Chapter 4C. Geohydrologic Summary of the Balkhab Copper Area of Interest

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4C.1 Introduction

This chapter describes the geohydrology of the Balkhab volcanogenic massive sulfide (VMS) copper area of interest (AOI) in northern Afghanistan identified by Peters and others (2007). The AOI is located in the Balkhab district of the Sari Pul Province, the Kishindih district of Balkh Province, and the Dara-i-Suf district of Sam Angan Province in northern Afghanistan (fig. 4C–1*a*,*b*), and is centered about 130 km (kilometers) southwest of the city of Mazari Sharif and about 130 km northwest of the village of Bamyan. The Balkhab prospect subarea covers 321 km^2 (square kilometers) of the 1,858-km^2 AOI.

Water is needed not only to process mineral resources in Afghanistan, but also to supply existing communities and the associated community growth that may accompany a developing mining economy. Information on the climate, vegetation, topography, and demographics of the AOI is summarized to provide information on the seasonal availability of, and seasonal demands for, water. The geohydrology of the AOI is described through the use of maps of streams and irrigated areas, generalized geohydrology and topography, and well locations. The results of lineament analyses are presented to identify areas where the rock may be more fractured than in other areas, which may be an indicator of high relative water yield and storage in bedrock aquifers. The results of field reconnaissance work conducted in the AOI by U.S. Geological Survey (USGS) minerals teams in November 2009 are described.

Afghanistan's recent turbulent history has left many of the traditional archival institutions in ruins, and most water-resource and meteorological data-collection activities had stopped by 1980. Recently (2011), nongovernmental organizations (NGOs), foreign government agencies, and the Afghan government have begun water-resource investigations; however, these activities and the amount of data collected are limited. This report summarizes the satellite imagery and climatic, topographic, geologic, surface-water, and groundwater data available. Geohydrologic inferences are made on the basis of an integrated analysis of these data and an understanding of conditions in other areas of Afghanistan.

4C.2 Climate and Vegetation

Climate information for the Balkhab VMS copper AOI is based on data generated for the Afghanistan agricultural-meteorological (Agromet) project. Agromet was initiated by the U.S. Agency for International Development and the United Nations Food and Agriculture Organization in 2003 to establish data-collection stations and develop country-wide agrometeorological services. Scientists with the Agromet project are assisting the Afghan Government to collect and analyze agricultural and meteorological data as they relate to crop production, irrigation, water supply, energy, and aviation. The USGS assumed responsibility for the operation of the project in 2005; by the end of August 2010, 87 Agromet stations were recording precipitation data and other parameters. Additionally, the Agromet project receives data from 18 Afghanistan Meteorological Authority (AMA) weather stations. The Agromet project has developed a database that includes data collected at the Agromet stations over the past 6 years (2005–2011), data collected at the AMA weather stations, and historical data collected at weather stations from 1942 to 1993. Data collected as part of the Agromet project are compiled annually by water year (September through August) and are reported in the Afghanistan Agrometeorological

Seasonal Bulletin (Seasonal Bulletin) published by the Ministry of Agriculture, Irrigation, and Livestock. Unless otherwise specified, the Agromet data cited in this report are from the agricultural season that extends from 1 September, 2009, to 31 August, 2010.

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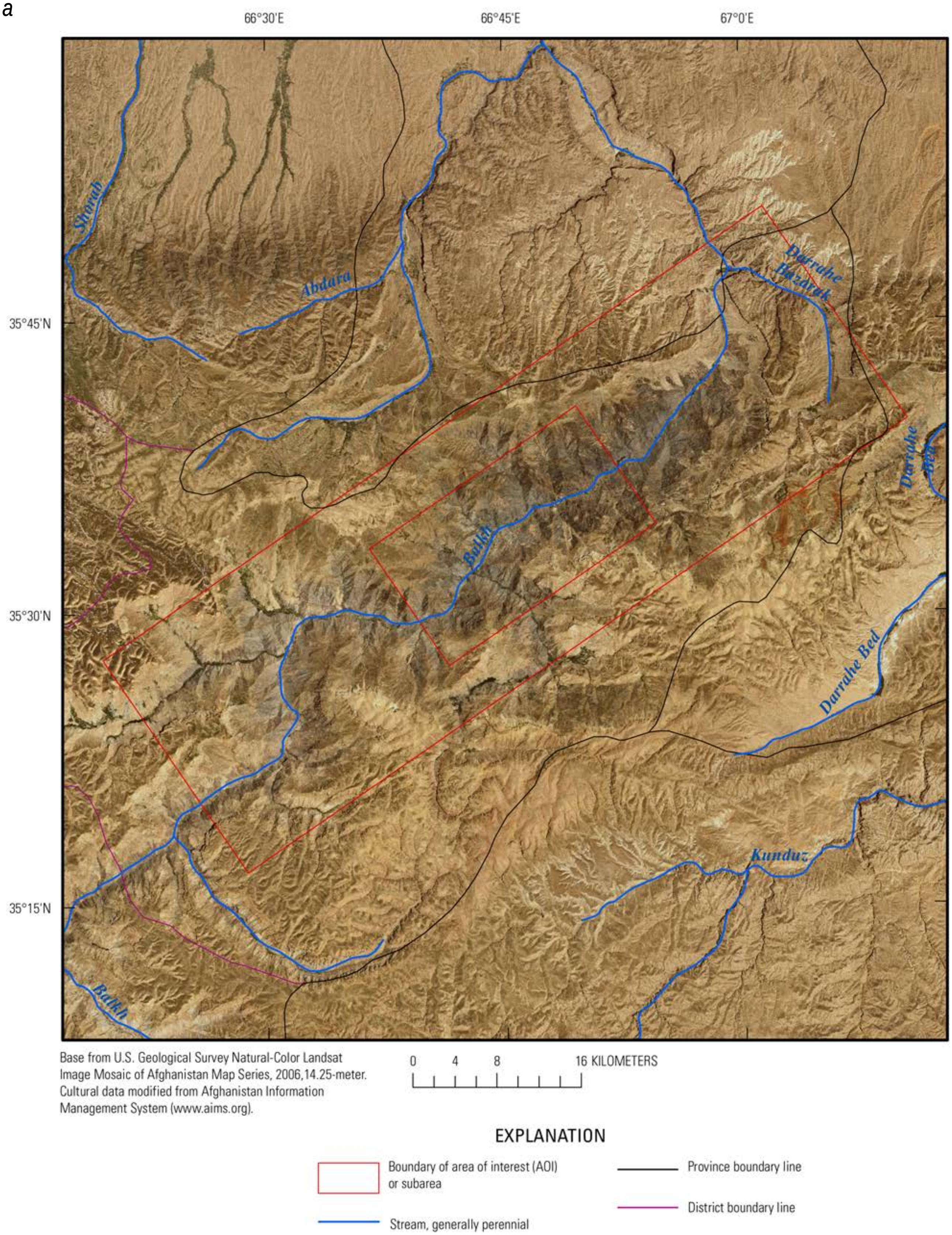

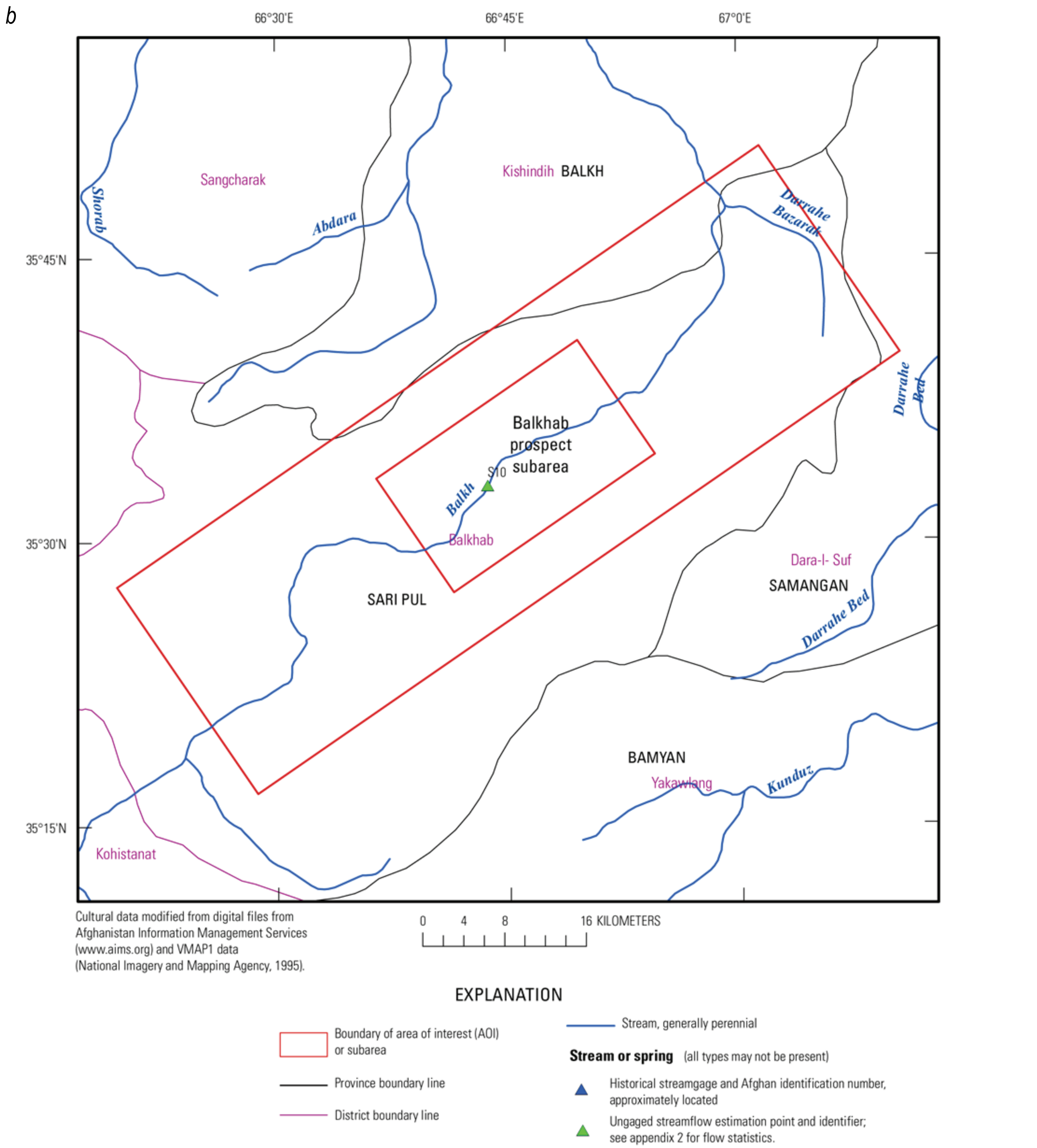

Figure 4C–1. *(a)* Landsat image showing the location of, and *(b)* place names, stream names, and streamgage station numbers in, the Balkhab volcanogenic massive sulfide copper area of interest in northern Afghanistan.

There are no Agromet stations within the AOI, but several stations encircle it. The closest station, the Yakawlang, is about 90 km south of the AOI. The AOI received 221 to 300 mm (millimeters) of precipitation for the 2009-2010 water year (Ministry of Agriculture, Irrigation, and Livestock, 2010, map 2); 61 to 80 mm of precipitation in February 2010, the month with the greatest rainfall (Ministry of Agriculture, Irrigation, and Livestock, 2010, map 3); and 19 to 23 mm of precipitation in October 2009, the month with the least rainfall (Ministry of Agriculture, Irrigation, and Livestock, map 4).

The elevation of the Yakawlang Agromet station is approximately 2,550 m (meters) above sea level (asl). The elevation of the AOI ranges from about 1,500 m asl in the northeast corner to more than 3,000 m asl in the western part. The Yakawlang station recorded 276 mm of precipitation during the 2009–2010 water year (Ministry of Agriculture, Irrigation, and Livestock, 2010). The maximum monthly total precipitation, 84 mm, occurred in February 2010. No precipitation was recorded at this station during October 2009 and 1 mm was recorded during July 2010.

The Bamyan (Bamian) Agromet station is approximately 100 km south-southeast of the center of the AOI at an elevation of about 3,200 m asl, and is the closest station to the AOI for which both water year 2009–2010 and long-term average (LTA) precipitation and temperature data are available (Ministry of Agriculture, Irrigation, and Livestock, 2010). These data are shown in table 4C-1.

Table 4C–1. Annual, long-term annual average, and long-term average minimum and maximum precipitation and temperature at the Bamyan Agrometeorological (Agromet) station.

[The station is about 100 kilometers south-southeast of the Balkhab volcanogenic massive sulfide copper area of interest, Afghanistan. AOI, area of interest; km, kilometers; m, meters; mm, millimeters; °C, degrees Celsius]

Agromet station	Distance from AOI center (km)	Elevation (m)	Precipitation				Temperature		
			2009–2010 annual (mm)	Long-term average[1]			Long-term average[1]		
				Annual (mm)	Monthly minimum (mm) and month	Monthly maximum (mm) and month	Minimum (°C) and month	Monthly mean (°C)	Maximum (°C) and month
Bamyan	100	3,200	207.4	142	0 August	34.3 April	–6.8 January	5.3	18.2 July

[1]Long-term averages are based on data from 1942 to 1993 and 2005 to 2010 as reported in the Afghanistan Agrometeorological Seasonal Bulletin (Ministry of Agriculture, Irrigation, and Livestock, 2010).

The Yakawlang Agromet station had a total of 21 reported snow days during the 2009–2010 water year, with the following distribution: November 2009, 1 day; December 2009, 6 days; January 2010, 4 days; February 2010, 9 days; and March 2010, 1 day. The total snow depth at the Yakawlang Agromet station is not reported. The snow-depth map for 17 January, 2010 (Ministry of Agriculture, Irrigation, and Livestock, 2010, map 6), indicates a snow depth of 30 to 100 cm (centimeters) in the AOI, but this measurement was made before the snowfall in February.

The average monthly high temperature at the Bamyan Agromet station for the 2009–2010 water year was 19.5°C (degrees Celsius) in July 2010 and the average monthly low temperature was -3.7°C in December 2009; (Ministry of Agriculture, Irrigation, and Livestock, 2010). The maximum monthly temperatures for the AOI during the 2009–2010 water year ranged from 28.0°C to 35.5°C (Ministry of Agriculture, Irrigation, and Livestock, 2010, map 12).

The “Potential Natural Vegetation” described in Breckle (2007) is the vegetation cover that would be present if it had not been modified by human activity. Today, as a result of continued exploitation such as grazing, farming, and deforestation, much of the original natural vegetation is found in only a few remote areas of Afghanistan. The destruction of the natural vegetation has resulted in the degradation and erosion of the soil cover in some areas. Many areas exhibit signs of long-lasting desertification caused by human activity.

The vegetation in the AOI is varied and is controlled primarily by elevation. Other factors that affect vegetation type are precipitation, soil type and depth, slope aspect, and human activity. At lower elevations in the stream valleys, the natural vegetation is azonal riverine (Breckle, 2007). Azonal riverine vegetation likely was present in the stream valleys, but the trees have been harvested for fuel and building materials. Most land suitable for farming has been plowed and planted, especially along major stream valleys and some of the ephemeral tributary stream valleys. Irrigated fields are present in many of the valleys in the AOI (fig. 4C–2). The upper elevations are dominated by alpine vegetation and are classified by Breckle (2007) as “thorny cushions, subalpine and alpine deserts and meadows.” The vegetation in the AOI is sparse in except in some irrigated areas near rivers (fig. 4C–2). Much of the

AOI had little vegetation during the field reconnaissance in November 2009, with the exception of some valley bottoms or near streambeds where groundwater may be near the land surface (fig. 4C–3).

4C.3 Demographics

There are few settlements in the Balkhab VMS copper AOI. Most are located along the Balkh River, or in the valley bottoms along tributary streams to the Balkh River (figs. 4C–1*a*,*b* and 4C–2), and may consist of only a few structures. The population density of the AOI as mapped by LandScan (Oak Ridge National Laboratory, 2010) indicates a dispersed and sparse population (fig. 4C–4). The population density shown in figure 4C–3 has a pixel resolution of about 1 km^2 (Oak Ridge National Laboratory, 2010). The population density in most of the AOI is less than 50/km^2, and is greater than 2,500/km^2 in only about 5 pixels.

The AOI is in a relatively deep (more than 2,000 m) gorge where the steep-walled Balkh River valley (Bohannon, 2005) isolates the villages in the area. The most populated villages are in the Abdara River valley (figs. 4C–1*b* and 4C–4), about 30 km north of the AOI. The nearest large settlement is the city of Maza-e Sherif, about 130 km to the north. There are very few roads within the AOI, and the roads on the province map of Sari Pul Province are shown as “tracks” (Afghanistan Information Management Service, 2003).

4C.4 Topography

The topography of the Balkhab VMS copper AOI is characterized by a steep-sided gorge containing the Balkh River; elevations at the bottom of the gorge are about 1,300 to 1,400 m asl and the areas above the gorge are more than 3,500 m asl in places (Bohannon, 2005). The Balkh River valley is oriented southwest to northeast (Davis, 2006) (fig. 4C–1*a*). The valleys formed by the tributary streams to the Balkh River are also steep-sided and deeply incised (fig. 4C–2).

4C.5 Geohydrology

The geohydrology of Afghanistan has been described in general terms by Abdullah and Chmyriov (1977, book 2). As defined in their “Geology and mineral resources of Afghanistan,” the Balkhab VMS copper AOI is in the Northern Afghan Artesian Region. The outcrops and near-surface rocks in the AOI can be grouped according to their physical and hydraulic properties. The generalized geohydrology of the AOI is shown in figure 4C–6 with the underlying topography to allow examination of the geohydrology in the context of relief. Figure 4C–7 shows the generalized geohydrology without topography for a clearer depiction of the geohydrologic units. Wells near the AOI (discussed in the Groundwater section) also are shown in figure 4C–7. Generalized geohydrologic groups were created from a country-wide geologic coverage (Doebrich and Wahl, 2006) by combining sediments and rocks into major sediment- or rock-type groups of similar hydrologic characteristics. The geohydrologic groups in the AOI, ranked from high to low relative hydraulic conductivity (Freeze and Cherry, 1979, table 2.3), are “limestones and dolostones, sedimentary rocks, and intrusive rocks and lavas” (figs. 4C–6, 4C–7). Doebrich and Wahl (2006) used geologic maps at a scale of 1:250,000, modified from Russian and Afghan Geological Survey (AGS) mapping, to generate the country-wide geologic coverage. The 1:250,000-scale geologic map that covers this AOI is provided by Turner (2005).

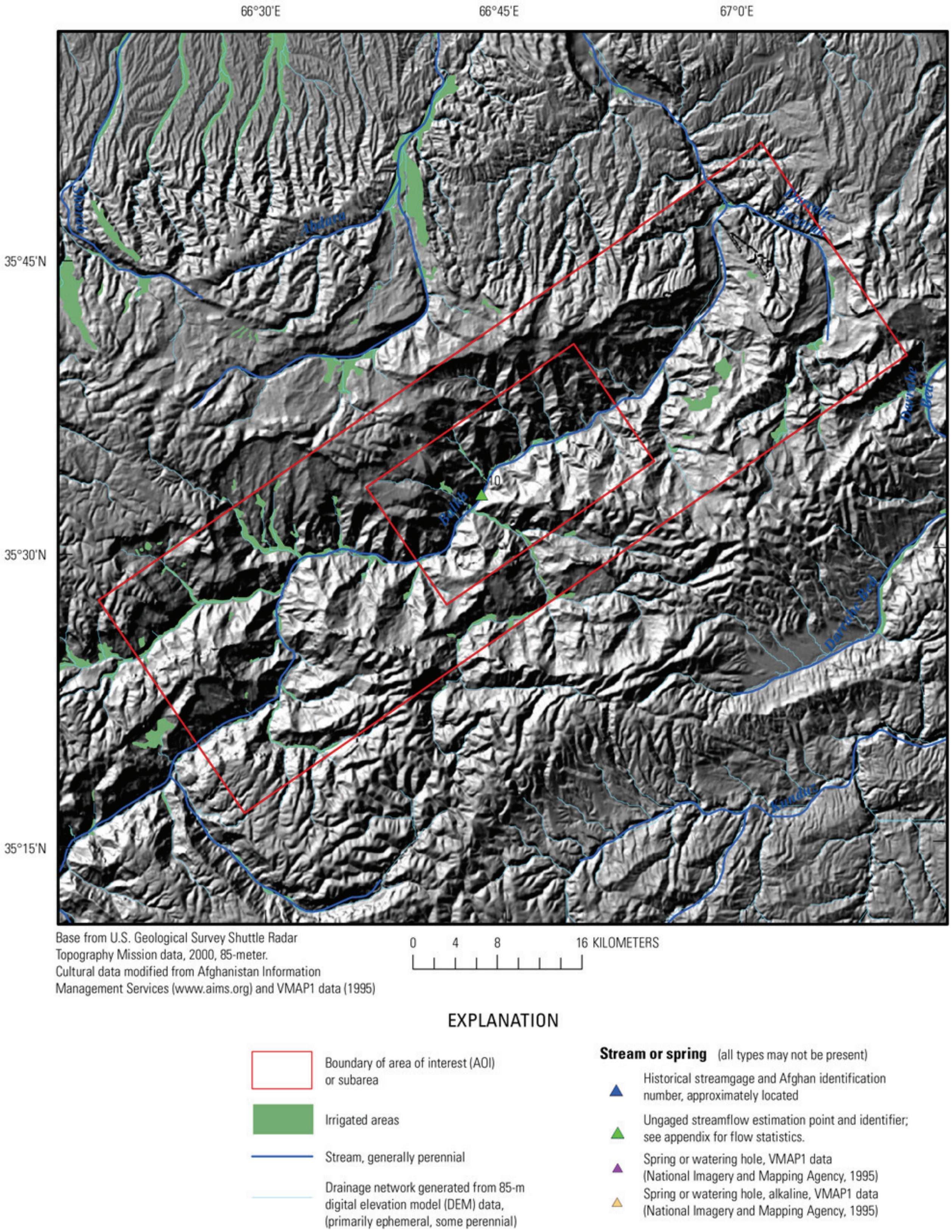

Figure 4C–2. Estimated-streamflow location, digitally generated drainage network, and irrigated areas in the Balkhab volcanogenic massive sulfide copper area of interest in northern Afghanistan.

The most deeply incised stream valleys are located in the sedimentary rocks geohydrologic group (fig. 4C–6). The limestones and dolostones geohydrologic group is prevalent at the high elevations. Scattered outcrops of the intrusive rocks and lavas are found, and a few northwest-trending faults have been mapped within and adjacent to the AOI (fig. 4C–7). The clastic and carbonate rocks in the AOI are flat lying and areally extensive within and adjacent to the AOI. Although no data are available for these units and the bedrock characteristics are unknown, it is likely that groundwater is present in these units. Field investigations including borehole drilling and testing would be needed to characterize the groundwater resources of the sedimentary rocks and the limestones and dolostones geohydrologic groups.

4C.5.1 Surface Water

A network of major, mostly perennial streams, modified from AIMS (Afghanistan Information Management Services, 1997) and VMAP1 (National Imagery and Mapping Agency, 1995), is shown in figure 4C–2. A network representing likely ephemeral streams, generated with a digital elevation model (DEM), also is shown in figure 4C–2. Surface-water resources in the Balkhab VMS copper AOI are dominated by the northeasterly flowing Balkh River, which is also known as the Band-i-Amer (figs. 4C–1*a*,*b* and 4C–2). The headwaters of the Balkh River are the Band-i-Amer lakes, about 90 km southeast of the AOI (or about 170 km along the river), in the Kohe Baba range in central Afghanistan (Democratic Republic of Afghanistan, undated (late 1970s)).

Figure 4C–3. Photograph showing vegetation in the Balkhab volcanogenic massive sulfide copper area of interest, Balkhab Prospect subarea, in northern Afghanistan. The Balkh River is in the background.

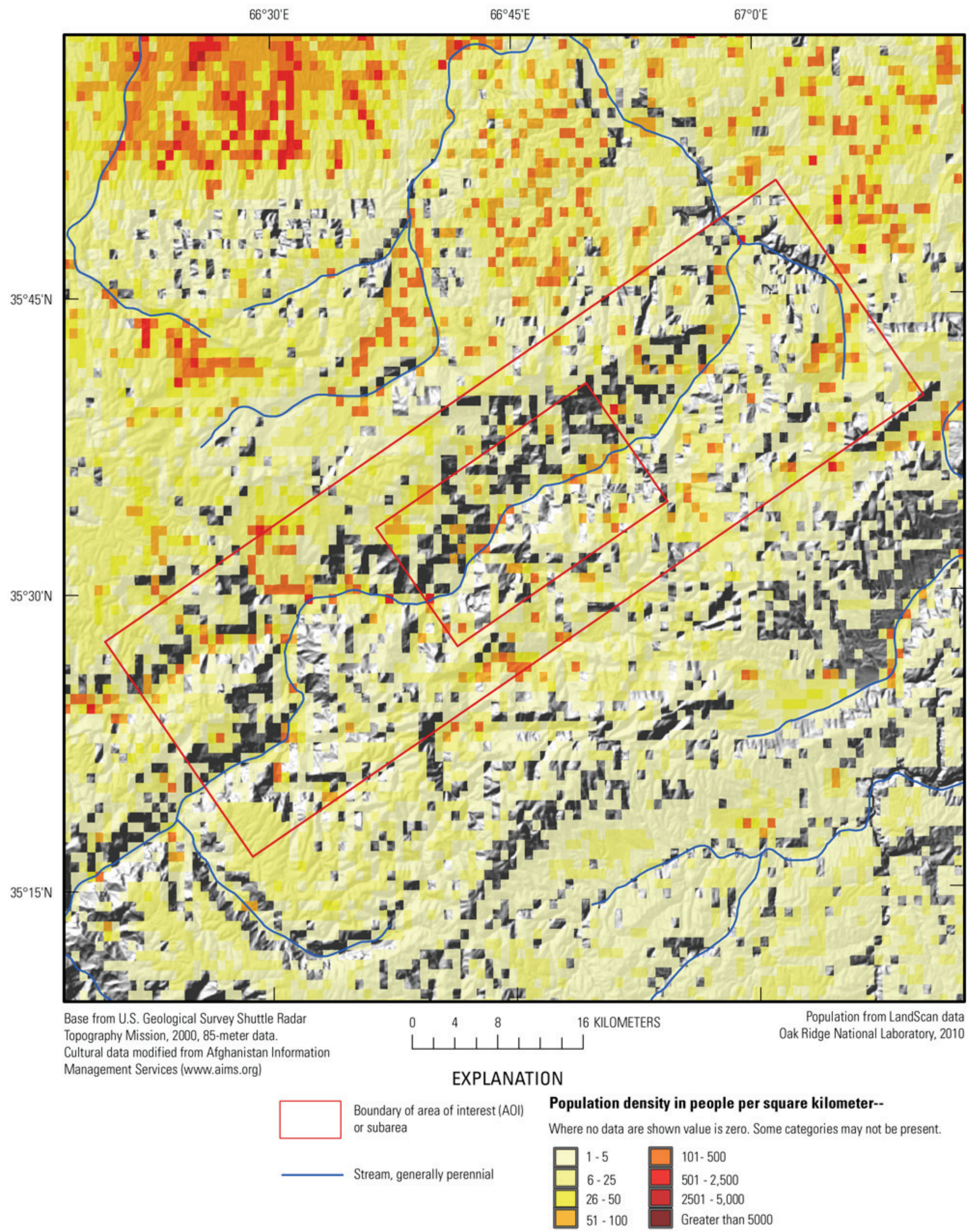

Figure 4C–4. Population density of the Balkhab volcanogenic massive sulfide copper area of interest in northern Afghanistan.

No streamgages are located within the AOI; however, there are two streamgages on the Balkh River, one upstream and one downstream from the AOI (Olson and Williams-Sether, 2010). The Balkh

River near Nayak streamgage station (Afghan identification number 12–0.000–9M) is located about 150 km upstream from the AOI. The period of record for this station is from 15 January, 1969, to 30 September, 1978. The drainage area is 1,453 km^2 and the elevation of the station is reported as 2,580 m asl. The annual mean streamflow for the period of record was 5.26 m^3/s with a standard deviation of 0.94 m^3/s (cubic meters per second). The mean annual streamflow per unit area for this station is 0.004 $m^3/s/km^2$. The highest maximum monthly mean streamflow was 20.6 m^3/s in June 1969, although in May 1976 the streamflow was 19.5 m^3/s. The lowest minimum monthly mean streamflow was 1.87 m^3/s in February 1972. A statistical summary of monthly and annual mean streamflow for the Balkh River near Nayak streamgage station (Olson and Williams-Sether, 2010) is shown in table 2. Statistical summaries of streamflow data for all available historical gages in Afghanistan can be accessed at *http://afghanistan.cr.usgs.gov/water.php*.

The Balkh River at Rabat-i-Bala streamgage station (Afghan identification number 12–0.000–1M) is located about 100 km downstream from the AOI. The period of record for this station is from 1 April, 1964, to 30 September, 1978. The drainage area is 18,035 km^2 and the elevation of the station is reported as 423 m asl. The annual mean streamflow for the period of record was 49.2 m^3/s with a standard deviation of 10.7 m^3/s. The mean annual streamflow per unit area for this station is 0.003 $m^3/s/km^2$. The highest maximum monthly mean streamflow was 169 m^3/s in June 1969, although in May 1976 the streamflow was 150 m^3/s. The lowest minimum monthly mean streamflow was 19.8 m^3/s in July and August 1971. A statistical summary of monthly and annual mean streamflow for the Balkh River near Rabat-i-Bala (Olson and Williams-Sether, 2010) is presented in table 4C–3.

Figure 4C–5. Photograph of the Balkh River, looking southwest toward headwaters areas, in the Balkhab volcanogenic massive sulfide copper area of interest in northern Afghanistan.

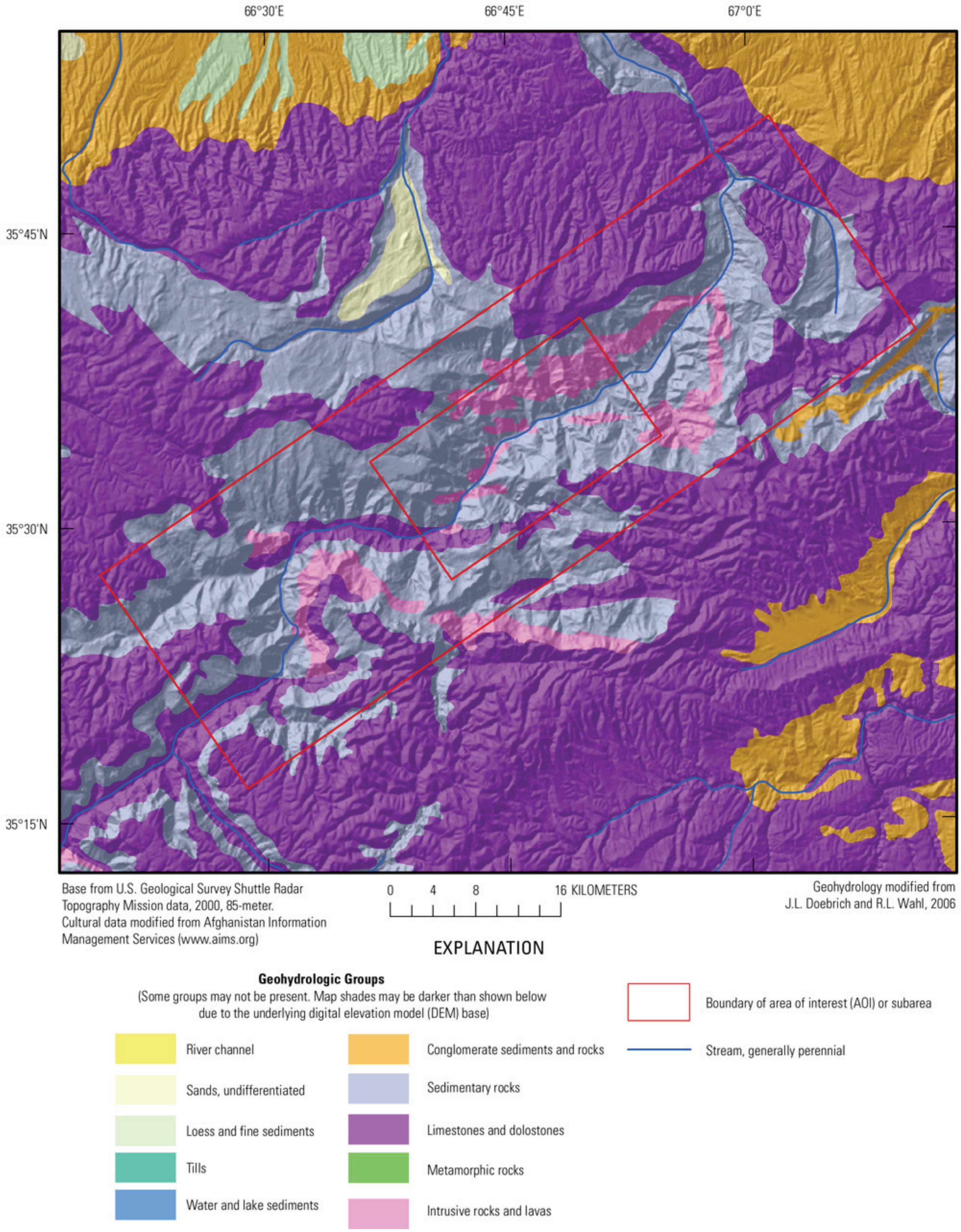

Figure 4C–6. Topography and generalized geohydrology of the Balkhab volcanogenic massive sulfide copper area of interest in northern Afghanistan.

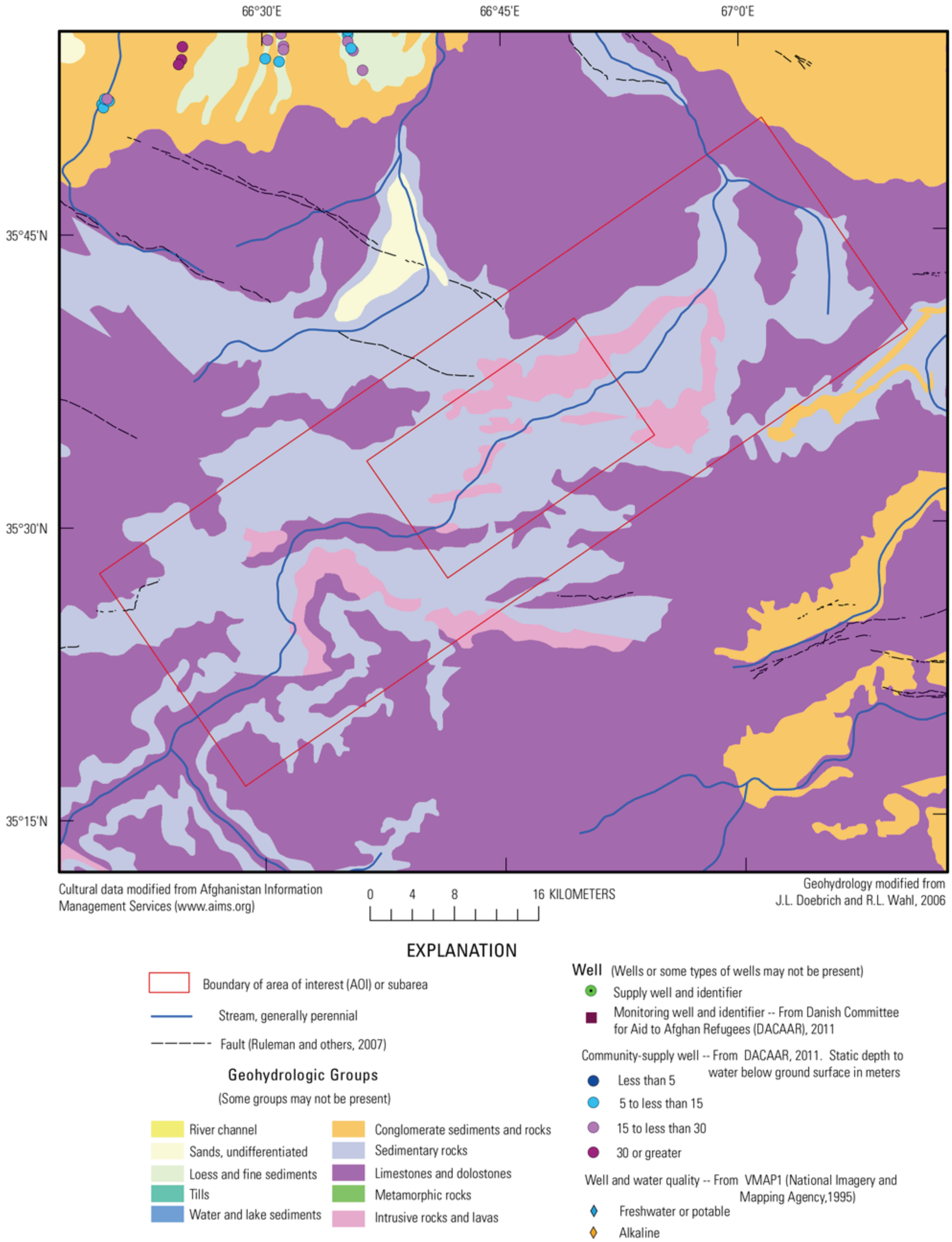

Figure 4C–7. Generalized geohydrology, mapped faults, well locations, and depth to water in the Balkhab volcanogenic massive sulfide copper area of interest in northern Afghanistan.

Streamflow statistics were estimated for selected ungaged streams that may be prominent in the AOI or subareas to provide some probable estimates of flow for these locations. Streamflow statistics for the Balkh River at streamflow estimation point S10, in the center of the Balkhab Prospect subarea (figs. 4C–1*b* and 4C–2), were calculated using a drainage-area-ratio technique (Olson and Mack, 2011; app. 2) and historical flows at the Balkh River at Rabat-i-Bala streamgage station (Afghan identification number 12–0.000–1M, table 4C-3); these streamflow statistics are presented in appendix 2. The Rabat-i-Bala streamgage station was selected as the most representative historical gage, based on drainage-basin size and location in Afghanistan, for use with this method at this location. For comparison, flows were also estimated by logarithmic interpolation between flows at the Balkh River at Rabat-i-Bala streamgage and flows at the Balkh River at Nayak streamgage and were found to be similar to the estimates derived by using the drainage-area-ratio technique (app. 2). The drainage area at point S10 is 7,664 km^2 and about 66 percent of that area is greater than 3,000 m in elevation (app. 2). The mean annual flow at S10 was estimated to be from 20 to 23 m^3/s. The low mean monthly flows were estimated to be about 10 m^3/s from October through February. The high mean monthly flows were estimated to be about 41 and 35 m^3/s and to occur in May and June, respectively. Minimum mean monthly streamflows were estimated to be about 6.5 to 7.0 m^3/s in July through September. Streamflows in the Balkh River were estimated to be fairly consistent, 14 to 18 m^3/s, during much of the year (app. 2). Streamflows at the Balkh River near Nayak (Afghan identification number 12–0.000–9M, table 4C-2) (Olson and Williams-Sether, 2010) were similarly regular, about 3 to 6 m^3/s, during much of the year.

The estimated mean annual flow for the Balkh River is 20 to 33 m^3/s. The streamflow statistics for the Balkh River indicate that the monthly flow has always been greater than zero during the period of record (Olson and Williams-Sether, 2010). Comparing streamflow data from the streamgage station at Nayak to those from the station at Rabat-i-Bala shows that the flow increases downstream. The Balkh River is likely the sole source of water for irrigation (fig. 4C–2) in the AOI, indicating that it is an important local water resource. Although the Balkh River may have the capacity to supply water for mining activities, close monitoring would be needed to protect the availability of water to meet local water needs, especially when the flow in the river is low.

No mapped springs are indicated in the AOI (fig. 4C-2) as determined from VMAP1 data (National Imagery and Mapping Agency, 1995), and no springs were observed during the field reconnaissance in November 2009. It is likely, however, that springs are present during periods of high precipitation and originate in the valley wall at the base of overlying sedimentary rock units (figs. 4C–6, 4C–7). No karezes (hand-dug water-supply tunnels commonly used in Afghanistan that are constructed in unconsolidated and semi-consolidated sediments) were apparent during reconnaissance flights conducted in the AOI, and they are not likely to be used in this terrain. Unmapped springs in the AOI may require particular attention if they are to be used to support mining activities, as local communities are likely to be dependent on the springs as a source of water supply.

4C.5.2 Groundwater

The only information available on the groundwater resources in the Balkhab VMS copper AOI is provided by Abdullah and Chmyriov (1977). There is no indication of community supply wells installed by NGOs or groundwater-monitoring wells (GWMs) in the AOI (Danish Committee for Aid the Afghan Refugees, 2011). The nearest community supply wells were installed in larger communities about 30 km north of the AOI.

Table 4C–2. Statistical summary of monthly and annual mean streamflow for the Balkh River near Nayak streamgage station.

[Afghan identification number 12–0.000–9M. m^3/s, cubic meters per second]

Month	Maximum		Minimum		Mean			
	Streamflow (m^3/s)	Water year of occurrence	Streamflow (m^3/s)	Water year of occurrence	Streamflow (m^3/s)	Standard deviation (m^3/s)	Coefficient of variation	Percentage of annual streamflow
October	5.77	1970	2.39	1972	3.81	0.89	0.23	5.84
November	5.50	1970	2.43	1972	3.68	0.86	0.23	5.63
December	4.54	1970	2.44	1972	3.55	0.66	0.19	5.44
January	4.26	1970	2.27	1972	3.55	0.71	0.20	5.44
February	4.82	1978	1.87	1972	3.47	0.99	0.29	5.31
March	5.22	1978	2.17	1972	3.87	0.95	0.24	5.93
April	9.40	1978	2.93	1972	6.41	1.69	0.26	9.83
May	19.5	1976	6.83	1971	13.6	4.61	0.34	20.9
June	20.6	1969	3.44	1971	10.7	5.50	0.52	16.4
July	9.99	1969	2.96	1971	4.95	2.11	0.43	7.59
August	6.56	1969	2.73	1971	3.78	1.10	0.29	5.79
September	6.12	1969	2.47	1971	3.91	0.92	0.23	6.00
Annual	6.62	1976	3.75	1971	5.26	0.94	0.18	100

Table 4C–3. Statistical summary of monthly and annual mean streamflow for the Balkh River at Rabat-i-Bala streamgage station.

[Afghan identification number 12–0.000–1M. m^3/s, cubic meters per second]

Month	Maximum		Minimum		Mean			
	Streamflow (m^3/s)	Water year of occurrence	Streamflow (m^3/s)	Water year of occurrence	Streamflow (m^3/s)	Standard deviation (m^3/s)	Coefficient of variation	Percentage of annual streamflow
October	51.1	1970	22.7	1978	36.6	7.91	0.22	6.17
November	53.5	1970	26.0	1978	36.9	7.66	0.21	6.23
December	47.3	1966	27.1	1978	35.8	6.47	0.18	6.04
January	47.3	1966	25.5	1973	34.5	5.91	0.17	5.83
February	48.2	1966	27.9	1975	34.8	5.47	0.16	5.86
March	55.9	1966	28.9	1971	39.6	7.53	0.19	6.67
April	104	1969	42.1	1971	59.4	15.3	0.26	10.02
May	150	1976	52.4	1971	101	31.1	0.31	17.07
June	169	1969	29.9	1971	95.3	39.5	0.41	16.07
July	104	1969	19.8	1971	47.7	20.1	0.42	8.05
August	65.0	1969	19.8	1971	35.8	10.7	0.30	6.04
September	55.4	1969	20.8	1971	35.3	8.15	0.23	5.95
Annual	74.7	1969	31.8	1971	49.2	10.7	0.22	100

Although few data are available from which to quantify the extent of this resource, considerable groundwater is likely to be present in the river-channel sediments in the Balkh River valley and possibly in some of the tributary streams. River-channel sediments, consisting of coarse sand, silt, and gravel, were observed during the 2009 field reconnaissance to the AOI (figs. 4C–3 and 4C–5) and likely contain many dug wells. These sediments are not mapped in the area, most likely because the mapping was conducted at a scale of 1:250,000 (figs. 4C–6 and 4C–7). The water table is likely to be near the land surface adjacent to the Balkh River, and possibly adjacent to ephemeral streams as well. The sand and gravel sediments adjacent to the Balkh River (fig. 4C–5) are likely to be tens of meters thick, and could possibly be more than 100 m thick in some sections of the river valley. Coarse-grained sediments near the Balkh River may provide considerable groundwater from river leakage to properly constructed wells. Geophysical surveys or drilling programs would help to assess the thickness and hydraulic characteristics of river-valley aquifers.

The clastic and carbonate sedimentary rocks of the sedimentary rock and the limestones and dolostones geohydrologic groups in the AOI may constitute aquifers with the capacity to transmit groundwater. The exposed sequence of these rocks is about 2,000 m thick in the Balkh River valley in the AOI. Drilling programs would help to confirm the characteristics and extent of sedimentary rock aquifers in the AOI. It is possible that, with close monitoring, water for mining activities could be extracted from supply wells completed in the sedimentary rock aquifers without adversely affecting the availability of the groundwater resource to meet the water-supply needs of local users.

4C.5.3 Lineament Analyses

Lineaments are photolinear features that could be the result of underlying zones of high-angle bedrock fractures, fracture zones, faults, or bedding-plane weaknesses. Lineament analyses of the Balkhab VMS copper AOI (B.E. Hubbard, T.J. Mack, and A.L. Thompson, unpub. data, 2011) were conducted using DEM and natural-color satellite imagery (fig. 4C–8) and Advanced Spaceborne Thermal Emission and Reflection (ASTER) Radiometry satellite imagery (fig. 4C–9*a*,*b*). Lineament identification and analysis have long been used as a reconnaissance tool for identifying areas in carbonate bedrock environments where groundwater resources are likely to be found (Lattman and Parizek, 1964; Siddiqui and Parizek, 1971). Lineament analysis is increasingly used to identify areas of high relative well yields in other bedrock settings, including crystalline bedrock (Mabee, 1999; Moore and others, 2002). The lineaments shown in figure 4C–8 were delineated visually, whereas those in figure 4C–9 were delineated using an automated process and on the basis of the multispectral characteristics of the land surface (B.E. Hubbard, T.J. Mack, and A.L. Thompson, unpub. data, 2011). Water wells in bedrock aquifers generally are most productive where boreholes are located in areas of highly fractured bedrock. Areas where lineament density is high, such as the center of the Balkhab Prospect subarea (figs. 4C–8 and 4C–9*a*,*b*), potentially are areas where bedrock fractures are more prevalent than in other areas of the AOI. Lineaments provide an indication of areas that warrant further investigation for optimal bedrock water-well placement. Lineaments may also indicate areas of preferential flow and storage of groundwater, and areas with a high density of lineaments may indicate high secondary porosity. Any lineament analyses, including those presented in this investigation, need to be corroborated by field investigations and additional data to confirm the nature of the lineaments and their relation to water-filled bedrock fracture zones.

Many lineaments that were mapped (figs. 4C–8 and 4C–9*a*,*b*) were observed during low-altitude field reconnaissance flights over the region. These features are important in that they may indicate the presence of zones of relatively greater storage and yield to bedrock wells for limited use, such as a local drinking-water source. Lineaments with an approximate north-south strike (figs. 4C–8) may represent a conjugate fracture pattern, orthogonal to the trend of the Balkh River, with potentially higher yielding bedrock aquifers than in other areas. Some large tributary streams in the AOI (fig. 4C–2) exhibit such a conjugate pattern.

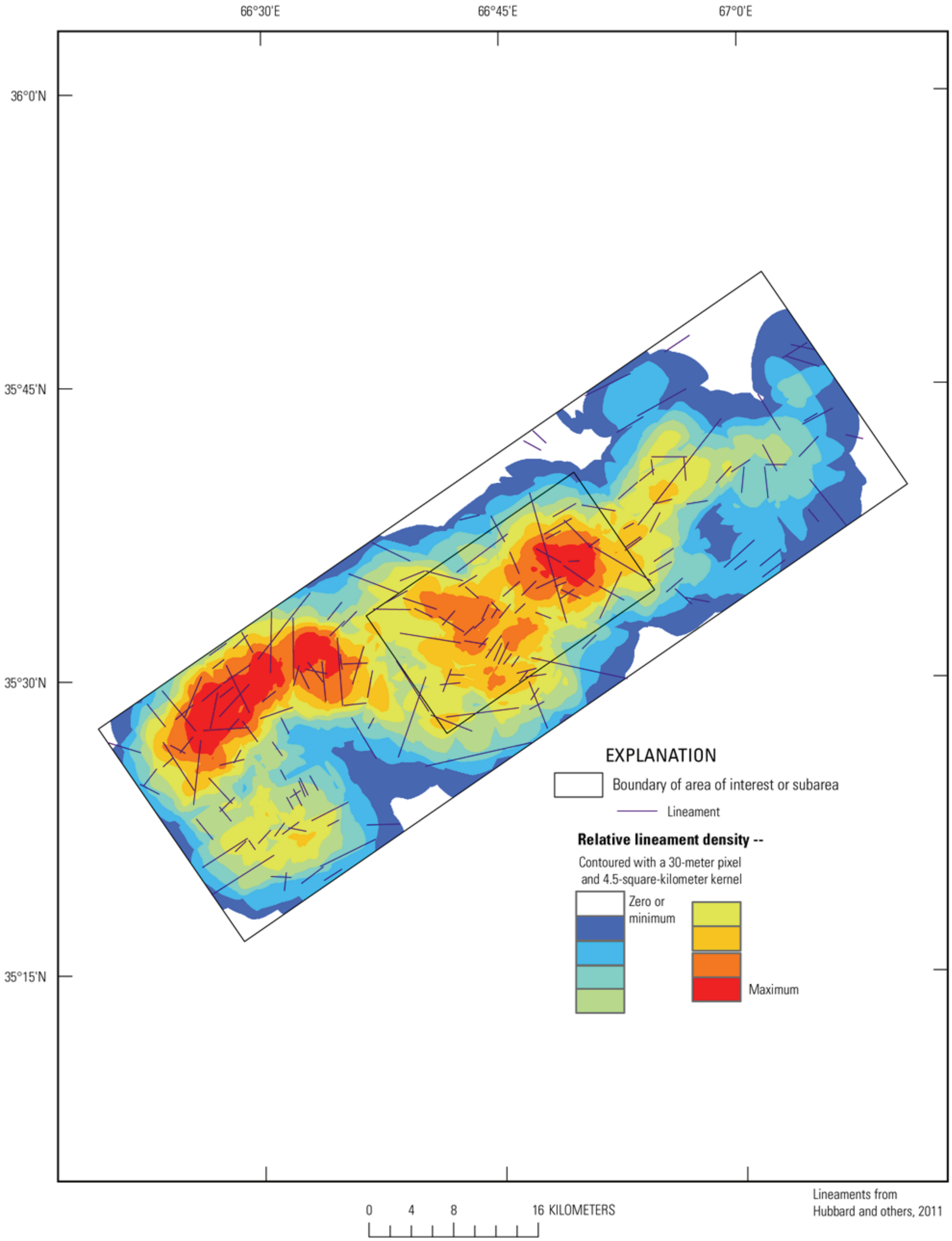

Figure 4C–8. Lineaments and lineament density based on 30-meter digital-elevation-model data and natural-color Landsat imagery in the Balkhab volcanogenic massive sulfide copper area of interest in northern Afghanistan.

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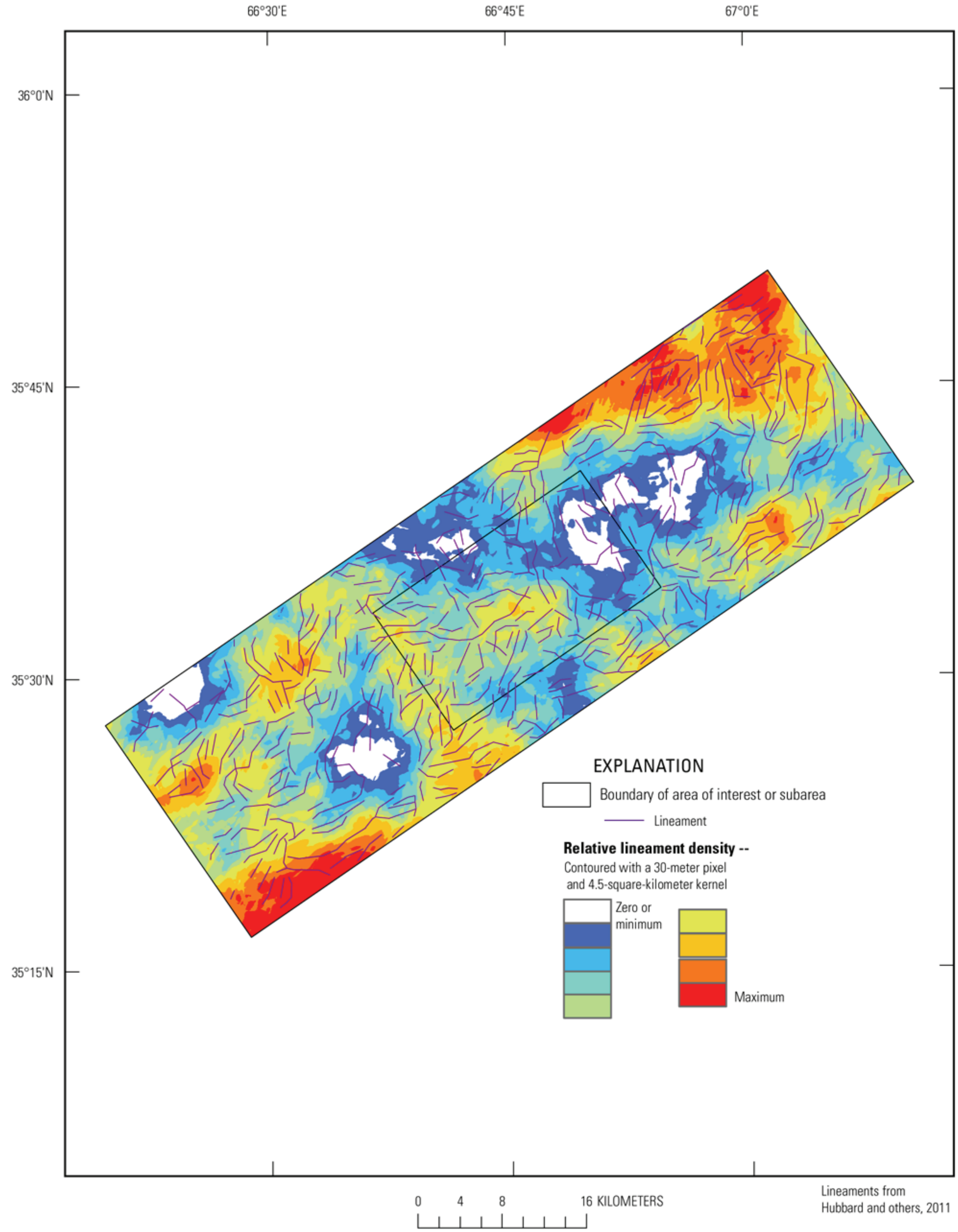
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35°30'N
35°15'N
EXPLANATION
Boundary of area of interest or subarea
Lineament
Relative lineament density --
Contoured with a 30-meter pixel
and 4.5-square-kilometer kernel
Zero or
minimum
Maximum
0 4 8 16 KILOMETERS
Lineaments from
Hubbard and others, 2011

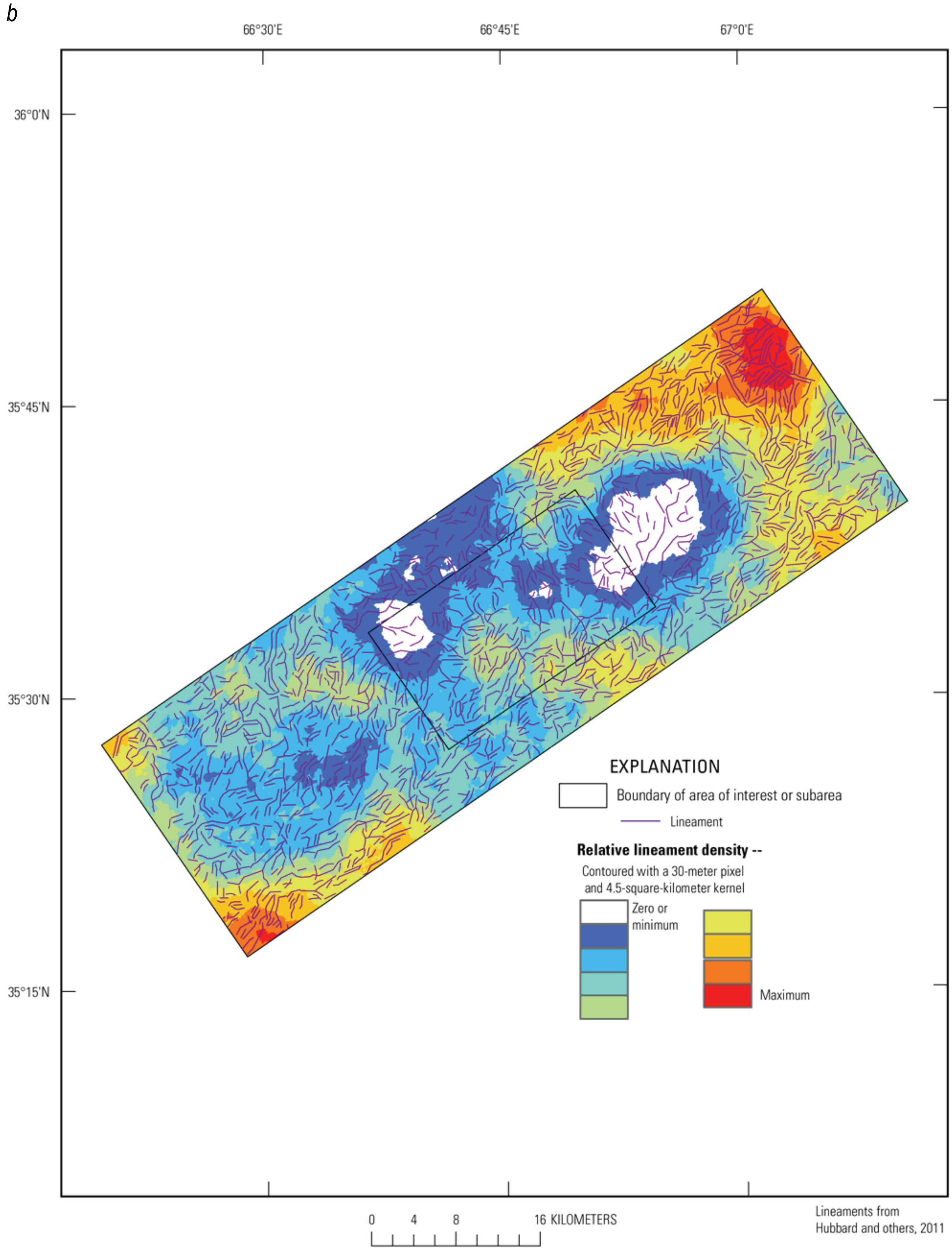

Figure 4C–9. *(a)* Lineaments and lineament density based on 30-meter multispectral Landsat imagery and *(b)* lineaments and lineament density based on 15-meter multispectral Landsat imagery in the Balkhab volcanogenic massive sulfide copper area of interest in northern Afghanistan.

4C.6 Summary and Conclusions

The availability of water resources for mining and other uses is likely to be greater in the Balkhab VMS copper area of interest (AOI) than in other areas of Afghanistan. The water resources in the AOI consist mainly of the Balkh River, although there may also be considerable groundwater in the AOI. The Balkh River is perennial, with an estimated average flow of 20 to 33 m^3/s. The water in the Balkh River is used for irrigation in the AOI; however, that irrigation appears to be limited more by available land area than by streamflow. Infiltration of water from the Balkh River probably provides considerable recharge to the shallow, coarse-grained alluvial aquifers in the river valley. Although the Balkh River may have the capacity to support mining activities, protection of local water resources would require quantification of streamflow and close monitoring of any new streamflow diversions, or groundwater withdrawals adjacent to the river. Groundwater likely is present in alluvial aquifers with limited areal extent adjacent to the Balkh River. The coarse-grained nature of the sediments that of which the river-valley aquifers are composed indicates the potential for recharge through river leakage or induced infiltration from the Balkh River. Determination of the thickness and hydraulic characteristics of the river-valley aquifers would help to confirm the availability of water in these aquifers.

A sequence of clastic and carbonate sedimentary rocks in the AOI may be a groundwater resource. No subsurface hydraulic information is available for the sedimentary rocks hydrogeologic group, but these rocks may be a source of groundwater in areas not adjacent to the Balkh River.

Some areas of the AOI, as indicated by generalized geohydrologic maps and lineament analyses, are likely areas for further exploration for groundwater resources. The quality and sustainability of water resources in the AOI remain to be determined, however. Careful evaluation and management of potential new surface-water or groundwater withdrawals would help to protect the quantity and quality of the existing supply for current local water uses. Field investigations including geologic mapping, geophysical surveys, and hydraulic well testing are needed to adequately characterize the extent and availability of groundwater resources in the AOI.

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