1.0 Introduction

1.1 Background

In February, 2002, at the request of the Department of State, and the then U.S. Ambassador to Afghanistan, Robert Finn, the U.S. Geological Survey (USGS) prepared a detailed proposal addressing natural resources issues critical to the reconstruction of Afghanistan. This proposal was updated and presented as a five-year work plan to United States Agency for International Development (USAID)-Kabul in February, 2004. This plan was accepted, funded, and work began in the Spring of 2004.

The planning document of the natural resources proposal (December, 2003) indicated that rebuilding and revitalization of the Afghanistan natural resources sector should initially focus on seven critical elements that were identified from discussion with Afghanistan government officials and with international donor organizations, and also resulting from review of reports and maps produced by these groups. The seven critical elements identified for implementation by the USGS are: (1) building of institutional capacity; (2) development of geospatial infrastructure; (3) assessment of oil and gas resources; (4) assessment of coal resources (including coal bed methane resources); (5) assessment of non-fuel mineral resources; (6) assessment of water resources; and (7) assessment of earthquake hazards. All of these interrelated critical activities have been undertaken concurrently to provide efficiency and economy of scale and effort.

In keeping with the updated five-year plan, the activities were planned in two phases (Phases I and II). Phase I focused on existing data and information. At the end of the Phase I, which lasted about two years, preliminary assessments were produced, of which this is one, and were made available for immediate integration into the planning process. This report addresses the Phase I assessment of non-fuel mineral resources. An earlier mineral assessment report concerning selected mineral deposit types was completed in 2006 (Ludington and others, 2007). Petroleum assessments for Phase I are included in Klett and others (2006) and Steinshouer and others (2006). Phase II, although based on the Phase I studies, proposes to focus on acquisition and interpretation of new data and will include field studies by the Afghanistan Geological Survey (AGS) that will make possible refinement and improvement of the preliminary assessment.

Some newly acquired data are incorporated into this Phase I preliminary non-fuel mineral assessment, including many results of a modern country-wide airborne geophysical survey that acquired gravity, magnetic, and hyperspectral data. The U.S. Naval Research Laboratory (NRL) completed the gravity and magnetic survey begun in January, 2006, and preliminary interpretations of these data are used in this report. NRL added both radar and orthophoto instruments to the payload, and these data were also partially available for use during Phase I; complete coverage will be available during Phase II assessments.

The main accomplishments of the Phase I non-fuel minerals work by the USGS that were incorporated in this report are:

(1) The acquisition from Russia of digital copies of the countrywide Afghanistan 1:500,000-scale geologic map, as well as an Afghanistan minerals database; from the Czech Geological Survey: reports on the geologic resources for cement plants; from the German Geological Survey (BGR): the 1967-68 airborne geophysics of the Katawaz and Helmand basins along with numerous reports on individual mineral deposits and coal and oil and gas data; and from the British Geological Survey (BGS): AGS reports inventory (at the moment there are more than 2,000 entries).

(2) Creation of a Geographic Information System (GIS) to support mineral resource assessment (Appendix I of this report).

(3) Field visits to the Aynak (copper), Haji Gak (iron), Logar Valley (chromium), Ghazni-Nabul-Kandahar Provinces (copper and gold), Jegdalek (ruby), and Panjshir Valley (emerald) localities to determine deposit type and geologic setting.

(4) Training of AGS staff in mineral resource assessment methodology in January, 2007 in Denver, CO and Reston, VA.

The following databases and reports were completed as part of this assessment:

(1) A searchable database of scientific literature on Afghanistan geology and mineral deposits. An upgraded version will be delivered in September, 2007. The current database has 1,157 published and 168 unpublished references. There are 884 scientific and 754 geographic/cultural keywords (Eppinger and Sipeki, 2006).

(2) A digital compilation of existing geologic and mineral resource data (ArcGIS project) (Doebrich and Wahl, 2006).

(3) A digital compilation of existing aeromagnetic surveys of the Helmand and Katawaz basins. Includes three reports on the digitized aeromagnetic and radiometric data. (Sweeney and others, 2006a, b and c).

(4) Maps of hydrothermal alteration for selected areas derived from ASTER image processing (Mars and Rowan, 2007).

1.2 Past Development

Afghanistan has abundant mineral resources, but they have not been successfully developed during the 20th century. Nor have they been systematically studied using modern mineral resource assessment methodologies. Most of the existing mineral resource information was gathered between the early 1950s and about 1985, when the Union of Soviet Socialist Republics (USSR) and its Eastern European allies provided Afghanistan with large amounts of technical assistance. Mineral resource studies included systematic geologic mapping, collection and analysis of rock and sediment samples, airborne geophysical surveys, and systematic mineral exploration. Many maps and reports from this era remain in the libraries of the Ministry of Mines (MOM) and the AGS, but by the end of Soviet intervention in 1989, many had been taken to the USSR, Eastern European countries, or elsewhere. Acquisition and compilation of these materials were the first activities of the USGS, and this information forms much of the factual basis for this preliminary non-fuel mineral resource assessment.

A wide variety of non-fuel mineral resources is known, including important deposits of copper, iron, chromium, silver, barite, sulfur, talc, magnesium, salt, mica, marble, rubies, emeralds, and lapis lazuli. By 1985, Soviet surveys had also delineated potentially exploitable deposits of asbestos, nickel, mercury, gold, lead, zinc, fluorspar, bauxite, beryllium, and lithium. The government of Afghanistan was actively preparing several of these deposits for exploitation when the Soviet intervention began. No further development was possible during the ensuing years of war and civil strife.

One of the most important and best-known deposits is the Haji Gak iron deposit. Located in Bamyan Province, about 90 km west of Kabul, the deposit is part of a discontinuous east-trending zone of iron concentrations more than 30 km long. This zone also contains the Khaish iron deposit. Primary ore consists mostly of magnetite and pyrite, with minor chalcopyrite, and averages more than 60 wt. percent iron. Part of the ore is oxidized to several forms of hematite. Soviet exploration identified a total of more than 2 billion metric tons of reserves, a figure that is roughly equivalent to worldwide annual production of iron ore. A feasibility study was completed, and development had begun in 1983.

Another extremely important deposit is the Aynak sediment-hosted copper deposit, along with the similar, though smaller, Darband and Jawkhar copper deposits. These are located in Kabul and Logar Provinces about 30 to 40 km southeast of Kabul. Copper has been mined here for more than 2,000 years; there a drilling program conducted in the 1980s identified a minable resource of 240 million metric tons of ore grading about 2.3 percent copper. More than 30 other occurrences are in the vicinity. Both a mill and a smelter under construction were abandoned about 1985.

A minor amount of chromite ore was mined in the early 1980s, primarily from two deposits, Mohammad Agha in Logar Province about 30 km south of Kabul, and Hesarak in Nangarhar Province about 90 km southeast of Kabul. Many small chromite deposits are located in surrounding areas.

About 12,000 metric tons of barite was produced annually from the Sangilyn vein barite deposit about 40 km northwest of Herat beginning about 1977. This deposit, which has reserves of nearly 1 million metric tons of ore, also contains small amounts of copper-, lead-, and zinc-bearing sulfide minerals.

Before the Soviet intervention, precious and semiprecious gemstones were a major industry in Afghanistan, which is one of the world's premier sources of lapis lazuli. Emeralds and rubies were also major products. During the civil war, production of gemstones declined. Most of the gemstones come from Badakshan and Nuristan Provinces in northeastern Afghanistan.

1.3 Assessment Methods

An assessment is an estimation or evaluation, in this case, of the amount of undiscovered mineral resource expected to be present within specific volumes of rock. Mineral resources are materials that are in such form that economic extraction of one or more commodities from the material is currently or potentially feasible. This assessment of non-fuel mineral resources is quantified, where possible, such that the results are expressed in numbers. Because of the uncertainty inherent in assessment of the unknown, the results are presented probabilistically. Mineral resource assessments provide government decision makers and potential private investors and explorationists with information on where undiscovered mineral deposits may be located, what kinds of deposits are likely to occur, and the kinds and how much metal or other commodity may exist in them. This information makes possible wise management of natural resources.

An assessment of mineral resources can take many forms. The simplest might be a statement like, "Yes, this is a good place to look for minerals." Another type might consist of an exhaustive inventory of the location, nature, and amount of known resources, in principle, much like what a shepherd does in counting sheep. For mineral resources, the latter approach would only be possible if the area were completely explored and no undiscovered deposits remained. This preliminary assessment of non-fuel mineral resources of Afghanistan was conducted by teams of scientists from both the USGS and the AGS using the methods described by Singer and Cox (1988) and Singer (1993) that were used in the U.S. National Assessment (U.S. Geological Survey, 2002). The main data used were the geologic map and mineral occurrences data bases (Orris and Bliss, 2002 and Doebrich and Wahl, 2006). Most of the deposit descriptions were derived from Abdullah and others (1977) and original references (often in Russian) are cited in that report and are also referred to in this assessment when appropriate.

Many of the assessment sections in this report refer to geochemical anomalies or geochemical mineral halo anomalies and this indicates use of an unreferenced derivative dataset of heavy mineral halos used in the GIS spatial analysis. Polygons used from this data set represent concentrations of different elements, such as Au, or Hg, or Pb and were derived from stream sediment sampling done by Russian workers during the 1960s and 1970s and include pan concentrate samples. The polygons are attributed with geology and mineralogy and represent a useful regional, but not complete distribution of some geochemically or base- or precious-metal mineral anomalous areas.

The maps and figures in this report contain numerous mineral occurrence locations that are represented by symbols derived from Doebrich and others (2006). Legends are provided with most of the figures in this report, but a complete legend of all the mineral deposit and commodity types is included at the end of this section in figure 1.0-6.

To aid in understanding this assessment, definitions are provided along with further discussion of technical terms used in this document.

Permissive tracts—To begin the assessment, the USGS-AGS assessment teams reviewed the geology of areas and selected appropriate deposit models. They then delineated permissive tracts for each type of deposit. The permissive tracts were defined by the geologic environments of formation described in the deposit model, such that the probability (*P*) of deposits of the deposit model type delineated occurring outside the tract is negligible (that is, *P* is less than 0.00001 to 0.000001) (Singer, 1993). In other words, the permissive tracts will contain all the undiscovered deposits postulated in the assessment. Geologic maps and maps showing the location and type of mineral deposits and occurrences are important in outlining the permissive tracts. Geophysical and geochemical maps are also useful, as well as knowledge about the exploration history.

Estimates of undiscovered resources were made to a depth of 1 km beneath the surface of the Earth. If an area of permissive rock is covered by more than 1 km of rock known to be barren or younger than the mineralizing event under consideration (non-permissive), it is excluded from the tract (fig. 1.0-1).

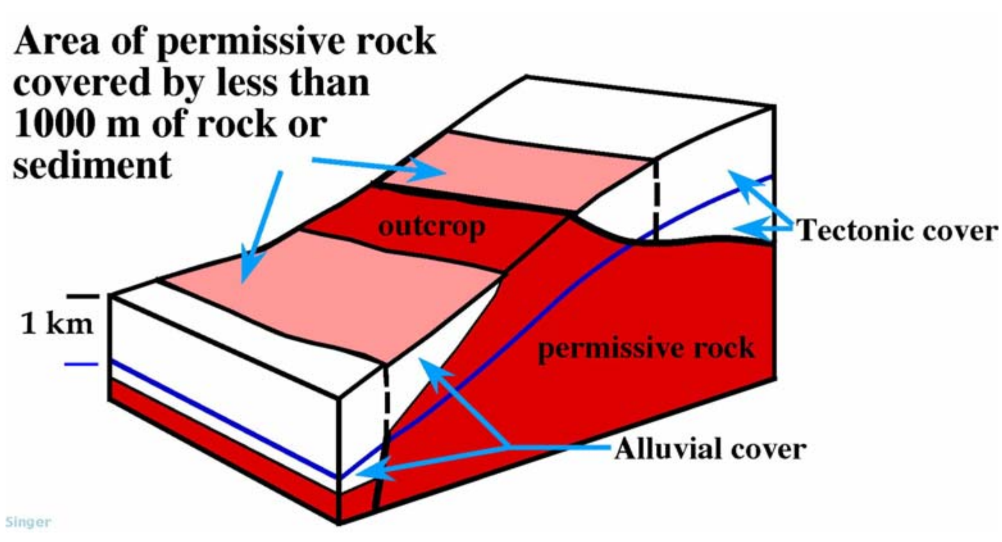

Figure 1.0-1. Diagram showing how permissive rock covered by less than 1 km (interval above blue line) is included in permissive tracts. After Singer (1996).

The somewhat arbitrary depth of 1 km, unless otherwise noted, was chosen as the limit below which deposits would not be estimated. Because some ore deposits have vertical extents of well over a kilometer, we have adopted the rule that if any part of a deposit is judged to occur in the upper kilometer of the Earth, it is counted.

This rationale is consistent with mining practice. Although deposits may be explored and developed at deeper levels (up to 3 km) once they have been discovered (usually at depths of less than 1 km), direct exploration is seldom conducted below 1 km.

***Grade and tonnage models*—**The teams reviewed the grade and tonnage data for known deposits (if any) in the tract and decided whether or not the worldwide models were appropriate for the tract. Reasoning by analogy, the undiscovered deposits estimated in the area should be similar in grade and tonnage to known examples. If the models are not appropriate, a quantitative estimate is not made. For many deposit types, these data are available in the form of grade and tonnage models in Cox and Singer (1986), Bliss (1992), and Orris and Bliss (2002). Grade and tonnage models help classify mineral deposits and also provide information about the potential value of undiscovered deposits.

***Numerical estimation*—**Whenever possible, the USGS-AGS assessment teams estimated the number of undiscovered deposits of each type in the permissive tracts. These subjective estimates depend on expert judgment. They are expressed in terms of the least numbers of deposits for specified cumulative probabilities. Commonly, estimators were asked for the least number of deposits believed to be present at a specified cumulative probability; and the answer is a specific number of deposits. The answers to a series of these questions for several quantiles (generally 0.9, 0.5, 0.1; sometimes 0.05 and 0.01 percent probability) were used to develop a cumulative probability distribution of numbers of deposits.

Teams included experts who were familiar with the deposit types in question (figs. 1.0-3 and 1.0-4). Teams used a variety of methods are used to arrive at consensus; the most common method was simply to continue the discussion until all agreed. However, many tools, including deposit density estimates and assumptions about exploration adequacy, were used to guide the final estimates (Singer, 1993; Singer and others, 2001). The result of the estimation process is a probability distribution of numbers of undiscovered deposits. Some details regarding the deposit estimation procedure are found in Root and others (1992), but in summary the following are true and are illustrated on figure 1.0-2.

The estimated numbers of deposits estimated for each permissive tract were consistent with the world-wide model. The assessors have assumed that approximately half of the deposits estimated have tonnages that are larger than the deposit tonnage model median and half of the deposits have grades that are larger than the deposit grade model median and are compatible with the geology in the tract and with the world-wide grade and tonnage and descriptive deposit models. That is, if 10 deposits were estimated, 5 of them were considered to be larger than the median tonnage on the grade and tonnage model, and 5 of them are considered to have a higher grade than the median grade on the grade and tonnage model. If the grade and tonnage model was based on district data, rather than data for individual deposits, then the assessors estimated numbers of undiscovered districts rather than deposits.

The deposits estimated should be consistent with the grade and tonnage model. That is, if 10 deposits are estimated, 5 of them are considered to be larger than the median tonnage, and 5 of them are considered to have a higher grade than the median grade. If the grade and tonnage model is based on district data rather than data for individual deposits, then the numbers of undiscovered districts are estimated.

There are many geologic, geochemical, and geophysical guides to estimating undiscovered deposits. Estimates can be guided by counting mineral occurrences, geochemical anomalies, or exploration "plays" and assigning to each a probability of its being a member of the grade and tonnage distributions.

Estimates can also be guided by analogy with well-explored areas that contain known numbers of deposits and that are geologically similar to the study area. One important factor in assessment of a particular tract is the degree of previous and current exploration activity. Exploration intensity may have two opposing influences. First, because many types of mineral deposit tend to occur in clusters, success in finding one deposit stimulates the search for others. When that search is not yet exhaustive, discovery of additional deposits is likely. On the other hand (and more rarely), exploration activity may be so thorough that the probability of an undiscovered deposit is minimal; no such areas exist in Afghanistan.

Simulation (Analysis)**—**To obtain the estimated amounts of metal or other commodity in undiscovered deposits, the probability distribution of estimates of the numbers of undiscovered deposits is combined with probability distributions for tonnage and grade using Monte Carlo simulation From each distribution, a number of deposits, a tonnage, and a grade are selected randomly. This is repeated by computer many thousands of times to create a new probability distribution, a distribution of contained metal (or other commodity) (fig. 1.0-2).

The Mark3 simulator (Root and others, 1992), now implemented by the USGS's EMINERS system **(**Duval, 2004**)**, is used to convert information about grade, tonnage, and number of deposits into information about amounts of contained metal. Probabilities for the existence of undiscovered deposits are stated as inequalities because mineral deposits occur only as discrete numbers of deposits. A simulator must be used because the probability distributions used to describe grade, tonnage, and number of deposits are empirical (i.e., not mathematical functions) and cannot easily be combined mathematically without several simplifying assumptions. The quantiles of the grade and tonnage distributions cannot be multiplied to generate the quantiles of contained metal. Multiplying quantiles could be successful only if the ordinal lists of grades and tonnages were identical, a very unlikely event.

The results of the quantitative parts of this non-fuel mineral resource assessment for undiscovered deposits are a series of numerical, probabilistic representations of the expert judgment of the USGS-AGS teams of geoscientists that made estimates of numbers of undiscovered deposits, and can be displayed in various ways. Class-interval histograms emphasize those amounts of metal that are most likely to exist. Cumulative histograms are especially useful because all the information generated by the simulation can be read from a single plot. Various quantiles and the expected means are best used for comparisons between and among estimates for different deposit types or different permissive tracts. No single number can adequately represent the magnitude of an estimate, because no single number can represent the spectrum in judgment that is inherent in the estimation process or the distribution of values that make up the grade and tonnage models.

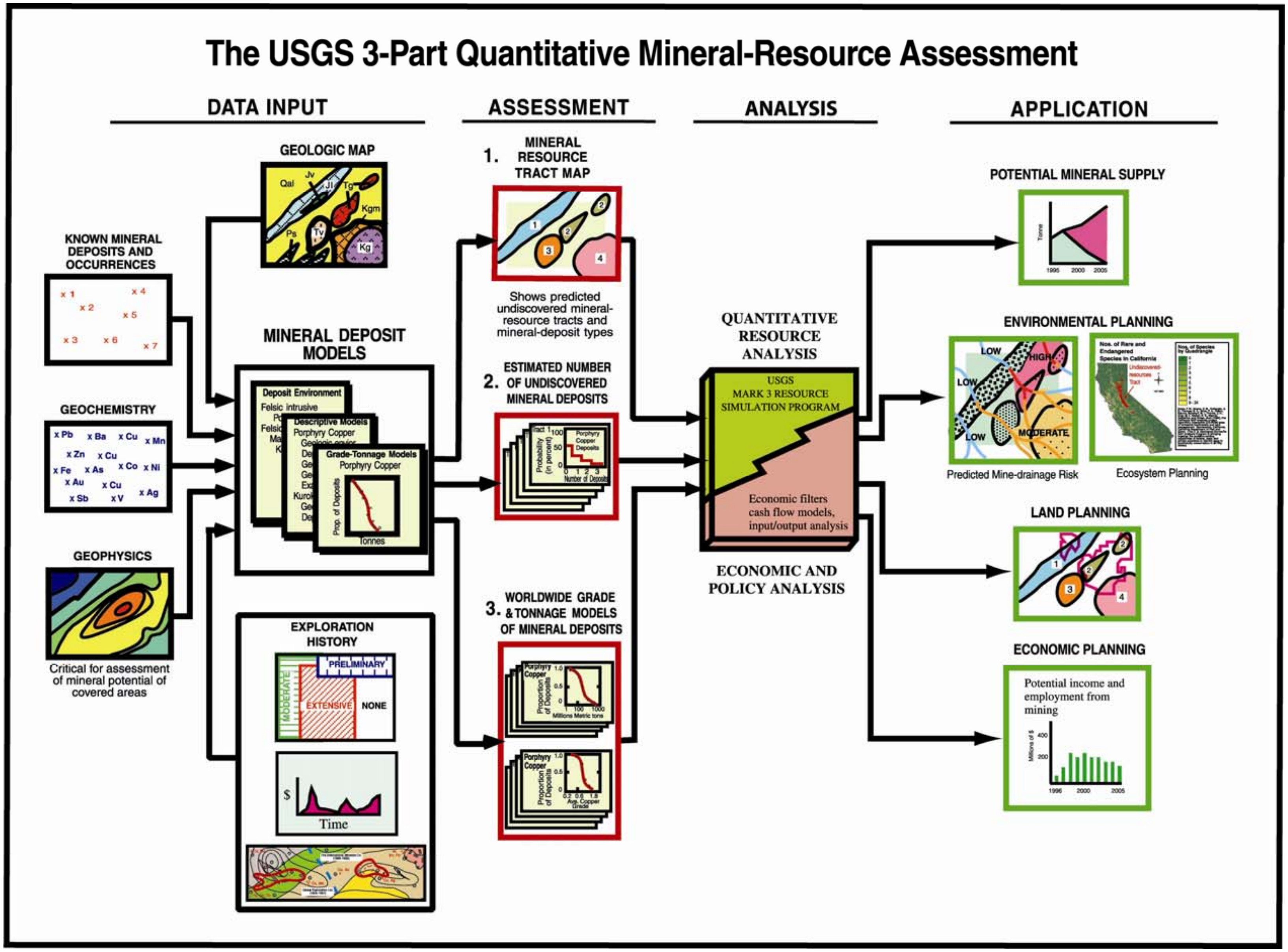

Figure 1.0-2. Flow chart of the 3-part USGS Mineral Assessment Methodology

Descriptive mineral deposit models are the systematically arranged information that describes the essential attributes (properties) of a class of mineral deposits (Barton, 1993). The models have two parts. The first part describes the general setting of the deposit type and is primary in the delineation of permissive tracts. The second part helps classify known deposits and occurrences. In some cases, correct classification of known deposits and prospects help identify geologic environments not clearly indicated by geologic maps (fig. 1.0-2).

It is possible to further subdivide some permissive tracts to highlight areas of special interest. For some tracts, favorable and prospective areas are designated within the permissive tracts, where the probability of occurrence of undiscovered deposits is judged to be higher. Land planning may benefit from information about differing levels of favorability this information is provided when appropriate. No separate estimates of numbers of undiscovered mineral deposits are made for favorable or prospective tracts.

Favorable tracts are a subset of the permissive tracts, and have a higher probability of occurrence for the deposit type in question. Although procedures for individual deposit types vary, they were generally delineated to include areas where there is evidence that a mineralizing process capable of generating deposits has affected the area. This evidence is primarily in the form of mineral prospects and occurrences, but could also include genetically related deposit types, areas of hydrothermal alteration, or geophysical or geochemical anomalies. Favorable tracts areas are likely to be the site of future mineral exploration and development.

Prospective tracts are a subset of favorable tracts. These generally are small, and serve to highlight areas where strong indications of mineralization processes are documented, such as altered zones or geophysical or geochemical anomalies; in most cases, they have a history of mineral production. These areas are very likely to be the site of continued or renewed mineral exploration and development.

1.4 Geologic History

Afghanistan exhibits complex and varied geology, with rocks representing every geologic age from Archean to the present. Located at the western end of the Himalayan mountain chain, the northern part of the country (north of the Herat/Badakhshan fault system; fig. 1.0-5) is part of Eurasia, whereas the area to the south is made up of accreted fragments of Gondwana. Thus, Afghanistan comprises an assemblage of varied crustal blocks separated by major fault zones, each block having a different history and metallogenic character. Principal facts and interpretations for this synthesis come primarily from Sengör (1984), Sengör and Natal'in (1996), Debon and others (1986), and information provided by the AGS at *http://www.bgs.ac.uk/afghanminerals/geology.htm*.

The Tethys Ocean (between Eurasia and Gondwana) began to close in Triassic time. This resulted in northward-facing subduction and the emplacement of a Triassic continental arc (Western Badakhshan, West Hindukush, and Feroz Koh plutonic belts; fig. 1.0-5). This subduction was the start of the Cimmeride (Triassic ~220 Ma) orogeny, which culminated in the accretion of the Farah Rod and the Helmand blocks by Early Cretaceous (~140 Ma). At about the same time, the Pamir and West Nuristan blocks also were accreted to Eurasia in what is now northeastern Afghanistan.

From Early Cretaceous until middle Tertiary (~30 Ma) time, general northward movement of the Indian subcontinent continued, and the attendant subduction resulted in emplacement of a series of mostly calc-alkaline plutonic and volcanic rocks into both the new and old parts of Eurasia. After the India-Eurasia collision, which took place about 50 Ma in this region, peraluminous granitoid rocks joined the calc-alkaline intrusions in the West Nuristan, Safed Khers, Wakhan, and Arghandab plutonic belts (fig. 1.0-5). This activity formed most of the rocks of the Farah Rod, Band-e Bayan, Khash Rod, Helmand, Arghandab, West Nuristan, Safed Khers, and Wakhan plutonic belts (Debon and others, 1986).

In the southwesternmost part of Afghanistan, intrusive and volcanic rocks of the Chagai igneous belt are the products of late Tertiary subduction of the Arabian oceanic floor beneath Eurasia. This subduction continues to the present.

The Arghandab, Farah Rod, Helmand, Khash Rod, and Spin Boldak plutonic belts are concealed by young sediments of the Sistan basin at their southwest end. In addition, parts of the Chagai igneous belt are concealed. Geophysical data (Sweeney and others, 2006a, b) help delineate the extension of these magmatic belts beneath the desert of southwestern Afghanistan.

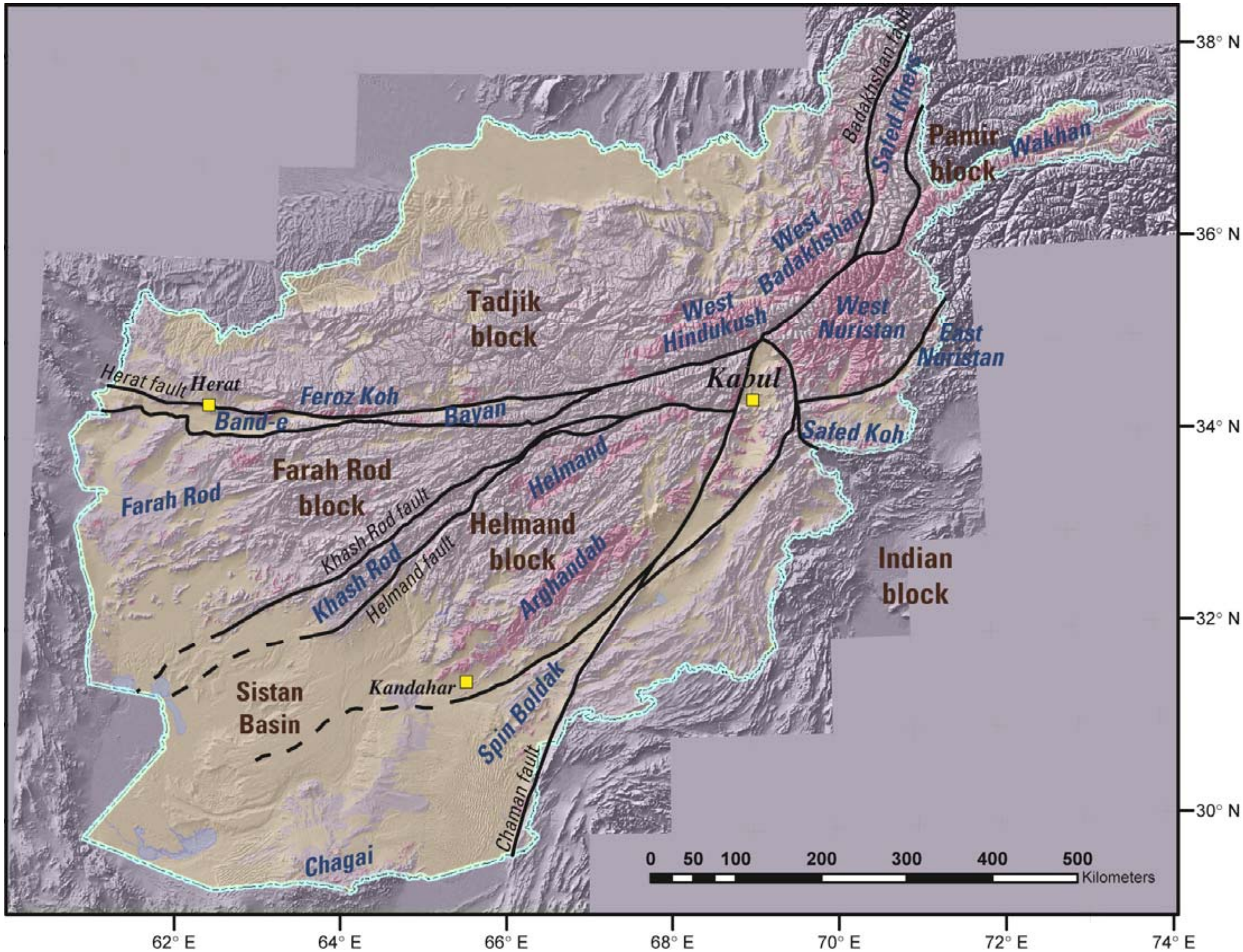

Figure 1.0-5. Map of Afghanistan showing major structural blocks (dark brown labels), plutonic belts (blue labels), and faults (black labels). Plutonic rocks are shown in red, other indurated rocks in beige, and unconsolidated Quaternary sediment in yellow.

1.5 Metallogeny

The classification and presentation of assessments for deposits of non-fuel minerals is arranged, for the most part, according to the scheme adopted by Cox and Singer (1986). Table 1.0-1 below summarizes this classification and indicates what part of this report contains discussion of each type of mineral deposit.

Table 1.0-1. Classification of mineral deposit models by deposit environment

Deposit Environment	Mineral Deposit Model	Section
Mafic and ultramafic intrusions – ophiolites	Podiform chromite	2.1
	Ultramafic-hosted talc-magnesite	2.2
	Serpentine-hosted asbestos	2.3
	Serpentinite	2.3
Alkaline intrusions in stable areas	Carbonatite	3.1
Felsic pegmatites	Be-Li pegmatites	4.3
	Sn-Nb-Ta pegmatites	4.3
	Pegmatitic ruby	12.2
	Garnets in pegmatite	12.4
	Tourmaline in pegmatite	12.4.1
Granitic intrusions – calcareous wallrocks	W skarn	4.1
	Sn skarn	4.1
	Replacement Sn	4.1
Granitic intrusions – other wallrocks	W veins	4.1
	Sn veins	4.1
	Sn greisen	4.1
Porphyry intrusions – calcareous wallrocks	Cu skarn	5.1
	Zn-Pb skarn	5.1
	Fe skarn	5.1
	Lazurite skarn	12.3
	Polymetallic replacement	5.1
Porphyry intrusions – other wallrocks	Porphyry Sn	4.1
	Porphyry Cu	5.1
Extrusive rocks - submarine	Volcanogenic massive sulfide	6.2
Extrusive rocks - subaerial	Hot-spring Hg	6.1
Clastic sedimentary rocks	Bedded barite	8.6
	Emerald veins	12.1
	Sediment-hosted Cu	7.2
	Sediment-hosted Pb-Zn	7.3

Chemical sedimentary rocks	Sedimentary Fe	8.1
	Bedded Mn	8.2
	Halite	8.3
	Phosphorite	8.4
	Celestite	8.5
	Sulfur	8.8
	Gypsum	8.8
Regionally metamorphosed rocks	Low-sulfide gold-quartz vein	9.1
	Natural graphite	9.2
	Jegdalek ruby	12.1
Surficial – residual	Laterite-type bauxite	10.1
Surficial – depositional	Placer Au-PGE	10.2
	Stream placer Sn	4.1
	Sand and gravel	10.3
Other	Dimension stone	11.0
Gemstones	Kunzite	12.4.1

The mineral deposit models discussed in Chapters 2 through 6 are, in general, magmatic-hydrothermal deposits, and can be considered the end products of magmatic activity. Those in Chapters 7 through 12 are not products of magmatism.

The genesis and characteristics of magmatic-hydrothermal deposits are strongly influenced by the petrology of the associated igneous rocks. The petrologic character is, in turn, strongly influenced by the tectonic environment during emplacement, as the tectonic environment controls not only how and where magmas are formed but their petrochemical composition. In some parts of the world, petrochemical information about intrusive belts can be a valuable guide to mineral exploration. In Afghanistan, there is a paucity of petrologic information about intrusive rocks; hence such data can be used as an exploration and assessment guide in only the broadest way.

With regard to felsic and intermediate-composition Phanerozoic magmatism, table 1.0-2 summarizes what is known about the relationship between tectonic environments, magma type, and associated magmatic-hydrothermal mineral deposits for Afghanistan. Numerous Precambrian plutons exist in the northeastern part of Afghanistan, but the high metamorphic grade of the wall rocks generally indicates that the erosion levels are deeper than the level at which most magmatic-hydrothermal deposits are formed. Information in table 1.0-2 on age and magma type is mostly from Debon and others (1986). Information on mineral deposits is primarily from Abdullah and others (1977).

Table 1.0-2. Metallogenic character of Afghanistan plutonic belts depicted on figure 1.0-5.

Plutonic belt	Age	Magma types	Mineral deposits*
Feroz Koh	Eocene to Oligocene (minor Triassic)	Calc-alkaline and subalkaline (minor alkaline)	Polymetallic veins, skarn Cu and Fe, vein barite

West Hindukush	Triassic	Calc-alkaline and subalkaline	Porphyry and skarn Cu (some Sn-bearing); polymetallic veins, pegmatite-hosted deposits
West Badakhshan	Triassic	Calc-alkaline and subalkaline	Porphyry and skarn Cu; polymetallic veins, pegmatite-hosted deposits
Safed Khers	Cretaceous, Oligocene	Mostly subalkaline	Polymetallic veins, skarn Fe and Cu, low-sulfide gold-quartz, pegmatite-hosted deposits
Wakhan	early Paleozoic, Cretaceous	Peraluminous (Lower Paleozoic), calc-alkaline	Pegmatite-hosted deposits, polymetallic veins
West Nuristan	Cambrian to Ordovician, Cretaceous, Oligocene to Miocene	Peraluminous (Cambro-Ordovician), calc-alkaline to subalkaline	Pegmatite-hosted deposits, a single skarn Fe
East Nuristan	Triassic, Cretaceous, Eocene to Oligocene(?)	No data	Pegmatite-hosted deposits
Safed Koh	Cretaceous	No data	None
Band-e Bayan	Cretaceous to Oligocene(?)	Alkaline to subalkaline	Polymetallic veins, barite veins, sediment-hosted Zn-Pb
Farah Rod	Cretaceous to Oligocene(?)	Calc-alkaline and subalkaline	Vein, skarn, replacement, greisen, and porphyry Sn and W, polymetallic veins, skarn Cu and Fe, hot-spring Hg, sediment-hosted Zn-Pb
Khash Rod	Cretaceous to Oligocene(?)	No data	Hot-spring Hg, a single polymetallic vein
Helmand	Cambrian to Ordovician, Cretaceous	Peraluminous (Cambro-Ordovician), calc-alkaline to subalkaline (Cretaceous)	Vein, skarn, replacement, greisen, and porphyry Sn and W, polymetallic veins, skarn Cu, Fe, and Pb-Zn, hot-spring Hg, pegmatite-hosted deposits
Arghandab	Jurassic, Cretaceous, Eocene to Oligocene	Calc-alkaline and subalkaline	Polymetallic veins (notably including Au-bearing), porphyry and skarn Cu (some Sn-bearing), vein and skarn W, skarn Fe and Pb-Zn, vein flurospar
Spin Boldak	Paleocene (and Oligocene?)	Calc-alkaline and subalkaline	Skarn and porphyry Cu
Chagai	Miocene to Present	No data	Porphyry Cu

* Includes both known and predicted deposit types.

In Afghanistan, there are five major intrusive stages correspond to tectonic events. The first is represented by a group of almost exclusively peraluminous intrusions of early Paleozoic (probably Cambrian to Ordovician) age in the West Nuristan, Helmand, and possibly the Wakhan plutonic belts. These plutons probably formed in a zone of crustal thinning that was related to initiation of the Khash Rod Ocean; they are part of a continent-scale belt of early Paleozoic peraluminous granites that extends throughout the Himalaya Range (Le Fort and others, 1986).

The second intrusive stage is Triassic, and is confined to the Eurasian craton in the West Hindukush, West Badakhshan, and parts of the Feroz Koh belt. These plutons form a continental arc related to north-directed subduction of Tethyan oceanic crust beneath Eurasia during the Cimmerian (Triassic in Early Cretaceous) orogeny. Although mineral deposits and prospects related to these plutons are uncommon, occurrence of a few copper skarns and polymetallic veins indicate that an environment permissive for porphyry copper deposits is present.

Cretaceous plutons are much more numerous and define the third intrusive stage. These are mostly intermediate-composition, calc-alkaline to subalkaline plutons that are part of plutonic belts (continental arcs) hundreds of kilometers long. They are present in the Farah Rod, Band-e Bayan, Helmand, Arghandab, West Nuristan, Safed Khers, and Wakhan belts. Along the border with Pakistan in the far east of the country, the East Nuristan plutonic belt is thought to represent a true island arc environment. The areas to the east of Kabul and the Chaman fault appear, like the Precambrian plutonic areas, to be eroded to levels that are deeper than those where most magmatic-hydrothermal deposits are formed. Pegmatite-related deposits are most common, and there is little evidence of porphyry copper environments. To the west, copper- and base-metal-bearing skarns and veins are relatively abundant, and the Cretaceous rocks in the Arghandab, Helmand, Band-e Bayan, and Farah Rod plutonic belts (fig. 1.0-5), which are probably subduction-related, are typical of those in porphyry copper terranes worldwide.

The fourth intrusive stage is Paleocene to Oligocene in age and corresponds to the Himalayan orogeny. These rocks are found in the Feroz Koh, Band-e Bayan, Farah Rod, Helmand, Arghandab, and Spin Boldak intrusive belts. Two distinct types of plutonic rocks were emplaced during this stage. In more or less close proximity to the Herat fault, in the Feroz Koh, Band-e Bayan, and Farah Rod plutonic belts, subalkaline to alkaline rocks, including volcanic rocks that fill grabens, probably represent magmatism that was triggered by continuing strike-slip movement on the Herat fault. The intrusives in the Spin Boldak plutonic belt may be related to similar movement on the Chaman fault. This movement is the result of westward escape of much of Afghanistan due to the penetration of the northwestern part of the Indian and Pamir blocks into Eurasia. Occurrence of several copper skarns and polymetallic veins associated with these subvolcanic alkaline plutons indicate that the environment is permissive for alkaline rock-related porphyry copper deposits.

The other Tertiary plutonic rocks are mainly aluminous to peraluminous and are found mostly in the plutonic belts to the east of Kabul, although a few such plutons occur in the northern part of the Arghandab belt and in the Farah Rod belt, where they are associated with tin deposits. These tin-related plutons probably formed by partial melting of continental crust triggered by crustal thickening related to the subduction of Indian continental crust below eastern Afghanistan.

Finally, in the far southwest of the country, intrusive rocks in the Chagai plutonic belt are of Miocene to Holocene age. We have little information about their composition, but they are related to ongoing northward subduction of Arabian oceanic crust beneath Eurasia. In Pakistan, the westward extension of this very short continental arc is characterized by the presence of several large porphyry copper deposits, such as Saindak and Reko Diq, which are currently under development (Singer and others, 2005).

The youngest igneous rocks in Afghanistan are volcanic, and are found in two areas. In the far southwest of Afghanistan, about 100 km north of the Chagai region, the Khanneshin carbonatite volcano is a Quaternary dome with an intrusive carbonatite core. Exploration has revealed zones of abundant rare-earth element and uraninite veinlets (Alkhazov and others, 1978). Interrupting the Arghandab plutonic belt, about 330 km northeast of Kandahar, the Dacht-e Nawar volcanic field is composed of trachyandesite to trachydacite (shoshonite) volcanoes with ages between about 3 and 1 Ma (Bordet and others, 1984); no known mineral resources are associated with this volcanic field.

1.6 Acknowledgements

This research was funded by United States Agency International Development (USAID)-Kabul with support by the U.S. Geological Survey Minerals Program and is greatly appreciated. The manuscript was improved by scientific reviews of individual chapters by B. Carter Hearn, Robert A. Ayuso, Klaus J. Schulz, Robert G. Luedke, William F. Cannon, John F. Slack, I-Ming Chou, Helen W. Folger, Gilpin R. Robinson, Susan J. Kropschot, Said H. Mirzad, and Jack H. Medlin. Constructive additional technical reviews of the entire manuscript were provided by Gregory T. Spanski, and Arthur P. Schultz. Translation of several Russian and German language manuscripts and advice on metallogeny and gold vein deposits was provided by Jan Kutina. Formatting was done by Francine Mihalasky and GIS support was provided by Paul G. Schruben, Mark J. Mihalasky, and Connie Dicken. Consultation on geoscientific elements in Afghanistan were provided by Carol A. Finn, John R. Sanfilipo, and Trude M. Ridley. Editing was provided by Kathie Rankin, Elizabeth D. Koozmin, and Kathy Y. Knutson.

References

Abdullah, Sh., Chmyriov, V.M., Stazhilo-Alekseev, K.F., Dronov, V.I., Gannan, P.J., Rossovskiy, L.N., Kafarskiy, A.Kh., and Malyarov, E.P., 1977, Mineral resources of Afghanistan (2nd ed.): Kabul, Afghanistan, Republic of Afghanistan Geological and Mineral Survey, 419 p.

Alkhazov, V.Y., Atakishiyev, Z.M., Azimi, N.A., 1978, Geology and mineral resources of the early Quaternary Khanneshin carbonatite volcano (southern Afghanistan): International Geology Review, v. 20, no. 3, p. 281–285.

Barton, P.B., Jr., 1993, Problems and opportunities for mineral deposit models, in Kirkham, R.V., Sinclair, W.D., Thorpe, R.I., and Duke, J.M., eds., Mineral Deposit Modeling: Geological Association of Canada Special Paper 40, p. 7–14.

Bliss, J.D., ed., 1992, Developments in mineral deposit modeling: U.S. Geological Survey Bulletin 2004, 168 p.

Bordet, P., Dubreuil, M., and Vachard, D., 1984, Geologie de l’Afghanistan Central—Cartes géologiques au 1/100.000 de Malestan et Dacht-e Nawar: Documents et Travaux, Institut Géologique Albert de l’Apparent, v. 7, 64 p., 2 maps, scale 1:100,000.

Cox, D.P., and Singer, D.A., 1986, Mineral deposit models: U.S. Geological Survey Bulletin 1693, 379 p., available on web at *http://pubs.usgs.gov/bul/b1693/*.

Debon, F., Afzali, H., Le Fort, P., and Sonet, J., 1986, Plutonic belts in Afghanistan—chemical-mineralogical characteristics, ages, and geodynamic frameworks, in Le Fort, P., Colchen, M., and Montenat, C., eds., Évolution des domains orogéniques d’Asie méridionale (de la Turkie à l’Indonésie): Mémoires Sciences de la Terre, v. 47, p. 129–153.

Doebrich, J.L., and Wahl, R.R., compilers, 2006, Geologic and mineral resource map of Afghanistan: U.S. Geological Survey Open–File Report 2006–1038, one sheet, scale 1:850,000, available on web at *http://pubs.usgs.gov/of/2006/1038/*.

Duval, J.S., 2004, Version 2.0 of EMINERS—economic mineral resource simulator: U.S. Geological Survey Open-file Report 2004–1344.

Eppinger, R.G., and Sipeki, J., Database of Geoscientific References through 2006 for Afghanistan, Version 1: U.S. Geological Survey Open–File Report 2006-1370, 9 p. and database, available on web at *http://pubs.usgs.gov/of/2006/1370/*.

Klett, T.R., Ulmishek, G.F., Wandrey, C.J., Agena, W.F., and the U.S. Geological Afghanistan Ministry of Mines and Industrial Joint Oil and Gas resource Assessment Team, 2006, Assessment of undiscovered technically recoverable conventional petroleum resources of northern Afghanistan: U.S. Geological Survey Report 2006–1253, v.1, 1 disk.

Le Fort, P., Debon, F., Pecher, A., Sonet, J., and Vidal, P., 1986, The 500 Ma magmatic event in alpine southern Asia—A thermal episode at Gondwana scale, in Le Fort, P., Colchen, M., and Montenat, C., eds., Évolution des domains orogéniques d'Asie méridionale (de la Turkie à l'Indonésie): Mémoires Sciences de la Terre, v. 47, p. 191–209.

Ludington, Steve, Orris, G.J., Bolm, K.S., Peters, S.G., and the U.S. Geological Survey-Afghanistan Ministry of Mines and Industry Joint Mineral Resource Assessment Team, 2007, Preliminary Mineral Resource Assessment of Selected Mineral Deposit Types in Afghanistan: U.S. Geological Survey Open–File Report 2007-1005, available on web at *http://pubs.usgs.gov/of/2007/1005/*.

Mars, J.C., and Rowan, L.C., 2007, Mapping phyllic and argillic-altered rocks in southeastern Afghanistan using advanced spaceborne thermal emission and reflection radiometer (ASTER) data: U.S. Geological Survey Open–File Report 2007-1006, available on web at *http://pubs.usgs.gov/of/2006/1006/*.

Orris, G.J., and Bliss, J.D., 2002, Mines and mineral occurrences of Afghanistan, U.S. Geological Survey Open–File Report 2002–110, 95 p., available on web at *http://geopubs.wr.usgs.gov/open–file/of02–110/*.

Root, D.H., Menzie, W.D., and Scott, W.A., 1992, Computer simulation program for quantitative mineral resource assessment: Nonrenewable Resources, v. 1, no. 2, p. 125–138.

Sengör, A.M.C., 1984, The Cimmeride orogenic system and the tectonics of Eurasia: Geological Society of America Special Paper 195, 82 p.

Sengör, A.M.C., and Natal'in B.A., 1996, Paleotectonics of Asia—Fragments and synthesis, *in* Yin, A., and Harrison, M., eds., The tectonic evolution of Asia: Cambridge University Press, p. 486-640.

Singer, D.A., 1993, Basic concepts in three–part quantitative assessments of undiscovered mineral resources: Nonrenewable Resources, v. 2, no. 2, p. 69–81.

Singer, D.A., 1996, Introduction to a folio on an analysis of Nevada's metal-bearing mineral resources, in Singer, D.A., ed., An analysis of Nevada's metal-bearing mineral resources: Nevada Bureau of Mines and Geology Open-File Report 96-2, Chapter 4, available on web at *www.nbmg.unr.edu/ofr962*.

Singer, D.A., and Cox, D.P., 1988, Applications of mineral deposit models to resource assessment: U.S. Geological Survey Yearbook 1987, p. 55–57.

Singer, D.A., Menzie, W.D., Sutphin, D.M., Mosier, D.L., and Bliss, J.D., 2001, Mineral Deposit Density—An Update: U.S. Geological Survey Professional Paper 1640–A, p. A1–A13.

Singer, D.A., Berger, V.I., Menzie, W.D., and Berger, B.R., 2005, Porphyry copper density: Economic Geology, v. 100, no. 3, p. 491–514.

Steinshouer, D.W., Klett, T.R., Ulmishek, G.F., Wandrey, C.J., Ronald R. Wahl, R.R., Hill, R.J., Pribil, Michael, Pawlewicz, M.J., King, J.D., Agena, W.F., Taylor, D.J., Amirzada, Abdulla, Selab, A.M., Mutteh, Abdul-Salam, Haidari, G.N. and Wardak, M.G., 2006, Petroleum Resource Potential GIS of Northern Afghanistan: U.S. Geological Survey Open-File Report 2006–1179, 1 disk.

Sweeney, R.E., Kucks, R.P., Hill, P.L., and Finn, C.A., 2006a, Aeromagnetic and gravity surveys in Afghanistan—A web site for distribution of data: U.S. Geological Survey Open-File Report 2006-1204, available on web at *http://pubs.usgs.gov/of/2006/1204/*.

Sweeney, R.E., Kucks, R.P., Hill, P.L., and Finn, C.A., 2006b, Aeromagnetic survey in western Afghanistan—A web site for distribution of data: U.S. Geological Survey Open-File Report 2006-1325, available on web at *http://pubs.usgs.gov/of/2006/1325/*.

Sweeney, R.E., Kucks, R.P., Hill, P.L., and Finn, C.A., 2006c, Radiometric survey in western Afghanistan: A website for distribution of Data, U.S. Geological Survey Open–File Report 2007-1042 available on web at *http://pubs.usgs.gov/of/2007/1042/*.

U.S. Geological Survey, 2002, Assessment of Undiscovered Deposits of Gold, Silver, Copper, Lead, and Zinc in the United States: U.S. Geological Survey Open–File Report 02-198, available on web at *http://pubs.usgs.gov/of/2002/of02-198/*.

Figure 1.0-6. Legend of Mineral symbols used in this report.