MAPPING GONDWANA-DERIVED TERRANE USING REMOTE SENSING SATELLITE DATA IN ANTARCTICA

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ABSTRACT: Gondwana-derived terranes are now separated by major faults or suture zone, which are rarely simple and easily recognizable lineaments. Different association of ore mineral systems such as deposits of sediment-hosted/orogenic gold and granite-related minerals is discovered in collision and subduction zones of the Gondwana-derived terranes. They are associated with large-scale, terrane-bounding fault systems and broad areas of deformation. Mineralization mostly associated with structurally-controlled complex lodes, veins, sheeted veins and veinlets in diverse orientations. Recognizing the structural significance of lineaments and curvilinear is very difficult in tropical, arid and Antarctic regions due to environmental obstacles. Remote sensing data could be used to detect geological structures associated with suture zones between Gondwana-derived terranes especially for large inaccessible regions where fieldwork is limited or nonexistent. Satellite remote sensing imagery is especially useful for geological investigations in Antarctica because of its remoteness and extreme environmental conditions that constrain direct geological survey. The highest percentage of exposed rocks and soils in Antarctica occurs in Northern Victoria Land (NVL). Exposed Rocks in NVL were part of the paleo-Pacific margin of East Gondwana during the Paleozoic time. The potential of orogenic gold mineralization in NVL is extremely high in the Bowers Terrane due to correlation with the gold mineralization in southeastern Australia and New Zealand, which were adjacent fragments to NVL during the Paleozoic. This investigation provides a satellite-based remote sensing approach for regional geological mapping in the NVL, Antarctica, focusing on the Bowers terrane with high potential for hosting orogenic gold mineralization. Spectral and Lineament analysis using remote sensing satellite data is a useful tool for mapping major geological structural features and detection of the boundary between the Gondwana-derived terranes and detailed structural analysis of fault systems and deformation with high potential for a variety of mineral resources, especially Antarctic regions.

1. INTRODUCTION

Gondwana-derived terranes are now separated by major faults or suture zone. Paleozoic gold formation occurred along all the active margin of Gondwana supercontinent, for instance in what is now Southeast Asia, eastern Australia, the South Island of New Zealand; southern South America and northern Victoria Land, Antarctica (Goldfarb et al., 2014). Gold mineralization associated with the margin of Gondwana is related to processes of subduction/accretion and magmatism. Therefore, they are associated with large-scale, terrane-bounding fault systems and broad areas of deformation. The terrane has been subjected to compressional or transpressional events involving folding, thrusting, reverse and strike-slip faulting (Goldfarb et al., 2014). Moreover, many granite-related ore deposits include different associations of elements such as Sn, W, U, Th, Mo, Cu, Au, Pb, Zn, Ag, Nb, Ta, Be, Sc, Li, Y, Zr, Sb, F, Bi, As, Hg, Fe, Ga, REEs and other metals occurred in collision and subduction zones of the Gondwana-derived terranes.
Remote sensing applications are especially useful when extreme environmental conditions constrain direct survey such as in Antarctica (Haselwimmer et al., 2011; Pour et al., 2017 a,b). The highest percentage of exposed rocks and soils in Antarctica occurs along the Transantarctic Mountains (TAM) from the Pacific to the Atlantic sides of the continent, especially in Northern Victoria Land (NVL) (Fig. 1) where over 5% of the emerged land is ice-free. Rocks now exposed in NVL were part of the over 4000 km long paleo-Pacific margin of East Gondwana during the Paleozoic time. This margin was the site of protracted convergence, with terrane accretion and collision(s) of arc and/or micro-continental masses (Cawood, 2005). Structural and lithological geology mapping is one of the most

prominent applications of remote sensing satellite data during last decades (Pournamdary et al., 2014 a,b; Pour and Hashim, 2014; Pour et al., 2017 a,b).

A few multispectral satellite remote sensing investigations have been conducted for geological applications in NVL, Antarctica. Mazzarini and Salvini (1994) used Landsat Multispectral Scanner (MSS) satellite data for structural analysis of tectonic blocks in the NVL. They employed an automatic method (Hough transform) to detect the lineaments. The occurrence of tectonic blocks in the NVL was defined by analyzing the spatial distribution of the linear structural features. This investigation provides a satellite-based remote sensing approach for regional geological mapping in the NVL, Antarctica, focusing on the Bowers terrane with high potential for hosting orogenic gold mineralization.

2. MATERIALS AND METHODS

2.1 Geology of the study area

Northern Victoria Land (NVL) is situated at the boundary between East and West Antarctica (Fig. 1), and belonged to the active paleo-Pacific margin of the East. The paleo-Pacific margin of the East Gondwana continent, comprising East Antarctica, Australia, Tasmania and New Zealand, was affected by the Ross-Delamerian Orogeny in the Cambrian time (Cawood, 2005). The evidence from geochemistry of volcanic rocks and petrography of clastic sediments in NVL indicates that orogenesis occurred during a phase of oblique subduction accompanied by the opening and subsequent closure of a back-arc basin. The tectonic architecture of NVL was predominantly established during the Neoproterozoic to Early Paleozoic Ross Orogeny (Estrada et al., 2016). The geological framework of NVL is commonly referred to the assembly and stabilisation of three different NNW-trending, Neoproterozoic to Early Palaeozoic, fault-bound lithotectonic units or "terranes" onto the East Antarctic Craton during the Early Palaeozoic Ross orogeny. These terranes from west to east are (Fig. 1): (i) the Wilson Terrane (WT), (ii) the Bowers Terrane (BT), and (iii) the Robertson Bay Terrane (RBT) (Estrada et al., 2016).

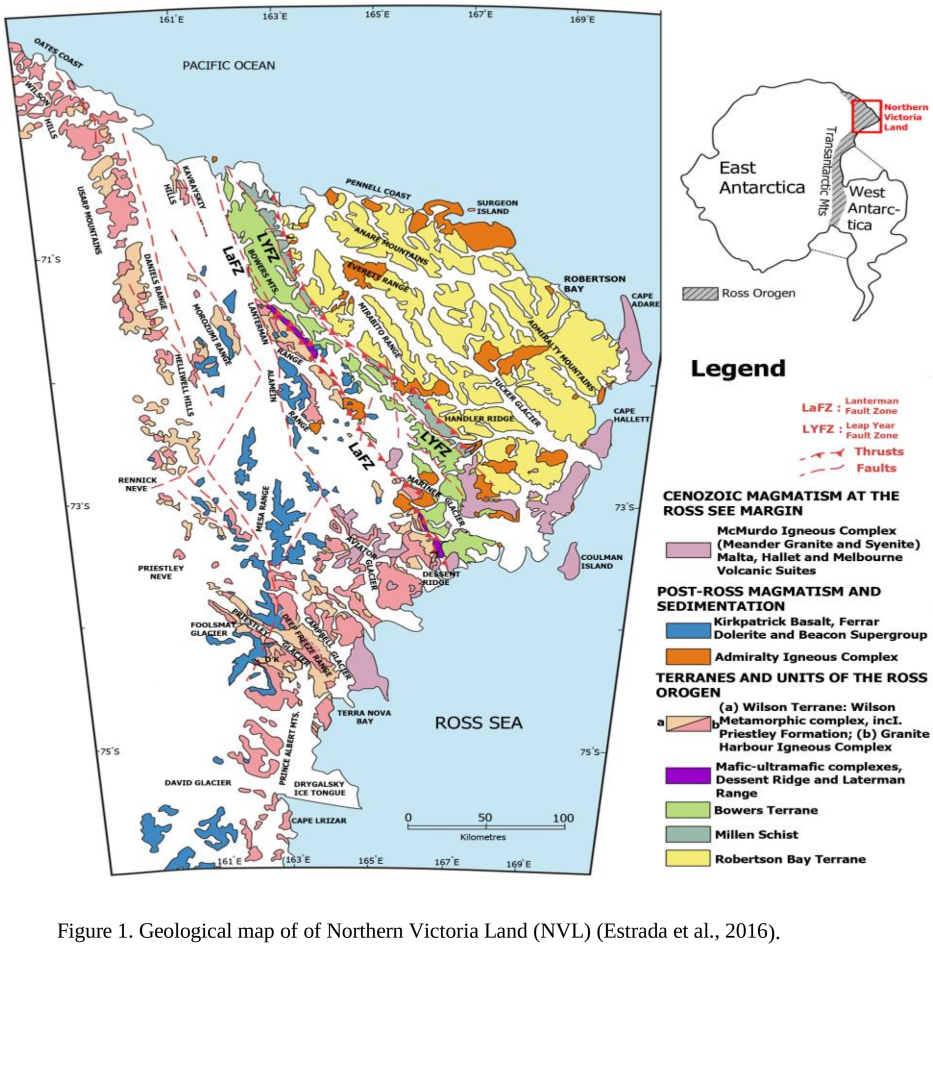

Figure 1. Geological map of of Northern Victoria Land (NVL) (Estrada et al., 2016).

2.2 Remote sensing data

In this study, seven Landsat-8 level 1T (terrain corrected) images covering the NVL were obtained through the U.S. Geological Survey Earth Resources Observation and Science Center (EROS) (http://earthexplorer.usgs.gov). Seven ASTER level 1T (Precision Terrain Corrected Registered At-Sensor Radiance) scenes covering the northern and central parts of the Bowers terrane and surrounding areas were obtained from U.S. Geological EROS (http://glovis.usgs.gov/). The Landsat-8 and ASTER datasets were processed using the ENVI (Environment for Visualizing Images) version 5.2 and Arc GIS version 10.3 software packages.

2.3 Data analysis

In this analysis, the atmospheric correction was applied to Landsat-8 scenes using Fast Line-of-sight Atmospheric Analysis of Spectral Hypercube (FLAASH) algorithm (Cooley et al., 2002). The FLAASH algorithm was implemented using the Sub-Arctic Summer (SAS) atmospheric and the Maritime aerosol models. During the atmospheric correction, raw radiance data from imaging spectrometer is re-scaled to reflectance data. Crosstalk correction was performed to the ASTER SWIR bands, aimed at removing the effects of energy overspill from band 4 into bands 5 and 9 (Iwasaki and Tonooka, 2005; Mars and Rowan, 2010). FLAASH atmospheric correction algorithm (Cooley et al., 2002) was applied to the VNIR and SWIR bands of the ASTER. In this study, several new band ratio indices were developed and implemented to Landsat-8 and ASTER spectral bands for mapping poorly exposed lithological units, geological structures and alteration mineral assemblages in Antarctic environments. New spectral-band ratio indices were calculated to map spectral signatures of snow/ice, iron oxide/hydroxide minerals, Al-OH-bearing and Fe, Mg-O-H and CO3 mineral zones, and quartz-rich felsic and mafic-to-ultramafic lithological units at regional scale.

3. RESULTS AND DISCUSSION

A full view of the NVL at regional scale was produced using Landsat-8 image mosaic map assigned to the NDSI (Fig. 2). In this analysis, for the Landsat-8 and ASTER surface reflectance data, the Normalised Difference Snow Index (NDSI) was calculated as the following band ratios.

NDSI for Landsat-8 = (band 3 - band 6) / (band 3 + band 6) (1)
NDSI for ASTER = (band 1 - band 4) / (band 1 + band 4) (2)

Glacier ice and snow appears with the hue of silver (high NDSI value) and poorly exposed lithologies as dark pixels (very low NDSI value) in the image map (Fig. 2). The geomorphological framework and geological structural features of the WT, BT and RBT are represented in Landsat-8 image mosaic map. Surface roughness and linear structural features related to litho-tectonic blocks especially in the boundary between terranes are recognizable (see Fig. 2). The linear structures of the trans-lithospheric faults, including the LaFZ and LYFZ, are intensely observable in Figure 3. The LYFZ marks the boundary between the RBT and the BT terranes, which is characterized by a complex deformational belt. Curvilinear structures associated with Millen Schist Belt show ductile deformation activity in this zone (see Fig. 2, close to LYFZ in the BT).

Figure 3 shows ASTER NDSI image mosaic map of the BT and surrounding areas. This image mosaic map shows a full view of geological structures and exposed lithologies in the northern and central parts of the BT. Brittle and ductile deformation features are obviously distinguishable in the image map (Fig. 3). Highest curvilinear densities are concentrated in the Millen Schist Belt (north-eastern part of the image map). Ductile deformation in the Millen Schist Belt is demonstrated by several isoclinal and upright folds, which strike NE–SW. Brittle structures (faults and fractures) are governed in the Bowers Mountain and strike NW–SE (Fig. 3), which correspond to the direction of the LaFZ and LYFZ fault zones.

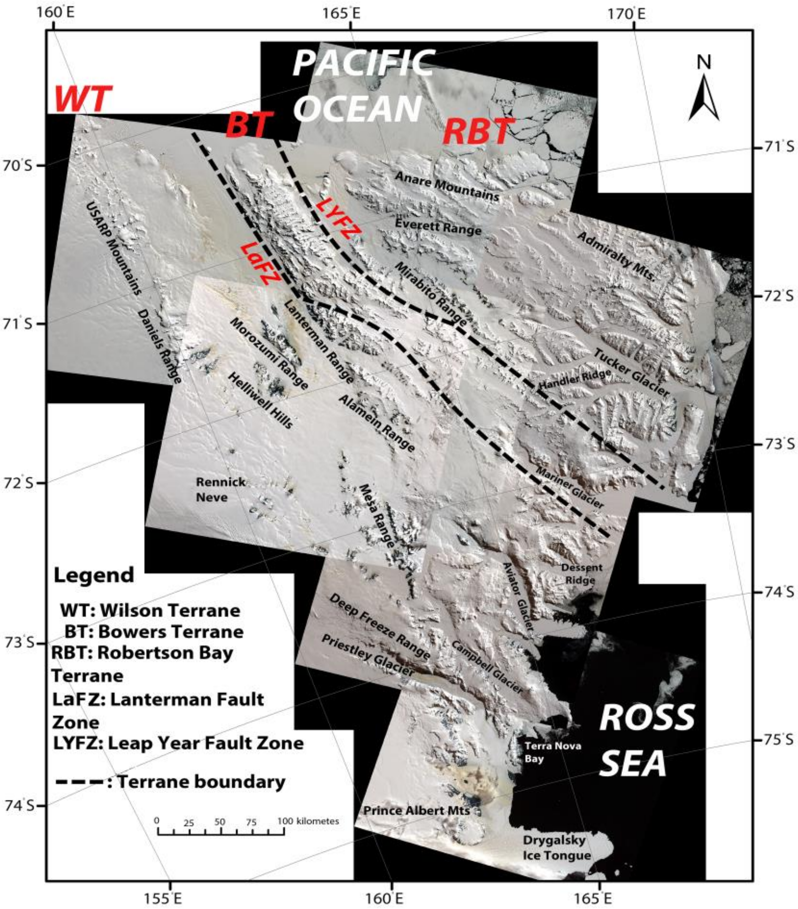

Figure 2. Landsat-8 NDSI image mosaic map for the Northern Victoria Land (NVL).

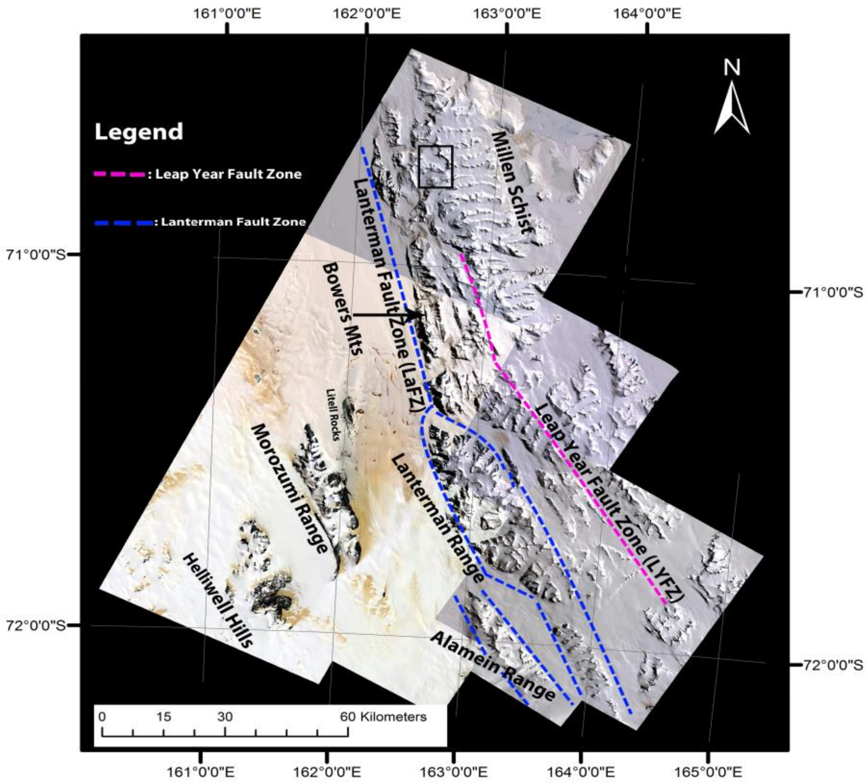

Figure 3. ASTER NDSI image mosaic map for the Bowers Terrane (BT) and surrounding areas.

The Fe-MI was applied to the Landsat-8 dataset covering the NVL. Bands 3, 4, 5 and 6 of Landsat-8 and bands 1, 2, 3 and 4 of ASTER were used for calculating Fe-minerals Index (Fe-MI).

Fe-MI for Landsat-8 = (band 6 / band 5) × (band 4 / band 3) (3)

Fe-MI for ASTER = (band 4 / band 3) × (band 2 / band 1) (4)

Figure 4 shows Landsat-8 Fe-MI image mosaic map at the regional scale. Most of the Fe-mineral abundance zones (magenta pixels) are concentrated in the WT especially in the Daniels Range, Morozumi range, Helliwell Hills, Lanterman Range, Alamein Range, Mesa Range and Prince Albert Mountains (Fig. 4). In the RBT, the rock exposures in Mirabito Range, Everett Range, Admiralty Mountains, Handler Ridge and exposed lithologies adjacent to Tucker Glacier contain Fe-mineral alteration zones. Distribution of Fe-minerals in the BT is very low and observable in some parts of the Bowers Mountains at a regional scale (see Fig. 4).

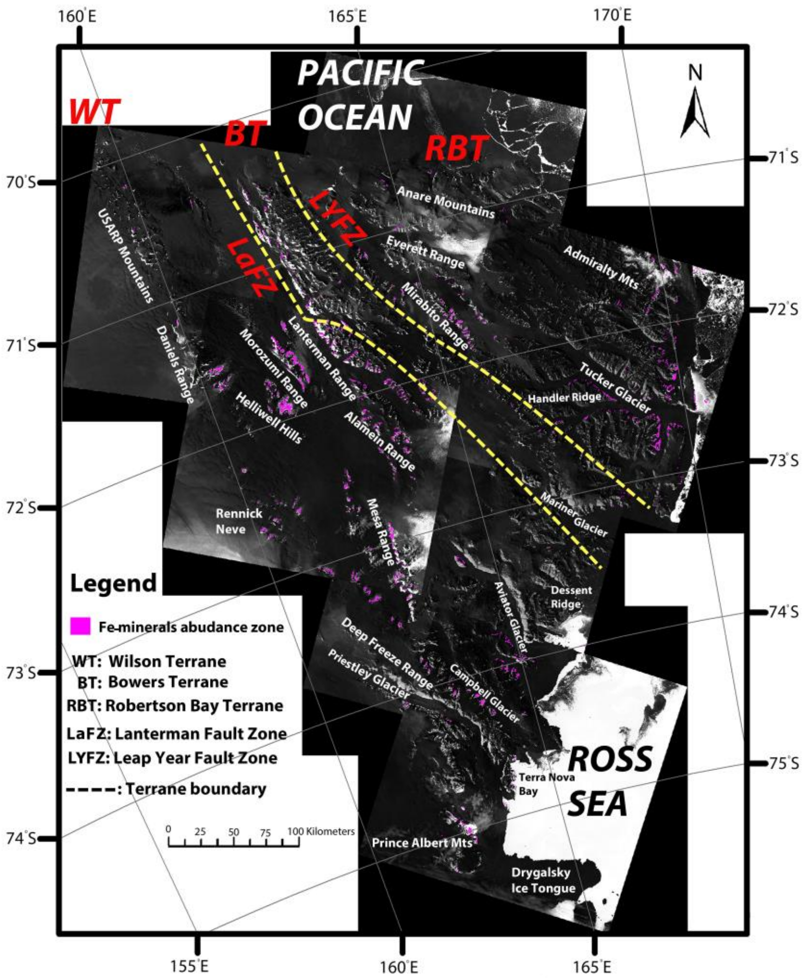

Figure 4. Landsat-8 Fe-MI image mosaic map for the Northern Victoria Land (NVL).

Figure 5 shows ASTER Fe-MI image mosaic map for the BT and surrounding areas. High Fe-mineral abundance zones (magenta pixels) are concentrated in the Morozumi range, Helliwell Hills, Litell Rocks and Lanterman Range, respectively (Fig. 5). Lithological units in these regions comprise Granite Harbour Intrusives (GHI), Wilson Terrane metamorphic complex, Kirkpatrick Basalt, Ferrar Dolerites and Beacon Supergroup. It seems that the highest surface distribution of Fe-minerals alteration zone is associated with Ferrar Dolerites and Kirkpatrick Basalt (mafic rock units), which is attributed to alteration products of primary mafic minerals within these lithological units.

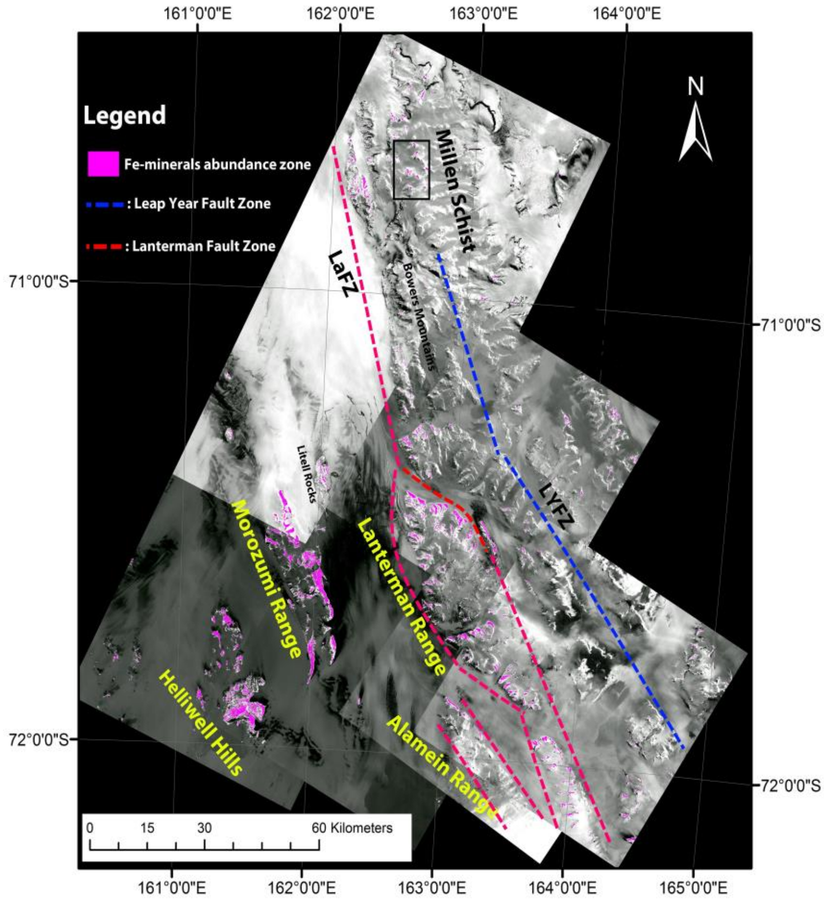

Figure 5. ASTER Fe-MI image mosaic map for the Bowers Terrane (BT) and surrounding areas.

4. CONCLUSIONS

This study used a satellite-based remote sensing approach by application of Landsat-8 and ASTER datasets for regional geological mapping and alteration mineral detection in the NVL, Antarctica. The NVL consists of three major fault-bounded tectonostratigraphic Gondwana-derived terranes, namely the WT, the BT and the RBT. Different association of ore mineral systems such as deposits of sediment-hosted/orogenic gold and granite-related minerals is discovered in collision and subduction zones of the Gondwana-derived terranes. They are associated with large-scale, terrane-bounding fault systems and broad areas of deformation. Mineralization mostly associated with structurally-controlled complex lodes, veins, sheeted veins and veinlets in diverse orientations, which are mostly associated with hydrothermal alteration zones. Satellite-based remote sensing approach could be used to detect geological structures and hydrothermal alteration zones associated with suture zones between Gondwana-derived terranes especially for large inaccessible regions where fieldwork is limited or nonexistent such in Antarctica. The proposed spectral-band ratio indices are especially useful for geological investigations in inaccessible locations and poorly exposed lithological units in Antarctica environments.

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