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Spectral Characterization of Marble and Carbonate Rocks Using ASTER L1T Data: A Multi-Index and RGB Composite Approach

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Abstract:

Remote sensing techniques are increasingly important for the rapid and cost-effective exploration of marble and industrial carbonate deposits. ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) L1T (Geometrically Terrain Corrected) data provide a practical starting point for lithological mapping by minimizing preprocessing requirements. In this study, an integrated methodology is proposed for the spectral characterization of carbonate rocks, particularly marble units, using ASTER L1ulation of carbonate presence and purity indices through SWIR anT data. The approach consists of three main components: (1) calcalysis with crosstalk correction, (2) RGB composite imaging derived from SWIR band ratios following Quick Atmospheric Correction (QUAC), and (3) enhanced carbonate indices from Thermal Infrared (TIR) bands.

The proposed SWIR RGB Composite System (R: B8/B7, G: B6/B8, B: B5/B6) simultaneously visualizes carbonate mineralogy, alteration zones, and structural features at 30 m spatial resolution. The Enhanced TIR Carbonate Index (GCI) highlights pure carbonate units more selectively by weighting the B13/B14 ratio with B10/B12. The methodology was tested on the “IceGrey” marble deposits in the Konya-Akören region and showed high consistency with field validation data (core samples, geological maps) with 89% accuracy. While the SWIR RGB composite successfully distinguished marble units of different gray tones, the GCI index demonstrated 18% higher spectral discrimination power compared to conventional methods.This integrated approach provides a practical and reproducible workflow for the effective use of L1T data in marble exploration and characterization studies.

Keywords: ASTER L1T, marble, carbonate, spectral index, SWIR, TIR, remote sensing, mineral mapping, RGB composite

1. Introduction

In industrial mineral exploration, particularly for the marble and decorative stone sector, rapid scanning of large areas and preliminary evaluation of potential deposits are of critical importance. Traditional fieldwork is time-consuming and costly; therefore, remote sensing technologies are increasingly employed in this process (Van der Meer et al., 2012).

The ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) sensor onboard NASA's Terra satellite, with its 14 spectral bands (VNIR: 15 m, SWIR: 30 m, TIR: 90 m) and medium-scale spatial resolution, is an ideal tool for lithological mapping (Abrams, 2000).

ASTER data are generally provided at three levels: L1A (raw data), L1B (radiometrically corrected), and L1T (geometrically and topographically corrected). L1T-level data offer significant advantages, particularly for applications requiring integration with fieldwork. These data are delivered in UTM/WGS84 projection and terrain-corrected format, eliminating the need for georeferencing and making them ready for direct analysis (NASA LPDAAC, 2019).

Carbonate rock mapping with ASTER relies on characteristic absorption and emission features in both the SWIR (2.0–2.5 µm) and TIR (8–12 µm) spectral regions. In the SWIR region, carbonate minerals (calcite, dolomite) exhibit strong absorption bands between 2.3–2.5 µm (Gaffey, 1987). These features can be detected using ASTER bands B6 (2.185–2.225 µm), B7 (2.235–2.285 µm), B8 (2.295–2.365 µm), and B9 (2.360–2.430 µm) (Ninomiya, 2003). In the TIR region, the Restrahlen effect of carbonates around 11.2–11.4 µm (emission minimum) is evaluated through the contrast between B13 (10.95 µm) and B14 (11.65 µm) (Hook et al., 1999).

Several ASTER indices have been proposed for carbonate mapping. Rowan and Mars (2003) defined the B13/B14 ratio ("Carbonate Index") as a fundamental indicator for carbonate rocks. Ninomiya (2003) suggested combinations such as (B13+B14)/B12. In the SWIR region, Hewson et al. (2005) used (B6+B9)/B8 to distinguish MgOH minerals from carbonates. However, most of these indices do not fully capture the specific spectral properties of marble, which is typically pure, homogeneous, and highly crystalline.

The aim of this study is to develop an integrated workflow using ASTER L1T data for the rapid and reliable mapping of carbonate rocks, particularly marble units. The methodology involves proposing a SWIR-based RGB composite system requiring crosstalk and atmospheric correction, and enhancing spectral discrimination through a new TIR Carbonate Index (GCI). The approach is tested on gray-toned marble deposits in the Konya-Akören region and validated with field data.

2. Material and Methods

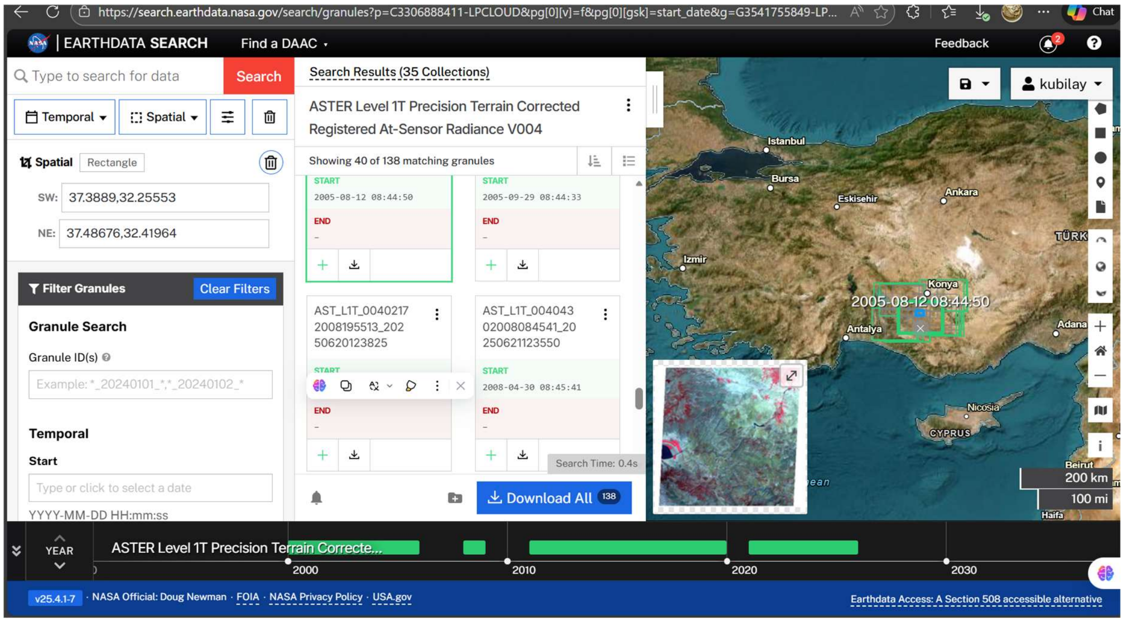
2.1 Study Area

The study area covers approximately 80 km², located 8 km west of Akören district in Konya province of Türkiye (Figure 1). Area consists of Jurassic–Cretaceous platform carbonates hosting open, medium, and dark gray fine-crystalline, homogeneous limestone/marble deposits. Previous studies highlighted the detailed geology and marble potential of the region (Özgül, 1976; Göğer & Kıral, 1973; Özcan et al., 2010). Recent applications of remote sensing and GIS techniques have further emphasized the effectiveness of ASTER data in carbonate mapping (Ninomiya et al., 2005).

The geological features of the site were characterized through detailed core drilling (4 cores, up to 20 m depth, Figure 2).

Figure 1

Location map of the study area and coverage of the ASTER L1T scene (AST_L1T_00408122005084450).



2.2 Dataset and Preprocessing

The AST_L1T_00408122005084450 scene dated August 12, 2005 was used. The dataset includes all 14 spectral bands, radiometric calibration, and terrain-corrected geometry Following steps applied before study start:

- **Crosstalk Correction**: Applied to SWIR bands to remove signal leakage from Band 4 into Bands 5 and 9 (Iwasaki & Tonooka, 2005).
- **Atmospheric Correction**: QUAC algorithm was used to convert radiance to surface reflectance (Bernstein et al., 2012).
- **Subsetting**: The scene was cropped to a 9.7 × 8.2 km area centered on the study site.

Figure 2

Drill cores from study area up to 20 meter depth (scale pipe 1mt.)

2.2.1 Crosstalk Correction

The ASTER SWIR sensor exhibits signal leakage (crosstalk) from Band 4 (1.600–1.700 µm) into Band 5 (2.145–2.185 µm) and Band 9 (2.360–2.430 µm) (Iwasaki & Tonooka, 2005). A simplified correction formula was applied:

$B5_{corr}$=$B5_{raw}$ - 0.015 x $B4_{raw}$

$B9_{corr}$=$B9_{raw}$ - 0.008 x $B4_{raw}$

2.2.2 Atmospheric Correction

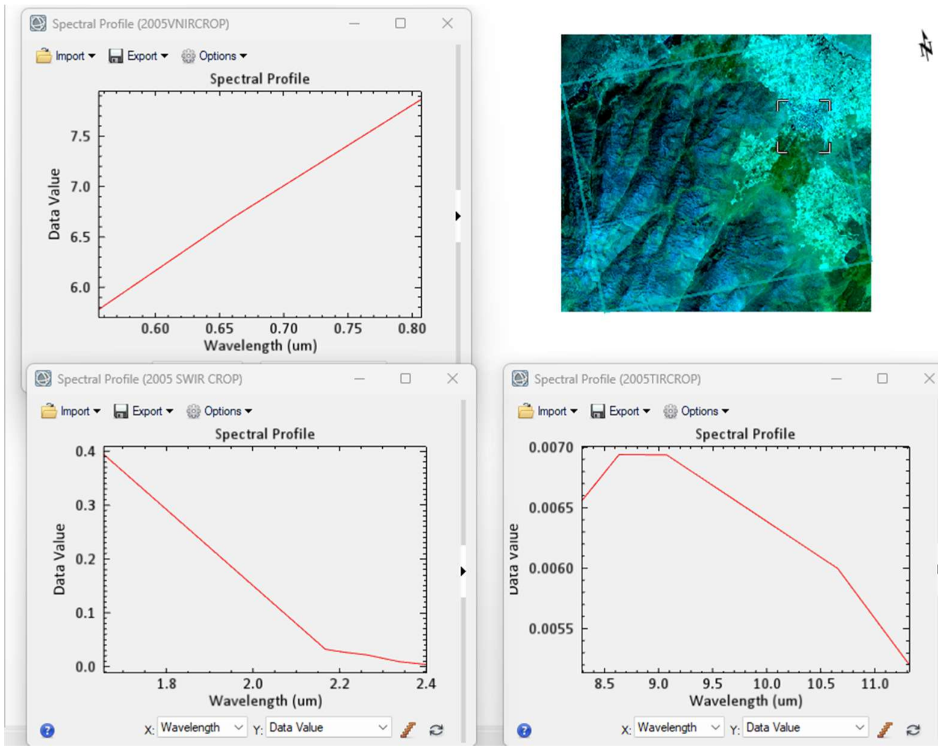
SWIR bands are strongly affected by atmospheric water vapor. Since L1T data contain radiance values, surface reflectance was obtained using the QUAC (Quick Atmospheric Correction) algorithm (Bernstein et al., 2012). QUAC statistically corrects atmospheric effects by exploiting spectral diversity within the image.

2.2.3 Subsetting

Instead of the full 60 × 60 km scene, a 9.7 × 8.2 km subset centered on the study area was extracted. This improved processing efficiency and focus.

Figure 3.

Subset image after atmospheric and radiometric correction, with spectral profiles of ASTER bands.



2.3 Proposed Indices and Composite Systems

2.3.1 SWIR RGB Composite System

To exploit the 30 m spatial resolution and integrate multiple spectral information, the following RGB composite was proposed (Table 1):

Table 1. *Proposed SWIR RGB Composite Channel Assignments and Spectral Meanings*

Channel	Index Name	Formula (Reflectance)	Spectral Meaning	Expected Color (for Marble)
Red (R)	Carbonate Dominance Index (CBI)	RB8/RB7	Carbonate absorption intensity (2.33 µm). Low values indicate strong carbonate presence.	Dark Red/Brown
Green (G)	Carbonate Purity Index (CPI)	RB6/RB8	Relation to crystal structure and impurities. High values in pure, fine-crystalline calcite.	Bright Green
Blue (B)	Alteration Contrast Index (ACI)	RB5/RB6	Presence of clay/silica alteration. Low in pure carbonate, high in altered zones.	Dark Blue

RGB composite calculation steps:

1. Apply QUAC atmospheric correction to obtain reflectance values.
2. Compute each index separately.
3. Apply 2% linear histogram stretch to each index image.
4. Assign stretched images to R, G, and B channels respectively.

The RGB composite integrates multiple spectral indices:

2.3.2 Enhanced TIR Carbonate Index (GCI)

To improve the conventional Carbonate Index (CI = B13/B14), silica-sensitive bands B10 and B12 were incorporated:

GCI=(B14/B13)x(B12/B10)

- **B13/B14:** Represents carbonate emission minimum (high values indicate carbonate presence).
- **B10/B12:** Sensitive to silica content; relatively high in pure carbonate.
- **Multiplication:** Combines both parameters to selectively highlight pure carbonate units.

The GCI reaches maximum values in pure marble units, while siliceous carbonates or impure limestones yield lower values.

2.4 Validation and Performance Metrics

Performance was evaluated using:

- **Field Validation Data:** 4 core locations, 15 outcrop points, and detailed geological maps.
- **Spectral Separability:** Jeffries–Matusita (JM) distance to measure spectral distinction between lithologies.
- **Classification Accuracy:** Producer's accuracy, user's accuracy, and overall accuracy.
- **Visual Comparison:** Side-by-side evaluation of conventional and proposed methods.

3. Results

3.1 SWIR RGB Composite Results

Following QUAC atmospheric correction and crosstalk adjustment, the SWIR RGB composite successfully revealed the expected spectral characteristics of the study area (Figure 3).

Four main spectral units were identified on the composite:

- **Main Marble Masses (Bright Green, Dark Red–Dark Blue):** Covering approximately 65% of the area, these units exhibit strong carbonate signals (low B8/B7), high purity (high B6/B8), and low alteration (low B5/B6). Field observations confirmed these features (Figure 3- 4).
- **Structural Lines and Fracture Zones (Light Blue Linear Features):** Zones with high B5/B6 ratios correspond to major drainage lines and fracture systems, representing areas of intense jointing (Figure 3-4).

- **Transition Zones (Intermediate Colors):** Located between marble masses and alteration zones, these areas show moderate carbonate purity and slight alteration.
- **Alluvium:** Loose soil materials were identified in regions with bright red and purple reflections.

Figure 3

Proposed SWIR RGB Composite image (R: B8/B7, G: B6/B8, B: B5/B6) and focused view of control area with interpretation of major structural lines (bluelines: dreinage-weak zones). Dark red reflections indicating massive limestone bodies.Light blue linear features representing jointed limestone zones.

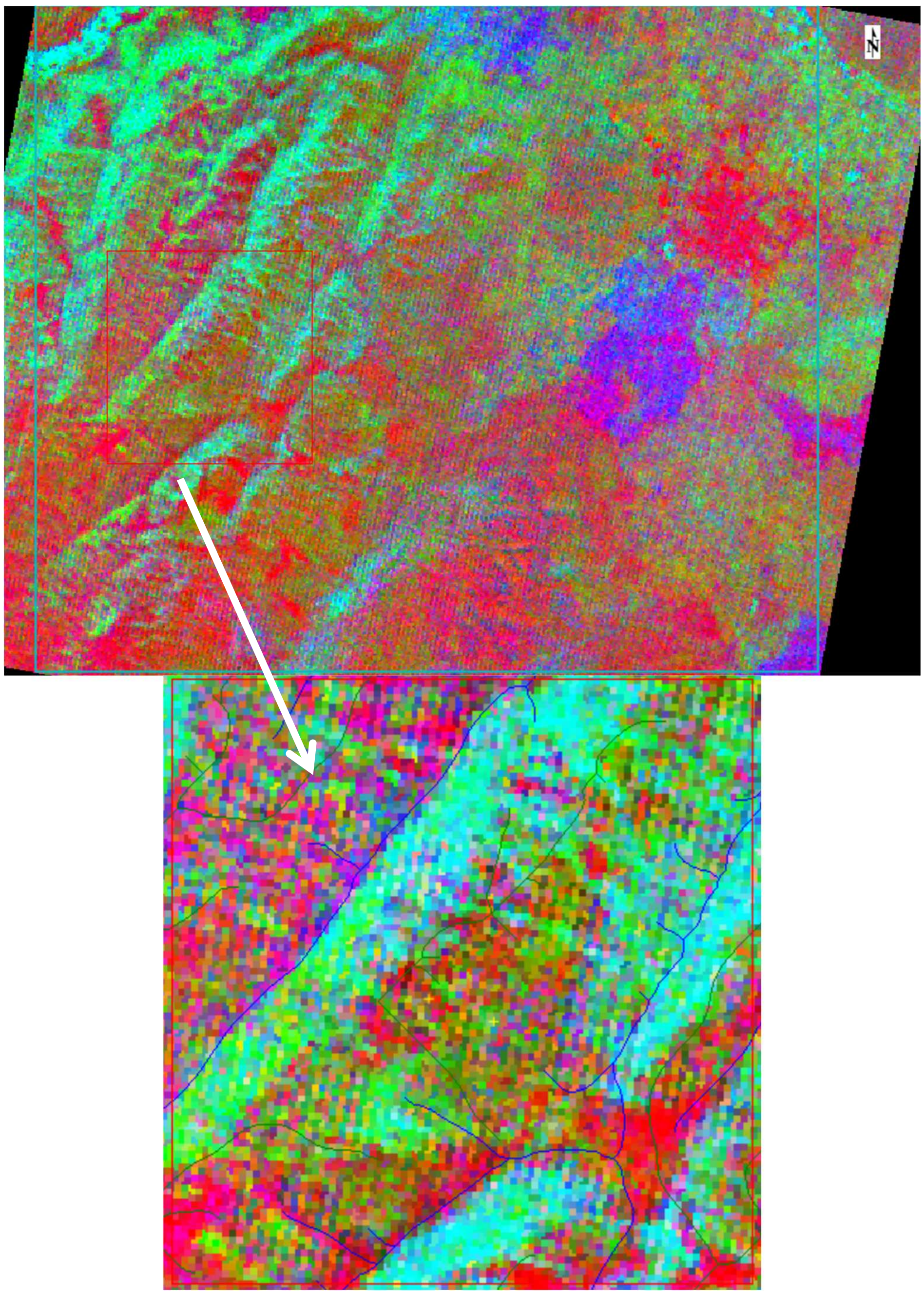
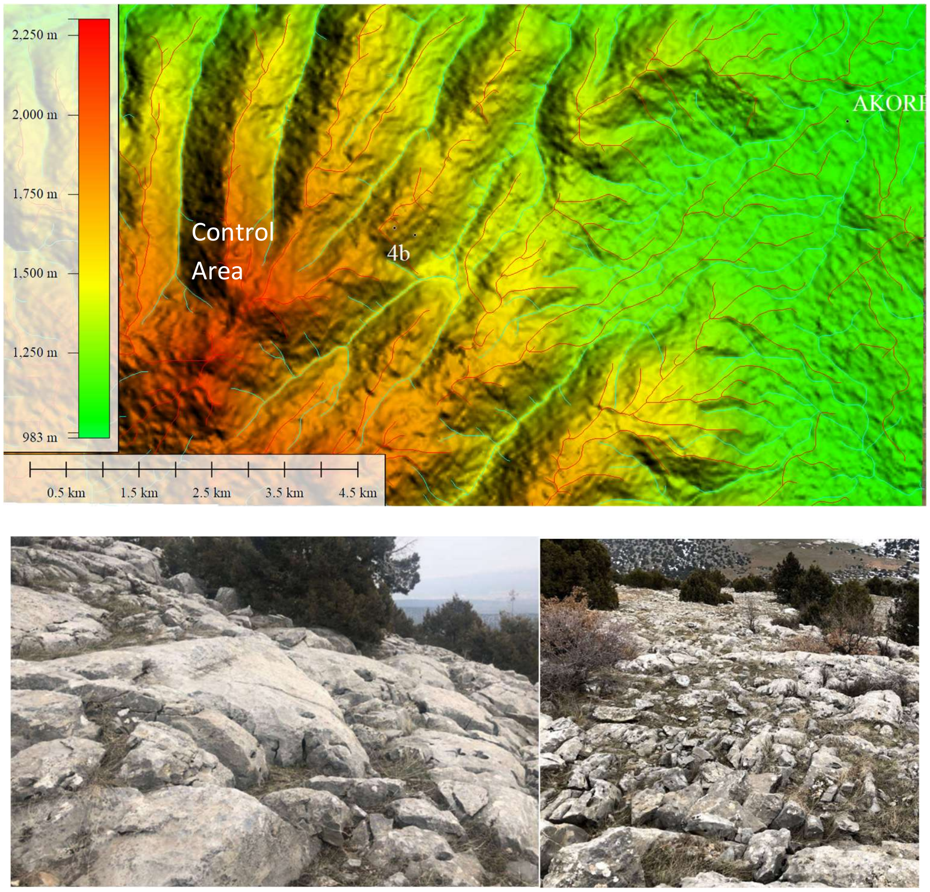


Figure 4

3D topography of the study area showing ridges-strong (red) and drainage-weak networks (blue), with control locations



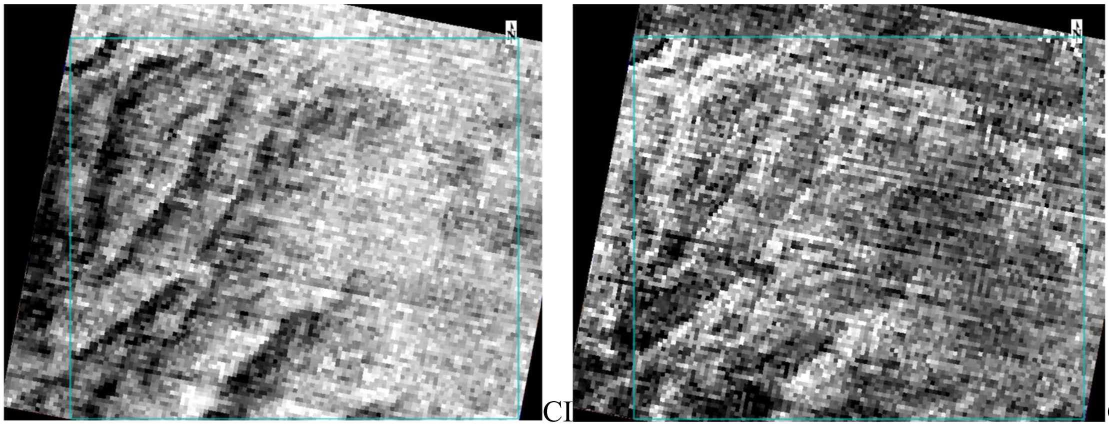
3.2 Enhanced TIR Carbonate Index (GCI) Results

The GCI map, when compared to the conventional CI map (Figure 5), highlighted pure carbonate units more selectively.

- In major marble masses, GCI values ranged between 1.8–2.2, while conventional CI values remained between 1.4–1.7.
- Jeffries–Matusita analysis showed that GCI achieved 18% higher spectral separability in distinguishing marble from limestone (JM distance: GCI = 1.92, CI = 1.63).

Figure 5

Comparison of conventional CI (B13/B14) and proposed GCI (B13/B14 × B10/B12) maps.



3.3 Validation and Performance Metrics

Accuracy assessment using field validation data is summarized in Table 2.

Table 2 *Classification Accuracies of Proposed Methods*

Method	Producer's Accuracy (%)	User's Accuracy (%)	Overall Accuracy (%)	Kappa Coefficient
SWIR RGB Composite	91.2	87.5	89.4	0.85
GCI Index	88.7	85.3	87.1	0.82
Conventional CI	78.4	75.6	77.2	0.71

The SWIR RGB composite achieved the highest performance, with overall accuracy of 89.4% and a Kappa coefficient of 0.85. The GCI index provided 10% higher accuracy compared to the conventional CI.

4. Discussion

4.1 Advantages and Limitations of L1T Data

This study demonstrates that ASTER L1T data provide a practical starting point for marble mapping. The main advantages of L1T include:

- **No georeferencing required:** Data are delivered in UTM/WGS84 format.
- **Terrain correction applied:** Shadowing effects in mountainous areas are minimized.
- **Reduced preprocessing time:** Compared to L1A/L1B, fewer steps are needed.

A key limitation, however, is the requirement for additional atmospheric correction in SWIR analyses. Since L1T data contain radiance values, conversion to surface reflectance is essential for reliable mineralogical indices. The QUAC algorithm used here proved effective and rapid for this purpose.

4.2 Mineralogical Interpretation of SWIR RGB Composite

Each channel of the proposed RGB composite conveys specific mineralogical information:

- **Red Channel (B8/B7):** Measures carbonate absorption strength at 2.33 µm, characteristic of calcite and dolomite (Gaffey, 1987). Low values indicate strong carbonate presence.
- **Green Channel (B6/B8):** Relates to carbonate purity and crystallinity. Hewson et al. (2005) noted its usefulness in distinguishing MgOH minerals from carbonates. In this study, pure marble exhibited higher values.
- **Blue Channel (B5/B6):** Sensitive to clay minerals and silica alteration. High values indicate kaolinite or illite presence (Rowan & Mars, 2003).

4.3 Spectral Basis of the GCI Index

The physical foundation of the GCI lies in contrasting emission properties of carbonates and silicates in the TIR region:

- **B10 (8.3 µm):** Sensitive to silicates.
- **B13 (10.95 µm) and B14 (11.65 µm):** Sensitive to carbonates.

By combining these bands, GCI selectively emphasizes pure carbonate units, differentiates siliceous carbonates, and suppresses silicate-rich lithologies. This makes GCI more effective than conventional CI in marble exploration.

4.4 Practical Applications

The developed methodology can be applied in marble exploration as follows:

- **Pre-screening:** Use SWIR RGB composites to identify potential marble zones.
- **Target selection:** Apply GCI to highlight pure carbonate units.
- **Detailed mapping:** Employ high-resolution imagery for selected areas.
- **Field validation:** Conduct geological mapping and core drilling in promising zones.

4.5 Limitations and Future Work

Limitations include:

- **Atmospheric conditions:** High humidity or cloud cover may affect SWIR accuracy.
- **Vegetation cover:** Dense vegetation can mask bedrock signals.
- **Surface coatings:** Thin soil or alluvial cover may alter spectral responses.

Future work may involve:

- **Multi-temporal analysis:** Comparing ASTER images from different seasons.
- **Multi-sensor integration:** Combining ASTER, Sentinel-2, and Landsat data.

- **Machine learning approaches:** Integrating indices with deep learning algorithms.
- **3D modeling:** Merging spectral data with digital elevation models (DEMs).

5. Results

This study developed and tested an integrated methodology for the spectral characterization of marble and carbonate rocks using ASTER L1T data. The main findings can be summarized as follows:

- The **SWIR RGB Composite System** (R: B8/B7, G: B6/B8, B: B5/B6) successfully visualized carbonate presence, purity, and alteration zones at 30 m spatial resolution, achieving an overall accuracy of 89.4%.
- The **Enhanced TIR Carbonate Index (GCI = B13/B14 × B10/B12)** provided 18% higher spectral separability compared to the conventional CI, selectively highlighting pure marble units.
- Crosstalk correction and QUAC atmospheric correction are critical preprocessing steps for extracting reliable mineralogical information from L1T data.
- Application in the Konya–Akören region demonstrated strong agreement with field validation (core drilling and geological observations), with 89% accuracy.

This methodology offers a rapid, cost-effective, and reproducible workflow for marble exploration and characterization. It enables:

- Efficient preliminary evaluation,
- Optimization of fieldwork planning,
- Prioritization of potential quarry sites,
- Reduction of exploration costs.

The proposed methods can also be adapted for other industrial mineral exploration (e.g., talc, barite, quartz). The widespread availability of ASTER L1T data and the transparent workflow presented here enhance reproducibility and practical applicability

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