Chapter 18C. Geohydrologic Summary of the Bakhud Fluorite Area of Interest

By Michael P. Chornack and Thomas J. Mack

18C.1 Introduction

This chapter describes the geohydrology of the Bakhud fluorite area of interest (AOI) in Afghanistan identified by Peters and others (2007) (fig. 18C–1*a*,*b*). The AOI is located in south-central Afghanistan in the Nesh, Dihrawud, Tirin Kot, and Chora Districts in Uruzgan Province and in the Sha Wali Kot, Khakez, and Ghorak Districts Kandahar Province (figs. 18C–1*a*,*b*). The AOI occupies a 3,638-km^2 (square kilometer) area.

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. Where these data are available, the depth to water and height of static water in wells are documented. 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.

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.

18C.1.1 Climate and Vegetation

Climate information for the Bakhud fluorite 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 U.S. Geological Survey (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.

a

Base from U.S. Geological Survey Natural-Color Landsat Image Mosaic of Afghanistan Map Series, 2006,14.25-meter. Cultural data modified from Afghanistan Information Management System (www.aims.org).

0 4 8 16 KILOMETERS

EXPLANATION

Boundary of area of interest (AOI) or subarea

Stream, generally perennial

Province boundary line

District boundary line

b

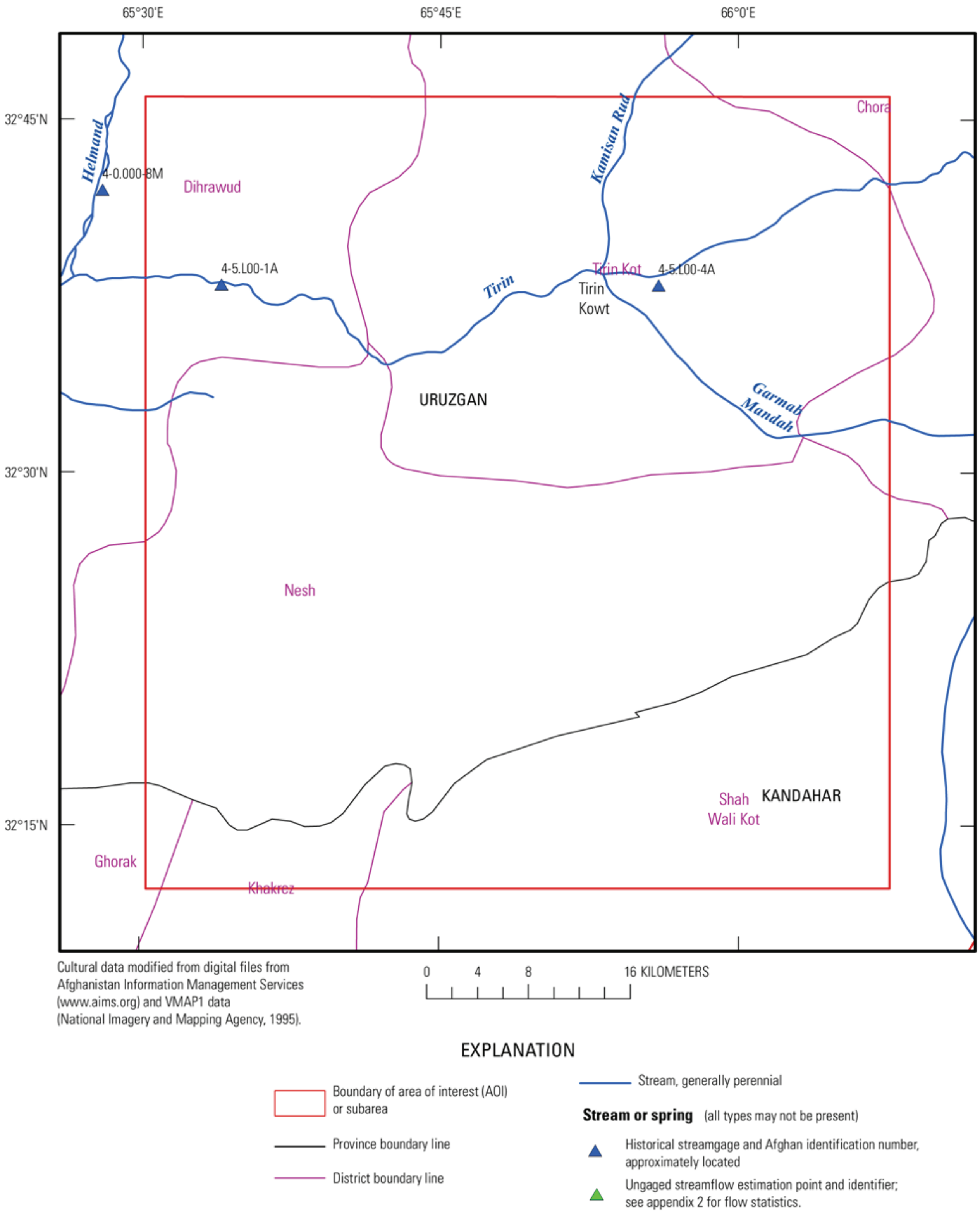


Figure 18C–1. (*a*) Landsat image showing the location of, and (*b*) place names, stream names, and streamgage station numbers in, the Bakhud fluorite area of interest in Afghanistan.

The Uruzgan Agromet station is located in Uruzgan Province in the Tirin Kot District on the Tirin River in the northern part of the AOI. Available data for this Agromet station include 2009–2010 water year and long-term average (LTA) precipitation data. There was no reported snowfall at the Uruzgan Agromet station during the 2009–2010 water year, but 15.2 cm (centimeters) of snowfall was recorded at this station during the 2008–2009 water year. Precipitation data for the Uruzgan Agromet station (Ministry of Agriculture, Irrigation, and Livestock, 2010) are shown in table 18C–1. Precipitation measurements made during 2008 and 2009 indicate that precipitation during this period was less than half the regional average (Andrew Clemens, U.S. Army Corps of Engineers, written commun., 2009).

The maximum monthly temperature in the AOI during the 2009–2010 season ranged from 44.2 to 44.8°C (degrees Celsius) (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 only in 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 mostly *Pistacia atlantica*-Woodlands as classified by Breckle (2007, p. 161). Much of the upland surface of the AOI is bedrock outcrop with thin alluvial cover and sparse vegetation. 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. There is extensive irrigation along the Tirin River valley and tributary stream valleys in the AOI (fig. 18C–2).

Table 18C–1. Annual, long-term annual average, and long-term average minimum and maximum precipitation and temperature at the Uruzgan Agrometeorological (Agromet) station in the Bakhud fluorite area of interest, Afghanistan.

[AOI, area of interest; km, kilometers; m, meters; mm, millimeters; °C, degrees Celsius; nr, not reported]

			Precipitation				Temperature		
					Long-term average[1]		Long-term average[1]		
Agromet Station	Distance from AOI center (km)	Elevation (m)	2009-2010 Annual (mm)	Annual (mm)	Monthly minimum and month (mm)	Monthly maximum and month (mm)	Minimum and month (°C)	Monthly mean (°C)	Maximum and month (°C)
Uruzgan	18	1,320	180.5	233.4	0[2]	53.3 January	nr	nr	nr

[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).

[2] Long-term average precipitation in June, August, and September was 0 mm.

18C.1.2 Demographics

The Bakhud fluorite AOI is sparsely populated, with most areas having 1 to 25 inhabitants per square kilometer as mapped by LandScan (Oak Ridge National Laboratory, 2010) (fig. 18C–3). Exceptions are the areas along the Tirin River and in the village of Tirin Kowt, located at the confluence of the Kamisan Rud, Garmah Mandah, and Tirin Rivers (fig. 18C–1*b*). In these areas, population density generally ranges from 101 to 500/km^2, but can be as high as 5,000/km^2. The more densely populated areas are small farming settlements and villages. Large areas within the AOI are estimated to be uninhabited, as indicated by the gray shading in figure 18C–3. The population density shown in figure 18C–3 has a pixel resolution of about 1 km^2 (Oak Ridge National Laboratory, 2010).

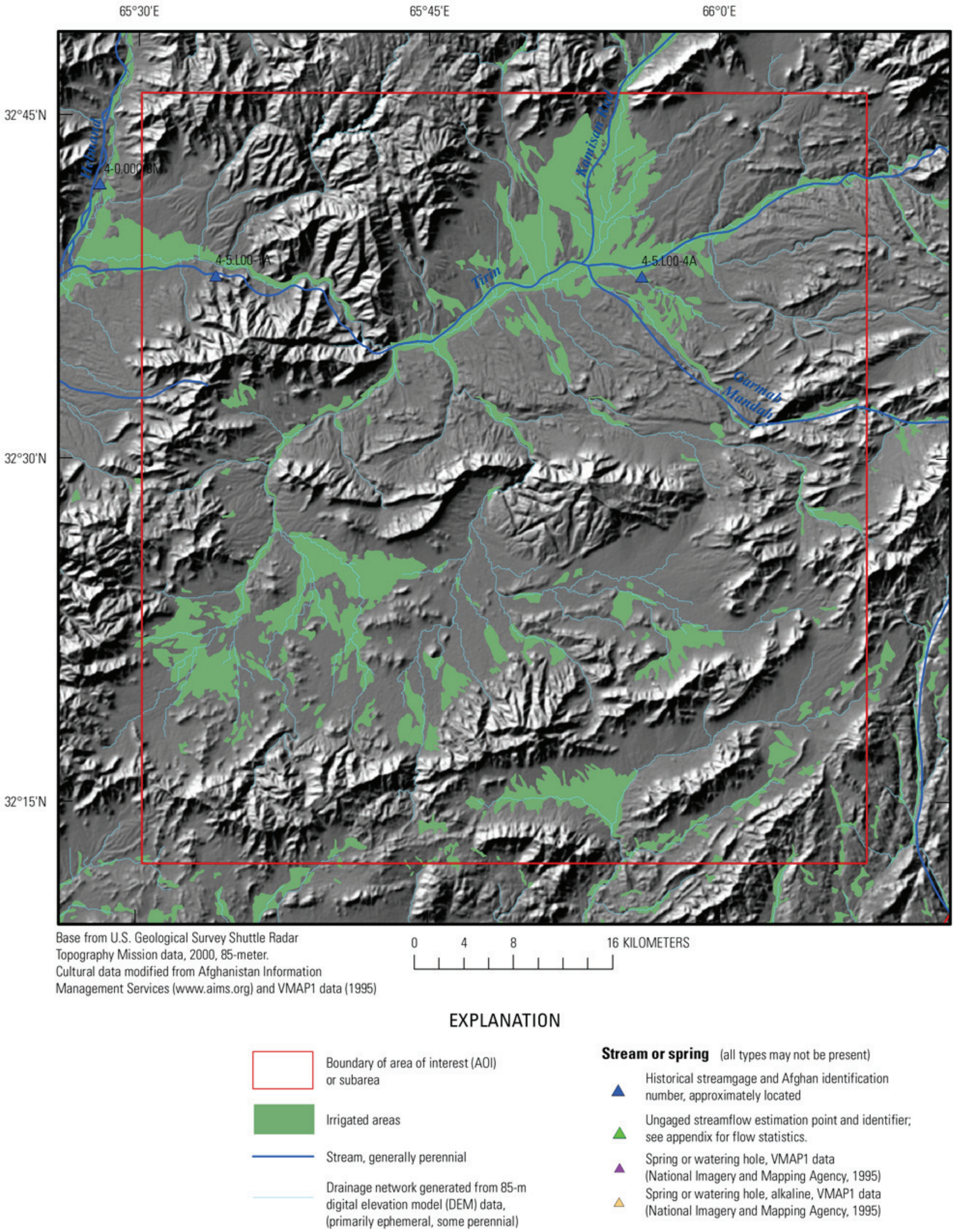


Figure 18C–2. Historical streamgage locations, digitally generated drainage network, and irrigated areas in the Bakhud fluorite area of interest in Afghanistan.

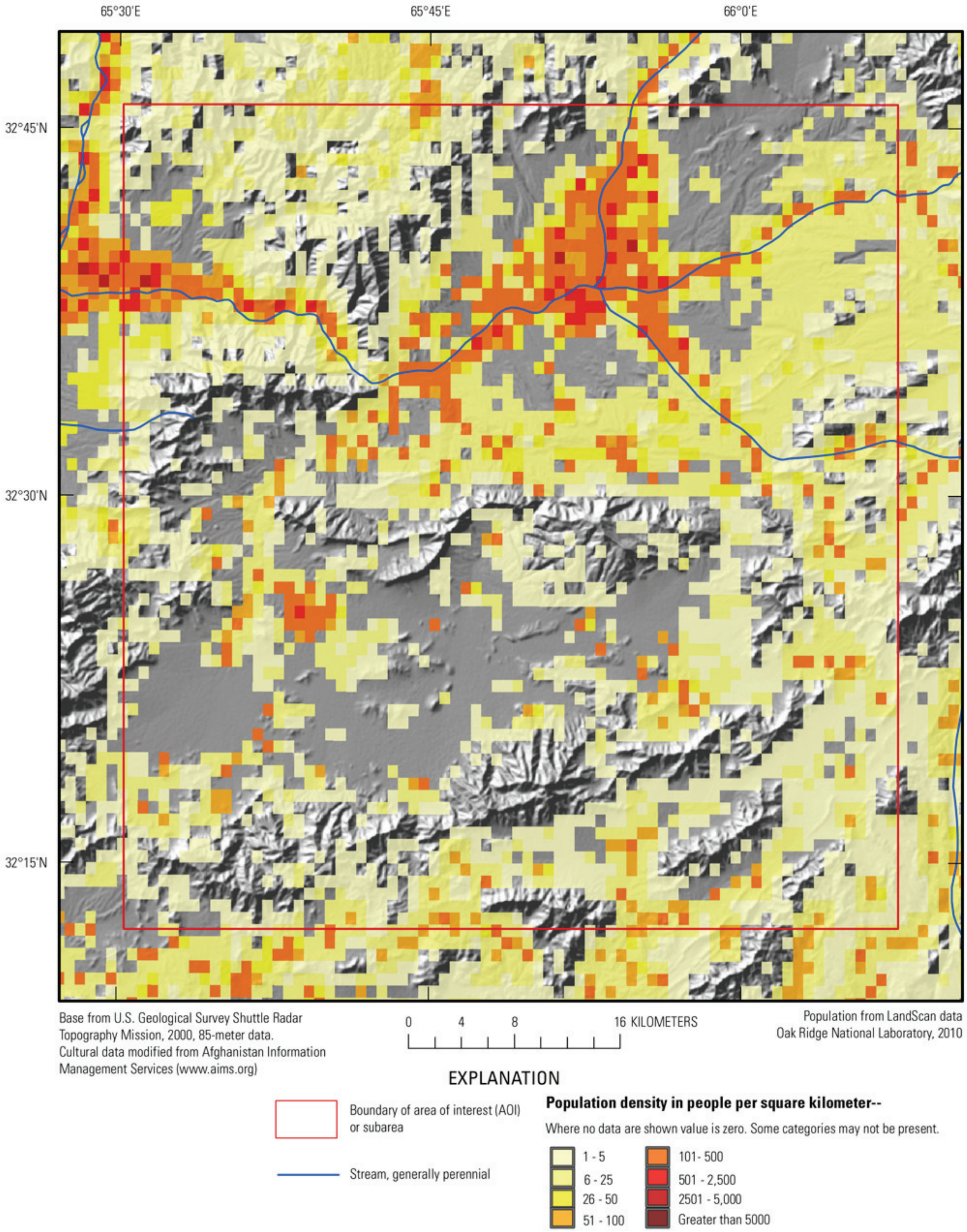


Figure 18C–3. Population density of the Bakhud fluorite area of interest in Afghanistan.

18C.1.3 Topography and Geomorphology

The topography of the Bakhud fluorite AOI consists of mountain ridges surrounded by wide valleys (Davis, 2006). There are two prominent mountain ridges, one trending approximately north-south and the other trending east-west. The ridges join near the southwest corner of the AOI, forming a valley in the middle of the AOI. This valley includes some small, isolated mountain ridges. The mountains reach elevations of 2,300 m (meters) above sea level (asl) within the AOI (Bohannon, 2005). The elevation of the valley along the Tirin River ranges from 1,100 m asl in the northwest corner of the AOI to almost 1,500 m asl in the northeast corner of the AOI. Elsewhere in the AOI, the elevation of the valley is about 1,500 m asl. A large valley was formed in the northeast corner of the AOI at the confluence of the Tirin, Kamisan Rud, and Garmab Mandah Rivers. The bedrock outcrops surrounding this valley are sedimentary rocks and limestones and dolostones; sands fill the valley bottom (fig. 18C–4).

18C.2 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 Bakhud fluorite AOI is in the southern Afghanistan 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 18C–4 with the underlying topography to allow examination of the geohydrology in the context of relief. Figure 18C–5 shows the generalized geohydrology without topography for a clearer depiction of the geohydrologic units. 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 "sands, undifferentiated; conglomerate sediments and rocks; limestones and dolostones; sedimentary rocks; and intrusive rocks and lavas" (figs. 18C–4, 18C–5). 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 Bohannon and Lindsay (2005)

The lower elevations within the AOI are mapped as the sands, undifferentiated geohydrologic group. Coarse-grained sands and gravels that are likely river-channel sediments (not shown in figures 18C–4 and 18C–5) are found in Tirin Kowt (fig. 18C–1*b*). The limited areal extent and thickness of these deposits precluded showing them on the 1:250,000-scale geologic map. Conglomerate sediments and rocks underlie the sands, crop out in central areas of the Tirin River valley, and represent a potential aquifer in the AOI (fig. 18C–4). The sedimentary rocks and the limestones and dolostones geohydrologic groups form the topographic highs and probably underlie the sands, undifferentiated geohydrologic group in the river valleys (fig. 18C–4). These groups are fairly extensive within and adjacent to the AOI and represent a possible groundwater resource that potentially could support mining activities.

18C.2.1 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 18C–2. A network representing likely ephemeral streams, generated with a digital elevation model (DEM), also is shown in figure 18C–2. Names of major streams and identification numbers for any streamgages and ungaged streamflow estimation sites in the Bakhud fluorite AOI are shown in figure 18C–1b.

There are two streamgage stations in the AOI. The Tirin River at Tirin streamgage station (Afghan identification number 4-5.L00-4A) is just upstream from the confluence of the Tirin and Garmab Mandah Rivers (figs. 18C–1*b*, 18C–2). This station is at an elevation of 1,358 m asl and has a drainage area of 3,680 km^2. The period of record for this station extends from 21 December, 1969, to 19 March, 1980 (Williams-Sether, 2008). The annual mean streamflow per unit area for this station is

0.0035 $m^3/s/km^2$ (cubic meters per second per square kilometer). The seasonal timing of maximum and minimum monthly streamflow is high flows in the spring and low flows in late summer and fall. A statistical summary of monthly and annual mean streamflows for this station is presented in table 18C–2. Statistical summaries of streamflow data for all available historical gages in Afghanistan can be accessed at *http://afghanistan.cr.usgs.gov/water.php*.

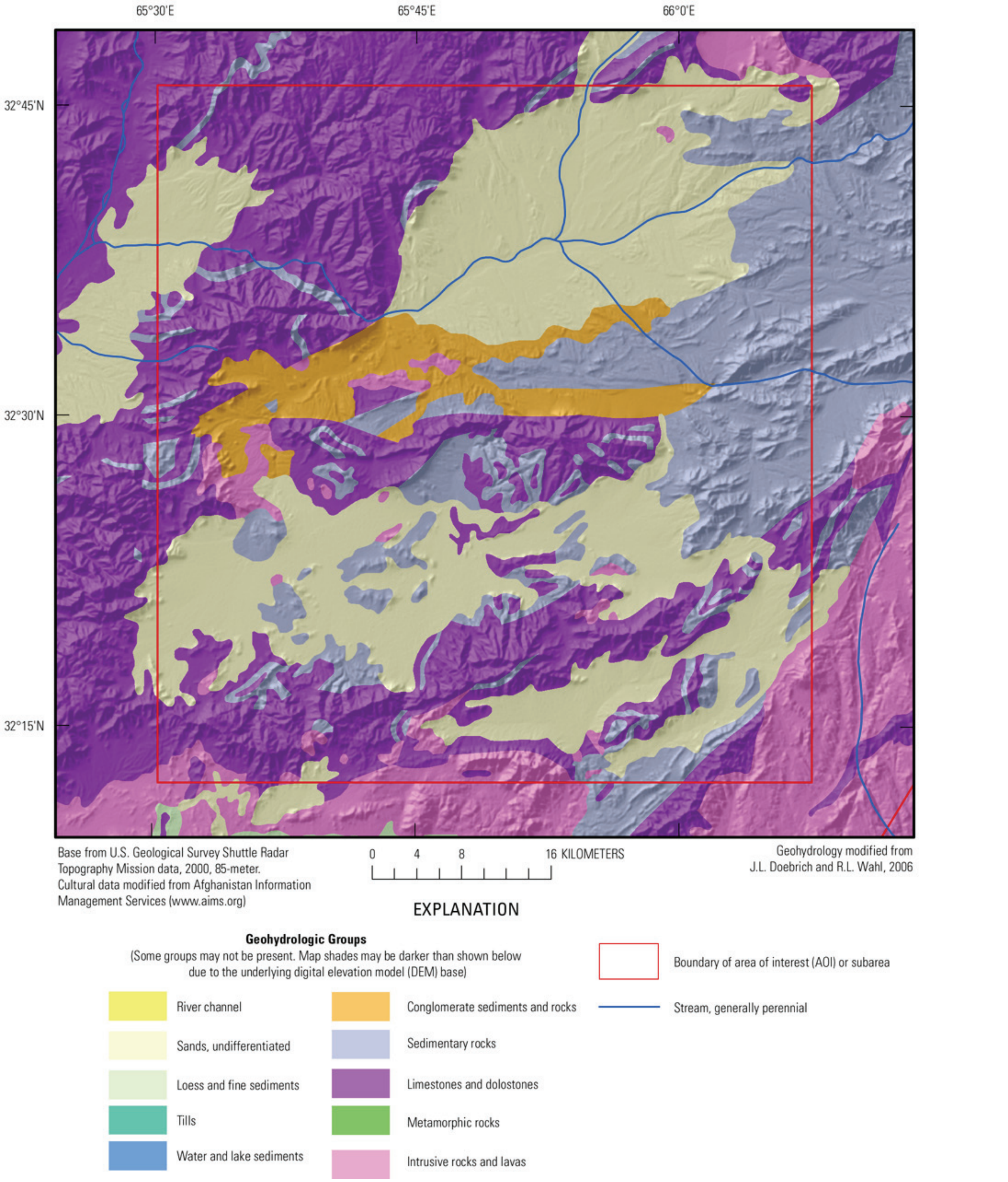


Figure 18C–4. Topography and generalized geohydrology of the Bakhud fluorite area of interest in Afghanistan.

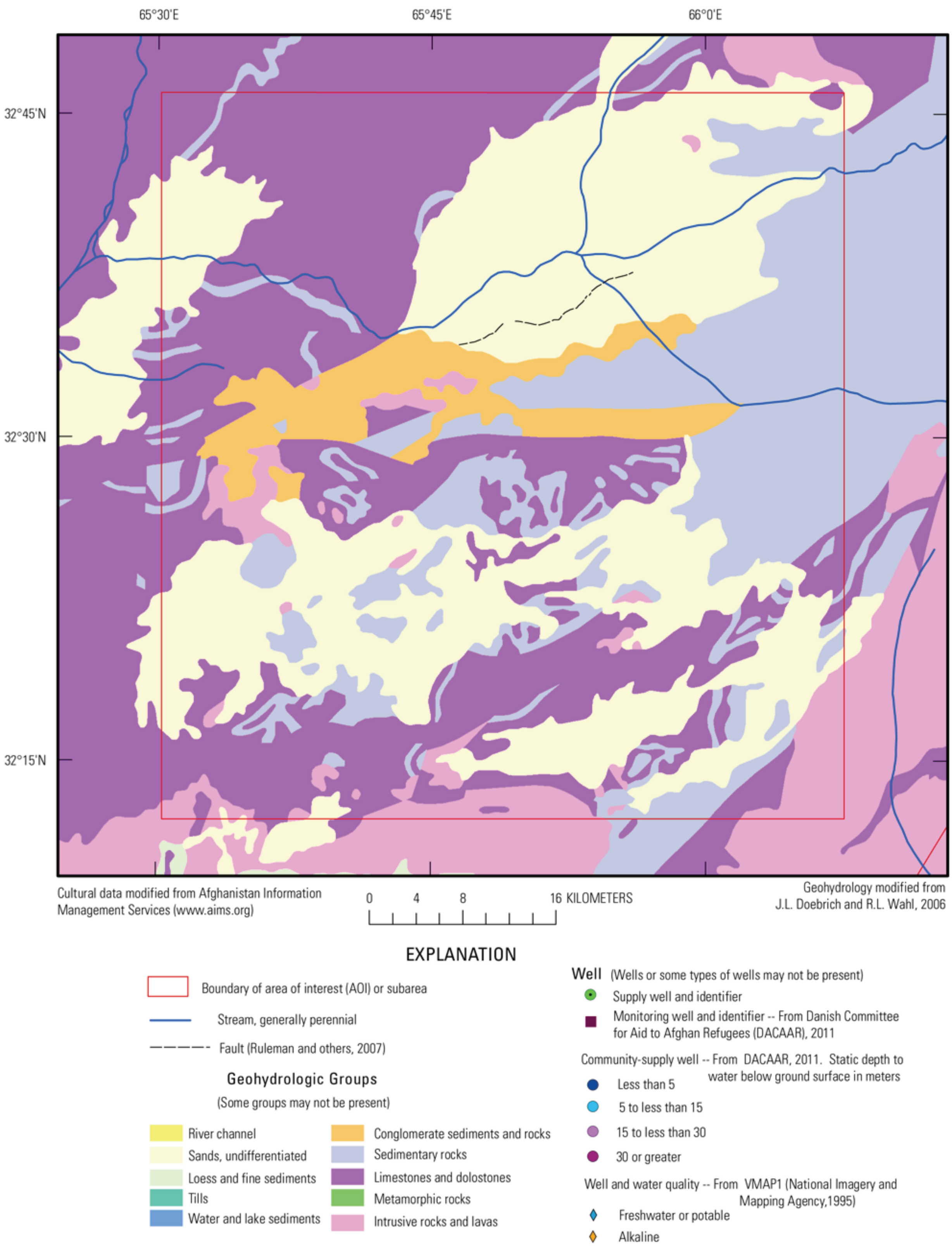


Figure 18C–5. Generalized geohydrology and mapped faults in the Bakhud fluorite area of interest in Afghanistan.

The other streamgage station in the AOI is the Tirin River at Anarjuy/Dehraout streamgage station (Afghan identification number 4-5.L00-1A). The station is near the western border of the AOI (figs. 18C–1*b*, 18C–2). This station is at an elevation of 1,115 m asl and has a drainage area of 8,055 km^2. The period of record for this station extends from 13 December, 1951, to 30 September, 1979 (Williams-Sether, 2008). The annual mean streamflow per unit area for this station is 0.0020 $m^3/s/km^2$. The seasonal timing of maximum and minimum monthly streamflow is high flows in the spring and low flows in late summer and fall. A statistical summary of monthly and annual mean streamflows for this station is presented in table 18C–3.

The three perennial streams that flow through the AOI (figs. 18C–1*b*, 18C–2) could possibly supply some quantity of water for mining activities. The extent of the irrigation mapped adjacent to these streams indicates that this surface water is an important resource for the local inhabitants in the AOI. The water from these rivers also provides recharge to the shallow alluvial aquifers in the river-valley bottoms. Any diversion of water from the rivers to support mining activities would have to be closely monitored to protect the water resources for use by the local population.

Table 18C–2. (on following page) Statistical summary of monthly and annual mean streamflows for the Tirin River at Tirin streamgage station (Williams-Sether, 2008).
[m^3/s, cubic meters per second]

4- 5.L00-4A TIRIN RIVER AT TIRIN

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	8.66	1977	2.86	1972	5.14	1.49	0.29	3.44
November	10.1	1977	4.10	1972	6.89	1.77	0.26	4.61
December	10.7	1977	4.37	1972	7.96	1.66	0.21	5.32
January	15.3	1977	7.20	1978	9.25	2.26	0.24	6.18
February	18.7	1977	9.18	1978	12.4	3.16	0.26	8.27
March	36.9	1972	11.6	1971	25.0	7.39	0.30	16.7
April	91.3	1976	8.67	1971	39.8	23.9	0.60	26.6
May	57.3	1976	2.26	1971	17.4	15.9	0.91	11.6
June	18.3	1976	1.91	1971	7.23	4.44	0.61	4.83
July	22.7	1976	2.08	1971	8.24	6.55	0.79	5.51
August	10.4	1976	1.74	1971	5.73	2.56	0.45	3.83
September	9.04	1976	2.25	1971	4.57	1.81	0.40	3.06
Annual	**23.4**	**1976**	**5.54**	**1971**	**12.8**	**4.77**	**0.37**	**100**

Table 18C–3. (on following page) Statistical summary of monthly and annual mean streamflows for the Tirin River at Anarjuy/Dehraout streamgage station (Williams-Sether, 2008).
[m^3/s, cubic meters per second]

4-5.L00-1A TIRIN RIVER AT ANARJUY/DEHRAOUT

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	13.1	1966	3.26	1964	6.62	2.55	0.39	3.44
November	19.0	1958	4.90	1972	9.78	3.57	0.37	5.09
December	28.6	1958	6.06	1972	12.9	5.29	0.41	6.72
January	29.9	1958	7.25	1963	14.4	5.57	0.39	7.51
February	46.0	1958	7.56	1963	20.0	9.09	0.45	10.4
March	70.3	1956	11.2	1963	33.2	14.8	0.45	17.3
April	115	1976	10.3	1971	44.0	25.0	0.57	22.9
May	71.0	1976	1.77	1971	22.5	16.2	0.72	11.7
June	26.6	1965	1.53	1971	9.21	6.74	0.73	4.79
July	28.4	1976	1.49	1971	8.41	7.07	0.84	4.37
August	18.4	1957	1.41	1971	6.05	3.95	0.65	3.15
September	14.2	1957	2.19	1971	5.15	2.99	0.58	2.68
Annual	**31.5**	**1976**	**6.87**	**1971**	**16.0**	**5.88**	**0.37**	**100**

18C.2.2 Groundwater

No community groundwater-supply wells are known to have been installed in the Bakhud fluorite AOI by NGOs, according to a database maintained by DACAAR (Danish Committee for Aid to Afghan Refugees, 2011), and no wells are shown in the VMAP1 database (National Imagery and Mapping Agency, 1995) (fig. 18C-5). There are likely to be dug wells completed in unconsolidated sediments in the AOI, particularly in low-lying areas and near perennial or ephemeral streams (fig. 18C–2).

A geohydrologic analysis of the groundwater conditions and resources near Tirin Kowt provided by the U.S. Army Corps of Engineers is summarized below (Andrew Clemens, U.S. Army Corps of Engineers, written commun., 2009). The depth to groundwater in the shallow, coarse-grained sand and gravel aquifers was about 26 to 36 m below ground surface (bgs) in 2009. The depth to groundwater may be as much as 330 m near the valley walls, far from the recharge provided by leakage of water from the river. Deep groundwater resources are known to be available in semi-confined conglomerate layers, up to 100 m bgs, which alternate with clay layers. Local cable-tool drilling methods are unable to penetrate to the deeper aquifers. The conglomerate aquifer may extend to 450 m or more bgs. Yields of wells in these aquifers are reported to be small, possibly as a result of the hardness of the water and the resulting mineral clogging of screens, and (or) as a result of declining water levels. In 2005 the groundwater at the military base in Tirin Kowt was found to contain high concentrations of sulfate (1,100 mg/L (milligrams per liter)), total dissolved solids (2,900 mg/L), magnesium (130 mg/L), zinc (8.2 mg/L), chloride (630 mg/L), and sodium (530 mg/L). Fluoride was detected at concentrations of 0.17 and 0.31 mg/L in 2004 and 2005, respectively.

18C.2.3 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 Bakhud fluorite AOI (B.E. Hubbard, T.J. Mack, and A.L. Thompson, unpub. data, 2011) were conducted using DEM and natural-color satellite imagery (fig. 18C–6) and Advanced Spaceborne Thermal Emission and Reflection Radiometry (ASTER) satellite imagery (fig. 18C–7*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 18C–6 were delineated visually, whereas those in figure 18C–7 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. Most of the AOI has predominantly northeast-trending lineaments that may reflect structural trends or bedding-plane weaknesses in the predominantly sedimentary rocks of the AOI. Areas where lineament density is high, such as in the limestones and dolostones geohydrologic group near the center and northwest of the AOI (figs. 18C–5, 18C–6, 18C–7*a*, 18C–7*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.

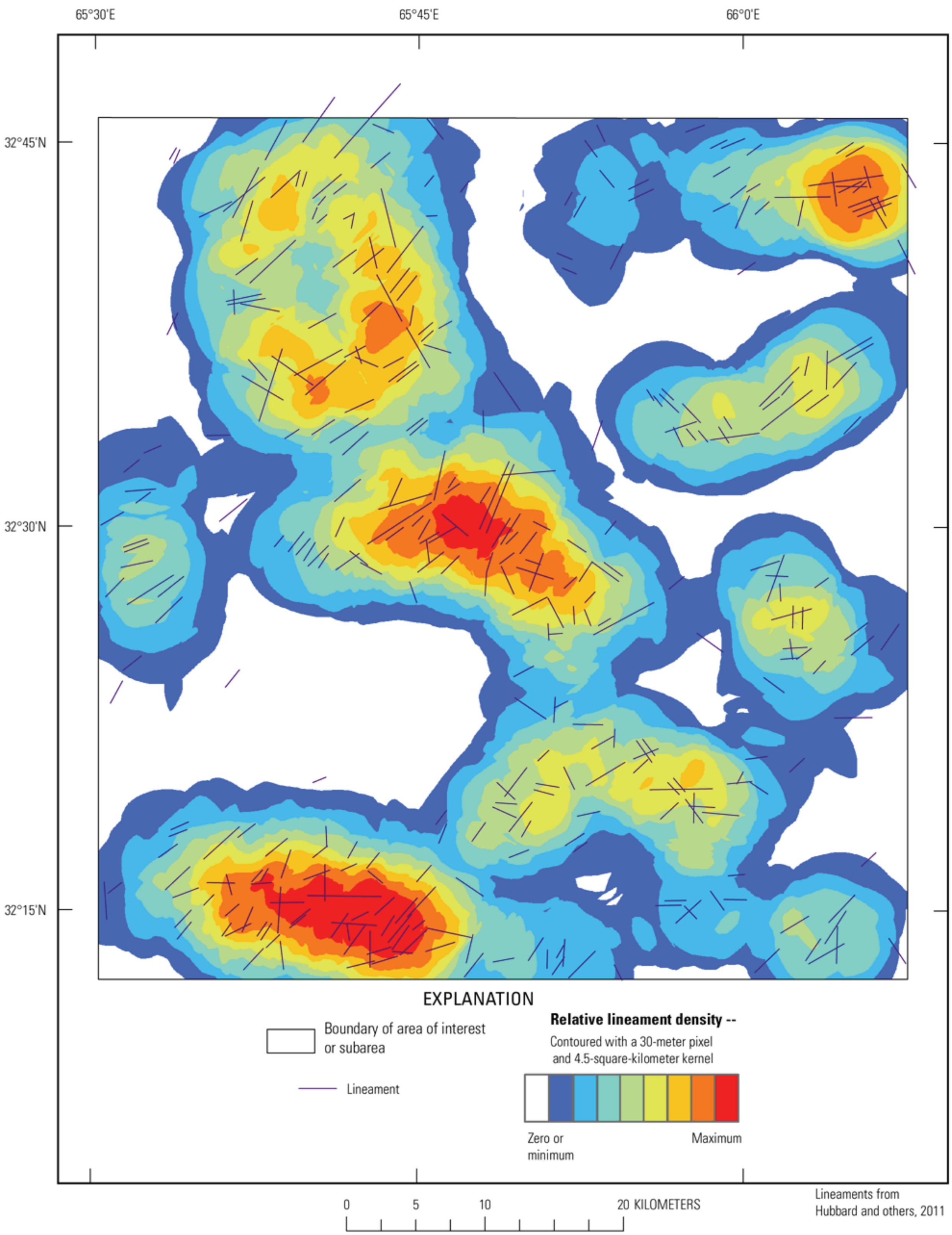
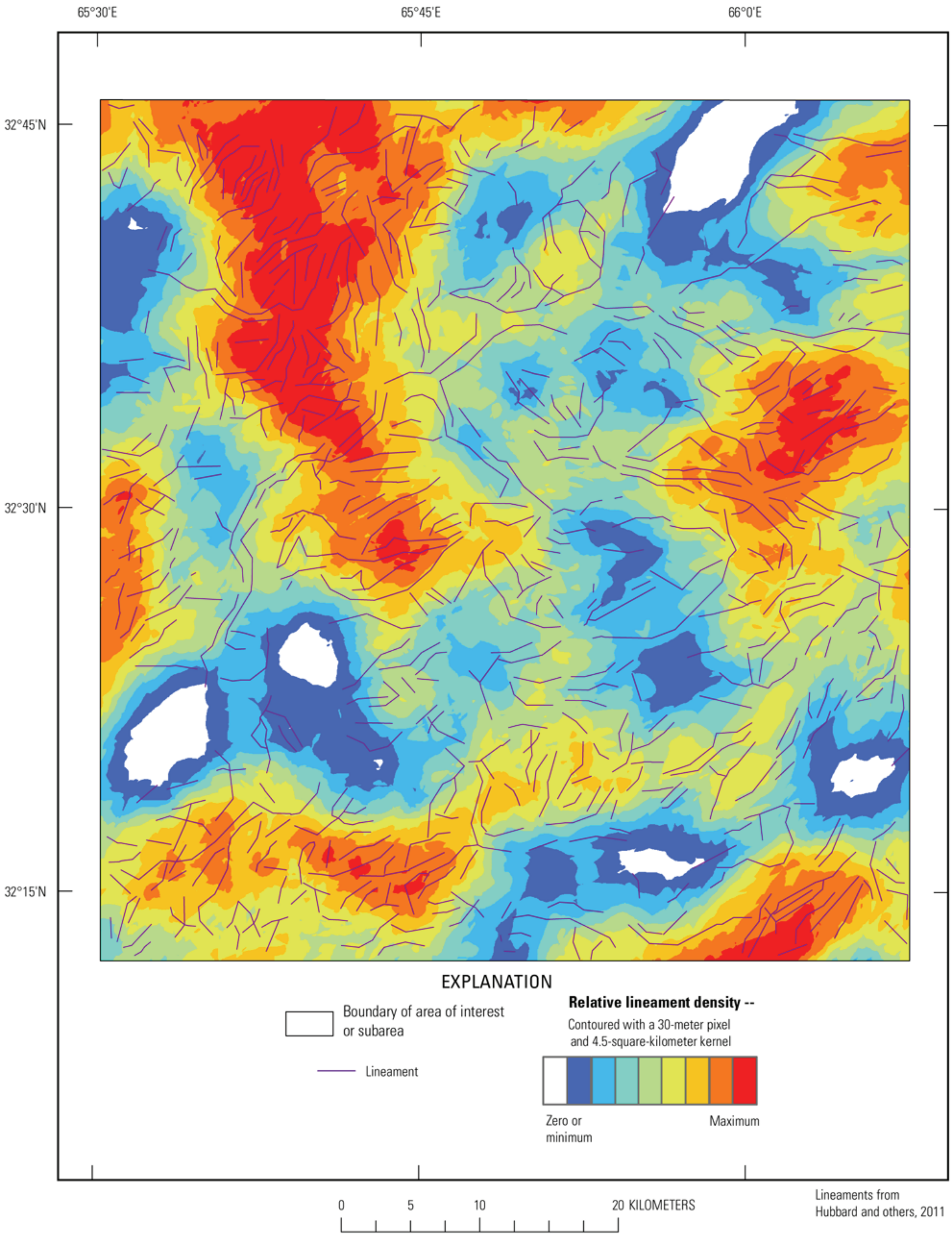


Figure 18C–6. Lineaments and lineament density based on 30-meter digital-elevation-model data and natural-color Landsat imagery in the Bakhud fluorite area of interest in Afghanistan.

a


65°30'E
65°45'E
66°0'E
32°45'N
32°30'N
32°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
5
10
20 KILOMETERS
Lineaments from Hubbard and others, 2011

b

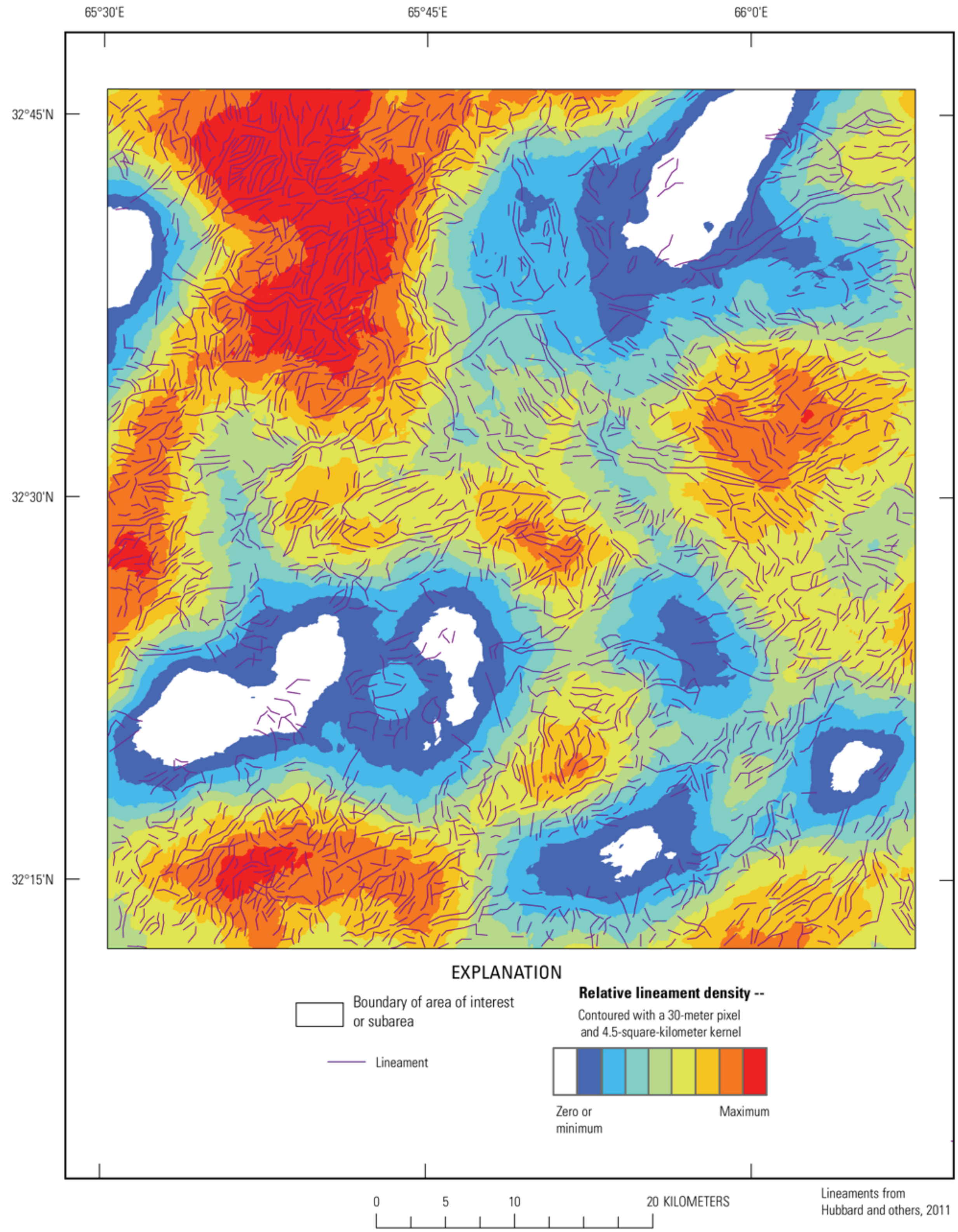


Figure 18C–7. (*a*) Lineaments and lineament density based on 30-meter multispectral Landsat imagery and (*b*) lineaments and lineament density based on 15-meter multispectral Landsat imagery in the Bakhud fluorite area of interest in Afghanistan.

18C.3 Summary and Conclusions

Water resources in the Bakhud fluorite area of interest (AOI) are limited, and it is unknown whether additional resources are likely to be available for mining. Water resources in the AOI and surrounding area consist mainly of surface water in the Tirin River and its tributaries. Most streams are highly utilized by the local population and represent the primary source of water for irrigation. The diversion of water from the rivers to support mining activities would need to be closely monitored, particularly during low-flow periods, so that the quantity and quality of the surface water remain sufficient to supply water for irrigation. Water leakage from irrigated fields is likely to provide recharge to the aquifers that supply groundwater to shallow wells for domestic consumption. Shallow alluvial aquifers less than 100 m (meters) thick are present in the valley bottoms of the AOI. Where present, they are a highly utilized groundwater resource, and water levels reportedly are declining. A semi-consolidated conglomeritic aquifer is also present; this aquifer may extend to 450 m or more below ground surface and may have the potential to provide additional water for mining-related activities.

No information about groundwater in the bedrock of the AOI or adjacent areas is available. 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. Close monitoring and careful 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.

18C.4 References Cited

Abdullah, Sh., and Chmyriov, V.M., eds. in chief, 1977, Geology and mineral resources of Afghanistan, book 2: Afghanistan Ministry of Mines and Industries, Afghanistan Geological Survey, reprinted 2008, British Geological Survey Occasional Publications No. 15, 292 p.

Afghanistan Information Management Service, 1997, Irrigated areas, 1:250,000 scale, Afghanistan Information Management Service Afghanistan Shape Files, accessed October 15, 2010, at *http://www.aims.org.af/.*

Bohannon, R.G., 2005, Topographic map of quadrangle 3264, Nawzad-Musa-Qala (423) and Dehrawat (424) quadrangles, Afghanistan: U.S. Geological Survey Open-File Report 2005–1115B.

Bohannon, R.G., and Lindsay, C.R., 2005, Geologic map of quadrangle 3264, Nawzad-Musa-Qala (423) and Dehrawat (424) quadrangles, Afghanistan: U.S. Geological Survey Open-File Report 2005–1115A .

Breckle, S.W., 2007, Flora and vegetation of Afghanistan: Basic and Applied Dryland Research, v. 1, no. 2, p 155–194.

Danish Committee for Aid to Afghan Refugees, 2011, Update on “National groundwater monitoring wells network activities in Afghanistan” from July 2007 to December 2010: Kabul, Afghanistan, Danish Committee for Aid to Afghan Refugees (DACAAR), 23 p.

Davis, P.A., 2006, Calibrated Landsat ETM+ mosaics of Afghanistan: U.S. Geological Survey Open-File Report 2006–1345, 18 p., also at *http://pubs.usgs.gov/of/2006/1345/.*

Doebrich, J.L., and Wahl, R.R., comps., *with contributions by* Doebrich, J.L., Wahl, R.R., Ludington, S.D., Chirico, P.G., Wandrey, C.J., Bohannon, R.G., Orris, G.J., Bliss, J.D., ____, and ____, 2006, Geologic and mineral resource map of Afghanistan: U.S. Geological Survey Open File Report 2006–1038, scale 1:850,000, available at *http://pubs.usgs.gov/of/2006/1038/.*

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Lattman, L.H., and Parizek, R.R., 1964, Relationship between fracture traces and the occurrence of ground water in carbonate rocks: Journal of Hydrology, v. 2, p. 73–91.

Mabee, S.B., 1999, Factors influencing well productivity in glaciated metamorphic rocks: Groundwater, v. 37, no. 1, p. 88–97.

Ministry of Agriculture, Irrigation, and Livestock and the Afghan Meteorological Authority of Ministry of Transport, 2010, The Afghanistan agrometeorological seasonal bulletin 2009–2010, no. 7, 26 p., accessed July 6, 2011, at *http://afghanistan.cr.usgs.gov/documents.php?cat=1*.

Moore, R.B., Schwarz, G.E., Clark, S.F., Jr., Walsh, G.J., and Degnan, J.R., 2002, Factors related to well yield in the fractured-bedrock aquifer of New Hampshire: U.S. Geological Survey Professional Paper 1660, 51 p., 2 pls.

National Imagery and Mapping Agency, 1995, Vector map (VMAP1): National Imagery and Mapping Agency database, available at *http://geoengine.nga.mil/geospatial/SW_TOOLS/NIMAMUSE/webinter/rast_roam.html*.

Oak Ridge National Laboratory, 2010, LandScan global population database 2009: Oak Ridge National Laboratory database, accessed February 1, 2011, at *http://www.ornl.gov/sci/landscan/*.

Peters, S.G., Ludington, S.D., Orris, G.J., Sutphin, D.M., Bliss, J.D., and Rytuba, J.J., eds., and the U.S. Geological Survey-Afghanistan Ministry of Mines Joint Mineral Resource Assessment Team, 2007, Preliminary non-fuel mineral resource assessment of Afghanistan: U.S. Geological Survey Open-File Report 2007–1214, 810 p., 1 CD–ROM. (Also available at *http://pubs.usgs.gov/of/2007/1214/*.)

Ruleman, C.A., Crone, A.J., Machette, M.N., Haller, K.M., and Rukstales, K.S., 2007, Map and database of probable and possible Quaternary faults in Afghanistan: U.S. Geological Survey Open-File Report 2007–1103, 39 p., 1 pl.

Siddiqui, S.H., and Parizek, R.R., 1971, Hydrogeologic factors influencing well yields in folded and faulted carbonate rocks in central Pennsylvania: Water Resources Research, v. 7, no. 5, p. 1295–1312.

Williams-Sether, Tara, 2008, Stream-flow characteristics of streams in the Helmand Basin, Afghanistan: U.S. Geological Survey Data Series 333, 341 p.