Chapter 7A. Summary of the Haji-Gak Iron Area of Interest

Contribution by Karine Renaud, David M. Sutphin, Stephen G. Peters, and Lawrence J. Drew

Abstract

The Haji-Gak iron area of interest in Bamyan, Parwan, and Wardak Provinces contains the Haji-Gak iron deposit and several other prospects and deposits. Three subareas have been delineated within the main area of interest. The Haji-Gak iron deposit (prospect subarea) in Bamyan Province is the best known and largest iron oxide deposit in Afghanistan. The Haji-Gak ore deposit is more than 12 kilometers (km) long and 3 kilometers (km) wide and contains 16 separate zones, some of which are as much as 5 km in length, 380 meters (m) wide and extend 550 m downdip. Seven of these zones have been studied in detail. Iron ore is primary and oxide. The primary ore [80 volume percent (vol. %) of the deposit] is present below 130 m, comprises mostly magnetite and pyrite as well as smaller amounts of other sulfide minerals, including chalcopyrite, and averages 61.3 weight percent (wt. %) iron. The remaining 20 vol. % of the iron ore is oxidized and consists of three hematitic ore types at slightly higher grades (more than 62.0 wt. %). The mineralization is structurally controlled. A previous Russian resource estimate for the entire deposit is 1,700 million metric tons (Mt), although the mining reserve estimate for the near surface oxide ore in the most explored area is 85 Mt.

The Chuy, Khaish, Khakriz, Kharzar, and Zerak sedimentary-rock-hosted iron deposits are adjacent and to the east of the main Haji-Gak iron deposit in the Northeastern Haji-Gak subarea and have also been explored. The Haji-Gak iron area of interest also contains barite deposits and mineralization near the Haji-Gak prospect subarea and in the Northeastern and Farenjal subareas. The Haji-Gak barite deposit in the Haji-Gak prospect subarea fills veins over an area of 10 square kilometers (km^2). The speculative resources of the largest vein are 36,200 metric tons with an average barium oxide content of 56 wt. % barium oxide. Additionally, the Haji-Gak prospect subarea contains the Haji-Gak limestone deposit with speculative resources over an area of 45 km^2 to a depth of 60 m and reported resource of 3.5 Mt. The Haji-Gak sandstone, also in the Haji-Gak prospect subarea, grades from 93.66 to 97.31 wt. % silicon oxide and contains speculative resource of 650,000 metric tons. Speculative resources are undiscovered resources that occur in unknown and undiscovered types of deposits in favorable geologic settings or in unknown types of deposits that have to be recognized. The quality of the silicon oxide raw material is suitable for manufacturing class-II dinas.

In the northeastern part of the Haji-Gak iron area of interest, Paleozoic strata contain the Farenjal barite and lead-zinc ore district. The subordinate mineralization consists of asbestos, copper, iron, manganese, and talc.

Extensive exploration has been done in the Haji-Gak prospect subarea for iron deposits. Afghan, French, German, and Russian feasibility studies on the main iron deposit were completed. The remainder of the Haji-Gak iron area of interest has not been explored to this level. A U.S. Geological Survey team visited the lower parts of the ore deposit area briefly in 2006 and 2009.

7A.1 Introduction

This chapter is a summary and interpretation of Kusov and others (1965b), correlating the report with the results of joint geologic and compilation activities conducted during 2009 to 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) (fig. 7A–1; table 7A–1) in the Haji-Gak iron area of interest (AOI) and subareas. Accompanying complementary chapters 7B, 7C, and 7D additionally address hyperspectral data, geohydrologic, and ore reserve assessments respectively of

the Haji-Gak iron AOI. Supporting AOI data and information for this chapter are available from the Ministry of Mines in Kabul.

We have attempted to translate the original Russian terminology and rock classification into modern English geologic usage as literally as possible without changing any implied genetic or process oriented implications in the original descriptions, using the age presented in the original report. A more recent study of the Haji-Gak area (Kusov, 1965a) substantially modified the ages for the Haji-Gak Formation from Proterozoic to Devonian and provided new interpretations of the geologic settings in which various units were deposited.

The Haji-Gak iron AOI is in east-central Afghanistan and consists of a main area and three subareas. The main area is 2,079 square kilometers (km^2) the Farenjal subarea is 557 km^2, the Northeast (NE) Haji-Gak subarea is 381 km^2, and the Haji-Gak prospect subarea is 180 km^2 (fig. 7A–2). The Haji-Gak iron AOI is located in parts of the Bamyan, Parwan, and Wardak Provinces and parts of the Bamyan, Beshud, Ghorband, Hisa-i-Awal, Markazi, Shekh Ali, Shibar, and Surkh-i-Parso Districts. Deposit types that are expected or known in the Haji-Gak iron AOI are Algoma iron, bedded barite, sandstone, and limestone.

7A.2 Previous Work

The Haji-Gak iron deposit has been explored since 1911, and geologic and engineering work has been summarized in many Soviet reports; however, modern reconnaissance and prospecting work did not start until 1965. The first recorded geologic exploration was by G. Hyden, Director of the Geological Survey of India, who explored the Haji-Gak iron deposit for the first time in 1911. During this expedition, a stratigraphic sequence for the area was constructed, and three formations were identified, along with their ages; the formations were Kalu (Awband Formation) of Early Devonian age, Haji-Gak of Devonian age, and Helmand of Carbonaceous age.

The Haji-Gak iron deposit was further investigated by K. Brueckl (1935, 1936), Popol and Tromb (1954), Bybochkin and Kurotchenko (1960), Momji and Chaikin (1960), de Lapparent (1961), and Mirzad (1961).

In Brueckl (1935, 1936) the hydrothermal siderite veins in the deposit and the hornblende granitic intrusion that was cut by these siderite veins were described and categorized. Brueckl (1935, 1936) proposed that formation of magmatic hydrothermal siderite veins, and by inference the iron ores, were genetically and spatially related to the granite. The hypotheses on iron ore genesis were bolstered by Bybochkin and Kurotchenko (1960) and Momji and Chaikin (1960).

Table 7A–1. Reserves and resources of the Haji-Gak iron deposit.
[Tabulation of data from Soviet exploration in the 1960s. NA, not available]

Soviet category	Equivalent classification	Ore type	Reserve, million metric tons of ore	Iron, weight percent	Sulfur, weight percent
A	Measured or proven	Oxidized ore	9.1	62.52	0.14
B	Measured or proven	Oxidized ore	19.2	62.69	0.09
C_1	Indicated or probable	Oxidized ore	65.1	62.15	0.13
C_1	Indicated or probable	Primary ore	16.2	61.3	4.56
C_1	Indicated or probable	Fragmental ore	1.2	60.62	0.08
C_2	Inferred or possible	All ore types	3,143	NA	NA
C_2	Inferred or possible	Fragmental ore	2.9	NA	NA
P_2	Hypothetical resources	All ore types	1,333.3	NA	NA
P_2	Hypothetical resources	Fragmental ore	8.6	NA	NA
	Total		1,769.9		

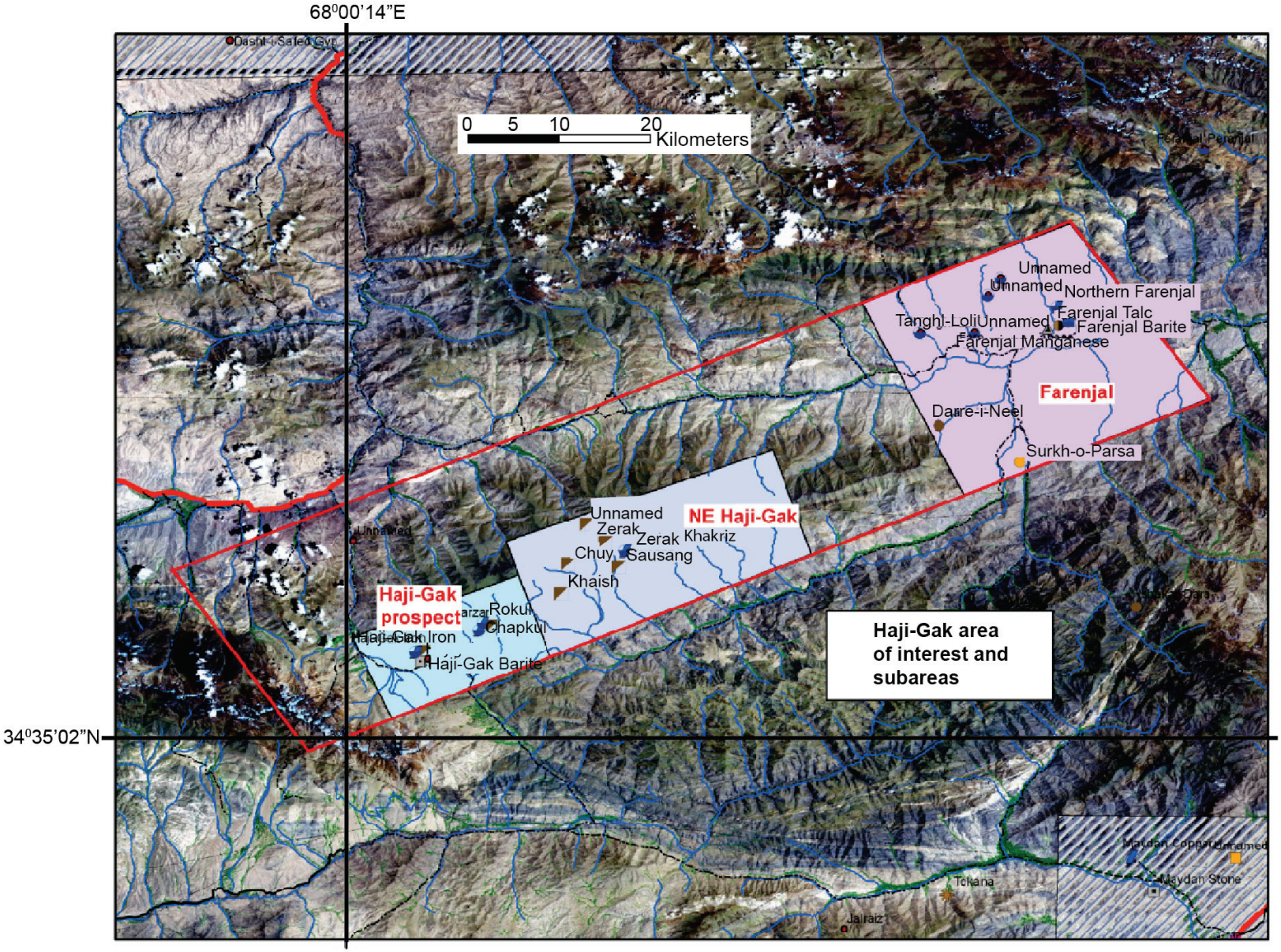


Figure 7A–1. LANDSAT image of the Haji-Gak iron area of interest (outlined in red), showing subareas (color-shaded areas) and major prospects (brown and blue triangles) and mineral occurrences (red and yellow circles). Data are from Peters and others (2007, p. 118–122).

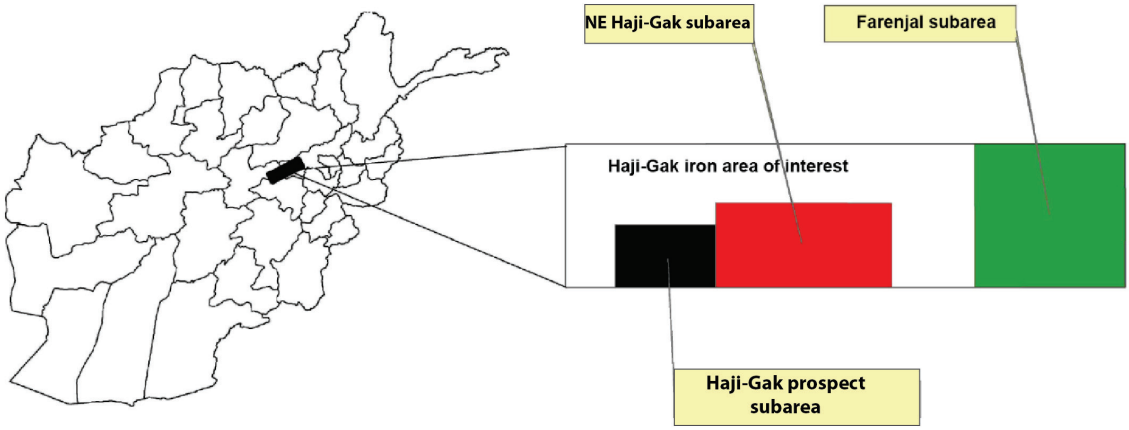


Figure 7A–2. Map showing the location of the Haji-Gak area of interest and subareas.

Popol and Tromb (1954) identified schist and three sedimentary sequences (from top to bottom), as follows: schist and limestone, red layers, and coarse-grained conglomerate. Devonian fauna was found in limestone. These sequences overlay the Kalu Formation that is in turn overlain by the Helmand Formation.

In de Lapparent, (1961) the Haji-Gak iron deposit was identified as an exhalative deposit, which suggested the deposit had undergone two types of metamorphism—greenschist facies and sericite dynamic-metamorphism.

The most extensive information about the deposit and its resources was provided by Momji and Chaikin (1961), Bybochkin and Kurotchenko (1961), and Mirzad (1961).

Most of the detailed prospecting has been done on the western part of Haji-Gak iron mineralized zone. This work was carried out by Russian and Afghan geologists and has been documented in many reports listed in the Selected References section of this chapter. This exploration is well documented by Kusov and others (1965a,b) and includes prospect and geological maps at different scales (fig. 7A–3). The work included the drilling of 4 holes, opening of 15 adits and 29 trenches, and hand specimen and microscopic description of ores and minerals, calculation of ore reserves, and the study of hydrogeology of the region.

Exploration and geologic work terminated in 1989 with the withdrawal of the Soviet army and the civil war that interrupted further activity by the Afghanistan Geological Survey (AGS). Although the AGS was able to preserve many of the Soviet reports, some of the reports were destroyed. The condition of the reports and maps ranges from poor to excellent.,

7A.3 Metallogeny

Iron deposits hosted in sedimentary rocks in Afghanistan mainly are present within Proterozoic sedimentary and volcanic-sedimentary rock packages (Peters and others, 2007, p. 118–122). Most iron deposits, including the large Haji-Gak iron ore deposit and its associated deposits, are present along a tectonized zone in the Har-i-Rod Fault zone in central Afghanistan. Additionally, an oolitic ironstone mineral occurrence also is known in the Late Paleozoic to Cenozoic sedimentary rocks (Nishiwak, 1970). Hematite vein deposits also are present in Proterozoic, Permian, and Oligocene rocks. Other major iron deposits in Afghanistan are in iron skarn bodies mainly around Oligocene intrusive bodies in the Kandahar and Badakshan Provinces. Some geologists believe that the Proterozoic-hosted deposits are products of contact metamorphism around the Oligocene intrusive bodies (Peters and others, 2007, p. 118–122).

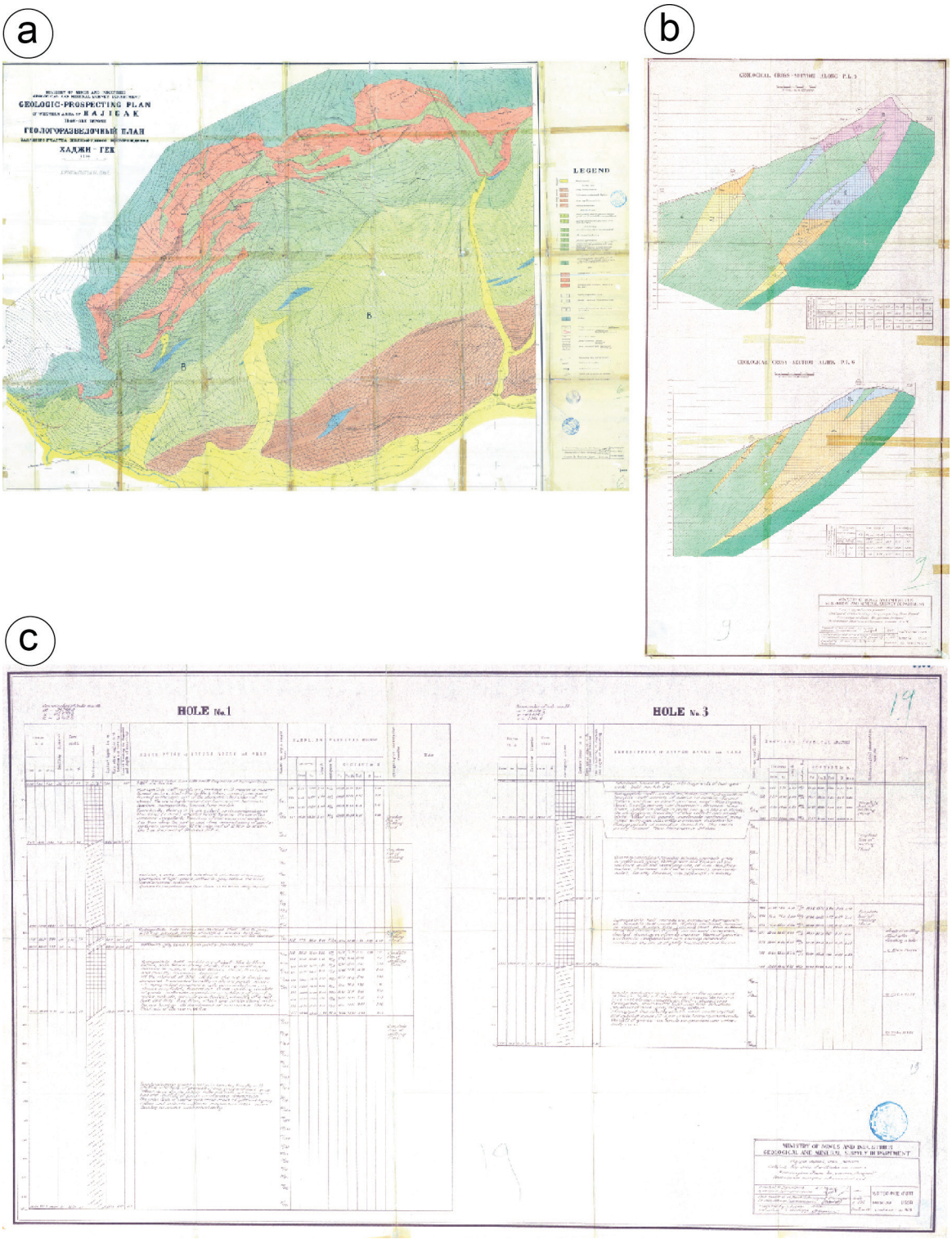


Figure 7A–3. Examples of illustrations from Soviet-era reports (Kusov and others, 1965a,b) on the Haji-Gak iron deposit. (*a*) Geologic prospecting plan of the western area of Haji-Gak; (*b*) Cross-sections used for calculations of ore reserves; and (*c*) Drill hole logs used for calculation of ore reserves. This scan is presented as an example of the style and type of study and reporting work that has been done in the past.

The main ore minerals within the sedimentary iron deposits in Afghanistan are hematite and magnetite and hematite, with smaller amounts of martite. The metallogenic age, mineralogy, textures, and sizes of the deposits make them compatible with several model types, such as Superior iron

deposits, Algoma iron deposits, and iron oxide copper-gold deposits. Sedimentary manganese deposits are a deposit type commonly associated with many sedimentary iron deposits throughout the world.

A permissive area for the occurrence of Haji-Gak-type iron deposits in Afghanistan was delineated by Peters and others (2007, p. 118–122) to encompass all Neoproterozoic sedimentary host rocks, which consist of greenschist facies schistose and phyllitic marble, dolomite, sandstone, and metavolcanic rocks (map unit Z_1scp) as well as associated Neoproterozoic metavolcanic andesite lava and interlayered sedimentary rocks (map unit Z_1al) (fig. 7A–4). Parts of the permissive tract outside the Haji-Gak iron area of interest are located in northern Kandahar, Zabul, Uruzgan, Ghazni, and Parwan Provinces (fig. 7A–4). A number of more favorable areas were also delineated to encompass the geology hosting deposits or occurrences like Haji-Gak (figs. 7A–5 and 7A–6). The updated favorable tract contains the Haji-Gak, Kharzar, Khaish, Chuy, Kharkiz, Darre-i-Neelee, and Zerak sedimentary-rock-hosted iron deposits (fig. 7A–6).

A southern part of the permissive area lies to the southwest of the Haji-Gak iron AOI and contains the Mangasak iron occurrence in Wardak Province and an unnamed stratabound manganese occurrence in northeastern Uruzgan province (fig. 7A–7). The Mangasak occurrence lies along the contact between Proterozoic gneiss and schist layers in a 1,200-meter (m)-long and 50- to -100-m-wide altered carbonated zone that contains magnetite as disseminations, nodules, and veinlets (Karapetov and others, 1970). The unnamed manganese occurrence consists of 1.5-m by 7-m lenses within Neoproterozoic cherty marl rocks (Abdullah and others, 1977).

Lack of unique and detailed descriptions of the Haji-Gak iron deposit at the time of assessment and questions concerning its genesis did not allow adequate model selection and this hampered the ability of the USGS Assessment Team in 2007 to make a quantitative assessment of the permissive area (Peters and others, 2007, p. 118–122). The main deposit types considered during the assessment process were Lake Superior-type iron deposits (Cannon, 1986a), Algoma iron deposits (Cannon, 1986b) and iron oxide copper-gold deposits (Cox, 1986; Haynes, 2000; Hitzman, 2000). After further study, the model that most closely resembles the Haji-Gak iron deposits is the Algoma iron type deposit, which is hosted by volcanogenic iron-bearing sequences mostly of Archean or Proterozoic age, similar to the Awband Formation at Haji-Gak. The Algoma iron type deposits form microbanded to mesobanded lenticular shapes that are less than 50 m thick and occasionally extend for more than 10 kilometers (km) along strike (Bekker, 2010), similar to the Haji-Gak iron deposit. Rock types that are associated with Algoma iron type deposits usually are mafic to felsic submarine volcanic rocks and deep-water clastic and volcanoclastic sediments. The textures of rocks in these iron deposits are pillowed greenstone, intermediate to felsic tuff and agglomerate, and poorly sorted clastic sediments (Cannon, 1986a,b). Individual volcanic rock layers are interbedded with deepwater greywacke and mudrocks.

7A.4 Known Deposits

The Haji-Gak iron AOI contains the Haji-Gak iron deposit (prospect subarea) in Bamyan Province and a number of other sedimentary rock-hosted deposits. Additionally there are several other deposits and prospects in the AOI and its subareas. The Haji-Gak iron deposit is the best known iron oxide deposit in Afghanistan, and similar occurrences of this type have been identified along a 600-km-long discontinuous east-west belt. The deposit is more than 12 km long and 3 km wide and contains 16 separate zones, some of which are up to 5 km long, 380 m wide, and extend 550 m downdip; seven of these zones have been studied in detail.

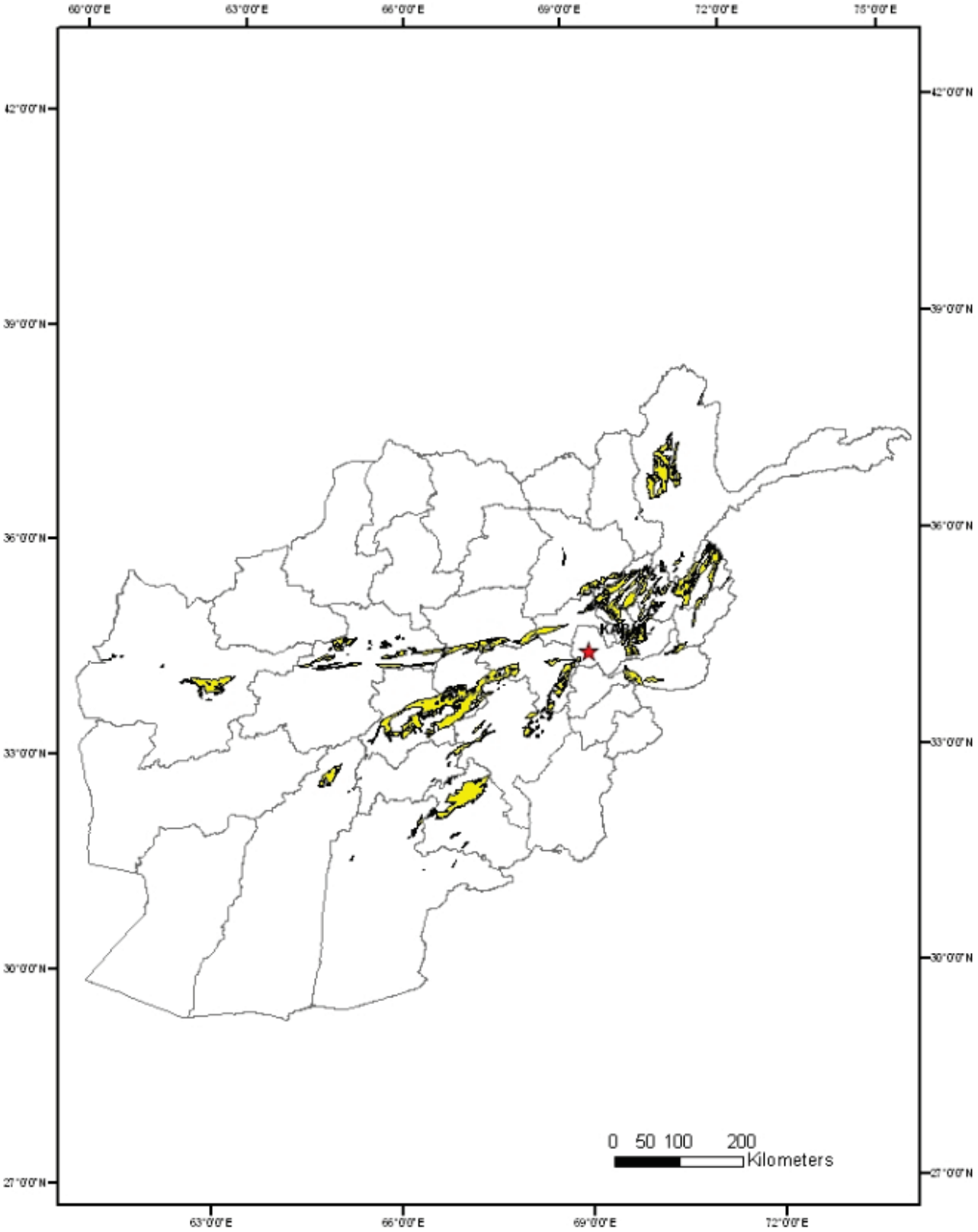


Figure 7A–4. Map of the Haji-Gak Neoproterozoic permissive tract sedFe-01 and the Paleoproterozoic permissive tract sedfe02 that contains undiscovered sedimentary-rock-hosted iron deposits, showing distribution of Proterozoic rocks that host the Haji-Gak iron deposit from Peters and others (2007). The red star is Kabul.

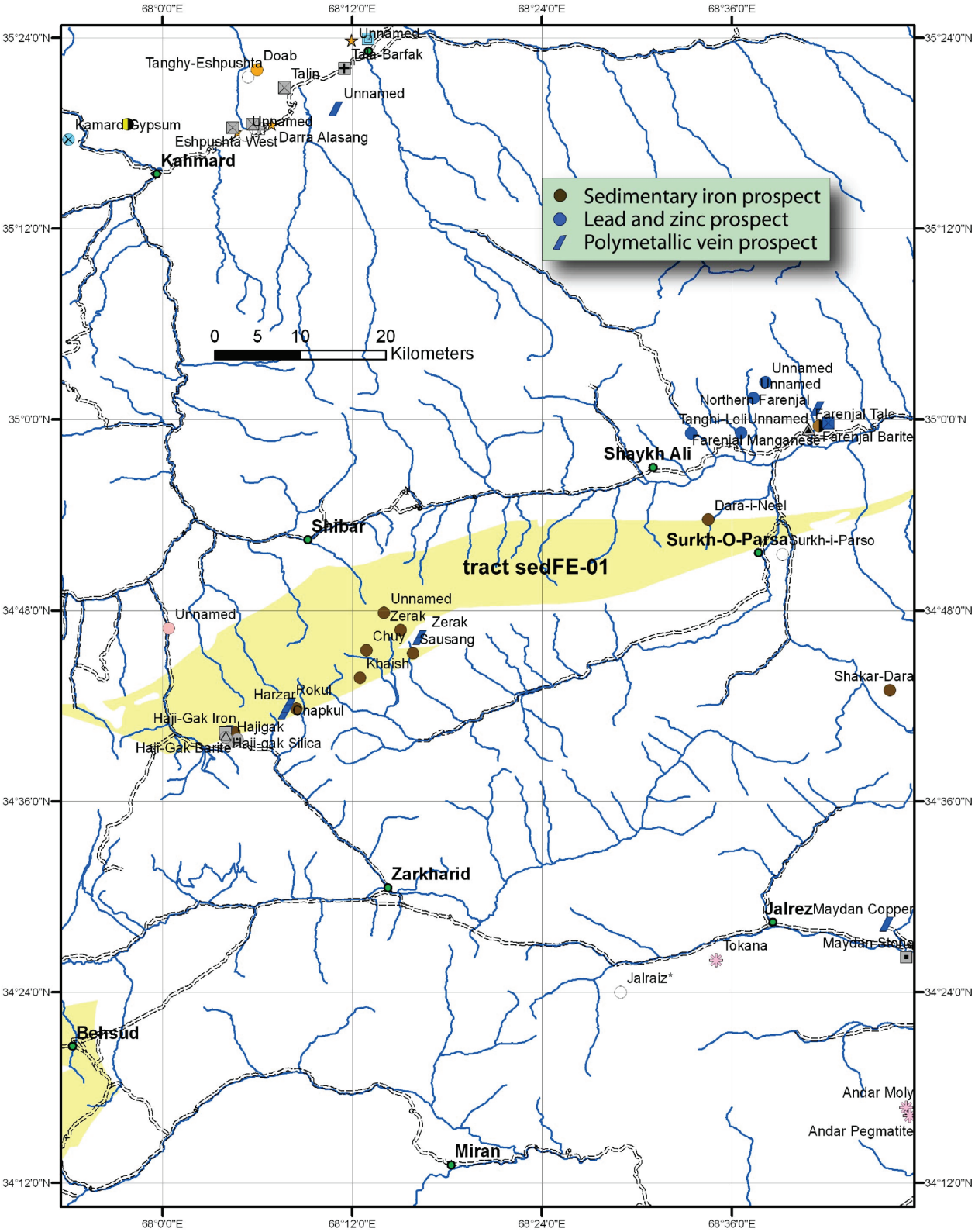


Figure 7A–5. Map showing parts of the permissive sedFe-01 Haji-Gak tract that contains the Haji-Gak and related deposits from Peters and others (2007).

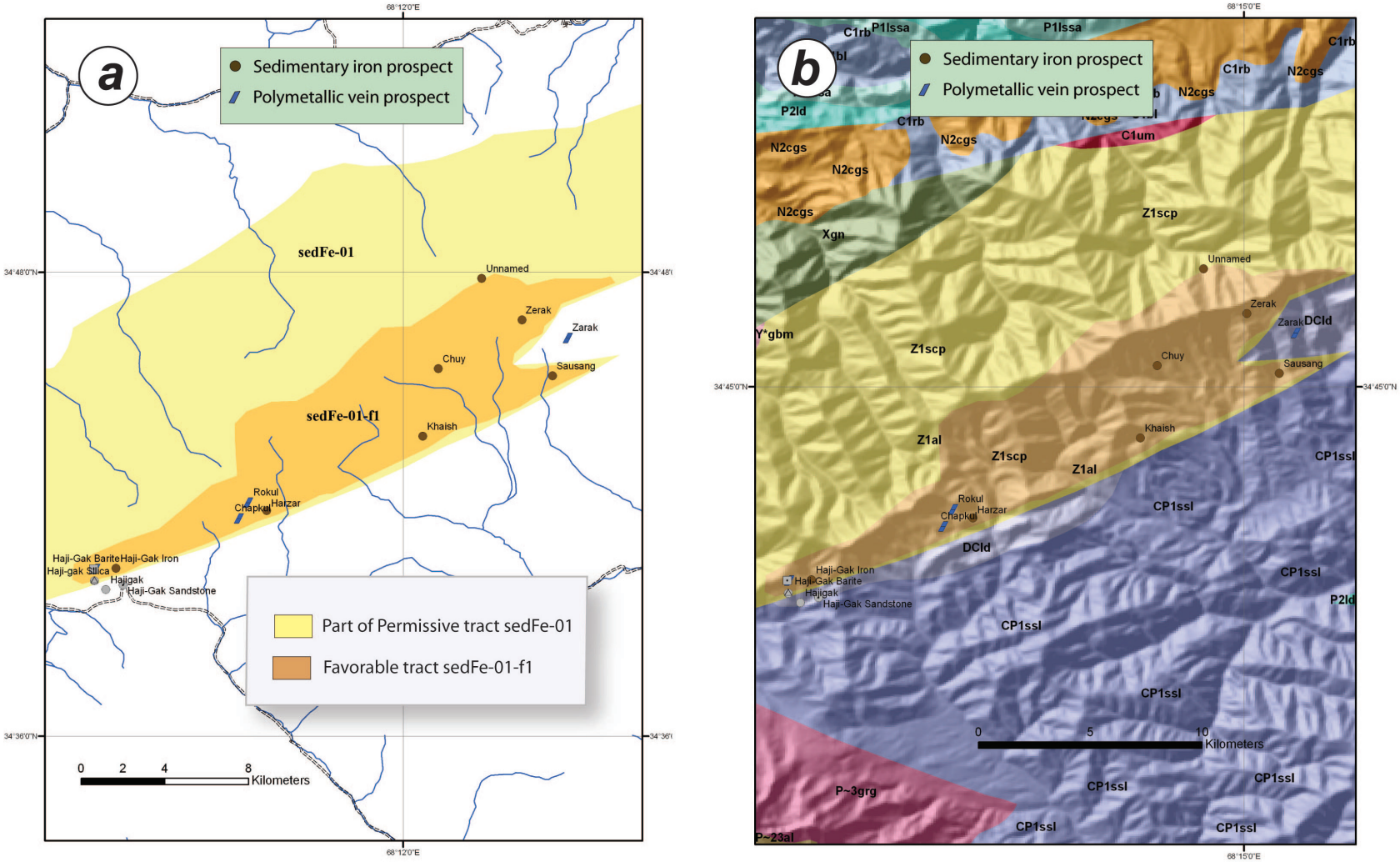


Figure 7A–6. Maps showing the location of the favorable sedFe-01-f1 Haji-Gak tract within larger permissive tract sedFe-01 tract from Peters and others (2007). (*a*) General location of favorable tract sedFe-01-f1. (*b*) Geologic units within and surrounding the Haji-Gak deposit. Host units within the tract consist of Z_1scp, Neoproterozoic greenschist, marble, dolomite, metavolcanic rocks including phyllite, schist, and sandstone; Z_1al, Neoproterozoic marble, dolomite, and metavolcanic rocks; DCld, Late Devonian to Mississippian limestone, dolomite, and schist;; and CP_1ssl , Carboniferous to Early Permian sandstone, siltstone, shale, and mafic volcanic rocks.

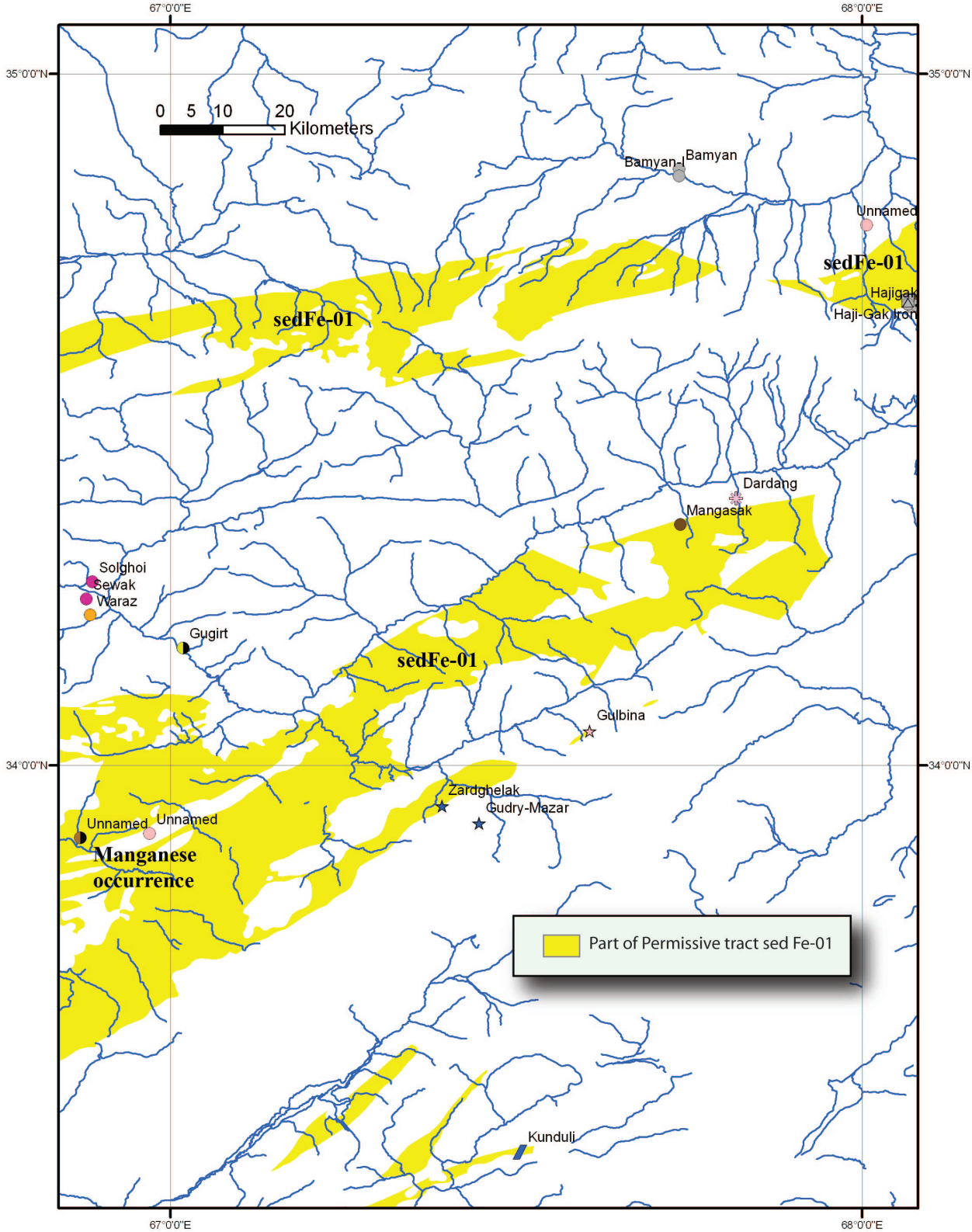


Figure 7A–7. Map showing southern parts of the permissivesedFe-01 Haji-Gak tract for undiscovered sedimentary iron deposits from Peters and others (2007). The southern parts of the tract contain the Mangasak iron occurrence and a stratabound unnamed manganese deposit to the southwest.

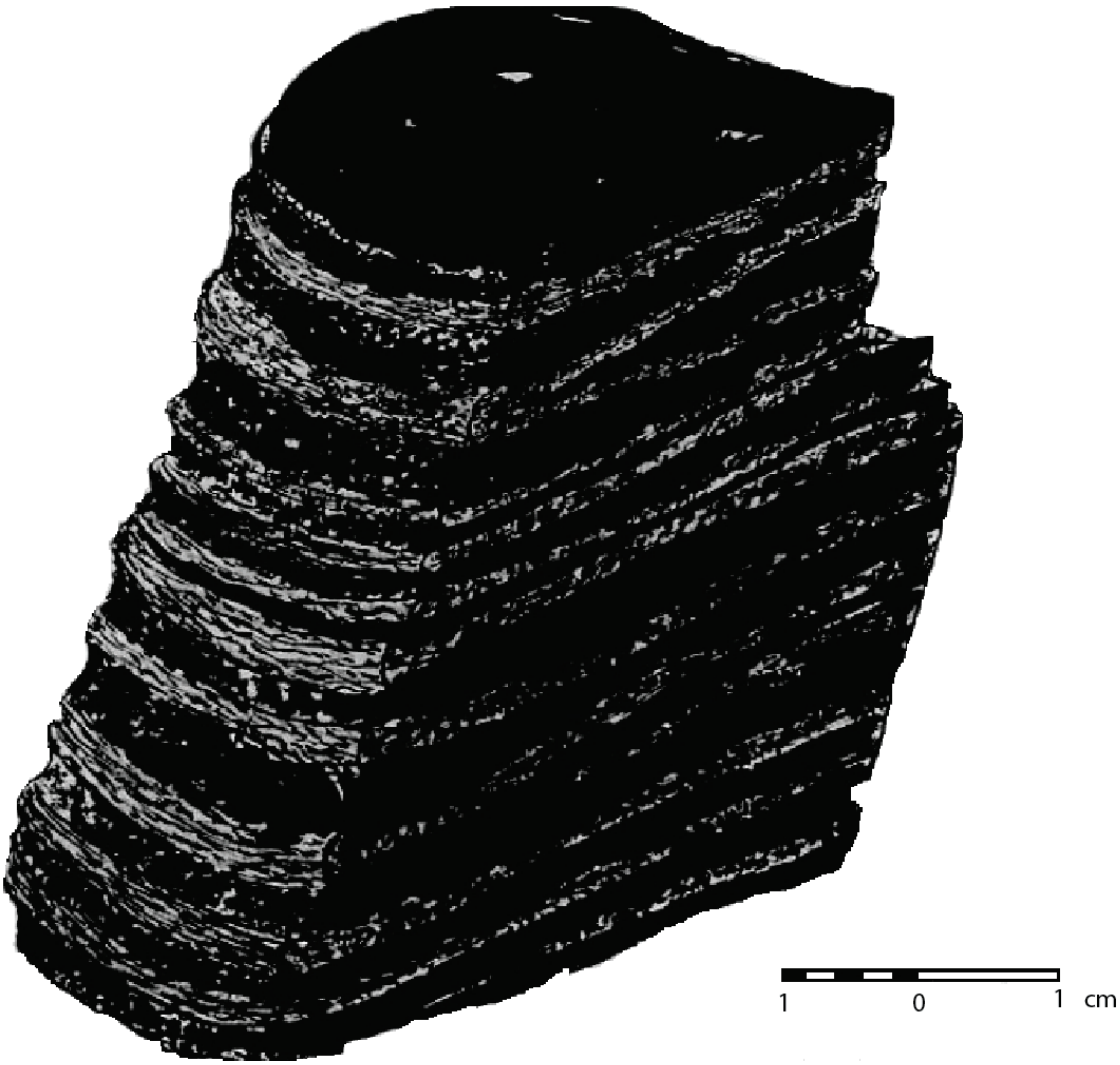


Figure 7A–8. Photograph of a banded hydrogoethite-hematite-semimartite. The light bands are made of hematite, and the black bands are made of magnetite, martite, and hydroxides. The sample in the photograph is from drill hole # 2 at a depth of 36.30 meters (Kusov and others, 1965a,b).

Iron ore is both primary and semioxide. The primary ore [80 volume percent (vol. %) of the deposit] is present below 130 m and comprises magnetite, pyrite, and minor other sulfide minerals, including chalcopyrite, and averages 61.3 weight percent (wt. %) iron. The remaining 20 vol. % of the ore is oxidized and consists of three hematitic ore types at slightly higher grades than the primary ore. The mineralization is structurally controlled. Previous Russian resource estimates for the entire deposit are 1,700 million metric tons (Mt), although the mining reserve estimate for the near-surface oxide ore in the most explored area is 85 Mt (table 7A–1; Momji and Chaikin, 1960; Mirzad, 1961; Kusov, 1963; Kusov and others, 1965a,b; Bouladon and de Lapparent1975; Abdullah and others, 1977).

The Haji-Gak orebody no. 1 extends 5 km, the strike of the deposit is southeasterly at 140° to 150º with a dip angle of 60° to 70º, and is 110 m thick. The Haji-Gak iron orebodies cover an area of 35 km^2. There are six drill holes, two adits and three reserves of about 20 Mt of ore (table 7A–1). The deposit was discovered in 1911 by G.T. Hyden of the Indian Geological Survey. The mineral composition of the Haji-Gak orebody no. 1 is 30 vol. % magnetite, 25 vol. % hydroxides, 20 vol. % martite, 7 vol. % quartz, and 5 vol. % hematite (Sutphin and others, 2010).

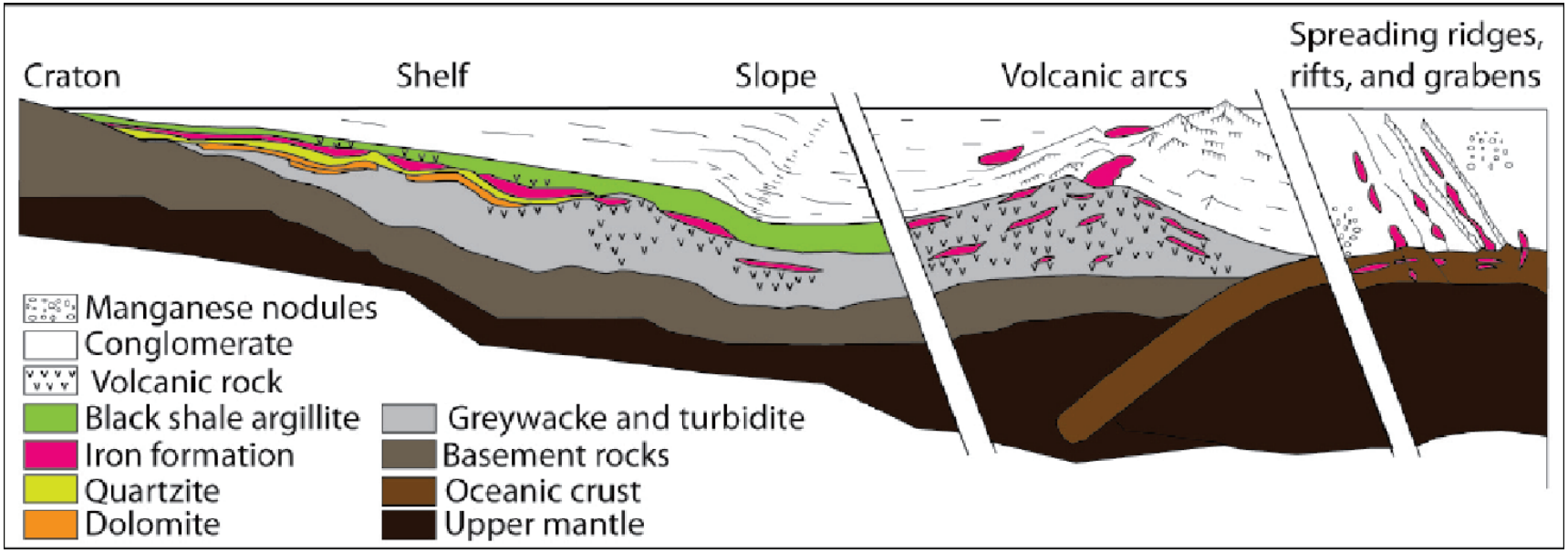


Figure 7A–9. Diagram of the environment most likely for the formation of sedimentary and volcanogenic iron deposits. The diagram shows the formation of Algoma iron type deposits near the Volcanic arc and Lake Superior type deposits near the upper shelf. Rocks of each type of deposit are represented. The Haji-Gak iron deposit contains rocks more closely related to volcanoclastic settings. Diagram modified from Gross (1973) and Peters (2010).

7A.5 Geology of the Haji-Gak Iron Deposit Area

The 1:1,000,000-scale geologic map of Doebrich and Wahl (2006) shows the Haji-Gak iron deposit to be hosted in Neoproterozoic sedimentary rocks, which are described as greenschist facies schistose and phyllitic marble, dolomite, sandstone, and metavolcanic rocks (map unit Z_1scp). The deposit is also interbedded with Neoproterozoic metavolcanic andesite lava and interlayered sedimentary rocks (map unit Z_1al).

The oldest part of the Haji-Gak Proterozoic stratigraphic succession, as described by Kusov and others (1965a,b), is the Neoproterozoic Kab Formation that contains quartz-sericite schist, phyllite, marble, and dolomite and porphyrite lenses (fig.7A–11). The Haji-Gak iron deposit is hosted by the Neoproterozoic Awband Formation, which, together with the underlying Kab Formation, forms the 4,500-m-thick Qala Group, a sequence of metavolcanic and metasedimentary rocks that comprise tuff, argillaceous rocks, and minor chert and marble. The Awband Formation comprises sericite and quartz-sericite schist, sandy quartz sericite schist, carbonate chlorite-sericite schist, marble, dolostone, and plagioporphyrite with scapolite, volcanic rocks, and tuff. The iron orebodies in the Neoproterozoic Awband Formation are overlain by the Green Schist Formation (fig. 7A–11) that is dominated by quartz-chlorite-sericite schist and quartz-chlorite schist, plagioporphyrite with scarce scapolite, and metavolcanic rocks that locally are intruded by granodiorite (figs. 7A–12, 7A–13, and 7A–14).

Intrusive complexes are present in the Proterozoic rocks of Haji-Gak iron deposit area. The oldest consists of small intrusions of quartz porphyry, plagiogranite, and quartz diorite, including granodiorite. The youngest includes sills, dikes, and small stocks of diabase. In addition, there are local occurrences of keratophyre and metasomatic carbonatite. Serpentine bodies also are present and comprise thin (up to 5-m) sills and dikes with microflaky and spotted textures. The serpentine rocks are green, schistose, and fine-grained. The primary mineralogy of the serpentine rock has been converted to secondary antigorite, talc, and magnesite as well as later minerals, such as brucite and carbonate, that are mostly developed in the Jowqul Formation and more rarely in the Kharzar Formation.

These Paleoproterozoic volcanoclastic rocks are unconformably overlain by the Upper Devonian Haji-Gak Formation that contains remnants of corals and brachiopods and comprises grey-black limestone injected with a thick network of white, coarse-crystalline barite veins, calcareous conglomerate and breccias, calcareous-clayey shale, sandy limestones, calcareous sandstones, and quartzite (figs. 7A–11 and 7A–15). The Lower Carboniferous Kharzar Formation unconformably overlies the Haji-Gak Formation and contains shale, sandstone, and quartzite. These formations are as thick as 500 to 900 m.

The Quaternary rocks are Holocene to Recent floodplain and fluvial, alluvial-colluvial, and fluvioglacial moraine deposits and glacial outwash. The deposits of fragmental iron ore are located in Recent colluvial deposits (figs. 7A–11 and 7A–15).

The Haji-Gak iron orebody and its host rocks are folded and faulted (fig. 7A–15). The predominant strike of the Proterozoic and Paleozoic rocks is between northeast and north-northeast, with a regional dip of approximately 50° towards the south-southeast or southeast and a general plunge of mesoscopic and macroscopic folding to the southeast (fig. 7A–16*a*,*b*). Strikes and dips of bedding and bedding plane parallel foliation were compiled in the study in 11 separate structural domains in the main Haji-Gak iron deposit area from the maps of Kusov and others (1965a,b) and these data were plotted as poles to planes and then contoured on equal area stereonets (fig. 7A–16*a*). Strikes of the fold axial planes were identified from inferred folding of the ore on the map, and dips of the axial planes were approximated from the stereonet plots. The results of this analysis confirmed that the dominant plunge of folds in the host rocks and the contained ores is about 40° to 50° southeast (fig. 7A–16*a*).

One major steeply dipping fault has juxtaposed the Neoproterozoic rocks against the crystalline Mesoproterozoic rocks (fig. 7A–15). Another fault has thrown Upper Devonian rocks against the Neoproterozoic Green Schist Formation. In addition, a number of north-south and north-west trending faults, some of which are probably thrusts, offset parts of the Neoproterozoic succession, including the

iron ore deposits. A series of thrust faults have been mapped by Kusov and others (1965a,b) and are also indicated by the increased thickness of the iron ore and its host rocks within the central zone of the Haji-Gak iron orebody. A final phase of faulting consisted of the development of north-south and northwest-southeast faults that have offset the iron ores. Later post-Cretaceous extension led to the further development of northwest-southeast faults and graben structures that are filled with Quaternary to Recent sediment.

Figure 7A–10. Photograph of the Haji-Gak iron deposit looking northeast. The dark-colored outcrops (indicated by arrows) along the ridge line are the outcropping parts of the Haji-Gak iron orebody. Photograph by Will Stettner, U.S. Geological Survey.

Zones of contact metamorphism contain breccia zones near the orebodies that are dense and massive and contain local relict bedding. These breccia zones are highly fragmented and have micrometagranoblastic and microgranoblastic textures. These zones comprise quartz, iron hydroxide minerals, hydromica, and sericite, as well as local zoisite. Microquartz is common in many of the volcanic rocks, and mylonitization zones also are present as lenses of mylonitized and brecciated limestone that are up to 5 m thick along the base of plagioporphyrite and quartz plagioporphyrite in the Green Schist Formation.

7A.6 Structural Geology

The rocks of the Haji-Gak iron ore deposit form a large horizontally extended monocline, which coincides with the south limb of the larger Khoh-e-Baba anticlinorium. The rocks strike northeast and dip southeast (azimuth from 120° to 170°, angle from 35° to 80°). The monocline also contains smaller folds and fractures. The orebodies are conformable with layering of the host rocks. The Haji-Gak iron ore field has been divided into three northeast structural zones by Kusov and others (1965b)—the northern, middle, and southern zones.

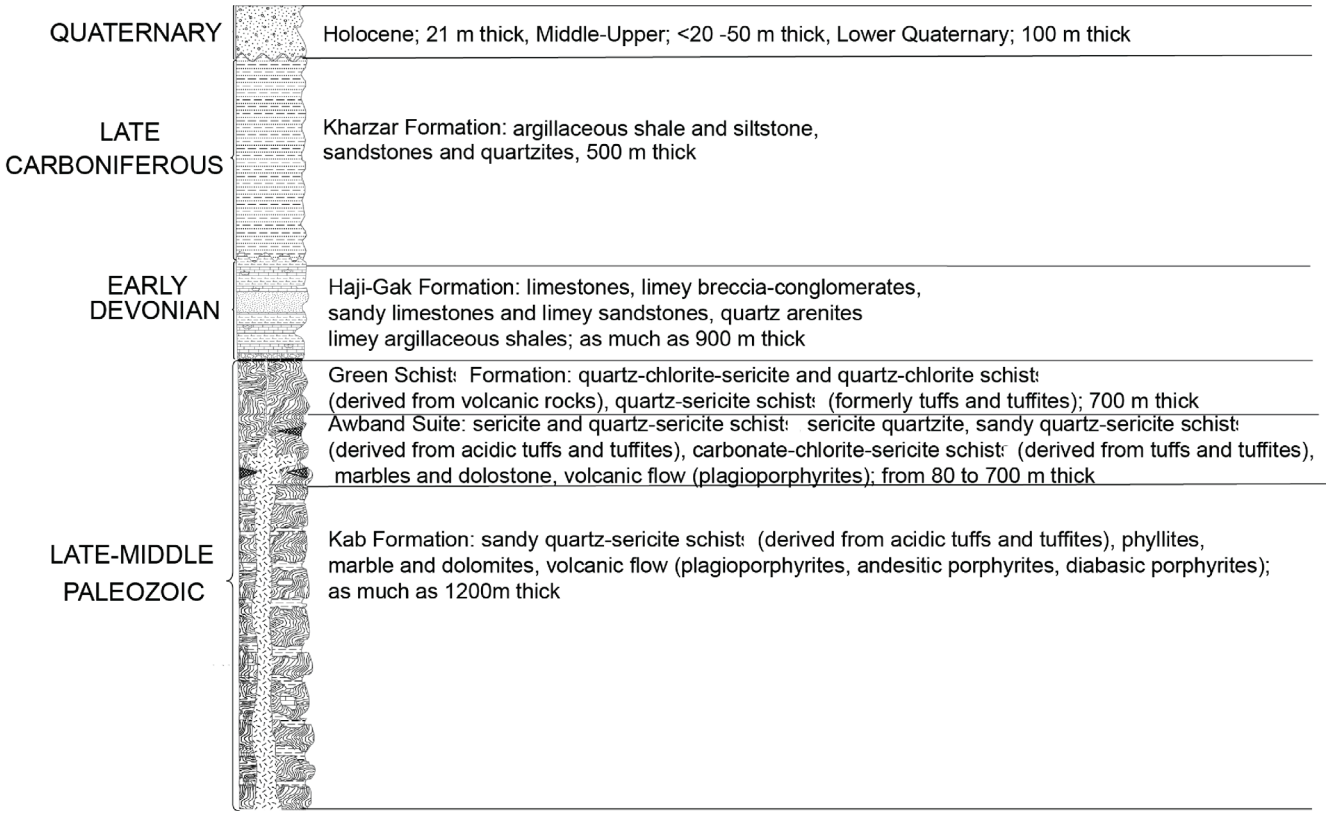
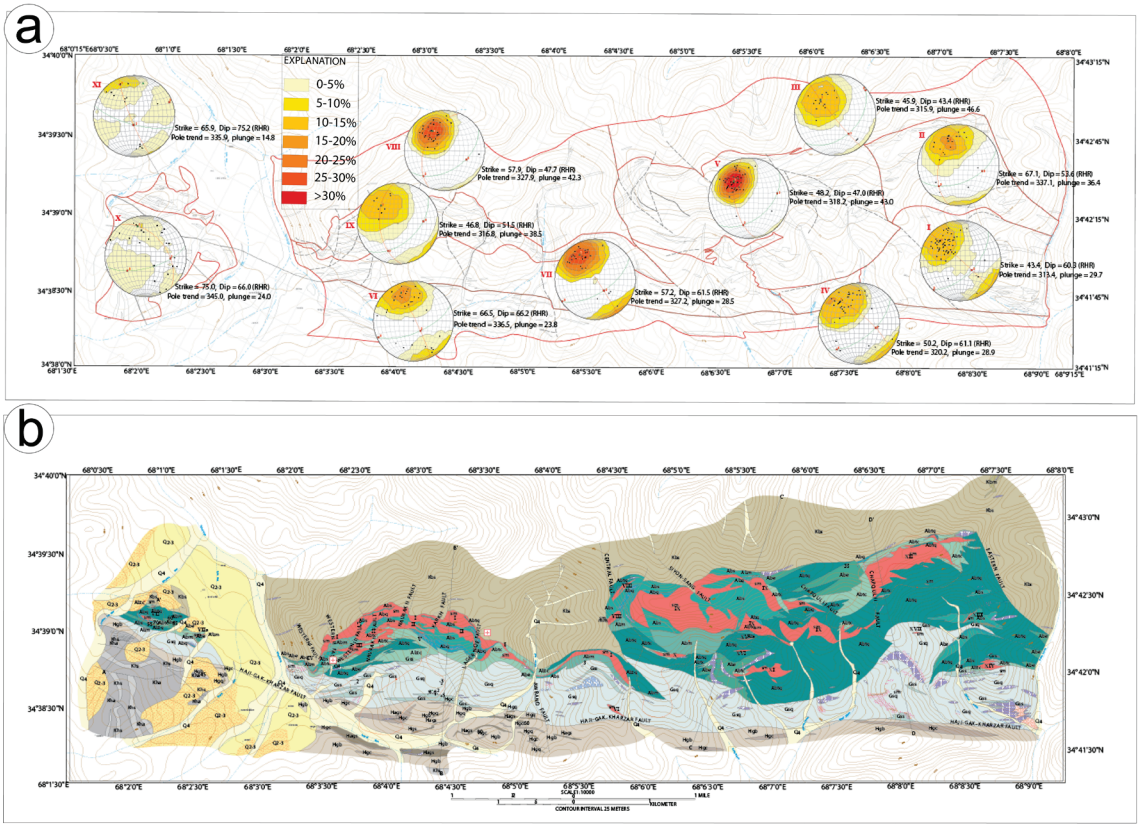


Figure 7A–11. Stratigraphic column of the Haji-Gak iron deposit area. Drafted from data from Kusov and others (1965b).

The northern structure zone contains cyclically repeated interbedded layers of schist with fine- to medium-textured phyllite as well as local interlayers of siliceous limestone (Kab Formation).Formation This zone is monoclinal and contains southeast dips (azimuth from 110° to 170°, dip angle from 35° to 60°). In addition, this zone contains small-scale isoclinal, locally recumbent folds. Faults in the northern structure zone are brittle, but flow cleavage and shear zones are parallel to the schistocity.

The middle structural zone consists of the Awband and Green Schist Formations. The northern border of this zone coincides with the contact between the Awband and Kab Formations, and orebodies I, IX, and XII are located along this locally faulted contact. The southern contact of the middle structural zone passes along the Haji-Gak-Kharzar Fault. This zone comprises rocks having contrasting physical characteristics, including iron ore, various schists, sericite quartzite, marble, volcanic rocks, and alkaline rocks. These mixed physical properties played a major role in intense dislocation in this section compared with that of other sections. The middle structural zone is also monoclinal with the steep southeast dips (50° to 80° southeast). Most secondary folding in the Haji-Gak iron district is present in this zone. There are small symmetric and asymmetric folds, overturned and recumbent with limbs with dip lengths that range from 20 to 200 m and extend along strike for between 200 and 600 m. Kink banding is present within the schist. The faulting in the middle structural zone is both mesoscopic and megascopic, and cleavage is well developed. Foliation and shearing are abundant in the middle structural zone, as are brittle faults. The iron orebodies are fractured parallel to cleavage. The banded ore is sheared and marked by flow cleavage parallel to the schistocity.



Q4 Flood-plain and alluvium deposits (HOLOCENE)
Eluvium-diluvium deposits (colluvium) (HOLOCENE)

Q2-3 Morainal deposits (QUATERNARY)

Q2-3 Glacio-fluvial drift (QUATERNARY)

KHARZAR FORMATION (LOWER CARBONIFEROUS)

Khs Sandstones and Quartzites sandstones

Kha Argillaceous shale and siltstones

HAJI-GAK FORMATION (UPPER DEVONIAN)

Hgb Grey limestone

Hgc Limey breccia-conglomerates

Hags Sandy limestones and limey sandstones

Hgq Quartz Sandstone

Hgs Limey argillaceous shales

GREEN SCHIST FORMATION (LOWER-MIDDLE PALEOZOIC)

Gsq Quartz-chlorite-sericite and quartz-chlorite schist (derived from volcanic rocks)

Gss Quartz-sericite schist (formerly tuffs and tuffites)

AWBAND FORMATION (LOWER-MIDDLE PALEOZOIC)

Abs Sericite and quartz-sericite schist

Abq Sericite quartzite

Abtq Sandy quartz-sericite schist (derived from acidic tuffs and tuffites)

sm Semi-oxidized hydrogoethite-semi-martite ore

gh Semi-oxidized carbonate-semi-martite ore

mm Semi-oxidized hydrogoethite-hematite-semi-martite

Non-oxidized pyrite-magnetite ore, carbonate-magnetite ore-pattern shown in core holes only

Abtc Carbonates-chlorite-sericite schist (derived from tuffs and tuffites)

Abm Dolomitic marbles

KAB FORMATION (LOWER-MIDDLE PALEOZOIC)

Kbs Sandy quartz-sericite schist and phyllites (derived from tuffs and tuffites) fragments

Kbm Marble and Dolomites

Kbe Volcanic Flow

INTRUSIVE ROCKS

Diabase

Figure 7A–12. Structural analysis of bedding and foliation of the Haji-Gak iron orebody from Renaud and others (2011a). (*a*) Contoured poles to bedding on equal area stereonets from 11 separate domains showing moderate plunges to the southeast. (*b*) Geologic map of the Haji-Gak iron ore deposit.

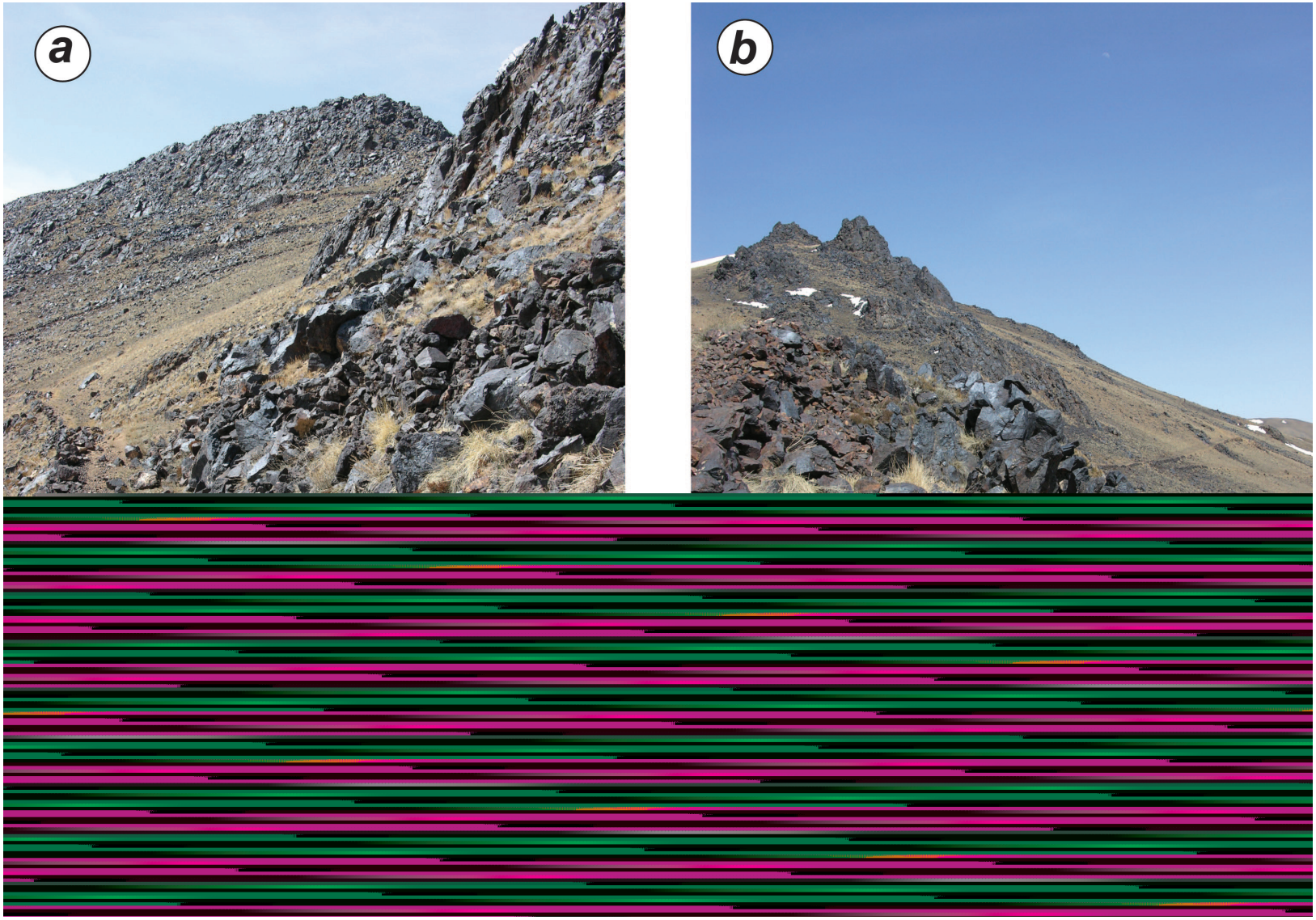


Figure 7A–13. Photographs of outcrops of the Haji-Gak sedimentary iron deposit in Bamyan and Wardak Provinces from Peters and others (2007). (*a*) Pathway along outcrops of iron ore. (*b*) Outcropping layers of iron ore along the crest of the main ridge at Haji-Gak. Photographs by Robert Bohannon, U.S. Geological Survey.