Chapter 25A. Summary of the South Helmand Travertine Area of Interest and Geology and Mineral Resource Potential of the Chagai Hills Region

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Abstract

This chapter summarizes and interprets available data for the South Helmand area of interest from joint geologic and compilation activities conducted from 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. Accompanying complementary chapters 25B and 25C address airborne hyperspectral data and geohydrologic assessments, respectively, of the South Helmand area of interest. Additional supporting data for this chapter are available from the Ministry of Mines in Kabul.

The study area is divided into two geological provinces, the Chagai Hills and the Sukalok-Arbu belt. The Chagai Hills province is underlain by a Cretaceous island-arc complex of basaltic volcanic rocks intruded by voluminous Cenozoic mafic to felsic plutons of dominantly granodiorite and granite composition. The Sukalok-Arbu belt lies to the north and west of the Chagai Hills and is underlain by rocks inferred to be of Miocene and younger age. These include three volcanic fields of probable Pliocene and Quaternary age that consist dominantly of andesitic and dacitic extrusive rocks, shallow intrusions, clastic sedimentary rocks, and travertine deposits. New satellite-based geologic mapping is presented for both provinces.

The only reported mineral occurrences in the study area are six aragonite (travertine) deposits which have long been a source of "onyx marble" ornamental stone. The large travertine deposits occur in the Sukalok-Arbu belt in association with young andesitic and dacitic volcanic and hypabyssal intrusive rocks. Small deposits also occur within the central Chagai Hills. Total resources are estimated at 3,077,000 metric tons (1,043,000 cubic meters). These travertine resources have not been fully explored and more work is needed.

The study area is part of a major porphyry copper (-gold-molybdenum) belt that extends from the Chagai Hills region of Afghanistan and Pakistan through northwestern Baluchistan Province of Pakistan and into southern Iran. Although no porphyry copper deposits have been reported for the study area, 48 deposits and prospects are reported from the Pakistan part of the belt. The results of this report indicate that the entire study area has significant potential for porphyry copper (-gold-molybdenum) deposits as well as associated mineral deposit types such as manto, polymetallic vein, and replacement and volcanogenic epithermal deposits. Remote sensing hyperspectral mineral mapping has indicated a number of locations within the study area that could host porphyry deposits. Because the Chagai Hills is an island-arc complex, it also has the potential for other mineral deposit types that occur in that environment such as volcanogenic massive sulfide deposits. The occurrence of the nearby Khanneshin carbonatite-hosted rare-earth deposits to the north indicates that the study area should be investigated for carbonatites. Although the study area has high mineral potential, it is presently mapped only at the broadest reconnaissance scale and is unexplored. In particular, detailed geochemical surveys are needed.

25A.1 Introduction

The South Helmand area of interest (AOI) is located in the southern Helmand Province of Afghanistan. This area of interest was defined because it contains travertine deposits of commercial interest. In addition, the broader region containing the Chagai Hills and outcrop areas to the north and
west also have significant potential for other types of mineral deposits, including porphyry copper, and a somewhat broadened study was defined to include the southwestern corner of Kandahar Province (fig. 25A–1). The area is approximately 50 by 200 kilometers (km). This report details the resource potential of the south Helmand travertine deposits and elaborates on the geology and mineral resource potential of the Chagai Hills region of Afghanistan. Aragonite is the only type of mineral deposit reported for the study area.

In contrast to most of southern Helmand and Kandahar Provinces, which consist mainly of desert with few rock outcroppings, the southern part of the study area contains the Chagai Hills, a rugged terrain largely underlain by volcanic and plutonic rocks (fig. 25A–2). The area is sparsely populated with occasional farms along the major drainages. The only towns in the AOI are those of Bahram Chah and Barab Chah, which lie at or close to the Pakistan border in the southernmost part of the Chagai Hills (fig. 25A–2). The bulk of the Chagai Hills is located in the northern Baluchistan Province of Pakistan.

Geographic names used in this paper are generally taken from the Geographic Names Database of the U.S. National Geospatial-Intelligence Agency (http://earth-info.nga.mil/gns/html/index.html). In regard to the largely Pashtun-derived geographic names used in this report, the terms "Ghar", "Gora", and the prefix "Koh-e" or sometimes "Koh-i" refer to features with positive relief, primarily mountains and hills, "Mandeh" and "Rod" to drainages, "Dasht" to flat areas or plains, and "Rayg" to sand dune areas. The international border between Afghanistan and Pakistan is not accurately fixed and is represented differently in various map and GIS sources and thus is not identical on maps shown in this report.

Google Earth imagery was used extensively in preparing this paper. The base imagery is from 2011 Cnes/SPOT, Europa Technologies, and 2011 GeoEye, U.S. Department of State Geographer. Google Earth uses a modified orthographic projection based on 1984 World Geodetic System (WGS 84)
datum. Extensive use is also made of the Google Earth software's three dimensional capabilities allowing oblique views of the Earth’s surface and approximate determination of elevations. These oblique views were obtained by screen capture software and enhanced with image processing software to improve the appearance of the images.

Figure 25A–2. Landsat 7 false-color composite of the study area. The southern part of the area comprises the Chagai Hills, a Cretaceous-Paleogene island-arc complex. Numerous light-colored intrusions are scattered throughout the dark-green to purple volcanic and volcaniclastic rocks of the Chagai Hills. North of the Chagai Hills complex are sparse outcrop areas of mostly Neogene and Quaternary volcanic and sedimentary rocks and hypabyssal intrusions of the Sukalok-Arbu belt. The area north of the Chagai Hills also contains extensive aeolian dune fields (yellowish) and alluvial pediments (darker streaked areas). The dashed white line marks the boundary between the two provinces.

25A.2 Previous Work
The geology of the study area is poorly known. No detailed geological mapping or geochemical surveys are available. The area was reconnaissance mapped at 1:500,000 scale (Abdullah and Chmyriov, 1977), and this mapping has been reproduced by the U.S. Geological Survey at 1:250,000 scale. Two of the U.S. Geological Survey (USGS) 1:250,000-scale quadrangles cover the study area (O’Leary and Whitney, 2005a, b). An updated countrywide 1:850,000-scale map based on the 1:500,000-scale mapping was also compiled by the USGS (Doebrock and Wahl, 2006). A reconnaissance heavy-mineral stream sediment survey was done in the study area (Abdullah and Chmyriov, 1977).

The mineral resources of Afghanistan including southern Afghanistan are summarized by Abdullah and others (1977), UNITED NATIONS ECONOMIC AND SOCIAL COMMISSION FOR ASIA AND THE PACIFIC (1995), and Abdullah and Chmyriov (2008). The USGS compiled mineral deposit data (Orris and Bliss, 2002; Doebrock and Wahl, 2006) and geophysical information (Sweeney and others, 2006). Detailed studies of the travertine resources and their geology were conducted by Slavin and others (1972), Sborshchikov and others (1974), and Samar in (1977). These travertine deposits have been mined and quarried since ancient times and used for carving and ornamental stone. The travertine occurrences are tabulated in Abdullah and others (1977) and in a revised version of the 1977 report as Abdullah and Chmyriov (2008).

The study area was also assessed for its porphyry copper potential by Peters and others (2007a; their tracts ppycu01 and ppycu02). Tract ppycu01 corresponds to the Chagai Hills portion of the present study area and tract ppycu02 to the Sukalok-Arbu belt (fig. 25A–2). In that study, it was estimated that tract ppycu01 has a 10-percent chance of containing three or more porphyry deposits and tract ppycu02 a 10-percent chance of containing two or more.
25A.3 Geologic Framework

The Chagai Hills of Afghanistan are one part of a broader geological province that forms the late Mesozoic-Cenozoic Chagai-Ras Koh arc complex that underlies southernmost Afghanistan, northern Baluchistan Province, Pakistan, and extends into southern Iran (figs. 25A–3 and 25A–4) (Sillitoe, 1978; Arthurton and others, 1982; Siddiqui, 2004; Siddiqui and others, 2009a). This region within Afghanistan and Pakistan is often referred to in the literature as the Chagai belt and, in regards to mineral deposits, as the Chagai District.

The Chagai arc complex is part of a series of island arcs that formed as a result of the closing of the Mesozoic Tethys ocean and is part of the orogenetic belt that runs from the Himalayas to Europe (Sillitoe, 1978; Tapponnier and others, 1981). Baluchistan and southern Afghanistan are underlain by the sole remaining subduction zone of the Tethys, the Makran subduction zone (fig. 25A–3).

The Chagai arc is interpreted to have been an oceanic island arc that accreted to the southern margin of the Eurasian plate early in the Cenozoic. It is generally accepted that it docked along the southern margin of an inferred continental block, the Central Afghan plate (Sillitoe, 1978; Arthurton and others, 1979, 1982). There is speculation that after accretion, magmatism in the Chagai arc changed from oceanic (ensimatic) to Andean arc (continental sialic) in character (Siddiqui and others, 2009b; Nicholson and others, 2010; Khan and others, 2010), implying that the Afghan plate underthrust the arc and supplied continental crustal contaminant to the mantle source melts. There is no direct evidence that the Chagai Hills are underlain by continental crust, and the assumption of a transition to an Andean arc environment is primarily based on the change in composition of the igneous rocks of the arc with time. The early island arc had oceanic tholeiitic composition volcanic rocks that changed later in the Cenozoic to somewhat more alkali andesite-dacite compositions with more evolved continental (Andean type) trace element geochemistry (Siddiqui, 2004; Perelló and others, 2008; Nicholson and others, 2010; Khan and others, 2010).

Figure 25A–3. Regional tectonic map of southern Afghanistan, western Pakistan, and southern Iran (modified from Perelló and others (2008) and Siddiqui and others (2009a)).

The Chagai Hills are underlain mostly by mafic volcanic and volcaniclastic rocks of Cretaceous age (Siddiqui, 2004) that form a rugged mountainous range along the Afghanistan-Pakistan border. Figures 25A–5 and 25A–6 present two generalized stratigraphic columns for the Chagai arc region in Pakistan. These stratigraphic columns represent the area from the Chagai Hills westward to the Iranian...
border, and thus not all of the rock units shown in these columns are necessarily present in the Chagai Hills region of Afghanistan.

For the purposes of this report, the study area is subdivided into two geological provinces, the Chagai Hills in the south and the Sukalok-Arbu belt to the north and west (fig. 25A–2). The reasons for this subdivision are presented below.

**25A.3.1 Chagai Hills**

Figure 25A–7 presents the mapping by Abdullah and Chmyriov (1977). They identify three stratigraphic units for the Chagai Hills: Cretaceous andesite lava and tuff and an Oligocene suite of intrusives composed of granite and granodiorite. This attempt to break the Chagai Hills into two layered rock units is extremely simplistic but may have some geological reality. An examination of the false-color Landsat image of figure 25A–2 shows that the geology of the Chagai Hills is quite complex. In a general way, two types of non-intrusive rock can be detected in the image, a dark greenish type and a dark reddish type. The green approximately corresponds to the andesite lava unit of Abdullah and Chmyriov and the reddish to the tuff. That is, the dark-green rocks tend to predominate in the southern and eastern parts of the Chagai Hills and the reddish rocks in the north and west. The map of Siddiqui (2004) indicates the bulk of the range as being underlain by Sinjrani Group mafic volcanic rocks but shows the northern part in Afghanistan as being underlain by Saindak Formation. Arthurton and others (1982) indicate that the Chagai Hills represent a "geanticline" and if so, then the core of the range is underlain by Sinjrani Group rock, and the northern flank in Afghanistan may have younger units exposed as shown on the Abdullah and Chmyriov (1977) map. It is, however, also clear that the distribution of rock types is much more complex than shown on the map of figure 25A–7 and that the 1977 map is a first approximation of the geology of the Chagai Hills. North and west of the Chagai Hills, the 1977 map shows the extension of the same andesite lava and tuff units, indicating that the rocks of the Chagai arc occur in those areas as well.

![Figure 25A–4](image)

**Figure 25A–4.** Regional geology of the Chagai belt in Pakistan taken from Perelló and others (2008).

The geology of the study area was reinterpreted using Google Earth imagery as a base and consulting other types of imagery as needed. The primary goals of this compilation were to provide more detailed mapping of the Sukalok-Arbu belt and of the plutonic rocks of the Chagai Hills. Unlike
Abdullah and Chmyriov (1977), no attempt was made to subdivide the Chagai Hills layered rocks. The resulting map is shown in figure 25A–8A and 25A–8B.

The Chagai Hills are underlain mostly by massive, poorly bedded, dark-green, reddish-gray to gray mafic (basaltic and andesitic) volcanic and volcaniclastic rocks. No sections of rock that appears to be dominantly sedimentary were observed. Bedding can be seen locally within the Chagai Hills, such as at the Showray Ghar massif (figure 25A–9), but more often outcrops appear massive and structureless.

A series of lensoidal limestone beds crops out over a length of 12 km near the northwestern margin of the Chagai Hills (figs. 25A–8A and 25A–8B). Given that limestones occur in the Sinjrani Group, Humai Formation, and Saindak Formations (fig. 25A–5), this occurrence is not diagnostic for stratigraphic unit assignment. Their lensoidal shape and intercalation within massive mafic volcanic rocks suggest they are part of the Sinjrani Group (Siddiqui, 2004; fig. 25A–5). Their occurrence presents an opportunity for fossil age determination.

The outcrops east of the main Chagai Hills in the area of Balowchar Ghar (fig. 25A–8B) may be in part a different stratigraphic unit from the Sinjrani Group. Here, massive mafic volcanic rocks are overlain on the west side of the range by a well-bedded west-dipping section (fig. 25A–11) that may contain limestone beds and thus may be the Humai or Saindak Formation. The area of scattered outcrops in the northeastern part of figure 25A–8B (Tanyagar Ghundêy) is difficult to interpret on imagery, and my mapping follows that of Abdullah and Chmyriov (1977; fig. 25A–7).

The bulk of the Chagai Hills is underlain by the Sinjrani Volcanic Group (Siddiqui, 2004). Siddiqui (2004) describes the Sinjrani as consisting of "basaltic to andesitic lava flows and volcaniclastics including agglomerate, volcanic conglomerate, breccia and tuff with subordinate amounts of shale, sandstone, limestone, and chert." He studied samples from massive flows from two localities within the Pakistan Chagai Hills (Dasht-e-Kain, ~29.55° N. and 64.51° E., and Chilghazi, ~29.40° N. and 64.22° E.) that are close to the Afghanistan border and thus should be representative of such rocks north of the border. Most samples contained phenocrysts of augite and plagioclase. His major element analyses are presented in table 25A–1. Based on these data, the samples ranged from basalt to andesite but are dominantly basaltic andesite (fig. 25A–12A, B). Siddiqui (2004) concluded on the basis of his major and trace element chemistry that the Sinjrani volcanic rocks have a tholeiitic oceanic island arc affinity. Strontium isotopic data showing initial \( {\text{Sr}}^{87}/ {\text{Sr}}^{86} \) ratios in the range 0.70383–0.70420 also indicate an ensimatic origin. Nicholson and others (2010) also present major and trace element chemistry for Sinjrani Group volcanic rocks of the Pakistan Chagai Hills that they interpreted as indicating an ensimatic oceanic arc affinity.

### Table 25A–1

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<th>Sample</th>
<th>Ch-10</th>
<th>Ch-7</th>
<th>Ch-5</th>
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<th>Ch-13</th>
<th>Ch-14</th>
<th>R-6</th>
<th>MRM-15</th>
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<td>99.99</td>
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<td>100</td>
<td>97</td>
<td>100</td>
<td>99.98</td>
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Figure 25A–5. Generalized stratigraphic sequence for the Chagai arc (Siddiqui and others, 2009b). Green indicates Mesozoic and Paleogene mafic volcanic rocks; gray-blue, Neogene and Quaternary volcanic and volcaniclastic rocks; browns and yellows, clastic sedimentary rocks; and blue, limestone.
Figure 25A–6. Summarized stratigraphic column for the Chagai belt of Perelló and others (2008).

Figure 25A–7. Geologic map of the Chagai Hills area taken from Abdullah and Chmyriov (1977). Heavy red lines are faults. Two black numbered dots indicate geochemical locations for analyses presented in table 25A–1.
Figure 25A–8A. Geologic map of the western half of the Chagai study area. Localities indicated with a black dot and “T” index number are travertine locations discussed in the travertine section of this report.
Figure 25A–8B. Geologic map of the eastern half of the Chagai study area. See explanation and scale on preceding figure.
Figure 25A–9. Google Earth oblique view looking south-southeast of the synformal 2.6x3.6 kilometer Showray Ghar massif of mafic volcanic rocks, presumably lava flows, (location shown on fig. 25A–8B). The approximately 200-meter-thick Showray Ghar section overlies other mafic volcanic and sedimentary rocks of the Chagai arc. The yellow line in the distance is the border with Pakistan. The low-relief white outcrop area in the upper right of the image at and south of the border is a granitic intrusion. The image illustrates the rugged relief and outcrop characteristics of the Chagai Hills.

Figure 25A–10. Google Earth oblique view looking west of south-dipping limestone (thin light-colored beds) interbedded with mafic volcanic and (or) volcaniclastic rocks (medium gray) in the northernmost Chagai Hills (northwest of the Koh-e-Samoli intrusion, fig. 25A–8A). Width of view at base of image is 2.6 kilometers. Center of outcrop area is located at 29.5364°E. and 63.7926°N.
Figure 25A–11. Google Earth view of well-bedded section at the southern end of the Balowchar Ghar outcrop looking north (29.623° E. and 64.937° N.). Width of view at bottom of image is 1.6 kilometers.

Table 25A–2. Major element analyses of Chagai area intrusive rocks.

[Analyses 1 through 5 from Abdullah and Chmyriov (1977), and 6 through 11 from Breitzman and others (1983) for Chagai Hills intrusives in Pakistan. Analyses 1 through 3 are for the Neogene Aynak Ghar intrusive (fig. 25A–8). Analysis 6 is for the Barab Chah granite (fig. 25A–8). The locations of analyses 1 through 3 and 4 through 5 are shown on figure 25A–7 as points 1 and 2, respectively]

<table>
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<tr>
<th>Rock type</th>
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<td>3</td>
<td>4</td>
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<td>Dacite</td>
<td>Dacite</td>
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</table>
Numerous large plutons intrude the volcanic rocks of the Chagai Hills (figs. 25A–7 and 25A–8) such that roughly a third of the range is underlain by plutonic rocks. These rocks are collectively called the "Chagai intrusives" (Jones, 1960; Siddiqui, 2004). In the Pakistani portion of the Chagai Hills, these intrusions include diorite, quartz-diorite, granodiorite, tonalite, granite, and minor monzodiorite, quartz monzonite, and gabbro (Breitzman and others, 1983; Siddiqui, 2004; Perelló and others, 2008), although granodiorite and granite are the dominant lithologies. These intrusive rocks in the Chagai Hills range in age from 44 to 18 mega-annum (Ma) (fig. 25A–13) (Breitzman, 1983; Perelló and others, 2008). One pluton dated by Breitman, the Barab Chah granite, extends into Afghanistan (pluton with the 37.7±2.2 Ma age location shown on fig. 25A–13). Perelló and others (2008) document that intrusions as early as 55 Ma occur in the Chagai arc west of the Chagai Hills. They note that the dominant mafic mineral of the gabbroic and dioritic rocks is amphibole, whereas biotite dominates in the more felsic plutonic rocks with subordinate amphibole. They also indicate that most of the Chagai intrusions have medium- to coarse-grained equigranular textures. All of the intrusive phases of the Chagai arc contain magnetite as an accessory mineral and thus belong to the magnetite magmatic series of Ishihara (1981).

Major element chemistry for the Chagai intrusives is presented in table 25A–2 and figure 25A–12. Their chemistry is similar to the calc-alkaline arc trend of the volcanic rocks but with more evolved compositions and higher K₂O content. Three analyses are presented in table 25A–2 for Afghanistan Chagai Hill intrusions (numbers 4–6). The first two of these are of a mafic intrusion at location 2 shown on figure 25A–7, and the third is for the Barab Chah granite (fig. 25A–8B). A sample of the Barab Chah granite (analysis 6) was collected by Breitzman and others (1983) from the Pakistan portion of the intrusion.

Based on the above information, the intrusions of the Afghanistan Chagai Hills likely have the same composition and age range. The morphology of the Afghanistan Chagai Hills intrusives is highly variable and ranges from those having significant (fig. 25A–14) to very low relief. On satellite imagery they range from having very little color contrast or differences in relief from their host rocks, and thus are difficult to recognize, to being very leucocratic (figs. 25A–9 and 25A–15) and easily differentiated. Because of the lack of specific compositional data for the Afghanistan Chagai intrusions, they are not subdivided on the map of figure 25A–8, except in a few cases where intrusions appeared sufficiently dark to be classed as mafic plutons (that is, gabbroic and (or) dioritic). Based on literature for the Pakistani intrusions, it is assumed that most of the unclassified intrusions shown in figure 25A–8 are granodiorite or granite.

Dikes are abundant throughout most of the Chagai Hills. Most are small, and only a few of the larger one are shown on figure 25A–8. It is assumed that most of them are within mafic volcanic rocks and are mafic in composition. Dikes cutting the younger plutonic rocks may be of more felsic composition.

A remarkable feature of the east-central part of the Chagai Hills is the occurrence of five large swarms of leucocratic veins or dikes. These are mapped and named on figure 25A–8. They are named for prominent peaks within each area except for the Bonzani swarm, which is named after a drainage that cuts it. The character of these swarms is illustrated in figures 25A–16 and 25A–17. Within each area, these features have a high density (fig. 25A–16) and are schematically shown on figure 25A–8. The Askan swarm represents an approximately 10-km-wide north-south-trending major structural zone that runs southward far into Pakistan. A detailed view of a portion of the Askan swarm is presented in figure 25A–17. It is not possible to ascertain the composition of these linear features, but they are leucocratic (white) and their emplacement pattern is more typical of veins than dikes. On this basis, it is assumed that they are quartz veins, aplite, alaskite, or some combination of these lithologies. They can be as wide as 30 m but most are less than 10 m.

### 25A.3.2 Extent of the Chagai Arc

As indicated above, a number of authors have suggested that the Chagai arc docked with a "Central Afghan" plate late in the Cretaceous or early Paleocene (Sillitoe, 1978; Arthurton and others,
1979, 1982; Siddiqui, 2004; Perelló and others, 2008; Khan and others, 2010). If so, how far north does the Chagai Hills arc assemblage extend and where is the suture zone with this plate?

Figure 25A–13. Geochronologic data for plutonic rocks of the Chagai belt (modified from Perelló and others (2008); see source for discussion and cited sources of data). Reko Diq, Saindak, Sor Baroot, Koh-i-Dalil, and all of the named locations shown in the Chagai Hills are porphyry copper deposits.

Figure 25A–14. Google Earth oblique view of Samoli Ghar, a felsic pluton 6.8 kilometers in diameter that forms the highest peak in the western part of the Afghanistan portion of the Chagai Hills (2,175-meter peak elevation and approximately 730 meters of relief). In the far distance are the peaks of Soro Ghar (right) and Torush Bab Ghar (left). Dune fields (tan) form the middle ground.

Figure 25A–18 shows the residual total intensity aeromagnetic map for the study area and the region to the north. The exposed Chagai arc rocks have a distinct and somewhat complex magnetic grain with linear trends to the north-northeast. To the north is a broad east-west-trending magnetic low, which suggests that a major geological boundary occurs between the two areas. Such a low is often associated
with non-magnetic sedimentary rocks and may indicate a deep basin such as a back-arc sedimentary wedge of the Chagai arc. Unfortunately, the area of the magnetic low is completely concealed beneath Quaternary to Holocene alluvium. The white dashed line of figure 25A–18 approximates the northernmost possible extent of Chagai Arc magmatic rocks. The younger volcanic fields of Sukalok, Torush Bab-Ghar, and Arbu correspond to positive magnetic signatures and are probably underlain by shallow intrusive complexes of similar age. If the magnetic highs within the Sukalok-Arbu belt are solely due to these younger igneous complexes, then the Chagai arc rocks may only extend approximately as far north as the dashed yellow line of figure 25A–18. Thus, depending on the nature of the rocks within the low magnetic trough, a suture zone between the Chagai Arc and the Afghan plate probably lies between the yellow dashed line and the Khanneshin magnetic ridge to the north. Due to lack of outcrops within the region of the Khanneshin magnetic ridge, other than the Khanneshin volcanic complex and late Cenozoic sedimentary rocks, the nature of the rocks underlying the ridge and the cause of the magnetic anomaly are unknown.

![Figure 25A-15. Google Earth view of 5.2-kilometer-long leucocratic granitic(?) pluton located at 29.44° E. and 63.86° N. Yellow line marks the Afghanistan-Pakistan border.](image)

**25A.3.3 Sukalok-Arbu Belt**

As shown in figure 25A–2, the study area is subdivided into two geological provinces, Chagai Hills and the Sukalok-Arbu belt. The basis for this subdivision is that the Sukalok-Arbu belt is interpreted here as not having any outcrops of Sinjrani Group rocks and being underlain by younger rock units. The Sukalok-Arbu belt is named after two prominent peaks of the belt (fig. 25A–8). There are no age determinations available for rocks of the Sukalok-Arbu belt but they are certainly younger than the rocks of the Chagai Hills, that is, younger than Cretaceous. The only detailed description available to the author for the rocks from the belt is that of Samarin (1977), who did field studies in the Torush Bab, Arbu, and eastern Sukalok volcanic fields. In this section, the rocks of the belt are described and regional stratigraphy summarized.
Figure 25A–16. Google Earth oblique view of the western part of the Askan vein swarm looking west. Distance from foreground to background is 3.7 kilometers. The veins or dikes generally dip steeply west.

The outcrop areas mapped by Abdullah and Chmyriov (1977) as Chagai rocks within the belt are exemplified by the Kaduh Ghar section shown on figure 25A–20. The rocks of this outcrop are not massive and poorly layered like the Chagai Sinjrani group rocks but well bedded and gently dipping. There are no age data for the Kaduh Ghar rocks. They look similar to the rocks exposed at Balowchar Ghar (fig. 25A–11), in which case they could be potentially as old as the Humai Formation (fig. 25A–5). In the Geographic Names Database of the U.S. National Geospatial-Intelligence Agency there is a "Kadu Ghar caves" location near the high point of the Kadu Ghar ridge (fig. 25A–20). This suggests that the light layers visible in the Kaduh Ghar section are limestone and the caves are the result of the solution of carbonate rock. Because limestones also occur in younger stratigraphic units of the area including the Juzzak, Saindak, and Amalaf Formations (fig. 25A–5), it is possible that the Kaduh Ghar section belongs to one of those units. Making such correlations, however, is hazardous since the stratigraphic section of Siddiqui (2009b; fig. 25A–5) is based on the stratigraphy of the southern Chagai Hills and areas to the west. Since the Kaduh Ghar layered rocks likely directly underlie the Pliocene to Quaternary rocks immediately to the north and are little deformed, it is tentatively assumed that they are Oligocene or Miocene in age. The relief of Kaduh Ghar relative to the Sukalok volcanic field suggests that the Kaduh Ghar section is upthrown on a concealed fault lying between the two areas.

Besides the Kaduh Ghar layered rocks, the rest of the Sukalok-Arbu belt consists of andesitic and dacitic volcanic rocks, plugs, hypabyssal intrusions, clastic sedimentary rocks, travertine, and several leucocratic intrusions of unknown composition. These rocks occur mainly in four outcrop areas, the Arbu, Torush Bab, and Sukalok volcanic fields and an area of widely dispersed poorly exposed outcrop west of the Chagai Hills and immediately north of the border with Pakistan (fig. 25A–8A).

The Arbu, Torush Bab, and Sukalok volcanic fields have similar geology. The Arbu field is named after Arbu Ghar, a volcanic neck at the north end of the field (Samarin, 1977). The Torush Bab
field is only about 3 km west of the Arbu field, and the two should probably be considered a single field, but for the sake of clarity in this report they are referred to separately. The Torush Bab field is named after Torush-Bab Ghar, a large volcanic neck at the north end of the field (fig. 25A–8A). The Sukalok volcanic field is named after Sukalok Ghar, a mafic intrusion in the western part of the field. Although the nearby Koh-e-Malekdokan and Aynak Ghar peaks are more prominent, the literature and geographic names database indicate the general area of the volcanic field is referred to by the Sukalok (or Sukaloq) name.

The oldest stratigraphic unit in the area of the Arbu volcanic field is a well layered, poorly exposed, gently folded section of what is assumed to be clastic sedimentary rocks (unit S1 of fig. 25A–21). This unit underlies the region of the three volcanics. Within the Arbu field, the lowest exposed unit is a variegated section of brown, tan, white, and gray sedimentary rocks that probably includes volcaniclastic rocks (unit S2 of fig. 25A–21). These sedimentary rocks are overlain by mafic volcanic rocks that according to Samarin (1977) are andesitic in composition (unit v of fig. 25A–21). As may be seen from figure 25A–22 these volcanic rocks form a very rugged terrain. Samarin (1977) describes the Arbu Ghar plug as an "andesite-dacitic neck within lavas of similar composition." One or two felsic intrusions also cut these sedimentary rocks (unit "fi" of fig. 25A–21). These two outcrop areas may represent a single intrusion beneath the overlying cover rocks. This intrusion appears similar to the intrusions of Koh-e-Malekdokan and Aynak Ghar that are known to be dacitic in composition and therefore are interpreted to be part of a related group of intrusions, here named the Malekdokan intrusive suite. Overlying the sedimentary rocks and volcanic rocks is a set of bedded travertine deposits. The travertine deposits of Arbu are discussed below in the travertine section of this report.

Figure 25A–17.  Google Earth view of central part of the Askan vein swarm intruding massive basaltic rocks of the Sinjrani Group and being cut by numerous west-trending faults. Yellow line is the Afghanistan-Pakistan border. Image is centered at 29.5442° N. and 63.3795° E.
Samarin (1977) indicates that for the eastern part of the Sukalok volcanic field where the travertine deposits occur, a section of Cretaceous intermediate volcanic rocks is overlain by Neogene varigated sandstones. He describes the lower volcanic sequence as "consisting of tuffs, tuff breccias, lavas, and lava breccias of andesitic, andesite-dacitic or dacitic composition" that have a moderate dip of 5°–20° but locally reach 45°–50°. Samarin (1977) states without elaboration that the Sukalok volcanic rocks are Cretaceous, presumably on the basis of their similarity to the mafic volcanic rocks of the nearby Chagai Hills. Based on drilling results, the tuffs are several meters up to 50 m thick. Many of these units are coarsely fragmental and include fine-grained and pelitic tuffs. Some of the volcanic rocks contain plagioclase and enstatite phenocrysts and less frequently quartz and biotite phenocrysts in a glassy groundmass with microlites of plagioclase, biotite, quartz, and iron oxides. Based on Samarin's descriptions, these rocks are relatively unaltered and more evolved than the basaltic rocks of the Chagai Hills. Samarin describes the "Neogene sediments" as transgressively and unconformably overlying the Cretaceous strata and in turn being overlain by a volcanogene and loose clastic formation of Late Neogene-Quaternary age. The Neogene sedimentary rocks consist of buffish-red to brick-red fine- to
medium-grained sandstones that are composed of "fragments of volcanites, plagioclase, orthoclase, and carbonate."

Aynak Ghar and Koh-e-Malekdokan are two felsic intrusions that form prominent peaks on the southern margin of the Sukalok volcanic field (fig. 25A–20). Samarin (1977) describes Aynak Ghar as a subvolcanic intrusion consisting of porphyritic rock with a fine-grained groundmass. The phenocryst assemblage consists of plagioclase and hornblende with sparse biotite and xenomorphic quartz. Samarin's description suggests that Aynak Ghar is underlain by andesitic or dacitic rock, and this suggestion is supported by its dacitic major element chemistry (table 25A–2, analyses 1–3; fig. 25A–12). The nearby Koh-e-Malekdokan peak to the southwest is similar in appearance to Aynak Ghar and is probably of similar composition. In the area of the travertine, north of Aynak Ghar, Samarin observed numerous dikes, up to 2-3 m thick, of similar lithology that he associates with the Aynak intrusion. These dikes were mingled with numerous calcite veins.

The Torush-Bab volcanic field contains travertine deposits, intermediate composition intrusions, and volcanic rocks that overlie clastic and volcaniclastic sedimentary rocks. Samarin (1977) does not describe Torush-Bab Ghar (his Legh-Ghar) in detail and only notes that the mountain is a volcanic neck. Figure 25A–23 shows the Torush-Bab Ghar massif and that it consists of a central stock intruding mafic volcanic rocks and clastic sedimentary rocks. The stock is dark in color, which suggests an andesitic or dacitic composition. Numerous dikes are also present within the Torush-Bab Ghar complex and other small intrusions may be present. In the southern part of the Torush-Bab volcanic field (fig. 25A–8A),

**Figure 25A–19.** Bouguer gravity anomaly map for the same region as shown for the magnetic map (fig. 25A–18) (from Abdullah and Chmyriov, 1977). The Chagai arc appears to be well delineated by a gravity high, and the apparent northern margin roughly corresponds with the dashed white line of the magnetic map. Symbols same as figure 25A–18.
Samarin (1977) describes two volcanic necks and Neogene sedimentary rocks. These intrusions are composed of hornblende and plagioclase phenocrystal andesitic-dacitic rocks “identical” to those of the Sukalok field (Samarin, 1977). Numerous dikes occur south of the necks (Samarin, 1977). The southern area also includes the Zoldag travertine deposits, which are described in more detail in the travertine section of this report.

**Figure 25A–20.** Google Earth oblique view looking west of the Kaduh Ghar layered rock section and Sukalok volcanic field (v.f.). The Kaduh Ghar outcrop is 9.6 kilometers long. The peaks of Koh-e-Malekdokan and Aynak Ghar are dacitic intrusions.

Erosional levels in the Sukalok, Torush Bab, and Arbu fields are of interest. Koh-e-Malekdokan has relief of approximately 750 m, and Torush Bab Ghar and Soro Ghar each have relief of about 350 m (figs. 25A–20 to 25A–23). Therefore, a minimum of 750 m of erosion has taken place in the Sukalok area since the time of emplacement of the Koh-e-Malekdokan intrusion. In the Arbu field, a mafic volcanic flow caps an approximately 200-m-thick section of layered rock, but other mafic flows occur at the base of this section, indicating volcanism in at least two episodes (fig. 25A–22). In the western Sukalok field, the Sorbarot Ghar dacitic flow dome (fig. 25A–24) appears to be extremely young and to have undergone very little erosion. From these relationships it is tentatively concluded that the volcanic and intrusive rocks in these fields are variable in age and may be as old as approximately the Miocene-Pliocene and possibly the Miocene and as young as the Quaternary.

The far western part of the Sukalok-Arbu belt appears to contain at least some volcanic and intrusive rocks of Miocene-Quaternary age. The area, however, is largely covered by aeolian and pediment alluvium that leaves scattered outcrops that on imagery are difficult to interpret. Figure 25A–25 shows two views of this area that illustrate the nature of this part of the belt. One notable feature is an extremely leucocratic presumably hypabssyal intrusion of a type not seen to the northeast (fig. 25A–25A). Figure 25A–25B shows a partially concealed leuocratic massif that probably is a dacitic intrusion similar to Koh-e-Malekdokan. Another interesting feature is a half-kilometer-diameter leucocratic low-relief circular outcrop area that may be a shallow intrusion or possibly a maar (fig. 25A–25C). Based on these features and those documented in the figure, it is concluded that this area contains rocks equivalent to those of the Sukalok volcanic field.
Figure 25A–21. Google Earth vertical view of the Arbu volcanic field. Symbols: S1, clastic sedimentary rocks; S2, clastic and volcaniclastic(?) sedimentary rocks; v, mafic volcanic flows, agglomerates, and plugs; mf, mafic lava flow; vn, mafic volcanic neck; fi, felsic intrusion; t, travertine; and qal, Quaternary-Holocene alluvium.
Figure 25A–22. View of the Arbu volcanic field looking south. In the foreground, bedded travertine (t) is overlying poorly consolidated clastic sedimentary rocks (s). In the distance are mafic volcanic flows and agglomerates (v). Note gently dipping mafic flow (unit "mf" of previous figure) capping the butte at the far right and behind it the peak of Soro-Ghar (1,753-meter peak elevation). Photograph taken at approximately 29.81° N. and 63.96° E. by Mike Chornack, U.S. Geological Survey.

Figure 25A–26 shows part of the Sukalok field and illustrates all of the basic stratigraphic relationships in the area of the volcanic fields. A folded sequence of variagated layered rocks (unit A) is overlain by dark layered rocks (unit B), which in turn are overlain by dark massive rocks (unit C). This entire sequence is in turn cut by andesitic and dacitic intrusions (D). In addition, there are numerous dikes of various orientation cutting the entire sequence. No specific information is available on the oldest sequence, unit A, but given their well-layered nature as seen throughout the area, it is assumed that they are clastic sedimentary rocks and may correlate with the Kaduh Ghar sequence. Given the dark color and layered nature of unit B, it is assumed that they are mafic volcaniclastic rocks and may correlate with those that lie below the Sorbarot Ghar dacitic flow (fig. 25A–24). The massive dark rocks (unit C) are assumed to be andesitic agglomeratic and flow rocks as described by Samarin (1977) for the travertine area just to the east of the image location. The entire sequence is intruded by hypabyssal intrusions (unit D) and numerous dikes. The gray dome at the bottom left of the image appears identical to the andesitic-dacitic hypabyssal intrusives seen in the Torush Bab volcanic field (fig. 25A–23). This same sequence appears to be present in the stratigraphic sequence exposed on the western flank of Aynak Ghar (fig. 25A–27), thus indicating that the Aynak Ghar intrusion is younger than most of the volcanics in the Sukalok volcanic field.
On a more regional basis the Shukalok-Arbu belt lies on the central southern margin of the Helmand basin, which occupies most of southern Afghanistan (Whitney, 2006). The Helmand basin is a structurally closed basin that began to form in the middle Tertiary as a result of collisional processes (Whitney, 2006). All drainage in the study area is into the basin. In the central portion of the basin only the upper 250 m of basin sediments are exposed, but the central part of the basin may be up to several thousand meters deep. Lacustrine units are found in the core of the basin but these wedge out into fluvial and eolian sediments on the flank. The exposed part of the section consists of two informal units, the Sistan beds of fluvial sediments and eolian sands and unit of coarse to fine gravel (Smith, 1974; Whitney 2006). Whitney concludes that the Sistan beds and overlying gravels are Neogene. Wittekind and Weippert (1973) and O’Leary and Whitney (2005a, b) map Sistan beds within the Sukalok-Arbu belt. If mapping is correct, sedimentation into the Helmand basin was contemporaneous with the Sukalok-Arbu volcanism.

Figure 25A–23. Google Earth vertical view of the Torush-Bab Ghar volcanic field. Units: S1, clastic sedimentary rocks; S2, clastic sedimentary and volcanioclastic rocks; m, mafic volcanic rocks; ad, andesitic to dacitic volcanic necks or domes; df?, dacitic flow dome(?) ; l, intermediate composition intrusive; t, travertine; and qal, Quaternary and Holocene alluvial deposits. Bright white areas are a mix of kaolinite, muscovite, other clays, and calcite (chap. 25B of this report).
Figure 25A–25. Google Earth vertical views of outcrops in the western part of the Sukalok-Arbu belt. A, General view to illustrate style of outcrop exposure and types of features. Reddish-brown textured material is sand dunes and pediment surfaces are light gray to pale red. Leucocratic pluton is at 29.5468° N. and 63.4848° E. B, Partially concealed felsic pluton at 29.4755° N. and 63.1483° E. C, Partially exposed circular leucocratic pluton, maar, or pipe surrounded by alluvium at 29.5297° N. and 63.6120° E.

Figure 25A–28 shows the area to the northwest of the Arbu volcanic field and north of the Torush-Bab volcanic field. Here a well-bedded sedimentary section (marked "S" on figure) approximately 100 m thick appears to unconformably overlie the same folded sedimentary sequence as do the Sokalok-Arbu volcanic rocks. These beds dip very gently northward toward the Helmand basin and are undeformed. Since they have to have been eroded back to their present position, they must have previously extended to the south and covered the Arbu and other volcanic fields, and thus these fields have been erosionally exhumed probably in the Quaternary. It is tentatively assumed that this sedimentary unit correlates with the Sistan beds. It is also notable that the rocks of the folded unit in the Sukalok-Arbu area have been eroded to a very flat-lying peneplane-like surface, which indicates a major pre-Sistan, that is, Pliocene or earlier, erosional episode.

The Sistan beds, however, cannot account for all of the section that must have been present in the Sukalok-Arbu area in the past. As already noted, relief on Koh-e-Malekdokan requires over 700 m of section to have been present in the area but removed subsequent to the intrusion of the Malekdokan stock. Figure 25A–29 shows some of the older stratigraphic section that is preserved on the flanks of Koh-e-Malekdokan. Here two well-bedded near-horizontal conformable sedimentary units (B and C) unconformably overlie another sedimentary sequence (unit A), which is assumed to be the folded unit underlies the volcanic fields. Given the proximity of this location to Kudah Ghar, unit A probably
correlates with the Kudah Ghar section. In the image, gray outcrops of the Kudah Ghar section are seen in the middle distance. Unit B is approximately 125 m thick and unit C 100 m thick. The presence of this relic section is probably due to contact metamorphism by the Malekdokan intrusion, which made these rocks more resistant to erosion.

![Figure 25A–26. Google Earth oblique view of the west-central part of the Sukalok field looking north.](image)

*Figure 25A–26. Google Earth oblique view of the west-central part of the Sukalok field looking north. A, folded sedimentary rocks, B, gently westward-dipping dark layered rocks overlying section A, C, mafic volcanic rocks. D, andesitic-dacitic plugs and intrusions. The dome at the bottom left center of the image is a half a kilometer in diameter and located at 29.6951° N. and 63.4843° E.*

Because of the extensive cover in the south Helmand and Kandahar region, the only area that can tentatively be correlated with the Sukalok-Arbu belt is the western part of the Chagai Belt in northwestern Baluchistan. Figure 25A–6 presents the stratigraphy of the Chagai belt as recognized by Perelló and others (2008). In that area, rocks of the Chagai Arc consist of subaerial volcanic rocks and red-bed clastic strata of the late Oligocene Dalbandin Formation dominate. The Dalbandin also locally contains andesitic units near its top. Overlying the Dalbandin is an approximately 400-m-thick section of early Miocene andesitic rocks which Perelló and others name the Reko Diq Formation. They describe this unit as consisting "predominantly of interbedded andesitic lava flows, autoclastic volcanic breccia, and pyroclastic debris of lapilli and breccia size." Overlying the Reko Diq volcanic rocks is the Pleistocene Kamerod Formation that consists of poorly consolidated coarse clastic sedimentary rocks interbedded locally with ashfall tuffs. The youngest rock unit in the area is the Pliocene to Pleistocene Koh-i-Sultan volcanic group (Siddiqui and others, 2009b). Perelló and others (2008) describe this unit as consisting of a number of lava domes, isolated vents, stratovolcanoes, and remnant eroded volcanic necks. The unit is named after the Koh-i-Sultan stratovolcano in northwestern Baluchistan. It is described as consisting of andesitic to dacitic block and ash flows, tuff, and lahars along with porphyritic plugs (Perelló and others, 2008; Siddiqui and others, 2009b). Siddiqui and others (2009b) note that the Pliocene volcanic rocks are generally dominated by andesites and the Pleistocene volcanic rocks by dacites. This assemblage is very similar to the magmatic rocks of the Sukalok-Arbu belt.
The Koh-i-Sultan volcanic rocks and intrusives are part of a belt of Pliocene-Quaternary volcanic rocks that extend from southern Iran to northwestern Baluchistan. The volcanic vents associated with this suite are shown on figure 25A–3 as red triangles. Based on the similarity in its rock assemblage and inferred age, the Sukalok-Arbu magmatic belt is inferred to be an extension of this belt. The Sukalok-Arbu area is sufficiently far away from the Reko Diq area that there is no reason to expect an exact correlation in stratigraphy, but overall they are similar. What is diagnostic about the Koh-i-Sultan group volcanic rocks is that they are described as consisting of andesite and dacite. All older Cenozoic volcanic units described in northwestern Baluchistan are andesitic only. This lithologic correlation along with the apparent late Cenozoic age of the Sukalok-Arbu igneous rocks indicates that they correlate with the Koh-i-Sultan volcanic group.
Figure 25A–28. Google Earth vertical view of the northern part of the Arbu volcanic field and sedimentary units exposed to the northeast of the field. North of the field a well-layered sedimentary section (S) overlies older folded sedimentary rocks. The base of the younger section is marked with a dashed line.

Figure 25A–29. Google Earth oblique view of the northeastern flank of Koh-e-Malekdokan (id - intrusive dacite) looking southwest. Here an approximately 230-meter-thick section of sedimentary rock (units B and C) unconformably overlie sedimentary rocks of unit A. The unit marked by a "t" is travertine. Unit qc is Quaternary-Holocene colluvium, and qal is Quaternary-Holocene fluvial alluvium. No vertical exaggeration.
25A.4 Economic Geology

25A.4.1 Known Deposits

Six mineral deposits are reported for the study area in Abdullah and others (1977) and Abdullah and Chmyriov (2008). All six are "aragonite" deposits and the descriptions of these deposits from Abdullah and others (1977) are presented in table 25A–3. A detailed study of these deposits was done by Samarin (1977). Based on the descriptions of Samarin (1977) and a field visit to two of the locations (Arbu and Sukalog) by USGS personnel in 2009, these are genetically travertine deposits. Travertine deposits are also common in the Chagai belt of northern Baluchistan province of Pakistan and have been long mined there (Arthurton and others, 1979; Perelló and others, 2008; Siddiqui and others, 2009b). Total estimated resources for south Helmand are 3,077,000 metric tons (t) (1,043,000 cubic meters, m³) (Slavin and others, 1972; Samarin, 1977) (table 25A–3).

Table 25A–3. Helmand Province travertine deposits that occur withing the study area.

<table>
<thead>
<tr>
<th>Location name</th>
<th>Index no.</th>
<th>Latitude and longitude</th>
<th>Estimated reserve (metric tons)</th>
<th>Description</th>
</tr>
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</table>
| Arbu                   | 5/600-IV  | 29°49' N. 63°58' E.    | 234,525 tons (79,500 m³)      | "In Lower Quaternary andesite-dacite vent surrounding Lower Quaternary clastics, are numerous tabular aragonite veins 100-200 meters long and 0.5-4.0 meters thick, having predominantly high-grade aragonite. Speculative reserves are 170,000 tonnes aragonite (Slavin et al., 1972; Eriomenko et al., 1974)."
| Zoldag                 | 7/600-IV  | 29°46' N. 63°52' E.    | 474,950 tons (161,000 m³)     | "In Lower Quaternary subvolcanic and Pliocene sediments are bed-like aragonite bodies; the largest is 250 meters long and 50 meters thick. The aragonite is usually of good quality consisting of large blocks. Speculative reserves are 580,000 tonnes aragonite (Slavin et al., 1972; Eriomenko et al., 1974)."
| Malik Dukan (Malekdokand) | 11/600-IV | 29°43' N. 63°36' E.    | 2,242,000 tons (760,000 m³)   | "In Eocene-Oligocene volcanic rocks, close to a Lower Quaternary dacite-andesite volcanic neck, are aragonite veins, up to 500 meters long and 1.2-5.0 meters thick, over a total area of 128,300 m². The green and yellow facing and ornamental aragonite is high grade. According to Chinze, 1960, the reserves are 42,200 tonnes. Speculative reserves are estimated to be 650,000 tonnes. The deposit has been worked for a long time. (Slavin et al., 1972)."
| Sukalog (Sukhlog)      | 9/600-IV  | 29°43' N. 63°27' E.    | 6,350 tons (2,150 m³)         | "Conformable with Eocene-Oligocene tuffs are small aragonite bodies, 50 by 50 meters and 15 by 20 meters across, each respectively 0.5 and 0.8 meters thick. Speculative reserves are 6,350 tonnes aragonite (Sborschikov et al., 1974)."
| Panawuk                | 20/600-IV | 29°34' N. 63°54' E.    | 1,000 tons (339 m³)           | "Dense, fine-grained, light-green, yellowish-green, white and brownish aragonite in Eocene-Oligocene volcanics, form a tabular body 12 meters in diameter and 3 meters thick. Speculative reserves are 1000 tonnes aragonite. (Sborschikov et al., 1974)."
| Muzdan                 | 21/600-IV | 29°34' N. 63°58' E.    | 118,000 tons (40,000 m³)      | "In Eocene-Oligocene volcanics are three tabular aragonite bodies 200 meters long and 1-2 meters thick, consisting of large blocky, green and yellow aragonite. Speculative reserves are 11,800 tonnes aragonite. (Sborschikov et al., 1974)."

25A.4.2 Travertine Deposits

Travertine is a rock dominantly composed of calcium carbonate. Travertine is formed by a variety of processes but can be classified into two main types: meteogene or thermogene (Pentecost and Viles, 1994; Pentecost, 2005). Meteogene travertines are formed from CO₂-bearing solutions derived from carbonate-bearing source materials and typically found in limestone terranes. These are commonly
deposits that form at ambient temperatures. Thermogene travertine deposits, in contrast, form from hot CO\textsubscript{2}-rich solutions, such as from hot springs, and are generally associated with volcanic activity.

The mineralogical form of the calcium carbonate in travertine may be either calcite and (or) aragonite. The two minerals are polymorphs, which means they have the same chemical composition but different crystal structures. The conditions that control which mineral precipitates are a complex balance of the chemistry of the solutions and the kinetics of deposition (Morse, 2003). Although originally reported as aragonite deposits, laboratory studies by Samarin (1977) indicate that, although both minerals occur in these deposits, they are dominantly composed of calcite.

In the ornamental stone industry travertine is considered a form of marble. In Afghanistan, travertine in the local market is typically referred to as “onyx marble” (Afghanistan Geological Survey, 2006). The term "onyx marble" is also widely used for travertine material in the ornamental or decorative stone industry worldwide (Hora, 1996). The selected use of this term for such rocks in Afghanistan is documented in detail by Samarin (1977, p. 11-12). The term “onyx” specifically refers to a type of chalcedony that is composed of silica, and the application of the term to travertine basically refers to the stone having an onyx-like appearance when polished. Although Samarin (1977) uses the term "onyx marble" throughout his report, he also notes in several places that these rocks have the appearance of travertine. He notes that the deposits in the Arbu, Zoldag, and Malekdokan areas are "genetically connected with the younger volcanic activity."

25A.4.3 Arbu Travertine Deposits

The Arbu travertine deposits occur within the northern part of the Arbu volcanic field (or "Arbu volcanic massif" of Samarin, 1977) (fig. 25A–30). These bodies occur within an area of about 3.5x4 km and range from about 80 to 600 m in length.

Samarin (1977) describes the Arbu deposit as consisting "... of a series of bed-like veins arranged as parallel incompletely arcs at the eastern foot of the andesite-dacitic neck within lavas of similar composition." From his description, it is clear he examined the deposits in the area east of the neck (Arbu Ghar) (fig. 25A–31). He indicates that the travertine dips 40°–50° near the neck (deposit marked by point C on fig. 25A–30) but only 20° farther away. He further notes that some gently dipping conformable bed-like bodies of travertine also occur within the Neogene sedimentary rocks and andesitic-dacitic lavas. Although some of the travertine may be locally intercalated with the Neogene sedimentary and volcanic rocks, their appearance on satellite imagery and from field investigation indicates that they dominantly overlie these beds (figs. 25A–31 and 25A–32, B). Morphologically they are bed-like and possibly deposited in small basins more or less contemporaneously with the formation of the volcanic field.

Samarin (1977) notes the thickness of the travertines in the area of the Arbu Ghar neck as being 0.5-4.5 m thick with an average thickness of 1.2 m. He observes that the travertine is strongly jointed and intensely weathered and dominantly light-green to yellowish-green and locally white to gray in color. Mechanical tests on one sample of the Arbu travertine determined that it is similar to travertines from the other deposits in south Helmand and suitable for manufacturing purposes and for building facades. The field examination by the USGS at location B of figure 25A–30 shows that the deposit there was approximately 2 m thick and the travertine was yellowish to white. Thus, it appears that the travertine deposits at Arbu are dominated by horizontally bedded deposits that average about 2 m in thickness but may be locally as thick as 4 m. However, a number of travertine deposits in the Arbu area, including the areally largest deposit to the east of point B on figure 25A–30, remain to be investigated, and the full potential of these deposits is still to be determined.

Samarin (1977) did not present reserve estimates for the Arbu travertine deposits. He did present two estimates from earlier work of Slavin and others (1972) of 56,250 m\textsuperscript{3} (165,938 metric tons) and by Shorshchikov and others (1974) of 79,500 m\textsuperscript{3} (234,525 metric tons). Because it is not known what deposits in the Arbu travertine field were used for these estimates, it is possible that that they are a significant underestimate.

Chapter 25A. Summary of the South Helmand Travertine Area of Interest 1703
25A.4.4 Zoldag and Surdik Travertine Deposits

Travertine deposits occur in the southern part of the Torush-Bab volcanic field. Two areas containing travertine deposits were recognized in this study and are designated as the Zoldag and Surdik deposits (fig. 25A–33). The Zoldag deposits are the same as the Zoldag aragonite occurrence listed in Abdullah and others (1977) and described in detail by Samarin (1977). The origin of the Zoldag name is not known. The Surdik deposit is not reported in Abdullah and others (1977) or Samarin (1977) and is described here for the first time.

The Zoldag deposits occur in the vicinity of two andesite-dacite volcanic necks (fig. 25A–34) where the travertine overlies and veins Pliocene sedimentary-volcaniclastic beds (Samarin, 1977). Samarin (1977) subdivides the travertine outcrops of the Zoldag deposits into two groups: (1) "steeply dipping vein-like" (45°–80°) and (2) "gently-dipping bed-like" (5°–10°). He notes that steeply dipping travertine is located in the immediate vicinity of the intrusive contacts, which implies that the travertine is either older than the necks or carbonate-bearing hydrothermal fluid conduits were localized in the vicinity of the neck margins. He also recognizes three deposits within the Zoldag occurrence: Main Ledge (or outcropping), Central Ledge, and Eastern Ledge. The Main Ledge is located immediately north of the western neck, the Central Ledge in between the two necks, and the Eastern Ledge along the northwestern flank of the eastern neck.

Samarin also notes that the bulk of the travertine is light- to dark-green colored but locally white, gray, and yellowish gray. He indicates that the Zoldag deposit has been worked for a long time and that the dark-green variety is prized in the local markets. The "Helmand Green Onyx-marble" shown in the Marble of Afghanistan pamphlet (Secretariat for the Ministry of Mines, undated) may be from this locality.

The main occurrence of steeply dipping travertine is at the northern margin of the western neck, which is also identified as the largest body of travertine at Zoldag (Samarin's (1977) "Main Ledge" deposit). The rest of the travertine in the Zoldag area is largely gently dipping and follows local topography (Samarin, 1977). Figure 25A–34.4 appears to show a sizable quarry on the Main Ledge deposit. Samarin describes the travertine deposit here as having "a complex vein-like shape and consists of a series of contiguous beds (veins)." He describes the deposit as being a complex of multi-generational veins that are steeply dipping to the north and "thin out obtusely into the enclosing rocks."

He states that the deposit here has an average thickness of 26 m with a maximum thickness of 44 m and is light- to dark-green colored. For the Zoldag deposits, Samarin (1977) estimated a resource of 161,000 m³ of material.
Figure 25A–30. Geologic map of the Arbu travertine area. Map symbols: t, travertine; s, Pliocene(?) clastic sedimentary rocks; sv, mixed sedimentary and volcanic(?) rocks; v, Pliocene-Quaternary(?) andesitic volcanic flows and necks; and qal, Quaternary alluvium. Red line represents a dike. Image base from Google Earth. Points marked with yellow spot: A, location of Arbu travertine deposit given by Abdullah and others (1977) (table 25A–3); B, photograph location of figure 25A–32; and C, area of travertine deposits examined by Samarin (1977).
The Surdik deposit is the largest identified travertine(?) deposit in southern Helmand province. It is here named after Surdik Ghar, the central peak of the deposit. It is surprising that the Surdik deposit is unreported since it is the dominant topological feature in its vicinity (figs. 25A–33 and 25A–34B). Previous mapping shows it as consisting of volcanic rocks (fig. 25A–7). It is approximately 0.7x2.8 km and up to 100 m high. It is morphologically unusual and consists of a spine-like, central axial ridge with convex slopes down to subhorizontal beds on the flanks. The straightness of the ridge suggests that an underlying structure, presumably a fault, controlled the fluids that formed the deposit. On imagery it appears to be coarsely layered. There is no indication of workings on the deposit. Should the material here prove to be of value, then it would have reserves significantly larger than any other south Helmand travertine deposit. Its identification as a travertine deposit is based on its coloration being identical to other south Helmand travertine deposits and its apparent bedded morphology on the flanks of the deposit. Hyperspectral data further confirm that it is a calcium carbonate deposit (chap. 25B of this report). An alternative interpretation for its origin is that it is an extrusive carbonatite deposit, in which case the horizontal lobate layers on the flanks of the unit are carbonatite flows. Whatever its genesis, the Surdik deposit requires further investigation.
Figure 25A–32. Photographs of Arbu travertine taken in the area of location B on figure 25A–30. A, View of approximately 2-meter-thick section of bedded travertine overlying clastic sedimentary rocks (note rock hammer for scale, lower center of image). B, Close-up of bedded travertine with zone of tufa near top (white porous material). Photographs by Mike Chornack, U.S. Geological Survey.
25A.4.5 Malekdokan Travertine Deposits

The Malekdokan travertine deposits are located in the eastern portion of the Sukalok volcanic field. The name of these deposits as given by Samarin (1977) and in earlier publications is "Malik-Dukan," but in Abdullah and Chmyriov (2008) and the Geographic Names Database of the U.S. National Geospatial-Intelligence Agency the name is spelled as "Malekdokan," which is derived from the mountain of that name, Koh-e-Malekdokan (fig. 25A–8A), and that spelling is adopted here.

Seven large deposits and over 30 small deposits occur within a 3x4.5-km area north of the Aynak-Ghar Mountain (Samarin, 1977) (figs. 25A–35 and 25A–36). Samarin (1977) describes the Malekdokan deposits collectively as "the largest one among the series of the onyx marble occurrences of the south of Afghanistan and has been known to the local population many years ago [sic]." He notes that at the time of his report, there was annual production of approximately 200-300 t per year. The Geographic Names Database has an entry for the "Ma’dan-e Rukham quarries," whose location matches the main deposits at Malekdokan.

Samarin (1977) describes the Malekdokan deposits as consisting mainly of "gently inclined or horizontally occurring blanket-like bodies." He states that drilling shows that the thickness of the deposits varies from 5 centimeters (cm) to 9 m and that "the direction of the bed dip is, as a rule, to the center of the ledge (inwards), forming a cup-like depression: the largest thickness of the ledges is registered in their middle portions." One drilled deposit had a massive zone 3 m thick that was without jointing or fractures, although jointing is typical.

Samarin states that the color of the travertine at Malekdokan is dominantly light to dark green, but that white, gray, and yellowish-gray material is also present. The travertine typically has a "zonal-banded structure consisting of rhythmically alternating lighter and darker layers."

For the seven main deposits identified by Samarin (1977), he estimates total reserves of 760,000 m³. He further states that for the 30 smaller deposits in the Malekdokan area that "...
thickness usually does not exceed 0.5 m, but sometimes it is up to 1.0–1.5 m. There is no blockish stones in such bodies (with some rare exceptions) and the onyx marble from these ledges can be used for manufacturing of small articles only."

Figure 25A–34. Google Earth oblique views of the Torush Bab area travertine deposits. A, View of the Zoldag travertine deposits looking south. The two gray knobs are the andesitic-dacitic volcanic "necks" described by Samarin (1977). Right-hand (western) neck is Jêg Ghar. B, View of the Surdik deposit (foreground, tan outcropping) looking northeast. In the middle distance are the Zoldag travertine deposits (tan), and in the far distance is the dark peak of Torush Bab Ghar (Legh-Ghar of Samarin, 1977). No vertical exaggeration.

25A.4.6 Other Travertine Deposits

The Sukalog (or Sukalok) deposits are reported by Samarin (1977) to consist of two small sheet-like bodies, one with dimensions of 50x50 m and the other 15x20 m. Samarin indicates that the travertine beds were approximately 0.5 m thick, strongly jointed and light-green, yellowish-green, and white in color. Samarin estimated the resource to be 2,150 m³ (6,350 t) and noted that the material at Sukalog can only be used for small article manufacture. Abdullah and others (1977) and Abdullah and
Chmyriov (2008) give the coordinates of the Sukalog deposits as 29°43' N., 63°27' E., but Samarin (1977) reports a different location of 29° 42' N., 63° 30' E. No deposits were identified on available satellite imagery at either location. There do appear to be small scattered travertine deposits in the area of 29°41'16" N., 63°29'00" E., but the small size of these deposits is such that they seem unlikely to be the Sukalog deposits. There are also two travertine deposits at 29°40'47" N., 63°32' 36" E. that are on the west side of and very close to the Sukalok-Mandekh (or Nilak Rod of fig. 25A–8A) main drainage, but they appear substantially larger than those described as the Sukalog deposits. Their dimensions are approximately 150x540 m and 210x870 m (fig. 25A–36). Samarin, however, describes the location of the Sukalog deposits as being on "left slope" (western side?) of the Sukalog-Mandekh River valley, which would support these two deposits being the Sukalog deposits.

**Figure 25A–35.** Geologic map of the Malekdokan travertine area. Point marked "MD" is the location of the "Malik Dukon" deposit given by Abdullah and others (1977). Symbols: t, travertine; s, clastic sedimentary rocks; sv, sedimentary-volcaniclastic and mafic volcanic rocks; v, andesitic-dacitic volcanic neck or flows; fi, felsitic intrusion; qal, Quaternary alluvium, and red lines, dikes.
Small travertine deposits also occur at three locations within the Chagai Hills. Table 25A–4 details their location and size. These are the Panawuk, Muzdan, and Samoli Southeast deposits.

The Panawuk travertine deposit (table 25A–3) is a cone-like knob that sits on the edge of a large drainage (fig. 25A–37A) in the northern Chagai Hills. It is located 1.5 km south of the location given by Abdullah and others (1977) (table 25A–3). As may be seen from figure 25A–37A, it contains a number of small quarry pits and thus has been mined. Samarin (1977) estimates that Panawuk has resources of 339 m$^3$ (1,000 t).

The Muzdan travertine deposits consist of three small travertine deposits and a number of other scattered very small outcrops of travertine that occur along a northeast trend for a distance of 3.5 km (fig. 25A–37B). Abdullah and Chmyriov (2008) also note that there are three deposits at Muzdan, but they may not be the same three larger deposits shown on figure 25A–37B (locations T2, T4, and T5). Samarin (1977) only investigated the T4 location. He described the deposit as consisting of "three beds that are gently inclined to the north." He indicates that the uppermost bed is the largest and is 1 to 2 m thick. They are colored green, yellowish-green, and white. He says that the onyx marble from this deposit is of high quality and can be used as industrial material and dimension stone. He estimates the resource as 40,000 m$^3$ (118,000 t). The other deposit at Muzdan that may have potential is the T2 deposit (fig. 25A–37B) that forms a flat-lying deposit capping a butte and may have a significant thickness. Its form suggests that it is an erosional relic of a larger deposit.

The Samoli Southeast travertine deposits are not reported in either Abdullah and others (1977) or in Samarin (1977). They are informally named here because of their location close to the southeastern

Figure 25A–36. Google Earth view of Malekdokan travertine area looking southwest. Travertine deposits (t) appear as mottled tan colored outcrops overlying mainly andesitic volcanic rocks (v). Malik Dukan and Aynak Ghar are young (Pliocene?) leucocratic dacitic intrusions. "Malik Dukan" deposits studied by Samarin (1977) are in the foreground. In the upper right part of the image is a leucocratic intrusion with a marked contact metamorphic aureole (black ringed intrusion). No vertical exaggeration.
base of Samoli Ghar. They consist of a cluster of three small deposits that occur over a distance of 0.75 km (fig. 25A–37C). Their location and dimensions are given in table 25A–4. All three have been heavily worked, as indicated by numerous small quarries and pits. Although resource estimates are not available for these three deposits, they are limited in size and probably contain less than 2,000 m³ of travertine each.

### Table 25A–4. Small travertine deposits of the Chagai Hills.

[Locations are shown on figure 25A–8A. “Map Id” is the location identification tag used on figure 25A–8A. If only one dimension is given for size, the deposit is roughly equidimensional]

<table>
<thead>
<tr>
<th>Location</th>
<th>Map Id</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Size (approx.)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panawuk</td>
<td>T1</td>
<td>29.55353</td>
<td>63.90176</td>
<td>55 m</td>
<td>Numerous small quarries.</td>
</tr>
<tr>
<td>Muzdan</td>
<td>T2</td>
<td>29.55981</td>
<td>64.02155</td>
<td>210 m</td>
<td>Numerous small pits.</td>
</tr>
<tr>
<td>Muzdan</td>
<td>T3</td>
<td>29.55428</td>
<td>64.00914</td>
<td>46×72 m</td>
<td>Several pits on flank.</td>
</tr>
<tr>
<td>Muzdan</td>
<td>T4</td>
<td>29.54546</td>
<td>63.99414</td>
<td>100×450 m</td>
<td>Numerous small pits.</td>
</tr>
<tr>
<td>Muzdan</td>
<td>T5</td>
<td>29.55154</td>
<td>63.99528</td>
<td>130 m</td>
<td>No observed quarries.</td>
</tr>
<tr>
<td>Samoli SE</td>
<td>T6</td>
<td>29.48022</td>
<td>63.97805</td>
<td>100 m</td>
<td>Numerous small quarries and pits.</td>
</tr>
<tr>
<td>Samoli SE</td>
<td>T7</td>
<td>29.47960</td>
<td>63.97476</td>
<td>100 m</td>
<td>Numerous small quarries and pits.</td>
</tr>
<tr>
<td>Samoli SE</td>
<td>T8</td>
<td>29.47598</td>
<td>63.97281</td>
<td>90 m</td>
<td>Numerous small quarries and pits.</td>
</tr>
</tbody>
</table>

### 25A.4.7 Mineral Resource Potential
This section of the report deals with the potential for the occurrence of other types of mineral deposits in the study area. The Chagai belt in Pakistan is known to contain a number of different types of metallic mineral deposits of which the most important are porphyry copper deposits, including the world-class Reko Diq porphyry system. Perelló and others (2008) report that there are 48 known porphyry copper, copper-gold, and copper-molybdenum deposits and prospects within the Chagai belt. The more important of these are shown in figure 25A–13. Within this area, porphyry copper type mineralization occurred in at least five different episodes: middle to late Eocene (43–37 Ma), early Miocene (24–22 and 18–16 Ma), middle Miocene (13–10 Ma), and less certainly late Miocene to early Pliocene (6 to ~4 Ma) (Perelló and others, 2008). The Reko Diq intrusive system was emplaced during the middle Miocene episode. In addition to porphyry deposits, Sillitoe (1978) and Perelló and others (2008) report the occurrence of manto-type copper, Kuroko-type volcanogenic massive sulfide, and magnetite-rich contact metamorphic deposits. Lead-copper veins are reported in the area of the Saindak porphyry copper deposit (Schmidt, 1968; Ahmed and others, 1972; Sillitoe and Khan, 1977). Rare earth deposits occur in association with the Quaternary Khanneshin carbonatite complex approximately 80 km north of the study area in south-central Helmand province (fig. 25A–19) (Alkhazov and others, 1978; chap. 21A of this report).

Because the Afghanistan portion of the Chagai Hills and Sukalok-Arbu belt is equivalent to the corresponding suites in Pakistan, it is expected that similar types of mineralization will occur in the study area. Data upon which to base a mineral resource assessment for the study area are very limited and include reconnaissance geologic mapping and several remote-sensing based studies that mapped alteration minerals (Mars and Rowan, 2006; chap. 25B of this report). In addition, generalized results of a heavy mineral survey presented by Abdullah and Chmyriov (1977) outline two anomalous areas for lead-zinc and three areas for tin within the study area. These data are summarized on figure 25A–38.

Phyllic (sericite or muscovite) and argillic (kaolinite ± alunite) alteration is typically associated with porphyry copper and vein type deposits (Rowan and others, 2006; Mars and Rowan, 2006; Berger and others, 2008; Sillitoe, 2010). The availability of the ASTER phyllic and argillic alteration mapping of Mars and Rowan (2007) and of the hyperspectral mineral mapping for the study area (chap. 25B of this report) permits assessment for mineral deposit types associated with such alteration.

Figures 25A–38 and 25A–39 summarize these data. The mapping of Mars and Rowan is shown in figure 25A-39. Areas with potential for porphyry-type mineralization within the Chagai Hills are marked on figure 25A–38 as locations 1–7 and discussed below. Numerous other locations with small areas of
phylllic and argillic alteration also occur throughout the Chagai Hills, and the map shown in figure 25A–38 is left to convey the details in regards to distribution. Also shown in figures 25A–38 and 25A–39 is the location of three porphyry copper deposits that occur in Pakistani Chagai Hills not far from the border with Afghanistan.

Summaries of Important Areas for Mineral Investment and Production Opportunities of Nonfuel Minerals in Afghanistan
Figure 25A–38. Alteration maps a, of the western part of the study area. Map is based on the geology map of 25A–7 with an overlay of various features of possible significance for mineral resource assessment of the study area; plutons of the Chagai Hills of Pakistan have been added to the map based on interpretation of Google Earth imagery; and b, of the eastern part of the study area. Symbolization same as for figure 25A–38A.
Figures 25A–39. Areas of phyllic and argillic alteration overlain on a true-color Landsat image (Mars and Rowan, 2007). Known porphyry copper deposits in Pakistan are shown with a black dot.

Figures 25A–40 and 25A–41 show areas of argillic alteration within the Khaki Ghar pluton. This pluton has a low relief and is cut by numerous dikes that generally have a northwest trend (fig. 25A–40). Two locations within it appear intensely altered (locations 1 and 2, fig. 25A–40). Both have a similar appearance on imagery, have dikes of a different trend from the Khaki intrusion, and appear distinct from the main pluton. They appear to be younger small intrusions into the main body. Another area exhibiting phyllic and argillic alteration occurs at the western end of the Khaki pluton (location 3, fig. 25A–41). Here three small, highly altered low-relief outcroppings of granitic rock occur within an area of alluvium (fig. 25A–41). These outcrops may represent a much larger cell of alteration concealed by the alluvial cover.

Figure 25A–40. Google Earth image of a portion of the Khaki Ghar intrusion, a low-relief diked leucocratic felsic pluton. Dashed red lines outline areas of argillic alteration as interpreted from ASTER imagery by Mars and Rowan (2007) (localities 1 and 2 of fig. 25A–38). Hyperspectral data (2 micrometer) indicate that both altered outcrops contain alunite and kaolinite (chap. 25B of this report). Image is centered at 29.5644º N., 64.1775º E.
Figure 25A–41. Google Earth image of altered plutonic rock in the western part of the Khaki Ghar pluton (location 3 of fig. 25A–38). Areas outlined by dashed blue lines contain kaolinite, and area outlined with a red dashed line contains alunite. Image is centered at 29.5610° N., 64.1005° E.

Figure 25A–42 shows the Par Rod-e-Khord pluton, which is named after the drainage that cuts its western margin (location 4, fig. 25A–38). This nearly 3-km-long pluton shows pervasive argillic alteration and oxidation throughout, along with areas of jarosite. One small area of alunite also occurs at the northern border. This pattern of alteration is compatible with epithermal acid sulfate gold mineralization.

Figure 25A–42. Google image of the 2.6-kilometer-long Par Rod-e-Khord pluton (locality 4 of fig. 25A–38), which contains areas of kaolinite (outlined with light blue lines), jarosite (gold lines), and alunite (red line) alteration. Yellow line represents a leucocratic dike. Pluton is also distinct from all other plutons in the Afghani Chagai Hills in that it appears reddish on imagery due to pervasive oxidation. Hyperspectral mineral mapping indicates coarse goethite throughout the pluton along with other ferric mineral phases. Alteration mineral mapping from chap. 25B of this report.
Figure 25A–43A and B shows a small half-kilometer-diameter ring-structured (?) felsic intrusion (location 5, fig. 25A–38). The intrusion is intensely altered and exhibits a concentric zonal arrangement with a core of alunite, pyrophyllite, and jarosite alteration and an outer zone of argillic alteration and oxidation (fig. 25A–43C and D). The intrusion is located within the Kalmuch vein swarm, and intense veining occurs in the immediate area of the intrusion (fig. 25A–43A and B). The area to the northwest of the intrusion also appears altered. This intrusion is the southern member of a cluster of small stocks and dikes (fig. 25A–38) and has a high probability for hosting porphyry-type or epithermal mineralization.

Figure 25A–43. Geology and alteration of a felsic pluton (location 5 of fig. 25A–38, 29.6147° N., 64.5495° E.). See chap. 25B of this report for details of hyperspectral mineral mapping displayed in panels C and D. A. Google Earth view of the pluton. B. Geologic sketch map (f, felsic intrusive; v, mafic volcanic rocks; qal, Quaternary alluvium; blue lines, leucocratic veins; and red line, dike). C. Two-micrometer hyperspectral mineral map (dark red, pyrophyllite ± alunite; red, alunite; magenta, alunite + kaolinite; blues, kaolinite ± dickite and muscovite; tan, calcite + montmorillonite; pale orange, muscovite; dark orange, illite; pale green, chlorite and (or) epidote; and dark green, calcite). D. One-micrometer hyperspectral mineral map (pale violet, jarosite; orange, coarse goethite; brown, coarse hematite; blues and pale green, various types of Fe² and Fe³ mineral phases; and black, not classified)

Figure 25A–44 shows the geology and alteration distribution at location 6 of figure 25A–38. Here, a small felsic intrusion ("fi", lower part of figure) exhibits argillic and goethitic alteration within the core of the intrusion. The alteration mapping of Mars and Rowan (2007) also shows that both outcrop areas of the stock have phyllic alteration. Scattered areas of argillic and goethitic alteration also occur in the area to the north and west of the intrusion. Veins of the Bozani swarm also occur in the area of the intrusion (green lines of fig. 25A–44) and some appear to be spatially associated with alteration (areas marked with an "A").
Figure 25A–44. Geology and alteration in the area of location 6 of figure 25A–38. Symbols: heavy dashed blue lines outline areas of kaolinitic alteration; heavy red areas, coarse-grained goethite; green lines, leucocratic dikes or veins; dashed thin black and white lines, inferred geologic contacts; heavy black solid line, fault; v, volcanic rocks; fi, felsic intrusion; mi, mafic intrusion; qal, Quaternary alluvium. The two kaolinitic areas marked by an "A" outline areas of small scattered patches of alteration. Southern leucocratic felsic pluton centered at 29.657° N. and 64.717° E. Google Earth image base. Mineral data from chap. 25B of this report.

Figure 25A–45 shows the alteration at location 7 (fig. 25A–38). Here large areas of kaolinitic alteration (chap. 25B of this report) are spatially associated with two intrusive bodies (although they may be continuous under cover). The alteration mapping of Mars and Rowan (2007) does not indicate any alteration in this area. There also appears to be significant diking associated with the intrusions.

Figure 25A–45. Area with extensive kaolinitic alteration outlined by dashed heavy blue lines (location 7 of fig. 25A–38) within the Towpi Ghundai range (fig. 25A–8B). The alteration appears to be associated with intrusive rocks (in) that intrude massive mafic volcanic rocks (v). Dikes are represented by red lines. Google Earth Image base. Alteration mapping from chap. 25B of this report.
Three areas of jarosite, all approximately 300-400 m in diameter (location 8, fig. 25A–38) occur at: 29°36'29" N. and 64°38'8" E., 29°36'13" N. and 64°39'47" E., and 29°35'44" N. and 64°40'36" E. (chap. 25B of this report). These areas of alteration are not associated with phyllic or argillic alteration and do not appear to be associated with intrusions. They may be associated with massive sulfide mineralization.

Areas of phyllic and argillic alteration also occur in the Arbu, Torush-Bab, and western Sukalok volcanic fields (fig. 25A–38). Perelló and others (2008) document that not only is porphyry mineralization associated with the Chagai Arc suite of intrusive rocks but important mineralization, including the Riko Diq porphyry system, occurs in association with the younger hypabyssal intrusions of Miocene and younger age. Thus the Sukalok-Arbu belt is also prospective for porphyry and epithermal types of mineralization. Unlike the Chagai Hills, much of the bedrock of the Sukalok-Arbu belt is under alluvial cover, making assessment of its mineral resource potential more difficult.

Figure 25A–38 shows five "heavy mineral haloes," two for tin and three for lead-zinc (Abdullah and Chmyriov, 1977). The details of this sample collection and analysis are not known and only the mineral halos are reported in Abdullah and Chmyriov (1977). The western lead-zinc halo occurs along a drainage just north of the Pakistan border. This drainage includes the Ganshero (formally Amuri) porphyry copper deposit, and it seems likely that this halo is derived from this deposit (fig. 25A–38A). The eastern lead-zinc halo is more interesting in that it has to indicate mineralization occurring within the Afghanistan portion of the Chagai Hills. The halo occurs within the single drainage area that includes the Kashi and Kalmuch vein swarms as well as small stocks including the localities 5 and 7 altered intrusions (figs. 25A–38, 25A–43, and 25A–45). Assuming this halo reflects some kind of mineralization, then it indicates the occurrence of vein-type or other base-metal mineralization in the drainage.

Three tin halos, presumably related to cassiterite, occur in alluvial flats within the Sukalok-Arbu belt (fig. 25A–38) and have to be derived from sources to the south or west since fluvial material movement is to the north and aeolian to the east. The evolved intrusive rocks of the southwestern Sukalok-Arbu area, areas within Pakistan or the vein swarms of the Chagai Hills, are possible local sources. There is, however, no obvious or known source for tin mineralization in the study area.

The Khanneshin carbonatite rare-earth element (REE) deposit (Abdullah and others, 1975; Vikhter and others, 1976; Alkhazov and others, 1978; Peters and others, 2007b; chap. 21A of this report) occurs within a Quaternary volcanic complex 80 km north of the Sukalok field (fig. 25A–18). It is part of the Koh-i-Sultan suite. Its occurrence suggests the possibility of carbonatites being found within the study area. Such rocks, including any type of alkaline igneous rocks, have not yet been identified in the study area. Vikhter and others (1976) state that they analyzed samples from the Zoldag travertine veins and found an anomalous amounts of barium, strontium, and REE. They suggest these are "products of hydrothermal activity of a carbonatite focus" and recommended further work. Samarin (1977) indicated that north of Aynak Ghar, there are abundant calcitic vein complexes that intruded the basement rock that were often associated with abundant mafic dikes. He presents anomalous trace element chemistry for the dikes (spectral analysis): Se, 0.035%; La, 0.02%; Sr, 0.06%; Ba, 0.03%; B, 0.03%; and Th, 0.03%. Samarin also indicated that the Neogene sedimentary rocks in the area of Aynak Ghar were also anomalous in strontium. These data are compatible with a carbonatite association (Singer, 1986). Based on these observations, an investigation of the Sukalok-Arbu travertine areas, and in particular the Surdik carbonate deposit, as possibly being associated with carbonatite magmatism is recommended.

Other features that could relate to the occurrence of carbonatites are the large north-trending leucocratic dikes in the western end of the Sukalok-Arbu belt as well as the leucocratic intrusions of the same area (figs. 25A–8A and 25A–25). Carbonatite dikes are mapped in the Khanneshin region (fig. 25A–18; Abdullah and Chmyriov, 1977). Another anomalous feature is an odd depression at the southwest end of the Kandu Ghar outcrop (fig. 25A–20) (29°621° N., 63.6796° E.). It appears to be an intrusive body that is poorly exposed and with negative relief. The appearance of the feature suggests that an unusual lithology underlies this oval-shaped area. Available hyperspectral mapping could be
used to attempt to define possible areas of fenitization, a type of alteration typically associated with carbonatites. Given that evolved igneous rocks of the Koh-e-Sultan magmatic suite are likely to occur in the study area, exploration for alkaline igneous rocks, carbonatites, and associated rare-earth and other types of mineralization, particularly in the western part of the Sukalok-Arbu belt, is warranted.

In addition to the use of the travertine deposits as a source of ornamental stone, their association with young volcanic rocks indicates that they are, at least in part, of the hot springs variety and might be related to hydrothermal systems with the potential for gold-silver and mercury hot springs type deposits (Berger, 1987; Rytuba, 1987; Hora, 1996). However, hot springs gold-silver deposits are typically associated with rhyolitic rocks, which appear to be lacking in the study area (Berger, 1987). The presence of carbonate vein-dike complexes as reported in Samarin (1977) in the areas of Malekdokan and Zoldag and possibly Arbu suggests that geochemical survey work in those areas is warranted.

25A.5 Summary of Potential

The Sukalok-Arbu belt has significant travertine deposits that have been a source of ornamental stone since ancient times. To date, these deposits have only supported small-scale mining but have the potential for systematic development at a larger scale. Although many of these deposits have been studied in detail, considerably more work is necessary to fully assess this resource.

Based on the occurrence of 48 known porphyry copper (-gold-molybdenum) deposits and prospects in the Pakistan part of the Chagai belt, the entire study area is deemed to have significant potential for this deposit type. The occurrence of a number of localities of plutonic rocks with associated phyllic, argillic, and in some cases jarosite and prophyllic alteration throughout most of the Afghanistan portion of the Chagai Hills indicates locations that may host such deposits. The environment is also favorable for polymetallic vein and replacement deposits. Since the study area is underlain by an island arc, it has the potential to host any deposit type, including massive sulfide deposits.

Other more conceptual possibilities are carbonatite-related rare earth deposits as indicated by the Khanneshin occurrence and hot-spring gold and mercury deposits related to the hot-spring systems that deposited the travertine. The Sukalok-Arbu belt is also favorable for the occurrence of volcanic-hosted epithermal deposits such as acid sulfate gold.

25A.6 Acknowledgments

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25A.7 References Cited


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