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Spectroscopic Study of Hydrous Magnesium Minerals (Serpentine) from Ultramafic Rocks along the Rikhabhdev Lineament, Rajasthan, India

Renu Chauhan*and Ronak Jain

School of Earth Sciences, Banasthali Vidyapith, Banasthali-304022, Rajasthan, India

Abstract:

Serpentine minerals, typically formed through the hydrothermal alteration of ultramafic rocks such as dunite, are commonly found in mid-ocean ridge environments and in ophiolitic complexes that have been uplifted onto continental crust, such as those present in mountain belts. This study focuses on the identification and characterization of serpentine and associated alteration products within the Rikhabdev ultramafic suite, located along the Rikhabdev lineament in the Aravalli Mountain Range, Rajasthan, India. The spectroscopic approach proves to be a powerful non-destructive tool for mineral mapping and enhances our understanding of alteration processes in ultramafic terrains. Spectral signatures of key minerals,including lizardite, chrysotile, antigorite, talc, tremolite, and dolomite,were collected and analyzed with the help of field-based reflectance spectroscopy. These spectral features were then compared with USGS reference spectra to confirm mineral identification. Serpentine has a characteristic absorption depth at 2.3µm. At the same time, other alteration products also have nearly similar wavelengths, but there is a differenceof nanometers that has been assessed through a spectroradiometer. So, this technique has the potential to detect the various serpentine minerals and alteration products. The presence of serpentine also has implications for methane release, contributing to broader geobiological and geochemical interpretations.

Keywords: *Serpentine, Reflectance Spectroscopy, Alteration Minerals, Non-destructive Analysis*

1. Introduction:

In the region encompassing and surrounding the study area, serpentine-group minerals, which are hydrous magnesium silicates, are found extensively within ultramafic rock types belonging to the Aravalli Supergroup. These ultramafic rocks predominantly occur in the form of serpentinite, and also include theirmetamorphosed derivatives such as talc-carbonate rocks**,** talc schist, and dolomite. Among the serpentine minerals present**,** lizardite andantigoriteare the most abundant, forming the principal component of massive serpentinites**.** In addition to antigorite, a smaller quantity of chrysotile is also observed.

Within serpentinites that have undergone alteration**,** carbonates (such as dolomite or magnesite) and talc tend to become the dominant mineral phases. These are often accompanied by minor but noteworthy occurrences of minerals such as chlorite**,** tremolite, and occasionally others, indicating low-grade metamorphismandhydrothermal alteration processes(Behera,2007).

Field observations in the study area reveal that the serpentinite rocks are generally fine- to medium-grained**,** hard**,** and compact**,** and occur as massive bodies often showing distinct jointing patterns. The rocks display a wide range of green hues, from light to dark shades, which is typical of serpentinizedultramafics. Additionally, magnetite crystals are frequently seen disseminated throughout the serpentinites, reflecting magmatic and alteration processes that enriched the rock in iron. The presence of ferruginous (iron-rich) material within the serpentine further supports the influence of hydrothermal fluids and alteration during or after the serpentinization process.

These rocks have undergone extensive hydration and alteration, forming mineral assemblages that are also observed on Mar**s**, particularly in the Nili Fossae region, as detected by instruments like MRO-CRISM and Mars Express-OMEGA (Ehlmann et al., 2010; Mustard et al., 2008).

Due to the clear and varied exposure of ultramafic rocks and their altered equivalents, the study area offers an excellent natural laboratory to investigate the spectral characteristics of hydrous magnesium silicates and other alteration minerals. These studies have important implications not only for understanding serpentinization processes on Earth but also for interpreting hyperspectral remote sensingdata for planetary.

This study investigates the formation of serpentine and associated alteration minerals through the process of serpentinization, employing a non-destructive, ASD FieldSpecspectroradiometer. The objective is to systematically assess its capability for high-resolution mineralogical detection and characterization in natural settings.

2. Study Area:

The study area is situated in and around Rikhabdev**,** in the southern part of Rajasthan, India (Fig. 1), and forms an integral part of the Aravalli Supergroup, one of the oldest Proterozoic mobile belts in the Indian shield (Ramakrishnan et al., 2008; Roy & Jakhar, 2002). Geographically, it falls within the Udaipur district and lies near the Rikhabdev Lineament, a prominent structural feature that demarcates the transition between different litho-tectonic units of the Aravalli terrain (Bakliwal& Ramasamy, 1987).

This region is characterized by the presence of ultramafic rocks, such as serpentinite, which occur as small lenses or elongated bodies within the metasedimentary and metavolcanic sequences. These ultramafics are considered remnants of ancient oceanic lithosphere and are thought to have been emplaced during Proterozoic tectonic events, most likely related to ophiolitic emplacement and subduction-related processes (Dilek & Furnes, 2011).

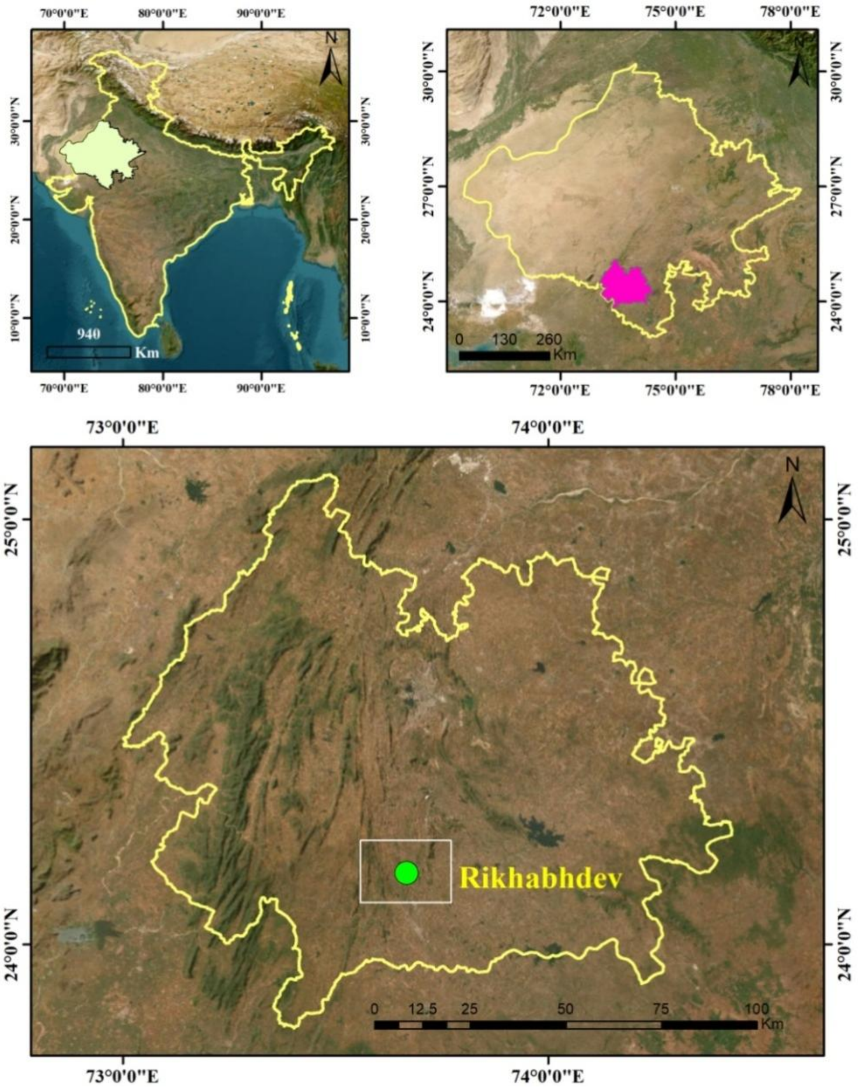

Fig. 1: Location Map of Study Area

The serpentinized ultramafic rocks in the Rikhabdev area consist mainly of antigorite, with minor amounts of chrysotileandlizardite, which differ in their physical appearance and structure,and accessory minerals like talc, carbonates, chlorite, and magnetite (Abu-Hamatteh, 2002). Chrysotile is characterized by its fibrous and silky texture, often associated with asbestos-type minerals. Lizardite is typically found as a massive, compact, and greenish variety of serpentine, while antigoritetends to form curved, fibrous, or platy crystals, and is more stable under higher temperature and pressure conditions (Brindley & Wan, 1975).

3. Methodology:

In the Rikhabdev region of Rajasthan, India, reflectance spectra were collected for several hydrous magnesium-bearing minerals. These include different types of serpentines (like antigorite, chrysotile, and lizardite) as well as other sheet silicate minerals such as chlorite and talc.

The present study employs an integrated approach using field-based reflectance spectroscopy and spectral library comparison to identify and characterize ultramafic minerals from the Rikhabdev ultramafic suite in the Aravalli Mountain Range, Rajasthan. The methodology includes the following steps:

Field Sample Collection:Representative rock samples were collected from various locations across the Rikhabdev ultramafic suite. The area is known for the occurrence of serpentinized peridotites, talc-carbonate rocks, and associated ultramafic lithologies.

Spectral Measurements: An ASD FieldSpec® spectroradiometer was used to acquire high-resolution reflectance spectra in the visible to shortwave infrared (VNIR-SWIR) region (350–2500nm). Spectral measurements were taken under controlled lighting conditions to minimize noise and ensure accurate spectral capture of mineral surfaces.

Spectral Processing and Analysis:The acquired spectra were processed to correct for noise, baseline shifts, and atmospheric effects. Spectral features, including absorption band position, depth, and width, were analyzed to identify diagnostic spectral characteristics of minerals.

Spectral Comparison with USGS Library:The processed spectra were compared with reference spectra from the USGS Spectral Library. Minerals such as lizardite, chrysotile, antigorite, talc, tremolite, and dolomite were identified based on close matching of absorption features, particularly in the 2200–2500nm regions.

Interpretation and Validation:The spectral data were interpreted in the context of ultramafic rock alteration processes such as serpentinization and carbonation. Mineral identification was further cross-verified with known mineralogical associations in similar geological settings. Where available, secondary geochemical data (e.g., XRD, XRF, SEM) from literature were used to support spectral interpretations.This method provides a rapid, non-destructive, and accurate

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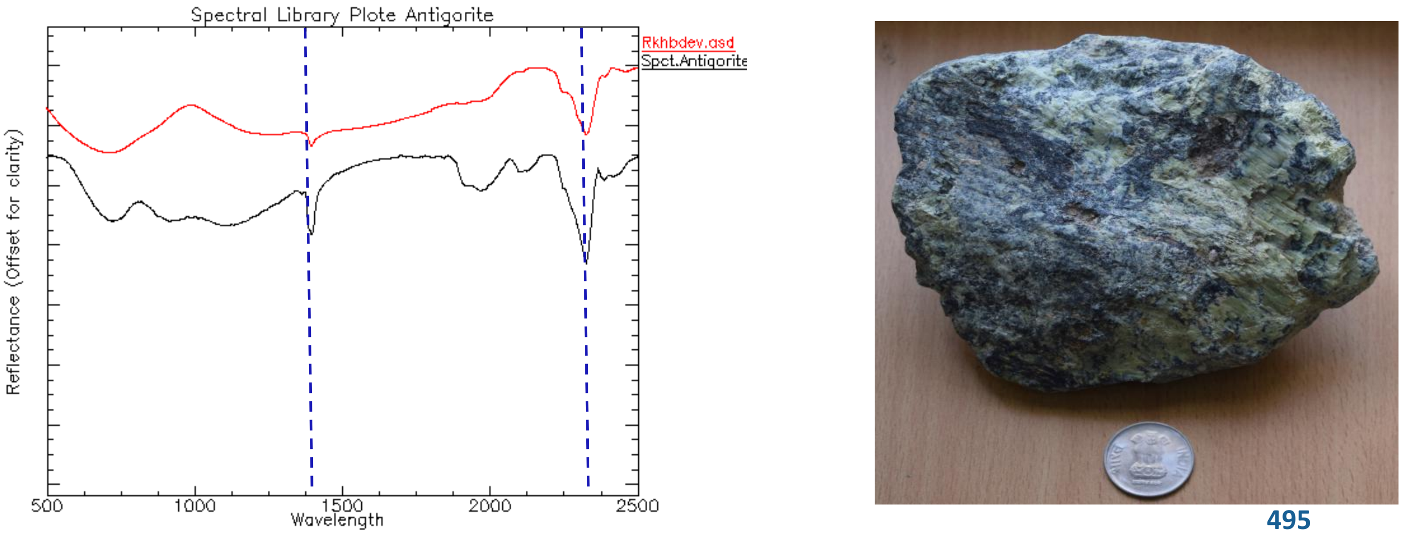
means of identifying ultramafic minerals in the field and supports broader geological and petrogenetic analyses.

4: Result

This study presents a detailed spectroscopic investigation of serpentine minerals found in the Rikhabhdev Ultramafic Suite. The area also contains various carbonate and phyllosilicate minerals. The analysis was focused on extracting key spectral features such as band center, band depth, and band width of hydrous magnesium minerals (serpentine) as well as other phyllosilicates like chlorite, talc, and dolomite. These measurements were taken from samples collected in the Rikhabdevregion to help identify the different mineral types present. Understanding these minerals can provide important clues about the ancient environmental and climatic conditions.Serpentines are a group of trioctahedral phyllosilicate minerals, with the general chemical formula $(Mg, Fe)_3 Si_2 O_5 (OH)_4$. They typically form through metamorphism, hydrothermal alteration, or the weathering of ultramafic rocks. These minerals usually develop in highly reducing environments and under alkaline (high pH) conditions.

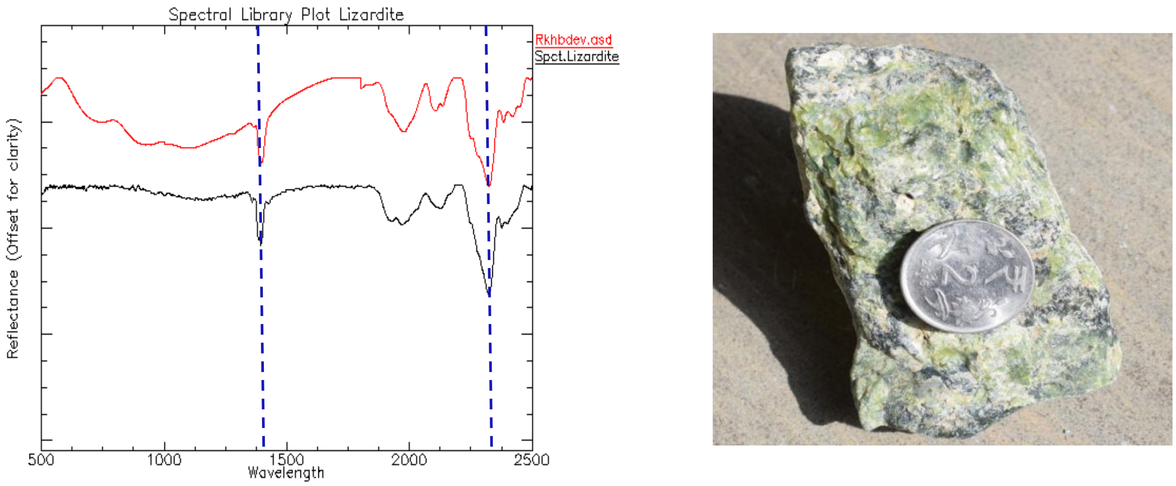
In Fig.2,the spectral plot compares the reflectance spectrum of a Rikhabdev field sample (red line, Rkhbdev.asd) with the USGS reference spectrum of antigorite (black line, Spct.Antigorite). The x-axis represents wavelength (500–2500 nm), covering visible to shortwave infrared regions, while the y-axis shows reflectance offset for clarity. Both spectra show key absorption features at 2332,1971, and 1393nm, which are typical of OH-bearing serpentine minerals like antigorite. The close spectral match confirms the presence of antigorite in the Rikhabdev sample, with minor differences likely due to natural variability or alteration.

Fig.2: Reflectance spectrum of antigorite from Rikhabdev area (red) taking from this rock and pure antigorite spectrum from the USGS spectral library (black). The spectrum of the sample shows absorption features at 2332, 1971, and 1393nm.



The spectral library plot compares the reflectance spectra of a field sample from the Rikhabdev ultramafic suite (red line, Rkhbdev.asd) with a standard reference spectrum of lizardite (black line, Spct.Lizardite) (Fig. 3). Both spectra exhibit characteristic absorption features at 2324, 1970, and 1390nm, which are indicative of hydroxyl (OH) and Mg–OH vibrations typical of lizardite. The close spectral similarity between the two suggests the presence of lizardite in the Rikhabdev sample, although minor differences may reflect natural variations, impurities, or the effects of weathering. This spectral match supports mineral identification and validates the use of field spectral data for hyperspectral remote sensing applications.

Fig.3: Reflectance spectrum of lizardite from Rikhavdev area (red) taking from this rock and pure lizardite spectrumfrom the USGS spectral library (black). The spectrum of the sample shows absorption features at 2324, 1970, and 1390nm.



In Fig.4, the spectral library plot compares the reflectance spectrum of a field sample from the Rikhabdev ultramafic suite (red line, sample spectrum labeled "Rkhbdev.asd") with the reference spectrum of chrysotile from the USGS spectral library (black line, labeled "Spct.Chrysotile"). Both spectra display characteristic absorption features at 2324, 1923, and 1387nmwavelength regions, corresponding to OH-stretching and Mg–OH bending vibrations typical of chrysotile. The close alignment of these features in the sample spectrum with the USGS reference confirms the presence of chrysotile in the Rikhabdev sample, while minor variations may indicate natural mineralogical differences, weathering, or mixed phases. This comparison supports the field identification of chrysotile and its relevance in hyperspectral mineral mapping studies.

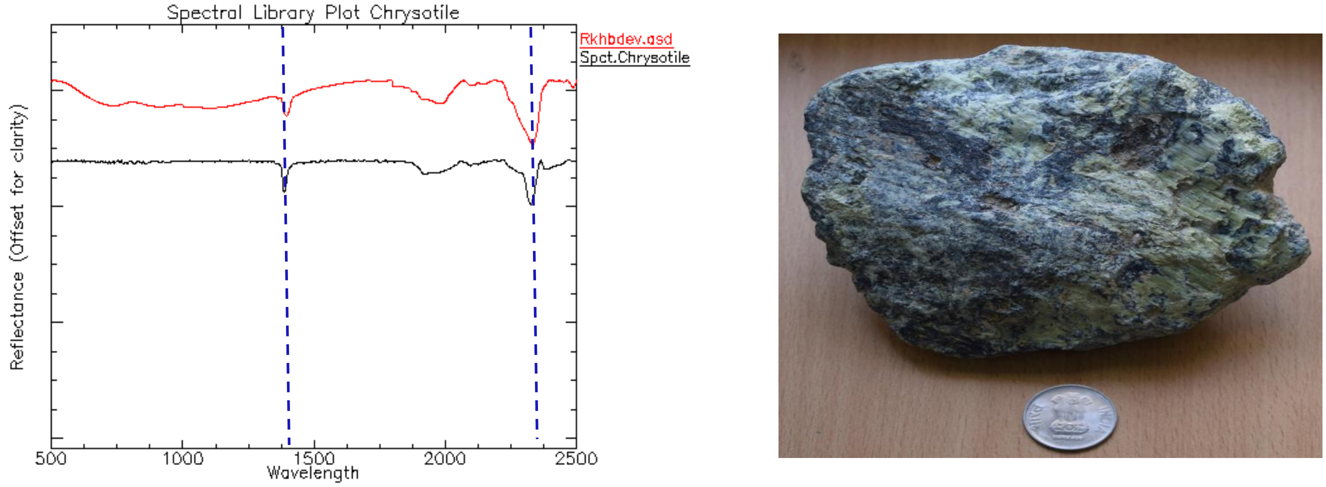
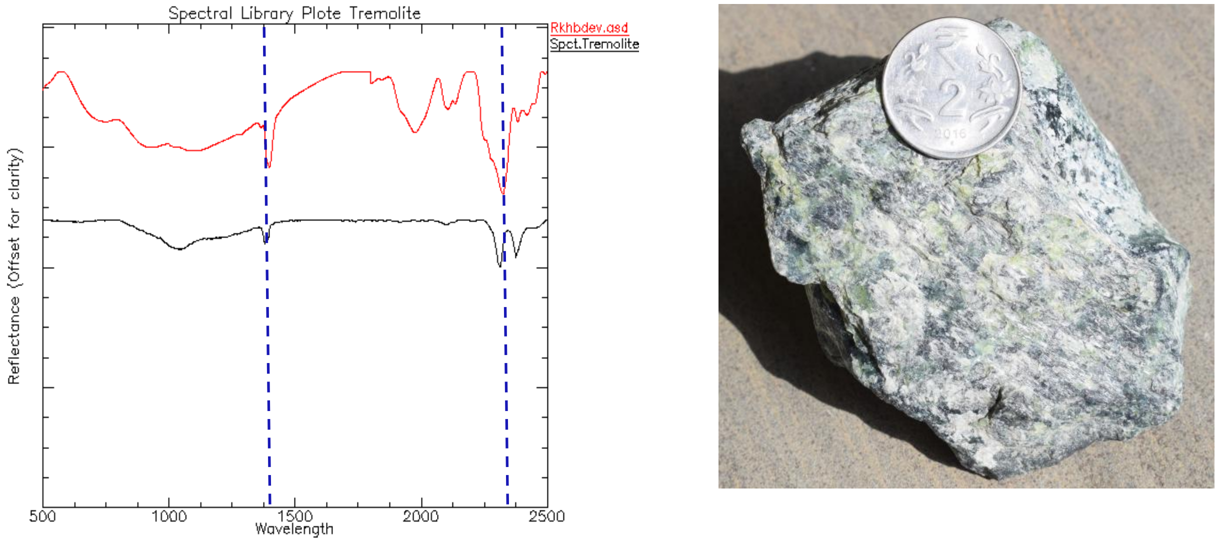


Fig. 4: Reflectance spectrum of chrysotile from Rikhavdev area (red) taking from this rock and pure chrysotile spectrum from the USGS spectral library (black). The spectrum of the sample shows absorption features at 2324, 1923, and 1387nm.

The spectral library plot compares the reflectance spectrum of a field sample from the Rikhabdev ultramafic suite (red line, labeled "Rkhbdev.asd") with the USGS reference spectrum of tremolite (black line, labeled "Spct.Tremolite") (Fig. 5). Both spectra exhibit prominent absorption features at 2315, 1380, and 1395nm, which correspond to OH-stretching and Mg–OH or Ca–Mg–OH bending vibrations—spectral characteristics typical of the amphibole group mineral tremolite. The strong similarity in band positions and shapes between the sample and reference spectra confirms the presence of tremolite in the Rikhabdev sample. Minor differences in band depth may be due to natural compositional variation, grain size effects, or surface alteration. This spectral agreement supports the use of field-measured spectra for accurate mineral identification



and remote sensing-based geological interpretation.

Fig.5: Reflectance spectrum of tremolite from Rikhabdev area (red) taking from this rock and pure tremolite spectrum from the USGS spectral library (black). The spectrum of the sample shows absorption features at 2315,1380, and 1395nm.

In Fig.6, the spectral plot compares the Rikhabdev field sample (red line) with the USGS reference spectrum of talc (black line). Both show key absorption features at 2314, 1907, and 1397nm, confirming the presence of talc in the sample. Talc is a phyllosilicate (sheet silicate)mineral, typically formed by the alteration of ultramafic rocks like peridotite and dunite during serpentinization or low-grade metamorphism**.**

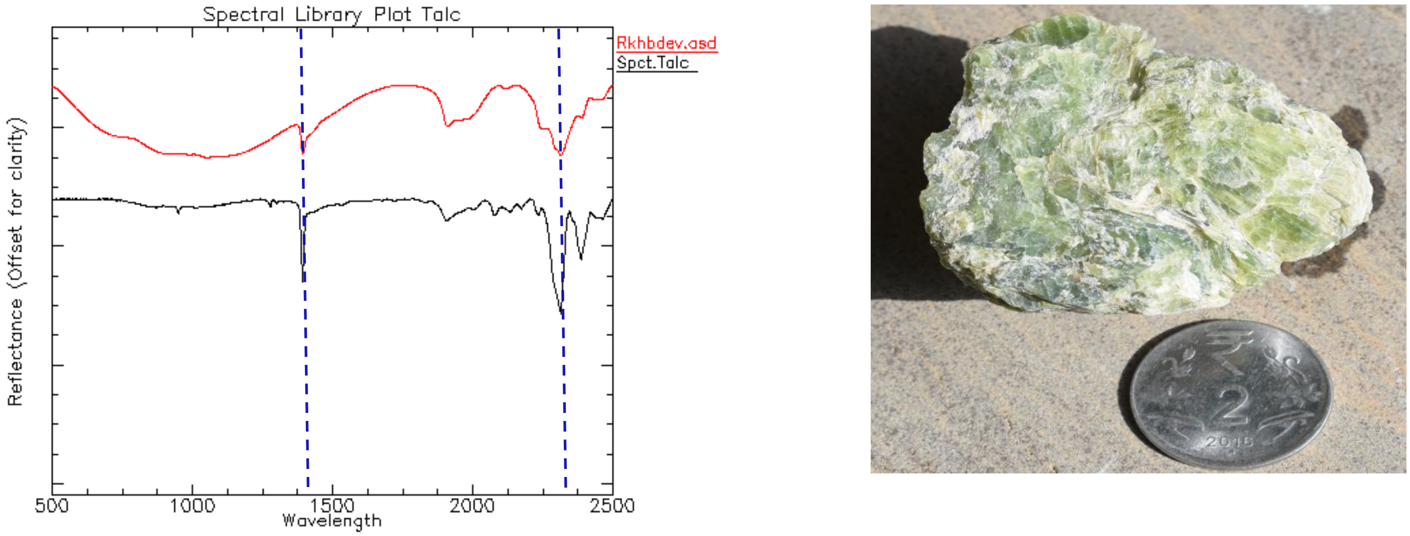


Fig.6: Reflectance spectrum of talc from Rikhabdev area (Red) taking from this rock and pure talc spectrum from the USGS spectral library (black). The spectrum of the sample shows absorption features at 2314,1907, and 1397nm.

The spectral plot compares the reflectance spectrum of a Rikhabdev field sample (red line, Rkhbdev.asd) with the USGS reference spectrum of dolomite (black line, Spct.Dolomite) (Fig. 7). Both spectra show key absorption features around 1986nm, and a strong carbonate absorption at 2315nm, indicating the presence of dolomite. The close match confirms dolomite in the sample. Dolomite is a carbonate mineral that commonly forms through the alteration ofultramafic rocks or in association with hydrothermal fluids, often seen in metamorphosed or serpentinized ultramafic suites.

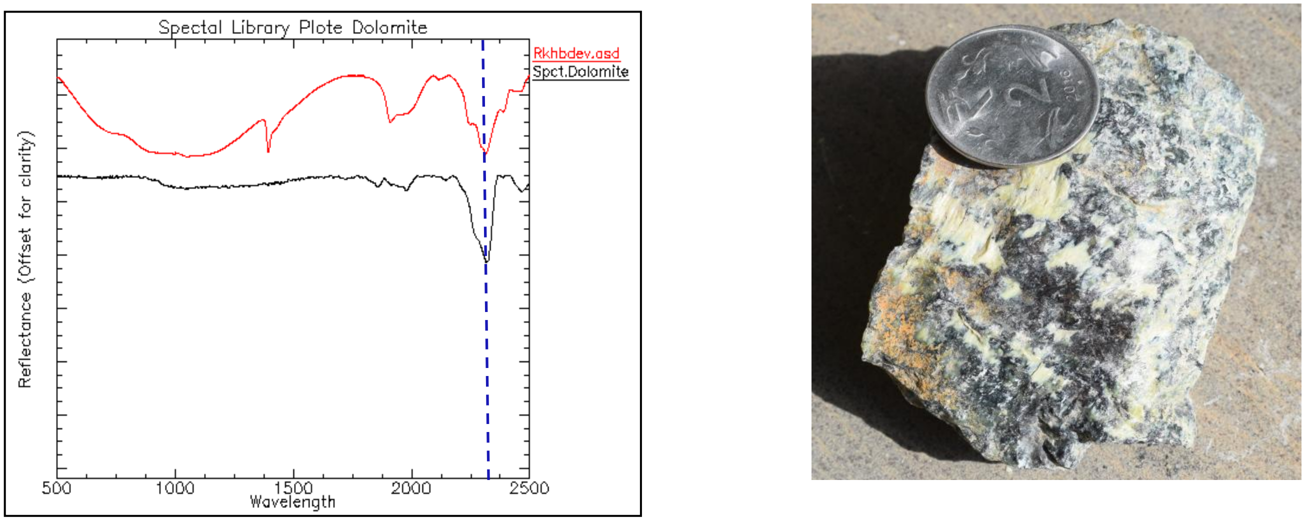


Fig.7: Reflectance spectrum of dolomite from Rikhabdev area (red) taking from this rock and pure dolomite spectrum from the USGS spectral library (black). The spectrum of the sample shows absorption features at 2315 and 1986nm.

A comparative assessment of these spectral features with the USGS mineral reference spectra was conducted to accurately identify specific minerals present in the field area. The spectral analyses of field samples from the Rikhabdev ultramafic suite, compared with USGS reference spectra, confirm the presence of key ultramafic-associated minerals: lizardite, chrysotile, and antigorite (all serpentine-group minerals), along with talc, tremolite, and dolomite. The serpentine minerals,such as lizardite, chrysotile, and antigorite,are phyllosilicates formed through the serpentinization of ultramafic rocks such as peridotite and dunite, characterized by diagnostic OH and Mg–OH absorption features near 1400, 1900, and 2300–2500 nm. Talc, also a phyllosilicate, forms under similar alteration conditions and shows overlapping spectral features in the same regions. Tremolite, an amphibole mineral, represents a higher-grade metamorphic transformation of ultramafic rocks and displays distinct absorptions linked to hydroxyl groups. Dolomite, a carbonate mineral, occurs as a secondary phase due to carbonation of ultramafic rocks, with prominent absorption at 2315nm. Together, these spectra reflect a progressive alteration and metamorphic pathway of ultramafic rocks, from serpentinization to carbonate and amphibole formation, aiding in the spectral identification and petrogenetic interpretation of ultramafic terrains.

5. Conclusion

This study successfully demonstrates the application of reflectance spectroscopy with the help of a spectroradiometer for the identification and characterization of serpentine and associated minerals within the Rikhabdev Ultramafic Suite in the Aravalli Mountain Range, Rajasthan. Spectral analysis, supported by comparative assessment with USGS mineral reference spectra, confirmed the presence of key ultramafic alteration minerals including lizardite, chrysotile, antigorite, talc, tremolite, and dolomite. These minerals reflect various stages of hydrothermal alteration, metamorphism, and carbonation processes commonly associated with ultramafic rocks. The integration of spectroscopic techniques with geological interpretation provides a reliable, non-destructive method for mineral mapping and enhances our understanding of serpentinization and related geochemical processes. Additionally, the identification of serpentine minerals also points to the potential for methane generation, highlighting the broader geobiological significance of these rocks. Overall, the study emphasizes the effectiveness of reflectance spectroscopy in mineral exploration and petrogenetic studies of ultramafic terrains.

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