3.0 Deposits related to alkaline intrusions

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In Afghanistan, the main deposits related to alkaline intrusive rocks are carbonatite deposits, intrusive or extrusive igneous rocks composed of more that 50 vol. percent calcite or other carbonate minerals such as dolomite. There is a poorly explored carbonatite at Khanneshin in southern Afghanistan. Magmatic systems with similar characteristics in other parts of the world may contain important amounts of barite, fluorspar, nepheline, rare-earth elements (REE), phosphate, niobium, tantalum, zirconium, copper and uranium. Other centers like Khanneshin may exist in the country.

3.1 Carbonatite (U-Th- REE-apatite)

Carbonatite and syenite intrusive rocks have been identified in southern Afghanistan. They consist of small volcanoes, plugs, and dikes in the Helmand Basin in the south part of the country (Abdullah and others, 1975; Vikhter and others, 1975, 1976, 1978). Carbonatites may contain large deposits of REE, copper, phosphate, vermiculite, and other commodities, and therefore identification and documentation of their location, size and character are important (Eriomenko and others, 1975; Alkhazov and others, 1977, 1978).

3.1.1 Descriptive model of carbonatite (U-Th- REE-apatite)

Carbonatite deposits (model 10, Singer, 1986a), or apatite-magnetite deposits and REE in carbonatite deposits, consist of apatite-magnetite and REE deposits and combinations of these in zoned complexes consisting of a central plug of carbonatite or syenite breccia surrounded by ring dikes and or cone sheets of alternating carbonatite-related rock types (Hogarth, 1986; Woolley, 1989).

Rock types are apatite-magnetite bearing rocks, soevite (calcitic carbonatite) and other carbonate-rich rocks. REE deposits tend to be present in ankerite carbonatite. In general, the rock types consist of pyroxenite, feldspathic pyroxenite, nepheline syenite, carbonatite, fenite, ijolite, dunite, picrite-porphyrites, and locally alkaline volcanic rocks. Alkalic fenitized wall rocks are also common. Igneous textures typically are hypidiomorphic-granular and poikiloblastic. Breccias can be abundant. Carbonatites show intrusive relations with fenitized wall rocks. Many known carbonatite complexes are intrusive into Precambrian shields; however, the carbonatites may be much younger. Depositional environments consist of multiple stages of crystallization in carbonatite magma and later deuteric and metasomatic processes. Tectonic setting is typically in continental shields. Carbonatite deposits are spatially related to fault lineaments such as the East African rift system. Deposits are locally related to alkaline volcanism.

Mineralogy consists of apatite-magnetite-type: apatite, magnetite, pyrochlore ± columbite ± perovskite ± niocalite. REE–type: barite, strontianite ± siderite ± rhodochrosite ± ankerite ± bastnaesite ± chlorite ± parisite ± monagite ± breunnerite. General: calcite, dolomite, fluorite, pyrrhotite, ilmenite, molybdenite, chalcopyrite, pyrite, sphalerite, (gold at Palabora) pyroxene, biotite, phlogopite, amphibole, spinel, ± galena, ± hematite, ± quartz, ± forsterite, ± serpentine, ± zircon ± sphene, ± anatase, ± rutile, ± brookite, ± fersmite. Ores minerals typically are disseminated and banded.

Alteration consists of fenitization (widespread alkali metasomatism of quartzo-feldspathic rock; mostly alkalic feldspar with some aegerine and subordinate alkali-hornblende and accessory sphene and apatite) near contacts of carbonatite intrusion; locally there is chloritization. Ores commonly are restricted to carbonatite dikes, sills, breccias, sheets, veins, and large masses, but may also be present in other rocks associated with the complex. Weathering may result in goethite-rich soil enriched in phosphate, niobium, and REE. Geophysical signature typically consists of radiometric anomalies, magnetic anomalies, and high gravity anomalies. Geochemical signature consists of elevated concentrations of Ba, Ce, Cu, Eu, La, Mn, Mo, Nb, P, Pb, S, Sm, U, V, Th, Ti, Y, Zn, and Zr. High concentrations of B, Be, Hf, Li, Sn, Ta, and W are rare.

According to Singer (1986b) carbonatite complexes may contain economic grades of uranium, thorium, titanium, iron, copper, vermiculite, zirconium or phosphorus and these commodities may form in different parts of the complex than the niobium-rich parts. Mean tonnage for most deposits is 60 million metric tons, and most deposits contain between 16 and 220 million metric tons. Mean niobium grade (wt. percent Nb_2O_5) is 0.58 and mean rare-earth oxide grade (wt. percent RE_20_5) is 0.35.

Field and laboratory parameters of carbonatite deposits

Geologic criteria:

- Distinctive igneous rock association that can include peridotite, pyroxenite, alnöite, urtite, ijolite, nepheline syenite, diorite, and carbonatite;
- Intrusions typically are circular to elliptical and lithologically zoned;
- Intense assimilation and metasomatism of wall rocks is common; distinction between intrusion and country rocks may be obscure;
- Principal ore minerals are pyrochlore-microlite, columbite-tantalite, bastnaesite, and apatite.

Geochemical criteria:

- Anomalous concentrations of Nb, REE, P, and U;
- Apatite and pyrochlore concentrations may be present in residual blanket-like deposits resulting from weathering of carbonatite.

Geophysical criteria:

- Annular magnetic and radiometric anomalies are particularly useful guides to carbonatite complexes.

3.2 Carbonatite (U-Th-REE-apatite) tract descriptions

Permissive tract cb01 Helmand Basin

Deposit Type—Carbonatite (U-Th-REE-apatite)

Age of Mineralization—Quaternary

Examples of Deposit Type—The Khanneshin group of uranium, thorium and REE mineral occurrences is present in the central part of the tract.

Exploration history—There is limited previous exploration in this part of Afghanistan, although discovery and description of the occurrences in the central and southeastern part of the tract indicate some ground prospecting. Geochemical stream sediment exploration may have taken place throughout the tract. The U.S. Geological Survey team has not visited the area.

Tract boundary criteria—Permissive tract cb01 Helmand Basin was delineated to include the volcanic carbonatite cone (map units Q_1kt and Qtcab) and location of the three Khanneshin uranium, thorium and REE mineral occurrences. In addition, the permissive tract includes north-striking carbonatite dikes to the east and west of the mineral occurrences and follows the shape of aeromagnetic anomalies beneath cover (fig. 3.0-1). A favorable tract cb01-f was constructed to include the carbonatite dikes and central volcanic zone, and a prospective tract cb-p1 was delineated to encompass the central volcanic area, the three mineral occurrences, and the local shape of the aeromagnetic signature (fig. 3.0-1).

The uranium-thorium mineralization in the Khanneshin area is distributed over a 40 km^2 area and includes a Lower Quaternary volcanic carbonatite complex, which is a strongly eroded strato-volcano, consisting of tuff, agglomerate, and subvolcanic carbonatitic igneous rocks. The main carbonatite rock types are soevite, barite-ankerite-fluorite carbonatite and associated tuff, alvikite and associated agglomerate and tuff. Leucite phonolite is also present. The rocks have high concentrations of REE, uranium, strontium, fluorine, phosphorous, niobium, and lead. REE concentrations are highest in the soevitic rocks and in ankerite-barite carbonatite. The ankerite-barite carbonatite contains REE barium-strontium carbonate minerals associated with fluorite. In some fluorite zones, the REE concentrations are several percent, accompanied by high concentrations of barite (up to 15 wt. percent).

The vent of the volcano is composed of ankerite-barite carbonatite within an 800–m-long, 50–m-wide fluorite-rich zone that is eroded to a 150 m depth and contains abundant earthy-yellow strontium-barium-rich material parts grading 0.3 to up to 6.0 wt. percent REE, >10 wt. percent strontium, and 10 wt. percent barium. Fluorite in the complex also contains REE 0.5 wt. percent lanthanum, 0.6 wt. percent cesium, and 0.05 wt. percent uranium.

Phosphate is present as apatite, which is common in the carbonatite complex. The major apatite concentrations are in kamaphorite xenoliths composed of magnetite-apatite, and in alvikite. The apatite in alvikite is a REE fluoro-apatite and represents 1.0 to 1.5 wt. percent of the total REE concentration level. Alvikite grades 8.3 wt. percent phosphorus pentoxide. Apatite in the matrix of agglomerate grades 1.55 to 2.29 wt. percent phosphorus pentoxide. There are eight apatite-mineralized zones (Eriomenko and Chmyriov, 1975).

The southern Khanneshin occurrence near the southern margin of the volcano (fig. 3.0-2) is 300 to 1,500 m long, up to 0.5 m wide, and contains uranium-bearing Neogene sandstone intruded by carbonatite dikes along southwest-striking faults that intersect radial fractures and other carbonatite dikes. The fault zones contain ferruginous clay and carbonate minerals as cement in the hydrothermally altered sandstone, which is replaced by dolomite and chlorite. The southern area also contains four mineralized zones, one of which is over 300 m long and 14.2 to 58.0 m wide, and is exposed by erosion to a 100 m depth. The most porous zones of coarse-grained sandstone contain the richest uranium values along strong fractures and joints. The 2– to 1.3–cm-wide uranium-bearing veinlets are symmetrically banded with outer dolomite selvages grading 0.5 wt. percent cerium, 0.4 wt. percent lanthanum, and 0.2 wt. percent barium. The inner parts of the veinlets consist of calcite with barium minerals. In the wide parts of the veinlets, late hyalite and uranium-bearing aragonite are present. The oxidized zone is up to 5.0 m wide and contains uranium silicate minerals, hydrous and phosphatic uranium minerals, and uranium-bearing gypsum (Semionov and others, 1967).

The northern Khanneshin mineral occurrence is hosted in sandy claystone in a 2,000–m-long and 2–to 25–m-wide silicified zone grading 0.006 to 0.015 wt. percent uranium and 0.002 to 0.010 wt. percent thorium (Eriomenko and Chmyriov, 1975).

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

Needs to improve assessment—The information that is most needed is prospect-scale (1:10,000) geologic mapping and geochemical sampling. Local prospects should be visited, resampled, and mapped in detail accompanied by ground radiometric surveys. Site visits would be required.

Optimistic factors—The area contains significant carbonatite mineralization in the exposed parts of the volcanic complex. Dikes and aeromagnetic data are compatible with additional carbonatite sources at depth in a 100–km-long, 25–km-wide area. Sampling has indicated significant concentrations and zones of uranium, phosphorous, thorium, and REE, as well as fluorite.

Pessimistic factors—Significant additional work needs to be done to establish a commercial deposit.

Numerical estimate—For the Khanneshin tract (cb01), the assessment team found that there is a 90 percent chance of 0 or more undiscovered carbonatite deposits, a 50 percent chance of 1 or more, a 10 percent chance of 2 or more, a 5 percent chance of 3 or more, and a 1 percent chance of 5 or more (table 3.0-1). The estimate is subjective and is based on expert opinion and analogy with geologically similar well-explored areas in other parts of the world. This estimate results in a mean estimate of 1.1 undiscovered carbonatite deposits. Probabilistic expected means for contained metals and rock are shown in table 3.0-2.

Table 3.0-1. Assessment team estimates of undiscovered carbonatite deposits in the cb01 Helmund Basin permissive tract

Probability (percent)	Estimated number of deposits
90	0
50	1
10	2
5	3
1	5

These estimates were used to generate probabilistic estimates of the amounts of niobium and REE contained in the undiscovered deposits using Monte Carlo simulation (see section 1.1). The results are tabulated in table 3.0-2 and shown graphically in figures 3.0-4 and 3.0-5.

Table 3.0-2. Mean estimates of metric tons of undiscovered phosphate, REE, niobium, and rock in undiscovered carbonatite deposits in the cb01 Helmund Basin permissive tract. [Values are rounded.]

Rock (metric tons)	P (metric tons)	REE (metric tons)	Nb (metric tons)
251,000,000	6,200,000	1,400,000	3,500,000

Considerations used in the estimation process were that at least eight possible centers of carbonatite plutonic or volcanic activity were present in the tract, such as the known Khanneshin volcano, a number of carbonatite dikes and aeromagnetic anomalies. The estimate was based on the limited exploration within the tract, and the possibility that additional deposits might be hidden under the extensive sedimentary and volcanic cover of the Helmand Basin based on aeromagnetic data (fig. 3.0-1)

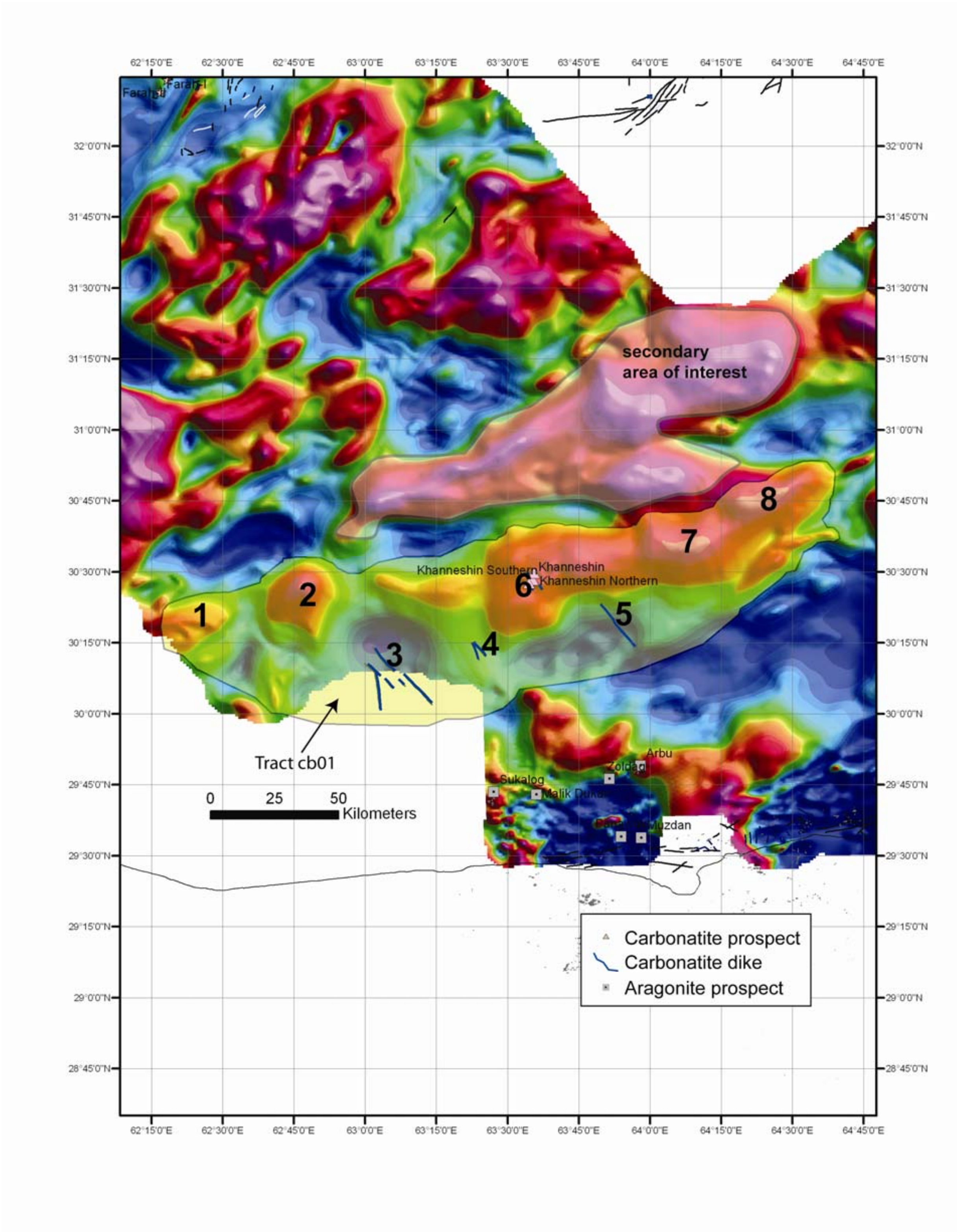


Figure 3.0-1. Map showing tract cb01 Helmund Basin (transparent yellow) and the eight possible areas (labeled 1 through 8) where carbonatite centers might be present within the tract, based on aeromagnetic data from Sweeney and others (2006). These targets form the basis of the quantitative estimate. Additionally, to the north, an aeromagnetic anomaly was designated by the USGS-AGS assessment team as a secondary area of interest for undiscovered carbonatite deposits.

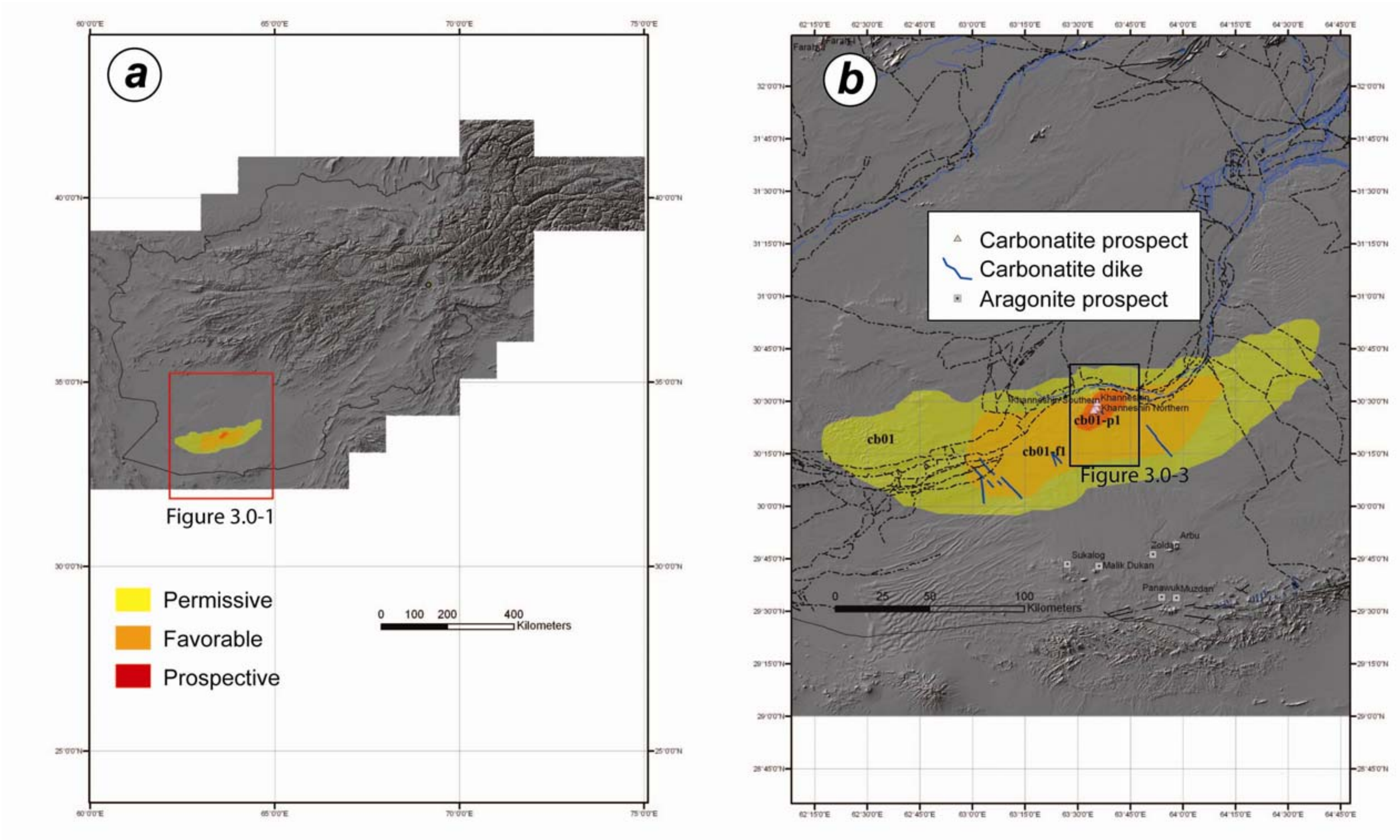
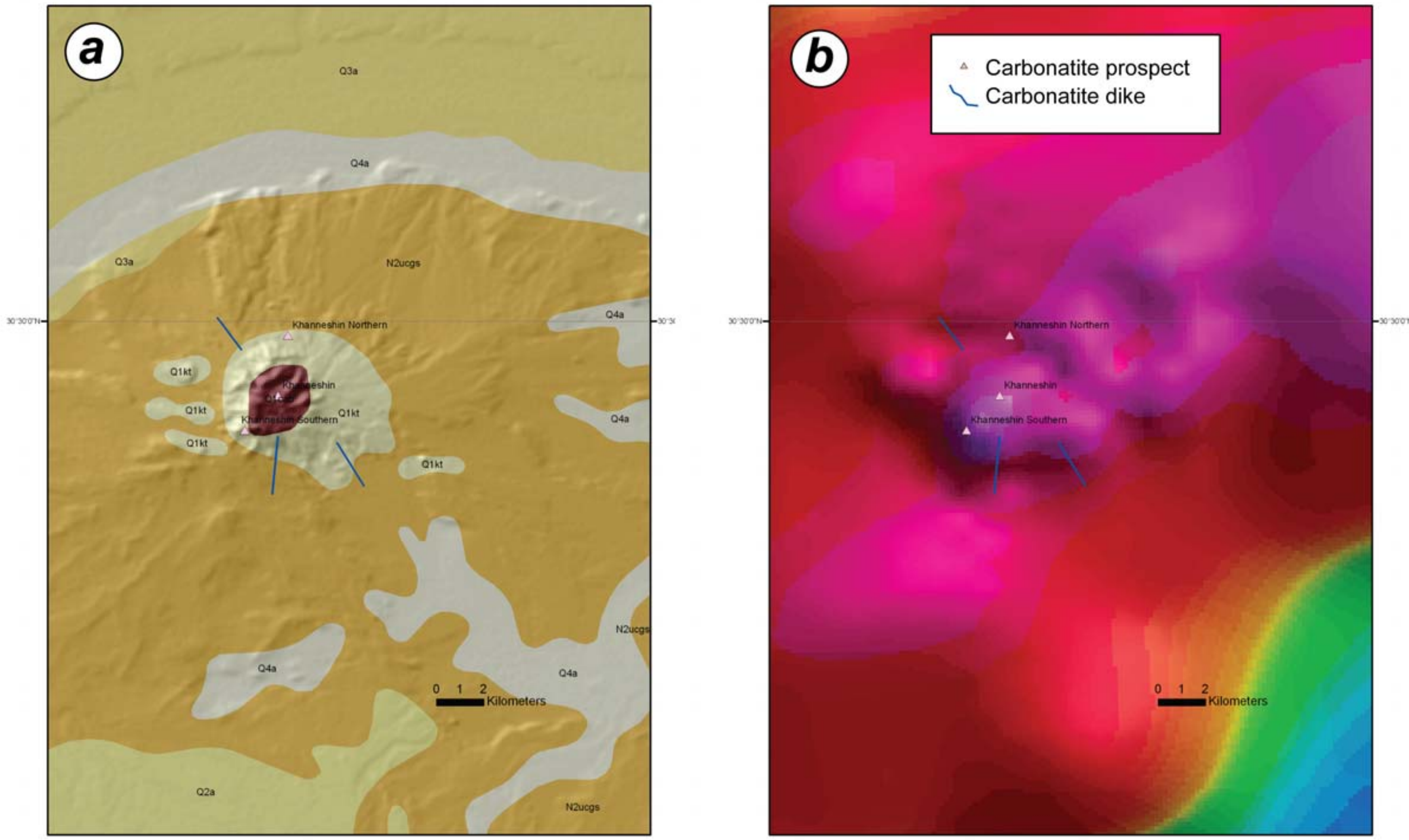


Figure 3.0-2. Map showing ranking of tracts in the carbonatite area of Khanneshin. (a) Location of permissive tract cb01 and internal favorable and prospective tracts in the Helmand Basin in southern Afghanistan for undiscovered carbonatite (U-Th- REE-apatite) deposits. (b) Map showing location of permissive tract cb01 in southern Helmand Basin showing location of Khanneshin uranium, REE, and phosphate occurrences and location of internal favorable and permissive tracts. Carbonatite dikes are shown in blue.



Q1cab = Early Quaternary rhyodacite-carbonatite.
Q1kt = Alkaline tuff, phonolite and soevite tuff and lava (Khanneshin Series).
Q2a = Middle Quaternary, alluvium shingly and detrital sediments, gravel, sand, and silt.
Q3a = Late Quaternary alluvium gravel, sand and silt.
Q4a = Quaternary conglomerate and sandstone alluvium.
Q34e = Late Quaternary and recent eolian deposits, sand.
N2ucgs = Late Pliocene conglomerate, sandstone, limestone, gypsum, salt and volcanic rocks.

Figure 3.0-3. Maps showing volcanic complex with the three Khanneshin carbonatite (U-Th- REE-apatite) mineral occurrences. (a) Geologic map showing units within the volcanic complex area. *(b)* Aeromagnetic expression (from Sweeney and others, 2006) of the volcano area shown in geologic map *(a)*.

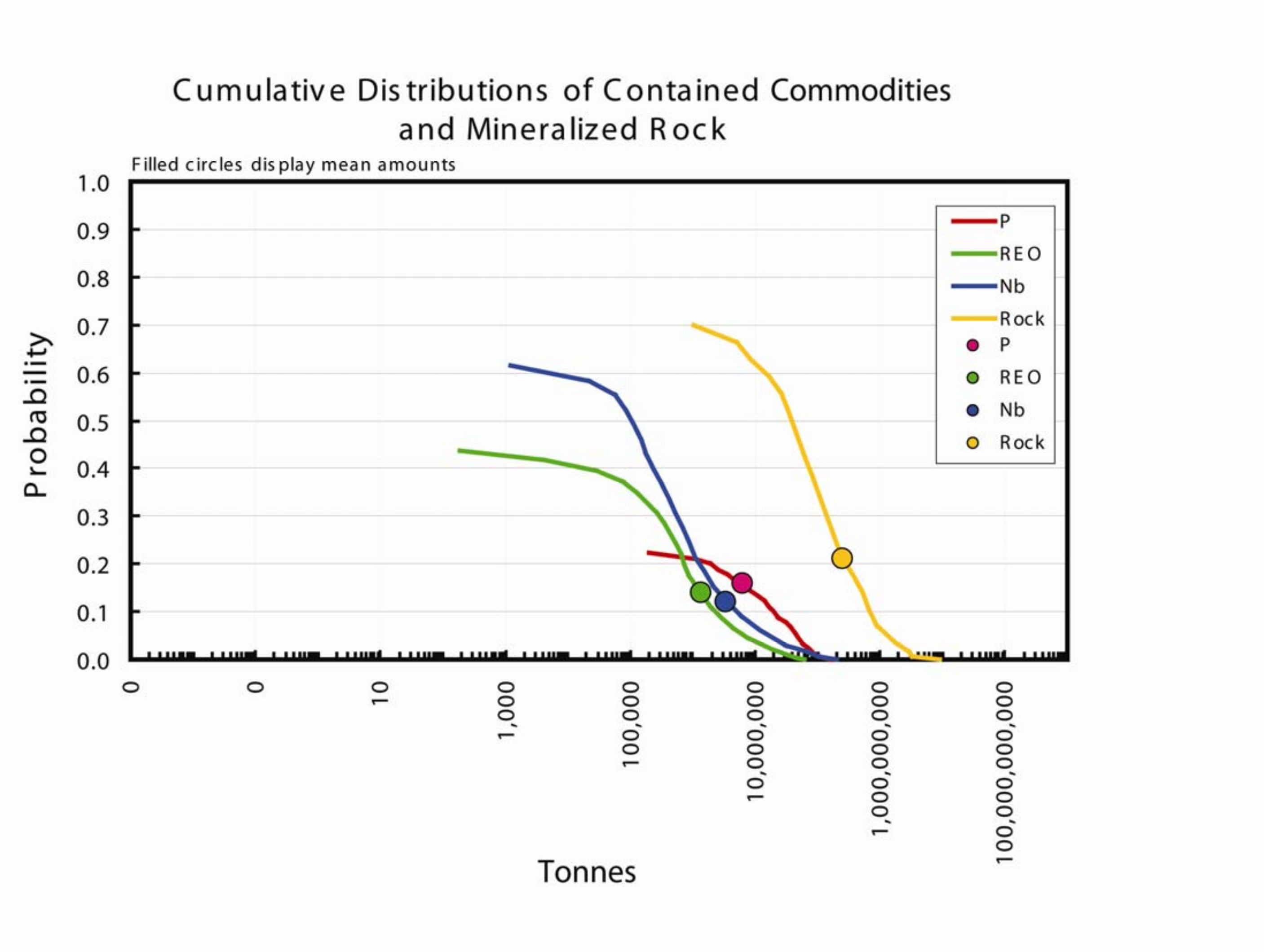


Figure 3.0-4. Cumulative distributions of phosphorous, REE, niobium and rocks for the probabilistic estimate of the Khanneshin Carbonatite permissive tract cb01 Helmand Basin, Helmand Province.

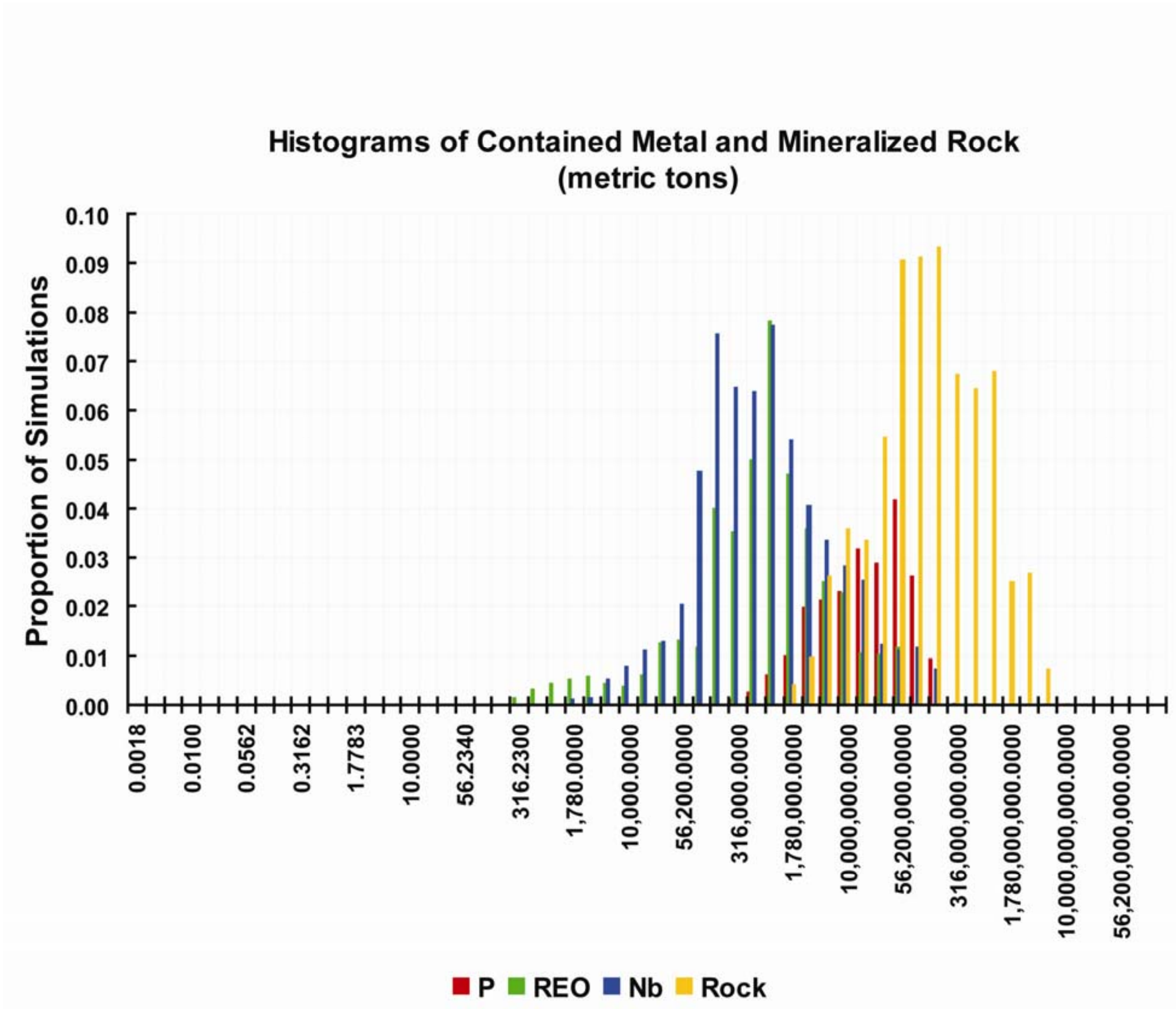


Figure 3.0-5 Histograms of estimated contained metal and mineralized rock for undiscovered carbonatite deposits containing phosphorous, REE, niobium and rocks for the probabilistic estimate of the Khanneshin carbonatite permissive tract cb01 Helmand Basin.

Table 3.0-3. Table showing probabilistic distribution of estimated contained metal and mineralized rock for undiscovered carbonatite deposits containing phosphorous, REE , niobium, and rocks for the probabilistic estimate of the Khanneshin Carbonatite permissive tract cb01 Helmand Basin.

The tract ID is **Khanneshin Carbonatite**

There is a 90% or greater chance of 0 or more deposits.
There is a 50% or greater chance of 1 or more deposits.
There is a 10% or greater chance of 2 or more deposits.
There is a 5% or greater chance of 3 or more deposits.
There is a 1% or greater chance of 5 or more deposits.

Estimated amounts of contained metal and mineralized rock (metric tons)

quantile	P	REO	Nb	Rock
0.95	0	0	0	0
0.90	0	0	0	0
0.50	0	0	110,000	37,000,000
0.10	20,000,000	2,300,000	5,386,000	690,000,000
0.05	46,000,000	6,400,000	15,000,000	1,100,000,000
mean	6,200,000	1,400,000	3,500,000	250,000,000
Probability of mean	0.16	0.14	0.12	0.21
Probability of zero	0.78	0.56	0.39	0.30

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