7.0 Deposits associated with sedimentary processes or rocks

Deposits associated with sedimentary processes or rocks include a number of metallic and industrial mineral deposit types and commodities. The most important metallic deposit type in Afghanistan is sediment-hosted copper represented by the Aynak and associated deposits (section 7.1). Deposits and occurrences of lead and zinc and barite also are present in the central part of the country (section 7.2). Industrial minerals that formed due to sedimentary processes or rocks include various types of deposits of clays (section 7.3) and limestone (section 7.4). Deposits related to chemical-sedimentary processes are discussed in section 8.0.

7.1 Sediment-hosted copper

Contribution by Stephen G. Peters and Walter J. Bawiec.

Sediment-hosted copper deposits are a large and diverse group that includes some of the richest and largest copper deposits in the world (Gustafson and Williams, 1981; Kirkham, 1989; Davidson and Large, 1998). Examples are copper deposits of the Zambian Copper Belt, which have produced in excess of one billion metric tons of copper at an average grade of approximately 2.7 wt. percent copper, as well as significant quantities of cobalt and silver (e.g. Selley and others, 2005).

7.1.1 Description of sediment-hosted copper deposit models

Sediment-hosted copper deposits are formed by fluid mixing in permeable sedimentary and (more rarely) volcanic rocks. Two fluids are thought to be involved: an oxidized brine carrying copper as a chloride complex, and a reduced fluid that commonly formed in the presence of anaerobic sulfate-reducing bacteria. For a sediment-hosted copper deposit to form, four conditions are required: (1) an oxidized source rock, (2) a brine to mobilize copper, (3) a reduced fluid to precipitate copper, and (4) conditions favorable for fluid mixing (Haynes, 1986a, b; Sverjensky, 1989; Ruffell and others, 1997).

Sediment-hosted copper deposits are restricted to a narrow range of layers within a sedimentary sequence but do not necessarily follow sedimentary bedding. They formed after the host sediment is deposited, but in most cases, prior to lithification of the host. Mineralization is independent of igneous processes. Host rocks comprise two types: calcareous or dolomitic siltstone, shale, and carbonate rocks of marine or lacustrine origin; and non marine sandstone, arkose, and conglomerate. In addition, the iron oxide copper-gold and basaltic copper deposit sub models may be applicable within some of the areas studied.

Deposits of the reduced-facies subtype (model 30b.1; Cox and others, 2003), also termed copper-shale or stratiform copper deposits, are hosted by reduced-facies marine or lacustrine rocks such as green, black, or gray shale, siltstone, thinly-laminated tidal facies or reefoid carbonate rocks, and dolomitic shale. The deposits consist of stratabound, disseminated copper sulfide minerals that occur in reduced-facies sedimentary rocks, which overlie, or are interbedded with, red-bed sedimentary sequences or subaerial basalt flows. Copper is mobilized in the red beds by oxidized brines and is derived from reduction of sulfate in marine or lacustrine sedimentary rocks (Davidson, 1965). Fine-grained clastic rocks and carbonate rocks host 69 percent of deposits and occurrences (Lindsey, 1982; Cox and others, 2003). Organic carbon and finely disseminated pyrite are common constituents. Host rocks for 16 percent of the occurrences are carbonaceous, bituminous, algal or stromatolitic. Thick, subaerial basalt flows are sources of copper in a few deposits (Brown, 1984). Evaporite beds are sources of brine for many deposits. Many of the most important sediment-hosted copper deposits formed during the metallogenic period of the Neoproterozoic when most of the world's continental masses were joined in the Rodinia supercontinent (Laznika, 1981; Kirkham, 1989; Kirkham and others, 1994).

Revised grade and tonnage models of the sediment-hosted copper deposits (Cox and others, 2003) contain data for copper, silver, and cobalt that were extracted from 133 deposits with tonnages and grades based on reserve and production data. For purposes of tonnage and grade sub modeling, a deposit is defined as one or more separate ore bodies separated from its nearest neighbor by less than 2,000 m. The median tonnage of the entire set of deposits is 11 million metric tons (Mt) and the mean copper grade is 1.7 wt. percent. A silver grade is available for 37 of these and the upper ten percent of deposits contains 30 g/t. Cobalt grade of the upper ten percent is 0.2 wt. percent based on data for 18 deposits. Distribution is log normal; tonnage and metal grades are independent. The reduced-facies subtype that we applied to the Aynak group of deposits consists of deposits that are typically large and rich in metals with a median tonnage of 33 million metric tons and grade of 2.3 wt. percent copper for 58 deposits worldwide (Cox and others, 2003).

The assessment for undiscovered sediment-hosted copper deposits in Afghanistan considered mainly one descriptive grade-tonnage sub model for sediment-hosted copper deposits, the reduced-facies model (Cox and others, 2003). This sub model supersedes the general sediment-hosted copper model (Cox, 1986; Mosier and others, 1986), which has been subdivided by Cox and others (2003) into three subtypes. The reduced-facies subtype is based on differences from the other subtypes in deposit form, characteristics, and environment of deposition.

Aynak, the largest and best known sediment-hosted copper deposit in Afghanistan, is a world-class copper orebody located about 30 km southeast of Kabul. The copper mineralization is stratabound and consists primarily of chalcopyrite and bornite disseminated in dolomitic marble and quartz-biotite-dolomite schist of the Neoproterozoic (Vendian)-Lower Cambrian Loy Khwar Formation. It has been delineated by more than 150 boreholes (Plotnikov and Slozhenikin, 1968; Slavin and others, 1972; Chmyrev and others, 1976; Chmyrev and Azmi, 1977; Sidiki, 1978; Yurgenson and others, 1981, 1985).

The Aynak orebody can be classified as a sediment-hosted copper deposit. It is believed to have formed by reactions between evaporitic brines and seawater circulating through underlying volcanic rocks that supplied the copper in the deposit. Some of the limestones and marls in the Loy Khwar Formation contain abundant carbon, probably former organic material that reacted with ascending solutions to fix copper sulfide minerals. Ludington and others (2006) indicated that it was unclear, whether this deposit should be classified as a reduced-facies subtype of the sediment-hosted copper model (Cox and others, 2003), so that team assessed the tract for deposits like Aynak. In addition to the Aynak deposit, numerous other sediment-hosted copper occurrences and prospects are present in the area, such as the Darband and Jawkhar prospects, which are north and east of the Aynak deposit. Considerable exploration was undertaken by Soviet geologists on a number of these prospects (ESCAP, 1995; Afghanistan Geological Survey, 2006a, b).

A summary of known resources in the Aynak ore field (Abdullah and others, 1977, and Ministry of Mines, written commun, 2007) are as follows:

Deposit	Metric tons Cu	Grade wt. percent Cu	Metric tons ore (million metric tons)
Aynak	11,330,000	1.64	690.8
Jawhar	164,800	0.33-2.56*	11.4
Darband	665,700	0.79	84.3
Taghar	86,800	0.18	48.2
Katasang	42,100	1.04	3.0
Dashtak	8,200	1.67	0.5
Kelaghey	43,000	0.91	4.7
Total	**12,340,600**	**1.46**	**842.9**

Two types of ores are known: the bornite type (with sub-ordinate chalcocite), which makes up the main orebody, and the chalcopyrite type, which is present above and below the main orebody. Transitions between the two ore types display a rhythmic-zoning, corresponding to the compositional layering of the sedimentary host rocks. The upper parts of the orebody are hosted within carbonaceous quartz-sericite-biotite schists, sandstones and breccia and contain chalcopyrite, pyrite with sphalerite and molybdenite. This upper part is underlain by sandstone, conglomerate, breccia, and dolomite and is dominated by bornite with lesser chalcopyrite, magnetite, molybdenite and cobaltite. The lower parts of the orebody are hosted in carbonaceous quartz-dolomite schists with breccia and contain chalcopyrite and pyrrhotite with lesser pyrite, cobaltite, siegenite, and sphalerite (Yurgenson and others, 1981).

Cobalt concentrations in the Aynak copper ores that contain cobaltite is in the range from thousands of per cent to 0.3 wt. percent cobalt. Cobalt minerals are present mainly in the chalcopyrite ores, pyrite-chalcopyrite, and bornite-chalcopyrite ores, where concentrations of cobalt are between 0.015 to 0.018 wt. percent cobalt. Cobaltite is the most common cobalt mineral in the deposit and occurs as dispersed disseminated 0.05– to 5–mm-sized crystals and aggregates. The main occurrences of cobaltite are in the lower parts of the main ore body in chalcopyrite ores. Cobaltite also is present in the upper parts of the main orebody. Cobaltite in the bornite-chalcopyrite ores is associated with linneite, smaltite, carrolite, and cobaltpentlandite. Spatial distribution of cobalt minerals in the orebody is related to the compositional variation of the layers in the host rocks and therefore also with the zoning of the copper minerals (Yurgenson and others, 1985).

7.1.2 Description of sediment-hosted copper assessment tracts

Two permissive tracts, sedcu01 and sedcu02 were delineated for sediment-hosted copper deposits in the Neoproterozoic sedimentary rocks. The northern tract, sedcu01 in Kabul and Logar Provinces contains numerous deposits and occurrences including the Aynak deposit. Additional favorable and prospective tracts were delineated within sedcu01. Tract sedCu02 to the south, which lacks known deposits, is dominated by younger intrusive-related copper deposits (fig. 7.1-1).

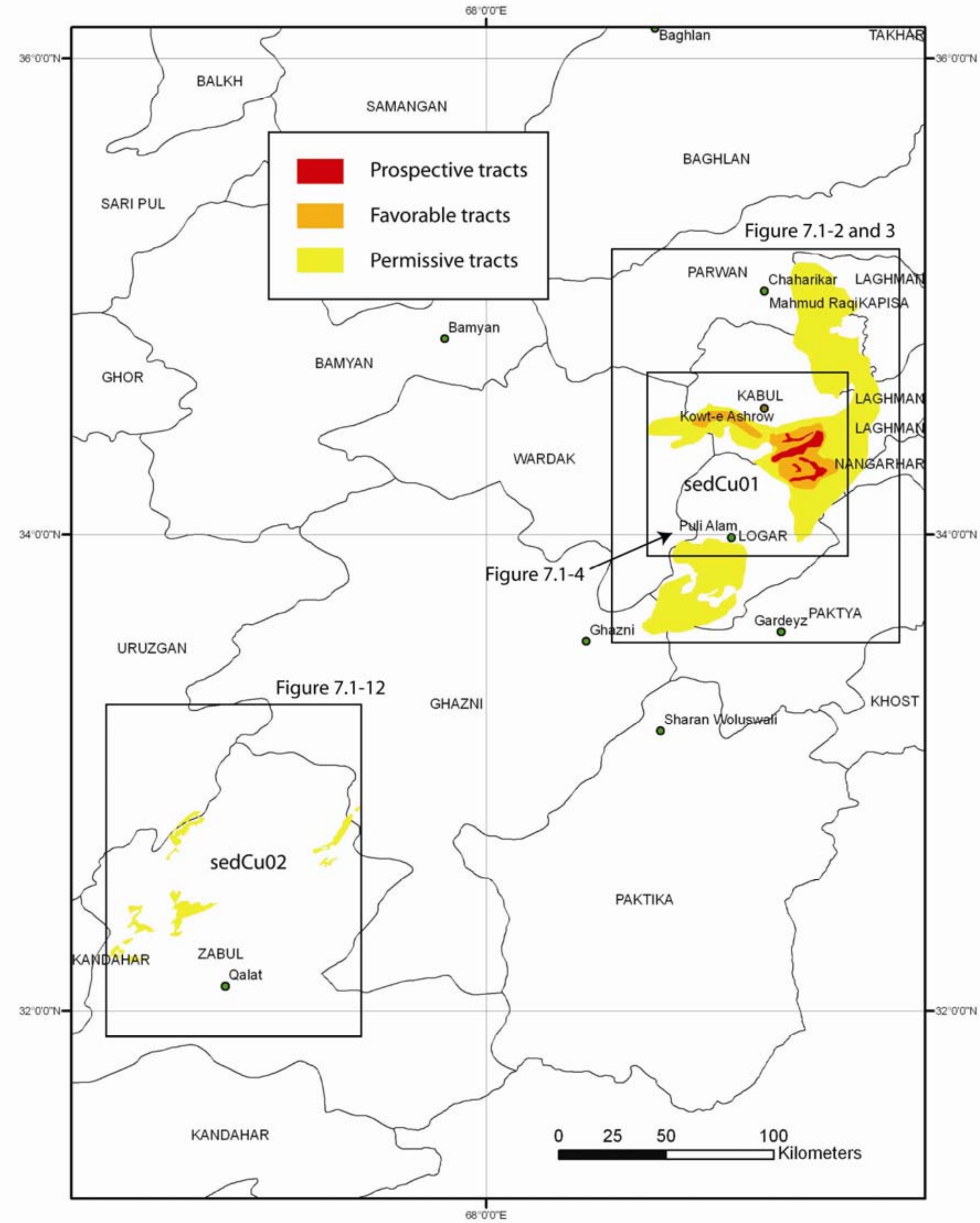


Figure 7.1-1. Map showing location of tracts sedcu01 and sedcu02 where undiscovered sediment-hosted copper deposits might be present.

Permissive Tract sedcu01 Aynak area

Deposit type—Sediment-hosted copper, reduced-facies subtype

Age of mineralization—Neoproterozoic to Early Cambrian

Examples of deposit type—The tract contains the Aynak, Darband, and Jawkhar sediment-hosted copper deposits and many other mineral occurrences.

Exploration history—The Aynak deposit and the surrounding areas were explored in the 1960s and 1970s. Main exploration work in the Aynak area started in 1974 and ended in 1978. Aynak has been explored by more than 150 boreholes (Kubatkin and others, 1978; Kolotov and others, 1981; Karim and others, 1992). Two major ore zones at Aynak Central and Aynak West were delineated by more than 30,000 m of drilling. The first copper occurrences in the Darband area were discovered in 1971 (Denikaev and others, 1971). In addition to drilling, geochemistry and ground geophysical methods were employed. During the same time period, about 40 prospects with similar characteristics were identified, a few of which have small measured or estimated resources (Afghanistan Geological Survey, 2006a).

Tract boundary criteria—The sedcu01 Aynak area permissive tract outlines the area within the Kabul tectonic block where map unit ***ZeꞒld*** may be present at depths less than 1 km, as well as at the surface. This map unit consists of marble, quartzite, meta-sandstone, and mica schist, and is the host rock for the Aynak deposits. To the south, the tract terminates against a large Oligocene granodiorite intrusion. Two versions of the tract were delineated. The first tract is from Ludington and others (2007). The second is revised for this report. Four small sedimentary-hosted copper prospects not included in the original tract to the west were included in a second version. Although these prospects are reported to occur in Ediacaran (formerly Vendian; that is, Neoproterozoic) rocks, the outcrop areas are restricted in thickness and extent and do not appear on the geologic map. The first tract was also revised after subtraction of Eocene intrusive dunite body, north Logar Province, in the south-central parts and extension of a western limb, south of the city of Kabul (figs. 7.1-1, 2 and 3). The dunite was assumed to be greater than 1 km thick. These two tracts represent two interpretations of the distribution of the host unit away from the known outcrops.

Important data sources—Geologic map, aeromagnetic and gravity data (Sweeney and others, 2006), mineral deposit database (Doebrich and Wahl, 2006), Aynak information CD (British Geological Survey, 2005)

Needs to improve assessment—The information most needed is an intermediate-scale (1:100,000) geologic map of parts of the tract distant from the Aynak deposit (particularly in the north). The rock mapped as ***ZeꞒld*** (from Doebrich and Wahl, 2006) northeast and south of Kabul should be visited and described, in an effort to understand why copper prospects are apparently absent in that region. The descriptions of the Aynak deposit should be evaluated to enhance proper classification of the deposit.

Optimistic factors—Large discovered copper resources exist in the tract, and a large number of prospects.

Pessimistic factors—Part of the tract is relatively well explored, and further discoveries there are not likely. The classification of the deposits is uncertain, and this leads to uncertainty in how to evaluate the importance of understanding the depositional environment of similar rocks distant from the Aynak deposit.

***Quantitative assessment*—**The estimate made in Ludington and others (2006) is strictly for "Aynak-type" deposits, as that team was uncertain of the correct classification of the deposits. For the Aynak area tract (sedcu01), Ludington and others (2006) found that there is a 90 percent chance of 1 or more undiscovered Aynak-type copper deposits, a 50 percent chance of 3 or more, and a 10 percent chance of 8 or more (table 7.1-1). The estimate is subjective and is based on expert opinion and analogy with geologically similar, well-explored areas in other parts of the world. This estimate results in a mean estimate of 3.83 undiscovered deposits. In order to quantify this estimate, because to grade and tonnage model exists for Aynak deposits, the Aynak deposit and its surrounding prospects and smaller deposits were assumed to reduced facies sediment-copper deposits. The estimates, using this model, then generate probabilistic estimates of the amounts of copper and cobalt contained in the estimated undiscovered deposits using Monte Carlo simulation using (see section 1.3) tabulated and shown graphically in table 7.1-1 and figures 7.1-8, and 7.1-9.

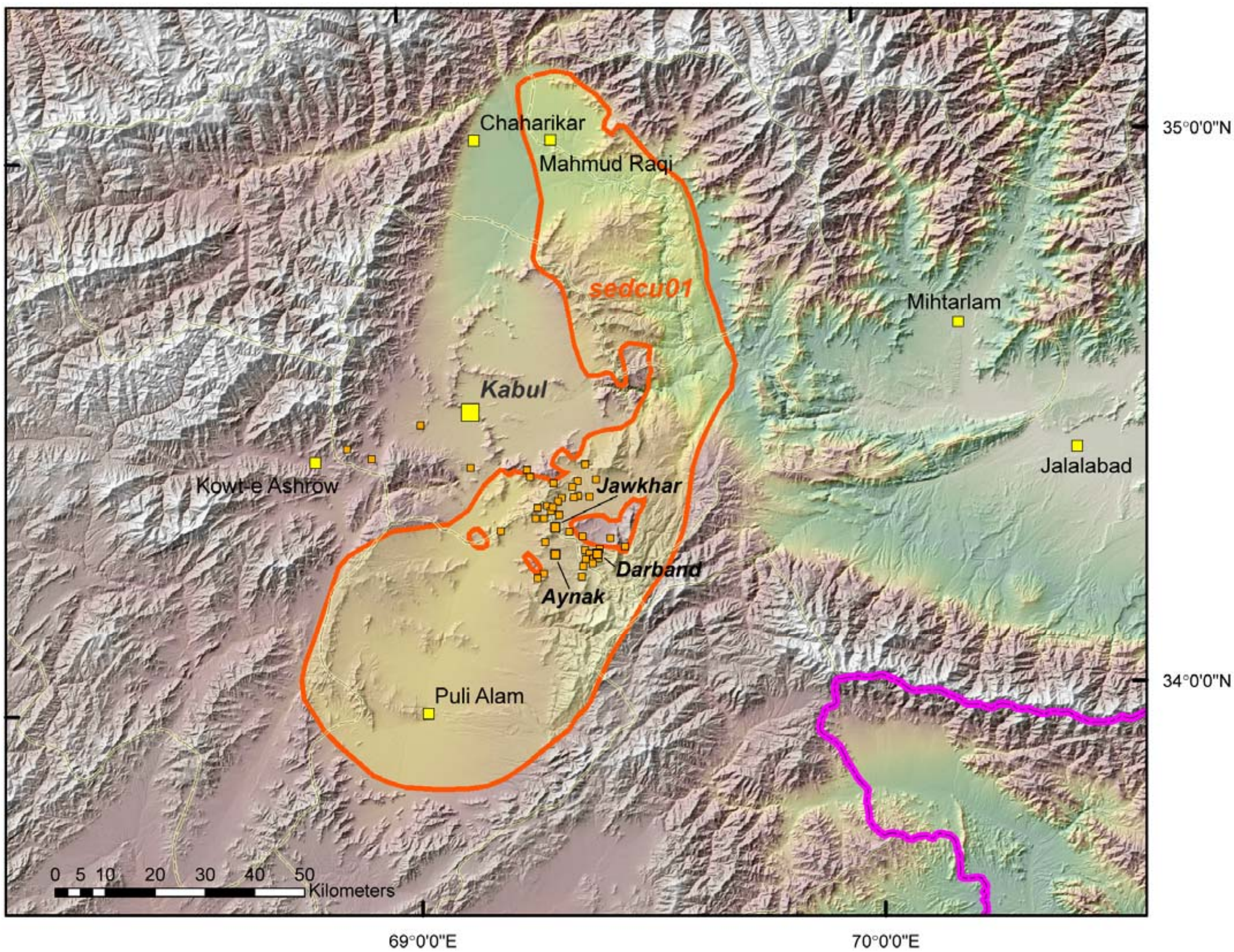


Figure 7.1-2. Map showing version one of permissive tract sedcu01, and locations of known deposits and prospects (orange squares) from Ludington and others (2007).

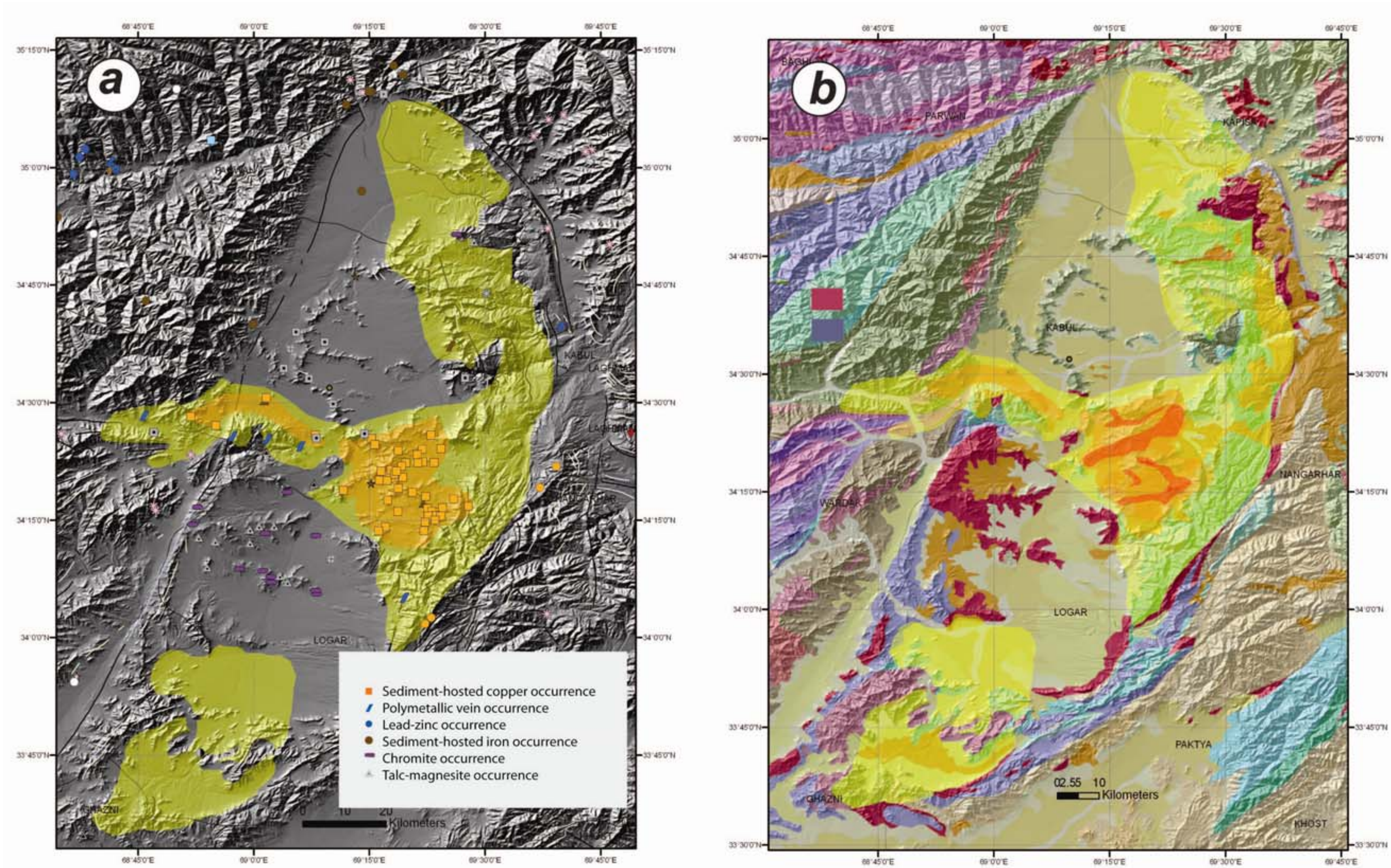


Figure 7.1-3. Maps showing modified of permissive tract sedcu01 after subtraction of Logar Eocene intrusive dunite body in the south-central parts and extension of a western limb, south of the city of Kabul. (*a*) Permissive and favorable tracts and major mineral occurrences. (*b*) Permissive, favorable, and prospective tracts overlain on geology of Doebrich and Wahl (2006).

Favorable tract sedcu01-f1

A favorable tract, sedcu01-f1, was delineated in the central parts of permissive tract sedcu01 to encompass known sediment-hosted deposits and mineral occurrences in a circular area southeast of Kabul, and also to include the favorable Proterozoic stratigraphic package ***Z€ld*** (fig. 7.1-3).

Prospective tracts within tract sedcu-f1

Within favorable tract sedcu01-f1, four separate prospective tracts, sedcu01-p1 Yagh-Darra-Ghuldarra, p2, p3 Aynak, and p4 Kawkhar-Darband-Kuhundara, were delineated on the basis of mineral occurrence clustering and structure (fig. 7.1-4). The four prospective tracts contain numerous sediment-hosted copper deposits in addition to Aynak. Each prospective tract may represent a folded surface, where mineralization appears to be concentrated near the crests of complex folds (figs. 7.1-6 and 7).

Prospective tract sedcu01-p1 Yagh-Darra-Ghuldarra

Three prospects, the Yagh-Darra, Ghuldarra I, and Ghuldarra II, are within the 20–km-long, prospective, east-trending tract in southern Kabul Province. Most of the lodes and stratigraphy strike east-west and dip gently to the north. The Yagh-Darra occurrence is 20 to 50 m thick and more than 20 km long. The Ghuldarra I occurrence is hosted within marble in two zones containing disseminated covellite, chalcopyrite, chalcocite, and malachite. One zone is 1 km long and 15 to 35 m thick; the other is 450 m long and 10 to 80 m thick (Shcherbina and others, 1975). Ghuldarra II is 30 to 50 m long and 2 to 5 m thick. There is a likelihood that prospective tract sedcu01-p1 is the hanging wall limb of a folded equivalent of strata within prospective tract sedcu01-p2 to the south (figs. 7.1-4 and 5).

Prospective tract sedcu01-p2

Sedcu01-p2 is a 25–km-long, 3–to 4–km-thick northeast-trending prospective tract that was delineated along a line of stratabound copper occurrences in northern Logar and southern Kabul Provinces (figs. 7.1-4 and 5). A number of clusters of deposits are present throughout this tract and were described, sampled, and mapped by Shcherbina and others (1975) and by Kutkin and Gusev (1977).

In the southwest parts of prospective tract sedcu01-p2 are the Kelaghey, Sorbog, Katasand, and Dashtak occurrences, which were evaluated by Kutkin and Gusev (1977). The Kelaghey (Kalagay) copper occurrence lies in the far west part of tract sedcu01-p2. Limited exploration included geological mapping at 1:2,000-scale, trenching, and geochemical sampling. Mineralization is within quartzite and consists of disseminated bornite, chalcopyrite, and minor malachite hosted in dolomite marble and quartzite over a 1.5– by 40–m-size area. One prospecting trench contains an average grade of 0.79 wt. percent copper over 7.1 m (Shcherbina and others, 1975; Kutkin and Gusev, 1977).

Northeast of Kelaghey, the Sorbog occurrence received limited exploration including 1:2,000-scale geological mapping, trenching, and geochemical sampling. The 540–m-long and 11.8– to 49–m-thick (average 22.3 m) mineralized zone is hosted within albitized marble. Mineralization consists of disseminated bornite, chalcopyrite, chalcocite, covellite, and minor malachite. Resources were estimated to be 34,800 metric tons of copper at an average grade of 0.91 wt. percent copper and a cut-off grade of 0.4 wt. percent copper. The Soviet survey concluded that the occurrence was “non-commercial” (Kutkin and Gusev, 1977).

The Katasang occurrence is an 800–m-long, 3.6– to 13.8–m-thick (average 7.2 m) mineralized zone within steeply dipping, albitized marble containing disseminated bornite, chalcopyrite, chalcocite, and minor malachite. Limited exploration carried out at this site included 1:2,000-scale geological mapping, trenching, and geochemical sampling and resulted in the calculation of a resource of 42,100 metric tons of copper at an average grade of 1.04 wt. percent copper. The occurrence was classified as "non-commercial", although more detailed exploration at depth was recommended (Kutkin and Gusev, 1977).

The Dashtak occurrence lies east of Kelaghey and is hosted within dolomitic marble in a 60– to 200–m-long and 1.2– to 17.3–m-thick oxidized zone that grades 1.67 wt. percent copper containing bornite, chalcopyrite, and pyrite with secondary chalcocite, covellite, and cuprite. Exploration carried out at this site included 1:2,000-scale geological mapping, trenching, drilling of two boreholes totaling 212.6 m, and channel and core sampling. A resource was estimated to be 8,200 metric tons copper at an average grade of 1.67 wt. percent copper. Soviet geologists concluded that the occurrence has limited importance on its own but may have potential if the Aynak deposit were to be developed.

The central parts of the sedcu01-p2 prospective tract contain the Palanghar, Zakhel, Kakhay, Charwazi, and Baghei occurrences that lie north of the Jawkhar deposit in a prospective tract to the south (figs. 7.1-4 and 5). The Zakhel I and II occurrences have received limited exploration including geological mapping at a scale of 1:2,000 scale, trenching, and geochemical sampling. Mineralization at Zakhel II consists of two (2) 500–m-long, 2- to 10–m-thick and 1,500–m-long, 20– to 35–m-thick marble-hosted zones grading 0.5 wt. percent and 0.59 wt. percent copper, respectively. Both zones contain malachite with bornite, chalcopyrite, and rare chalcocite and covellite (Shcherbina and others, 1975). Because only a few samples contained copper concentrations above 1.3 wt. percent copper, the occurrence was considered to have no economic importance (Kutkin and Gusev, 1977).

The Palangar occurrence consists of a 750–m-long and 6.1– to 16.1–m-thick (average 11.4 m) zone containing disseminated chalcopyrite, chalcocite, and rare malachite hosted in dolomitic marble and carbonaceous mica-quartz schist. Limited exploration consisting of 1:2,000-scale geological mapping, trenching, and geochemical sampling resulted in delineation of a resource in a central zone (up to 1 m depth) of 187 metric tons copper. The occurrence was considered to have no economic importance (Kutkin and Gusev, 1977).

The Kakhay occurrence consists of two 200– and 250–m-long and 2.0– and 2.3–m-thick zones containing disseminated bornite, chalcopyrite, and minor malachite that grades 0.58 and 1.05 wt. percent copper, respectively. Exploration consisted of geological mapping at 1:2,000-scale, trenching, and geochemical sampling (Kutkin and Gusev, 1977). The Baghkei (Barkhei) occurrence is hosted in marble and schist and is 400 to 500 m long and 3 to 10 m thick and grades 1.45 wt. percent copper (Shcherbina and others, 1975). The numerous Charwazi occurrences are hosted in greenstone, slate, and marble and generally are about 400 to 150 long and 3 to 5 m thick grading about 1.89 wt. percent copper (figs. 7.1-4 and 5).

The northeastern part of the sedcu01-p2 prospective tract contains the Charkai, Kharuti, Mirzakhan, and Dawankhel occurrences. The Kharuti occurrence is hosted within marble schist and consists of nine 100– to 900–m-long and 3– to 35–m-thick copper-bearing zones that grade between 0.15 and 0.94 wt. percent copper. The Charkari occurrence is 200 m long and 3 to 5 m thick grading 0.2 wt. percent copper. The Mirzkhan occurrence consists of two 500–m to 800–m-long 10– to 35–m-thick zones grading 0.24 to 0.32 wt. percent copper (Shcherbina and others, 1975). The Dawankhel occurrence is 500 m long and 5 to 8 m thick grading 1.1 wt. percent copper.

The Taghar occurrence in the far northeast part of prospective tract sedcu01-p2 (figs. 7.1-4 and 5) was explored in 1977 and delineated as a large mineralized area hosted in micaceous carbonate rocks, phyllite, garnet-mica schist, and marble and consists of 19 discontinuous copper-bearing zones that range from a few hundred meters to 6,000 m long and several meters to 200 m thick. The irregular zones contain chalcopyrite, bornite, chalcocite, covellite, malachite, and azurite in veinlets, pods, and disseminations. Mineralized sections between 3 and 25 m and 40 to 70 m thick (and up to 100 to 200 m thick). grade 1 to 2.64 wt. percent copper (Shcherbina and others, 1975). Reserves at the C_2 category level cover and area of 31 $km^2$and are estimated at 86,800 metric tons Cu with 0.18 wt. percent copper (Ministry of Mines written comm. 2007).

Prospective tract sedcu01-p3 Aynak

A 5–km-long prospective tract sedcu01-p3 was delineated around the Aynak deposit and the Akarkhel deposit to the northwest (figs. 7.1-4 and 5). The Aynak deposit lies in the axis of the east-trending Aynak anticline. The tract was drawn to include the stratigraphic extensions of the Aynak anticline.

At the Aynak deposit, the complex anticline is asymmetric, and the exposed parts are approximately 4 km long and up to 2.5 km thick. As a result of folding, the Aynak deposit is divided into two parts, with the Central Aynak zone located on the shallow-dipping eastern limb of the Aynak anticline and the Western Aynak zone lying in the western end of the structure (Gusey and others, 1979; Chernov and Fenogenov, 1980; Yashchinin and Giruval', 1981; Zaycev, 1988; Akhmadi, 1992) (figs. 7.1-4 and 5).

Resource estimates at Aynak vary depending on the area estimated, the resource category, data used and the estimator. Exploration at Aynak includes over 150 boreholes, 70 trenches, 9 adits, and surface geological and geophysical surveys. At a cut-off grade of 0.4 wt. percent copper, the main orebody at Central Aynak extends 1,850 m along strike and 1,200 m down dip and has a maximum thickness of 210 m. The Western Aynak main body extends 2,230 m along strike and 1,640 m down dip, and has a maximum thickness of 214 m, based on a similar cut-off (Chmyrev and others, 1977; Akocdzhanyan and others, 1977; Yashchinin and others, 1977). Industrial reserves in the central sector are 4.83 million metric tons with 2.37 wt. percent copper using a 0.7 wt. percent copper cut-off. Total reserve estimation of the Central zone is 6.8 million Cu with an average Cu content of 1.73 wt. percent copper and a cut-off at 0.4 wt. percent copper. Industrial reserve estimation of the western sector is 1.4 million metric tons Cu having an average Cu content of 1.61 wt. percent and a cut-off grade of 0.4 wt. percent Cu. Total reserves in the western sector are 4.55 million tones with an average Cu content of 1.53 wt. percent Cu. The total resources at Aynak (central + western) is 11.33 million metric tons Cu with an average Cu content of 1.64 wt. percent at a 0.4 wt. percent Cu cut-off grade, corresponding to 690.9 million metric tons of ore (written comm. Ministry of Mines, 2007). Work conducted by the British Geologic Survey resulted in a resource estimation of 240 million metric tons of ore at 2.3 wt. percent copper and includes several large orebodies and a number of smaller lenses; http://www.bgs.ac.uk/afghanminerals/docs/copper_A4.pdf: http://www.bgs.ac.uk/afghanminerals/docs/Aynak_A4.pdf).

The Akarkhel occurrence lies approximately 4 km northwest of Aynak and consists of a 50– to 60–m-thick zone of unknown length containing chalcopyrite, chalcocite, and malachite hosted in slate (Shcerbina and others, 1975).

Prospective tract sedcu01-p4 Kawkhar-Darband-Kuhundara

An arcuate 25– to 30–km-long prospective tract sedcu01-p4 was delineated along the Logar-Kabul Province boundary in the southern part of favorable tract sedcu01-f2 (figs. 7.1-4 and 5). The tract outline approximates the area of an inferred antiform (figs. 7.1-4 and 5) with the nose closing to the east. The tract contains the Jawkhar deposit in the northeast part, the Darband deposit in the eastern part, and the Khundara occurrence in the western part.

At the Jawkhar (Dzhavkhar) deposit, 15, 150– to 440–m-long and 3– to 29–m-thick mineralized zones have average grades ranging from 0.49 to 1.20 wt. percent copper, with a maximum grade of 2.43 wt. percent copper. Mineralization occurs within albitized zones and consists of hypogene chalcopyrite and bornite, with auxiliary magnetite, ilmenite, pyrrhotite, and sphalerite. Supergene zones contain bornite, chalcocite, covellite, cuprite, native copper, and malachite. Detailed exploration at Jawkhar included 1:2,000-scale geological mapping, trenching, and the construction of 1,257 m of adits. A total of 1,635 channel samples and 1,191 other types of samples were taken for chemical analysis. This work resulted in the estimation of a resource of 79,700 metric tons of copper with an average grade of 0.74 wt. percent copper. Unfortunately, few exploration records for Jawkhar exist as they were destroyed or lost over the last 20 years (Kutkin and Gusev, 1977). The total reserves at C_2 category for the Jawkhar, Dashtak, Sar Bagh and Kata Sang areas are reported as 164, 800 metric tons copper with a copper content of between 0.33 and 2.56 wt. percent copper (written comm., Ministry of Mines, 2007).

A number of mineral occurrences occur between the Jawkhar and Darband deposits in the northwest part of the prospective tract sedcu01-p4 (figs. 7.1-4 and 5) including the Lalmi-Tanghi, Gezghay copper, Batkehl I and III, and Janguzay IV occurrences. The Lalmi-Tanghi occurrence consists of 200–m-long and 0.2– to 0.4–m-thick stratabound zones hosted within quartz-mica schist grading 1.35 to 3.40 wt. percent copper. The Gezghay copper occurrence consists of 5– to 15–m- (up to 300 m) long, 0.1– to 1.0–m-thick mineralized lenses in micaceous calcareous schist containing quartz veins and veinlets that contain disseminated covellite, chalcocite, and chrysocolla grading 0.13 to 1.0 wt. percent copper. The Batkehl I occurrence is within marbled limestone, quartzite, and biotite schists in four closely spaced zones, which together are 400 to 800 m long and 26 to 32 m thick and contain disseminated chalcopyrite and malachite grading 0.5 to 1.94 wt. percent copper (Shcherbina and others, 1975). The Batkehl III occurrence is hosted in amphibole-garnet slate in a 400–m-long and 6– to 30–m-thick zone containing disseminated chalcopyrite and covellite grading 0.4 to 2.0 wt. percent copper. The Janguzay IV occurrence is hosted in marbled limestone, amphibolite, and slate and contains five 300– to 500–m-long and up to 6–m-thick zones grading 0.4 to 4.46 wt. percent copper.

The Darband copper deposit lies near the crest or nose of the inferred Jawkhwar-Darband-Kuhundara antiform (figs. 7.1-4 and 5) that corresponds to the eastern extension of the axial plane of the Aynak anticline. The deposit is hosted in 70 to 80º north-dipping silicified micaceous marble with interbedded biotite-amphibole schist and amphibolite of the Loy Khwar and Welayati Formations, and can be traced for 7,000 m along strike over a width of 100 to 1,000 m. Mineralization at Darband occurs as disseminated-veinlets, and as aggregates containing chalcopyrite and bornite, with chalcocite, as well as pyrite, pyrrhotite, molybdenite, hematite, magnetite, and minor galena, sphalerite, cobaltite, arsenopyrite, nickel minerals, and gold. Bornite is the dominant ore mineral in the deposit, comprising 67 to 100 vol. percent of the sulfide minerals. Supergene copper minerals are also present in the 150– to 200–m-thick oxidized zones, which are composed of malachite, cuprite, covellite, azurite, and chrysocolla, gradually changing at depth to a mixed zone of native copper, chalcopyrite, and cuprite. About 25 stratabound mineralized zones have been delineated. A few zones are discordant and composed of silicified rocks and veinlets of quartz in faults or crush zones. Exploration work enabled division of the area into four prospects, designated Eastern Darband, Central Darband, Western Darband, and Lagernaya. The entire area was mapped at a scale of 1:2,000, and the mineralization was sampled by surface trenches that were initially spaced 50 m apart. Eleven exploratory adits, totaling 9,062 m in length, were driven into the deposit at the Eastern, Central, and Western Darband prospects. Fifty-seven surface boreholes were drilled with a total length of 8,752 m. Of these, 14 boreholes were drilled in the Lagernaya prospect, and the remainder in Eastern, Central, and Western Darband. This work resulted in the estimation of 84.3 million metric tons of inferred or possible ore reserves with 665.7 thousand metric tons of estimated contained copper, with an ore grade of 0.79 wt. percent copper, using a cut-off grade of 0.4 wt. percent copper. Minchenok and others (1979) (written comm., Ministry of Mines, 2007) indicated that additional resources may be present beneath areas of Neogene sedimentary cover that were not explored (see also Denikaev and others, 1971; Chmyrev and others, 1977).

A cluster of deposits lies south of the Darband deposit within the thick part of prospective tract sedcu01-p4, including the Batkehl II and IV, Janguzay I, II, and III, and the Gughimayden stratabound mineral occurrences (figs. 7.1-4 and 5). The Batkehl II and IV occurrences are hosted in biotite-garnet-amphibolite schists and both contain two zones about 250 to 450 m long and 5 to 9 m thick containing disseminated chalcocite, bornite, covellite, malachite, and azurite grading between 0.69 to 0.96 wt. percent copper. The Janguzay I occurrence is within amphibolite in a 500–m-long and up to 6–m-thick zone grading 2.05 wt. percent copper. The Janguzay II occurrence, within marbled limestone and slate and contains four zones that are 300 to 1,300 m long and 1.5 to 15 m thick grading 1.55 to 3.28 wt. percent copper. The Janguzay III occurrence within amphibolite consists of three 300– to 1,200-m long, 1– to 6–m-thick zones grading 0.2 to 3.0 wt. percent copper. The Gughimayden occurrence is a quartz vein in marble that is 30 to 40 m long and 2 to 3 m thick containing malachite and chalcopyrite that grades 0.84 wt. percent copper (Shcherbina and others, 1975).

The southwest part of the prospective tract sedcu01-p4 Kawkhar-Darband-Kuhundara between the Gughimayden, Khundara, and Pachi mineral occurrences is covered by Neogene sediments. The Pachi occurrence, within strongly albitized rocks, is a 400–m-long, 4– to 48–m-thick zone and grades 0.9 to 1.6 wt. percent copper. The Khundara occurrence is within slate and marble, and consists of three mineralized zones that are between 200 to 300 m long and 10 to 20 m thick and grade 0.8 to 1.6 wt. percent copper (figs. 7.1-4 and 5).

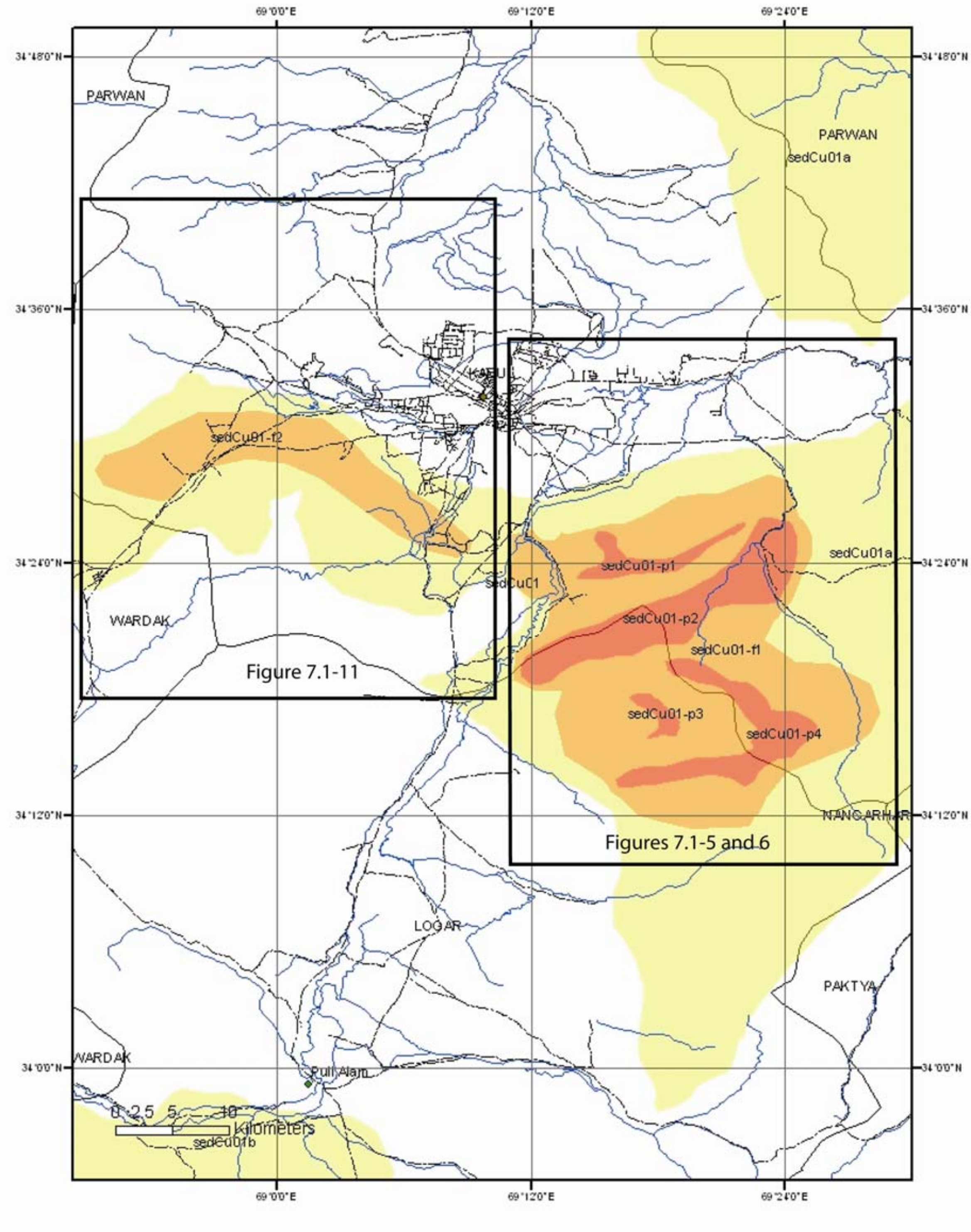


Figure 7.1-4. Map showing location of central parts of permissive tract sedcu01 Aynak including two internal favorable tracts sedcu01-f1 and sedcu01-f2.

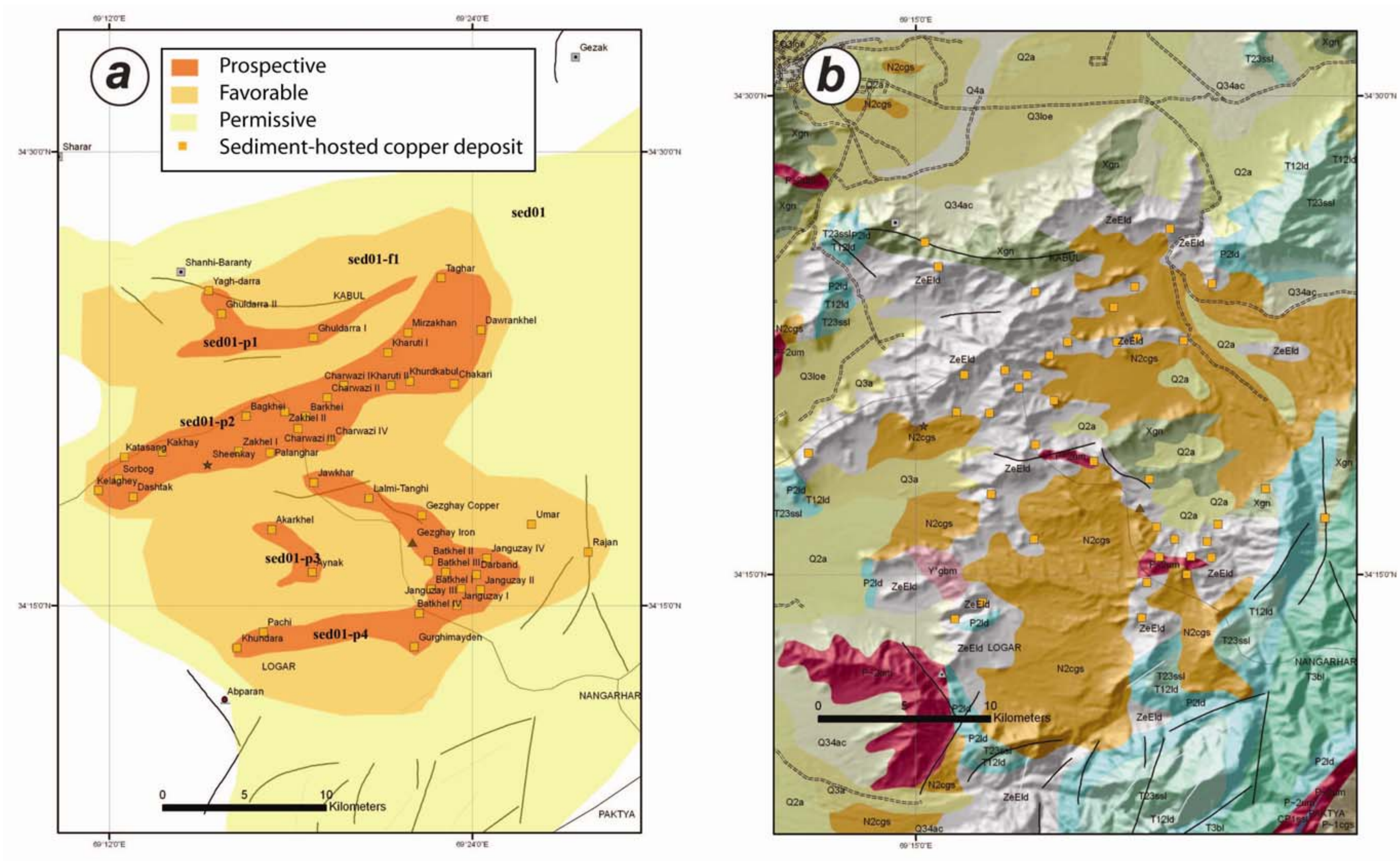


Figure 7.1-5. Maps showing location of favorable tract sedcu01-f1 and prospective tracts sedcu01-p1, p2, p3 and p4, Kabul and Logar Provinces. (*a*) Outline and location of favorable tract sedcu01-f1 and prospective tracts and location of known mineral occurrences and deposits. (*b*) Geology of tract sedcu01-f2. Units from Doebrich and Wahl (2007).

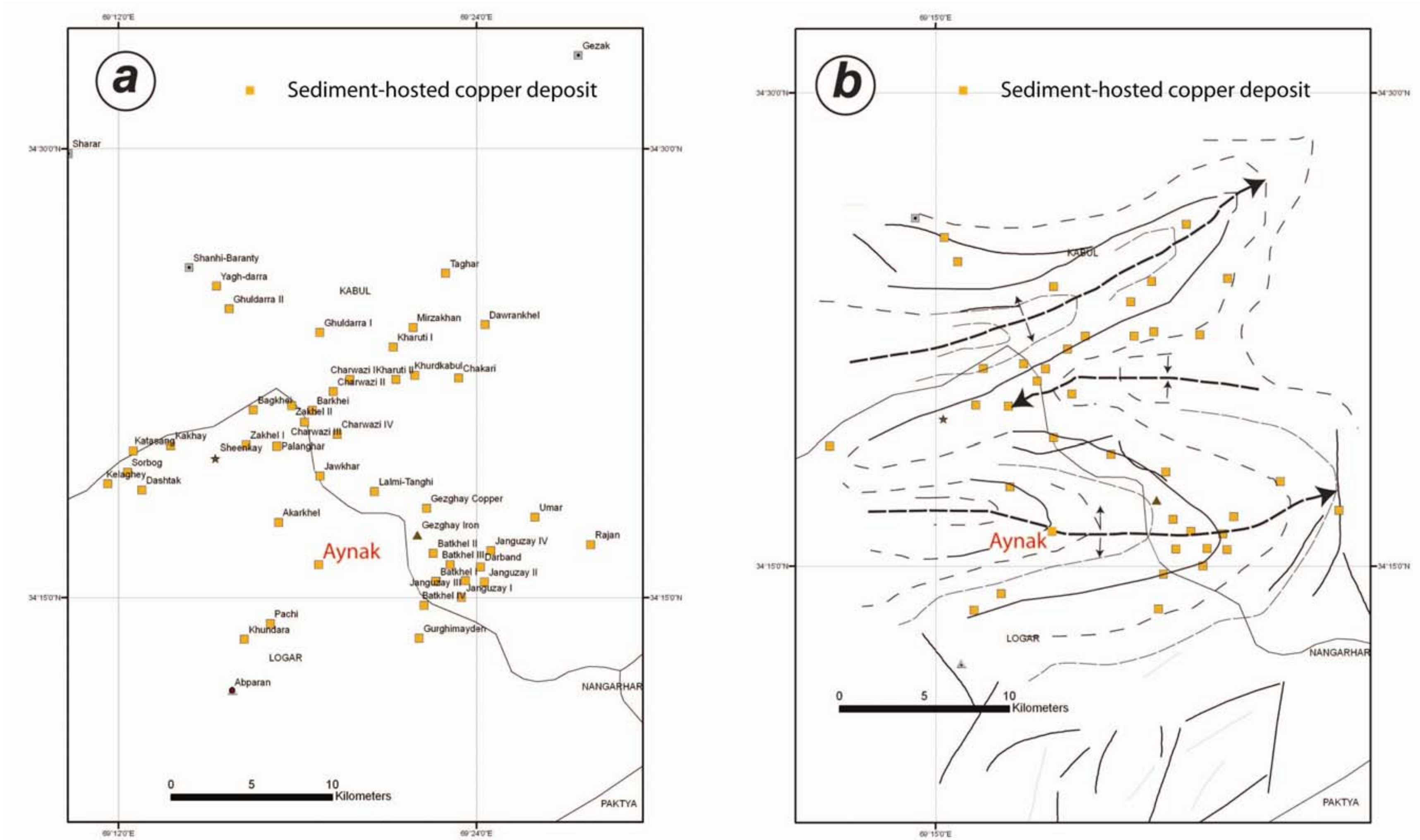
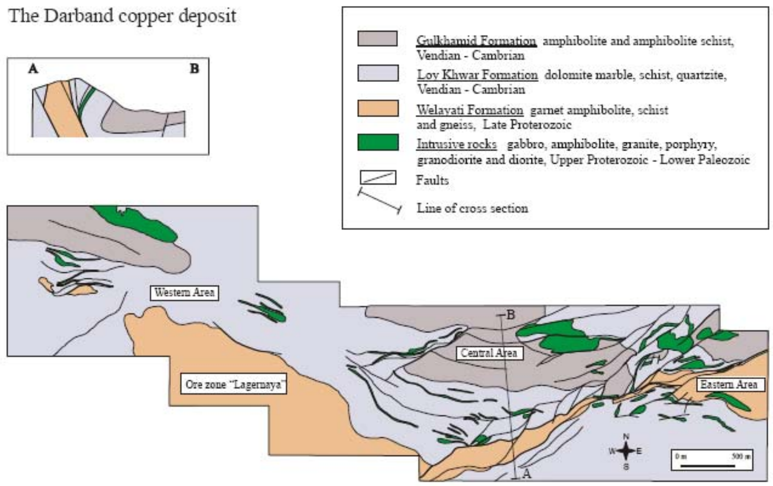
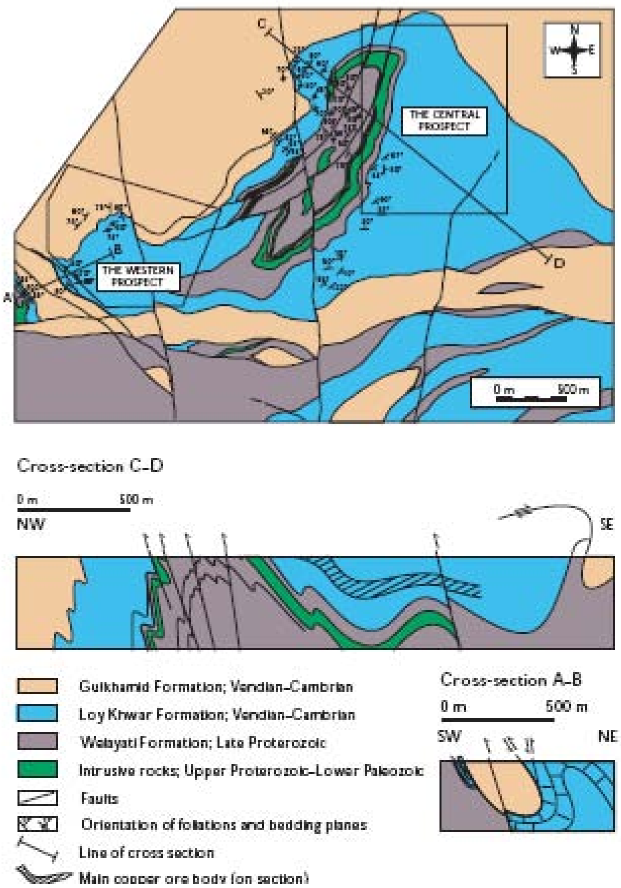


Figure 7.1-6. Map showing location of stratabound copper occurrences in southern Kabul and northern Logar Provinces. (*a*) Location and names of main occurrences. (*b*) Structural interpretation made during this study of favorable tract sedcu01-f2 on the basis of existing form line from Russian maps. Dark dotted lines show fold axial planes of antiformal and synformal structures. Grey dashed and solid lines are form lines showing the shape of these structures. Extensive internal folding is present within the rocks and is not shown (see fig. 7.1-7).



a



b

Figure 7.1-7 Geologic maps and sections of the (a) Darband and (b) Aynak sediment-hosted copper deposits in the Kabul district (Afghanistan Geological Survey, 2006a and b; *http://www.bgs.ac.uk/afghanminerals/docs/Aynak_A4.pdf*). (Some text may not be legible because of the quality of reproduction.)

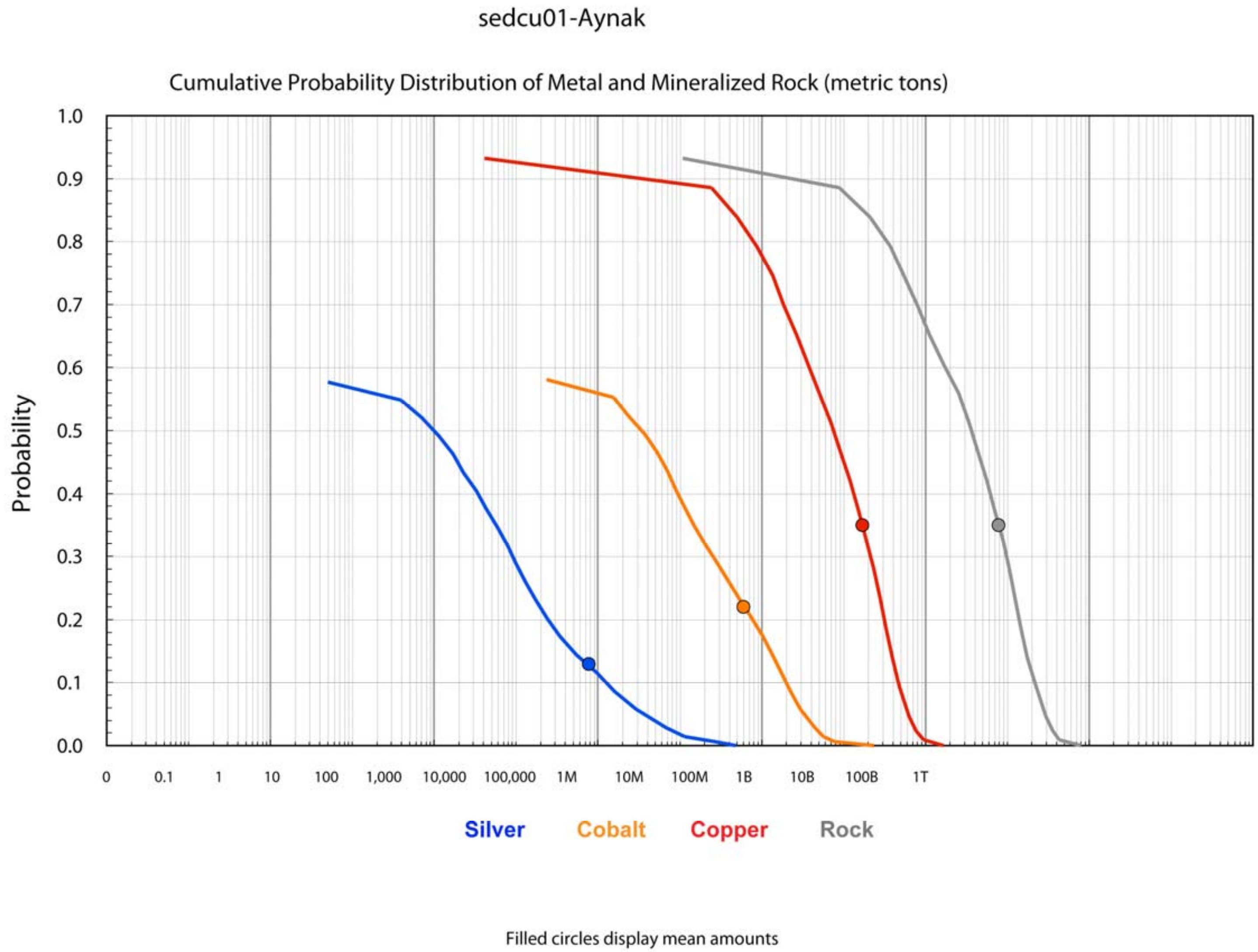


Figure 7.1-8. Cumulative distribution of estimated contained metal and mineralized rock in permissive tract sedcu01 Aynak for undiscovered sediment-hosted deposits, assuming that Aynak-type deposits have the same grade-tonnage distribution as that for sediment-hosted reduced-facies copper deposits.

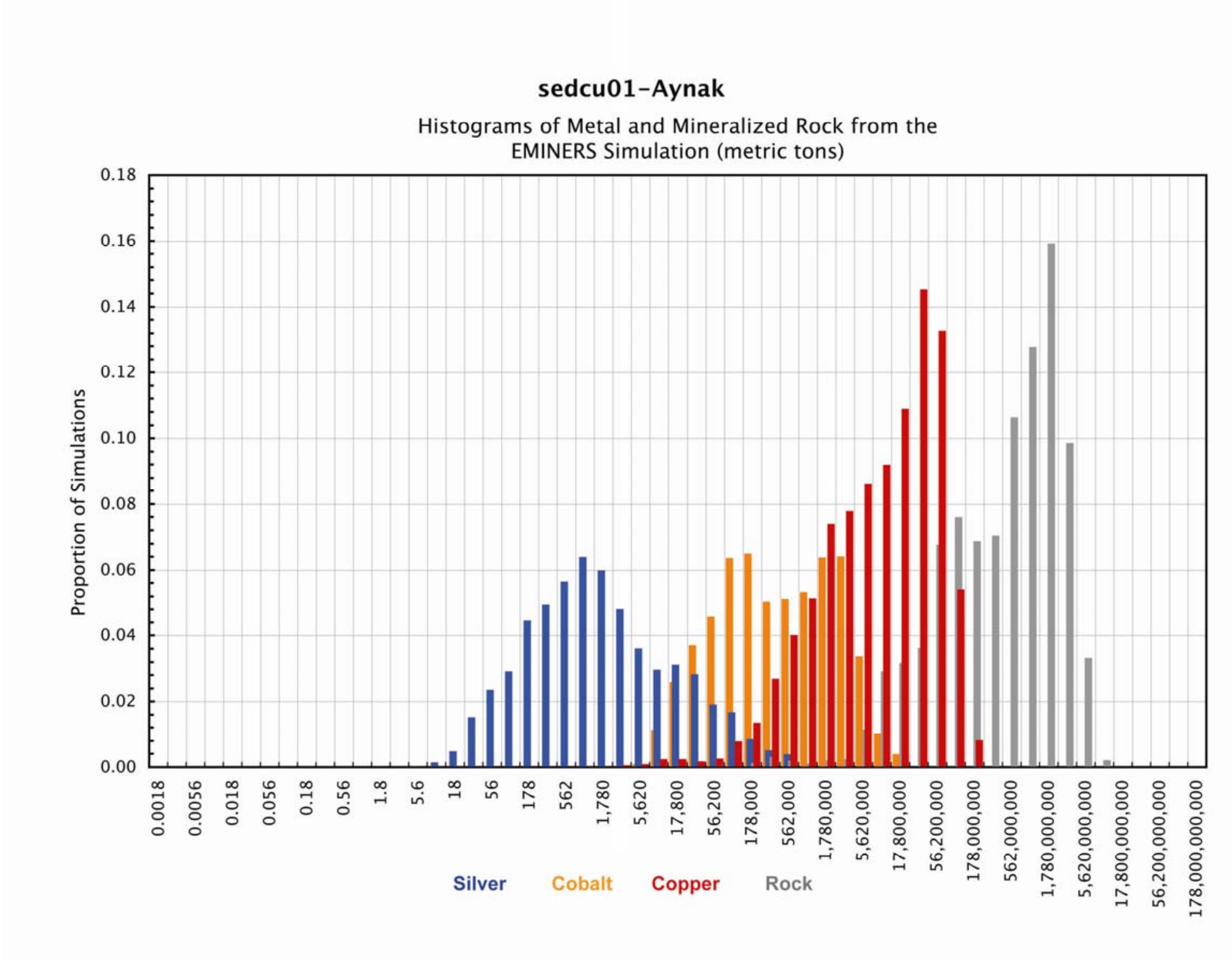


Figure 7.1-9. Histograms of estimated contained metal and mineralized rock in permissive tract sedcu01 Aynak for undiscovered sediment-hosted deposits, assuming that the Aynak-type deposits have the same grade-tonnage distribution as that for sediment-hosted reduced-facies copper deposits.

Table 7.1-1. Table of output for permissive tract sedcu01 Aynak for undiscovered sediment-hosted deposits, assuming that the Aynak-type deposits have the same grade-tonnage distribution as that for sediment-hosted reduced-facies copper deposits. The mean expected number of undiscovered deposits is 3.8.

quantile	Cu	Ag	Co	Rock
0.95	0	0	0	0
0.90	160,000	0	0	6,200,000
0.50	7,500,000	100	34,000	360,000,000
0.10	47,000,000	12,000	1,991,000	2,100,000,000
0.05	61,000,000	35,000	3,100,000	2,900,000,000
mean	17,000,000	7,700	600,000	770,000,000
Probability of mean	0.35	0.13	0.22	0.35
Probability of zero	0.07	0.42	0.42	0.07

The Mark3 index is 30b.2 – Reduced-Facies Sediment-Hosted Cu. Amounts are in tonnes.

Favorable tract sedcu01-f2 Khaidarabad-Sultan Padshah

A favorable tract sedcu01-f2 was delineated west of favorable tract sedcu01-f1 to include the Khaidarabad and Sultan Padshah stratabound copper deposits and a number of unnamed deposits within permissive tract sedcu01 (fig. 7.1-10). The geology of the tract (Doebrich and Wahl, 2006) does not match the descriptions of the bedrock in the deposits (Abdullah and others, 1977), but an assumption was made that the metasedimentary rocks underlying Ordovician sedimentary rocks to the west are part of the Neoproterozoic to Cambrian sequence and that they underlie and may outcrop within the permissive and favorable tract in an eastern-tending synclinorium.

The Khaidarabad occurrence is within Vendian to Cambrian ferruginous micaceous quartzite in a 1–km-long, 3– to 10–m-thick zone containing disseminated hematite and magnetite and also malachite and chalcopyrite grading not over 0.3 wt. percent copper. The Sultan Padshah occurrence is hosted in marbled limestone and sandy schist in a 200–m-long, 20– to 30–m-thick zone containing numerous quartz veins with disseminated chalcopyrite and covellite grading 0.6 wt. percent copper over a thickness of 1.5 m. (Shcherbina and others, 1975). The unnamed stratabound prospects in the west part of the tract have similar characteristics to the Khaidarabad and Sultan Padshah occurrences.

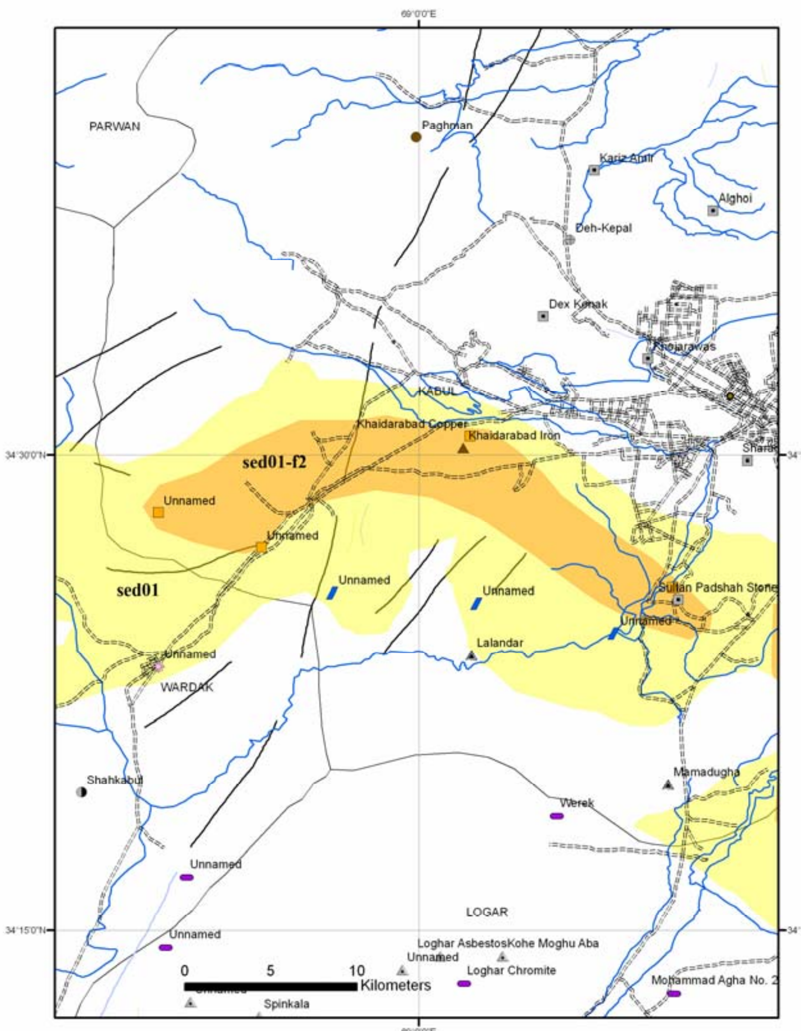


Figure 7.1-10. Map showing location of favorable tract sedcu01-f2 Khaidarabad-Sultan Padshah within permissive tract sedcu01 Aynak area for undiscovered sediment-hosted copper deposits in Kabul Province.

Permissive Tract sedCu02 Kundalyan sedimentary copper

***Deposit type*—**Sediment-hosted copper, reduced-facies subtype

***Age of mineralization*—**Neoproterozoic to Early Cambrian

***Examples of deposit type*—** No known stratabound copper-bearing mineral occurrences are within any of the tract areas, although a number of copper skarn occurrences are present in the southern parts of the tract, especially near the Kundalyan porphyry copper prospect (see section 5.0).

***Exploration history*—**No known exploration for stratabound copper deposits has taken place within the tract. However, extensive exploration for igneous-related, base- and precious-metal deposits has occurred throughout and adjacent to most parts of the tract.

Tract boundary criteria*—**Permissive tract sedcu02 was delineated for map unit ***Z€ld in the southwestern part of Zabul Province. The tract is discontinuous and contains four main groups with multiple parts (fig. 7.1-11).

***Important data sources*—**Geologic map information (Doebrich and Wahl, 2006), aeromagnetic and gravity data (Sweeney and others, 2006), mineral deposit database (Orris and Bliss, 2002), Aynak information CD (British Geological Survey, 2005).

***Needs to improve assessment*—**The information that is most needed is intermediate-scale (1:100,000) geologic mapping of the parts of the tract that have anomalous concentrations of copper minerals.

***Optimistic factors*—**Large copper resources occur in the tract to the north in the same stratigraphic sequence.

***Pessimistic factors*—**No known stratabound occurrences are present in the tract.

***Quantitative assessment*—**No estimate was made due to low probabilities of occurrence and insufficient knowledge about the tract.

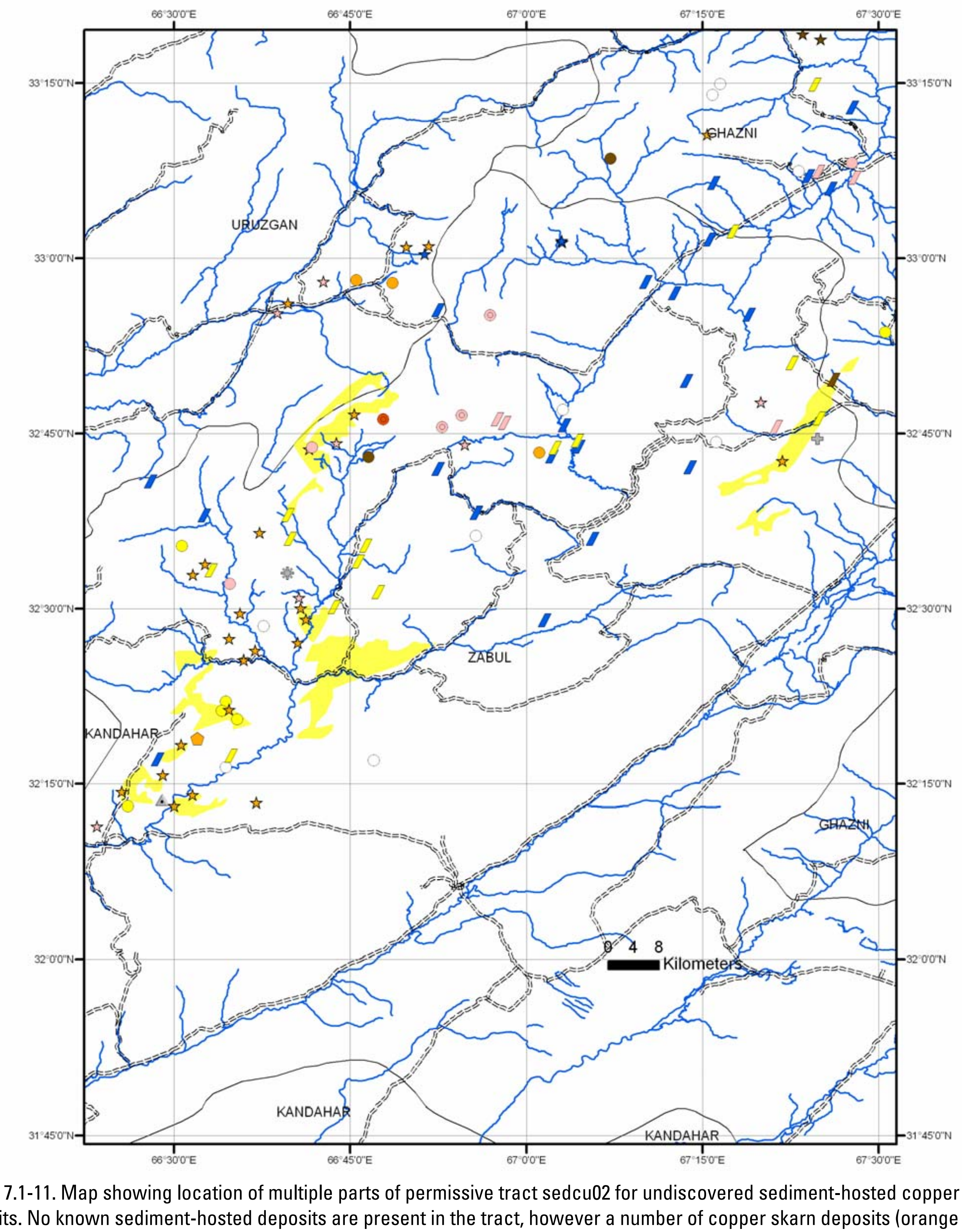


Figure 7.1-11. Map showing location of multiple parts of permissive tract sedcu02 for undiscovered sediment-hosted copper deposits. No known sediment-hosted deposits are present in the tract, however a number of copper skarn deposits (orange stars) occur in the area. Symbols based on legend in Doebrich and Wahl (2006).

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7.2 Sediment-hosted lead-zinc deposits

Contribution by Stephen G. Peters.

A number of sedimentary rock-hosted, vein-style lead-zinc deposits occur in central Afghanistan along a major structural zone mainly in carbonate rocks. The size and style of these deposits are in need of further study. These Pb-Zn-Ba-(± Cu ±Ag) deposits are of interest due to their potential to support local mining activity.

No major lead-zinc deposits associated with sedimentary rocks have been identified in Afghanistan, but significant lead-zinc mineral occurrences have characteristics that show promise for the discovery of large stratabound deposits, particularly within the Kopeh Dag-Hindu Kush metallogenic zone (Jankovic, 1984). A good example is the Nalbandon lead-zinc prospect where approximately 2 million metric tons of ore have been identified grading 6.64 wt. percent combined lead and zinc. Common zoning associated with these deposits is calcite-barite at the stratigraphic base, calcite-galena (sphalerite) and pyrite with minor barite in the center, and galena-sphalerite-pyrite with traces of barite at the top. Permissive sedimentary sequences, based on occurrences in Afghanistan or inferred from deposits worldwide (Leach and others, 2005) are Devonian to Jurassic and Lower Cretaceous in age. In addition, the possibility exists that these deposits may also be present within the many Proterozoic sedimentary and volcano-sedimentary sequences of Afghanistan. The carbonate-hosted lead-zinc and barite occurrences present in several Phanerozoic stratigraphic units has been interpreted to have been remobilized from lower levels, and redeposited in upper sequences within veins, and shear and stratabound zones (Tahirkheli and Kahn, 1959; Siebdrat, 1965; Plotnikov and Slozhenikin, 1968; Sheer and others, 1969; Jankovic, 1984).

Known lead and zinc deposits in Afghanistan are associated with Phanerozoic sedimentary rocks and may be classified as either: (1) sedimentary-exhalative (sedex) zinc-lead-silver deposits, (2) Mississippi Valley-type zinc-lead deposits, or (3) sandstone-hosted lead-zinc deposits. Some deposits and occurrences are closely associated with large accumulations of bedded barite that may be of additional economic importance.

Three tracts were delineated in Afghanistan that are permissive for sediment-hosted lead-zinc deposits. The most promising area is within tract pbzn01 in the central parts of Ghor Province.

Additional lead-zinc deposits at Darra-i-Nur and Kalai-Assad in Kandahar Province are classified as skarn or replacement deposits and are related to contact zones of Oligocene granite, although they occur in similar Triassic sedimentary rocks like the stratabound deposits in permissive tract pbzn01. The post-Eocene Spira lead-zinc occurrence in Paktya Province is within a fault and may be related to epithermal mineralization in the area.

7.2.1 Descriptive models for sediment-hosted lead-zinc deposits and associated models

Descriptive models for sediment-hosted lead-zinc deposits and descriptions of associated models are described below for comparison with characteristics and features of sediment-hosted lead-zinc deposits in Afghanistan. The descriptive models are important to allow quantitative assessment of known areas where permissive tracts have been delineated, if the characteristics are compatible. In addition, if no known deposits are present or if the characteristics are not well described, the descriptive models list the characteristics that are needed to either discover undiscovered deposits or augment what is known about existing occurrences so that they can be further assessed.

The Phanerozoic lead-zinc deposits are described below as well as associated deposits such as Phanerozoic sedex zinc-lead-silver deposits, Mississippi Valley-type Zn–Pb, and sandstone-hosted Pb–Zn. Proterozoic deposits in Afghanistan may include sedex Pb–Zn–Ag (Broken Hill-type) and sedex Zn-Pb (Balmat Type) deposits. Possibly associated with stratabound Pb–Zn deposits are sedimentary manganese, bedded barite deposits, and phosphate deposits.

Phanerozoic sedex zinc, lead-silver (Zn-Pb-Ag) deposits. Mineral deposits in Afghanistan that may fit the Phanerozoic sedex Zn–Pb–Ag deposit model are those in Ghor Province (fig. 7.2-3). Although the Afghanistan deposits are apparently small and lack economic potential (as currently known), orebodies of this type worldwide in Phanerozoic rocks contain significant tonnages of Zn, Pb, and Ag. Paleozoic sequences are most prospective, but important sedex Zn–Pb–Ag deposits occur in Mesozoic rocks elsewhere including Late Jurassic marine strata in Cuba that host a major deposit (Santa Lucia) contains 19 million metric tons of ore at an average grade of 5.7 wt. percent zinc, 1.8 wt. percent lead, and 30 g/t silver (Leach and others, 2005).

The sedimentary-exhalative Zn–Pb (model 31a) (Briskey, 1986a; see also Goodfellow and others, 1993; Leach and others, 2005) does not require formation strictly by syngenetic mineralizing processes, as the ores also can form by hydrothermal replacement of carbonate beds during sedimentation or early diagenesis. Deeply-weathered deposits may be represented by cryptic non-sulfide Zn concentrations in oxide, carbonate, and(or) silicate minerals that are easily overlooked yet can constitute large, high-grade orebodies (Hitzman and others, 2003). Deposits may occur in either carbonate rocks or black shale. The presence of several features is prospective: synsedimentary growth faults; rapid facies changes; local fault-scarp conglomerates; and plugs, dikes, and(or) sills. Stratiform beds or lenses of pyrite or marcasite can be lateral facies equivalents of the base-metal deposits. Bedded barite may overlie the sulfide deposits or form a lateral facies; in some cases barite is extensively replaced by Zn–Pb–Ag mineralization. Many other deposits of this type (for example, deposits in Ireland) consist of sulfide replacements of carbonate beds, including reef and mud bank complexes.

Mineralogy typically consists of sphalerite, galena, pyrite, marcasite, and barite. In unmetamorphosed deposits hosted in black shale, sulfide minerals may be very fine grained and extremely difficult to recognize in the field, thus important occurrences can easily be missed. Black shale that appears to be unusually heavy for its size (that is, very dense) should be carefully examined for the possible presence of fine-grained sphalerite and galena. A special chemical solution called “zinc zap” (Hitzman and others, 2003) can readily identify the presence of high Zn in oxidized form in slightly, to extensively, weathered outcrops. Alteration may include locally intense silicification or dolomitization of carbonate host rocks such as limestone and calcareous shale. Some carbonate-hosted deposits are associated with hydrothermal “black-matrix” dolomite breccias that extend up to hundreds of meters laterally from the orebodies (Hitzman and others, 2002).

Deposits can vary in geometry from stratiform beds to thick lenses, many of which occur adjacent to or near synsedimentary growth faults. Within the Phanerozoic cover rocks of Afghanistan, sedex deposits are likely to be relatively undeformed with the exception of local zones that may be offset by high-angle faults. Geochemical signature consists of elevated concentrations of Zn, Pb, Ag, Ba, Mn, Tl, As, and Sb. Elevated Mn and Tl typically show a broad envelope around the deposits, mainly in hanging wall rocks (both carbonate and shale), but also in lateral facies for up to several kilometers or more from the deposits. Geophysical signatures are gravity highs, and the deposits may show induced polarization and(or) electromagnetic anomalies, although neither of these is required to be present.

Specific suggestions are to carefully study the sedimentary lithofacies, in both carbonate and shale and search for black shale, and fine-grained sphalerite and galena; use “zinc zap” as described by Hitzman and others (2003).

Mississippi Valley-type Zn–Pb. - Mississippi Valley-type (MVT) Zn–Pb deposits (model 32a, Briskey, 1986b, b; also see Leach and Sangster, 1993) are a varied family of epigenetic ores occurring predominantly within dolostone and in which Pb and Zn are the major commodities. Although found throughout the world, the major districts are in the United States, Canada, and Poland. Deposits generally are small (most are <2 million metric tons of ore), zinc-dominant, with grades seldom exceed 10 wt. percent combined lead and zinc. Well-known examples include the Old Lead Belt and Viburnum Trend, Tri-State, Upper Mississippi Valley, Central Tennessee, and East Tennessee districts in the US mid-continent region; the Nanisivik, Polaris, Gays River, Monarch-Kicking Horse, and Pine Point districts in Canada,; and the Cracow-Silesia district in Poland.

Host rocks are dominantly platform carbonate rocks, typically dolomitic; locally, ore bodies occur in sandstone, conglomerate, and calcareous shale. Calcarenite is the most common host lithology. Textures of the host rocks include tidalite, stromatolite finger reefs, reef breccias, slump breccias, oolites, cross bedding, and micrite. Deposits typically occur at the margins of foreland basins. Ore controls are generally specific to a district and include depositional margins of shale units (shale edges), limestone-dolostone transitions, reef complexes, solution-collapse breccias, faults, and pinch-outs of favorable host rocks against basement topography. Known deposits are in Cambrian to Lower Ordovician, Devonian to Carboniferous and Triassic strata. The most common tectonic setting is undeformed orogenic foreland carbonate platforms at the margins of stable cratonic areas. Some deposits occur in carbonate sequences in foreland thrust belts bordering foredeeps or are associated with rift zones.

Ore mineralogy consists of galena, sphalerite, chalcopyrite, pyrite, and marcasite, as well as minor siegenite, bornite, tennantite, barite, bravoite, digenite, covellite, arsenopyrite, fletcherite, adularia, pyrrhotite, magnetite, millerite, polydymite, vaesite, djurleite, chalcocite, anilite, and enargite in decreasing order of abundance. Gangue minerals are chiefly dolomite and minor quartz. Ore textures are dominated by open-space filling and replacement of carbonate units. Early fine-grained replacement is generally followed by main-stage coarse-grained replacement and vuggy or colloform open-space filling. Hypogene leaching of galena is common.

Alteration consists of regional dolomitization; brown, ferroan, and bitumen-rich dolomite; extensive carbonate dissolution and development of residual shale; mixed-layer illite-chlorite altered to 2M muscovite; dickite and kaolinite in vugs; and very minor adularia. Silicification is normally minimal but is important in some districts. Organic matter typically is altered to insoluble, hydrogen-poor material. Deposits generally lack internal mineralogical or chemical zoning although exceptions exist. Sulfide cement in collapse breccias, ranging in habit from extremely large crystals to aphanitic botryoidal or geopetal textures, such as internal sediments and “snow-on-the-roof”, are diagnostic of MVT deposits. Geochemical signatures of carbonate strata are subdued. Amounts of Pb, Zn, Cu, Mo, Ag, Co, and Ni are detectable in insoluble residues and are regionally anomalous. Background values for carbonates are approximately Pb = 9 ppm, Zn = 20 ppm, and Cu = 4 ppm.

Sandstone-hosted Pb–Zn. In Afghanistan, much of the Phanerozoic sedimentary section is permissive for occurrences of sandstone-hosted Pb–Zn deposits. These deposits (model 30a, Briskey, 1986b) are strata-bound to stratiform concentrations of galena and sphalerite in multiple, thin, sheet-like ore bodies within arenaceous sedimentary strata. Main rock types are continental, terrigenous, and marine quartzitic and arkosic sandstone, conglomerate, grit, and siltstone with local evaporates. These rocks typically contain well-developed bedding, cross bedding, paleochannels, liquification structures, and intraformational slump breccias. Quartz and subordinate calcite cement also are present. Ages of the host rocks generally are Proterozoic to Cretaceous. Host rocks were deposited in combined continental and marine environments including piedmont, fluvial, lagoonal-lacustrine, lagoonal-deltaic, lagoonal-beach, and tidal channel-sand bar. Ore-bearing strata commonly are succeeded by marine transgressions.

Deep weathering and regional peneplanation during stable tectonic conditions, accompanied by marine platform or piedmont sedimentation associated with at least some orogenic uplift characterize the tectonic setting. In addition, a sialic basement is typically present, mainly consisting of granite or granitic gneiss. Associated deposit types include sediment-hosted copper. Mineralogy consists of fine- to medium-crystalline galena, locally with subordinate sphalerite, pyrite, barite, and fluorite. Minor chalcopyrite, marcasite, pyrrhotite, tetrahedrite-tennantite, chalcocite, freibergite, bournonite, jamesonite, bornite, linnaeite, bravoite, and millerite also may be present. Quartz and calcite are the common gangue minerals, and organic debris occurs in some deposits.

Ore textures consist of clots of galena 0.5 to several centimeters in diameter, disseminations 0.1 to 1 mm in diameter, and locally massive ores. Ore and gangue minerals are intergrown. Galena bands locally are cross bedded. Deposits are locally controlled by the intergranular porosity of the host rocks. Ore may be massive where it is localized by porous sedimentary structures, impermeable barriers, faults, joints, and fractures. Deposits are located within or immediately above paleochannels. Weathering produces surface oxidation of galena to cerussite, minor anglesite and pyromorphite; chalcopyrite to malachite, azurite, covellite, and chalcocite; and(or) sphalerite to smithsonite, hemimorphite, hydrozincite, and goslarite. Geochemical signatures consist of anomalous concentrations of lead and zinc in host rocks and derivative soils; Ba, F, and Ag are enriched in lowermost parts of some deposits. Zinc concentrations tend to increase upward in the deposits. Sialic basement may contain anomalous lead concentrations. Background values in sandstone are approximately Pb = 7 ppm and Zn = 16 ppm.

Proterozoic sedex Pb–Zn–Ag (Broken Hill-type). - The largest and most valuable type of Pb–Zn deposits are sedimentary-exhalative or sedex deposits. Although no sedex Pb–Zn deposits are known in Afghanistan, a number of sedimentary sequences in the country are permissive for their occurrence. These deposits are large and the relative production and economic impact are very significant. For example, the giant Broken Hill orebody in Australia is the largest and richest stratiform, sedex-type Pb–Zn–Ag deposit in the world with a total size (production + reserves) of about 180 million metric tons at an average grade of 13.0 wt. percent Pb, 12.0 wt. percent Zn, and 175 g/t Ag. The Cannington orebody, also in Australia, has production + reserves of 44 million metric tons at 11.6 wt. percent Pb, 4.4 wt. percent Zn, and 538 g/t Ag; this orebody is currently the largest Ag producer in the world (over 30 million oz/yr, 2001-2002).

Permissive tract pbzn03 has been delineated using metamorphosed sedimentary and Proterozoic volcanic rocks, particularly rocks of Mesoproterozoic to Neoproterozoic age (1.3 to 1.8 Ga). Deep-water lithofacies are most favorable, especially pelitic and psammitic sequences with minor amphibolite/mafic gneiss and felsic gneiss of extrusive and(or) shallow intrusive origin (including sills). Deposits of this type elsewhere may be very large and have significant past production (Broken Hill, Australia) and future reserves (Cannington, Australia) for Pb, Zn, and Ag with by-product Cd.

The mineral deposit model applicable to Afghanistan is the Broken Hill-type Pb–Zn–Ag model (see Walters and others, 2002). The main features of the model are strata-bound and locally stratiform lenses of massive galena, sphalerite, and minor pyrrhotite or pyrite within metamorphosed siliciclastic sequences of Paleoproterozoic age that also contain minor amphibolite/basic gneiss and felsic orthogneiss of rhyolitic to dacitic origin (metamorphosed flows or sills). Sulfide orebodies typically occur at several different stratigraphic levels, each of which contains different proportions of Zn, Pb, Ag, and related gangue minerals.

Presence of quartz-magnetite iron formation, quartz-gahnite layers or lenses, and stratiform manganese silicate units (layers or lenses), including those composed largely of spessartine garnet or rhodonite. Fine-grained spessartine-quartz units can be easily misidentified in the field as iron-stained quartzite; their potential occurrence should be carefully evaluated. Stratiform siliceous tourmaline-rich rocks can also be prospective, some of which may superficially resemble graphitic siltstone or amphibolite (in other words, tourmaline misidentified as amphibole).

Mineralogy consists of high-grade concentrations of galena, sphalerite, minor pyrrhotite, and generally rare chalcopyrite in a highly variable gangue of quartz, carbonate, fluorite, apatite, Ca–Mg pyroxenes, Mn–silicates, gahnite, and(or) local barite. Ores commonly have very high silver contents, with some arsenic and(or) antimony; gold contents are typically low. Alteration is principally manganiferous (Mn–silicates) and locally siliceous (quartz). Deposits are likely to be highly deformed with evidence for multiple periods of penetrative deformation and complex shearing/faulting (including pre-metamorphic thrusts). Geochemical signature is elevated concentrations of Pb, Zn, Ag, Cu, As, Sb, Mn, Ca, F, and(or) P. Geophysical signature consists of gravity highs; associated iron-formations produce magnetic highs if line spacing of surveys are of sufficient density.

Panned concentrates collected from streams and drainages should be checked for gahnite, a green Zn–spinel mineral that is especially good as a regional-scale prospecting guide for this deposit type.

Proterozoic Sedex Zn-Pb (Balmat-type) Balmat-type Zn–Pb deposits are known in Afghanistan, but they are an important deposit type to consider because of the permissive geology and because sulfide deposits of the Balmat district in the United States have significant past production + reserves of 41 million metric tons of ore at an average grade of 9.4 wt. percent Zn and 0.3 wt. percent Pb. Permissive tract pbzn03 was delineated in Proterozoic metamorphosed sedimentary rocks, especially rocks of late Mesoproterozoic age (1.0 to 1.3 Ga). Shallow-water facies are more favorable environments of deposition, especially platform carbonate units including those with evidence for supratidal deposition (for example, presence of stromatolites and(or) evaporites).

Balmat-type Zn–Pb deposits (see deLorraine and Dill, 1982; deLorraine, 2001) are stratabound and locally stratiform lenses and layers of massive sphalerite with minor galena and pyrite occurring within metamorphosed shallow-marine carbonate sequences. Due to post-ore deformation, sulfide minerals commonly are discordant to primary bedding. Shallow-water platform carbonate sequences are composed mainly of marble (calcareous and dolomitic) with several possible associated (and interbedded) sedimentary lithologies including quartzite, talc-tremolite schist, quartz-diopside rock, and massive bedded anhydrite. Some marble units may be graphitic. Deposits are likely to be highly deformed with evidence for multiple periods of penetrative deformation and complex shearing/faulting (including premetamorphic thrusts). Remobilization of sulfides along thrust faults and shear zones is characteristic, including the transport of sulfides tens to hundreds of meters from their original setting. Deposits can occur at several stratigraphic levels over hundreds of meters of section.

Mineralogy consists of sphalerite, minor galena, and generally minor pyrrhotite or pyrite; chalcopyrite is typically rare but may be more abundant (minor) in some deposits. Sphalerite commonly has high concentrations of Hg; pyrite may have high Co and(or) Ni. Alteration is nearly absent; local thin zones adjacent to orebodies may show hydrothermal removal of graphite and possible silicification of carbonate beds. Geochemical signatures show elevated concentrations of Zn, Pb, Cu, Hg, Co, and(or) Ni. Silver concentrations generally are low. Copper typically is very low in Balmat-type deposits and Au is absent. Geophysical signatures consist of gravity highs with possible induced polarization anomalies. Deposits generally lack an electromagnetic anomaly owing to the Zn–rich nature of the sulfide deposits.

Deposits possibly associated with strata-bound Pb–Zn deposits

Bedded barite, phosphate, and associated evaporite deposits also may be present in the stratigraphic interval that hosts Pb–Zn deposits. The characteristics of these deposit types are outlined below so they can be documented or searched for in the field.

Sedimentary Mn deposits - Shallow-marine Mn deposits are unknown in Afghanistan, but the deposit type is present in geologic environments similar to those that host stratabound Pb–Zn deposits. The USGS-AGS Assessment Team suggests that potential for this deposit type be included in the permissive tracts for those deposits. Manganese deposits are important because the giant Molango orebody in Mexico has reserves of over 200 million metric tons, with identified resources that total approximately 15 billion metric tons at an average grade of 10 wt. percent Mn. Sedimentary Mn deposits (model 34b; see also Force and Cannon, 1988) are large concentrations of Mn oxide and(or) carbonate minerals that occur in shallow-marine transgressive sequences that have nearby, temporally equivalent anoxic deep-water facies.

Formation of possible shallow-marine Mn deposits within this generally favorable setting is controlled by effects of oceanic circulation and upwelling and of local sedimentary environments. Ores may be either manganese oxides, which locally occur as oolites and pisolites and are very distinctive, or bedded manganese carbonate. Oxide-facies Mn-rich beds contain black oolites or pisolites. Bedded Mn-rich carbonate rocks that would likely be identified as dolomite in the field show abundant secondary manganese minerals on weathered faces or joints. Any “dolomite” that shows unusual amounts of secondary manganese oxides on weathered surfaces or joints should be tested chemically for manganese content. Alteration comprises secondary manganese oxide concentrations. Geochemical signature consists of Mn–anomalous zones defined by detailed chemical stratigraphy that identify significant stratigraphic units. Such anomalous units may have regional extent and help guide exploration to the most favorable strata.

Specific suggestions for exploration are that a few well-exposed stratigraphic sections or drill holes be assayed for manganese content, on intervals of a meter or two, in order to search for regionally anomalous units. Such units, if found, should receive special attention in field mapping and be examined for possible secondary manganese minerals and assayed for manganese if such secondary alteration is found. Oxide facies are very distinctive rocks and should be easily recognizable in field mapping if they are not highly modified by weathering. Carbonate facies can be very cryptic and may appear to be dolomite on field examination. “Dolomite” within defined favorable intervals should be closely examined for indications of high concentrations of manganese.

Bedded barite deposits Bedded barite deposits (model 31b, Orris, 1986) or stratiform barite deposits consist of stratiform accumulations of barite interbedded with dark-colored cherty and calcareous sedimentary rocks. Host strata are generally dark-colored chert, shale, mudstone, limestone or dolostone, and also quartzite, argillite, and greenstone. Deposits range in age from Proterozoic to Paleozoic. The depositional environment is epicratonic marine basins or embayments (typically with smaller locally restricted basins). The tectonic setting of the deposits is associated with hinge zones controlled by synsedimentary faults. The deposits may be spatially associated with sedimentary-exhalative Zn–Pb deposits.

Mineralogy consists of barite ± minor witherite ± minor pyrite, galena, or sphalerite. Barite typically contains several percent organic matter plus some H_2S in fluid inclusions. Ore textures are stratiform, commonly lensoid to poddy, with laminated to massive ore and barite nodules or rosettes. Barite may exhibit primary sedimentary features. Small inclusions of country rock may show partial replacement by barite. Alteration is typified by secondary barite veining; weak to moderate sericitization also may be present. Weathering is indistinct, generally resembling limestone or dolostone. Weathered-out rosettes or nodules are present locally. Geochemical signature consists of elevated Ba and where peripheral to sediment-hosted Zn–Pb, may have lateral (Cu)–Pb–Zn–Ba zoning or regional manganese haloes. Organic C content is usually high.

Phosphate deposits Upwelling-type phosphate deposits (model 34c, Mosier, 1986) are phosphorite sediments from a major stratigraphic unit within a sequence of marine sediments that were deposited in upwelling areas of basins with good connection to the open sea. These Precambrian through Miocene age deposits are associated with marl, shale, chert, limestone, dolomite, and volcanic materials. The depositional environment is marked by high productivity of plankton. Deposition occurs mostly in warm waters at low latitudes, mostly between the 40th parallels. Tectonic setting is shelf, platform, and slope. Associated deposit types are sedimentary Mn. Mineralogy consists of apatite + fluorapatite + dolomite + calcite + quartz + clays (montmorillonite or illite) ± halite ± gypsum ± iron oxides ± siderite ± pyrite ± carnotite. Ore textures are pellets, nodules, phosphatized shells, and bone material. Deposits form in basins, or parts of basins, favorable for the accumulation of organic-rich sediments and for their evolution into phosphorite. Individual beds can be one meter thick or more and may extend over hundreds of square kilometers. Weathering products are limonite and goethite. Geochemical signatures are elevated concentrations of P, N, F, C, and(or) U. The deposits commonly are anomalously radioactive. Favorable geologic conditions may exist in the same rocks as for sedimentary Mn deposits.

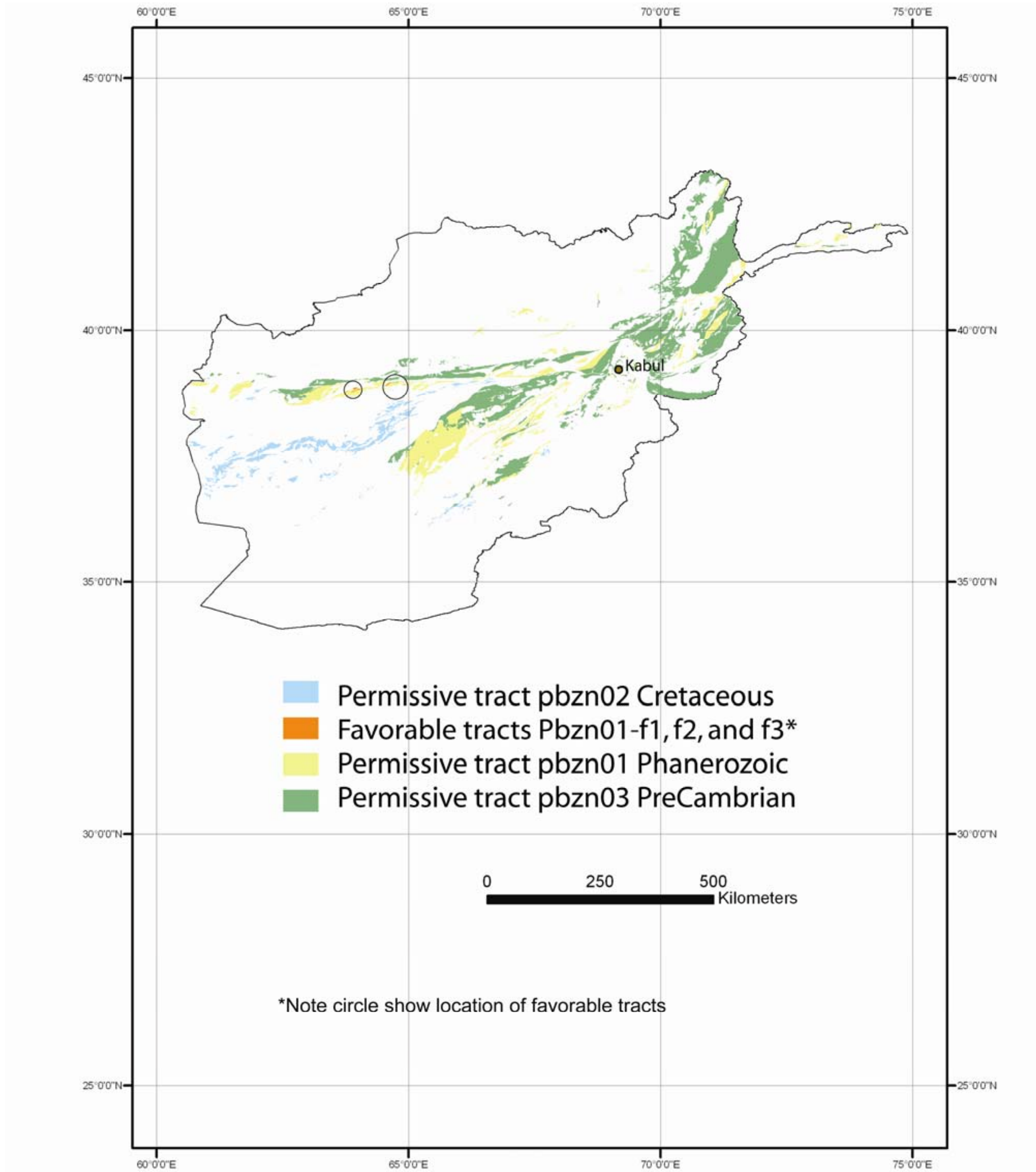

Figure 7.2-1. Map showing location of permissive and favorable tracts for sediment-hosted lead-zinc deposits in Afghanistan.1

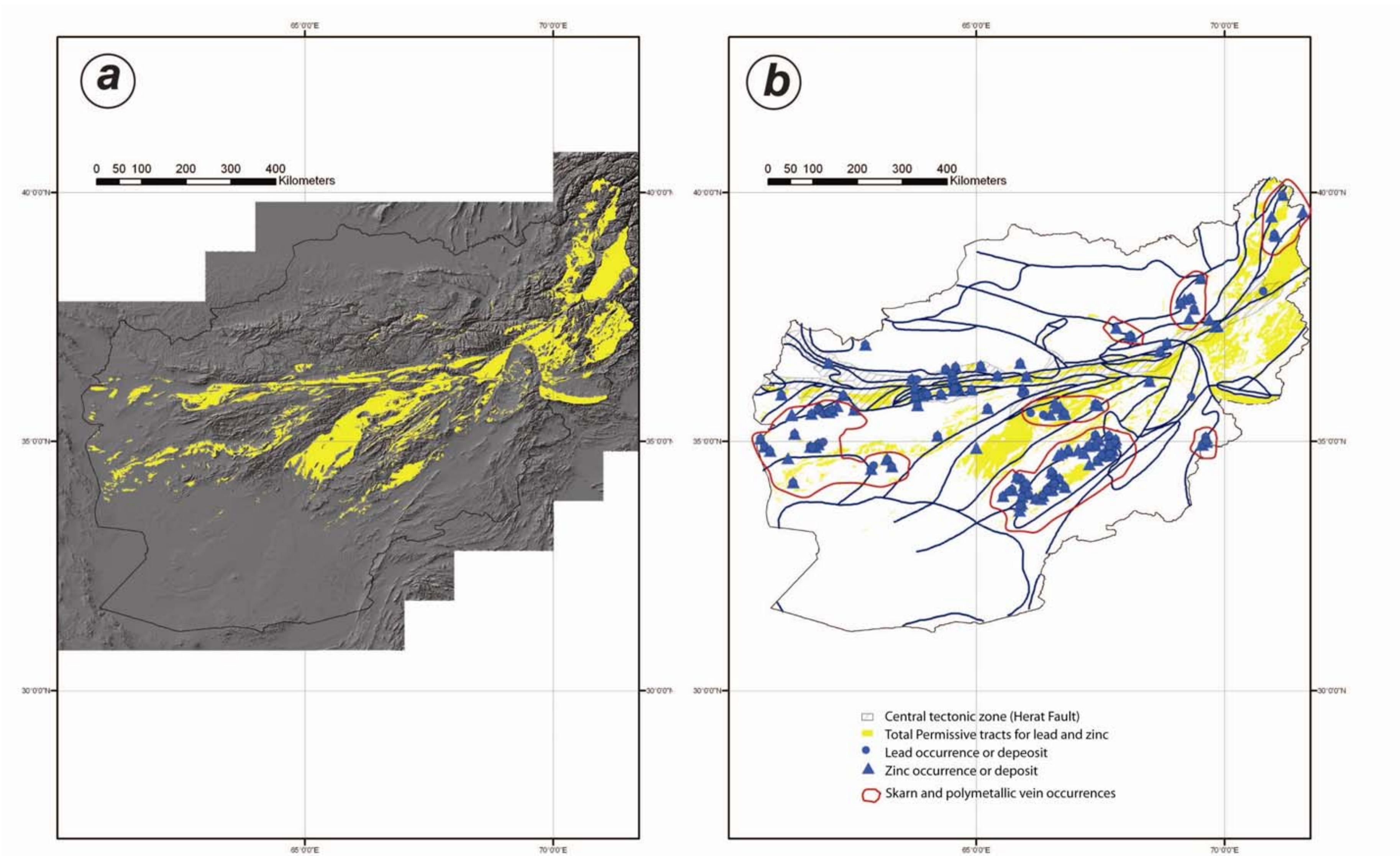

Figure 7.2-2. Maps showing location of all permissive tracts for sediment-hosted lead-zinc deposits in Afghanistan. (*a*) Three tracts pbzn01, pbzn02, and pbzn03. (*b*) Map showing distribution of all lead and zinc occurrences and deposits. Many occurrences in the south and north are related to magmatic activity, whereas those in the central part of the country are related to a tectonic zone proximal to the Herat Fault.

7.2.2 Sediment-hosted lead-zinc tract descriptions

Permissive tract pbzn01 sediment-hosted lead- zinc—Phanerozoic

Deposit type— Phanerozoic sedex zinc-lead-silver (Zn-Pb-Ag) deposits, Mississippi Valley-type zinc-lead deposits, sandstone-hosted lead-zinc deposits

Age of mineralization—Late Paleozoic to Mesozoic

Examples of deposit type—A number of stratabound lead-zinc mineral occurrences (Sarghul, Nalbandon, Hassan Sansalaghay, and Gharghanaw) are present in western and central Ghor Province in Paleozoic and Mesozoic strata. These rocks may contain resources of Zn, Pb, Ag, Ba, and Cd.

Exploration history—There is only limited previous exploration in this part of Afghanistan, although discovery and description of the occurrences in the central part of the tract indicate some ground prospecting for lead and zinc. Geochemical stream sediment exploration has taken place throughout the tract and several parts of the tract contain anomalous mineral halos of lead and zinc. The USGS Assessment Team has not visited the area. Metallurgical tests were done on the Nalbandon occurrences and exploration was carried out there by the German Geological Mission to Afghanistan.

Tract boundary criteria—Permissive tract pbzn01 sediment-hosted lead-zinc—Phanerozoic was delineated by the USGS-AGS Assessment Team and includes Late Paleozoic and Early Mesozoic marine sedimentary rocks (map units DC_1d, $P_{2l}d$, CP_1ssl, $T_{13}dd$, T_3nrsls, and $J_{12}ssl$) (fig. 7.2-3) that are in central Afghanistan and extend from Herat Province in the west through central Ghor Province into Bamyan, Sari Pul, Samangan, Baghlan, and Parwan Provinces to the east. The Provinces of Uruzgan, Ghanzi, and Wardak contain large areas of permissive stratigraphy. Several favorable tracts (tracts pbzn01-f1, f2, and f3) were delineated in the central part of permissive tract pbzn01 Ghor Province. These tracts are defined by clusters of known stratabound and vein or discordant lead-zinc occurrences, which also contain larger geochemical halo anomalies of lead, mercury, and gold (fig. 7.2-4). Other parts of the permissive tract pbzn01 coincide with lead-zinc geochemical halo anomalies, where lead-zinc mineral occurrences are absent have not been designated as favorable.

Important data sources—Geologic map, LANDSAT imagery, mineral occurrence database, and geochemical anomaly map (Doebrich and Wahl, 2006; Orris and Bliss, 2002; Abdullah and others, 1977).

Needs to improve assessment—Intermediate-scale (1:100,000) geologic mapping and geochemical sampling. Local prospects should be resampled and mapped, which would require site visits. Because geologic units in the tract span an age range of about 200 million years, it is uncertain whether there were more than one metallogenic interval and if all of the relevant stratigraphic units were selected. To be more accurate, additional permissive units within Devonian to Jurassic strata should be considered.

Optimistic factors—A number of stratabound lead and zinc occurrences and associated vein lead-zinc occurrences are present within the tract, especially the central part. Additionally, many parts of the tract coincide with lead and zinc geochemical halo anomalies.

Pessimistic factors—The mineralization may be epigenetic and related to local structures and is not necessarily associated with the host strata; therefore the choice of tract outline and genetic model are in question. Large parts of the tract may contain barren stratigraphy.

Numerical estimate—No estimate was made due to lack of information about the known mineral occurrences and the correspondence with the deposit models.

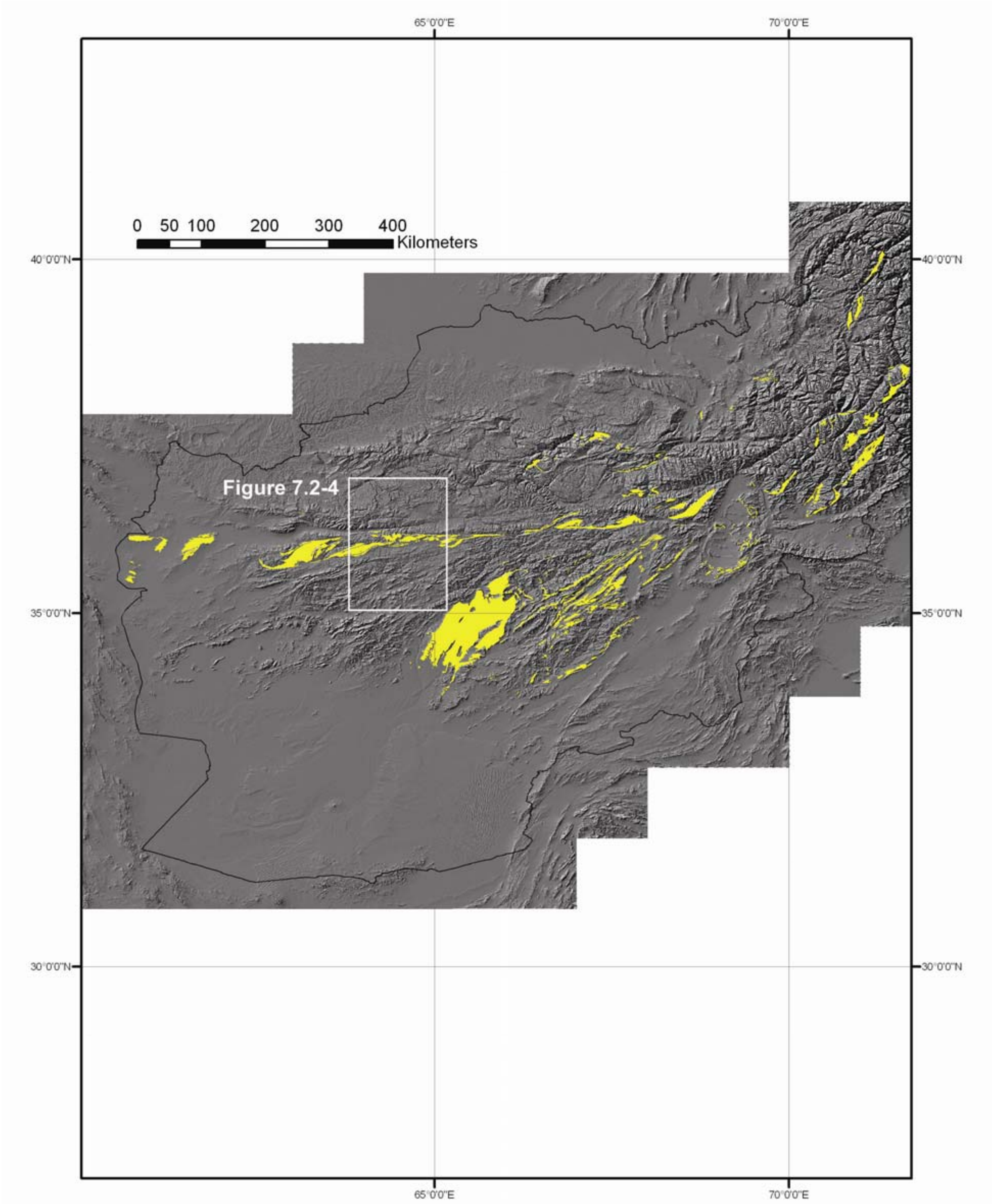

Figure 7.2-3. Map showing location of permissive tract pbzn01 Phanerozoic sediment-hosted lead-zinc. The known deposits and occurrences are within central Ghor Province, although some parts of the tract have lead and zinc geochemical-mineral halo anomalies. Separate sediment-hosted lead-zinc tracts were delineated for Tertiary, Cretaceous, and Proterozoic sedimentary packages (pbzn02, pbzn03, and pbzn04).

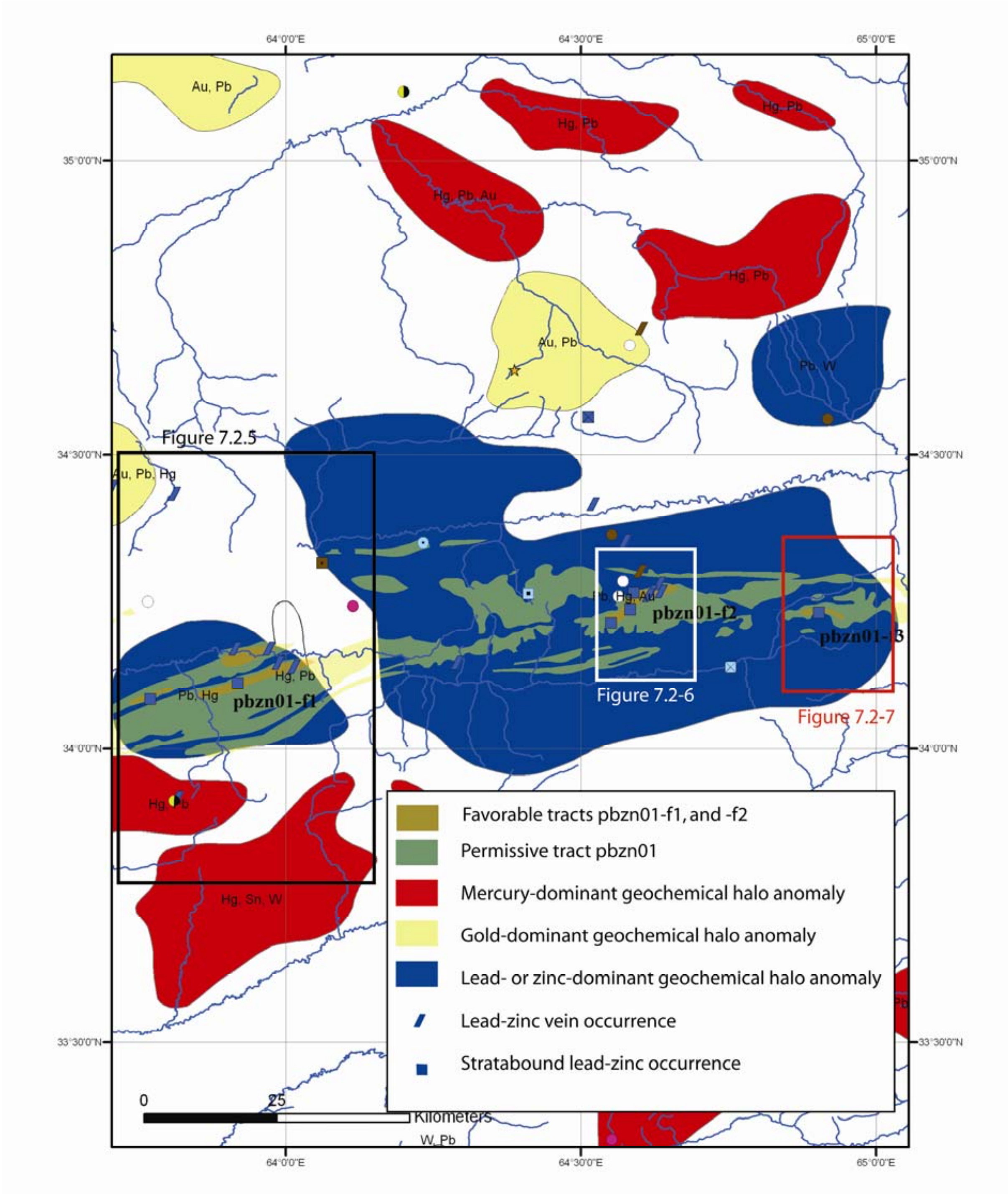

Figure 7.2-4. Central parts of permissive tract pbzn01 Phanerozoic sediment-hosted lead-zinc in Ghor Province, showing the location of favorable tracts pbzn01-f1 Nalbandon, -f2 Gharghanawl-Gawmazar, and -f3 East Ghor. The favorable tracts contain known mineral deposits or occurrences of stratabound lead and zinc, and also are within geochemical halo anomalies of lead, mercury, and(or) gold.

Favorable tract pbzn01-f1 Nalbandon

Favorable tract pbzn01-f1 was delineated within the permissive tract pbzn01 in three parts central Ghor Province to enclose the stratabound occurrences of Sarghul and Nalbandon, vein occurrences of Zawar, Minora, and Palang-Khana, and the on-strike stratigraphic extensions within Triassic and Lower to Middle Jurassic limestone, marl, sandstone, shale, and siltstone (fig. 7.2-5). The Nalbandon occurrence is hosted in Triassic calcareous and clayey siliceous sedimentary rocks in an 850–m-long and 3– to 9–m-thick mineralized zone containing sphalerite, galena, and minor boulangerite with pyrite, chalcopyrite, and pyrrhotite. The ore grades 5.77 wt. percent zinc and 0.87 wt. percent lead. Inferred reserves between the surface and the adit level are about 2 million metric tons of ore grading 6.64 wt. percent lead and zinc or 100,000-130,000 metric tons zinc, and 10,000 to 12,000 metric tons lead.

The other occurrences within favorable tract pbzn01-f1 are associated with shear zones and faults. The Sarghul lead-zinc occurrence is within Lower to Middle Jurassic limestone within a 1,700–m-long and up to 7.5–m-thick shear zone containing galena and sphalerite within sandstone lenses, accompanied by chalcopyrite and pyrrhotite grading 0.3 to 2.7 wt. percent lead (German Geologic Mission, 1969). Minora II is in Triassic porous siltstone along a fault zone containing ferruginous quartz veins grading 0.1 wt. percent lead with traces of zinc and copper (Dronov and others, 1972). The Palang-Khana occurrence is hosted in Lower to Middle Jurassic shale within two 0.4 to 1.5 m thick brecciated ferruginous zones containing silica veinlets and sparse galena grading 0.3 wt. percent lead and up to 0.5 wt. percent zinc with traces of copper.

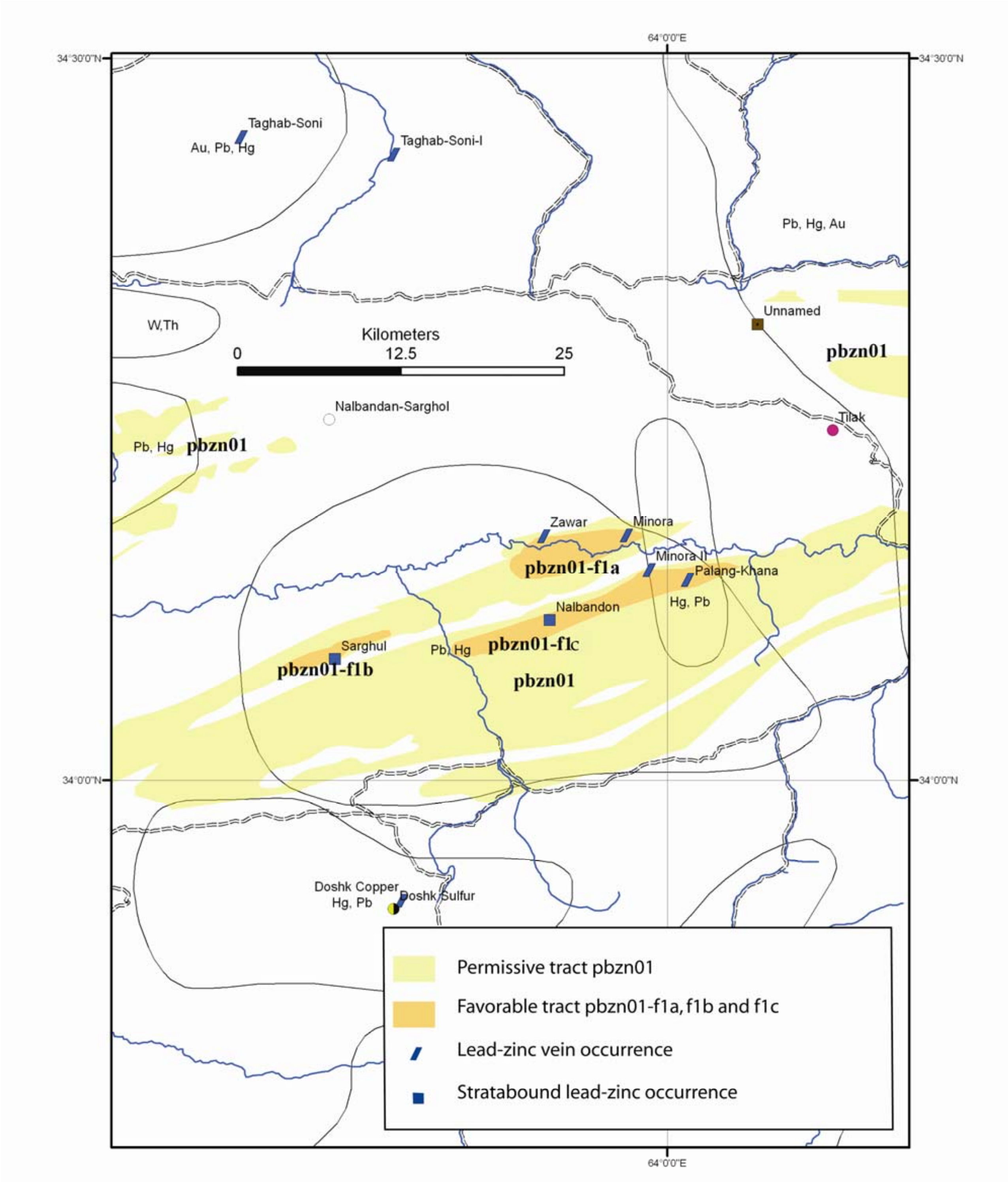

Figure 7.2-5. Map showing location of favorable tract pbzn01-f1 in three parts, one of which contains the Nalbandon deposit. See figure 7.2-4 for location.

Favorable Tract pbzn01-f2 Gharghanawl-Gawmazar

Favorable tract pbzn01-f2 was delineated to the east of favorable tract pbzn01-f1 in the northern part of permissive tract pbzb01 in central Ghor Province to enclose the stratabound occurrences of Gharghanaw and Hasan Sansalaghay, the vein occurrences of Shekhlawast, Gawmazar I, II, II, and IV, and on-strike extensions within Triassic and Lower to Middle Jurassic limestone, marl, sandstone, shale, and siltstone (fig. 7.2-6).

The Gharghananaw I and II mineral occurrences are hosted in lower Middle Jurassic calcareous to slaty sedimentary rocks within bedding-plane shear zones that are 200 to 300 m from each other, 50– to 100–m-long, and 5– to 20–m-thick grading 1.6 to 12.0 wt. percent lead, 1.0 to 1.6 wt. percent zinc, and containing traces of copper (Dronov and others, 1972). The Hasan Sansalaghay lead-zinc occurrence is within Lower to Middle Jurassic sandstone and limestone in a 15–m-long, 2.0–m-thick shear zone grading 4.9 wt. percent lead, up to 1.0 wt. percent zinc, 0.9 wt. percent copper, and traces of antimony (Dronov and others, 1972).

The Shekhlawast vein occurrence lies in Triassic slaty sandstone along a silicified bedding-plane shear zones and grades 0.5 wt. percent lead, 0.05 to 0.3 wt. percent zinc, 0.1 to 3.0 wt. percent arsenic, and 0.1 to 1.0 wt. percent antimony (Dronov and others, 1972). The Gawmazar I and II occurrences, in 100–m-long, 1.5– to 5.0–m-thick silicified and carbonated, ferrugineous shear zones in Upper Triassic sandy slate, grade 6.0 to 10.0 wt. percent lead, 0.07 to 0.10 wt. percent zinc, 0.16 wt. percent copper, and up to 0.4 g/t gold. The Gawmazar III occurrence is hosted in Upper Permian slaty sandstone in a 1.0– by 50–m-wide shear zone grading up to 10 wt. percent lead and 0.1 to 0.5 wt. percent zinc.

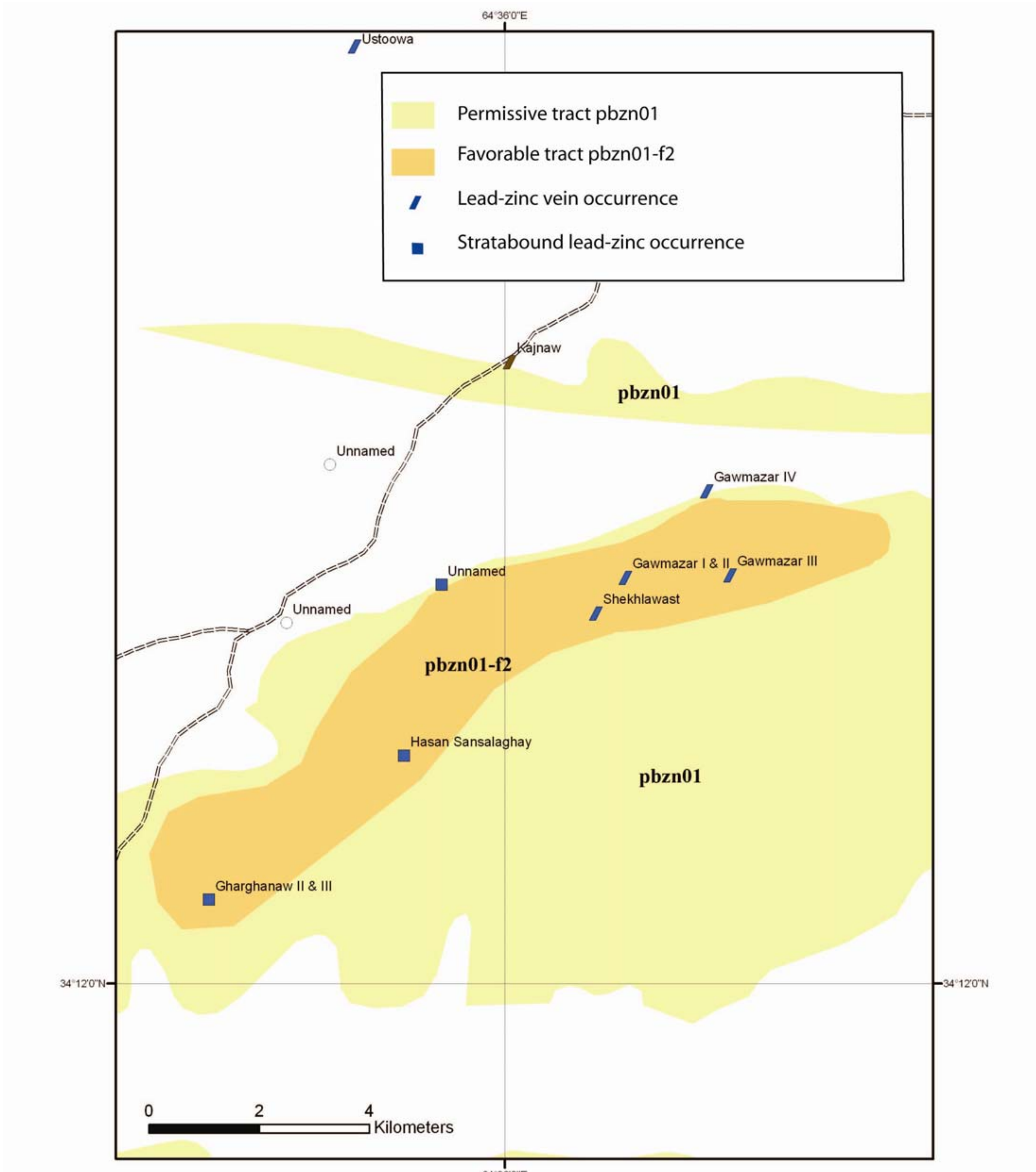

Figure 7.2-6. Favorable tract pbzn01-f2 Gharghanawl-Gawmazar in Ghor Province containing the Gharghanaw, Hasan Sansalaghay, Shekhlawas, and Gawmazar lead-zinc occurrences. Most of these occurrences have commercial grade lead and zinc values within silicified bedding-plane shear zones in Jurassic or Triassic sedimentary rocks. See figure 7.2-4 for location.

Favorable Tract pbzn01-f3—East Ghor

A third favorable tract, pbzn01-f3 East Ghor, was delineated in eastern Ghor Province to include an unnamed lead-zinc-bearing mineralized zone in Upper Devonian to Lower Carboniferous limestone. The occurrence contains galena and is present in a 100–m-long, 3– to 10–m-thick shattered zone containing anomalous concentrations of lead, zinc, and copper (Abdullah and others, 1977; Orris and Bliss, 2002). The area lies within a large geochemical halo anomaly rich in lead, mercury, and gold (shown on figure7.2-4) (fig. 7.2-7).

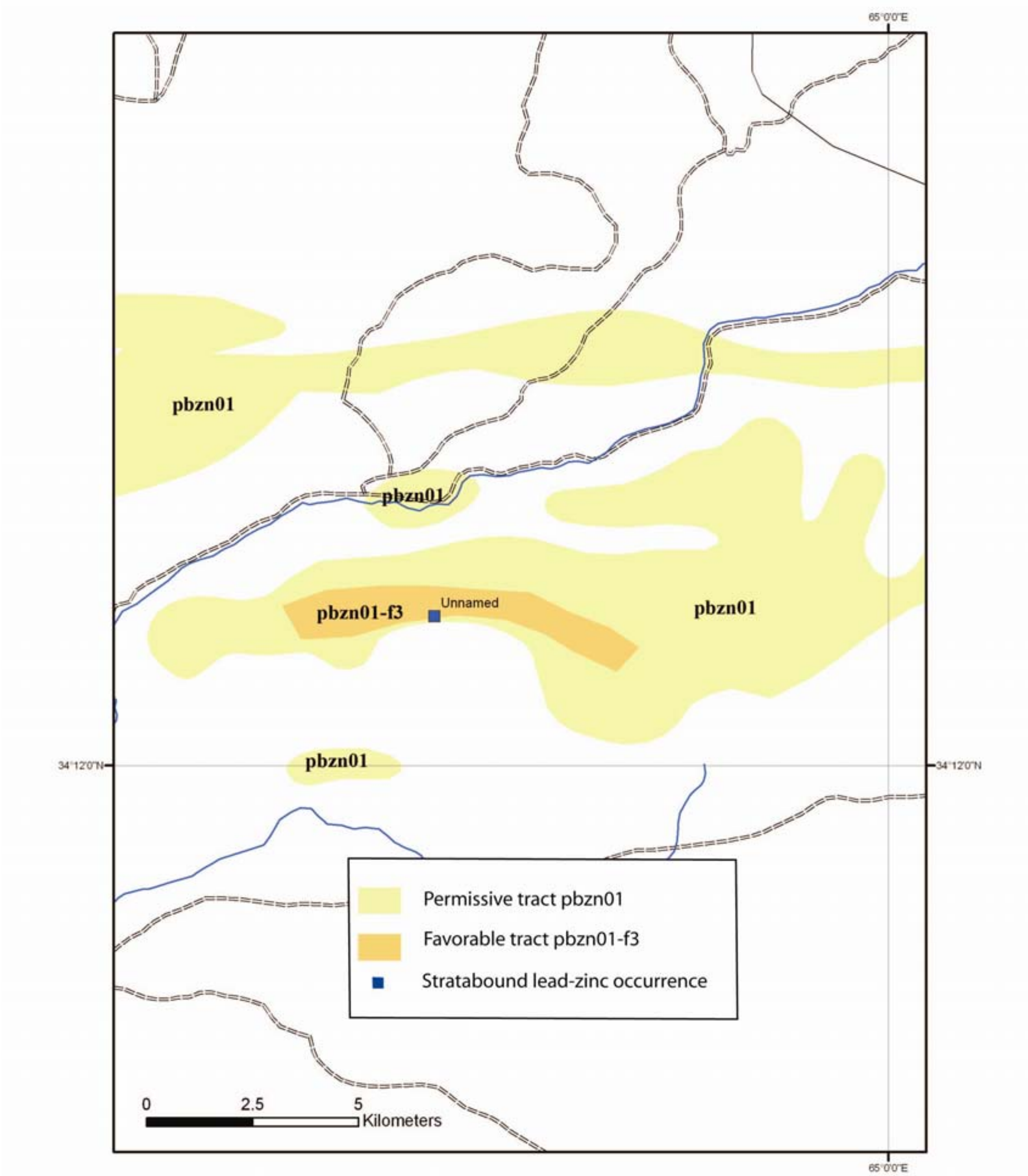

Figure 7.2-7. Favorable tract pbzn01-f3 in east-central Ghor Province. The area lies within a large lead, mercury, and gold geochemical halo anomaly. See figure 7.2-4 for mineral halo anomaly and for location.

Geochemical anomalous areas in tract pbzn01

Five areas that contain the permissive stratigraphy that define tract pbzn01sediment-hosted lead-zinc Phanerozoic coincide with geochemical halo anomalies. Four of these are in the eastern part of Afghanistan in Takhar, Samangan, Parwan, and Bamyan Provinces (fig. 7.2-8), and the fifth is in western Afghanistan in Herat Province (figs. 7.2-9, -10, and -11)

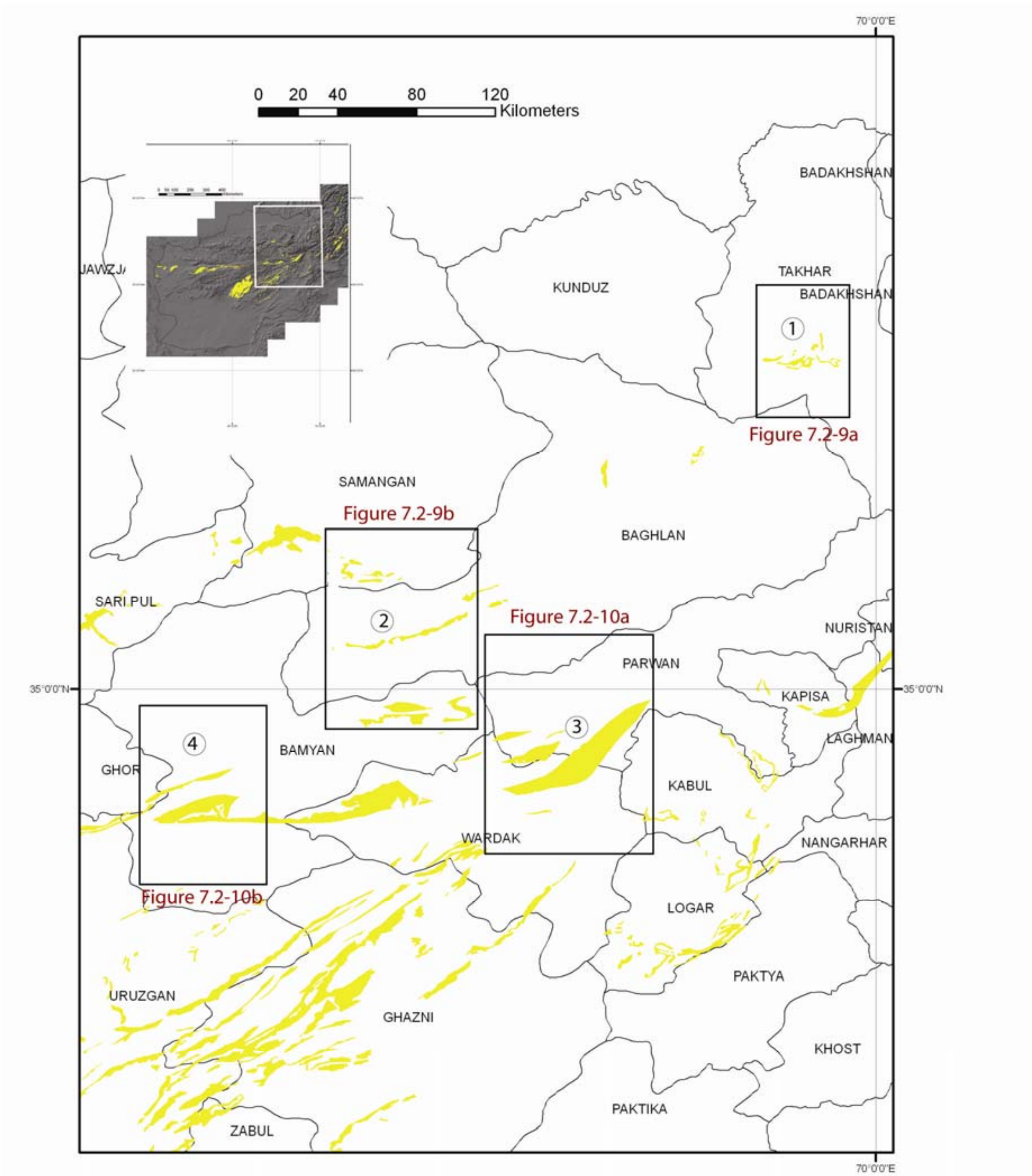

Figure 7.2-8. Four areas within eastern Afghanistan that contain permissive stratigraphy for the occurrence of stratabound sediment-hosted lead-zinc deposits in rocks of Paleozoic and Early Mesozoic age. Inset shows location of figure within Afghanistan.

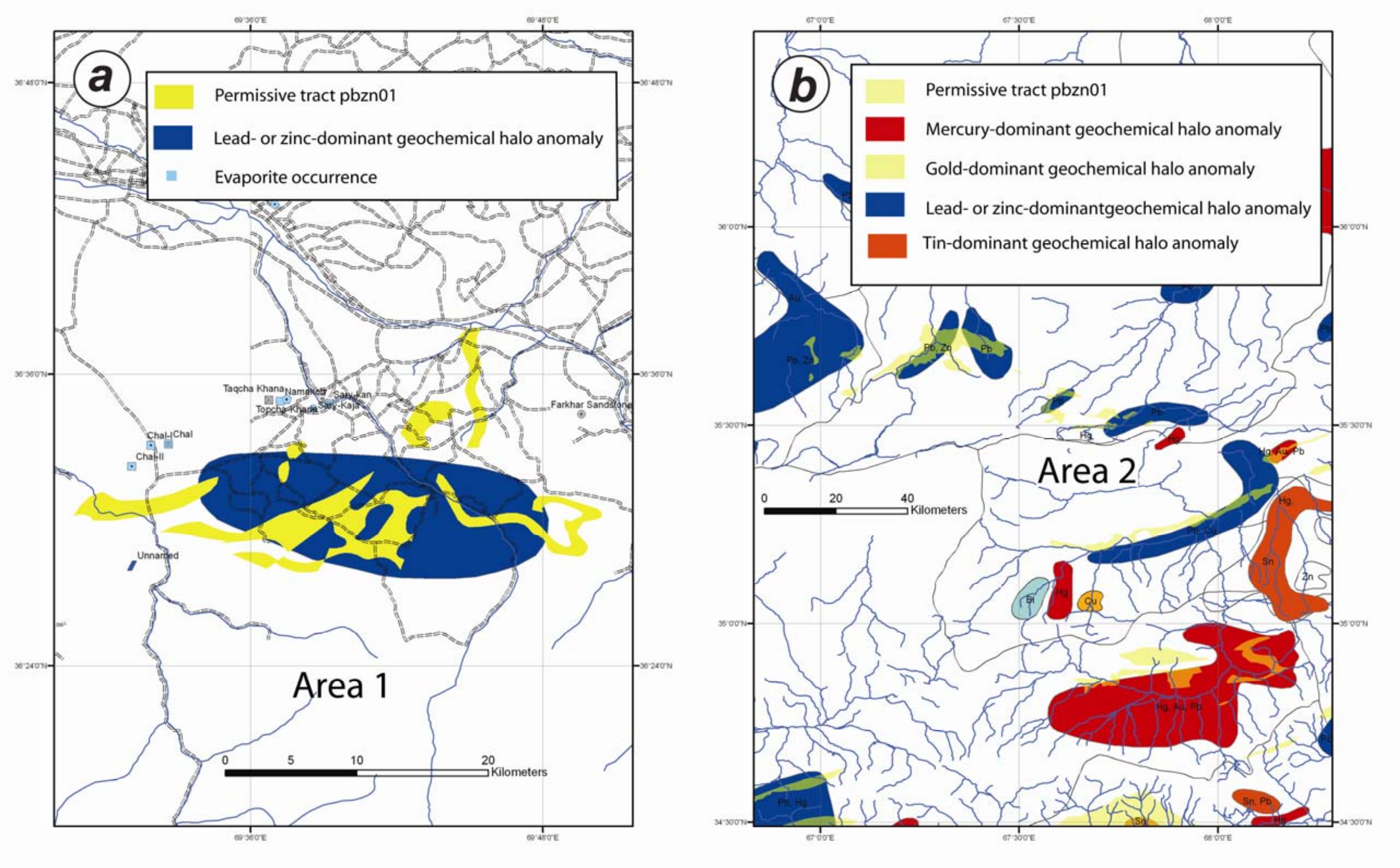

Figure 7.2-9. Map showing location of areas of interest 1 and 2 for undiscovered lead and zinc deposits. (*a*) Area 1 within permissive tract pbzn01 (yellow) in relation to geochemical halo anomaly for lead in Takhar Province. (*b*) Area 2 within permissive tract pbzn01 (yellow) in relation to geochemical halo anomaly for lead in Samangan Province.

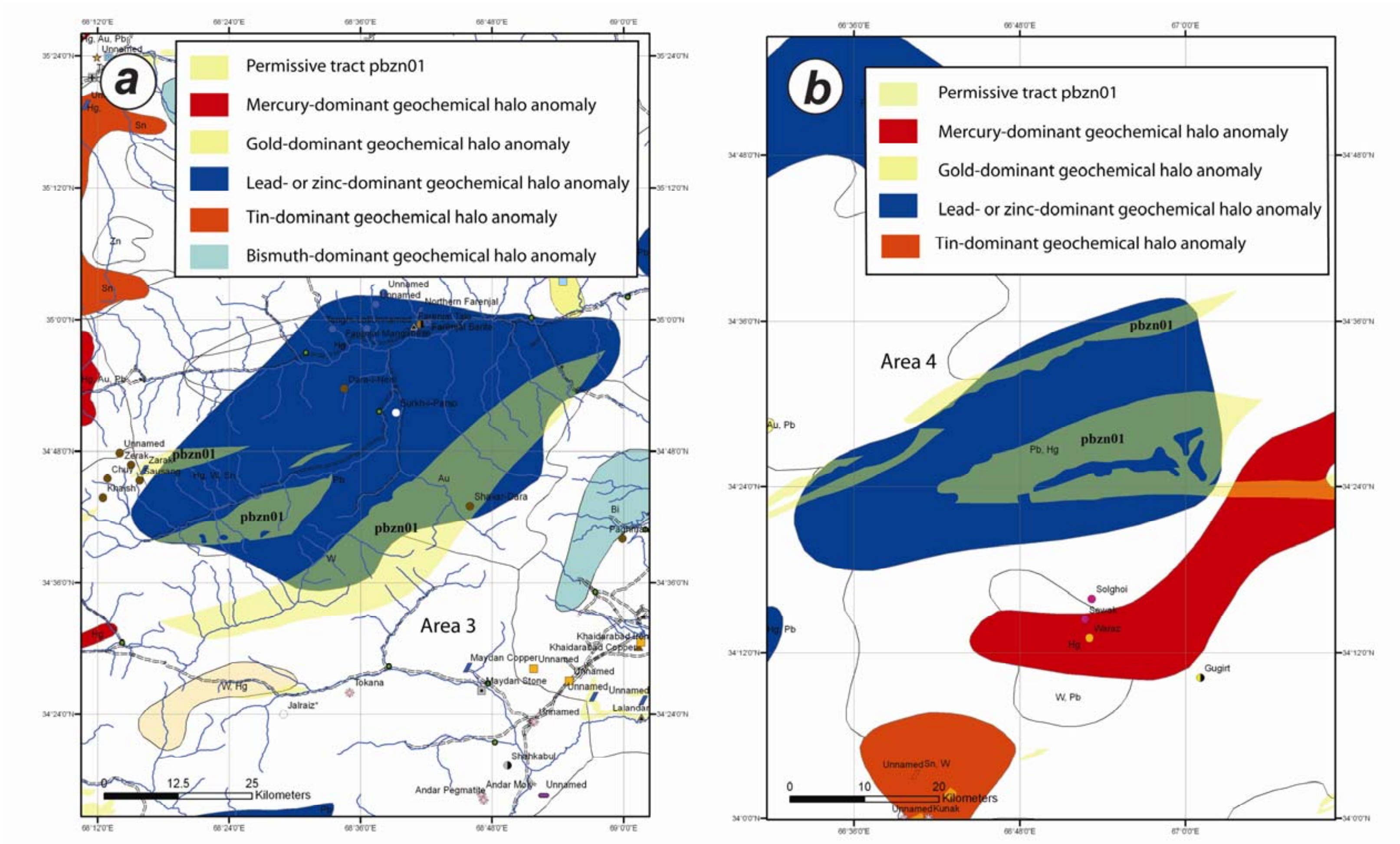

Figure 7.2-10. Map showing location of areas of interest 3 and 4 for undiscovered lead and zinc deposits. (*a*) Area 3 within permissive tract pbzn01 (yellow) in relation to geochemical halo anomaly for lead in southern Parwan and northern Wardak Provinces. (*b*) Area 4 within permissive tract pbzn01 (yellow) in relation to geochemical halo anomaly for lead in Bamyan Province.

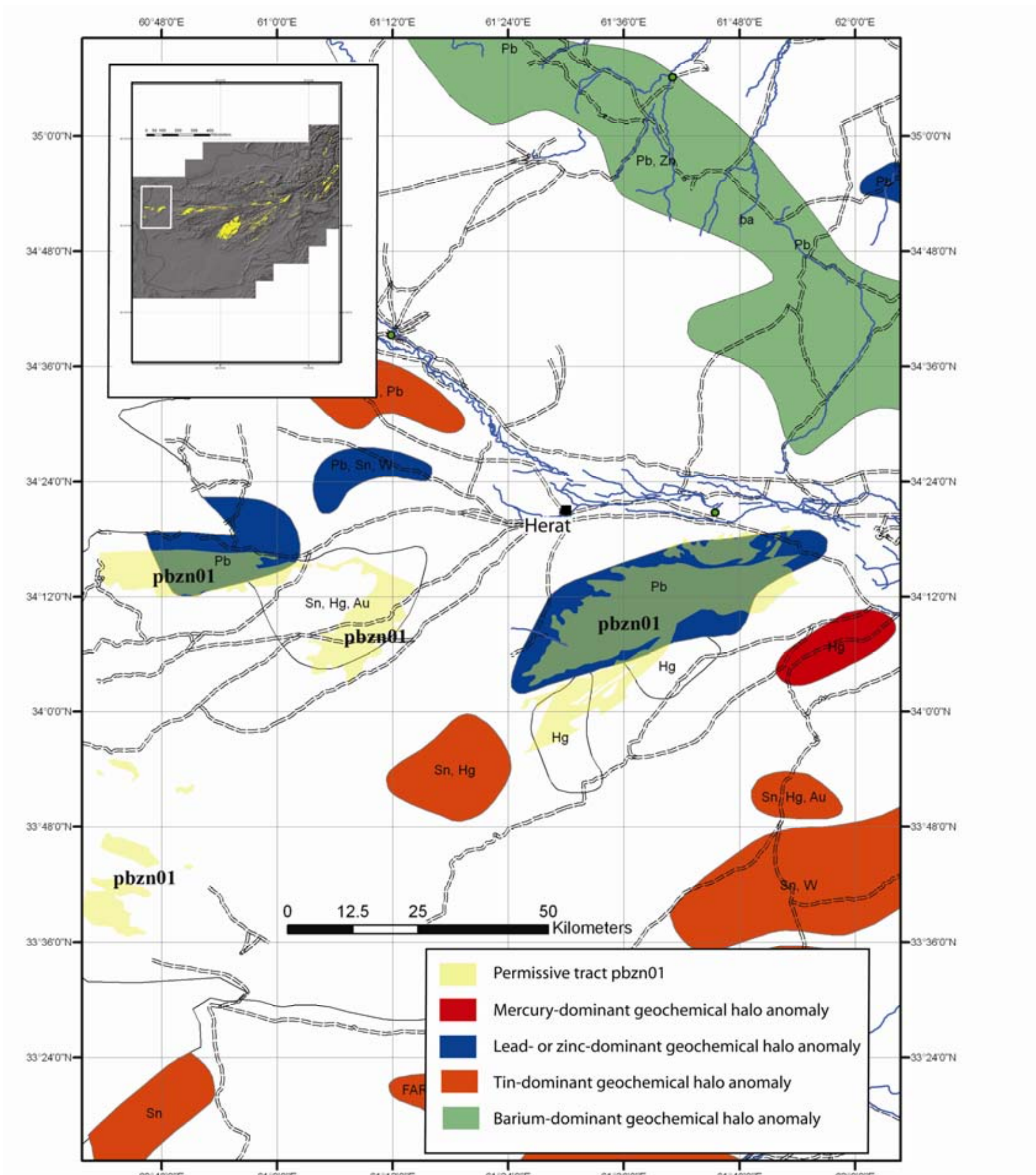

Figure 7.2-11. Map showing location of area 5 within permissive tract pbzn01 (yellow) in relation to geochemical halo anomaly for lead in Herat Province. Inset shows location inside Afghanistan

Permissive Tract pbzn02 sediment-hosted lead-zinc—Cretaceous

Deposit type— Phanerozoic sedimentary-exhalative (sedex) zinc, lead-silver deposits, Mississippi Valley-type zinc-lead deposits, sandstone-hosted lead-zinc deposits

Age of mineralization—Early Cretaceous

Examples of deposit type—The Talah stratabound lead-zinc occurrence is present in Uruzgan Province in Cretaceous strata. No other lead-zinc occurrences are known within the tract.

Exploration history—There has been only limited previous exploration in this part of Afghanistan, although discoveries and descriptions of the occurrences in the central and southeastern parts of the tract indicate some ground prospecting. Geochemical stream sediment exploration has taken place throughout the tract. The U.S. Geological Survey team has not visited the area.

Tract boundary criteria—The tract was based on the presence of Lower Cretaceous limestone, marl, sandstone, and conglomerate (map unit K1baplss) within the central and western parts of Afghanistan and includes the Talah stratabound lead-zinc occurrence in Uruzgan Province (fig. 7.2-12). No geochemical halo anomalies of lead or zinc coincide with the tract. The Talah occurrence is hosted in Lower Cretaceous limestone in a 20– to 25–m-thick shear zone containing veinlets and disseminations of galena grading 0.5 to 2.0 wt. percent zinc with traces of zinc and copper (Orlov and others, 1974).

Important data sources—Geologic map, geochemical halo anomalies, LANDSAT imagery, mineral deposit database (Abdullah and others, 1977; Orris and Bliss, 2002; Doebrich and Wahl, 2006).

Needs to improve assessment—Intermediate-scale (1:100,000) geologic mapping and geochemical sampling. The Talah lead-zinc occurrence should be and resampled and mapped, which would require site visits.

Optimistic factors—The presence of the Talah lead-zinc occurrence may indicate that the Lower Cretaceous sedimentary host rocks are permissive for stratabound mineralization either as epigenetic or syngenetic deposits. The coincidence of these strata with mercury and polymetallic geochemical halo anomalies to the southwest suggests that the beds are associated with hydrothermal mineral deposits.

Pessimistic factors—Only one occurrence of lead and zinc is known in the tract. No lead or zinc geochemical halo anomalies coincide with the permissive stratigraphy. Most of the tract is associated with the mercury occurrences and deposits in the southwestern part of Afghanistan and not with lead-zinc occurrences.

Quantitative assessment—No estimate was made due to lack of information about the known mineral occurrences and correspondence with the deposit models.

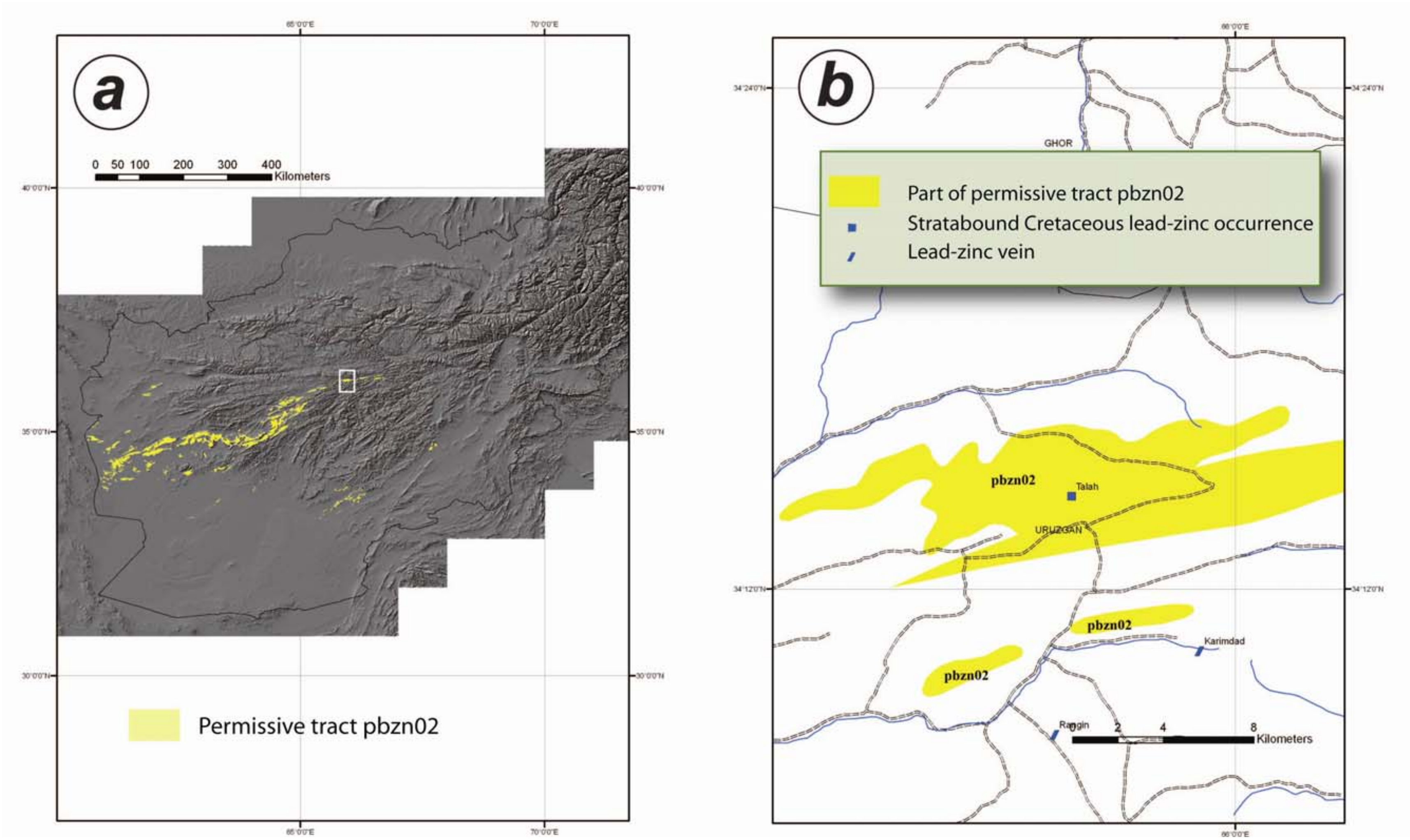

Figure 7.2-12. (*a*) Map showing location of permissive tract pbzn02 for sediment-hosted lead zinc deposits within Lower Cretaceous sedimentary rocks. (*b*) Location of the Talah lead-zinc occurrence within permissive tract pbzn02 in Uruzgan Province in the eastern parts of the tract (see inset in (*a*) for location).

Permissive Tract pbzn03 sediment-hosted lead-zinc—Proterozoic

***Deposit Type*—**Proterozoic sedex Pb–Zn–Ag (Broken Hill-type), Proterozoic sedex Zn-Pb (Balmat-type).

***Age of mineralization*—**Proterozoic

***Examples of deposit type*—**There are no examples of the deposit types in the tract.

***Exploration history*—**No known previous exploration other than geochemical stream sediment exploration has taken place for lead-zinc deposits in Proterozoic stratigraphy. However, exploration has been carried out in Proterozoic sequences in the Aynak area for sediment-hosted copper deposits.

***Tract boundary criteria*—**The permissive tract encompasses all known Precambrian sedimentary and volcano-sedimentary rock units of all metamorphic grades. The tract also includes Archean rocks in Badakhshan Province because more age dating in these rocks is necessary do conclude that they do not include Proterozoic inliers. Although deposits of these types are unknown in Afghanistan, Proterozoic strata contain some of the world's larger lead and zinc deposits. Few lead or zinc geochemical halo anomalies are present with the exception of an area in Parwan Province that has stratabound iron deposits (fig. 7.2-13).

***Important data sources*—**Geologic map, geochemical halo data, mineral deposit database (Doebrich and Wahl, 2006; Orris and Bliss, 2002; Abdullah and others, 1977).

***Needs to improve assessment*—**Intermediate-scale (1:100,000) geologic mapping and geochemical sampling. Local prospects should be resampled and mapped, which would require site visits.

***Optimistic factors*—**Proterozoic rocks throughout the world with similar stratigraphy and lithologies in Afghanistan contain large stratabound lead-zinc deposits. Stratabound deposits of iron and copper are present in Proterozoic rocks in Afghanistan.

***Pessimistic factors*—**No lead-zinc deposits or occurrences are known in the Proterozoic rocks of Afghanistan.

***Quantitative estimate*—**No quantitative assessment was attempted by the USGS-AGS Assessment Team due to lack of information about the host stratigraphy and lack of known occurrences of lead and zinc.

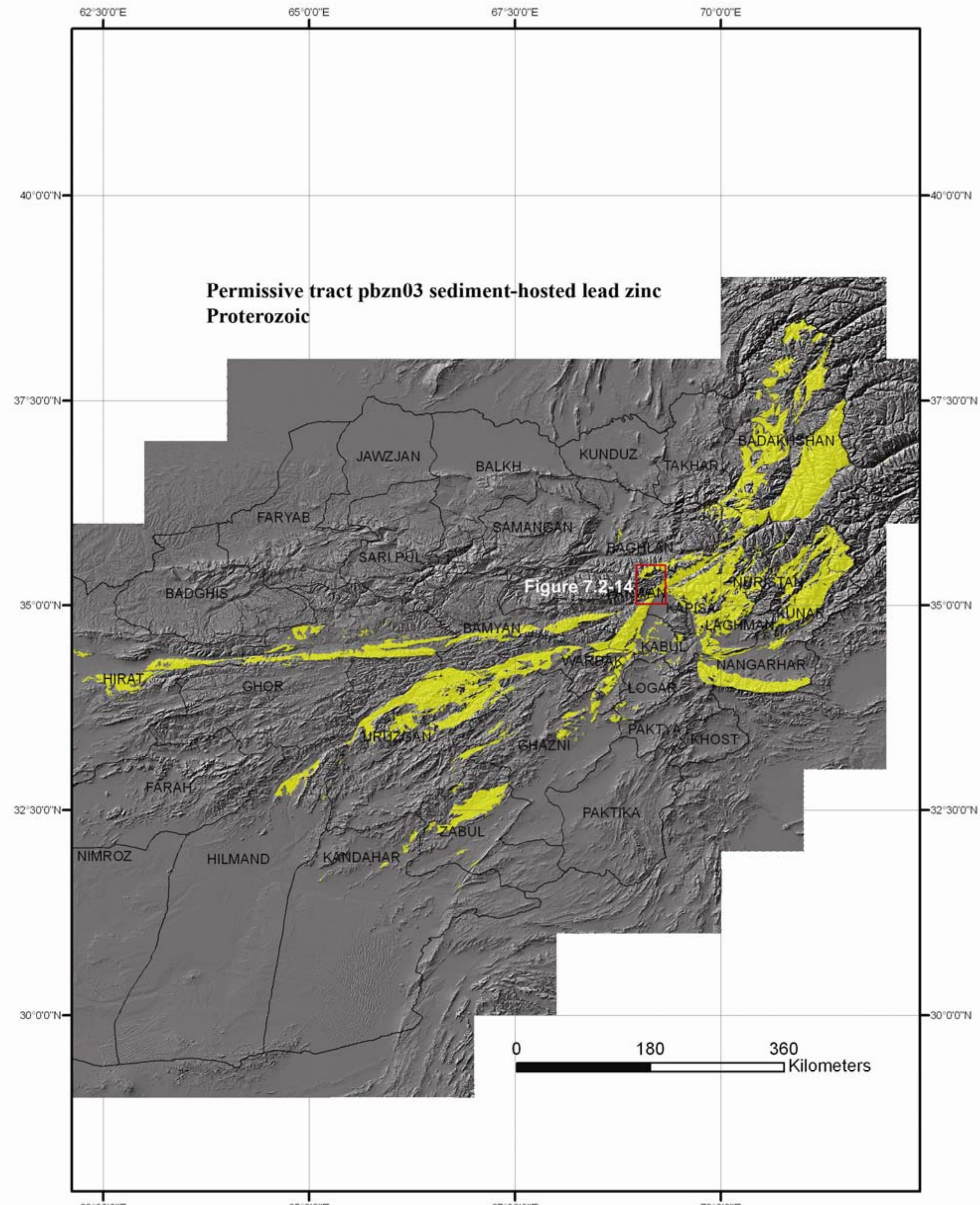

Figure 7.2-13. Permissive tract pbzn03--Proterozoic (and al Precambrian) rocks in Afghanistan that may have potential for sediment hosted lead-zinc deposits.

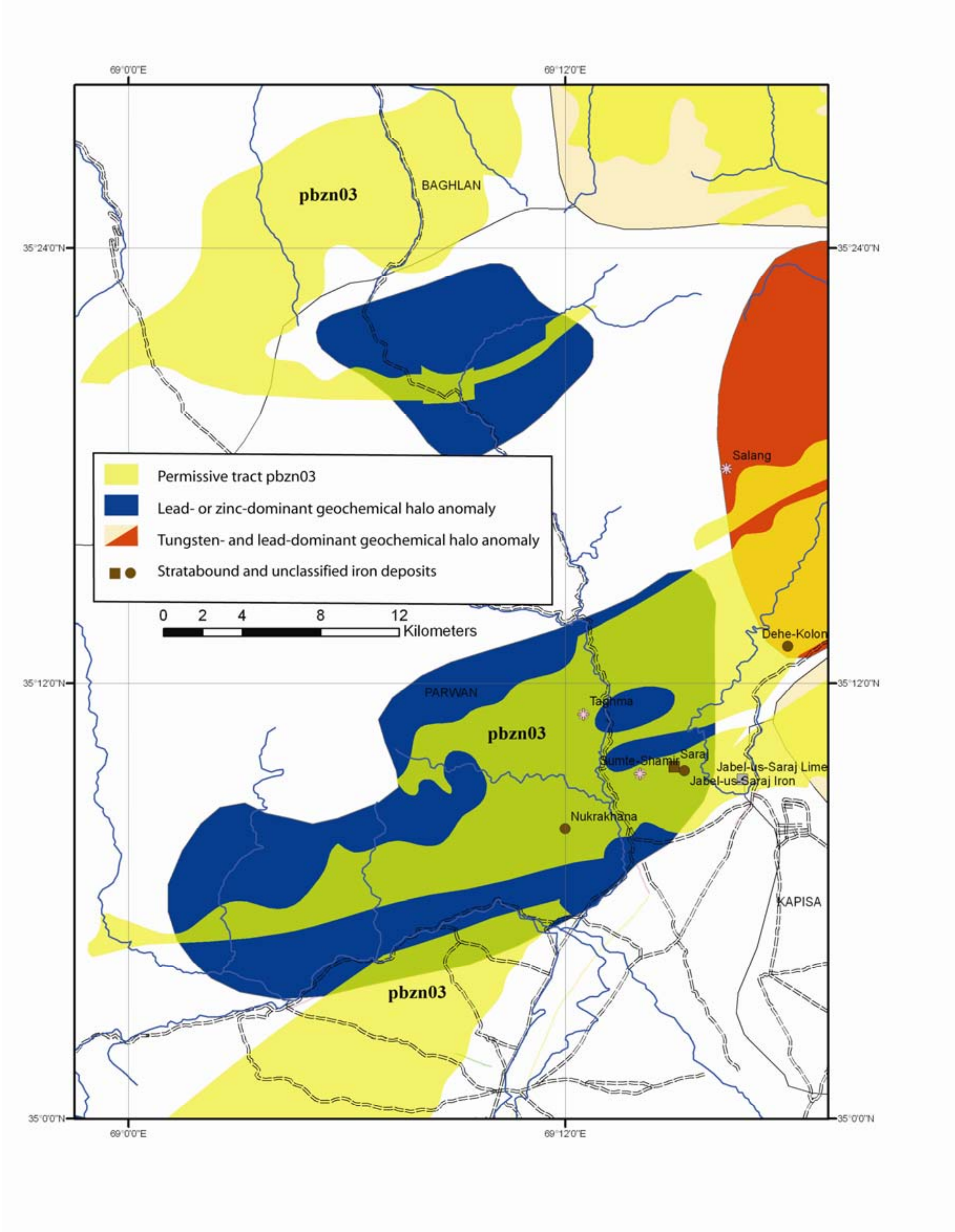

Figure 7.2-14. Map of parts of permissive tract pbzn03 for sediment-hosted lead-zinc deposits in Proterozoic rocks (yellow) in Parwan Province, showing overlap of the tract with two geochemical halo anomalies of lead (blue). The southern most part of the tract contains stratabound iron occurrences (other symbols from Doebrich and Wahl, 2006).

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7.3 Clays

Contributions by James D. Bliss and Stephen G. Peters

Afghanistan contains abundant clays adequate for use in local construction. With the exception of the kaolin associated with coals, little information is available about the composition of the clays. Further investigation into the type and composition of the clays would be necessary to determine where efforts should be directed towards developing them for other specialized uses. Analysis of ASTER imagery proved to be an important tool in the location of occurrences of bedded clays, carbonates, ultramafic rocks, and hydrothermal alteration zones associated with ore deposits. The three categories of clays considered by the USGS-AGS Assessment Team were brick and refractory clays, porcelain, and adobe-brick clay. The clays occur mainly associated with sedimentary clay-rich zones in Mesozoic and Cenozoic strata.

7.3.1 Brick and refractory clays

Brick and refractory clays are present in the west in Herat Province, in the central parts of the country in Samanghan and Baghlan Provinces, and in Kabul Province (fig. 7.3-1). The clays occur mainly in Upper Jurassic and in Cenozoic clay-rich sedimentary rocks.

Herat Province contains the Karukh and Malumat brick and fire-clay occurrences within calcareous silty and sandy material in Quaternary sedimentary formations (map unit Q_2a) (fig. 7.3-2) (Abdullah and others citing manuscript by Mikhailov written in 1965). An area of interest was delineated by selecting unit Q_2a (fig. 7.3-1a), which also has clay occurrences in the Loghar Valley.

In Samanghan and Baghlan Provinces the, coal-bearing Jurassic units that contain sedimentary kaolin in unspecified map unit J_{12}ssl was buffered in the GIS to 1 km (figs. 7.3-1b, 7.3-3). Clay occurrences include Rafak in the Ruyi Du Ab District within Lower Cretaceous siltstone that consists of a green to gray 5–m-thick clay bed. The Nalak occurrence, in Upper Triassic weathered diorite porphyry, is a tabular deposit about 13 m thick consisting of gray, laminated clay. The Talin occurrence is hosted in Lower to Middle Jurassic rocks and contains five clay beds, 500 m long and 0.5 to 2.7 m thick. Speculative resources are 385,000 metric tons clay (Abdullah and others, 1977). The Dahane-Tor occurrence is in Lower to Middle Jurassic clay-rich sedimentary sequences and is blue-gray, 40 to 50 m thick and suitable for manufacturing of brick and roof tile. The Shabashak occurrence is alkaline and suitable for drilling mud and as moulding clay.

Cenozoic sedimentary rocks also contain clay-rich deposits (figs. 7.1-2, and 7.3-4). The Deh-Kepal occurrence consists of Quaternary clays grading 5.63 percent silica and 5.04 wt. percent hematite. Speculative resources of clay suitable for the ceramic industry are about 2,200,000 m^3 to a depth of 5 m. The Surkhab and Kaukpar occurrences in Puli Khumri and Nahrin districts, Baghlan Province, are hosted within sedimentary bentonite units of Neogene sandstone and conglomerate beds (Abdullah and others, 1977).

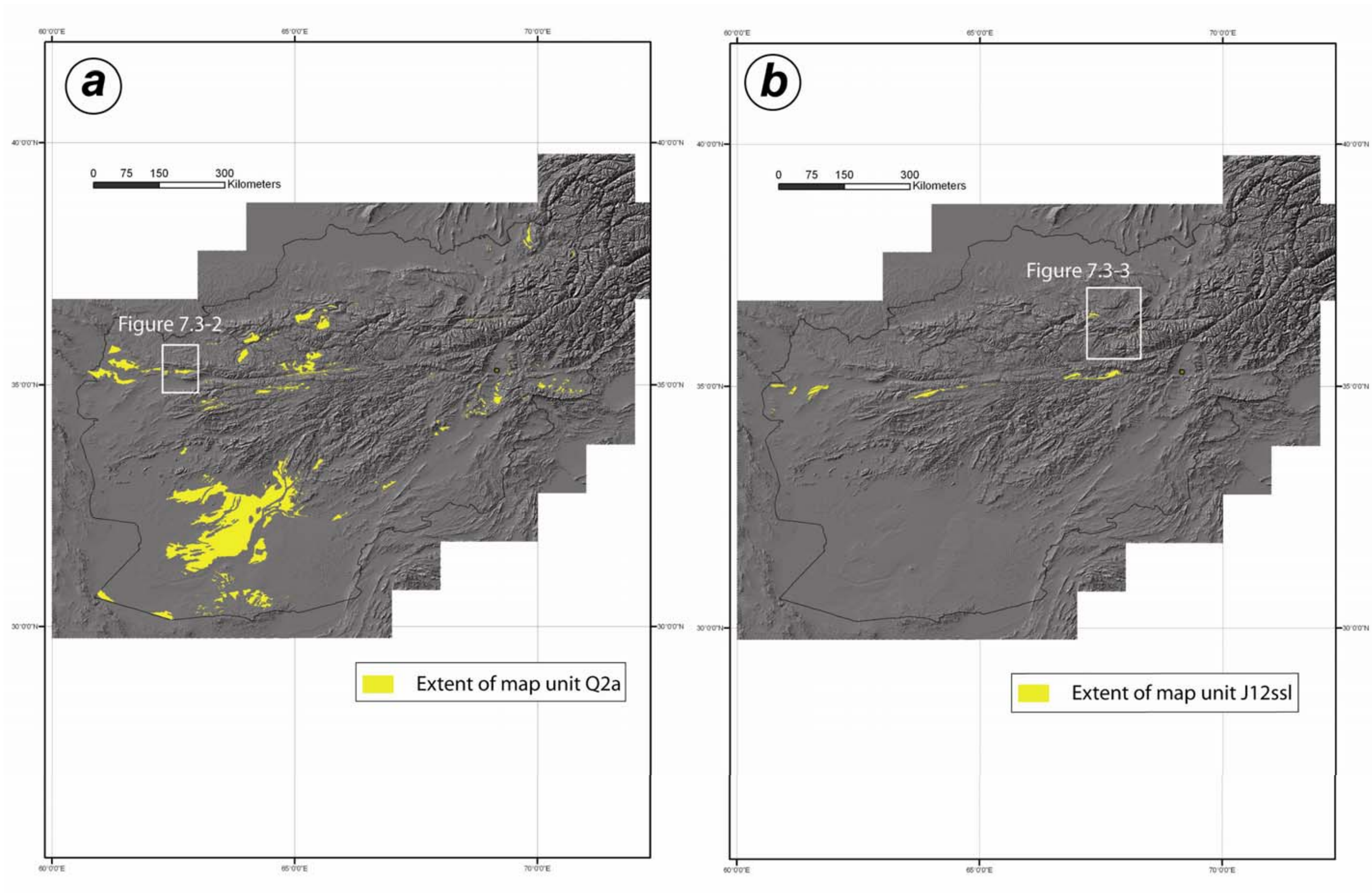

Figure 7.3-1. Maps showing location of some map units that host clay deposits in Afghanistan. (*a*) Distribution of map units Q_2a. (*b*) Distribution of map unit $J_{12}ssl$.

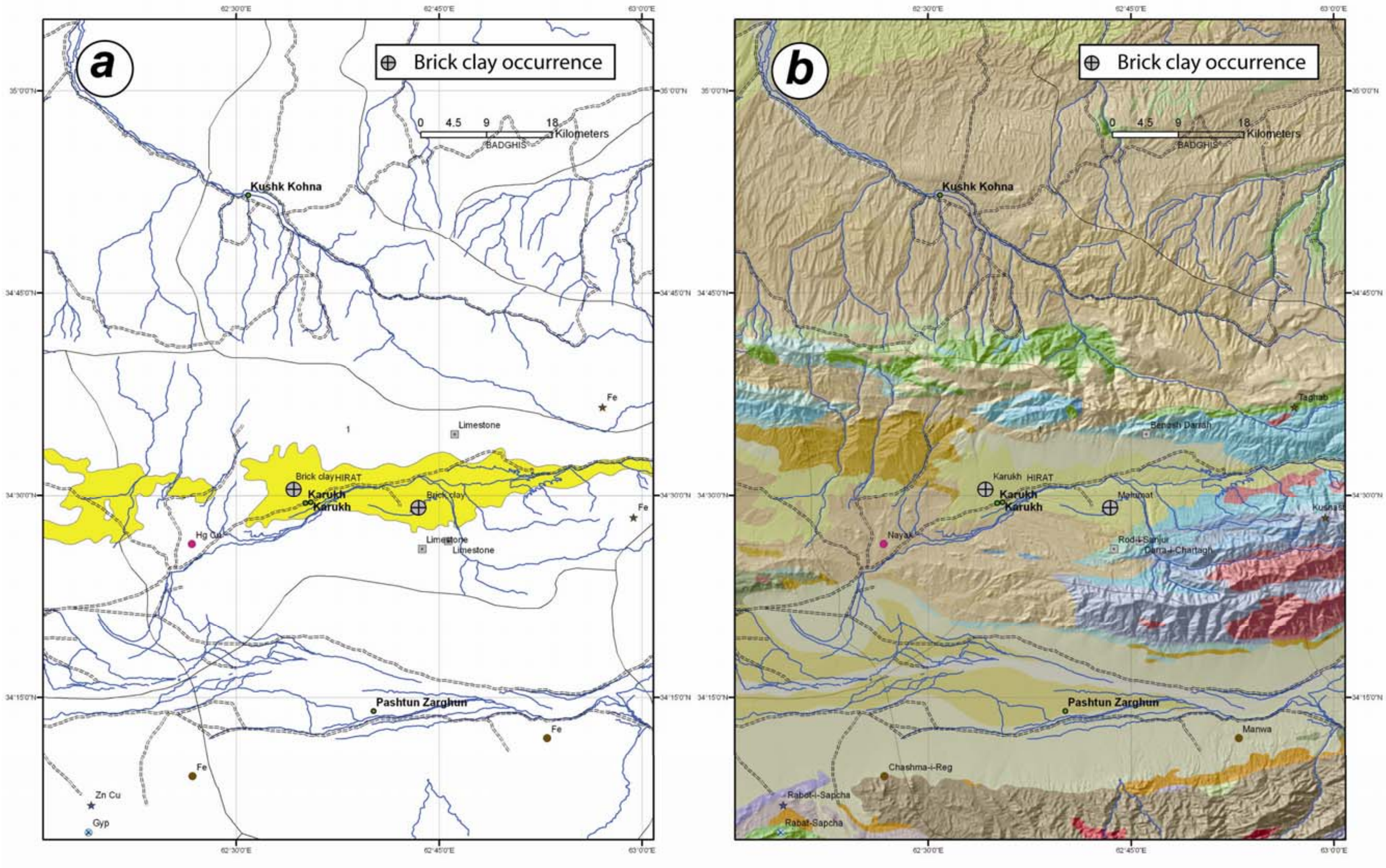

Figure 7.3-2. Maps showing distribution of brick-clay occurrences in Herat Province within Cenozoic sedimentary rocks, map unit Q_2a. (*a*) Part of permissive tract for brick-clay from unit Q_2a including the Kurukh and Mahumat occurrences. (*b*) Geology of the Kurukh and Mahumat area in (*a*) from Doebrich and Wahl (2006).

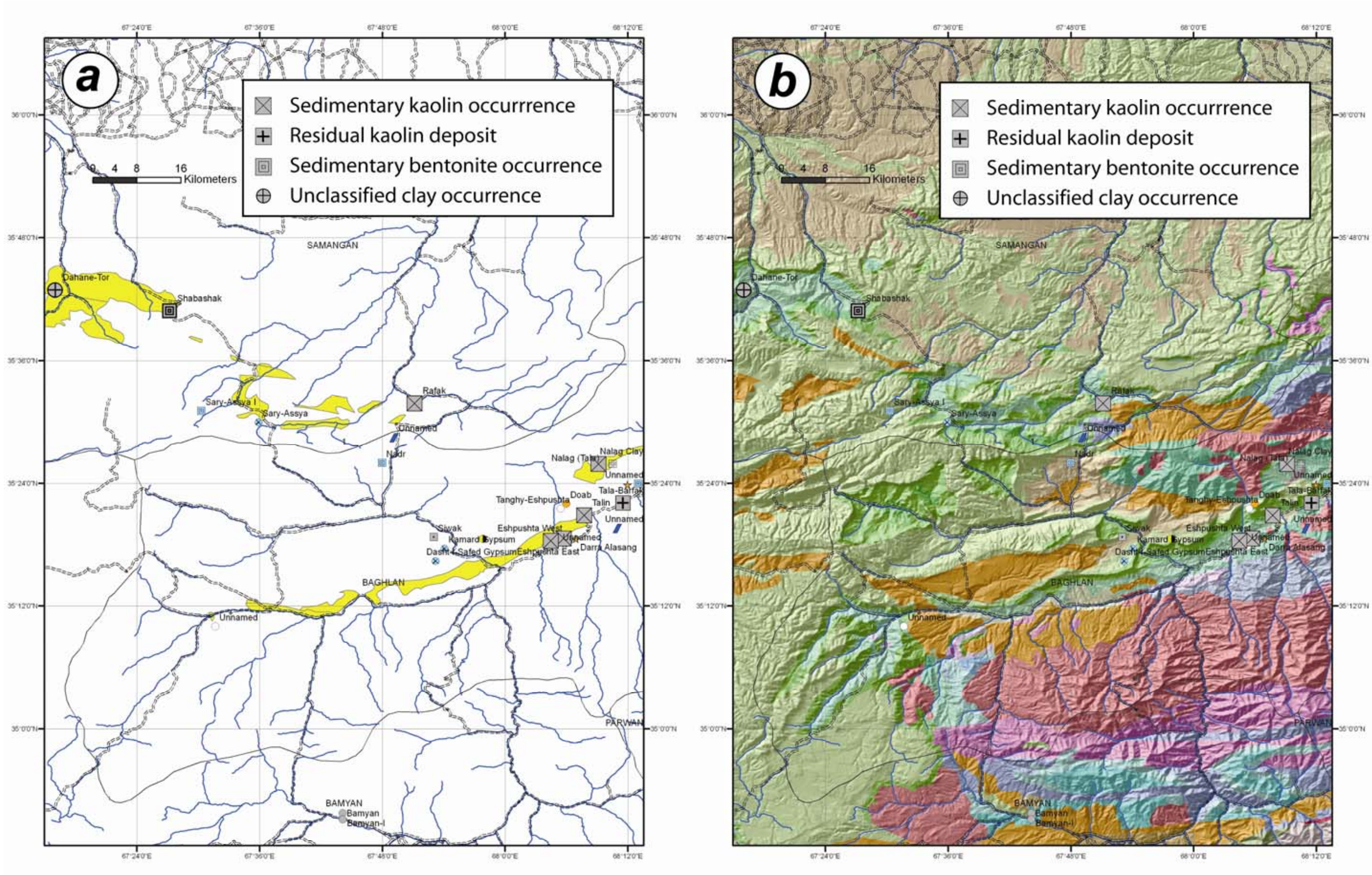

Figure 7.3-3. Maps showing distribution of clay deposits and occurrences in Mesozoic rocks in Samanghan and Baghlan Provinces. (*a*) Deposits and occurrences and tract constructed from map unit J_{12}ssl. (*b*) Geology of area and symbols shown in (a) from Doebrich and Wahl (2006).

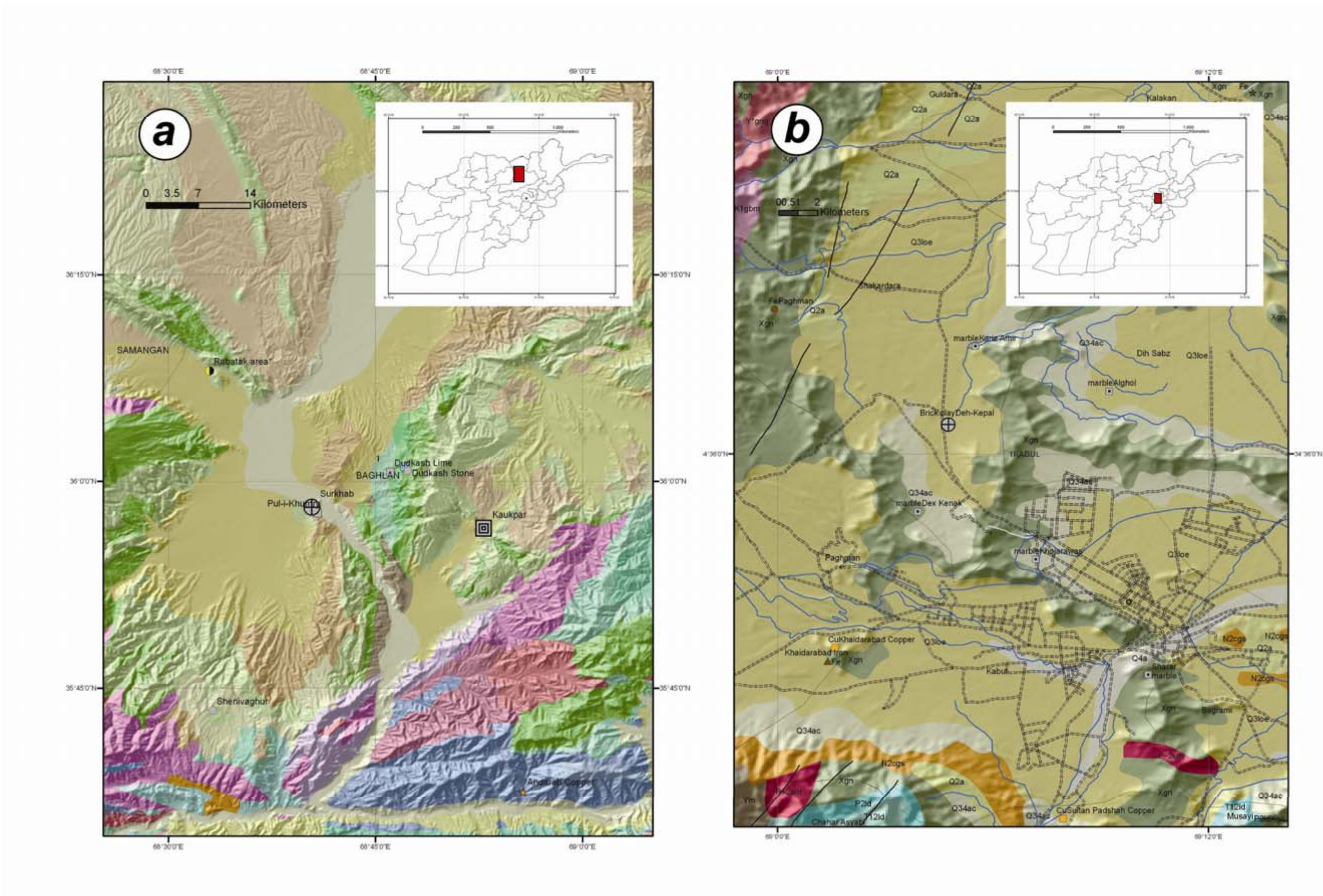

Figure 7.3-4 Maps showing distribution of clay occurrences in eastern Afghanistan hosted in Cenozoic sedimentary rocks. (*a*) Clay deposits in eastern Samanghan Province within Neogene sedimentary rocks. (*b*) Location of the Deh-Kepal deposit northwest of Kabul that contains abundant brick clay. Insets show location of (a) and (b) in Afghanistan. Geology from Doebrich and Wahl (2006).

7.3.2 Porcelain

Porcelain and pottery clays are present in Takhar and Baghlan Provinces and additional potential sites of quarries have been identified elsewhere in Baghlan Province. The Topcha-Khana occurrence is hosted in Upper Jurassic conglomerate as a 4– to 5–m-thick dark gray to black, thin-bedded, platy carbonaceous clay bed (fig. 7.3-3). The clay has 63.27 wt. percent silica, 0.54 wt. percent titanium dioxide, 17.62 wt. percent alumina, 1.51 wt. percent hematite, 1.28 wt. percent iron oxide, 0.10 wt. percent lime, 1.34 wt. percent magnesia, 0.42 wt. percent sodium oxide, 2.8 wt. percent potassium oxide, and 0.23 wt. percent sulfite. The comparatively low alumina and titanium dioxide contents make this a semi-acid clay; the hematite and titanium dioxide give it an intense color. The clay was used by factories in Kunduz and Kabul to manufacture porcelain pottery, dishware, and insulators. Speculative resources are 3,000 m^3 of clay to a 5 m depth (Meshkovskiy, 1965a, b; Abdullah and others, 1977) (fig. 7.3-4b).

The Tala-Barfar occurrence in Baghlan Province (fig. 7.3-3) is hosted in Upper Triassic kaolinized sedimentary beds that are over 1,000 m long and up to 250 m thick and about 20 m thick overlying a small quartz porphyry intrusive body. The occurrence has been exploited by the Kunduz and Kabul factories to make porcelain goods. Speculative resources of the white, roasting kaolin are 100,000 to 150,000 metric tons (Mikhailov and others, 1967; Chmyriov and others, 1972, 1976). Two potential quarry cites were identified by Chmyriov and others (1975-cited in Abdullah and others, 1977) for the mining of porcelain-grade kaolin. The first is East-Eshpushta (Middle to Upper Triassic sediments) and the second is West-Eshpushta (Lower to Middle Jurassic sediments), both in Baghlan Province

7.3.3 Adobe clay

This section describes clays and other earth materials for making and building with adobe and other types of bricks in Afghanistan and discusses improved and new methods.

Historically, buildings in many of the villages and towns in Afghanistan are constructed using adobe brick—that is, bricks that are dried in the sun and not fired. Afghans are among the 30 percent of the world's population that live in earthen houses. Expertise, therefore, can be expected to exist in Afghanistan for locating the best sources of soil that produces suitable brick and the best methods in their preparation. However, this review of methods and issues on sun-dried brick may provide additional ideas that have been applied elsewhere in the world and that are worth considering. These proposed modifications may lead to improving adobe brick fabrication and building design and to reduced risk of collapse of structures during earthquakes. Other topics for future investigation are also suggested.

The Afghanistan climate is suitable for adobe brick fabrication given that much of the country is either Subtropical Steppe or Subtropical Desert that are both amenable to brick preparation (warm, sunny) and preservation (low rainfall.) Only the northwestern part of the country is in the Mid-Latitude Steppe or Highland Climate, and is less-amenable to adobe brick preparation and less-suited for use of this type of building material.

Most clay used in preparation of adobe bricks is the product of pedological or soil formation and not of geologic processes. A soils map has been prepared for Afghanistan by the U.S. Department of Agriculture and available on the following website:

http://soils.usda.gov/use/worldsoils/mapindex/afghanistan-soil.html; accessed July 26, 2007

Soils are classified worldwide into 5 groups based on temperature and moisture. A set of 4 or 5 units within the 5 groups are complexly named. This may suggest that there is some refinement possible in the classification. How it may be applicable to clay content is unclear. One important issue that may be worth exploring is whether or not adobe brick quality can be improved if material from higher quality clay deposits is used in the adobe brick recipe given below. The following review includes information that is readily locatable on the Worldwide Web as well as an overview on Afghanistan prepared by the Department of Geography and Environmental Engineering, U.S. Military Academy, West Point, USA. This review discusses the making and using of adobe bricks and includes adobe brick recipes, a summary of improved preparation methods, the use of stabilizers, and mitigation of seismic risk. In addition, a discussion of other earth materials that may be suitable for use as adobe bricks is presented including the impact on cultural attitudes of using alternative materials.

Making and using adobe bricks

Preparation of adobe brick mix includes the use of clay, sand, and natural polymers (straw, animal manure, etc.) combined with sufficient water to create a dough-like consistency. The mixture is put into brick molds or empty waxed milk containers. In most locations (and this is probably true in Afghanistan), soil is the primary source of sand and clay for adobe brick. In fact, raw materials for the best adobe bricks come from soils with clay contents that do not exceed 30 percent. The rest of the materials are sand, silt, gravel, or some combination of all three. Historical adobe structures are made from materials having more than half sand and about 3 percent organic material. One source suggests that clay content may be as high as 70 percent. Soils containing clays that are highly expansive, for example bentonite, are generally unsuitable for making bricks. As a rule, low organic content is also desirable. The best soil types for adobe brick fabrication are sandy loam, loamy sand, or sandy clay loam. A simple test that can be used to evaluate material for use in brick preparation involves filling a clear glass container half with dirt and half with water. After agitation and settling, the proportions of gravel, sand, silt, and clay can be seen as zones. One of the keys to making sun-dried adobe bricks that perform well is insuring that the ratio of clay and sand is consistent, and that the right amount of moisture is present. However, stabilizers allow some problematic soils to be used.

The suitability of most sun-dried adobe bricks for buildings can be improved by using a variety of machines that compress the soil so that the brick has a higher density (Graham and Burt, 2001.) Adding hydraulic rams and automated delivery systems can result in construction of bricks with a compression strength of 8,300 to 9,400 kPa and production rates as high as 300 to 320 bricks per hour. However, this type of equipment is less likely to be available in Afghanistan.

Stabilizers are materials added to the adobe brick mixture that reduce shrinkage and cracking. Examples include bitumen and asbestos. Some stabilizers can potentially contaminate the air within the building by giving off gas or releasing disintegrating fibers from the surface of interior walls. Studies made of adobe masonry in Peru (Vargas and others, 1986) show that bricks can have improved seismic strength through reduction of microcracking during drying shrinkage that seems to be independent of either the soil or water chemistry or percent of silt or sand. Good workmanship increases compression strength, as does wetting the adobe bricks before placement. Addition of straw was important to seismic performance, particularly if the mud mixture for brick fabrication was allowed to set for several days, which allowed the straw to better bind with the plastic mixture. Achenza and Fenu (2006) studied a number of waste materials rich in natural polymers to determine their suitability to improve the performance of earthen material used for construction of adobe bricks. These included polymers found in beets and tomato residue produced during sugar and tomato-sauce manufacturing. They also noted that both lime and cement have a positive effect on brick durability and strength, but that those natural polymers help make exposed bricks less erodable. Polymers reduce porosity as well as increase compression strength.

Contaminates that may reduce the durability of adobe bricks include water-soluble salts including sulfates, chlorides, nitrates, and nitrites. Salts may be recrystallized if the brick become wet and cause the surface to spall. Mud needs to have low levels of salts to be suitable for adobe brick fabrication. Another improvement in adobe bricks can be made by firing using simple techniques as described at: (*http://www.quentinwilson.com/making-adobe-bricks/*; accessed July 26, 2007).

Adobe structures are protected form the elements (at least in the Spanish tradition) by using a mixture of three parts sand to one part lime, mixed with water to create a plaster. Lime is an important component that is derived from limestone and shells. Other types of material also may be suitable including plastic sheets and materials that prevent moisture from entering the wall along the join with the roof.

Adobe brick structures worldwide do not withstand earthquakes well. If a structure is built with adobe brick, some type of reinforcement is needed. Adequate wall thickness is also important for insuring that load-bearing walls do not fail during a seismic event. Additives that improve seismic strength include small amounts of manure, sodium carbonate (a dispersive agent), and cement in amounts greater than 10 percent. As Blondet and others (2002) noted at the web site below, one problem is that ways of addressing seismic risk have been discovered during the 30 years of research in Peru and elsewhere, but that local populations are reluctant to adopt any of these methods “on their own accord” (Blondet and others, 2002, p. 7.)

http://www.world-housing.net/Tutorials/AdobeTutorial/Reference_2.pdf; accessed July 26, 2007

Some reinforcement materials that have been investigated and discovered to prevent or delay structure collapse are: wooden boards, 1.3 cm-diameter rope, chicken wire mesh, and welded mesh. Collapse was delayed in walls that used welded mesh positioned to simulate beams and columns, nailed to the adobe with bottle caps. Blondet and others (2002) suggested that some type of industrial and cheaply-manufactured material like plastic tubes may be suitable. Research on both natural and man-made material needs to continue in the search for reinforcements that will make adobe structures resistant to collapse in earthquakes including material found in Afghanistan.

A specific example of a possible way to reduce earthquake damage by using a frame made of string, bamboo (or perhaps some other comparable material), and wire is described by Dowling at the following web site:

http://www.abc.net.au/tv/newinventors/txt/s1794024.htm; accessed July 26, 2007

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7.4 Limestone

Contributions by Greta J. Orris and Karen S. Bolm.

Humans have utilized limestone since before the Egyptian Second Dynasty when it was used in the construction of the Giza pyramids (Oates, 1998). Common usage of the term limestone may include other carbonate rocks because many of these rocks may occur together. Carbonate rocks include limestone, chalk, marble, dolostone, carbonatite, travertine, shells, and other rocks that contain significant calcite, aragonite, or dolomite; these rocks form approximately 15 percent of Earth’s sedimentary crust (Freas and others, 2006). For the purposes of this assessment, limestone is defined as a carbonate rock containing greater than 50 percent calcite and(or) dolomite, with calcite predominating. Subordinate amounts of dolostone or marble are not uniformly distinguished when geologic maps are prepared, and hence are assumed to be locally present within the limestone units. Discussion of limestone, marble, and travertine as building or dimension stone is contained in section 11.0.

Limestone is an extremely versatile commodity that is typically available at a fairly low cost. Crushed limestone is used for aggregate, concrete, ballast, and fill. Limestone for use dimension stone needs strength, resistance to staining and weathering, and an aesthetic appeal. Ground calcium carbonate is used as filler in a variety of commodities from paper to pharmaceuticals, coatings, fertilizers, and other products. Among other applications, lime (CaO) is consumed for environmental uses such as waste water treatment and flue gas desulfurization, as a soil treatment, in the production of steel and iron and other metals, in the production of chemicals, and in sugar refining (Harben, 2002; Oates, 1998, Freas and others, 2006).

Purity and other parameters determine potential usage. There is a trend to develop limestone deposits for multiple uses—for example, aggregate, cement, and chemical flux.

7.4.1 Descriptive deposit model

Most limestone of economic importance was deposited in a relatively shallow marine environment from a variable mix of biogenic, and to a lesser degree, chemical and mechanical processes minerals (Oates, 1998; Freas and others, 2006). Ages of deposits exploited for limestone range from Precambrian to recent. Limestones that were deposited in relatively high-energy depositional environments tend to contain less non-carbonate material and thus be higher grade (Freas and others, 2006). Deposits are commonly large and spatially extensive. Sedimentary sequences that contain limestone may also have dolomite, siltstone, and shale. Minor variations in depositional processes and conditions can lead to heterogeneity in $CaCO_3$ grade, susceptibility to weathering, trace element content, and other factors that may negatively impact suitability of the limestone for development. Some sedimentary limestone deposits are of continental origin and can also be quite extensive.

Carbonate rocks are susceptible to post-depositional alteration that may affect the $CaCO_3$ content, trace element content or physical characteristics. These processes may enhance or detract from the suitability of the deposits for development. Some of these processes may lead to the formation of sulfide minerals, which can limit the use of the limestone for environmental reasons.

Because of the importance of limestone and other carbonate sedimentary rocks as source rocks for petroleum, and extensive literature exists on the genesis, classification, and general description of carbonate rocks, but much of it has little bearing on the utility of limestone for a designated use. Scholle and others (1983) provide a comprehensive overview of carbonate depositional environments. In the final analysis, most communities tend to find a way to utilize what is easily available to fill their needs.

Examples of Deposit Type**—**Limestone deposits are widespread and common in most parts of the world.

Probable Age(s) of Mineralization**—**Limestone deposits can be of any age, Precambrian to Recent.

Known Occurrences in Afghanistan**—**Limestone occurrences are widespread in Afghanistan. Figure 7.4-1 shows the distribution of geologic map units containing significant or minor amounts of limestone. It should be noted that size and extent of a limestone unit does not necessarily correlate with the likelihood of its economic development or use. Small, or less than optimal quality limestones are commonly developed before regionally extensive or high-grade deposits because of various localized economic factors.

Exploration Guides**—**Exploration is largely detailed examination (sampling) of the limestone or sequence of carbonate rock to determine any variability in chemical composition or physical strength or other property that would impact the intended use. Compositional heterogeneity presence of trace metals and minerals, depth of weathering, and other details that can be learned from closely-spaced sampling, are all important for stability the viability of a potential economic deposit, whether for cement or building stone.

7.4.2 Limestone Tract Description

Permissive Tract—lms01

Deposit types**—**Limestone

Age of mineralization**—**Early Carboniferous, Late Permian to Late Triassic, Triassic, Late to Middle Jurassic, Late Cretaceous to Paleocene

Examples of deposit type**—**The Early Carboniferous Sabz deposit in Badakshan Province has speculative limestone resources of about 500 million metric tons (ESCAP, 1995). The Early Triassic Darra-I-Chartagh deposit in Herat Province is more than 5 km long, more than 200 m thick, and is suitable for cement production. The Late Cretaceous to Paleocene limestone mined at the Pul-I-Khumry deposit in Baghlan Province covers several thousand km^2, is 300-500 m thick, and currently produces limestone for cement. The Middle Triassic limestone at the Rod-I-Sanjur deposit in Herat Province is up to 400 m thick (ESCAP, 1995). Other occurrences include the Benosh-Darrah deposit in Heart, and the Jamarchi-Bolo and Bakunvij quarries in Badakhshan (ESCAP, 1995).

Exploration history**—** Soviet and Afghan geologists identified a number of limestone deposits during geological surveys in the 1970s, but very little is known about exploration specifically for limestone deposits, especially information quality.

Importance of deposits**—**Limestone is the most important component in cement, and lime has many additional uses in infrastructure, agriculture, and industry. Most currently active limestone quarries are mined on a small scale and provide building stone for local markets; larger operations would use standard open-pit mining methods. The demand for limestone normally increases with increasing GDP.

Tract boundary criteria**—**The main limestone tract (fig. 7.4-2) was delineated using the digital geologic map of Afghanistan (Doebrich and others, 2006; Ludington and others, 2007). The tract consists of those map units that have limestone or marble identified as a major or dominant component. Although limestones of different ages may well have different potential, we combined all ages of limestone for this tract because we lack information to develop criteria for establishing differing probabilities of occurrence in rocks of different ages. Areas of less promise consist of map units in which limestone is listed as only a minor component (fig. 7.4-3).

Important data sources—The main sources for information on limestone resources in Afghanistan include the geologic map (Doebrich and Wahl, 2006), mineral deposit database, data from oil and gas assessment, ESCAP report (Economic and Social Commission for Asia and the Pacific, 1995, and Abdullah and others (1997). A number of references on cement and limestone-dolomite fluxes in Abdullah and others (1977) may contain additional details on some of the limestones. However, these references were not available to the assessment team.

Needs to improve assessment—Information about consistency of chemical and physical properties of limestone within known deposits would be particularly helpful, together with information about the quality of specific stratigraphic units. This would require extensive field investigations with a large-scale sampling program.

Optimistic factors—Limited information about limestone quality indicates high (more than 90 percent) values of $CaCO_3$ in limestones of varying ages. Limestone is widespread and occurs in large masses that could host large deposits. Some limestones have been metamorphosed, which can improve the quality for some uses.

Pessimistic factors—There is almost no information about quality or consistency of quality of limestones of any age.

Quantitative assessment—Available information is insufficient to allow a quantitative assessment.

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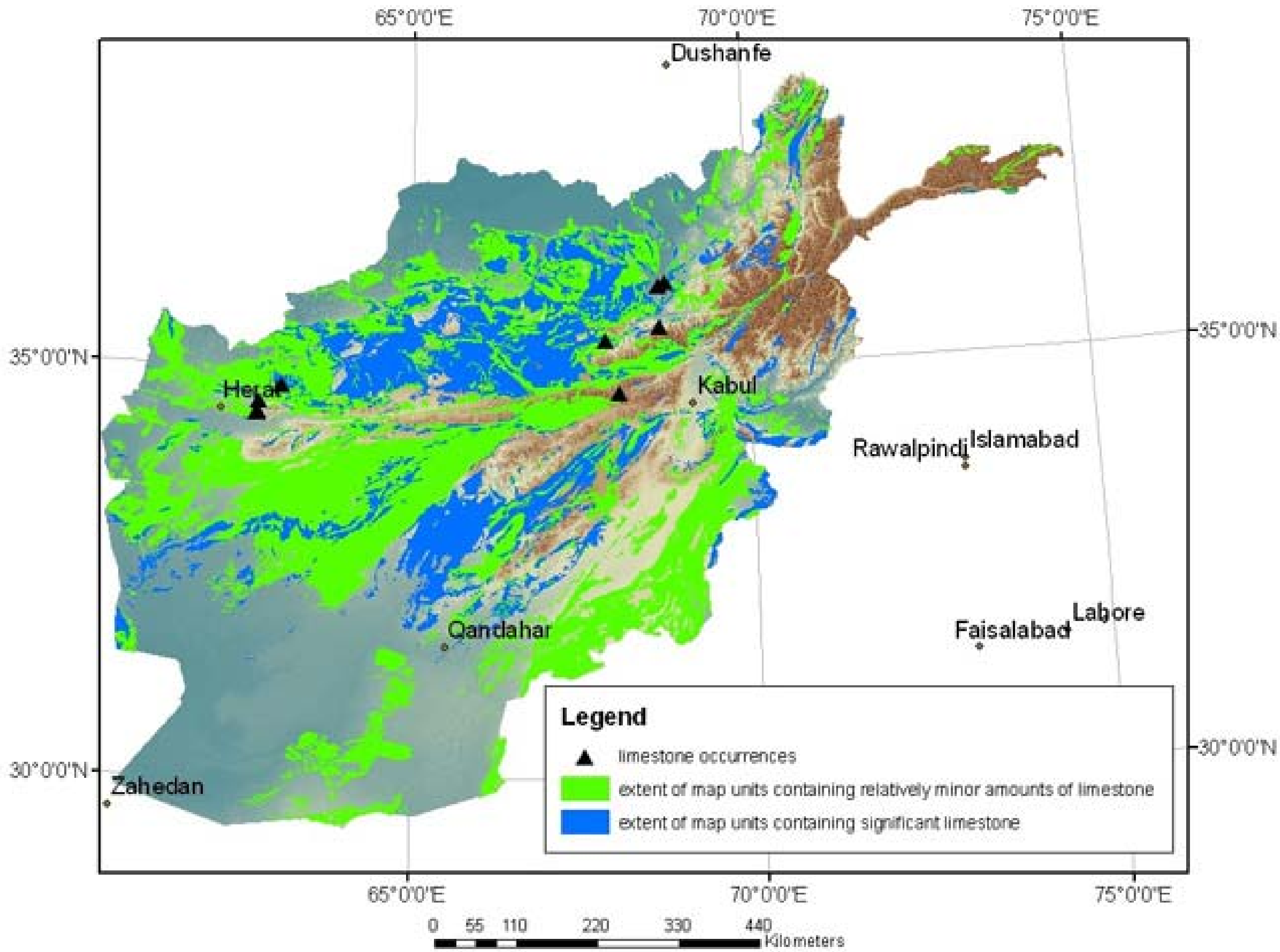

Figure 7.4-1. Distribution of limestone-bearing units in Afghanistan.

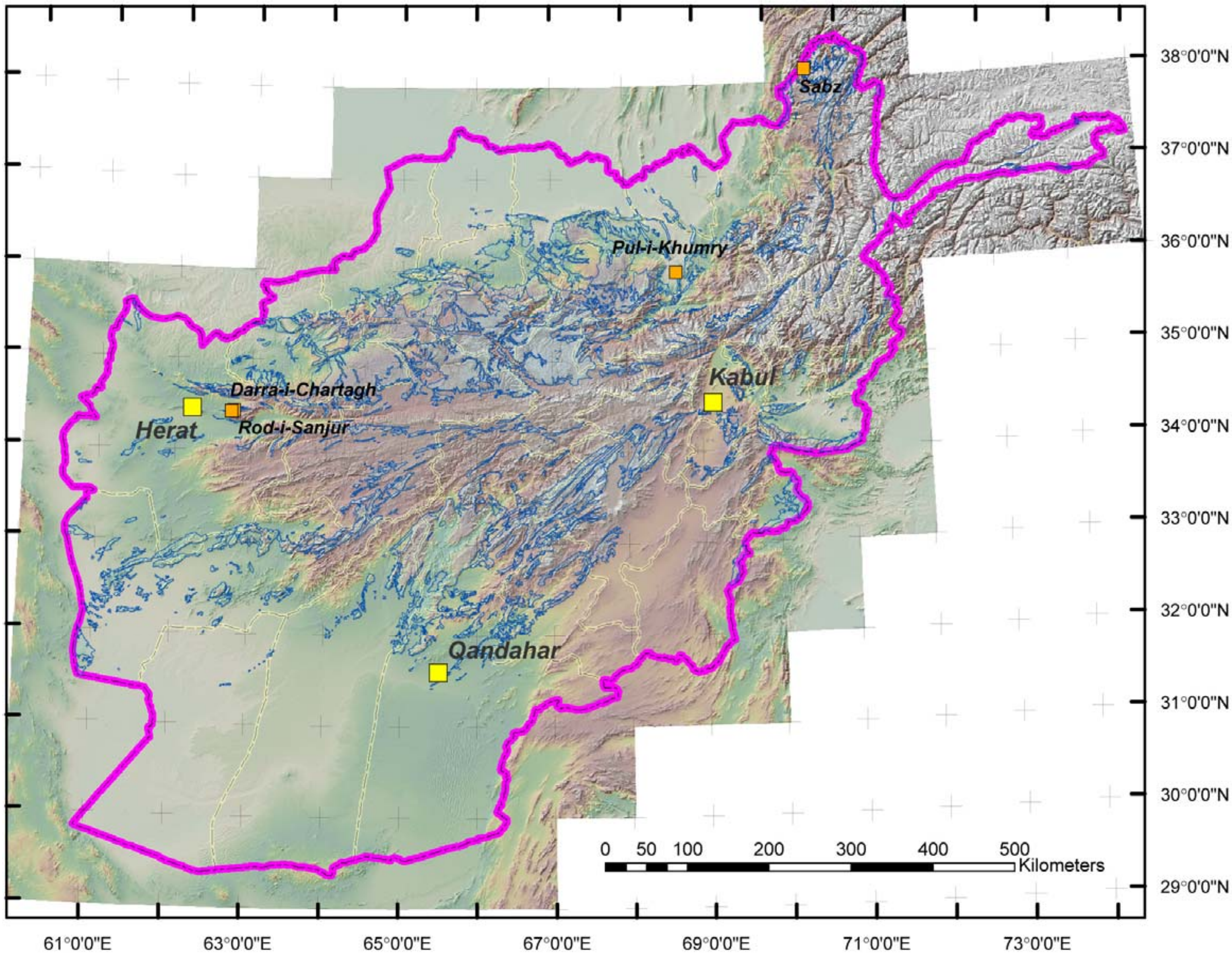

Figure 7.4-2. Map showing tract lms01 and some important known limestone deposits and prospects (orange squares). Larger yellow squares are major cities.

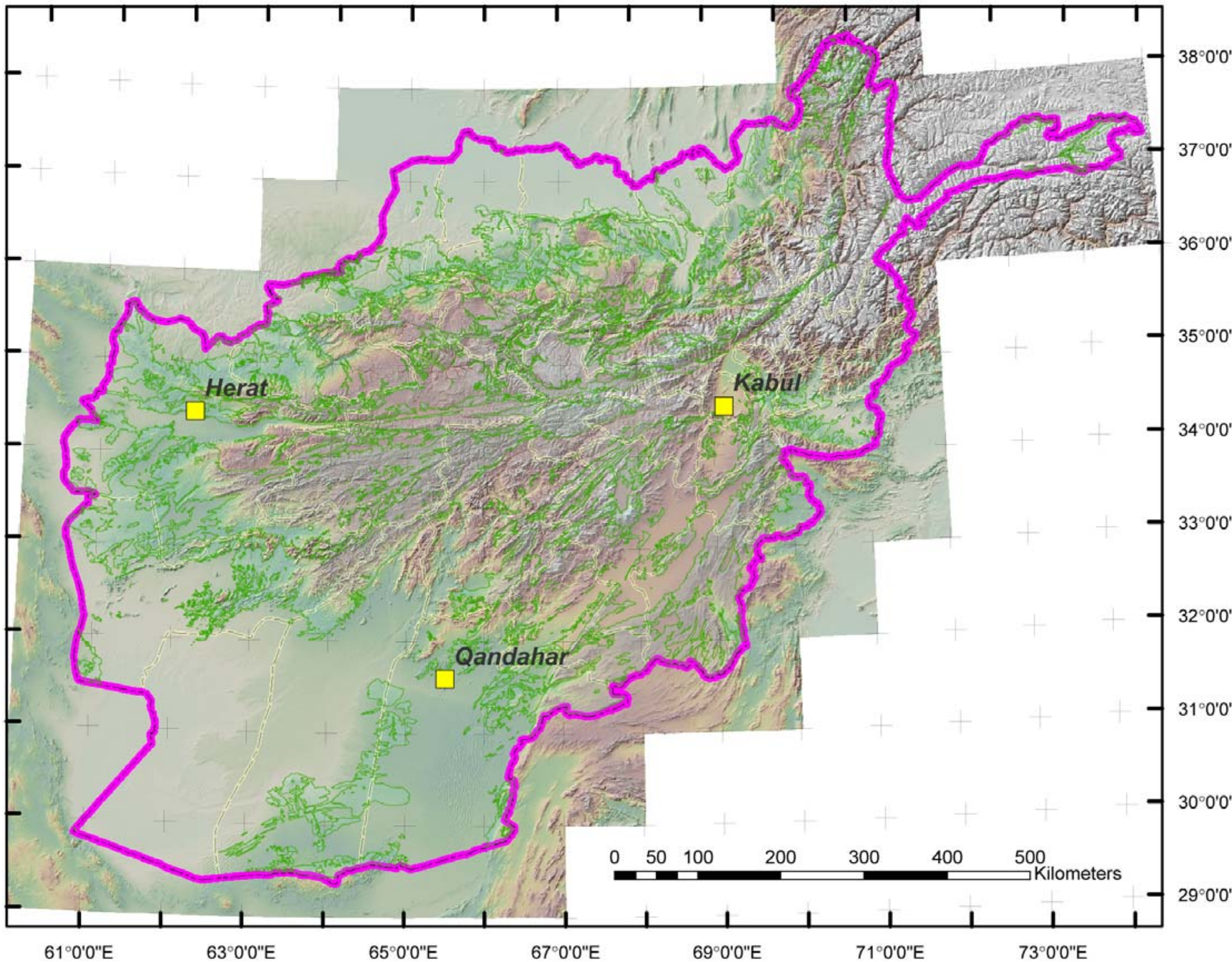

Figure 7.4-3. Map showing geologic map units from Doebrich and Wahl, (2007 (green outlines) in which limestone is a minor component.