Chapter 4A. Summary of the Balkhab Copper Area of Interest

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Abstract

This chapter summarizes and interprets results for the Balkhab copper area of interest (AOI) and its subarea that have come from geologic and compilation activities that were conducted jointly between 2009 and 2011 by the U.S. Geological Survey (USGS), the U.S. Department of Defense Task Force for Business and Stability Operations (TFBSO), and the Afghanistan Geological Survey (AGS). Accompanying chapters 4B and 4C address hyperspectral data and geohydrologic assessments, respectively, of the Balkhab copper AOI. Supporting data for this chapter are available from the Afghanistan Geological Survey Data Center in Kabul.

The Balkhab copper volcanogenic massive sulfide (VMS) prospect lies within the Balkhab copper AOI and is part of an eroded exposure of deformed pre-Triassic, mainly Ordovician rocks, in Sar-i-Pul Province that lies in a canyon unconformably below horizontal Mesozoic sedimentary rocks (Peters and others, 2007). Copper mineralization consists of a silicified limonite-bearing 4,000- to 5,000-m-long, 300- to 400-m-wide deformed and faulted rock that contains at least four areas of extensive malachite, azurite, pyrite, and disseminated chalcopyrite, bornite, and galena grading from 0.25 to 1.34 weight percent (wt. %) copper. A number of old surface and underground workings are present in the high-grade areas. Old slag piles yield samples assaying 1.68 wt. % copper (Kafarskiy and others, 1972). Work by the Afghanistan Geological Survey in 2008 and 2009 confirmed the highly mineralized copper zones. Detailed mapping and sampling began in 2010. In addition, the Balkhab copper AOI contains a number of anomalous or mineralized areas and targets besides the main Balkhab copper prospect in the subarea.

The presence of the Balkhab copper prospect and various other copper showings throughout the Paleozoic rocks, the abundant water supply, and the Balkhab coal deposits in the northeast part of the Balkhab copper AOI and elsewhere in the Mesozoic rocks make the Balkhab copper AOI a promising area for mineral exploitation. Oxide copper ores are abundant in parts of the mineralized zones and may be amenable to hydrometallurgy.

4A.1 Introduction

The Balkhab copper area of interest (AOI) is in northern Afghanistan (fig. 4A–1) and covers parts of southeastern Sar-i-Pul Province (Balkhab Administrative District), northwestern Balkh Province (Kishindih Administrative District) and the far eastern parts of Sam Angan Province (Dar-i-Suf Administrative District). The main Balkhab copper AOI is 1,858.31 square kilometers (km^2), and the Balkhab prospect subarea is 321 km^2 (fig. 4A–2). The main mineral deposit types of interest are volcanogenic massive sulfide (VMS) (Kuroko- or Bimodal-felsic type), including oxide copper ores, coal deposits, and possible granite-hosted gold deposits.

4A.2 Previous Work

At the Balkhab copper prospect there is evidence of mineral extraction activity on the oxide copper outcrops at Balkhab as old as 3,000 years (Abdul Kadir Akkhunzada, Afghanistan Ministry of Mines, oral commun., 2008), because of its proximity to the Silk Road trade routes. It is likely that

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continuous extraction of copper has taken place from at least then to today by surface and underground workings. The age of the slag piles that resulted from ancient smelting furnaces is not known, nor have the different mine workings been dated. Modern geologic investigations began in the area with the work of Mikhailov (1967) as part of coal studies in the area. The copper area was visited by Kafarskiy and others (1972), who conducted trench and grid sampling and also made a geologic map of the main Balkhab copper prospect area. Sborshchikov and others (1973) also conducted regional geologic investigations in the area.

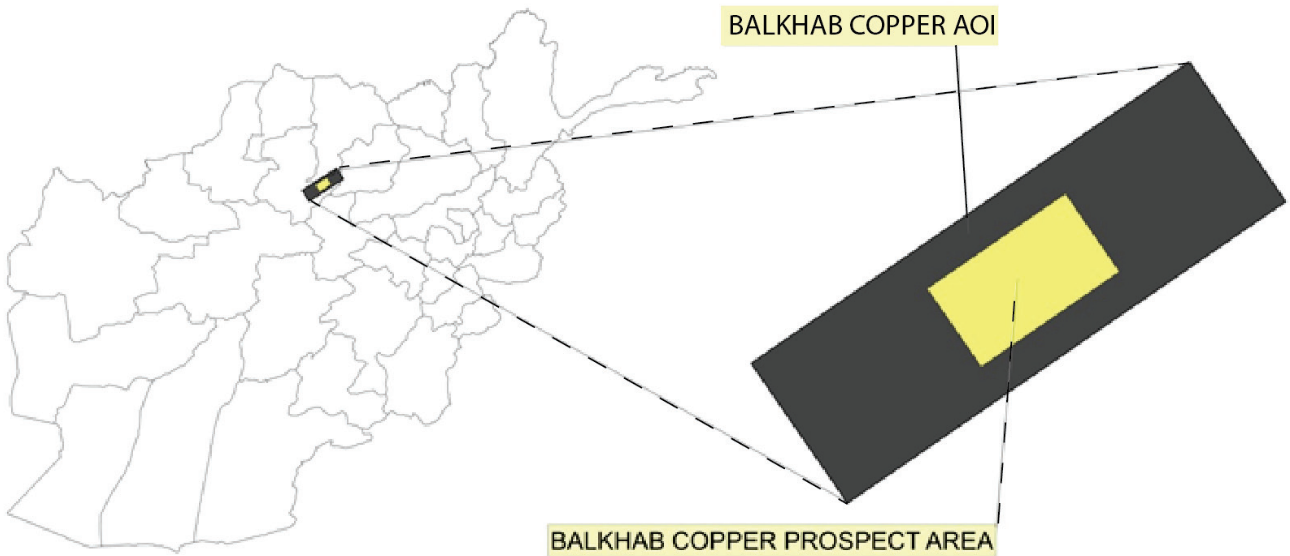

Figure 4A–1. Location of the Balkhab copper area of interest and the Balkhab copper prospect subarea in northern Afghanistan, Sar-i-Pul Province.

The Balkhab copper prospect and surrounding areas were mentioned by Abdullah and others (1977), Economic and Social Commission for Asia and the Pacific (ESCAP), (1995), and Metal Mining Agency of Japan (1998) as part of regional compilations of mineral occurrences in Afghanistan. U.S. Geological Survey (USGS) compilations by Orris and Bliss (2002) and Doebrich and others (2006) suggested that the Balkhab copper mineralization is of the volcanogenic massive sulfide type, and Peters and others (2007) speculated that it was of the Kuroko subtype or Bimodal-felsic type of VMS deposits. No quantitative assessment for undiscovered VMS deposits was conducted by the USGS in 2007 because of lack of information.

Recent interest in the Balkhab copper AOI and its copper occurrences was initiated by the Ministry of Mines of Afghanistan from a request in 2007 by local villagers to the former Minister of Mines, H.E. Mohammad Ibrahim Adel, to examine the copper mineralization. The Ministry dispatched Engineer Abdul Kadir Akkhunzada, who examined the area and conducted reconnaissance sampling in 2008 (figs. 4A–2 and 4A–3). In 2009, an Afghanistan Geological Survey district mapping party, led by Engineer Abdul Gaffer, conducted field work and sampled the copper mineralization. They produced maps and reports, which showed the general mineralized zone was more than 60 meters (m) thick and dipped southerly into the hillside (fig. 4A–4).

A scoping mission was undertaken to the area in 2009 by the USGS and the U.S. Department of Defense Task Force for Business and Stability Operations (TFBSO) (U.S. Department of Defense Task Force for Business and Stability Operations, 2010), and brief descriptions support the volcanogenic nature of the mineralized system. In 2010, the TFBSO, USGS, and AGS initiated a 50-m-sized grid geologic mapping and sampling program over the area of known mineralized rock and mine workings. Results of this work are pending. Sabins and Ellis (2010a,b) conducted remote-sensing targeting analysis on the area for both copper deposits and coal. Recent work has focused on developing geophysical and drill targets; seven mineralized targets have been identified in the Balkhab copper AOI and its subarea from anomalies in the remotely sensed data. Security issues have prevented extensive field work in the area in recent times, and, therefore, most interpretations and analysis have been by remote sensing methods.

An inventory of individual datasets compiled for the Balkhab copper AOI and its subarea is included with the data information package in the Data Center of the Afghanistan Geological Survey and specifies which data have been compiled. Most existing mineral-resource information has been gathered from reports written during the 1970s 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 USGS (Peters and others, 2007) and recent field work by the Afghanistan Geological Survey (AGS), provided much of the basis for analysis and interpretation during the period 2009 through 2011. The Balkhab copper AOI and its subarea are also thought likely to host deposits that might have near-term mineral production, with some areas of mineralized rock forming surface bodies with promising metallurgical and mining characteristics.

Figure 4A–2. Photograph of malachite- and azure-coatedphyllite from Balkhab copper prospect. Photograph by Stephen G. Peters, U.S. Geological Survey.

4A.3 Geology

The Balkhab copper AOI contains deformed Middle to Late Paleozoic sedimentary and volcanic rocks that are exposed in the central parts of an eroded canyon of the Balkh River (figs. 4A–1 and 4A–5). The Paleozoic rocks are overlain unconformably by near-horizontal Mesozoic sedimentary rocks (Mikhailov, 1967; Kafarskiy and others, 1972; Doebrich and others, 2006). The oldest rocks mapped are Ordovician sandstone, siltstone, and shale (unit Ossl) (units from Doebrich and others, 2006), which are sheared, low-grade greenschist metamorphic rocks (figs. 4A–5 and 4A–6). These are overlain by Silurian to Devonian schistose limestone, dolomite, and sandstone (unit SD_ld), which are, in turn, locally overlain by Mississippian (Early Carboniferous) volcanic rocks, limestone, and sandstone (unit C_lrb), and by Early Permian limestone and sandstone (P_1lssa) and Late Permian limestone and dolomite (P_2ld). These basement rocks were intruded locally by a Mississippian dunite mass (C_1um) south of the Balkh River and an Early Triassic(?) medium- to fine-grained biotite-chlorite granite porphyry north of the Balkh River (T_3agp).

The Mesozoic rocks consist of two main sequences. The first is a wedge of Lower Mesozoic rocks that is present only in the eastern parts of the Balkhab copper AOI. They are Late Triassic (Rhaetian) volcanic rocks, sandstone, and mudstone (T_3val) and are overlain by Early to Middle Triassic sandstone and siltstone (J$l_2$ssl), which in turn are overlain by Late Jurassic conglomerate (J_3cgs) and by an Early Cretaceous sequence of red sandstone and conglomerate (K_1ssc). The second sequence overlies the entire area, including the Paleozoic rocks in the western part of the Balkhab copper AOI, and consists of Late Cretaceous sandstone, siltstone, and limestone (K_2ssl). The youngest two sedimentary units are Late Cretaceous to Paleogene limestone and sandstone (KP_1ld), and local valleys are filled with Pliocene conglomerate and sandstone.

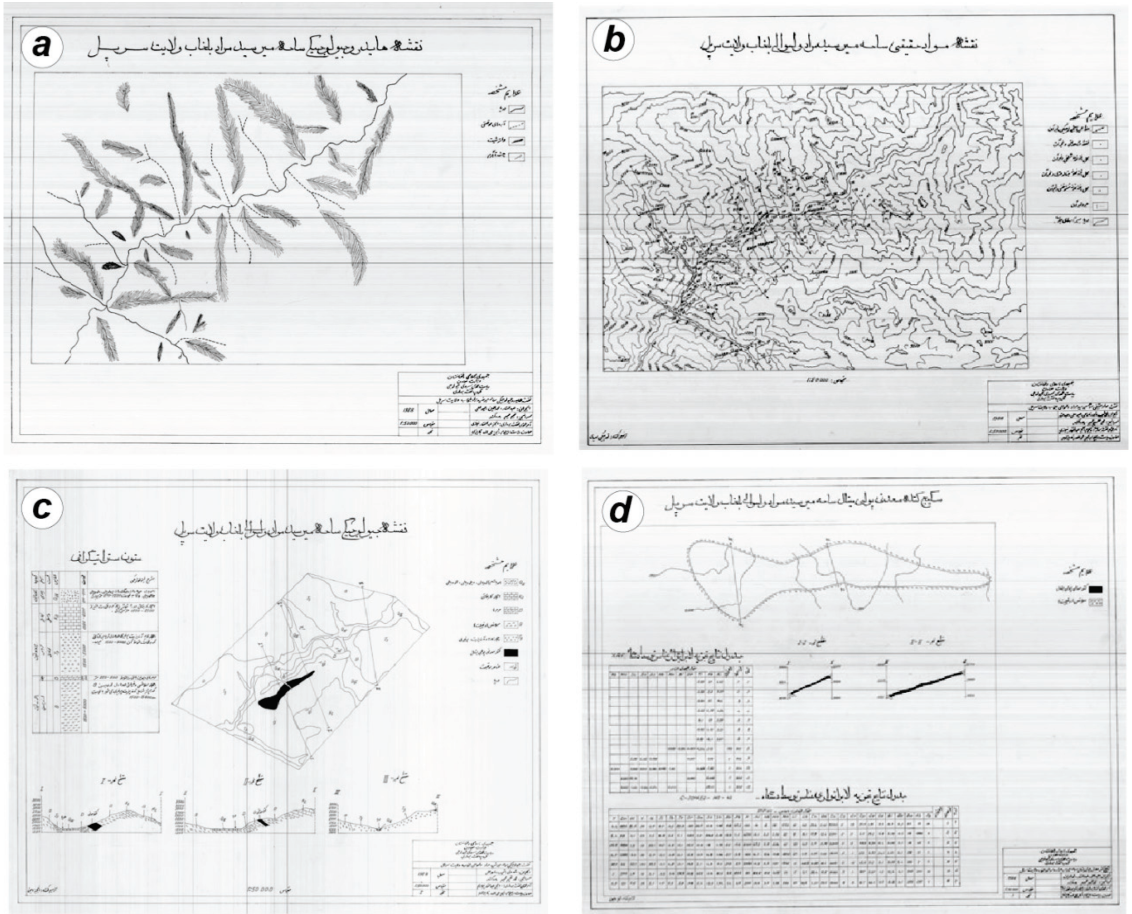

Figure 4A–4. Maps produced by the Afghanistan Geological Survey (AGS) from 2009 field work in the Balkhab copper prospect area. (*a*) Outline of drainage areas. (*b*) Sampling map with topographic contours. (*c*) Geologic map of the main mineralized zone with cross sections; orebody in black. (*d*) Detailed measurements of the main mineralized zone and cross sections. The main copper-mineralized zone dips southerly into the hillside. These maps are available in the AGS archives and are illustrated here as examples of the type of work that was conducted.

Copper-sulfide mineralized zones are within or proximal to layers of quartzofeldspathic rocks (felsic volcanic rocks), which make up parts of the basement metamorphic sequence. The low-grade Ordovician to Silurian-Devonian volcano-sedimentary metamorphic rocks in the Balkhab copper AOI are highly deformed and extensively faulted (figs. 4A–5 and 6*a*,*b*). The rocks are pervasively sheared green- to gray- to black-colored chloritic phyllite and schist (figs. 4A–6*a*,*b*). Chloritic schist and phyllite also enclose layers and lenses of black chert and jasper, and blocks and sheets of serpentinite, and extensive sheet-like layers (tens of meters thick) of brecciated and altered quartzofeldspathic schistose felsic volcanic rocks (fig. 4A–6). Many of the quartzofeldspathic layers are extensively mineralized, in zones centimeters to meters thick, with porphyroblastic euhedral cubes of pyrite, chalcopyrite, and bornite (fig. 4A–6*d*). Subsequent weathering of the pyrite-rich seams and layers has left an iron-oxide staining on the rocks.

A medium- to fine-grained chloritic granite porphyry (leucogranite) lies west of the main mineralized zone on the north side of the canyon (fig. 4A–5*b*). The granite porphyry is propylitically altered and contains through-going quartz-pyrite veinlets marked by an absence of alteration selvages. This stock locally contains extensive quartz stockworks in the wall rock of the granite porphyry north of the main Balkhab River drainage. Geochemical sampling of the more promising stockwork zone by the USGS in 2009 did not show more than trace amounts of precious or base metals.

The host rocks around the copper mineralization in the Balkhab copper prospect contain strong east-striking foliation and shears. Faulting in these rocks is intense, and tight folding is common (figs. 4A–5 and 4A–6). Some of the faults are brittle, and much of the shearing is parallel to the schistosity and is locally mylonitic (Alex Chaihorsky, U.S. Department of Defense Task Force for Business and Stability Operations, 2010, written commun.). This suggests that any mineralization that formed coeval with the volcanism has been faulted and folded. Some layering in the rock may be flow banding in the more felsic volcanic rocks. This would imply that the deformation might be highly partitioned along sheared and mylonitic zones.

Conspicuous white stains of the metamorphic rocks immediately beneath the unconformity are either clay alteration of the mineralized felsic volcanic horizons in the older metamorphic sequence or a Permian-Carboniferous age paleosol resulting from a peneplanation surface below the horizontal Mesozoic strata. For this reason, copper mineralization on the high slopes of the canyon, closer to the Mesozoic contact, may be the most oxidized, whereas mineralized zones on the lower slopes, far below the Mesozoic contact, are more likely to be below the original paleo-oxide zone.

4A.4 Metallogeny

Distribution of known or interpreted volcanogenic massive sulfide (VMS) deposits in Afghanistan is restricted to the mostly covered Late Paleozoic volcanic rocks in the north of the country and also to Jurassic and Oligocene volcanic rocks in the west (Doebrich and others, 2006; Peters and others, 2007).

According to Peters and others (2007), the Balkhab copper prospect contains geologic characteristics that most closely resemble Kuroko or Bimodal-felsic VMS deposits (see also Singer, 1986; Franklin and others, 2005; Shanks and others, 2009) or a Noranda-type VMS deposit, also referred to as felsic to intermediate volcanic type deposit. This family of mineralized systems contains copper- and zinc-bearing massive sulfide deposits hosted in volcanic rocks that are dominantly of intermediate to felsic composition. The main associated rocks in these deposits throughout the world are marine rhyolite, dacite, and subordinate basalt and associated sedimentary rocks, principally organic-rich mudstone or shale and pyritic siliceous shale.

The rock types and geologic environment on the Balkhab copper AOI match closely those found in Kuroko or Bimodal-felsic VMS deposits. Extensive field and laboratory investigations are necessary to confirm this tentative classification. Typical rocks associated with Kuroko or bimodal-felsic VMS deposits are lava flows, volcanoclastic rocks, breccia, bedded sedimentary rocks, and in some cases, felsic lava domes. The Kuroko or Bimodal-felsic VMS deposits form toward the more felsic tops of volcanic or volcanic-sedimentary sequences. Deposits are present near centers of felsic volcanism. Pyritic siliceous rock (exhalite) may mark horizons at which deposits occur. Geochemical signatures in gossan may be high values of lead, with gold typically present. Adjacent to the deposit there is enrichment in magnesium and zinc, and depletion in sodium. Within deposits the ores are enriched in Cu, Zn, Pb, Ba, As, Ag, Au, Se, Sn, Bi, and Fe (Singer, 1986; Franklin and others, 2005; Shanks and others, 2009).

4A.5 Known Deposits

The Balkhab copper prospect was described by Abdullah and others (1977). The Balkhab copper prospect has not been well-studied and documented geologically; however, preliminary investigations have documented rocks and geochemistry of the rocks and ores that are compatible with the Kuroko or Bimodal-felsic VMS deposit model (Peters and others, 2007; U.S. Department of Defense Task Force for Business and Stability Operations, 2010). Samples of (1) fine-grained intergrown hexagonal pyrrhotite(?), chalcopyrite, and bornite from outcrop (fig. 4A–6*c*) and (2) relict layers of pyrrhotite in geochemical samples from the slag pile associated with mining activities are both compatible with a volcanogenic genesis. The sheared felsic rocks contain interlayered narrow zones of millimeter-wide porphyroblastic pyrite cubes (fig. 4A–6*d*). This does not conflict with the hypothesis that the copper-mineralized rocks may be associated with the felsic volcanic host rocks in which they occur.

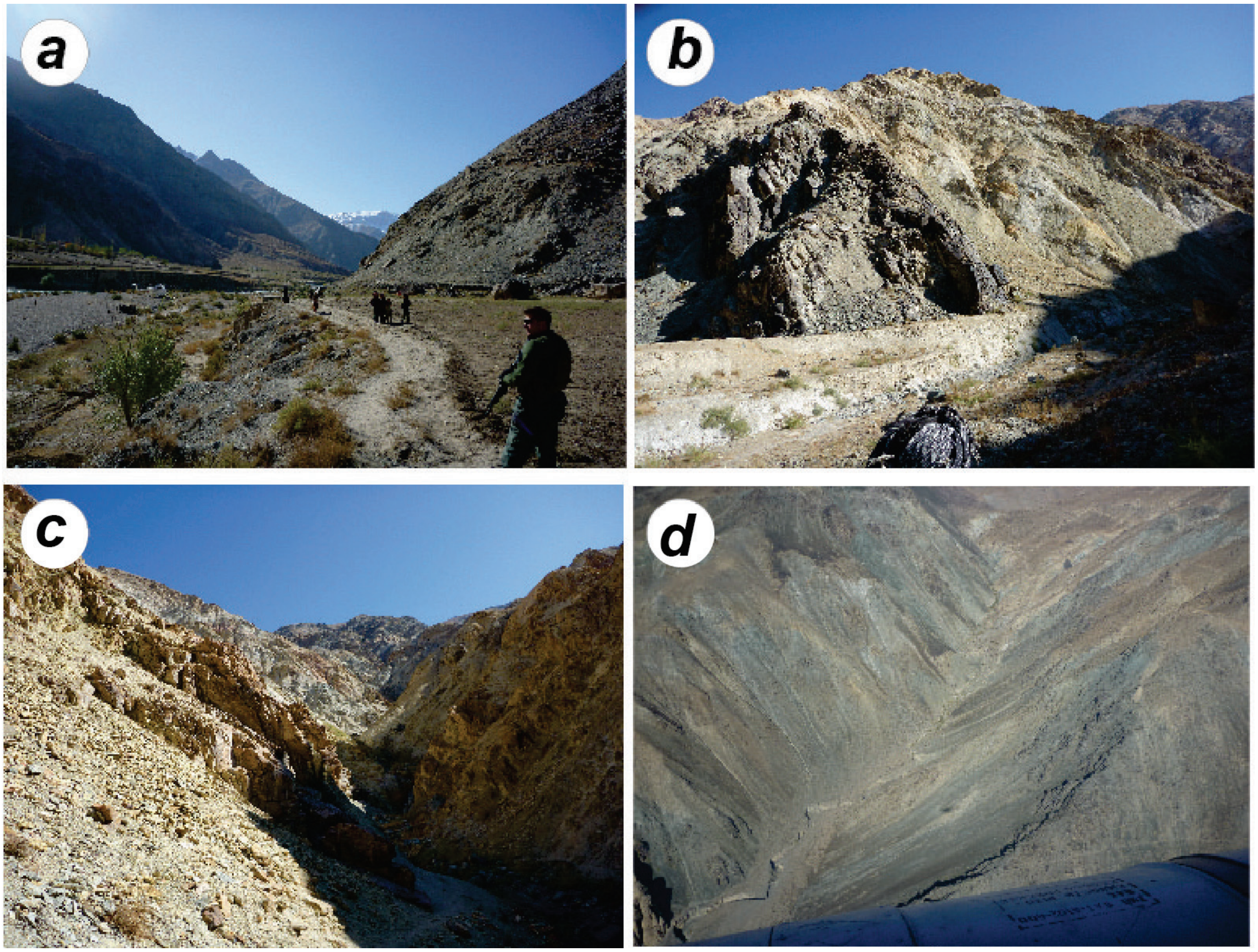

Figure 4A–5. Photographs of the Balkhab copper area of interest (AOI). (*a*) Floodplain of the Balkhab River and the steep topography of the river gorge (long. 66.73341°E., lat. 35.55851°N.). (*b*) Photograph of dark, highly sheared granite porphyry (left foreground) faulted against steep-dipping felsic metavolcanic rocks, south bank of the Balkhab River. (*c*) Rusty-weathering quartzofeldspathic schist and gneissic-texture felsic metavolcanic rocks of the Balkhab copper prospect area, south bank of the Balkhab River (long. 66.73750°E., lat. 35.55285°N.). (*d*) Aerial view of a dry tributary stream in a watershed showing extremes in elevation in Balkhab copper AOI. Photographs by Robert D. Tucker, U.S. Geological Survey.

The Balkhab copper prospect is described by Kafarskiy and others (1972) and Abdullah and others (1977) as copper- and lead-mineralized rock in a zone that contains copper concentrations which range from 0.25 to 1.66 weight percent (wt. %) copper (tables 4A–1 and 4A–2). Mineralized zones mapped by Kafarskiy and others (1972) are reproduced on figure 4A–7*a*.

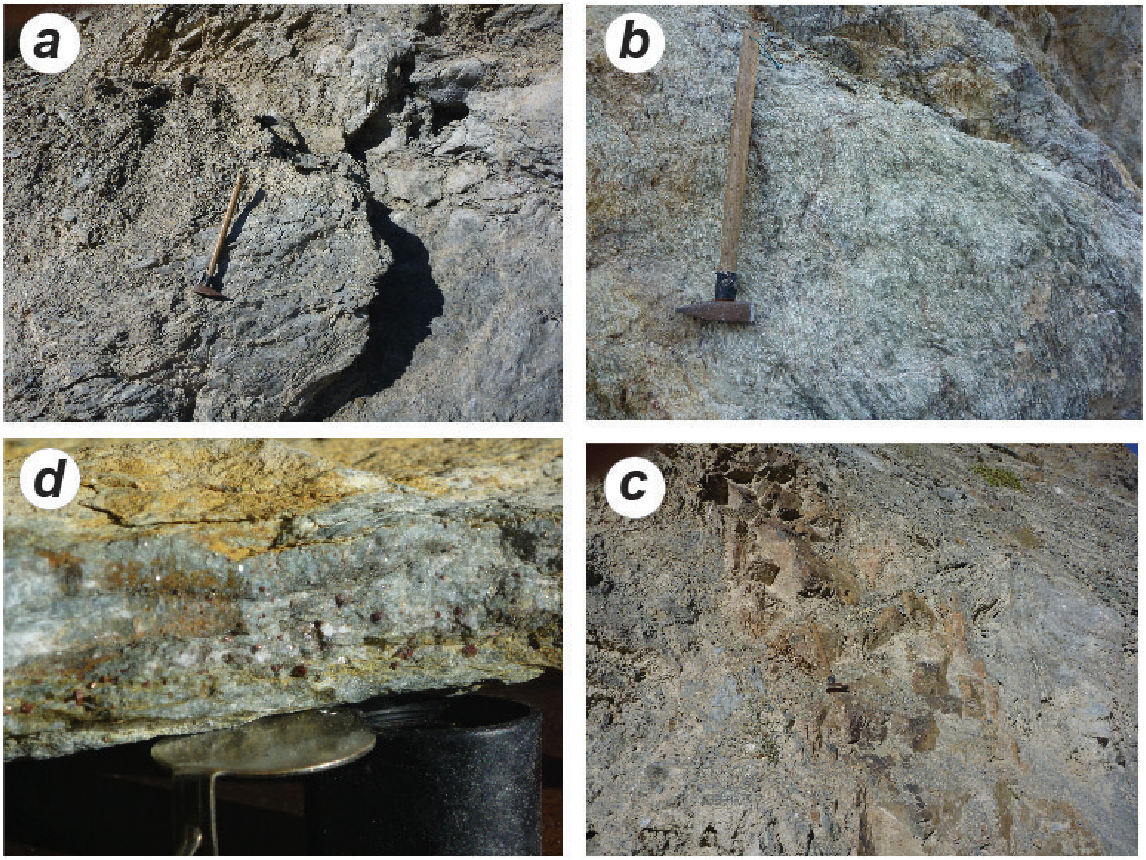

Figure 4A–6. Photographs of rocks and outcrops from the Balkhab copper prospect area. (*a*) Greenschist facies metamorphic rocks of the Balkhab copper area (long. 66.73318°E., lat. 35.55659°N.). (*b*) Foliated and kinked quartz-feldspathic schist-gneiss (felsic metavolcanic) of the Balkhab copper prospect area (long. 66.73747°E., lat. 35.55294°N.). (*c*) Closeup of mineralized felsic metavolcanic gneiss with euhedral cubes of pyrite. Hand lens for scale. (*d*) Meter-thick layer of brown-weathering black metachert and metasiltstone within chloritic schist. Hammer for scale. Photographs by Robert D. Tucker, U.S. Geological Survey.

4A.6 Prospects and Anomalies

Kafarskiy and others (1972) describe a tectonic zone at the Balkhab copper prospect containing Ordovician(?) sandy schist below Upper Triassic rocks. The copper mineralization at the Balkhab copper prospect was described as a wide hydrothermal-metasomatic zone. The Soviet workers concluded that most of this mineralization was constrained to a zone of faults and specific gray zones within the schistosity of metatuff and volcanic rocks and was also at the "top" of hypabyssal granite intrusions. Figure 4A–7 interprets the "ore zones" mapped by Kafarskiy and others (1972) to lie within a sheath of deformation of folded metavolcanic stratigraphy. The mineralized zone is evident along the hillside as a gray-colored layer of rock, tinted mainly by sulfide minerals (fig. 14A–8). Geochemical sampling by the AGS has taken grab samples from the Balkhab copper prospect area that contain concentrations of 11,000 parts per million (ppm) copper, 1,900 to 6,890 ppm zinc, as much as 5,288 ppm lead, 1,987 ppm cobalt, 110 to 3,939 ppm arsenic (as much as 155,000 ppm arsenic), and 500 to 1,000 ppm phosphorus.

The main copper, lead and zinc mineralization is contained within highly fractured siliceous and limonitized rocks, which contain thin zones of pyrite and occasional galena. In the oxidized areas, malachite and azurite are present along highly fractured zones parallel to schistosity. The entire mineralized copper zone was mapped by Kafarskiy and others (1972) to extend between 4 and 5 km and was measured between 300 and 400 m thick. The mineralized zone was outlined as four individual areas of intensive mineralization that are from 20 to 50 m long along the fault zone. An interpretation and mapping of ASTER imagery by Sabins and Ellis (2010a) produced a geologic map of the main mineralized zone of the Balkhab copper prospect, and this zone closely matches the reconnaissance geologic map of Kafarskiy and others (1972). Further interpretation and analysis have yielded an "envelope" around the mapped mineralized bodies and metavolcanic rocks that indicates a gently southwest-plunging isoclinal fold as indicated in figure 4A–7. The "envelope" also contains significant zones of iron and clay alteration (fig. 4A–7*b*, Sabins and Ellis, 2010a).

The fractured and mineralized zones at the Balkhab copper prospect lie unconformably below horizontal Early Cretaceous and Late Triassic sedimentary and volcanic rocks (fig 4A–8*a*,*b*). These mineralized zones are fractured, sheared, and silicified and have a pronounced schistosity. The zones are strongly stained by iron oxide minerals and contain quartz, malachite, and azurite (figs. 4A–9*d* and 4A–10). Several mine excavations follow the oxide mineralized zones, especially when marked by malachite and azurite (fig 4A–9). Many of these workings are "glory holes," or open pit diggings, but several consist of shafts, tunnels, and galleries (fig. 4A–9).

A number of malachite-stained outcrops strike across the hillside for hundreds of meters (fig. 4A–10). Iron staining also is prevalent in some of the outcrops and underground workings (fig. 4A–11). The size of a small mineralized zone, according to Kafarskiy and others (1972), is 0.5 to 2.5 m thick and 180 to 200 m long. Large mineralized zones are about 150 to 800 m long (figs. 4A–7, 4A–10, and 4A–11). The content of copper in the mineralized zones, based on the spectral results, is 0.3 to 0.7 wt. % copper (Kafarskiy and others, 1972; Abdullah and others, 1977). The mineralized zones were sampled by grid sampling (table 4A–1) and by trenching by Kafarskiy and others (1972), and two different methods were used and compared (table 4A–2). Based on a combination of grid and trench sampling and other sampling, the average content of copper in these zones was reported by Kafarskiy and others (1972) to be 0.5 wt. % copper, with between 0.02 and 0.07 wt. % zinc, by spectral analysis, whereas chemical analysis showed the average content of copper to be 0.57 wt. % copper and 0.07 wt. % zinc with traces of tin and arsenic (tables 4A–1 and 4A–2). Kafarskiy and others (1972) recommended detailed geologic studies as well as geophysical studies and reconnaissance drilling.

Table 4A–1. The results for spectral and chemical analysis of grid sampling in the main Balkhab copper mineralized area.

[Data are from Kafarskiy and others (1972). Cu, copper; Zn, zinc; wt. %, weight percent]

Rank	Sample no.	Description	Spectral analysis, in wt. %		Chemical analysis, in wt. %	
			Cu	Zn	Cu	Zn
1	1516	crushed schist	0.02	0	0	0
2	1516–1	quartz	0.03	0	0	0
3	1516–4	silicified schist	0	0.02	0	0
4	1516–8	silicified schist	0.5	0.03	0.56	0
5	1517	silicified schist	0.7	0.03	0.51	0
6	1517–1	malachite and limonite	0.5	0.03	0.56	0
7	1517–2	malachite and limonite	0.7	0.03	0.6	0
8	1517–3	malachite and limonite	1	0.07	0.71	0
9	1517–4	quartz	0.3	0	0.25	0
10	1517–6	dacite	0.02	0	0	0
11	1518	dacite	0.02	0	0	0
12	1518–1	schist	0.5	0.03	0.61	0
13	1518–4	dacite	0.03	0.03	0	0
14	1518–5	schist	0.02	0	0	0
15	1518–7	schist	0.03	0	0	0
16	1517–7	slag	1	0	1.66	0.12
17	1518–2	schist	0	0	0	0.07

Table 4A–2. The results of spectral and chemical analysis of trench sampling in the mineralized zones of the Balkhab copper prospect.

[Data are from Kafarskiy and others (1972). Cu, copper; Pb, lead; wt. %, weight percent]

Rank	Sample no.	Spectral analysis, in wt. %		Chemical analysis, in wt. % Cu
		Cu	Pb	
1	1125–1	0.5	0	0.34
2	1125–2	0.3	0	0.31
3	1125–3	0.7	0	0.83
4	1125–4	0.3	0	0.19
5	1125–5	1	0	1.34
6	1125–6	1	0	0.98
7	1125–7	1	0	0
8	1125–8	0.5	0	0
9	1125–9	1	0	0
10	1125–10	0.7	0	0.23
11	1125–11	0.3	0	0.3
12	1125–13	0.07	0	0
13	1125–14	0.1	0.03	0

4A.7 Remote-Sensed Anomalies

The Balkhab copper AOI is delineated to encompass favorable Paleozoic stratigraphy for VMS deposits exposed in the Balkh River Canyon (fig. 4A–12). Mapping of ASTER and hyperspectral images has identified a number of areas that have anomalous signatures of iron and clay minerals. These areas contain anomalous zones that have similarities to the main Balkhab copper prospect area. Sabins and Ellis (2010a) used a “mask” of the upper contact of the deformed Paleozoic rocks with the overlying horizontal Mesozoic rocks in order to map only the underlying potential host rocks for the copper deposits of the Balkhab type (fig. 4A–12). Their study resulted in the identification of seven anomalous areas within the Balkhab copper AOI and its subarea (fig. 4A–12); the first anomalous area is the main Balkhab copper prospect. Each anomalous area will require extensive field mapping and sampling to determine if there is potential for additional copper mineralization. The three most extensive anomalous zones are 2, 3, and 5 (fig. 4A–12), which are briefly described below.

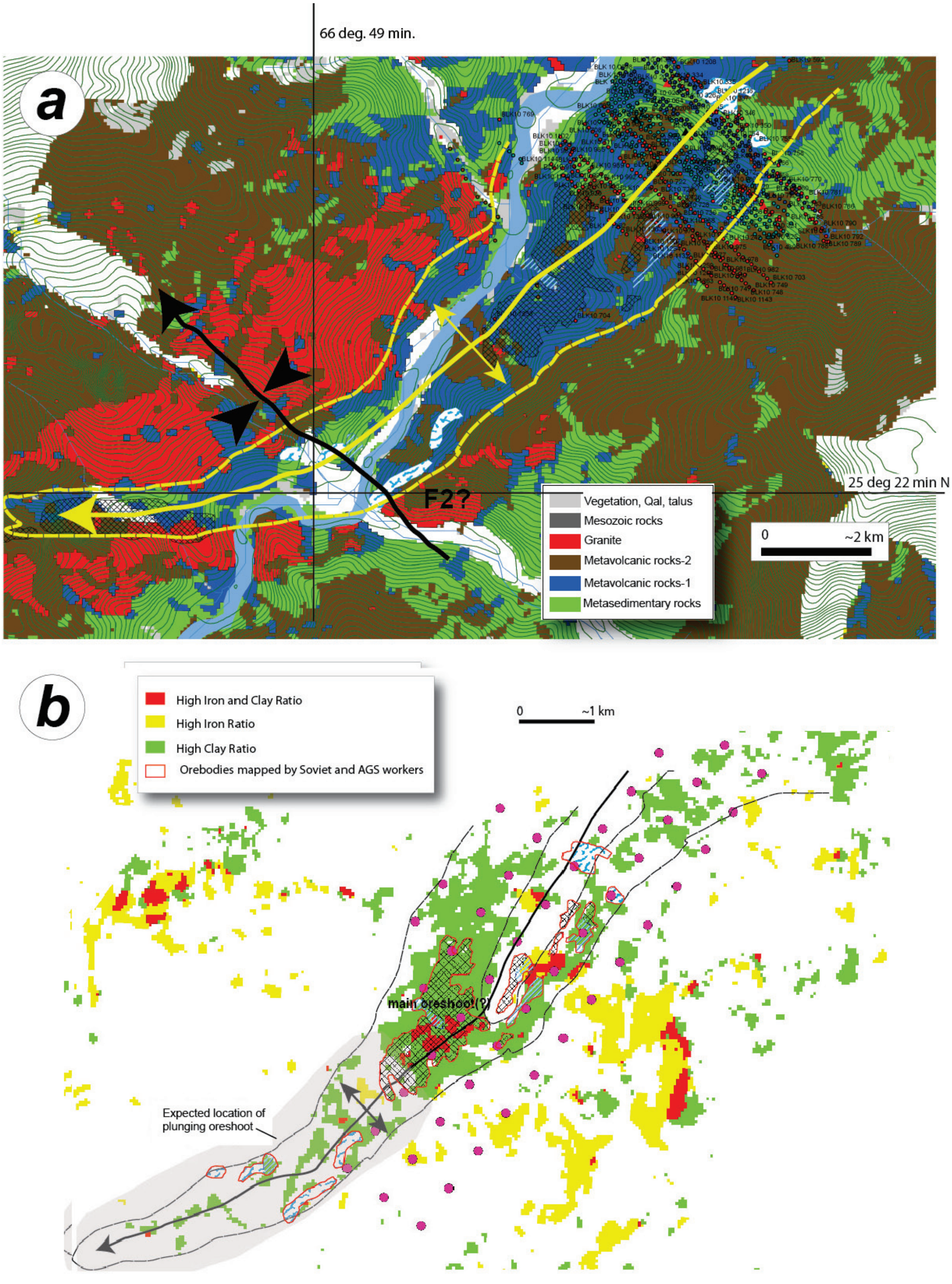

Figure 4A–7. Structural geology of the main Balkhab copper prospect mineralized zone. (*a*) "Geologic Map" constructed by Sabins and Ellis (2010a) from ASTER mapping of different rock units. Yellow outline is the enclosing area of the known, mapped, or suspected outcropping ore zone mapped by Kafarskiy and others (1972), interpreted here as a refolded southwest-plunging fold. (*b*) Hyperspectral anomalies located by Sabins and Ellis (2010a) plotted with ore outlines from Kafarskiy and others (1972) and "envelope" of folding interpreted from geologic map (*a)* above. Red and blue circles in north part of (*b*) are sample points from AGS 50-m^2 sampling grid.

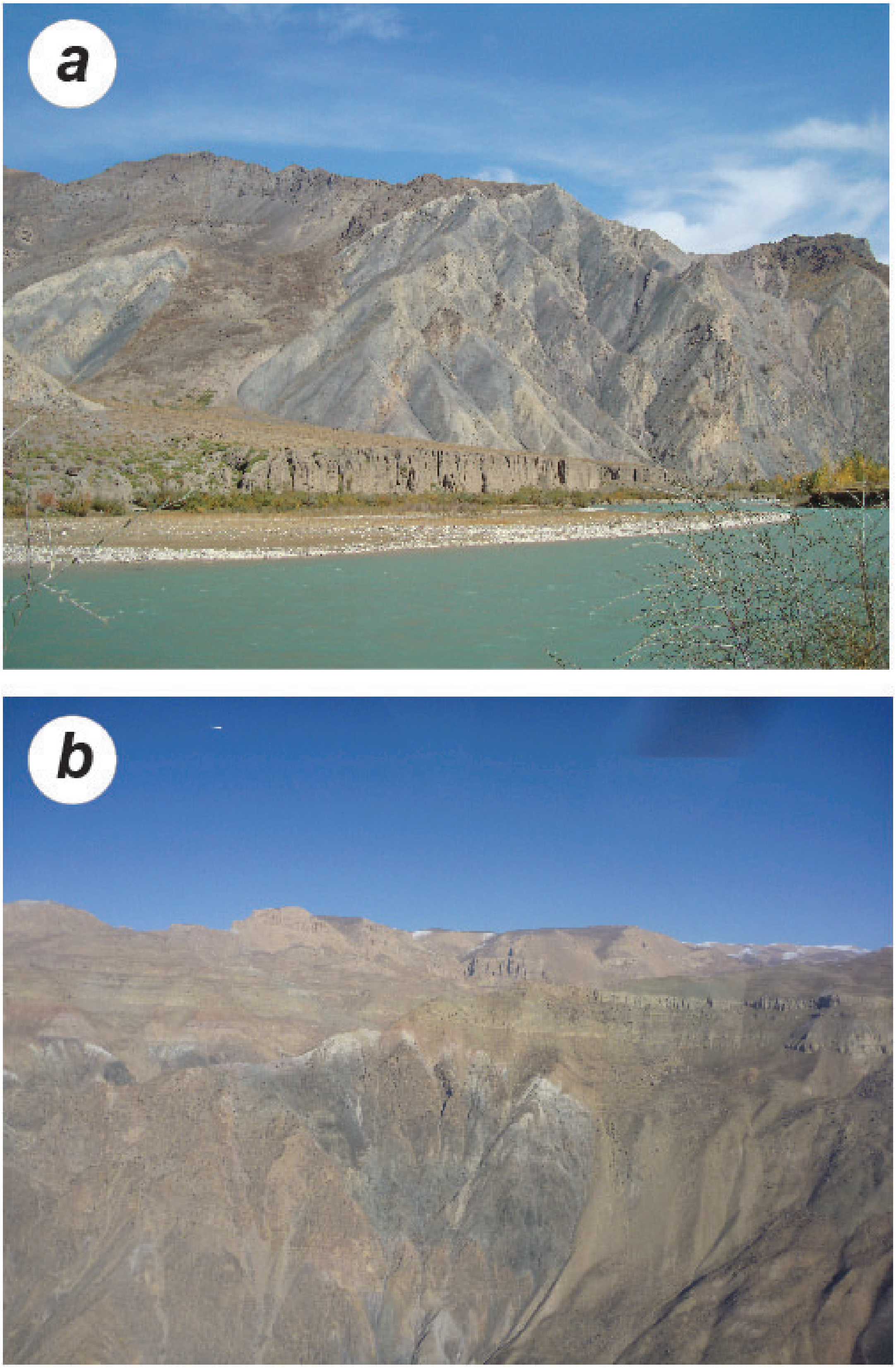

Figure 4A–8. Photographs of the Balkhab copper prospect area, looking south. (*a*) View from the river showing gray mineralized rocks with brown cap rocks and colluvial cover.(*b*) View from the air showing gray mineralized zone capped by horizontal Mesozoic strata and also covered by colluvial rocks (on right side) and footwall Paleozoic strata (on left side). Photograph (*a*) by Afghanistan Geological Survey, and (*b*) by Robert D. Tucker, U.S. Geological Survey.

Anomalous zone 2 lies to the northeast of the Balkhab copper prospect in the Balkhab copper prospect subarea (fig. 4A–12) and consists of three main zones of extensive iron, secondary iron minerals plus clays, and other alteration minerals and clay; the largest is about 1. 5 km long by 1 km wide (zone *X* on fig 4A–13). The other two zones (zones *Z* and *Y*) are about 1,000 by 200 m and 500 by 500 m in size. The anomalous area lies on the south side of the Balkh River and may be the northeastern extension of the Balkhab copper prospect (figs 4A–13 and 4A–14).

Anomalous area 3 lies to the southwest of the Balkhab copper prospect in the Balkhab prospect subarea and consists of a northeast-striking, 3-km-long, 1-km-wide zone of secondary iron minerals plus clays and other alteration minerals that are mainly on a north-facing hillside but also traverse across a valley to the adjacent north-facing hillside (figs. 4A–12 and 4A–14). Anomalous zone 3 may be a folded or faulted extension of the Balkhab copper prospect mineralized system (fig. 4A–12).

Anomalous zone 5 lies 25 km west of the Balkhab and may represent the northeastern part of a mineralized system that extends to the southwest into anomalous zone 6 and 7 (fig. 4A–12). Anomalous area 5 is boomerang-shaped and consists of two large areas that are approximately 2 km long and 1 km wide; each occupies the hillsides and is separated by a drainage. It is likely that the mineralized zone is continuous across the drainage (fig. 4A–15). This analysis (Sabins and Ellis, 2010a) suggests that there are possibly three mineralized systems, the first along anomalous areas 1, 2, and 3, the second along anomalous areas 5, 6, and 7, and a third at anomalous zone 4 (fig. 4A–12).

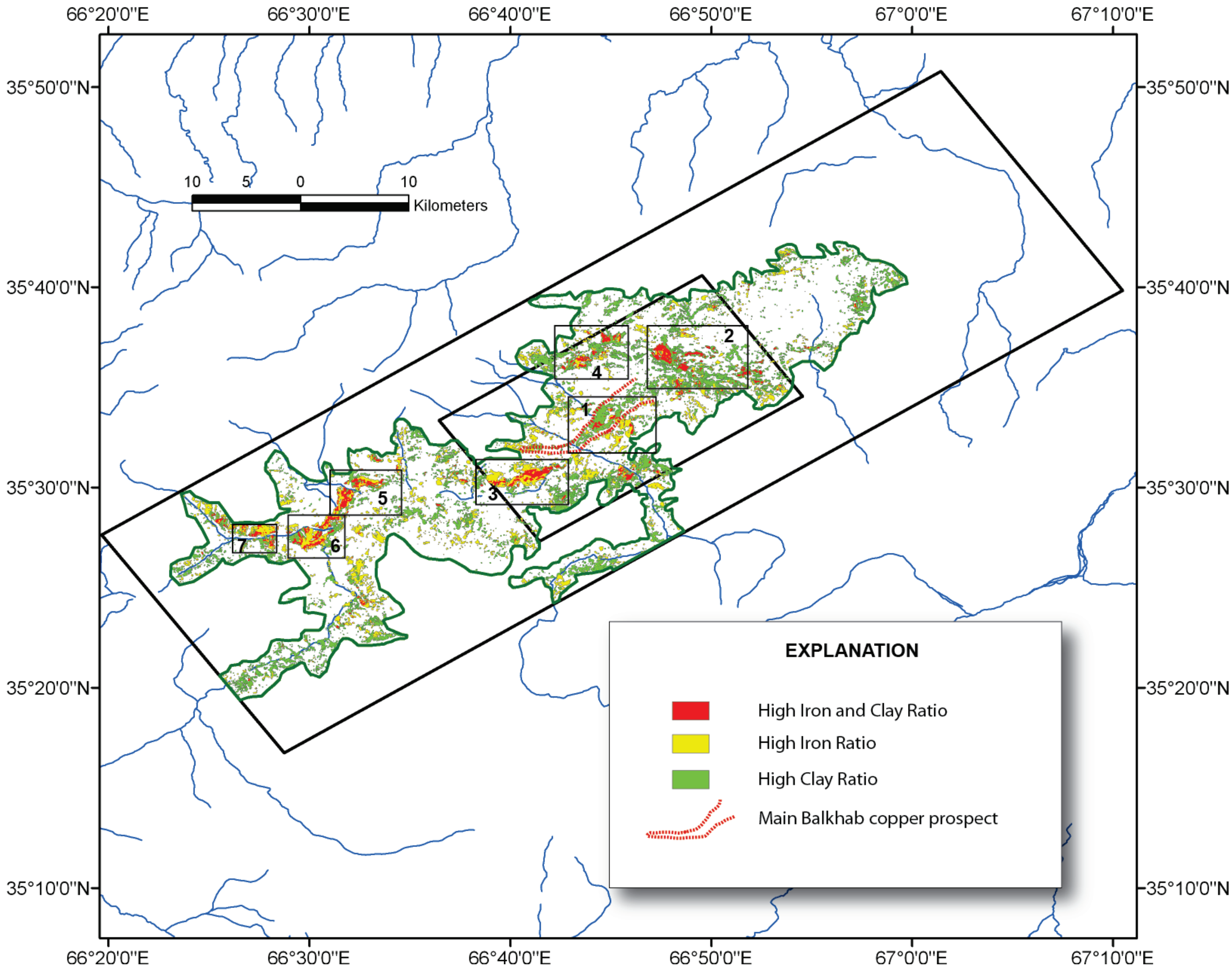

Figure 4A–12. Anomalous zones determined from Landsat Thematic Mapper alteration patterns in the Balkhab copper area of interest and the Balkhab copper prospect subarea. Seven anomalous areas were identified by Sabins and Ellis (2010a) and are numbered in the rectangles.

4A.8 Metallurgical Slag

Slag piles are present in the Balkhab copper prospect area, but no current distribution or age of the slag piles is known. Figure 4–A16 shows a slag pile in the main Balkhab River valley and a closeup of a hand specimen-scale slag piece. The slag is made up of fayalite and spinel (confirmed by X-ray diffraction) but includes relatively abundant circular droplets of a copper-iron-sukfur phase (fig. 4A–17). In addition, the spinels, typically euhedral, are marked by titanium-rich rims. Melt textures are well developed throughout. Quartz is also present, as is an albite-equivalent phase. Traces of molybdenum and bismuth as sulfide phases also are present (fig. 4A–13). The chemical analysis of slag showed the content of copper to be 1.68 wt. % and zinc to be 0.12 wt. % (Kafarskiy and others (1972).

A scanning electron microscope (SEM) study was conducted on some of the slag specimens by Theodore (2010). The samples were vacuum impregnated using blue-stained epoxy prior to polishing in order to preserve delicate intergrown textural relations. All SEM images depicted (fig. 4A–17) are in a back-scattered mode, wherein minerals with higher effective atomic number are brighter on the resulting electron micrographs. On the electron micrographs, the numbers along the bottom are, from left to right, magnification, bar scale in microns, kilovolts used, and working distance (in millimeters) (fig. 4A–17).

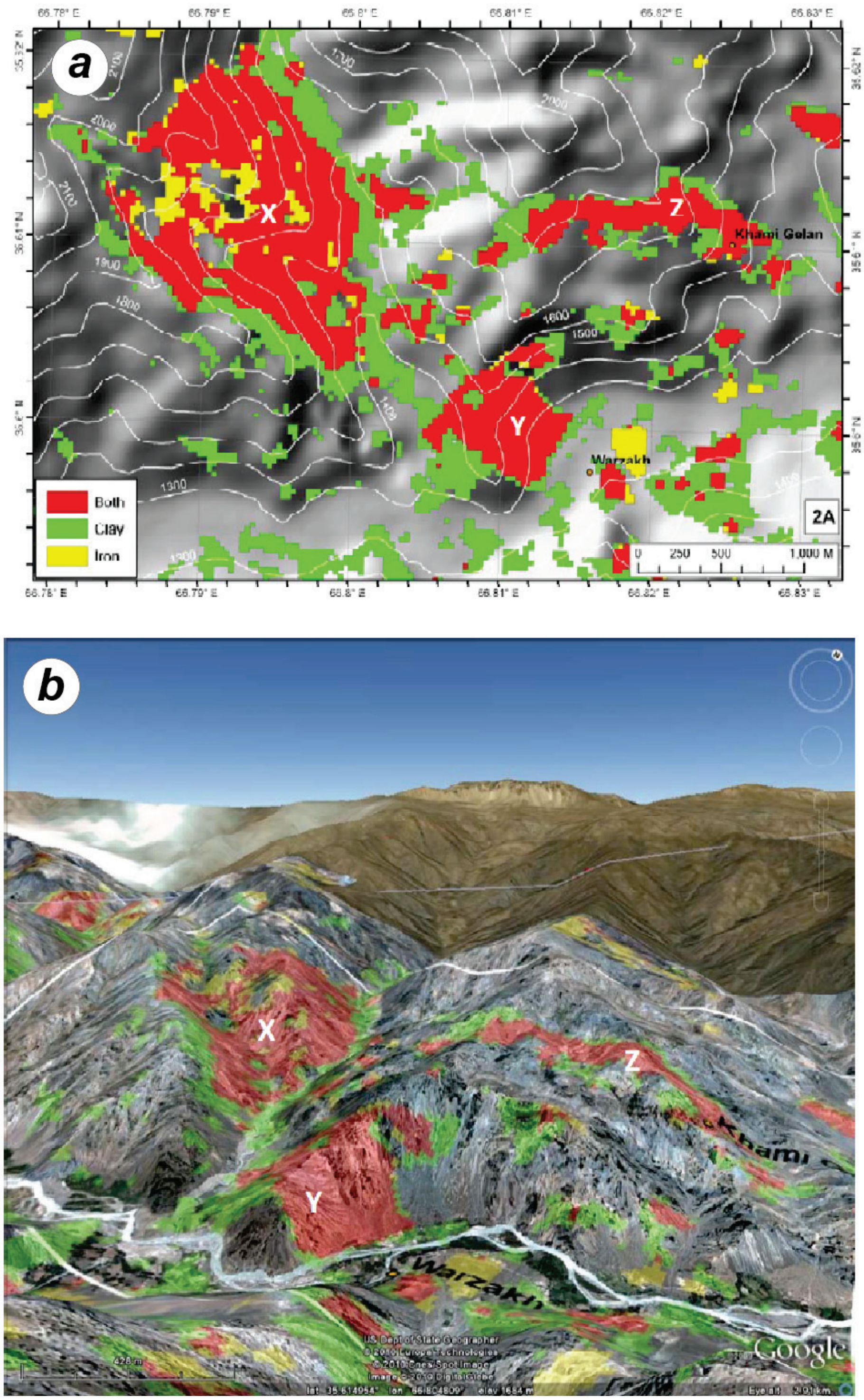

Figure 4A–13. Images of Balkhab anomalous zone 2, Balkhab copper area of interest, Sar-i-Pul Province. (*a*) Landsat Thematic Mapper alteration pattern on digital elevation model and contour map, Balkhab anomalous area 2. (*b*) Alteration patterns draped on IKONOS image. Green means secondary iron minerals plus clays and other alteration minerals (disregard green pattern in drainages, which is vegetation.) Red means iron plus secondary iron minerals plus clays and other alteration minerals. View is toward northwest from south of Balkhab River. West is toward the left. Vertical exaggeration is 1.5×. White outline is anomalous area 2 outline from figure 4A–12 (from Sabins and Ellis, 2010a). Image copyright [2010,2011] Google Maps. X, Y, and Z are target areas of Sabins and Ellis (2010a).

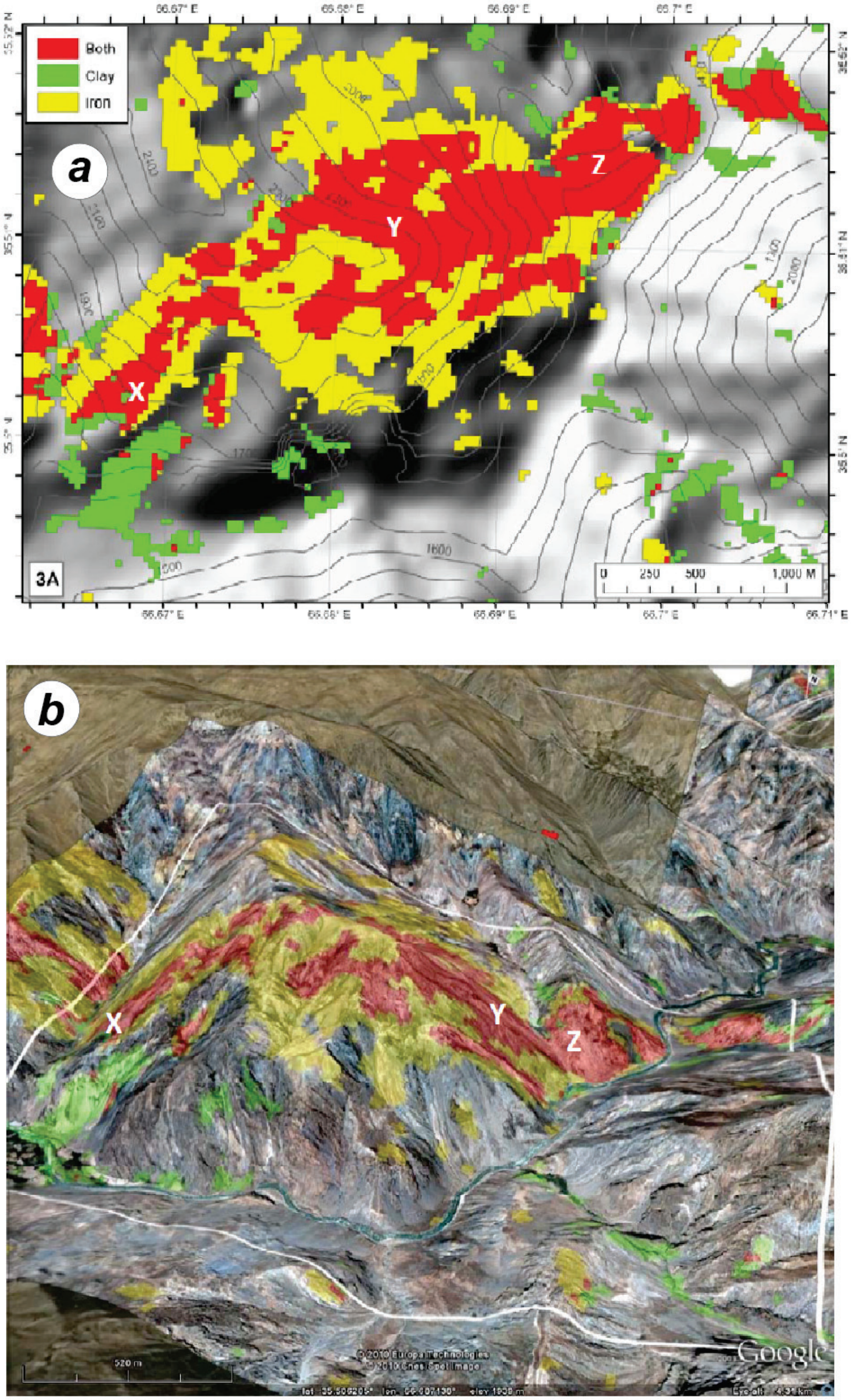

Figure 4A–14. Images of Balkhab anomalous zone 3, Balkhab copper area of interest, Sar-i-Pul Province. (*a*) Landsat Thematic Mapper alteration pattern on digital elevation model and contour map. (*b*) Alteration patterns draped on IKONOS image. Green means secondary iron minerals plus clays and other alteration minerals (disregard green pattern in drainages, which is vegetation.) Red means iron plus secondary iron minerals plus clays and other alteration minerals. View is toward northwest from south of Balkhab River. West is toward the left. Vertical exaggeration is 1.5X. White outline is anomalous area 3 outline from figure 4A–12 (from Sabins and Ellis, 2010a). Image copyright [2010,2011] Google Maps. X, Y, and Z are target areas of Sabins and Ellis (2010a).

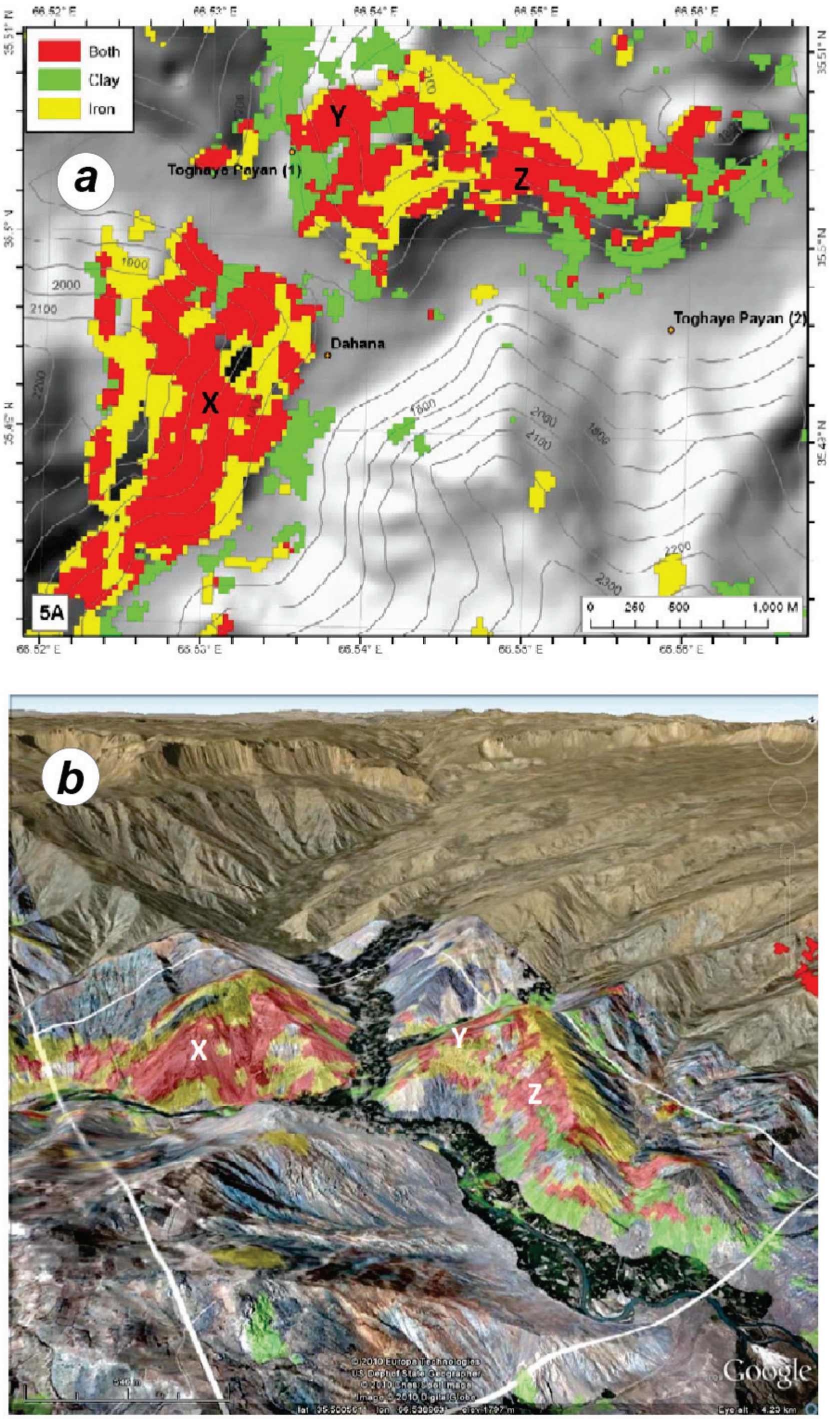

Figure 4A–15. Images of Balkhab anomalous zone 5, Balkhab copper area of interest, Sar-i-Pul Province. (*a*) Landsat Thematic Mapper alteration pattern on digital elevation model and contour map. (*b*) Alteration patterns draped on IKONOS image. Green is secondary iron minerals plus clays and other alteration minerals. Yellow is iron. Red is iron plus secondary iron minerals plus clays and other alteration minerals. View is toward the northwest along the Balkhab River. Vertical exaggeration is 1.5X. White outline is anomalous area 5 outline from figure 4A–12 (from Sabins and Ellis, 2010a).). Image copyright [2010,2011] Google Maps. X, Y, and Z are target areas of Sabins and Ellis (2010a).

4A.9 Coal Resources

Coal in the eastern parts of the Balkhab copper AOI is in Mesozoic rocks of the central Afghanistan platform. Aside from landslides and minor faults, the Balkhab coal measures are undeformed and lack the regional metamorphism of other Afghanistan coals. The coal is located in rugged terrane with limited access (Mikhailov, 1967; U.S. Geological Survey, 2005; Hare and others, 2008; Sabins and Ellis, 2010b).

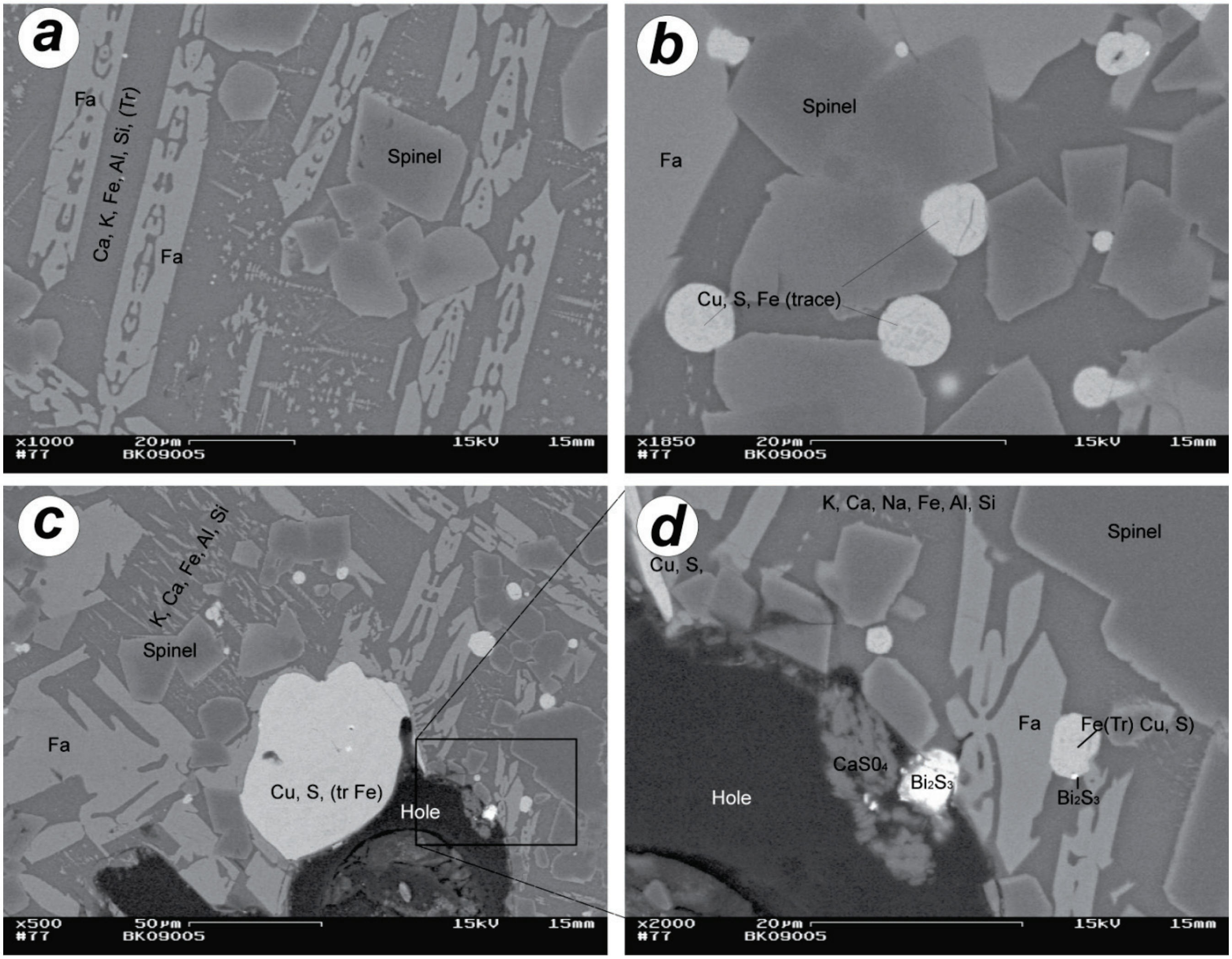

Figure 4A–17. Scanning electron microscope (SEM) photographs of Balkhab slag samples. (a) Sample BK09005 showing blades of oriented fayalite (Fa) and spinel crystals in a matrix of calcium, potassium, iron, aluminum, and silica glass. (b) Closeup of dots of copper, iron, and sulfur with spinel and fayalite crystals. (c) Large grains of copper and sulfur with trace iron along with fayalite, and spinel and potassium, calcium, iron, aluminum, silicon matrix. (d) Closeup of part of (c) showing bismuthanite inclusions and clumps. SEM photographs courtesy of Theodore (2010).

The coal measures are overlain by massive, resistant limestone that forms cliffs throughout the region (fig. 4A–18). As shown on figure 4A–19, the top of the coal measures closely follow the base of map unit KPg_1ld (Doebrich and others, 2006), composed largely of Late Cretaceous/Paleocene carbonate strata. The map unit is described as "Resistant Carbonate Beds." The base of the coal measure is within the map unit K_2ssl composed of Late Cretaceous clastic sedimentary rocks. The Cretaceous age for the Balkhab coal measures differs from the Jurassic age attributed to coal in most of the north Afghanistan platform by the U.S. Geological Survey (2005). Two possible explanations are

1. The Late Cretaceous age assignment of unit K2ssl on the geologic map is incorrect and the map unit is actually Jurassic in age.
2. The Balkhab coal is of Cretaceous rather than Jurassic age.

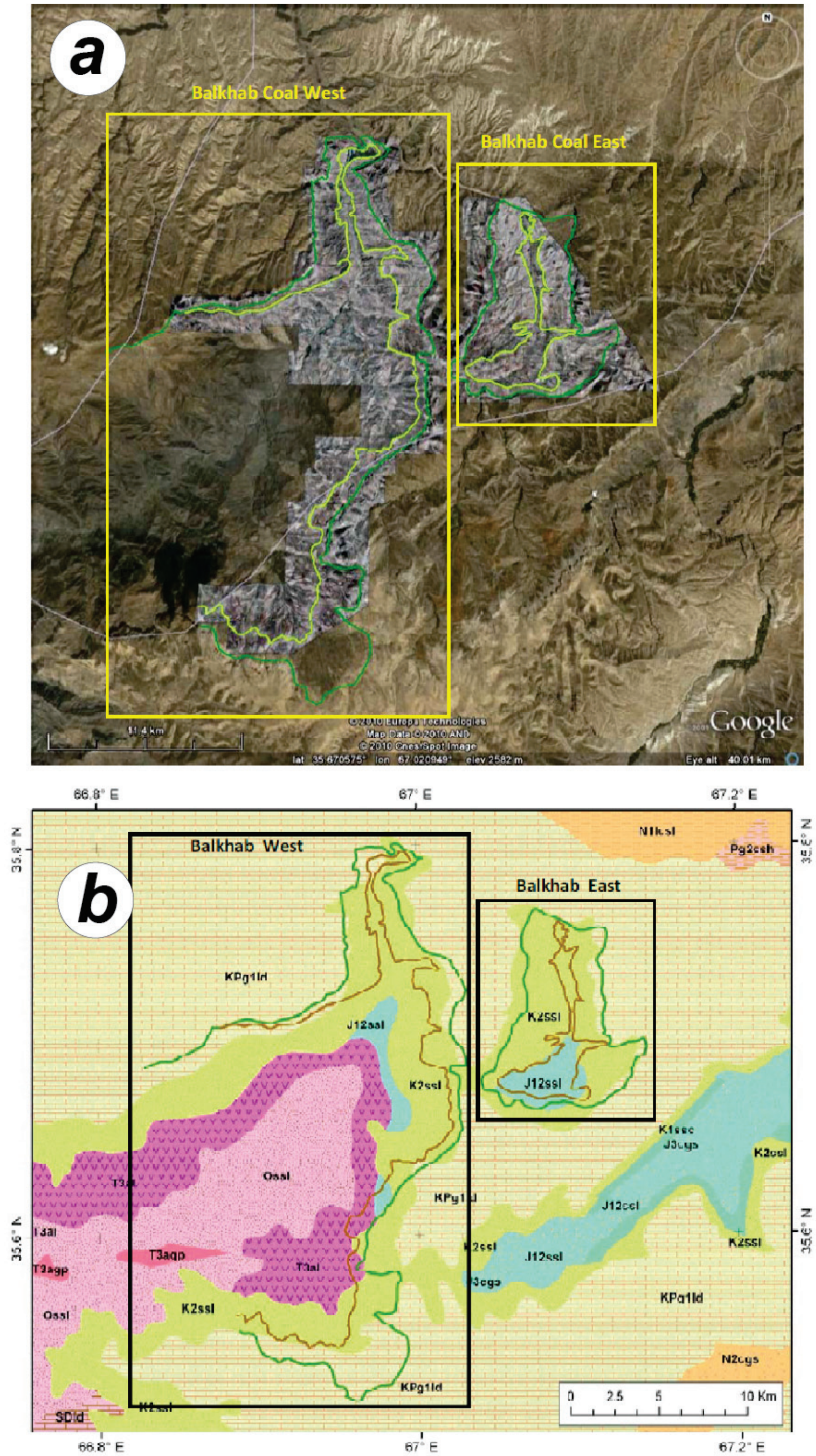

Figure 4A–18. Maps of the northeast part of Balkhab copper area of interest showing location of Balkhab East and Balkhab West coal areas. (*a*) Google map image. Dark green line is the top of coal measures. Light green line is the base of coal measures. Image copyright [2010,2011] Google Maps. (*b*) Geologic map of Balkhab East and Balkhab West coal measures. Dark green line is the top of coal measures. Brown line is the base of coal measures. Explanation for geologic map: KPg1ld, Late Cretaceous/Paleocene; K2ssl, Late Cretaceous; J12ssl, Early-Middle Jurassic; T3al, Late Triassic-Rhaetian; Ossl, Ordovician. Reproduced from Sabins and Ellis (2010b), after Doebrich and others (2006)

The coal beds are nonresistant, fine-grained sedimentary rocks that weather to slopes with a basal thin, light-gray, resistant bed (fig. 4A–20). The coal beds are underlain by dark-gray shale that is, in turn, underlain by a conspicuous nonresistant red unit that may correlate with a "Red Grit" unit that is spatially associated with coal deposits elsewhere in northern Afghanistan. The red beds are underlain by dark-gray shale. These stratigraphic relationships are consistent throughout the area.

There is one large-scale coal mining operation in the Balkhab copper AOI where a surface long-wall mine (540 meters long) has been opened (fig. 4A–20). The lack of a spoil dump suggests that that the mine has just been opened or that operations are suspended. Coal beds commonly ignite and burn both along strike and down dip. Lightning strikes, brush fires, and spontaneous combustion are possible natural causes. Campfires and poorly maintained spoil piles are man's contribution to coal fires. The heat oxidizes iron minerals in the adjacent sediments and causes conspicuous red coloration. The heat fuses the poorly consolidated sand and clay into hard, brick-like rubble called "clinkers."

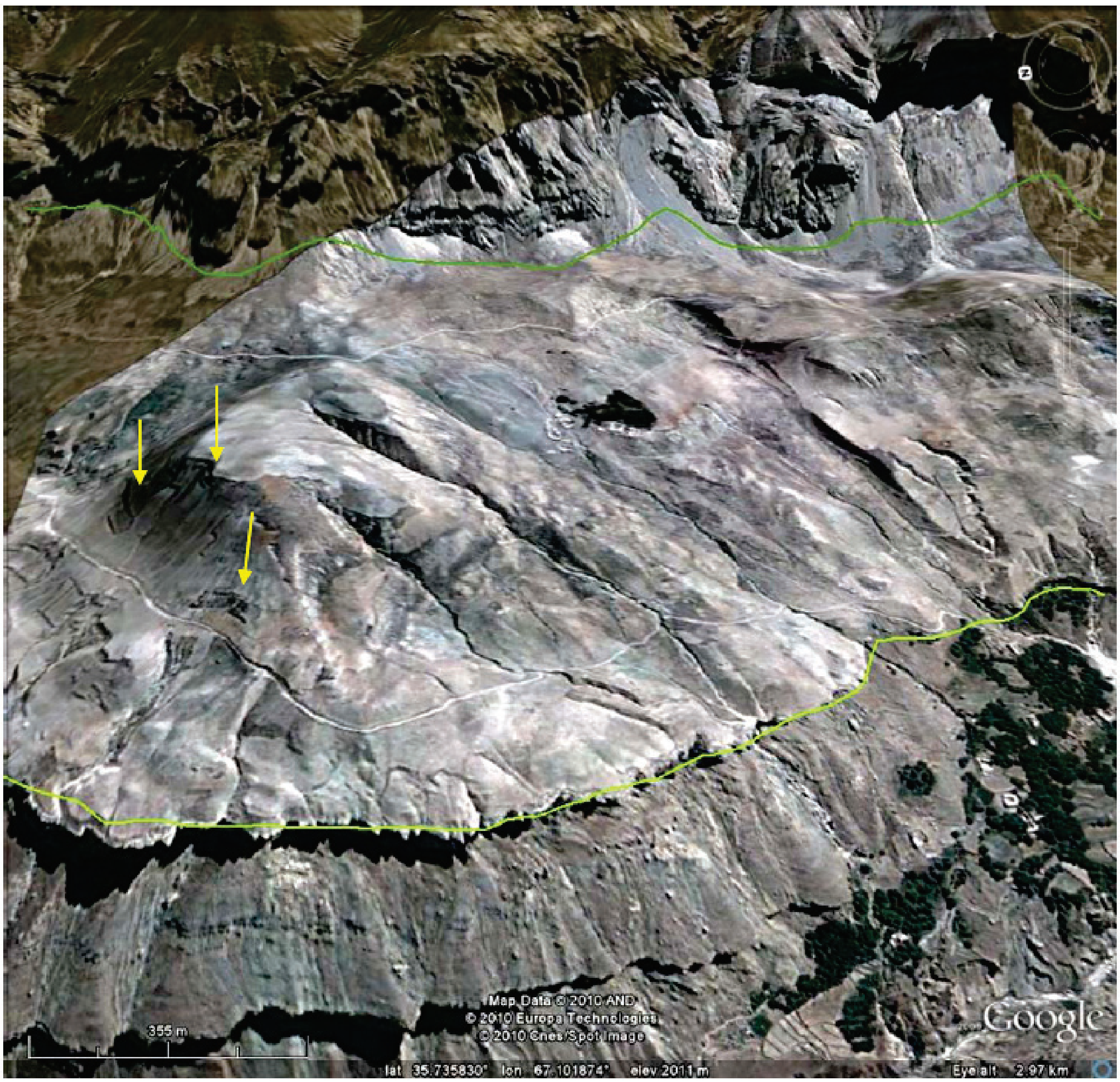

Figure 4A–19. Balkhab East Coal subarea 5, looking east. Dark green is top of coal measures. Light green is base of coal measures. Yellow arrows are coal beds. Subarea 5 has only limited evidence of coal measures or mining activity. Reproduced from Sabins and Ellis (2010b). Image copyright [2010,2011] Google Maps.

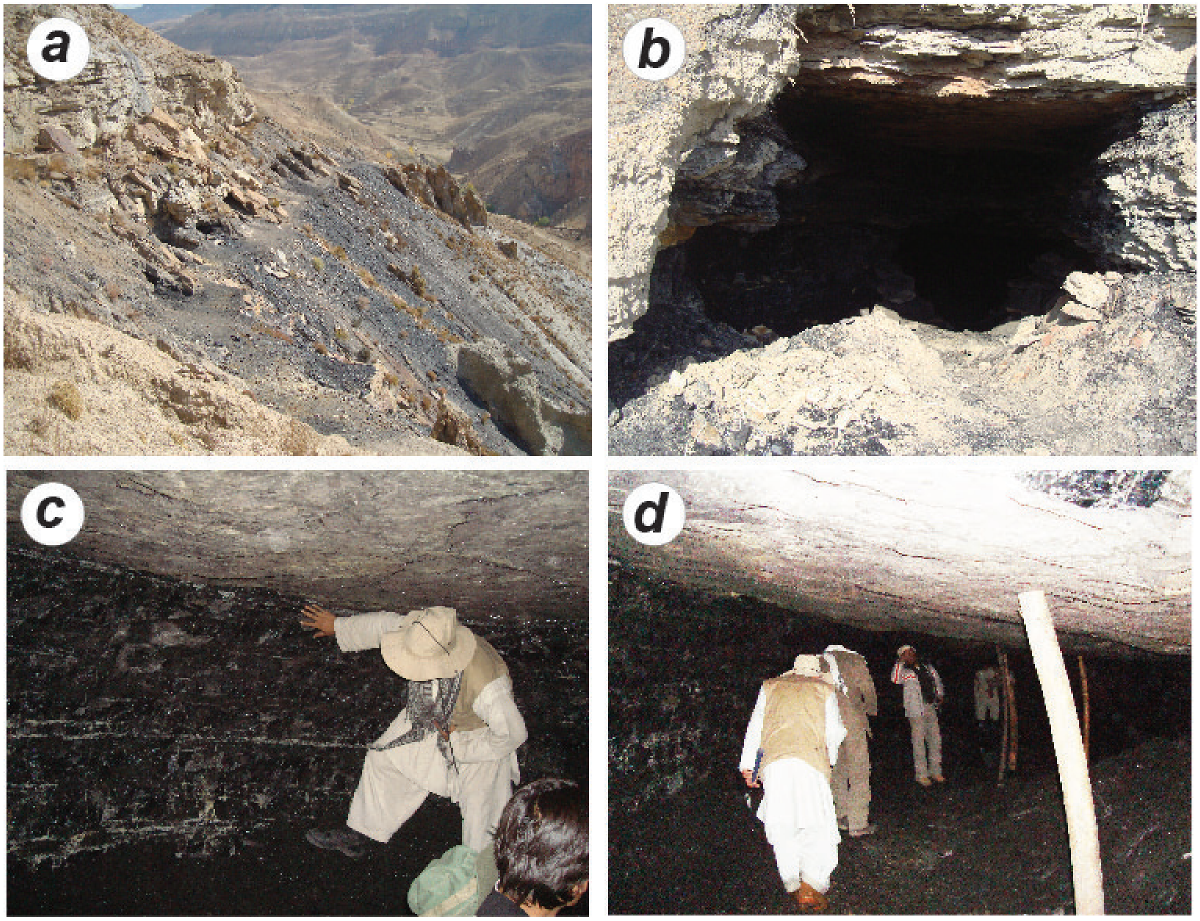

Figure 4A–20. Photographs of coal deposit in the Balkhab copper area of interest. (*a*) View of outcrop of coal seam and small adits. (*b*) Closeup of one of the adits. (*c*) A 0.5-meter-high coal seam in underground workings. (*d*) Underground excavation with supported hanging wall. Photographs by the Afghanistan Geological Survey.

4A.10 Summary of Potential

The Balkhab copper area of interest shows considerable potential for economic copper deposits. The main area of known mineralization is the Balkhab copper prospect, which contains outcropping copper-mineralized rock, extensive oxide copper zones, previous mining activity, and promising extensions down dip and along strike to the northeast and southwest. Additional mineralized zones, perhaps the size of the Balkhab copper prospect, may also exist in the Balkhab copper AOI to the southwest in anomalous altered areas 5, 6, and 7 (fig. 4A–12). These copper deposits plus various other copper showings throughout the Paleozoic rocks, along with the abundant water supply, and the Balkhab coal deposits in the northeast part of the Balkhab copper AOI, and elsewhere in the Mesozoic rocks, make the Balkhab copper AOI a promising area for mineral exploitation. The oxide copper ores are abundant and may be amenable to hydrometallurgy.

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