.50	0	0	0	0	0
0.10	2,000,000	28,000	37	130	440,000,000
0.05	4,800,000	99,000	120	970	980,000,000
mean	1,200,000	28,000	24	360	220,000,000
Probability of mean	0.14	0.10	0.12	0.08	0.15
Probability of zero	0.69	0.83	0.82	0.88	0.69

The Mark3 index is 84 – Porphyry Cu New General 2005. Amounts are in metric tons.

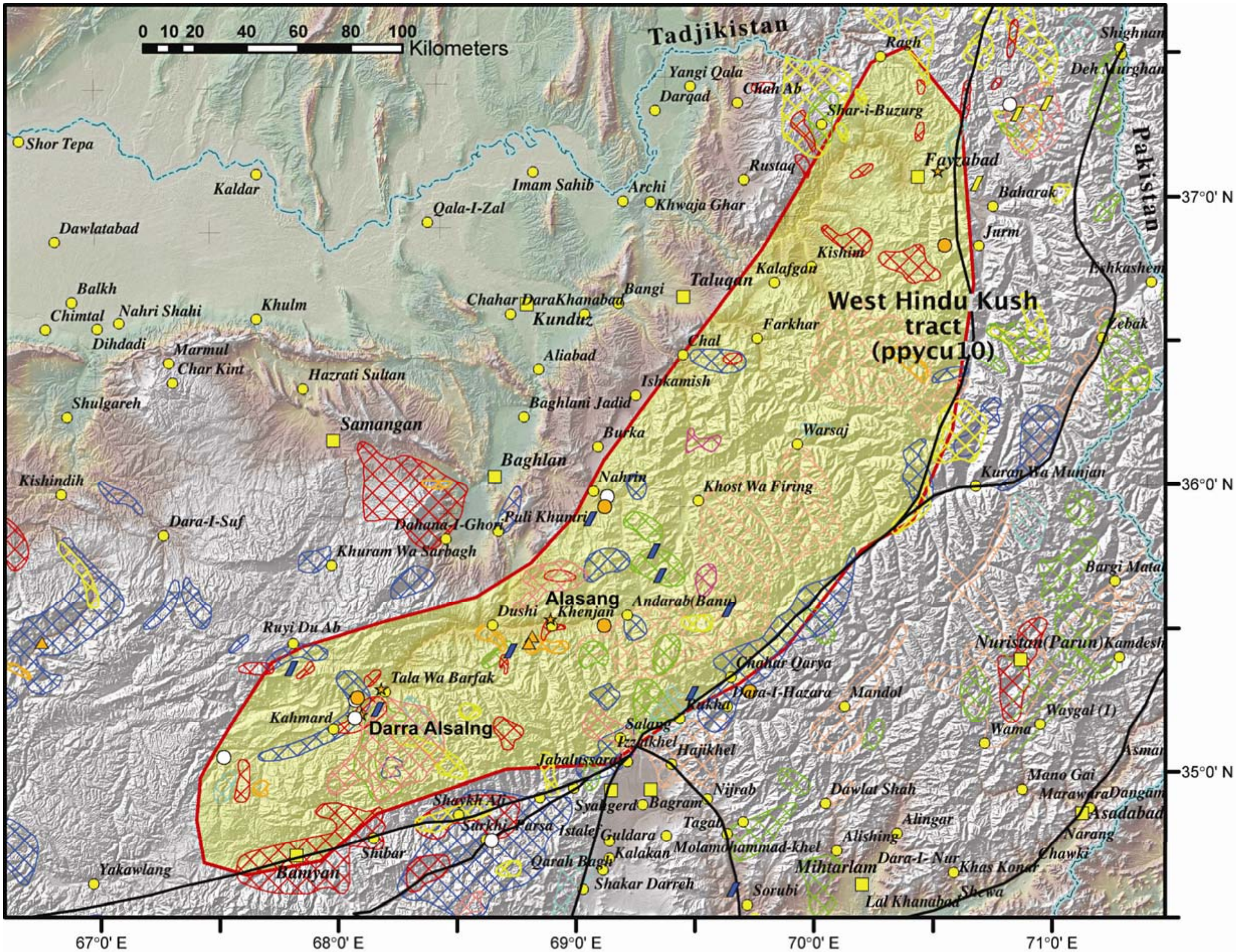

Figure 5.1-33. Map showing the West Hindu Kush permissive tract (ppycu10) for undiscovered porphyry copper deposits and skarn copper deposits. Crosshatch indicates mineral halos: red – mercury; orange – copper; yellow – gold; blue – lead-zinc; green – tin; turquoise – bismuth; flesh – tungsten. Mineral occurrence symbols from Doebrich and Wahl (2006)

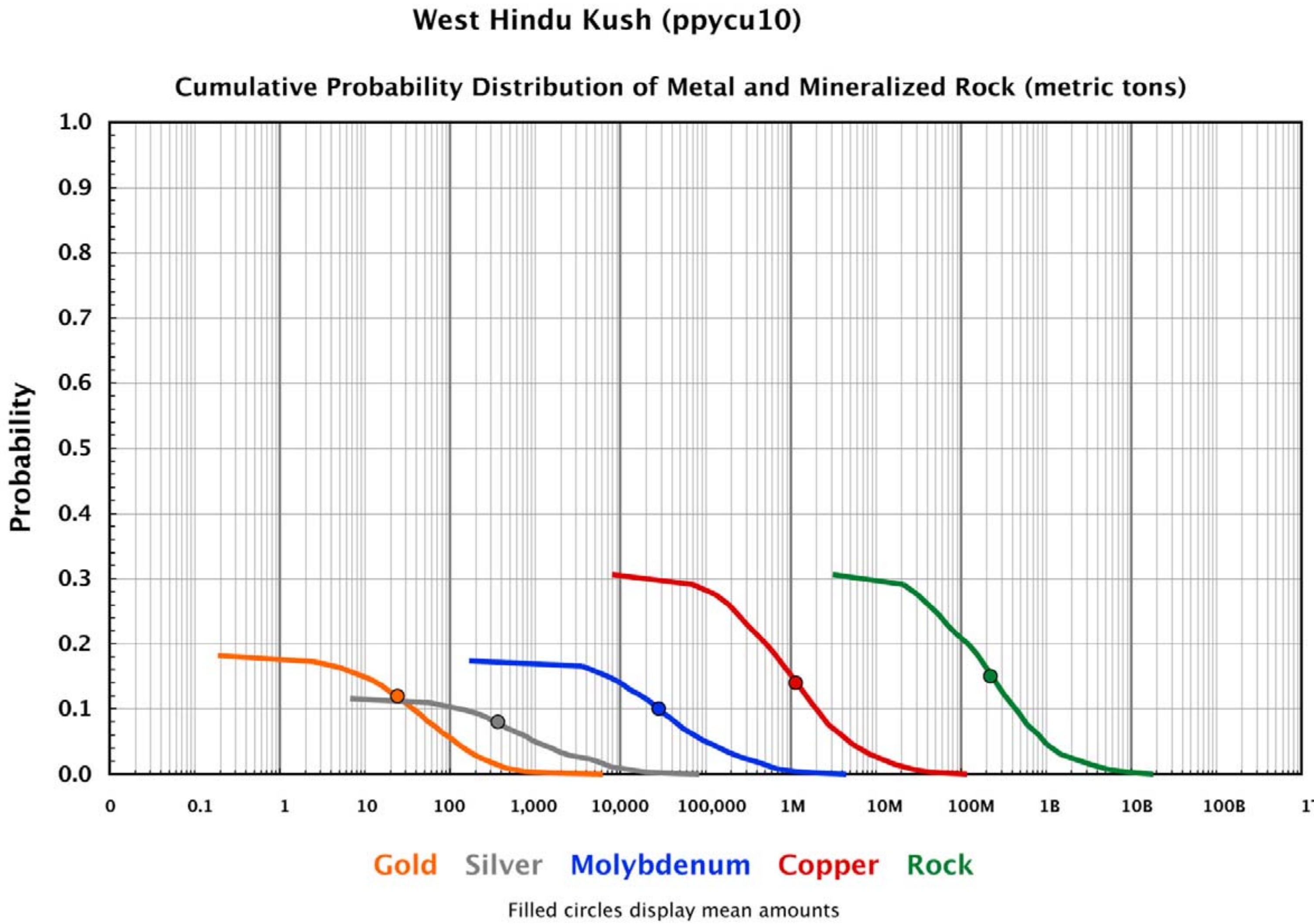

Figure 5.1-34. Cumulative distribution of estimated contained metal and mineralized rock in the West Hindu Kush permissive tract (ppycu10).

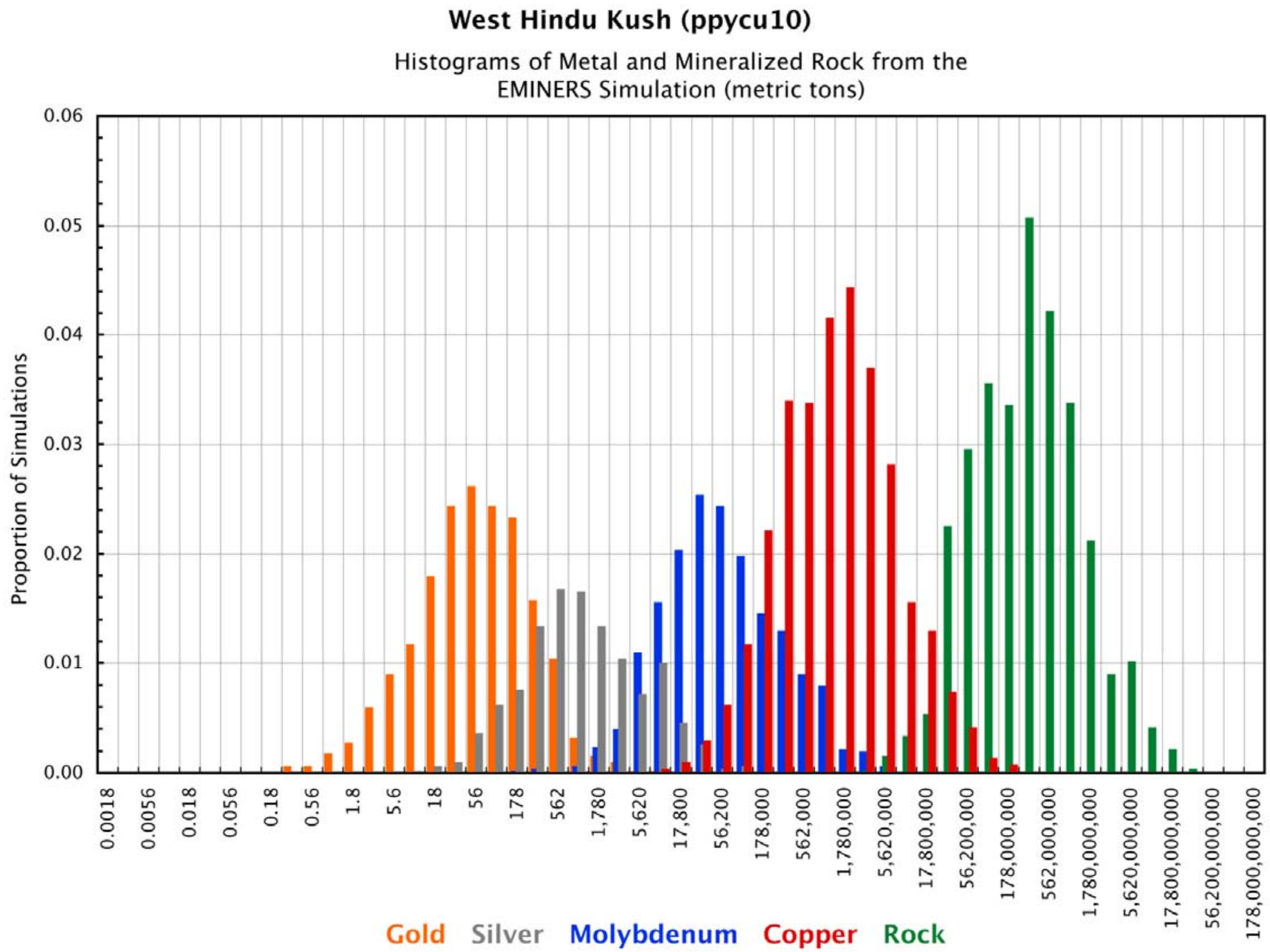

Figure 5.1-35. Histograms of estimated contained metal and mineralized rock in the West Hindu Kush permissive tract (ppycu10).

West Badakhshan tract (ppycu11)

This small tract is in the far northeast corner of Afghanistan, close by the border with Tadjikistan, and is permissive for porphyry copper deposits. There are four unnamed mineral prospects in the tract. The only known intrusive rocks in the tract are two small bodies of Mississippian (?) ultramafic rock and a small pluton of Mississippian (?) diorite. Debon and others (1987) present no information about this area.

The tract is delineated entirely on the basis of the locations of three unnamed copper occurrences in Carboniferous rocks and the fact that a schematic map of copper prospects on the website of the Afghanistan Geological Survey [*http://www.bgs.ac.uk/afghanminerals/docs/copper_A4.pdf*] highlights these three prospects, and the text describes the "discovery of Miocene copper porphyry-style mineralisation in Badakhshan." Available geologic maps indicate that the nearest Miocene igneous activity was at least 200 km to the south. We are not certain of the source of this assertion about porphyry-style mineralization in Badakhshan. The location and limits of the tract are shown in figure 5.1-36.

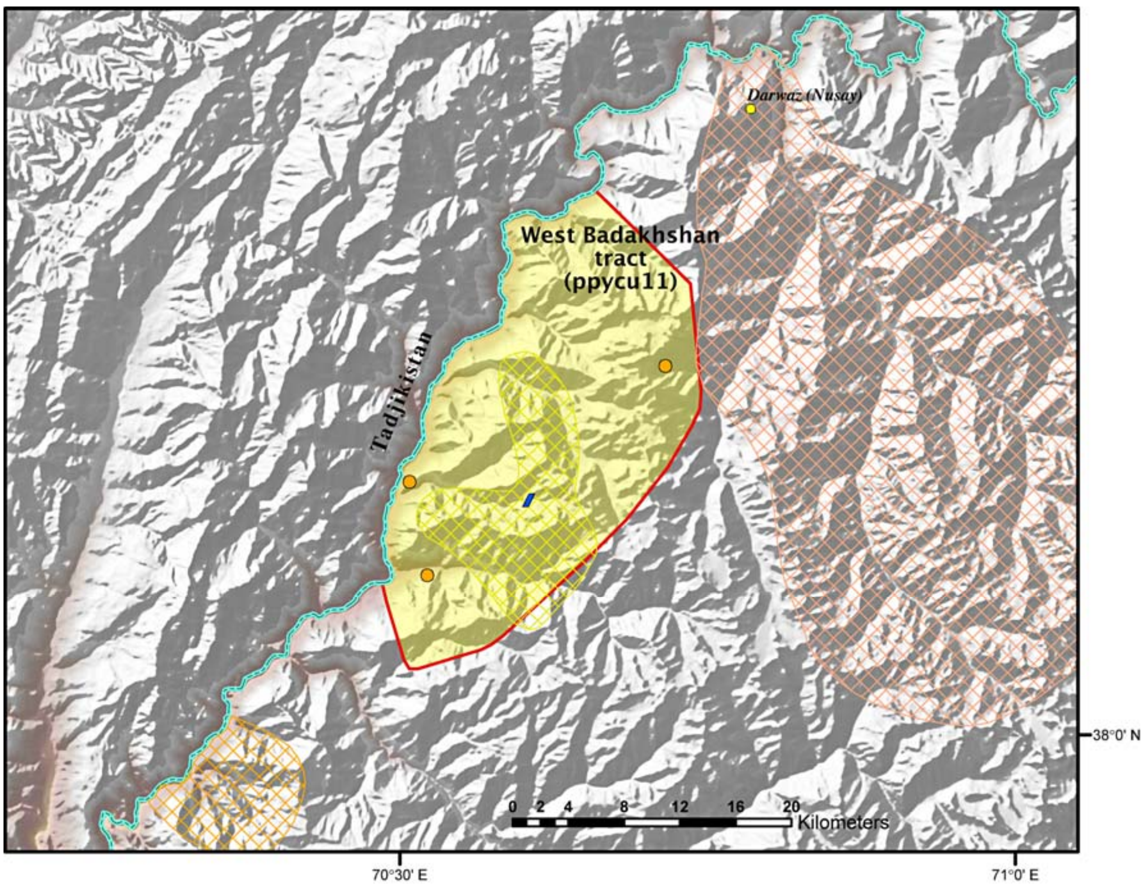

Figure 5.1-36. Map showing the West Badakhshan permissive tract (ppycu11) for undiscovered porphyry copper deposits. Crosshatch indicates mineral halos: orange – copper; yellow – gold; flesh – tungsten.

In order to improve the assessment of this tract, more information should be obtained from the authors of the Afghanistan Geological Survey website. There is a gold mineral halo in the tract.

There is little information about past exploration in this part of Afghanistan, although the presence of identified prospects indicates that there has been some activity. The U.S. Geological Survey Assessment Team did not visit the area. Because of the lack of information for this area, the assessment team made no quantitative estimates.

Helmand tract (ppycu12)

This tract is in central Afghanistan and is permissive for porphyry copper and skarn copper deposits. There are no porphyry copper prospects in the tract, but there are a few polymetallic vein and base-metal skarn prospects.

The tract coincides in large part with the Helmand plutonic belt of Debon and others (1987). This plutonic belt includes both Cambro-Ordovician peraluminous granite and Cretaceous calc-alkaline and subalkaline intrusive rocks.

The tract is delineated primarily on the basis of the outcrop area of map units P_3gd and P_3gdy (Doebrich and Wall, 2006), which consist of granodiorite, granosyenite, and granite. The map units are designated as Oligocene in age, but the information in Debon and others (1987) suggests that many of the rocks are Cretaceous. The tract was extended to include the mineral prospects that were suspected to be related to these igneous events. The location and limits of the tract are shown in figure 5.1-37.

Although there are a number of mineral prospects in the tract, most of them are tin- and tungsten-bearing (see fig. 4.1.1). Skarns are rare as the plutons intrude primarily Paleozoic and Mesozoic siliciclastic sedimentary rocks. It is noteworthy that several tin-bearing rare-metal pegmatites are found in the western part of the area, suggesting that much of this composite batholith may have been eroded to mesozonal depths, which is deeper than most porphyry and stockwork deposits.

The information that is most needed to improve the assessment of this tract is intermediate-scale (1:100,000) geologic mapping and geochemical sampling of the known prospects. Both would require site visits. The U.S. Geological Survey assessment team did not visit this area.

The relatively small number of prospects and occurrences in the tract suggests limited potential for numerous porphyry copper deposits. Nevertheless, the geologic environment appears appropriate and the level of exposure is permissive. The petrochemistry of the intrusive rocks is similar to that of the rocks in the Argandhab tract to the south.

The area has received some attention in the past, as evidenced by the presence of identified prospects. The U.S. Geological Survey assessment team did not visit the area.

The assessment team estimated that there is a 90 percent chance of 0 or more undiscovered porphyry copper deposits, a 50 percent chance of 0 or more, and a 10 percent chance of 1 or more (table 5.1-12; figs. 5.1-38, 5.1-39,). The amounts of contained metal that result from the Monte Carlo simulation based on this estimate are illustrated and summarized in table 5.1-12 and figures 5.1-38 and 5.1-39.

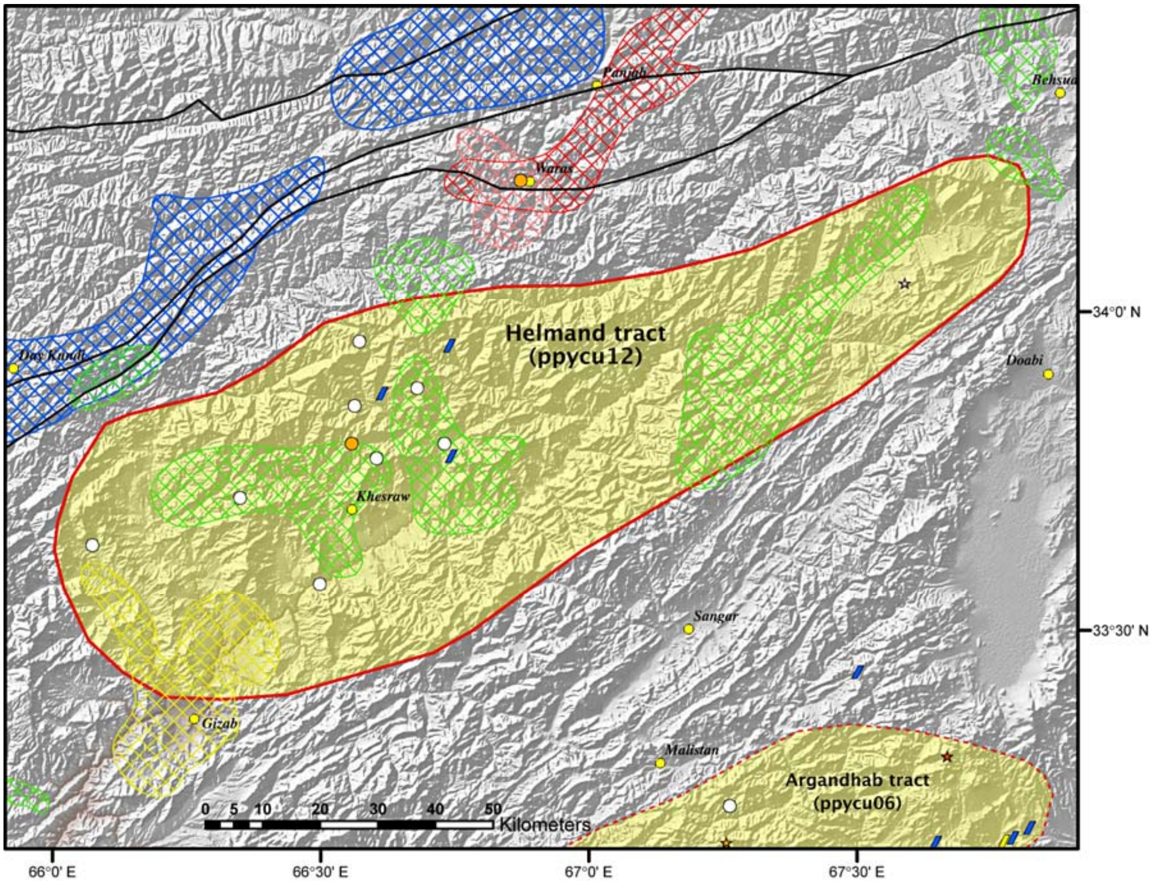

Figure 5.1-37. Map showing the Helmand permissive tract (ppycu12) for undiscovered porphyry copper and skarn copper deposits. Crosshatch indicates mineral halos: red – mercury; yellow – gold; blue – lead-zinc; green – tin; flesh – tungsten. Mineral occurrence symbols from Doebrich and Wahl (2006).

Table 5.1-12. Table summarizing statistical parameters for the assessment of the Helmand permissive tract (ppycu12). The mean expected number of deposits is 0.3.

quantile	Cu	Mo	Au	Ag	Rock
0.95	0	0	0	0	0
0.90	0	0	0	0	0
0.50	0	0	0	0	0
0.10	2,100,000	32,000	43	190	480,000,000
0.05	4,800,000	110,000	120	1,200	1,000,000,000
mean	980,000	27,000	24	290	210,000,000
Probability of mean	0.16	0.11	0.12	0.09	0.17
Probability of zero	0.70	0.83	0.81	0.88	0.70

The Mark3 index is 84 – Porphyry Cu New General 2005. Amounts are in metric tons.

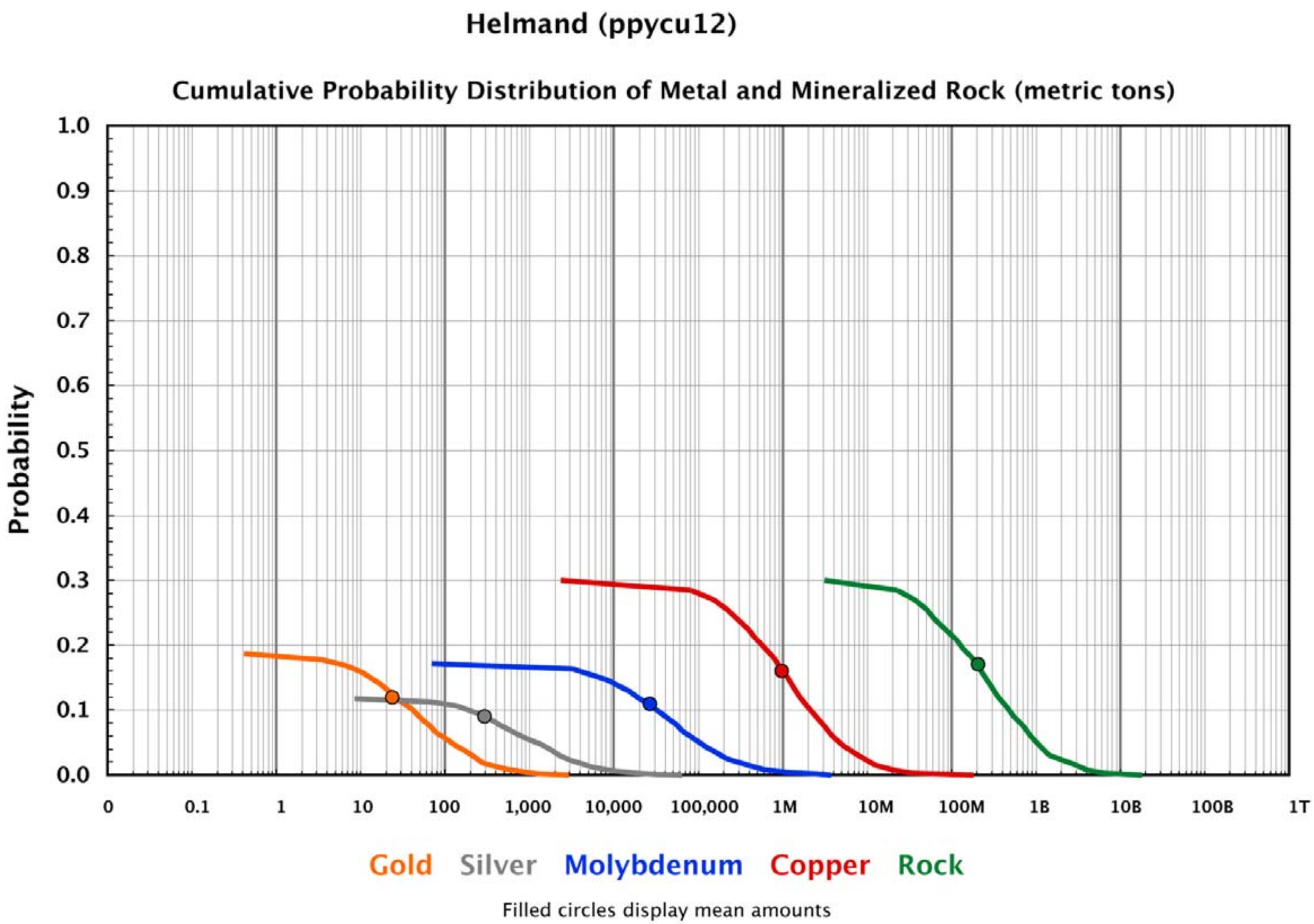

Figure 5.1-38. Cumulative distribution of estimated contained metal and mineralized rock in the Helmand permissive tract (ppycu12).

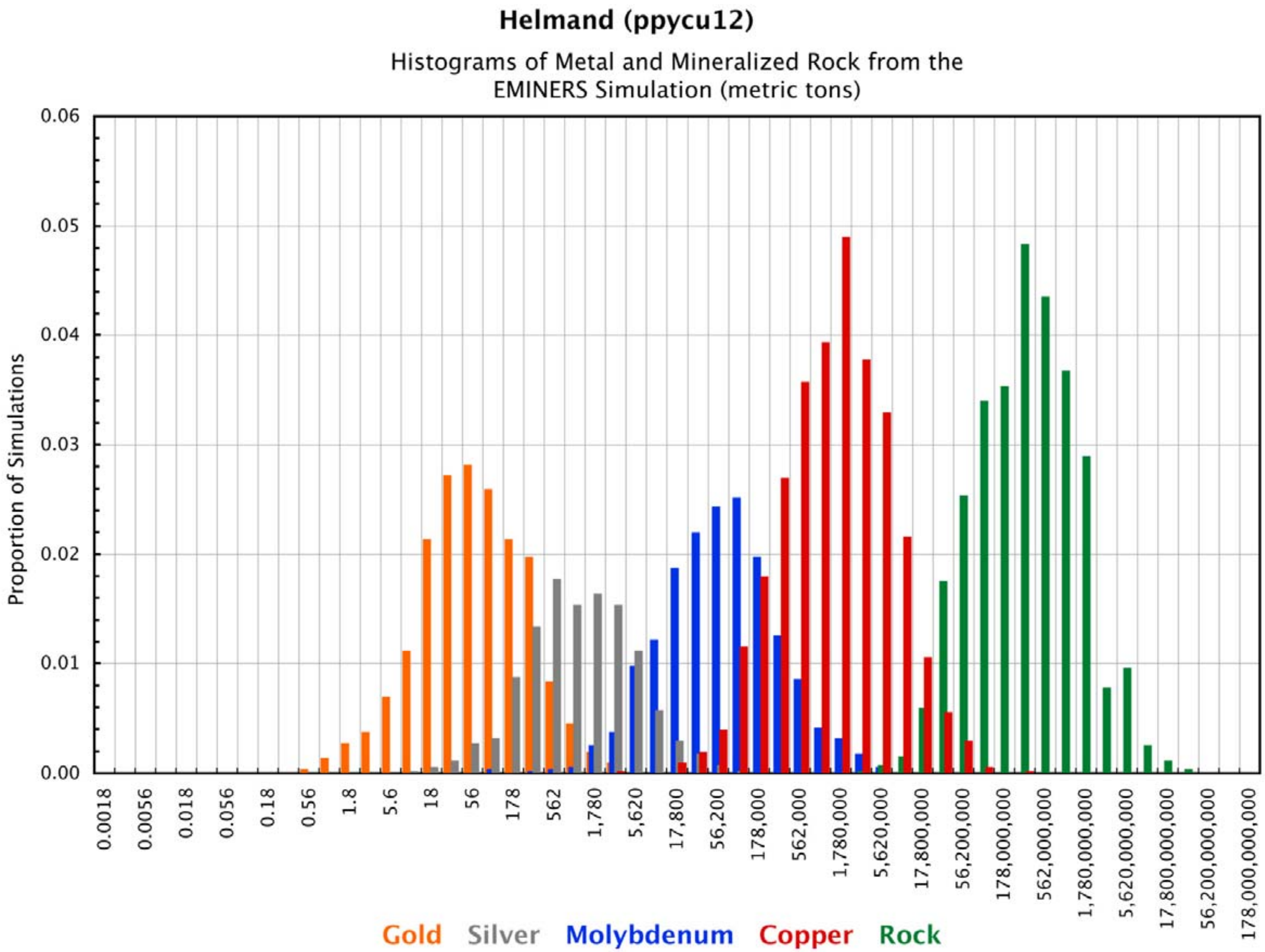

Figure 5.1-39. Histograms of estimated contained metal and mineralized rock in the Helmand permissive tract (ppycu12.)

Summary

Igneous rocks typical of geologic provinces containing porphyry copper deposits are common in Afghanistan. Most of the country is part of the Tethyan geodynamic belt, which contains porphyry copper deposits in the Carpathian Mountains, of southern and eastern Europe, and in the Himalayas in central Asia. Relatively little is known about specific characteristics of the known porphyry copper prospects in Afghanistan and there are no known deposits. We therefore assessed this deposit type using the general porphyry copper deposit model as described by Singer and others (2005). We delineated 12 permissive tracts for porphyry copper deposits (fig. 1). In some cases, the tract is also permissive for copper skarn deposits, but we did not make estimates of numbers of undiscovered deposits of this type. We created a distinct tract for each combination of characteristics, primarily age or presumed age. The total estimate resulted in a mean expected values of 28.5 million metric tons of Cu, 0.71 million metric tons Mo, 683 metric tons Au, and 9000 metric tons Ag. Tracts ppycu02, ppycu05, and ppycu07 have the highest predicted deposit densities and they are the most attractive areas for exploration (table 5.1-13)..

Table 5.1-13. Summary of Estimates of undiscovered porphyry copper deposits in Afghanistan.

tract id	tract name	90th	50th	10th	*Expected (mean) number of deposits, λ	Coefficient of Variation, $C_v = (sx/\lambda)x100$	**Standard deviation, sx	tons/rock	metric tons copper	metric tons molybdenum	metric tons gold	metric tons silver
ppycu01	Chagai-east	0	1	3	1.3	90	1.17	821,800,000	4,212,000.00	109,100.00	97.53	1,416.00
ppycu02	Chagai west	0	1	2	1.0	79	0.79	664,100,000	3,257,000.00	85,170.00	82.46	1,062.00
ppycu03	Spin-Boldak	0	0	2	0.6	147	0.88	399,700,000	2,067,000.00	47,010.00	53.89	639.60
ppycu04	Saindak-north	0	0	3	0.9	140	1.26	593,600,000	2,977,000.00	80,100.00	74.36	913.50
ppycu05	Kundalyan-Zarkashan	0	1	2	1.0	79	0.79	650,800,000	3,279,000.00	78,820.00	80.44	1,130.00
ppycu06	Arghandab	0	0	2	0.6	147	0.88	424,600,000	2,165,000.00	61,040.00	51.28	640.10
ppycu07	Katawaz	0	0	2	0.6	147	0.88	394,200,000	2,031,000.00	52,700.00	48.47	585.20
ppycu08	Feroz Koh	0	0	2	0.6	147	0.88	396,000,000	2,012,000.00	49,980.00	47.75	672.10
ppycu09	Farah Rod	0	1	3	1.3	90	1.17	838,300,000	4,338,000.00	105,600.00	99.38	1,353.00
ppycu10	West Hindu Kush	0	0	1	0.3	167	0.50	223,100,000	1,151,000.00	27,980.00	23.90	361.60
ppycu11	Badakhshan											
ppycu12	Helmand	0	0	1	0.3	167	0.50	205,100,000	980,200.00	26,510.00	23.51	294.00
Total Porphyry					**8.5**			**5,611,300,000**	**28,469,200.00**	**724,010.00**	**682.97**	**9,067.10**

5.2 Pluton-related gold deposits

Contribution by Stephen G. Peters

Pluton-related gold deposits and occurrences in Afghanistan mainly are polymetallic gold-quartz veins and skarns, which are in northern Kandahar, northwestern Zabul and southwestern Ghazni Provinces (fig. 5.2-1) and are associated with Oligocene and Cretaceous plutons. These gold-rich deposits and occurrences are discussed in the following section. In addition, lode gold occurrences associated with metamorphic rocks in Badakhshan, Parwan and Baghlan Provinces are discussed in section 9.1 and gold placer deposits are discussed in section 10.2. A number of geochemical mineral halo anomalies also are present in north central Afghanistan and in the Katawaz Basin area in the east part of the country and some of these have characteristics of epithermal precious-metal deposits (section 6.1) (fig. 5.2-1).

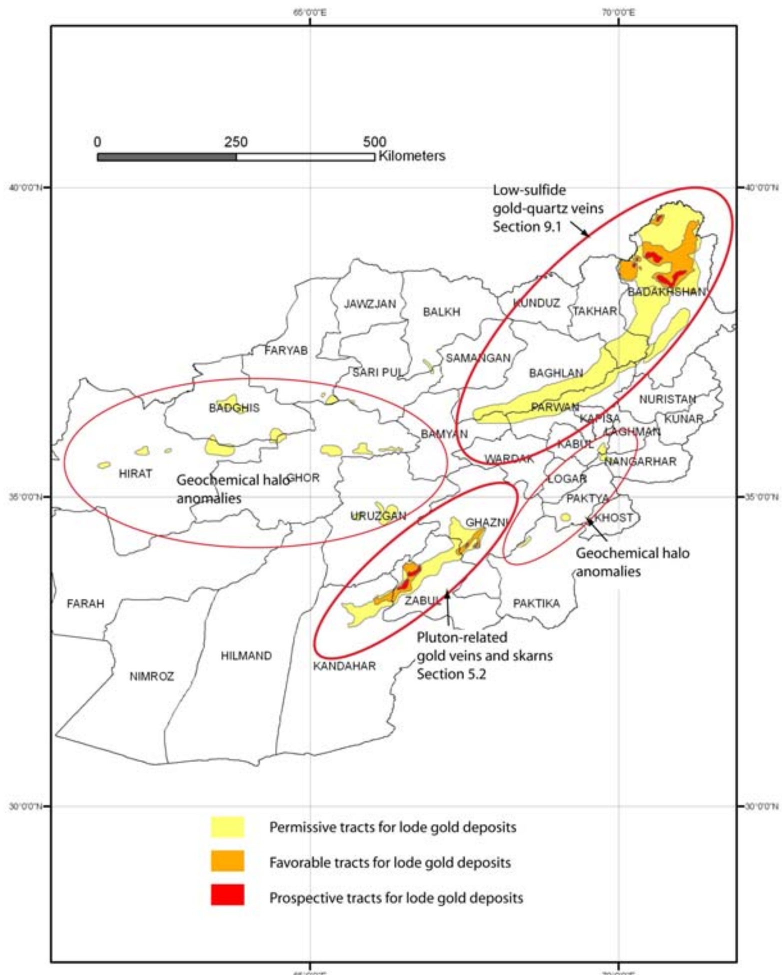

Figure 5.2-1. Map showing location of tracts for lode gold deposits in Afghanistan. Section 5.2 discusses the pluton-related gold veins and skarns in Kandahar, Zabul and Ghazni Provinces.

5.2-1 Description of tracts for pluton-related gold deposits.

Tracts permissive for lode gold deposits for all of Afghanistan are shown on figure 5.2-1. Permissive tracts gold01, gold 02 and gold04 are discussed in section 9.1 under deposits associated with regional metamorphism. Tract gold03 Kandahar-Zabul-Ghanzi is associated with plutonic igneous rocks and is discussed below. Additional details and model descriptions about gold-rich mineralization associated with this plutonic belt are contained in section 5.1 dealing with porphyry copper and related deposits. The main gold-rich deposit model types are polymetallic veins and skarns.

Permissive tract—gold03 Kandahar-Zabul-Ghanzi gold

Deposit types—gold-rich polymetallic veins and gold-rich skarn deposits

Age of mineralization—Cretaceous and Tertiary

Examples of deposit type—In the south part of the gold03 tract, in the Shah Wali Ko Mizan and Daychopan Districts, the Baghtu, Kadilak, Assanak, Tughra, and Outcrop 543 gold-bearing occurrences are present, as well as a number of gold-rich skarn occurrences. In the north part of the gold03 tract, in North Arghandab, Jaghuri, Muqur and Southwest Qarabagh Districts, the Lashkar-Qala, Bolo Gold, Sufi Kademi, and Dynamitic Gold, as well as Mugur and Zardak occurrences and numerous gold-rich skarns also are present.

Exploration history—Substantial exploration has taken place along the Kundalyan-Zarkashan belt, mostly for copper, but also for gold, other base-metals, and tin and tungsten. Both the Kundalyan and Zarkashan areas were explored by trenches, tunnels, and diamond drilling by Soviet and Afghan geologists. The U.S. Geological Survey Assessment Team paid a brief (10 minute) visit to one dump at Kundalyan and flew over the Zarkashan area. Small amounts of past production of gold and base metals also are reported in the Garangh copper-gold skarn area (Dovgal and others, 1971). The Tughra gold and Sufi Kademi mineral occurrences are reported as ancient workings. Drilling has taken place at the Dynamitic gold occurrence.

Tract boundary criteria—A gold03 Kandahar-Zabul-Ghanzi permissive tract was delineated based on a distinctive group of mapped Cretaceous intrusive rocks (map unit ***KP_1gbm*** from Doebrich and Wahl, 2006) that are spatially related to the known porphyry copper, copper-gold skarn and polymetallic deposits and prospects. The intrusive rocks are alkaline in nature, and relatively oxidized. The boundaries were refined using aeromagnetic data, as parts of the tract contain strong positive magnetic anomalies (Sweeney and others, 2006).

Favorable tracts gold03-f1 and gold03-f2 were delineated in two parts of the permissive tract gold03 to encompass mineral occurrences, alteration zones from ASTER, and to approximate anomalous forms and shapes in the aeromagnetic contours. In addition, four prospective tracts, gold03-p1, gold03-p2, gold03-p3, and gold03p4, were also delineated within these favorable tracts and these represent four (4) clusters of mineralized occurrences. There are two prospective clusters in the south and two prospective clusters in the north (fig. 5.2-2); they are described from north to south below

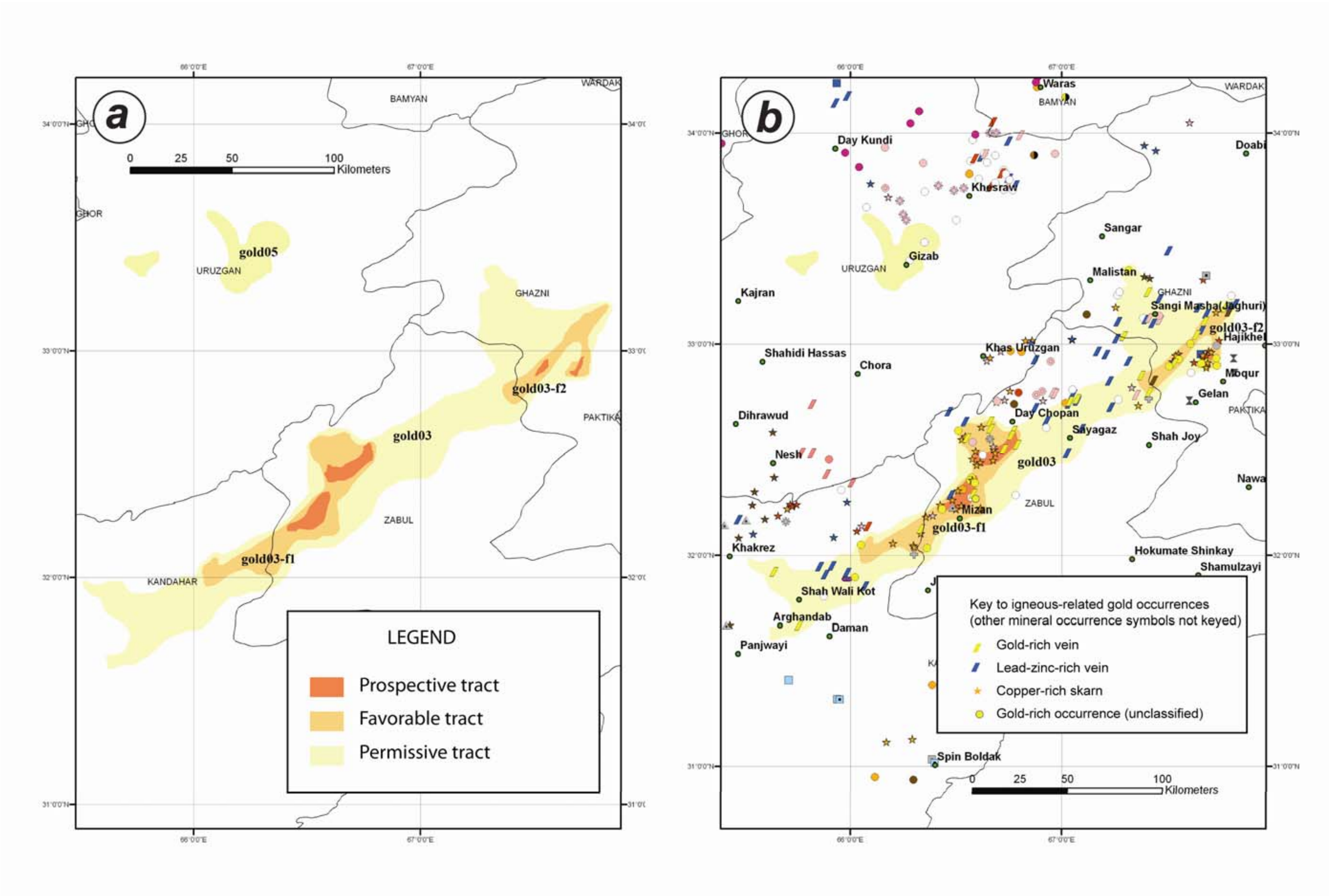

Figure 5.2-2. Map showing location of permissive tract gold03 and two internal favorable tracts gold03-f1 and gold03-f2 (orange) for undiscovered pluton-related gold deposits. Prospective tracts also are shown. Symbols represent different metallic and non-metallic mineral occurrences from the legend of Doebrich and Wahl (2006).

Favorable tract gold03-f1.

Favaorable tract gold03-f1 is a 50–km-long, 10– to 15–km-wide northeast-trending zone that contains two main clusters of gold-rich occurrences, which have been delineated as prospective tracts, but other gold-rich occurrences also are present within the favorable tract (figs. 5.2-2 and 5.2-3). For instance, the Baghtu, Kadilak, and several copper skarn occurrences in the south (fig. 5.2-2). The Kadilak occurrence lies in Upper Triassic limestone within two brecciated, hematitic zones with siliceous-calcareous zones that are 90 and 200 m long and 0.2 to 2.5 m wide and contains disseminated pyrite, chalcopyrite, bornite, chalcocite, galena and hematite, grading 70 g/t gold, 2.5 wt. percent lead, 3.0 wt. percent zinc, and 0.87 wt. percent copper (Dovgal and others, 1971). In addition, the Asanzay (3.8 g/t gold), Charsu (1.59 to gold), Outcrop no 7273, Arghasu I, II, and II and Dorushak and Ghumbad skarn occurrences are present in the southern part of favorable tract gold03-f1 (see also section 5.1) (fig. 5.2-2).

Prospective tract gold03-p1-Kundalyan-gold.

The Kundalyan Prospective tract gold03-p1 over laps permissive porphyry copper tract ppycu05 and contains a number of gold-rich copper skarns including the Baghawan, Bolo Copper, Tourva (Jurwa) Arghatu and Garangh copper skarns, as well as the Kundalyan porphyry copper occurrences described in section 5.1. The tract closely follows the magnetic signature of the underlying Cretaceous plutonic rocks (fig. 5.2-4). The north part of the tract contains the Assanak, Tughar and Outcrop no 543 gold occurrence (figs. 5.2-4 and 5.2-5a). Small amounts of past production of gold and base metals also are reported in the area (Dovgal and others, 1971). The Assanak occurrences is hosted in Carboniferous to Lower Permian marbled limestone in a strongly brecciated pyrite-bearing zone that is 150 m long and 1 to 2 m wide grading 2.2 g/t gold with anomalous traces of copper, zinc, and lead (Mesechko and others, 1971). The Tughra occurrence contains ancient workings that are hosted in brecciated Vendian-Cambrian rocks in strongly mineralized zones that are 250 m long and 5 to 6 m wide grading 0.1 to 6.5 g/t gold and contain significant concentrations of copper, lead, and zinc (Plotnikov and others, 1968). The Outcrop No 543 is hosted in Vendian-Cambrian dolomitized limestone in a brecciated calcareous and serpentinized fault zone that is 100 m long and 1.5 to 2.5 m wide containing disseminated chalcopyrite and grades 9.3 to 13.2 g/t gold, 1.03 to 3.6 wt. percent copper with anomalous concentrations of zinc and bismuth (figs. 5.2-3 and 5.2-4).

Prospective tract gold03-p2

Prospective tract gold03-p2 is a 20 to 25 km long, 5 to 7 km wide northeast trending zone that contains a number of gold-rich copper skarn occurrences in its southern part. These coincide with prospective tract ppycu04 for porphyry copper deposits and a number of unnamed gold-rich vein occurrences in the northeastern part (fig. 5.2-5b).

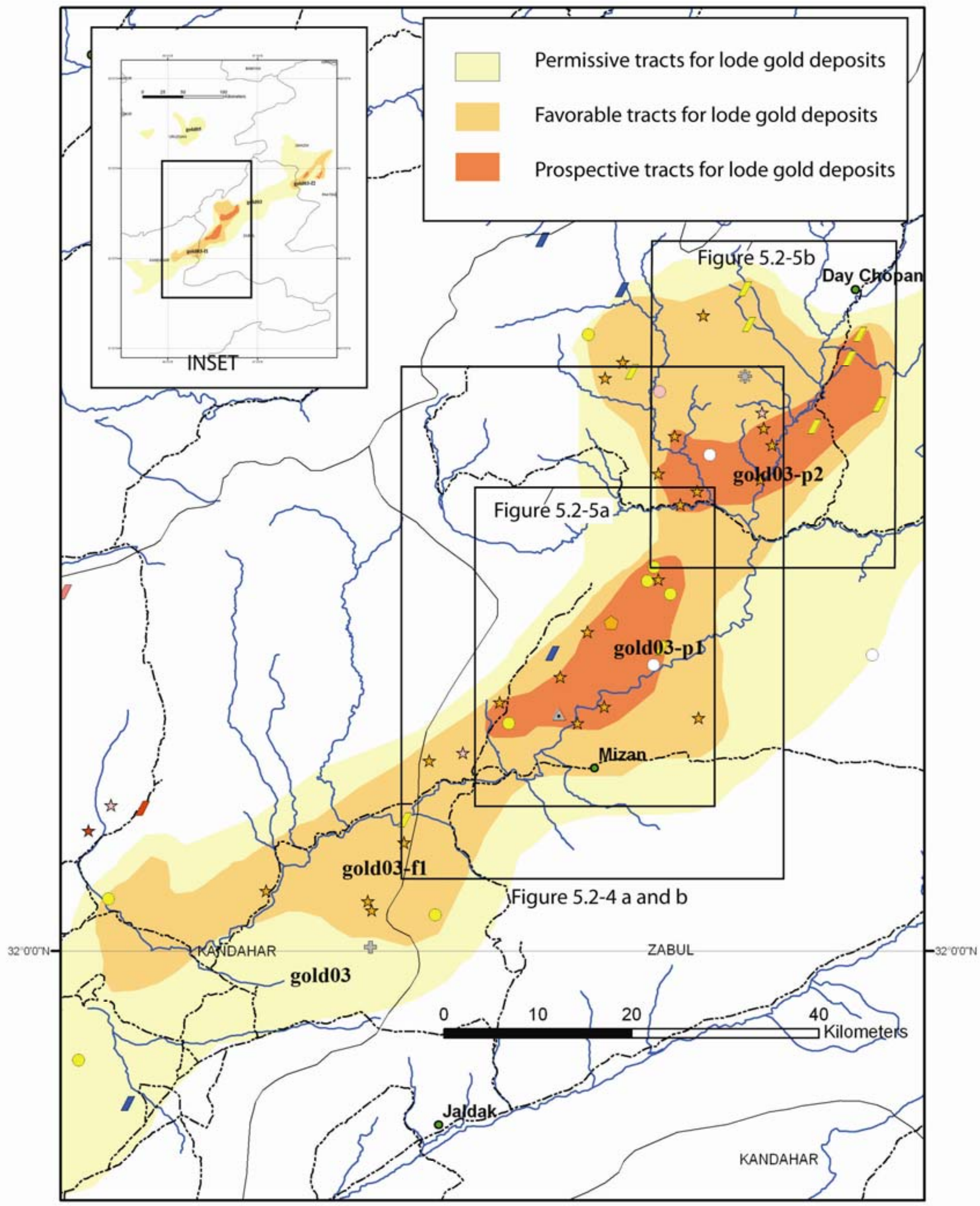

Figure 5.2-3. Map showing location of favorable tract gold03-f1 in Kandahar and Zabul provinces with internal prospective tracts gold03-p1 and gold03-p2.

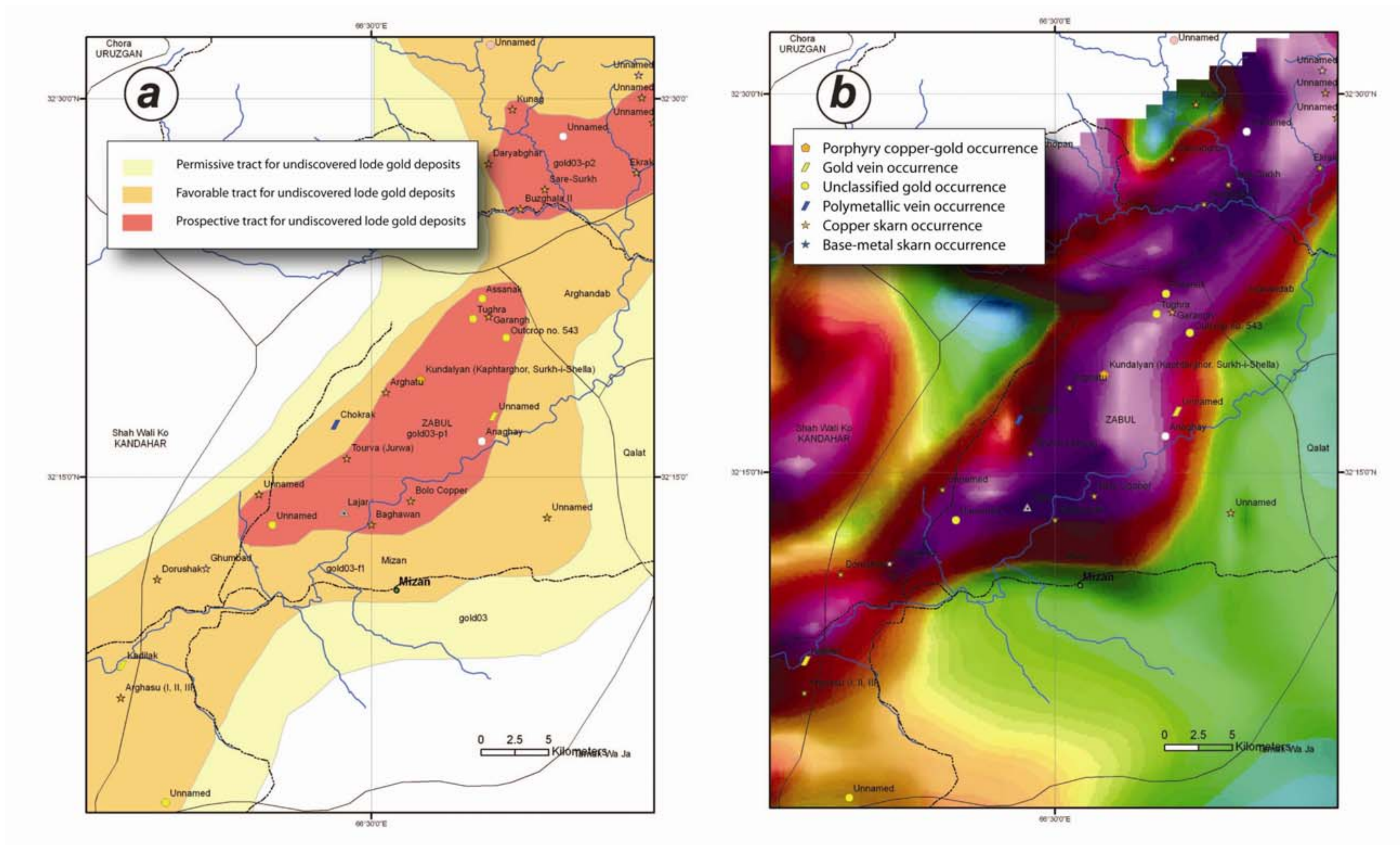

Figure 5.2-4. Maps showing parts of tract permissive gold03-f1 where aeromagnetic data were available for use in the assessment. (*a*) Area of the Kundalyan porphyry prospect and prospective tract gold01-p1 in Zabul Province. (*b*) Contoured aeromagnetic map of area in (a)

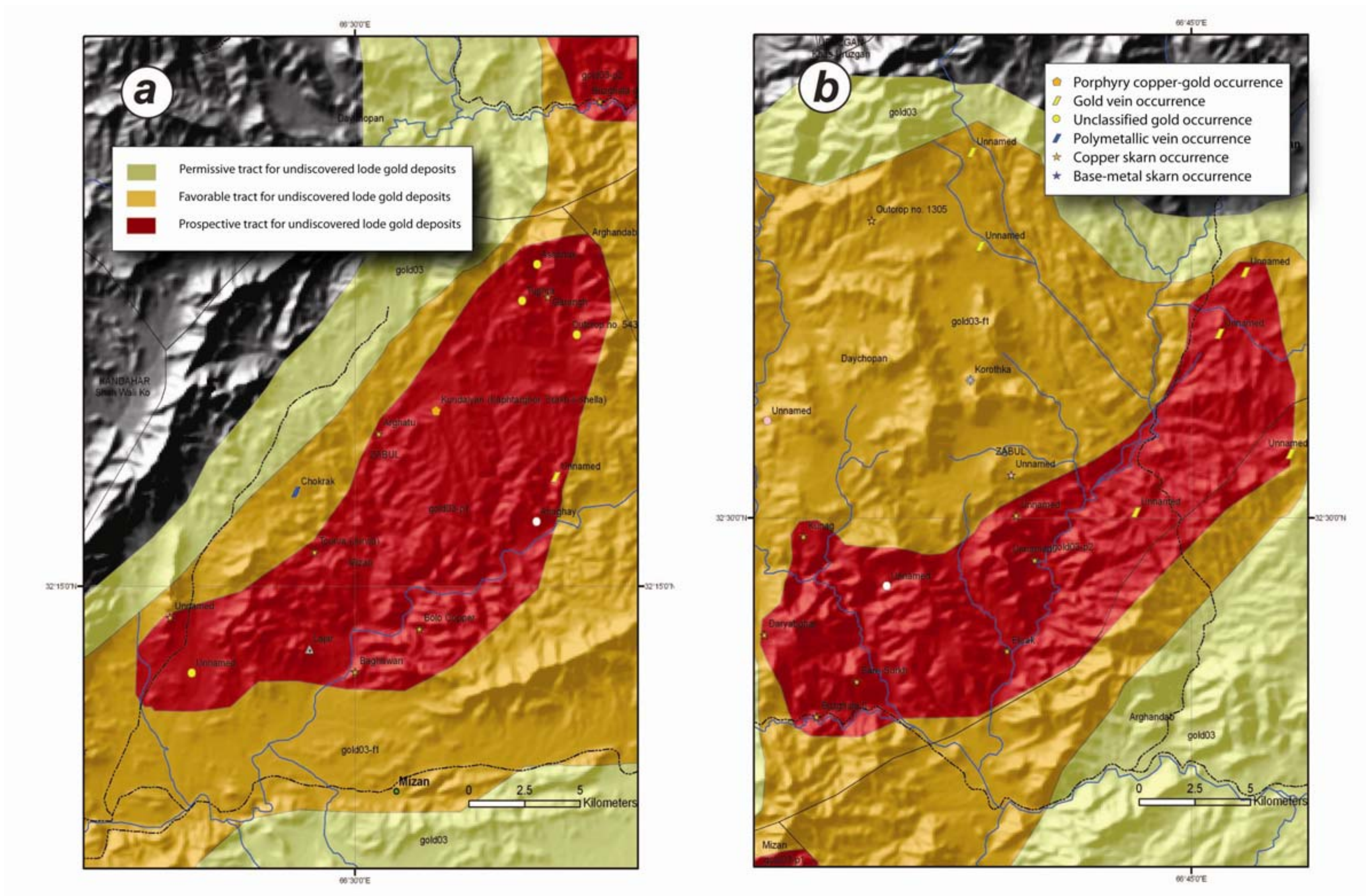

Figure 5.2-5. Map showing location of prospective tracts gold03-p1 and gold03-p2 in Zabul Province. (*a*) Prospective tract gold03-p1 surrounding the Kundalyan porphyry copper mineralized system for undiscovered pluton-related gold deposits in Mizan District. (*b*) Prospective tract gold03-p2 surrounding a number of gold skarns and gold veins in Daychopan District.

Favorable tract gold03-f2

Favorable tract gold03-f2 was delineated in Ghazni Province along a 60–km-long, approximately 10–km-wide, zone along the eastern contact with an Oligocene granite and Cretaceous plutons. A southern 20–km-long zone lies in the eastern lobe along the western contact with a Cretaceous pluton that contains a number of gold-rich mineral occurrences associated with these contacts (fig. 5.2-6). Two prospective tracts, gold03-p3 and gold03-p4, were delineated within the favorable tract.

Prospective tract gold03-p3 Bolo gold.

The Bolo gold03-p3 was delineated around a number of gold-rich occurrences adjacent to the eastern contact of a Cretaceous granite pluton. The tract contains the Bolo gold, Laghzar, Bella, Lashkar-Qala, and Utkul gold occurrences, as well as a number of other pluton related gold-bearing base-metal occurrences (fig. 5.2-7a). The Bolo gold occurrence is present in both a brecciated zone that grades 0.8 to 34 g/t gold and in a zone of ferruginous rocks grading 10 to 11 g/t gold. The Alaghzar copper occurrence contains grades of between 0.1 to 1.6 g/t gold with to up to 35 g/t gold and between 0.1 and 3.1 wt. percent copper. The Bela copper skarn occurrences contain grades of 0.1 to 1.4 g/t gold with traces of copper and zinc. The Lashkar-Qala gold occurrence is hosted in Upper Permian marbled, dolomitized, altered limestone along a fault zone that is 160 m long and up to 9.5 m wide containing disseminated pyrite, chalcopyrite with native gold grading 0.1 to 19.4 g/t gold (averaging 1.1 g/t gold) and up to 2.4 to 3.5 wt. percent copper. The Utkul gold occurrence also is hosted in Upper Permian marble in a 300–m-long, 0.5–m-wide fault zone containing sulfide minerals; mineralized zones are 1.0 to 5.0 by 0.5 m grading 10 to 11 g/t gold.

Prospective tract gold03-p3 Dynamitic.

A prospective tract gold03-p4 was delineated along the western contact of a Cretaceous granitic pluton (map unit **KP$_1$gbm** from Doebrich and Wahl, 2006) (fig. 5.2-7b). The tract contains the Choh-i-Surkh and Dynamitic gold occurrences and several gold-rich copper skarn occurrences that are described in section 5.0. The Dynamitic gold occurrence is hosted in 0.6– to 1.2–m-thick brecciated zones in Middle Triassic marble and limestone that grade 4 to 70 g/t gold. The Choh-i-Surkh gold occurrence has similar geology and lies in 100–m-long and 0.2– to 2.5–m-wide zones grading 0.6 to 3.2 g/t gold (Mescheriakov and others, 1969; Kovalenko and others, 1971). The 6–km-long Zarkashan placer gold deposit also drains from the prospective tract within the major drainages.

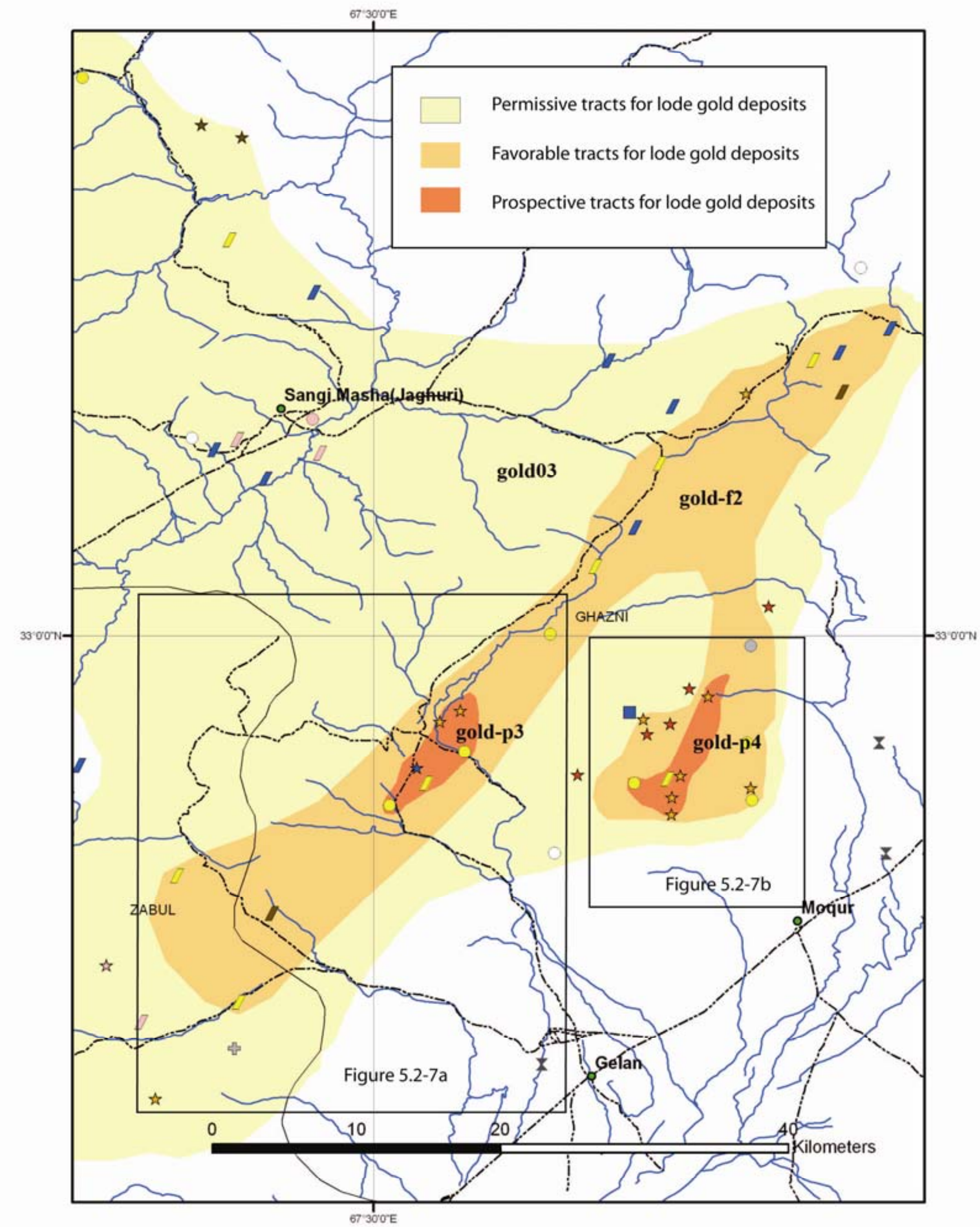

Figure 5.2-6. Map showing location of tract gold03-f2 tract favorable for undiscovered pluton-related gold deposits and location of internal prospective tracts gold03-p3 and gold03-p4.

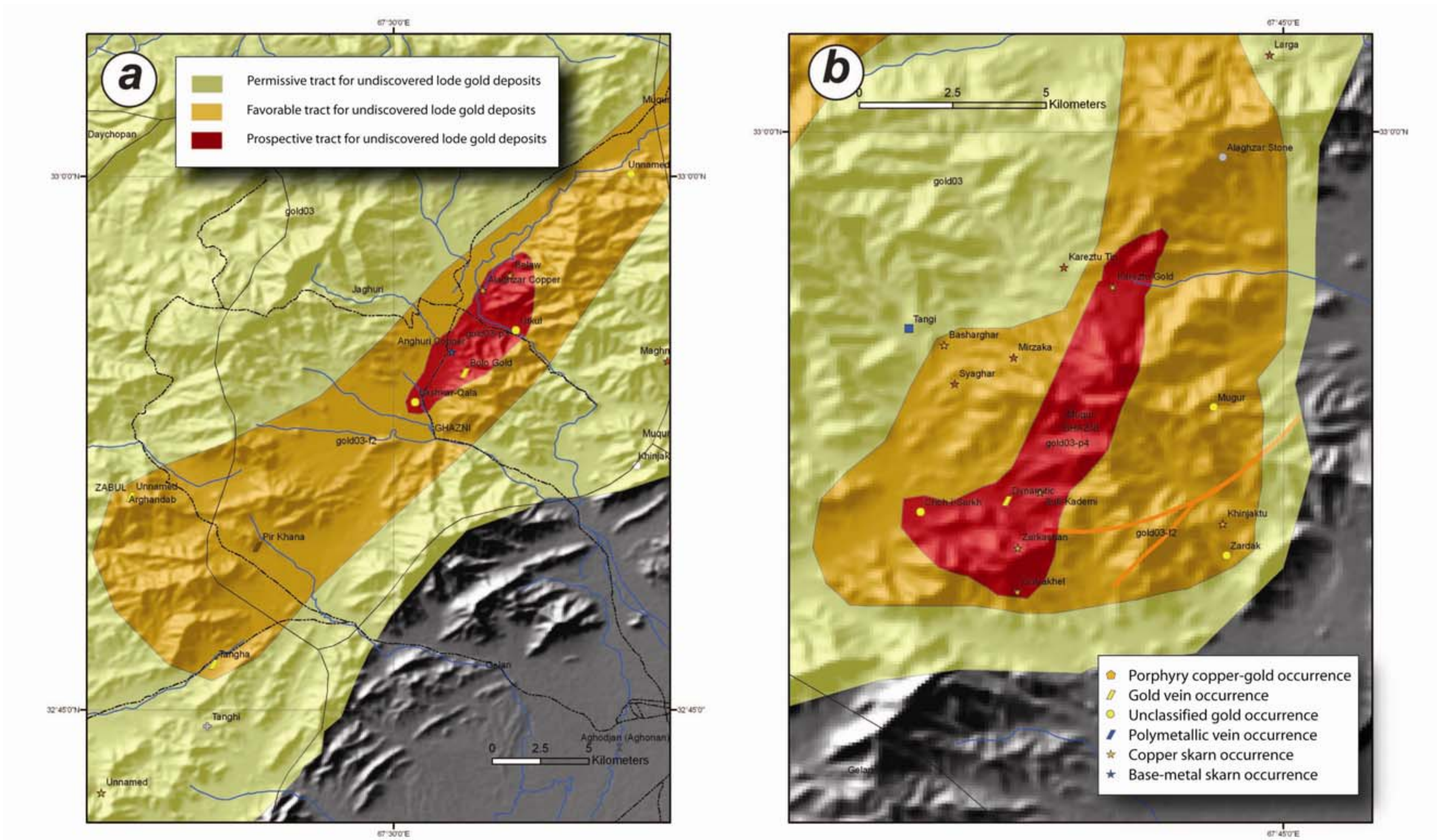

Figure 5.2-7. Maps showing location of Prospective tracts gold03-p3 and gold01-p4 in Ghazni Province. (*a*) Map showing location of Prospective tract gold03-p3 in Jaghuri district containing the Bolo Gold, Utkul and Alaghzar Copper and other occurrences. (*b*) Map showing Prospective tract gold03-p4 in Muqur District containing the Zarkashan skarn/porphyry copper occurrence, the dynamite gold occurrences and several other gold-rich occurrences. Orange lines represent known alluvial gold placer occurrence (see section 10.2).

Needs to improve assessment—This permissive tract requires field examination and detailed mapping to determine what the distribution of gold mineralized rock is. Several man-months in each of the two parts of the tract would be needed. The magnetite-rich skarns would respond well to ground magnetometer surveys. In addition, the mineralization age should be determined, to confirm which mineralized systems are related to the Cretaceous plutons and which are related to Oligocene plutons exposed in the area (fig. 5.2-4b and Doebrich and Wahl, 2006).

Optimistic factors—The presence of relatively well-explored deposits (Kundalyan and Zarkashan) is the most important positive indication. The gold-rich mineral occurrences are indications that the area may have significant economic favorability. Previous mining activity in the area is also a favorable indication. The petrologic characteristics of the associated intrusive rocks and the available assays suggest that the copper deposits found here might be gold-bearing.

Pessimistic factors—The previous exploration did not reveal economically important porphyry copper-style deposits (section 5.1). No significant gold production has been noted by previous workers.

Quantitative assessment—No quantitative estimate was done because of lack of an appropriate deposit models.

References

Abdullah, Sh., Chmyriov, V.M., Stazhilo-Alekseev, K.F., Dronov, V.I., Gannon, P.J., Lubemov, B.K., Kafarskiy, A.Kh., and Malyarov, E.P., 1977, Mineral resources of Afghanistan (2nd ed.): Kabul, Ministry of Mines and industries of the Democratic Republic of Afghanistan, Afghan Geological and Mines Survey, United nations Development programme support Project AFG/74/12, 419 p.

Ahmad, M. U., 1992, Porphyry copper in Pakistan: Geological Survey of Pakistan, no. 9, 21 p.

Ahmed, W., Khan, S.N., and Schmidt, R.G., 1972, Geology and copper mineralization of the Saindak Quadrangle, Chagai district, West Pakistan: U.S. Geological Survey Professional Paper 716–A, 21 p.

Ahmad, M.U., Siddiqui, R.H., and Chaudhary, M.A., 1986, Geological and geochemical exploration and preliminary evaluation of Dasht-e-Kain porphyry copper-molybdenum prospect, Chagai district, Baluchistan, Pakistan: Geological Survey of Pakistan, Mineral Resources Records, v. 72, 44 p.

Bliss, J.D., and Cox, D.P., 1986, Grade and tonnage model of polymetallic veins, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 125–129.

Bordet, P., Dubreuil, M., and Vachard, D., 1984, Geology of central Afghanistan; geologic maps at 1/100000 of Malestan and Dacht-E Nawar: Documents et Travaux de l'Institut Geologique Albert de Lapparent, vol.7, 63 p.

Breitzman, L. L., Birnie, R. W., and Johnson, G. D., 1983, Fission-track ages of the Chagai intrusives, Baluchistan, Pakistan: Geological Society of America Bulletin, v. 94, p. 253–258.

Chmyriov, V.M., and Mirzad, S.H. , 1972, Geological map of Afghanistan: Ministry of Mines and Industries of Royal Afghanistan, Department of Geology and Mines, scale 1:1,000,000.

Cox, D.P., 1986a, Descriptive model of Fe skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 94.

Cox, D.P., 1986b, Descriptive model of polymetallic veins, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 125.

Cox, D.P., 1986c, Descriptive model of porphyry Cu, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 76.

Cox, D.P., 1986d, Descriptive model of porphyry Cu, skarn-related deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 82.

Cox, D.P., 1986e, Descriptive model of porphyry Cu-Au, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 110.

Cox, D.P., 1986f, Descriptive model of porphyry Cu-Mo, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 115.

Cox, D.P., 1986g, Descriptive model of Zn-Pb skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 90.

Cox, D.P. and Theodore, T.G., 1986, Descriptive model of Cu skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 86.

Debon, F., Afzali, H., Le Fort, P., and Sonet, J., and Zimmermann, J.L., 1987, Plutonic rocks and associations in Afghanistan—typology, age, and geodynamic setting: Mémoires Sciences de la Terre, No. 49, 132 p.

Doebrich, J.L., and Wahl, R.R., 2006, Geologic and mineral resource map of Afghanistan: U.S. Geological Survey Open-file Report 2006-1038, 1 sheet scale 1:850,000, available on line at *http://pubs.usgs.gov/of/2006/1038/*.

Douvgal, Yu.M., Chalyan, M.A., Nagalev, V.S., Demin, A.N., Vaulin, V.A., Belich, A.I., Sonin, I.I., Kononykhin, E.T., Zharikhin, K.G., Maksimov, N.P., Skvortsov, N.S., and Kharitonov, A.P., 1971, The geology and minerals of the south–eastern part of Central Afghanistan: Department of Geological and Mineral Survey, Kabul, scale 1:200,000, unpub. data.

Drew, L.J., and Menzie, W.D., 1993, Is there a metric for mineral deposit occurrence probabilities?: Nonrenewable Resources, v. 2, p. 92–105.

Dronov, V.I., Kalimulin, S.M., and Sborshchikov, I.M., 1972, The geology and minerals of North Afghanistan: Department of Geological and Mineral Survey, Kabul, unpub. data.

Efimenko, V.N., Rulkovskiy, M.F., Potapov, V.V., Koshelev, Yu.M., and Gorbunov, A.G., 1973, Report on the results of prospecting for tin within the Darrahe–Nur and the "Tourmaline" occurrences area in 1971: Department of Geological and Mineral Survey, Kabul, unpub. data.

ESCAP, 1995, Geology and mineral resources of Afghanistan: Atlas of mineral resources of the ESCAP region, v. 11, United Nations, New York, 82 p.

Jones, G.M. and Menzie, W.D., 1986, Grade and tonnage model of Cu skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 86–89.

Kabakov, O.N., 1973, Summary on tin occurrences in Afghanistan: Department of Geological and Mineral Survey, Kabul, unpub. data.

Kafarskiy, A.Kh., Stazhilo-Alekseev, K.F., Pyzhyanov, I.V., Achilov, G.Sh., Gorelov, A.I., Bezulov, G.M., and Gazanfari, S.M., 1972, The geology and minerals of the Western Hindu Kush and the eastern part of the Bande-Turkestan: Department of Geological and Mineral Survey, Kabul, unpub. data.

Kazmi, A.H., and Qasim Jan, M., 1997, Geology and tectonics of Pakistan: Graphic Publishers, Karachi, 554 p.

Khasanov, R.M., Plotnikov, G.I., Bayazitov, R., Sayapin, V.I., and Trifonov, A., 1967, Report on revised estimation investigations of mineral deposits and occurrences of copper, lead, zinc and gold in 1965–V. I–II: Department of Geological and Mineral Survey, Kabul, unpub. data.

Koshelev, Yu.M., Drannikov, V.S., and Konev, Yu.M., 1972, Report on geological prospecting in South–Eastern Afghanistan in 1972: Department of Geological and Mineral Survey, Kabul, scale 1:500,000, unpub. data.

Leaman, P., and Staude, J.-M., 2003, Metallogenic evolution of the western Tethys of Turkey and Iran: MMAJ Forum Presentation, 24 p., available on line at [*www.mmaj.go.jp/mric_web/MMAJ_Forum*.

Mars, J.C., and Rowan, L.C., 2007, Mapping phyllic and argillic-altered rocks in southeastern Afghanistan using advanced spaceborne thermal emission and reflection radiometer (ASTER) data: U.S. Geological survey Open-file Report 2007-1006, available on line at *http://pubs.usgs.gov/of/2007/1006/*.

Meshcheryakov, E.P. and Borozenets, N.I., 1970, Report on geological-exploration results obtained within the Moqur mineralized area in 1969. V. I-II: Department of Geological and Mineral Survey, Kabul, unpub. data.

Montenat, C., Vachard, D., Ouedraogo, A., Bebien, J., and Desmet, A., 1986, Le bassin volcano-sédimentaire de Kandahar (Afghanistan)-un jalon de la marge active Nord-Téthysienne au malm et au Crétacé inférieur, *in* Le Fort, P., Colchen, M., and Montenat, C., eds., Orogenic evolution of southern Asia (from Turkey to Indonesia): Mémoires Sciences de la Terre, no. 47, p. 253-283.

Morris, H.T., 1986, Descriptive model of polymetallic replacement deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 99.

Mosier, D.L. 1986, Grade and tonnage model of Zn-Pb skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 90–93.

Mosier, D.L. and Menzie, W.D., 1986, Grade and tonnage model of Fe skarn deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 94–97.

Mosier, D.L., Morris, H.T., and Singer, D.A., 1986, Grade and tonnage model of polymetallic replacement deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 101–104.

Orris, G J, and Bliss, J D. 2002, Mines and Mineral Occurrences of Afghanistan: U.S. Geological Survey Open-file Report 02-110, available on line at *http://geopubs.wr.usgs.gov/open-file/of02-110/*.

Plotnikov, G.I. and Slozhenikin, A.P., 1968, Report on the results and revised evaluation work of copper, lead–zinc, and gold occurrences in Afghanistan carried out in 1967: Department of Geological and Mineral Survey, Kabul, unpub. data.

Shcherbina, Yu.I., Tarasenko, V.I., and Palvanov, G., 1974, Report of the Adreskan crew on the results of prospecting–evaluation work carried out within the Okhankashan copper–gold–bearing occurrence: Department of Geological and Mineral Survey, Kabul, unpub. data.

Sillitoe, R. H., and Khan, S. N., 1977, Geology of Saindak porphyry copper deposit, Pakistan: Institution of Mining and Metallurgy Transaction Section B, v. 86, p. B27–B42.

Sillitoe, R.H., 1978, Metallogenic evolution of a collisional mountain belt in Pakistan: a preliminary analysis: Journal of the Geological Society of London, v. 135, p. 377–387.

Singer, D.A., 1986, Grade and tonnage model of porphyry Cu, skarn-related deposits, *in* Cox, D.P., and Singer, D.A., eds., Mineral deposit models: U.S. Geological Survey Bulletin 1693, p. 82–85.

Singer, D.A., Berger, V.I., and Moring, B.C., 2005, Porphyry copper deposits of the world: database, map, and grade and tonnage models; U.S. Geological Survey Open-file Report 2005-1060, [available on line at *http://pubs.usgs.gov/of/2005/1060/*.

Spector, A., Hood, P.J., Farah, A., and Ahmed, W., 1987, Applications of aeromagnetic data to mineral-resources exploration—Baluchistan, Pakistan in M.F. Kane, N.W. O'Hara, M.S. Redford, J., Tanner, C. Weber, eds., The Utility of Regional Gravity and Magnetic Anomaly Maps, Society of Exploration Geophysicists, Tulsa, p. 132–143.

Sweeney, R.E., Kucks, R.P., Hill, P.L, and Finn, C.A., 2006, Aeromagnetic and gravity surveys in Afghanistan: A web site for distribution of data: U.S. Geological Survey Open-file Report 1204, available on line at *http://pubs.usgs.gov/of/2006/1204/*.

Tarasenko V.I., Kovalenko A.C., Arwanitaki S.B., Borozenets N.I., 1973, Report on the results of geological prospecting and survey for copper and base metals carried out by the Andreskan and Dusar teams in Western Afghanistan in 1971-1972: Department of Geological and Mineral Survey, Kabul, unpub. data.