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Wide area lithologic mapping with ASTER thermal infrared data: Case studies for the regions in/around the Pamir Mountains and the Tarim basin

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Abstract. After the authors have proposed the mineralogical indices, e.g., Quartz Index (QI), Carbonate Index (CI), Mafic Index (MI) for ASTER thermal infrared (TIR) data, many articles have been applied the indices for the geological case studies and proved to be robust in extracting geological information at the local scale. The authors also have developed a system for producing the regional map with the indices, which needs mosaicking of many scenes considering the relatively narrow spatial coverage of each ASTER scene. The system executes the procedures very efficiently to find ASTER data covering a wide target area in the vast and expanding ASTER data archive. Then the searched ASTER data are conditioned, prioritized, and the indices are calculated before finally mosaicking the imagery. Here in this paper, we will present two case studies of the regional lithologic and mineralogic mapping of the indices covering very wide regions in and around the Pamir Mountains and the Tarim basin. The characteristic features of the indices related to geology are analysed, interpreted and discussed.

1. Study area

Two study areas in the central Asia are examined: 1) The Pamir Mountains in Tajikistan and the surrounding area, bounded by latitude 37° to 40° North and longitude 71° to 74° East; 2) The Tarim basin and the surrounding area, bounded by latitude 36° to 42° North and longitude 78° to 90° East. The latter is quite vast, therefore, the lithologic mapping just for the north-eastern marginal area of the Tarim basin, bounded by latitude 39° to 42° North and longitude 87° to 90° East is shown here.

2. ASTER data, mineralogical indices and mapping procedures

ASTER was launched onboard Terra, the first of NASA's EOS series of satellites, in December 1999. It obtains multispectral image of the Earth not only in the VNIR and SWIR, but also in the TIR (five bands between 8 and 12-μm, 90-m resolution, NEΔT<0.3 K at 300 K). After the launch of ASTER in 1999, the ASTER VNIR and TIR subsystems keep observing the earth for more than 16 years, although the SWIR subsystem had stopped operation by trouble in 2008. ASTER data are available at no cost for everyone from the data distributor, the National Institute of Advanced Industrial Science and Technology (AIST) and USGS as a result of policy change announced in April 2016,

After the confirmation of analogies among the thermal infrared spectral properties measured in laboratory, in situ and remotely sensed ones [1], mineralogical indices, Quartz index (QI), carbonate

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index (CI) and mafic index (MI) are proposed [2] with the calculation among the ASTER-TIR bands:

$$QI = band11 \times band11 / band10 / band12, \quad (1)$$
$$CI = band13 / band14, \quad (2)$$
$$MI = band12 / band13 / CI^3 = band12 \times band14^3 / band13^4. \quad (3)$$

QI is positively sensitive to quartz, especially to the sedimentary rocks rich in quartz. Also, QI indicates quite low value for the sulphate minerals typically gypsum. Weaker than gypsum but feldspar minerals and granitic rocks rich in the feldspar minerals also indicates low value in QI. CI indicates high value for the typical carbonate rocks, i.e., limestone and dolomite. MI is inversely correlates to the bulk SiO_2 content of the target silicate or igneous rocks. MI indicates quite high value for the ultramafic rocks, the main composition of ophiolite. MI indicates quite low value for high silica rocks typically sedimentary rocks rich in quartz where QI indicates quite high. Many studies applying the indices have clarified the characteristics of the indices [3] as summarized partly in Table 1.

Table 1. Characteristic features of the indices for geological materials

Expected material	Features in indices	Colour in index image
Quartz rich / Silicates poor with some carbonates	QI>1.05, MI<0.8 and CI>1.02	Yellowish red
Quartz rich / Silicates poor with minor carbonates	QI>1.05, M<0.8 and CI<1.02	Pure red
Quartz rich / Feldspars poor with some mafic minerals	QI > 1.05 and MI > 0.82	Red to purplish red
Carbonates	CI > 1.05	Light green
Sulphates	QI < 0.98	Deep green
Ultramafic	MI > 0.92	Light purple
Feldspars rich granitic rocks	Relatively low QI / Image pattern	Dark bluish green
Feldspars poor granitic rocks	Image pattern	Dark pinkish purple
Mafic rocks	Relatively high MI (≈0.90)	Deep blue

Lithologic mapping are accomplished according to the characteristics of the indices summarized in Table 1. The ASTER radiance at the sensor data (Level-1B data) are used for the mapping.

The procedures for producing the mosaic lithologic maps covering wide area [3] are described as follows: Firstly, the browse images of the ASTER data covering the required areas are checked before downloading. The next step is to calculate the indices (i.e., QI, CI and MI) for the respective data, and carefully check the images of the VNIR data and the indices manually. The CI index images should be checked carefully as they can be heavily affected by the atmospheric water content and as a result should be omitted as useless data. During the course of the checking, the priority ranking of each ASTER data is determined, and the mosaic images of the indices covering the area of interest are produced as the regional maps. In the case of this study, we produce the mosaic images mapped for every 1°×1° region of the Earth surface, and then joined them together to produce the regional maps covering the entire study area.

3. Result

Figure 1 shows one of the result regional maps of the indices, the false colour composite image of the indices assigning QI for red, CI for green and MI for blue, for the Tajikistan Pamir Mountains study area. Figure 2 shows the same kind of the result for the north-eastern marginal area of the Tarim basin study area. For both of the cases, the fixed data range of each index, 0.97 to 1.055 for QI, 1.005 to 1.055 for CI and 0.79 to 0.95 for MI, is linearly converted to the intensity of each colour, so that the meaning on the colours or the intensities in the map images is kept through the cases. The boundary between the ASTER scenes is not so significant in the maps even though the fixed data range is applied, which suggests the stability of the indices even though the radiance at the sensor data without atmospheric corrections are adopted for calculating indices with the equations (1) to (3).

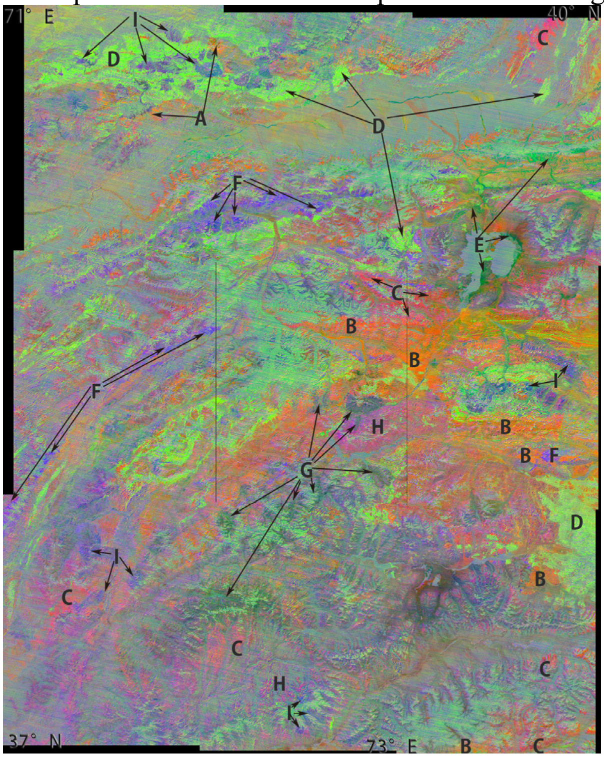

Figure 1. Mosaic colour composite image of QI, CI and MI with a linear contrast stretch of 0.97-1.055 (QI; Red), 1.005-1.055 (CI; Green) and 0.79-0.95 (MI; Blue) using ASTER Level-1B products, covering the Tajikistan Pamir Mountains study area bounded by latitude 37° to 40° North and longitude 71° to 74° East, in a Universal Transverse Mercator (UTM) map projection. The annotations indicate the locations discussed in the text.

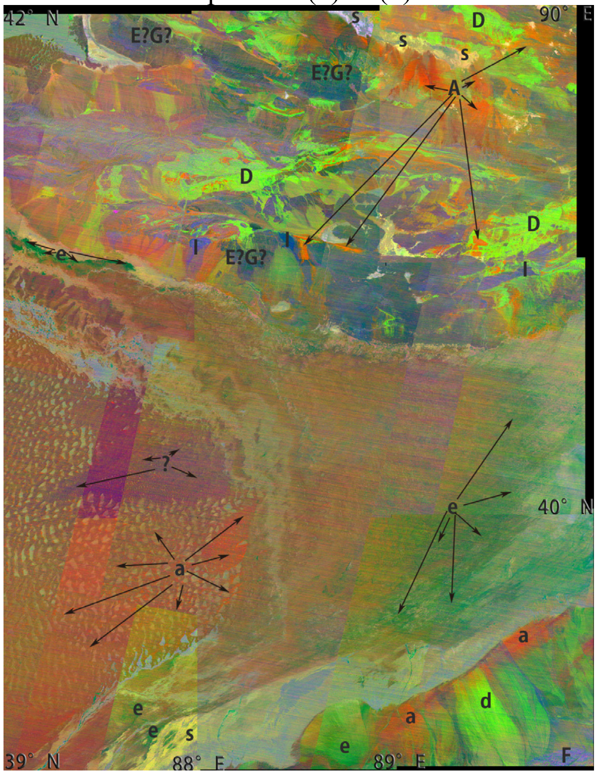

Figure 2. Mosaic colour composite image of QI, CI and MI with a linear contrast stretch of 0.97-1.055 (QI; Red), 1.005-1.055 (CI; Green) and 0.79-0.95 (MI; Blue) using ASTER Level-1B products, covering the north-eastern marginal part of the Tarim basin study area bounded by latitude 39° to 42° North and longitude 87° to 90° East, in a Universal Transverse Mercator (UTM) map projection. The annotations indicate the locations discussed in the text.

4. Discussion

The lithologic features characterized with the indices are analysed based on Table 1. The prominent features are annotated with the alphabetic characters (a part of them are accompanied with the arrowed lines) in Figures 1 and 2, which indicate the geological bodies discussed below. The geological interpretations made here are just only with the features appeared on the indices without any presupposed geological information. In the sense, the discussions made here are preliminary ones, which need to be discussed further with the field geological data.

4.1. The Tajikistan Pamir Mountains study area

Ninomiya and Fu [4] made a lithologic mapping with the indices for the Chinese region of the Pamir Mountains. This study makes it for the Tajikistan Pamir Mountains area. Various kinds of lithologic units exhibit particular features in the colour index image (Figure 1). The bodies "A" denote yellowish red, expected as "Quartz rich / Silicates poor with some carbonates". This type is predicted as non-metamorphosed quartzose sedimentary rocks. Quartzose rocks with reddish colour (QI > 1.05) are widely distributed; however, most of them in the Pamirs are also relatively high in MI (> 0.82). The bodies "B" with pure reddish colour are expected as "Quartz rich / Feldspars poor with some mafic minerals", which are predicted as low-grade metamorphosed quartzose sedimentary rocks typically pelitic schist. The bodies "C" with reddish pink colour are with higher MI (> 0.85), which are predicted as high-grade metamorphic quartzose rocks namely gneissose sedimentary rocks.

The bodies "D" with light greenish colour are carbonate rocks. Also, the bodies "E" with deep greenish colour are gypsum deposits and layers. The bodies "F" of light bluish purple with high MI (> 0.92) are ultramafic rocks. The bluish bodies around the ultramafic rocks and the ones suggested as "I" are expected to be mafic rocks (e.g., gabbro and basalt). The dark greenish bodies "G" with characteristic texture including the ones around the snowy mountains seem "Feldspars rich granitic rocks", and the ones of dark pinkish purple indicated as "H" seem "Feldspars poor granitic rocks".

4.2. The Tarim basin study area

Various kinds of geological units exhibit particular features in the colour index image covering the Tarim basin study area (Figure 2). Outcrops are developed well in the northern part and the southernmost-eastern part. The other parts are covered with the deposits in the north-eastern part of the Tarim basin. The annotated capital characters indicate rocks, and small characters indicate deposits.

Many quartzose rocks with reddish colour are distributed for example the bodies "A". In this area, most of the quartzose rocks are with relatively low MI (< 0.8). This suggests that they are non-metamorphosed sedimentary rocks. Also, many marine sedimentary layers of carbonates with light greenish colour are widely distributed for example the bodies indicated as "D". The deep or dark greenish bodies "E?G?" are also distributed widely in the northern mountainous area. They are distributed with the relation to the bluish silicate rock bodies (typically the bodies "I"), so that perhaps they are the "Feldspar rich granitic rocks". However, it needs to check in the field. The bodies "I" seem to be mafic rocks, and the ones "F" seem to be mafic to ultramafic rocks.

The deposits also denote the characteristic colours in the composite index image (Figure 2) here at the eastern marginal region of the Tarim Basin. The reddish colour of the bodies "a" suggests the high quartz content. The light greenish colour of the bodies "d" suggests the high calcite content. The deep greenish colour of the bodies "e" is reflecting the high gypsum content. The source of the reddish purple colour at the bodies "?" is not determined yet. The whitish yellow or whitish blue colour at the bodies "s" , which are distributed at both the deposit and mountainous regions, is reflecting the features of high for all the three indices (i.e., QI, CI and MI). Such features are expected for salt deposits. Comparing the multi-temporal images, most of these whitish yellow or blue bodies are not stable, that is, they are appearing or disappearing along with the condition of climate.

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