13A Summary of the Panjsher Valley Emerald, Iron, and Silver Area of Interest

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Abstract

This chapter summarizes and interprets results from joint geologic and compilation activities conducted during 2009 to 2011 by the U.S. Geological Survey, the U.S. Department of Defense Task Force for Business and Stability Operations, and the Afghanistan Geological Survey in the Panjsher Valley emerald, iron, and silver area of interest (AOI) and subareas. The complementary chapters 13B and 13C address hyperspectral data and geohydrologic assessments, respectively, of the Panjsher Valley emerald, iron, and silver AOI. Additionally, supporting data for this chapter are available from the Afghanistan Ministry of Mines in Kabul.

The emerald deposits of the Panjsher Valley are the main site for mining gemstone-grade emerald crystals in Afghanistan. The geology of the Panjsher Valley consists of Middle Paleozoic metamorphic rocks represented by a Silurian-Lower Carboniferous marble and Lower Carboniferous and Upper Carboniferous-Lower Permian terrigenous schist. Intrusive rocks include small bodies of gabbro diorite and quartz porphyry and a large intrusion of gneissic granite of the Laghman Complex. The area has an imbricate-block structure elongated to the southwest and northeast. Multiple tectonic events are related to structures within and parallel to the regional-scale Hari Rod fault system.

Emerald mineralization in the Panjsher Valley AOI is genetically related to the Laghman Granitoid Complex and is controlled by elongated tectonic zones along the contacts between the carbonate and schist. The Panjsher Valley emerald district contains the following emerald occurrences from the west to east: Khinj, Mikeni I, Mikeni II, Rewat, and Darun. The Buzmal' Mine is located to the north, close to Panjsher Valley. There are three types of emerald mineralization: (1) mineralization within or adjacent to tectonized diorite dikes (parts of the western zone containing the Buzmal', Khinj, and Rewat emerald occurrences); (2) mineralization within shear fractures in schist (locality in the eastern zone containing the Darun, Khinj, and Mikeni I and II emerald occurrences); and (3) mineralization in or adjacent to hydrothermally altered and albitized quartz porphyry dikes.

Detailed exploration has covered only small parts of the Panjsher Valley emerald deposits at Buzmal' and Khinj, and the extension of the emerald-bearing zones at depth has been carried out only minimally at the Khinj emerald occurrence. Economic concentrations of emerald in the western zone at Khinj, estimated from exploration results, suggest that considerable resources of gemstone-grade emerald are likely to exist in the mining district.

Altered mafic and ultramafic rocks, a potential source of chromium, are commonly directly associated with emeralds. Some quartz porphyry intrusive bodies, which are a potential source of beryllium, are present in the vicinity of the emerald zones, but these intrusions are not ubiquitous. Variably metamorphosed graphitic shale is exposed throughout the emerald zone. Emerald-bearing host rocks are extensively sheared and faulted as a result of structural activity along the continental-scale tectonic zone of the Hindu Kush. Hydrothermal alteration is present in all emerald-bearing zones. Stable isotopes and fluid inclusions suggest a metamorphic or magmatic source, and the fluid inclusions were highly saline. Beryllium-bearing hydrothermal fluids, derived from magmatic fluids associated with emplacement of evolved granitoids of the Laghman Complex, may have gained access to chromium-bearing ultramafic and mafic rocks along shear zones. Alternatively, beryllium and presumably

chromium were derived from the interaction of saline-rich fluids of uncertain origin with black shale that was proximal to the emerald deposits.

Panjsher emeralds have been described in the literature. The quality of the emerald crystals varies from mine to mine. Most miners feel that the highest quality crystals come from the Mikeni and Khinj localities. Crystals are transparent to translucent or opaque and generally range from 4 to 5 carats, although a 190-carat crystal has been reported. They can easily be distinguished from Pakistani emeralds and other world emerald deposits by differences in trace element content.

13A.1 Introduction

The Panjsher Valley emerald, iron, and silver area of interest (AOI) lies in the Panjsher Valley in eastern Afghanistan. The main AOI, Panjsher Valley, is 958.68 square kilometers (km^2) and a silver-iron subarea (111 km^2) and emerald subarea (125 km^2) lie within its central parts (fig. 13A–1). The Panjsher Valley emerald, iron, and silver AOI lies within Parwan Province and includes the Hisa-e-Awal Panjsher District. Mineral deposit types in the AOI are emerald, hematite-magnetite ores, silver-bearing-iron ores, and polymetallic carbonate-hosted deposits.

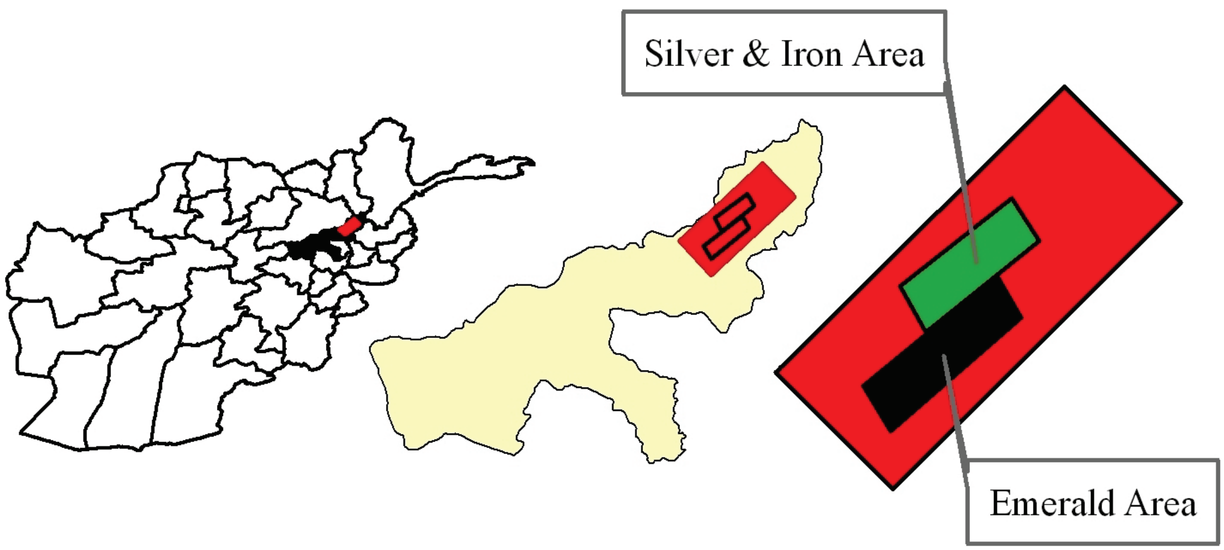

Figure 13A–1. Location of the Panjsher Valley emerald, iron, and silver area of interest and subareas.

13A.2 Previous Work

Panjsher Valley emerald and iron deposits have been mined for thousands of years. Kusov and others (1965) conducted exploration and mapping for the iron and silver ores in the Panjsher Valley, and Kafarsky and others (1972) conducted field work in the emerald fields. Geological exploration and research studies conducted by Soviet and Afghan geologists between 1975 and 1976 (Samarin and Akkermantsev, 1977) were the first specialized studies on the emeralds. The exploration work, on the scale 1:25,000, covered an area of about 100 km^2 and included a 5-kilometer (km)-wide and 20-km-long belt of metamorphic rocks along the Panjsher River as well as detailed exploration work at a scale of 1:2,000 that focused on the occurrences of Buzmal' and Khinj. This work produced a schematic map of the Panjsher Valley emerald field at 1:25,000 scale and geological maps of the occurrences of Buzmal' and Khinj at 1:2,000 scale, accompanied by detailed plans and profiles. This previous work was compiled by Abdullah and others (1977), the United Nations Economic and Social Commission for Asia and the Pacific (1995), the Metal Mining Agency of Japan (1998), and Peters and others (2007). Additional field and laboratory work on the Panjsher Valley emeralds was conducted by Hammarstrom (1989), Seal (1989), Seal and others (1991), and Bowersox and others (1991). The Afghanistan

Geological Survey restarted work in 2009 in the Panjsher Valley, mostly to reassess the iron occurrences for silver.

13A.3 Regional Geologic Setting

The Panjsher Valley emerald, iron, and silver AOI lies within a complex fault system that juxtaposes sedimentary rocks of presumed Paleozoic age that have been metamorphosed to upper greenschist facies against high-grade metamorphic schist and gneiss of presumed Precambrian age. Ultramafic rocks, both of presumed Carboniferous and Precambrian ages, form fault-bounded lozenges within the tectonic zone. The complex fault system (Schadchinev, 1975; Samarin and Akkermantsev, 1977) is discussed by Chmyriov and others (1976). These authors suggest a Hercynian age (circa 300 million years ago) for much of the latest tectonic activity. A set of granitoid plutons and other igneous bodies of presumed Oligocene age (Laghman Intrusive Complex; Schadchinev, 1975) were intruded into these older fault systems (fig. 13A–2).

Metamorphic rocks are prevalent in the Panjsher Valley emerald, iron, and silver AOI, but their age and origin is not well understood. Because of the lack of isotopic ages, scientists have expressed a low confidence in the ages assigned to metamorphic and plutonic rocks and to their assumed ages of tectonic activity, especially regarding rocks in the northeastern part of Afghanistan (L.W. Snee, U.S. Geological Survey, 2005, written commun.). Strongly foliated, high-grade layered gneiss at the entrance into the valley contains color banding (fig. 13A–3) and reflects compositional variation from felsic to mafic. Amphibolite and augen gneiss also are present. The augen gneiss is quartzofeldspathic with biotite and garnets that were present during a strong shear deformation event (fig. 13A–4). Compositionally, the gneissic rocks are similar to gneisses that extend northeastward from the Panjsher River Gorge and are in fault contact with metasedimentary rocks to the northwest (fig. 13A–5).

Metasedimentary units form two extensively faulted sedimentary packages, one dominated by clastic and the other dominated by carbonate rocks (fig. 13A–2). Metasedimentary rocks lie between two belts of Proterozoic gneiss, and the metasedimentary rocks generally are of lower metamorphic grade (figs. 13A–2 and 13A–6). Metamorphic grade is variable from very-low-grade to upper greenschist facies. The ages of these metasedimentary rocks are not well documented and therefore may vary from the oldest Ordovician clastic sedimentary to younger Silurian to Devonian age limestone and dolomite (Abdullah and others, 1977). However, the oldest rocks are Silurian to Lower Carboniferous and that the carbonate rock and clastic rocks range in age from Carboniferous and Permian to Triassic (Samarin and Akkermantsev, 1977).

Fine-grained, thinly laminated carbonaceous phyllite (fig. 13A–6*a*-*c*) is interbedded with massive, up to 1-meter (m)-thick discontinuous sandstone layers. This low-grade carbonaceous phyllite contains angular quartz fragments in a fine-grained dark matrix that is dominated by graphite (fig. 13A–6*a*). The more massive lenses in figures 13A–6*b* and 13A–6*c* are carbonate-cemented quartz-rich sandstone blocks. At higher metamorphic grade, this rock underwent prograde metamorphism from spotted phyllite (fig. 13A–6*b*) to schist (fig. 13A–6*c*).

Carbonate rock composition in the AOI ranges from massive limestone to dolomite and grades into carbonate-cemented, bedded sandstone with metamorphic grades that vary from low-grade to completely recrystallized marble. The thickness of the carbonate series in the area does not exceed 2,000 m (Schadchinev, 1975; Samarin and Akkermantsev, 1977).

Three complexes of intrusive rocks intrude all the sedimentary units. The oldest are part of a middle-Carboniferous to early-Permian gabbro diorite complex. These rocks generally are present as veins or dikes that cross cut both the presumed Silurian to Carboniferous age limestone and dolomite and the Carboniferous to Permian clastic units. The dikes are most common in zones of tectonic disturbance and in emerald-mineralized areas. The mafic rocks generally are altered, not greater than 5 m wide, up to 300 m long, and northeast trending (Samarin and Akkermantsev, 1977; L.W. Snee, U.S. Geological Survey, 2005, written commun.) and contain plagioclase, pyroxene, and hornblende; the hornblende is primary and an alteration product of pyroxene.

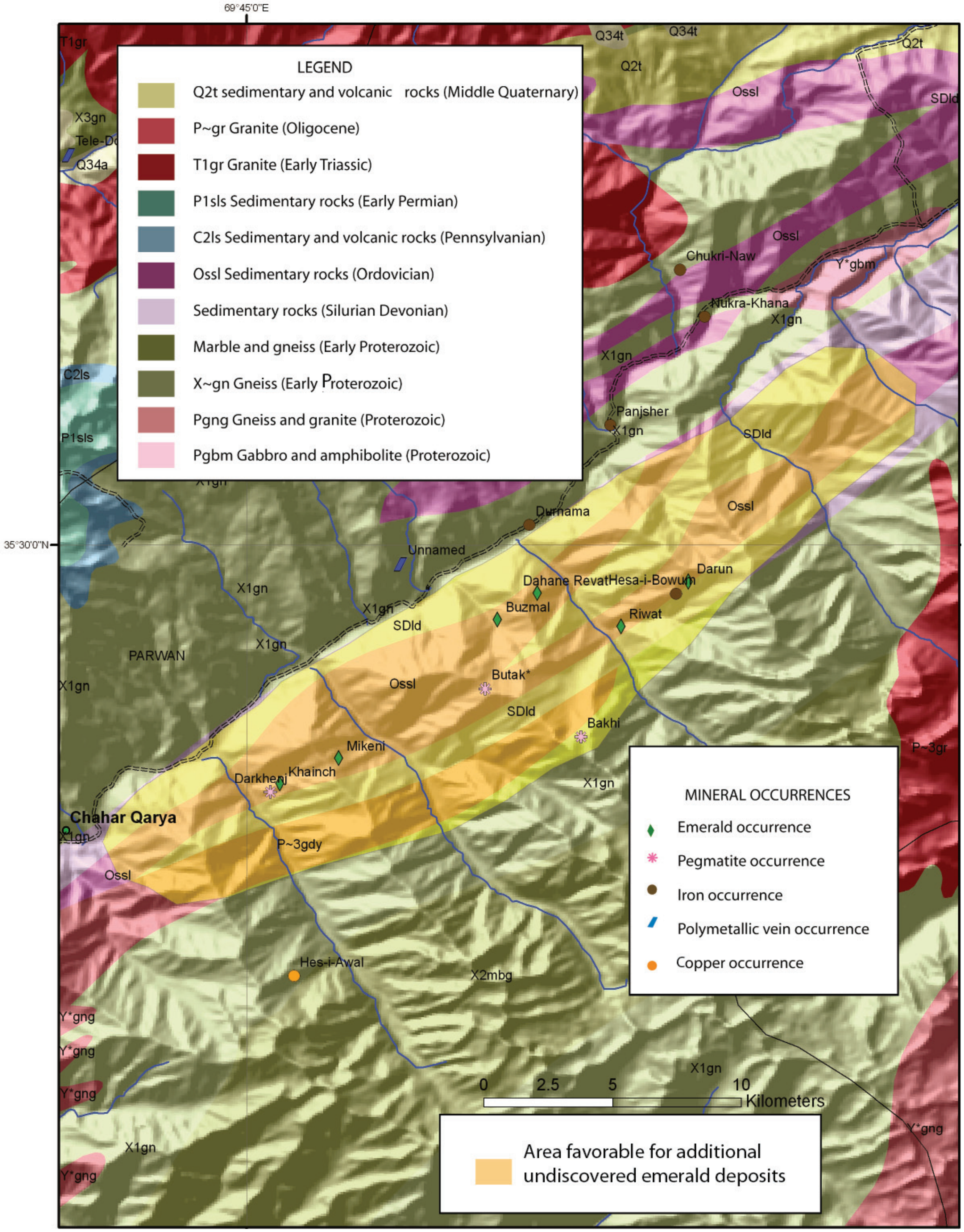

Figure 13A–2. Geologic map of the general area of the Panjsher Valley emerald, iron, and silver area of interest showing favorable area for undiscovered emerald deposits. Yellow, permissive, orange, favorable). Map from Doebrich and Wahl (2006), modified from Peters and others (2007).

Figure 13A–3. Photograph of layered high-grade Precambrian(?) gneisses at Panjsher River Gorge. Photograph by Lawrence W. Snee, U.S. Geological Survey.

A second complex of igneous rocks comprises Late Triassic quartz porphyry veins and dikes within the carbonate rocks (Samarin and Akkermantsev, 1977). These light-gray- to yellow-brown-colored dikes also are present in tectonically disturbed zones. These veins and dikes trend parallel to the northeast-trending structural grain. The dikes contain phenocrysts of quartz, plagioclase, and potassium feldspar in a fine-grained quartzofeldspathic groundmass (L.W. Snee, U.S. Geological Survey, 2005, written commun.).

The third major group of intrusive rocks exposed in the Panjsher Valley AOI comprises granite, granodiorite, and syenogranite of the Oligocene(?) Laghman Intrusive Complex (Schadchinev, 1975; Abdullah and others, 1977; Samarin and Akkermantsev, 1977). In addition, intrusive rocks and gneisses are intimately intermingled (fig. 13A–7) in some locations, and the true extent and variations in the deformation of the Laghman Intrusive Complex are not well known. Most of these intrusive rocks are massive and show no evidence of significant metamorphic overprint. Primary minerals in this granodiorite also show no evidence of later metamorphism or deformation.

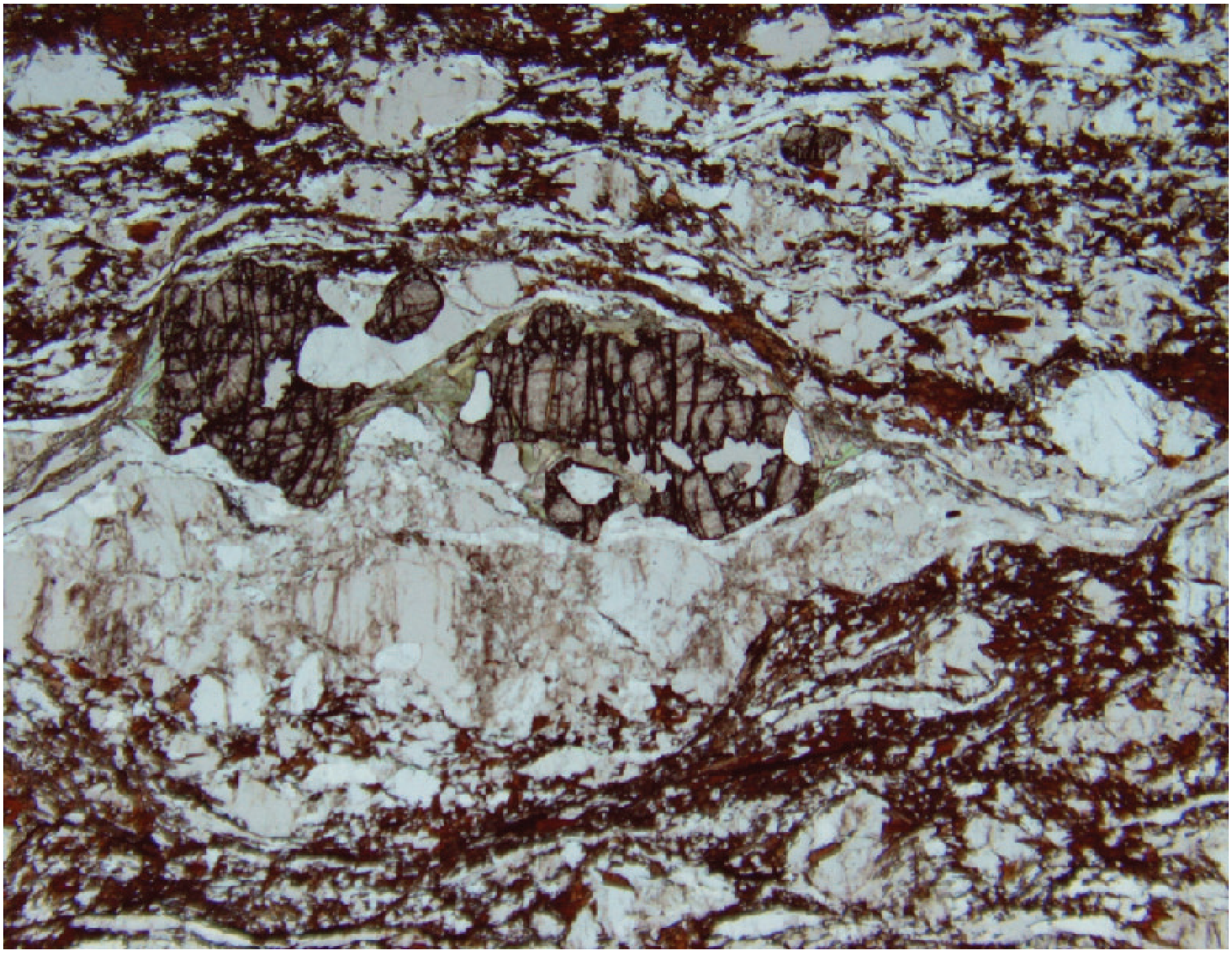

Figure 13A–4. Microphotograph of garnets in high-grade sheared Precambrian(?) gneiss from Panjsher River Gorge. Plane light; field of view is approximately 5 millimeters. Photograph by Lawrence W. Snee, U.S. Geological Survey.

13A.4 Metallogeny

The Panjsher Valley emerald, iron, and silver AOI lies within the Har-i-Rod-Panjsher Metallogenic Zone (fig. 13A–8; Abdullah and others, 1977; Peters and others, 2007), which stretches from the western frontier eastward through the whole country as far as and beyond the upper reaches of the Panjsher River. The Har-i-Rod-Panjsher Metallogenic Zone contains a variety of mineral occurrence types and commodities, including barite, emerald, gold, iron, lead, manganese, mercury, silver, sulfur, and zinc. The zone displays an extremely complex heterogeneous structure and contains Paleozoic, Mesozoic, and Cenozoic rocks belonging to different structural-formational zones. Proterozoic rocks also outcrop in upthrown blocks throughout much of the zone. Specific features of this metallogenic zone are extensive Paleozoic and Mesozoic nappe outliers and imbricate structure zones. The largest deep-seated structures within the zone are the Hari-Rod and parallel faults, which form a system of contiguous subparallel faults, producing a narrow belt of thrust sheets. Also, within the zone are numerous diagonal-longitudinal faults that outline separate structural subzones. Fault blocks and diagonal northwest-trending faults commonly are characterized by right-lateral displacements. Igneous rocks within the Har-i-Rod-Panjsher Metallogenic Zone vary in age and composition and represent most geologic time periods; most of the igneous rocks are present in the zone within orogenic igneous complexes.

Figure 13A–5. Faulted contact between Precambrian(?) gneisses to the east (left) and Paleozoic(?) metasedimentary rocks to the west (right). View to the northwest from the south bank of Panjsher River. Photograph by Lawrence W. Snee, U.S. Geological Survey.

13A.5 Geology

The Panjsher Valley emerald, iron, and silver AOI lies adjacent to the Hari-Rod fault that trends westward into western Afghanistan (figs. 13A–2 and 13A–8). This entire fault structure crosses Afghanistan and is one of the most significant and complex in Afghanistan (Chmyriov and others, 1982; United Nations Economic and Social Commission for Asia and the Pacific, 1995). In the Panjsher Valley, high-grade metamorphic rocks on both sides of this fault are separated from each other by a thin, up to 5-km-wide belt of low-grade metasedimentary rocks consisting of graphitic schist and marble (fig. 13A–2). Scattered throughout the terrane are fault-bounded lozenges of ultramafic rocks (L.W. Snee, U.S. Geological Survey, 2005, written commun.).

Mineral deposit models for emerald deposits include the emerald veins as well as metasomatic or shear zone models discussed in Peters and others (2007). The best known emerald deposits of the Panjsher Valley lie along the valley's southeastern side near the village of Khinj; although emeralds also have been reported on the northwestern side of the valley. The emerald mineralization is localized along linear zones that contain fracturing and brecciation of hydrothermally altered gabbro diorite dikes, marble, schist and quartz porphyry. Emeralds are present in two zones [in a northwestern zone (Buzmal' locality) and in a southeastern zone (the other occurrences)] and are located near the contacts between Silurian-Lower Carboniferous carbonate rocks and Upper Carboniferous-Permian clastic rocks. Along the contacts, a series of closely spaced, steep-dipping faults contain zones of fracturing, brecciation, boudinage, and cataclasis as well as intensely hydrothermally altered rock (including secondary biotite, phlogopite, epidote, albite, potassium-feldspar, quartz, tourmaline, sulfide and carbonate minerals, chlorite, and muscovite). The beryllium mineralization in the zones that contain the emeralds is superimposed on a complex system of fractures in hydrothermally altered (carbonate-sulfide) rocks (gabbro diorite, marble, schist), especially near hydrothermally altered phlogopitized and chloritized diorite dikes (gabbro diorites).

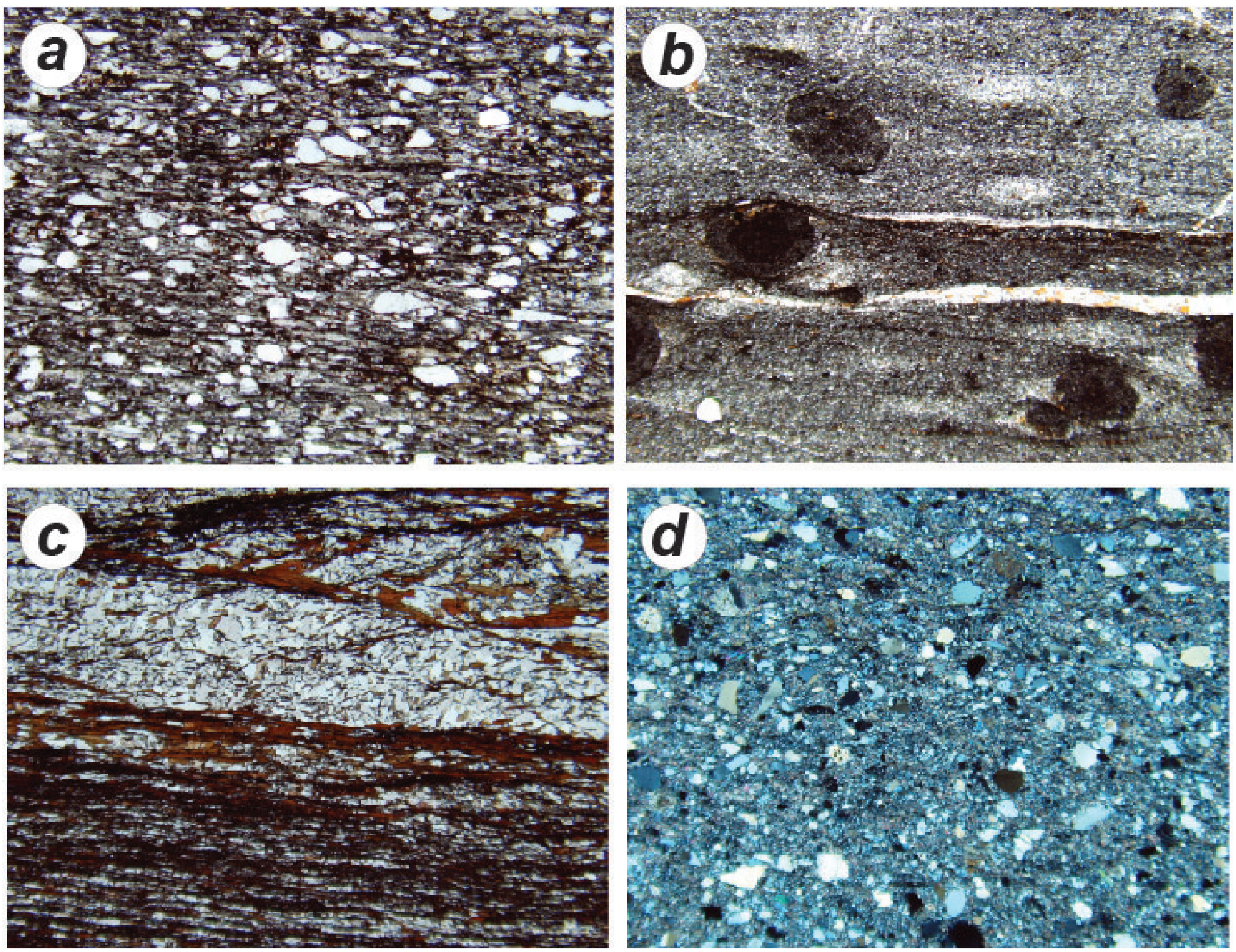

Figure 13A–6. Microphotographs of metasedimentary rocks in the Panjsher Valley area of interest. Field of view of each image is approximately 5 millimeters. (*a*), Low-grade dark gray carbonaceous phyllite. (*b*), Dark gray spotted carbonaceous phyllite. This sample is at slightly higher metamorphic grade than (*a*). (*c*), Dark gray carbonaceous schist. This sample is at higher metamorphic grade than (*b*). (*d*), Carbonate cemented sandstone. Angular grains of quartz, feldspar, iron oxides and mica in fine-grained carbonate matrix. Photographs by Lawrence W. Snee, U.S. Geological Survey.

Figure 13A–7. Photograph of granite and gneiss intermingled in an area east of the Panjsher River, by Lawrence W. Snee, U.S. Geological Survey.

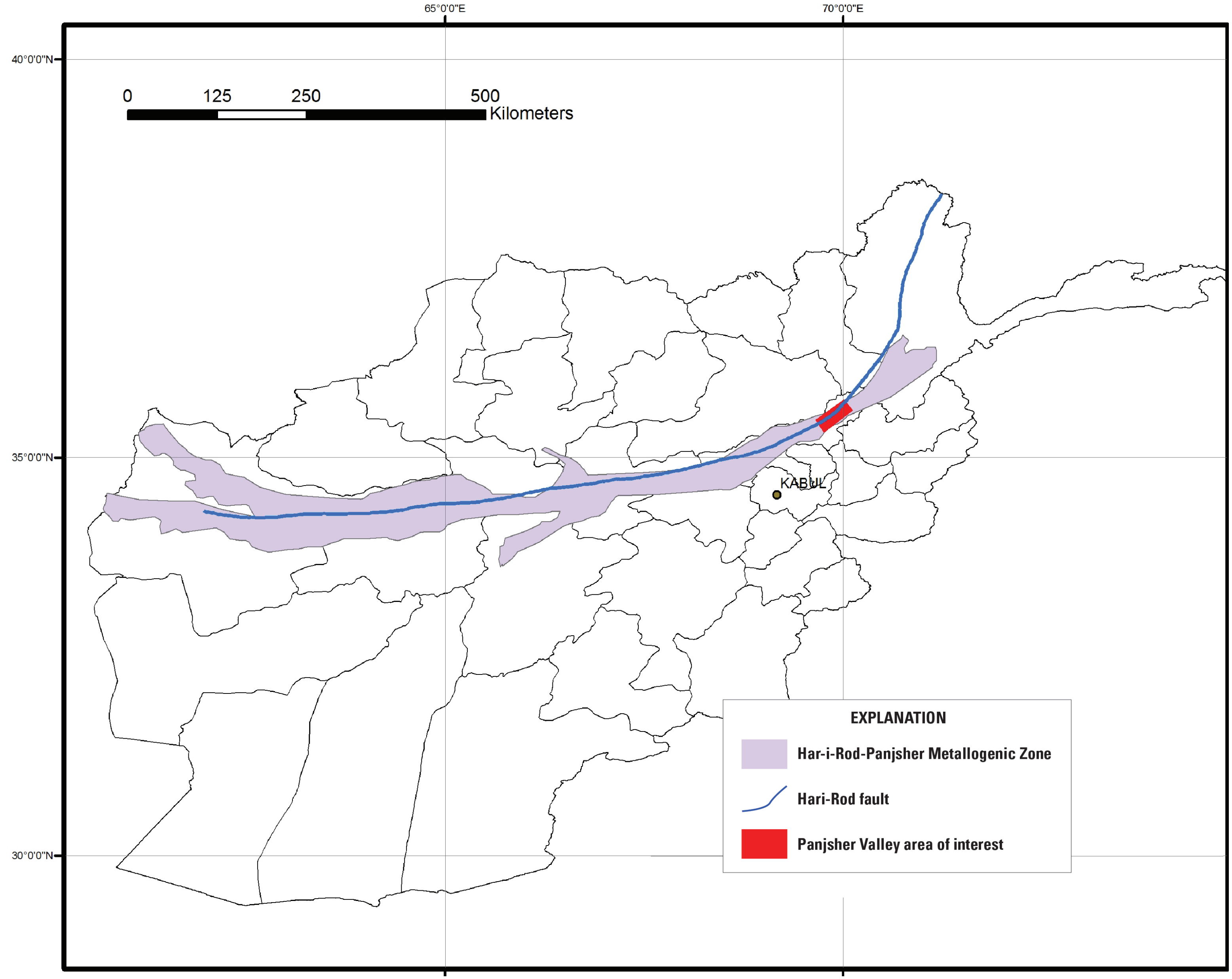

Figure 13A–8. Map showing location of the Har-i-Rod Metallogenic Zone and the Hari-Rod fault in relation to the Panjsher Valley emerald, iron, and silver area of interest. Data are from Peters and others (2007).

The most favorable zones for the emeralds are shear zones that have been intruded by gabbro diorite or other dikes. The gabbro diorite dikes normally are strongly altered and sheared. The presence of quartz-porphyry dikes also is favorable. Veinlets of carbonate minerals (with specular hematite in place), quartz, quartz-carbonate, pyrite-carbonate, and quartz-tourmaline-carbonate are common. Tourmaline-albite-carbonate-iron oxide alteration also is common. Microcline, white mica, and biotite or phlogopite also form alteration products. Beryl crystals form in clusters within the alteration and in veinlets. Some beryl crystals are overprinted with postdepositional fracturing (L.W. Snee, U.S. Geological Survey, 2005, written commun.).

13A.6 Geologic Character of the Panjsher Valley Emerald Deposits

The emerald-bearing zones occupy an area about 3 km wide and 20 km long in the Panjsher Valley emerald, iron, and silver AOI that trends northwest and is confined to the southeastern side of the Panjsher River. The mountain ridge that parallels the Panjsher River rises steeply in elevation from about 2,200 m in the valley to almost 5,500 m in the peaks to the southeast. The primary emerald-bearing zones are a few miles to the east of the Panjsher River at about 3,200 m elevation but as high as 4,000 m. Access to the mineralized areas is by footpaths, generally following the streams (fig. 13A–9).

The rocks in this emerald-rich belt consist of highly faulted carbonate and clastic sedimentary rocks, which are variably metamorphosed to phyllite, schist, and marble. Intruded into these units are mafic gabbro diorite and felsic quartz porphyry bodies. Within this belt, seven emerald-bearing zones have been defined (Samarin and Akkermantsev, 1977); three of these occurrences—Khinj (western zone), Buzmal', and Rewat—are in carbonate host rocks, and the other four—Khinj (eastern zone), Mikeni I, Mikeni II, and Darun—are in clastic host rocks. All these occurrences lie along the fractured and altered contact between the carbonate and clastic units (fig. 13A–10). The best emeralds are from the Khinj and Mikeni occurrences. Annual emerald production values are unknown, but estimates range up to $50 million for production in 2000 (L.W. Snee, U.S. Geological Survey, 2005, written commun.).

The most favorable geological precondition for emerald mineralization is the presence of the granites of the Laghman Intrusive Complex. The emerald mineralization is localized along linear zones of slight fracturing and brecciation containing hydrothermally altered gabbro diorite dikes, marble, schist, and quartz porphyry. The emerald mineralization is present within a northwestern zone (Buzmal') and a southeastern zone along the contact between the Silurian-Lower Carboniferous carbonate rocks and the Upper Carboniferous-Permian clastic rocks. The contact typically contains a series of closely spaced steep-dipping faults that contain complicated structural features, such as small-scale folding, fracturing, brecciation, boudinage, and cataclasis, as well as intense hydrothermal alteration that is marked by secondary biotite, phlogopite, epidote, albite, quartz, tourmaline, sulfide and carbonate minerals, chlorite, and muscovite (Samarin and Akkermantsev, 1977). The beryllium mineralization, with gem-quality emeralds, is superimposed over these altered structural zones at the carbonate-clastic-rock contacts (fig. 13A–10).

The source of chromium, which gives beryl crystals the green color, is most likely from the hydrothermally altered phlogopitized and chloritized gabbro diorite dikes. The emerald mineralization rarely extends beyond the area of hydrothermally altered gabbro diorite dikes; emeralds are not present in all dikes, but are present typically only in large dikes in the southeastern zone. Within the dikes, the emeralds are most likely to occur in zones of albite and chlorite where they are cut by veins containing quartz and potassium-feldspar and carbonate and sulfide minerals or tourmaline.

The beryl mineralization in hydrothermally altered rocks forms as small inclusions, individual crystals, or aggregates. This mineralization, commonly metasomatically, replaces yellow coarse-grained vein dolomite, or quartz, potassium-feldspar, or iron carbonate. These minerals are present in veinlets in the gabbro diorite, marble, schist, and rarely, quartz porphyry at the contact with gabbro diorite. As a rule, all the beryl crystal is strongly fractured, nontransparent, and no greater than 3.5 by 0.6 centimeters (cm) in size; commonly the beryl crystal is 1.0 to 1.5 by 0.2 to 0.1 cm or smaller. The color variations of the beryl stones mostly are bluish-green and, in some cases, blue or colorless and rarely emerald-green.

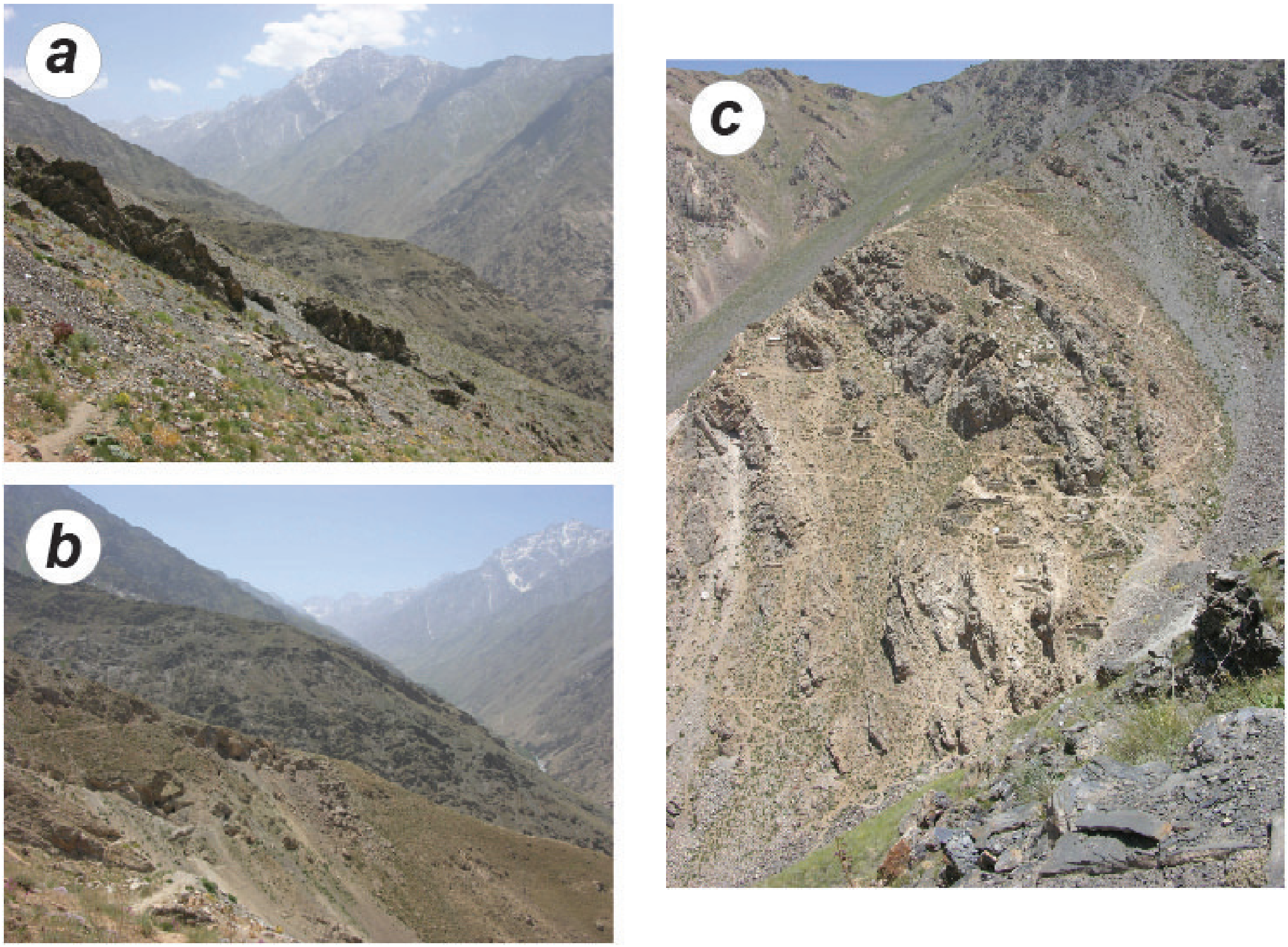

Figure 13A–9. Photographs from the Khinj emerald mining area Panjsher Valley, by Lawrence W. Snee, U.S. Geological Survey. (*a*), Trails along the hillsides. (*b*), Trails and workings along the ridges near the Khinj eastern zone. (*c*), Trails along the ridges near the Khinj mining area.

Remnants of cavities in the quartz, potassium-feldspar, and carbonate veins are thought to be the principal repositories of the emerald mineralization and are interpreted to be the latest hydrothermal events in the host zones (Samarin and Akkermantsev, 1977).

Veinlets of carbonate (with specular hematite in places; figs. 13A–11 and 13A–12), quartz, quartz-carbonate, pyrite-carbonate, and quartz and tourmaline-carbonate are common. Tourmaline and albite carbonate and iron oxide alteration is common (figs. 13A–13*a*-*c*). Microcline, white mica, and biotite or phlogopite also form alteration products. Beryl crystal forms in clusters within the alteration and in veinlets. Evidence for postdepositional fracturing is exhibited by some beryl crystals (fig. 13*a*–13*d*).

Panjsher emeralds have been described by Bowersox (1985), Kazmi and Snee (1989), and Bowersox and others (1991). The quality of the emerald crystals varies from mine to mine. Most miners believe that the highest quality crystals come from the Mikeni and Khinj localities. Crystals are transparent to translucent or opaque and generally range from 4 to 5 carats, although a 190-carat crystal was reported by Bowersox (1985). Crystals normally are euhedral and prismatic, although in some places, crystals have been naturally etched by later reactive fluids. Color zoning is common, and interiors are pale and exteriors are dark green. The green color of all emeralds is the result of a small amount of chromium or vanadium instead of aluminum in the beryl crystal structure (Deer and others, 1986, p. 372–409). In Panjsher Valley emeralds, chromium concentrations range up to 19,180 parts per million (ppm), and vanadium concentrations range up to 690 ppm according to measurements by neutron activation (Snee and others, 1989). Hammarstrom (1989) measured chromium concentrations up to 13,700 ppm and vanadium concentrations up to 3,100 ppm by electron microprobe and also showed that the brightly colored green areas of emerald are enriched with chromium. Chemically, Panjsher Valley emeralds fall within the range expected for natural emeralds (Snee and others, 1989) but appear to be most similar to Colombian emeralds. They are easily distinguished from Pakistani emeralds (Hammarstrom, 1989; Snee and others, 1989) and other world emerald deposits (Groat and others, 2002) by differences in trace element content.

13A.7 Origins of the Panjsher Valley Emerald Deposits

Emerald is one of the rarest and most precious gemstones because unusual circumstances are necessary to combine chromium and beryllium together in the natural environment (L.W. Snee, U.S. Geological Survey, 2005, written commun.). Emerald results when aluminum in the beryl crystal structure is substituted with a small amount of chromium or vanadium (Sinkankas, 1981; Deer and others, 1986, p. 372–409) [For an alternative definition of emerald, see Farm (1975).]

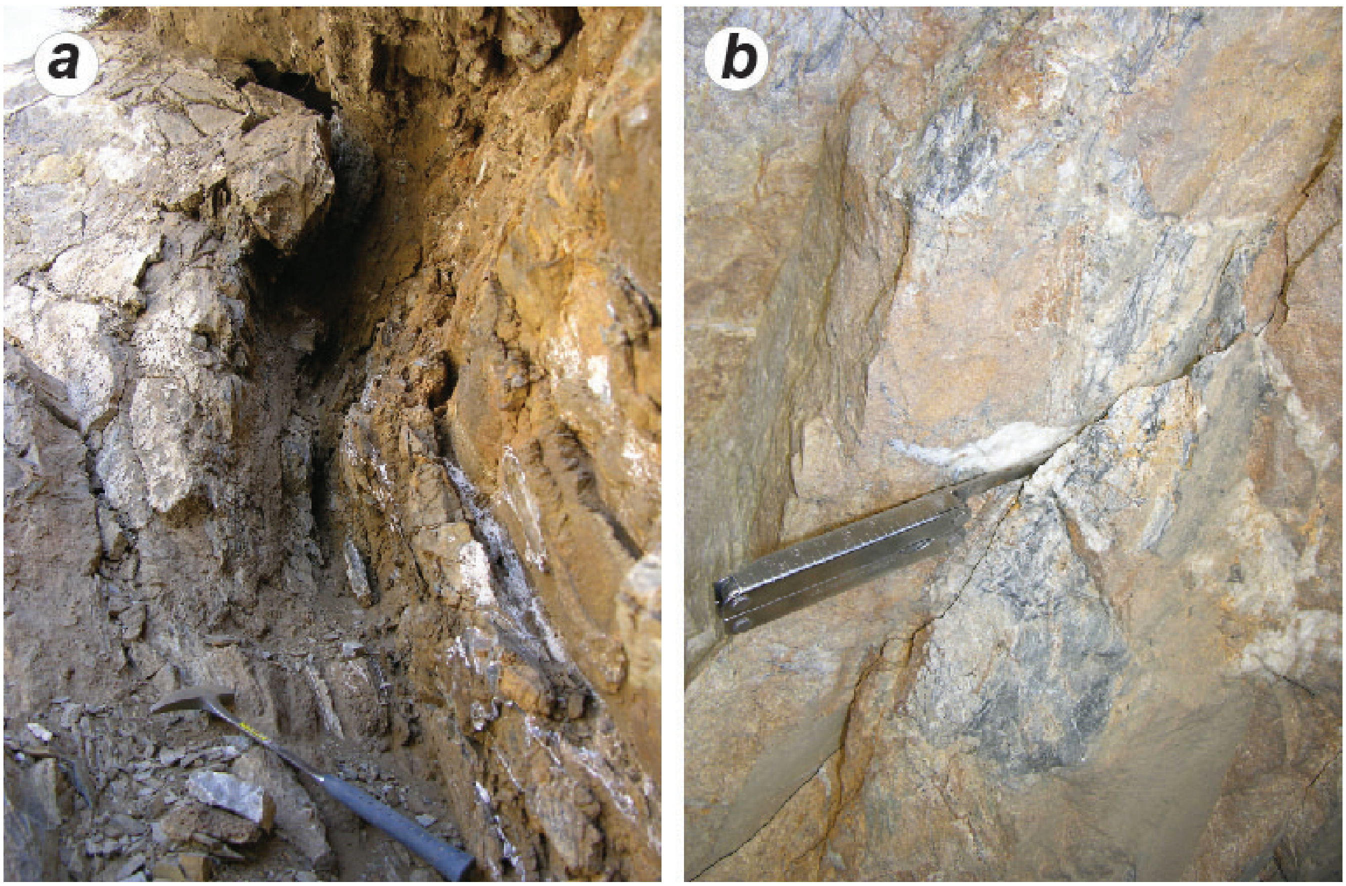

Figure 13A–10. Photographs of outcrop scale alteration zones typical of emerald mineralization in the Panjsher Valley, by Lawrence W. Snee, U.S. Geological Survey. (*a*), Sheared contact zone between carbonate and mafic rocks with typical reddish-brown iron oxide stain from hydrothermal fluids. (*b*), Hydrothermal alteration and quartz-carbonate veins that commonly carry emerald; tool shown for scale.

Beryllium and chromium are geochemically incompatible because beryllium has a very small atomic radius (0.3 angstrom; Shannon and Prewitt, 1969; L.W. Snee, U.S. Geological Survey, 2005, written commun.). Therefore, beryllium is excluded from the crystal structure of most minerals, but it remains in fluid or magma until the last stages of the magmatic processes. Beryllium also has a small crustal abundance (5 ppm or less; Krauskopf, 1955; Beus, 1965; Wedepohl, 1978). Thus, beryllium-bearing minerals generally are only found in late-stage igneous rocks, such as pegmatite, or form from beryllium that has been scavenged from beryllium-bearing source rocks by hydrothermal processes.

Chromium, on the other hand, is found in significant amounts in ultramafic and some "primitive" mafic rocks. Ultramafic rocks crystallize early in magmatic processes and are at the opposite end of the geological spectrum from those that carry beryllium. Chromium also is found in significant amounts, up to 5,000 ppm (Krauskopf, 1955), in some black shale; the vanadium content of some black shale can be as high as 14,000 ppm reference. The source of the high concentrations of chromium and vanadium in black shale is uncertain, but Krauskopf (1955) recognizes the importance of provenance, and Snee and Kazmi (1989) suggest that a high chromium content could reflect the presence of ultramafic and chromium-rich mafic rocks in the source area of the shale. Many authors (Kazmi and Snee, 1989; Ottaway and others, 1994; Schwarz and Giuliani, 2001; Groat and others, 2002) have described these conditions in known world emerald deposits, and several authors (Snee and Kazmi, 1989; Schwarz and Giuliani, 2001) categorize and classify emerald deposits based on geologic environment.

The favorable conditions for the formation of Panjsher Valley emeralds (Samarin and Akkermantsev, 1977) include:

- ☐ nearby occurrence of the rare-metal-enriched granites of the Laghman Complex
- ☐ zones of tectonic disturbance and shearing
- ☐ hydrothermally altered biotitized (phlogopitized) and chloritized gabbro diorite dikes, marble, schist, and quartz porphyry
- ☐ the contact between the carbonate and clastic sedimentary rocks

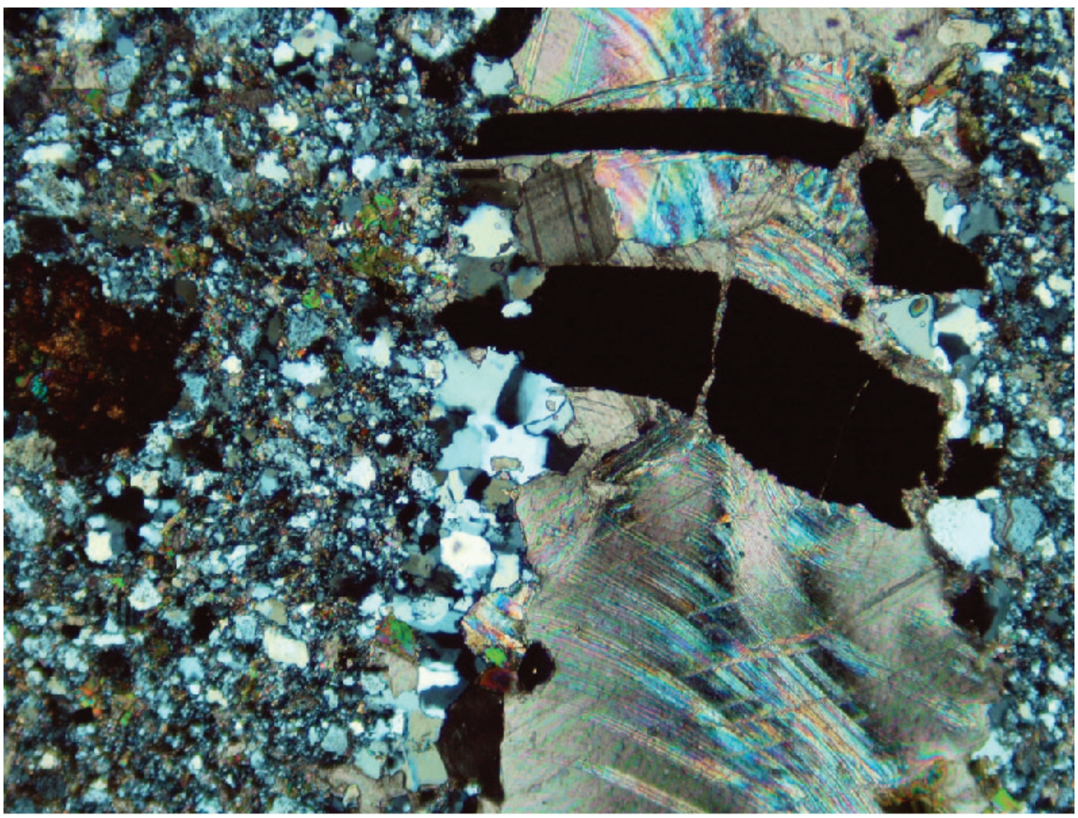

Figure 13A–11. Microphotograph of specular hematite (opaque mineral) in carbonate veinlet (vertical zone in right center of figure) cutting carbonate host rock (fine grained matrix) as seen under plane-polarized light. Photograph by Lawrence W. Snee, U.S. Geological Survey.

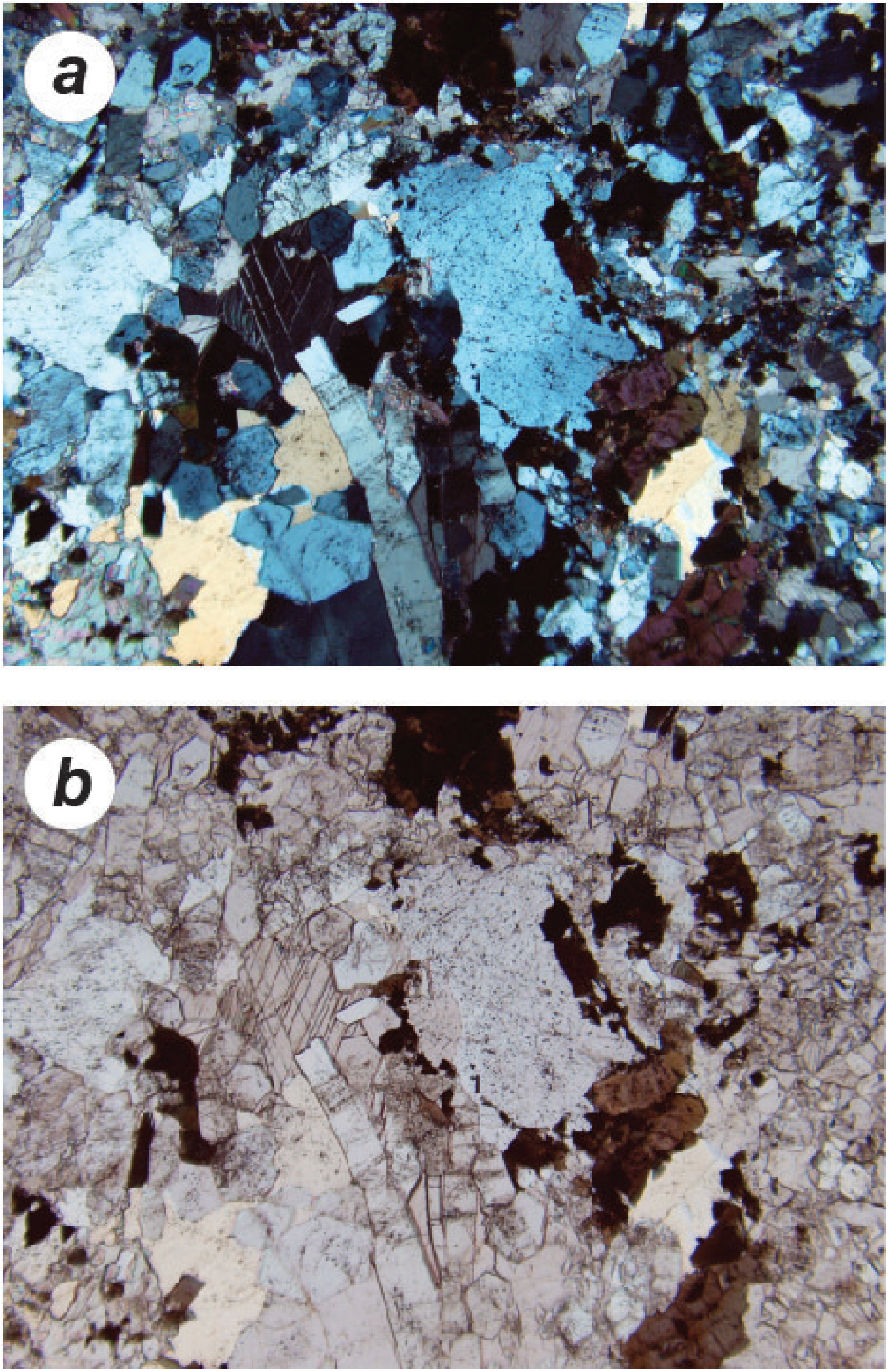

Figure 13A–12. Microphotographs of specular hematite (opaque mineral) in carbonate veinlet cutting carbonate host rock (fine-grained material) As seen under (a), polarized light, and (b), plane-polarized light. Photograph by Lawrence W. Snee, U.S. Geological Survey.

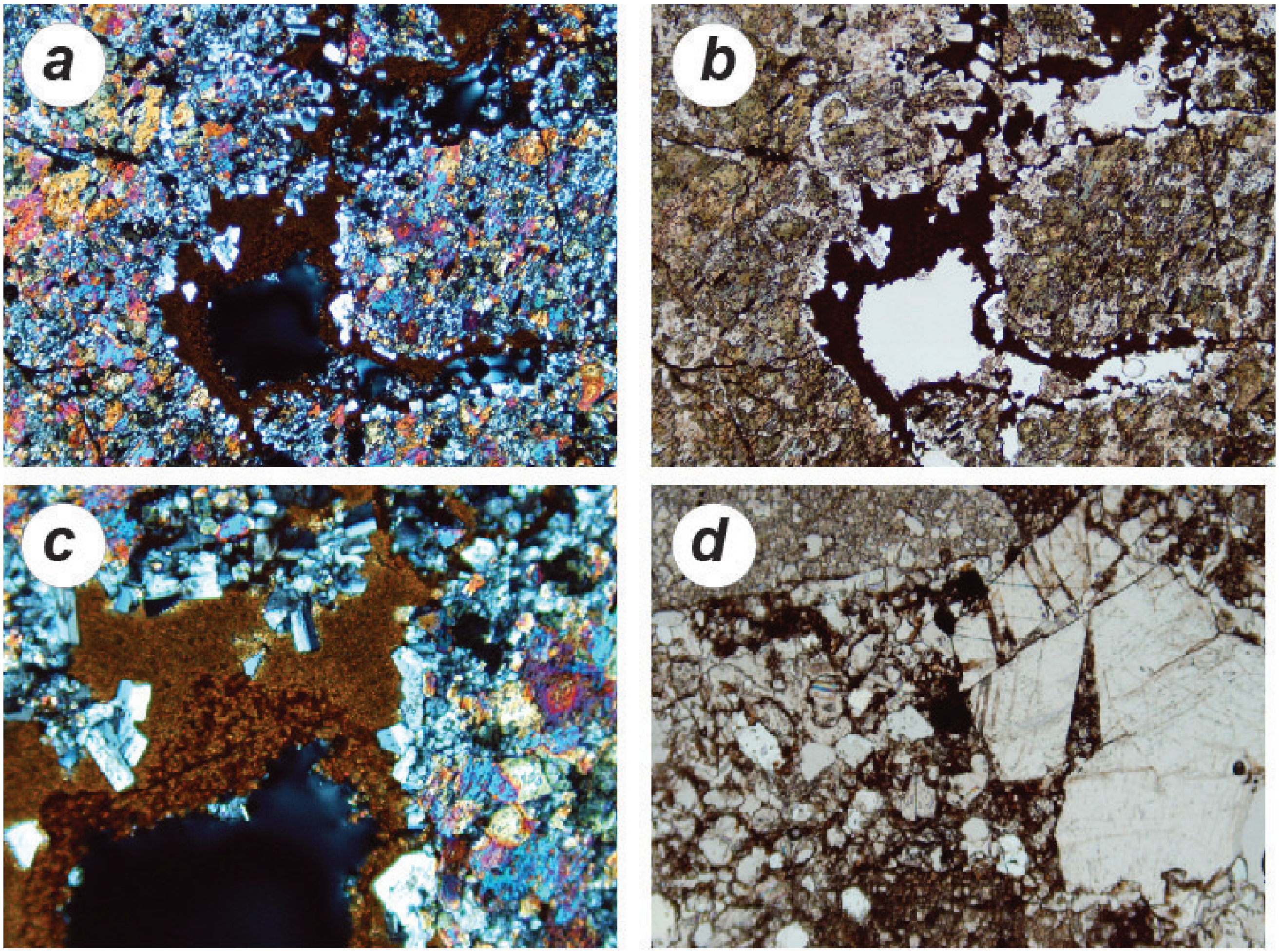

Figure 13A–13. Microphotographs of secondary textures and minerals from the Panjsher Valley emerald fields, by Lawrence W. Snee, U.S. Geological Survey. (*a*) and (*b*), Alteration phases that include albite, iron oxide, tourmaline, and carbonate as seen under plain-polarized and cross-polarized light; field of view is approximately 5 millimeters (mm). (*c*), Close up of alteration phases including albite, iron oxide, tourmaline, and carbonate in cross-polarized light; field of view is approximately 2 mm. (*d*) Cracked hydrothermal beryl crystals in cross-polarized light; field of view is approximately 5 mm.

Distinct sources for both chromium and beryllium are needed; the chromium source for Panjsher Valley emeralds is from mafic (gabbro diorite) igneous rocks (Samarin and Akkermantsev, 1977). Beryllium is transported along faults and fractures to the chromium-bearing host rocks by hydrothermal fluids that are derived during magmatic processes derived from the emplacement of the Laghman Igneous Complex. Aside from quartz porphyry dikes, no chemically evolved igneous rocks or pegmatites exist in the mineralized area of the Panjsher Valley. Laghman Complex granitoids are located to the east, in Nuristan, where they are the host rock and likely source for numerous rare-metal pegmatites, some of which contain beryl .

Alteration assemblages associated with the Panjsher Valley emeralds include colorless and blue beryl, albite, and tourmaline, as well as other minerals. These alteration assemblages are consistent with a derivation from evolved magmatic hydrothermal fluids and are compatible with origin from the Laghman Igneous Complex. According to Renders and Anderson (1987), beryllium is transported in hydrothermal fluids as hydroxyl, chloride, and fluoride complexes. Fluid inclusions in the emeralds are saline and of a composition that could transport beryllium.

In recent years, work done on Colombian emeralds by Beus (1979), Ottaway and Wicks (1991), Giuliani and others (1992, 1995, 1997), and Ottaway and others (1994) has resulted in an alternative hypothesis for the source of beryllium and chromium in Colombian emerald deposits. In the Colombian model, beryllium and chromium are derived from organic-rich black shale, which is exposed within the sedimentary units that host the emeralds. As noted earlier in this report, black shale in some parts of the world contains a significant abundance of chromium and vanadium, but near the Colombian emerald deposits, chromium abundance is only on the order of 30 to 40 ppm. In the Colombian model, hydrothermal brines derived from the dissolution of evaporates transported sulfate to the black shale along fractures and faults. The sulfate then reacted with the organic matter in the shale and released beryllium, chromium, and vanadium, which ultimately precipitated as emerald. Considering the very low concentrations of beryllium, chromium, and vanadium in the host rock shale, this process must have been highly efficient.

Sabot and others (2002) have proposed a similar model for the formation of the Panjsher Valley emeralds and report, as did Seal (1989) and Bowersox and others (1991), the presence of high-salinity inclusions. The inclusions in Panjsher Valley emeralds are very similar to those of Colombian emeralds. Experimental analysis of Panjsher Valley inclusion fluids showed them to be highly saline with chlorine content of more than 200,000 ppm, sodium more than 73,000 ppm, potassium nearly 20,000 ppm, and very low bromine abundance, indicating derivation from the dissolution of halite. The stable isotope analyses suggested that sulfur and boron were derived from an evaporite source. The above authors also described natural organic compounds and graphite in the emeralds, and these were linked to thermochemical reduction of sulfate by organic matter in shale. Presumably, then, beryllium, chromium, and vanadium were released effectively from the wall rocks by the reaction of the sulfate with organic matter, a process similar to that proposed for the formation of Colombian emeralds.

As do other emeralds of the world, Panjsher Valley emeralds contain fluid inclusions. Seal (1989) and Bowersox and others (1991) described numerous primary, three-phase, and other multiphase inclusions with distinct morphologies and crystallographic orientations (fig. 13A–14). Multiphase inclusions contain up to eight daughter minerals, water-rich brine, and carbon dioxide liquid and gas. Although not all solid phases in the inclusions are identifiable, some of the most abundant solids are halite and sylvite, and Seal (1989) estimated the salinity of the fluid to be approximately 37 weight percent of sodium chloride and potassium chloride. The salinity of waters in the fluid inclusions of Panjsher Valley emeralds is high, making them distinct from all other emeralds except those of Colombia (Ottaway and others, 1994; Giuliani and others, 1997; Seal, 1998; Sabot and others, 2002). Giuliani and others (1997) estimated Panjsher Valley emerald formation temperatures to be between 200° and 350°C, but did not comprehensively define why the temperature estimate covers a broader range with both lower and higher temperature limits. Although in the lower range of emerald formation temperatures for many other deposits (Groat and others, 2002), both of these estimates are similar to formation temperature estimates for Colombian emeralds (Giuliani and others, 1992; Cheilletz and others, 1994; Ottaway and others, 1994).

13A.8 Metamorphosed Iron Deposits

Iron deposits and occurrences along and within the Har i-Rod-Panjsher Metallogenic Zone (fig. 13A–8) extend for 600 km from western to eastern Afghanistan in the central part of the country (fig. 13A–8). The iron occurrences and deposits are hosted by Proterozoic metamorphic carbonate and volcanic rocks. The iron deposits are both hematite-magnetite, siderite-magnetite, and ferruginous quartzite types. The hematite-magnetite type is the most common deposit, and the largest example is the Haji Gak iron ore deposit, the largest hematite-magnetite deposit in the Middle East (Abdullah and others, 1977)

The Haji Gak iron ores mainly occur as beds that are conformable with the host stratigraphy, but occasionally the iron ore is in lenses or veins. The Late Proterozoic country rocks at Haji Gak include quartz-sericite and carbonate-chlorite-sericite schist, greenschist, altered intermediate volcanic rocks, quartzite and marmorized dolomite. Economic concentrations of iron ore are found mainly along the contacts between the volcanic rocks and terrigenous carbonate rocks. The country rocks are silicified, sericitized, and carbonatized. The contacts of the Haji Gak iron orebodies with the country rocks are fairly distinct, though in places (particularly in carbonate rocks), the country rocks are impregnated and pierced by hematite-magnetite veins. The Haji Gak iron deposit comprises primary and semioxidized ores, the oxidized zone reaching a thickness of 100 m. The primary ores of the Haji Gak iron deposit consist of magnetite and hematite with irregularly disseminated pyrite, semioxidized ore (hydrogoethite-semimartite, hydrogoethite-hematite-semimartite, and carbonate-semimartite types).

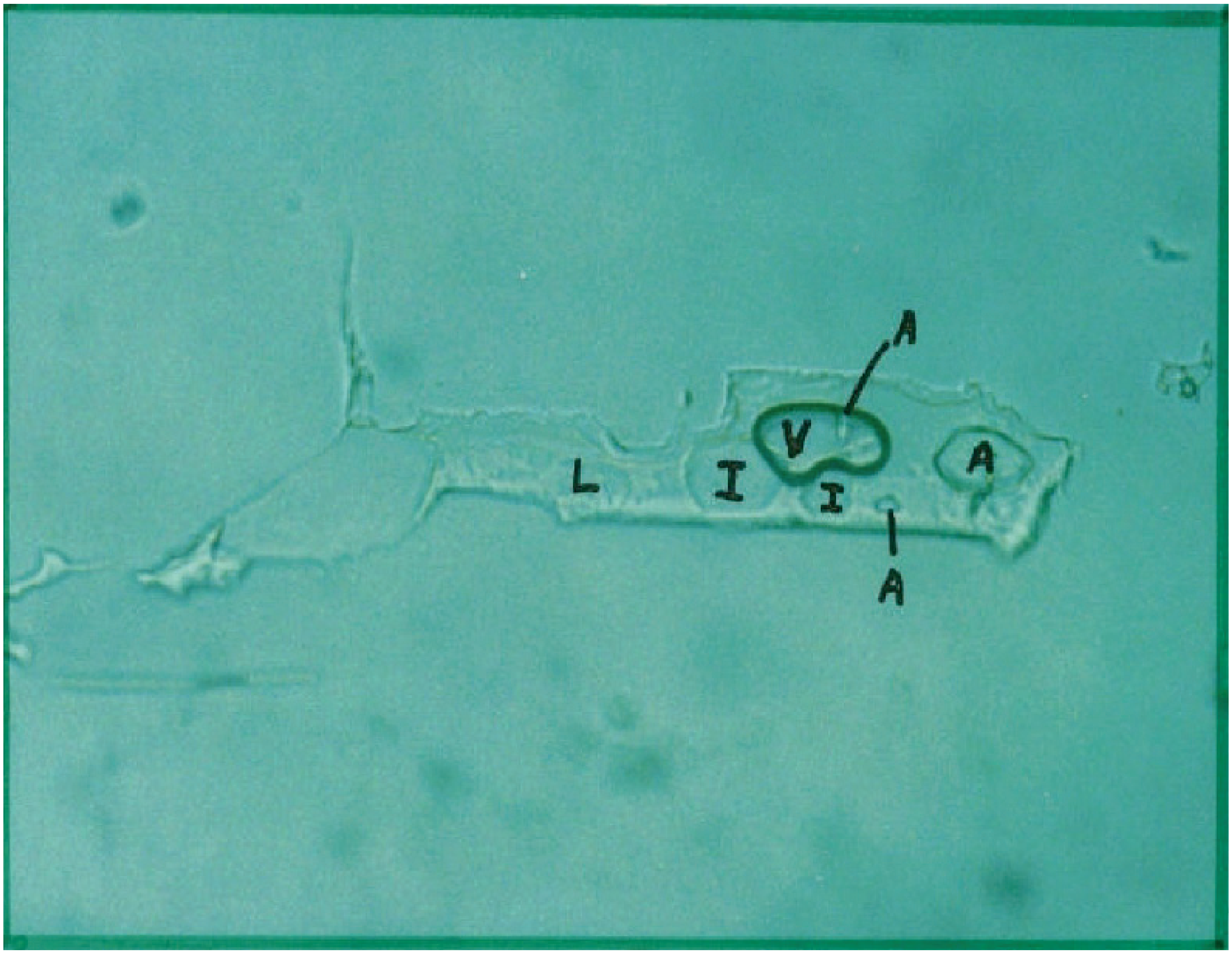

Figure 13A–14. Microphotograph of fluid inclusion in emerald from the Panjsher Valley. L, liquid inclusion; V, vapor inclusion; A and I, other inclusion types. Photograph by Lawrence W. Snee, U.S. Geological Survey.

The deposits of the siderite-hematite (ferrocarbonate) along the Har-i-Rod-Panjsher Metallogenic Zone in the Panjsher Valley subarea (figs. 13A–1 and 13A–15) are thick and extensive bed-shaped lenticular bodies or pods of siderite-hematite that are as much as 30 m thick and several kilometers long. These orebodies occur in Proterozoic carbonate rocks, and examples are present in the Panjsher River basin in the Panjsher Valley AOI (Chukrinaw, Nukrokhona, and other deposits). The principal constituents of the ores are hematite and siderite. Apart from the iron minerals, the ore contains some copper, lead, manganese, silver, and zinc. The contacts of the ore bodies with the marmorized limestone are well defined. The iron content reaches 60 to 65 weight percent iron. The inferred reserves of iron ore from the deposits of this group have been estimated to be hundreds of million metric tons. It should be noted, however, that the reserves of iron ores are spread over numerous isolated pods.

13A.9 Known Deposits

The known emerald deposits of the Panjsher Valley lie along the valley's southeastern side near the village of Khinj (Kazmi and Snee, 1989; Bowersox and others, 1991), although emeralds also are present on the northwestern side of the valley (fig. 13A–16; Samarin and Akkermantsev, 1977; Sabot and others, 2002).

The largest and most well-known area is the Khinj emerald prospect area (fig. 13A–17), which has both surface and underground excavations. The Khinj emerald prospect contains two emerald-bearing zones, the western and eastern zones. The western zone consists of a series of steep-dipping en echelon dikes of gabbro diorite, within which the emerald-bearing mineralization occurs in quartz-carbonate and quartz-microcline veinlets that are developed in the albitized and biotitized rocks. The western zone is 2 to 4 m thick and locally up to 10 m wide and can be traced along surface outcrops for 400 m. The western Khinj zone has been mined to a depth of 30 m. The eastern Khinj zone consists of a system of hydrothermally altered shear zones in schist, typically containing secondary albite, carbonate, and quartz. The eastern zone is 120 m wide and can be traced at the surface for 150 m.

Mining at the Khinj emerald prospect in 1976 produced 3,360 grams (g) of emerald crystals, of which 591.2 g (2,950.8 carats) was gemstone-grade quality crystals, 32.3 g (161.5 carats) being suitable for face cutting and 557.9 g (2,789 carats) suitable for convex-cutting. The emerald resource extracted from the western zone from 1976 through 2010 is 3,125.4 g of emerald crystals, and from the eastern zone, 234.6 g of emerald crystals. The content of gemstone-grade quality of emerald crystals is 7.5 carats per cubic meter of the "productive" mass in the western zone and 0.6 carat per cubic meter in the eastern zone. Emerald resource reserves for the Khinj emerald prospect (for the western and eastern zones) as of January 1, 1977, were 439.9 kilograms (kg) of emerald crystals, of which 65 kg (324,625 carats) was gemstone-grade quality crystals, 3.6 kg (17,860 carat) of that being suitable for face-cutting and 61.4 kg (306,765 carats) suitable for convex-cutting.

Emerald occurrences are also present in a number of other localities in the Panjsher Valley AOI, such as at Buzmal' (figs. 13A–18 and 13A–19), Mikeni, Darun, and Rewat (fig. 13A–16).

The Rewat emerald district is located along the Panjsher River. Beryl mineralization, including emerald, lies along a strip extending for about 15 km. The mineralization consists of albite, tourmaline, pyrite, and silicified rocks in a fault zone that offsets Silurian-Lower Carboniferous carbonate rocks from Carboniferous-Lower Permian siliceous-shaly rocks. The favorable zone encloses a great number of gabbro diorite and quartz porphyry veins and dikes. The orebodies are small, emerald-bearing quartz-ankerite and dolomite veins and stringers that commonly are contained in metasomatically altered gabbro diorite, dolomitic marl, quartz-biotite schist, and quartz porphyry. High-grade emeralds are most abundant in the altered gabbro diorite dikes. Wide albitized zones and small massifs of albitized granite carrying beryl mineralization are of particular interest to prospectors (fig. 13A–16).

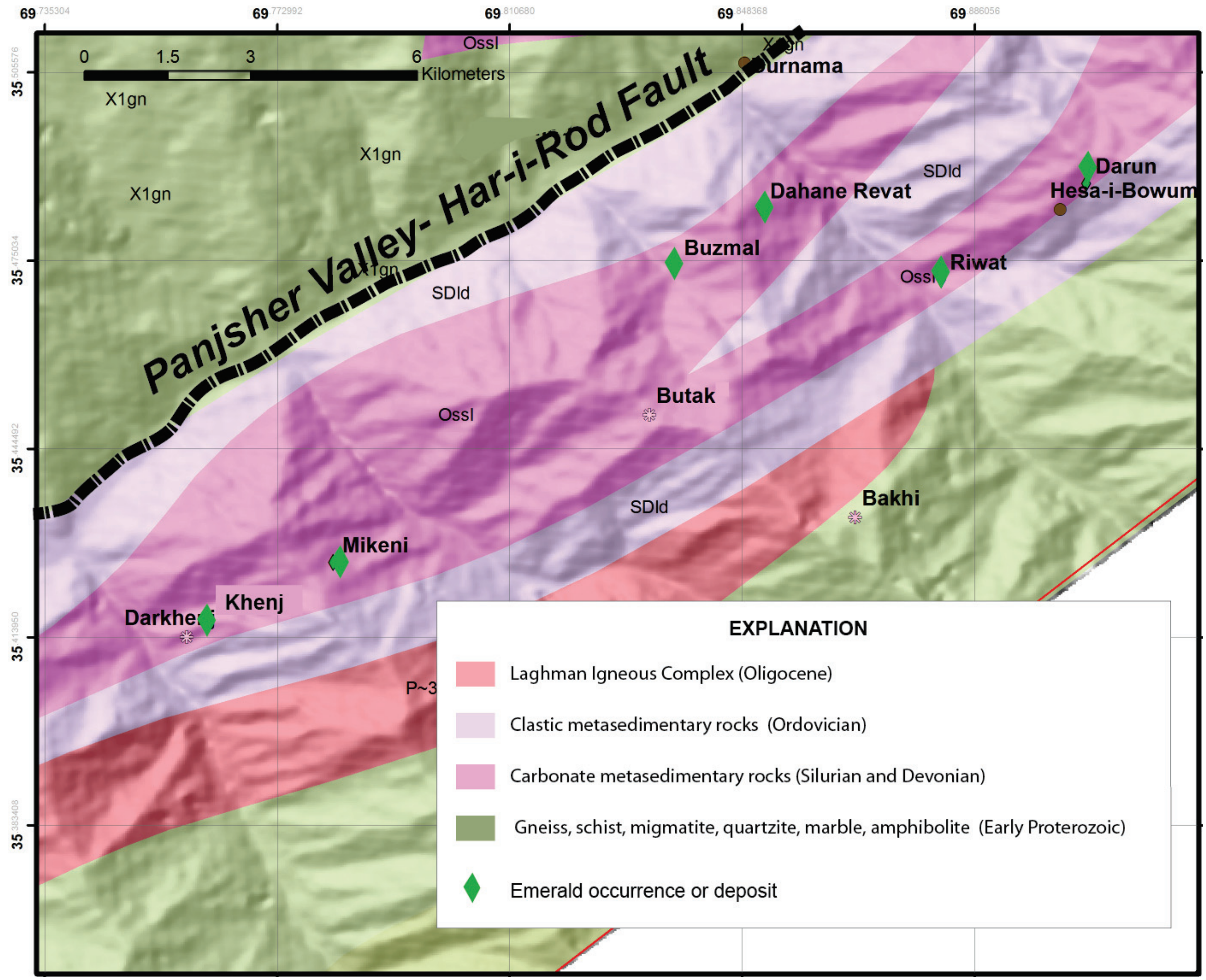

Figure 13A–16. Geologic map of the central parts of the Panjsher Valley showing the main emerald occurrences in Paleozoic metasedimentary rocks. Geology is from Doebrich and Wahl (2006).

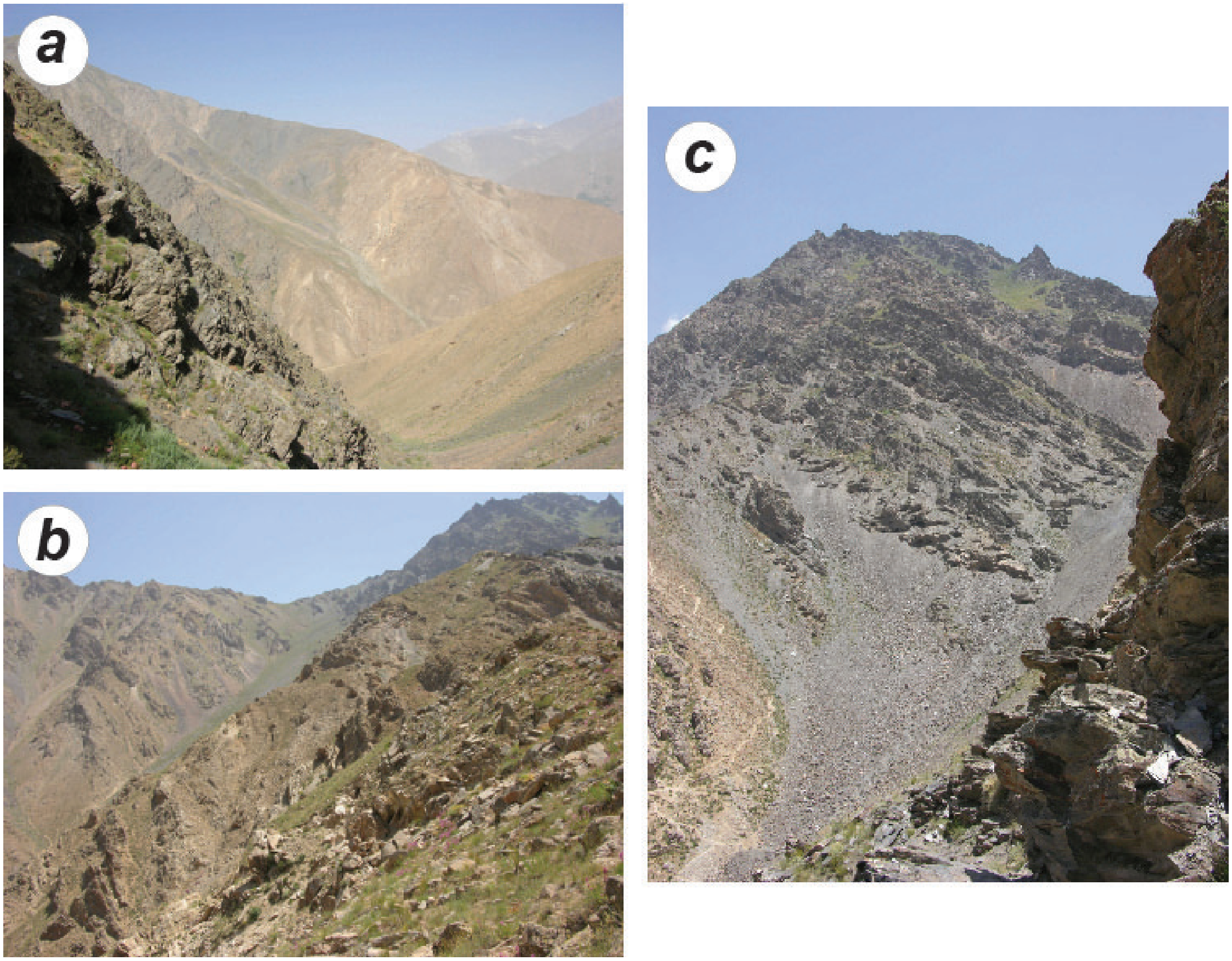

Figure 13A–17. Photographs of the Khinj emerald mine area, by Lawrence W. Snee, U.S. Geological Survey. (*a*) Well-developed contact between clastic and carbonate rocks in the mountains east of the western zone. (*b*) Khinj emerald prospect in the high peaks in the western Khinj zone. (*c*) Khinj emerald mines high in the ridge.

Figure 13A–18. Photograph of Buzmal' emerald workings, by Lawrence W. Snee, U.S. Geological Survey.

13A.10 Prospects and Anomalies—The Panjsher Iron Ore District

The Panjsher iron ore district is in the Panjsher River Basin and lies within the Panjsher iron and silver subarea (fig. 13A–1) in a zone of imbricate structures and differently oriented fault blocks. These blocks comprise Proterozoic and Lower Paleozoic rock, which outcrop near the Central Badakhshan fault. The geology of the Panjsher Iron area consists of marble host rock with several hematite-bearing areas that are 10 to 20 m wide and 3 to 5 km long. The known iron occurrences belong to the siderite-hematite formation. The siderite-hematite ores lie in extensive sheets and lenticular bodies that are enclosed in the Proterozoic carbonate strata. The hematitic bodies assay between 33 and 65 weight percent iron and contain minor manganese, copper, lead, silver, and zinc, which occasionally may form in economic concentrations. For example, some samples from the Chukrinaw deposit are recorded to have up to 1,223 grams of silver per metric ton of ore mined. The Chukrinaw prospect (35°36'24"N, 69°53'40"E) consists of hematite ore lenses, which are 2 to 15 m wide and up to 1 km long and are hosted in Proterozoic marble (Kafarsky and others, 1972).

Other iron areas in the subarea show evidence of previous mining. Examples are the Chukri-Naw iron occurrence that comprises 2- to 15-m-wide and 1-km-long siderite-hematite lenses and contains significant silver and marmorization (figs. 13A–20 and 13A–21). The Nukra-Khana iron occurrence contains hematite lenses, beds, and veins that are 2 to 19 m wide and several hundred to thousands of meters long. The Durnama iron area also has a number of hematite lenses in Proterozoic marble with trace amounts of copper and zinc. Some lenses are 1 to 5 m wide and 10 to 60 m long (Kusov and others, 1965).

13A.11 Summary of Potential

Detailed exploration has covered only a small part of the Panjsher Valley emerald deposits at Buzmal' and Khinj, and the extension of the emerald-bearing zones at depth has been done only in a small way at the Khinj occurrence. Economic concentrations of emerald in the western zone at the Khinj emerald mining district, resulting from exploration, suggest considerable resources of gemstone-grade emerald are likely in the mining district.

Bowersox and others (1991) estimated that, the annual production of emeralds in the Panjsher Valley area was worth $10 million in 1991, when 5,000 villagers were engaged in emerald mining. With peace, technical assistance, proper equipment, local support, and training, the potential for $300 million to $400 million per year in 10 years may be possible.

Emerald miners in the Panjsher Valley generally excavate into the contact zone between carbonate and clastic host rocks; dynamite commonly is used, to the detriment of the crystals. Mining activity was reported at the Khinj and Mikeni localities (L.W. Snee, U.S. Geological Survey, 2005, written commun.). Miners follow yellow hydrothermal alteration zones and veins in search of emeralds. Some tunnels extend only a few meters into the hillside; but some extend more than 200 m underground. Tunnels do not contain structural reinforcements.

An important consideration to be addressed is the future of the Panjsher Valley emerald deposits. This concern applies to several aspects. First, the mining techniques used in the Panjsher Valley endanger the stones and the miners. Explosives are commonly used; mines are holes into the Earth that are not reinforced. The miners would benefit from training in modern gemstone mining techniques and mine safety as well as knowledge of current mining equipment and procedures. Consideration should be given to developing a plan that allows the primary resource planning and extraction to remain with the Afghan miners, with minimal damage to the mineral resources and maximum output for the world market. The preparation and exportation of the gemstones needs to be carefully considered. Currently, most emeralds leave the country without being registered or reported as exports (L.W. Snee, U.S. Geological Survey, 2005, written commun.). Afghanistan could potentially benefit from developing a domestic cutting and exporting industry (L.W. Snee, U.S. Geological Survey, 2005, written commun.).

Based on the unconfirmed reports of silver-rich iron zones, the precious metal potential in the Panjsher Valley may be significant.

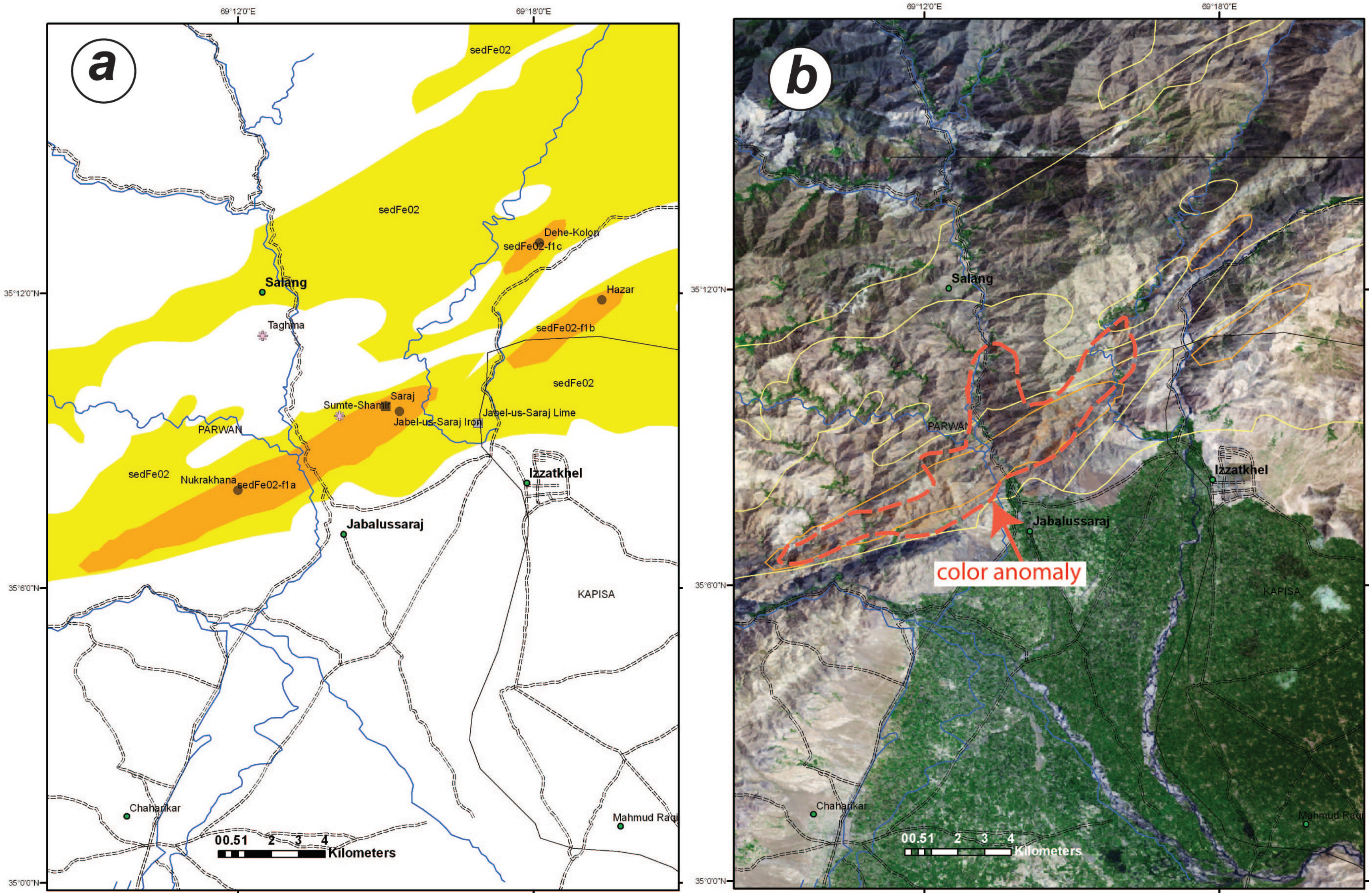

Figure 13A–15. Map and image showing the location of stratabound iron deposits in the Panjsher Valley area of interest, from Peters and others (2007). (*a*) Permissive (yellow) and favorable (orange) tracts from sedimentary iron assessment. (*b*) Landsat image showing color anomaly generated by these deposits; yellow outlines are permissive tracts, orange outlines are favorable tracts, and red dashed-line outline is the color anomaly.

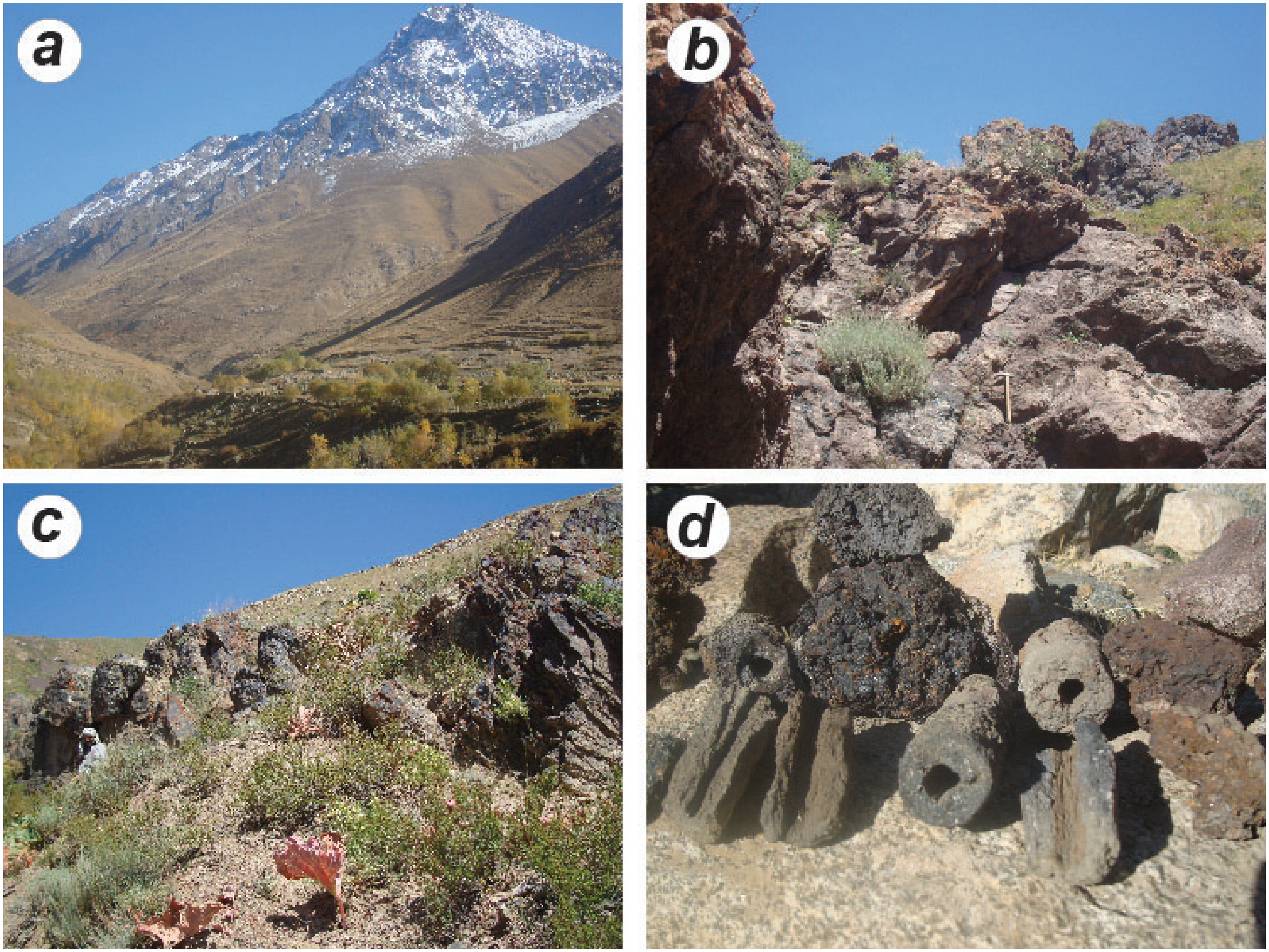

Figure 13A–20. The iron areas of the Panjsher Valley area of interest. (*a*) View showing relief in the Panjsher Valley area. (*b*-*c*) Iron pod outcrops. (*d*) Slag and “tools” from ancient workings of iron and iron-silver lodes in the northwestern Panjsher Valley area. Photographs by the Afghanistan Geological Survey.

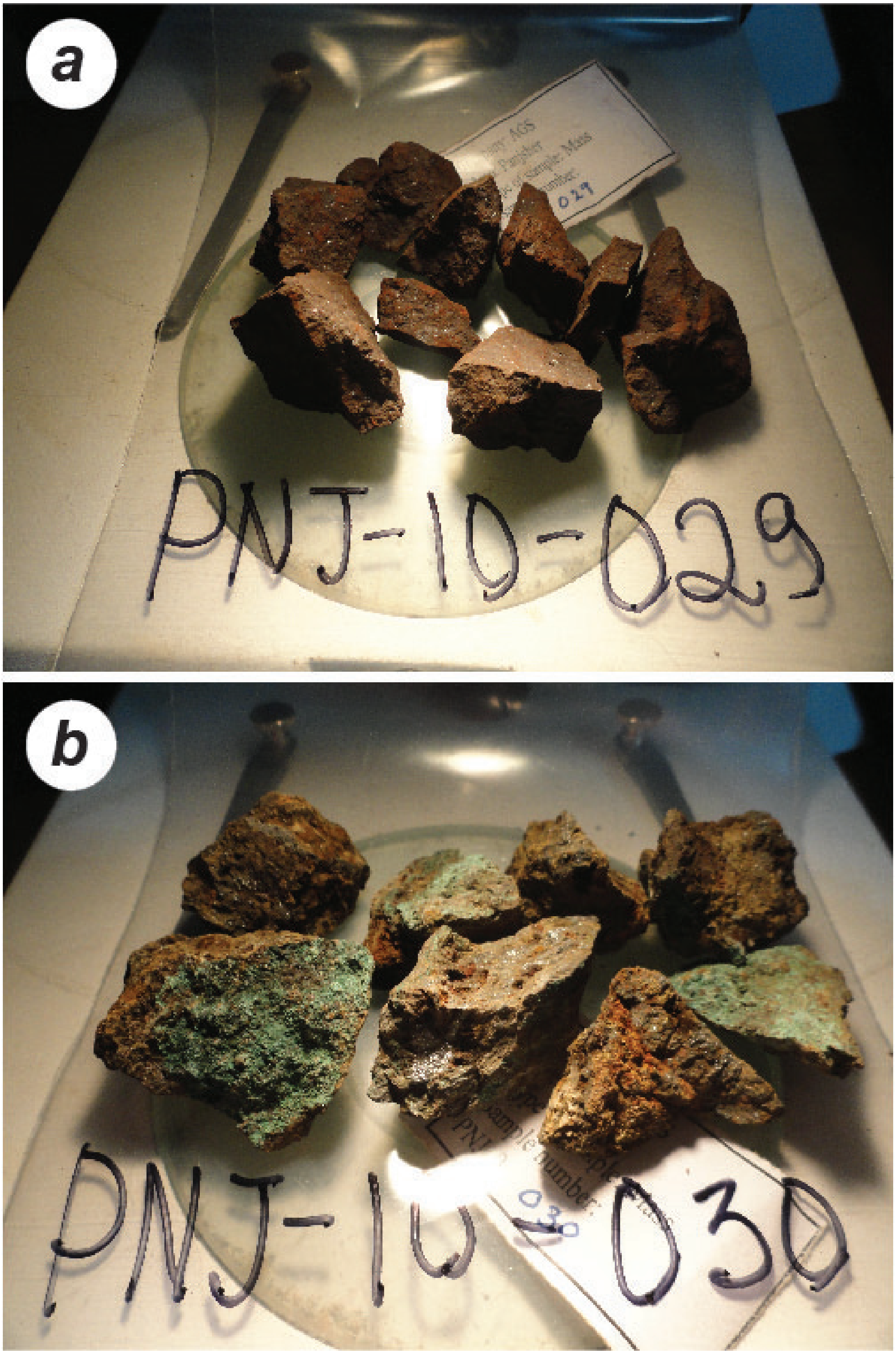

Figure 13A–21. Samples from iron-bearing zones in the Panjsher Valley area of interest. (*a*) Sample PNJ–10–029, iron-rich calcareous rocks. (*b*) Sample PNJ–10–030, iron-rich, calcareous rocks pitted with remnant weathered pyrite. Photographs are by the Afghanistan Geological Survey

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