9.0 Deposits related to regionally metamorphosed rocks

Afghanistan has large areas of ancient high-grade metamorphic rocks permissive for the occurrence of deposit types that result from the processes of regional metamorphism. An important deposit type related to regionally metamorphosed rocks in Afghanistan is low-sulfide gold-quartz veins, which form in clusters in the northern part of the country in Badakhshan Province (section 9.1) (*http://www.bgs.ac.uk/afghanminerals/preciousMetal.htm*). Small graphite occurrences also are present in regionally metamorphosed Archean and Proterozoic rocks in the northeast part of Afghanistan (section 9.2). Metasomatic and metamorphic talc and magnesite deposits may also be important sources of these commodities in Afghanistan (section 9.3). Additionally, some of the iron and possibly base-metal deposits proximal to highly metasomatized and deformed zones along the Herat fault zone may also be related to regional metamorphism (section 7.2). Gold placers derived from low-sulfide gold-quartz veins are discussion in section 10. Additional gold occurrences and deposits that are related to igneous rocks are discussed in section 5.2.

9.1 Low-sulfide gold-quartz veins

Contribution by Stephen G. Peters.

Gold-quartz veins, many with characteristics of low-sulfide gold-quartz veins, are present in the northern parts of Afghanistan in Badakhshan Province (Bothman, 1953; Abdullah and others, 1977). A number of these gold-quartz veins may be of sufficient size to support a local gold industry. Additional discoveries of small- to medium-sized deposits are likely in this remote area. This deposit type also commonly generates secondary alluvial placer gold deposits. Additional assessment of lode gold deposits is contained in section 5.0 for igneous-related gold, and in section 10.2 under deposits related to weathering and surficial processes.

Gold quartz veins typically form in older metamorphic rocks elsewhere in the world. The Proterozoic and Archean rocks in Afghanistan have similarities to rocks found in gold-bearing zones in other parts of the world. Elsewhere in the world, Archean greenstone belts have been prolific producers of gold from primary deposits in the Superior Province, Canada (4,500 metric tons Au), Yilgarn craton, Western Australia (2,350 metric tons Au), and Zimbabwe craton (2,200 metric tons Au). Drew (2003) has emphasized the Archean as a major period of lode Au mineralization world-wide. Archean lode gold deposits are characterized by gold–bearing quartz veins with low sulfide mineral contents. The deposits may be distributed in ore districts as several hundred Au deposits or prospects each containing +/- 1 metric ton gold each and one or more giant gold deposits. Even the relatively small craton of Zimbabwe has produced two deposits each in excess of 100 metric tons gold and a further 26 deposits have yielded more than 10 metric tons gold each. Similar style gold districts also are known in Phanerozoic rocks.

Given the significant endowment of gold in Precambrian areas with similar geology, it seems legitimate to ask why Precambrian greenstones and related terranes of Afghanistan have not produced significant lode gold. Characteristics and descriptions of primary gold deposits in Badakhshan Province, Afghanistan are similar to deposits in other productive cratons. These common features include quartz with low-sulfide mineral content that is present in stockworks and massive veins, which are structurally controlled and are hosted by all lithologies of the belts.

9.1.1 Descriptions of low-sulfide gold-quartz vein deposit model

The main model applicable to gold deposits associated with metamorphic rocks in northern Afghanistan is the low-sulfide gold-quartz vein model that can be applied to many of the areas in the Province of

Badakhshan and parts of Takhar, Baghlan and Parwan Province. Some occurrences, however, the Baharak and Fayz Avad Districts may also be related to plutonism.

Low-sulfide gold–quartz veins. Low-sulfide gold-quartz veins (model 36a, Berger, 1986; Drew, 2003) or orogenic veins, greenstone-hosted gold, or mesothermal quartz veins consist of gold in massive to wispy, multiple, persistent quartz veins that are hosted mainly in regionally metamorphosed volcanic rocks and volcanic sediments. Rock types typically are greenstone belts; oceanic metasedimentary rocks, and regionally metamorphosed volcanic rocks. Examples of host rocks are greywacke, chert, shale, and quartzite, alpine-type gabbro, serpentine, and late granitic batholiths.

Depositional environments are typically continental margin mobile belts, and accreted margins. Vein ages generally are post-metamorphic and locally cut granitic rocks. The veins commonly are present in fault and joint systems that are produced by regional compression. Associated deposit types are placer Au–PGE, volcanogenic massive sulfide (VMS), and Homestake-type gold deposits. Mineralogy consists of quartz + native Au + pyrite + galena + sphalerite + chalcopyrite + arsenopyrite ± pyrrhotite. Locally present are telluride minerals ± scheelite ± bismuth ± tetrahedrite ± stibnite ± molybdenite ± fluorite ± fuchsite. Productive quartz is grayish or bluish in many instances because of the fine-grained sulfide minerals in the vein and quartz may contain rehealed breccia and ribbon quartz. Open-space fillings and stylolitic textures also may be common features. Carbonate minerals of Ca, Mg, and Fe may also be abundant.

Orebodies form as saddle reefs, sheets, oblong oreshoots, and locally in wide stockworks. Many textures commonly are destroyed by vein deformation. Alteration consists of quartz + siderite and (or) ankerite + albite in veins with halos of carbonate and montmorillonite alteration. Chromian mica + dolomite and talc + siderite are present in areas of ultramafic rocks. Sericite and disseminated arsenopyrite + rutile in granitic rocks are common. Veins are persistent along regional high-angle faults and joint sets. The best deposits are present in areas with greenstone. High-grade oreshoots locally form along metasediment-serpentine contacts. Disseminated ore bodies form where veins cut granitic rocks. Abundant quartz chips are present in soil. Gold may be recovered from soil by panning. Arsenic usually is the best pathfinder for the deposits, as well as Ag, Pb, Zn, and Cu.

9.1.3 Description of low-sulfide gold-quartz vein tracts

Permissive tracts for undiscovered low-sulfide gold-quartz vein deposits have been delineated on the basis of metamorphosed stratigraphic units that host primary lode deposits and the location of Late Hercinian (Late Paleozoic) deformation (fig. 9.1-1a). The northern most permissive tract, gold01, was delineated mainly in Proterozoic rocks of northern Badakhshan Province, but additional tracts also were delineated in Archean rocks in Badakhshan Province (tract gold04), and in a southern belt of Proterozoic rocks in Takhar, Baghlan, and Parwan Provinces (tract gold02) (fig. 9.1-1). It is likely that most of these occurrences are due to orogenic processes (fig. 9.1-1b). Some Phanerozoic host rocks on the eastern and western sides of the permissive tract gold01 may also include gold-bearing pluton-related deposits of skarn and polymetallic veins. Results of this assessment indicate that the age of the mineralization may be Late Paleozoic as part of fluid that was generated during the Hercinian orogenic event, rather than during Proterozoic events. The presence of Precambrian rocks would then be an indicator of depth. Pluton-related gold deposits associated with porphyry copper systems (tract gold03) are discussed in section 5.2. Gold placer deposit tracts are included in section 10.2 under deposits related to weathering and surficial processes.

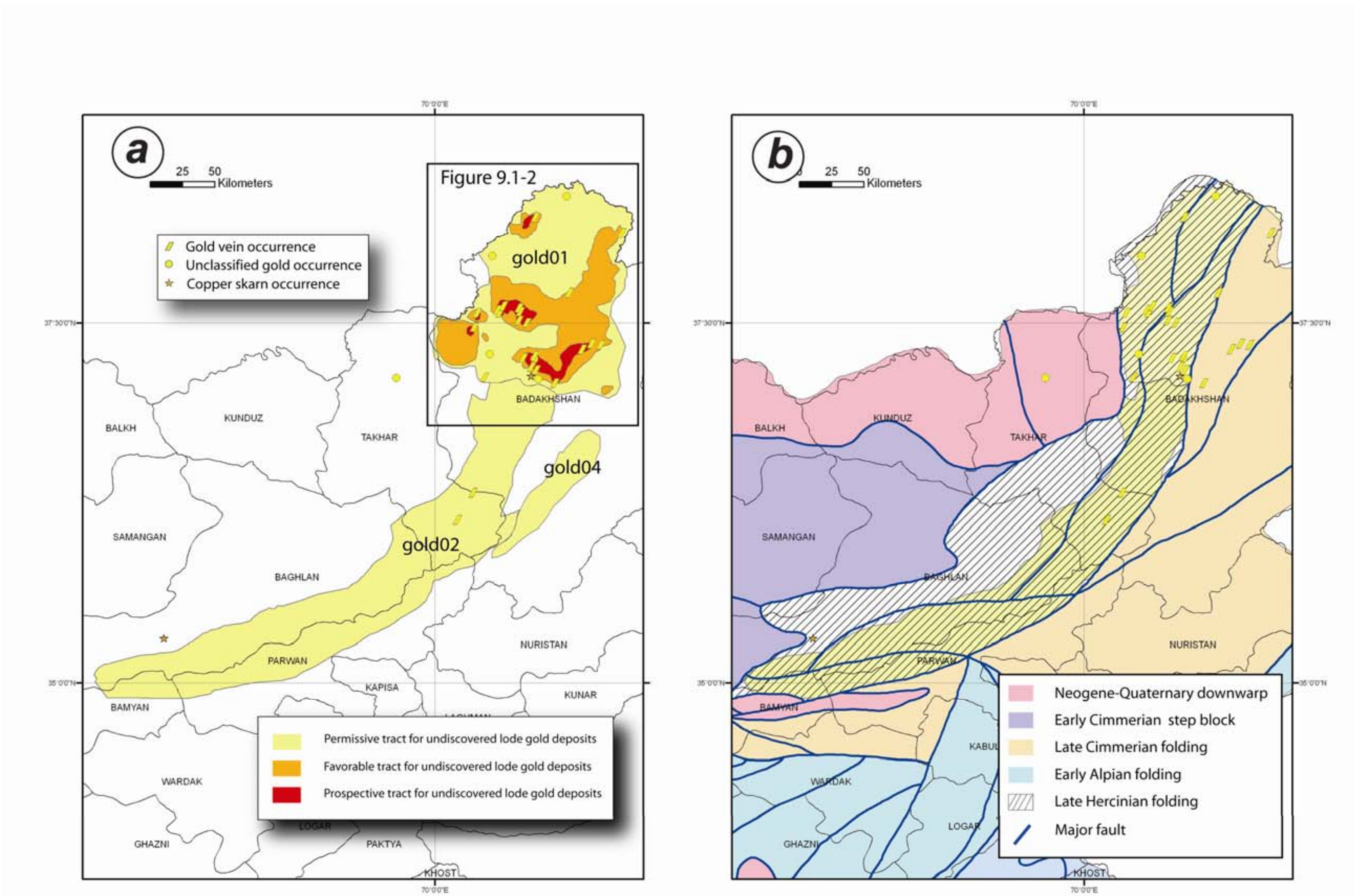

Figure 9.1-1. Map showing location of permissive tracts gold01, gold02, and gold 04 in northern Afghanistan, (*a*) permissive, favorable and prospective tracts for low-sulfide gold vein deposits hosted within areas underlain by PreCambrian rocks discussed in section 9.1. (*b*) Location of tracts. Gold vein tracts superimposed over major tectonic and fault zones in northern Afghanistan. Most of the gold veins are present within a northeast-trending zone of Late Hercinian folding. Note that tract gold03 is discussed in chapter 5.2.

Permissive tract—gold01 Badakhshan

Deposit types—low-sulfide gold-quartz veins, (skarn, and polymetallic veins).

Age of mineralization—Proterozoic to Phanerozoic

Examples of deposit type—A number of gold-quartz veins are located in the tract, including the Shenghan, Kadar, Neshebdur, Rishaw, Vekagur, Chilkonshar, Nakahchir and several unnamed occurrences. Many of these may be due to regional metamorphism.

Exploration history—There is no known extensive exploration for low-sulfide gold-quartz veins in the tract. The area is remote and mountainous. The number of known occurrences and the descriptions of these occurrences testify to some ground prospecting and site visits.

Tract boundary criteria—Tract gold01 was delineated on the basis of the presence of exposed and covered Proterozoic rocks that mainly are Early Proterozoic biotite-amphibolite, garnet-biotite gneiss, migmatite, quartzite, and marble (map units ***Xgn*** and ***X3gn***). The tract was additionally drawn to include the known low-sulfide gold-quartz occurrences and associated deposits in northern Badakhshan Province that are hosted in these or adjacent rocks. The tract also coincides with several gold geochemical halo anomalies derived from stream sediment sampling. The tract contains some Phanerozoic rocks including Siluro-Devonian and Permo-Carboniferous sedimentary rocks and intrusives, as well as Triassic cover rocks, and in the southwest parts, some Tertiary sedimentary and volcanic cover rocks (fig. 9.1-2). The thickness of the cover rocks may exceed 1 km locally and therefore some of the areas of the tract containing these cover rocks may be non-permissive.

A number of favorable and prospective tracts also were delineated in permissive tract gold01. These enclose known gold mineral occurrences and geochemical halo anomalies (fig. 9.1-2). Designation of the favorable and prospective tracts generally follows concepts described in section 1.3. Commonly favorable tracts are broad areas that include favorable host rocks, and geochemical halo anomalies. Prospective tracts are smaller and are roughly equivalent to mining districts and include groups or clusters of known gold occurrences.

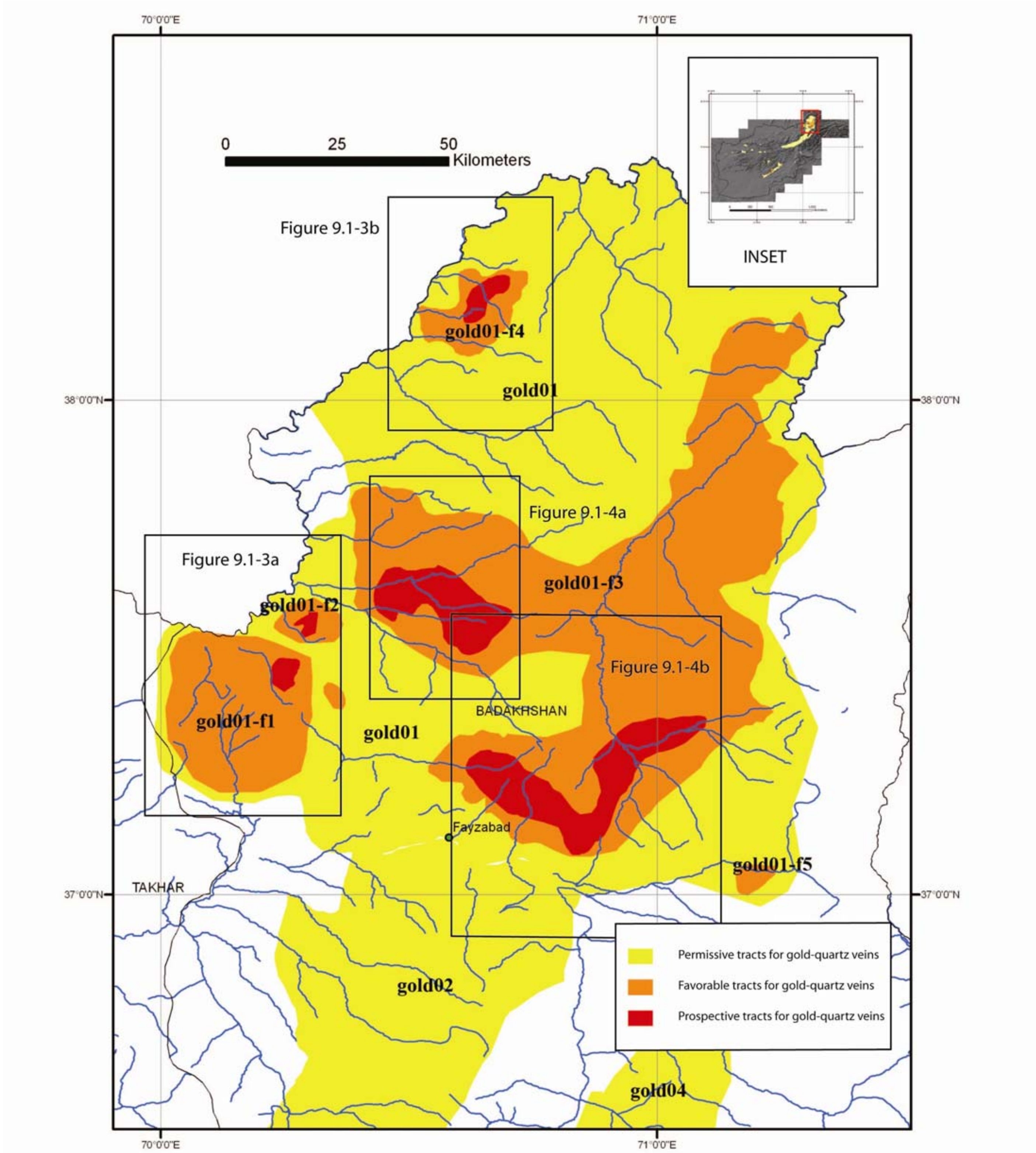

Figure 9.1-2. Map showing location of permissive tract gold01 and favorable and prospective tracts within it in northern Afghanistan in Badakhshan Province. Inset shows the location of the figure and also other lode gold tracts in Afghanistan discussed in chapter 5.2.

Favorable tract gold01-f1

Favorable tract gold01-f1 was delineated on the basis of the presence of a large, circular geochemical halo gold anomaly and contains a prospective tract (*gold01-p1*) that contains the Chilkorshar low-sulfide gold-quartz vein occurrence (fig. 9.1-3a). A number of stream drainages in or proximal to the tract also were deemed as permissive for gold placer deposits within the tract (see section 10.2). This tract, and favorable tracts gold01-f2 and gold01-f4 are hosted within Late Paleozoic volcanic rocks along the western margin of permissive tract gold01 and may therefore could represent a different metallogenic style of gold deposits related to volcanism rather than to regional metamorphism. Coincidently, the volcanism and deformation are both Late Hercinian and therefore these to processes could be linked. Further investigation is recommended by the USGS-AGS assessment team to better understand the age and nature of the genesis of the gold deposits.

Prospective tract gold01-p1 Chilkorshar. The prospective tract gold01-p1 Chilkorshar, was delineated based on proximity to the low-sulfide gold-quartz vein occurrence at Chilkorshar in the north part of the tract and the southern part of the tract was extended to the southwest along the regional tectonic grain (fig. 9.1-3a). The Chilkonshar occurrence is present within a 21 km^2 mineralized area in Lower Carboniferous volcanic rocks in a 285–m-long, 0.2– to 6.5–m-wide fault zone containing about 40 quartz veins. Four of the veins have commercial gold concentrations that average 12.3 to 84.9 g/t gold with speculative resources of about 245 kg gold, averaging 16.1 g/t gold (Semionov and others, 1967).

Favorable tract gold01-f2

Favorable tract gold-f2 lies to the north of the larger favorable tract gold0-f1 within permissive tract gold01 in northern Badakhshan Province and contains the prospective tract Shenghan gold-p2 low-sulfide gold-quartz vein occurrence (fig. 9.1-3a).

Prospective tract gold01-p2 Shengan. Prospective tract gold01-p2 Shenghan was delineated within favorable tract gold01-f2 to include the Shenghan gold-quartz vein occurrence in its northern parts (fig. 9.1-3a). The Shenghan gold occurrence represents gold-bearing quartz showings over an area of 110 km^2. The northern parts of the tract are composed of Lower Carboniferous volcanic rocks and limestone and the southern part contains Early Carboniferous gabbro and diabase plutonic rocks. All the host rocks contain quartz veinlets and veins up to a few decimeters long and a few centimeters to a few meters wide. The largest 25 veins grade 0.1 to 0.4 g/t gold (Guguev, 1967).

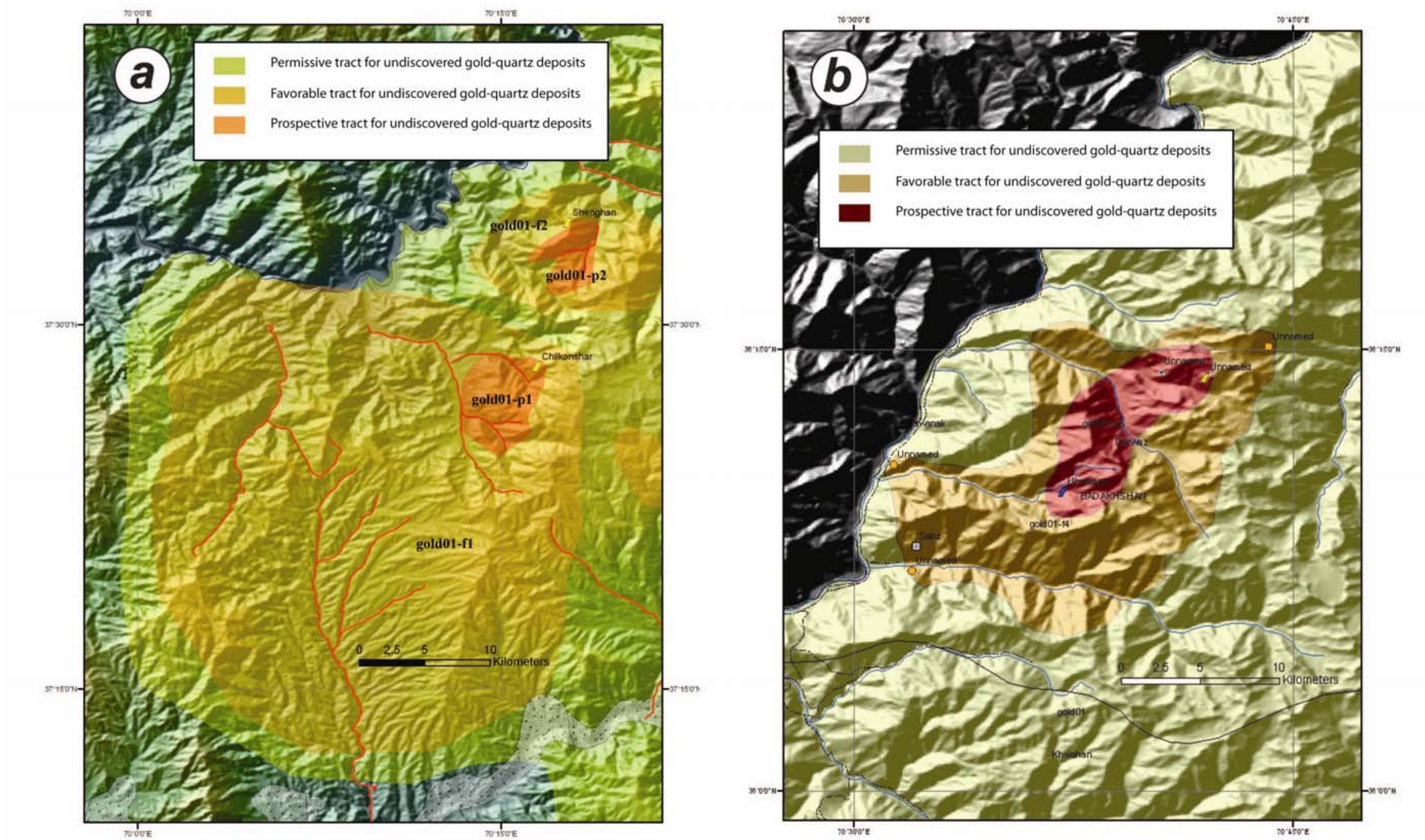

Figure 9.1-3. Maps showing locations of favorable tracts on the western side of permissive tract gold01. (*a*) Favorable tracts gold01-p1 and gold01-p2 in Shahri Buzar and Ragh Districts in Badakhshan Province. (*b*) Favorable tract gold01-f4 and prospective tract gold01-p5 in Darwaz District, Badakhshan Province. These gold occurrences are hosted in Late Paleozoic volcanic rocks and have either a volcanogenic association or may also be related to plutonism rather than to orogenic processes, such as low-sulfide gold-quartz vein deposits.

Favorable tract gold-f3

Favorable tract gold01-f3 was delineated in the central and eastern parts of permissive tract gold01 and contains a number of gold anomalous geochemical halos and a number of low-sulfide gold-quartz vein occurrences in the west and southern parts (fig. 9.1-4a). The favorable tract was draw to encompass known gold geochemical halo anomalies and occurrences within the eastern and central parts of permissive tract gold01. Within favorable tract gold01-f3 two prospective tracts gold01-p3 and gold01-p4 were delineated to enclose similar known low-sulfide gold-quartz vein occurrences.

Prospective tract gold01-p3 Kadar-Neshebdu-Vekadur. Prospective tract gold01-p3 Kadar-Neshebdu-Vekadur was delineated in the western parts of favorable tract gold01-f3 and encloses a number of known low-sulfide gold-quartz vein occurrences (fig. 9.1-4a). These include the Kadar, Neshebdur, Rishaw, and Vekadur occurrences. The Kadar (Kalar) occurrence is hosted in Lower Triassic granodiorite in a 400–m-long, 20– to 70–m-wide shear zone that contains numerous quartz veinlets with disseminated pyrite and chalcopyrite and grades of 0.1 to 1.6 g/t gold. The Neshebdur occurrence is in weathered Proterozoic gneiss and contains three 120– to 360–m-long, 1.5– to 4.0–m-wide quartz veins containing galena, sphalerite, arsenopyrite, pyrite, and chalcopyrite and grades 0.2 to 1.1 g/t gold. The Rishaw occurrence is hosted in Lower Carboniferous marbled limestone and consists of a 400–m-long, 0.6– to 2.3–m-wide quartz vein that grades up to 5 g/t gold (Semionov and others, 1967). The Vekadur occurrence is one of the larger gold occurrences in Afghanistan and is hosted in Proterozoic mica schist and amphibolite that is intruded by diabase dikes and quartz keratophyre. The tabular orebody is 350 m long and 2 m wide and can be traced down dip for 110 m. Mineralization consists of ochreous, brecciated schists containing high gold concentrations along gently and steeply dipping fissures. The brecciated rocks grade 46.7 g/t silver and contain arsenopyrite, galena, chalcopyrite, and scheelite. Calculated resources are 958.3 kg gold averaging 4.1 g/t gold (Nazarov, 1965 and Guguev, 1967).

Prospective tract gold01-p4 Furmorah-Nakhchir-Par. The prospective tract gold01-p4 Furmorah-Nakhchir-Par was delineated in the southeastern parts of favorable tract gold01-f3 and contains a number of unnamed low-sulfide gold-quartz vein occurrences and the Furmorah and Nakahchir-Par occurrences. Unnamed occurrences in the west part of the tract are associated with Lower Triassic granite, or are hosted in shattered, mineralized zones in Proterozoic shale or amphibolite, which typically contain some galena, arsenopyrite, chalcopyrite, and pyrite. These deposits have characteristics similar to pluton-related gold deposits rather than to regional metamorphic deposits. The Furmorah gold occurrence lies proximal to a number of iron skarn occurrences, such as the Syakh Jar and Furmorah iron skarns, and consists of an 80–km^2-size mineralized area along the outer contact between Oligocene granite that intrudes Upper Permian to Upper Triassic sandstone and limestone. Mineralized zones consist of garnetiferous and garnet-magnetite skarn that grade 3.3 g/t gold. Away from the skarn areas, mineralization consists of quartz-sulfide veins grading 0.1 to 2.8 g/t gold and up to 1.0 wt. percent copper, 1 to 3 wt. percent arsenic, 0.1 wt. percent tungsten trioxide and up to 0.5 wt. percent molybdenum (Semionov and others, 1967). The Nakahchir-Par occurrence is hosted in Upper Triassic to Middle Jurassic sandstone in a hornfelsed, silicified zone that is 300 m long containing abundant pyrite, pyrrhotite, chalcopyrite, and 80 cm long lenses of magnetite. The strongest mineralization is in a 25–m-long zone grading 0.4 g/t gold, 0.04 wt. percent copper, and up to 0.06 wt. percent tungsten trioxide (Sborshchikov and others, 1973).

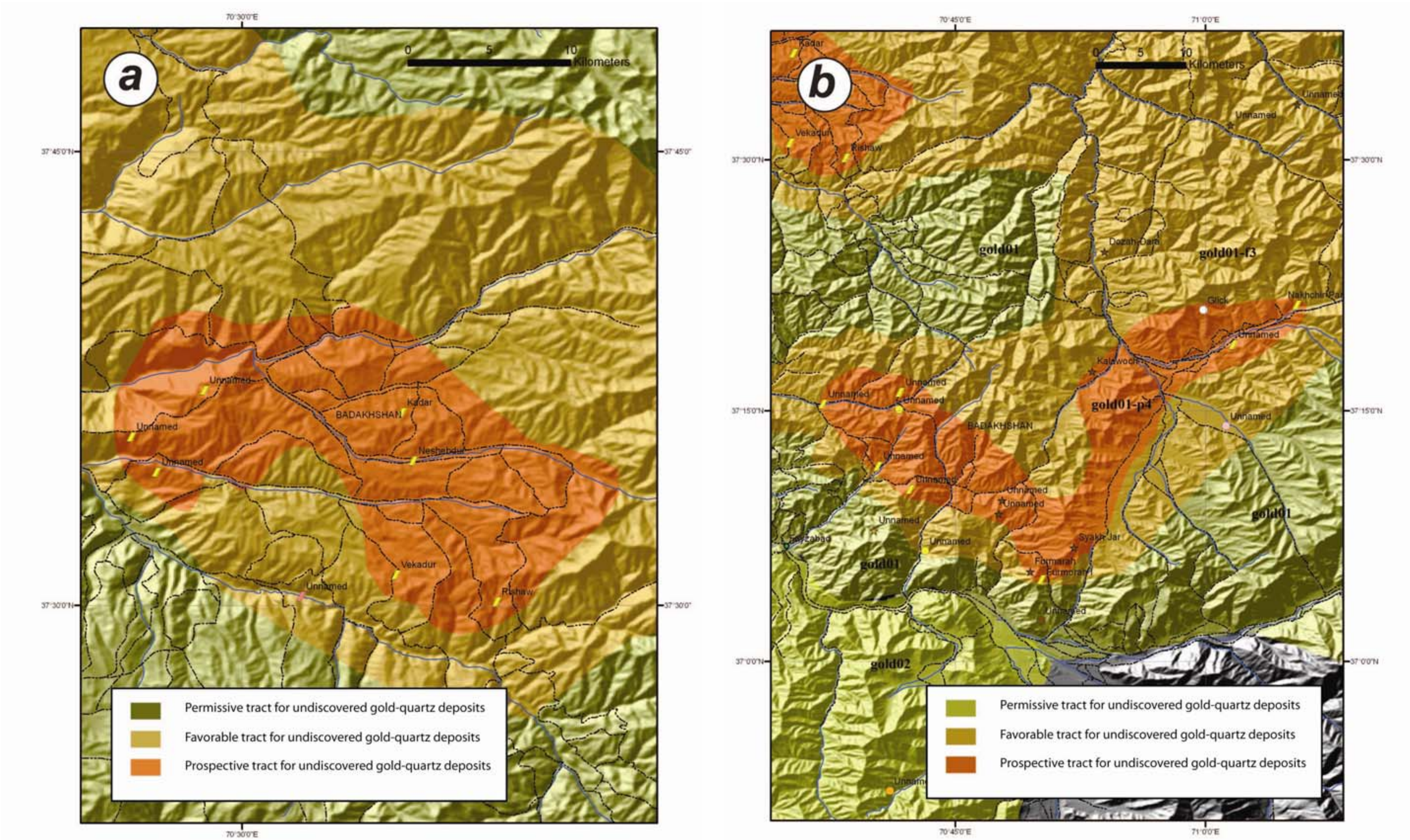

Figure 9.1-4. Maps showing location of prospective tracts gold01-p3 and gold01-p4 in Badakhshan Province, northern Afghanistan that lie in favorable tract gold01-f3. (*a*) Map showing location of prospective tract gold01-p3 in Ragh district containing the Ragh, Kadar, Neshebdur, Vekadur and Rishaw low-sulfide gold-quartz vein deposits. (*b*) Prospective tract gold01-04 containing pluton-related gold occurrences consisting of polymetallic veins and skarns in the Fayz Abad and Baharak Districts. Low-sulfide gold-quartz veins may not be present in gold01-p4.

Favorable tract gold01-f4.

Favorable tract gold01-f4 was delineated in the far northwest part of permissive tract gold01 in Badakhshan Province in Darwaz District. The tract was delineated to encompass most of a gold geochemical halo gold anomalous zone and several unnamed gold-quartz vein occurrences. Prospective tract gold01-p5 was also delineated in the northern parts of the favorable tract to include two of the main unnamed quartz vein occurrences (fig. 9.1-3b). These occurrences are hosted in volcanic rocks and may be similar to those in gold01-f1a and gold01-f2.

***Needs to improve assessment*—**Metallogeny and origin of these deposits also need to be determined.

***Optimistic factors*—**There are a number of gold occurrences and geochemical halo anomalies present and the area is remote and probably has not been well prospected.

***Pessimistic factors*—**The deposits seem to fit a number of deposit models and may not all be low-sulfide gold-quartz vein deposits, which makes the permissive tract difficult to assess.

***Quantitative assessment*—**No quantitative assessment was made, due to the lack of information regarding the deposits models and the geology.

Permissive tract—gold02 Pusida

***Deposit types*—**low-sulfide gold quartz veins

***Age of mineralization*—**Proterozoic to Phanerozoic

***Examples of deposit type*—**The Pusida gold occurrence and an unnamed occurrence are in the tract

***Exploration history*—**Much of the tract, especially the southern part has been explored geochemically. The area is remote and mountainous and therefore the exploration probably was not thorough.

Tract boundary criteria*—**The tract was delineated along outcrops of Proterozoic rocks in the southern part of the tract (units ***X1gn and ***X3gn***) that are intruded by Triassic granitoids (mainly map units ***Tgdg*** and ***T1gr***) and locally are overlain by Siluro-Devonian and Permo-Carboniferous sedimentary and volcanic rocks (mainly map units ***SDld, P1sls*** and ***C_2ls***). The tract also encompasses two gold occurrences, including the Pusida gold vein—in its center parts in Warsaj District, Takhar Province—and a number of gold geochemical halo anomalies (fig. 9.1-5).

The Pusida gold vein is hosted in Proterozoic schist, amphibolite, and gneiss in 150–m-long, 0.5– to 3.0–m-wide (locally up to 20 m wide) shear zones that contain quartz veins and grade 0.1 to 1.1 g/t gold and up to 3 g/t gold in small shear zones (Kolchanov and others, 1967).

***Needs to improve assessment*—**The Pusida and the unnamed gold occurrences should be visited and mapped. The source of gold in the remainder of the tract should be investigated.

***Optimistic factors*—**The tract coincides with a number of gold-rich geochemical anomalies and has similar geologic features to the gold01 permissive tract in the north. The two gold occurrences indicate that gold-mineralizing events have taken place in the tract.

***Pessimistic factors*—**The gold occurrences are sparse and not high grade or large and there is not a clear description of the occurrences that can fit them or classify them into a known mineral deposit model.

***Quantitative assessment*—**No quantitative assessment was attempted because the deposit model was not well defined and there was little information to assure that the deposits might be present throughout the tract.

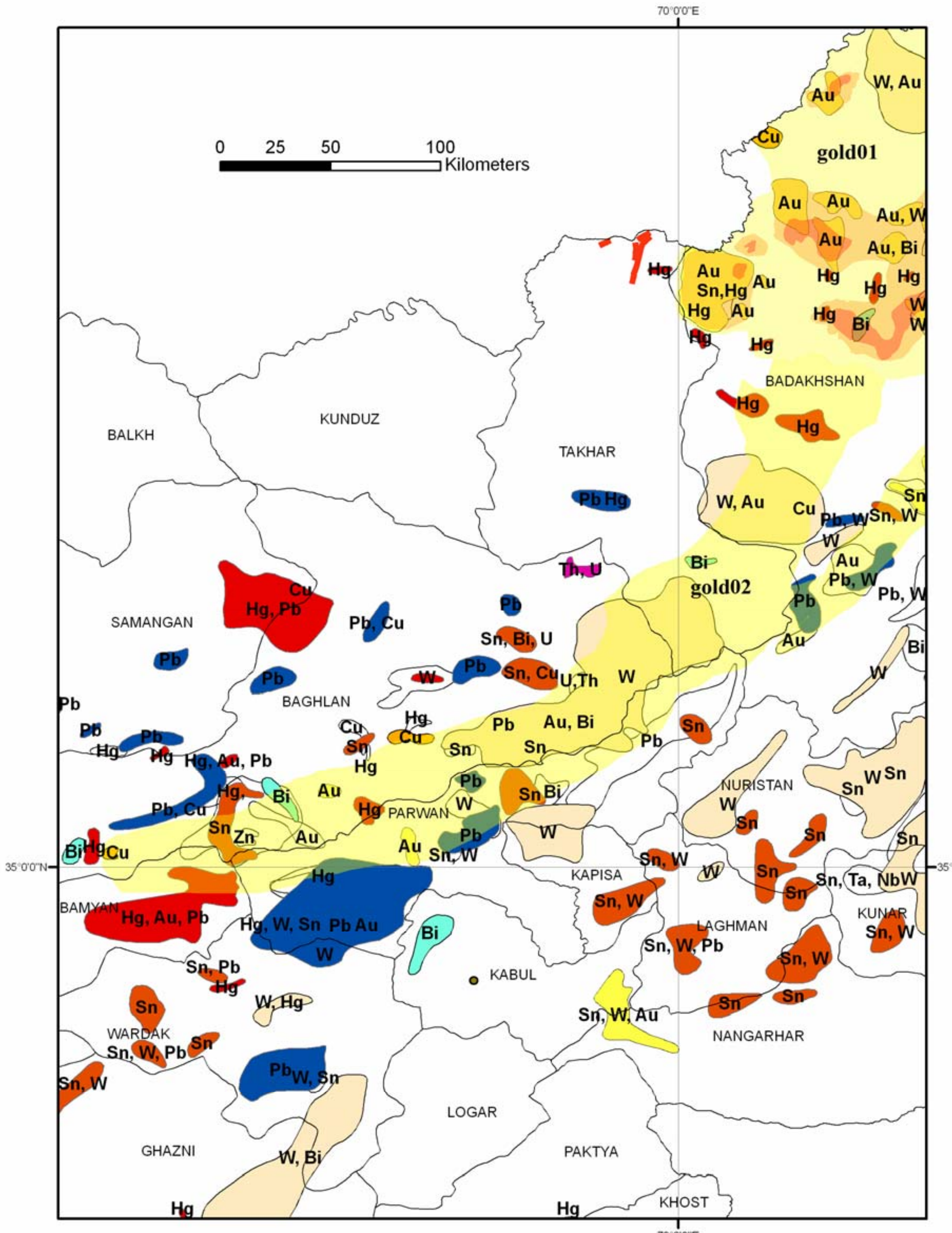

Figure 9.1-5. Map showing location of permissive tract gold02 (light yellow) and location of numerous gold halo mineral-geochemical anomalies within and adjacent to the tract. The tract is permissive for undiscovered low-sulfide gold-quartz vein deposits.

(Note: Permissive tract gold03 is discussed in section 5.2 under pluton-related gold)

Permissive tract—gold04 Archean

Deposit types—low-sulfide gold-quartz veins

Age of mineralization—Archean(?)

Examples of deposit type—None, although a number of gold-rich geochemical anomalies are present.

Exploration history—No known significant exploration has taken place in the tract, although a number of geochemical halo anomalies and some mineral occurrences in the east central parts indicate that ground prospecting has taken place in the tract.

Tract boundary criteria—A 100–km-long, 20–km-wide permissive tract gold04 was delineated in northern Badakhshan Province and Jurm and Kuran Wa Mun Districts along a northeast-trending zone in Archean bed rock (map units ***Vgn*** and ***Wgn***) consisting of Late and Meso Archean biotite-garnet, sillimanite-biotite, and amphibolite gneiss, including local marble and quartzite. The zone is marked by a number of gold-rich geochemical halo anomalies and a few lead and tin anomalies. An unnamed polymetallic vein is present in the east central part of the tract that is composed of mineralized quartz veinlets containing galena and hematite. Because many low-sulfide gold-quartz veins are associated with Archean rocks, this separate tract was delineated in these older rocks.

Needs to improve assessment—There is little information available about this area and therefore the tract should be visited and prospected for gold.

Optimistic factors—Archean rocks are known to be productive hosts for gold-quartz veins world wide. There are a number of gold-rich geochemical halo anomalies in the tract.

Pessimistic factors—No known gold occurrences are present.

Quantitative assessment—No assessment was performed due to lack of data.

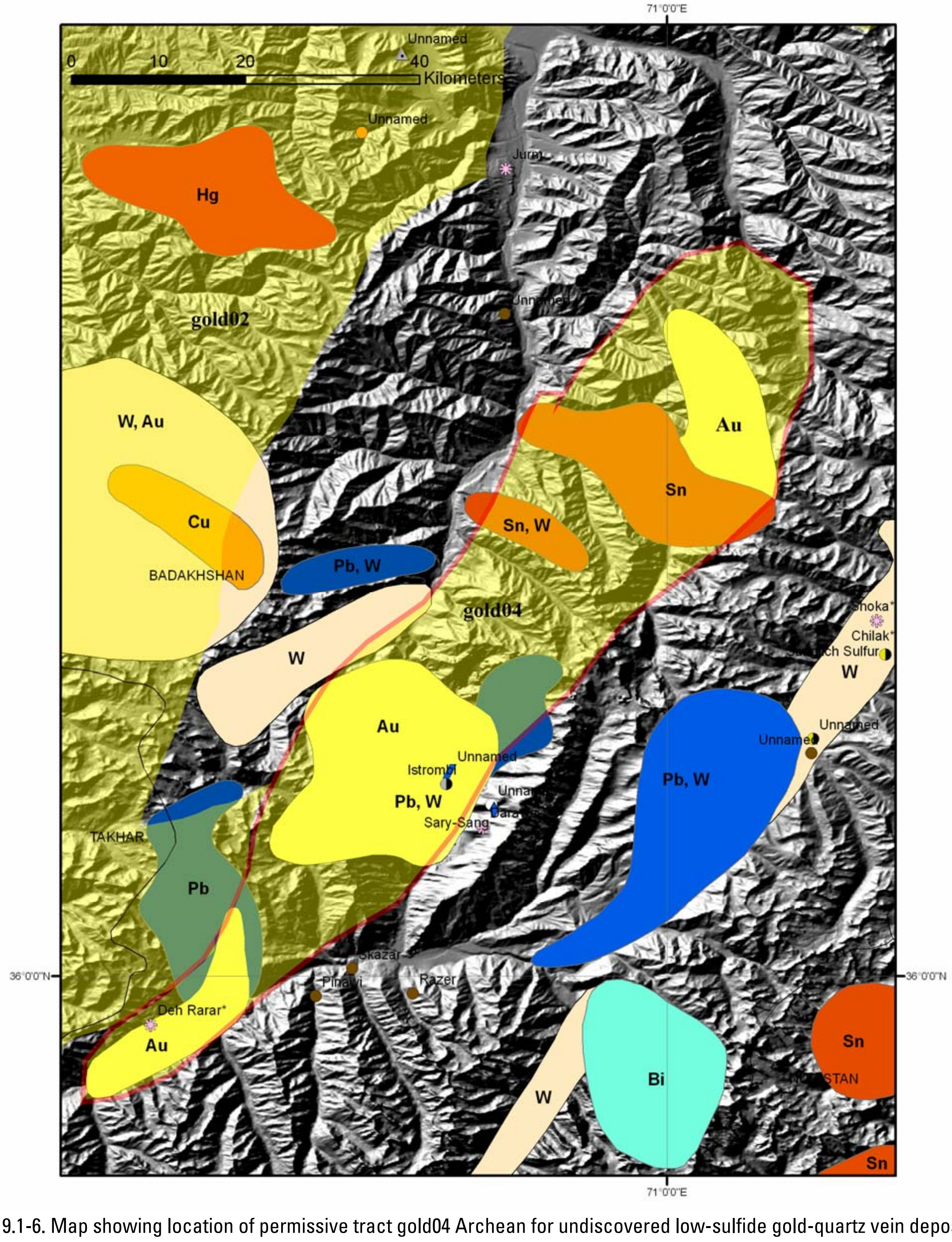

Figure 9.1-6. Map showing location of permissive tract gold04 Archean for undiscovered low-sulfide gold-quartz vein deposits in Badakhshan Province and location of geochemical mineral halo anomalies.

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9.2 Natural Graphite

Contributions by David M. Sutphin and Walter J. Bawiec.

Graphite is one of the most common allotropes of carbon; diamond is another. At room temperature and atmospheric pressure, it is the most stable form of carbon known (*http://www.chem.wisc.edu/~newtrad/CurrRef/BDGTopic/BDGtext/BDGDmnd.html*). Graphite occurs as a mineral (natural graphite), but it can be produced synthetically. It has important properties such as chemical inertness, low thermal expansion, and lubricity that make it almost irreplaceable for certain uses in steelmaking and refractories (Krauss and others, 1988). Natural graphite has many other industrial applications including in batteries, brake linings, crucibles for handling molten metals, lubricants, and powdered metals. In 2005, China accounted for almost 70 percent of the world's annual reported natural graphite production, and India accounted for another 12 percent (Olson, 2006).

There are two types of natural graphite, either crystalline (which is of two varieties, flake or lump graphite) or microcrystalline (known commercially as amorphous graphite). They are found in three metamorphic environments. Flake graphite forms in syngenetic metasediments; lump graphite is found in epigenetic veins in high-grade metamorphic regions; and microcrystalline graphite is the product of contact metamorphosed coal (Krauss and others, 1988).

Identified graphite resources for Afghanistan are quite small (Abdullah and others, 1977; ESCAP, 1995), even though the country has large areas of ancient high-grade metamorphic rocks permissive for the occurrence of such deposits. This scarcity of graphite resources may be due in part to a lack of modern exploration, but is more likely that the large amounts of organic carbonaceous material required to form graphite deposits were not preserved in the original sedimentary rocks and therefore, only limited amounts of graphite were produced by subsequent metamorphism. The potential for significant undiscovered graphite resources in Afghanistan is not high. Future discoveries, however, may provide graphite in locally significant quantities. As far as can be determined from historical data, Afghanistan has never been a significant producer of natural graphite of any type.

There are six identified natural graphite occurrences in the database of mineral occurrences of Afghanistan (figure 9.2.1) (Orris and Bliss, 2002; Bowersox and Chamberlin, 1995; Abdullah and others, 1977). Four of these (Khawri, Sanglich, Shahkabul, and Yagh-Darra) are disseminated flake occurrences; the description of another occurrence (Istrombi), citing assays of 50 to 69 graphite percent, suggests it is a disseminated flake deposit with a vein-type component or a vein-type graphite occurrence. The final occurrence (Charkh) contains microcrystalline graphite (Orris and Bliss, 2002; Abdullah and others, 1977). The locations of the known graphite occurrences in Afghanistan are shown in figure 9.2.1.

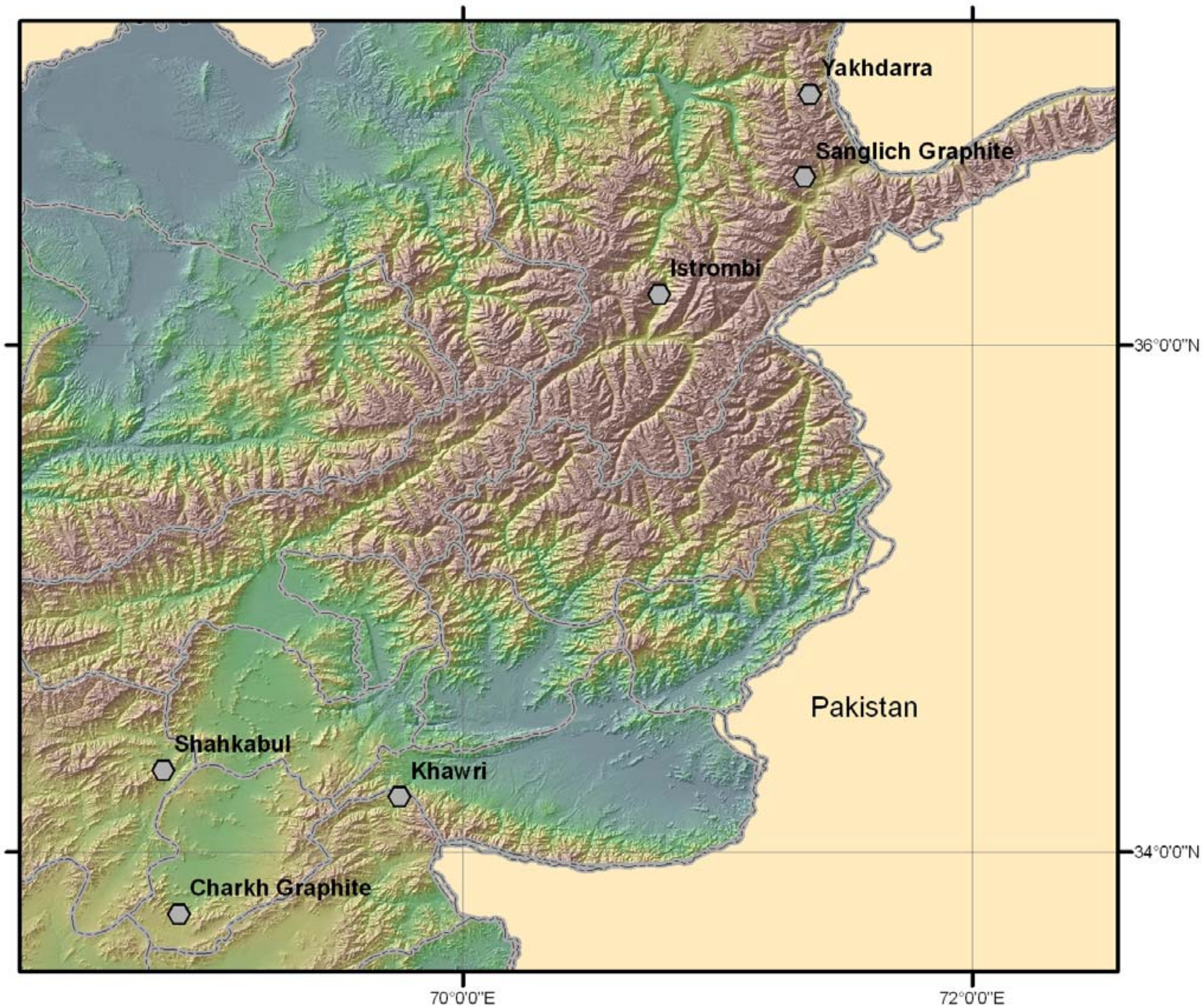

Figure 9.2-1 Locations of the six known graphite occurrences (grey circle) in Afghanistan.

9.2.1 Description of Graphite Deposit Descriptive Models

Graphite occurs in nature in several forms that are concisely summarized in Rakovan and Jaszczak (2002). As noted above, the three forms of natural graphite, disseminated flake, lump, and microcrystalline, form in different metamorphic environments. Economically significant concentrations of flake graphite are found in metamorphic rocks such as marbles, schists, and gneisses; microcrystalline graphite is found in graphitized masses formed through solid-state transformation of carbonaceous sediments that are usually rich in organics; and lump graphite occurs in veins as epigenetic precipitations from C-O-H fluids in metamorphic and igneous rocks. These different metamorphic environments where natural graphite forms were the basis for the development of three graphite mineral deposit models, all of which are relevant for graphite deposits in Afghanistan: disseminated (or crystalline) flake graphite (model 37f, Sutphin, 1991a; Sutphin and Bliss, 1900), microcrystalline (or amorphous) graphite (model 37k, Sutphin, 1991b), and vein graphite (Sutphin, 1991c).

Disseminated flake graphite deposits develop syngenetically from the metamorphism of precursor naturally occurring organic carbonaceous material in sedimentary rocks that have been subjected to garnet grade or higher regional metamorphism at temperatures from 300 °C to 1,200 °C (Weiss and others, 1981). These deposits are commonly hosted by porphyroblastic and granoblastic marble, paragneiss, and quartzite. Alumina-rich paragneisses and marbles in upper amphibolite or granulite-grade metamorphic terrains are the most favorable host rocks. Clinopyroxenites, amphibolite, quartzite, and pegmatite may also host disseminated graphite deposits (Simandl, and Kenan, 1997a and b). These deposits form when the original detrital organic material is graphitized during regional metamorphism of the host shales, sandstones, and limestones deposited in paleo-environments favorable for the accumulation and preservation of organic materials.

Highest flake graphite grades are commonly associated with rocks located at the contacts between marbles and paragneiss and deposits are thickest within fold hinges. Minor feldspathic intrusions and iron formations also contain disseminated flake graphite (Simandl and Kenan, 1997a and b). Associated rock types include granite intrusives, aplite, orthogneiss, and charnockite. Grade and tonnage of producing mines and developed prospects varies substantially. In Afghanistan, local natural disseminated graphite occurrences are mostly found in Archean age high-grade metamorphic rocks (Istrombi, Sanglich, and Yagh-Darra) or in Proterozoic marble (Shahkabul).

Bliss and Sutphin (1992a) determined that the median grade and tonnage of disseminated flake deposits are 9.0 vol. percent and 240,000 metric tons, respectively. Depending on market conditions, large deposits containing high proportions of coarse flakes, which can be easily liberated, may be economic with grades as low as 4 vol. percent. The deposits typically are stratabound and consist of individual beds or lenses that range up to 30 m thick with lengths to 2 km or longer. They may be any age, but are commonly Archean to late Proterozoic metamorphosed continental margin or intercratonic basinal sediments. Vein graphite deposits may be associated with disseminated flake graphite deposits.

Vein graphite deposits are epigenetic deposits that form in relatively deep, high-grade metamorphic environments associated with igneous activity; these are conditions that are common on the continental shield (Simandl and Kenan, 1997b). They are a deposit type associated with disseminated flake graphite deposits. These deposits may be lenses, pods, dikes, vugs, or veins (Sutphin, 1991b). The veins may be as much as 3 m thick and extend for several hundred meters. They are hosted in many of the same rocks types as flake graphite deposits, such as paragneiss, quartzite, and clinopyroxenite, and also wollastonite-rich rocks and pegmatites. Sri Lanka is famous for its vein graphite deposits that are a consequence of granulite facies metamorphism (Katz, 1987). There is no grade and tonnage model for vein graphite deposits, but the typically contain 40 to 90 percent fixed carbon before hand sorting. The origin of vein-type graphite deposits in places such as Sri Lanka was for a long time controversial (Weis and others, 1981; Dissanayake, 1994). Rumble and others (1986a and b`) provide evidence for the formation of vein graphite deposits by hydrothermal processes. This occurs when solutions containing CO_2 and methane (CH_4) from biogenic material and from the decomposition of carbonaceous sediments precipitate carbon in the form of graphite upon mixing with fluids having different CO_2/CH_4 ratios. There is no grade and tonnage model for vein graphite deposits.

Microcrystalline (amorphous or cryptocrystalline) graphite deposits are formed by the contact metamorphism of coal beds or other highly carbonaceous sediments by nearby intrusions. Coal is graphitized producing dull black, earthy microcrystalline graphite that may or may not be recognizable as having previously been coal. Intrusives may be cross-cutting diabasic or granitic dikes or adjacent sills. Host rocks are usually quartzites, phyllites, metagraywackes, and conglomerates. The tectonostratigraphic setting of microcrystalline graphite deposits is a commonly continental margin or intercratonic basinal sediments having coal seams or other highly carbonaceous sedimentary beds that have been metamorphosed by nearby igneous intrusions or by regional metamorphism. Faulting and folding may control the amount of graphitization. These deposits generally range in age from Mississippian to Cretaceous, but may be younger. Areas to prospect are those in which such highly carbonaceous beds have been cut by intrusion(s) or subjected to regional metamorphism (Sutphin, 1991c). Charkh, the one provisionally identified microcrystalline graphite occurrence in Afghanistan, is said to be located in Proterozoic formations adjacent to an Oligocene granitic intrusion into Permian sedimentary rocks (Abdullah and others, 1977; Orris and Bliss, 2002). Deposits may consist of several beds each a few meters thick and be several miles in length and width. Size and grade of these deposits are dependent on the characteristics of the original coal seams and sediments. Bliss and Sutphin (1992b) showed that microcrystalline graphite deposits have a median size of 130 thousand metric tons and a median grade of 46 percent. Major mines often contain more than 80 vol. percent graphitic carbon, and the largest deposits may contain more than 10 million metric tons of ore-grade material. The unit value of microcrystalline graphite can be as little as 10 percent of that of coarsely crystalline flake graphite (Worldwide Producers, Ltd., 2006).

9.2.2 Description of Graphite Assessment Tracts

Tracts permissive for the occurrence of undiscovered graphite deposits were delineated in northeastern Afghanistan. Tract dvg01 was delineated in Archean age high-grade metamorphic rocks and tract dvg02 was delineated in Middle Proterozoic to Cambrian age high grade metamorphic rocks for disseminated flake and vein graphite. Tract mcg01 was delineated in zones of contact metamorphism for microcrystalline (amorphous) graphite.

Permissive tracts

Permissive tracts for both disseminated and vein graphite deposits were chosen mainly on the basis of the rock descriptions accompanying the geologic map. Low-grade metamorphosed limestones, dolomites, marble, quartzite, metasandstone, and mica schists of the Arghandab Tectonic Zone and the Kabul Massif of so-called Vendian complex to Cambrian age are chosen as permissive for these types of deposits. Within these low-grade metamorphic rocks are often interbedded schists gneiss, marble, and amphibolites where precursor organic material may have been graphitized. There is one reported graphite deposit, Shahkabul, which is said to occur in middle Proterozoic rocks described as green schist, gneiss, quartzite, marble, and amphibolite (Abdullah and others, 1977; Orris and Bliss, 2002). Areas of interest for hypothetical occurrences of microcrystalline graphite are discussed at the end of this chapter.

Tract ID: dvg01—Natural graphite in Archean age high-grade metamorphic rocks

Deposit type—Disseminated flake and vein graphite

Age of mineralization—Archean

Examples of deposit type— There are three identified natural graphite occurrences in tract dvg01 (Orris and Bliss, 2002; Abdullah and others, 1977). From their descriptions, two of these (Sanglich and Yagh-Darra) are disseminated flake occurrences; the description of Istrombi, citing assays of 50 to 69 graphite percent, suggests it is a disseminated flake deposit with additional vein-type mineralization or a vein-type graphite occurrence.

At the Sanglich graphite occurrence in Badakhshan Province, Archean metamorphosed crystalline schist and gneiss contains a high-grade graphite lens 50 m long and > 5 m thick with occasional large white quartz crystals. Speculative resources are 5,000 metric tons graphite (Abdulla and others, 1977 from manuscript by Sultan Ahmed Popol written in 1945). The Yagh-Darra graphite occurrence in Badakhshan Province is located in Archean gneiss as a flaky, densely disseminated graphite zone 200 to 250 m long and 10 m thick (Denikaev and others, 1973). Istrombi graphite occurrence in Badakhshan Province manifests as graphite lenses 40 to 50 m long and as much as 10 m thick, with microcrystalline graphite in isolated nests and veinlets assaying 50 to 69 vol. percent graphite with accessory hematite, iron oxide minerals, and quartz (Mayorov and others, 1965). The graphite occurs in dolomitized marble and calciphyre within rocks mapped as Middle Archean biotite-garnet gneiss, amphibole, marble, and quartzite. Istrombi appears to be a vein graphite deposit having microcrystalline graphite in Archean marble.

Exploration history—There is no reported exploration in this remote and rugged glaciated area, however, there are three reported graphite deposits in Archean rocks in this tract.

Tract boundary criteria—Tract dvg01 is defined by the presence of metamorphic rocks of Archean age.

Important data sources—Geologic map, mineral deposit database (Doebrich and Wahl, 2006; Orris and Bliss, 2002; Abdullah and others, 1977).

Needs to improve assessment— Tract dvg01 needs field examination and detailed mapping by someone experienced in the geology of graphite mineral deposits and exploration. It also needs geophysics, such as AMT, that exploits the electrical conductivity of natural graphite deposits. Sampling of stream sediments may indicate the presence of graphite flakes and assist in locating deposits.

Optimistic factors—The presence of rock of Archean age high-grade metamorphic rocks is very positive. Elsewhere in the world, these types of rocks contain graphite deposits. The presence of three known graphite occurrences in the tract is also very positive. The remoteness and rugged terrain may mean that the tract is mostly unexplored.

Pessimistic factors—Tract dvg01 is very remote, in rugged terrain, and the climate may be uninviting. The known occurrences are small and are not well known. Natural disseminated flake graphite is a high-volume/low-value commodity with a low priority for exploration money.

Quantitative assessment—Estimates of undiscovered disseminated flake graphite deposits in tract dvg01 were made by the team of experienced mineral resource assessors.

Table 9.2-1. Probability estimates of undiscovered disseminated flake graphite deposits in tract dvg01.

	Probability			
Estimator	**90 %**	**50 %**	**10%**	**Total**
1	0	0	5	1.500
2	0	1	10	3.400
3	0	2	10	3.800

4	0	2	10	3.800
5	0	2	12	4.400
Consensus	0	2	10	3.800

The figures in table 9.21-1 show that the geoscientists' estimates varied from as few as 1.5 deposits to 4.4 deposits, a factor of about 2.9. For the natural graphite in Archean age high-grade metamorphic rocks tract (dvg01), the assessment team found that there is a 90 percent chance of 0 or more undiscovered disseminated flake graphite deposits, a 50 percent chance of 2 or more, and a 10 percent chance of 10 or more. Consensus estimates were not made at the 5 percent or 1 percent probability levels. The estimate is subjective and is based on expert opinion and analogy with geologically similar well-explored areas in other parts of the world. This estimate results in a mean estimate of 3.800 undiscovered deposits. These estimates were used to generate probabilistic estimates of the amounts of chromite and rare-earth elements contained in the undiscovered deposits using Monte Carlo simulation (see section 1.3). The results are tabulated in table 9.2-2 and shown graphically in figures 9.2.3, and 4.

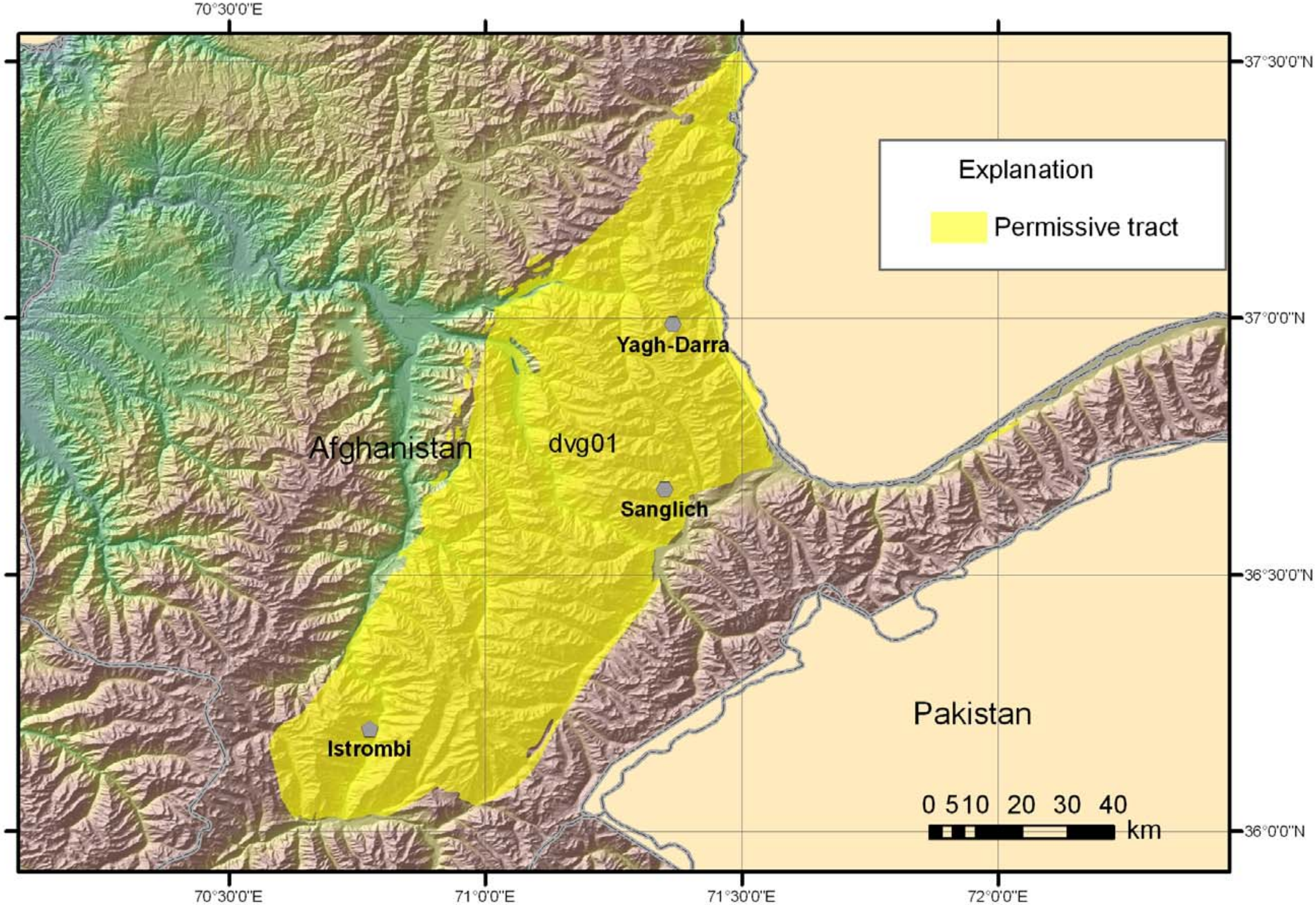

Figure 9.2-2. Map showing location of tract dvg01, which is permissive for the occurrence of disseminated flake and vein graphite deposits in Archean age metamorphic rocks in Afghanistan.

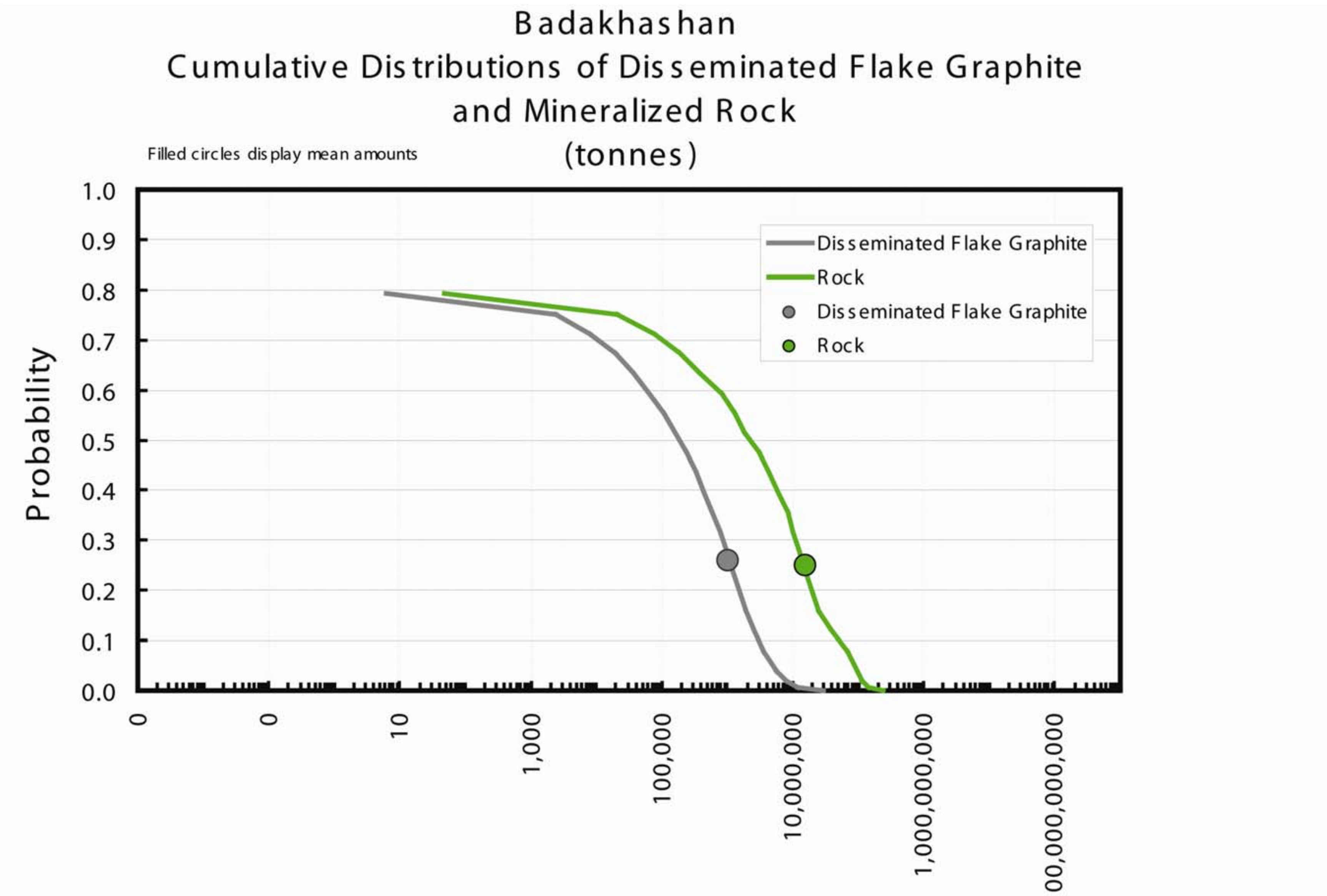

Figure 9.2-3. Cumulative distributions for flake graphite and rocks for the probabilistic estimates of the Badakhshan Archean permissive tract.

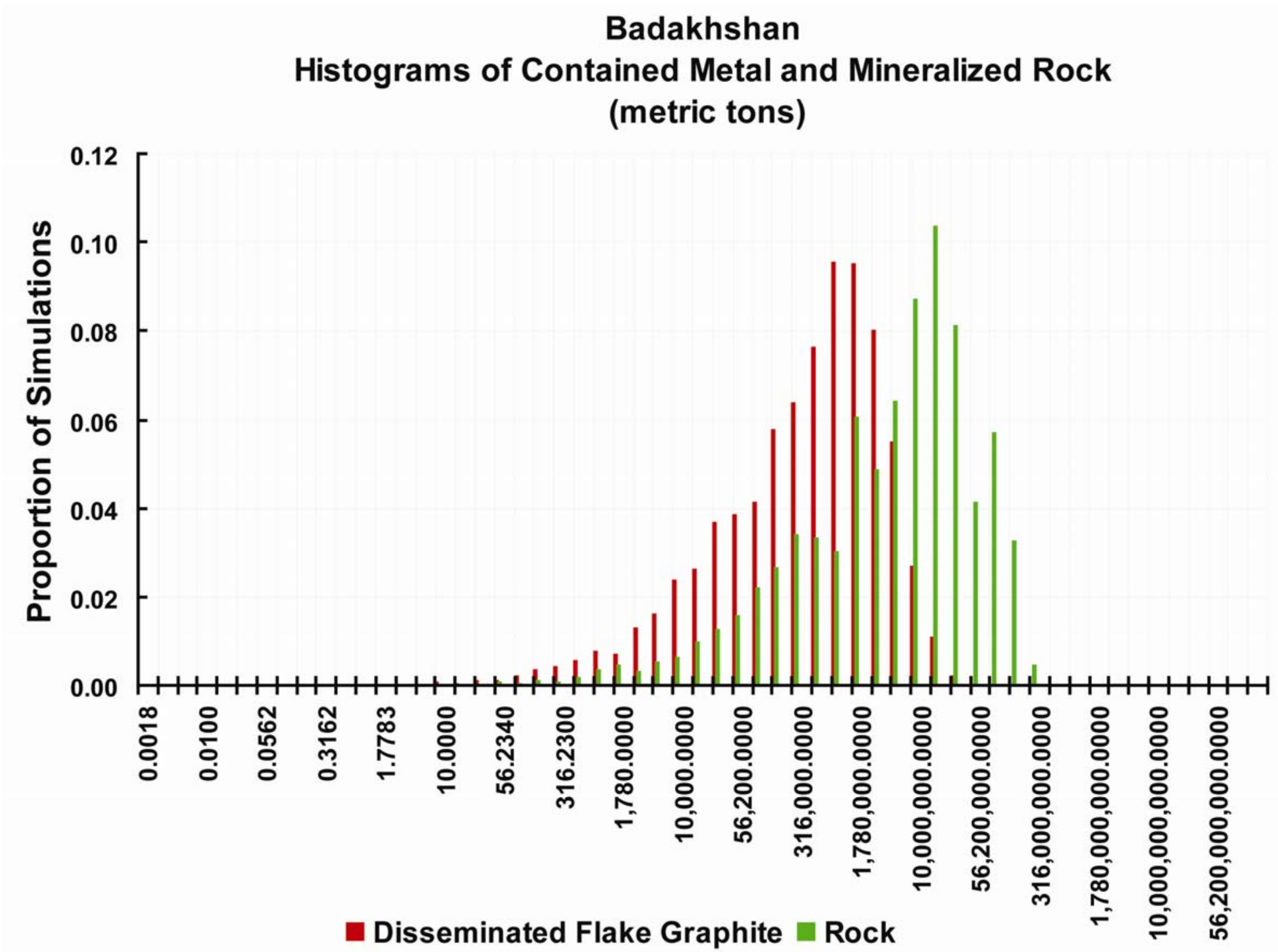

Figure 9.2-4. Histograms of estimated contained flake graphite and mineralized rock for undiscovered disseminated flake graphite deposits for the probabilistic estimate for the Badakhshan Archean disseminated flake graphite tract

Table 9.2-2. Table showing probabilistic distribution of contained metal and mineralized rock for undiscovered disseminated flake graphite deposits for the probabilistic estimates of the Badakhshan Archean permissive tract.

There is a 90 percent or greater chance of 0 or more deposits.
There is a 50 percent or greater chance of 2 or more deposits.
There is a 10 percent or greater chance of 10 or more deposits.

Quantile	Disseminated flake graphite (tonnes)	Rock (tonnes)
0.95	0	0
0.90	0	0
0.50	190,000	2,300,000
0.10	3,100,000	53,000,000
0.05	4,900,000	90,000,000
mean	1,100,000	15,000,000
Probability of mean	0.26	0.25
Probability of zero	0.21	0.21

Tract ID: dvg02— Natural graphite in Middle Proterozoic to Cambrian age high-grade metamorphic rocks

Deposit type**—**Disseminated flake and vein graphite

Age of mineralization**—**Early Proterozoic to Cambrian

Examples of deposit type**—**The Khawri graphite occurrence in Paktia Province about 75 km ESE of Kabul (figure 9.2.3) is in graphite-bearing quartzite and marble, which contains as much as 2 vol. percent scabby (flake) graphite. The graphite-bearing formations lie within other Proterozoic metamorphic rocks (Denikaev and others, 1971. 1973). From the description, Khawri is a low-grade disseminated flake deposit.

Exploration history**—**There is no information on the exploration history of this tract, however the presence of the Khawri occurrence is evidence of at least previous rudimentary exploration. Surface rocks near Kabul and other population centers have probably received significant surface exploration.

Tract boundary criteria**—**Presence of regionally metamorphosed high-grade metamorphic rocks of Early Proterozoic age including varieties of gneiss, amphibolite, marble, migmatite, quartzite, and various schists. These high grade rocks form in a metamorphic environment favorable for creation of undiscovered disseminated flake or vein graphite mineralization.

Important data sources**—**Geologic map, mineral deposit database (Doebrich and Wahl, 2006; Orris and Bliss, 2002; Abdullah and others, 1977).

Needs to improve assessment**—**Large-scale geologic map, geophysics, such as AMT, that exploits the electrical conductivity of natural graphite deposits. Stream-sediment mineral surveys identify residual detrital graphite flakes in pan samples.

Optimistic factors**—**The presence of ancient high-grade metamorphic rocks such as amphibolite gneiss, marble, migmatite, quartzite, and schist, that have an identified flake graphite occurrence is very positive, because elsewhere in the world these types of rocks contain graphite deposits. The remoteness of much of the tract and ruggedness of the terrain may mean that much of the tract is lightly explored. That the Khawri occurrence is 1.5 m thick and > 1 km long may indicate a significant graphite resource.

Pessimistic factors**—**Parts of tract dvg02 are remote, in rugged terrain, and the climate may be uninviting. The Khawri occurrence is low grade for a flake graphite deposit. Natural disseminated flake graphite is a high-volume/low-value commodity with a low priority for exploration money.

Quantitative assessment**—**No estimate of the numbers of undiscovered disseminated flake graphite deposits was done,

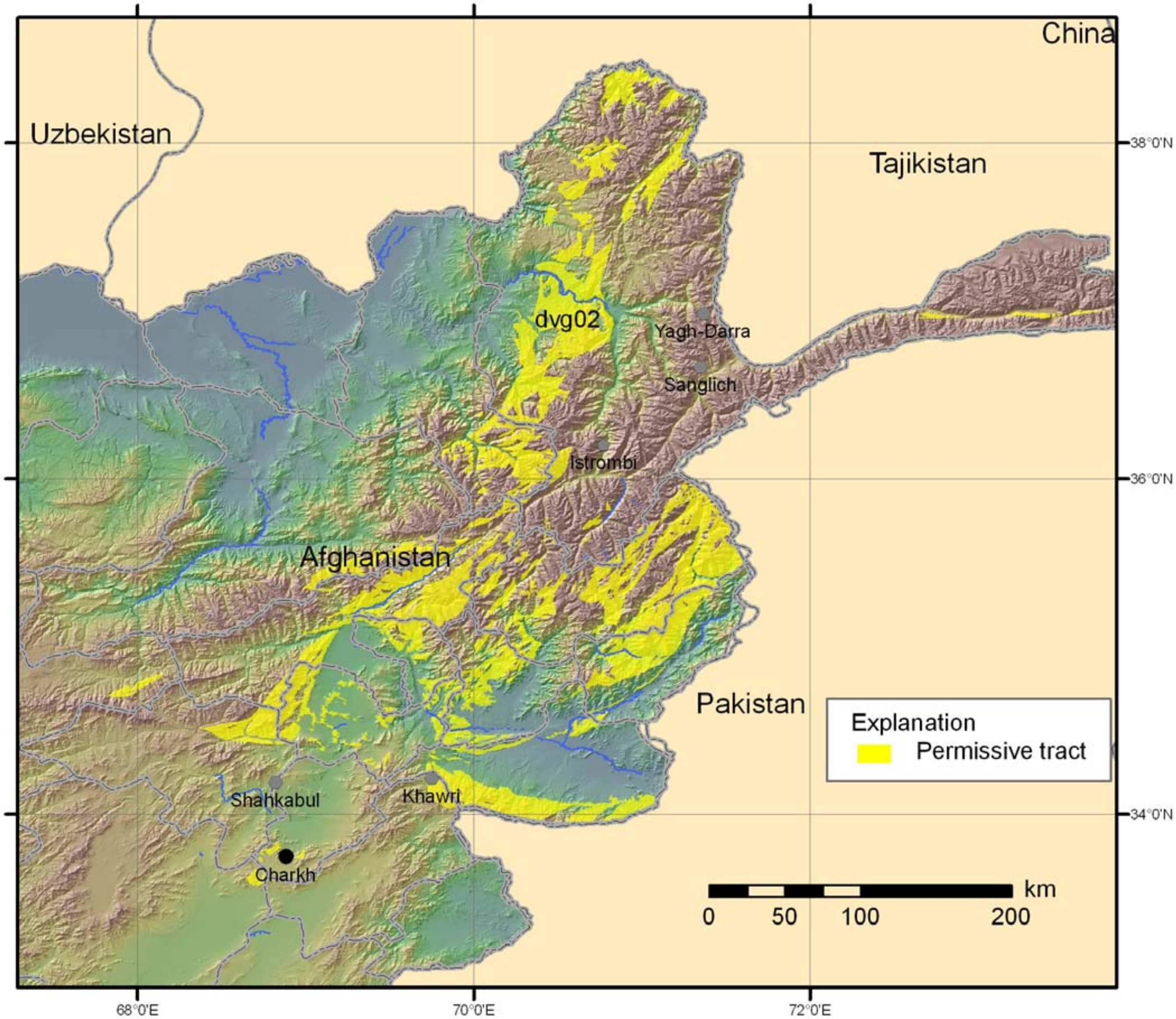

Figure 9.2-5. Location of permissive tract dvg02, which was delineated on the presence of Middle Proterozoic to Cambrian age high-grade metamorphic rocks. Tracts other than dvg02 are not shown.

Microcrystalline (amorphous) graphite tracts

Tract ID—mcg01 Microcrystalline graphite in contact metamorphic rocks

Deposit type—Microcrystalline (amorphous) graphite

Age of mineralization—Early Proterozoic to Quaternary

Examples of deposit type—Graphite at the Charkh occurrence in Loghar Province occurs in Proterozoic rocks next to an Oligocene granitic plug intruding Upper Permian sedimentary rocks. Graphite-bearing zones are >1,000 m long and a few meters to 40 or 50 m thick (sometimes as much as 100 m thick) (Denikaev and others, 1971).

Exploration history—The quantity and quality of exploration are unknown. However, the presence of the Charkh graphite occurrence in the tract is an indicator of exploration.

Tract boundary criteria— Permissive tracts are areas where in the probability of deposits occurring outside the tract is negligible. In the case of microcrystalline graphite in Afghanistan, however, the 1:500,000-scale geologic map does not divide the rocks into units fine enough to be of use. Thus, almost the entire country minus the intrusive rocks is permissive for the occurrence of microcrystalline graphite. Such a tract is not very informative or helpful in exploration. Instead, tract mcg01, permissive for this form of graphite, was defined as those areas with potential for the presence of highly carbonaceous stratified sedimentary rocks noted from Doebrich and Wahl (2006) in contact with intrusive rocks of the same age or younger. Such a geologic setting would allow the heat from the intrusions to graphitize the carbonaceous strata and form microcrystalline graphite deposits. Tentative favorable and prospective tracts were delineated in a number of areas of interest for microcrystalline graphite deposits shown in figure 9.2.7.

The permissive rock types include both continental and nearshore marine sediments. Several areas in the country consist of these stratified sedimentary rocks containing hard coal, brown coal, and peat adjacent to younger igneous intrusions. When the sedimentary rocks are younger than the intrusions they were not considered permissive. After future fieldwork, or when more information becomes available, those rocks not having significant accumulations of carbonaceous material should be omitted from tracts.

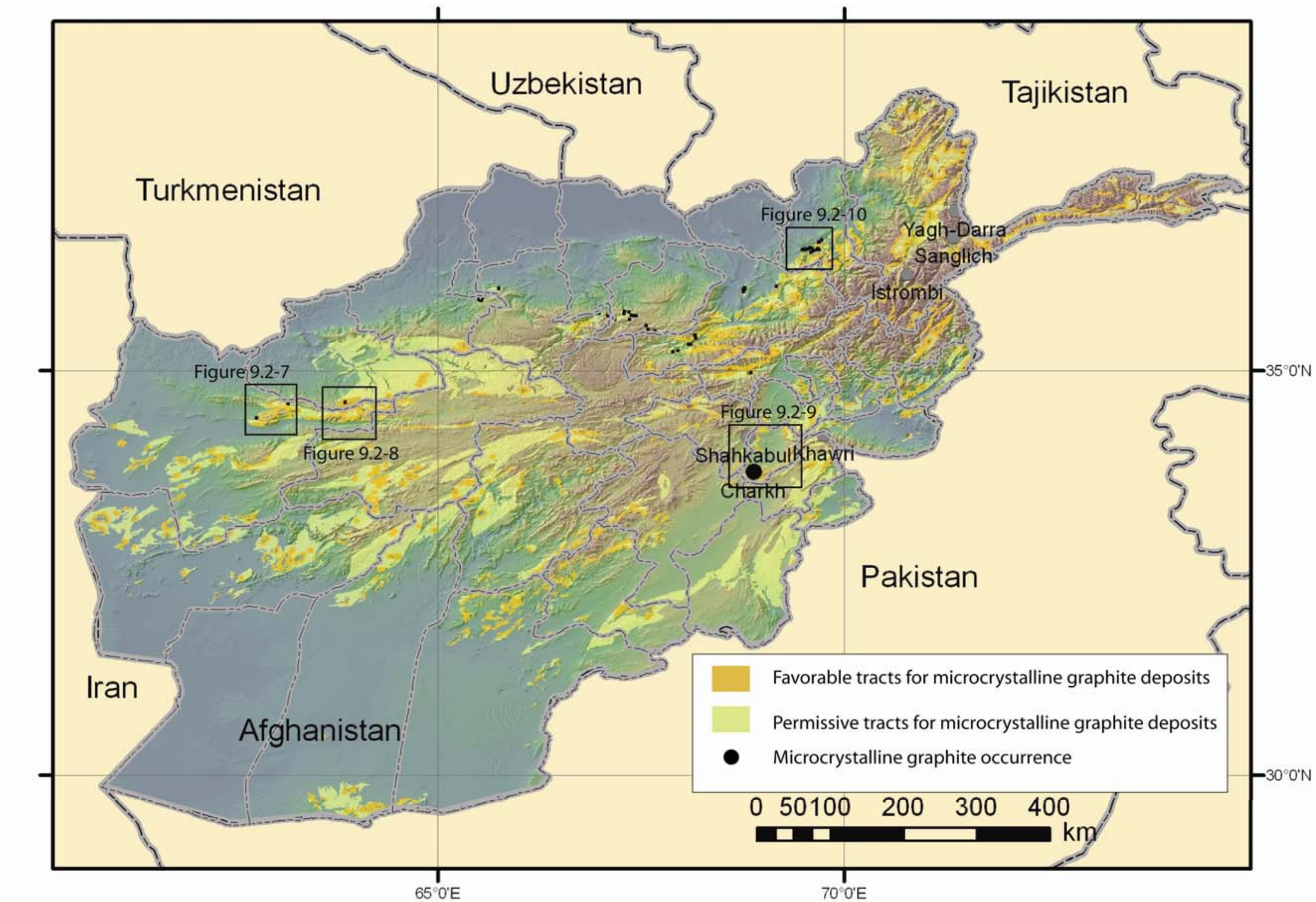

Figure 9.2-6. Permissive and favorable tracts for the occurrence of microcrystalline graphite deposits in Afghanistan with reported graphite, coal, and peat occurrences (small black dots). Boxes show figures where specific areas of interest are discussed.

Areas of Interest

Areas of interest for the occurrence of microcrystalline graphite deposits are highlighted below where permissive sedimentary rocks likely to contain concentrations of natural organic matter as indicated by the presence of known coal or peat occurrences occur within 3 km of intrusive rocks of the same age or younger. Such a geologic setting would be favorable for the heat from the intrusions graphitizing carbonaceous material in the rocks and creating microcrystalline graphite deposits. Within tract mcg01, there are areas of interest for the occurrence of microcrystalline graphite.

Shere-Arman area. The westernmost of these areas of interest (figure 9.2-7), is in eastern Herat Province. East-southeast of Karuh, at the Mississippian (Lower Carboniferous) Palowana hard coal occurrence, the stratified rocks in the tract consist of Lower Tournaisian to Visean (Lower-to-Middle Mississippian) age limestone, shale, sandstone, mudstone and conglomerate. The sedimentary rocks have been intruded by Late Triassic granitic rocks that were probably important in producing the hard coal at Palowana. These conditions are favorable for creation for the formation of natural microcrystalline graphite. Northeast of the area, is a narrow occurrence of Early-to-Middle Jurassic coal-bearing stratified rocks hosting the small Majid-i-Chubi hard coal deposit. In the vicinity of these beds are Late Triassic granitic intrusions that may have graphitized the coal beds.

Palowana area. Another area of interest may be the most promising of the five prospective tracts delineated (figure 9.2-8). It is located roughly 100 km east of the previous area of interest in the eastern panhandle of Herat Province and in southern Badghis Province where Miocene diorite porphyry, granodiorite porphyry, and associated igneous rocks types intrude Middle Triassic to Late Triassic rocks mapped as sandstone, siltstone, mudstone, carbonaceous shale, limestone, marl, and acid and mafic volcanic rocks. This tract (figure 9.2-8) contains the very small Shere-Arman hard coal occurrence of Early to Middle Triassic age in carbonaceous shales. In some places in the tract the sedimentary rocks are practically surrounded by igneous intrusions, which should be a good environment for creating microcrystalline graphite.

Charkh graphite area. A third area of interest for undiscovered microcrystalline graphite deposits (figure 9.2-9), is known to contain the Late Permian terrigenous rocks that host the Charkh microcrystalline graphite occurrence and rocks of similar age within three km of the Oligocene age intrusions that flank the prospect tract east and west. These rocks consist of Late Permian conglomerates, siltstones, limestones, marls, dolomites, and other stratified sedimentary rocks that may contain organic material that may have been graphitized by contact metamorphism with the nearby and probably underlying Oligocene age intrusions. The Paleozoic age rocks are overlain by undifferentiated Pliocene age continental sediments consisting of conglomerate, siltstone, sandstone, clay, limestone, marl, gypsum, salt, and acid and mafic volcanic rocks too young to have been heated by the older intrusions.

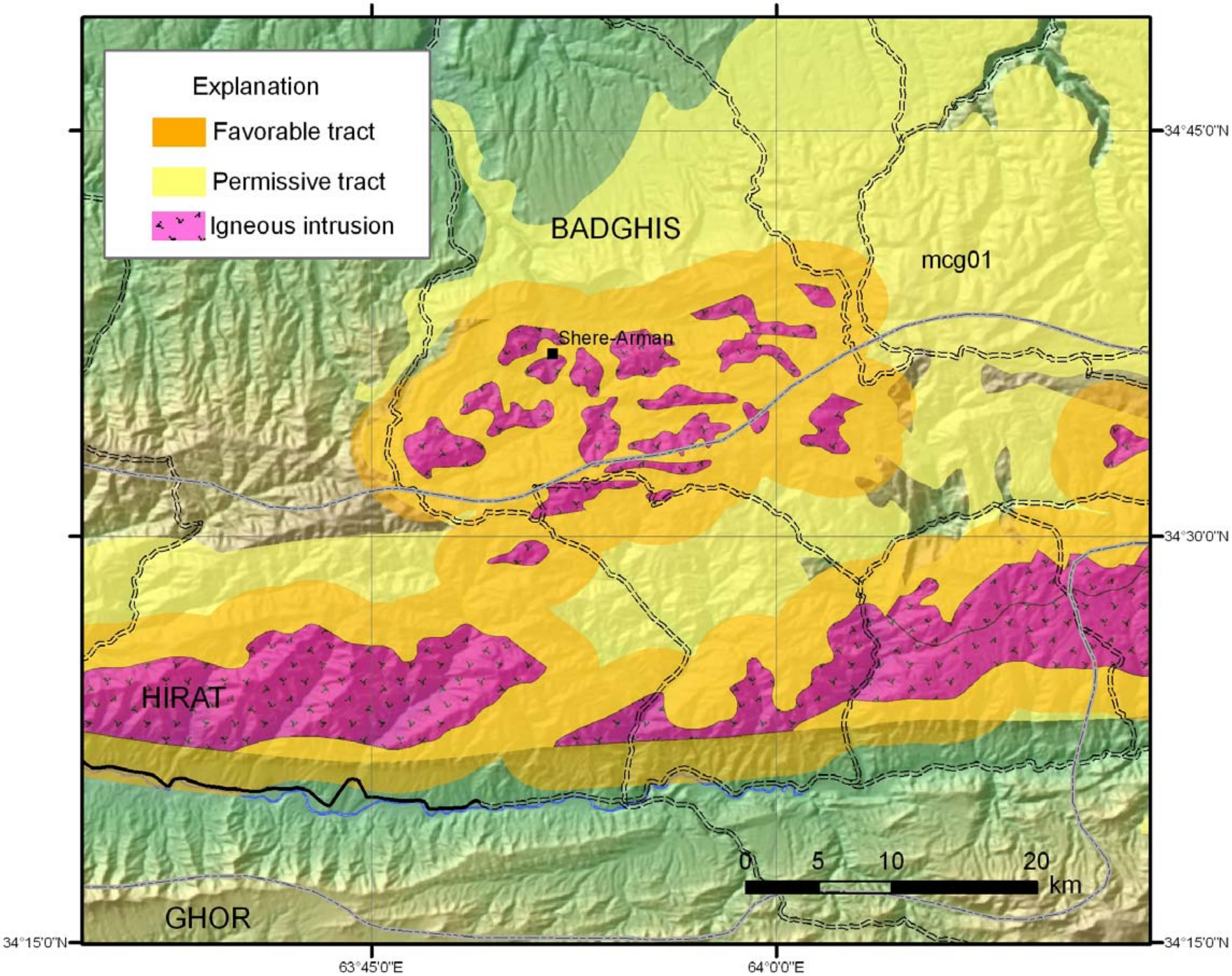

Figure 9.2-7. Map of the Shere-Arman area, an area of interest for microcrystalline graphite where organic-rich beds and younger intrusions occur together in Badghis and Herat Provinces.

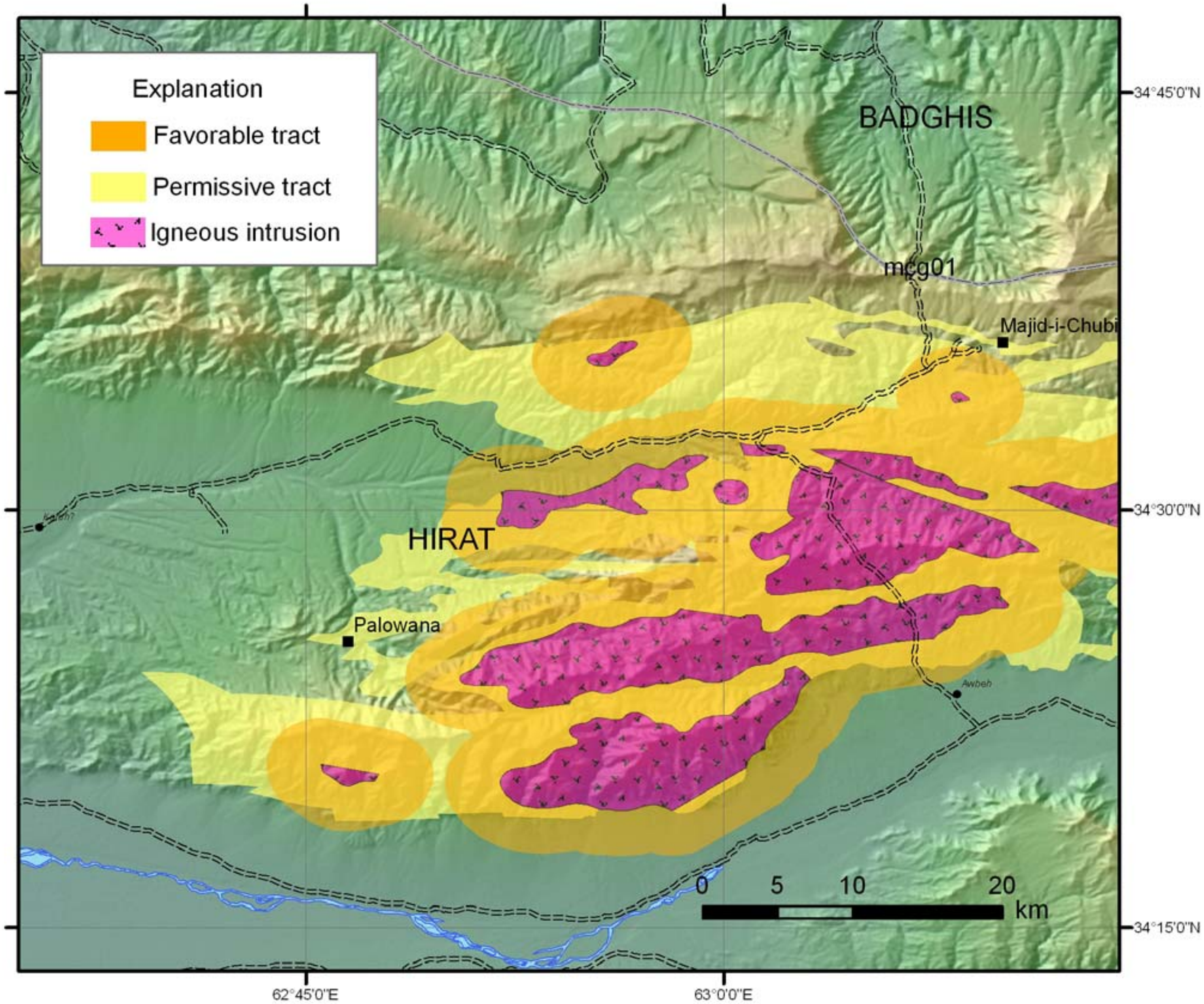

Figure 9.2-8. Palowana area, an area of interest for microcrystalline graphite where organic-rich beds and younger intrusions occur together in Herat Province.

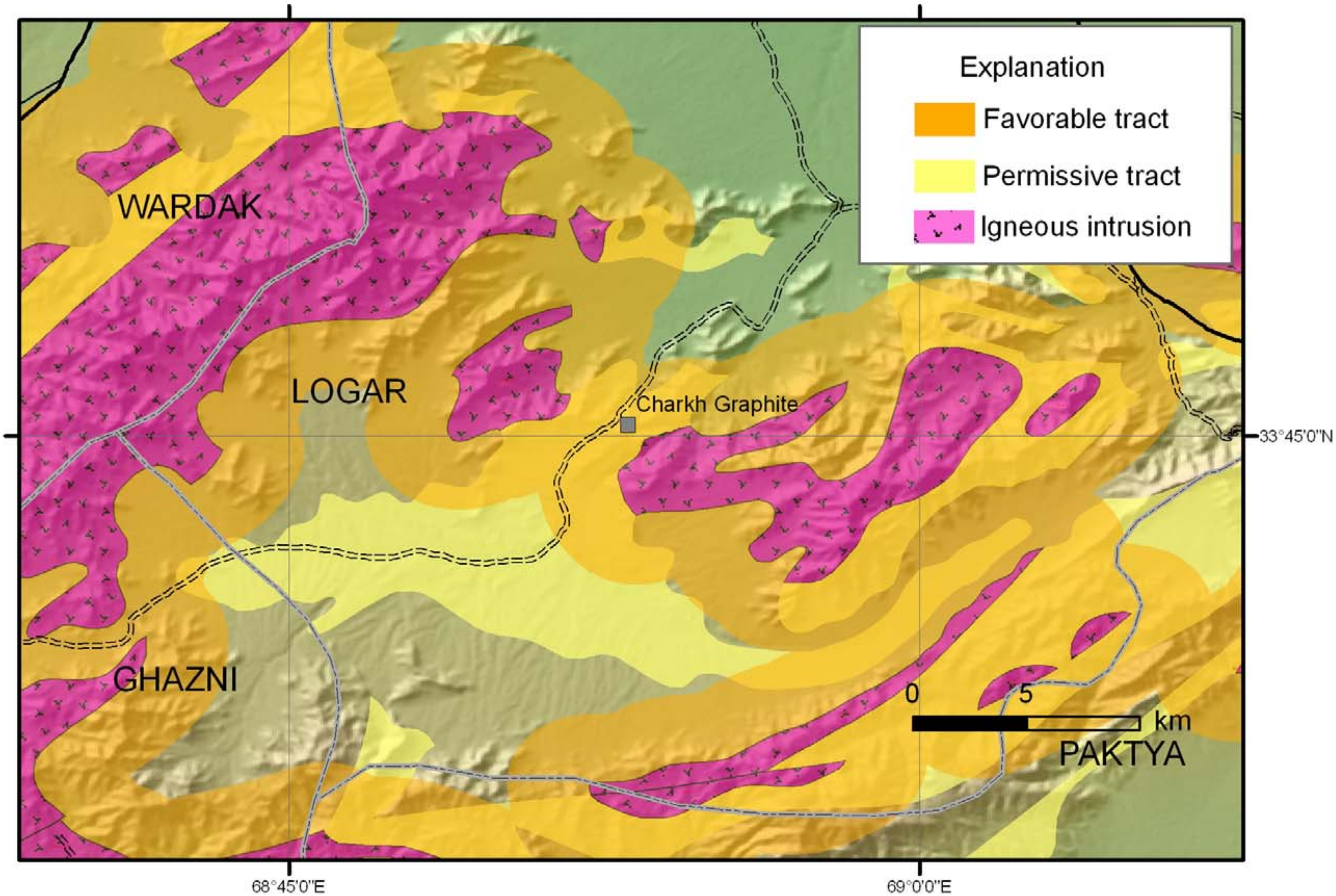

Figure 9.2-9. Map of the Charkh graphite area showing permissive and favorable tracts in an area of interest for the occurrence of microcrystalline graphite deposits in Afghanistan in the vicinity of the Charkh microcrystalline graphite occurrence.

Bazarak area. The final area of interest (figure 9.2.10) is in central Takhar Province between the villages of Eskames and Farhar and includes at least 15 Jurassic age hard coal occurrences. The rocks associated with the coal deposits are Late Triassic (Rhaetian) to Late Jurassic conglomerate, sandstone, siltstone, limestone, and gypsum beds of the North Afghanistan zone and limestone, marl, sandstone, and siltstone of Farakhrud Basin. The local igneous intrusions are Mississippian and Late Triassic in age, which makes them too old to have had any thermal influence on the younger coal seams. The presence of the minable amounts of hard coal at several sites within the tract, however, makes the tract mcg01-p4 favorable for the occurrence of microcrystalline graphite at least for reconnaissance exploration.

Important data sources**—**Geologic map, mineral deposit database (Doebrich and Wahl, 2006; Orris and Bliss, 2002).

Needs to improve assessment**—**Large-scale geologic map, geophysics, such as AMT, that exploits the electrical conductivity of natural graphite deposits.

Optimistic factors**—**Much of western and southern Afghanistan consists of sedimentary rocks that were deposited in environments suitable for the accumulation of organic material that may have been available for graphitization by a nearby intrusion. There are numerous intrusions within tract mcg01 adjacent to the sedimentary rock units. The remoteness of parts of the mcg01 and rugged of the terrain may mean that some of the tract is lightly explored. The presence of the Charkh occurrence and its proximity to Kabul are positive factors.

Pessimistic factors**—**Parts of tract mcg01 are in terrain that is rugged and remote. Creation of microcrystalline graphite requires an abundance of organic material in the host rocks and a natural source of intrusive or extrusive heat. These factors have to come together to produce microcrystalline graphite. Microcrystalline graphite is much less valuable per unit than disseminated flake graphite.

Quantitative assessment**—**No estimate of the numbers of undiscovered disseminated flake graphite deposits was done. Tract mcg01 may have additional undiscovered microcrystalline graphite occurrences.

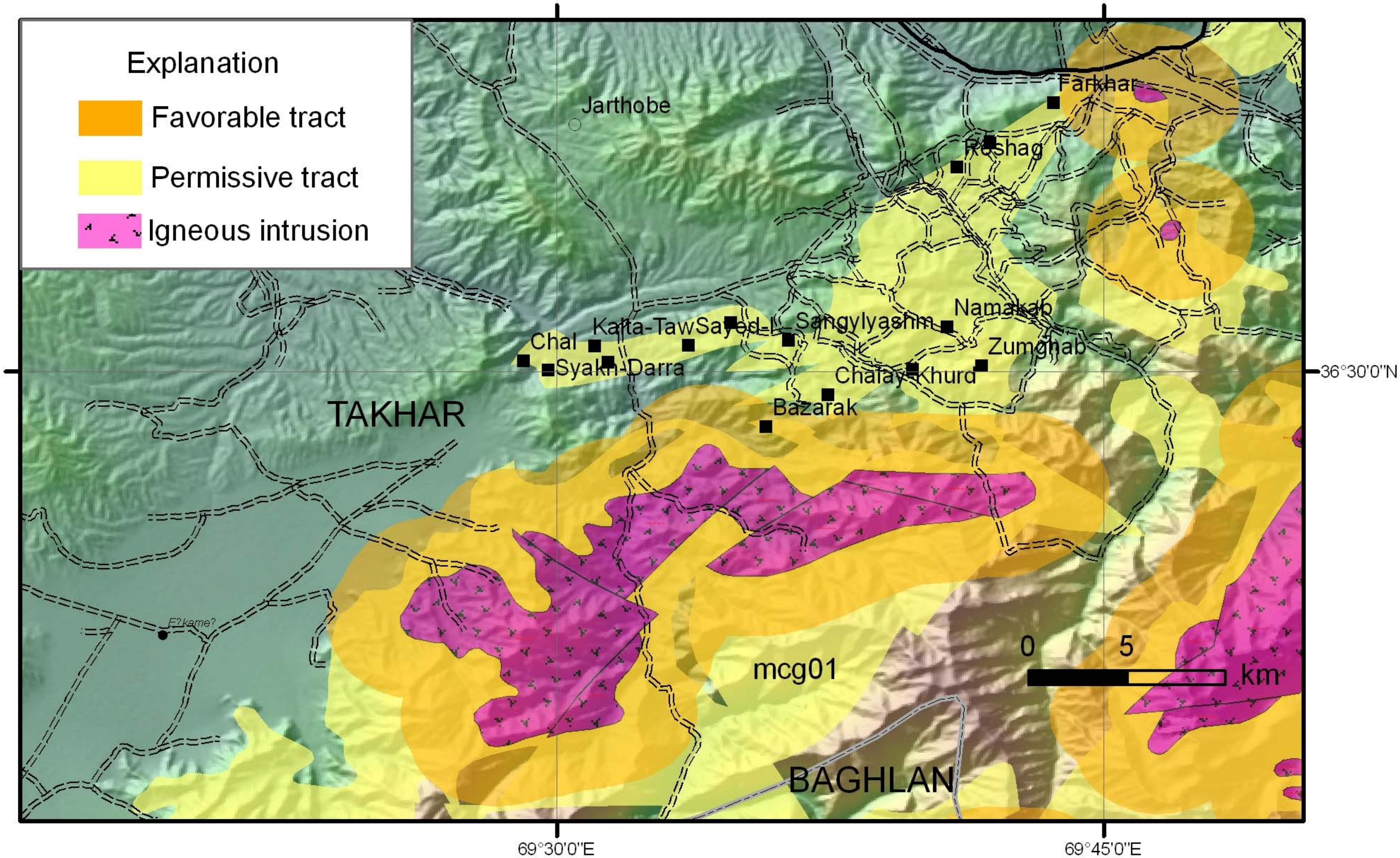

Figure 9.2-10. Map of the Bazarak area showing permissive, favorable, and prospective tracts for the occurrence of microcrystalline graphite deposits in Afghanistan with the Charkh graphite occurrence.

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9.3 Metasomatic and Metamorphic Talc and Magnesite

Contribution by Greta J. Orris and Karen S. Bolm.

Deposits of metasomatic and metamorphic talc and magnesite are the major source of talc in the world. The Achin deposit south of Jalalabad is the largest talc-magnesite deposit in Afghanistan, and it is possible that additional deposits might be located in the same type of rocks.

Talc and magnesite are two magnesium-rich minerals that may occur in the same or spatially associated deposits; especially in deposits hosted by ultramafic and carbonate rocks. The term "talc" is a mineral name, but it is also commonly used to describe rocks that contain the mineral in variable amounts. Massive talcose rock is called steatite, and an impure massive variety is known as soapstone (Virta, 2005). The mineral talc is an extremely soft mineral with a Mohs hardness of 1 (as compared to diamond with a hardness of 10) Talc, which is most familiar to people as talcum powder, but has many other uses, is a hydrous silicate mineral with the chemical formula $Mg_3Si4O_{10}(OH)_2$. Although talc is commonly relatively pure in composition, small amounts of aluminum, iron, manganese, and titanium may be present as impurities. Talc can be translucent white, apple green, dark green, or brown, depending on the composition of these impurities. Structurally, talc is composed of microscopic platelets. The bonds holding these platelets together are very weak, which enable the platelets to slide by one another and result in the greasy feel of talc (U.S. Geological Survey, 2000).

Magnesite ($MgCO_3$) is the dominant industrial mineral source for magnesia (MgO). Magnesia is characterized by its inertness and high melting point and is commonly used to produce high-temperature refractories, chemicals and fertilizer, and magnesium--the lightest of the structural metals (Harben and Kužvart, 1996a; Bodenlos and Thayer, 1973; Kramer, 2001). Most magnesite and magnesia extracted from brines and seawater are processed into dead-burned magnesia (calcined at a temperature exceeding 1,450 °C) or caustic-calcined magnesia (calcined at a lower temperature that leaves a small amount of CO_2 in the resulting compound). Dead-burned magnesia is used dominantly for refractories, while caustic-calcined magnesia is the preferred starting material for chemicals, cement, filler, fertilizers, and many other uses (Harben and Kužvart, 1996a) The assessment of Afghanistan's undiscovered magnesite resources is limited to magnesite in non-sedimentary, non-brine deposits.

Concerns have been expressed about the association of asbestos with talc. In carbonate-hosted talc deposits, tremolite is the most common asbestiform minerals, but chrysotile may also be present. Overall, most talc is asbestos free (*http://www.emporia.edu*). However, the general public is in contact with talc in powders and its potential for inhalation has drawn the attention of health researchers (*www.ima-eu.org*). In mining and processing talc, miners and factory workers may be at a greater risk because of prolonged expose to fine particles of talc. When talc is being mined and processed, high concentrations of talc particles may be in the air and workers could inhale it into their lungs. When massive concentrations are inhaled, long term accumulation may collect in the lungs. Inhalation of too much talc dust may cause lung disease and other health problems. Talc has not proven to be a cause of human lung cancer, even in mine and factory workers. Research shows talc miners have the same mortality rate as non talc miners with regard to lung cancer (*http://www.emporia.edu*).

9.3.1 Talc and Magnesite Deposit Models

In addition to ultramafic talc-magnesite deposits (section 2.2, this report), talc and magnesite may occur together in metasediments, especially dolostone. Magnesite deposits in metasediments may also be called Veitsch-type magnesite, carbonate-hosted magnesite, sparry magnesite, and crystalline magnesite. Talc deposits in these rocks are referred to as carbonate-hosted or dolomite-hosted talc deposits. For this report, we will refer to these deposits as metasomatic and metamorphic talc or magnesite deposits (M-M talc and M-M magnesite for short). There have been numerous attempts to model magnesite and talc in carbonate rocks (Page 1998a and b; Simandl and Handcock, 1998; Simandl and Paradis, 1999). Talc and magnesite may or may not be found together in these deposits.

Metasomatic and metamorphic magnesite deposits are believed to form through the interaction of magnesium-rich fluids with the host rocks. The fluids may be hydrothermal or derived from low-grade or contact metamorphism (Koons, 1981; Harben and Kuzvart, 1996; Page, 1998a). Replacement is selective and the mineralization is dependent on the composition of the host rock. This results in stratabound to stratiform deposits of crystalline magnesite that are commonly hosted by dolostone, but also by limestone and clastic sediments. Deposits of this type range from tens of thousands of tons to over 100 million metric tons in size and may extend several kilometers along strike (Simandl and Handcock, 1998). M-M talc is the main associated deposit types.

Metasomatic and metamorphic talc deposits form in a manner similar to magnesite. The availability of SiO_2 may favor the formation of talc over magnesite or the formation of talc from magnesite (Harben and Kuzvart, 1996; Simandl and Paradis, 1999). Tremolite may form with the talc and this could pose a potential health concern. Talc deposits in these geologic settings are typically much smaller than the magnesite deposits; ranging from tens to hundreds of meters along strike (Simandl and Paradis, 1999).

Although both talc and magnesite occur in both ultramafic-hosted deposits and metasomatic and metamorphic deposits, talc deposits in ultramafic rocks tend to be larger than those in found in altered carbonate sediments. The reverse holds for magnesite; magnesite deposits of the M-M replacement type tend to be larger than those hosted by ultramafic rocks. However, in specific instances, it can be extremely difficult to impossible to predict whether a deposit will contain talc or magnesite or some unknown combination of the two, especially in the absence of detailed geologic information.

Exploration guides—M-M magnesite and talc deposits may be associated with unconformities, intrusive margins, and (or) faults. Talc can be an indicator in overlying soils. Magnesite deposits commonly have light-colored surface exposures. None of these measures or geophysics is necessarily definitive.

Examples of deposit type— Deposits that belong to this deposit type include: the Mt. Brussiloff magnesite deposit, British Columbia, Canada; the Staka magnesite deposit, southern Urals, Russia; Trimouns talc deposit, France; and the Gouverneur talc deposit in New York, USA.

Known occurrences—There are two (2) metamorphic and metasomatic magnesite-talc deposits known in Afghanistan; there may be several additional occurrences (Orris and Bliss, 2002) (table 9.3-1).

Table 9.3-1. Some metasomatic talc-magnesite occurrences in Afghanistan.

Name	Province	Commodity	Short Description	Reference
Achin	Nangarhar	magnesite, talc	magnesite & talc associated with marble and andesite porphyry	Abdullah and others, 1977
Ghunday (Mamahel)	Nangarhar	asbestos, talc	talc & magnesite(?) associate with marble and gabbro	Abdullah and others, 1977
Tangha (not shown on map)	Paktia	talc	talc in marble	Chmyriov and others, 1973

9.3.2 Permissive tract for metasomatic talc-magnesite

Tract Afmmtlcmg. Because they form in the same types of rocks and from some of the same processes, one tract is used to delineate the permissive area for both metasomatic talc and magnesite. One tract

(Afmmtlcmg) was delineated as being permissive for the occurrence of magnesite and talc resulting from metasomatic and metamorphic processes in carbonate and related sediments. The tract includes both the Achin and Ghunday deposits and is based on a lithologic unit that contains both amphibolite dikes and carbonates.

Examples of Deposit Type: The following descriptions are from Abdullah and others, 1977. The Achin Mg-talc deposit and the Ghunday talc-Magnesite deposit are both found within the tract in Nangarhar Province. At Achin, magnesite and talc occur in Proterozoic dolomite and dolomitic marble that is intruded by andesite porphyry and porphyry dikes. The talc-bearing zone is up to 2,000 m long and contains speculative reserves of 1.25 million metric tons talc. Parallel to the talc zone are several magnesite bodies up to 765 m long and 70 m thick that assay 30-38 percent MgO. Speculative resources in these bodies total 31.2 million metric tons magnesite. At Ghunday, a 2,000–m-long, talc-bearing zone occurs near the contact of Proterozoic marble and gabbro-diabase. Over 50,000 t of high-grade talc have been mined from this deposit.

Probable Age(s) of Mineralization. The age of the metamorphic and metasomatic replacement deposits expected within the tract is Proterozoic.

Exploration History: There has been some production of talc and early work by the Russians identified 2 areas of speculative reserves. No evidence of more thorough or more recent methodical exploration.

Tract boundary criteria: The tract is defined by the surface extent of the Proterozoic carbonate-bearing rocks (map units X_1gn, X_2mbg, and Ygng from Doebrich and others, 2006) with associated amphibolite dikes in the area of the Ghunday and Achin deposits.

Needs to improve assessment: The assessment team recognized more detailed geology and occurrence descriptions may have been useful and no grade and tonnage model was available.

Optimistic factors: Occurrence of known talc and magnesite-talc deposits within tract and belief that area has not been methodically explored for these commodities, especially at shallow depths.

Pessimistic factors: Lack of detailed geology and deposit descriptions.

Quantitative assessment—No quantitative assessment of this deposit type was made.

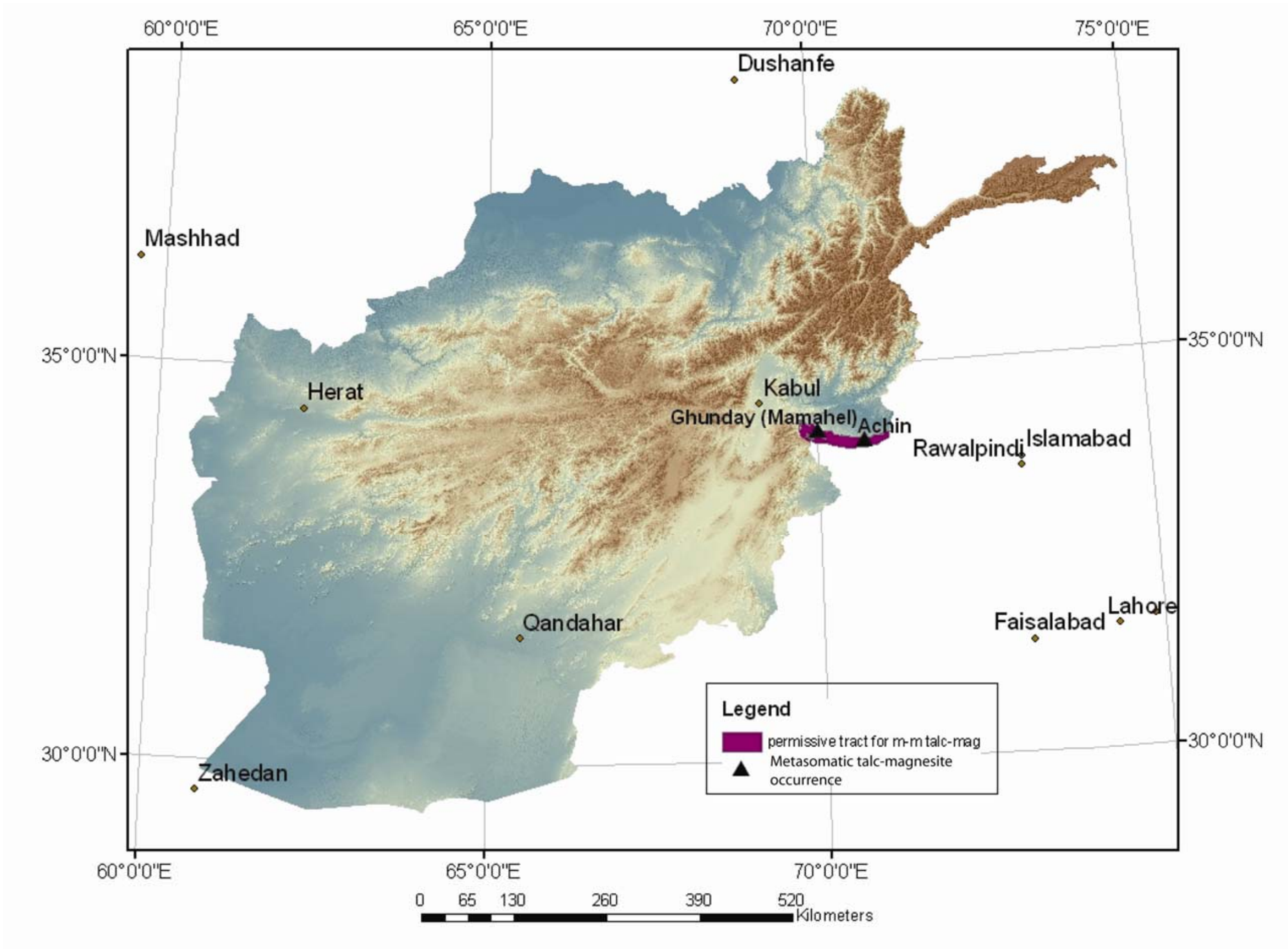

Figure 9.3-1. Known talc-magnesite occurrences in Afghanistan and tracts and areas of interest permissive for their presence.

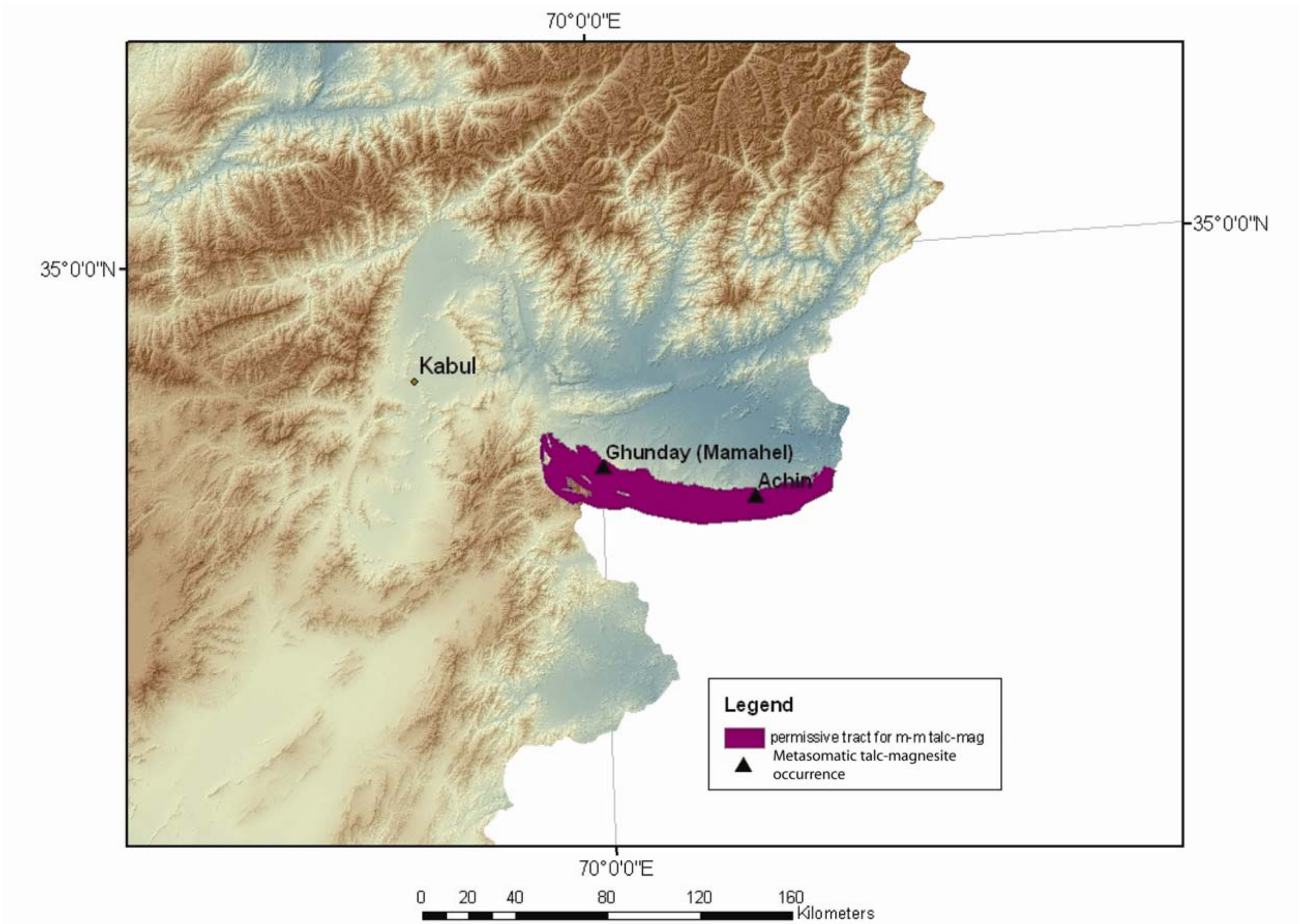

Figure 9.3-2. Detail view of fig. 9.3-1. The largest known magnesite deposit in Afghanistan, Achin, is present within the delineated tract. More detailed geology and occurrence descriptions are needed to determine tracts for other potential M-M magnesite occurrences.

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