Chapter 10A. Summary of the Kundalan Copper and Gold Area of Interest

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Abstract

This chapter summarizes and interprets results for the Kundalan copper and gold area of interest (AOI) and its subareas resulting from joint geologic and compilation activities conducted from 2009 to 2011 among the U.S. Geological Survey (USGS) of the Department of the Interior, and the Task Force for Business and Stability Operations (TFBSO) of the Department of Defense, as well as the Afghanistan Geological Survey (AGS) of the Ministry of Mines of Afghanistan. Accompanying complementary chapters 10B and 10C address hyperspectral data and geohydrologic assessments, respectively, in the Kundalan copper and gold AOI. In addition, supporting data for this chapter are available from the Ministry of Mines, Kabul.

Numerous copper- and gold-bearing prospects are present in the Kundalan copper and gold AOI, including the Kundalan copper-gold skarn deposit. The measured resources of the Kundalan copper-gold skarn deposit are 21,400 metric tons (t) of copper, 1.6 t gold, and 133.4 t molydbenum at an average grade of 1.21 weight percent (wt. %) copper (ranging from 0.66 to 4.03 wt. % copper), 0.9 grams per metric ton (g/t) gold (ranging from 0.3 to 3.1 g/t gold), and 0.14 wt. %molydbenum, and as much as 10 g/t silver and 0.03 wt. % bismuth. Small past production of gold and base metals also is reported from many prospects in the AOI (Douvgal and others, 1971). Outside the skarn areas, argillic hydrothermal alteration is present (Abdullah and others, 1977). Most copper and gold prospects in the Kundalan copper and gold AOI are reported to contain commercial-grade ores of copper and (or) gold, and many prospect areas have potential for these commodities to be present in commercial volumes. Future initial mine exploration and later development in many of the prospects, and specifically in the Kundalan copper-gold skarn deposit, could result in near-term small- to medium-sized gold mining operations.

The Kundalan copper-gold skarn deposit also has potential to increase in size. Recent field and compilation work has confirmed that much of the known mineralized rock in the major Kundalan copper-gold-molybdenum deposit may be open to the east and west beneath colluvial cover. A hypothetical significant additional resource, therefore, remains untested and would be compatible with a mineralized system of the size indicated by the aeromagnetic anomaly underlying the area. Future airborne- and ground-magnetic surveys will be important in understanding the potential size and location of additional mineralization beneath colluvial cover.

Examples of gold-rich copper skarns in the Kundalan copper and gold AOI are the Assanak occurrence, which is 150 meters (m) long and 1 to 2 m wide and grades 2.2 g/t gold with anomalous traces of copper, zinc, and lead (Mesechko and others, 1971). In addition, the Tugra gold occurrence contains ancient workings in strongly mineralized zones that are 250 m long and 5 to 6 m wide and grade 0.1 to 6.5 g/t gold and also contain significant concentrations of copper, lead, and zinc (Plotnikov and Slozhenikin, 1968). The Outcrop no. 543 occurrence is hosted in a brecciated calcareous and serpentinized fault zone that is 100 m long and 1.5 to 2.5 m wide, containing disseminated chalcopyrite, and grades 9.3 to 13.2 g/t gold, 1.03 to 3.6 wt. % copper with anomalous concentrations of zinc and bismuth.

In the south part of the Kundalan copper and gold AOI, the Charsu-Ghumbad subarea contains clusters of gold occurrences that were delineated as prospective by Peters and others (2007). These mineral occurrences include the Baghtu and Kadilak gold occurrences, and several copper skarn

occurrences. The Kadilak gold occurrence lies in brecciated hematitic zones that are 90 and 200 m long and 0.2 to 2.5 m wide containing disseminated pyrite, chalcopyrite, bornite, chalcocite, galena, and hematite, and grading 70 g/t gold, 2.5 wt. % lead, 3.0 wt. % zinc, and 0.87 wt. % copper (Douvgal and others, 1971). In addition, the Asanzay (3.8 g/t gold), Charsu (1.59 g/t gold), Outcrop no. 7273, Aghast I, II, and II, and Dorushak and Ghumbad gold and copper skarn occurrences also are present in the southern part of Charsu-Ghumbad subarea.

The USGS Assessment Team (Peters and others, 2007) estimated that there is a 50-percent chance of one or more, and a 10-percent chance of two or more porphyry copper deposits being present in either the Kundalan or Zarkashan areas. This is an optimistic estimate for a relatively small area.

10A.1 Introduction

The northeast-elongated Kundalan copper and gold area of interest (AOI) is in south-central Afghanistan in the Provinces of Zabul and Kandahar and within the administrative districts of Shah Wali Kot, Tamak Wa Jaldak, Mizan, Qalat, Arghandab, and Dayampan. The area of the main Kundalan copper and gold AOI is 2,576.01 square kilometers (km^2), and internal subareas are the Charsu-Ghumbad subarea (327 km^2), Baghawan-Garangh subarea (330 km^2), and Kunag skarn subarea (738 km^2) (figs. 10A–1 and 10A–2). Mineral deposit type(s) that are known or likely to be found in the Kundalan copper and gold AOI are porphyry copper-gold, copper-(gold) skarn, gold-rich polymetallic veins, and gold-rich skarn deposits.

An inventory of individual datasets compiled for the Kundalan copper and gold AOI and subareas is included with the data information package in the Ministry of Mines of Afghanistan for the Kundalan copper and gold AOI. Most existing mineral-resource information has been gathered from reports written between the early 1950s and about 1985 by geologists from the Union of Soviet Socialist Republics (USSR) and its Eastern European allies, who provided Afghanistan with technical assistance. This information, combined with a preliminary assessment by the U.S. Geological Survey in 2007 (Peters and others, 2007), provided much of the basis for technical work during 2009 through 2011 and the descriptions and conclusions in this chapter. The Kundalan copper and gold AOI and its subareas also are thought to be likely to host deposits that might have near-term mineral production. In addition, some deposits in the Kundalan copper and gold AOI are near-surface bodies with promising metallurgical and mining characteristics.

10A.2 Previous Work

A number of gold and copper prospects in the Kundalan copper and gold AOI contain previous workings that may be hundreds and in some cases thousands of years old. Small past production of gold and base metals is reported in the Garangh copper-gold skarn area (Douvgal and others, 1971). The Tugra gold (near Kundalan) mineral occurrence also is reported as having ancient workings (Abdullah and others, 1977). The first Soviet geologists to report on the area were Khasanov and others (1967), Plotnikov and Slozhenikin (1968), and Mesechko and others (1971), who all brought attention to the significanct mineralized rock in the area.

The Kundalan copper porphyry-skarn deposit was subsequently explored by trenches, tunnels, and diamond drilling by Soviet and Afghanistan geologists (Douvgal and others, 1971; Litvinenko and others 1971). Several subsequent compendiums of mineral deposits in the region have mentioned the Kundalan copper-gold area (Abdullah and others, 1977; ESCAP, 1995; MMAJ, 1998; Orris and Bliss, 2002; Afghanistan Geological Survey, 2006; Doebrich and others, 2006; Peters and others, 2007) and speculated that it represented a porphyry copper system. Aeromagnetic data were collected in flyovers of parts of the area by Soviet workers combined with new flights that were all compiled by Sweeney and others (2006). These data showed positive magnetically anomalous zones above the mineralized areas. The U.S. Geological Survey Assessment Team visited the area briefly both in 2006 and 2010 (TFBSO, 2011).

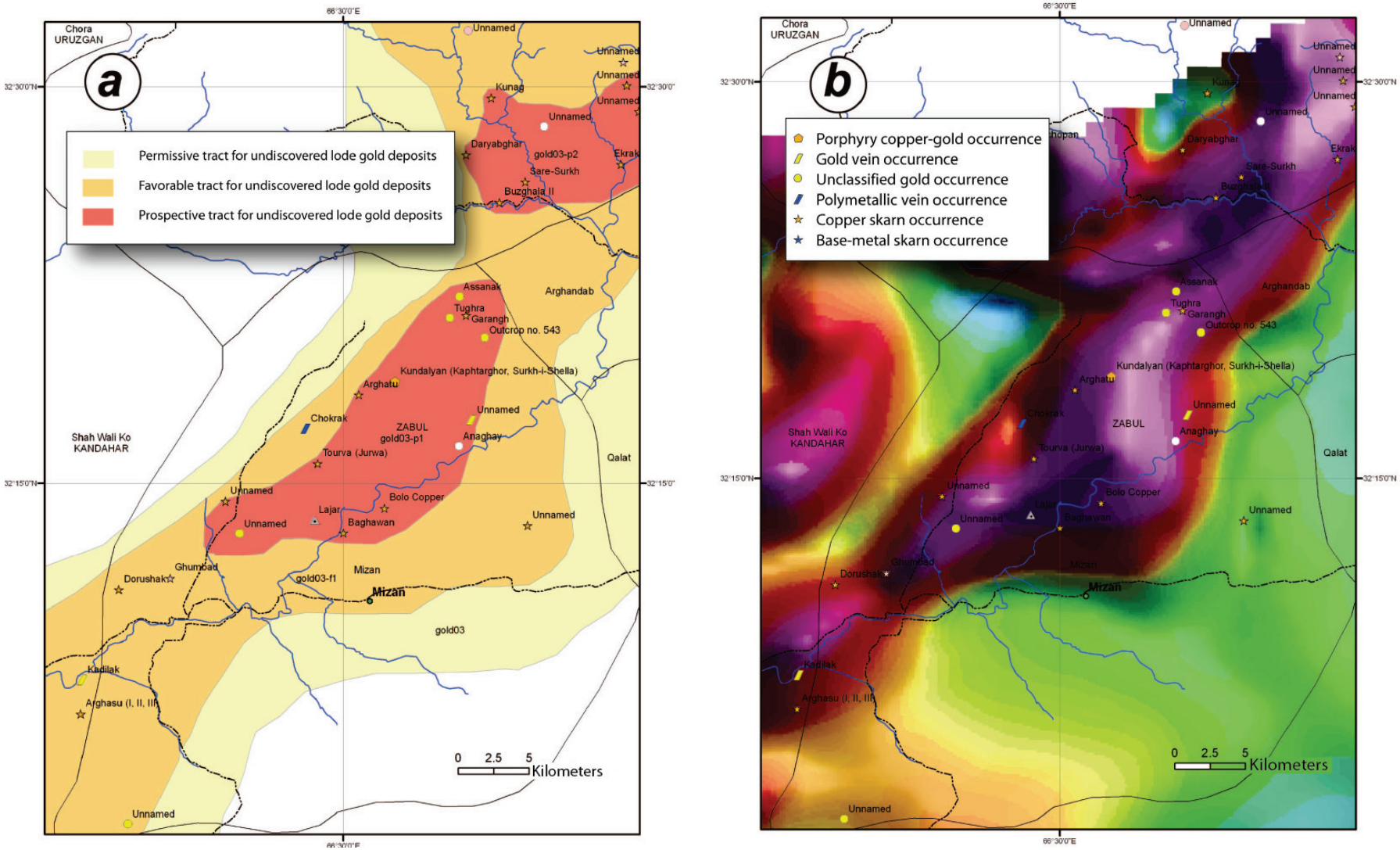

Figure 10A–1. Maps showing area around and within Kundalan copper and gold area of interest, where aeromagnetic geophysical data help outline gold-copper mineralized zone. Adapted from Peters and others (2007). (*a*) Permissive, favorable, and prospective mineral tracts that approximate the area of interest for the Kundalan area. (*b*) Contoured aeromagnetic map from Sweeney and others (2006) of area in (*a*) showing spatial congruence of mineralized occurrences and magnetic anomaly. Warmer colors indicate increasing higher magnetism of underlying rock.

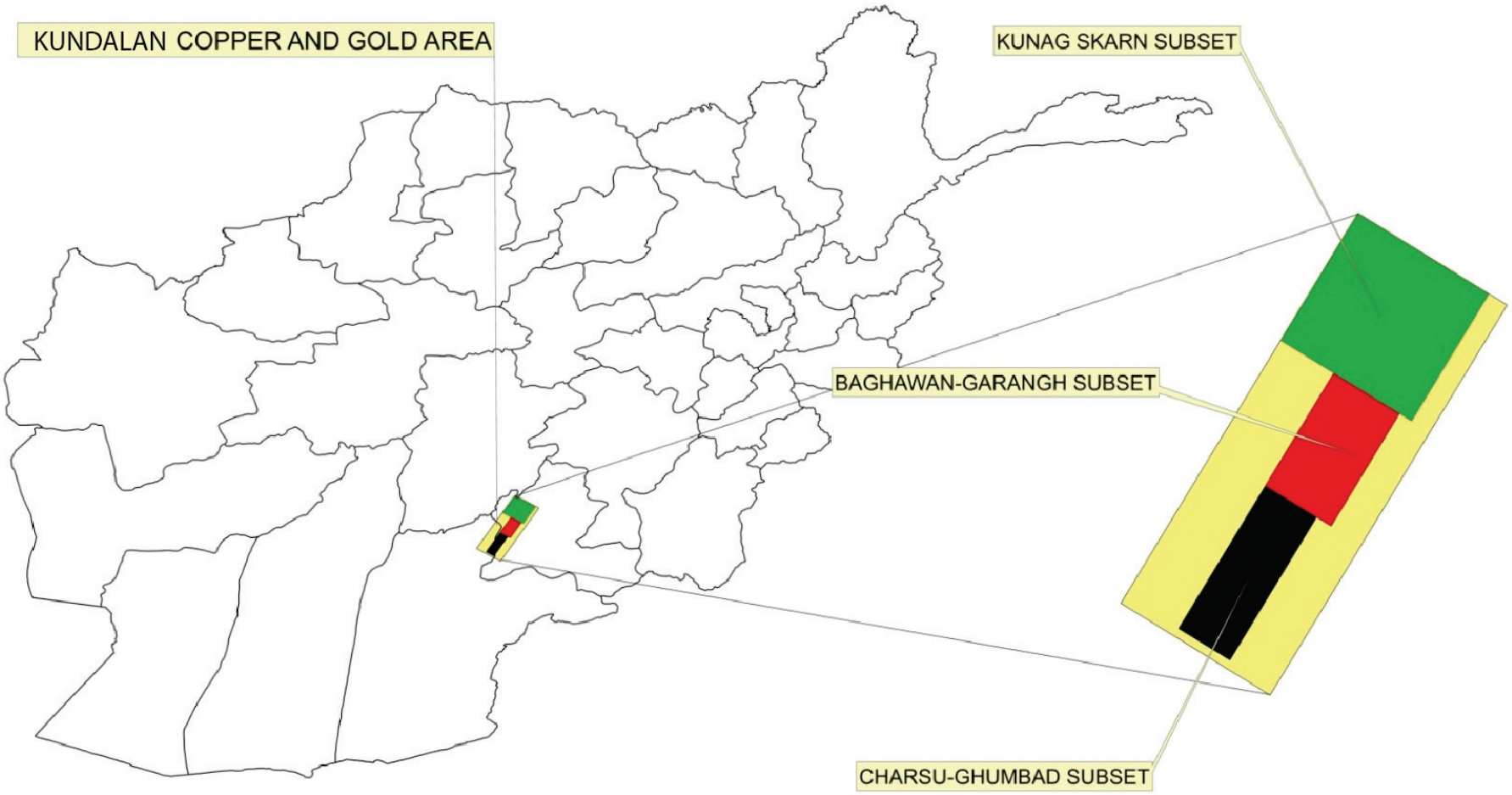

Figure 10A–2. Location of the Kundalan copper and gold area of interest and its subareas, Afghanistan.

10A.3 Metallogeny

Mineral deposits related to felsic to intermediate porphyritic igneous rocks in Afghanistan include porphyry copper and associated deposits, such as polymetallic skarns and veins and copper- and gold-bearing parts of the same systems. Kundalan copper and gold AOI is one of a number of areas in Afghanistan that contain occurrences and geologic features that show promise for future discovery and development of world-class deposits.

About 200 igneous-related hydrothermal mineral deposits and occurrences in Afghanistan contain copper as a major commodity. Many of these occurrences also contain gold. Most are classified as copper skarn (about 50 prospects) and polymetallic vein (about 70 prospects) occurrences and deposits (Abdullah and others, 1977; Doebrich and others, 2006). These deposit types typically are spatially associated with and are located in the same geologic environments as porphyry copper deposits (see Singer and others, 2008; John and others, 2010). Thus, their presence is direct evidence that geologic environments in many parts of Afghanistan are permissive for porphyry copper deposits. Furthermore, igneous rocks typical of geologic provinces that contain porphyry copper deposits also are common in Afghanistan. Most prospective porphyry copper prospects in Afghanistan are associated with Cretaceous through Late Tertiary plutonic rocks that lie within a number of igneous belts that are part of Tethyan magmatic arcs (Ludington and others, 2007). Most young igneous-related copper and copper-gold prospects, like Kundalan, Zarkashan, and Spin Boldak, are located in east Afghanistan, and other coeval magmatic arcs also are present in the Band-e Bayan, Farah Rod, Helmand, Arghandab, and Chagai areas (fig. 10A–3) (Peters and others, 2007).

Porphyry copper deposits are an extremely important source of copper worldwide and are found in plutonic rocks in magmatic arcs in North and South America, Europe, Asia, and the southwestern Pacific Ocean. The Tethyan arcs, stretching from the Carpathian Mountains of south and east Europe through East Asia, are the setting for numerous important porphyry copper deposits both to the west (Sar Chesmeh, Iran), south (Reqo Diq, Pakistan), and east (Yulong, Tibet) of Afghanistan. Several of the known copper-bearing mineral occurrences of all classifications in Afghanistan, including Kundalan and Zarkashan, contain measured resources estimated by Soviet workers.

Tracts of permissive geology were delineated from porphyry copper and porphyry copper-gold type deposits in Afghanistan by Ludington and others (2007), and Peters and others (2007), and quantitative estimates were made for the probabilistic number of deposits that might be present in each of these permissive tracts (figs. 10A–3 and 4). Regional metallogenesis for porphyry copper deposits was summarized by Doebrich and others (2007), who suggested that Triassic, Cretaceous, and Paleocene to Miocene intrusive and volcanic rocks represent areas where porphyry copper deposits may exist in Tethyan magmatic arcs in Afghanistan. A synthesis of geologic, mineral deposit, aeromagnetic geophysical, remote sensing, and geochemical data delineated regions permissive for undiscovered porphyry copper deposits. Doebrich and others (2007) indicated that the Makran arc, Zarkashan, and Kundalan regions had the greatest potential for undiscovered porphyry copper deposits. Concealed segments of magmatic arcs in southern Afghanistan, defined from aeromagnetic data, also represent prospective targets for exploration.

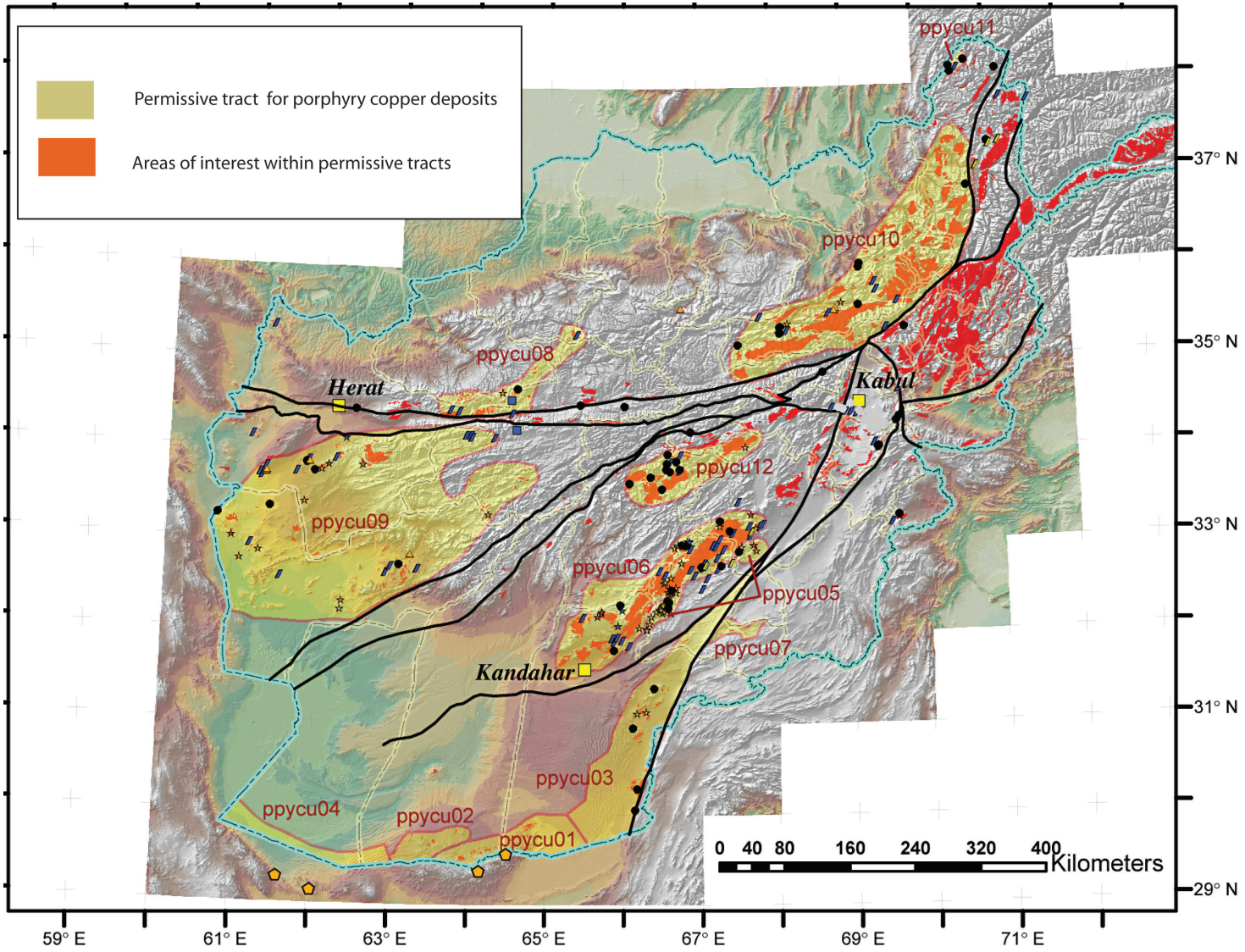

Figure 10A–3. Areas permissive for porphyry copper and porphyry copper-gold and associated plutonic deposits in Afghanistan (from Peters and others, 2007). Kundalan area is in the south part of the ppycu05 tract northeast of the city of Kandahar. Orange and black symbols represent mineral occurrences from Doebrich and others (2006).

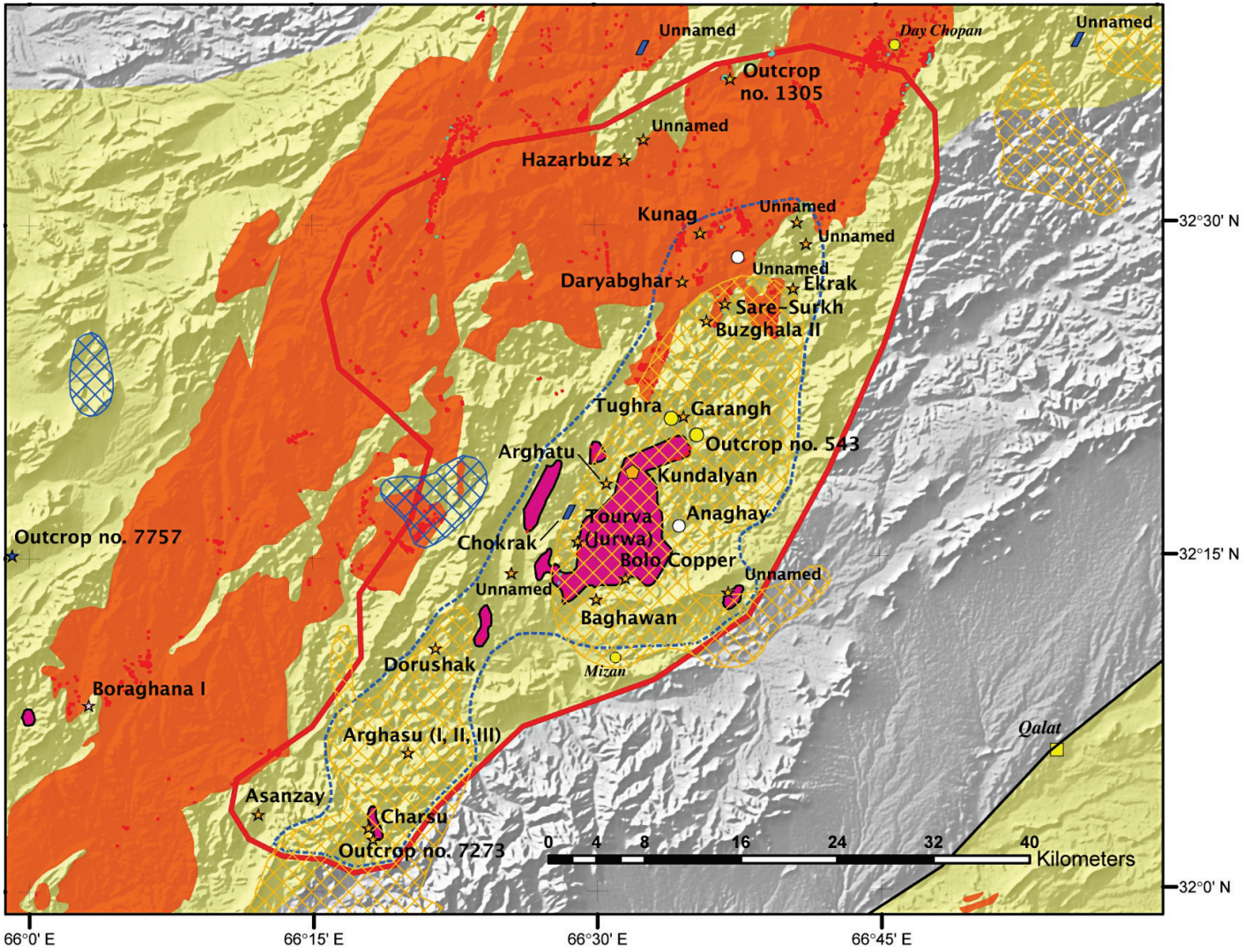

Figure 10A–4. Digital elevation map of the Kundalan part of the Kundalan-Zarkashan porphyry copper permissive tract of Peters and others (2007) and Ludington and others (2007). Exposed alkaline Cretaceous to Paleogene intrusive rocks are in pink (map unit KP1gbm of Doebrich and others, 2006). Orange area contains rocks of main Oligocene Arghandab igneous belt. Blue crosshatch is a tin mineral halo probably related to Arghandab igneous rocks; gold crosshatch is gold mineral halo probably related to the alkaline Cretaceous to Paleogene igneous rocks. Blue dashed line outlines most favorable part of the tract. The Kundalan copper and gold area of interest boundaries were derived from these data.

10A.4 Geology

Numerous copper- and gold-bearing prospects are present in the northeast-trending Kundalan copper and gold AOI that coincide with favorable and prospective areas identified by Peters and others (2007) (fig. 10A–5). Most of these prospects are reported to contain commercial-grade ores of copper and gold and many may have potential economic value. Initial mining development in many of the prospects or in the Kundalan copper-gold deposit could develop into small- to medium-sized gold mining operations. The Kundalan copper-gold deposit contains known resources of copper, gold, and molybdenum derived from sampling and resource calculations based on trenching, underground excavations, and drilling. Extensions of the orebody have not been tested.

The Kundalan copper and gold AOI contains Cretaceous-Paleogene alkaline intrusive rocks that form a prominent magnetic high that outlines a probable large northeast-trending underlying plutonic complex, and the known copper and gold deposits and prospects are clustered above the plutonic rocks that compose the magnetic anomaly (fig. 10A–6).

Most skarn-type copper and gold occurrences were formed along or proximal to contacts between Oligocene granite and diorite and carbonate rocks of different ages. Gold is found in garnet, garnet-vesuvianite, garnet-pyroxene and ludwigite-magnetite skarn all along the northeast-trending Kundalan copper and gold AOI. Gold of hydrothermal origin also is present in shear zones and quartz veins that were emplaced in Paleozoic and Upper Triassic limestone and dolomite within the AOI and its subareas. Tungsten is found in garnet and pyroxene-garnet skarns at the contacts between Oligocene granite and Middle and Upper Jurassic limestone. The spatial distribution of these elements also is expressed in a number of stream-sediment geochemical dispersion halos (fig. 10A–7).

The Kundalan copper-gold deposit lies in the center of the Kundalan copper and gold AOI in a valley adjacent to a north-northwest-striking fault zone. Copper is present in copper-porphyry-related skarns that contain magnetite-chalcopyrite, pyrite-chalcopyrite, and gold. The known mineralized Kundalan area is broken by faults into many skarn blocks that form a mosaic. Recent field vists and observation has confirmed that much of the known mineralized rock at the main Kundalan copper-gold-molybdenum deposit is open beneath colluvial cover, which would be compatible with a large-sized system indicated by the aeromagnetic anomaly (fig. 10A–6). The Kundalan copper-gold deposit consists of 13 lens-like skarn orebodies that are as much as 12.5 m thick and 158 m long. The host Precambrian carbonate rocks are intruded by Oligocene diorite of the Zarkashan Complex. The magnetite pyroxene-garnet-phlogopite skarns contain chalcopyrite, magnetite, pyrite, sphalerite, tetrahedrite, chalcocite, molybdenite, galena, enargite, bornite, covellite, malachite, and native copper.

10.5A Known Deposits

The Kundalan copper-gold deposit (fig. 10A–8) lies within the Baghawan-Garangh subarea in the Kundalan copper and gold AOI and has three parts, the Kundalan, Kaptarghor, and Surkh-i-Shela copper-gold deposits. The deposit was classified as a porphyry copper prospect at least 30 years ago (Abdullah and others, 1977; Singer and others, 2008) because of the mineralogy of the ores and because of the alteration assemblages in the mineralized rocks. Both northeast and southwest of Kundalan, a number of gold-bearing copper skarn prospects, as well as smaller outcrops of alkaline diorite, help further define the favorable area. Much of the Kundalan copper-gold deposit area also corresponds to a gold geochemical halo (figs. 10A–7). The Kundalan copper-gold skarn deposit is restricted to three isolated inliers of Proterozoic and Vendian to Cambrian metamorphic rocks in contact with an intrusion of Late Cretaceous to Paleocene diorite. The inliers lie in a 40- to 50-m-wide band along the north-northwest-striking 5-km-long Kundalan Fault Zone (fig. 10A–8).

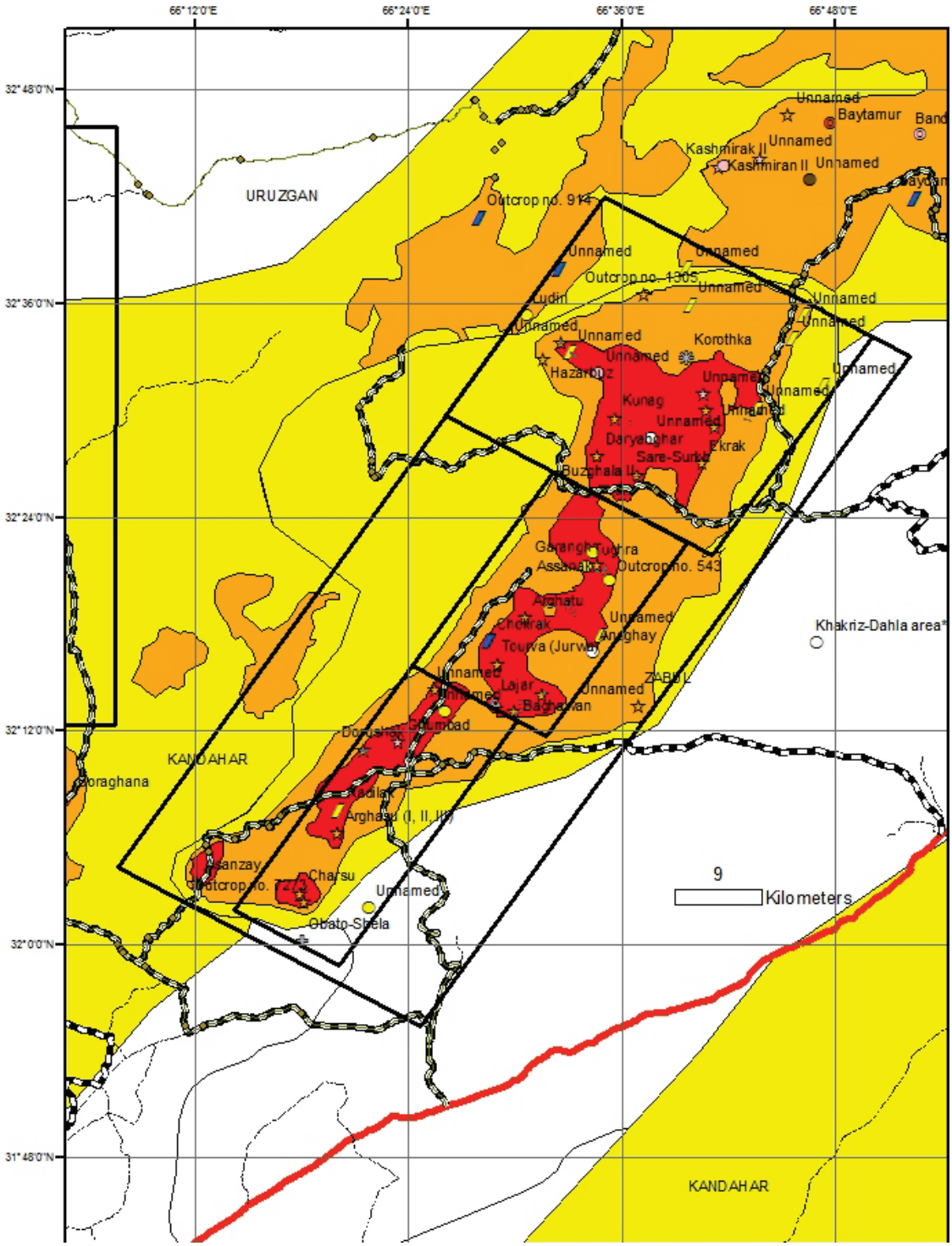

Figure 10A–5. Permissive (yellow), favorable (orange) and prospective (red) mineral potential tracts for porphyry copper-gold deposits in the Kundalan copper and gold area of interest from Peters and others (2007). The outline of main Kundalan copper and gold area of interest contains the three subareas, Charsu-Ghumbad, Baghawan-Garangh, and Kunag skarn. The main road system is shown in dashed lines. The red line is the Kabul-Kandahar highway.

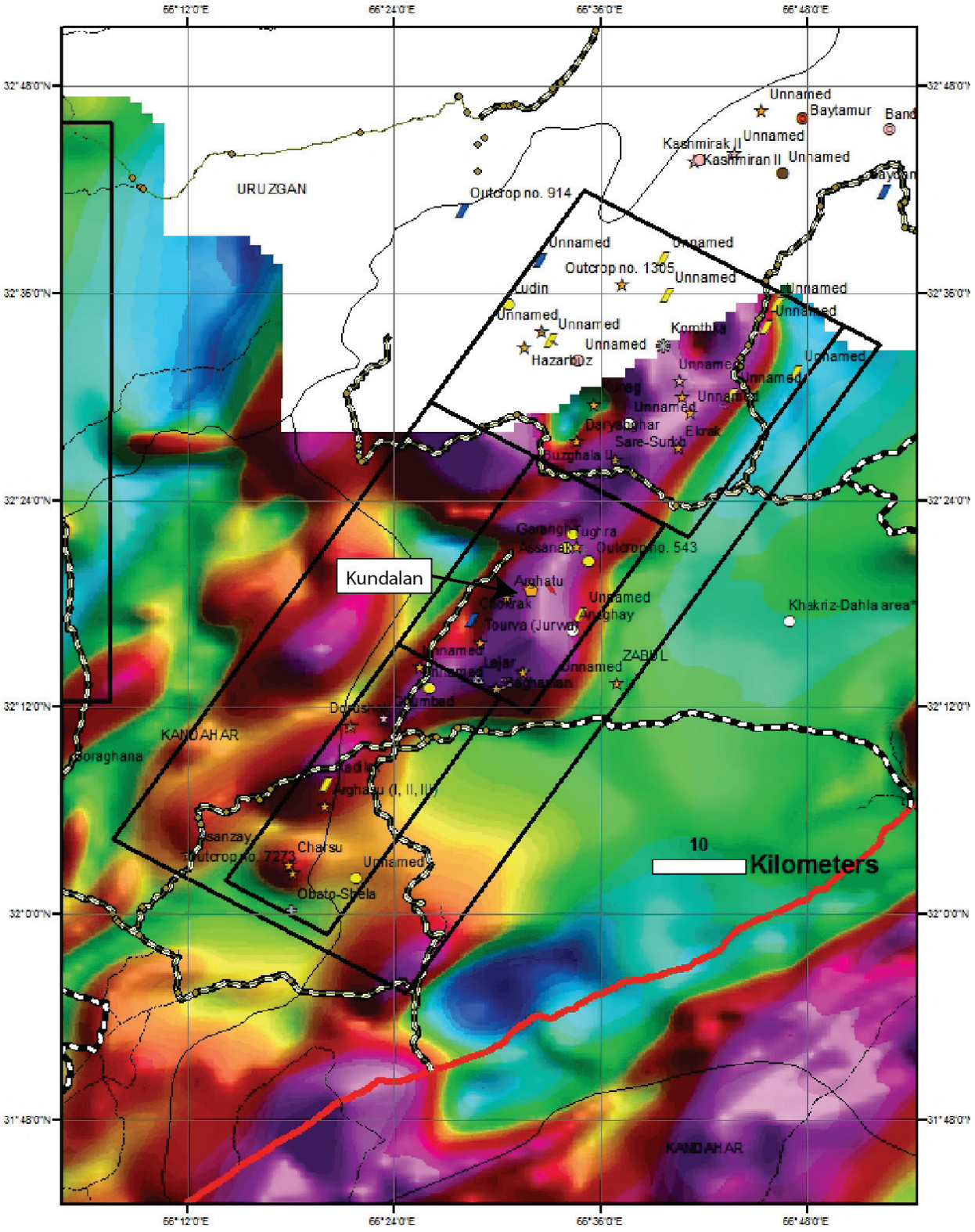

Figure 10A–6. Aeromagnetic anomaly map from Sweeney and others (2006) showing the Kundalan copper and gold area of interest and the subareas, Charsu-Ghumbad, Baghawan-Garangh, and Kunag skarn. The outline of the main Kundalan copper and gold area of interest contains Kundalan copper-gold deposit and gold and copper occurrences in the Kundalan copper and gold area of interest. Warmer colors indicate increasing magnetic properties of bedrock.

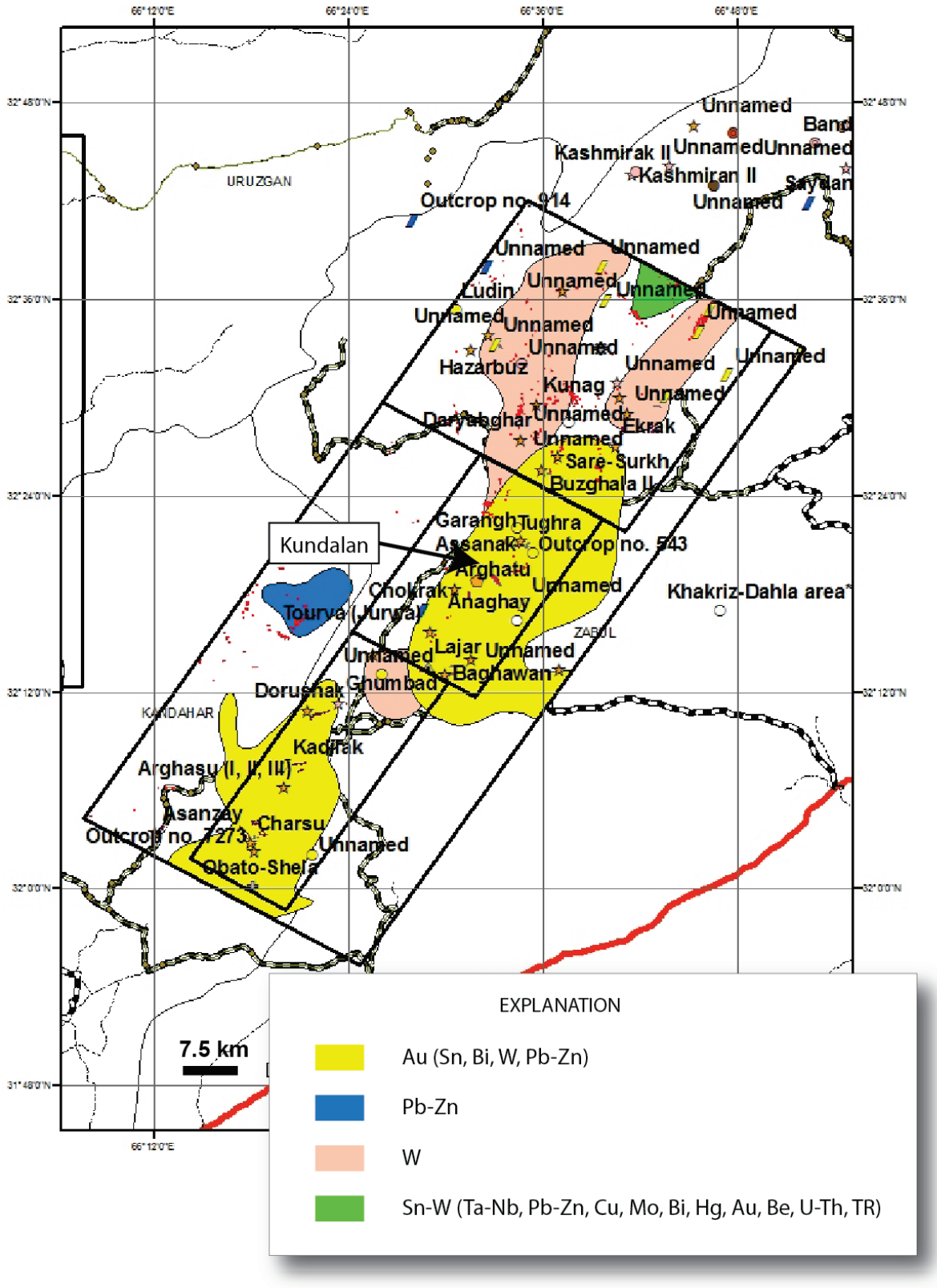

Figure 10A–7. Map of Kundalan copper and gold area of interest and subareas, Charsu-Ghumbad, Baghawan-Garangh, and Kunag skarn subareas. Main Kundalan copper and gold area of interest and subareas is coincident with stream-sediment geochemically anomalous halos outlined by Soviet workers. Small red areas are areas of exploration. Data from Peters and others (2007).

The Kundalan copper-gold skarn deposit is localized along a 400-m-long, 1.5-km-wide inlier that consists of marmorized and skarned limestone, chert, and skarn. The chief minerals in the skarn are pyroxene, garnet, amphibole, phlogopite, and magnetite. Mineralization is present both in skarn and chert. There are 13 orebodies along the Kundalan Fault Zone that are from 2.65 to 12.3 m thick and from 36 to 175 m long, containing 0.62 to 1.2 weight percent (wt. %) copper and 0.5 to 2 grams per metric ton (g/t) gold. The Category C_1+C_2 reserves (Soviet classification system, roughly equivalent to "probable" and "possible" reserves) are 13,600 metric tons (t) of copper, the average content being 1.07 wt. % copper and 1.1 t of gold, the average content being 0.9 g/t gold (Litvinenko and others, 1971) (figs. 10A–8 and 9).

The Kundalan copper-gold skarn deposit area was explored by a series of trenches, adits, and drill holes. Data were presented on cross sections for about 5 km of strike length along a north-northwest-trending zone that is exposed in a valley (figs. 10A–8, 9, 10, and 11). The Kundalan copper-gold deposit has been explored where a northwest-striking stream has eroded through colluvial cover and exposed a dioritic intrusive intruding Precambrian, Cambrian, and Carboniferous limestone (figs. 10A–12, 13, 14, and 15). The skarn zone contains brecciated stromatolitic (?) limestone and contains large areas of layered calc-silicate rock related to skarn formation (Litvinenko and others, 1971). Malachite-stained siliceous skarn and porphyroblastic marble also are common in the mineralized zone (fig. 10A–13).

The Kaptarghor copper-gold deposit is a 50- to 120-m-wide and 700-m-long area composed of skarn, chert, and metasomatitic rocks. Mineralization is restricted to zones of hematitic kaolinite-quartz and metasomatized carbonate rocks. There are three orebodies that are 2.59 to 3.89 m thick and as much as 155 m long, assaying 1.84 to 4.03 wt. % copper, 0.8 to 3.1 g/t gold, and 0.02 to 0.18 wt. % molydbenum. The Category C_1+C_2 reserves (Soviet classification, roughly equivalent to "probable" and "possible" categories) are 3,700 t of copper, averaging 3.8 wt.% copper; 282.3 kg of gold, averaging 2.9 g/t gold; and 127.3 t of molydbenum with the average content of 0.13 wt.% molydbenum (Plotnikov and Slozhenikin, 1968; Litvinenko and others, 1971; Abdullah and others, 1977).

The Shela-i-Surkh deposit area embraces a 40- to 120-m-wide and 1-km-long southern inlier in the Kundalan area. The northern parts contain garnet and pyroxene-garnet skarn with chert interbeds, and the southern parts contain hydrothermally altered pelitic and carbonate rocks, intrusive bodies, and hematite-kaolinite-quartz, quartz-carbonate, and carbonate metasomatite. The orebodies lie within pyroxene-garnet and garnet skarns and hematite-kaolinite-quartz metasomatite. Eight orebodies have been delineated in the area. They vary in thickness between 1 and 10 m and in length between 40 and 173 m and contain (averaged for each body) 0.66 to 1.75 wt. % copper, 0.3 to 0.5 g/t gold, and 0.17 wt. % molydbenum. The Category C_2 reserves ("possible" ore) of the Shela-i-Surkh area are 4,100 t of molydbenum (0.17 wt. % molydbenum on average) (Plotnikov and Slozhenikin, 1968; Litvinenko and others, 1971; Abdullah and others, 1977).

Ores at the Kundalan copper-gold skarn deposit are pyrite-chalcopyrite (the Kundalan and Shela-i-Surkh areas) and molybdenite-chalcocite (the Kaptarghor area) types. The former type is disseminated, fills veinlets, or, more rarely, constitutes isolated nests. The primary ore minerals are chalcopyrite and pyrite and more seldom sphalerite, gray copper ore, and enargite. The latter type is present as disseminations or, more rarely, as veinlet fillings localized in kaolinite-hematite-quartz metasomatite. Minerals of the second type of ore include chalcocite, bornite, and molybdenite; more seldom are chalcopyrite, pyrite, and sphalerite (Plotnikov and Slozhenikin, 1968; Litvinenko and others, 1971; Abdullah and others, 1977).

The Category C_1+C_2 ("probable" and "possible" reserves) of the total Kundalan area copper-gold skarn deposit are 21,400 t of copper (average copper content of the ore is 1.21 wt. % copper); 1.6 t of gold (with the average gold content of 0.9 g/t gold); and 133.4 t of molydbenum (averaging 0.14 wt. % molydbenum). The ores also contain Ag (more than 10 grains to 10 g/t silver) and bismuth (as much as 0.3 wt. %) (Litvinenko and others, 1971; Abdullah and others, 1977).

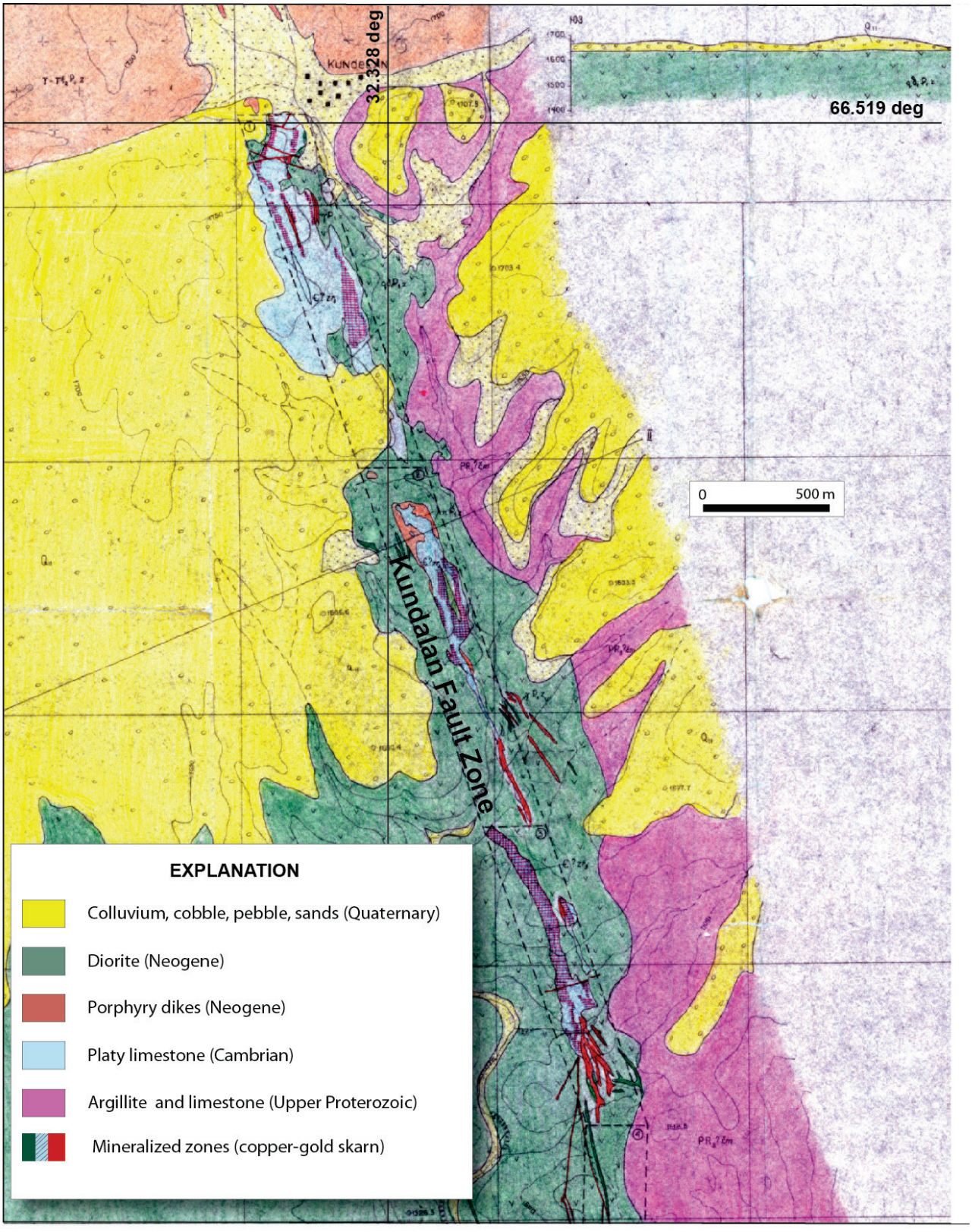

Figure 10A–8. Geologic map and cross section of the Kundalan copper-gold deposit area. (Reproduced and modified from Litvinenko and others, 1971). This is an example of the style of mapping conducted by the Soviet and Afghanistan geologists. Note the colluvial cover to the east and west of the exposed mineralized zones.

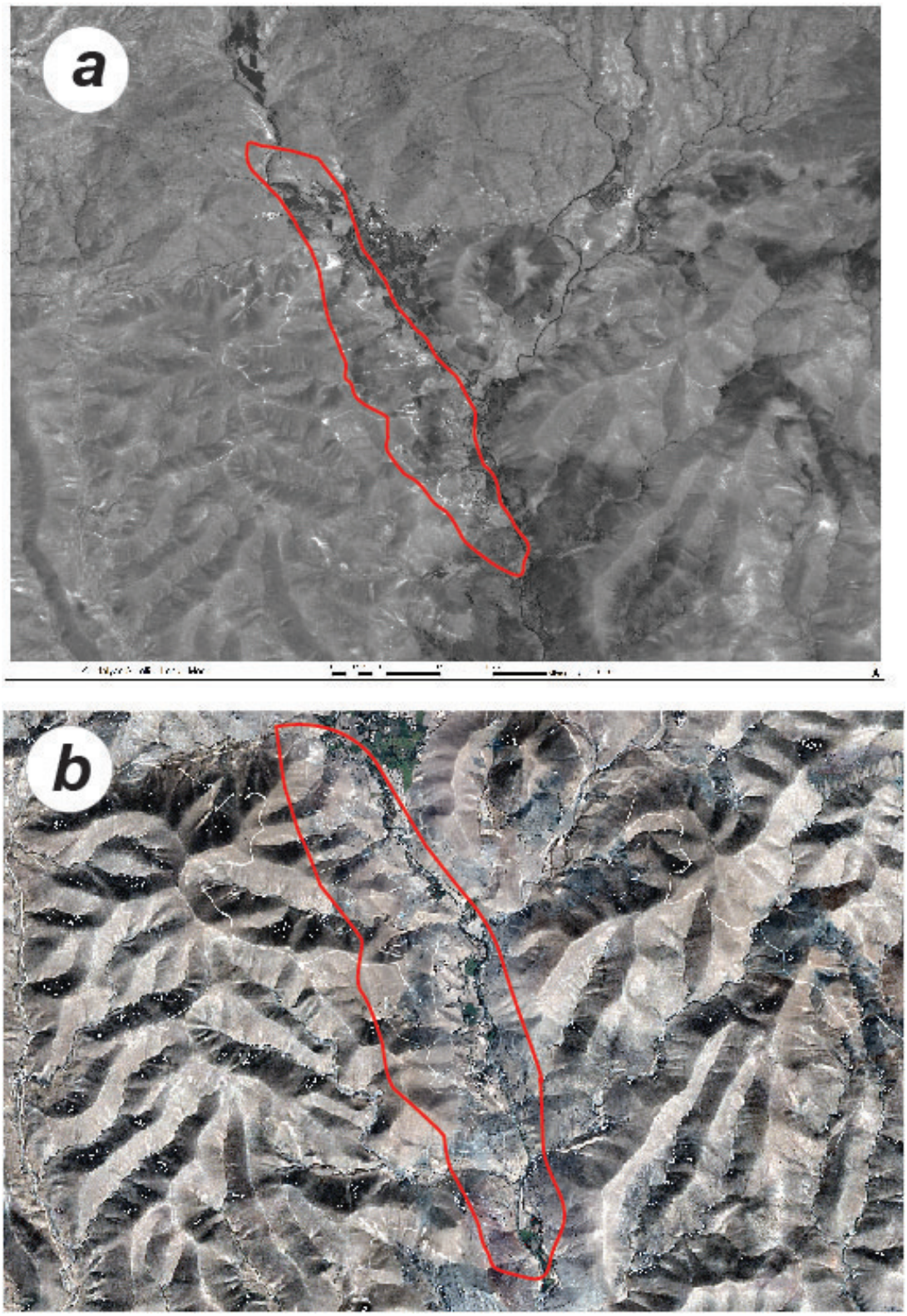

Figure 10A–9. Photographic remote images of the Kundalan copper-gold deposit area. (*a*) Landsat image of Kundalan copper-gold skarn deposit area showing outline in red of area of trenches. (*b*) Air photographic (IKONOS) image of Kundalan copper-gold skarn deposit showing area of trenching (red outline).

Figure 10A–10. Photograph showing aerial view of Kundalan area looking north. Barren subdued slopes in foreground are colluvial cover over map unit KP_1gbm of Doebrich and others (2006). Lower hills and knobby outcrops in medium ground are Precambrian, Cambrian, and Carboniferous limestone and hill at the skyline is Permian cherty and slaty rocks (Photograph by Steve Ludington from Peters and others, 2007).

Figure 10A–11. Photograph showing evidence of mineral exploration in Kundalan copper-gold skarn deposit area, looking southeast. A sample from the dump in foreground contains chalcopyrite. Photograph by Steve Ludington (2005) from Peters and others (2007). Note trenching in the background.

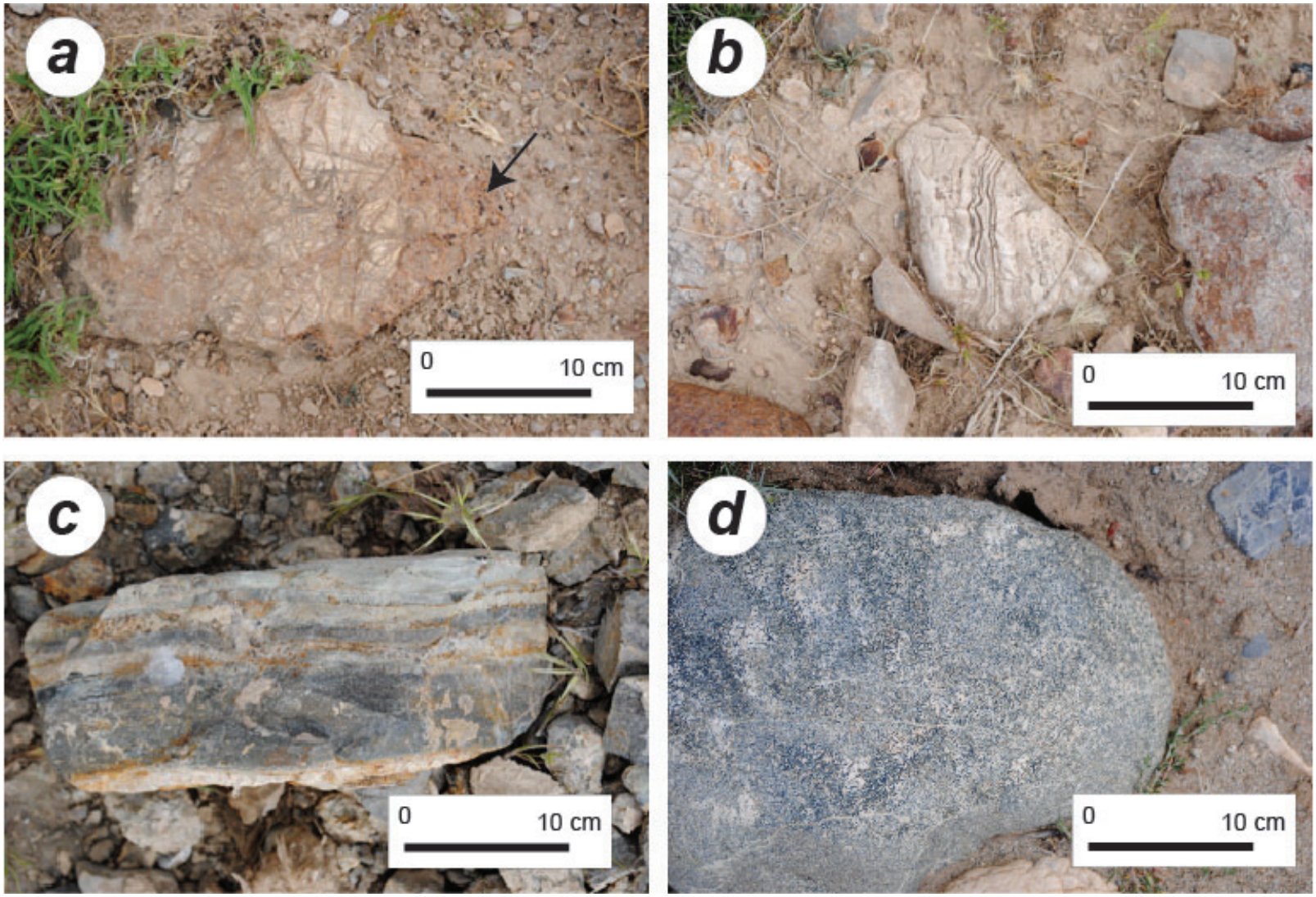

Figure 10A–12. Photographs of rock types present in the Kundalan copper-gold skarn deposit. (*a*) Brecciated limestone with iron-oxide-gossan area (arrow). (*b*) Stromatolitic (?) Cambrian limestone. (*c*) Layered calc-silicate rock related to skarn. (*d*) Fine-grained Oligocene diorite. Photographs by Emily Scott and Stephen Peters.

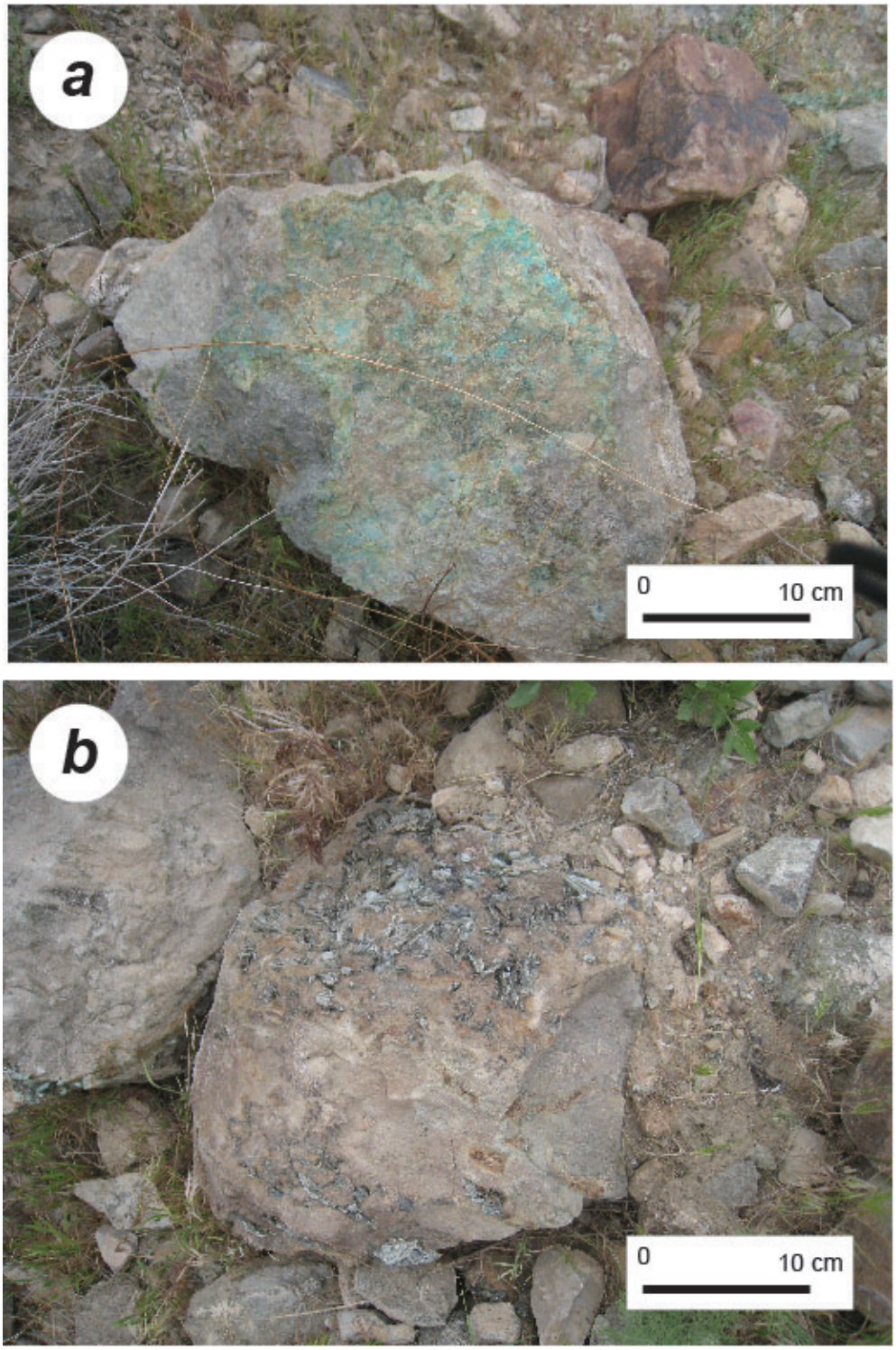

Figure 10A–13. Photographs of skarn and mineralized rock from the Kundalan copper-gold skarn deposit taken in 2010 by Emily Scott. (*a*) Malachite-stained siliceous skarn from northern trenches. (*b*) Porphyroblastic muscovite in marble in skarn zone.

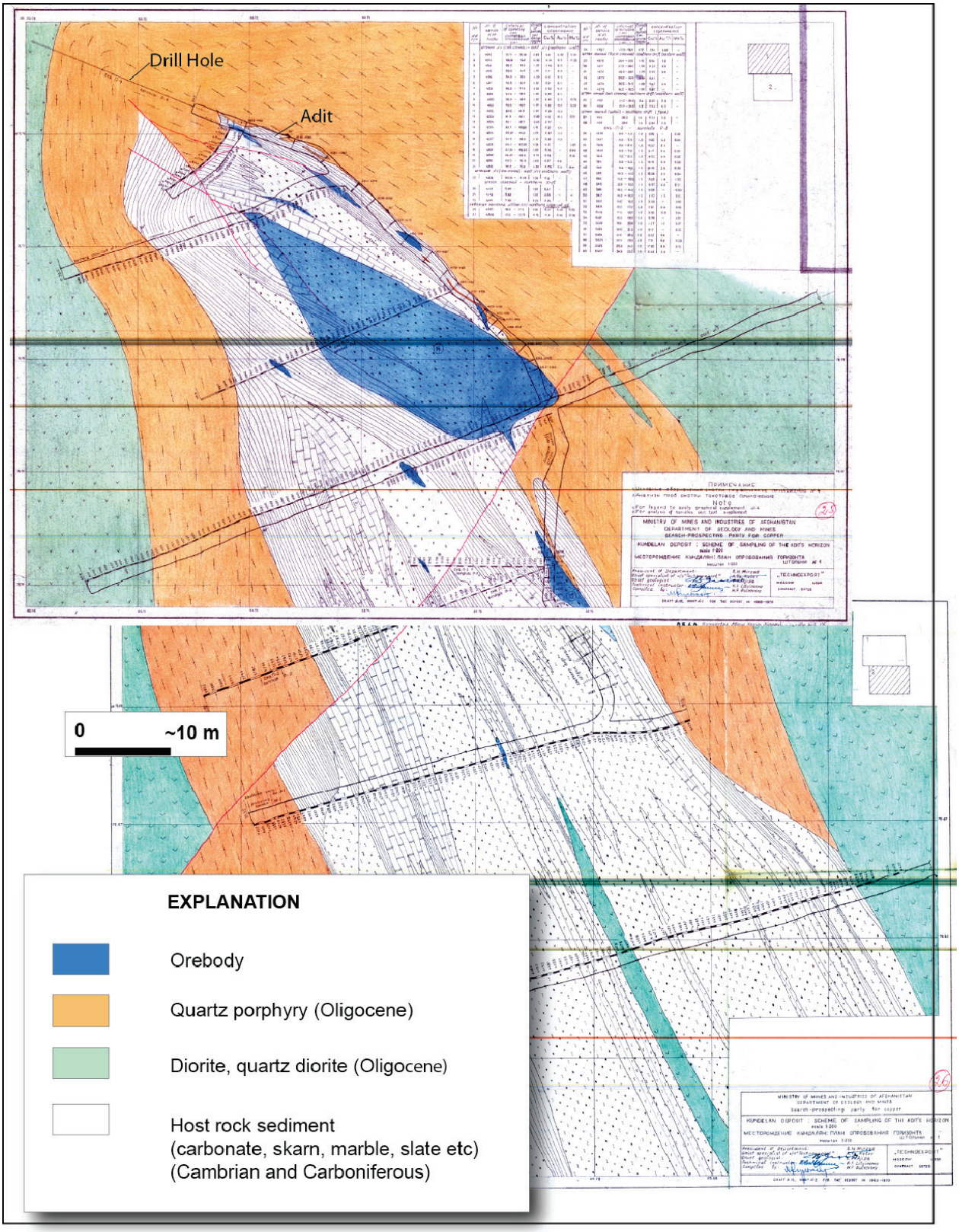

Figure 10A–14. Plan maps of the Kundalan copper-gold skarn deposit, Zabul Province, Afghanistan, showing sampling along cross-cutting exploration adits and drill hole. (Reproduced and modified from Litvinenko and others, 1971). Example of detail of work conducted on the deposit by Soviet workers..

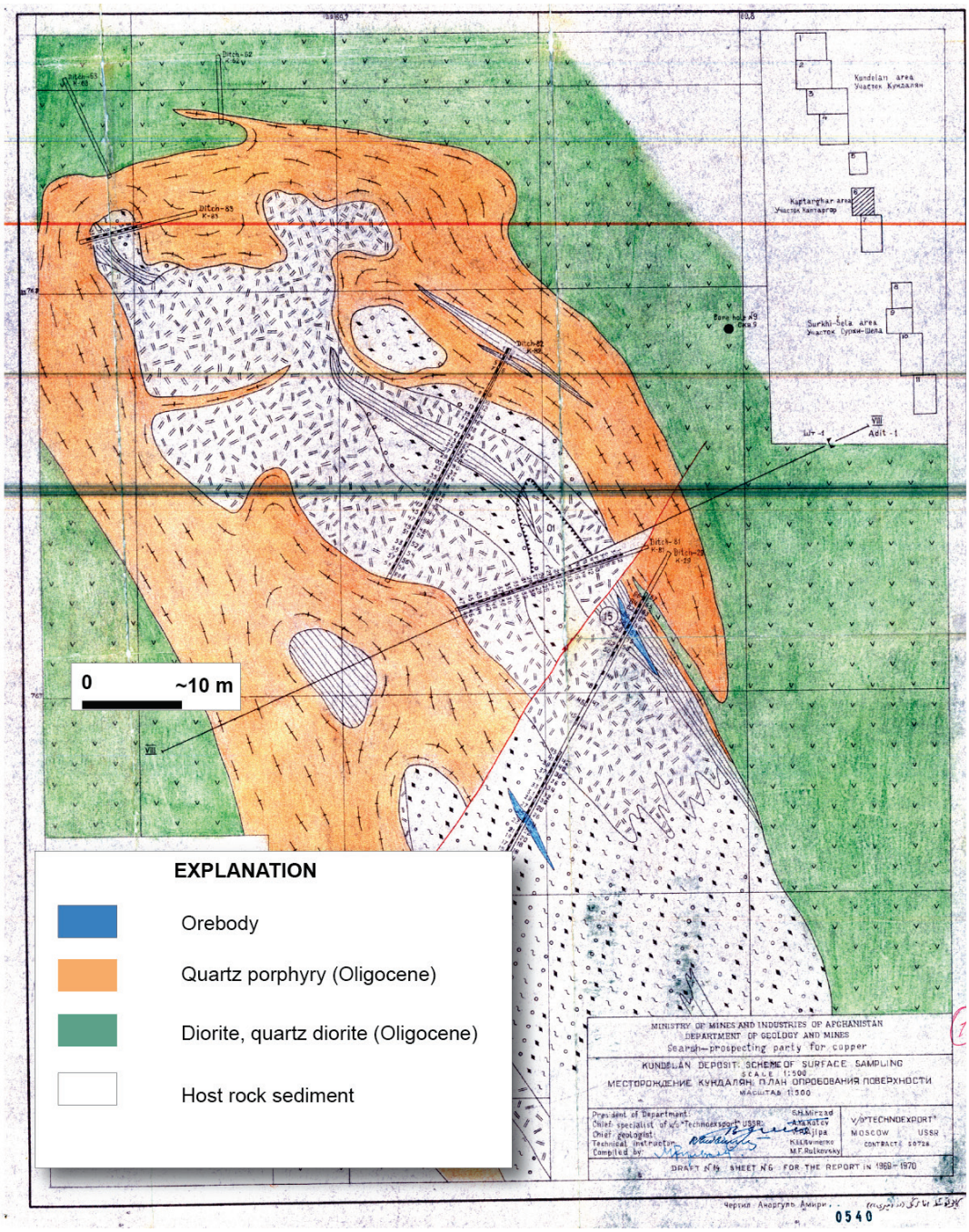

Figure 10A–15. Example of cross section through central part of Kundalan copper-gold deposit, Kabul Province (see fig. 10A-14). (Reproduced and modified from Litvinenko and others, 1971). This is an example of several sections through the orebody based on figure 10A–14 and included to show the level of Soviet-based work.

10.6A Prospects and Anomalies

Several copper and copper-gold and gold prospects and occurrences are present peripheral to or away from the main Kundalan copper-gold skarn deposit in the Kundalan copper and gold AOI and its subareas (table 10A-1). Prospects generally cluster near and around the Kundalan group of deposits in the Baghawan-Garangh subarea. In addition, the Kunag skarn and Charsu-Ghumbad subareas contain several copper-gold prospects and occurrences.

Table 10A–1. Main areas and prospects in the Kundalan copper and gold area of interest.
[Data are from Abdullah and others (1977). Au, gold; Cu, copper; g/t, grams per metric ton; kg, kilogram; Pb, lead]

Area	Prospect	Size (meters)	Gold grades (g/t Au)	Comments
Kundalan	Kundalan	2.65–12.3, 36–175	0.5–2	1.1 g/t Au
Kundalan	Kaptarghor	50–120 × 700	0.8–3.1	282.3 kg Au
Kundalan	Shela-i-Surkh	1–10, 40–173	0.3–0.5	154.5 t Au
Garangh	Assanak	1 × 150	2.2	Skarn, Cu, Au, Pb
Garangh	Tugra	5–6 × 250	0.1–6.5	Breccia
Garangh	Outcrop 543	1.5–2.5 × 100	9,3–13.2	Breccia with Cu
Garangh	Garangh	3 × 250	5–8	Ancient workings, vg
Dorushak	Dorushak	Multiple zones	1.1–12.4	33 g/t Au
Kadilak-Arghasu	Kadilak	0.2–2.5 × 90–200	70	Breccia, limestone, 2 zones
Kadilak-Arghasu	Arghasu (I, II, III)	0.2–7 × 50–200	2.7 and 127	Multiple zones
Hazarbuz	Hazarbuz	1–10.6 × 200	0.3–1.8	Skarn
Hazarbuz	Area IIIa	1.5– 3 × 100	0.3–1.9	Limestone zones
Hazarbuz	Area IIIb	Contact zone	0.3–1.2	Small skarn bodies

10.7A Baghawan-Garangh Subarea

Besides containing the main Kundalan copper-gold skarn deposit, the Baghawan-Garangh subarea contains the Garangh-Tugra, Assanak, Outcrop 543, Arghatu, Anghay, Lajar, Baghawan, and Tourva gold prospects (figs. 10A–1, 10A–5, 10A–6, and 10A–7; table 10A–1). The locations and brief descriptions of these prospects are summarized in Abdullah and others (1977) and Orris and Bliss (2002). Most prospects lie proximal to metasomatized contacts of Late Cretaceous-Paleocene intrusive rocks into carbonate sequences, similar to the main Kundalan copper-gold deposit (figs. 10A–16, 10A–17, and 10A-18).

The Garangh copper-gold prospect is north of the Kundalan copper-gold deposit and lies along the contact of lobes of the same intrusive body as Kundalan. Mineralized rock is localized along a zone of skarn and serpentinized rock, as much as 3 m wide and 250 m long, at the contact between Vendian-Cambrian limestone and Late Cretaceous-Paleocene diorite stocks (figs. 10A–17 and 18). Ore minerals are chalcopyrite, chalcocite, and pyrite, as well as rare native gold flakes. The highest concentrations of gold recorded for the Garangh gold ores by Soviet workers was 36 g/t gold; the average high concentrations were between 5 and 8 g/t gold. Copper concentration of these rocks is 2.63 wt. % copper (between 1 and 2 wt. % copper on average). The Garangh copper-gold occurrence was also mined in ancient times (Plotnikov and Slozhenikin, 1968; Douvgal and others, 1971).

The Assanak copper-gold occurrence (figs. 10A–1, 10A–5, 10A–6, and 10A–7) is in a zone of heavily brecciated, pyritized, and marmorized limestone of Carboniferous to Early Permian age. The zone, 1 to 2 m wide and 150 m long, assayed 2.2 g/t gold, 0.26 wt. % copper, 1 wt. % zinc, and 2.96 wt. % lead (Plotnikov and Slozhenikin, 1968; Douvgal and others, 1971).

The Tugra copper-gold prospect (figs. 10A–1, 5, 6, and 7) is confined to a zone of brecciated rocks with sulfide minerals; the mineralized zone is 5 to 6 m wide and 250 m long in Vendian-Cambrian pellitic and sandy rocks. Metal concentrations of the mineralized zones are 0.1 to 6.5 g/t gold, 0.06 to 2.03 wt. % copper, 0.4 to 14.15 wt. % lead, and 0.05 to 5-35 wt. % zinc (Plotnikov and Slozhenikin, 1968; Douvgal and others, 1971).

Outcrop 543 (figs. 10A–1, 5, 6, and 7) is a zone of brecciated, carbonated, and serpentinized rock that contains disseminated chalcopyrite and chrysocolla films that extend for about 100 m into Vendian-Cambrian limestone. The width of the zone is 1.5 to 2.5 m. Gold content of the mineralized zone varies between 9.3 and 13.2 g/t gold. The rock carries 1.03 to 3.6 wt. % copper, 0.1 wt. % zinc, and 0.002 wt. % bismuth. (Plotnikov and Slozhenikin, 1968; Douvgal and others, 1971).

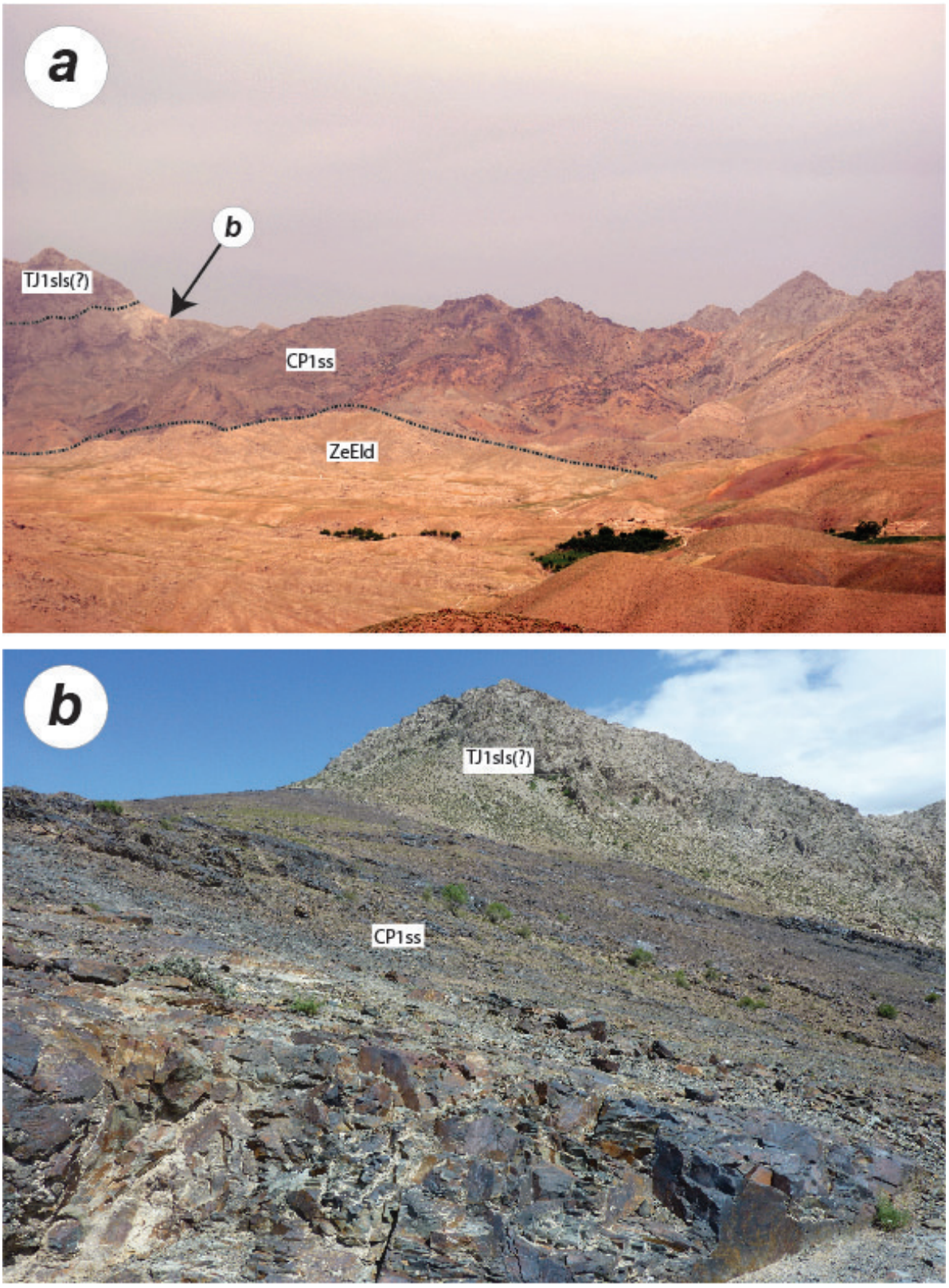

Figure 10A–16. Photographs from north of Garangh copper-gold prospect area, Kundalan copper and gold area of interest. (*a*) View looking north showing Precambrian rocks (units from Doebrich and others, 2006) in the foreground and Paleozoic and Mesozoic rocks in background. Photograph by Stephen Peters. (*b*) Close-up view of contact between Paleozoic rocks (foreground) and Mesozoic rocks on skyline. Approximate location shown in (*a*) with arrow. Photograph by Micheal Moore.

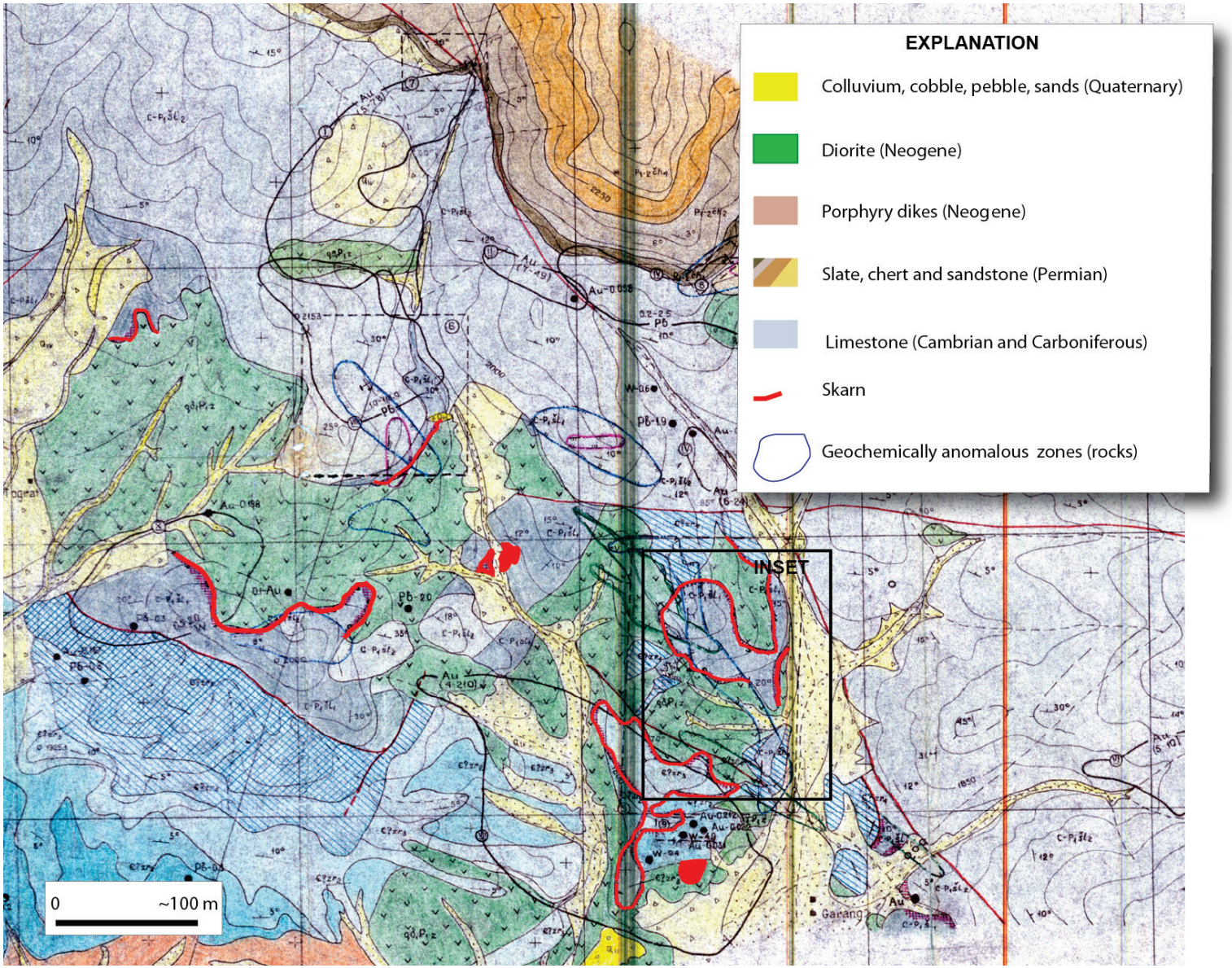

Figure 10A–17. Geologic map of Garangh-Tugra copper and gold prospect area. Green color is main Late Cretaceous to Early Cenozoic diorite stock that intrudes Cambrian and younger calcareous sedimentary rocks and produces contact copper-gold skarn. Inset is shown in figure 10A–18 and illustrates location of known ancient workings in these zones (reproduced and modified from Plotnikov and Slozhenikin, 1968; Douvgal and others, 1971; Litvinenko and others, 1971).

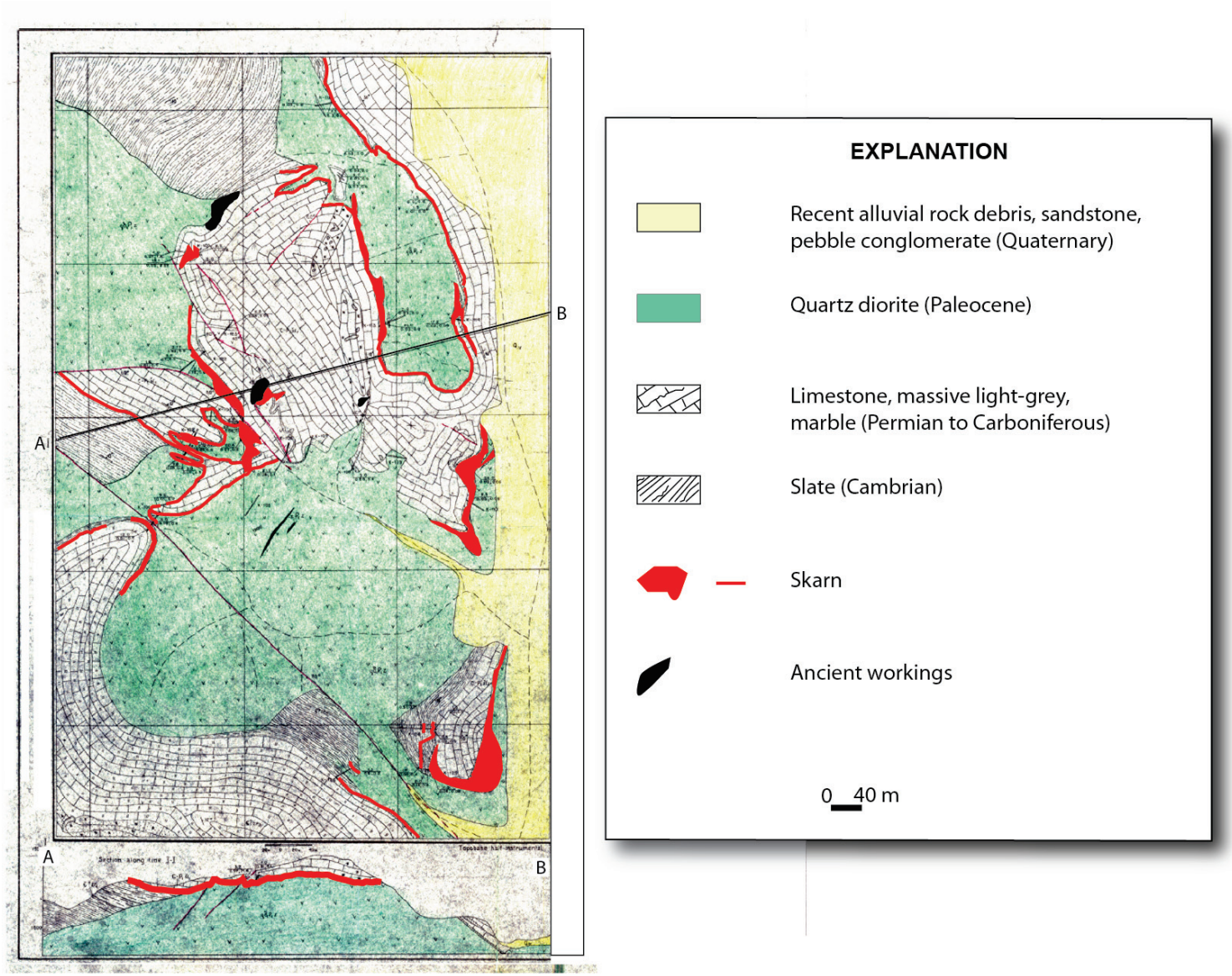

Figure 10A–18. Geologic map and cross section of part of Garangh copper and gold prospect area, Zabul Province, Afghanistan (inset from fig.10A–17). (Reproduced and modified from Plotnikov and Slozhenikin, 1968; Douvgal and others, 1971, and Litvinenko and others, 1971). Example of the type of mapping conducted by Soviet and Afghanistan geologists.

10A.8 Kunag Skarn Subarea

The Kunag skarn subarea is in the north part of the Kundalan copper and gold AOI and contains numerous copper-gold skarn occurrences. The area also contains numerous patches of sericite alteration, some of which are along linear patterns proximal to mapped faults. The Kunag skarn subarea contains the Hazarbuz, Buzghala II, Sare-Surkh, Daryabghar, and Kunag occurrences and the Ekrak and several unnamed gold-bearing copper skarns in the east part of the subarea (figs. 10A–1, 5, 6, and 7). The occurrences may be associated with Oligocene granite bodies, rather than with Upper Cretaceous diorite. Garnet-diopside and garnet-pyroxene skarn zones also contain silicification, sericitic alteration, and hornfels. Skarn is adjacent to igneous contacts between the igneous rocks and Middle to Upper Paleozoic limestone and sandstone, as well as Cambrian limestone. The Kunag skarn subarea contains anomalous amounts of tungsten and gold in stream-sediment samples and has an anomalous magnetic high under parts of the area (fig. 10A–19).

The Buzghala II occurrence in the Kunag skarn subarea is hosted in serpentinite, similar to the occurrences to the south in the Garangh copper-gold skarn prospect. The mineralized zones usually are less than 500 m long and generally are less than 20 m thick. The mineralized zones contain base-metal sulfide minerals and some gold (Douvgal and others, 1971; Nagaliov and others, 1971).

The Hazarbuz prospect is in an epidote-garnet skarn zone, varying in thickness from 1 to10.6 m and 200 m long, occurring at the contact between an intrusion of Oligocene granite and Upper Permian limestone. The skarn contains disseminated pyrite, chalcopyrite, and bornite, with 0.86 to 1.55 wt. % copper and 0.3 to 1.8 g/t gold (Douvgal and others, 1971; Nagaliov and others, 1971).

Other zones nearby consist of heavily ochreous, serpentinized, and silicified rock and small skarn bodies at the contact between Oligocene granite and an inlier of Upper Permian dolomite.

10A.9 Charsu-Ghumbad Subarea

The Charsu-Ghumbad subarea lies in the southwest part of the Kundalan copper and gold AOI (fig. 10A–2). It contains the Ghumbad, Dorushak, KadilakKadilak, Arghasu, Charsu and Obato-Shela copper-gold prospects. The subarea includes an anomalous zone of stream-sediment gold samples, and several aeromagnetic anomalies directly underlie most prospects. The subarea also contains northwest- and northeast-striking faults (Peters and others (2007) (fig. 10A–20). Garnet-pyroxene skarn occurrences are present in lenses, between 50 and 500 m long and 1 to 10 m thick and contain pyrite, chalcopyrite, bornite, chalcocite, galena, and magnetite.

The Dorushak copper-gold prospect is a shattered and hydrothermally altered skarn that lies along the exocontact of an intrusion of Late Cretaceous-Paleocene diorite in contact with Middle to Upper Jurassic limestone (fig. 10A–20). Mineralized zones of brecciated limestone contain disseminations and veinlets of pyrite, chalcopyrite, and gray copper ore, as well as coatings of chrysocolla. In these zones, copper concentrations range from 0.83 to 7.68 wt. % copper and the gold content is as much as 33 g/t gold. In the epidote-diopside, epidote-garnet, and diopside-garnet skarns, small 1- to 3-m-thick lenses, contain scattered particles of chalcopyrite, bornite, pyrite, hematite, and magnetite. The contents are 1.36 to 2.59 wt. % copper and 1.1 to 12.4 g/t gold. Nearby hydrothermal alteration has produced ochre-colored zones in the gray limestone (fig. 10A–21) (Plotnikov and Slozhenikin, 1968; Douvgal and others, 1971).

The Kadilak gold occurrence lies along two 0.2- to 2.5-m-wide, 90- to 200-m-long brecciated zones that contain disseminated sulfide minerals, similar to those in the skarn assemblages. The occurrence consists of two mineralized zones localized in Upper Triassic limestone. The mineralized rock consists of limestone and hematite fragments cemented by quartz-carbonate material with disseminated pyrite, chalcopyrite, bornite, chalcocite, galena, and hematite. Average metal concentrations are 70 g/t gold, 2.5 wt. % lead, 3.0 wt. % zinc and 0.87 wt. % copper (Douvgal and others, 1971; Nagaliov and others, 1971).

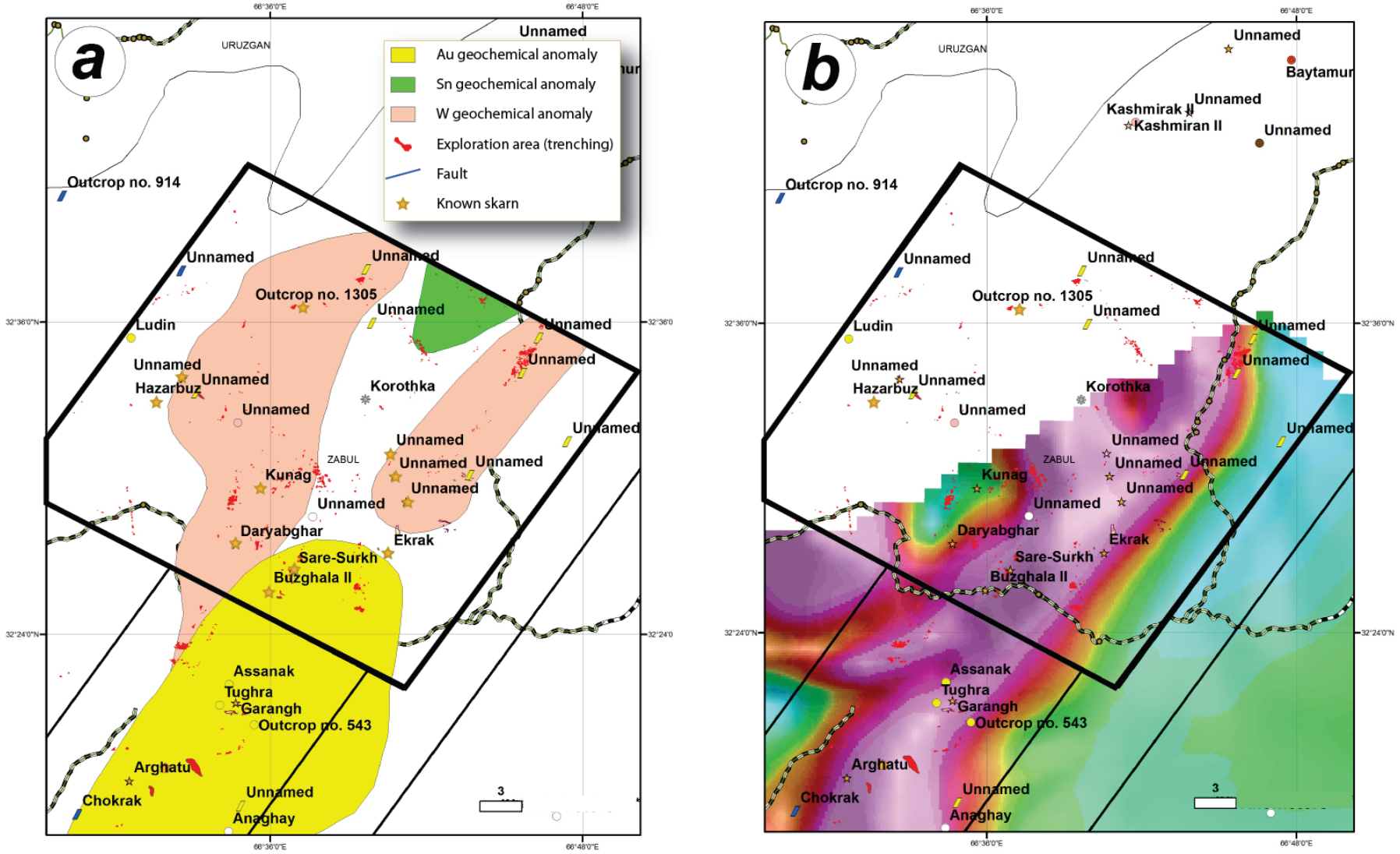

Figure10A–19. Maps showing features of Kunag skarn subarea, Kundalan copper and gold area of interest, Zabul Province, Afghanistan. (*a*) Stream sediment anomalous areas; from Peters and others (2007). (*b*) Aeromagnetic anomalies from Sweeney and others (2006). Warmer colors indicate higher magnetism in bedrock. Most copper and gold occurrences in subarea lie in either geochemical or geophysical anomalous area (modified from Peters and others, 2007). Red polygons indicate areas of trenching and exploration.

The Aarghasu (I, II, III) occurrences are restricted to the exocontact of an intrusion of Late Cretaceous-Paleocene diorite and Upper Triassic-Lower Jurassic limestone. It is represented by zones of skarn and hydrothermally altered, brecciated rocks. Diopside skarn makes up lenses as thick as 3 to 4 m and as long as 12 m. Rocks are serpentinized and carry disseminated pyrrhotite and chalcopyrite. Concentrations of the mineralized zones are 0.03 to 9.41 wt. % copper (1.25 wt. % copper on the average), 0.1 to 20 g/t gold (2.7 g/t gold on average), 0.06 to 0.59 wt. % lead, and 0.27 to 0.55 wt. % zinc. The zones of shattered and ferruginous intrusive rocks and limestone vary in thickness between 0.2 and 7 m and in length between 50 and 200 m. The mineralized rocks contain disseminated pyrite, chalcopyrite, bornite, magnetite, and hematite. Concentrations of metals in the mineralized zones are 0.1 to 2.32 wt. % copper, 0.96 wt. % lead, 0.27 wt. % zinc, and as much as 127 g/t gold (24.2 g/t gold on average) (Douvgal and others, 1971).

The Asanzay copper-gold prospect lies over a circular aeromagnetic high and contains a copper-gold skarn in a faulted area along the contact between small Late Cretaceous to Paleocene diorite plugs and Upper Permian marbled limestone and is composed of up to a 200-m-long and 0.3- to 0.4-m-thick garnet-diopside skarn zone with disseminated pyrite and chalcopyrite, grading 3.8 g/t gold, 0.84 wt. % copper, with trace base metals (Douvgal and others, 1971) (fig. 10A–20).

The Charsu area contains the Charsu deposit and Outcrop no. 7273 skarn copper-gold occurrences (Abdullah and others, 1977). The prospects lie over an aeromagnetic high and the occurrences also lie along a northwest-striking fault zone (fig. 10A–20). The Charsu occurrence is present along the contact between Late Cretaceous to Paleocene diorite and Middle to Upper Jurassic marble and dolomitized limestone, producing diopside-garnet skarn, and magnetite-hematite-skarn in lenses. There are two areas, both containing skarn as much as 600 m long and 10.4 m thick, with irregular disseminated pyrite, chalcopyrite, covellite, bornite, malachite, cuprite, azurite, and gold grading between 0.53 and 1.82 wt. % copper. Speculative tonnage in the second area is 13,000 t of copper and 1.59 t of gold (Douvgal and others, 1971). Outcrop no. 7273 has a similar geology and tenor to the Charsu deposit and is as much as 100 m long and 7 m wide (Douvgal and others, 1971).

10A.10 Summary of Potential

Presence of relatively well-explored gold- and copper-bearing prospects at the Kundalan copper-gold deposit and presence of numerous other copper and copper-gold prospects within the Kundalan copper and gold AOI and its subareas are important positive indicators for overall economic potential of this area. The petrologic characteristics of the associated intrusive rocks and the available assays suggest that the porphyry copper-like system discovered here by Soviet workers is gold-bearing. Although most exploration conducted prior to 1979 has delineated or discovered copper-gold skarn systems, no unequivocal porphyry copper system has been identified (Peters and others, 2007).

Future discoveries and definition of resources will require detailed field examination and detailed geologic mapping to determine if there is porphyry-style mineralized rock in addition to the skarn deposits. At the same time, further exploration of skarns could result in development of a viable relatively small-tonnage mine. The magnetite-rich skarns would respond well to aerial and ground magnetometer surveys. In addition, the mineralization age should be determined to confirm which mineralized systems are related to the Cretaceous and Paleogene plutons and which are related to Oligocene plutons exposed in the area. There may be significant potential beneath the colluvial cover adjacent to the known resources.

The USGS Assessment Team (Peters and others, 2007) estimated that there is a 90-percent chance of one or more undiscovered porphyry copper deposits in the Kundalan or Zarkashan areas, a 50-percent chance of one or more, and a 10-percent chance of two or more. The amounts of contained metal that result from a Monte Carlo simulation based on this estimate are illustrated and summarized in table 10A-2. This is a relatively optimistic estimate for such a small area.

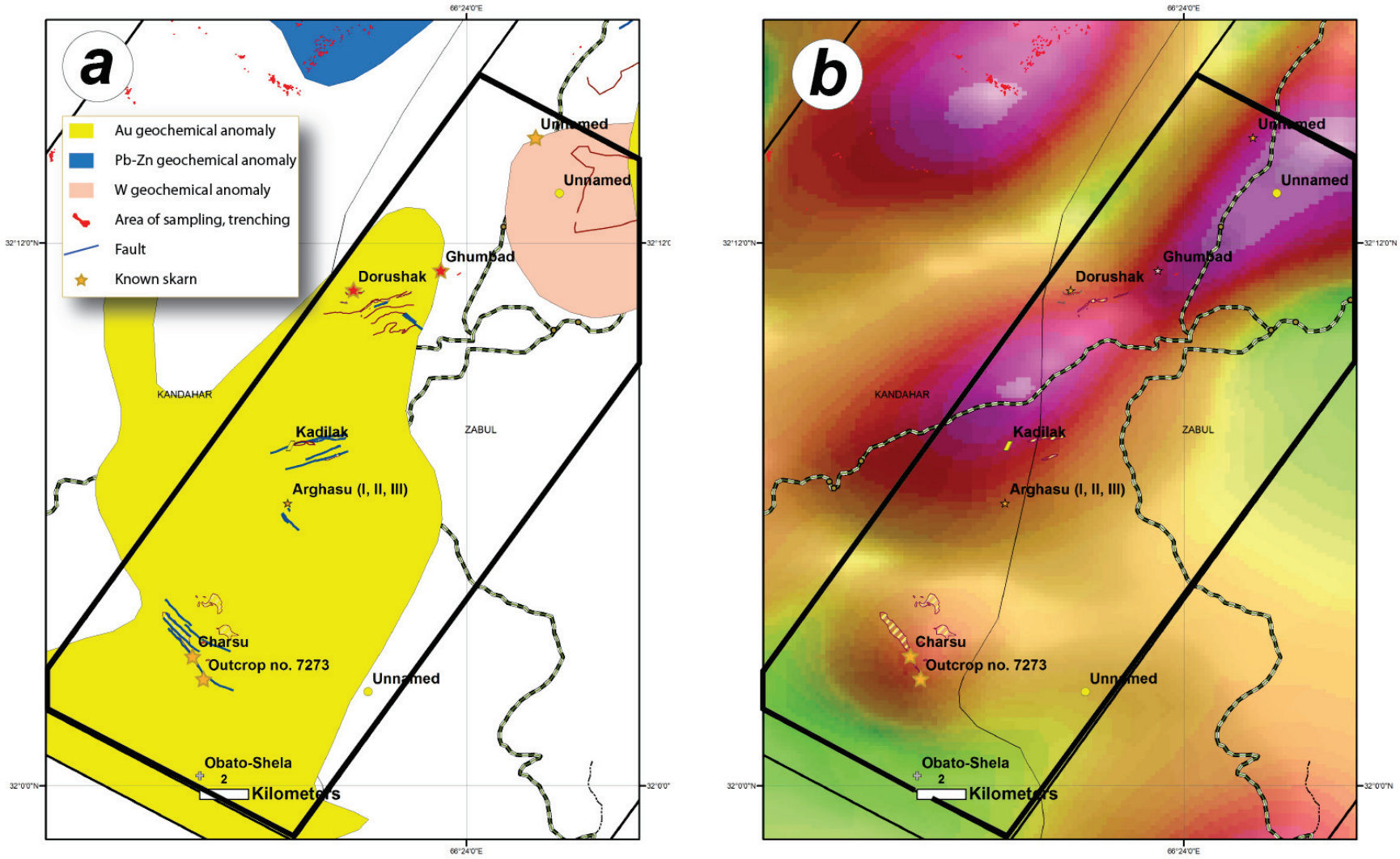

Figure 10A–20. Maps showing location and features of Charsu-Ghumbad subarea, Kundalan copper and gold area of interest. (*a*) Geochemical stream anomalies (from Peters and others, 2007) showing southern part of subarea is dominated by anomalous gold and northern part by tungsten anomaly. (*b*) Aeromagnetic anomalies from Sweeney and others (2006) in subarea showing that most copper-gold prospects lie above or adjacent to the anomalous zones.

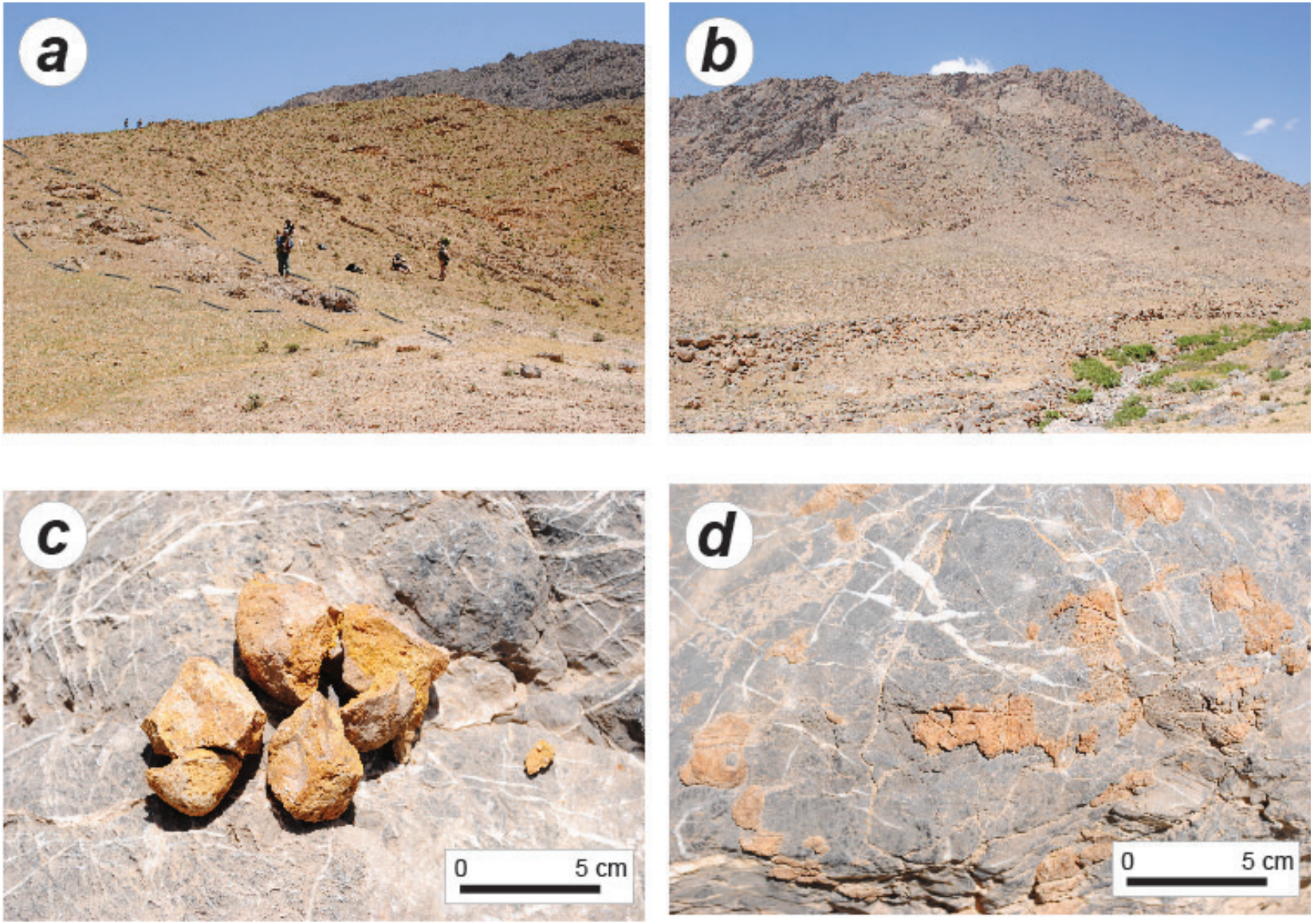

Figure 10A–21. Photographs of rocks near Dorushak gold prospect taken in 2010. (*a*) View looking northeasterly showing hydrothermal zone (between dashed lines) in limestone. (*b*) Siliciclastic rocks on skyline overlying carbonaceous rocks in foreground. (*c*) Ochre-colored mineralized rocks from creek bed containing trace amounts of gold. (*d*) Orange-colored mattes and white calcite veins overprinting gray limestone. Photographs by Stephen Peters.

Table 10A–2. Table summarizing statistical parameters for the assessment of the Kundalan-Zarkashan permissive tract.

[Data are from Peters and others (2007; tract ppycu05, fig. 10A–3). The mean expected number of deposits is 1.0. Amounts are in metric tons. The Mark3 index is 84–Porphyry copper New General 2005. Ag, silver; Au, gold; Cu, copper, Mo, molybdenum]

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

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