

Chapter 2A. Summary of the Aynak Copper, Cobalt, and Chromium Area of Interest

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Abstract

This report summarizes and interprets available data for the Aynak copper, cobalt, and chromium area of interest (AOI) and its subareas from joint geologic and compilation activities conducted during 2009 to 2011 between the U.S. Geological Survey, the U.S. Department of Defense Task Force for Business and Stability Operations, and the Afghanistan Geological Survey.

Numerous copper-cobalt and several chromium, talc-magnesite, and asbestos target zones are present in the Aynak AOI, located in southern Kabul, northern Logar, and Wardak Provinces. The AOI derives its name from the world-class Aynak copper-cobalt deposit that is currently estimated to contain 240 million metric tons of ore at 2.3 percent copper. An estimate of the contained cobalt resource is not available due to insufficient assays; however, cobalt content of ores ranging from 0.015 to 0.3 percent have been reported and may represent significant added value.

Aynak belongs to a class of deposits hosted in sedimentary rocks that are commonly laterally continuous over extensive areas. The presence of the Aynak deposit, several smaller deposits, and more than 40 prospects and occurrences is indicative of the significant future potential of the area for the discovery of additional economically important copper-cobalt deposits. The known deposits and prospects occur at the surface within complexly folded Neoproterozoic strata. Structural analyses suggest that the four main clusters of deposits are exposed in the crests of folds and that this pattern may be useful to project exploration for similar deposits under younger cover. The two southern deposit clusters contain the Aynak and Jawkhar-Darband-Kuhndara deposits which were the subject of a mineral tender package that was awarded to China Metallurgical Group Corporation. The two northern clusters remain open to mineral exploration and are included within the four copper-cobalt subareas described in this report. The northern areas require additional geological mapping, geochemical and geochronological sampling, data compilation, and geophysical studies to better delineate the favorable Neoproterozoic host rocks.

Discovery of additional copper-cobalt deposits in the Aynak AOI would benefit in the early stages of exploitation and production from the ongoing infrastructure development at the Aynak deposit and the close proximity of the area to Kabul. With easy access to transport corridors, local labor sources, and the materials supply center in Kabul, it is reasonable to expect that medium-sized deposits or several smaller deposits in aggregate could be put into production with short lead times, short payback periods and, in time, likely lead to larger mining ventures.

The occurrence and minor past exploitation of podiform chromite deposits, talc-magnesite, and asbestos in the Logar Ophiolite Complex in the Logar Valley just southwest of the Aynak deposit are of lesser importance to the economic recovery of Afghanistan. Podiform chromite deposits are typically small and do not represent a significant target for future exploration. However, recent documentation of platinum group elements in the Logar chromitites is of interest and could be amenable to small-scale mining if significant quantities of platinum group elements are identified. Additional sampling of the known chromite deposits and geochemical analyses are required to investigate this potential.

2A.1 Introduction

The Aynak copper, cobalt, and chromium area of interest (AOI) is located in eastern Afghanistan in southern Kabul, northern Logar, and Wardak Provinces and includes parts of the Maydan Shahr, Nirkh, Chahar Asyab, Bagرامي, Musayi, Khaki, Jabbar, Pull Alam, and Muhammad administrative districts. The area of the main Aynak AOI is 3,439.37 square kilometers (km²), which contains five subareas. Four of the subareas, Kelaghey-Kakhay (27 km²), Bakhel Charwaz (40 km²), Yagh-Darra Ghul-Darra (57 km²), and Kharuti Dawrankhel (66 km²) are prospective for copper-cobalt deposits. A fifth subarea, Logar valley (1,013 km²), is prospective for chromite and possibly platinum group element (PGE) deposits (fig. 2A-1).

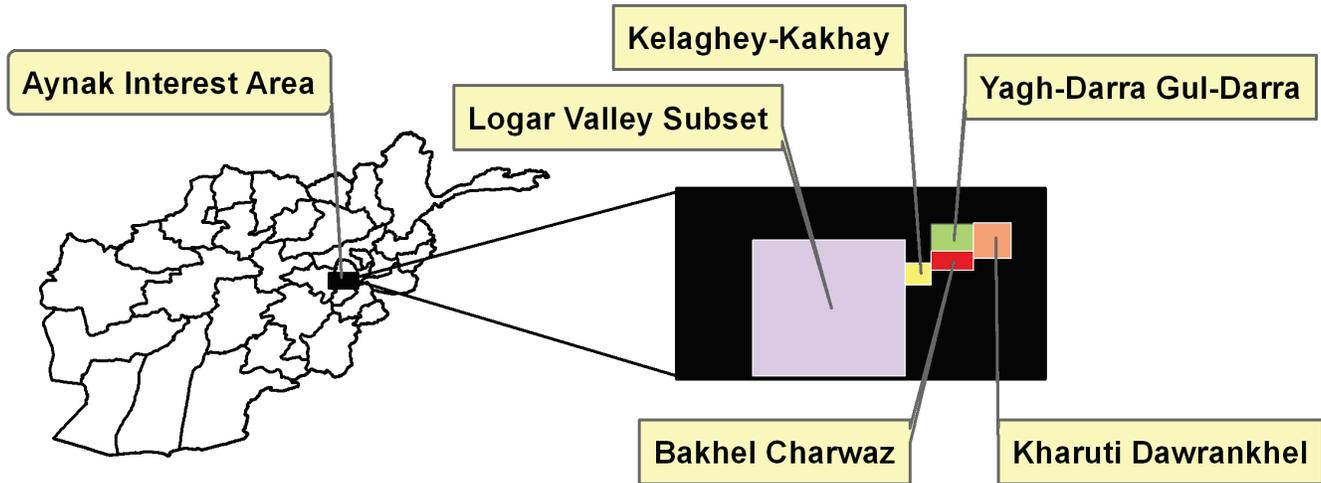


Figure 2A-1. Location of the Aynak copper, cobalt, and chromium area of interest and subareas.

Mineral deposit types that may be present in the Aynak AOI are sediment-hosted copper (cobalt) deposits, secondary (transported) copper deposits, podiform chromite deposits, serpentine-hosted asbestos deposits, and talc-magnesite deposits. In addition, podiform chromite deposits have the potential to contain PGEs.

Most existing mineral resource information has been gathered from reports written between the early 1950s and about 1985 by geologists from the Union of Soviet Socialist Republics (USSR) and its eastern European allies who provided Afghanistan with technical assistance. This previous information, combined with a preliminary nonfuel mineral resource assessment by the U.S. Geological Survey in 2007 (Peters and others, 2007), provided much of the factual basis for technical work during 2009 through 2011. During this period, Afghan Geological Survey crews were busy gathering new data on other less well prospected AOI's, and only a single reconnaissance visit to several of the Aynak subareas was made by personnel of the USGS (figs. 2A-2 and 2A-3). The Logar subarea was not visited. Resulting new data are, therefore, extremely limited and this current summary is compiled mainly from pre-existing sources. The following English language summaries were relied upon heavily: the geology and exploration of the Aynak and western Aynak areas by Russian workers released in the Aynak Information Package by the Afghan and British Geological Surveys (British Geological Survey 2005a,b,c); the USGS preliminary nonfuel mineral resource assessment of Afghanistan (Peters and others, 2007); geological mapping in the Kabul North and Kabul South quadrangles at 1:100,000 scale (Bohannon, 2010a,b); and a recent paper on the chromite and PGE resources of the Logar Ophiolite Complex (Benham and others, 2009). The Aynak AOI and subareas also are thought to be likely to develop near-term mineral production. Additionally, some deposits in the Aynak AOI and subareas are near-surface bodies with promising metallurgical and mining characteristics.



Figure 2A–2. General aerial view of the north Aynak area. Photograph by Ted Theodore, U.S. Geological Survey.

2A.2 Geology

The Aynak AOI and subareas are located within the Kabul tectonic block, one of many fragments of ancient continental crust interleaved with oceanic crust that was trapped between the Eurasian and Indian cratons during closure of the Tethyan sea from late Paleozoic to Cretaceous times (Tapponnier and others, 1981). Bounded on both the west and east by major terrane-bounding faults, the Kabul block is a north-northeast trending, lenticular-shaped sliver about 200 kilometers (km) long and 50 km wide (British Geological Survey, 2005a). The block has a broadly anticlinal structure that exposes a core of Precambrian metamorphic rocks flanked by Late Paleozoic and Mesozoic rocks. Within the Kabul block, the main structural features are the Kabul Anticline Elevation and the Aynak Syncline Zone (British Geological Survey, 2005a). The Kabul Anticline Elevation is in the northern part of the block and is about 50 km wide and trends northwesterly. The northeastern limb dips at 40 to 50 degrees and the southwestern limb dips at 70 to 80 degrees. The Aynak Syncline Zone, situated to the south of the Kabul Anticline Elevation, is elongated in an east-west direction, and is 60 km long and up to 20 km wide. The Aynak Syncline Zone hosts most of the copper deposits in the Kabul block (British Geological Survey, 2005b).

Precambrian crystalline basement rocks in the Aynak syncline zone consist of amphibolite facies and higher grade metamorphic rocks of the Paleoproterozoic Sherdarwaza series and the (assumed) Neoproterozoic Kharog and Weyalati Formations, all of which are intruded by small lenticular and stock-like metamicrogabbro and migmatitic granite bodies (British Geological Survey, 2005b; Bohannon, 2010b; fig. 2A–4). The Sherdarwaza series consists of gneiss, migmatite, and schist with lesser amphibolite, quartzite, and marble. These lithologies occur in rhythmic sequences of basal quartzites upwards into gneisses, mica schists, amphibolites, and marbles. Individual sequences vary

from several meters to several tens of meters for a total thickness of more than 1,900 meters (m) in the central Kabul block (British Geological Survey, 2005b). The Kharog Formation conformably overlies the Sherdarwaza series, generally shares the same spatial distribution, and mainly consists of gray to light-gray quartzite that is interbedded at the base with conglomerates and with schist, gneiss, amphibolite, and marble in the upper parts of the formation. The nonquartzite layers in the upper part share similar composition, texture, and metamorphic grade with counterpart lithologies in the Sherdarwaza series. The Kharog Formation is up to 2,500 meters (m) thick (British Geological Survey, 2005b; Bohannon, 2010b). The Welayati Formation overlies and is conformable with the Kharog Formation and is distributed throughout the Aynak District and northern Logar valley. The Welayati formation consists of a basal schist, a middle amphibolite, and alternating schist and amphibolite in the upper part as well as plagiogneisses, quartzites, and marbles. The Welayati Formation is 1,200 to 1,500 m thick (British Geological Survey, 2005b; Bohannon, 2010b).



Figure 2A-3. General view of the Precambrian metamorphic rocks (background) and flat-lying Neogene alluvium (foreground) in the north Aynak area. Photograph by Ted Theodore, U.S. Geological Survey.

Recent uranium/lead-zircon (laser ablation) geochronological studies of amphibolitic schist and gneiss from the Sherdarwaza series gave Paleoproterozoic ages of 2,383 and 2,378 Ma, respectively (Bohannon, 2010b). The schist sample indicates that a metamorphic overprint occurred at 1,820 Ma, which obscures the origin of the protolith. Possibilities include a mafic igneous rock emplaced at 2,394 Ma or a mafic metasediment with a variety of detrital zircon sources. The ages of the Kharog and Welayati Formations are not well documented, but they are assumed to be of Neoproterozoic age by Bohannon (2010b). The high-grade metamorphic rocks of the Sherdarwaza series and Kharog and Welayati Formations may be the crystalline basement of the northern Indian plate (Bohannon, 2010b).

In the Aynak AOI, the older, high-grade Proterozoic basement rocks are overlain unconformably by a lower grade greenschist facies carbonate-clastic and volcanosedimentary cover sequence of

Neoproterozoic (Vendian) to Cambrian age. The lower calcareous schist is named the Loy Kwar Formation and is the main host rock for the copper-cobalt deposits in the Aynak syncline zone. The conformably overlying volcanosedimentary schist is called the Gulkhamid Formation. The age of these units is uncertain and is based upon fragments of Neoproterozoic stromatolites in the Loy Kwar Formation. The presence of the alga *Tannuofia* (stromatolite *tannuofia*) suggests that the unit may be early Cambrian, resulting in the commonly assigned Vendian/Cambrian age (British Geological Survey, 2005b; Bohannon, 2010b). The Gulkhamid Formation is devoid of fossil remains and has apparently not been dated. Earlier reports correlated the Gulkhamid Formation with similar mafic schists of the Weyalati Formation (British Geological Survey, 2005b; Bohannon, 2010b).

The Loy Kwar Formation is widespread throughout the central part of the Kabul block and consists of a thick metasedimentary sequence of repetitive layers of dolomitic marble, carbonaceous quartz schist, and quartz-biotite-dolomite schist. The lower Loy Kwar Formation is lithologically variable with layers of basaltic conglomerate, actinolite schist, calcareous biotite-schist, fine-grained breccia, banded biotite schist, quartzite, and dolomitic marble. Pyrite, chalcopyrite, bornite, chalcocite, pyrrhotite, and traces of molybdenite are present near the base of the formation. Marble, sandstone, quartzite, and carbonate-rich schist make up the middle of the formation and are host to much of the bornite-rich ore at Aynak. The upper parts of the formation consist of carbon-quartz schist with dark gray dolomite intercalations and gray, fine-grained, banded dolomite marble (British Geological Survey, 2005b; Bohannon, 2010b). Owing to the importance of the Loy Kwar Formation as a host for copper deposits, it has been more intensively studied and described than other rocks in the area. Resulting schemes for subdividing the formation have been inconsistent and confusing, with as many as seven members and numerous submembers designated by various previous workers. Many of the subdivisions are thin (2 to 6 m) and possibly laterally discontinuous, adding to the confusion (Bohannon, 2010b). A more detailed description, based upon seven members identified at the Aynak deposit and used in the Aynak Information Package (British Geological Survey, 2005a), is shown in figure 2A–5.

The Gulkhamid Formation has been poorly described by previous workers due to the assignment of these widespread rocks to the Weyalati Formation. It consists of metamorphosed intermediate volcanic rocks with conglomerate, metasandstone, and schistose tuff at the base and interstratified green-gray lava, tuff, breccia, and tuffaceous sandstone of andesitic to dacitic composition in the upper part. Primary volcanic textures and fabrics are preserved, and the measured thickness of the unit is about 1,000 m, although geophysical data suggest it may reach thicknesses of 2,000 m (Kubatkin and others, 1978; British Geological Survey, 2005b).

Numerous small intrusive bodies occur in the Aynak AOI and consist primarily of plagiogranite porphyry and syenite porphyry. They mostly intrude the Weyalati, Loy Kwar, and Gulkhamid Formations and intrude the Sherdarwaza series to a lesser extent. They are thought to be of Vendian/Cambrian age (British Geological Survey, 2005b; Bohannon, 2010b).

Phanerozoic sedimentary rocks are present in marginal areas of the Kabul block and unconformably overlie the variably metamorphosed Proterozoic basement rocks described above. These rocks are mostly Early Carboniferous to Early Permian and consist of carbonate and continental clastic platform sequences. These rocks are sparse in the Aynak AOI. The Carboniferous through Early Cretaceous sequence is about 5 km thick (British Geological Survey, 2005b). Poorly consolidated, coarse-grained fluvial and fluviolacustrine sediments cover large areas of the Kabul block where they fill intermontaine depressions. These units are referred to as the Latabang Formation and are of Miocene to Recent age (British Geological Survey, 2005). They reach a maximum thickness of 600 m (British Geological Survey, 2005) and cover extensive parts of the Aynak District, especially in the area between the Aynak and Darband deposits and in the vicinity of Kurdkabul and Dawrankel (Bohannon, 2010b).

The Logar Ophiolite Complex (LOC) is located about 30 km south of Kabul and underlies an area about 65 km long by 45 km wide just west of the Aynak District and southwest of the copper-cobalt subareas described in this report. The LOC has a roughly ellipsoidal outcrop pattern elongated to the north-northwest and covers an area of about 2,000 km² centered on the Logar Valley (figs. 2A–6 and

2A–7). The LOC is an obducted fragment of oceanic crust that was thrust over the Kabul block during the Himalayan orogeny. The LOC is bounded on the west by the steeply dipping, north-south trending Pagman Fault and is separated from the underlying autochthonous rocks of the Kabul block along its northern and northeastern boundaries by the Abparan thrust fault (Benham and others, 2009). The major rock types in the Logar Valley chromite subarea are serpentinitized harzburgite and dunite with minor noritic dikes in the southernmost areas.

In more detail, the LOC consists of several major lithostratigraphic units—a lower ultramafic complex, which is separated from a pillow lava complex by a thin gabbro unit, and dike complex (fig. 2A–8; Benham and others, 2009). The pillow lava complex is overlain by a volcanosedimentary sequence, which is in turn overlain by accretionary wedge sediments. The LOC is believed to be Cretaceous in age, because the lower part of the volcanosedimentary sequence has been dated as Early Cretaceous and the upper part as Late Cretaceous (Benham and others, 2009).

The ultramafic complex mostly consists of dunite and harzburgite with minor lherzolite, wehrlite, serpentinite, and serpentinite breccias. The central part is cut by basaltic dikes ranging in composition from basalt to basaltic andesite which varies texturally to microgabbro and gabbro-diorite. The upper part of the ultramafic complex consists of layered ultramafic and mafic rocks, including an uppermost melanocratic layered gabbro (fig. 2A–8; Benham and others, 2009). The ultramafic complex is about 2,800 m thick and is host to the podiform chromite deposits in the LOC.

The pillow lava complex consists of dark gray-green, aphyric to porphyritic, spilitized, basaltic to andesitic pillow lavas with rare layers of volcanic breccia, tuff, agglomeratic tuff, and tuff breccia. The volcanic rocks are occasionally interlayered with radiolarite, hyaloclastite, and muddy limestone (fig. 2A–8; Benham and others, 2009). The pillow lava complex is about 1,700 to 1,800 m thick. The pillow lava complex was formed in a deep oceanic environment which is consistent with the ophiolite origin of the LOC (Benham and others, 2009).

2A.3 Metallogeny of Sediment-Hosted Copper Deposits

Sediment-hosted copper deposits are a large and diverse group of mineral deposits that include some of the richest and largest copper deposits in the world (Gustafson and Williams, 1981; Kirkham, 1989; Davidson and Large, 1998; Hitzman and others, 2005), such as the copper deposits of the Central African Copper Belt, which have produced in excess of 1 billion metric tons (Gt) of copper at an average grade of about 2.7 percent copper, as well as significant quantities of cobalt and silver (Selley and others, 2005).

Sediment-hosted copper deposits are restricted to a narrow range of layers within a sedimentary sequence but do not necessarily follow sedimentary bedding. They formed after the host sediment is deposited, but in most cases, prior to lithification of the host. Mineralization is independent of igneous processes. Host rocks are of two types—low-energy calcareous or dolomitic siltstones, shales, and carbonate rocks of marine or lacustrine origin; and high-energy sandstones, arkoses, and conglomerates of continental origin. Low energy host rocks are thin-bedded to finely laminated and exhibit bacterial mat structures, stromatolites, fenestral structure, reef-building coral structures, mudcracks, crossbedding, and other features of tidal environments. High-energy host rocks exhibit conglomerate- and sandstone-filled channels, scour-and-fill structures, crossbedding, parallel lamination, mud rip-up clasts, and ripple marks. Deposits of two distinct types are formed in these host rocks, reduced facies copper and redbed copper. Depositional environments include highly permeable sediments in epicontinental shallow-marine basins near the paleoequator

Proximity to sabkhas and other environments that produce high evaporation rates are also favorable factors. Halite, sylvite, gypsum, and anhydrite deposits occur in the same sedimentary sequences. Sandstone uranium, unconformity uranium, and Kipushi-type copper-lead-zinc deposits can occur in the same districts. In addition, the iron oxide copper-gold and basaltic copper deposit sub models may be applicable within some of the areas studied.

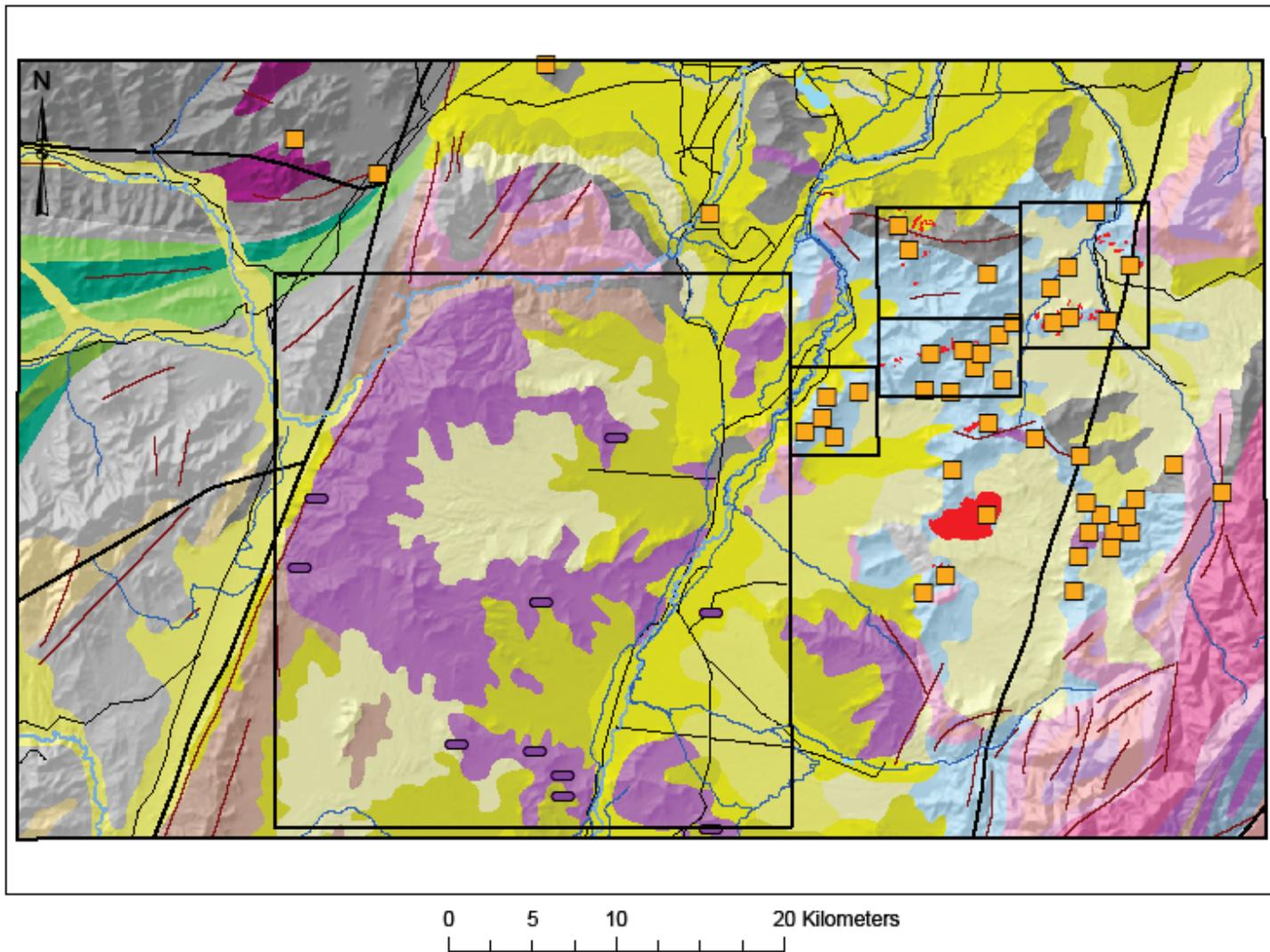


Figure 2A-4. Geology and mineral occurrences of the Aynak copper-cobalt and chromium area of interest based on Russian sources (Peters and others, 2007).

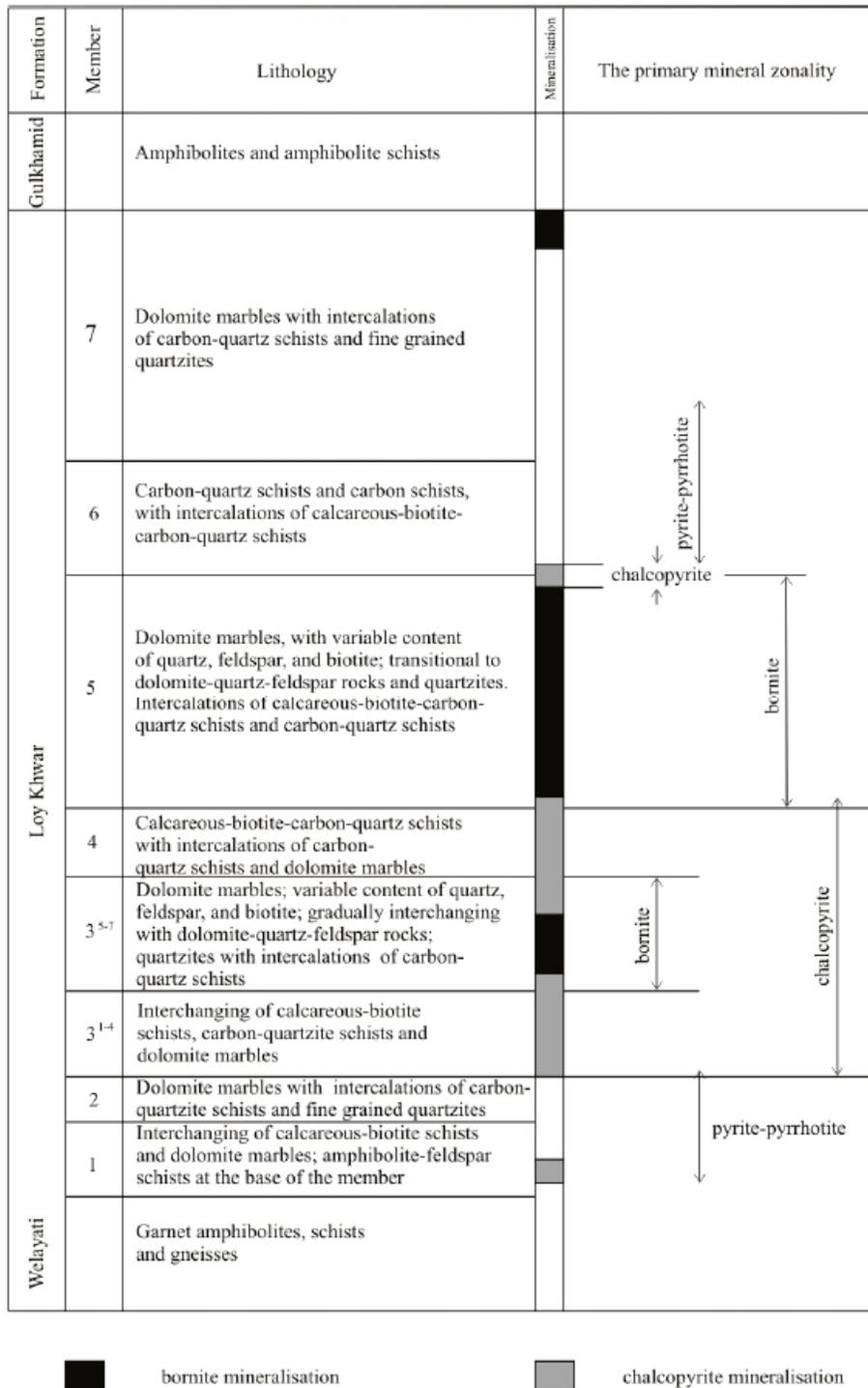


Figure 2.A–5. Diagram showing the detailed stratigraphy of the Loy Kwar Formation as described by the British Geological Survey (2005a) at the Aynak deposit and primary mineral zonation of the copper-cobalt orebodies (British Geological Survey, 2005a, after Zaycev and others, 1988).

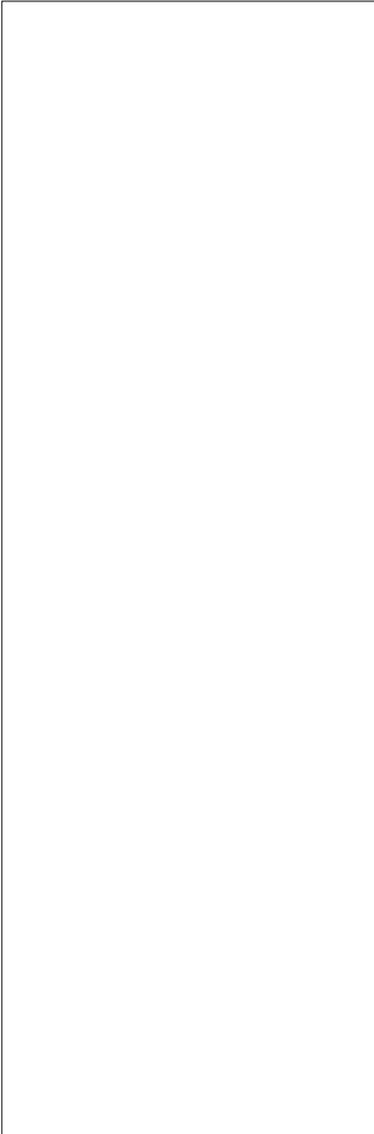
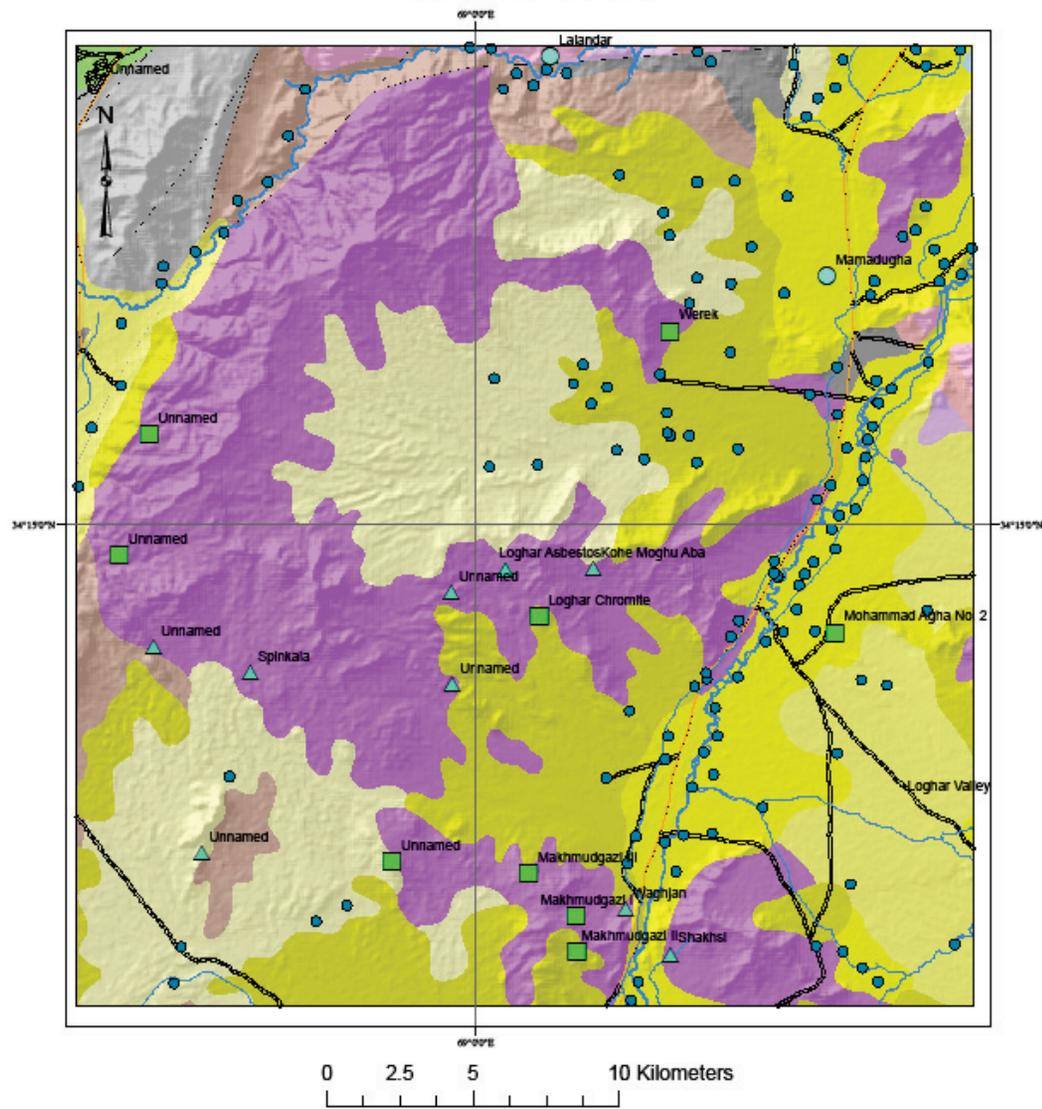


Figure 2A-6. Map showing the geology and location of podiform chromite, asbestos, and talc-magnesite occurrences in the Logar Ophiolite Complex. Geology from Russian sources (Peters and others, 2007).



Figure 2A–7. Landsat TM imagery showing the Logar Ophiolite Complex.

Deposits of the reduced-facies subtype (model 30b.1; Cox and others, 2003), also termed copper-shale or stratiform copper deposits, are hosted by reduced-facies marine or lacustrine rocks, such as green, black, or gray shale; siltstone; thinly-laminated tidal facies or reefoid carbonate rocks; and dolomitic shale. The deposits consist of stratabound, disseminated copper sulfide minerals that occur in reduced-facies sedimentary rocks, which overlie, or are interbedded with, redbed sedimentary sequences or subaerial basalt flows. Copper is mobilized in the redbeds by oxidized brines and is derived from reduction of sulfate in marine or lacustrine sedimentary rocks (Davidson, 1965). Fine-grained clastic rocks and carbonate rocks host 69 percent of the deposits and occurrences (Lindsey, 1982; Cox and others, 2003). Organic carbon and finely disseminated pyrite are common constituents. Host rocks for 16 percent of the occurrences are carbonaceous, bituminous, algal, or stromatolitic. Thick, subaerial basalt flows are sources of copper in a few deposits (Brown, 1984), and evaporite beds are sources of brine for many deposits.

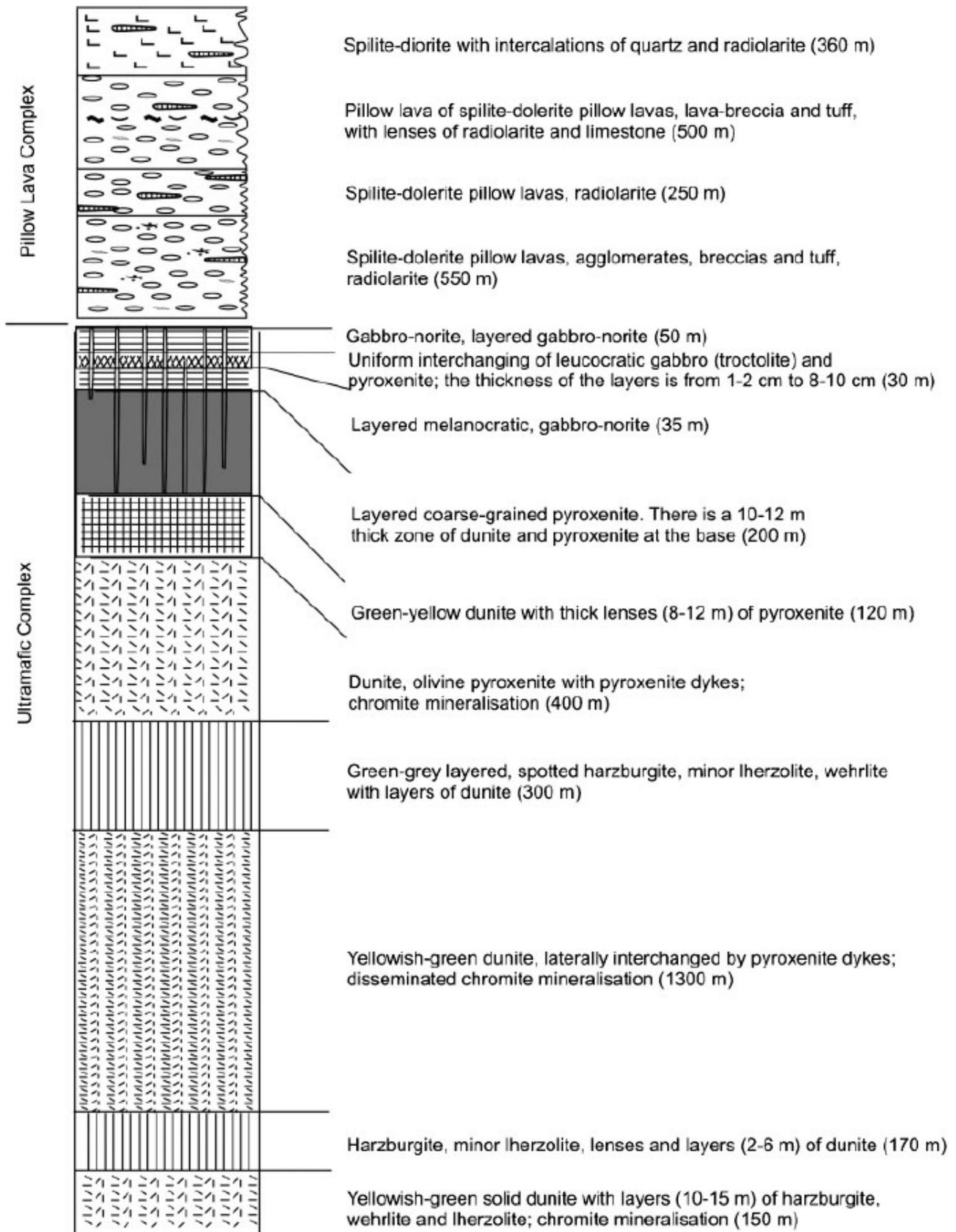
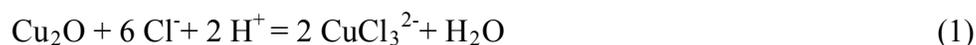


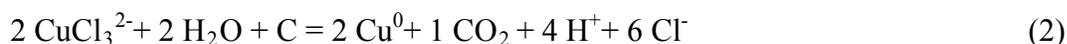
Figure 2A-8. Lithological section through the ultramafic complex and pillow lava complex of the LOC (Benham and others, 2009, after Nevretdinov and Mirzamon, 1979).

The following summary of the process leading to the formation of a sediment-hosted copper deposit is based on Cox and others (2003). Such deposits are formed by fluid mixing in permeable sedimentary and (more rarely) volcanic rocks. Two fluids are involved: an oxidized brine carrying copper as a chloride complex, and a reduced fluid, commonly formed in the presence of anaerobic sulfate-reducing bacteria. For a sediment-hosted copper deposit to form, four conditions are required:

1. An oxidized source rock must be present. This rock must be hematite stable and must contain ferromagnesian minerals or mafic rock fragments from which copper can be leached. In Zambia, erosion of an early formed porphyry copper deposit is thought to have contributed copper to the source rock. Typical source rocks are continental red sandstone, shale, conglomerate, and subaerial volcanic rocks. Marine volcanic rocks are unsuitable as source rocks, because they have not degassed their volatile components. The reduced sulfur, which is contained in marine volcanic rocks, precludes the formation of a hematite-stable environment. Leaching of copper from the source rock at moderately low pH may be described by equation 1.



2. Following equation 1, a source of brine must be present that mobilizes copper. Evaporites are commonly interbedded with redbeds and act as brine sources, but any sedimentary environment in which evaporation exceeds rainfall will produce brines. Brines may also form by evaporation of sea water where connection with the open sea is restricted, as in rift valleys. The brines are generally rich in sodium, because other cations, potassium, calcium, and magnesium, are removed during the formation of clays, sulfates, and carbonates. Davidson (1965) directed attention to the coincidence of evaporite deposits with Phanerozoic stratabound sediment-hosted copper deposits in many parts of the world, and proposed that brine derived from evaporites was the transporting medium for copper and other metals.
3. A source of reduced fluid to precipitate copper and form a deposit must be present. The chemistry of brine formation, as well as copper mobilization and precipitation, was described by Rose (1976) and Rose and Bianchi-Mosquera (1993). Reduced fluids can be derived from organic-rich shales and carbonate rocks, from pockets of liquid or gaseous hydrocarbons in the host sediments, or from any sedimentary fluid in equilibrium with pyrite. In equation 2, copper-rich brine contacts organic material and produces native copper.



Note that HCl appears on the right of this equation and others below. This enables the solution of carbonates and the replacement of calcite cement by native copper.

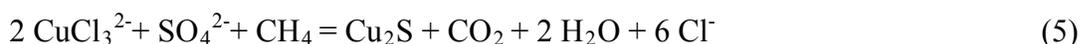
Sulfide in the form of finely disseminated pyrite is commonly found in reduced host sediments. The amount of pyrite in typical black shale is insufficient to supply all of the sulfur in high-grade copper deposits. A more abundant source of sulfide is from reduction of sulfate by carbonaceous material, promoted by bacterial activity in the sediment (Sweeney and Binda, 1989) (eq. 3).



Reaction of chloride complex with sulfide produces chalcocite



Sulfate ion is commonly abundant in brines derived from evaporates and may accompany copper-rich oxidized solutions. The following reaction (eq. 5) results when and where the brine mixes with reduced fluids:



Action of sulfate-reducing bacteria is required to drive this reaction at near-surface temperatures.

4. Conditions must be favorable for fluid mixing. Haynes (1986a,b) concluded that most sulfide ores are precipitated within 50 centimeters (cm) of the sediment-water interface, because bacterial sulfate reduction below this depth is inhibited. Prelithification permeability in shale provides bedding-parallel sites for fluid mixing. Fluid pressures derived from sediment compaction is an important factor in fluid mixing, and deposits are most commonly situated at basin margins where mixing is most likely to take place.

Faulting or folding may produce a hydraulic head that causes one fluid to invade the site of another. Disruption of sedimentary sequences by salt intrusion can also promote fluid mixing (Jowett, 1986; Avila-Salinas, 1990; Ruan and others, 1991).

A permeable host rock or other open space must be present in which the fluids can mix. Intergranular space in fine-grained sediments prior to compaction and lithification is a common site for deposition. Solution cavities in carbonate rocks are less common depositional sites (MacKevett and others, 1997). If any of these four conditions are not met, a deposit will not form, even in the most favorable rock environments (Haynes, 1986a,b; Sverjensky, 1987, 1989; Ruffell and others, 1997; Cox and others, 2003; Hitzman and others, 2005).

Many of the most important sediment-hosted copper deposits formed during the metallogenic period of the Neoproterozoic when most of the world's continental masses were joined in the Rodinia supercontinent (Laznika, 1981; Kirkham, 1989; Kirkham and others, 1994). No Archean deposits are known. The Upper Proterozoic rocks and, especially, Neoproterozoic rocks are the most productive. Permian rocks in Europe and Lower Carboniferous rocks in Central Asia are less important. Other small deposits are found throughout the Phanerozoic.

2A.3.1 Economic Geology

The characteristics of sediment-hosted copper-cobalt deposits in the Aynak AOI are best exemplified by features of the Aynak deposit. The Aynak deposit is hosted in rocks of the Loy Kwar and Gulkhamid Formations that are folded into a complex asymmetric anticline. The exposed parts are about 4 km long and up to 2.5 km thick. As a result of folding, the Aynak deposit is divided into two parts, with the Central Aynak zone located on the shallow-dipping eastern limb of the Aynak anticline and the Western Aynak zone lying in the western end of the structure (Gusev and others, 1979; Chernov and Fenogenov, 1980; Yashchinin and Giruval', 1981; Zaycev and others, 1988; Akhmedi, 1992) (fig. 2A–9).

Two types of ores are known: the bornite type (with subordinate chalcocite), which makes up the main orebody, and the chalcopyrite type, which is present above and below the main orebody. Transitions between the two ore types display a rhythmic zoning, corresponding to the compositional layering of the sedimentary host rocks. The upper parts of the orebody are hosted within carbonaceous quartz-sericite-biotite schists, sandstones, and breccia, and they contain chalcopyrite, pyrite with sphalerite, and molybdenite. This upper part is underlain by sandstone, conglomerate, breccia, and dolomite, and it is dominated by bornite with lesser chalcopyrite, magnetite, molybdenite, and cobaltite. The lower parts of the orebody are hosted in carbonaceous quartz-dolomite schists with breccia, and they contain chalcopyrite and pyrrhotite with lesser pyrite, cobaltite, siegenite, and sphalerite (Yurgenson and others, 1981).

Cobalt concentrations in the Aynak copper ores that contain cobaltite range from thousandths of a percent to 0.3 percent cobalt. Cobalt minerals are present mainly in the chalcopyrite ores, pyrite-chalcopyrite, and bornite-chalcopyrite ores, where concentrations of cobalt are between 0.015 to 0.018 percent cobalt. Cobaltite, the most common cobalt mineral in the deposit, occurs as dispersed disseminated crystals and aggregates that are 0.05 to 5 millimeters (mm) in size. The main occurrences of cobaltite are in the lower parts of the main ore body in chalcopyrite ores. Cobaltite also is present in the upper parts of the main orebody. Cobaltite in the bornite-chalcopyrite ores is associated with linneite, smaltite, carrolite, and cobaltpentlandite. Spatial distribution of cobalt minerals in the orebody

is related to the compositional variation of the layers in the host rocks and, therefore, also with the zoning of the copper minerals (Yurgenson and others, 1985).

2A.3.2 Greater Aynak Subarea

2A.3.2.1 Exploration History

The Aynak deposit and the surrounding areas were explored in the 1960s and 1970s. The first copper occurrences in the Darband area were discovered in 1971 (Denikaev and others, 1971). The main exploration work in the Aynak area started in 1974 and ended in 1978. In addition to drilling, geochemistry and ground geophysical methods were employed. During the same time period, about 40 prospects with similar characteristics were identified, some that have small measured or estimated resources (Afghanistan Geological Survey, 2006a).

2A.3.2.2 Known Deposits

Aynak, the largest and best known sediment-hosted copper deposit in Afghanistan, is a world-class copper orebody located about 30 km southeast of Kabul. The copper mineralization is stratabound and consists primarily of chalcopyrite and bornite disseminated in dolomitic marble and quartz-biotite-dolomite schist of the Neoproterozoic (Vendian)-Lower Cambrian Loy Khwar Formation. Two major ore zones at Aynak Central and Aynak West were delineated by more than 30,000 m of drilling. (Plotnikov and Slozhenikin, 1968; Slavina and others, 1972; Chmyrev and others, 1976; Chmyrev and Azmi, 1977; Sidiki, 1978; Yurgenson and others, 1981, 1985).

The Aynak orebody can be classified as a sediment-hosted copper deposit, that is believed to have been formed by reactions between evaporitic brines and seawater circulating through underlying volcanic rocks that supplied the copper in the deposit. Some of the limestones and marls in the Loy Khwar Formation contain abundant carbon, probably former organic material that reacted with ascending solutions to fix copper sulfide minerals.

In addition to the Aynak deposit, numerous other sediment-hosted copper occurrences and prospects are present in the area, such as the Darband and Jawkhar prospects, which are east and north of the Aynak deposit, respectively. Considerable exploration was undertaken by Soviet geologists on a number of these prospects (United Nations Economic and Social Commission for Asia and the Pacific, 1995; Afghanistan Geological Survey, 2006a,b).

A summary of known resources in the Aynak ore field (Abdullah and others, 1977; Ministry of Mines, written commun., 2007) is discussed below and the resources are listed in table 2A-1.

In 2006, the USGS and the AGS conducted a mineral assessment of copper resources in Afghanistan (Ludington and others, 2006; Peters and others, 2007) that resulted in the delineation of an area favorable for the discovery of additional copper deposits in the Aynak AOI. The favorable tract was designated as sedcu01-f1 and contained four separate prospective tracts delineated on the basis of mineral occurrence clustering, geology, and structure. Two of these favorable tracts, sedcu01-p1 Yagh-Darra Ghul-Darra, corresponding to the Yagh-Darra Ghul-Darra subarea, and sedcu01-p2, corresponding to the Kelaghey-Kakhay, Bakhel Charwaz and Kharuti Dawrankhel subareas, are described in this report. Two more, the p3 Aynak, and p4 Jawkhar-Darband-Kuhndara favorable tracts, were designated to the south. Subsequently, the favorable tracts of Aynak and Jawkhar-Darband-Kuhndara were the subject of a mineral tender by the Afghan government, which was awarded to the China Metallurgical Group Corporation. The four prospective tracts contain numerous sediment-hosted copper deposits in addition to Aynak. Each prospective tract may represent a folded surface, where mineralization appears to be concentrated near the crests of complex folds (figs. 2A-10, 2A-11, and 2A-12).

A 5-km-long prospective area (tract sedcu01-p3) was delineated around the Aynak deposit and the Akarkhel deposit to the northwest (figs. 2A–11a and 2A–12a). The Aynak deposit lies in the axis of the east trending Aynak anticline. The tract was drawn to include the stratigraphic extensions of the Aynak anticline.

2A.3.2.3 Aynak-Akarkhel

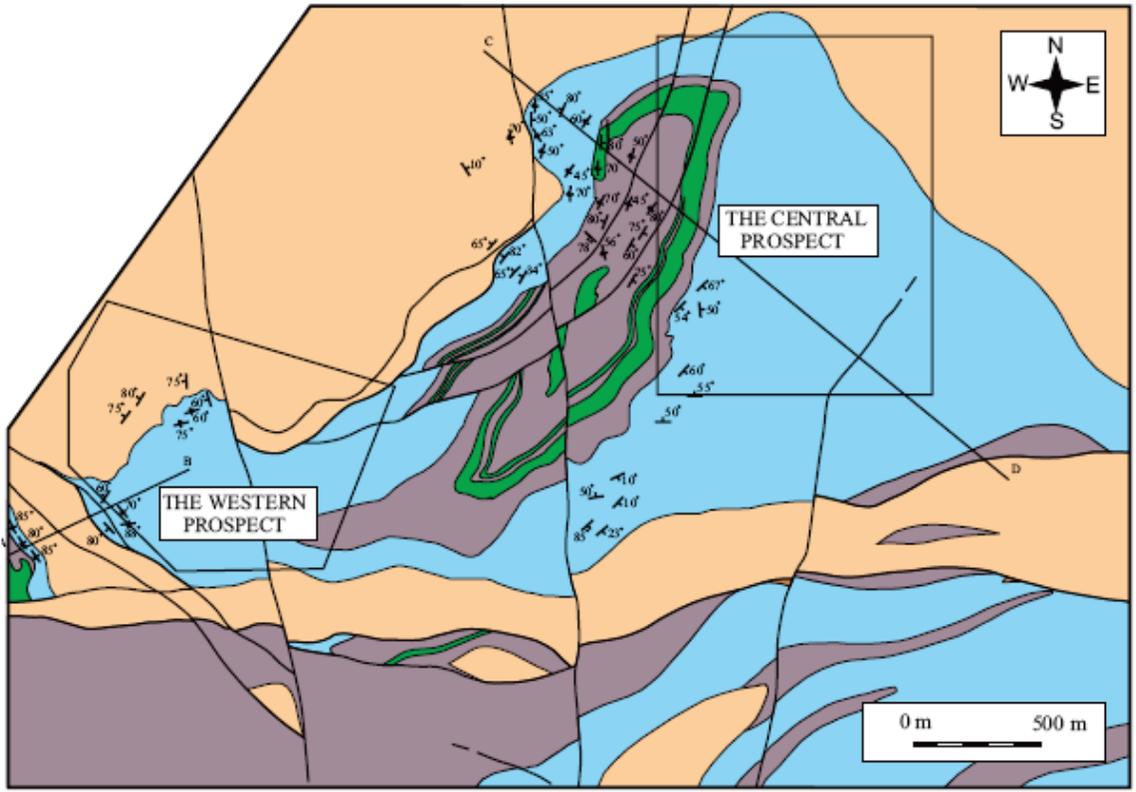
Several resource estimates have been reported for the Aynak deposit, which vary depending on the area estimated, the resource category, data used, and the estimator. Exploration at Aynak includes more than 150 boreholes, 70 trenches, 9 adits, and surface geological and geophysical surveys (Kubatkin and others, 1978; Kolotov and others, 1981; Karim and others, 1992). At a cutoff grade of 0.4 percent copper, the main orebody at Central Aynak extends 1,850 m along strike, 1,200 m downdip, and has a maximum thickness of 210 m. Based on a similar cutoff grade, the main body at Western Aynak extends 2,230 m along strike, 1,640 m downdip, and has a maximum thickness of 214 m (Chmyrev and others, 1977; Akocdzhanyan and others, 1977; Yashchinin and others, 1978, fig. 2A–9). “Industrial reserves” in the central sector are 4.83 million metric tons (Mt) with 2.37 percent copper using a 0.7 percent copper cutoff. Total reserve estimation of the Central Zone is 6.8 million metric tons of copper with an average copper content of 1.73 percent copper and a cutoff at 0.4 percent copper. Industrial reserve estimation of the western sector is 1.4 Mt of copper, with an average copper content of 1.61 percent and a cutoff grade of 0.4 percent copper. Total reserves in the western sector are 4.55 Mt with an average copper content of 1.53 percent copper. The total resources at Aynak (central and western) is 11.33 Mt of copper with an average copper content of 1.64 percent at a 0.4 percent copper cutoff grade, corresponding to 690.9 Mt of ore (Ministry of Mines, written commun. 2007; Peters and others, 2007). Work conducted by the British Geologic Survey resulted in a resource estimation of 240 Mt of ore at 2.3 percent copper and includes several large orebodies and a number of smaller lenses (Afghanistan Geological Survey, 2006a,b).

The Akarkhel occurrence lies about 4 km northwest of Aynak and consists of a 50- to 60-m-thick zone of unknown length containing chalcopyrite, chalcocite, and malachite hosted in slate (Shcherbina and others, 1975).

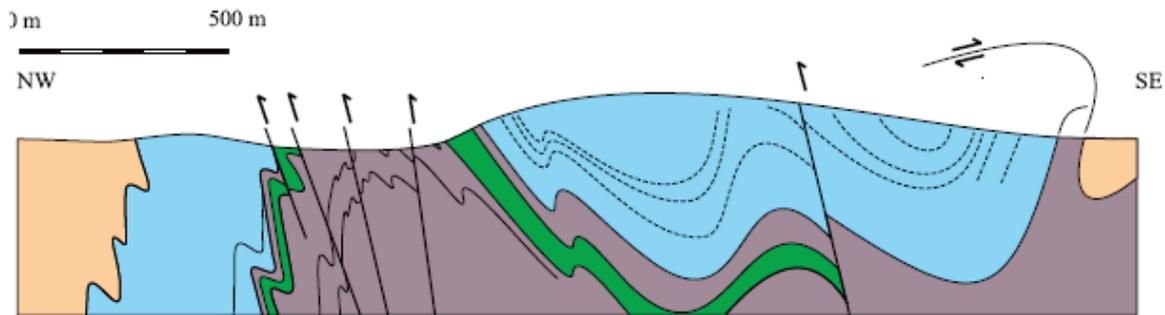
Table 2A–1. Deposits and prospects in the Aynak area with total contained copper, copper grade, and ore tonnage.

[From Abdullah and others, 1977; Peters and others, 2007]

Deposit	Copper, in metric tons	Grade weight, percent copper	Ore, in million metric tons
Aynak	11,330,000	1.64	690.8
Jawkhar	164,800	0.33–2.56	11.4
Darband	665,700	0.79	84.3
Taghar	86,800	0.18	48.2
Katasang	42,100	1.04	3.0
Dashtak	8,200	1.67	0.5
Kelaghey	43,000	0.91	4.7
Total	12,340,600	1.46	842.9



Cross section C - D



- Gulkhamid Formation; Vendian - Cambrian
- Loy Khwar Formation; Vendian - Cambrian
- Welayati Formation; Late Proterozoic
- Intrusive rocks; Upper Proterozoic - Lower Paleozoic
- Faults
- Orientation of foliations and bedding planes
- Line of cross section

Cross section A - B

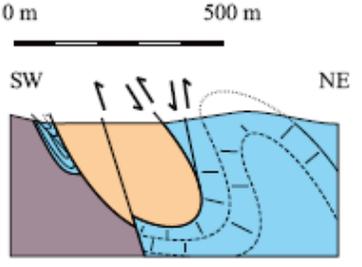


Figure 2A-9. Geologic map and cross-section at the Aynak sediment-hosted copper deposit (Afghanistan Geological Survey, 2006a).

2A.3.2.4 Jawkhar-Darband-Kuhndara

An arcuate 25- to 30-km-long prospective area (tract sedcu01-p4) was delineated along the Logar-Kabul Province boundary to the east of the Aynak deposit (figs. 2A–11*a*, and 2A–12*a*). The outline of the prospective area approximates the area of an inferred antiform (figs. 2A–12*b*) with the nose closing to the east. The tract contains the Jawkhar deposit in the northeastern part, the Darband deposit in the eastern part, and the Khundara occurrence in the western part.

At the Jawkhar (Dzhavkhar, Kawkhar) deposit, fifteen 150- to 440-m-long and 3- to 29-m-thick mineralized zones have average grades ranging from 0.49 to 1.20 percent copper, with a maximum grade of 2.43 percent copper. Mineralization occurs within albitized zones and consists of hypogene, chalcopyrite, and bornite, with auxiliary magnetite, ilmenite, pyrrhotite, and sphalerite. Supergene zones contain bornite, chalcocite, covellite, cuprite, native copper, and malachite. Detailed exploration at Jawkhar included 1:2,000-scale geological mapping, trenching, and the construction of 1,257 m of adits. A total of 1,635 channel samples and 1,191 other types of samples were taken for chemical analysis. This work resulted in the estimation of a resource of 79,700 metric tons (t) of copper with an average grade of 0.74 percent copper. Unfortunately, few exploration records for Jawkhar exist as they were destroyed or lost during the past 20 years (Kutkin and Gusev, 1977). The total resources in the C₂ category for the Jawkhar, Dashtak, Sorbog, and Katasang areas are reported as 164,800 t of copper, with a copper content of between 0.33 and 2.56 percent copper (Ministry of Mines, written commun., 2007).

A number of mineral occurrences occur between the Jawkhar and Darband deposits in the northwestern part of the prospective area (figs. 2A–11*a*, and 2A–12*a*), including the Lalmi-Tanghi, Gezghay copper, Batkehl I and III, and Janguzay IV occurrences. The Lalmi-Tanghi occurrence consists of 200-m-long and 0.2- to 0.4-m-thick stratabound zones hosted within quartz-mica schist grading 1.35 to 3.40 percent copper. The Gezghay copper occurrence consists of 5- to 15-m (up to 300-m)-long, 0.1- to 1.0-m-thick mineralized lenses in micaceous calcareous schist containing quartz veins and veinlets that contain disseminated covellite, chalcocite, and chrysocolla grading 0.13 to 1.0 percent copper. The Batkehl I occurrence is within marbled limestone, quartzite, and biotite schists in four closely spaced zones, which together are 400 to 800 m long, 26 to 32 m thick, and contain disseminated chalcopyrite and malachite grading 0.5 to 1.94 percent copper (Shcherbina and others, 1975). The Batkehl III occurrence is hosted in amphibole-garnet slate in a 400-m-long and 6- to 30-m-thick zone containing disseminated chalcopyrite and covellite grading 0.4 to 2.0 percent copper. The Janguzay IV occurrence is hosted in marbled limestone, amphibolite, and slate and contains five 300- to 500-m-long and up to 6-m-thick zones grading 0.4 to 4.46 percent copper.

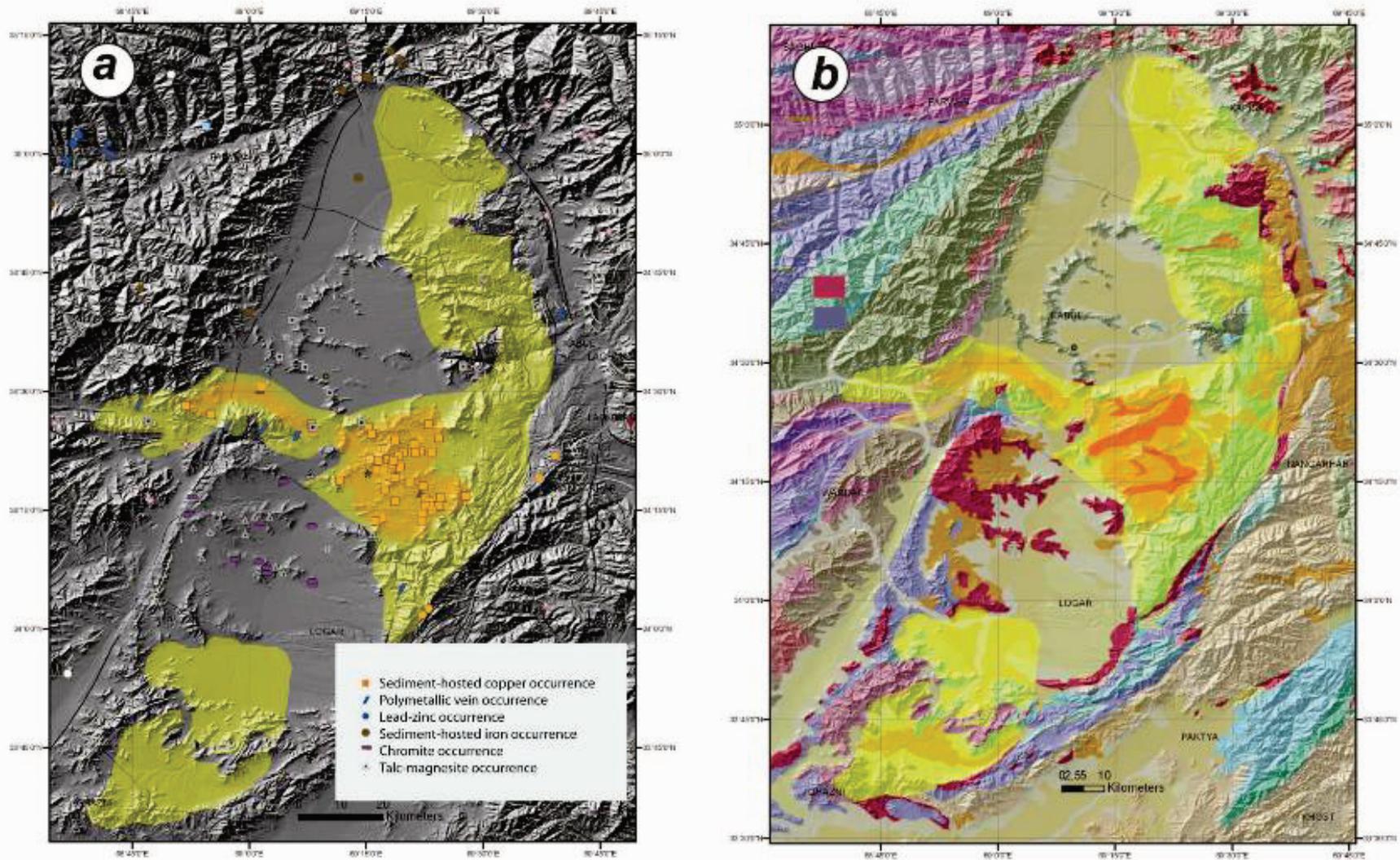


Figure 2A-10. Maps showing the location of the Aynak AOI from Peters and others (2007) (a) Assessment map showing areas of potential and main prospects. (b) Permissive, favorable, and prospective areas for sediment-hosted copper overlain on the geology of Doebrich and Wahl (2006).

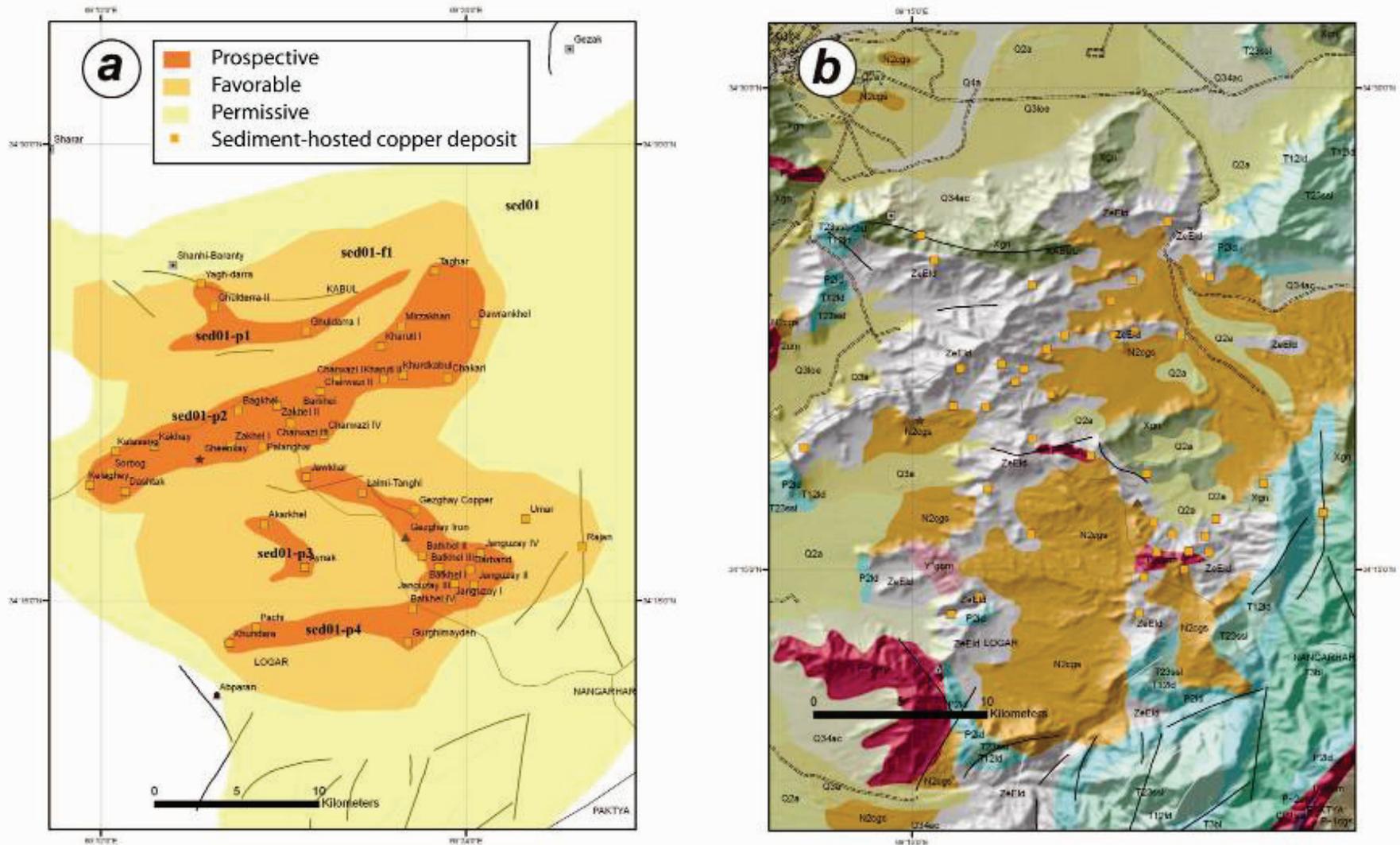


Figure 2A-11. Maps showing location of favorable tract sedcu01-f1 and prospective tracts sedcu01-p1, p2, p3 and p4, Kabul and Logar Provinces. (a) Outline and location of favorable tract sedcu01-f1 and prospective tracts and location of known mineral occurrences and deposits. (b) Geology of tract sedcu01-f2. From Peters and others (2007). Units from Doebrich and Wahl (2006).

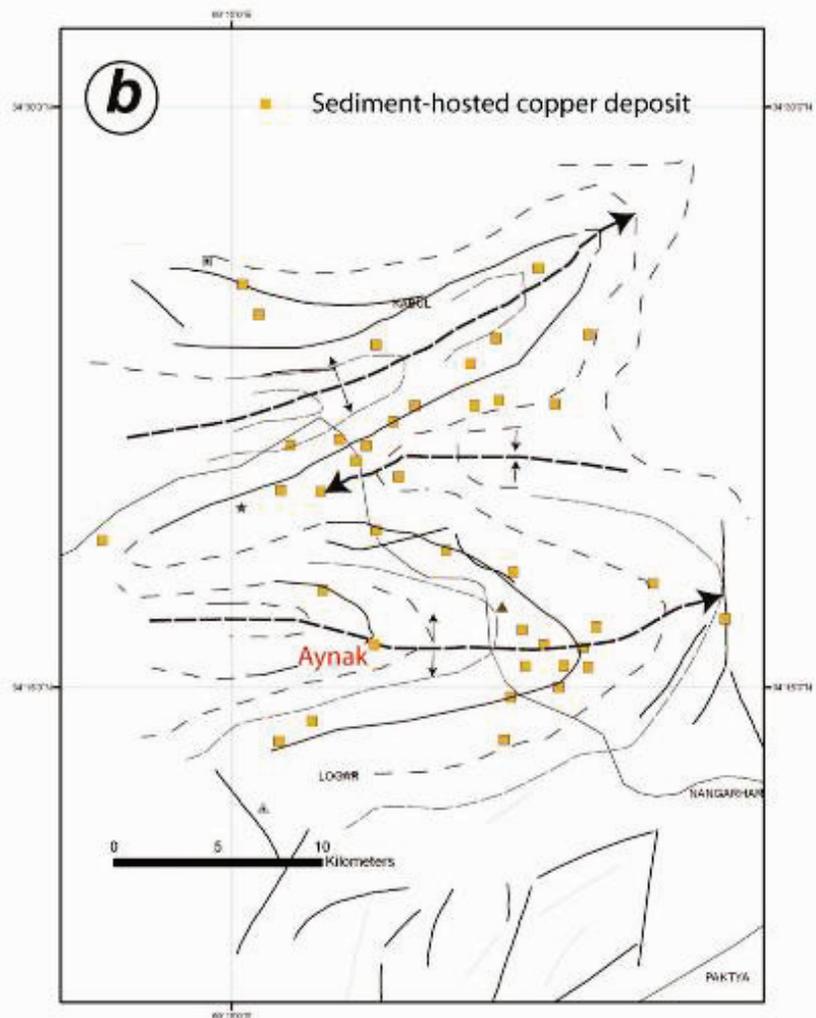
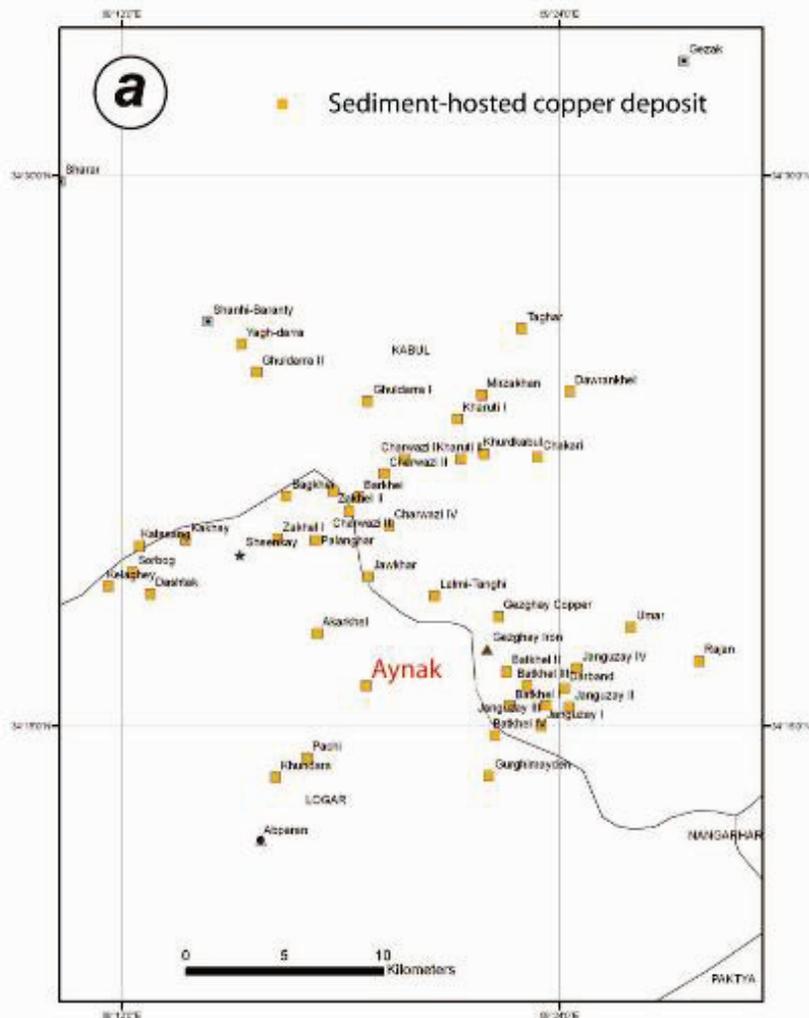


Figure 2A–12. Maps showing location of stratabound copper occurrences in southern Kabul and northern Logar Provinces. (a) Location and names of main occurrences. (b) Structural interpretation of favorable tract sedcu01-f2 on the basis of existing formlines from Russian maps. Dark dotted lines show fold axial planes of antiformal and synformal structures. Grey dashed and solid lines are formlines showing the shape of these structures. Extensive internal folding is present within the rocks and is not shown. From Peters and others (2007).

The Darband copper deposit lies near the crest (or nose) of the inferred Jawkhar-Darband-Kuhundara antiform (figs. 2A–11a, and 2A–12b) that corresponds to the eastern extension of the axial plane of the Aynak anticline. The deposit is hosted in 70 to 80 degrees north-dipping silicified micaceous marble with interbedded biotite-amphibole schist and amphibolite of the Loy Khwar and Welayati Formations, and can be traced for 7,000 m along strike over a width of 100 to 1,000 m (fig. 2A–13). Mineralization at Darband occurs as disseminated-veinlets, and as aggregates containing chalcocite and bornite, with chalcocite, as well as pyrite, pyrrhotite, molybdenite, hematite, magnetite, and minor galena, sphalerite, cobaltite, arsenopyrite, nickel minerals, and gold. Bornite is the dominant ore mineral in the deposit, comprising 67 to 100 volume percent of the sulfide minerals. Supergene copper minerals are also present in the 150- to 200-m-thick oxidized zones, which consist of malachite, cuprite, covellite, azurite, and chrysocolla, gradually changing at depth to a mixed zone of native copper, chalcocite, and cuprite. About 25 stratabound mineralized zones have been delineated. A few zones are discordant and composed of silicified rocks and veinlets of quartz in faults or crush zones. Exploration work enabled division of the area into four prospects, designated Eastern Darband, Central Darband, Western Darband, and Lagernaya. The entire area was mapped at a scale of 1:2,000, and the mineralization was sampled by surface trenches that were initially spaced 100 m apart. Later trenches were 50 m apart. Eleven exploratory adits, totaling 9,062 m in length, were driven into the deposit at the Eastern, Central, and Western Darband prospects. Fifty-seven surface boreholes were drilled with a total length of 8,752 m. Of these, 14 boreholes were drilled in the Lagernaya prospect, and the remainder in Eastern, Central, and Western Darband. This work resulted in an estimate of 84.3 Mt of inferred or possible resources with 665,700 t estimated to contain copper, with an ore grade of 0.79 percent copper, using a cutoff grade of 0.4 percent copper (British Geological Survey, 2005c; Peters and others, 2007). Minchenok and others (1979) (Ministry of Mines, written commun., 2007) indicated that additional resources may be present beneath areas of Neogene sedimentary cover that were not explored (see also Denikaev and others, 1971; Chmyrev and others, 1977).

A cluster of deposits is present south of the Darband deposit within the prospective area, including the Batkehl II and IV, Janguzay I, II, and III, and the Gughimayden stratabound mineral occurrences (figs. 2A–11a, and 2A–12a). The Batkehl II and IV occurrences are hosted in biotite-garnet-amphibolite schists and both contain two zones about 250 to 450 m long and 5 to 9 m thick containing disseminated chalcocite, bornite, covellite, malachite, and azurite grading between 0.69 to 0.96 percent copper. The Janguzay I occurrence is within amphibolite in a 500-m-long and up to 6-m-thick zone grading 2.05 percent copper. The Janguzay II occurrence is within marbled limestone and slate and contains four zones that are 300 to 1,300 m long and 1.5 to 15 m thick grading 1.55 to 3.28 percent copper. The Janguzay III occurrence is within amphibolite and consists of three 300- to 1,200-m long, 1- to 6-m-thick zones grading 0.2 to 3.0 percent copper. The Gughimayden occurrence is a quartz vein in marble that is 30 to 40 m long and 2 to 3 m thick, containing malachite and chalcocite that grades 0.84 percent copper (Shcherbina and others, 1975).

The southwestern part of the Jawkhar-Darband-Kuhundara antiform between the Gughimayden, Khundara, and Pachi mineral occurrences is covered by Neogene sediments. The Pachi occurrence, within strongly albitized rocks, is an 800-m-long, 4- to 49-m-thick zone and grades 0.9 to 1.6 percent copper (Peters and others, 2007). The Khundara occurrence is within slate and marble, and consists of three mineralized zones that are between 200 to 300 m long and 10 to 20 m thick and grades 0.8 to 1.6 percent copper (figs. 2A–11a, and 2A–12a; Peters and others, 2007).

2A.3.3 Kelaghey-Kakhay Subarea

The Kelaghey-Kakhay copper subarea lies in the northern part of the Aynak copper district (fig. 2A–4). Surface exploration and mapping have identified signs of mineralization along a northeast trending zone in the central parts of the subarea coincident with a northeasterly trending range of hills

(figs. 2A–14 and 2A–15). The area may contain sediment-hosted copper deposits similar to Aynak at depth. A total of five separate occurrences have been identified.

The Darband copper deposit

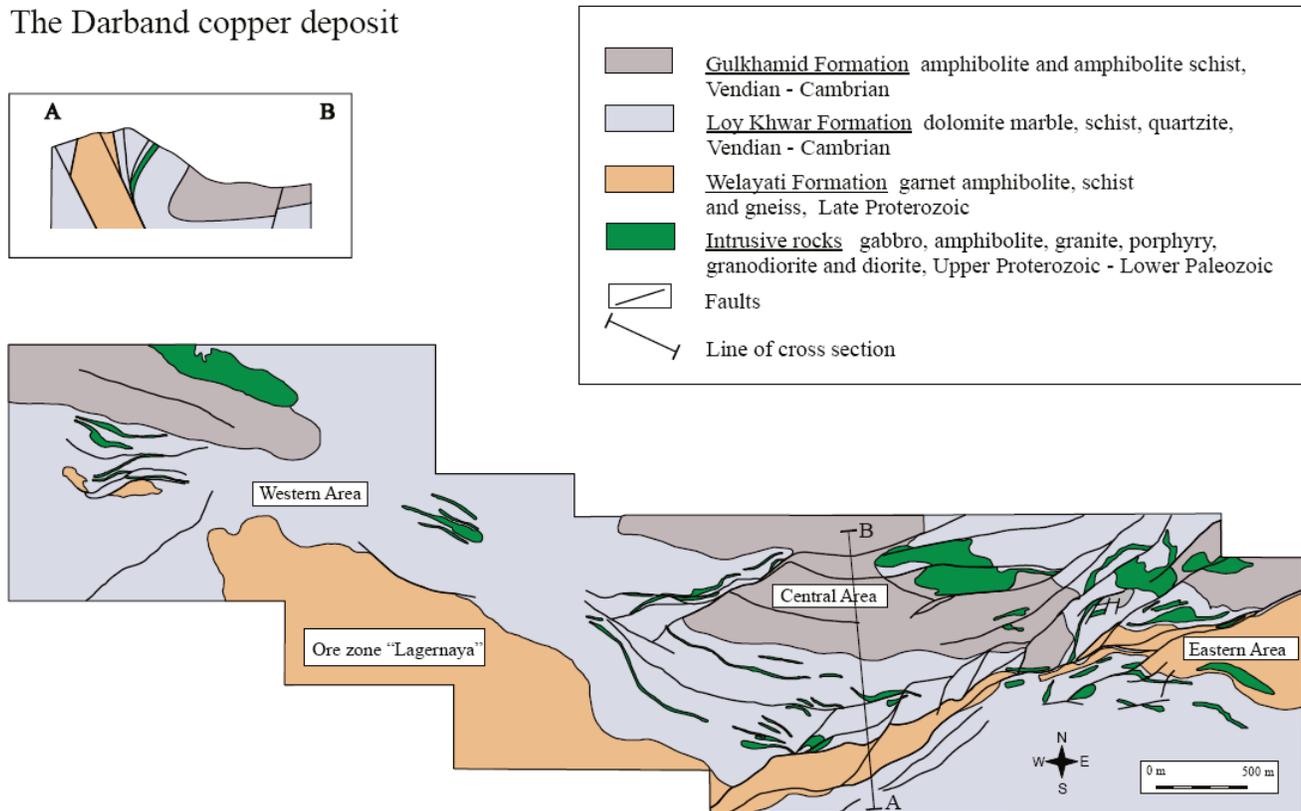


Figure 2A–13. Simplified geologic map and cross-section of the Darband sediment-hosted copper deposit (British Geological Survey, 2005c, and Afghanistan Geological Survey, 2006b, based upon Minchenok and others, 1977).

2A.3.3.1 Location

The Kelaghey-Kakhay copper-cobalt subarea is located 18 to 20 km south of Kabul in the Musavya District of Kabul Province and the Muhammad Agh District of Logar Province. An unimproved (tertiary) road accesses the villages of Katasang, Suryawun, and Shadkhana along the north side of the range. The villages of Dashtak (Loy Kalay) and Cagay are located in the valley on the south side of the range (fig. 2A–14).

2A.3.3.2 Previous Work

The Kelaghey-Kakhay copper-cobalt subarea is in the southwestern part of prospective tract sedcu01-p2 (Peters and others, 2007; figs. 2A–11a and 2A–12a). The Kelaghey, Sorbog, Katasand, and Dashtak occurrences were evaluated by Kutkin and Gusev (1977).

2A.3.3.3 Geology

The geology of the subarea (as mapped by Bohannon, 2010b) is dominated by the Welayati Formation which makes up most of the outcropping rocks along the northeast trending range of hills that cuts through the center of the subarea (fig. 2A–14, 2A–15). This suggests that the dominant lithologies should be amphibolite facies schist, amphibolite, plagiogneisses, quartzites, and marbles. An outcrop in

the southern valley floor at the Dashtak occurrence is mapped as the Loy Kwar Formation, and a thin strip of Loy Kwar Formation rocks are mapped along the southern margin of the range just to the south of the Kelaghey and Sorbog occurrences. Outcrops of undifferentiated Weyalati and Loy Kwar Formation rocks occupy the ridge crest between the Katasang and Sorbog occurrences and along the ridge crest at the Kakhay occurrence to the northeast as well as a large east-northeast trending band along the northern flank of the range. Presumably, these rocks are represented by the lithologies of the Weyalati Formation mixed in with the repetitive layers of dolomitic marble, carbonaceous quartz schist, and quartz-biotite-dolomite schist that characterize the Loy Kwar Formation. A thin band of (assumed) Neoproterozoic intrusive rocks is exposed along the northeastern part of the range just north of the subarea boundary.

2A.3.3.4 Known Deposits

No known deposits are present in the Kelaghey-Kakhay subarea.

2A.3.3.5 Prospects and Anomalies

The Kelaghey (Kalagay) copper occurrence lies in the far western part of the subarea. Limited exploration included geological mapping at 1:2,000 scale, trenching, and geochemical sampling. Mineralization is within quartzite and consists of disseminated bornite, chalcopyrite, and minor malachite hosted in dolomite marble and quartzite over a 1.5- by 40-m-size area. One prospecting trench contains an average grade of 0.79 percent copper over 7.1 m (Shcherbina and others, 1975; Kutkin and Gusev, 1977).

Northeast of Kelaghey, the Sorbog (Sar Bagh) occurrence received limited exploration including 1:2,000-scale geological mapping, trenching, and geochemical sampling. The 540-m-long and 11.8- to 49-m-thick (average 22.3 m) mineralized zone is hosted within albitized marble. Mineralization consists of disseminated bornite, chalcopyrite, chalcocite, covellite, and minor malachite. Resources were estimated to be 34,800 t of copper at an average grade of 0.91 percent copper and a cutoff grade of 0.4 percent copper (Kutkin and Gusev, 1977). The Soviet survey concluded that the occurrence was “noncommercial.”

The Katasang occurrence is an 800-m-long, 3.6- to 13.8-m-thick (average 7.2 m) mineralized zone within steeply dipping, albitized marble containing disseminated bornite, chalcopyrite, chalcocite, and minor malachite. Limited exploration conducted at this site included 1:2,000-scale geological mapping, trenching, and geochemical sampling, and resulted in the calculation of a resource of 42,100 t of copper at an average grade of 1.04 percent copper (Kutkin and Gusev, 1977). The occurrence was classified as “noncommercial,” although more detailed exploration at depth was recommended.

The Dashtak occurrence lies east of Kelaghey and is hosted within dolomitic marble in a 60- to 200-m-long and 1.2- to 17.3-m-thick oxidized zone that grades 1.67 percent copper containing bornite, chalcopyrite, and pyrite with secondary chalcocite, covellite, and cuprite. Exploration conducted at this site included 1:2,000-scale geological mapping, trenching, drilling of two boreholes totaling 212.6 m, and channel and core sampling. A resource was estimated to be 8,200 t of copper at an average grade of 1.67 percent copper. Soviet geologists concluded that the occurrence has limited importance on its own but may have potential if the Aynak Deposit were to be developed.

The Kakhay occurrence is located in the northeastern end of the subarea on the south side of the range facing the village of Cagay. Limited exploration included geological mapping at 1:2 000 scale, trenching, and geochemical sampling. Mineralization is represented by disseminated bornite, chalcopyrite, and minor malachite. Kakhay consists of two mineralized zones 200 and 250 m long and 2.0 and 2.3 m thick, with average copper contents of 0.58 and 1.05 percent, respectively, and which are considered to have no economic importance (Shcherbina and others, 1975; Kutkin and Gusev, 1977).

2A.3.4 Bakhel-Charwaz Subarea

The Bakhel-Charwaz copper-cobalt subarea lies in the northern part of the Aynak copper district (fig. 2A–4). Surface exploration and mapping has identified signs of mineralization along an eastern trending zone for about 8 km in the central part and also along the southeastern margin of the subarea (figs. 2A–15 and 2A–16). The area may contain sediment-hosted copper deposits similar to Aynak at depth. A total of nine separate occurrences have been identified.

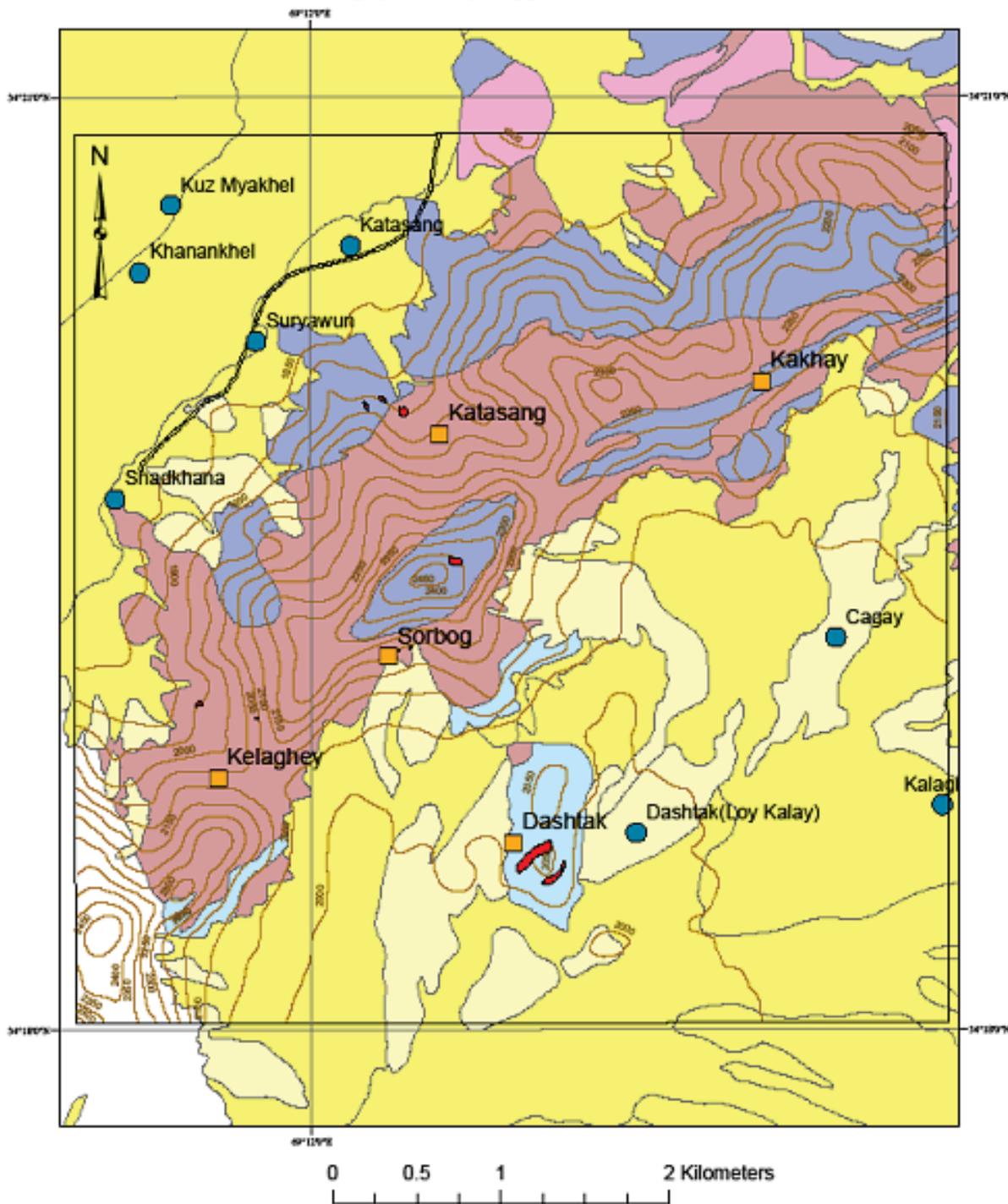


Figure 2A–14. Geology and mineral occurrences of the Kelaghy-Kakhay copper-cobalt subarea. From Bohannon (2010b).

- 50 m Contour Intervals (ASTER_GDEM)
- ===== Tertiary
- Villages
- Exploration areas
- Trenches
- sediment-hosted Cu
- Fault, normal, buried
- Fault, normal, inferred
- Fault, normal, proven
- Fault, thrust, inferred
- Fault, thrust, proven

Geology 1:100,000 scale

LITHOSTRATIGRAPHIC UNITS

- Surficial series
- Lataband series
- Quartz-rich intrusion
- Intrusions of Anyak District
- Intrusive amphibolite
- Gulkhamid Formation
- Gulkhamid and Loy Khwar Formations undifferentiated
- Loy Khwar Formation
- Welayati Formation
- Kharog Formation
- Sherdarwaza Formation

Figure 2A–15. Legend for figures showing the geology and mineral occurrences of the Kelaghy-Kakhay, Bakhel-Charwaz, Yagh-Darra Ghul-Darra, and Kharuti-Dawrankhel copper-cobalt subareas.

2A.3.4.1 Location

The Bakhel-Charwaz subarea is located about 10 to 15 km southeast of the City of Kabul in the Musavi and Khaki Jabbar Districts of the Kabul Province and the Muhammad Agh District of the Logar Province; no roads exist in this subarea. The mineral occurrences are located in a mountainous region near the villages of Zakhel and Baghgay (figs. 2A–16 and 2A–17). Surface workings of the Bagkhei and Zakhel II occurrences are distributed around the head of the valley to the north of the village of Zakhel, and the Zakhel I and Palanghar occurrences are located to the southwest and southeast of the village, respectively. The Barkhei, Charwazi III, and Charwazi IV occurrences are located in the mountains to the north, northwest, and southeast of the village of Baghgay. The Charwazi II and Charwazi I occurrences are located in the far northeasternmost corner of the subarea.

2A.3.4.2 Previous Work

The Bakhel-Charwaz copper-cobalt subarea is in the central part of prospective tract sedcu01-p2 (Peters and others, 2007; figs. 2A–11a and 2A–12a). The Zakhel I and II occurrences have received limited exploration, including geological mapping at 1:2 000 scale, trenching, and geochemical sampling. Limited exploration at Palanghar consisted of 1:2,000-scale geological mapping, trenching, and geochemical sampling.

2A.3.4.3 Geology

The geology of the subarea (as mapped by Bohannon, 2010b) is dominated by outcrop of undifferentiated Weyalati and Loy Kwar Formation rocks, especially in the northern, central, and eastern parts of the subarea (fig. 2A–16). This indicates that the dominant lithologies are probably amphibolite facies schist, amphibolite, plagiogneisses, quartzites, and marbles of the Weyalati Formation and repetitive layers of dolomitic marble, carbonaceous quartz schist, and quartz-biotite-dolomite schist of the Loy Kwar Formation (fig. 2A–18).

Rocks of the Weyalati Formation underlie the undifferentiated Weyalati and Loy Kwar Formations in the southwestern quadrant of the subarea at and west of the Zakhel I occurrence, southwest of the Bagkhei occurrence, and surrounding the Palanghar occurrence in the south-central part of the subarea. A thin, east-west trending band of Weyalati Formation is present between the Bagkhei, Zakhel II, and Barkhei occurrences in the center of the subarea and in an area along the northern border of the subarea to the west of the Charwazi I and II occurrences. Neoproterozoic intrusive rocks are present to a greater degree in the Bakhel-Charwaz subarea and outcrop prominently in the west-central, central, and northeastern parts of the subarea. Neoproterozoic intrusive rocks are interbedded with the east-west trending strip of Weyalati Formation at the head of the valley between the Bagkhei and Zakhel II occurrences where they appear to be associated with most of the surface workings. A large mass of Neoproterozoic intrusive rocks to the west of the village of Baghgay may be associated with surface workings in the vicinity of the Charwazi III occurrence.

A normal fault of unknown vertical displacement or direction of throw projects diagonally through the subarea for about 7 km along a northeastern trend from the Zakhel I occurrence through the northeastern corner of the subarea. All nine of the known occurrences in the subarea are distributed within a few kilometers of the fault, and the fault and the outcrop pattern of the mapped units in the subarea follow a northeasterly trend consistent with the perceived pattern of folding in the north Aynak region (Peters and others, 2007; fig. 2A–12b).

2A.3.4.4 Known Deposits

No known deposits are present in the Bakhel-Charwaz subarea.

2A.3.4.5 Prospects and Anomalies

The Bakhel-Charwaz subarea contains nine occurrences. From southwest to northeast they are named Zakhel I, Palanghar, Bagkhei, Barkhei, Charwazi III, Zakhel II, Charwazi IV, Charwazi II, and Charwazi I.

The Zakhel, Palanghar, Bagkhei, Barkhei, and Charwazi occurrences lie north of the Jawkhar deposit. The Zakhel I occurrence consists of two copper-bearing zones, 1 km long and 20 to 100 m wide, hosted in marble of Vendian-Cambrian age (presumably the Loy Kwar Formation). Sampled intervals of 0.34 percent copper over 25 m, 0.53 percent copper over 90 m, and 1.06 percent copper over 40 m were reported. The Zakhel II occurrence consists of two irregularly mineralized zones, one 500 m long and 2 to 10 m wide, and the second 1,500 m long and 20 to 35 m wide hosted in marble of Vendian-Cambrian age (presumably the Loy Kwar Formation). Sampling in one of these zones determined copper values over an interval of 27 m grading 0.5 percent, and an interval of 32 m grading 0.59 percent. The mineralized zones at both of the Zakhel occurrences contain malachite with bornite, chalcopyrite, and rare chalcocite and covellite (Shcherbina and others, 1975). Only a few samples contained copper concentrations above 1.3 percent copper, and the occurrences were considered to have no economic importance by Kutkin and Gusev (1977).

The Palanghar occurrence consists of a 750-m-long and 6.1- to 16.1-m-wide (average 11.4 m) stratiform zone containing disseminated chalcopyrite, chalcocite, and rare malachite hosted in dolomite

marble and carbonaceous-mica-quartz schist. Details reported by Abdullah and others (1977) indicate that three copper-bearing zones 2 to 8 m wide and 70, 150, and 450 m long are present and that copper values in these zones average 0.55 to 3.18 percent. A resource in a central zone (up to 1 m depth) of 187 t of copper was reported based upon limited exploration consisting of 1:2,000-scale geological mapping, trenching, and geochemical sampling. The occurrence was considered to have no economic importance (Kutkin and Gusev, 1977).

The Barkhei (Baghgay) occurrence is hosted in marble and carbonate-mica schist of Vendian-Cambrian age. It consists of two copper-bearing zones, 3 to 10 m in thickness and 400 and 500 m in length. In these zones, a 5-m interval contains 1.45 percent copper and a 4-m interval, 0.34 percent copper (Shcherbina and others, 1975; Abdullah and others, 1977).

The Charwazi (Charwozi) occurrences are hosted in greenschist, slate and marble of Vendian-Cambrian age. The Charwazi I occurrence consists of a copper-bearing zone 8 m wide and 100 to 150 m long averaging 1.3 percent copper. The Charwazi II occurrence consists of a copper-bearing zone 3 to 5 m wide and 150 m long, with a 5-m interval containing 1.89 percent copper. The Charwazi III occurrence consists of a copper-bearing zone 1 m thick and 300 m long containing 0.48 percent copper. The Charwazi IV occurrence consists of a copper-bearing zone between 5 and 15 m wide and 400 m in strike length averaging 0.26 percent copper (Shcherbina and others, 1975; Abdullah and others, 1977).

2A.3.5 Kharuti-Dawrankhel Subarea

The Kharuti-Dawrankhel copper-cobalt subarea lies in the northern part of the Aynak copper district (fig. 2A-4). Surface exploration and mapping has identified mineralization along an east-west trending 4-km-long range of hills in the south-central part, in the valley floor in the central part, and along the southwestern flank of the mountain range in the northeastern part of the subarea (figs. 2A-15 and 2A-19). The area may contain sediment-hosted copper deposits similar to Aynak at depth. A total of seven separate occurrences have been identified.

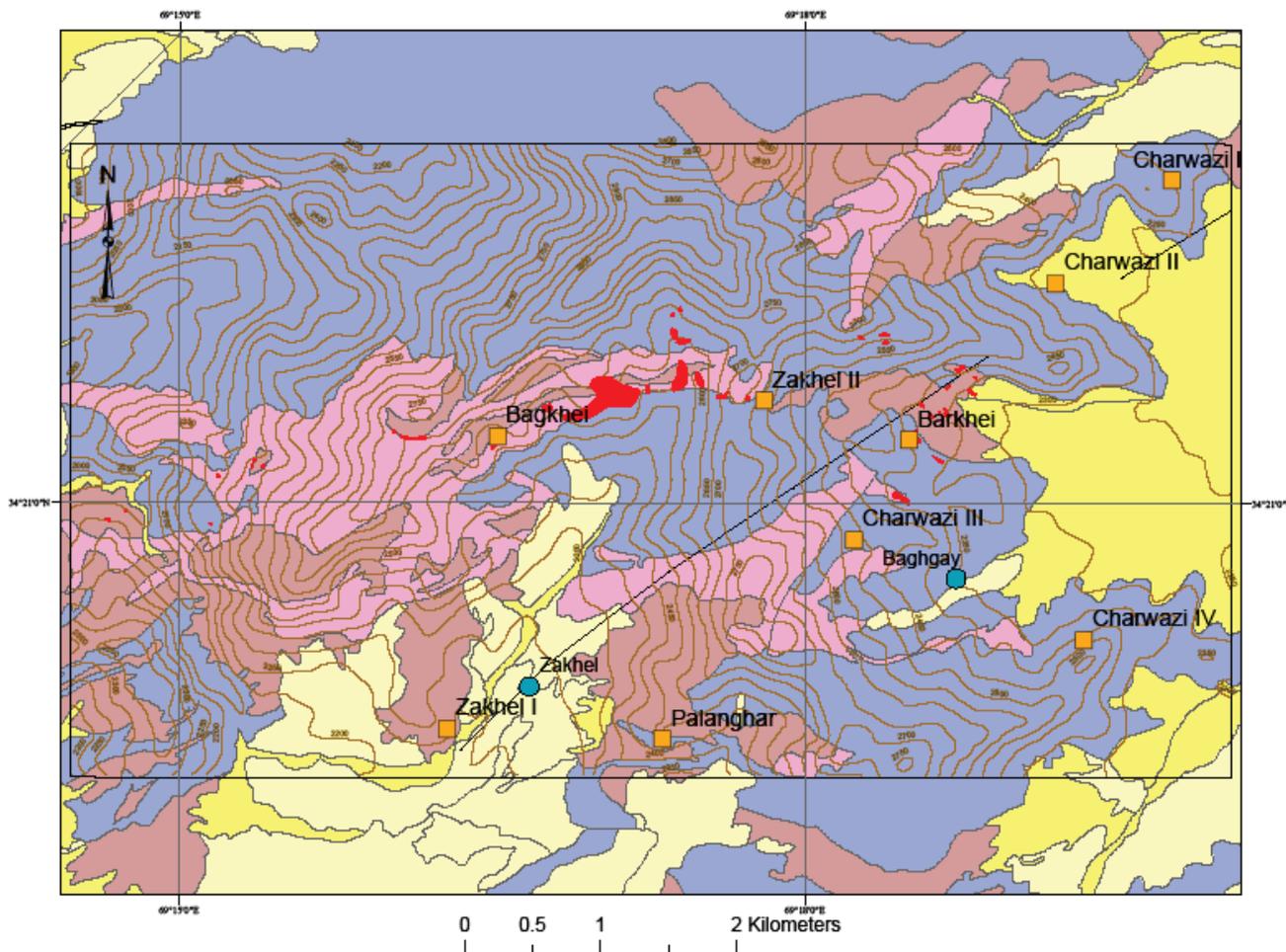


Figure 2A-16. Geology and mineral occurrences of the Bakhel-Charwaz copper-cobalt subarea (based upon Bohannon, 2010b).

2A.3.5.1 Location

The Kharuti-Dawrankehl copper-cobalt subarea is located 25 km southeast of Kabul in the of Khaki Jabbar and Bagrami Districts of the Kabul Province. An unimproved (tertiary) road accesses the valley floor through the mountain range on the northern border of the subarea and runs southward through the villages of Kurd-Kabul, Malik Khel and Khaki Jabbar before exiting the southeastern corner of the subarea. A second road forks off from the north-south road in the north-central part of the valley and exits through the eastern border of the subarea north of the village of Sheman Zay. The villages of Taghar, Mirza Khan Karez, Aynak, and Kharoti are located on the valley floor along the western side of the subarea (fig. 2A-19).

2A.3.5.2 Previous Work

The Kharuti-Dawrankehl copper-cobalt subarea is in the northeast part of prospective tract sedcu01-p2 (Peters and others, 2007; figs. 2A-11a and 2A-12a). The Chakari, Kharuti, Mirzakhan, and Dawankhel occurrences were evaluated by Shcherbina and others (1975) and Kutkin and Gusev (1977).



Figure 2A–17. Aerial view of the Barkhei-Zakhel prospect area within the Bakhel-Charwaz subarea. Photograph by Ted Theodore, U.S. Geological Survey.

2A.3.5.3 Geology

The geology of the subarea (as mapped by Bohannon, 2010b) is dominated by the Lataband series and recent alluvium of the Surficial series which cover the valley floor in the northwestern, central, southern, and southeastern parts of the subarea (figs. 2A–15, 2A–19, 2A–20). A fundamental transition between mapped geologic units can be observed in figure 2A–19, where rocks in the southeastern half of the subarea are almost exclusively the high-grade gneiss, migmatite, and schist with lesser amphibolite, quartzite, and marble of the Paleoproterozoic Sherdarwaza Formation, and rocks in the northwestern half are mapped as younger, lower grade, greenschist facies carbonate-clastic, and volcanosedimentary rocks of the Neoproterozoic cover sequence. Three major outcrop areas of Precambrian rocks are present in the subarea. An east-west trending range of hills in the southern part of the subarea hosts the Kharuti II, Khurdkabul, and Chakari occurrences (fig. 2A–19), in addition to numerous other surface workings, and is dominated by rocks of the Sherdarwaza Formation. Neoproterozoic intrusive rocks are present at the western end of the range and a small hill consists of Weyalati and undifferentiated Weyalati and Loy Kwar Formation rocks. Similarly, the northern and northeastern quadrants of the subarea contain a mountain range consisting of Sherdarwaza Formation rocks in the eastern part of the range, which host the Taghar and Dawrankhel occurrences. The western part of the range is dominated by rocks of the Weyalati Formation intruded by several large Neoproterozoic intrusive bodies. The hills in the west-central part of the subarea consist of Weyalati and undifferentiated Weyalati and Loy Kwar Formation rocks intruded by numerous small to medium-sized Neoproterozoic intrusions. The Kharuti I and Mirzakhel occurrences are located in Surficial series alluvium just to the east of these hills.



Figure 2A–18. Photograph of laminated marble in the Bagkhei prospect area (GPS 34.34856° N, 69.28179° E) within the Bakhel-Charwaz subarea. Photograph by Ted Theodore, U.S. Geological Survey.

2A.3.5.4 Known Deposits

No known deposits are present in the Kharuti-Dawrankehl subarea.

2A.3.5.5 Prospects and Anomalies

The Kharuti-Dawrankehl subarea contains the Kharuti (Kharoti) I and II, Khurd Kabul, Chakari, Mirzakhan, and Dawrankhel, and Taghar occurrences. The Kharuti I occurrence consists of a copper-bearing zone 5 to 10 m wide and 200 m long in marble (thought to be of Vendian-Cambrian age by Shcherbina and others, 1975). The 10 m wide interval averages 0.99 percent copper.

The Kharuti II occurrence is hosted in a marble-schist (thought to be of Vendian-Cambrian age by Shcherbina and others, 1975) and consists of nine 100- to 900-m-long, 3- to 35-m-wide copper-bearing zones that grade between 0.15 and 0.94 percent copper (Shcherbina and others, 1975; Abdullah and others, 1977). In 2009, a team of USGS geologists visited the area of the Karuti II occurrence and reported their observations of a 300-m thick section of amphibolite facies mica schist, calcsilicate gneiss, marble, and mafic to felsic gneisses (amphibolite and quartzofeldspathic gneiss) of probable volcanic origin intruded by a 5-m-thick meta-aplite intrusion (figs. 2A–21 to 2A–23). Their observations of high-grade metamorphic rocks in the area are consistent with the mapping of Bohannon (2010b), which indicates the presence of the Paleoproterozoic Sherdarwaza Formation in this range of hills in contrast with the assumed Vendian-Cambrian age of rocks in the area reported by Shcherbina and others (1975). Additional detailed mapping and geochronological studies are required to resolve this conflict.

The Khurdkabul occurrence consists of three copper-bearing zones with widths ranging from 5 to 50 m and lengths from 800 to 900 m in marble, phyllite, micaceous carbonate, and garnet-mica schist (thought to be of Vendian-Cambrian age by Shcherbina and others, 1975). The mineralization consists of covellite, chalcopyrite, and chalcocite in irregular disseminations and veinlets. Average grades of 0.18 to 0.36 percent copper are reported from 5- to 37-m-thick intervals (Shcherbina and others, 1975; Abdullah and others, 1977).

The Chakari occurrence consists of a copper-bearing zone in marble (thought to be of Vendian-Cambrian age by Shcherbina and others, 1975). The zone is 200 m long, 3 to 5 m wide, and grades 0.2 percent copper.

The Mirzakhan occurrence consists of two copper-bearing zones, 10 to 35 and 10 to 20 m wide and 800 and 500 m long, respectively. A 35-m interval contains 0.24 percent copper and a 20-m interval, 0.32 percent copper (Shcherbina and others, 1975).

The Dawankhel occurrence is a 500-m long and 5 to 8 m wide copper-bearing zone that has been traced at the contact between marble and carbonate-mica schist (thought to be of Vendian-Cambrian age by Shcherbina and others, 1975) with an average grade of 1.1 percent copper.

The Taghar occurrence is a large mineralized area hosted in micaceous carbonate rocks, phyllite, garnet-mica schist, and marble, and consists of 19 discontinuous copper-bearing zones that range from a few hundred meters to 6,000 m long and several meters to 200 m wide. The irregular zones contain chalcopyrite, bornite, chalcocite, covellite, malachite, and azurite in veinlets, pods, and disseminations. Mineralized sections between 3 and 25 m and 40 to 70 m wide (and up to 100 to 200 m wide) grade 1 to 2.64 percent copper (Shcherbina and others, 1975). Resources at the C₂ category level cover an area of 31 km² and are estimated to be 86,800 t of copper at a grade of 0.18 percent (Ministry of Mines, written commun., 2007; Peters and others, 2007).

2A.3.6 Yagh-Darra Ghul-Darra Subarea

The Yagh-Darra Ghul-Darra copper-cobalt subarea lies in the mountainous northwestern part of the Aynak copper district (fig. 2A-4). Surface exploration and mapping has identified mineralization along an east trending zone in a 6 km² area in the northwestern part and additional occurrence in the eastern part of the subarea (figs. 2A-15 and 2A-24). The area may contain sediment-hosted copper deposits similar to Aynak at depth. A total of three separate occurrences have been identified.

2A.3.6.1 Location

The Yagh-Darra Ghul-Darra copper subarea lies 10 to 20 km southeast of Kabul in the Bagrami, Musayi, and Khaki Jabbar Districts of the Kabul Province. The majority of the area consists of steep, mountainous terrain and there are no roads in the area. The village of Gul Dara is located near the head of the valley in the southwestern corner of the subarea about 2 km south of, and at the foot of the ridge below, the Ghuldarra II occurrence (fig. 2A-24).

2A.3.6.2 Previous Work

The Yagh-Darra Ghul-Darra copper-cobalt subarea is centered on the prospective tract sedcu01-p1 of Peters and others (2007; figs. 2A-11a and 2A-12a). The mineralized trend in the Yagh-Darra Ghul-Darra subarea is probably the hanging wall limb of equivalent folded strata to the south that defines the east-northeast trending sequence of prospects and occurrences contained within the Kelaghey-Kakhay, Bakhel Charwaz, and Kharuti Dawrankhel subareas (figs. 2A-11a, and 2A-12b). The southern limb of folded strata defines a 25-km-long, 3- to 4-km-thick northeast trending prospective tract that is delineated along a line of stratabound copper occurrences in northern Logar and southern Kabul Provinces (figs. 2A-11a, and 2A-12b). Prospecting in the Yagh-Darra Ghul-Darra copper-cobalt

subarea has taken place at the surface around the copper occurrences and includes some trenching around the Yagh-Darra occurrence (fig. 2A–25). The Ghuldarra I and II and Yagh-Darra occurrences were evaluated by Shcherbina and others (1975) and Kutkin and Gusev (1977).

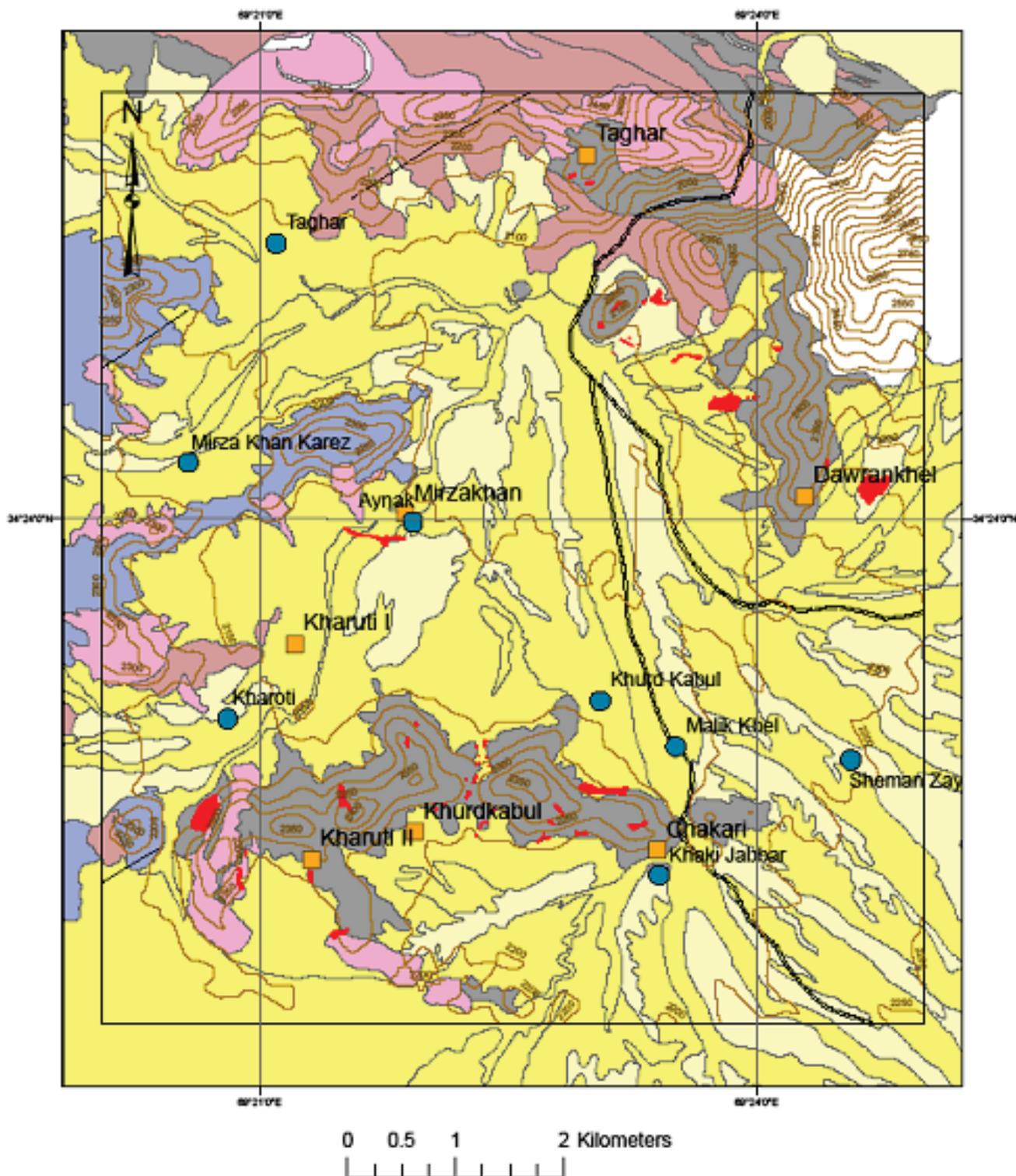


Figure 2A–19. Geology and mineral occurrences of the Kharuti-Dawrankhel copper-cobalt subarea. From Bohannon (2010b).



Figure 2A–20. General view looking southeast from the Kharuti II prospect toward the Khurd Kabul and Chakari prospects in the Kharuti-Dawrankehl subarea. Photograph by Ted Theodore, U.S. Geological Survey.

2A.3.6.3 Geology

The geology of the subarea (as mapped by Bohannon, 2010b) is dominated by a central mass of Weyalati Formation rocks and large masses of Neoproterozoic intrusive rocks that outcrop in the highest part of the subarea. The eastern and western flanks of the range, as well as most of the southern part of the subarea, are mapped as undifferentiated Weyalati and Loy Kwar Formations, suggesting that the dominant lithologies present should be amphibolite-facies schist, amphibolite, plagiogneisses, quartzites, and marbles of the Weyalati Formation and repetitive layers of dolomitic marble, carbonaceous quartz schist, and quartz-biotite-dolomite schist of the Loy Kwar Formation. Rocks of the Paleoproterozoic Sherdarwaza Formation are mapped along the northern margin of the subarea. In contrast to the other subareas, the Yagh-Darra Ghul-Darra subarea contains a prominent northwest trending series of elongated amphibolite intrusions of Neoproterozoic age that cut the Weyalati and Sherdarwaza Formations along the northern margin of the subarea; a quartz-rich intrusion of Cretaceous age is also present near the village of Gul Dara. A prominent normal fault of unknown vertical displacement or direction of throw bisects the subarea along an east-northeastly trend from the village of Gul Dara, passing just to the north of the Ghuldarra I occurrence (fig. 2A–24).

2A.3.6.4 Known Deposits

No known deposits are present in the Yagh-Darra Ghul-Darra subarea.

2A.3.6.5 Prospects and Anomalies

The Yagh-Darra Ghul-Darra subarea contains the Ghuldarra I and II, and Yagh-Darra occurrences. The Ghuldarra I occurrence is hosted in marble (thought to be of Vendian-Cambrian age by Shcherbina and others, 1975) in two zones containing disseminated covellite, chalcopyrite, chalcocite, and malachite. One zone is 1 km long and 15 to 35 m wide and the other is 450 m long and 10 to 80 m wide (Shcherbina and others, 1975; Abdullah and others, 1977).



Figure 2A–21. Contact between intrusive meta-aplite and foliated dark amphibolite gneiss in the vicinity of the Kharuti II prospect in the Kharuti-Dawrankehl subarea. Photograph by Ted Theodore, U.S. Geological Survey.

The Ghuldarra II occurrence consists of a copper mineralized zone 30 to 50 m long and 2 to 5 m wide hosted in a marble layer (thought to be of Vendian-Cambrian age by Shcherbina and others, 1975). The occurrence averages 0.55 percent copper (Shcherbina and others, 1975; Abdullah and others, 1977).

The Yagh-Darra occurrence consists of an irregularly mineralized marble bed 20 to 50 m thick and more than 2 km long hosted in quartzite and micaceous garnet-amphibolite schist (thought to be of Vendian-Cambrian age by Shcherbina and others, 1975). One mineralized interval assayed 0.75 percent copper (Shcherbina and others, 1975; Abdullah and others, 1977). In 2009, a team of USGS geologists visited the area of the Yagh-Darra occurrence and reported their observations as follows:

“Precambrian rocks of the Yagh-Darra locality are reportedly biotite-amphibole gneisses and migmatitic gneisses of Paleoproterozoic age. At Yagh-Darra the bedrock consists of steeply northwest-dipping amphibolite facies metaclastic rocks (marble, calc-silicate gneiss, muscovite-biotite schist, and quartzite) and lesser mafic and felsic gneisses (amphibolite and

quartzofeldspathic gneiss) of probable volcanic origin (fig. 2A–26). None of the rocks show signs of partial melting; some of the metamafic gneisses formed pod-like boudins (100 m × 35 m) within quartzofeldspathic gneiss and schist. Few intrusive igneous rocks were observed, except for a meta-aplite dike (5 m thick) sheared at its margins, that cut discordantly across the metamorphic layering (figs. 2A–27 and 2A–28). We saw little sign of copper mineralization at this locality. Where present, copper minerals consisted of rare green copper carbonates in marble and calc-silicate gneiss at or near the contact with mafic and felsic metavolcanic strata (fig. 2A–29). Although the area had many signs of quarry activity, only one had signs of copper mineralization. Quartz-potassium feldspar veins were observed at one locality (GPS 34.422261° N, 69.26019° E) but no signs of copper mineralization were evident.”

2A.4 Metallogeny of Podiform Chromite Deposits

Podiform chromite deposits are lenticular-shaped, pod-like masses of massive coarse-grained to finely disseminated chromitite in the lowermost ultramafic parts of ophiolite complexes (Duke, 1983, 1996; Albers, 1986; Singer and Page, 1986). Tabular, rod-shaped, and irregularly shaped bodies are also observed. They form in the lower part of the oceanic lithosphere as magmatic segregation deposits occurring in elongate pockets along spreading plate margins. They are subsequently preserved in collision zones when fragments of oceanic crust are scraped off into the mélangé above subduction zones. They are, therefore, common features of accretion zones at continental margins and, along with their ophiolite host sequences, mark the closure of ocean basins between major crustal blocks.



Figure 2A–22. Isoclinally folded marble in the vicinity of the Kharuti II prospect in the Kharuti-Dawrankehl subarea. Photograph by Ted Theodore, U.S. Geological Survey.

Rock types present in a complete ophiolite sequence consist of basal tectonized ultramafic rocks (mostly harzburgite), ultramafic cumulates (dunites and harzburgites), noncumulate and cumulate mafic

rocks (gabbros), a basaltic sheeted dike complex, pillowed basaltic lavas, and a covering of marine sedimentary rocks. The tectonites are thought to represent the residual, partially melted mantle, and the contact with the less deformed, layered ultramafic cumulates has been interpreted to represent the boundary between the mantle and the oceanic crust (the petrological Moho). Discordant bodies of dunite (and chromitite) are suggested to represent intrusions through the upper mantle and lower crust (Cawthorn and others, 2005). The chromite deposits are most common in the uppermost tectonized harzburgites and lower parts of ultramafic cumulates, which are commonly serpentized. Most podiform chromite deposits worldwide are Phanerozoic in age with important examples in the Phillipines (Tertiary), Albania (Jurassic), Turkey (Paleozoic), and Kazakhstan (Paleozoic). A few Proterozoic examples are known in Egypt and Sudan (Duke, 1996).



Figure 2A–23. Mica schist with near-vertical schistosity in the vicinity of the Kharuti II prospect in the Kharuti-Dawrankehl subarea. Photograph by Ted Theodore, U.S. Geological Survey.

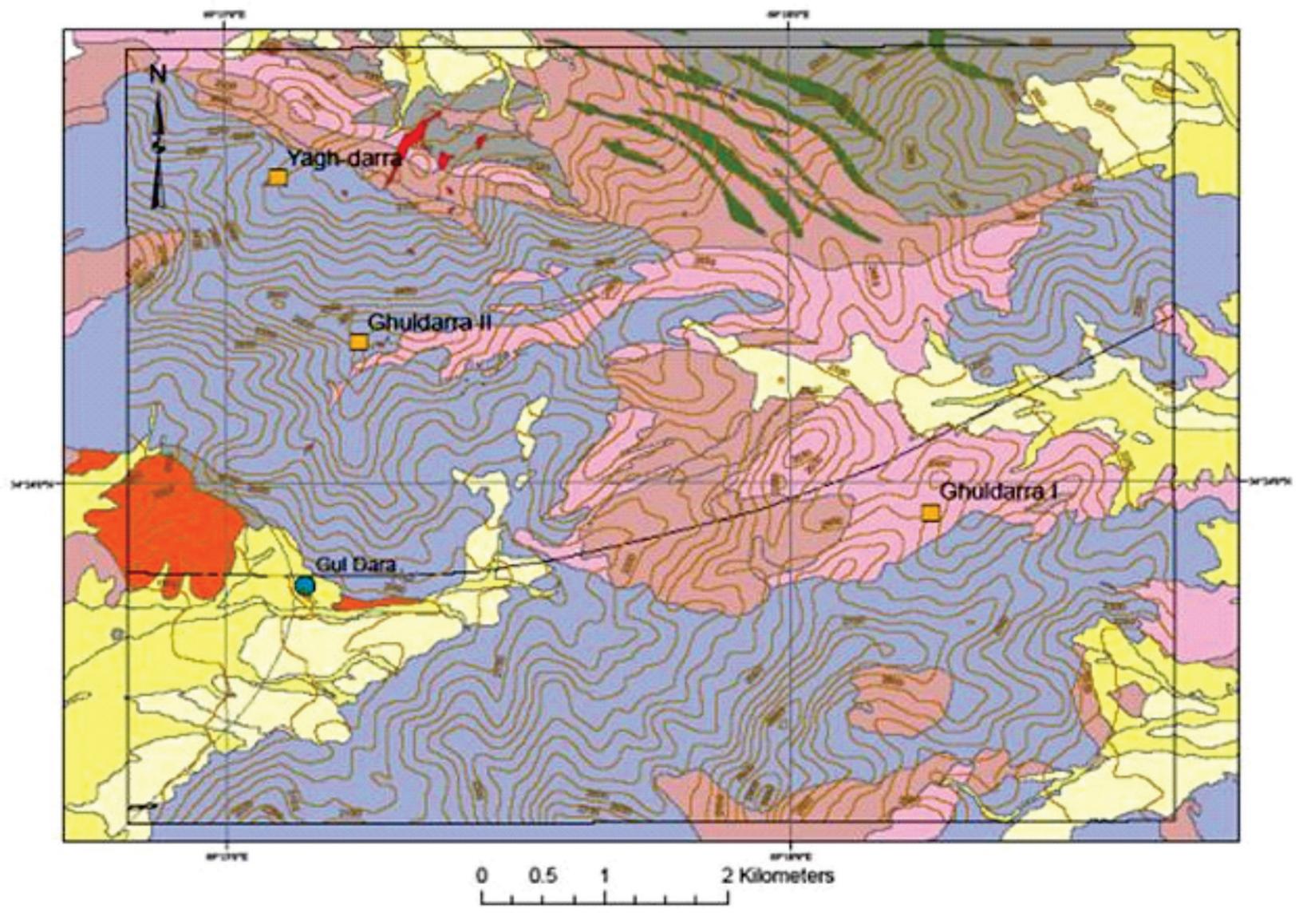


Figure 2A-24. Geology and mineral occurrences of the Yagh-Darra Ghul-Darra copper-cobalt subarea. From Bohannon (2010b).



Figure 2A–25. View looking north from the vicinity of the Yagh-Darra prospect. Photograph by Ted Theodore, U.S. Geological Survey.



Figure 2A–26. Photograph showing inclined high-grade metamorphic rocks near the Yagh-Darra prospect. From bottom to top: marble and calc-silicate gneiss, amphibolite, and mica schist. Photograph by Ted Theodore, U.S. Geological Survey.

Podiform chromite deposits are generally quite small with individual deposits ranging from a few tens to millions of metric tons with deposits greater than 1 Mt being rare. The largest known pod contains about 13 Mt of high-aluminum chromitite grading 36.5 percent Cr_2O_3 . The largest mines

generally exploit a number of pods with some mines producing from as many as 20 chromitite pods (Duke, 1996). In terms of dimensions, most podiform chromite bodies are the size of an autobus or a small building. A large deposit would be 100 to 200 m long, 50 m wide, and 10 m thick.



Figure 2A–27. Photograph of meta-aplite felsic dike cutting across amphibolite (foreground) and mica schist (background). Photograph by Ted Theodore, U.S. Geological Survey.



Figure 2A–28. Photograph of meta-aplite felsic dike (GPS 34.42783° N, 69.26404° E) cutting across amphibolite (foreground) and mica schist (background). Photograph by Ted Theodore, U.S. Geological Survey.

Chromite is the major ore mineral, which when in massive, near-monomineralic aggregates is referred to as the ore-rock chromitite. Ferrichromite, magnetite, ruthenium-osmium-iridium alloys, and the platinum group mineral laurite are possible accessory ore minerals. Gangue minerals in chromitite include olivine, orthopyroxene, clinopyroxene, and plagioclase. Secondary minerals include serpentine, chlorite, tremolite, talc, and carbonate. Chromitite displays a wide range of textures, from those clearly related to magmatic processes, to those produced during either brittle or ductile deformation. Layering is common and can be a result of cumulate textures, modal grading, and grain-size grading. Nodular textured chromite grains are a common and perhaps diagnostic feature of podiform chromite deposits and consist of loosely packed, ellipsoidal chromite nodules 5 to 20 mm in diameter in dunite matrix (Duke, 1996). Textures produced during deformation include lineation and foliation of chromite and olivine grains; stretching, boudinage, and fracturing of chromite grains; brecciation; and mylonitization. Chromite grains in massive chromitite tend to occur as coarse-grained (5 to 10 mm), interlocking anhedral.



Figure 2A–29. Photograph of an abandoned trench in the Yagh-Darra area showing secondary copper minerals (green) at the contact between calc-silicate gneiss (left) and quartzofeldspathic gneiss (felsic metavolcanics to the left). Photograph by Ted Theodore, U.S. Geological Survey.

The chemical composition of chromite is variable, because chrome spinels form a solid solution having the general formula $(\text{Mg}, \text{Fe}^{2+})(\text{Cr}, \text{Al}, \text{Fe}^{3+})_2\text{O}_4$. Naturally occurring chromites have a wide range of chemical compositions that are indicative of the tectonic setting and, therefore, of the deposit subtype. Chromite from podiform deposits are low in Fe^{3+} and TiO_2 , and the major compositional variation is in the amount of chromium-aluminum substitution. The $\text{Mg}:(\text{Mg}+\text{Fe}^{2+})$ ratio in chromite from podiform chromite deposits does not vary greatly but does show a slight negative correlation with the $\text{Cr}:(\text{Cr}+\text{Al})$ ratio. Systematic variation of chromite compositions across individual deposits has been observed in some deposits and includes the upward decrease in the $\text{Cr}:\text{Fe}$ ratio in a single lens. A significant increase of $\text{Cr}:\text{Fe}$ and $\text{Cr}:(\text{Cr}+\text{Al})$ with increasing depth below the petrologic Moho has also been documented (Duke, 1983). Podiform chromite deposits are highly resistant to weathering and oxidation. However, despite this characteristic the discovery of a significant number of PGE-bearing

podiform chromite deposits has been preceded by the discovery and exploitation of PGE placer deposits downstream of the podiform chromite deposits.

Two podiform chromite grade and tonnage models have been produced. The major podiform chromite deposit model was built using data from 174 deposits from around the world (Singer and others, 1986). Major podiform chromite deposits have a mean tonnage of 20,000 t with 80 percent of the deposits ranging from 2,200 to 200,000 t; 80 percent of the grades range from 33 percent to 52 percent chromite; the mean is 46 percent (Singer and others, 1986). Figure 2A–30 shows the major podiform tonnage model with the estimated tonnages of six known Afghanistan chromite deposits superimposed (Volin, 1950). The other grade and tonnage model, minor podiform chromite deposits, does not apply to the Logar Ophiolite Complex (LOC).

2A.4.1 Ultramafic-Hosted Talc-Magnesite

Talc and magnesite are two magnesium-rich minerals that may occur in the same or spatially associated deposits; this includes deposits hosted by ultramafic 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, 2007). The mineral talc is extremely soft 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 $Mg_3Si_4O_{10}(OH)_2$. 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 consists 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 (Bodenlos and Thayer, 1973; Harben and Kužvart, 1996a; Kramer, 2001). Most magnesite and magnesia extracted from brines and seawater are processed into dead-burned magnesia (calcined at a temperature exceeding $1,450^\circ\text{C}$) 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 predominantly for refractories, whereas caustic-calcined magnesia is the preferred starting material for chemicals, cement, filler, fertilizers, and many other uses (Harben and Kuzvart, 1996a).

Health concerns have been expressed about the association of asbestos with talc (<http://www.natural-health-information-centre.com/talc.html>) The alteration of serpentinite by silicon-rich fluids may produce chrysotile asbestos as well as talc. In addition, tremolite amphibole (which can be asbestiform) may be an intermediate product of carbonation of serpentinite. Chrysotile forms at a lower temperature than talc and differs in some other formational conditions, so although chrysotile is chemically similar to talc, it is unlikely that it will be present within the part of a talc deposit that has a grade suitable for mining. Overall, most talc is asbestos free. The general public is in contact with talc in powders and its potential for inhalation has drawn the attention of health researchers. In mining and processing talc, miners, and factory workers may be at a greater risk because of prolonged exposure to fine particles of talc. When talc is being mined and processed, large amounts of dust particles may be in the air and workers could inhale it into their lungs. When massive concentrations are inhaled, long-term accumulation may occur in the lungs, and too much inhalation may cause lung disease and other health problems (<http://www.knowabouthealth.com/talc-powder-can-pose-severe-health-risk/2362/>). Talc has not been proven to cause human lung cancer, even in mine and factory workers. Research shows talc miners have the same mortality rate as nontalc miners with regard to lung cancer.

There have been numerous attempts to develop descriptive models of ultramafic-hosted magnesite, talc, and talc-magnesite mineral deposits (Paradis and Simandl, 1996; Page 1998a,b; Simandl and Ogden, 1999). Talc and magnesite are commonly found together, but also separately as replacements for serpentinite. Asbestos deposits, magnesite deposits, and podiform chromite deposits are commonly associated deposits, as are “verde antique” dimension stone deposits (Page, 1998a,b; Simandl and Ogden, 1999). The following description draws from the previously referenced deposit models as well as other sources.

Magnesite, talc, and mixed talc-magnesite deposits occur in serpentinitized zones within ultramafic rocks in tectonically transported rocks and greenstone belts, which may or may not have an ophiolite affiliation (Simandl and Ogden, 1999). Deposits are commonly associated with large faults or shear zones. Serpentinites that contain these deposits have undergone additional carbonation and alteration by hydrothermal fluids containing a significant amount of carbon dioxide (Pohl, 1990, McCarthy and others, 2006). Whether talc and (or) magnesite forms from this process is a function of the carbon dioxide and magnesium content of the altering hydrothermal fluids, the original magnesium content of the host rock, the completeness of the alteration process, and the spatial relationship of the alteration to regional faults and siliceous country rocks (Koons, 1981; Harben and Kužvart, 1996a,b; Simandl and Ogden, 1999). In progressive carbonation of serpentinite, talc-magnesite mineralization will be followed by quartz-magnesite and magnesite. Talc content may also result or be enhanced from steatization of talc-carbonate rock by subsequent Silicon-rich fluids or from the metamorphic reaction of serpentinite and talc-carbonate rock with siliceous country rock (Harben and Kužvart, 1996b; McCarthy and others, 2006).

Ultramafic magnesite deposits are commonly small compared to other deposits of magnesite, although the size range of the deposits is quite variable. Deposits consist of cryptocrystalline magnesite in the form of veins, nodules, stockworks, and lenses in altered serpentinite (Page, 1998b; Kramer, 2001). Deposits related to regional fault systems cutting through ultramafic rocks are commonly magnesite rich (Simandl and Ogden, 1999).

Ultramafic talc deposits are the most abundant type of talc deposits, although the majority of world production of talc is from metasedimentary deposits (McCarthy and others, 2006). In place of magnesium within its crystal lattice, talc from serpentinite-hosted deposits may contain significant levels of iron, nickel, and (or) chromium that affect the color of the talc and cannot be removed. Talc grades are commonly higher near the periphery of the ore bodies where steatization may have been more pronounced (Harben and Kužvart, 1996b; McCarthy and others, 2006).

Whether or not a deposit will contain talc or magnesite, or some unknown combination of the two, can be extremely difficult or impossible to predict, especially in the absence of detailed geologic information. No studies of the Afghanistan ultramafic rocks and their serpentinitization are available that would allow scientists to discern whether talc or magnesite could be the dominant magnesium mineral. Ultramafic talc and magnesite deposits may be spatially associated with chrysotile asbestos, podiform chromite, nickel laterite, and “verde antique” dimension stone deposits in related rocks (Page, 1998a,b; Simandl and Ogden, 1999). Known occurrences in Afghanistan indicate that only talc with spatially associated asbestos has been definitively identified in the ultramafic rocks; the known magnesite-dominated deposits are believed to be a different deposit type. Grade and tonnage modeling indicates that there is a continuum between talc-only and magnesite-only deposits within serpentinitized ultramafic rocks, but grade and tonnage models were constructed separately for talc and magnesite, as many deposits contain only one of the commodities in significant amounts. Magnesite may occur with or without talc in the ultramafic rocks. Therefore, the tracts should be considered permissive for both talc and magnesite, although known occurrences do not contain magnesite and, in the absence of better information, would suggest that magnesite is unlikely to occur in significant amounts in these rocks.

Ultramafic-hosted talc-magnesite deposits commonly correspond to aeromagnetic lows; unserpentinitized parts of ultramafic host rocks present strong magnetic anomalies (Simandl and Ogden, 1999). Deposits are commonly found near contacts with country rocks and in, or near, faults and

fractures, as well as spatially associated with podiform chromite and serpentine-hosted asbestos deposits (Page, 1998a,b). Deposits may be relatively resistant to weathering and may accumulate as residue above and near buried talc bodies (Blount and others, 1995; Page, 1998b) or form topographic lows that can be covered by lakes and swamps (Simandl and Ogden, 1999).

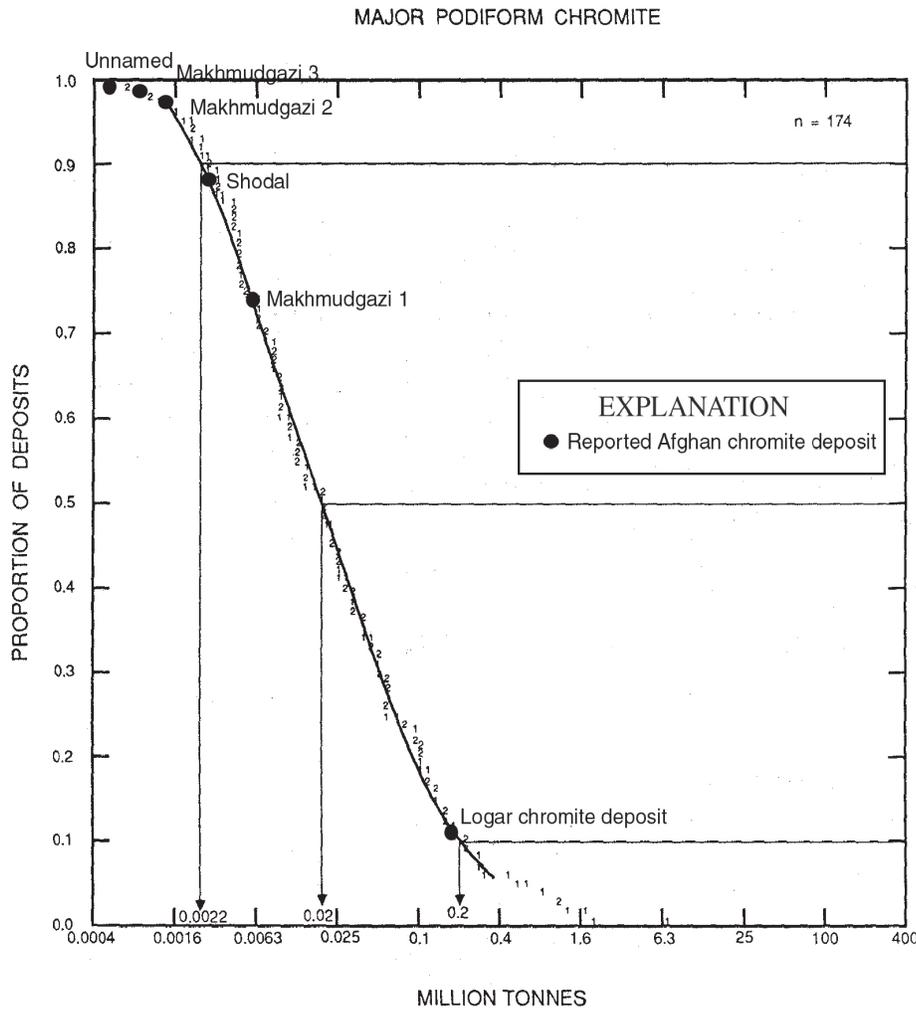


Figure 2A-30. Graph showing estimated tonnages of Afghan podiform chromite occurrences plotted on the major podiform chromite tonnage curve (from Peters and others, 2007, after Singer and others, 1986).

2A.4.2 Serpentine-Hosted Asbestos

The commercial term "asbestos" is applied to a group of six fibrous (large length-to-width ratio) silicate minerals amenable to mechanical separation into fine filaments of considerable tensile strength and flexibility. These minerals are essential to modern technology in certain relatively low-volume uses by virtue of their unique combinations of physical and chemical properties (Shride, 1973; Jensen and Bateman, 1981).

These fibrous minerals share several properties which qualify them as asbestiform fibers: (1) they are found in bundles of fibers which can be easily separated from the host matrix or cleaved into thinner fibers; (2) the fibers exhibit high tensile strengths and show high length, such as their diameter (aspect) ratios that range from a minimum of 20 up to greater than 1,000; (3) they are sufficiently flexible to be spun; and (4) macroscopically, they resemble organic fibers, such as cellulose (Virta, 2002).

Properties that are used to evaluate asbestos as to its ultimate use are flexibility, length of fiber, tensile strength, and chemical reactivity, in addition to resistance to heat, electrical conductance, and filtration characteristics (Shride, 1973). Uses for asbestos include roofing products, gaskets, and friction materials. Asbestos was once used in automobile brake pads and shoes, but since the mid-1990s, most brake linings are now asbestos free. The resistance of asbestos to fire has long been exploited for a variety of purposes. In ancient Egypt, asbestos was used in fabrics used as burial cloths. Nearly all asbestos produced worldwide is chrysotile (Virta, 2002). In 2005, world production increased to 2.40 Mt from 2.36 Mt that was produced in 2004 (Virta, 2007).

Asbestos minerals, which differ in chemical composition and physical properties, fall into two broad groups—serpentine and amphibole. The serpentine group consists of the mineral chrysotile, traditionally the most valuable variety of asbestos and produced in the greatest quantity. The amphibole group includes anthophyllite, crocidolite, amosite, tremolite, and actinolite (Jensen and Bateman, 1981). Riebeckite (known under the variety name crocidolite) and amosite make up much of the remaining production, with very minor production of anthophyllite, tremolite, and actinolite (Shride, 1973).

Chrysotile or "white asbestos" has fine fibers that can be spun into as much as 4.35 km of thread per kilogram. Some varieties withstand 2,750°C (Jensen and Bateman, 1981). Chrysotile asbestos occurs in two geologic settings, (1) from stockworks of veins in serpentized peridotite, pyroxenite, and dunite (ultramafic-hosted asbestos); and (2) from veins confined to thin serpentine layers in limestone and other carbonate rocks. This assessment of asbestos resources in Afghanistan deals exclusively with ultramafic-hosted chrysotile deposits. Chrysotile is less harmful than the other types of asbestos since it is less friable, and therefore less inhalable.

Crocidolite or "blue asbestos" comes chiefly from South Africa where it occurs as a long, coarse, flexible spinning fiber with low fusibility and high resistance to acids (Jensen and Bateman, 1981). Anthophyllite occurs as mass fiber, and is a short, brittle, nonspinning fiber used mostly in insulation. Amosite is an iron-rich variety of asbestos that occurs in long splintery, coarse fibers, some of which can be spun. Amosite is chiefly used as a binder for heat insulators (Jensen and Bateman, 1981). Tremolite and actinolite have little commercial value.

Chrysotile asbestos deposits occur as chrysotile asbestos in stockworks and veins in serpentized ultramafic rocks that consist of harzburgite, dunite, wehrlite, and pyroxenite (Duke, 1984; Page, 1986; Hora, 1997; Obolenskiy and others, 2003). Serpentinities may be part of an ophiolite sequence in unstable accreted oceanic terranes, within Alpine-type ultramafic rocks, or in synvolcanic intrusions of komatiitic affinity in Archean greenstone belts.

The serpentinite host rocks must have a nonfoliated texture and must be located near a fault that was active during a change in orientation of the regional stress field (Hora, 1997). Subsequent deformation and igneous intrusion may be important. The serpentized ultramafic rocks are highly fractured and veined and may be intruded by pegmatite dikes (Obolenskiy and others, 2003). White chrysotile asbestos replaces massive ultramafic and serpentized ultramafic bodies and fills fractures that developed in shear zones near contacts between serpentized bodies and igneous rocks that were emplaced into serpentinite (Wrucke, 1995). Associated minerals include magnetite, brucite, talc, and actinolite-tremolite (Page, 1986).

Orris (1986) modeled the grades and tonnages of 50 serpentine-hosted asbestos deposits and determined that 80 percent have between 2.7 and 8.0 percent asbestos and from 4.6 to 150 Mt of material. The mean grade and tonnage are 4.6 percent asbestos and 26 Mt.

2A.4.3 Economic Geology

2A.4.4 Characteristics of the Logar Podiform Chromite Deposits

The characteristics of the podiform chromite deposits in the Aynak AOI are best exemplified by features of the Logar deposits. Maps of some of the known podiform chromite deposits in Logar Valley are included in figures 2A–31 through 2A–39. The major host-rock types are serpentized harzburgite and dunite with minor noritic dikes in the southernmost part of the LOC. These rock types were noted but not mapped by Volin (1950). Chromite deposits are predominantly found in envelopes of dunite surrounded by harzburgite, typical of chromite occurrences in ophiolites, and also in association with kilometer-sized bodies of lherzolite and cross-cutting orthopyroxenite dikes (Benham and others, 2009). Most of the deposits are relatively small with dips between 32 and 45 degrees toward the southwest. The largest body (Logar #5) consists of two lenses, one 97.5 m long and 10 m wide, and a second 65 m long and up to 5 m wide (figs. 2A–34 through 2A–36). The margins of all the chromite bodies are sharp and irregular, and the immediate wallrocks are generally serpentized and have developed close-spaced planar fabric and fracturing parallel to the contacts (Benham and others, 2009).

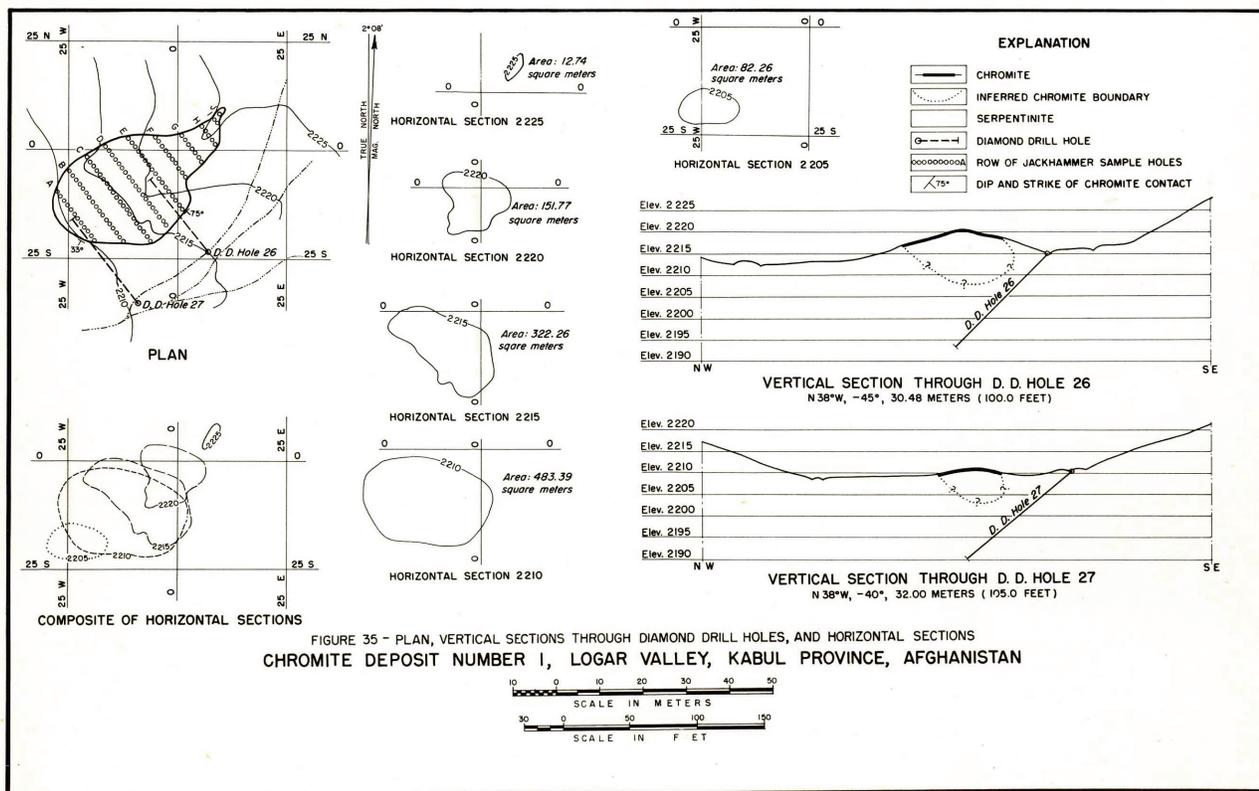


Figure 2A–31. Vertical cross section of chromite deposit number 1 in the Logar Valley, Afghanistan. From Volin (1950).

Two small chromite quarries visited by the British Geological Survey in 2006 (Benham and others, 2009) are described as containing massive chromitite, areas of disseminated mineralization with occasional blebs of chromite associated with 1- to 2-cm thick carbonate veins and, less commonly, submassive chromitite. Petrographic study of chromitites indicates the presence of 5 to 10 percent interstitial silicate minerals in the ultramafic lithologies, most of which is olivine with minor alteration to serpentine. More thoroughly altered samples contain mostly serpentine and chlorite with remnant

olivine. Chromite grains are generally fresh with red to red-brown margins and minor darkening along fractures. Altered samples show alteration of chromite to ferrite-chromite and magnetite. Some samples contain thin carbonate veinlets (Benham and others, 2009).

Platinum group minerals (PGM) were found in two samples. One sample consisted of an 8-micron-sized grain of native platinum with minor iron that was present in a dunite sample associated with fine-grained serpentinization of olivine; the second sample contained a 10-micrometer-size grain of ruthenium-iridium alloy along a chromium spinel-chlorite grain boundary. The presence of PGM, in association with alteration minerals serpentinite and chlorite, indicates possible remobilization of these minerals during alteration of the host rocks (Benham and others, 2009).

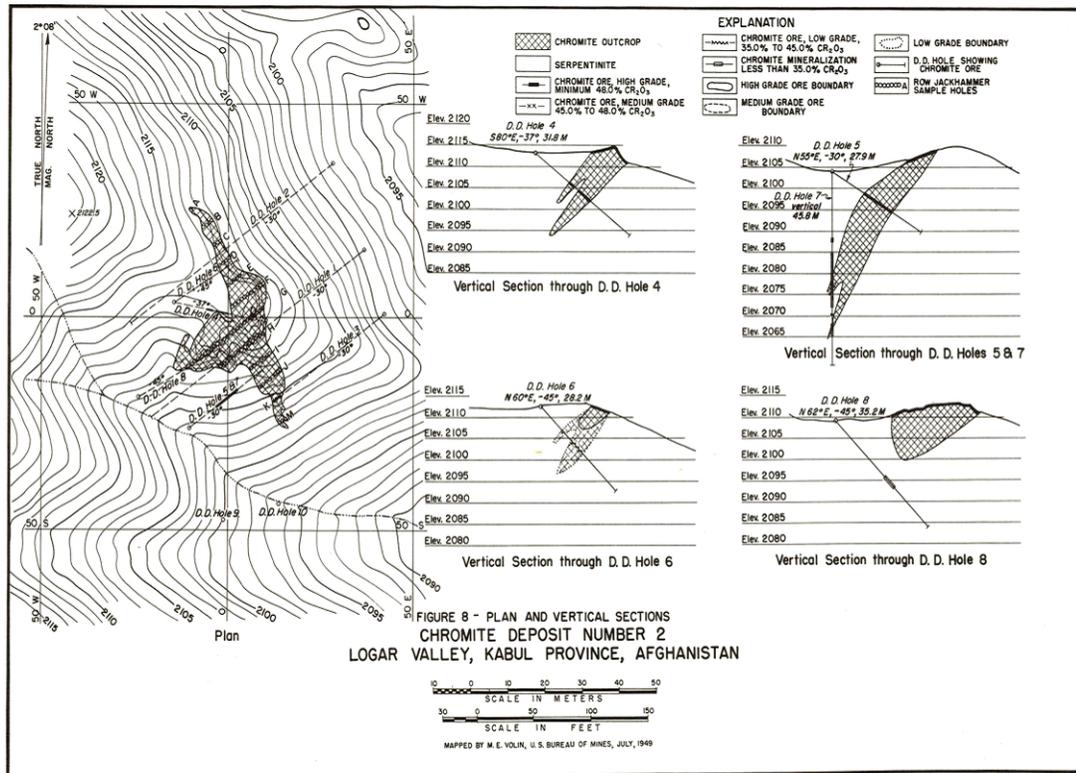


Figure 2A-32. Map view and cross sections of chromite deposit number 2 in the Logar Valley, Afghanistan (Volin, 1950).

2A.4.5 Logar Valley Chromite Subarea

2A.4.5.1 Location

The Logar Valley chromite subarea is located in the northern part of Logar Valley in northeastern Afghanistan starting 33 km south of Kabul and extending 15.5 km southward into the valley in the Muhammad Agh, Chahar Asyab, Maydan Shahr, Nirkh, and Puli alam Districts of Kabul and Logar Provinces. The Logar River traverses the valley south to north before it joins the Kabul River east of Kabul. The occurrences are mostly clustered in two groups about 9 km apart in the hills on the western side of the valley, and all are easily accessible from the Kabul-Gardez road located next to the Logar River (figs. 2A-5 and 2A-6). A northern cluster of deposits is located about 7 km northwest of the village of Muhammad Agha, and a southern cluster is located to the southwest of Dewalak about 5 km south of Muhammad Agha (Benham and others, 2009).

2A.4.5.2 Exploration History

Chromite occurrences are present in the Logar Valley and delineate a 45-km-long section mostly along the western flank of the valley with the northernmost occurrence about 14 km south of Kabul (figs. 2A–4, and 2A–6). Chromite mineralization in the area was first recognized by the U. S. Bureau of Mines in 1949–1950 (Volin, 1950). Volin (1950) documented 10 surface outcrops of chromite, numbered 1–10, occurring as massive lenses, pods, and irregular-shaped bodies of massive chromitite, predominantly hosted within small dunite pods in harzburgite (Siebdrat, 1971). Four of the areas (1, 2, 3, and 5) contain 27 diamond-drill holes totaling 975.7 m. The other areas were sampled by a combination of jack-hammer holes, channel sampling, and trenching. Details of the results of the work can be found in Volin (1950).

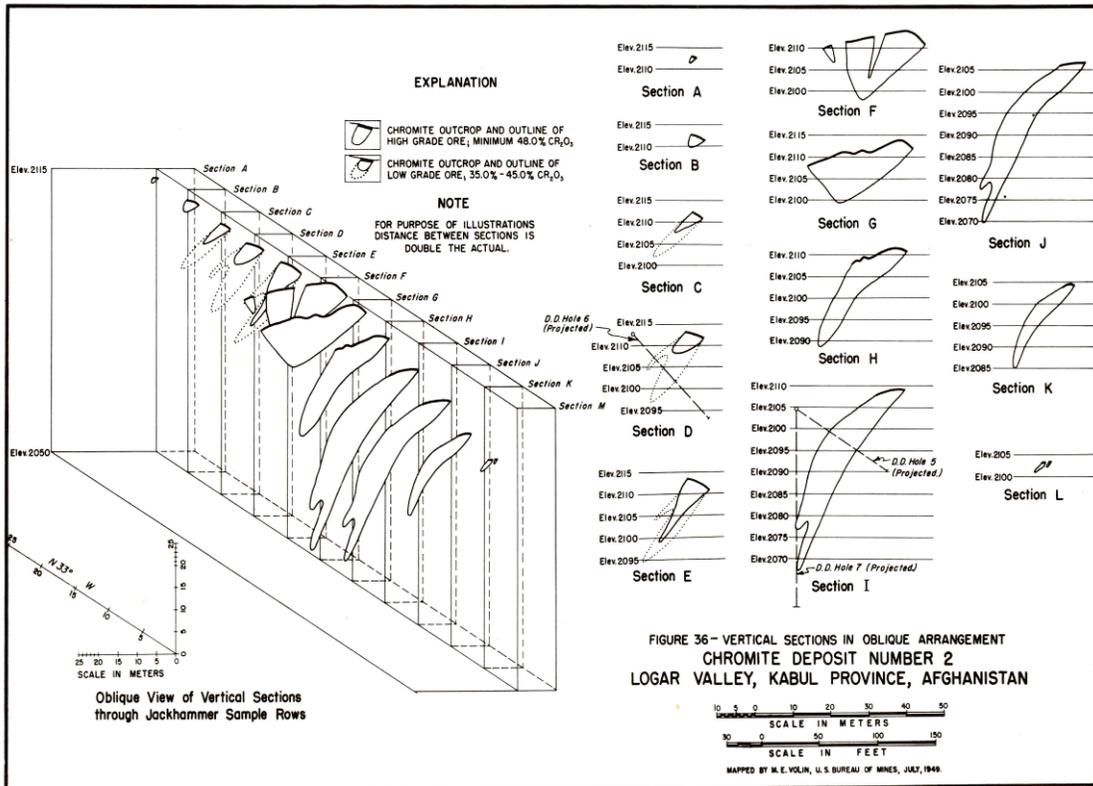


Figure 2A–33. Vertical cross sections of chromite deposit number 2 in the Logar Valley, Afghanistan (Volin, 1950).

Additional surveys in the region during the 1970s by Soviet and Afghan geologists identified copper, chromite, beryl, mica, graphite, and asbestos occurrences in the region; however, the additional chromite bodies in the LOC were reported to be isolated lenses a few meters in size and, therefore, not economically important (Denikaev and others, 1971; Nevretdinov and Mirzamon, 1979; Benham and others, 2009).

Additional work by the (German) Federal Institute for Soil Research identified 18 lenticular-shaped chromite bodies, including some of those previously identified by the U.S. Bureau of Mines (USBM) (Siebdrat, 1965; 1971; Benham and others, 2009). The main sources of information concerning the chromite deposits in the Logar Valley are Volin (1950), Siebdrat (1965; 1971), and Benham and others (2009). In a review of previous work in the LOC, Benham and others (2009) state that kilometer-sized bodies of lherzolite (and, later, cross-cutting orthopyroxenite dikes) are also commonly associated with outcrops of chromite. This study is consistent with Siebdrat's work (1965; 1971) wherein chromite

is associated with harzburgite and dunite. Benham and others (2009) concluded that the observed association of rock types represent the upper part of the mantle sequence close to the mantle transition zone. Volin (1950) and his crew carried out mapping, drilling, channel sampling, and chemical analyses on the chromite deposits in the region. The ultramafic-mafic rocks that host these deposits in Afghanistan are part of a series of ophiolites emplaced during the Eocene that extend from Afghanistan and western Pakistan through the Arabian Peninsula (Gnos and others, 1997).

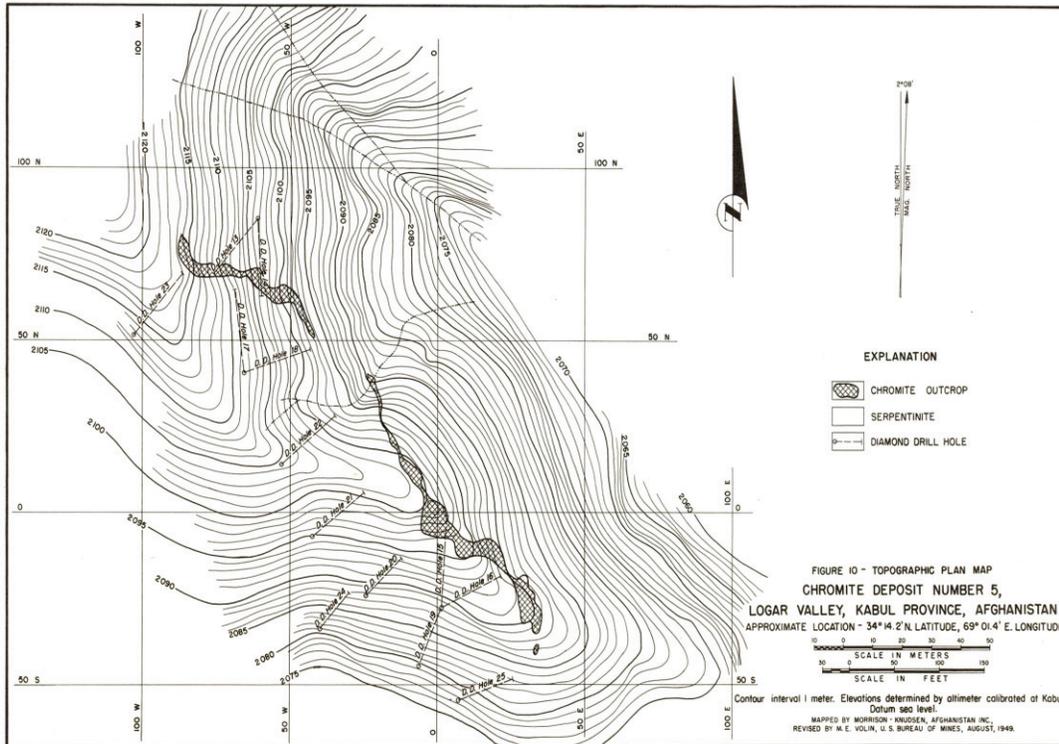


Figure 2A–34. Map view of chromite deposit number 5 in the Logar Valley, Afghanistan (Volin, 1950).

2A.4.5.3 Geology

The major rock types are serpentinized harzburgite and dunite with minor noritic dikes in the southernmost areas. These rock types were noted but not mapped by Volin (1950). The chromite deposits are all found in envelopes of dunite surrounded by harzburgite, typical of chromite occurrences in ophiolites.

2A.4.5.4 Known Deposits

The Logar deposits (figs. 2A–6, 2A–31 through 2A–36) are located about 8 km west of the Logar River on the southern flank of Qatarsang where they occur as two parallel lenticular chromite zones. The zones strike northwest, are 10 to 100 m long and 1 to 10 m thick, and predominantly consist of chromite in the middle of a large Eocene ultrabasic intrusive. The three largest deposits (1, 2, and 5) are collectively referred to by Abdullah and others (1977) as the Logar chromite deposit. The drilling investigations at these three deposits—and projection of the smaller deposits to a depth of 8 m (an arbitrary but reasonable estimate)—yielded a resource estimate of 181,200 tons containing 35.8 to 57.5 percent Cr_2O_3 . Of this, about 15 percent (27,000 tons) is high-grade metallurgical chromite with 55.9 percent Cr_2O_3 and a Cr:Fe ratio of 3.5:1. The remaining resource contains less than 45 percent Cr_2O_3 and high levels of Al_2O_3 (Benham and others, 2009). The three largest deposits (the Logar chromite deposit) make up 92 percent of the total and of these, only two contained high-grade ore. Later

work by Siebdrat (1965; 1971) increased the resource estimates to about 3 million tons of “visible or probable” ore and an additional 200,000 tons as “possible,” although it is unclear what reporting standard was used or whether these additional resources were based upon new drilling or geophysical data. Little chromite is reported to remain at the surface in these deposits, as most of the chromite has been removed by quarrying (Benham and others, 2009).

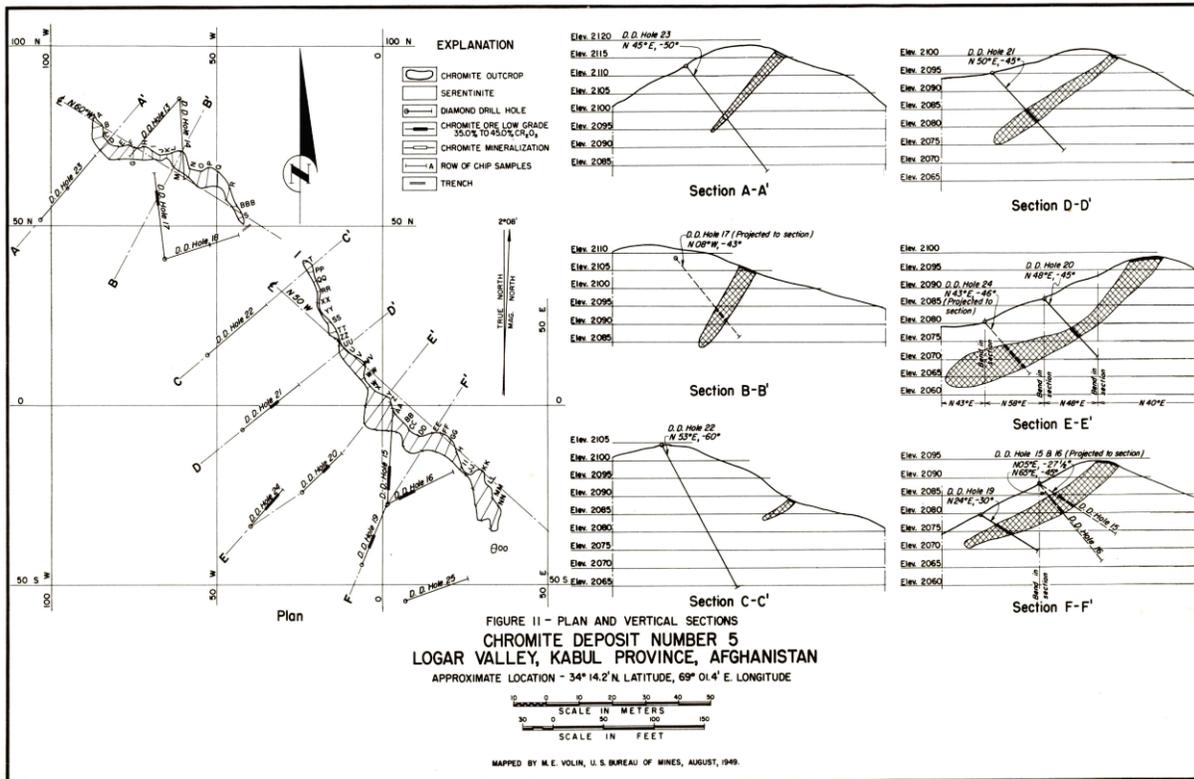


Figure 2A-35. Map view and cross sections of chromite deposit number 5 in the Logar Valley, Afghanistan (Volin, 1950).

2A.4.5.5 Prospects and Anomalies

The Werek chromite occurrence is located on the curving eastern flank of Tor Werek Ghar (fig. 2A-6). The occurrence grades 37.3 percent Cr₂O₃ and occurs as a 29-m by 3-m-thick body in an Eocene ultrabasic plug (Shcherbina and others, 1975). No estimate of resources is known.

The Makhmudgazi 1 occurrence (fig. 2A-6), located on the northern slope of Kohe Saydmahmude Ghazi about 2 km west of the Logar River, consists of two massive chromite occurrences that are 5 by 40 m and 3 by 50 m, as well as a number of small lenses in Eocene ultrabasic rocks. Volin (1950) estimated resources to be 5,600 tons grading 43.4 percent Cr₂O₃.

The Makhmudgazi 2 occurrence (fig. 2A-6) is situated about 1 km south of Makhmudgazi 1 in an Eocene peridotite. This occurrence consists of a number of chromite lenses ranging from 1 by 5 m to 2 by 51 m. Volin (1950) reports the resources to total 1,300 ton grading 43.4 percent Cr₂O₃.

Makhmudgazi 3 occurs on the northern slope of Kohe Saydmahmude Ghazi about 3 km west of the Logar River. Two massive chromite occurrences, each between 30 and 40 m long and 0.3 and 0.5 m thick occur in Eocene ultrabasic rocks (fig. 2A-6). Resources were estimated in 1950 to be 840 tons grading 42.3 percent Cr₂O₃ (Volin, 1950).

At Koh-i-Kalawur, along the southeast foot of Kohe Saymahmude Ghazi east of the Logar River, seven chromite lenses as large as 4.5 by 27 m are hosted in an Eocene ultrabasic plug (fig. 2A-40). Resources were estimated to be 4,300 tons grading 42.8 percent Cr₂O₃ (Volin, 1950). This occurrence

may be, or is located near, the Kulangar No. 10 chromite occurrence reported by Bowersox and Chamberlin (1995).

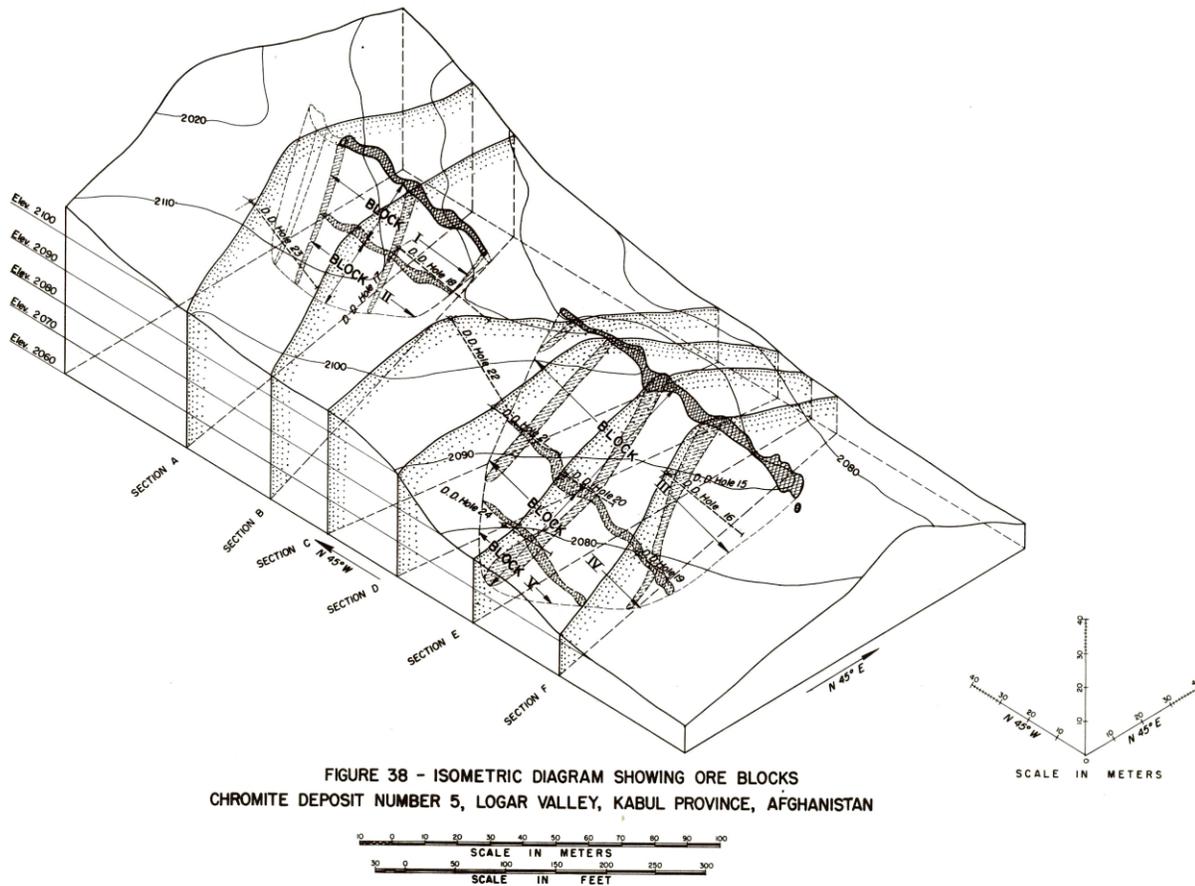


FIGURE 38 - ISOMETRIC DIAGRAM SHOWING ORE BLOCKS
CHROMITE DEPOSIT NUMBER 5, LOGAR VALLEY, KABUL PROVINCE, AFGHANISTAN

Figure 2A-36. Three dimensional representation of ore blocks in chromite deposit number 5 in the Logar Valley, Afghanistan (Volin, 1950).

Volin (1950) reports an unnamed chromite showing at $34^{\circ}16'20''$ N, $68^{\circ}53'10''$ E, which is on the western flank of Sro Ghar and south of the merger of the Kabul River and a river from the northwest. Chromite float is seen in eluvial talus covering an area of 30 by 20 m that is derived from an Eocene peridotite (Volin, 1950). No estimate of resources was reported.

Another unnamed chromite showing is also reported at $34^{\circ}14'10''$ N, $68^{\circ}52'20''$ E, which is on the western flank of the mountains between Sro Ghar and Tor Ghar. Several chromite lenses are present up to 6 to 20 m long and as much as 10 m thick in Eocene ultrabasic intrusive rocks (Volin, 1950). No estimate of resources was made by Volin.

A third unnamed chromite showing can be found at $34^{\circ}08'50''$ N, $68^{\circ}58'05''$ E. A chromite lens about 10 m long and 2 m thick occurs in Eocene ultrabasic intrusive rocks at this site (Volin, 1950). Resources are estimated at 200 tons grading 44.1 percent Cr_2O_3 .

A cluster of asbestos deposits and occurrences is centered about 35 to 45 km south to southwest of Kabul. The Logar asbestos deposit in Logar Province consists of asbestos in serpentinized zones in fault zones along the contact of porphyry and lamprophyre dikes in Eocene peridotite. Chrysotile occurs in stockworks of variable size in serpentinized zones that are a few tens of meters to 600 m long and as much as 5 or 6 m thick. The stockworks consist of thin veinlets containing 0.8 to 9.0 percent asbestos fiber (United Nations Economic and Social Commission for Asia and the Pacific, 1995).

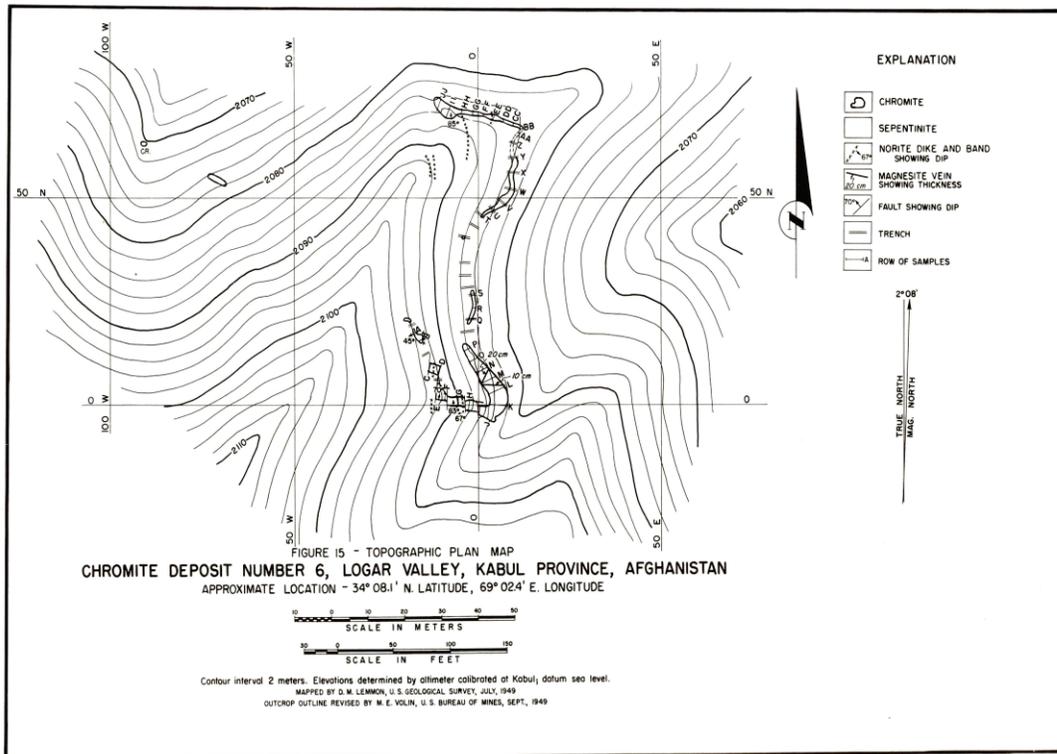


Figure 2A-37. Map view of chromite deposit number 6 in the Logar Valley, Afghanistan (Volin, 1950).

The Spinkala asbestos occurrence is present in Eocene peridotite in a serpentinized zone that is 50 to 700 m wide with predominant slip-fiber asbestos and minor cross-fiber asbestos. The occurrence grades 0.25 to 7.88 percent chrysotile asbestos (Shcherbina and others, 1975). Cross-fiber asbestos at the Kohe Moghu Aba occurrence is found in a 300 m long by 20 to 50 m thick zone along diabase dikes in Eocene serpentinite. The mineralized zone grades 3.83 percent asbestos (Shcherbina and others, 1975).

The Abparan asbestos occurrence has been identified as an asbestos-bearing zone in a 500-m-long Eocene peridotite zone. The mineralized zone is about 300 m long and 5 to 20 m wide with asbestos in veinlets 1 to 15 mm thick (Shcherbina and others, 1975).

The Waghjan asbestos occurrence is found in Eocene peridotite along a 500-m-long zone where lenticular asbestos-bearing bodies 30 to 80 m long and 0.3 to 3.0 m thick have cross-fiber veinlets 0.5 to 5.0 mm thick (Shcherbina and others, 1975).

At the Shakhsi asbestos occurrence, strongly serpentinized asbestos-bearing zones 30 to 200 m long and 0.3 to 6 m thick occur along faults in Eocene peridotite. These mineralized zones carry as much as 9.5 percent chrysotile asbestos with an average of 0.8 percent asbestos (Shcherbina and others, 1975) (fig. 2A-40).

Four additional asbestos showings are present in Logar Province. At the first showing, cross-fiber asbestos veinlets having fibers 4 to 5 mm long are found in a serpentinized zone 150 to 200 m long and 20 to 30 m wide in Eocene ultramafic rocks (Shcherbina and others, 1975). The second showing occurs as serpentinized zones in Eocene peridotite. The zones are a few tenths of meters long and 0.3 to 0.5 m thick with cross-fiber asbestos in veinlets (Shcherbina and others, 1975). The third showing consists of serpentinite zones as much as 30 m long and 0.1 to 1.0 m thick in Eocene peridotite. The zones carry cross-fiber asbestos in veinlets 2 to 5 mm thick (Shcherbina and others, 1975). The last reported asbestos showing in Logar Province is located mainly along the contact between diorite-gabbro and Eocene peridotite where a zone 1,200 m long and 100 to 200 m thick contains chrysotile asbestos veinlets having fibers 1.5 to 2 mm long (Shcherbina and others, 1975).

The Lalandar talc-magnesite occurrence is located close to the contact between small Eocene ultramafic bodies and interbedded slate and marbled limestone of Late Permian age. The occurrence

consists of four pervasive talc-bearing zones 100 to 800 m long with 20 by 30 m nests and lenses of talc. These occurrences have been exploited by local residents (Shcherbina and others, 1975) and may or may not be of the ultramafic type.

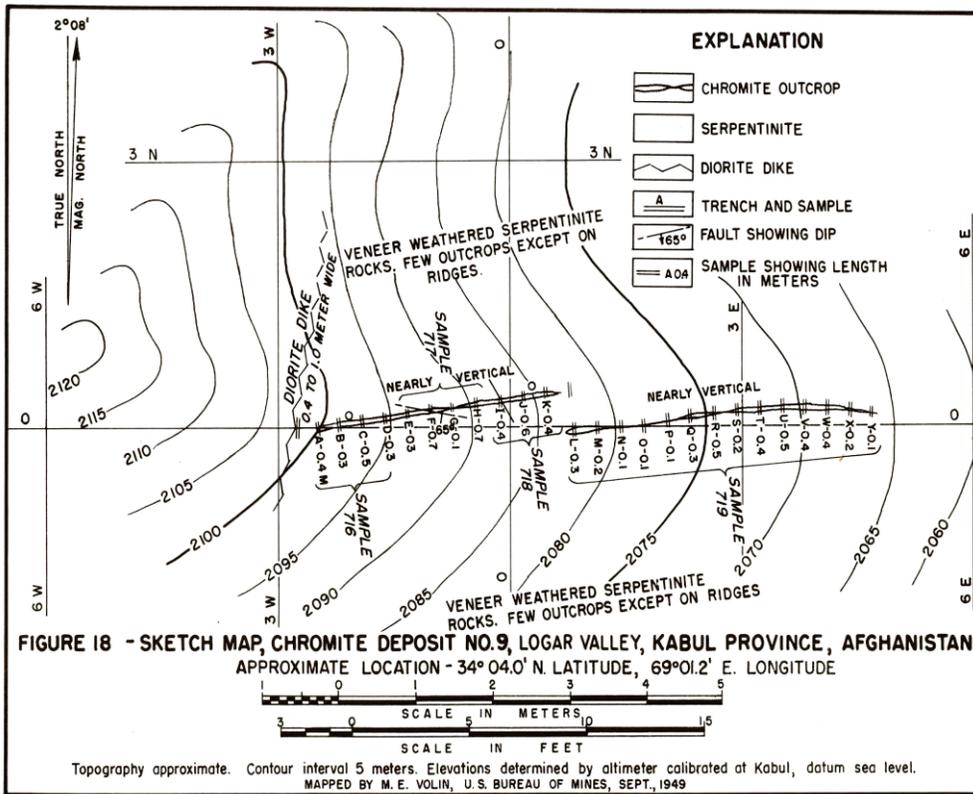


Figure 2A-38. Map view of chromite deposit number 9 in the Logar Valley, Afghanistan (Volin, 1950).

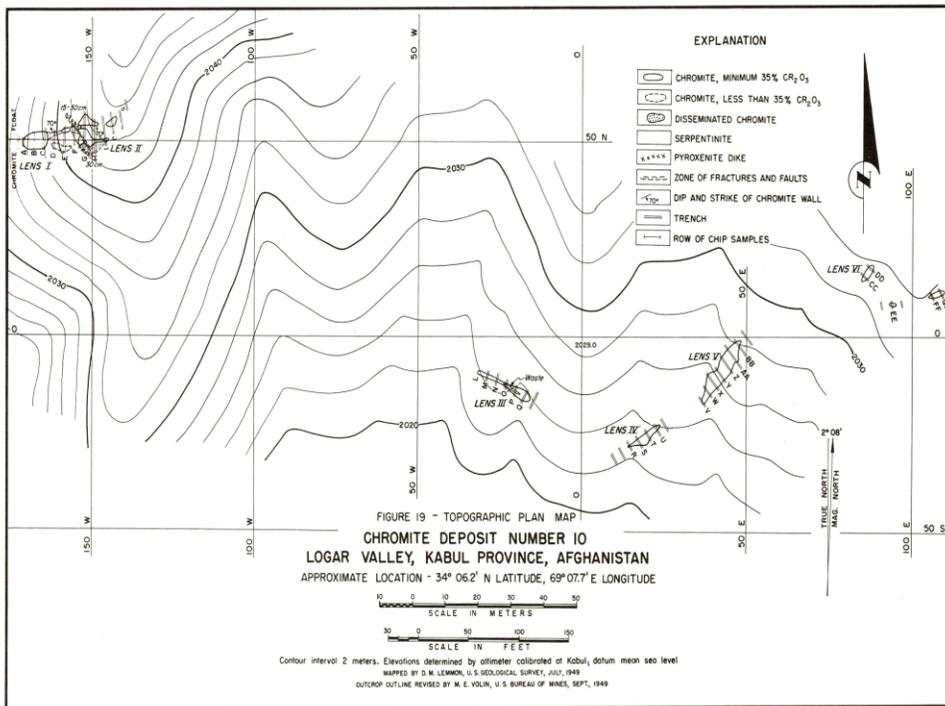


Figure 2A-39. Map view of chromite deposit number 10 in the Logar Valley, Afghanistan (Volin, 1950).

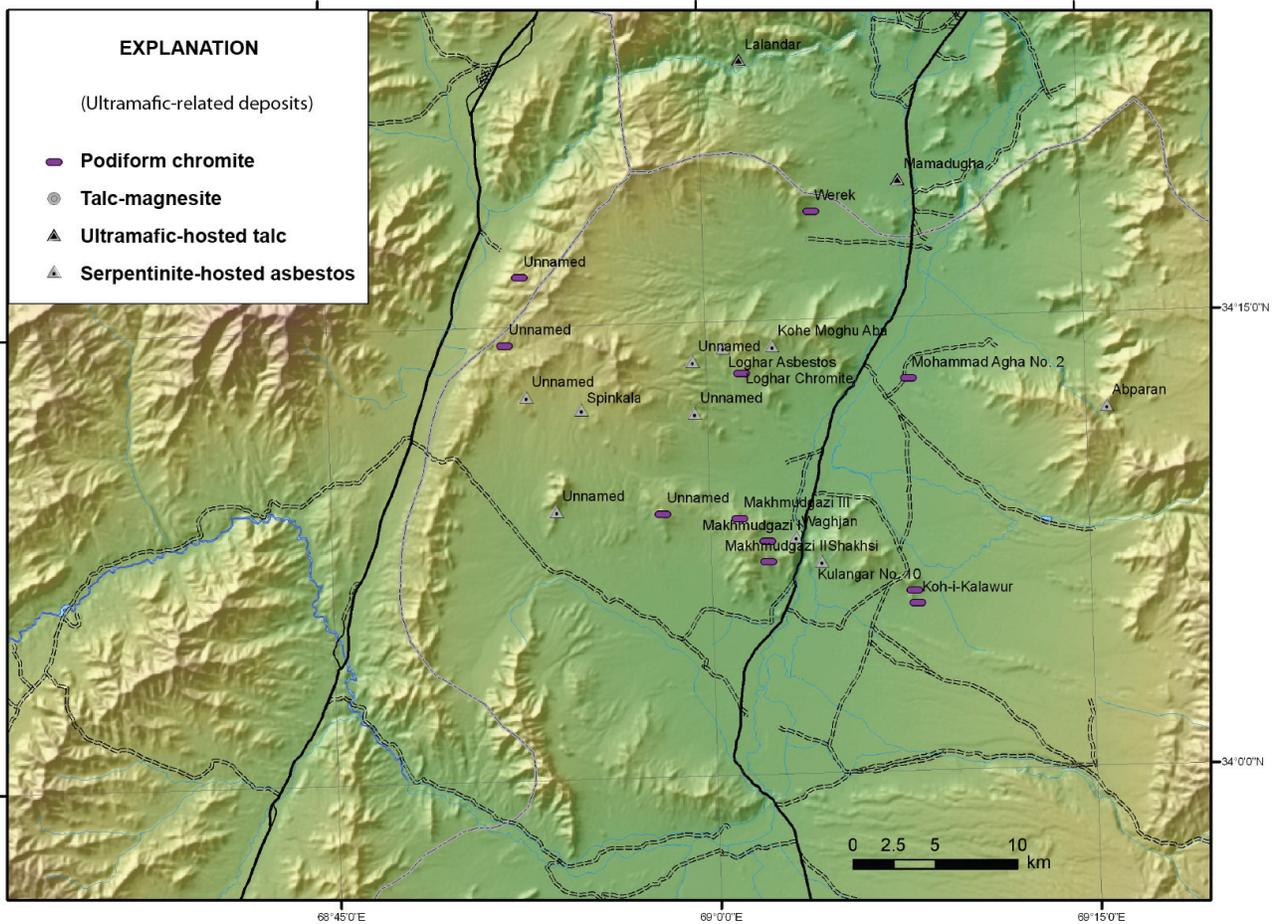


Figure 2A–40. Locations of chromite occurrences in the Logar Ophiolite Complex. Imagery base map, 90 m shaded DEM from Peters and others (2007).

2A.5 Summary of Potential

Sediment-hosted copper deposits are large, relatively low grade deposits that may also contain significant amounts of cobalt, silver, uranium and, less commonly, gold and platinum group elements as byproducts. The extraction of these deposits would require hundreds of million dollars in capital investment (<http://www.newsecuritybeat.org/2010/03/copper-in-afghanistan-chinese.html>) and also require significant resources of operational power and transportation infrastructure. Development from discovery to production may take up to 10 or more years. The deposits commonly are mined by large open-pit mines, but especially rich deposits may also be mined by underground methods. Sediment-hosted copper deposits are commonly associated with a number of other deposit types, such as halite, potash, gypsum, and anhydrite deposits, which occur in the same sedimentary sequences. Sandstone uranium, unconformity uranium, and Kipushi-type copper-lead-zinc deposits can occur in the same districts. In addition, the iron oxide copper-gold and basaltic copper deposit submodels may be applicable within some of the areas that were studied.

In light of the presence of the world-class Aynak copper-cobalt deposit and a number of smaller deposits with reported resources, the future potential for discovery of additional copper-cobalt deposits in the Aynak area of interest and subareas is regarded as high.

Podiform chromite deposits are generally very small deposits that are not economically feasible to extract unless significantly large numbers are present such that sufficient tonnages in aggregate can be achieved. Some podiform chromite deposits contain platinum group elements as byproducts, which can represent significantly enhanced economic value. These deposits occur in the ultramafic parts of

ophiolite sequences that are also host to industrial mineral deposits of talc-magnesite and asbestos. The mining of asbestos, however, can have undesirable environmental consequences which decreases the likelihood of exploitation. Although the future potential for additional discovery and exploitation of chromite deposits in the Logar Valley is regarded as low, chromite deposits may be suitable for artisanal mining and direct transport of chromite ore to smelters.

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