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FTIR and UV-Vis Assessment of Impact-Generated Glass, Vesicular Basalt and Weathered Red Boles in the Lonar Crater System

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ABSTRACT: This study presents a combined FTIR and UV–Vis spectroscopic investigation of three representative geological materials from the Lonar impact structure in Maharashtra: glassy impactites, vesicular basalt, and red bole soil. The FTIR spectra of the glassy material display strong Si–O stretching bands between 1200–960 cm^{-1}, confirming an amorphous silicate framework produced by rapid quenching during the meteorite impact. Complementary UV–Vis measurements reveal distinct absorbance features at 334 nm and 259 nm, characteristic of natural volcanic glasses. Vesicular basalt samples show FTIR signatures consistent with primary basaltic minerals and post-impact alteration, while the UV–Vis response near 334 nm reflects compositional variations associated with vesicle formation and degassing processes. The red bole soils exhibit FTIR bands attributable to clay minerals, carbonates, and iron oxides, indicating extensive weathering under alkaline–saline lake conditions, supported by UV–Vis absorbance at 331 nm and 256 nm linked to iron-rich phases. When combined, these spectroscopic results provide a coherent view of melt generation, vesiculation, mineral alteration, and pedogenesis within the Lonar crater environment. The study enhances understanding of the crater's geological evolution and highlights the value of vibrational and optical spectroscopy for characterizing terrestrial impact structures.

KEYWORDS: Lonar Crater, FTIR spectroscopy, UV–Vis spectrophotometry, Vesicular basalt

I. INTRODUCTION

Meteorite impact structures are among Earth's most remarkable geological features, offering crucial insights into planetary evolution, crustal deformation, and the interaction between terrestrial surfaces and extraterrestrial bodies. Lonar Lake, located in the Buldhana district of Maharashtra, stands as a rare and well-preserved hypervelocity impact crater formed entirely within Deccan basalt. Its unique geological setting makes it an invaluable natural laboratory for studying processes comparable to those observed on the Moon and Mars. Across India, such impact-generated landforms hold significant scientific and ecological relevance, helping to reconstruct the planet's geological history and post-impact environmental transformations.

Remote sensing and Geographic Information System (GIS) techniques have become essential tools for identifying, monitoring, and interpreting meteorite impact structures. High-resolution satellite imagery, digital elevation models, and drone-based surveys enable detailed assessment of crater morphology, ejecta patterns, sediment distribution, and hydrological changes (Maloof et al., 2010). At Lonar, these technologies help delineate deformation features, brecciation, and structural variations within and around the crater, while GIS mapping supports correlations between geological, ecological, and hydrological parameters to understand its post-impact evolution.

Beyond its geological value, Lonar Lake also represents a significant ecological and Astro biological site. Its closed, alkaline, and saline water system hosts diverse extremophilic microorganisms, offering analogues for potential life in extraterrestrial environments. The impact origin of the basin has shaped its hydrology, mineral assemblages, and long-term geomorphic stability. However, increasing anthropogenic pressures—such as agriculture, groundwater extraction, and unregulated development—pose threats to the preservation of its geological and ecological integrity (Jethe, 2024). These concerns highlight the need for integrated investigations using field studies, remote sensing, and geospatial analyses.

The main objective of this research is to document and interpret evidence of impact-related features within and around Lonar Lake through comprehensive geological, geomorphological, and ecological assessment. By consolidating such data, the study contributes to a deeper understanding of India's planetary geology while supporting global efforts in conserving and interpreting natural impact structures

.II. STUDY AREA

Lonar Lake, located near the town of Lonar in Buldhana district, Maharashtra, is a rare meteorite impact crater formed in the basaltic flows of the Deccan Traps. The lake lies at an elevation of about 563 m and spans a circular depression roughly 1.88 km in diameter, with raised rims and ejecta deposits marking the impact structure. Positioned at 19.98°N and 76.31°E, the crater and its surroundings cover around 4–5 km², forming a closed geological and hydrological system. The region has a semi-arid climate, receiving 700–900 mm of rainfall annually, mainly from the southwest monsoon. High summer temperatures and significant evaporation contribute to the lake's alkaline (pH 9–11) and saline water chemistry. As an endorheic basin, the lake receives water from runoff and springs, with evaporation as the primary outlet. Geologically, the area preserves features such as brecciated basalt, impact melt glass, and uplifted rims, making it one of the best examples of an impact crater in basaltic terrain. Surrounding soils derived from basalt are moderately fertile but alkaline, supporting mixed agriculture, settlements, and forest patches. The lake's extreme conditions host specialized microorganisms, adding ecological and Astro biological significance.

III. METHODOLOGY

Ultraviolet (UV) Spectroscopy

A. **Sample Preparation:**
The rock and soil samples were finely powdered and dispersed in appropriate solvents to achieve a uniform suspension suitable for optical measurements.

B. **Instrument:**
UV-Visible spectra were obtained using a double-beam UV-Visible spectrophotometer capable of recording high-resolution absorbance data.

C. **Data Collection:**
Absorbance measurements were recorded across the wavelength range of **200–800 nm**, covering both ultraviolet and visible regions to capture electronic transitions associated with mineral phases.

D. **Data Interpretation:**
The resulting spectra were evaluated to determine optical band gaps and assess variations in electronic structure, enabling comparison of compositional differences among the samples.

Fourier Transform Infrared (FTIR) Spectroscopy

A. **Sample Preparation:**
The powdered samples were treated with dilute **HCl** to remove carbonate impurities and improve sample uniformity. The materials were then air-dried before analysis.

B. **Instrument:**
FTIR measurements were conducted using a **PerkinElmer Spectrum Two** FTIR spectrometer, equipped to record mid-infrared spectra with high precision.

C. **Data Collection:**
Infrared spectra were collected over the range of **400–4000 cm^{-1}**, covering the fundamental vibrational frequencies of major mineral groups.

D. **Data Interpretation:**
Spectral features were examined to identify characteristic absorption bands associated with **Si–O**, **Fe–O**, **Mg–O**, and **–OH** vibrations. These bands were used to determine the mineral phases and functional groups present in the samples.

This methodology provides a reliable framework for characterizing the mineralogical and chemical properties of the Lonar Lake materials, ensuring accurate identification of their structural and compositional features.

IV. RESULTS AND DISCUSSION

The combined FTIR and UV-Vis analyses provide a clear framework for interpreting the mineralogical, structural, and chemical characteristics of the three Lonar Lake samples. These spectroscopic results highlight how impact melting, volcanic processes, and long-term weathering have each contributed to the distinct signatures observed in the glassy material, vesicular basalt, and red bole soils. By comparing their absorption features, the data reveal the interconnected geological processes that shaped the crater and continue to influence its present environment.

A. Glassy Material (Impactite Glass)

FTIR Findings:

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The glassy samples display strong, broad absorption bands between **1200–960 cm⁻¹**, reflecting Si–O stretching vibrations typical of amorphous silicate glass. This spectral pattern aligns with materials formed through high-temperature melting and rapid quenching, a process expected during the Lonar impact event. The absence of well-developed crystalline peaks further reinforces the non-crystalline nature of the melt products. Complementary Mössbauer evidence showing enhanced **Fe^{3+} content** indicates oxidation during the impact's thermal pulse, a feature consistently noted in previous impact glass studies (Fig1).

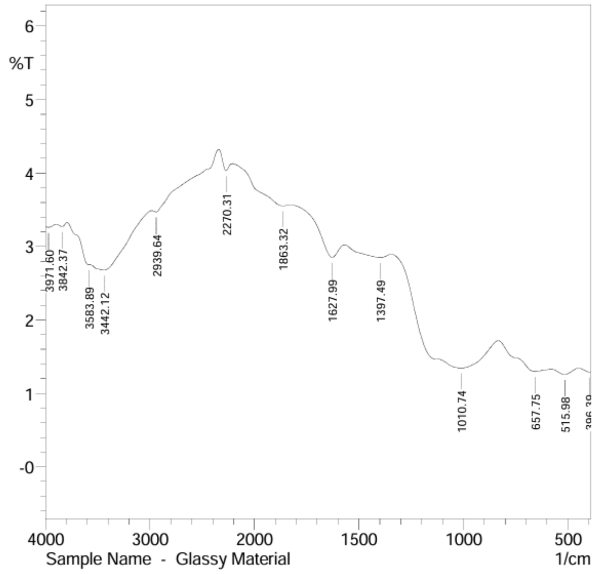

Fig1: FTIR Spectrum of the Glassy Material Sample

UV-Vis Findings:

Distinct absorption peaks at **334 nm** and **259 nm** point toward electronic transitions commonly associated with natural silicate glasses. These features correspond to the presence of iron-bearing structural units and defect centres created during rapid cooling. The similarity of these peaks to those documented in volcanic and extraterrestrial glasses highlights the sensitivity of UV-Vis in detecting subtle structural variations within amorphous materials (Fig 2).

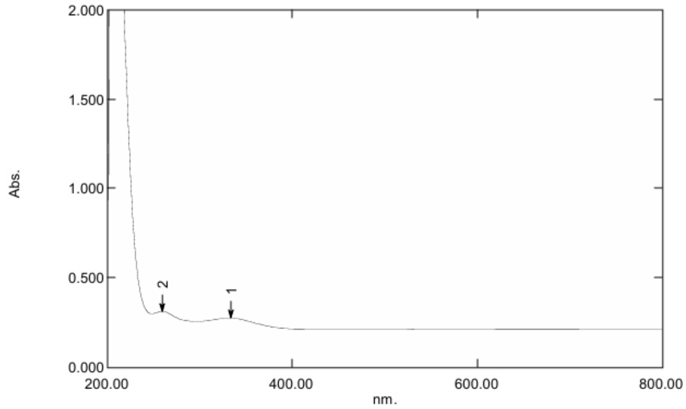

Fig 2: UV Spectrum of the Glassy Material Sample

Together, FTIR and UV-Vis results confirm that the glass is a high-temperature impact product characterized by amorphous silica networks, oxidation of iron, and preserved quenching textures. These findings also align with earlier work on impactites from both terrestrial and planetary settings, emphasizing the unique physicochemical conditions under which the Lonar glasses formed.

B. Vesicular Basalt

FTIR Findings:

The vesicular basalt exhibits absorption features attributable to common basaltic minerals, including Si–O stretching in silicates and signatures of alteration phases introduced by post-impact groundwater flow. The FTIR spectra reflect a mix of primary volcanic mineralogy and secondary weathering products, indicating that the rock has undergone hydrothermal or aqueous modification after crater formation(Fig 3)..

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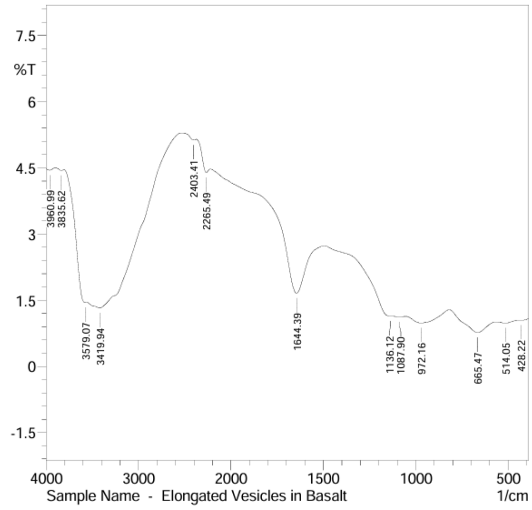

Fig3: FTIR Spectrum of the vesicular basalt Sample

UV-Vis Findings:

An absorption feature near **334 nm** appears consistently in the vesicular basalt. This wavelength is typical of transitions involving iron-bearing silicates and alteration minerals, suggesting that the vesicles and surrounding basaltic matrix retain traces of both primary magmatic phases and secondary chemical changes(Fig 4).

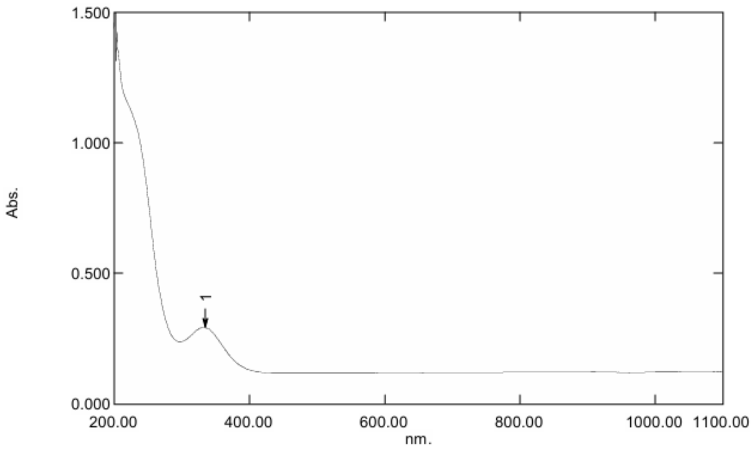

Fig 4: UV Spectrum of the vesicular basalt Sample

The physical structure—elongated vesicles—and the spectroscopic data combine to illustrate the basalt's role in Lonar's hydrological system. The vesicles enhance porosity, allowing groundwater circulation that contributes to the crater's saline lake environment. Spectral evidence of alteration supports the notion that circulating fluids introduced mineralogical changes in the basalt, linking the rock's physical fabric to chemical weathering and regional hydrogeology.

C. Red Bole Soils

FTIR Findings:

The red bole soils show distinct absorption bands corresponding to **clay minerals, carbonates, silicates, and iron oxides**. These spectral features indicate extensive chemical weathering of basalt under alkaline, saline, and periodically wet conditions around the lake. The presence of clay and Fe-oxide phases reflects long-term paedogenic processes and interactions with mineral-rich lake water(Fig 5)..

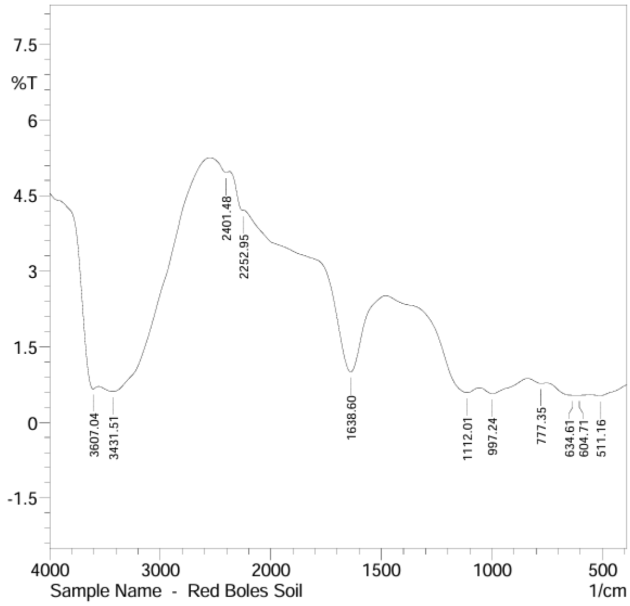

Fig5: FTIR Spectrum of the red bole soils Sample

UV-Vis Findings:

Absorption peaks at **331 nm** and **256 nm** are characteristic of iron oxides and clay-organic mixtures—minerals typically enriched in mature weathering horizons. These signatures confirm the soils' origin as altered basalt layers that developed during periods of limited volcanic activity, corresponding to red bole horizons known from other Deccan basalt sequences (Fig 6).

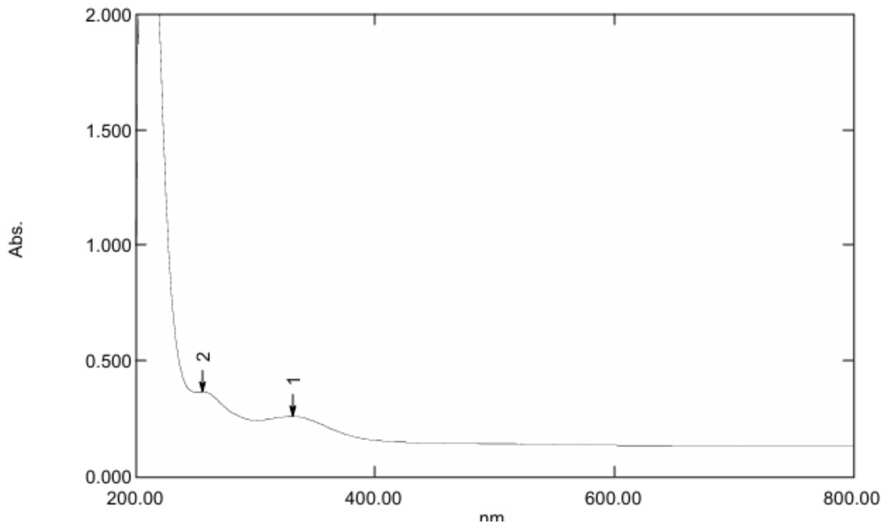

Fig 6: UV Spectrum of the red bole soils Sample

The combined spectroscopic evidence highlights the complexity of chemical weathering processes at Lonar. FTIR identifies the mineral phases forming the backbone of red bole development, while UV-Vis provides insight into the electronic transitions linked to Fe-bearing clays and oxides. These soils act as important markers of past environmental conditions, recording variations in climate, hydrology, and lake chemistry.

V. CONCLUSION

The combined FTIR and UV-Vis analyses of the glassy material, vesicular basalt, and red bole soils from Lonar Lake provide a clear understanding of the crater's geological, chemical, and environmental evolution. The glassy impactites exhibit strong silicate absorption bands and characteristic UV peaks that confirm their origin as rapidly quenched melt products formed during the meteorite impact, with additional evidence of iron oxidation supporting high-temperature

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shock conditions. The vesicular basalt shows vibrational signatures of primary basaltic minerals along with features linked to alteration, reflecting both its volcanic origin and its role in regulating groundwater flow through its porous structure. The red bole soils reveal a mineral assemblage dominated by clays, carbonates, and iron oxides, indicating long-term weathering of basalt under alkaline and saline conditions influenced by the lake's hydrology.

Together, the spectroscopic results highlight the interaction between impact processes, volcanic substrates, and post-impact environmental change that shaped the Lonar crater system. FTIR provides detailed information on mineral phases and structural changes, while UV-Vis offers insights into electronic transitions, compositional variations, and weathering signatures. The integration of these techniques strengthens the interpretation of Lonar Lake as a rare and well-preserved basaltic impact structure and underscores its significance as a key site for geological, hydrological, and Astro biological research.

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