Chapter 14C. Geohydrologic Summary of the Tourmaline Tin Area of Interest

By Thomas J. Mack and Michael P. Chornack

14C.1 Introduction

This chapter describes the geohydrology of the tourmaline tin area of interest (AOI) in western Afghanistan identified by Peters and others (2007) (fig. 14C–1*a*,*b*). This AOI occupies an area of 1,365 km^2 (square kilometers) in the Anar Dara and Shindand Districts in the Farah and Hirat Provinces (fig. 14C–1*a*,*b*).

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 bedrock may be more fractured than in other areas, which may be an indicator of high relative water yield and storage in bedrock aquifers.

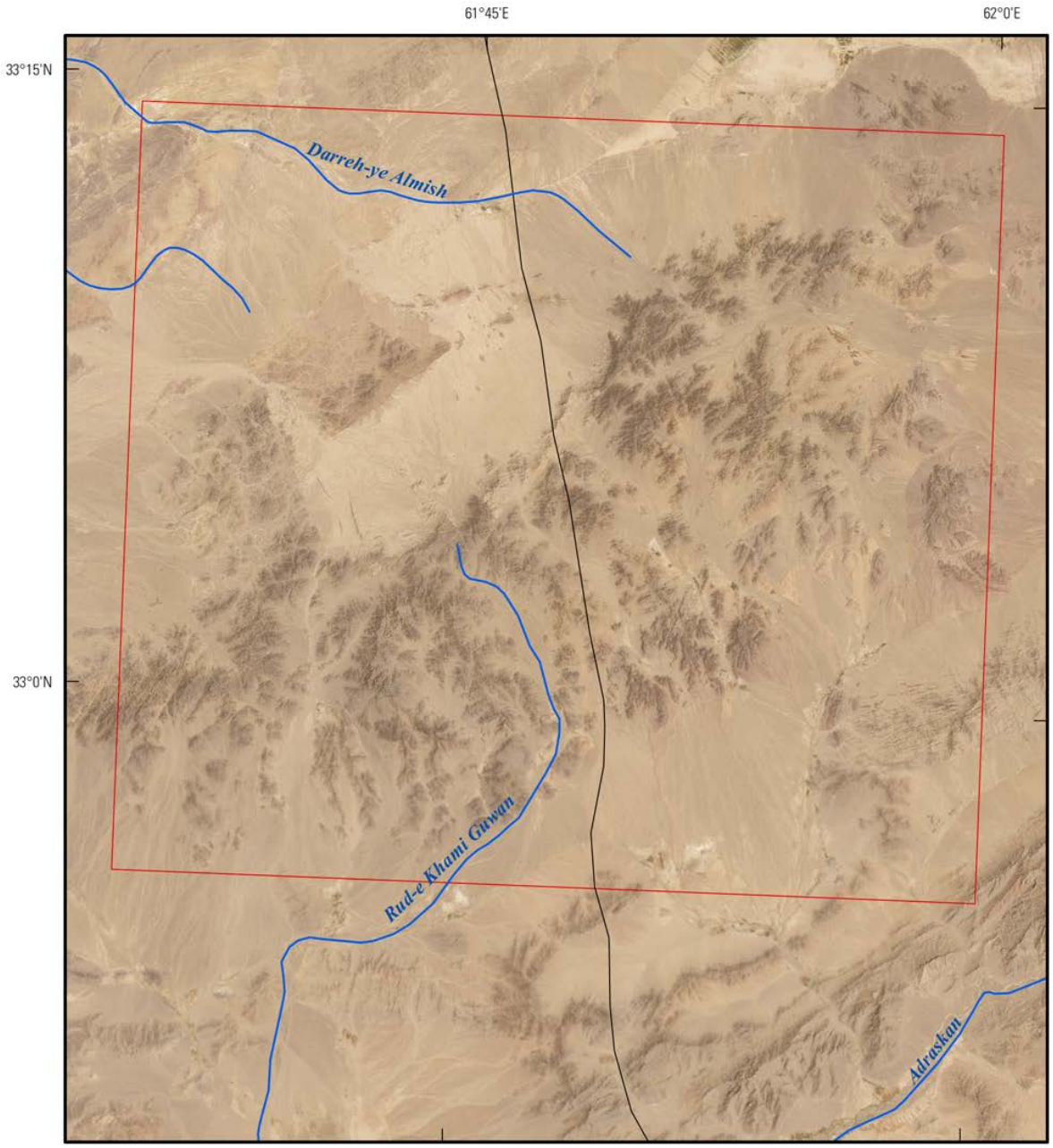
Afghanistan's recent turbulent history has left many of the traditional archival institutions in ruins, and most water-resource and meteorological data-collection activities had stopped by 1980. Recently (2011), nongovernmental organizations (NGOs), foreign government agencies, and the Afghan government 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.

14C.1.1 Climate and Vegetation

Climate information for the tourmaline tin 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.

The Shindand AgroMet station is located in Hirat Province approximately 40 km (kilometers) northeast of the center of the AOI. This station is the Agromet station that is closest to the AOI for which 2009–2010 water year and long-term average (LTA) precipitation data are available. Precipitation data for this Agromet station (Ministry of Agriculture, Irrigation, and Livestock, 2010) are shown in table 14C–1. No snowfall was reported for this station during the 2009–2010 water year, but 15 cm (centimeters) of snow was reported during the 2008–2009 water year.

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 2 4 8 KILOMETERS

EXPLANATION

Boundary of area of interest (AOI) or subarea

Province boundary line

District boundary line

Stream, generally perennial

b

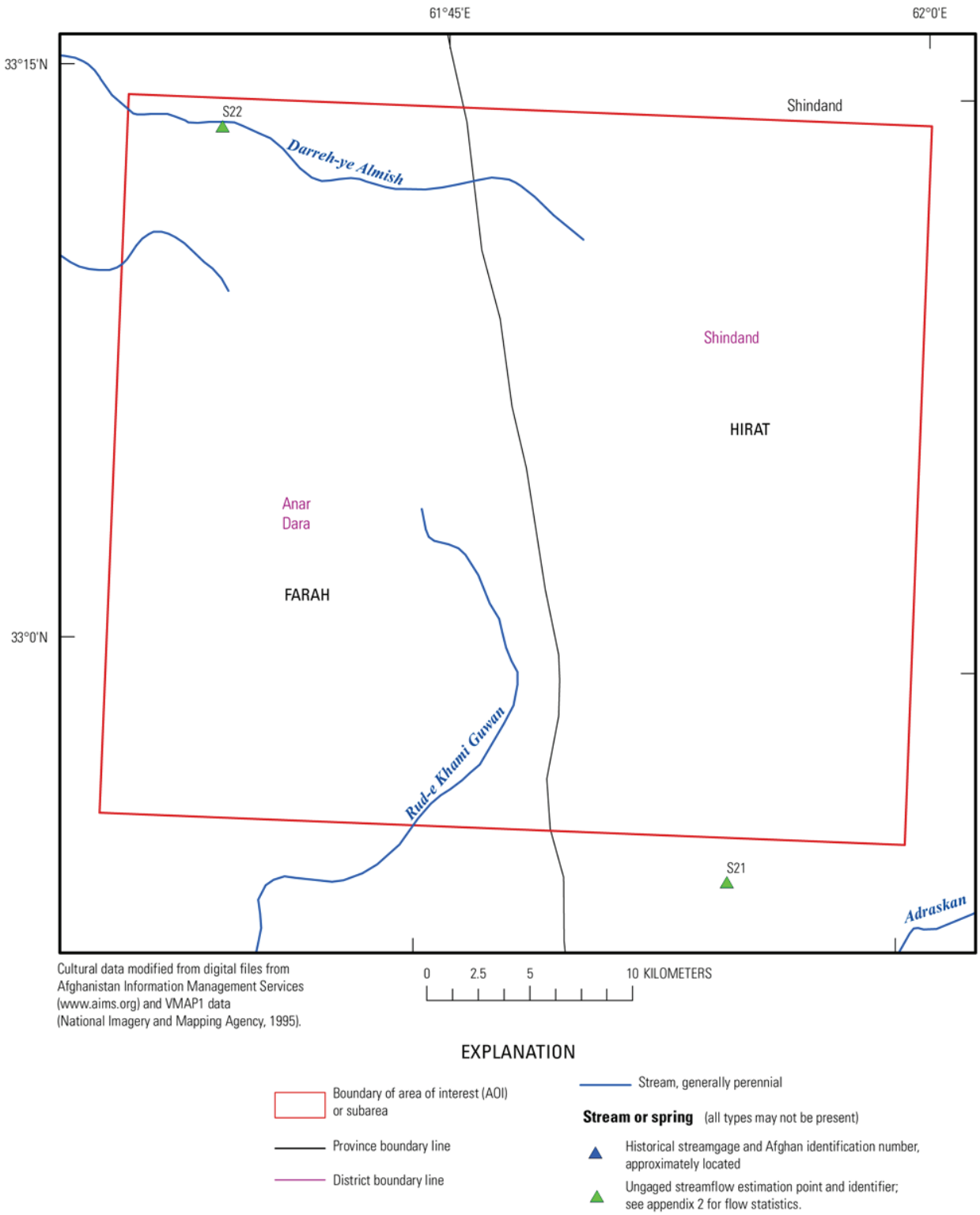


Figure 14C–1. (*a*) Landsat image showing the location of, and (*b*) place names, stream names, and streamgage station numbers in, the tourmaline tin area of interest in western Afghanistan.

Information available for the Hirat Agromet station located 150 km north of the center of the AOI includes 2009–2010 water year and LTA precipitation and temperature data. Precipitation and

temperature data for this Agromet station (Ministry of Agriculture, Irrigation, and Livestock, 2010) are shown in table 14C–1.

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 as classified by Breckle (2007, p. 161) changes from northwest to southeast across the AOI. A small zone of vegetation described as "other deserts, rich in chenopod" in the northwest corner abruptly changes to "dwarf *Amygdalus*-semidesert" at slightly higher elevations to the east and southeast. As the elevation continues to increase to the south and east, the "*Amygdalus*-woodlands" becomes the dominant vegetation type. Much of the upland surface of the AOI is bedrock outcrop with thin alluvial cover. Very little land in the AOI is suitable for farming, and there are few irrigated areas (fig. 14C–2).

Table 14C–1. Annual, long-term annual average, and long-term average minimum and maximum precipitation and temperature at the Shindand and Herat Agromet stations, 40 km northeast and 150 km north, respectively, of the tourmaline tin area of interest, in western 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)
Shindand	40	1,070	198	195.6	0 multiple months[2]	50.8 May	nr	nr	nr
Hirat	150	920	198	224.7	0 multiple months[3]	49.9 March	3.1 January	13.8	29.6 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).

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

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

14C.1.2 Demographics

The tourmaline tin AOI is sparsely populated, with most areas either being uninhabited or having from 1 to 25 inhabitants per km^2 (square kilometer) as mapped by LandScan (Oak Ridge National Laboratory, 2010) (fig. 14C–3). Approximately half the AOI may be inhabited (fig. 14C–3). In a few areas, population density ranges from 101 to 500/km^2. These areas are probably small farming settlements, some of which may be transient. The population density shown in figure 14C–3 has a pixel resolution of about 1 km^2 (Oak Ridge National Laboratory, 2010).

14C.1.3 Topography

The topography of the tourmaline tin AOI consists of a dissected, northeast-trending, mountainous area surrounded by sediment-covered desert plains (fig. 14C–4). The highest elevations, in the northeast part of the AOI, are slightly more than 1,500 m (meters) above sea level (asl) (Bohannon, 2005). The elevations of the lower areas average 1,000 m asl. Many of the landforms in the lower elevation areas appear to have been formed by desert eolian and fluvial processes.

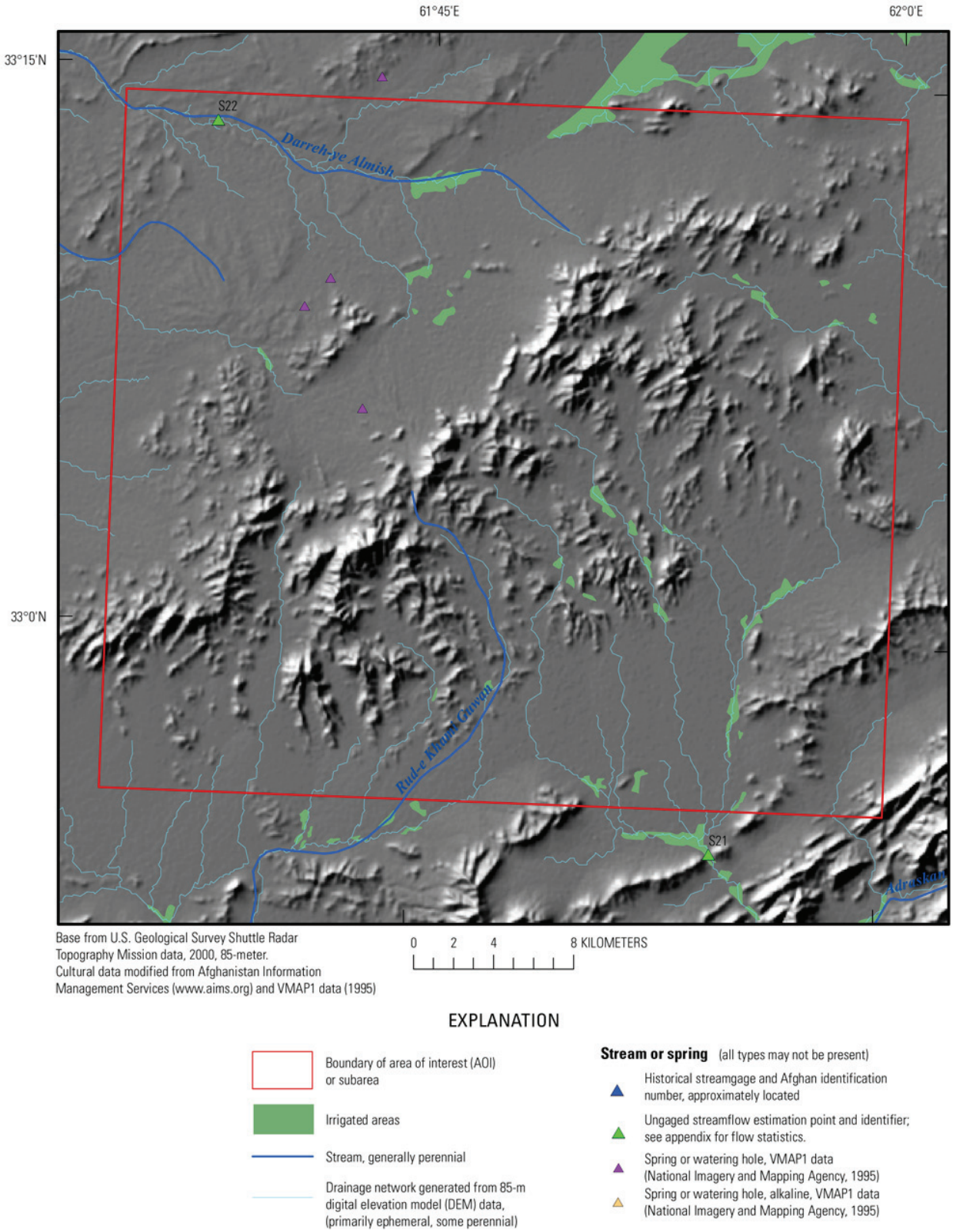


Figure 14C–2. Historical streamgage locations, digitally generated drainage network, and irrigated areas in the tourmaline tin area of interest in western Afghanistan.

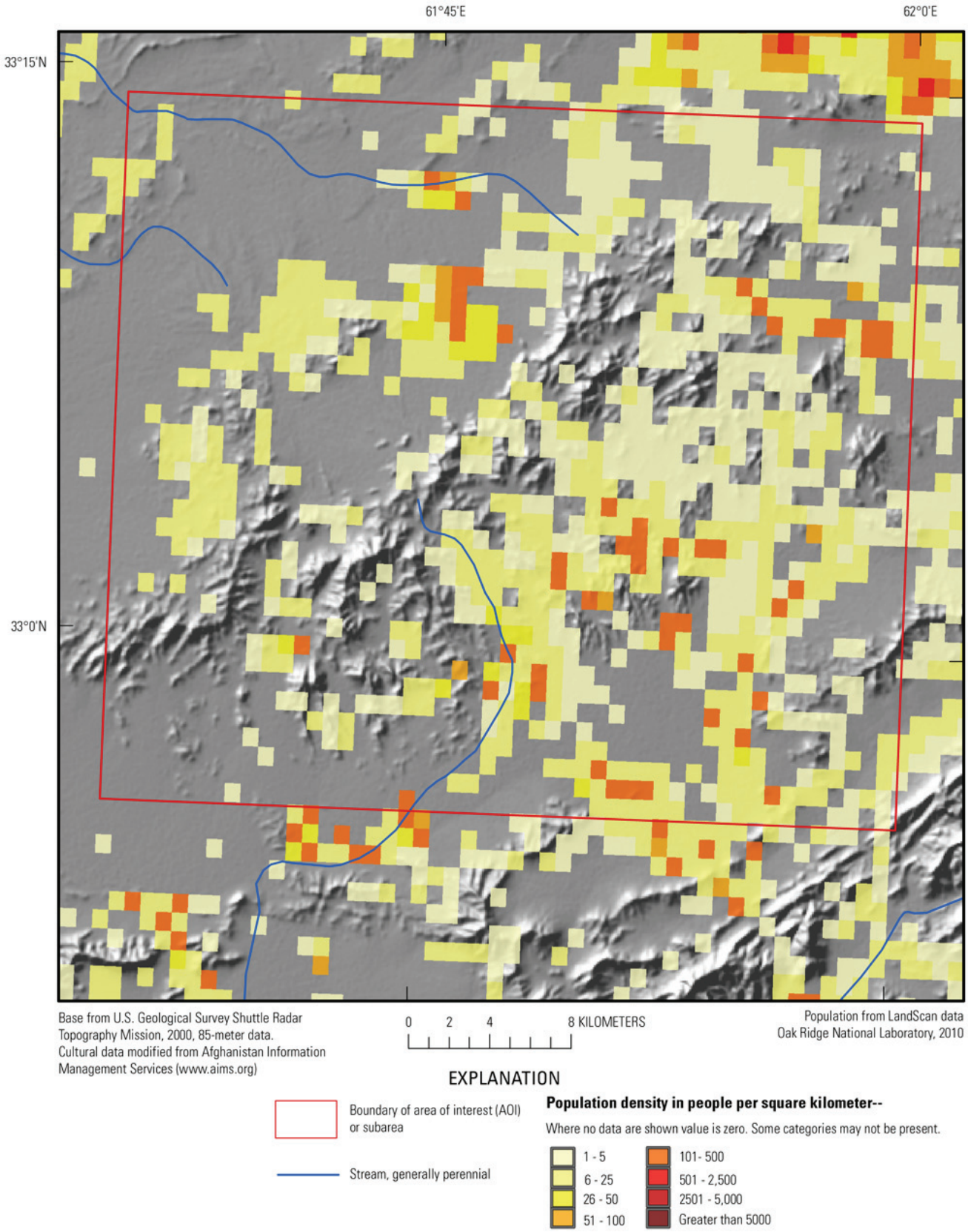
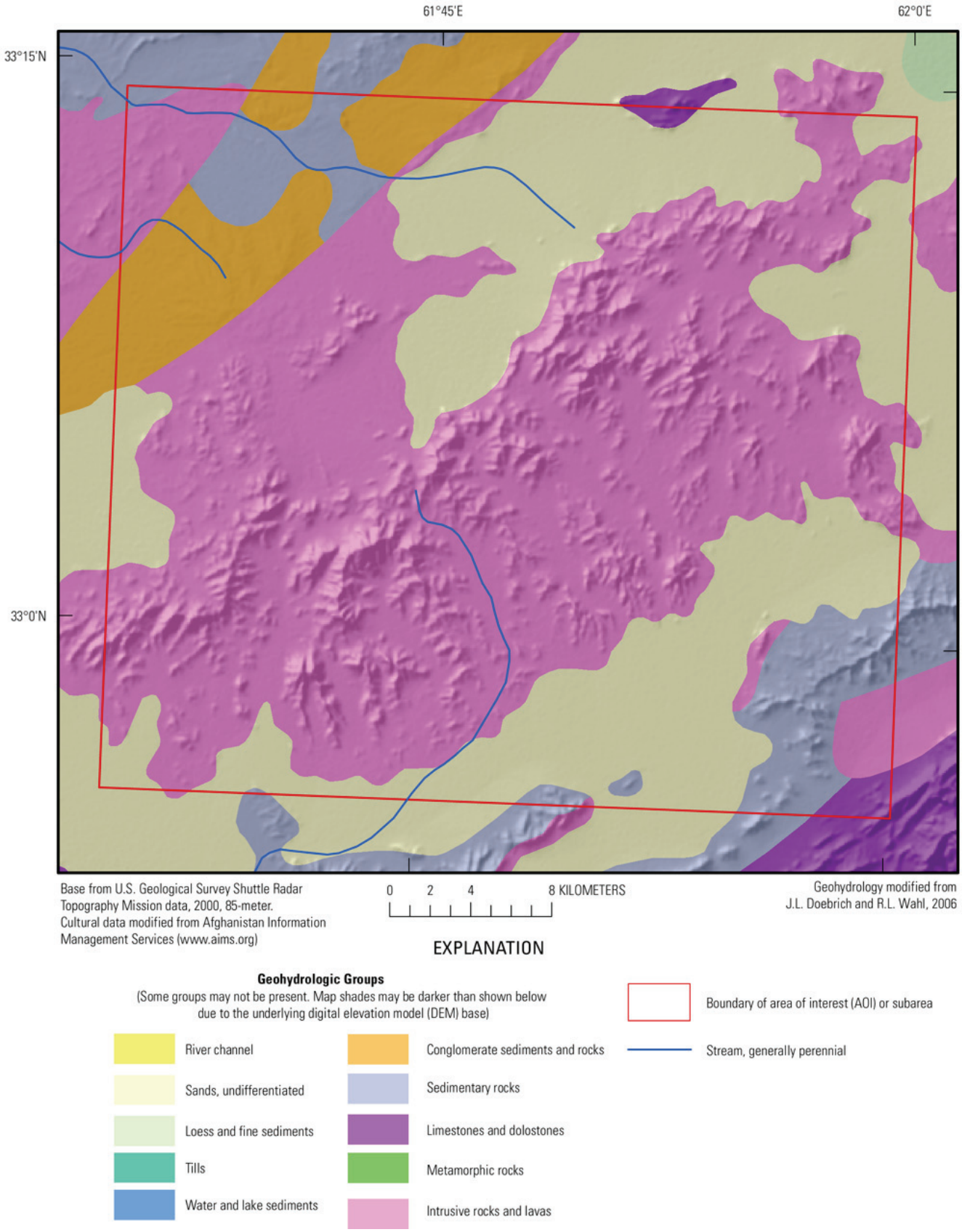


Figure 14C–3. Population density of the tourmaline tin area of interest in western Afghanistan.



14C–4. Topography and generalized geohydrology of the tourmaline tin area of interest in western Afghanistan.

14C.1.4 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 tourmaline tin 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 14C–4 with the underlying topography to allow examination of the geohydrology in the context of relief. Figure 14C–5 shows the generalized geohydrology without topography for a clearer depiction of the geohydrologic units. Any mapped wells present in the AOI (discussed in the Groundwater section) are shown in figure 14C–5. 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. 14C–4, 14C–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 maps that cover this AOI are provided by Bohannon and Lindsay (2005) and Litke (2005).

The sands, undifferentiated geohydrologic group is mapped at the lower elevations of the AOI, generally surrounding the outcrops of the intrusive rocks and lavas geohydrologic group (figs. 14C–4, 14C–5). No information is available on the thickness of this unit but, on the basis of the width of the outcrop areas, the maximum thickness may be less than 1,000 m. In a preliminary analysis of historical and recent aeromagnetic data (Sweeney and others, 2006; Shenwary and others, 2011), Drenth (2009) estimated the thickness of sediments overlying basement rock in a larger sedimentary basin 30 km southeast of the AOI to be at least 1,000 m, and possibly more than 2,000 m. The conglomerate sediments and rocks geohydrologic group is present in the northwest corner of the AOI (figs. 14C–4, 14C–5). This geohydrologic group occupies a small area and no information is available on its thickness. The sediments and rocks of this group appear to have been deposited on the intrusive rocks and lavas and sedimentary rocks geohydrologic groups.

The intrusive rocks and lavas geohydrologic group constitutes the largest mapped unit in the AOI (figs. 14C–4, 14C–5). As shown in figure 14C– 2, a substantial part of this area is covered by alluvial material, and only the higher elevation areas appear to consist of bedrock outcrop. The sedimentary rocks geohydrologic group crops out in the northwest and southeast corners of the AOI (figs. 14C–4, 14C–5). These rocks are probably not an important groundwater resource within the AOI. If extensive outcrops are present adjacent to the AOI, this unit could be a potential source of groundwater. The limited information on the geohydrologic units indicates that field studies are needed to assess the groundwater resources in the AOI**.**

14C.1.5 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), in the tourmaline tin AOI is shown in figure 14C–2. A network representing likely ephemeral streams, generated with a digital elevation model (DEM), also is shown in figure 14C–2. Mapped springs, identified in the Vector Map (VMAP1) database (National Imagery and Mapping Agency, 1995), are shown in and adjacent to the AOI. Names of major streams and identification numbers for any streamgages and ungaged streamflow estimation sites in the AOI are shown in figure 14C–1*b*.

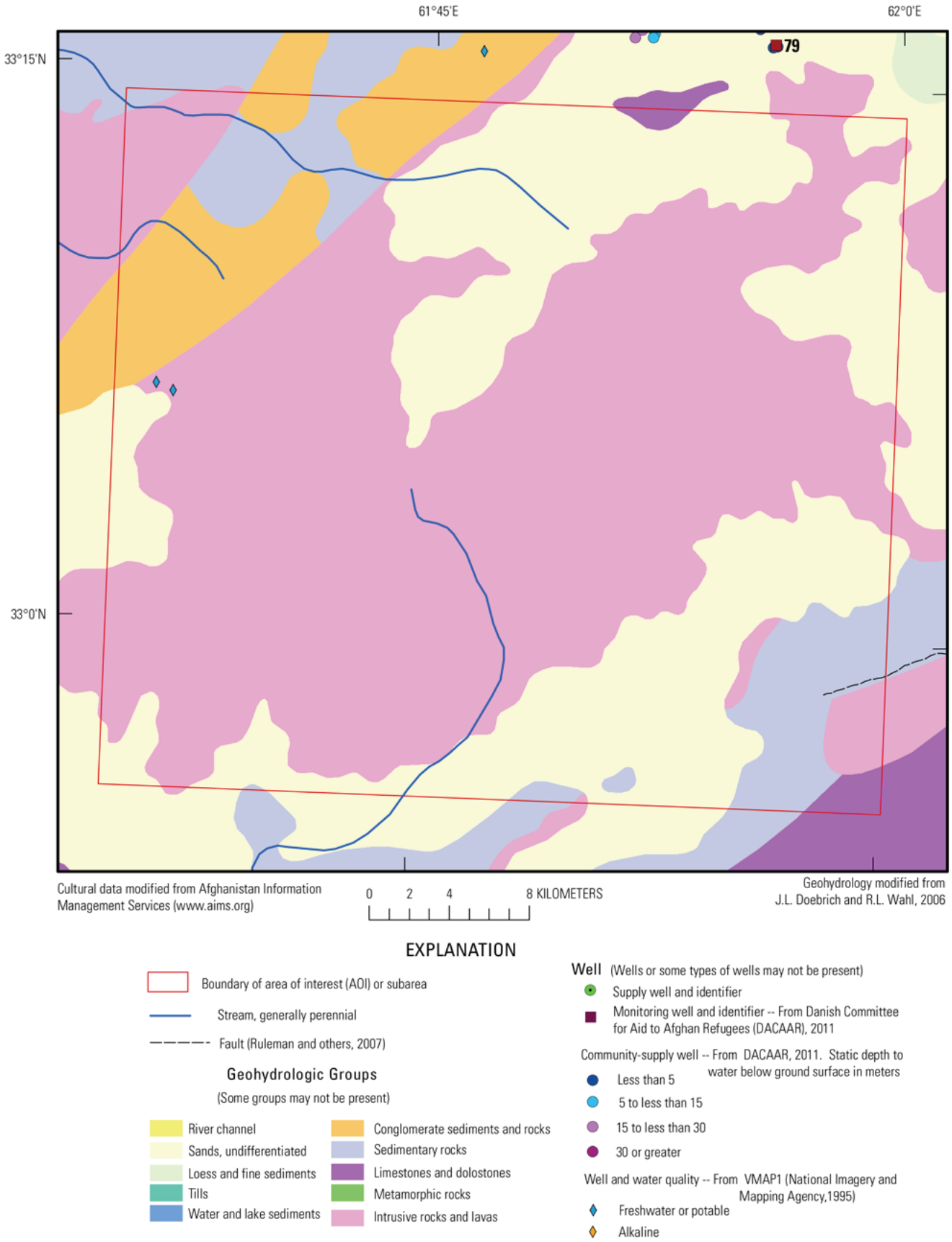


Figure 14C–5. Generalized geohydrology, mapped faults, and well locations in and near the tourmaline tin area of interest in western Afghanistan.

The streamgage station nearest to the AOI is the Adraskan River at Adraskan station (Afghan identification number 7-0.000-7M), located approximately 75 km northeast of the center of the AOI (Williams-Sether, 2008). This station is at an elevation of 1,340 m asl and has a drainage area of 1,970 km^2 and a period of record that extends from 30 March, 1933, to 30 September, 1978 (Williams-Sether, 2010). The annual mean streamflow per unit area for this station is 0.0033 $m^3/s/km^2$ (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 early fall. A statistical summary of monthly and annual mean streamflows for this station is presented in table 14C–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 Rud-i-Gaz River near Adraskan streamgage station (Afghan identification number 7-5.R00-1A) is about 83 km northeast of the AOI and 7 km from the Adraskan River at Adraskan streamgage station. This station is at an elevation of 1,380 m asl and has a drainage area of 2,180 km^2 and a period of record that extends from 12 May, 1963, to 30 September, 1978 (Williams-Sether, 2010). The annual mean streamflow per unit area for this station is 0.0025 $m^3/s/km^2$. The seasonal timing of maximum and minimum monthly streamflow is high flows in the spring and low flows in late summer and early fall. A statistical summary of monthly and annual mean streamflows for this station is presented in table 14C–3.

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, presented in appendix 2, were calculated for points S21 and S22 (figs. 14C–1*b* and 14C–2) on selected streams in the AOI or subareas, using a drainage-area-ratio method (Olson and Mack, 2011) based on historical flows at the Adraskan River at Adraskan streamgage station (Afghan identification number 7-0.000-7M) and the Rud-i-Gaz River near Adraskan streamgage station (Afghan identification number 7-5.R00-1A) (Williams-Sether, 2008). These streamgage stations were selected as the most representative historical gages, on the basis of their size and proximity to the AOI, for use with this method. The areas of the drainage basins for which flow was estimated were small, however, and the resulting flow estimates should be considered rough approximations. The estimated mean annual streamflow at point S21 (app. 2), with a drainage area of 415.7 km^2, is about 1.16 m^3/s (cubic meters per second). By applying the same method, the estimated mean annual streamflow at point S22 is 0.71 m^3/s. The seasonal timing of maximum and minimum monthly streamflow, with high flows in the spring and low flows in late summer and early fall (app. 2), probably is similar to that at the Adraskan River at Adraskan streamgage station.

Little irrigation occurs in the AOI; where irrigation does occur, the source of the water is probably the alluvial material. Aerial images show that traditional hand-dug water tunnels (karezes) have been constructed in the alluvial sediments; the karezes are used to transport water for domestic supply and irrigation.

14C.1.6 Groundwater

No NGO community groundwater-supply wells have been installed in the tourmaline tin AOI, according to a database maintained by DACAAR (Danish Committee for Aid to Afghan Refugees, 2011). A group of community supply wells is present about 5 km north of the AOI (fig. 14C–5); the depth to water in these wells is generally between 5 and 15 m (fig. 14C–5). Two wells are identified in the VMAP1 database (National Imagery and Mapping Agency, 1995); these wells are shown in figure 14C–5. Additional dug wells likely are completed in unconsolidated sediments in the AOI, particularly in areas near the Darreh-ye Almish and Rud-e Khami Guwan streams (fig. 14C–2); however, no additional information is available about shallow supply wells, which may or may not exist in the AOI. Similarly, no information is available on groundwater resources in the bedrock aquifers of the AOI. VMAP1 data (fig. 14C–5) indicate that the two wells in the AOI contain fresh or potable water;

however, no other water-quality information is available for the unconsolidated or bedrock aquifers in the AOI. During USGS reconnaissance visits to the Dusar-Shaida AOI, layers of saline groundwater were found to be present in similar basins. These conditions may also be present in the tourmaline tin AOI.

One groundwater-monitoring well (GWM 79) less than 3 km from the AOI (fig. 14C–5) is monitored by DACAAR for groundwater levels and specific conductance. Another well, GWM 63, about 40 km east-northeast of the center of the AOI is also monitored by DACAAR. Hydrographs of water levels in groundwater-monitoring wells in the AOI, provided by DACAAR, are shown in appendix 3. The hydrographs show the date in week number and year, groundwater specific conductance in microsiemens per centimeter at 25° Celsius (µS/cm), and depth to water in meters below ground surface (bgs). The depth to water in GWM 79 was about 6 to 8 m and had a seasonal fluctuation of 1 to 2 m. Groundwater specific conductance was about 2,000 µS/cm. This well is likely constructed in unconsolidated sediments. Alluvial basins occupy only a small percentage of the AOI. Limited groundwater may be available in the sedimentary rocks in the AOI; however, no information about this potential resource is available.

Shallow groundwater resources may be present in the sands, undifferentiated geohydrologic group. Deeper groundwater could be present in thick sequences of sediments in this group; however, as a result of the low precipitation and high evaporation rates that characterize this region, deep groundwater could be recharged very slowly and may be as much as thousands to tens of thousands of years old (Mack and others, 2010). Where it is sufficiently thick, the conglomerate sediments and rocks group may have limited groundwater availability.

14C.1.7 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 tourmaline tin AOI (B.E. Hubbard, T.J. Mack, and A.L. Thompson, unpub. data, 2011) were conducted using DEM and natural-color satellite imagery (fig. 14C–6) and Advanced Spaceborne Thermal Emission and Reflection Radiometry (ASTER) satellite imagery (fig. 14C–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 14C–6 were delineated visually, whereas those in figure 14C–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. Many lineaments in the AOI are aligned to the northeast in a pattern that may be related to a structural trend or bedding-plane weaknesses. Some lineaments are coincident with the mapped faults in the southeast area of the AOI (fig. 14C–5). Areas where lineament densities are high (figs. 14C–6, 14C–7*a*, 14C–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.

Table 14C–2. Statistical summary of monthly and annual mean streamflows for the Adraskan River at Adraskan streamgage station (Williams-Sether, 2008).

[m^3/s, cubic meters per second]

7- 0.000-7M ADRASKAN RIVER AT ADRASKAN

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	1.77	1970	0.149	1964	0.79	0.50	0.64	1.02
November	4.50	1978	0.703	1972	1.69	1.00	0.59	2.19
December	19.3	1969	0.415	1964	2.79	4.62	1.66	3.61
January	10.7	1969	1.02	1971	3.03	2.65	0.87	3.93
February	19.5	1972	1.57	1971	7.66	5.24	0.68	9.93
March	40.8	1972	2.46	1971	17.9	10.4	0.58	23.2
April	57.1	1976	3.85	1963	23.4	17.6	0.75	30.4
May	34.4	1967	2.80	1970	13.4	9.40	0.70	17.4
June	10.9	1976	0.715	1970	3.98	3.00	0.75	5.17
July	3.52	1972	0.306	1970	1.35	0.93	0.69	1.75
August	2.04	1976	0.010	1971	0.58	0.53	0.92	0.75
September	1.37	1976	0.010	1971	0.56	0.42	0.75	0.72
Annual	**13.0**	**1972**	**1.89**	**1971**	**6.53**	**3.60**	**0.55**	**100**

Table 14C–3. Statistical summary of monthly and annual mean streamflows for the Rud-i-Gaz River near Adraskan streamgage station (Williams-Sether, 2008).

[m^3/s, cubic meters per second]

7- 5.R00-1A RUD-I-GAZ RIVER NEAR ADRASKAN

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	1.10	1977	0.062	1972	0.51	0.33	0.66	0.77
November	2.48	1978	0.209	1971	0.96	0.62	0.65	1.46
December	11.9	1969	0.410	1965	1.74	2.84	1.63	2.65
January	6.68	1969	0.602	1964	2.07	1.51	0.73	3.15
February	8.14	1969	1.04	1971	4.51	2.42	0.54	6.86
March	39.9	1972	1.75	1967	19.3	13.4	0.70	29.3
April	76.7	1976	6.45	1971	24.2	18.7	0.77	36.9
May	25.6	1976	1.29	1971	9.10	8.14	0.89	13.8
June	4.80	1967	0.232	1971	1.78	1.53	0.86	2.70
July	1.93	1976	0.075	1971	0.75	0.58	0.77	1.14
August	1.16	1976	0	1970, 1971	0.39	0.35	0.90	0.59
September	1.05	1976	0	1971	0.40	0.34	0.85	0.61
Annual	**13.2**	**1976**	**1.05**	**1971**	**5.47**	**3.31**	**0.61**	**100**

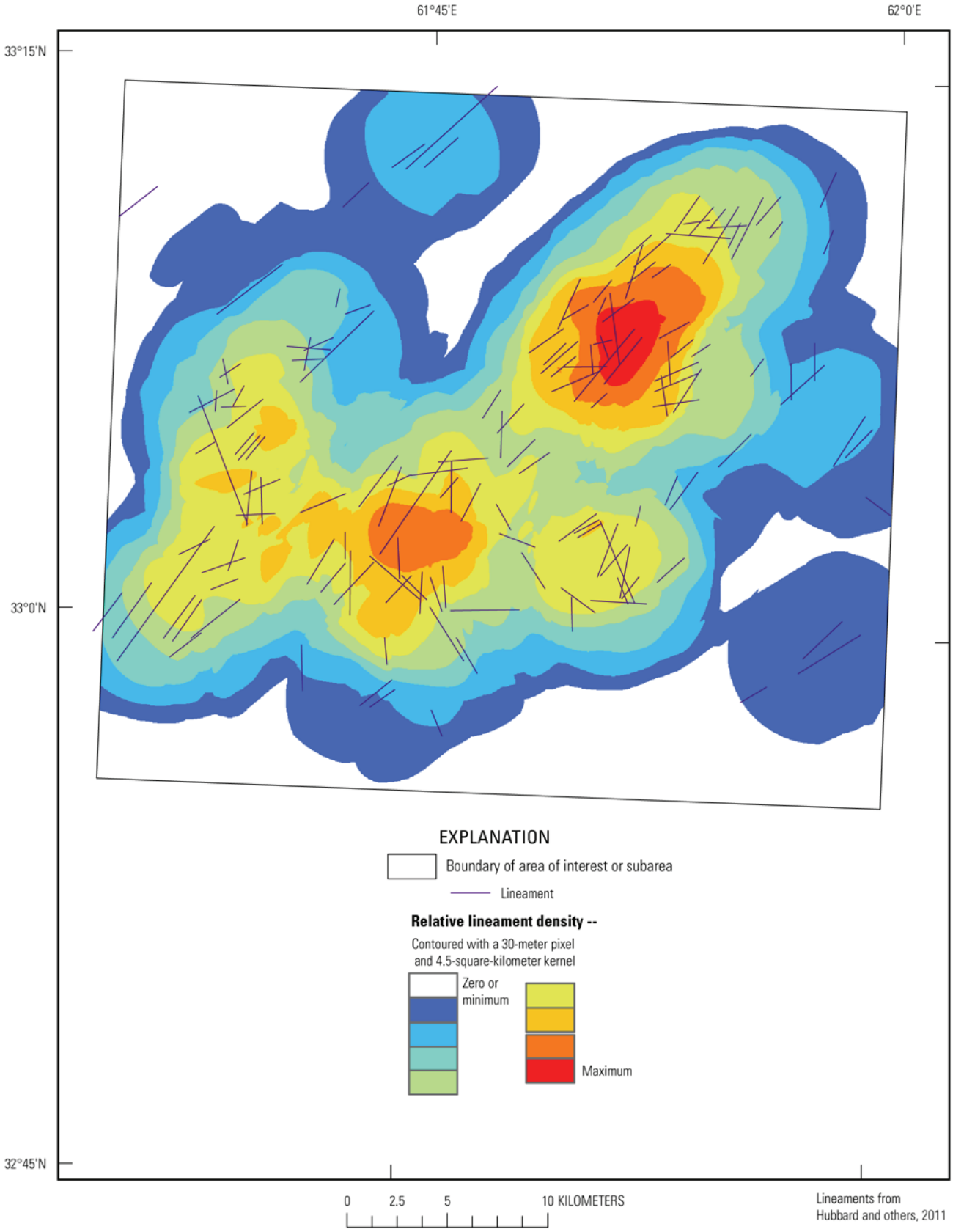
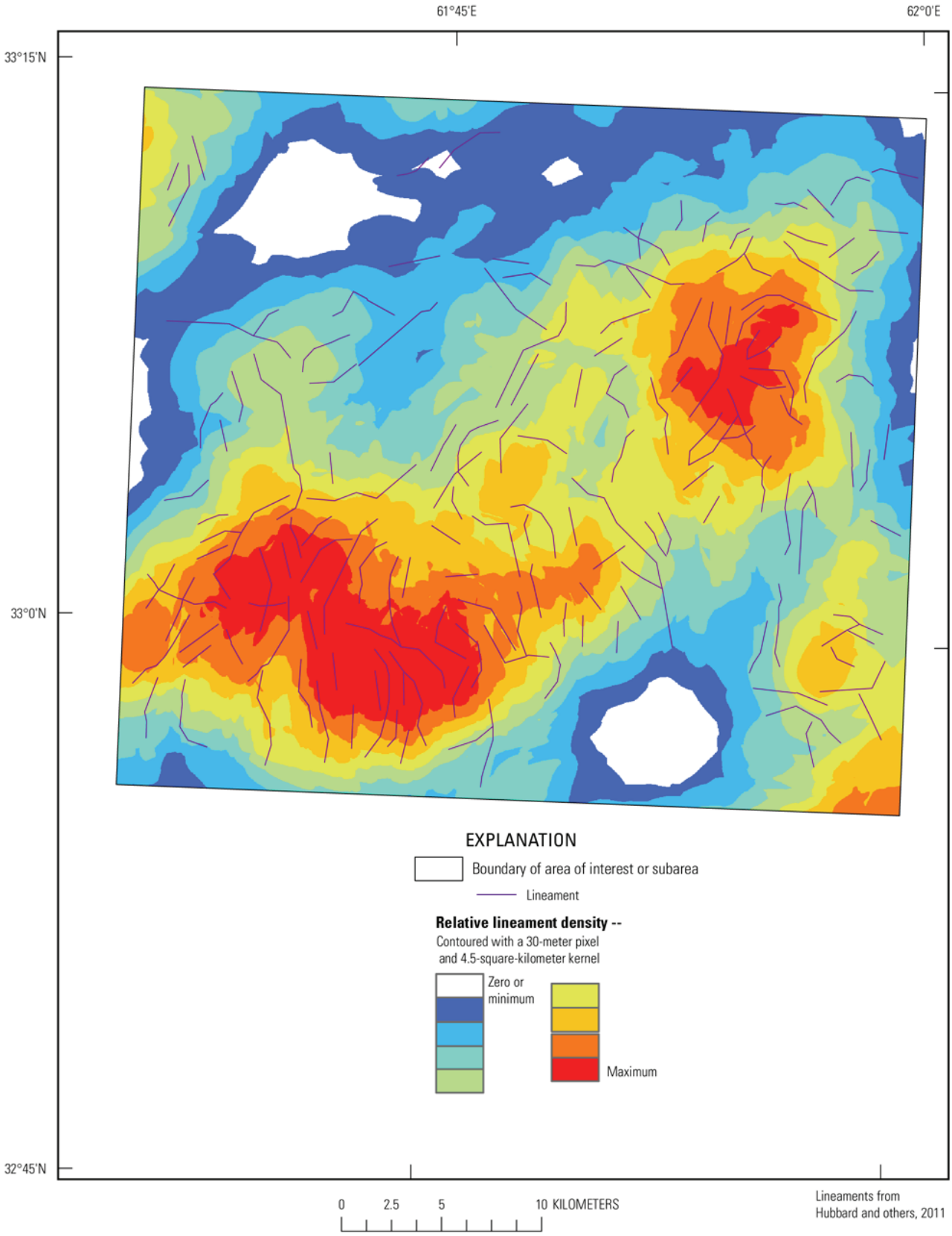


Figure 14C–6. Lineaments and lineament density based on 15-meter digital-elevation-model data and natural-color Landsat imagery in the tourmaline tin area of interest in western Afghanistan.

a


61°45'E
62°0'E
33°15'N
33°0'N
32°45'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
2.5
5
10 KILOMETERS
Lineaments from
Hubbard and others, 2011

b

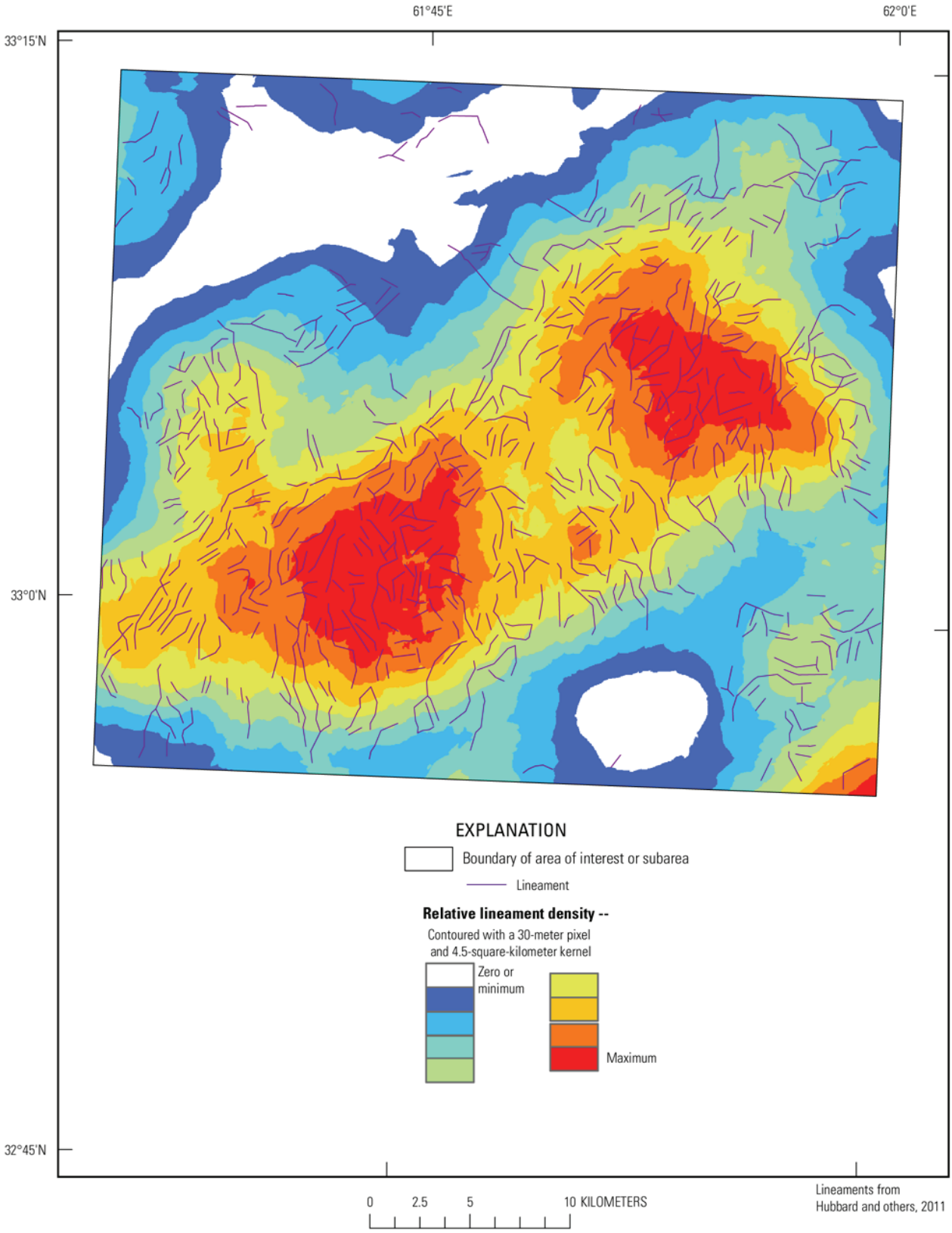


Figure 14C–7. (*a*) Lineaments and lineament density based on 30-meter multispectral Landsat imagery and (*b*) lineaments and lineament density based on 15-meter multispectral Landsat imagery in the tourmaline tin area of interest in western Afghanistan.

14C.2 Summary and Conclusions

The availability of water resources for mining and other uses is likely to be more limited in the tourmaline tin area of interest (AOI) than in other areas of Afghanistan. There are few perennial streams within the AOI and the Adraskan River, a large perennial stream, is 5 km outside the AOI boundary. Water resources in the AOI and surrounding area consist mainly of shallow groundwater. Shallow alluvial aquifers are likely in the sands, undifferentiated geohydrologic group in the valley bottoms of the AOI; however, saline groundwater was found near the land surface in similar basins to the north. Most streams are highly utilized by the local population and represent the primary source of water for irrigation. The diversion of water from the streams to support mining activities would need to be closely monitored to ensure that the quantity and quality of the surface-water flow remain sufficient to supply water for irrigation. Streamflow also would need to be monitored to ensure that the streams continue to provide recharge to the aquifers that supply groundwater to the shallow wells for domestic consumption.

No information about deep groundwater in 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.

14C.3 References Cited

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