

Chapter 1. Introduction to Summaries of Important Areas for Mineral Investment and Production Opportunities of Nonfuel Minerals in Afghanistan

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Although Afghanistan has abundant mineral resources (Peters, 2007; U.S. Department of Defense, 2010), most have not been successfully developed, nor have the resources been systematically explored since the 1970s using modern methods. Compilation and interpretation of Soviet data and information resulted in a preliminary quantitative resource assessment of nonfuel mineral resources in Afghanistan (Peters and others, 2007), according to the methods described by Singer and Menzie (2010). This preliminary assessment resulted in the recommendation of 24 areas of interest (AOIs) that required further study (fig. 1–1; table 1–1). Many of the areas were deemed likely to have potential for artisan mining (fig. 1–2). These AOIs and subareas (fig. 1–3) also were thought to be likely to develop near-term mineral production. Even though a wide variety of nonfuel mineral resources are known, some commodities are experiencing current favorable market prices, and therefore some AOIs may rank higher than others. In addition, some deposits in Afghanistan are near-surface bodies that have promising metallurgical and mining characteristics and therefore offer a shorter lead time, which might also affect their priority.

This report summarizes the results of joint geologic activities from 2009 to 2011 between the U.S. Geological Survey (USGS), the U.S. Department of Defense Task Force for Business and Stability Operations (TFBSO), and the Ministry of Mines’s (MOM) Afghanistan Geological Survey (AGS). The work was funded by the TFBSO. The main activities included (1) compiling, interpreting, and reporting on data within areas of interest; (2) conducting scoping field missions to selected AOIs and gathering new data; (3) conducting additional fieldwork by the AGS; (4) performing activities related to industrial minerals; and (5) carrying out geohydrologic and hyperspectral studies in support of mineral development.

Each chapter in this report summarizes mineral resource studies in each of 24 areas of interest (AOI) and in 33 subareas resulting from joint geologic and compilation activities that were conducted by the USGS, TFBSO, and AGS (figs. 1–1, 2, and 3). The “A” chapters in this report discuss the geologic setting and mineral resources of each AOI. Accompanying complementary chapters “B” and “C” address hyperspectral data and geohydrologic assessments, respectively, in each of the AOIs. In addition, supporting data packages and archival reports for each chapter and AOI are available on the public USGS Afghanistan Web site (<http://afghanistan.cr.usgs.gov/>) and (or) from the AGS Data Center in Kabul (<http://mom.gov.af/en/>; <http://www.bgs.ac.uk/afghanminerals/>), and in a separate viewer at <http://mapdss2.er.usgs.gov/>. Oil and gas assessments have been carried out separately (Klett and others, 2006).

Because the focus of this report is on each of the 24 AOIs within Afghanistan (fig. 1–1), the potential for early economic extraction is emphasized in each chapter for a number of different mineral, commodity, and deposit types. The AOIs were selected by the USGS (Peters and others, 2007) where known deposits and resources had been identified earlier by Soviet and Afghanistan geologists. These AOIs were studied, sampled, and documented by the Soviets, and therefore the geology and mineral deposits in the AOIs are documented by a number of archival reports and maps. These AOIs commonly contain known measured mineral reserves or resources that were calculated from sampling in trenches, drill holes, and (or) underground workings. Road access also is common in most of the AOIs, permitting

a number of the AOIs to be field checked by USGS and TFBSO geologists between 2009 and 2011. These listed AOIs are the most likely areas to be mined first in Afghanistan; considering the vast number of mineralized areas in the country, they are the areas that bear the least amount of financial risk.

The USGS compiled digital GIS data for each of the 24 AOIs and for each of the additional 33 subareas. These digital data include previously published data by the USGS and new data that were generated during the 2009-2011 joint USGS-TFBSO project. All data generated by the USGS are published and are available publicly. The sum of USGS digital data within each AOI comprises a Data Package (fig. 1–4). Data in each AOI are interpreted and summarized in individual chapters in this report, and these summaries, combined with scanned archival reports, maps, and other information, form Information Packages for each AOI. The information packages are designed to be used for the construction of Bidding Packages for each AOI and subarea (fig. 1–4). The bidding packages are intended to provide legal access to the mineral resources according to the mining law(s) of Afghanistan in order for investors and mining firms to develop the mineral wealth of the country.

The inventory of individual datasets that were compiled for each AOI and its subareas is designated to be part of the AGS Data Center, Kabul (fig. 1–4). Most existing mineral-resource information was gathered from reports written between the early 1950s and about 1985 by geologists from the Union of Soviet Socialist Republics (USSR) and its Eastern European allies, who provided Afghanistan with technical assistance (Abdullah and others, 1977; Eppinger and others, 2006; British Geological Survey, 2008). This information, combined with the preliminary assessment by the USGS (Peters and others, 2007) and new hyperspectral and geohydrologic data compilations, provided the basis for the summary chapters in this report. The USGS also participated in the planning and execution of several USGS-TFBSO scoping missions to several of the AOIs where additional data were collected and areas were field checked.

The potential and risk associated with many of the mineral occurrences is not directly measurable for a number of reasons:

1. Not all mineralized occurrences in Afghanistan are contained within the 24 priority areas identified (figs. 1–1, 1–2, and 1–3);
2. There are many other promising areas of mineral potential in addition to the AOIs;
3. Within and between the priority areas are anomalies of geophysical, geochemical, or remote sensing data; these anomalies have data signatures that differ from the surrounding areas but commonly have characteristics similar to mineralized areas within Afghanistan or elsewhere in the world. Commonly, these anomalies are remote and have not been visited or documented; however, they attest to the greater potential and future of mineral extraction in the country.
4. A number of industrial mineral areas are clustered in small basins that contain a variety of commodities, commonly clays, coal, gypsum, and limestone; examples of these are located in Herat, Baghlan, and Takhar Provinces (fig. 1–1).

Industrial minerals in Afghanistan are summarized in chapter 16A and are addressed in several of the AOIs, specifically the Baghlan Clay-Gypsum, Bakhud Fluorite, Dudkash Industrial Minerals, Ghunday-Achin-Magnesite-Talc, Khanneshin Carbonatite, North Heart Barium-Limestone, Nuristan Pegmatites, South Helmand Travertine, and Takhar Evaporite AOIs (table 1–1; figs. 1–1 and 1–2). Materials and commodities—such as clay, gypsum, limestone, crushed stone, building stone, celestite, phosphate, and so on—in these AOIs are commonly used for local industries and for construction of infrastructure. Areas where a variety of industrial mineral occurrences cluster have the potential to be areas of future industrial centers.

Sand and gravel deposits were grouped into two deposit types for assessment in Peters and others (2007). The two groupings were (1) fluvial deposits associated with rivers and streams in watersheds with or without glaciation and (2) sand and gravel deposits in alluvial fans developed by streams as they flow from mountainous areas into flatter areas. The quantitative assessment provided an estimate of how much sand and gravel might be present in a set of river basins as well as near roads and towns within

each basin that may be more accessible for development. These areas considered permissive for sand and gravel deposits were included as shapefiles in each data package for each AOI.

Lithium resources are addressed in chapters on pegmatites—the Daykundi Tin-Tungsten AOI (chapter 5A) and the Nuristan Pegmatite AOI (chapter 24A) (table 1–1). An assessment of lithium in these pegmatites was not undertaken by the USGS, nor were undiscovered resources estimated for boron or lithium in the evaporite lakes due to a paucity of understanding and data (Peters and others, 2007). A lithium project was initiated in the evaporite lakes by the TFBSO between 2009 and 2010 in Herat, Ghazni, Nimruz, and Farah Provinces, and after field missions to five locations, TFBSO geologists estimated that Afghanistan may have significant lithium in its many evaporite lakes (U.S. Department of Defense Task Force for Business and Stability Operations, 2011). All reports on the lithium missions are available through the TFBSO.

The following sections of this introductory chapter outline the makeup of the data and information packages that accompany the AOIs, the new Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer Global Digital Elevation Map (GDEM) data, and other new datasets, including hydrographic databases, ASTER mapping, hyperspectral data, geophysical data, and geohydrology data and interpretations. The final parts of this introductory chapter summarize the mineral scoping field missions conducted as part of the USGS-TBSFO-AGS project and summarize the archival reports and data available in Kabul. A summary of the important AOIs is also included.

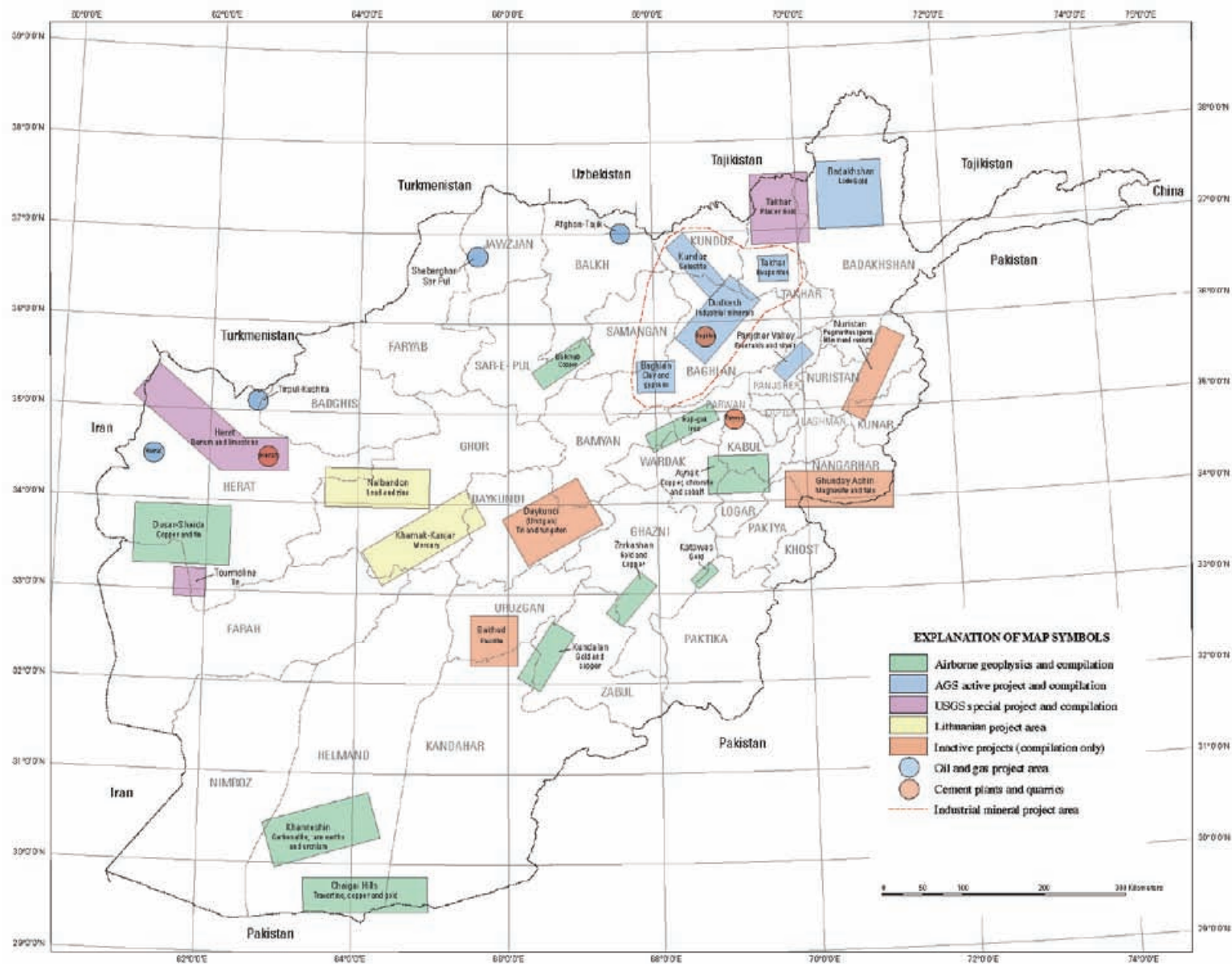


Figure 1–1. Map of Afghanistan showing the areas of interest, which are summarized by chapter in this report and which were the focus of the U.S. Geological Survey-U.S. Department of Defense Task Force for Business and Stability Operations scoping project that took place during fiscal years 2009–2011.

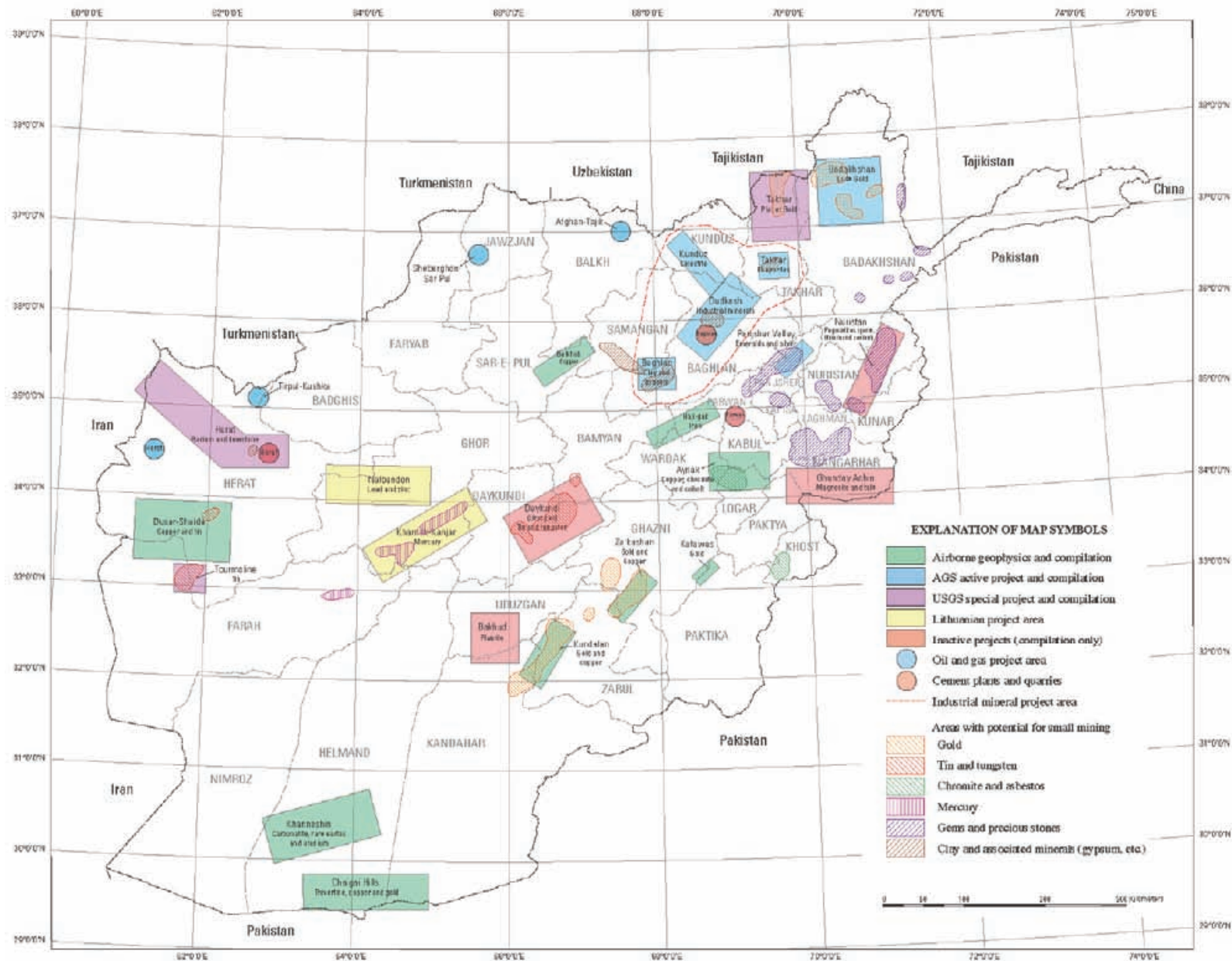


Figure 1-2. Map of Afghanistan showing the mineral areas of interest and potential areas for small (placer or artisanal) mining operations.

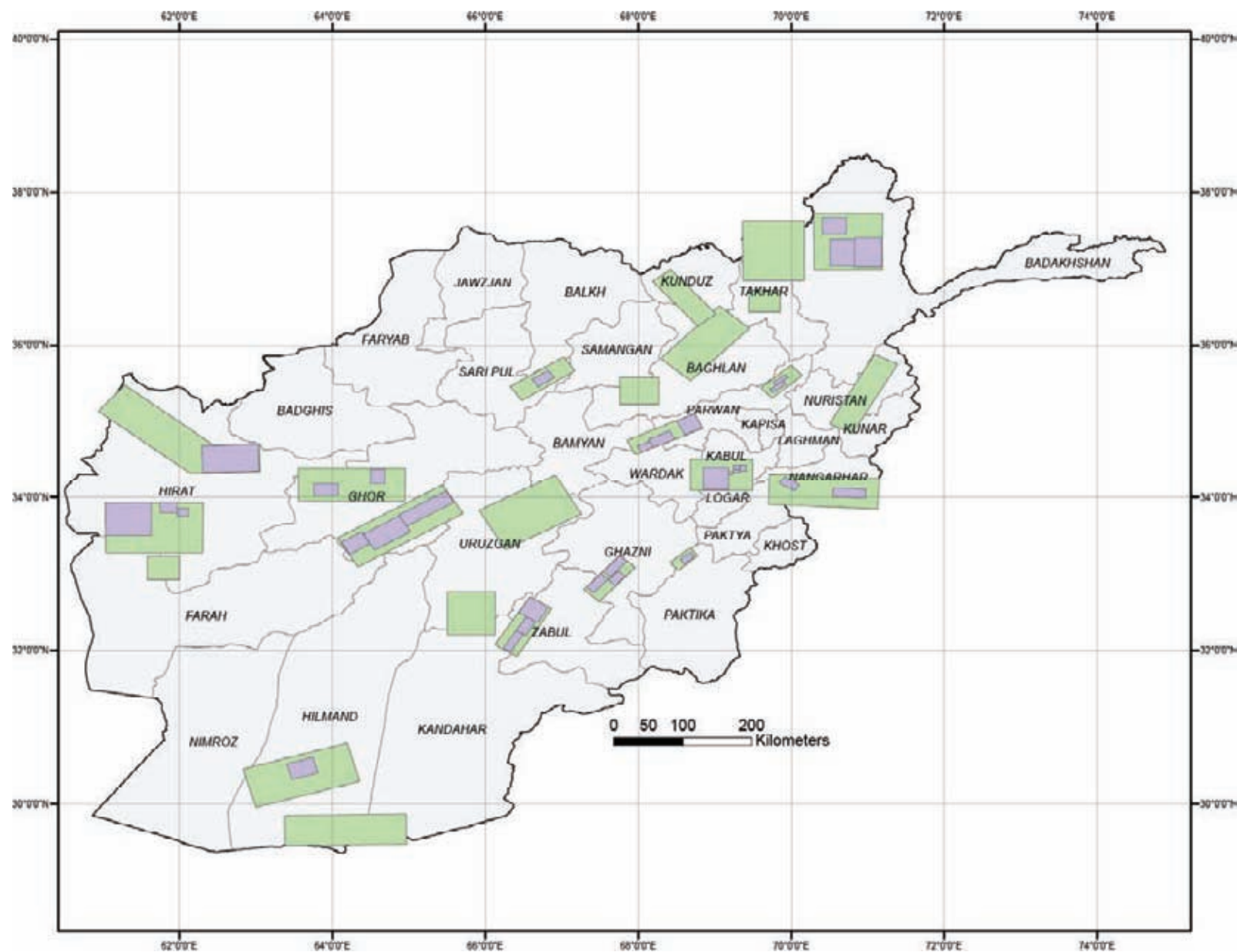


Figure 1–3. Map of Afghanistan showing areas of interest (AOIs) discussed in this report (green rectangles), and subareas within each AOI (purple rectangles). Base map from data published in Peters and others (2007).

Total Information Package Compiled by USGS

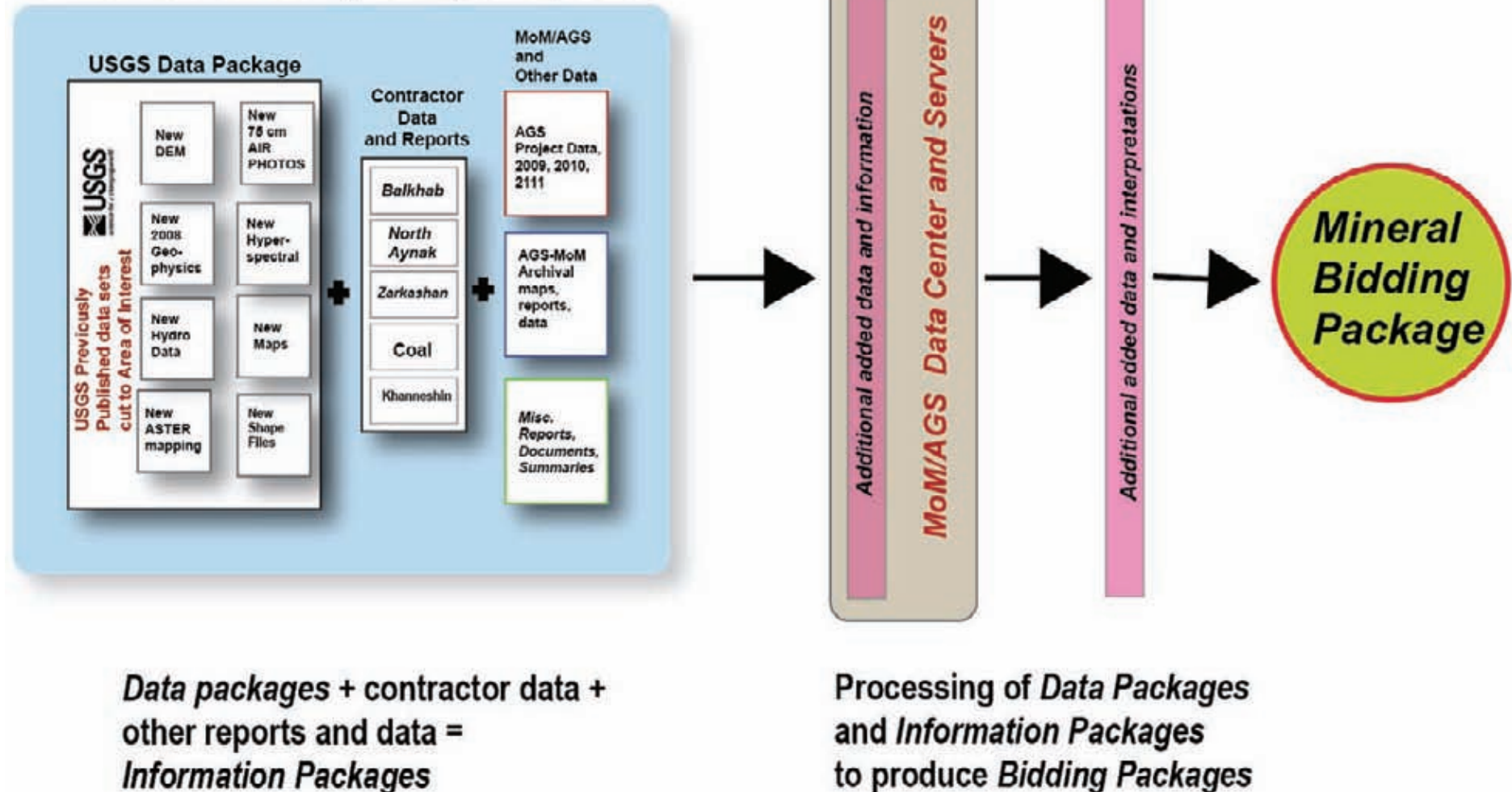


Figure 1–4. Flow chart and classification of data and information packages for each mineral area of interest leading to a bidding package. The area in blue is the information package, a combination of U.S. Geological Survey and other data. Each data package and information package complements the chapters in this report and is available at <http://afghanistan.cr.usgs.gov/>.

Table 1–1. List of chapters in this report showing areas of interest (AOIs) and the presence or absence of subareas and commodities in each AOI.

[Ag, silver; As, arsenic; ASTER, Advanced Spaceborne Thermal Emission and Reflection radiometer; Au, gold; Ba, barium; Co, cobalt; Cu, copper; Fe, iron; Hg, mercury; Li, lithium; Mo, molybdenum; NA, not available; Nb, niobium; P, phosphorus; Pb, lead; REE, rare earth elements; Sb, antimony; Sn, tin; Sr, strontium; Ta, tantalum; Th, thorium; U, uranium; W, tungsten; Zn, zinc]

Chapter	Area of interest	Subareas	Deposit models	Main commodities	Minor or possible commodities	Comments
2A 2B 2C	Aynak copper (Logar chromite)	Yes	Sediment-hosted copper, podiform chromite	Cu, Co, Ag	Marble chromite, asbestos, talc	Reserves at Aynak, Jawhar, and Darband deposits
3A 3B 3C	Badakhshan gold	Yes	Gold-quartz veins, gold and iron skarn	Au, Fe	Ag, Cu, U	Weka Dur deposit contains 958 kilograms of gold
4A 4B 4C	Balkhab copper	Yes	Volcanogenic massive sulfide	Cu	Pb, Zn, coal	Balkhab copper prospect
5A 5B 5C	Daykundi tin, tungsten, and lithium	No	Greisen tin-tungsten, tin-tungsten-skarn, lithium pegmatite	Sn, W, Li	Cu, Pb-Zn,	Taghawlor lithium pegmatite field
6A 6B 6C	Dusar-Shaida copper and tin	Yes	Porphyry copper, volcanogenic massive sulfide, tin-copper skarn	Cu, Sn	Pb, Zn, W	Shaida Porphyry copper prospect
7A 7B 7C 7D	Haji-Gak iron	Yes	Volcanogenic iron(?)	Fe	Ba, marble, sandstone, U, Cu	1.7 billion metric tons plus iron ore
8A 8B 8C	Katawas gold	Yes	Epithermal gold-silver	Ag, Ag (?)	Hg, W(?)	ASTER anomaly
9A 9B 9C	Karnak-Khanjar mercury	Yes	Epithermal mercury, base-metal skarn	Hg	Sb, As, Au, Ag(?)	Mercury belt
10A 10B 10C	Kundalan copper and gold	Yes	Porphyry copper-gold and skarn	Cu, Au, Mo	Ag, Pb	Copper and gold resource; multiple occurrences
11A 11B 11C	Nalbandon lead and zinc	Yes	Sediment-hosted lead-zinc	Pb, Zn	Ag(?)	Extensive mineral field
12A 12C	North Takhar gold placer	No	Gold placer	Au	NA	Past production, gold resources
13A 13B 13C	Panjsher Valley emerald, iron, and silver	No	Emerald, sedimentary iron and silver	Emerald, Fe, Ag	NA	Major emerald mining area

Chapter	Area of interest	Subareas	Deposit models	Main commodities	Minor or possible commodities	Comments
14A 14B 14C	Tourmaline tin	No	Tin-tungsten vein, placer tin	Sn (W)	Cu(?)	Previous mining for placer tin
15A 15B 15C	Zarkashan copper and gold	Yes	Porphyry copper-gold and skarn	Cu, Au	Ag, Pb	Copper and gold resource; multiple occurrences, gold placers
17A 17B 17C	Baghlan clay and gypsum	No	Bauxite, clay, gypsum	Bauxite, clay (kaolin), – gypsum		Tala Barfak bauxite deposit contains resources. Clay deposits are extensive.
18A 18B 18C	Bakhud fluorite	No	Sediment-hosted fluorite, fluorite vein, polymetallic skarn	Fluorite	Zn, Pb, Ag, Sb, Ba	Main fluorite district in Afghanistan
19A 19B 19C	Dudkash industrial minerals	No	Limestone cement, dolomite, bedded celestite, gypsum clay	Limestone cement, dolomite, celestite, gypsum clay,	Coal	Puli Khumri area and Tangi-Murch celestite deposit
20A 20B 20C	Ghunday-Achin magnesite and talc	Yes	Metasomatic magnesite-talc, ultramafic-hosted asbestos	Magnesite, talc, asbestos	Graphic, coal, marble	Achin and Ghunday magnesite-talc deposits near Tora Bora
21A 21B 21C	Khanneshin carbonatite	Yes	Carbonatite	REE, U, P	Th, Ba, Sr, limestone	Significant REE prospect and uranium resources
22A 22B 22C	Kunduz celestite	No	Bedded celestite, oil and gas, bedded phosphate deposits	celestite (SrSO ₄)	Oil and gas	About 1 million metric tons of celestite in speculative resource and Katar oil occurrence
23A 23B 23C	North Herat barium and limestone	No	Bedded barite, vein barite, chemical limestone, marble, clay, iron skarn	Ba, limestone, marble, NA clay, Fe		Major barite field, marble factory, industrial center
24A 24B 24C	Nuristan pegmatite	No	Pegmatites	REE, Li, Sn, and mica	Ta, Nb	Paron (Jamanak-Pasgushta) and Pachigram pegmatite fields; lithium resources
25A 25B 25C	South Helmand travertine	No	Travertine, porphyry copper-gold	Travertine (onyx)	Cu, Au, Mo	Travertine production, porphyry copper-gold deposits in adjacent Pakistan
26A 26B 26C	Takhar evaporite	No	Salt dome, clay, sandstone	Salt, clay silica	Coal, oil and gas	Rock salt deposit at Namakab; porcelain and pottery clay

1.1 Data and Information Packages

Digital geographic information system (GIS) data were compiled for each AOI and its subareas, as illustrated in figures 1–5 and 1–6a,b. The purpose of the data compilation was to provide Data packages and information packages for each AOI and subarea to be publically available in the AGS Data Center, Kabul and on the USGS Website. These packages are intended to be used by the Afghanistan Government to complement, backup, and construct bidding packages for potential investors in each of the AOIs (fig. 1–4). These data also are the basis for the summary chapters in this report. Data consist of previously acquired and published digital data (Peters and others, 2007) and new data generated between 2009 and 2011, such as:

- New 20-m and 40-m Digital Elevation Models (DEMs)
- Advanced Land Observation Satellite (ALOS) multispectral images
- Hyperspectral data and maps
- ASTER mapping data and maps
- 2008 geophysical data
- Data from USGS-TFBSO scoping missions
- Data from AGS fieldwork
- Data gathered, scanned, compiled, and interpreted from archives of the AGS and MOM

The data compilation process consisted of many parts (fig. 1–5). Completion of the 57 spatial Data packages was dependent on communication and collaboration among the AGS, the MOM, the TFBSO, and various USGS disciplinary expertise teams. Spatial data within each AOI data package are from published USGS data. Inclusion of data into AOIs or subareas is based on the extent of the spatial data for each AOI. The datasets available for Afghanistan depend on the geographical location and extent of each dataset. Therefore, each data package does not contain the same data. For example, the German geologic data only cover southern Afghanistan, and thus, are only available in the southern AOIs. The Soviet geologic data, however, span the whole of Afghanistan and are compiled in all of the AOIs and subareas (fig. 1–6).

Data Standards (fig. 1–5) were applied to all data packages so that they comply with the following data standards:

1. Vector data—are in shapefile format.
2. Raster data—are in Tagged Image File Format (TIFF).
3. Projection parameters—WGS 1984 Datum is used for projecting data within the AOIs. USGS AOIs in Afghanistan span two Universal Transverse Mercator (UTM) zones. Data in AOIs or subareas are projected to their local UTM zones (for example, UTM Zone 41 N. or UTM Zone 42 N.) (fig. 1–7).
4. Metadata—are compliant with the Federal Geographic Data Committee (FGDC) standards. All Metadata files are in Extensible Markup Language (XML) format and imbedded into each spatial dataset.

Compiled data were inventoried (fig. 1–5) for each AOI and subarea by use of inventory spreadsheets for each of the 57 data packages. These inventory spreadsheets are compiled in appendix I. The inventory spreadsheets list available spatial data and categorize the data into groups as they appear in each of the ArcMap map projects (MXDs) (for example, geologic data, hydrologic data).

ArcMap Maps (MXDs) and Legends (Layer Files) were created for each of the 57 data packages. MXDs are projected to the local UTM zone of each of the AOIs and subareas (fig. 1–5). Data within the MXDs are organized into data groups and have been attributed with a rectified legend. For example, when the countrywide Soviet geologic data were subset to each AOI and subarea, in most cases, the subsets did not contain the same geologic units as the original dataset. Thus, each subset of the Soviet geologic data was analyzed to determine which geologic units actually covered the subset area. Then, the legend of each subset was rectified to reflect the proper geologic units present in the AOI. The data

legends can be viewed and edited within the MXD and are saved with each dataset in the file directories of the data packages.

Data grouping (figs. 1–5 and 1–8) of the individual 57 datasets was performed throughout the compilation activity. Because viewing of datasets simultaneously in the table of contents of the MXD is confusing, all the datasets within each MXD and within the file directory of the data packages are organized into groups of similar data. Specifically, datasets that convey hydrographic insight are grouped under hydrologic data, and so on.

A data naming convention (fig. 1–5) was addressed as each dataset was added to the database. In many cases, the name of the new file was the same as the original file from the published dataset.

Map templates (fig. 1–5) were created for each of the 57 ArcMap MXDs. Each map template was designed to allow the end user to quickly plot out hard copies of desired themes. The map templates contain and exceed all the basic map elements required by cartographic standards, such as title, location illustration, scale (text and bar), north arrow (true north and magnetic declination), and grid.

Furthermore, through trial and error, each map template has been sized to produce hard copy maps that can be hand carried and used in the field. These data and information packages are available for download from <http://afghanistan.cr.usgs.gov/>.

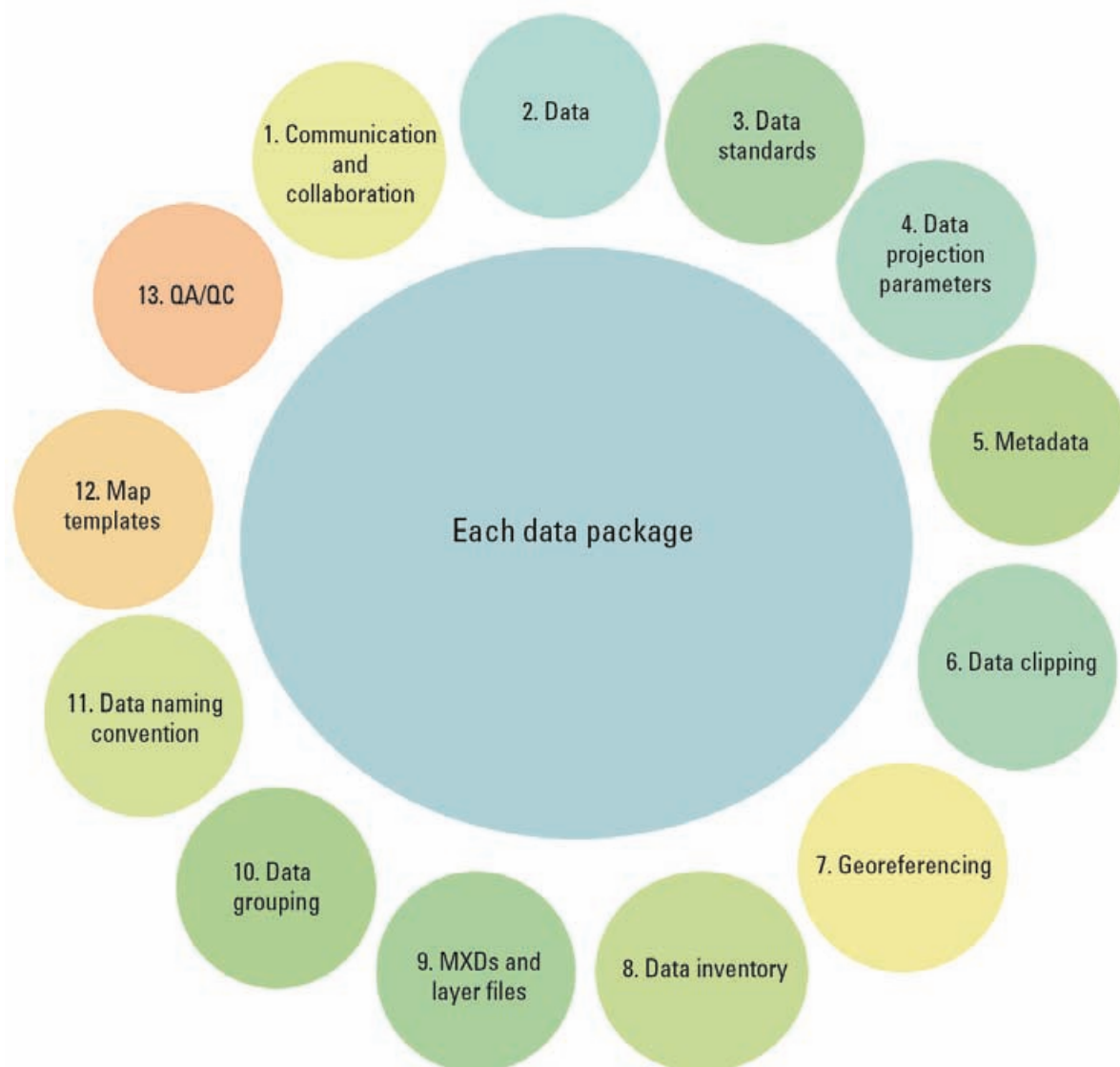


Figure 1–5. Spatial data package compilation procedure and protocol.

Quality assurance and quality control (QA/QC) (fig. 1–5) were implemented across all data packages to ensure a consistent product; standards for data formats were established prior to the start of the project. Data were integrated in a data package only if (1) data were subset to each AOI and subarea; (2) data were projected to the local UTM zones; and (or) (3) metadata were established and comply with FGDC standards. Integration of data into the data package means that the data were in an ArcGIS map project. In this phase, the data were tweaked to ensure that (1) the legend was properly attributed and saved in the file directory; (2) the data were labeled in the map project (for example, Geologic unit); (3) the data were transparent, if the dataset was of a type that could be draped over on the terrain so that topographic features are visible; and (4) the data were grouped and labeled in the table of contents of the ArcGIS map projects.

1.2 ASTER GDEM Digital Elevation and Hydrographic Databases

Compilation and delivery of new multi-use Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer Global Digital Elevation Map (GDEM) digital elevation and hydrographic databases were designed for the 24 USGS AOIs and subareas and include (1) processed Digital Elevation Models (DEMs), (2) 100-m, 50-m, and 25-m interval contour datasets, (3) shaded relief (depicting cartographic relief in 3-D), and (4) detailed topographic databases with hydrographic flow paths (fig. 1–9).

A DEM is a digital cartographic representation of elevation. Launched in 1999 aboard the Canadian and Japanese Terra spacecraft, managed by NASA (<http://terra.nasa.gov/>), the imaging instrument ASTER utilizes its Visible and Near Infrared (VNIR) (backwards looking) sensor to generate stereo pairs, matched with its Short Wave Infrared (SWIR) sensor to generate DEMs. The accuracy of ASTER GDEM has been validated by Federal agencies such as USGS and the National Geospatial-Intelligence Agency (NGA), as well as third-party assessors.

The multiuse ASTER GDEM digital elevation and hydrographic data were developed for the AOIs to improve location and analytical capabilities. Prior to 2010 all USGS products used Shuttle Radar Topography Mission (SRTM) DEM 90-m data. The ASTER is a more accurate sensor than SRTM in measuring elevation in areas with higher and steeper elevations.

The main DEM products include reference maps that are provided for each AOI and subarea. Each reference map contains place names and major streams, as well as province and district boundaries (fig. 1–9). Datasets are provided in GIS user-ready format for use with most GIS software. Data packages contain FGDC-compliant metadata for each dataset component.

ASTER GDEM applications include methods for mineral assessments and geologic mapping by showing geologic structure and site topography (Chirico, 2011). All data layers are included and integrated into USGS mineral assessment data packages for each AOI with all data converted to Adobe Illustrator format for cartographic purposes and publication. These data are available on the Web at <http://afghanistan.cr.usgs.gov/>. Examples of ASTER GDEM products are portrayed in figures 1–10, 1–11, 1–12, and 1–13.

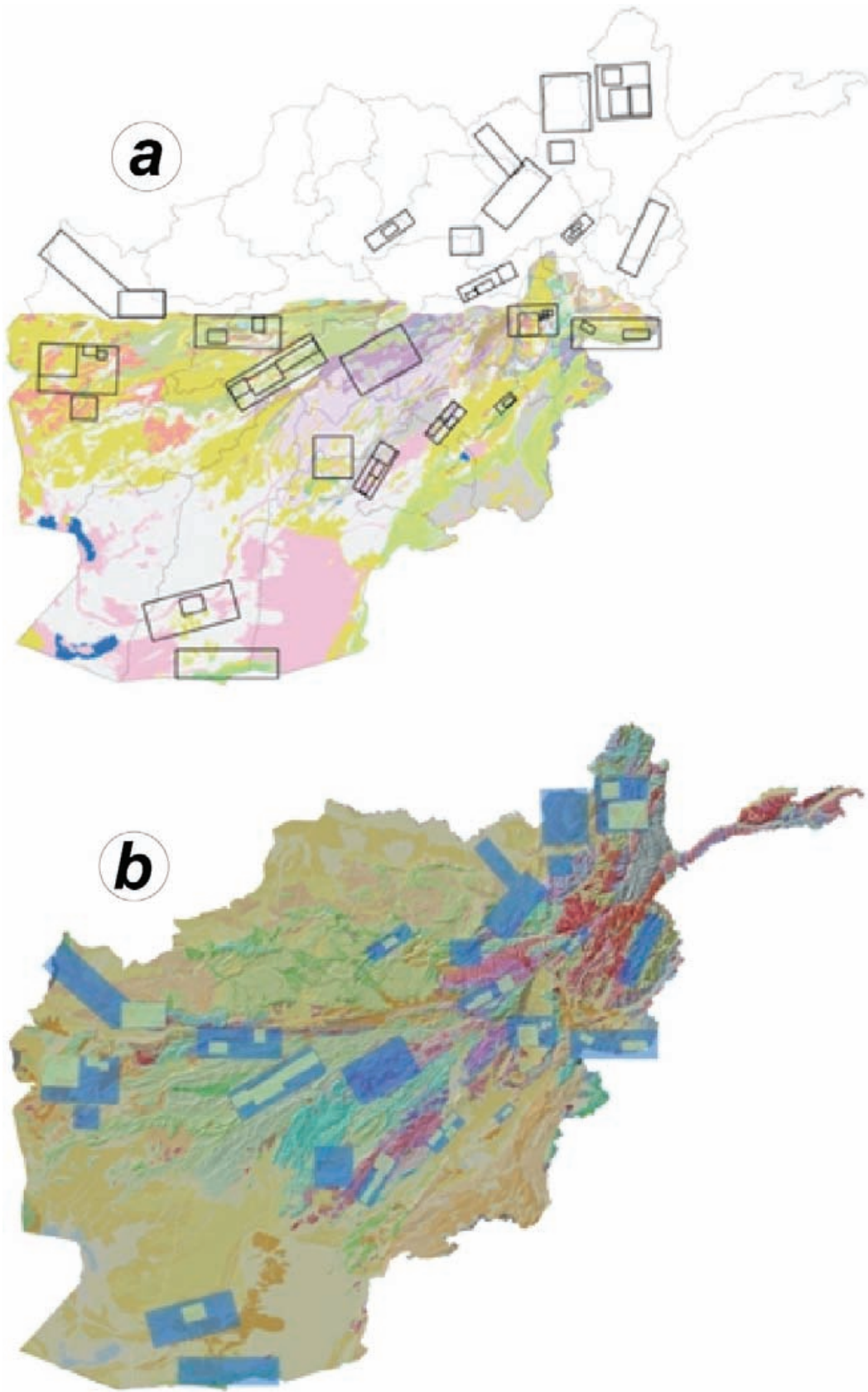


Figure1–6. Maps showing an example of different datasets overlaying different areas of interest. All areas of interest do not contain the same data. (a) German geologic data cover only the southern part of Afghanistan. (b) Russian geologic data are available for all of Afghanistan (Doebrich and others, 2006).

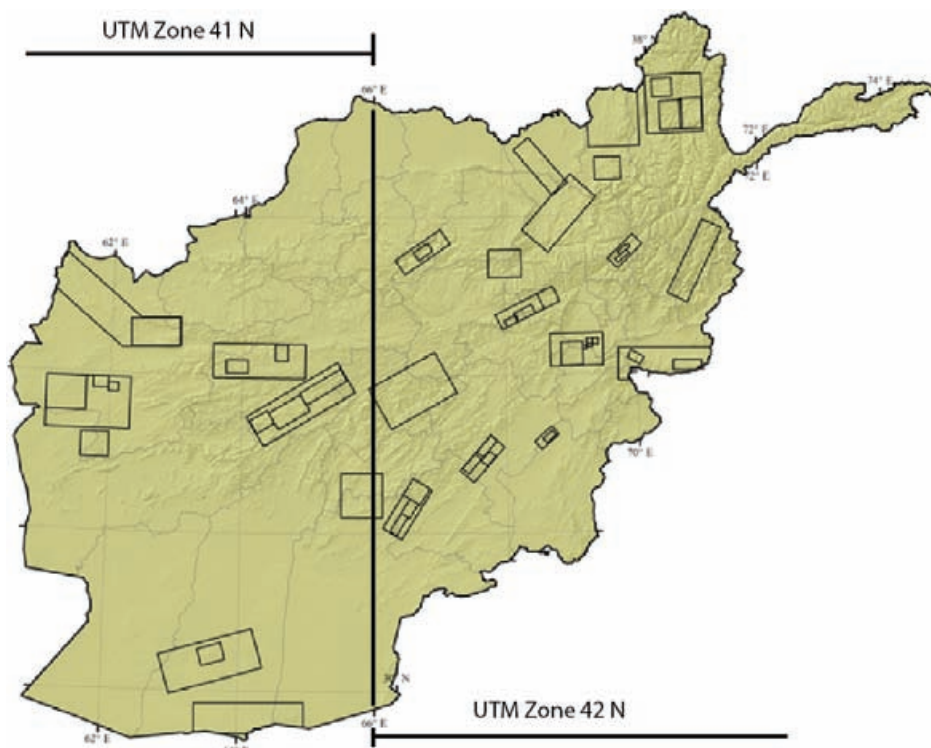


Figure 1–7. The USGS project areas in Afghanistan span across two UTM Zones. UTM Zone 41 N. (62°E. to 66°E.) lies to the west and UTM Zone 42 N. (66°E. to 72°E.) lies to the east.

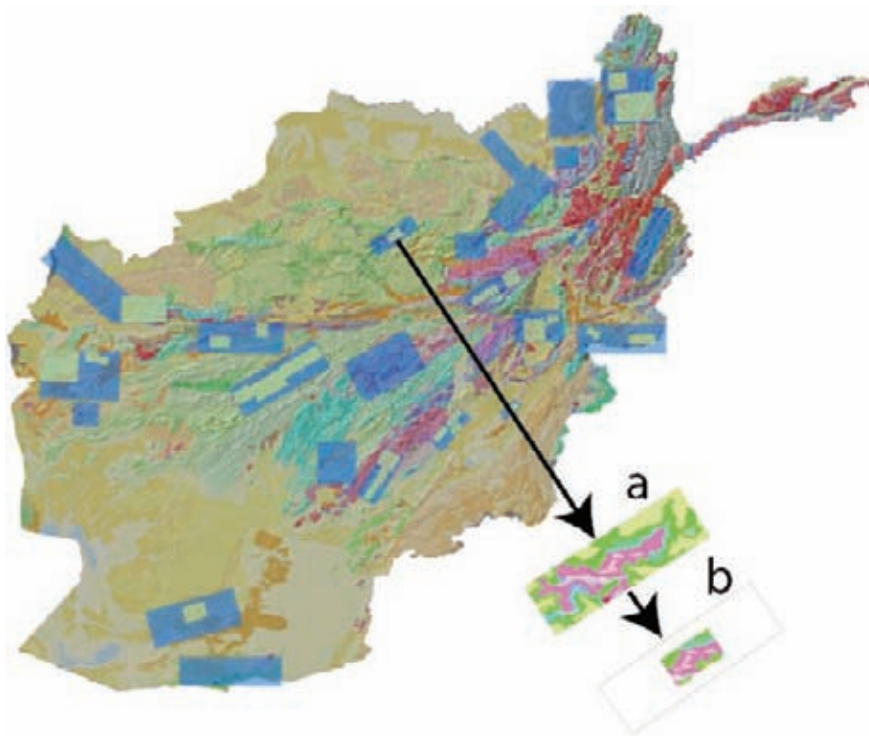


Figure 1–8. Map showing example of data clipping to area of interest outline to internal subarea. (a) Russian geologic data clipped to Balkhab copper area of interest. (b) Russian geologic data clipped to the Balkhab Copper Prospect subarea (Doebrich and others, 2006).

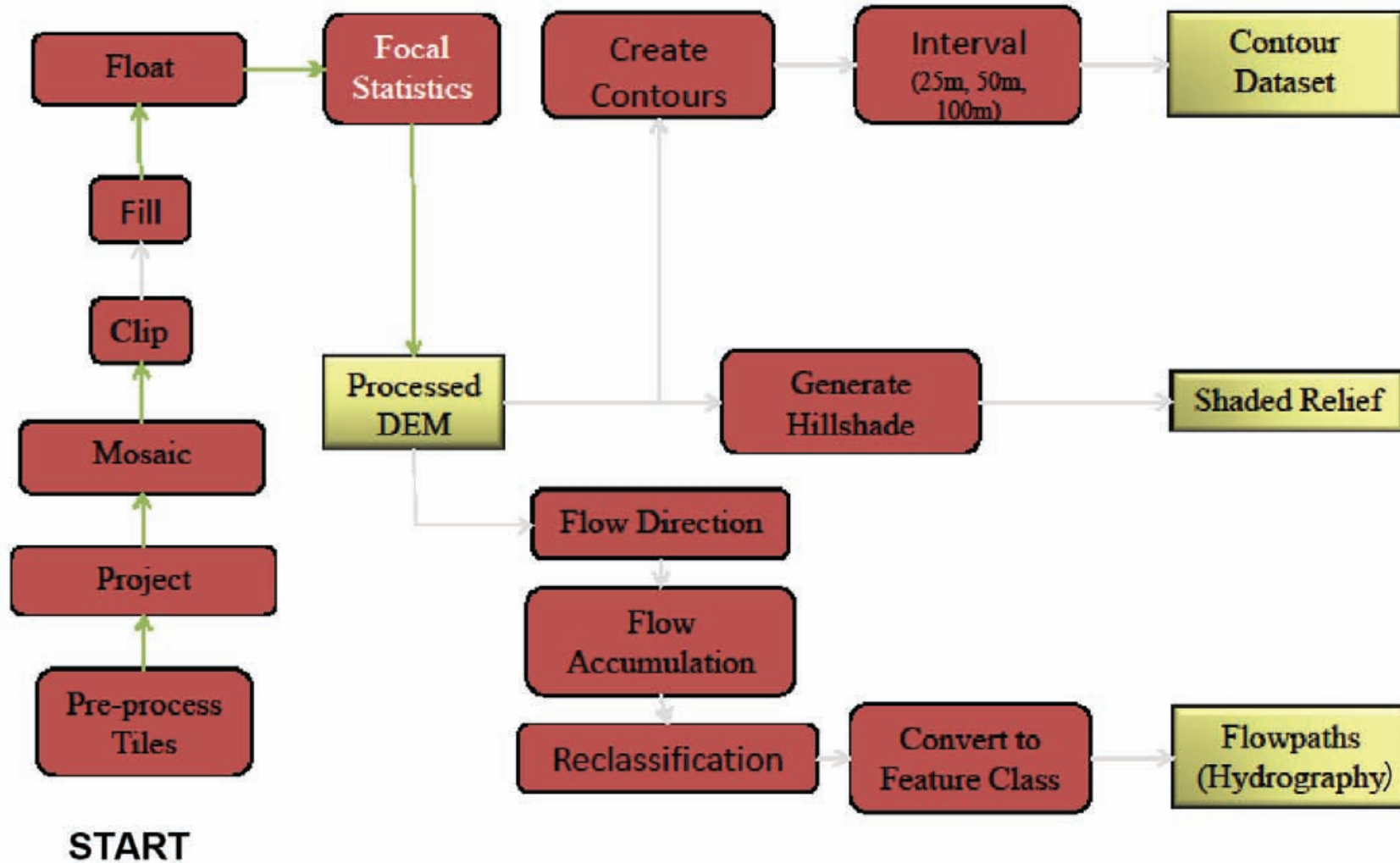


Figure 1–9. Geoprocessing history of the Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer Global Digital Elevation Map (GDEM) datasets compiled and generated for the areas of interest in the U.S. Geological Survey-U.S. Department of Defense Task Force for Business and Stability Operations Project.

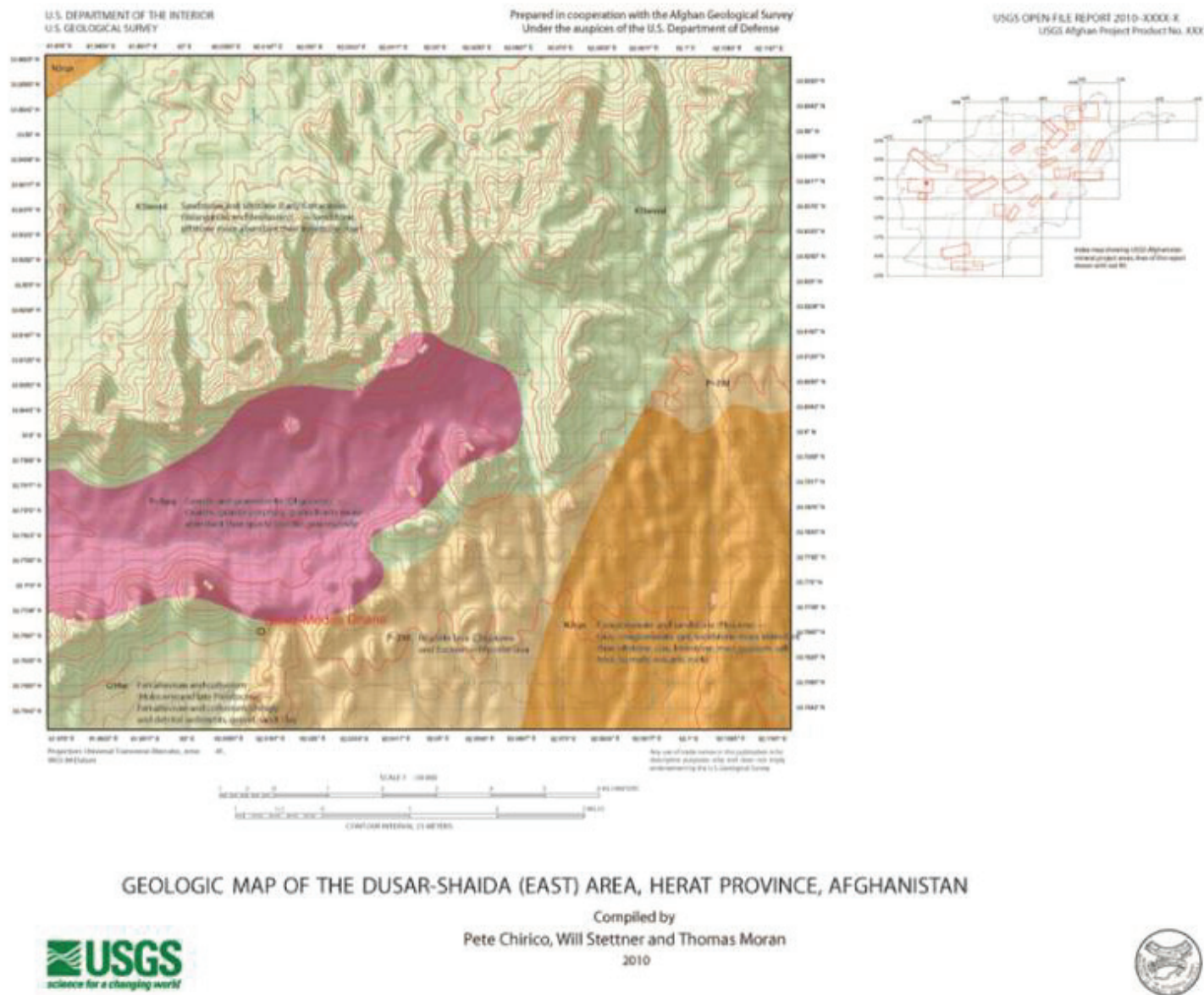


Figure 1–10. Example of topographic and geologic maps generated with the new Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer Global Digital Elevation Map (GDEM) 30-meter contour mapping and shaded relief. Example from the subarea within the Dusar-Shaida area of interest, described in chapters 6A, 6B, and 6C in this report.

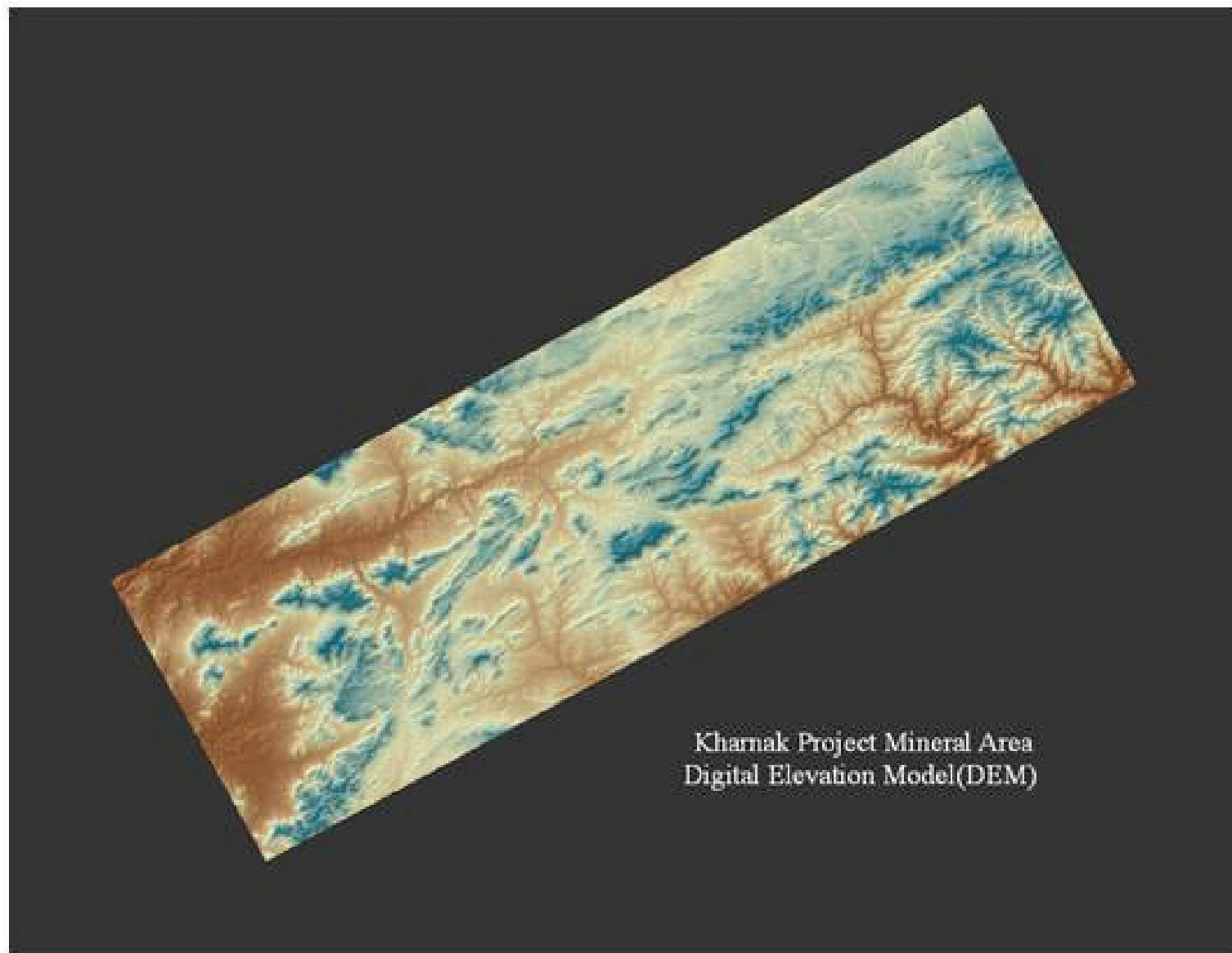
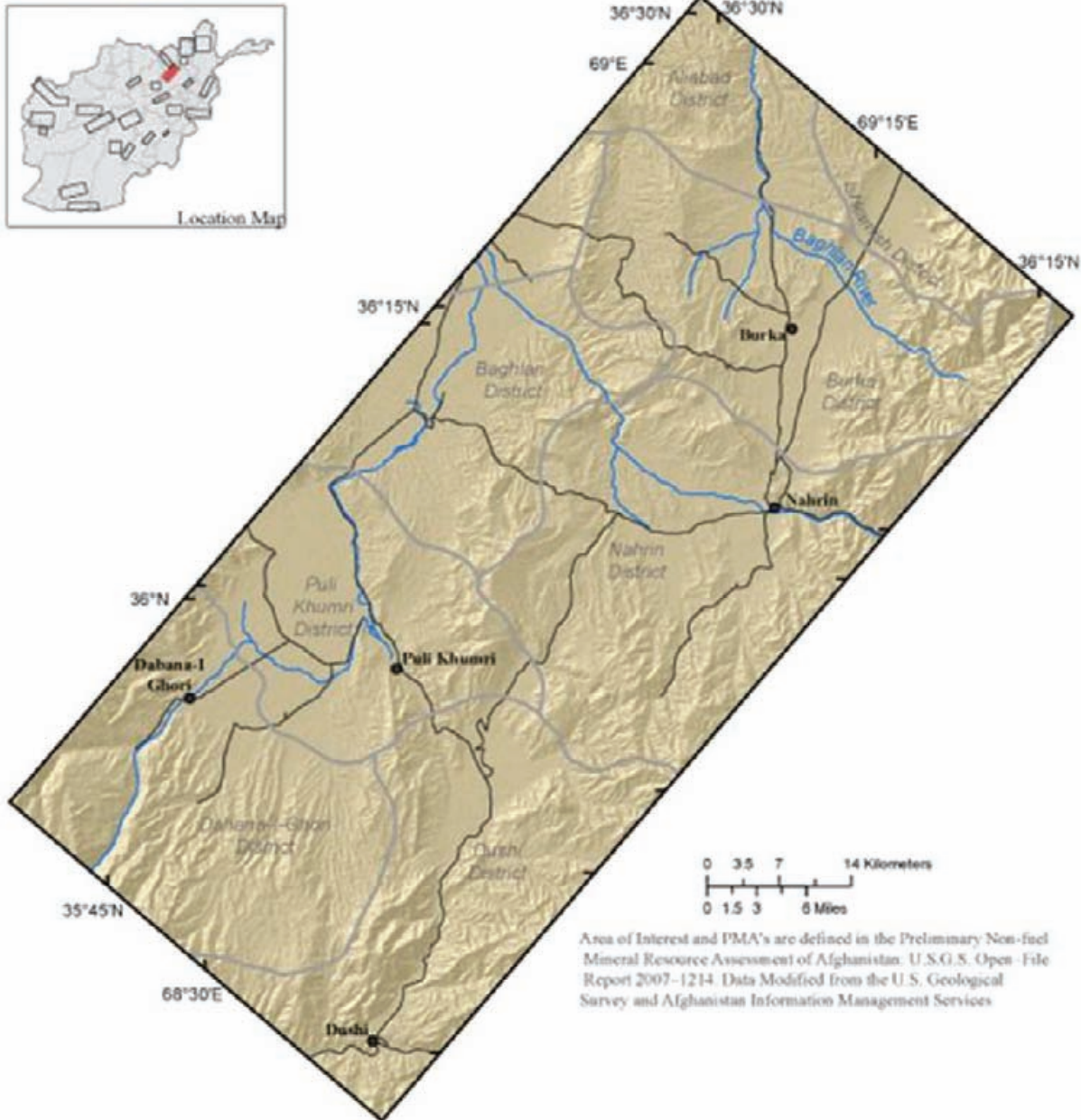


Figure 1–11. Visual applications: DEM data enable users to visualize landforms to enhance mapping and resource assessments. Example from the Karnak-Khanjar mercury area of interest, described in chapters 9A, 9B, and 9C in this report.



Dudkash Area of Interest

Figure 1-12. Example of product from the Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer Global Digital Elevation Map (GDEM) 30-meter dataset, showing place map for the Dudkash industrial minerals area of interest, described in chapters 19A, 19B, and 19C in this report. These maps are available for all areas of interest.

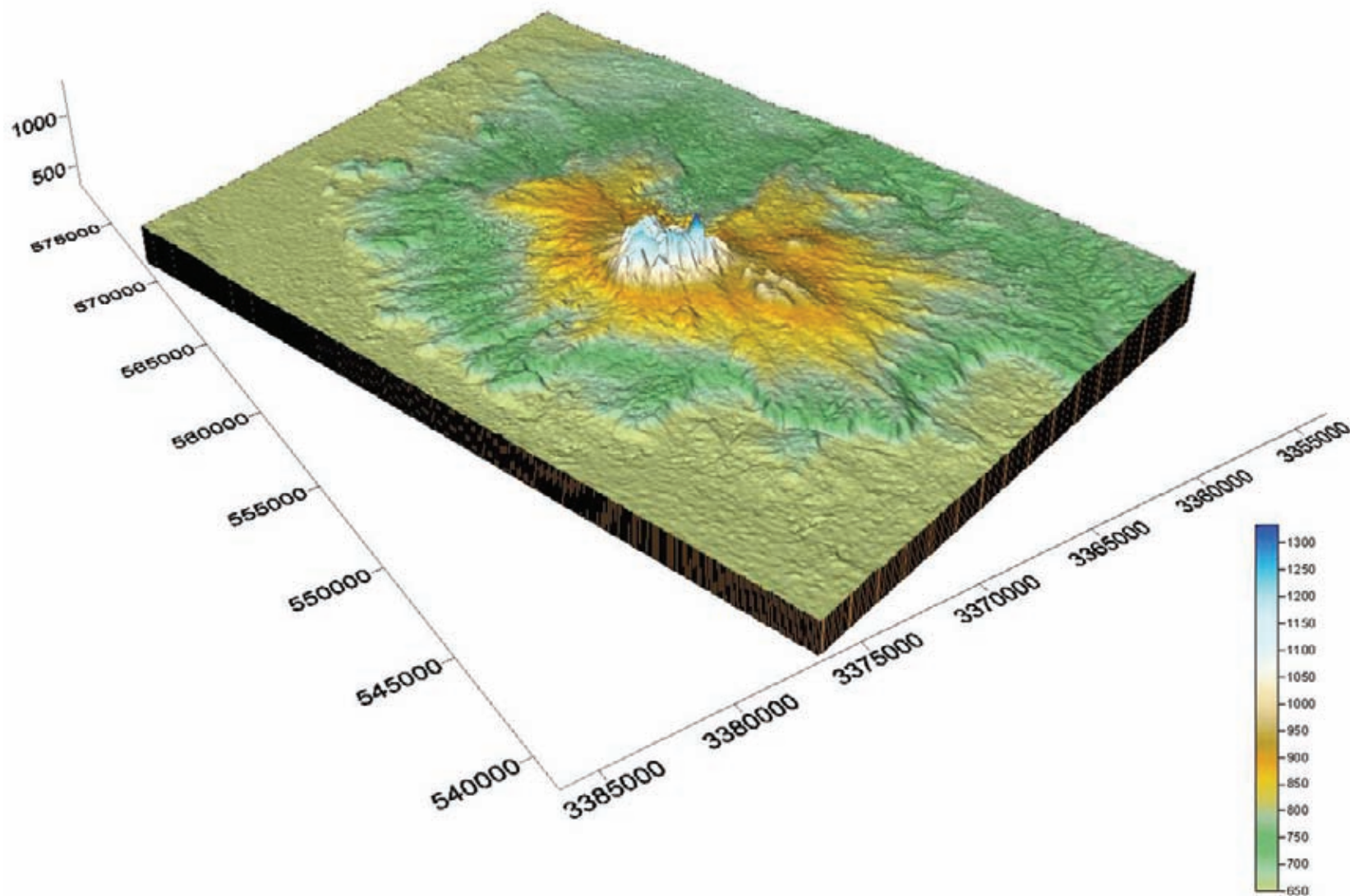


Figure 1–13. Three-dimensional map of the Khanneshin carbonatite area of interest, discussed in chapters 21A, 21B, and 21C, produced by Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer Global Digital Elevation Map (GDEM) 30-meter data. Scale is in meters.

1.4 ASTER Mapping

The ASTER radiometer consists of multispectral bands (14 bands) and 1 backward-looking band for stereo pair DEM. The 60 by 60 km acquisition area (along a continuous swath) is within a 16-day repeat cycle (4 days with off-nadir pointing) and has been in operation since 2001 and now has global coverage. Mapping of ASTER images produced anomaly maps for (1) carbonate minerals for cement, and clays for bricks; (2) other industrial minerals (for example, magnesite, gypsum, silica); and (3) mineral anomalies possibly related to metallic ores.

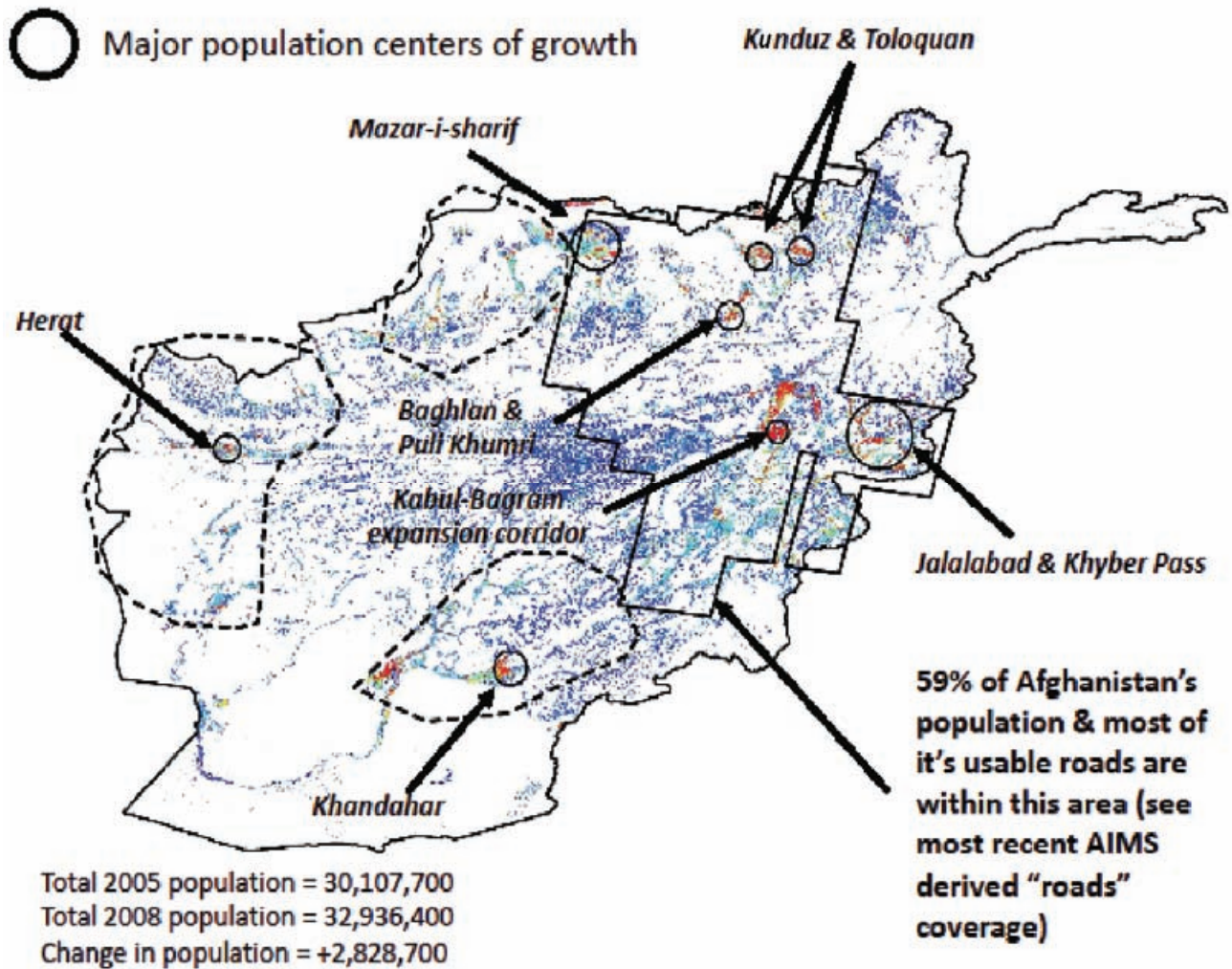


Figure 1–14. Map showing “lights at night,” major centers of population of distribution by Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer mapping (solid black planar outline) conducted for industrial minerals. The map shows 2005-2008 Landscan Change Analysis of the populations. Warmer colors indicate higher concentrations of population.

The primary goals of the ASTER mapping task between 2009 and 2011 were to use ASTER to distinguish carbonate rock exposures from clastic sedimentary rock exposures and to delineate favorable areas that can target quarries to support cement and building industries within the AOIs. Secondary by-products of the task were to delineate favorable areas for mafic and ultramafic rocks that may contain talc, asbestos, chromite, and clay-rich bedded sedimentary deposits (for example, brick and pottery). In addition, alteration zones indicative of volcanogenic massive sulfide and porphyry copper deposits were mapped in host metamorphic and volcanic rocks.

Specific localities mapped in detail were the Balkhab copper, Zarkashan copper and gold, and Tourmaline Tin AOIs. Spatial representation of the distribution of ASTER mapping of major population centers, and AOIs are contained on figures 1–14, 1–15, and 1–16. The results of the ASTER mapping for each AOI are contained within the data packages and are available on the Web at <http://afghanistan.cr.usgs.gov/> and from the AGS Data Center in Kabul (<http://mom.gov.af/en>; <http://www.bgs.ac.uk/afghanminerals/>).

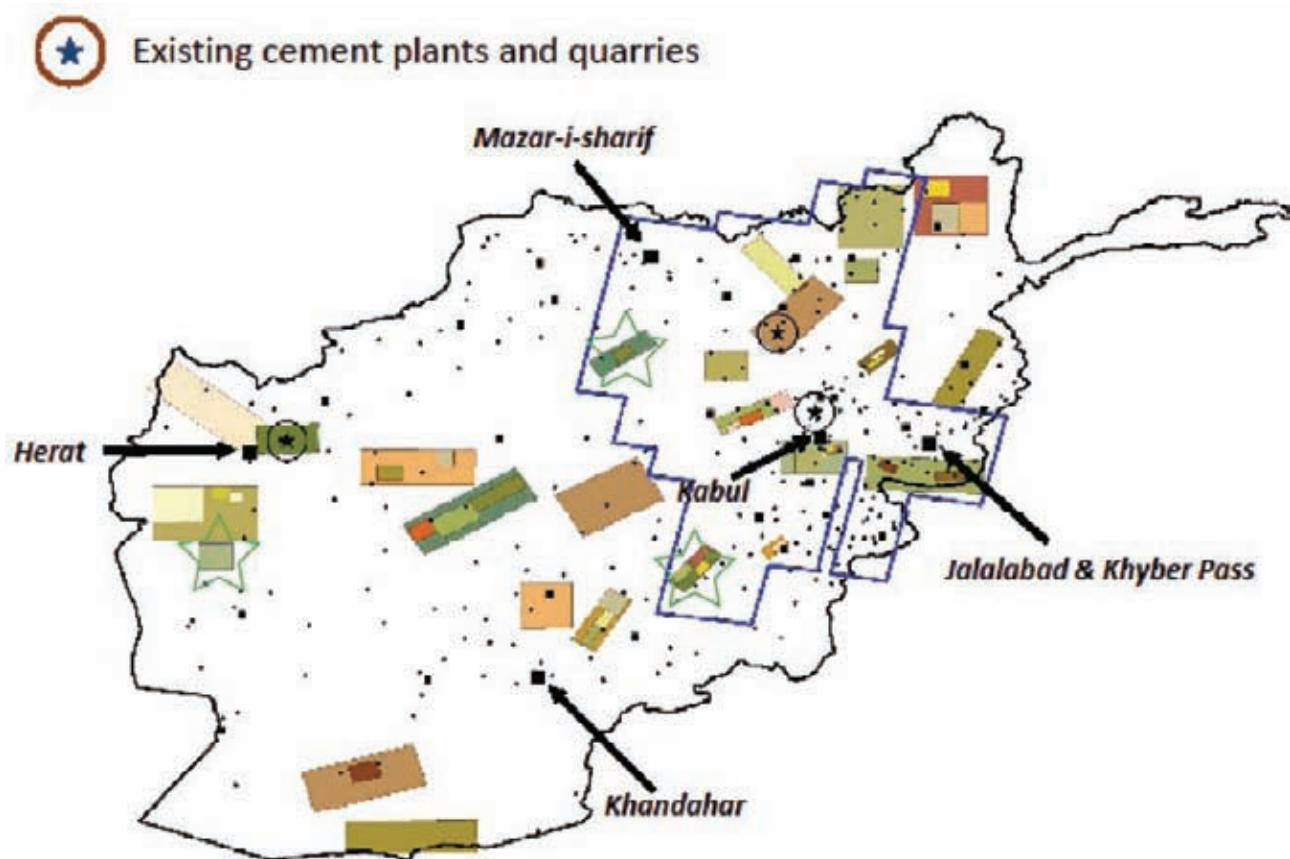


Figure 1–15. Map showing location of areas of interest (AOIs) and subareas and distribution of Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer mapping coverage. Note that detailed mapping was also carried out on Tourmaline, Zarkashan, and Balkhab AOIs (stars). These data are available in the data packages, which are available on the Web at <http://afghanistan.cr.usgs.gov/> and from the AGS Data Center, Kabul (<http://mom.gov.af/en>; <http://www.bgs.ac.uk/afghanminerals/>).

What are industrial minerals and what can ASTER tell us about them and (or) their value? These minerals tend to be high-bulk, low-unit-value materials where transportation is a significant cost factor when the minerals are utilized at distances from their source areas. Mapping results are best used in context with other ancillary data such as roads, population, and infrastructure to determine an “index of development” for identifying high-priority source material areas.

The quality of industrial minerals varies depending on local practice. For example, ASTER can provide some information about clay types, clay abundances, mixtures, and impurities but cannot provide information about local practice, manufacturing, and suitability. Also, carbonate rocks contain varying amounts of impurities such as organic compounds and detrital, insoluble minerals as well as clays, quartz, and feldspars. ASTER can provide some information about carbonate purity such as insoluble residue contents (based on weathering) and can also suggest the degree of mixing between calcite and dolomite.

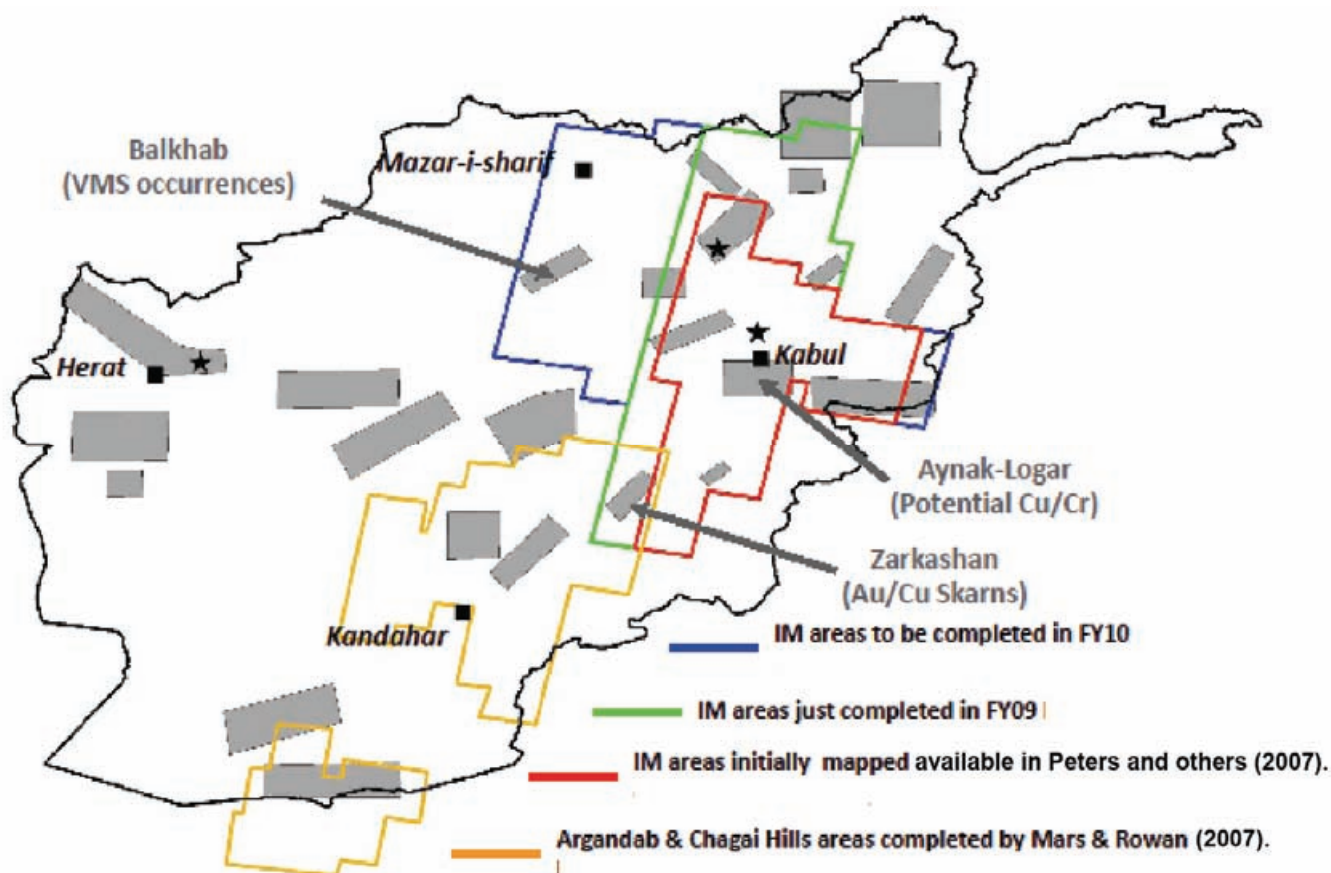


Figure 1–16. Map showing location of areas of interest and total coverages for Advanced Spaceborne Thermal Emission and Reflection (ASTER) radiometer mapping resulting from the recent compilations and mapping. IM, industrial mineral.

1.5 Hyperspectral Data

Hyperspectral data delivery to the data packages consisted of compiling the hyperspectral data into a geodatabase within 24 areas and 28 subareas with metadata. The datasets included (1) a surface materials map of Afghanistan: iron-bearing minerals ($1\mu\text{m}$ —28 classes) and (2) a surface materials map of Afghanistan: carbonates, phyllosilicates, sulfates, altered minerals, and other minerals ($2\mu\text{m}$ —32 classes). The geodatabase also included national datasets of mineral maps and ancillary datasets for each AOI and subarea.

The template geodatabases (GDB), generated using batch clipping from the Arctoolbox to create metadata for each national mineral map and resulted in the generation of a total of 104 *.xml files, which are FGDC-compliant (<http://geo-nsdi.er.usgs.gov/validation/>).

Computer analysis of the HyMap spectroscopic data of each AOI in Afghanistan used spectrum matching techniques to identify the occurrence of selected materials at the surface based on characteristic absorption features (absorption bands) in the HyMap data compared to a library of spectral standards (Cocks and others, 1998; Kokaly and others, 2008). Previous USGS analyses of existing geologic data of Afghanistan revealed numerous areas with indications of potential mineral resources of various types (Peters and others, 2007). From these areas of interest, several were selected for follow-on studies using modern hyperspectral remote sensing data to further characterize surface materials. Examples of hyperspectral mapping and analysis in selected AOIs are shown in figures 1–17a,b, 1–18a,b, and 1–19.

Balkhab Copper Area of Interest

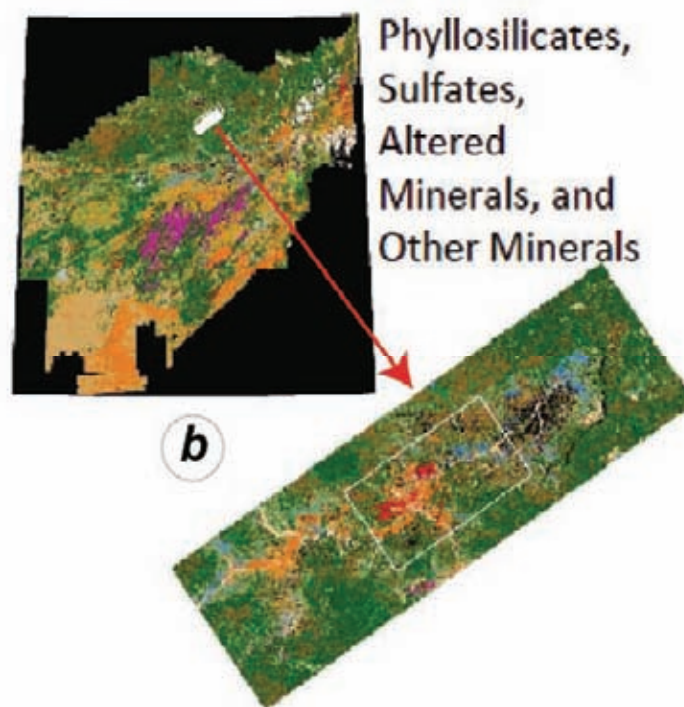
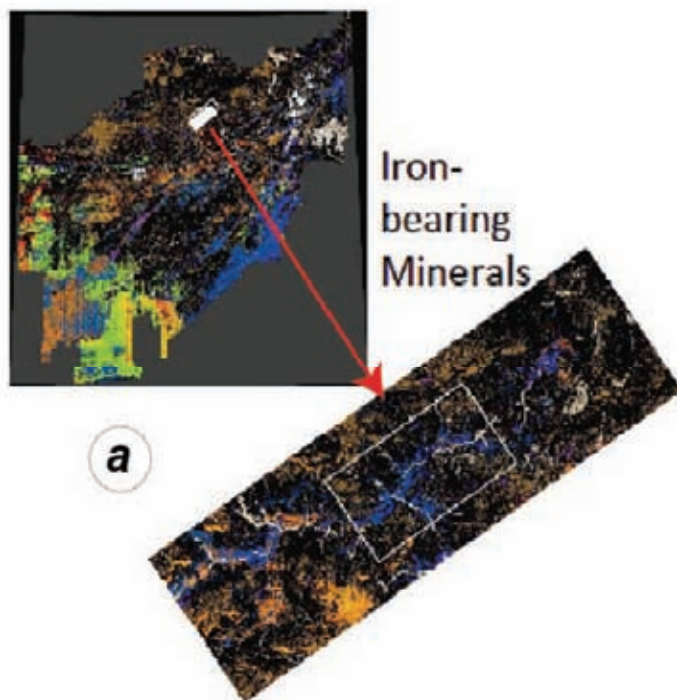


Figure 1-17. Example of hyperspectral mapping at the Balkhab area of interest showing both (a) iron-bearing and (b) carbonate-phyllosilicate distributions. Images of these data are included in the data packages for each area of interest and are available for download at <http://afghanistan.cr.usgs.gov/> and from the AGS Data Center in Kabul (<http://mom.gov.af/en>; <http://www.bgs.ac.uk/afghanminerals/>).

Khanneshin Carbonatite

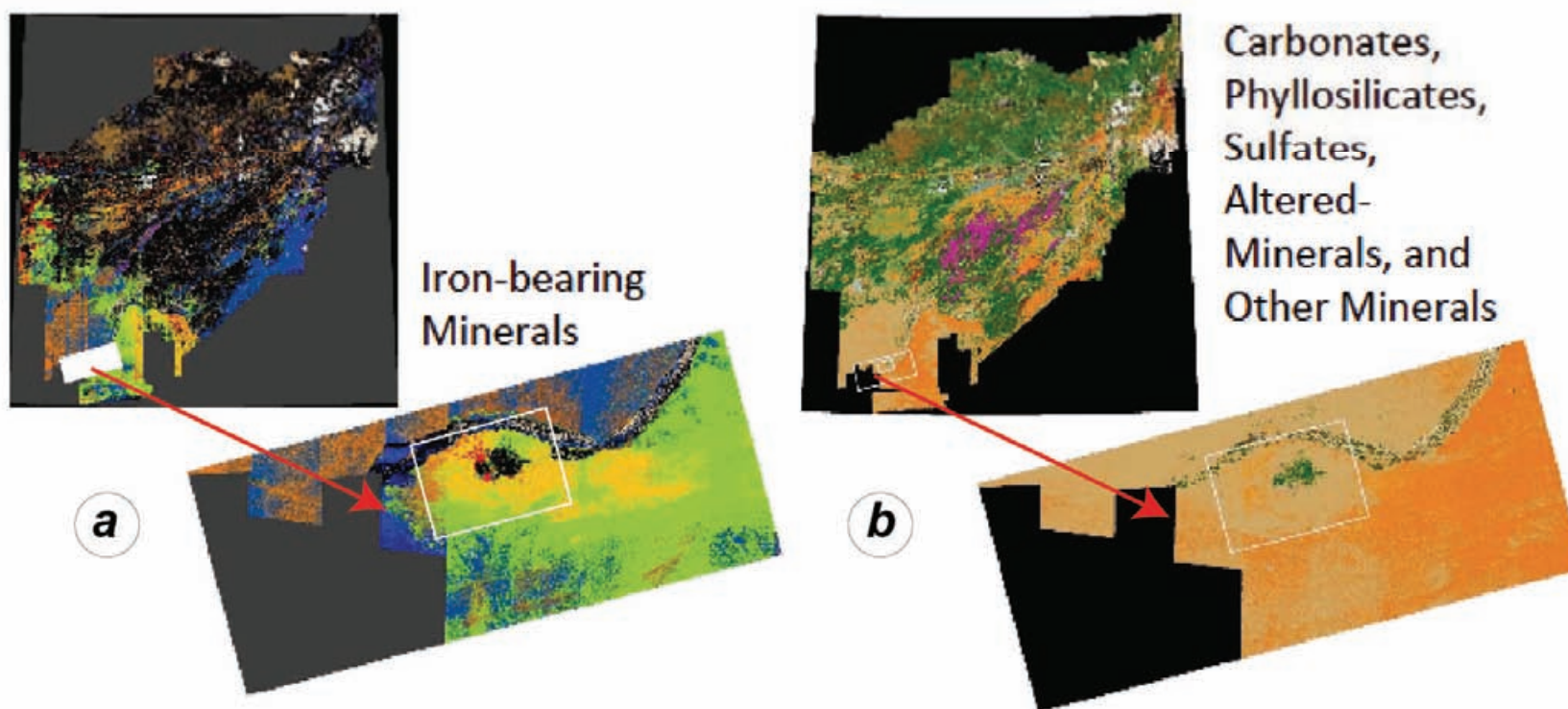


Figure 1-18. Examples of hyperspectral mapping at the Khanneshin carbonatite area of interest showing both (a) iron-bearing and (b) carbonate-phyllosilicate presentations. Images of these data are included in the data packages for each area of interest and are available for download at <http://afghanistan.cr.usgs.gov/> and from the AGS Data Center in Kabul (<http://mom.gov.af/en>; <http://www.bgs.ac.uk/afghanminerals/>).

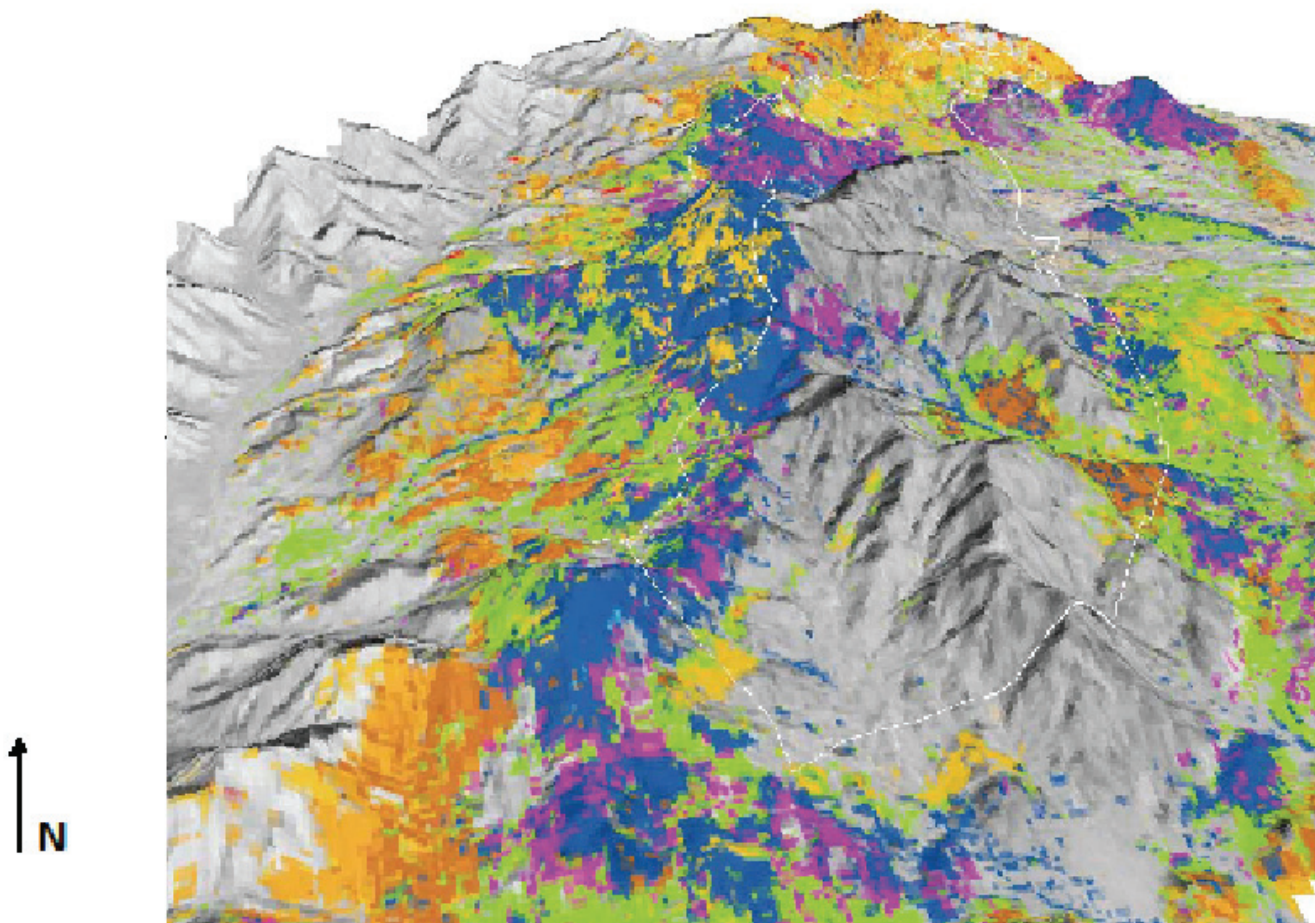


Figure 1–19. Three-dimensional diagram showing anomalous contact zones (blue, purple, orange, yellow, and green) around the Zarkashan intrusive (gray areas in right central parts of diagram) in the Zarkashan copper and gold area of interest. These anomalous zones represent combinations of favorable alteration minerals that are associated with copper and gold mineralization. The hyperspectral data were analyzed as part of the summary chapters in this report and are included in the data packages for each area of interest.

1.6 Geophysical Data

Geophysical data delivery involved clipping aeromagnetic and gravity data for each AOI and subareas with embedded metadata for each AOI data package. The main new data assimilated within the existing dataset were from the aeromagnetic survey in Afghanistan, which is a composite of aeromagnetic and ground magnetic surveys conducted through 2008 (Shenwary and others, 2011) (fig. 1–20). These data were newly published in 2010. The previous datasets (Sweeney and others, 2006a, b; 2007) are integrated within the new compilation and include:

- Afghanistan gravity dataset—<http://pubs.usgs.gov/of/2008/1089/>
- Russian magnetic dataset—<http://pubs.usgs.gov/of/2006/1325/>
- Russian radiometric dataset—<http://pubs.usgs.gov/of/2007/1042/>
- German magnetic dataset—<http://pubs.usgs.gov/of/2006/1204/>

The geophysical datasets were batch clipped using Arctoolbox for each AOI and subarea where data were available. An example of the images supplied to the database is contained on figure 1–20. Additionally, a unique color legend was developed for inclusion with the data for each clipped set of data. Images of these data are included in the data packages for each AOI and are available for download at <http://afghanistan.cr.usgs.gov/> and from the AGS Data Center, Kabul (<http://mom.gov.af/en>; <http://www.bgs.ac.uk/afghanminerals/>).

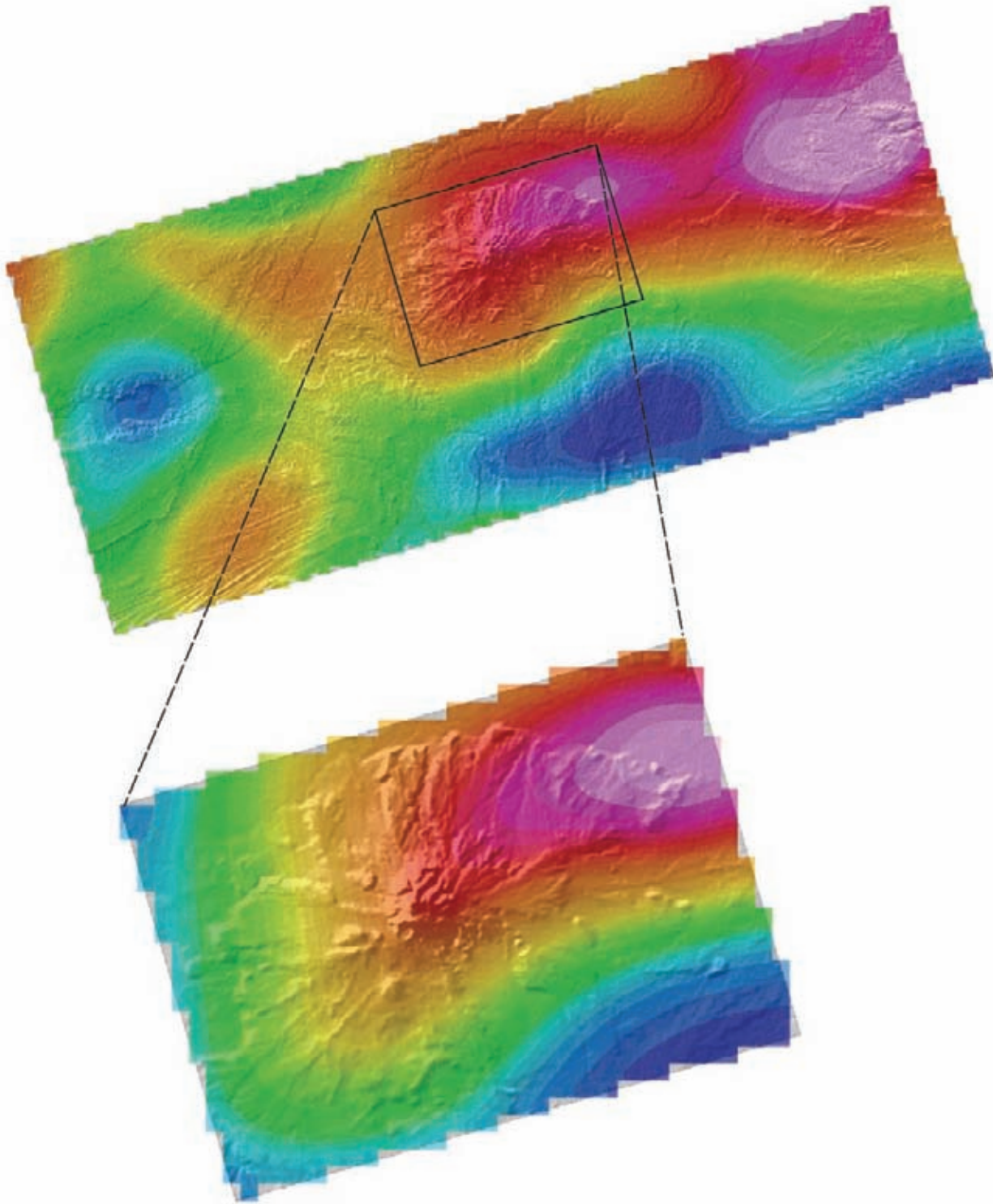


Figure 1–20. Map of the Khanneshin carbonatite area of interest (see fig. 1–1) with shaded relief and aeromagnetic data from Shenwary and others (2011). Smaller map inset shows subarea of the Carbonatite Volcano subarea. This is an example of the new (2008) composite geophysical data for the Khanneshin carbonatite area of interest and subarea.

1.7 Geohydrologic Data and Interpretations

Water is needed for processing mineral resources in Afghanistan. However, water also is needed for existing communities and for associated community growth that may accompany a developing mining economy. The climate and vegetation within each AOI are described to provide information on

the seasonal availability of water and on the seasonal demands for water. The topography and demographics also are described in each summary chapter (“C” chapters) to provide information on the villages, towns, and cities and their locations in the AOIs. The availability of surface-water and groundwater resources, the current use of water resources, and potential concerns, or data needs, regarding water use for mining activities also are discussed in each chapter C. In each chapter, a section on geohydrological data presentation and analysis discusses the influence of geology, population density, lineaments, and lineament density for rock aquifer groundwater (figs. 1–21a–d).

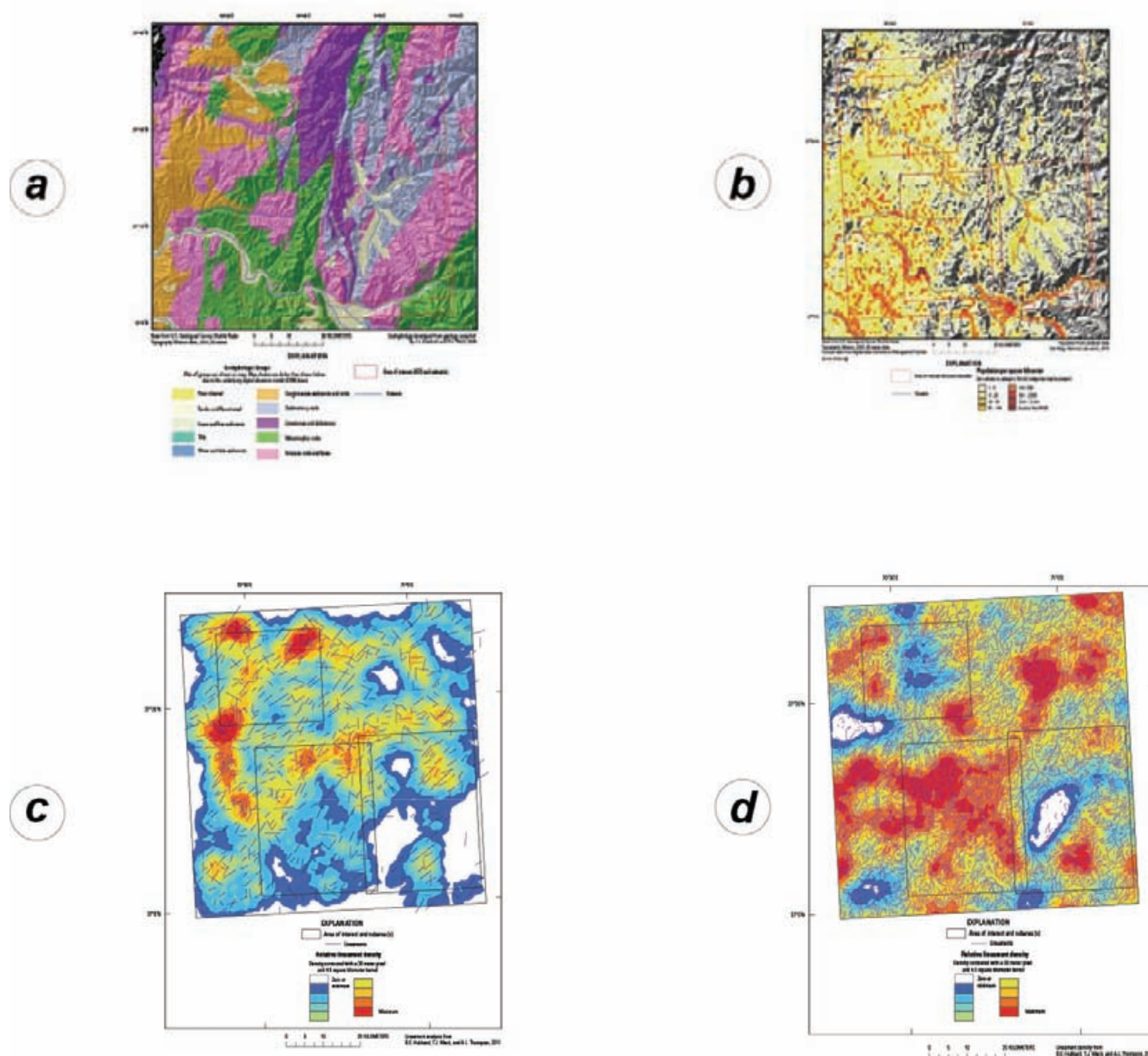


Figure 1–21. Examples of geohydrological data presentation and analysis from the Badakhshan gold area of interest, discussed in chapter 3C. (a) Generalized geologic map. (b) Population density (warmer colors equal higher density). (c) Lineaments and lineament density based on 30-meter imagery. (d) Lineaments and lineament density based on 15-meter imagery.

Geohydrologic activities in support of mineral development included the completion of the analysis of historical streamflows for Afghanistan. Results of this analysis are available in Williams-

Sether (2008), Olson and Williams-Sether (2010), and Vining (2010). Because all historical streamflow data for Afghanistan are now available in the USGS digital database, it was possible to estimate streamflows for each of the AOIs. More detailed hydrogeologic assessments also are provided in each chapter C in this report for areas visited during the 2009–2011 USGS-TFBSO scoping missions for the Khanneshin carbonatite, Balkhab copper, Haji-Gak iron, Aynak copper and cobalt, and Dusar-Shaida copper and tin AOIs.

1.8 Mineral Scoping Missions

Mineral scoping missions were undertaken during 2009, 2010, and 2011 by USGS and TFBSO personnel to the Khanneshin carbonatite, Chaigai Hills travertine, Balkhab copper, Haji-Gak iron, Aynak copper and cobalt, Kundalan copper and gold, Zarkashan copper and gold, and Dusar-Shaida copper and tin AOIs (fig. 1–1). Transport, security, logistics, and access in each case were arranged through the TFBSO, its contractors, and the International Security Assistance Force (ISAF) and U.S. Military. In many cases, the scoping missions received full military support from the United States or ISAF-NATO command, and in other cases certified security and aviation contractors were used (figs. 1–22*a-d* and 1–23). Technical fieldwork on the scoping missions consisted of short 1-day visits (30 minutes to several hours) that involved rapid geologic mapping, geochemical, and hydrologic sampling (figs. 1–22*a-d*). When the field parties landed where known Soviet observations had been taken, the old data and observations were confirmed and deemed accurate.



Figure 1–22. Photographs of U.S. Geological Survey-U.S. Department of Defense Task Force for Business and Stability Operations scoping missions. (a) Preparation and planning of missions at forward operating base for Kundalan copper and gold area of interest. Photograph by Stephen Peters, U.S. Geological Survey. (b) Stream sediment sampling in Zarkashan copper and gold AOI. Photograph by Stephen Peters. (c) Field team for second Khanneshin scoping mission. Photograph by unidentified soldier. (d) Reconnaissance mapping and sampling in the Haji-Gak AOI. Photograph by Thomas J. Mack, U.S. Geological Survey.

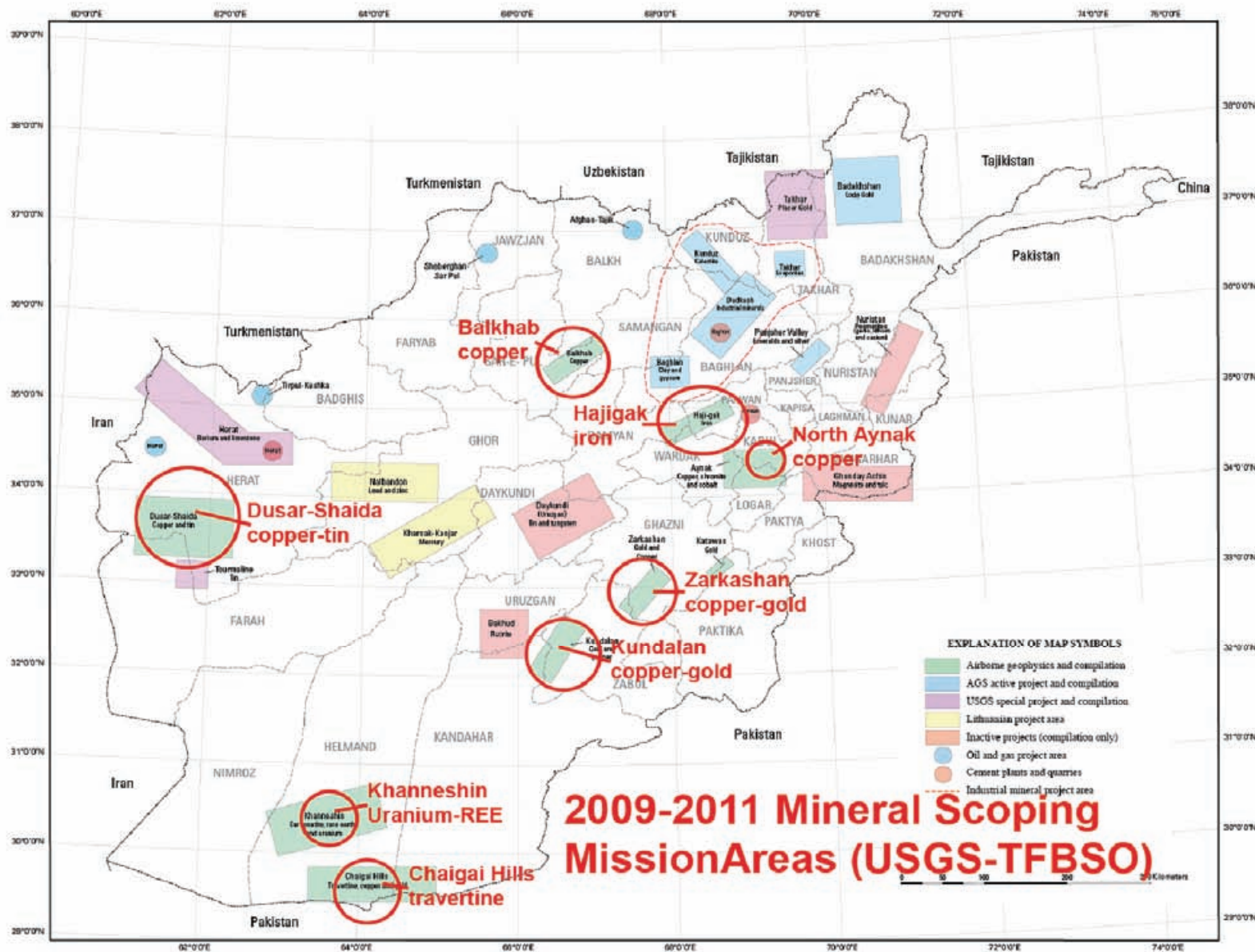


Figure 1–23. Map showing areas where mineral scoping missions were conducted by the U.S. Geological Survey and the U.S. Department of Defense Task Force for Business and Stability Operations. The field visits took place between September 2009 and March 2011.

1.9 Archival Data and Reports

Archival data and reports were compiled and assembled for each AOI and are included in the information packages. The archives of the AGS and Ministry of Mines (MOM) have extensive holdings (figs. 1–24*a-d*) and have been summarized in Abdullah and others (1977), United Nations Economic and Social Commission for Asia and the Pacific (1995), and Eppinger and others (2006) and were cataloged and indexed by the British Geological Survey (2008). Afghanistan’s recent 30 years of conflict left many traditional archival institutions in ruins, and all data collection activities stopped at some point during the conflict years. Recently, nongovernment agencies (NGOs), foreign government agencies, and the Afghan government have begun technical investigations of natural science issues; however, these activities are limited. Therefore, USGS efforts have focused on searches of the literature, use of companion geologic data and remotely sensed data, acquisition or restoration of as much historic data as possible, use of basic principles, and drawing of analogies from limited first-hand knowledge of some areas of Afghanistan. The quantity of data available for each AOI is not consistent; therefore the content of each summary chapter varies. In addition, the individual chapters use place names and spellings as consistently as possible; however, there are no universally agreed upon translations from the various Afghan languages and dialects to English. Place name spellings in different digital databases vary, and therefore different spellings vary within the report and sometimes within individual chapters. The data packages and scanned reports and maps for each AOI are available in the Data Center at the AGS (fig. 1–25).



Figure 1–24. Photographs of the Afghanistan Geological Survey Archival Report and Map Library, Kabul. (a) Report Library showing books on table and shelves. (b) Typical bindings illustrating the condition of many of the reports. (c) Map room and map table. (d) Close-up of reports showing indexing numbers. Photographs by Fahim Zaheer, USGS Liaison Officer.



Figure 1–25. Photograph of Afghanistan Geological Survey (AGS) Data Center installed in the AGS building in May 2011. The U.S. Geological Survey (USGS) regional data and the data for each of the 24 areas of interest and the 33 subareas that accompany this report are available from this data center. Photograph by Fahim Zaheer, USGS Liaison Officer.

1.10 Summary of Important Areas of Interest

A number of areas of interest (AOIs) and subareas were identified as important because of interpretations of new data gathered and compiled by the USGS and TFBSO between 2009 and 2011. This work confirmed the geologic concepts or mineral potential that had been interpreted from previous compilations in these areas. These areas are Badakshan gold, Balkhab copper, Haji-Gak iron, Northern Aynak copper and cobalt (and chromite), Zarkashan copper and gold, Kundalan copper and gold, Khanneshin carbonatite, and Dushan-Shaida copper and tin (fig. 1–26). Many of these areas have known outcropping or measured resources with favorable geometries for mining and (or) routine metallurgical parameters. These characteristics may translate into lower capital costs, short lead times, and short payback periods. Many of these AOIs may possibly contain ore deposits that are medium to world class in size.

Development of a mineral deposit commonly is not direct and efficient. This may be especially true in Afghanistan. Changing metal prices, markets, and technologies contribute to stopping and starting of exploration programs. The high risk and high cost of exploration without immediate payback may cause many companies to stop exploration or to sell their data and property to other companies. These risks affect the economics of extraction in the mining areas. It is common for mining districts to open and then close after a few years and then to open again. Most mining districts may be operated throughout their lifecycles by numerous mining companies. Mining districts commonly start out as small operations and then develop, with time, into larger operations as the knowledge of the district grows, as metal prices increase, or as labor and infrastructure improve. The mineral industry and mining districts generally benefit by having two or more mining companies operating within one mining district because competition provides innovation and allows interaction of labor, supplies, capital, and infrastructure.

Each mineral commodity may require different exploration approaches, differing mining, and different metallurgical techniques. Metal deposits, such as copper or iron, have relatively uniform and predictable exploration, mining, and metallurgical approaches, and their sales and marketing usually are conducted according to uniform world price markets. Many industrial minerals, by contrast, are used in local industries and may be produced according to standards and specifications required by the local markets.

Several scales of mining activities and mineral commodity types are represented in the AOIs of mineral investment and production opportunities. These different development scales of mining have differing timeframes and different social and economic impacts. Differing size operations may be regulated differently under the Afghanistan mineral law. The smallest scale mining activity is artisanal mining, which is commonly conducted for commodities of high unit value, such as gem and precious stones and gold. These activities usually involve operations valued at less than \$500,000 and may involve single family size groups or hundreds and thousands of individuals in a specific mining district.

Small- to medium-scale mining might involve deposits with gross in-place values ranging from \$500,000 to \$9,000,000 and commonly would be financed by local or regional companies or individuals. Examples might be a 60,000 ounce gold mine, or a cement plant, or a limestone or marble quarry. These operations would have short lead times of less than 5 years. These operations generally employ hundreds of individuals and generally have an impact on goods and services in the surrounding communities.

The large-scale, world class deposits would likely involve international investors, have longer lead times of greater than 5 years, have gross in-place values of over 1 billion dollars, and may contribute to decades of export and economic growth. Examples of these larger deposits are the Aynak copper-cobalt and Haji-Gak iron deposits. Other examples are the Khanneshin carbonatite, and the porphyry copper-gold prospects such as in the Kundalan and Zarkashan copper, gold AOIs. Operations resulting from the mining of these large deposits may employ several hundreds of highly trained individuals, but may directly employ thousands of individuals in the supply and service industries.

A number of factors increase the risk of developing mineral opportunities in countries similar to Afghanistan. The operating environment in Afghanistan may be challenging and expensive. Many of the areas of mineral opportunity are in remote, rugged mountains that lack infrastructure, power, and a proximal trained workforce. Some of the exploration environment in Afghanistan is seasonal due to the harsh winters in the higher altitudes. Security, tribal conflicts, and local politics are also challenges that need to be overcome in order to develop mineral properties.

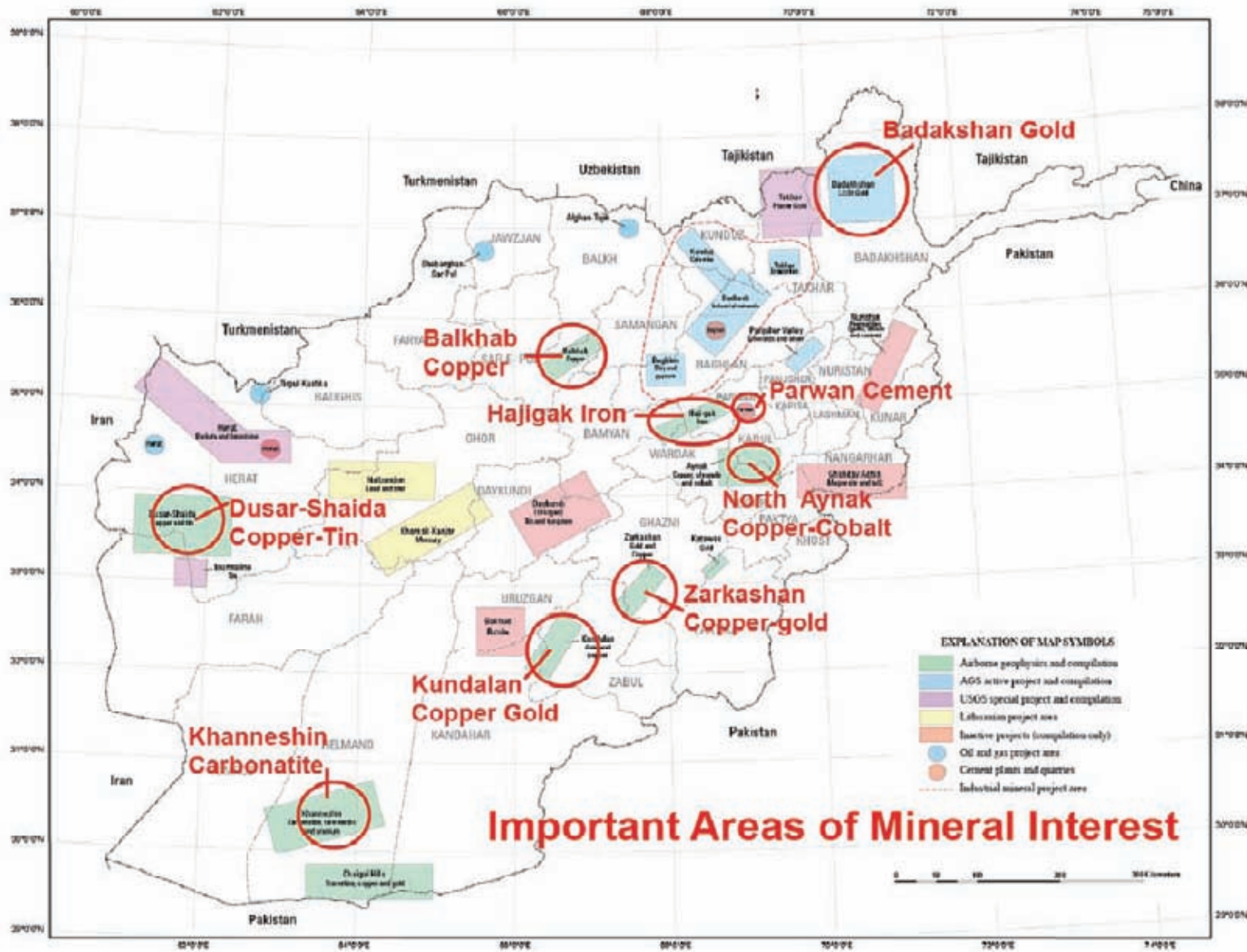


Figure 1–26. Map showing areas of interest and specific important areas of mineral interest identified from analysis and interpretation of new data between 2009 and 2011.

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

Contribution by Stephen G. Peters,¹ Robert D. Tucker,¹ Abdul Gaffer,² and Bernard E. Hubbard¹

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 (km²), and the Balkhab prospect subarea is 321 km² (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

¹U.S. Geological Survey.

²Afghanistan Geological Survey.

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.

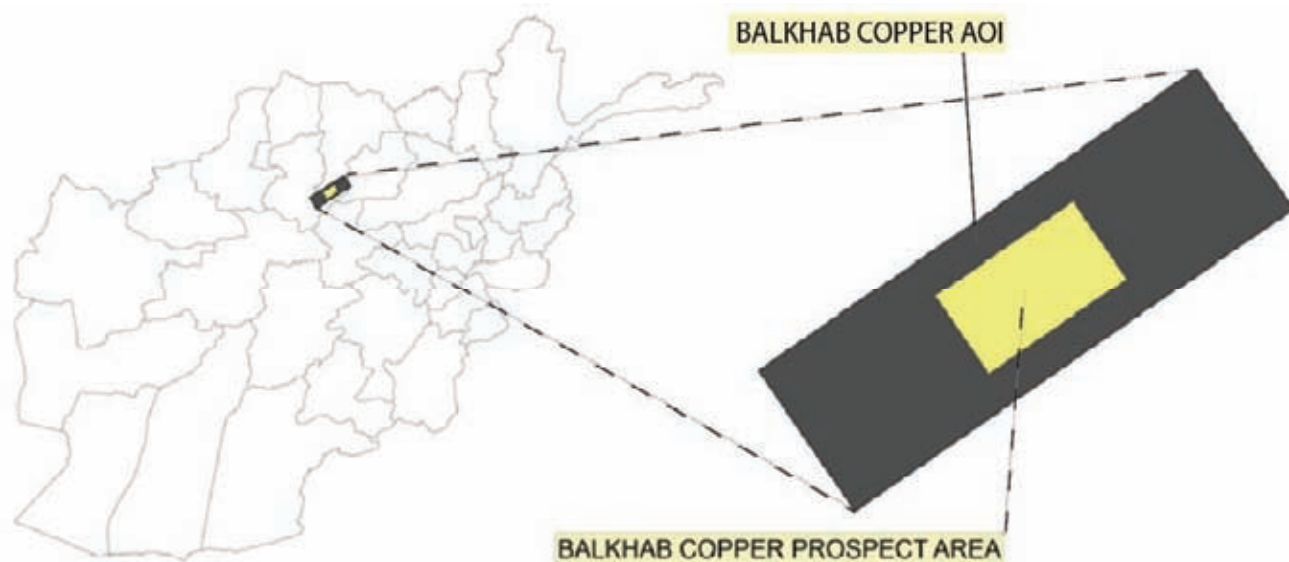


Figure 4A–1. Location of the Balkhab copper area of interest and the Balkhab copper prospect subarea in northern Afghanistan, Sar-i-Pul Province.

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 azurite-coated phyllite from Balkhab copper prospect collected by Engineer Abdul Kadir Akkhunzada, Ministry of Mines, in 2008. 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_{1d}), which are, in turn, locally overlain by Mississippian (Early Carboniferous) volcanic rocks, limestone, and sandstone (unit C_{1rb}), 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}).



Figure 4A–3. Photograph of engineers Abdul Kadir Akkhunzada (left) from the Ministry of Mines and Abdul Gaffer (right) from the Afghanistan Geological Survey, who were responsible for the recent rediscovery and exploration of Balkhab copper prospect. Photograph by Stephen G. Peters, U.S. Geological Survey.

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 (Jl_2ssl), 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.

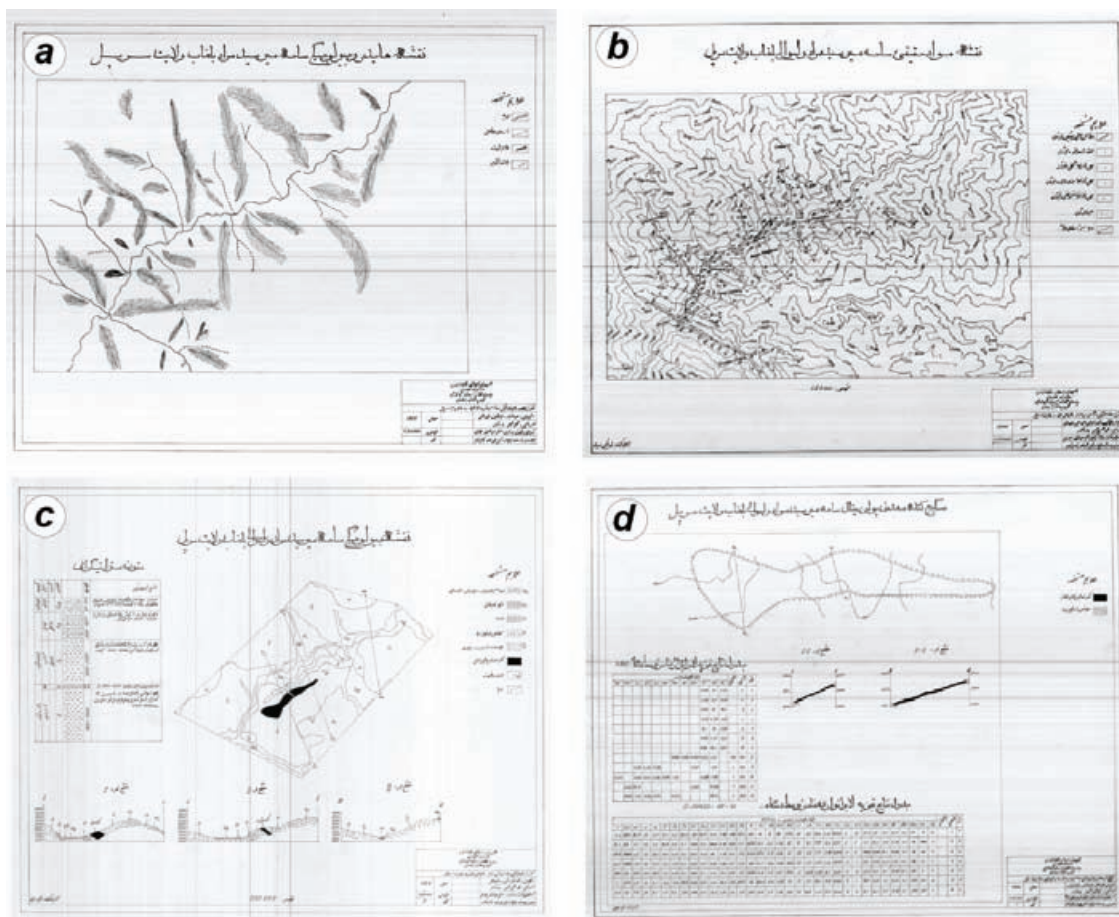


Figure 4A-4. Maps produced by the Afghanistan Geological Survey (AGS) from 2009 field work in the Balkhab copper prospect area. (a) Outline of drainage areas. (b) Sampling map with topographic contours. (c) Geologic map of the main mineralized zone with cross sections; orebody in black. (d) Detailed 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 6a,b). The rocks are pervasively sheared green- to gray- to black-colored chloritic phyllite and schist (figs. 4A-6a,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-6d). 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-5b). 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–6c) 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–6d). 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.

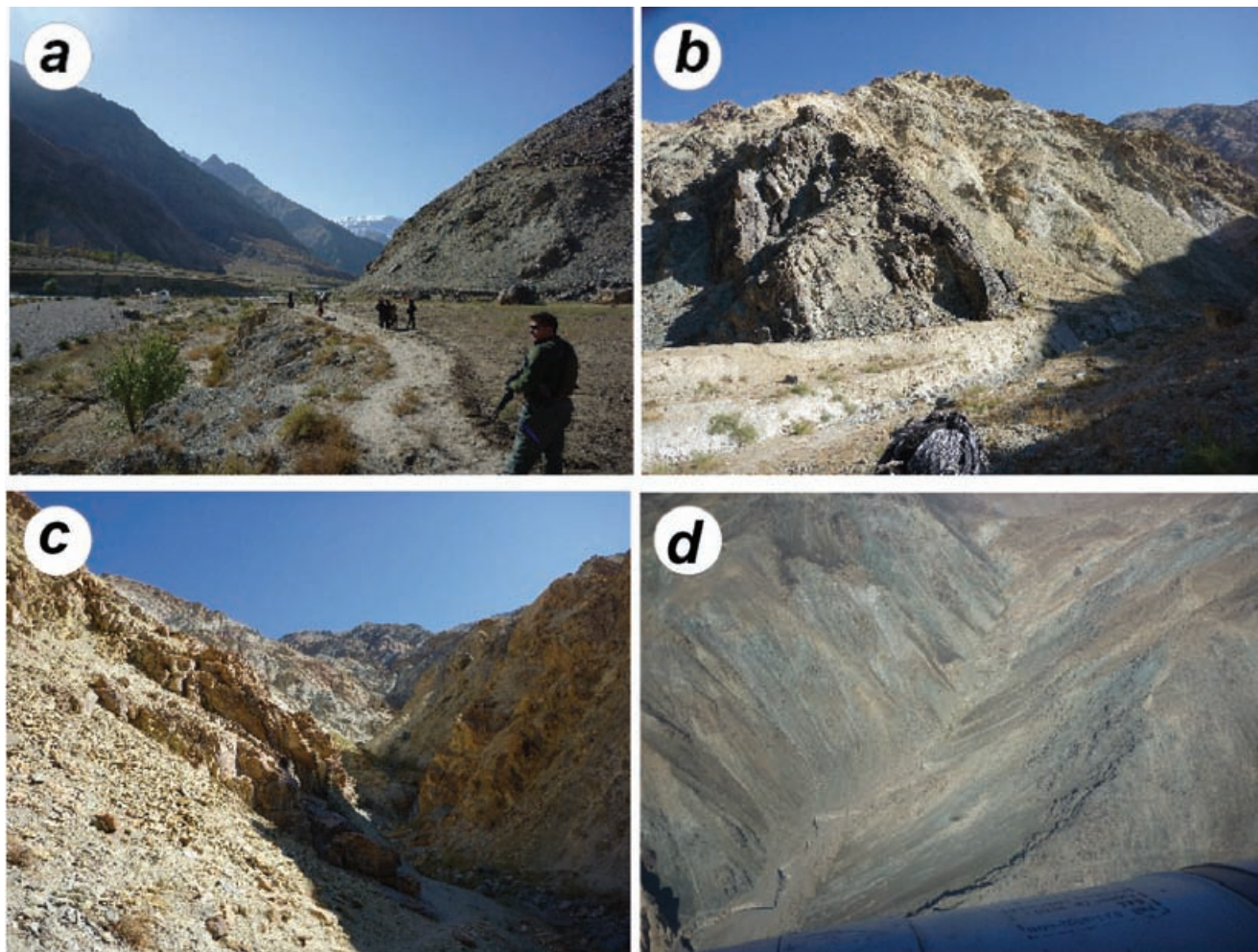


Figure 4A–5. Photographs of the Balkhab copper area of interest (AOI). (a) Floodplain of the Balkhab River and the steep topography of the river gorge (long. 66.73341°E., lat. 35.55851°N.). (b) Photograph of dark, highly sheared granite porphyry (left foreground) faulted against steep-dipping felsic 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–7a.

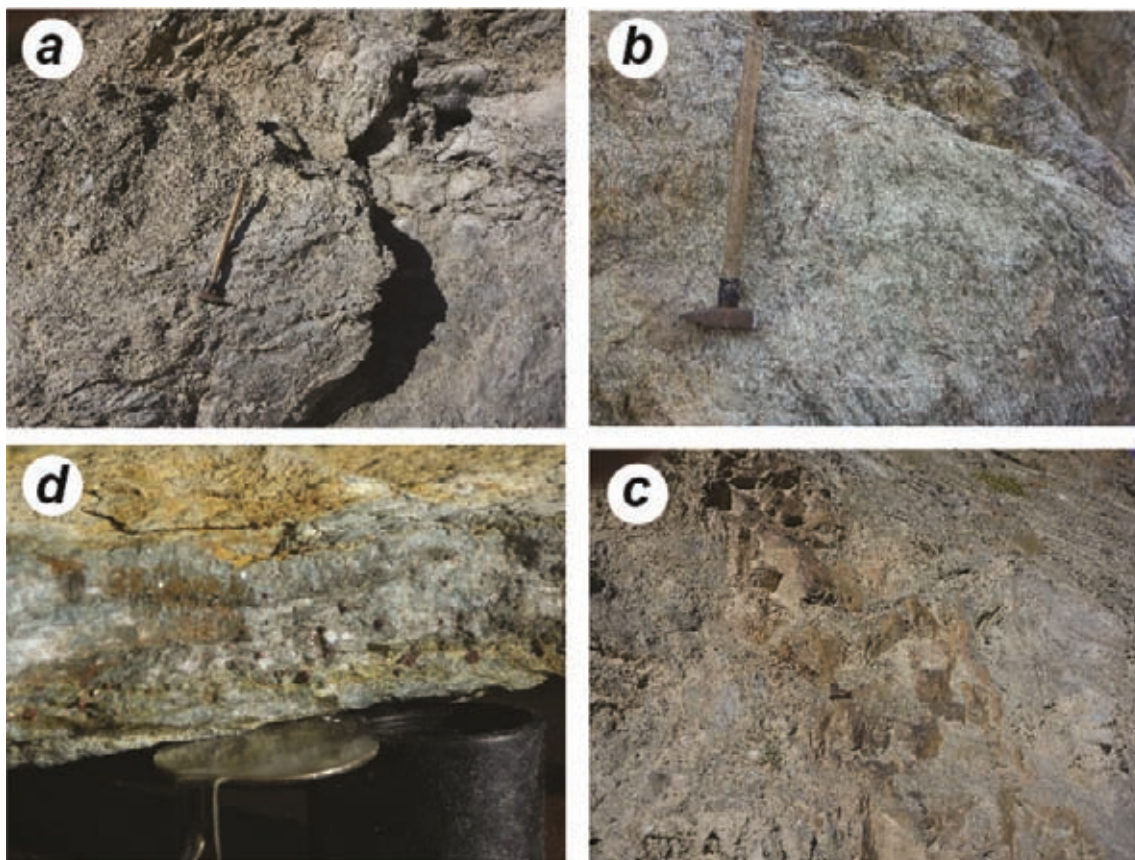


Figure 4A-6. Photographs of rocks and outcrops from the Balkhab copper prospect area. (a) Greenschist facies metamorphic rocks of the Balkhab copper area (long. 66.73318°E., lat. 35.55659°N.). (b) Foliated and kinked quartz-feldspathic schist-gneiss (felsic metavolcanic) of the Balkhab copper prospect 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–7b, 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–8a,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–9d 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.

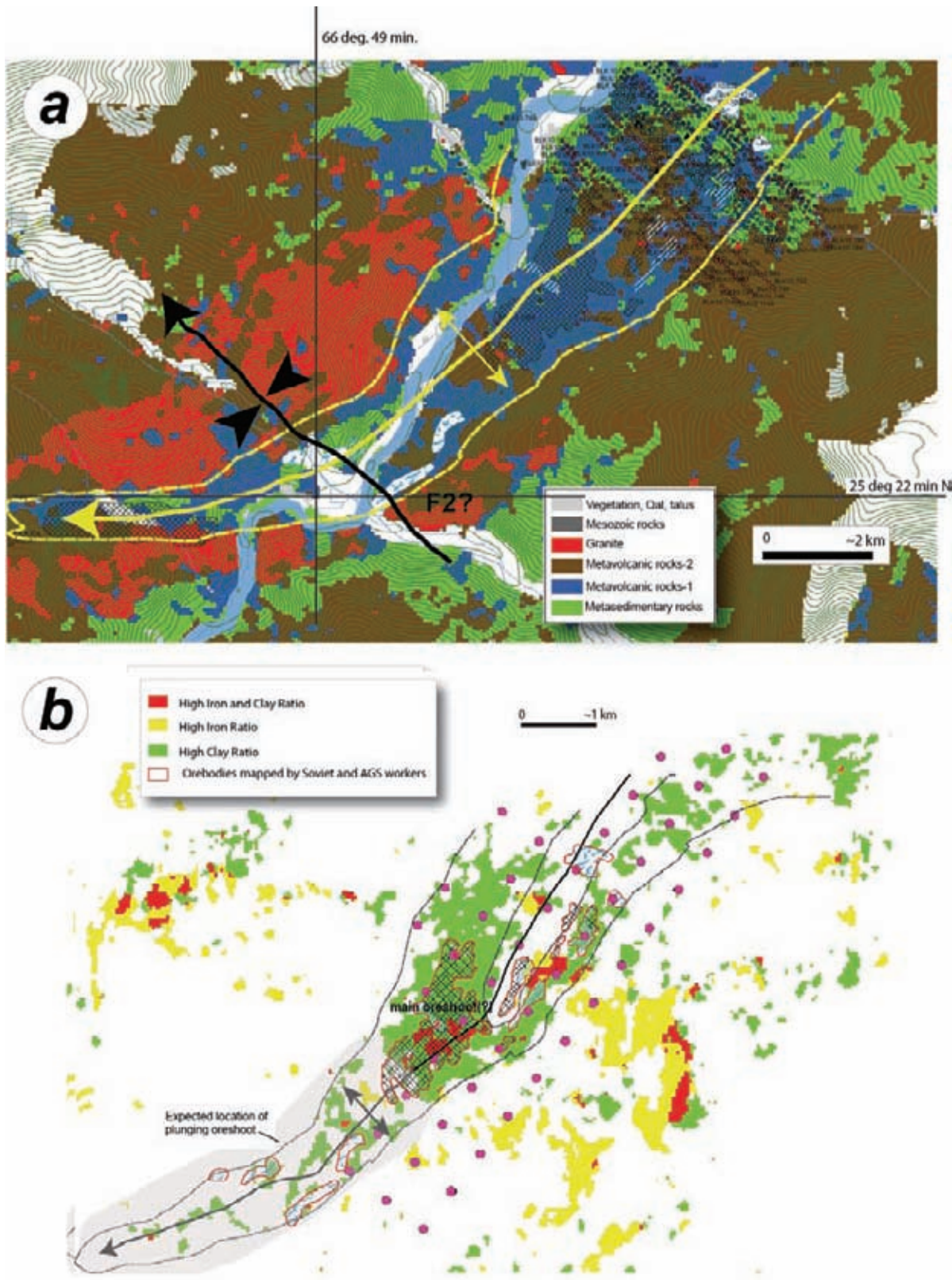


Figure 4A-7. Structural geology of the main Balkhab copper prospect mineralized zone. (a) "Geologic Map" constructed by Sabins and Ellis (2010a) from ASTER mapping of different rock units. Yellow outline is the enclosing area of the known, mapped, or suspected outcropping ore zone mapped by Kafarskiy 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-m² sampling grid.

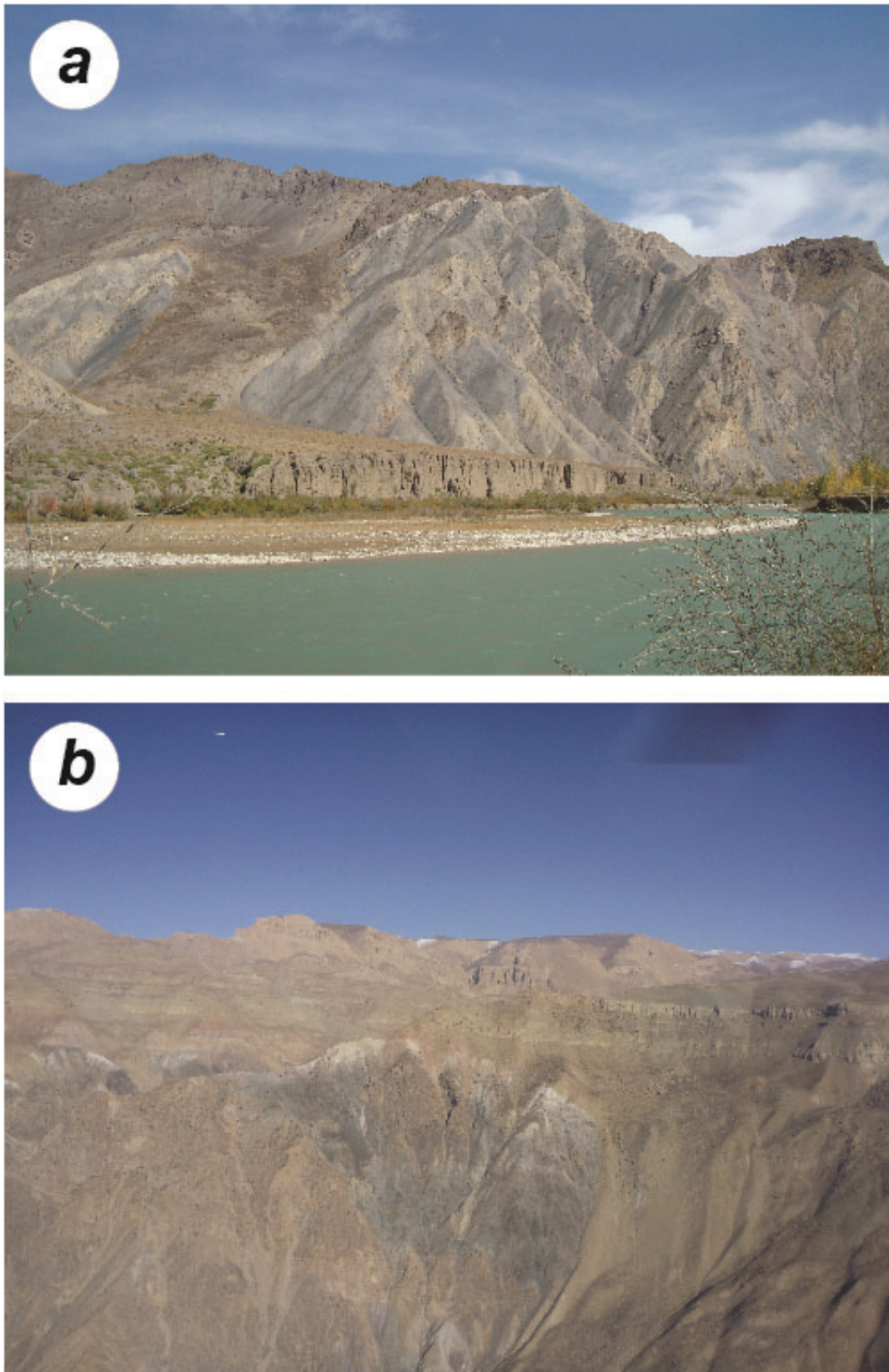


Figure 4A-8. Photographs of the Balkhab copper prospect area, looking south. (a) View from the river showing gray mineralized rocks with brown cap rocks and colluvial cover. (b) View from the air showing gray mineralized zone capped by horizontal Mesozoic strata and also covered by colluvial rocks (on 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.



Figure 4A-9. Photographs of underground and surface workings in the Balkhab copper prospect area. (a) Narrow workings dipping into the hillside following schistosity and bedding in the host rocks. (b) Local “glory holes” sunk into the mineralized zones along the hillside. (c) Interior of a shaft inside the mine workings. (d) Narrow crawl hole excavated along malachite-rich zone. Photographs by Abdul Gaffer, Afghanistan Geological Survey.

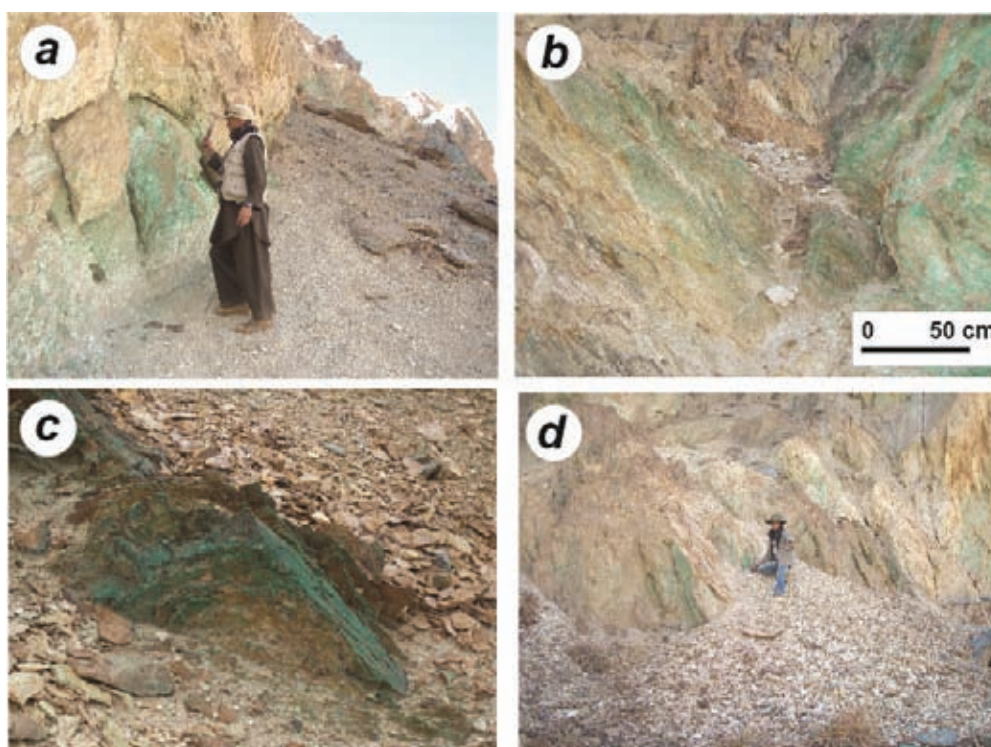


Figure 4A-10. Photographs of copper oxide mineralization in outcrop in the Balkhab copper prospect. (a) Malachite in foreground and background parallel to schistosity. (b) Malachite zone in rill on side of the hill. (c) Typical malachite-stained foliated outcrop. Field of view is 2 meters. (d) Malachite-stained outcrops above rubble pile. Photographs by Abdul Gaffer, Afghanistan Geological Survey.

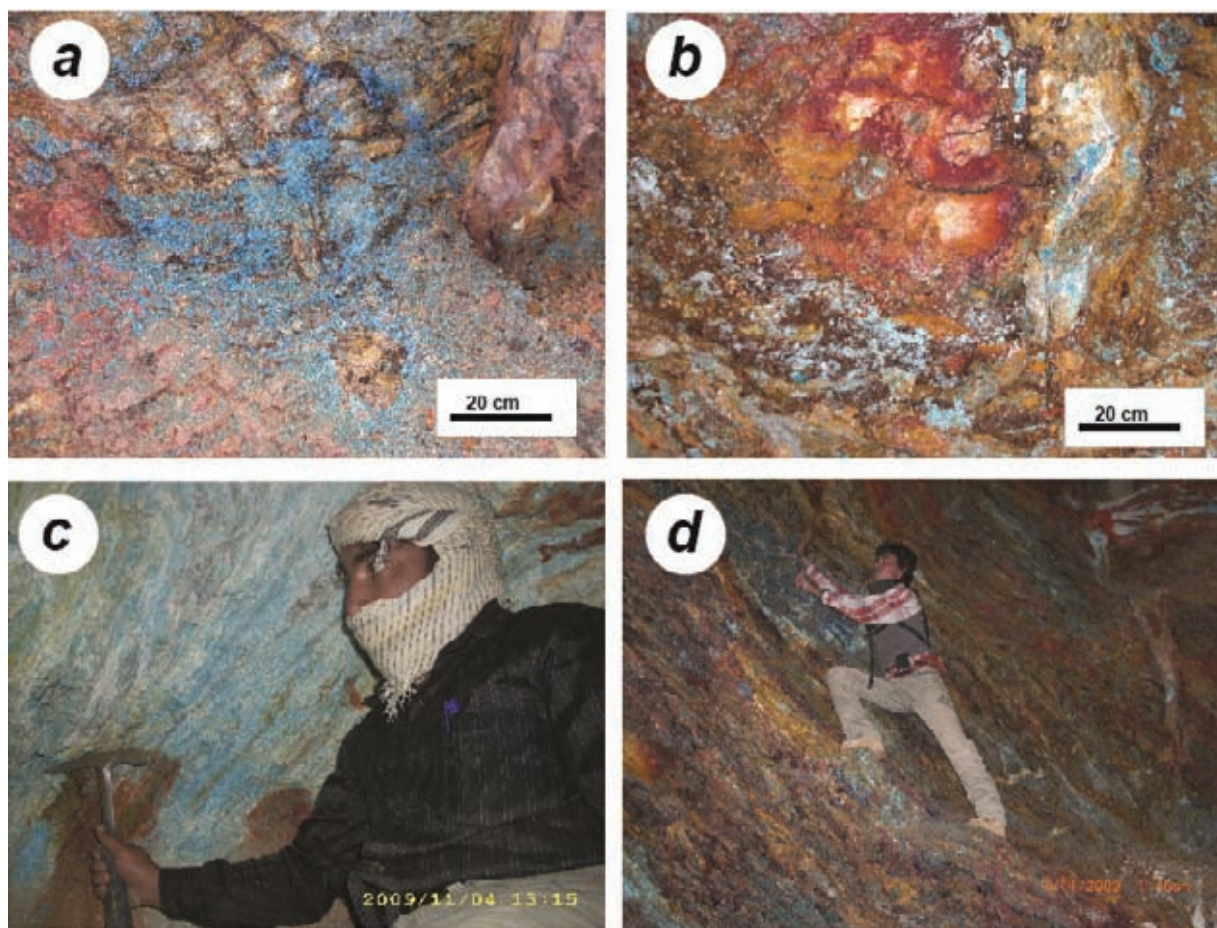


Figure 4A-11. Photographs of iron-rich mineralized zones in the Balkhab copper prospect area in underground workings. (a) Brecciated zone with bedded azurite and red iron-stained oxide minerals. (b) Red-stained iron-oxide zone rimmed by copper oxides. (c) Layered malachite and azurite along schistosity and layering in felsic volcanic rocks. (d) Interlayered malachite and red-stained mineralized zone in gallery. Photographs by Abdul Gaffer, Afghanistan 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).

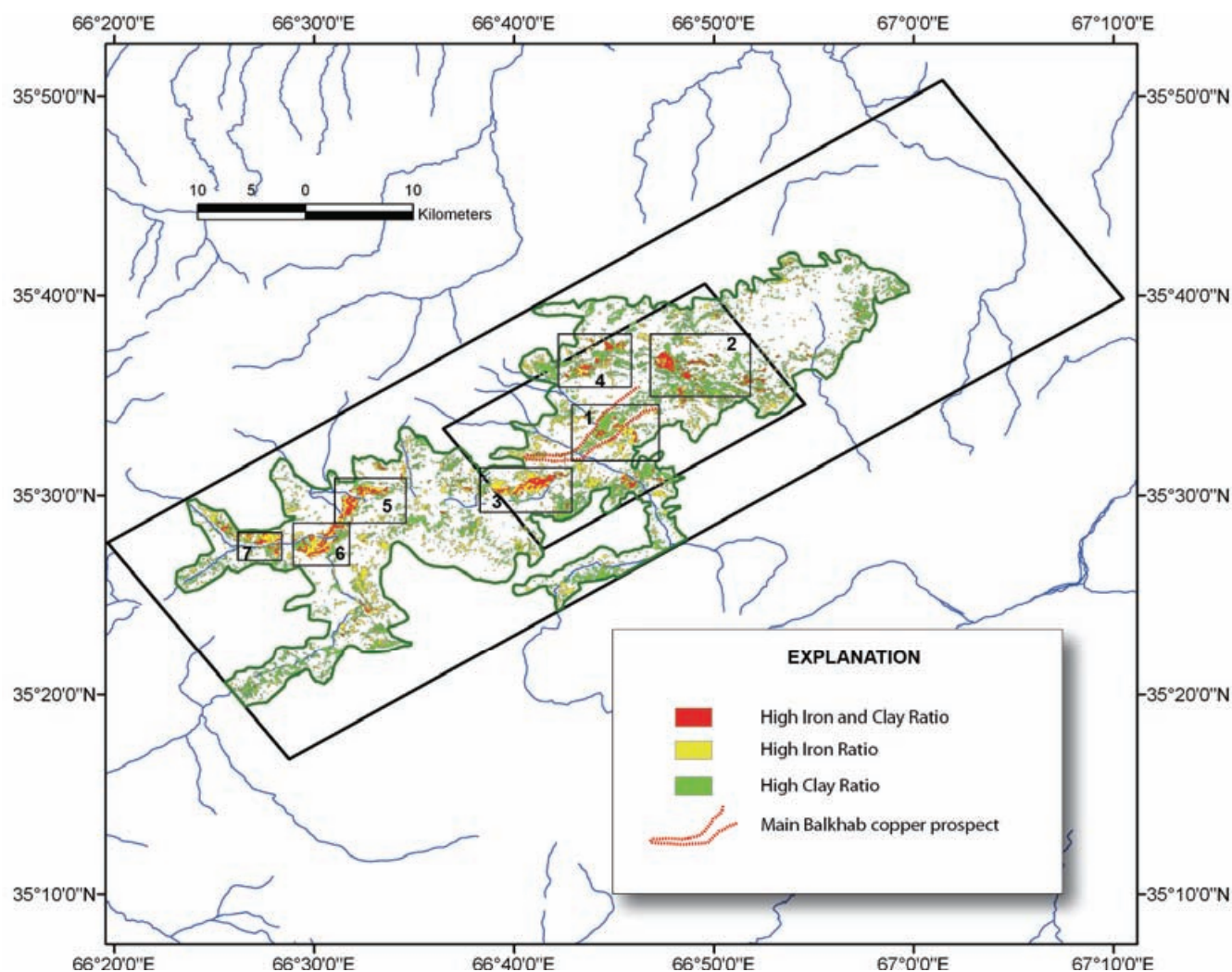


Figure 4A-12. Anomalous zones determined from Landsat Thematic Mapper alteration patterns in the Balkhab copper area of interest and the Balkhab copper prospect subarea. Seven anomalous areas were identified by Sabins and Ellis (2010a) and are numbered in the rectangles.

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-sulfur 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).

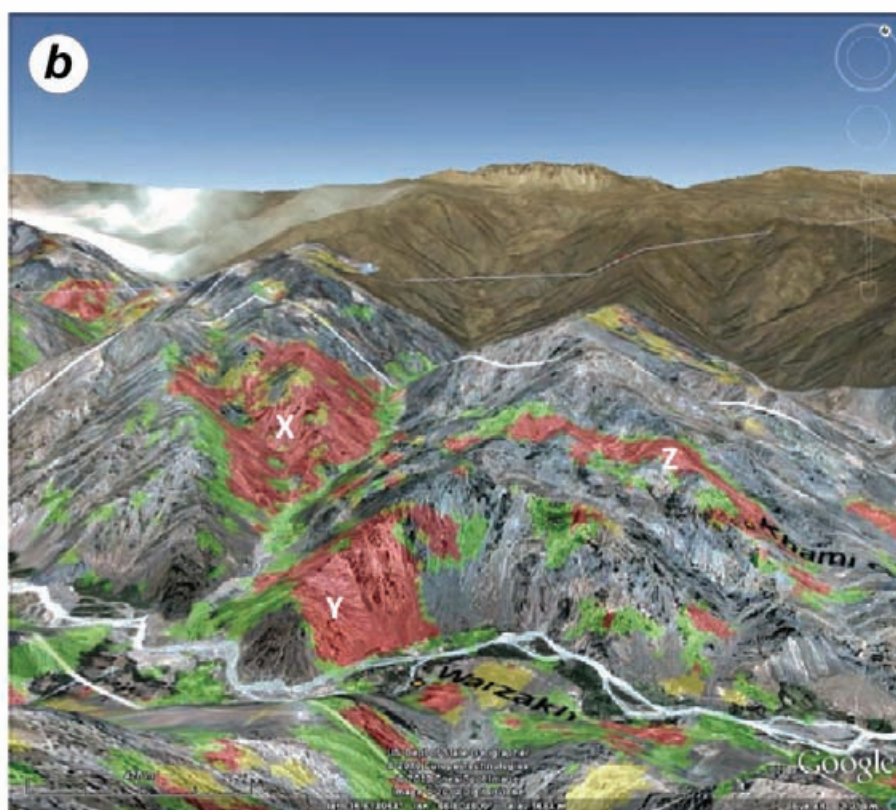
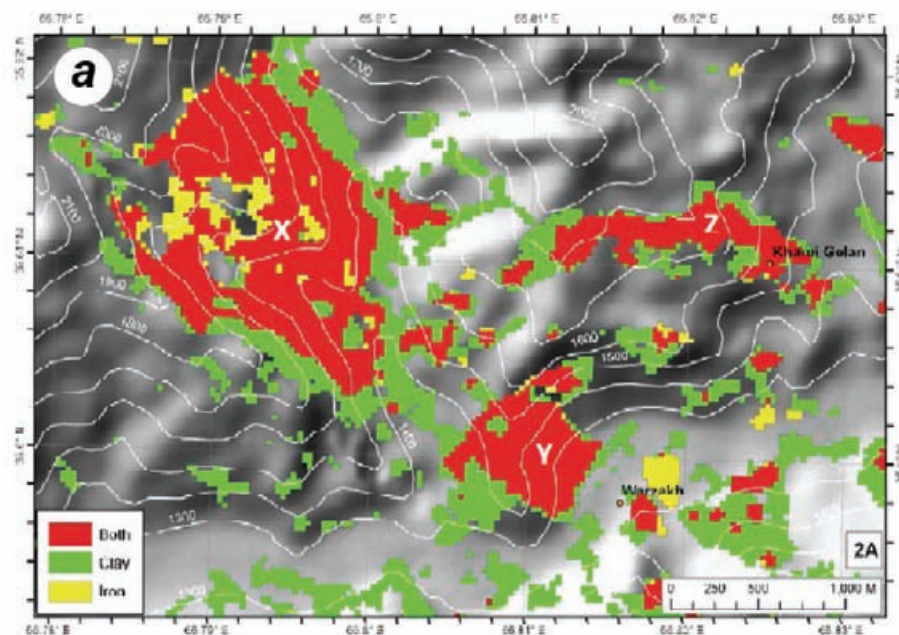


Figure 4A-13. Images of Balkhab anomalous zone 2, Balkhab copper area of interest, Sar-i-Pul Province. (a) Landsat Thematic Mapper alteration pattern on digital elevation model and contour map, Balkhab anomalous area 2. (b) Alteration patterns draped on IKONOS image. Green means secondary iron minerals 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).

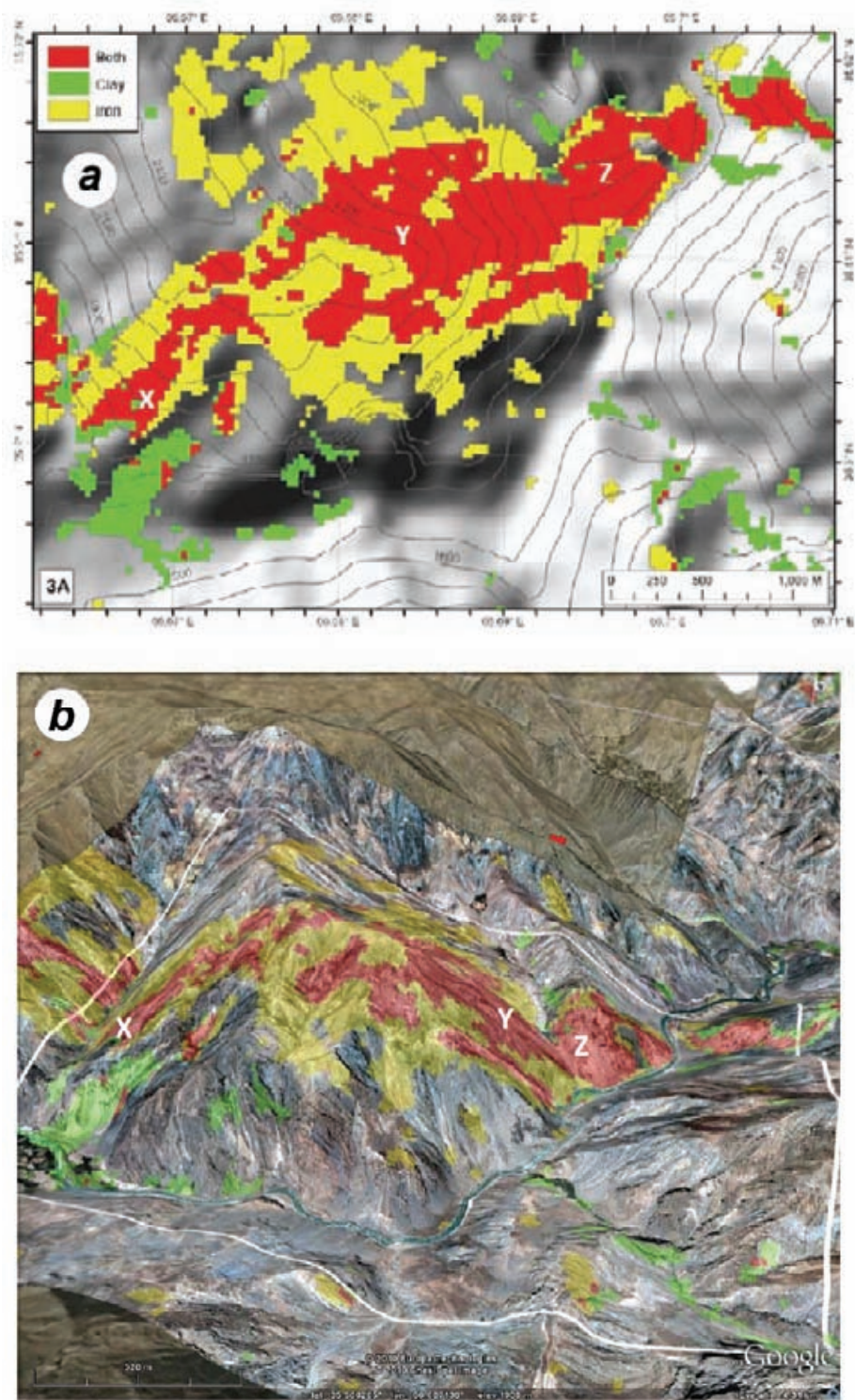


Figure 4A-14. Images of Balkhab anomalous zone 3, Balkhab copper area of interest, Sar-i-Pul Province. (a) Landsat Thematic Mapper alteration pattern on digital elevation model and contour map. (b) Alteration patterns draped on IKONOS image. Green means secondary iron minerals plus clays and other alteration 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).

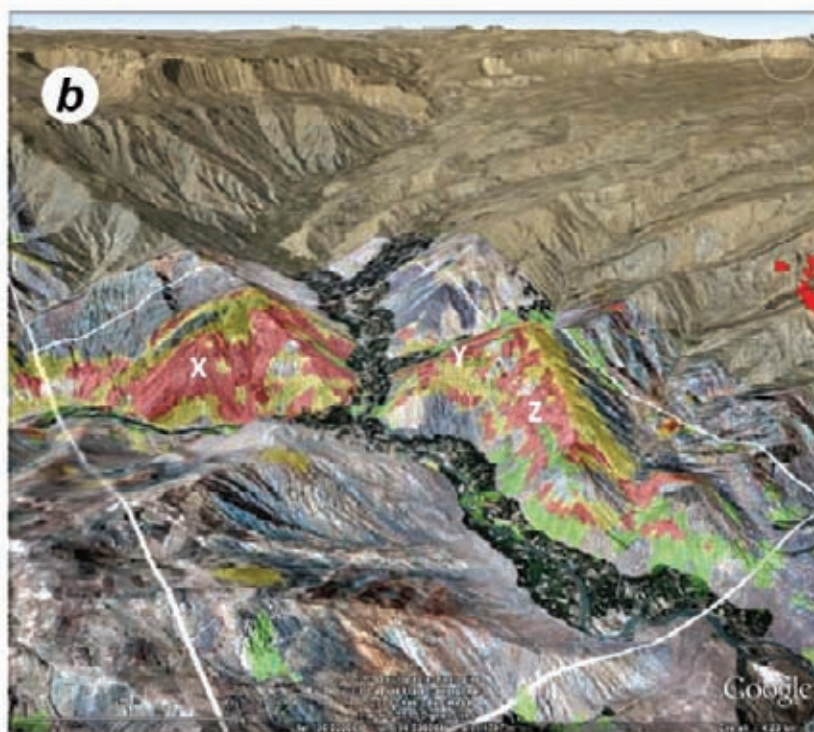
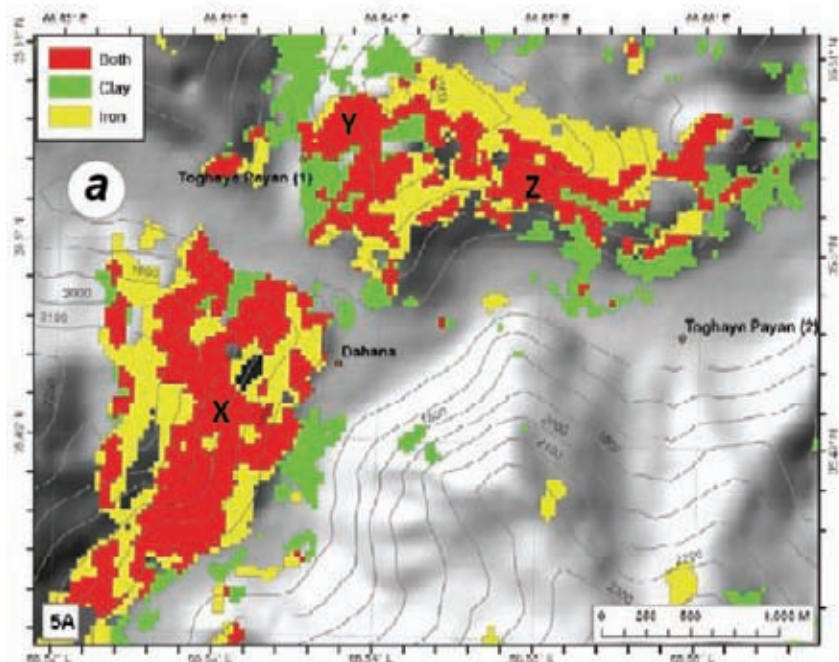


Figure 4A-15. Images of Balkhab anomalous zone 5, Balkhab copper area of interest, Sar-i-Pul Province. (a) Landsat Thematic Mapper alteration pattern on digital elevation model and contour map. (b) Alteration patterns draped on IKONOS image. Green is secondary iron minerals plus clays and other alteration 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).

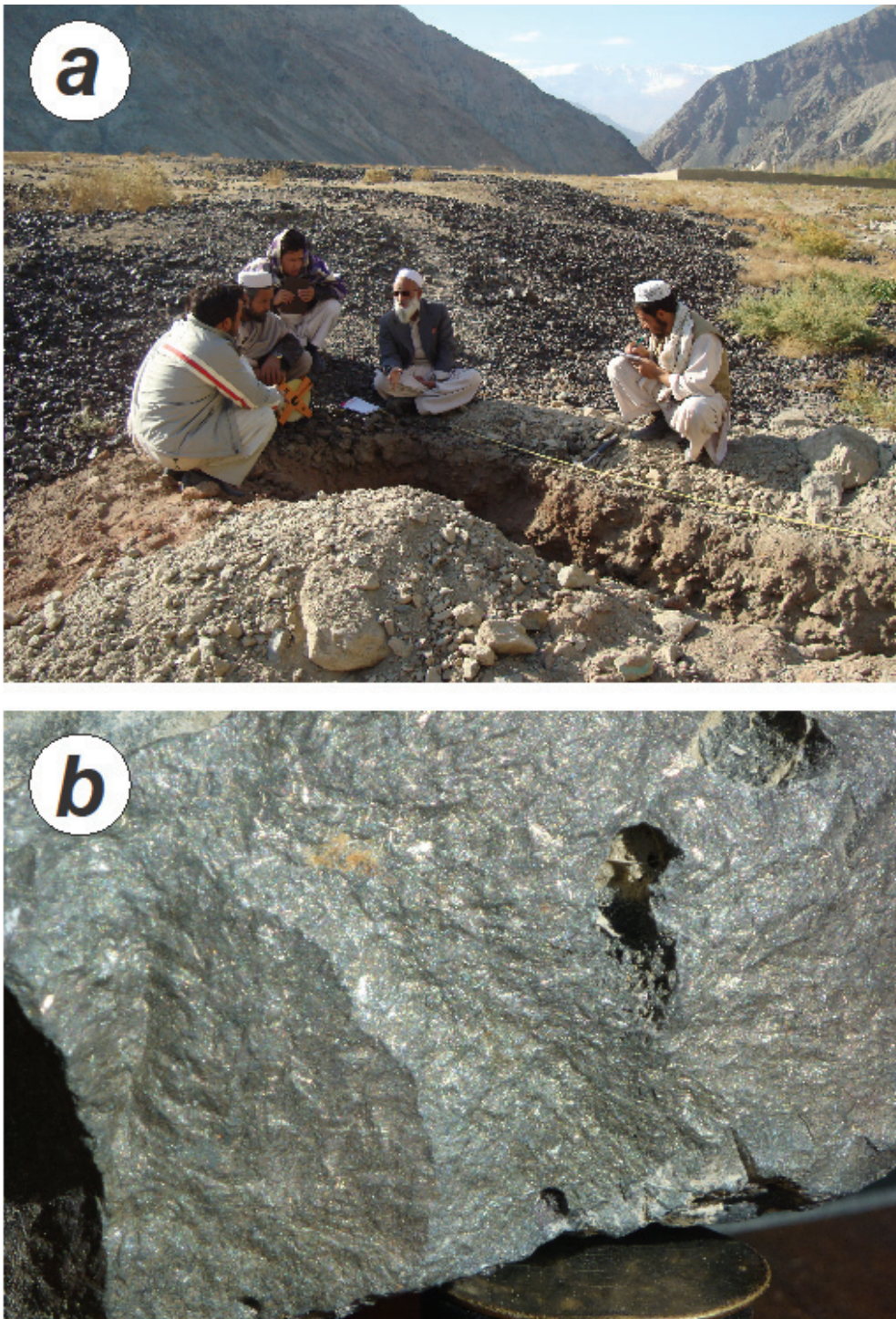


Figure 4A-16. Photographs of slag from the Balkhab copper area of interest. (a) Slag piles from metallurgical smelting in the Balkh River Valley. Photograph by AGS. (b) Hand specimen of metallic slag. Photograph by Robert D. Tucker, U.S. Geological Survey.

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).

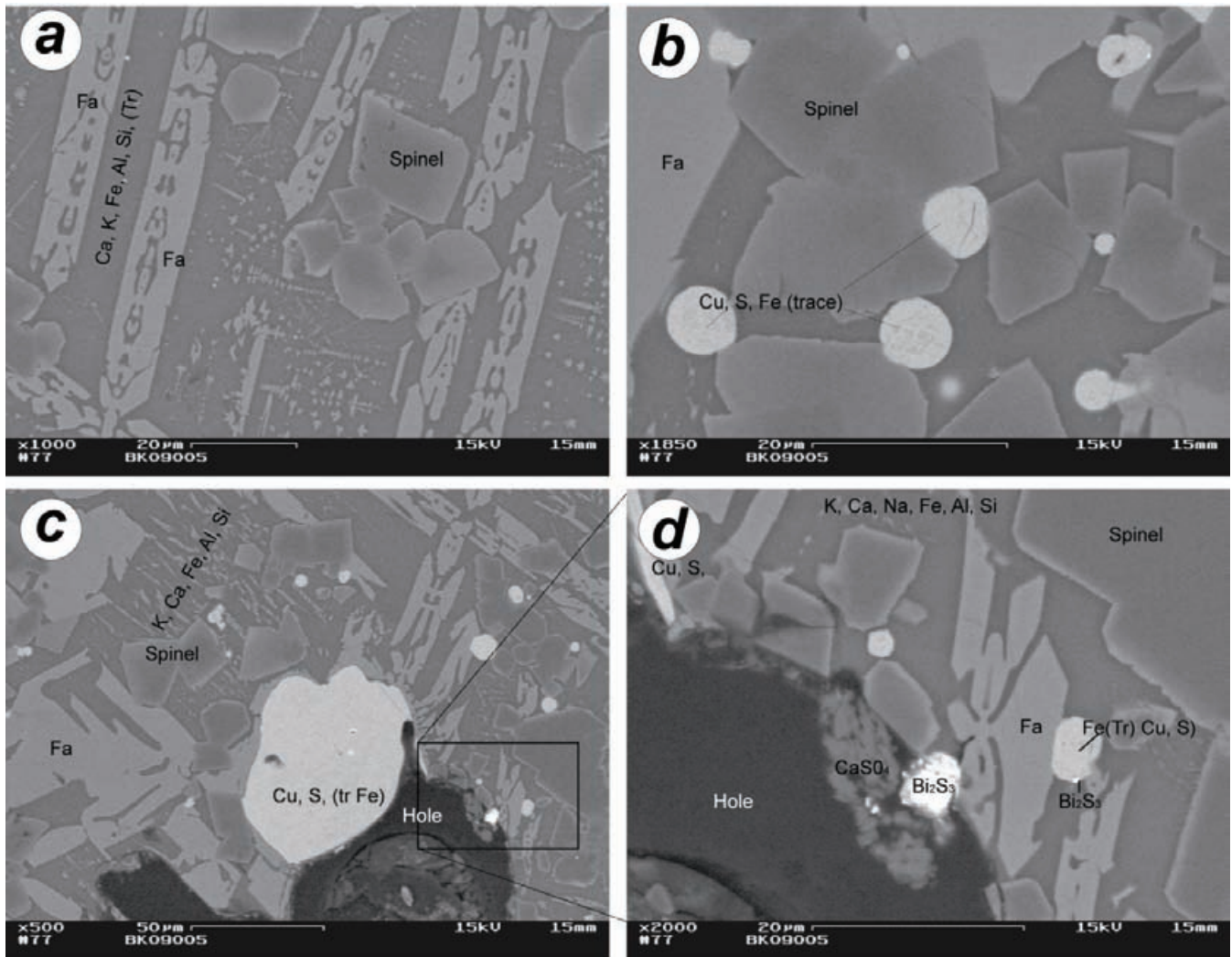


Figure 4A-17. Scanning electron microscope (SEM) photographs of Balkhab slag samples. (a) Sample BK09005 showing blades of oriented fayalite (Fa) and spinel crystals in a matrix of calcium, potassium, iron, aluminum, and silica glass. (b) Closeup of dots of copper, iron, and sulfur with spinel and fayalite 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 KPg₁ld (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 K₂ssl 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.

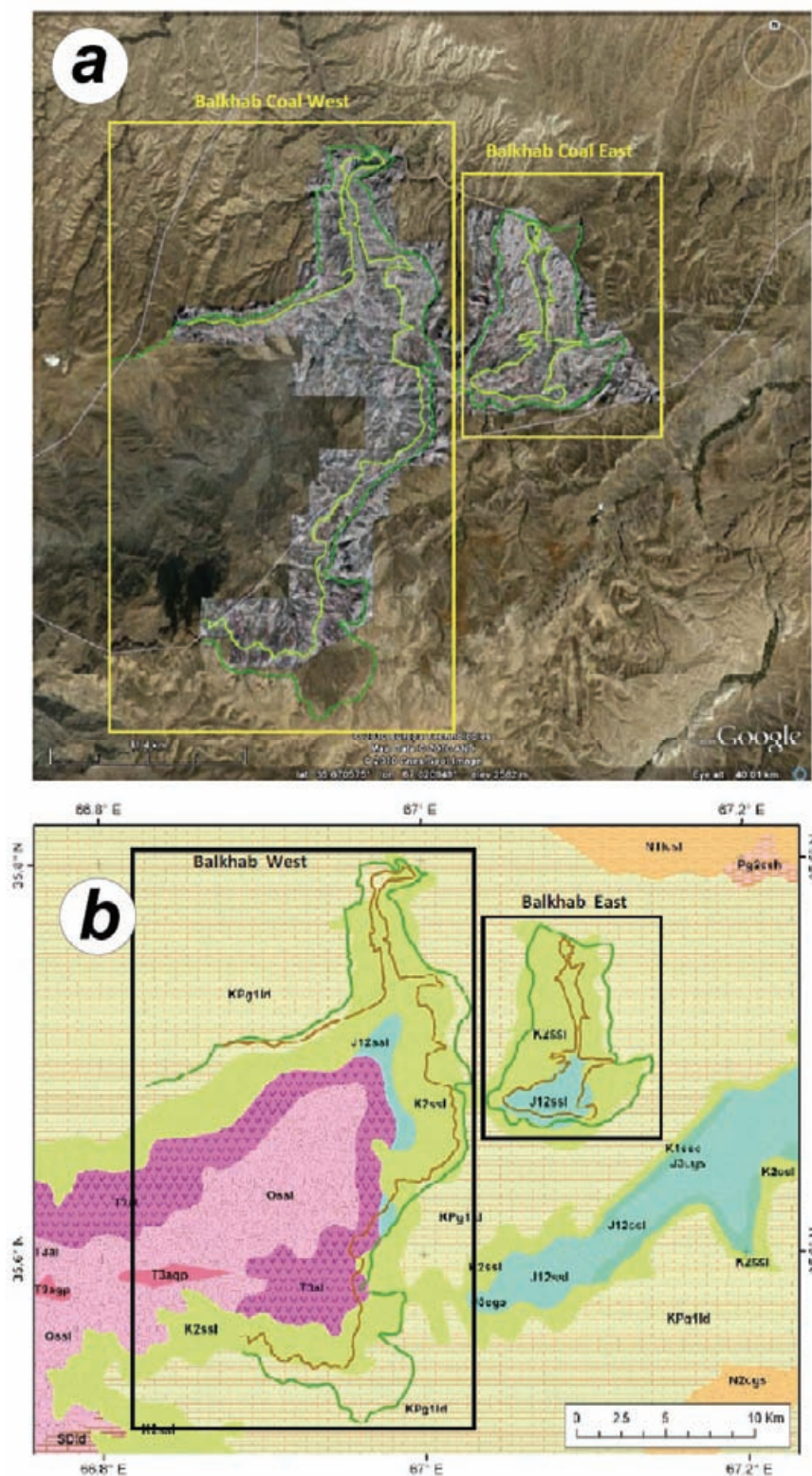


Figure 4A-18. Maps of the northeast part of Balkhab copper area of interest showing location of Balkhab East and Balkhab West coal areas. (a) Google map image. Dark green line is the top of coal measures. Light green line is the base of coal measures. Image copyright [2010,2011] Google Maps. (b) Geologic 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.”

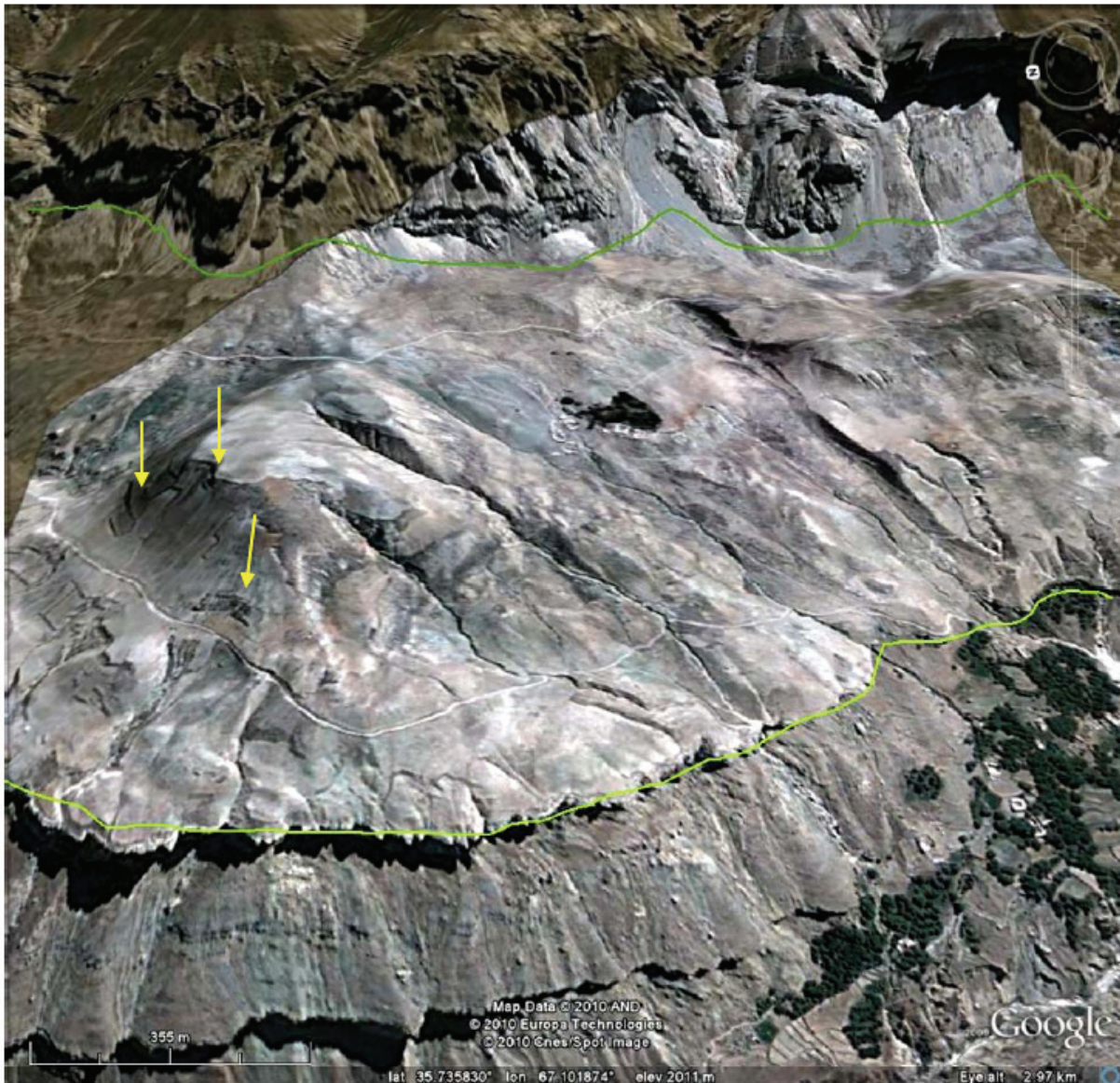


Figure 4A–19. Balkhab East Coal subarea 5, looking east. Dark green is top of coal measures. Light green is base of coal measures. Yellow arrows are coal beds. Subarea 5 has only limited evidence of coal measures or mining activity. Reproduced from Sabins and Ellis (2010b). Image copyright [2010,2011]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

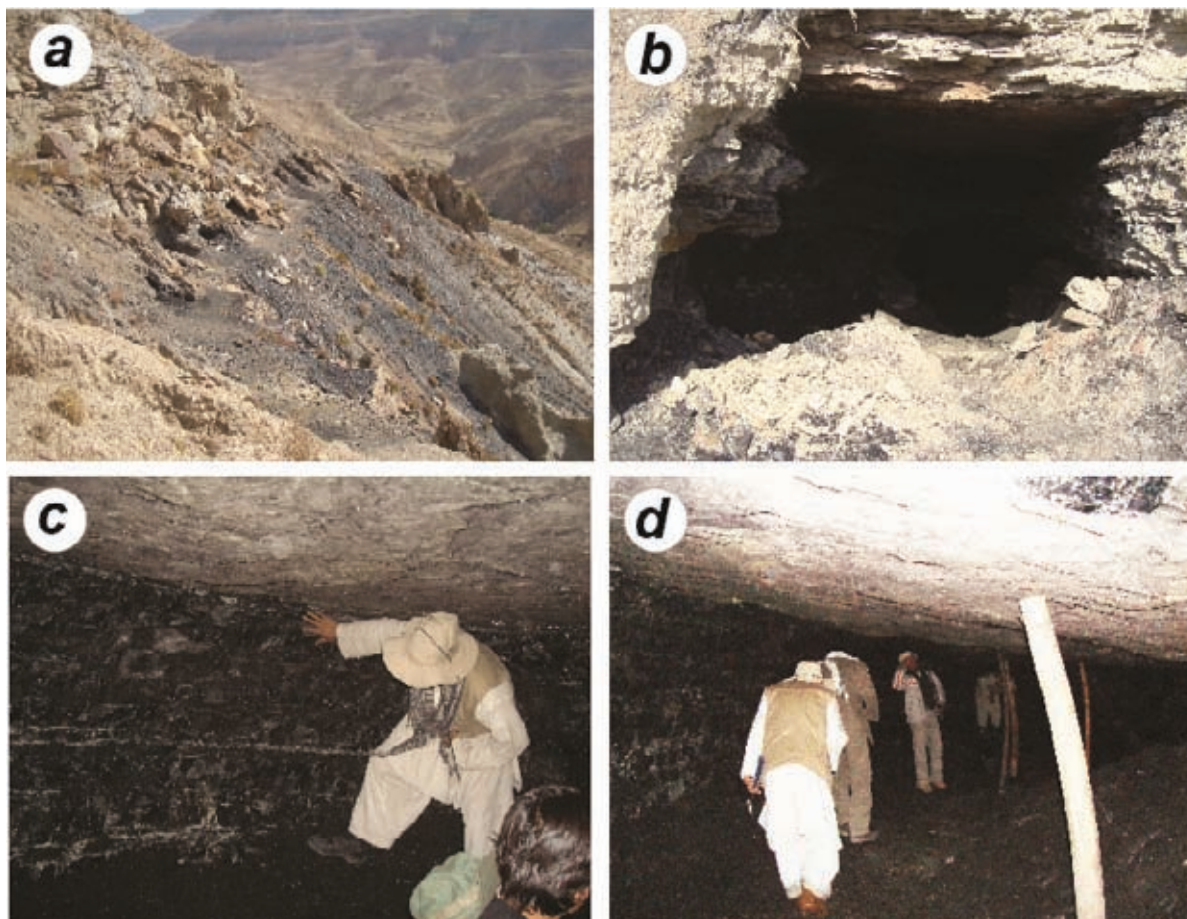


Figure 4A-20. Photographs of coal deposit in the Balkhab copper area of interest. (a) View of outcrop of coal seam and small adits. (b) Closeup of one of the adits. (c) A 0.5-meter-high coal seam in underground workings. (d) Underground excavation with supported hanging wall. Photographs by the Afghanistan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