Research article

Identification of hydrothermal altered/weathered and clay minerals through airborne AVIRIS-NG hyperspectral data in Jahajpur, India

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Abstract

Advanced visible infrared imaging spectrometer-new generation (AVIRIS-NG) airborne Hyperspectral data has 5nm spectral resolution which allows us to identify characteristic spectral signatures of the different altered and weathered mineral assemblage. In this study Airborne AVIRIS-NG hyperspectral data were used to identify the different altered, weathered and clay group of minerals in the Jahajpur, Bhilwara, India. In the study area, different hydrothermal minerals such as Montmorillonite, Smectite and Talc were identified. Apart from this, Goethite/Limonite mineral spectral signatures were identified using the AVIRIS-NG data in the VNIR (visible and near infrared) region of the electromagnetic spectrum. Minerals thus identified were verified by the conventional geological analysis viz. petrography and XRD of the field samples collected from the study area. The results of the conventional geological methods and spectroscopy were in good confirmation with the results found through the analysis of the AVIRIS-NG data. Identified minerals show a good indication of the advance argillic alteration in the study area which stand in confirmation with the geology of the area. Spectral analysis of the AVIRIS-NG data reveals that the reflectance spectra of the airborne AVIRIS-NG Hyperspectral data found promising for mineral identification and mapping.

1. Introduction

The Ghevaria plateau region of western Jahajpur belt contains India’s largest world class Talc deposits [1]. The main minerals in the this area are Talc, Clay (Montmorillonite, Kaosmec), and iron oxides/hydroxides (Goethite and Limonite) [2, 3, 4] These minerals are deposited on along the two parallel ridge trending from Ghevaria to Jahajpur in NE-SW direction [5, 6, 7, 8] The iron ore consist of fine grained, friable, granular or platy texture [4, 5, 6, 7, 8]. Hard limonite outcrop occurs as small lenses in BIF zone embedded in dolomitic outcrops [3, 9]. Determination of zone of mineralization by conventional geology requires detection of a surface geo-chemical anomaly.

Traditional feasible study of mineral deposits is time consuming and expensive. In process of exploration of deposits take various steps and factors such as genesis, lithology, geomorphology, laboratory analyses and other related facilities. So, to minimize the cost and time, using advance techniques such as remote sensing [10] is the need of the hour. The techniques of remote sensing in field of science and technology have vital role for identification of surface features, abundance and surfacial extensions [11, 12]. Among the constraint of limited and detailed application capability of broad band remote sensing a new technique invented thirty years before in a form of hyperspectral remote sensing. Only some spectral remote sensing experts have utilized the hyperspectral remote sensing, albeit, to gather the information in the field of mineral exploration. Over the time, hyperspectral remote sensing became more mature, powerful and fastest growing technology. Hyperspectral remote sensing has sufficient potential compare to other remote sensing data on the basis of accuracy, capability and dimensionality. Since, the last three decades airborne and spaceborne hyperspectral sensors like as advanced visible infrared imaging spectrometer (AVIRIS), airborne imaging spectrometer (AIS), Hyperspectral Digital Imagery Collection Experiment (HYDICE), Hyperspectral Mapper (HYMAP), digital airborne imaging spectrometer (DAIS) and HYPERION respectively have been used for Geological, mineral identification, lithological discrimination and mapping [13, 14, 15]. Over the decades, airborne hyperspectral remote sensing has come up with much more capability in earth surface and atmosphere. The spectral range of 0.35μm to 2.5μm is most suitable for detection of spectral features of atmospheric gases, rocks, vegetation, minerals and soils. These spectroscopic detection are based on electronic

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https://doi.org/10.1016/j.heliyon.2020.e03487
Received 1 January 2019; Received in revised form 2 May 2019; Accepted 21 February 2020
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transitions, fundamental, overtone and combination bands of vibrational absorptions [16, 17, 18].

The 0.35μm to 2.5μm spectral range is dominated by reflected sun light and is well suited for detecting the spectral features related to electronic transitions [19, 20, 21](e.g., iron oxides), harmonics and vibrational absorptions due to combination bands [22, 23] (e.g., OH, SO₄, CO₃, CH₄ etc.) [24, 25, 26, 27, 28, 29] in minerals, soils, vegetation, and the atmosphere. Particularly hyperspectral image are very effective in mapping of alteration mineral and lithological variations [14, 26, 30, 31, 32].

To evaluate the success of airborne hyperspectral remote sensing in a joint programme of ISRO-NASA have made flight to capture image using AVIRIS-NG hyperspectral sensors for mineral mapping on February 6, 2016 in various locations of Jahajpur region of Bhilwara district, Rajasthan, India [33, 34, 35].

AVIRIS-NG hyperspectral sensor measures reflected electromagnetic radiation in 425–427 bands covering VNIR-SWIR. AVIRIS-NG have better spatial (8.1 meter) and spectral (5 nm) resolution including enhanced capabilities and free from spectral (smile/spikes) and spatial (keystone) distortion [34, 36, 37]. Significance of the AVIRIS-NG is that i) combination of large image swath, ii) fine spatial resolution, (iii) permit direct attribution of reflection of particular location and iv) higher sensitivity due to improved signal to noise ratio and 5 nm spectral resolution [38].

Aim of this research work to identify and discriminate the surface minerals such as mica, clay group of minerals (Kaolinite, Montmorillonite, Talc, and Kaosmec), iron oxides/hydroxides (Goethite/Limonite, Hematite and Magnetite), carbonate minerals (Calcite, Dolomite), sulphate minerals (Alunite, Jarosite) and Silica minerals (Quartz). Mapping of all above group of minerals allows identification of understand the different alteration facies. AVIRIS-NG hyperspectral data used for discrimination and mapping of minerals which contain Fe³⁺, Al- O/ OH, Mg-O/ OH, CO₃⁻, and SO₄⁻ [11], [24,25,26,27], [39], [40]. Kaolinite, Alunite are most common minerals for advanced argillic alteration and Montmorillonite, Kaosmec defines argillic alteration process, among others [41, 42].

2. Data and methodology

The AVIRIS-NG (Airborne Visible/Infrared Imaging Spectrometer) is a push-broom imaging spectrometer which includes 598 across track elements of 1 mrad instaneous field of view (IFOV). The measurement of AVIRIS-NG is associated with nadir looking on ground and with readout rate of 100 Hz across 425-427 bands in range of 0.38 μm to 2.51 μm [36]. The measurement of radiance at the sampling rate of 5 nm with 6nm FWHM approximately [37]. The design of new class of imaging spectrometers of AVIRIS-NG is based on the design of AVIRIS with some modifications and enhancements. AVIRIS measures solar irradiance with scanning mechanism of whisk-broom in across track elements with 224 bands of 10 nm spectral resolution. The AVIRIS-NG data is free from smile/spikes and keystoner error and have high signal to noise (S/N) ratio which helps to identify alteration minerals in the area of the western Jahajpur belt of Bhilwara district, Rajasthan. The S/N ratio (precision) and accuracy is better in AVIRIS-NG (Specification of AVIRIS-NG [32, 33, 34, 36, 37, 38, 43]) compared to AVIRIS [38]. The specification details of AVIRIS-NG have shown in below Table 1.

AVIRIS-NG is a hyperspectral imaging spectrometer with 427 contiguous spaced 5nm bands from 0.38 to 2.51μm and 8.1m spatial resolution; [34, 36, 37, 38]. In this study, assessment and ability of AVIRIS-NG data was done through mapping of different assemblages of minerals their association with meta-sedimentary, metamorphic and igneous suites. Identification and verification of remote sensing data adopted two method i.e. visual/digital Interpretation of image and field samples spectra [44, 45] which were compared with USGS spectral library and evaluation of sensor capability through spectroscopic and conventional geological analyses for mineral identification. The spectral feature extraction was implemented before visual interpretation of image preceded by preprocessing and determination of mineral identification. To achieve accurate and reliable information from target, complete removal of distortions in the image was required. Hence, topographic and atmospheric corrections were applied.

In the process of image processing parameter shown in Table 1 used as input parameters for FLAASH (atmospheric correction using Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes). To identify diagnostic and discriminative spectral response of minerals in alteration zone radiance was corrected to absolute reflectance. In next step, dark subtract method was used to remove negative values of reflectance in image. In this study, assessment and ability of AVIRIS-NG data were identified through mapping of different assemblages of minerals their association with meta-sedimentary, metamorphic and igneous rocks. The identified spectra of minerals verified through field sample spectroscopy, petrography and XRD analyses. At the time of field investigation 24 samples were collected. The measurement of collected samples was done by spectroradiometer in laboratory environment.

### Table 1. Specification of AVIRIS-NG

| Spectral | Spatial |
|----------|---------|
| Range | 380 to 2510 nm | Range | 34° Field of view |
| Position | 5 nm | Sampling | 1 mrad |
| Response | Response 1 to 1.5 × sampling | Response | 1 to 1.3 × sampling |
| Calibration | ±0.3 nm | Sample Distance | 0.3 m to 20 m |
| Radiometric | Geo. Model | Full 3 Axes cosines |
| Range | 0 to max Lambertian | Uniformity |
| Precision (SNR) | N2000 @ 600 nm N800 @ 2200 | Spectral cross track | N95% Across FOV |
| Accuracy | 95% | Spectral IFOV variation | N95% Spectral direction |
| Sensor Altitude | 4.8 km | Spectral Range | 380 nm to 2510 nm |
| Spatial Resolution | 8.1 m | Spectral Coverage | Continuous |
| Swath Width | 1.9–11 km (Low–High altitude) | Spectral Resolution | 5nm ± 0.5 nm |
| VNIR Range | 400nm–1000nm | SWIR range | 900nm–2510nm |
| IFOV (mrad) | 1.0 mrad | Total number of bands | 425 |
| Site Name: | Jahajpur, India | Comments: Alt | 27.44 kft |
| FLIGHT NAME: | ang20160204070941 | SOG – 221 kts | Clouds – Clear |
| Investigator: | ISRO | Solar Azimuth: | 41.92 |
| MCRS | 46.3 | Solar Elevation: | 178.75 |
| Date: | 2/4/2016 UTC 15:41 | Rotation: | -45 |
3. Geology of the study area

The Jahajpur region of Bhilwara district is a city and municipality located at 25.62°N 75.28°E with an average elevation of 334 meters above mean sea level. Here Chainpura, Madhopura, Abhaypura, Ghevaria, Omkarpura, Itwa, Pachanpura; Chhabadiya locations were selected for mineral identification for field visit. All these locations lie at a distance between 12 to 80 kilometers from Jahajpur tehsil across the river Banas in the direction of east and south east.

The NW Indian shield have an Archean basement [6, 46, 47]. Bhilwara Gneissic complex is the oldest cratonic nucleus of NW Indian shield and forming Proterozoic super crustal covering basement to all. Successive deposition of Aravali (Paleoproterozoic) and Delhi (Meso-Neoproterozoic) supracrustals over this Archean basement is common [6, 47]. Delhi and Aravali Supergroup have highly tectonized contact at places causing boundary problems. The NE trending fringe of Aravali fold belt has been designated as the Jahajpur belt [6, 46, 48]. Jahajpur Belt is known as fringe of Precambrian of southeastern Aravali fold. According to [6], Great Boundary Fault tectonically limit the Jahajpur belt which is in the east, juxtaposed with well preserved western sedimentary sequence of Vindhyan Super Group [6]. Hindoli group and Magalwar Complex delimited our study area in the east and west respectively [49]. Hindoli (Late Archean/Paleoproterozoic) and Jahajpur (Paleoproterozoic) Groups both are included with two meta sedimentary litho-packages belonging to green schist facies [6]. The main rocks of Jahajpur Group are dolomites, quartzites and phyllites, associated with polyphase deformation because of compressional orogeny. The chronological age of these rocks is around 1.5 Ga [6, 46, 48]. Jahajpur belt is controlled in NE-SW trending tectonic trough. The Banas river channels associated with choking/disorganization during Neogene tectonic movements [49]. There is Quaternary sedimentation in the Jahajpur basin. A linear alluvial valley formed by two troughs in the western Jahajpur basin [50, 51]. The lithological map of the study area has shown in above (Figure 1).

4. Spectral characterization of minerals

The mineral map shows only Hematite and Goethite to mostly occupy the deforested open pit mines area. The absorption at 0.63–0.71 μm and 0.85–1.00 μm in Limonite/Goethite and hematite by crystal field and by charge transfer absorption at 0.48 μm and 0.55 μm respectively [19, 20]. According to [21, 42], amorphous and hydrous equivalents (Limonite) of Goethite and Hematite and ferric hydroxide minerals have strong absorption in VNIR due to crystal field at 0.87 μm for Hematite and 0.93 μm for Goethite [21, 42]. Abundance of iron oxide (hydro) directly related to depth of absorption and shape, particle size and physicochemical property influence on spectral absorption [19, 20, 52]. Goethite and Hematite have most notable change through decreasing particle size and overall increase in reflectance [21, 53]. The minerals which identified in hyperspectral image are Talc, Montmorillonite, Kaosmec which have strong absorption features at 2.2 μm [54, 55] and weaker absorption at 1.33–1.41 μm, while the stronger absorption at 1.80–1.93 μm band in montmorillonite is affected by bound water molecules in the hydrous clay. The diagnostic absorption features of clay (Smectite, Illite, Kaolinite and Montmorillonite) minerals can be identified spectroscopically in spectral range of 2.0–2.5 μm on the basis of their characteristic H₂O and OH absorption because of overtone combination [22, 55, 56]. According to [22, 57] in SWIR of EMR region, reflectance spectra of minerals determined through water and hydroxyl, carbonate and sulphate. Generally hydroxyl is bound to Mg or Al and Al–OH, which produce the absorption features of clay minerals near 2.2 μm [22]. The absorption near 2.3 μm due to Mg-OH in clay minerals. Clay minerals absorption peak around 2.2 μm due to the combination of OH stretch and Al-OH bending modes [58, 59]. According to [60] absorption features near 2.2 μm to 2.3 μm are diagnostic for all clay group minerals because of the combination of cations –OH bend plus OH stretch [60]. Due bound water in the sample, strong absorption band at 1.9 μm is also apparent.

Figure 1. Geological map of the western Jahajpur belt.

LITHOLOGICAL MAP OF THE WESTERN JAHAJPUR BELT BHILWARA

LELAND

Rock_Type

Berach Granites
Conglomerate/ Gritty Quartzite
Dolomite
Dolomite with BIF
Garnet bearing quartz-mica schist
Grey Phyllite
Meta Greywacke
Quartzite

Figure 1. Geological map of the western Jahajpur belt.
Figure 2. Identified minerals spectra through AVIRIS-NG image.
5. Result

5.1. The AVIRIS-NG spectra of minerals

Each and every feature of earth surface including minerals have reflected characteristic pattern denoted as spectral response curve in electromagnetic spectrum. Differentiation of minerals in electromagnetic spectrum through filtering of reflected light to a specific wavelength. These spectral response curve depend upon variety of absorption processes, dependency of wavelength, profile of shape, and mean reflectance intensity [10, 61].

After preprocessing and atmospheric correction, AVIRIS-NG hyperspectral remote sensing data analyzed for mineral identification (Figure 2). The mineral identification is based on absorption and reflectance features in SWIR and VNIR region of EMR respectively. To understand actual and accurate position of absorption features of
minerals, resampled USGS spectral library spectra were matched with the AVIRIS-NG extracted spectra of minerals. Near the Ghevaria village, occurrence of talc mineral reflecting absorption features at 2.31 μm with presence of doublet at 2.28 μm (Figure 3). In this study in village of Omkarpura Limonite, Montmorillonite also reflecting absorption features at 0.54, 0.92 and 2.20 μm (Figure 4), respectively.

5.2. Spectral features of the minerals

The evaluation, interpretation, and mineral analysis of image spectra completed along with field spectra which measured by field ASD spectroradiometer from field samples of the study area corresponding to USGS library spectra.

To generate laboratory or field sample (mineral) spectra of minerals the ASD FieldSpec 4 version of ASD Spectroradiometer applied for measurement with specifications of fastest, accuracy, portability in full range of 0.35–2.50 μm of electromagnetic spectrum. It provides uniform data collection in UV/VIS/NIR/ SWIR region. The sample measurement in SWIR region are available in 6nm, 8nm, 10nm and 30 nm [11, 62].

The Talc minerals are identified in image through image spectra in the location of Ghevaria, Pachanapura, Chainpura, Chhabadiya area of

![Figure 6](image1.png)

**Figure 6.** Matching of Kaosmec from image spectra, field sample spectra w.r.to USGS spectra (Rampura old clay mines near Ghevaria talc mines).

![Figure 7](image2.png)

**Figure 7.** X-ray diffraction analysis of Talc minerals in study area (Ghevaria).

![Figure 8](image3.png)

**Figure 8.** X-ray diffraction analysis of Clay minerals in study area (Omkarpura).
Jahajpur, which is differentiated on the basis of different diagnostic absorption features.

In the Ghevaria area the Talc minerals interpreted through image spectra, which have shown distinct absorption features are at 2.31 μm with doublet at 2.28 μm due to vibrational absorption features of Mg-OH. Sharp absorption features at 1.33–1.41 μm and 1.80–1.94 μm due to the OH⁻ stretching and H-O-H overtones respectively. Due to the combination of dolomite and overtones bands of CO₃ have shown absorption found at 2.0 μm and 2.37 μm-2.38 μm. Four weaker absorption presents at 0.46 μm, 0.57 μm, 0.93 μm and 1.14 μm due to presence of Fe³⁺, O₃ and H₂O respectively in the VNIR region of EMR spectrum (Figure 3).

The Limonite (Fe³⁺O(OH).nH₂O minerals identified in field and imagery in Omkarpura, Itwa, Bhainroo Khera and Meera Nagar and differentiated on diagnostic absorption features. The Limonite minerals found in study area in dolomitic rocks which is a hydrothermal alteration product associated with mineralization of base metal. Distinct electronic absorption features in image spectra at 0.54, 0.92 was found for Limonite [11, 42]. Due to presence of OH⁻, absorptions near 1.33 μm to 1.41 μm and 1.80 μm to 1.93 μm occur. Some minor absorption features are at 0.41 μm, 0.51 μm, 0.62 μm, 0.67 μm, 0.69 μm due to O₂, 0.75 μm due to O₂, 1.14 μm due to H₂O, some absorption due to presence of Al-OH at 2.20 μm [21, 42, 65] (Figure 5).

The Montmorillonite minerals interpreted through field and image spectra in Itwa and Omkarpura on the basis of distinct absorption features at 2.2 μm [54, 55, 58, 59] due to presence of Al-OH and OH⁻ and H-O-H absorption (bound molecules) 1.3–1.4 μm (weaker) and 1.80–1.93 μm (strong) [66] (Figure 4). Some minor absorption features

![Figure 9. X-ray diffraction analysis of iron oxides minerals in study area (Omkarpura).](image)

![Figure 10. X-ray diffraction analysis of clay minerals (Rampura).](image)

Table 2. The list of identified minerals through XRD.

| Sr. No. | Location       | d-spacing [Å]                                                                 | Inferred Mineral              |
|---------|----------------|-------------------------------------------------------------------------------|-------------------------------|
| 1       | Gheoriya       | 9.12369, 8.84476, 3.06                                                         | Talc                          |
| 2       | Omkarpura      | 9.54274, 9.127                                                                 | Montmorillonite               |
| 3       | Omkarpura      | 4.17414, 2.66125, 2.43532, 2.21752, 1.70579                                    | Goethite                      |
| 4       | Rampura (Near Gheoriya) | 9.78056, 6.93169, 4.36314, 4.21236, 4.18245, 3.81571, 3.55622, 3.34116, 3.31522 | Kao-smectite                  |
are also detected in image spectra such as 0.92 μm, 1.14 μm due to H2O, 0.76 μm due to O2, 0.57 μm due to O3, 0.47 μm, and 0.51 μm due to Fe3⁺.

The Kaomc minerals interpreted through field and image spectra in Rampur old mines area near Ghevaria village on the basis of distinct absorption features at 2.2 μm and 2.1 μm due to Al-OH, due to OH⁻ and H-O-H absorption at 1.3–1.4 μm (Strong bond water molecule) and 1.8–1.9 μm (weaker bond water molecule) respectively [66](Figure 6). In field sample spectra absorption due to presence of Al-OH at 2.2 μm and 2.1 μm. Due to OH⁻ and H-O-H absorption at 1.4 μm and 1.9 μm respectively (Figure 6).
In field (Spectroscopy) spectra major absorption due to Al-OH at 2.20 μm, OH⁻ and H-O-H at 1.41 μm and 1.92 μm respectively (Figure 6) [59, 67].

5.3. XRD analysis of the minerals

To confirm the minerals X-ray powder diffraction (XRD) method was used. For XRD mineralogical verification dry powder method at less than 200 microns size fraction was used [68].

The chemical information about crystallography, thus obtained, is versatile and non-destructive. The XRD analysis providing phase analysis of different materials. Multipurpose High Resolution X-ray Diffractometer of “Panalytical Xpert PRO MRD XRD”, which is a diffractometer for thin films (for single crystals and polycrystalline (diffraction & XRR)) from RT to 900 °C and measurement from powders. The function of XRD method works simultaneously such as data collection of new sample and analysis of previous sample by instrument control of function of computer which is associated with dual monitor. This whole setup is divided in three segment of instrument action it should be i.e.: 1) Data controller 2) High score plus 3) Data viewer. The data controller operates the control of instrument and collection of data. The high score plus operates data visualization and analysis. The data viewer operates data visualization and presentation [69].

Figures 7, 8, 9, and 10 have shown characteristic curve of different varieties of clay and iron oxides and hydroxides minerals which associated values are listed in Table 2. The 20 range of measurement for clay and talc are 5°-30° and for iron oxides/hydroxides: 5°-80°. The measurement for XRD analysis of all respected minerals run on step size of 0.02° within step time of 0.05/second.

6. Discussion

6.1. Mineralization

In the field investigation, physical characteristics of minerals and rocks revealed that there is stain of iron oxide on rocks and the top of the mountains and surface is indicating the alterations. These alterations occur due to alternating redox potentials at the time of weathering (Figure 11 A, B, E & G). Near Omkarpura and Itwa village, some gossanized outcrops are identified in dolomitic quartzite along the ridge which is trending NW-SE across the river Banas in southern zone. The limonite deposits of banded iron patches exposed in Dolomite with Quartz and Clay. The BIF zone is highly oxidized with limonite characterized by botryoidal structure, flow accumulation, yellowish red and orange color in presence of water with Clay (white color) pocket (Figure 11 G & H). The outcrops are highly resistive to erosion and according to appearance of structure and physical property and dominance of Fe content rich minerals (Figure 11 G & H). Figure 11 F shows clay pockets which are intercalated with some small patches of Goethite. Surrounding these outcrops, some clay and talc lenses are reported in the study area. The occurrence of Talc deposit is found confined to Dolomitic Limestone/Quartzite along the ridge from Gheveria to Jahajpur in form of veins and lenticular pockets with varying dimensions. On ground, the surface color is stained to yellow and red but with increasing depth, color changes to snow-white. The Limonite and Clay alteration can be also seen near Omkarpura village mines (Figure 11 G & H).

6.2. Alteration

According to [22] alteration phases can be interpreted as a function of variation in shape and wavelength position of Al-OH [22]. Presence of Montmorillonite indicates the Al-OH absorption at short wavelength where relative high alteration (low temperature argillic alteration phases). Argillic alteration phases are confined to intermediate wavelength Al-O/H absorption by minerals such as Kaolinite-Smectite and potassic alteration phase dominated by Montmorillonite. According to [24], around 2.30–2.35 μm range, Carbonate show the absorption, where pure dolomite and calcite and show absorption at 2.30 μm and 2.35 μm respectively. In same way Pyrophyllite (at 2.32 μm), Epidote (at 2.33 μm), Talc (at 2.30 μm), Chlorite (at 2.32 μm) show absorption [24] with three weaker bands occur near 2.12–2.16 μm, 1.85–1.87 μm and 1.97–2.00 μm. These types of alteration phases are indicative for propylitic alteration phases. Pyrophyllite alteration also followed advanced argillic alteration. The rocks and mineral alteration near Omkarpura and Ghevaria open pit mines area defines the indication of increase E and increase rate of common silicate weathering and leaching of huge amount of silica which influence typical gossans mineralogy with predominance of Goethite/Limonite [11, 67, 70]. The BIF zones of hematite/magnetite are associated with Dolomite quartzite outcrop. Weathering and erosion process involved in BIF zone of Hema tite/Magnetite and altered to Limonite [71]. Limonitization with clay deposits is result of increase in acidity and increase the rate of weathering of silicate minerals. The alterations in near Itwa, Ghevaria, Omkarpura, and Rampura, Talc and clay deposits are result of increasing acidity and increasing rate of silification and selective Dolomite weathering. Dolomite alteration has taken place in presence of water and gave rise to Talc, Calcite and release of carbon dioxide.

The indicator minerals of phyllic, propylitic, argillic, advance argillic and gossans are Talc, Montmorillonite, Kaosmec and Limonite/Goethite/Hematite among others [42]. The ore body is surrounded wall rock metasomatism in association of argillic-phyllic circular zonation pattern outwardly [42]. Within argillic alteration, supergene alteration processes identified near Omkarpura produces Limonite, Goethite mineral or deposits under oxidation and reduction environment resulting in formation of oxide-rich zone which are yellowish to reddish brown colored altered rocks known as “Gossans” [71, 72]. The phyllic zone of alteration facies can be distinguished through presence of Muscovite and argillic alteration facies zone by Kaolinite and/or Dickite [42].

7. Conclusion

The application of AVIRIS-NG airborne hyperspectral remote sensing data has shown proficient and robust capability for differentiation and identification of hydrothermal altered minerals and minerals which are generated through process of weathering in phyllite, banded iron formation, quartzite and talcosite dolomite of Gheveria, Omkarpura and Itwa village of southern ridge part of western Jahajpur belt across and along the Banas river. The higher spatial, spectral resolution including capability of higher signal to noise ratio of AVIRIS NG hyperspectral remote sensing data enhanced the minute variations in absorption and reflectance response curve precisely and accurately which helped in identification of various alteration and weathered rocks and minerals. These results are the demonstration of the usefulness, proficiency, accuracy of AVIRIS-NG hyperspectral data and capability of methods involving remote identification of minerals. The observed results of AVIRIS NG hyperspectral remote sensing data verified and validated through field investigation, laboratory analyses such as spectroscopy and XRD analyses. The integration of conventional analysis method and advanced method of hyperspectral remote sensing techniques were found suitable for this study. AVIRIS NG hyperspectral remote sensing data are thus found to be most suitable for mineral identification, mapping, facies alteration and weathering of rocks.

Declarations

**Author contribution statement**

M. K. Tripathi: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.
H. Govil: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

S. L. Chattoraj: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement
This work was supported by Space Application Centre, Indian Space Research Organization India (EPS/A/4.2/2017).

Competing interest statement
The authors declare no conflict of interest.

Additional information
No additional information is available for this paper.

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