

Introduction

Phyllic and argillic-altered rocks are the result of hydrothermal alteration and are typically associated with porphyry copper and other vein-alteration ore deposits (Lowell and Guilbert, 1970; Cox and Singer, 1986). Alunite and kaolinite are common minerals found in argillic-altered rocks, whereas phyllic-altered rocks typically contain sericite (muscovite).

Phyllic and argillic-altered rocks were mapped in the southern and southeastern parts of Afghanistan using Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data (Fig. 1). The areas mapped include the volcanic and igneous intrusive rocks of the Chagai Hills in the Helmand and Qundahar provinces, the Argandab igneous intrusive complex in the Zabul and Ghazni provinces and Miocene diorite intrusive rocks in the eastern part of the Zabul province (Chmyriov and Mirzad, 1972). The Chagai Hills and Argandab igneous intrusive complex are part of the Tethyan magmatic arc, which contains extensive copper deposits in Pakistan and Iran (Leaman and Staude, 2002; Mars and Rowan, 2006).

ASTER measures reflected radiation in 3 bands between 0.52 and 0.86 μm (VNIR); in 6 bands from 1.6 to 2.45 μm (SWIR); and emitted radiation in 5 bands in the 8.125 to 11.65 μm wavelength region (TIR) with 15-m, 30-m, and 90-m resolution, respectively (Fujisada, 1995). ASTER also has a back-looking VNIR telescope with 15-m resolution. Thus, stereoscopic VNIR images can be acquired at 15-m resolution. The swath-width is 60 km, but ASTER's pointing capability extends the total cross-track viewing capability to 252 km (Fujisada, 1995). The spectral bands of the ASTER SWIR subsystem were designed to measure reflected solar radiation in one band centered at 1.65 μm , and five bands in the 2.10–2.45 μm region in order to distinguish $\text{Al}(\text{OH})_3$, $\text{Fe,Mg}(\text{OH})_2$, H_2O , and CO_2 absorption features (Rowan and Mars, 2003; Fujisada, 1995). Previous studies document identification of specific minerals, such as alunite, kaolinite, calcite, dolomite, and muscovite, as well as mineral groups, through analysis of ASTER data (Rowan and Mars, 2003; Rowan et al., 2003). Alunite, kaolinite and muscovite have absorption features positioned at 2.165 and 2.2 μm that are defined by ASTER bands 4 (1.65 μm), 5 (2.165 μm), 6 (2.2 μm), and 7 (2.26 μm) (Fig. 2; Mars and Rowan, 2006).

Methods

ASTER level 1-B radiance data (33 scenes) were downloaded from the EROS Data Center and converted to reflectance data using ACORN atmospheric correction software (Acorn, 2003). The 30-m resolution SWIR data were resampled by a factor of 2 to correspond to the VNIR spatial dimensions. The 15-m resolution 6 SWIR and 3 VNIR bands were combined to form 9-band 15-m spatial resolution data sets.

The 33 individual ASTER scenes used in this study were recorded at a different viewing angles ranging from nadir to 8.2 degrees off nadir, which causes integration of up to 600 m in high relief terrain. Therefore, each 9-band image was geometrically registered to orthorectified Landsat TM data (NASA, 2003). The Landsat mosaic data has a spatial resolution of 28.5 m and spatial accuracy of ± 30 m. Although this registration corrects for the off-nadir viewing effect, the images were not corrected for terrain displacement. Using a second order polynomial warp registration algorithm and at least 9 ground control points for each ASTER scene produced RMS errors of less than 2.0 (60 m). The mosaic of Landsat 4 and 5 data (band 7) was also used as a base map to illustrate regional ASTER alteration for the study area (Fig. 1). Argillic and phyllic alteration units derived from the ASTER data were converted to vector data and overlain on the Landsat mosaic (Fig. 1).

Correction of ASTER data using Hyperion Hyperspectral Data

Comparisons of ASTER reflectance data to spectra taken in situ from calibration sites in the United States, from laboratory samples, and from calibrated hyperspectral data indicate anomalously low reflectance for ASTER band 5 (Mars and Rowan, 2006). When band 5 is too low the spectra are more similar in shape to argillic minerals such as Alunite (Fig. 2), and the mapping algorithms will overestimate phyllic alteration and underestimate argillic alteration (Mars and Rowan, 2006). Hyperion data were resampled to ASTER bandpasses and used to correct ASTER band 5. Hyperion, a hyperspectral instrument flown on board the EO1 satellite platform, has 196 spectral bands in the 0.45 to 2.4 μm region (Kruse et al., 2003). Although Hyperion coverage is limited to a small swath (10 km orbital swath) of the ASTER data, the Hyperion data can be properly calibrated to reflectance using the additional Hyperion atmospheric bands not available in ASTER data.

Hyperion radiance data were calibrated to reflectance data using ACORN atmospheric removal software. The Hyperion reflectance data were resampled to ASTER VNIR-SWIR bandpasses and georegistered to the orthorectified Landsat TM imagery (NASA, 2003). Average spectra were extracted from areas of overlap for the ASTER and Hyperion scenes. A scalar correction consisting of the ASTER resampled Hyperion band ratio 5/6 divided by the ASTER band ratio 5/6, was applied to all ASTER band 5 data. A total of 4 Hyperion scenes were used to correct the 33 ASTER scenes that covered the study area. An average of the scalar correction value (5.4 percent) was used to correct the ASTER data for the study area.

Logical Operator Algorithms

IDL logical operator algorithms were developed and used to map argillic and phyllic-altered rocks (Fig. 3; ENVI, 2006). For each pixel the logical operator algorithm performs a series of band ratios. Each logical operator determines a true or false value for each ratio by comparing the band ratio to a predetermined range of threshold values. All of the ratios in the algorithm have to be true in order for a value of 1 to be assigned to an output byte image, otherwise a 0 value is produced. Thus, a byte image consisting of zeros and ones is produced with each algorithm. Reflectance hyperspectral data from a calibration site in Cuprite, Nevada, and spectra taken from field samples were resampled to ASTER bandpasses and spectroscopically assessed to determine the range of ratios and band ratio values for constraining the logical operator algorithms (Mars and Rowan, 2006). The logical operator algorithm combines multiple band ratios used to mask dark pixels, green vegetation, and map alteration into a single algorithm which streamlines regional mapping and provides a consistent approach for mapping altered rocks across the entire study area.

Phyllic Band Ratio Logical Operator Algorithm

The first part of the Phyllic Band Ratio Logical Operator (PBRL) algorithm performs a band 3/2 ratio to mask out green vegetation (Fig. 3A). A spectral analysis of image and library spectra suggests that band 3/2 ratio threshold values of 1.3 and less typically constitute areas that lack green vegetation. The ratio does not mask out dead vegetation, which has 2.17 and 2.33- μm cellulose absorption features.

The PBRL algorithm performs a threshold of band 4 to mask out pixels with low reflectance (Fig. 3A). Pixels with low reflectance contain anomalously high band 5 and band 9 values, which may be due to energy leakage from the band 4 detector into adjacent band 5 and band 9 detectors (Iwasaki et al., 2001; Rowan and Mars, 2003). The energy leakage is referred to as "crosstalk" (Iwasaki et al., 2001; Rowan and Mars, 2006). Pixels with low reflectance that are affected by "crosstalk" in this study typically include shadowed areas, and dark, mafic and ultramafic rocks. Abnormally high band 5 and 9 values due to "crosstalk" produce anomalous band 6 and 8 absorption features. Spectral analysis of ASTER image spectra suggests that ASTER band 4 pixels with DN values less than 2600 have inaccurate spectral signatures due to "crosstalk" and, therefore, were excluded using a digital mask.

Spectral analysis of ASTER image spectra and resampled 2 ASTER laboratory spectra showed that band ratios 4/5, 5/6 and 7/6 were needed to map the 2.165 μm and 2.2 μm absorption features, thereby delineating phyllic and argillic alteration (Figs. 2 and 3). Band ratios 4/5 and 5/6 map the 2.165 μm and 2.2 μm absorption features, respectively (Figs. 2 and 3A). Spectral analysis of ASTER spectra indicates that band 5 must be at least 5 percent higher than band 6 in order to map as phyllic alteration, thus, the 5/6 band ratio delineates phyllic from argillic alteration by classing ratio values of higher than or equal to 1.05 as phyllic alteration. ASTER spectra of phyllic-altered rocks also illustrate that band 4 is at least 25 percent higher than band 6, and band 7 is 5 percent higher than band 6. Thus, values in the PBRL algorithm for band ratios 4/5, and 7/6 must be higher than 1.25, and higher than or equal to 1.05, respectively, to classify a pixel as phyllic alteration (Figs. 2 and 3A).

Figure 4A. ASTER false color composite image of the northeast-trending magmatic belt in the Argandab intrusive complex. Vegetation-trending in the image is red. Fault lines in yellow are from the Russian 1:1,000,000 map (Chmyriov and Mirzad, 1972).

Figure 4B. ASTER image of band 3 and argillic and phyllic alteration of the northeast trending magmatic belt in the Argandab intrusive complex.

Figure 4C. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4D. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4E. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4F. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4G. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4H. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4I. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4J. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4K. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4L. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4M. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4N. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4O. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4P. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4Q. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4R. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4S. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4T. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4U. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4V. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4W. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4X. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4Y. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4Z. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AA. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AB. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AC. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AD. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AE. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AF. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AG. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AH. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AI. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

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Figure 4AK. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AL. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AM. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AN. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AO. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AP. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AQ. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AR. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AS. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AT. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AU. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AV. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AW. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AX. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AY. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4AZ. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BA. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BB. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BC. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BD. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BE. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

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Figure 4BG. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BH. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BI. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BJ. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BK. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BL. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BM. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BN. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BO. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BP. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BQ. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BR. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BS. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BT. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BU. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BV. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BW. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BX. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BY. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4BZ. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4C0. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4C1. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4C2. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4C3. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4C4. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4C5. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4C6. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4C7. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4C8. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4C9. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4CA. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4CB. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4CC. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

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Figure 4CE. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

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Figure 4CH. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4CI. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4CJ. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4CK. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

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Figure 4CN. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4CO. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4CP. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4CQ. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4CR. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

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Figure 4CW. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4CX. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

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Figure 4CZ. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4D0. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

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Figure 4D2. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4D3. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4D4. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4D5. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4D6. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4D7. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4D8. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4D9. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

Figure 4DA. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

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Figure 4DE. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

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Figure 4DF. ASTER image of band 3 and argillic and phyllic alteration of Miocene igneous intrusive and volcanic rocks of the Chagai Hills.

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