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Application of Xrd (X -Ray Diffraction) and Laser Diffraction Techniques in Clay Mineralogical Studies of Rann of Kutch Sediment

Samiksha Verma[1], V.K. Singh[2]

[1,2] MSOS, Department of Chemistry, Maharishi University of Information Technology IIM Road, Lucknow, 226013, U.P. (India)

Corresponding author - [2]Vinod Kumar Singh, drvks151068@gmail.com

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ABSTRACT

The present study focuses on the application of X-Ray Diffraction (XRD) and laser diffraction techniques in the mineralogical and granulometric analysis of clay-rich sediments collected from the Rann of Kutch. The Rann of Kutch represents a unique geomorphological and sedimentological environment influenced by marine, fluvial, and aeolian processes. Understanding the clay mineral composition and particle size distribution of its sediments is essential for interpreting depositional environments, climatic conditions, and sediment transport mechanisms. X-Ray Diffraction (XRD) was employed to identify and characterize the crystalline clay minerals present in the sediment samples. The analysis revealed the dominance of minerals such as illite, kaolinite, smectite, and chlorite, indicating varied sediment sources and weathering conditions. Laser diffraction technique was used to analyze particle size distribution and sediment texture. This method provided rapid, accurate, and reproducible measurements of fine-grained sediments ranging from clay to silt fractions. The combined application of XRD and laser diffraction techniques offers a comprehensive approach for clay mineralogical investigations. While XRD provides qualitative and semi-quantitative mineral identification, laser diffraction complements it by delivering detailed granulometric data.

Keywords: .XRD, Laser Diffraction, Clay Minerals, Sediments, Rann Kutch, Gujrat

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INTRODUCTION

Clay minerals are among the most sensitive indicators of geological and environmental processes. They form through weathering, transportation, deposition, and alteration of rocks under different climatic and tectonic conditions. The identification and characterization of clay minerals help researchers understand sediment source, transport mechanisms, weathering intensity, depositional environments, and paleoclimate.

The Rann of Kutch is a large seasonal salt marsh extending across Gujarat and bordering Pakistan. It consists of the Great Rann and the Little Rann of Kutch. The region experiences arid to semi-arid climatic conditions, periodic marine incursions, and seasonal flooding, making it a dynamic sedimentary basin. Sediments in this region contain significant amounts of clay minerals such as illite, kaolinite, smectite, chlorite, and mixed-layer clays.

Traditional sedimentological methods often fail to provide detailed mineralogical information. Therefore, advanced techniques such as X-Ray Diffraction (XRD) and Laser Diffraction are increasingly applied for accurate mineralogical and granulometric studies. These techniques play a vital role in modern geological, environmental, and sedimentological research.

Study Area of the Rann of Kutch

The Rann of Kutch is situated in a tectonically active region influenced by the Kutch Rift Basin. The area has experienced several geological events including marine transgressions, regressions, earthquakes, and climatic fluctuations. Sediments in the Rann are derived from multiple sources such as:

- Indus River system
- Local streams and rivers

- Aeolian deposits
- Marine sediments
- Weathered volcanic and sedimentary rocks

The depositional environment includes tidal flats, mudflats, saline marshes, and ephemeral lakes. Fine-grained sediments dominate the region, making it ideal for clay mineralogical investigations.

MATERIAL AND METHODS

The major clay minerals commonly identified in the sediments include:

Clay Mineral	Characteristics	Geological Significance
Illite	Potassium-rich mica clay	Indicates physical weathering and marine influence
Smectite	Expanding clay mineral	Suggests volcanic source and chemical weathering
Kaolinite	Aluminum silicate clay	Forms in humid tropical weathering
Chlorite	Magnesium-iron rich clay	Indicates low-grade metamorphic sources
Mixed-layer clays	Combination of clay minerals	Reflects diagenetic alteration

The relative abundance of these minerals helps reconstruct environmental and climatic conditions of the Rann region.
X-Ray Diffraction (XRD) Technique
Principle of XRD

X-Ray Diffraction is one of the most reliable techniques for identifying crystalline minerals. The method is based on the diffraction of X-rays by atomic planes within a crystal lattice. When monochromatic X-rays strike a crystalline substance, constructive interference occurs according to Bragg's Law:
$n\lambda = 2d\sin\theta$

Where:

- n = order of reflection
- λ= wavelength of X-rays
- d = interplanar spacing
- θ = diffraction angle

Each mineral produces a characteristic diffraction pattern that acts as its fingerprint.
1. Sample Collection
Sediment samples are collected from different locations in the Rann of Kutch, including mudflats, saline areas, and tidal regions.
2. Sample Preparation

- Samples are dried and powdered.
- Organic matter and carbonates are removed chemically.
- Clay fraction (<2 µm) is separated by sedimentation techniques.

3. Run the sample in laser Diffraction Particle Size Analyser
4. Oriented Mount Preparation
Clay suspensions are deposited on glass slides to produce oriented clay mounts.
5. XRD Measurement and analysis
The samples are analyzed using an X-ray diffractometer. Diffractograms are recorded over specific angular ranges.
5. Mineral Identified
Minerals are identified using standard reference patterns and peak positions.

Application of XRD in Rann of Kutch Sediments

1. Identification of Clay Minerals X-Ray Diffraction (XRD) is one of the most reliable techniques for identifying crystalline clay minerals present in sediments. In the Rann of Kutch, XRD analysis is extensively used to identify minerals such as illite, smectite, kaolinite, chlorite, and mixed-layer clays. These minerals occur in varying proportions depending upon the source rocks, weathering conditions, and depositional environments. The principle of XRD is based on the diffraction of X-rays by the crystal lattice of minerals. Each mineral has a unique diffraction pattern that helps in its identification. In sediment studies, powdered samples are exposed to X-rays, and the resulting diffraction peaks are recorded. The position and intensity of peaks reveal the mineral composition.
In the Rann of Kutch sediments:

- **Illite** commonly indicates physical weathering and continental sediment supply.
- **Smectite** suggests volcanic source material and arid to semi-arid climatic conditions.
- **Kaolinite** reflects intense chemical weathering under humid climatic conditions.

Thus, XRD provides accurate mineralogical characterization of the sediments and helps researchers understand sediment composition and regional geology.

2. Climatic Changes

Clay mineral assemblages are highly sensitive to climatic fluctuations. XRD analysis helps reconstruct paleoclimatic conditions by identifying dominant clay minerals.

For example:

- High **smectite** content generally reflects arid and semi-arid climates with limited leaching and possible volcanic contributions.
- Increased **kaolinite** abundance indicates warm and humid climatic conditions with intense chemical weathering.
- Presence of **illite** often suggests moderate weathering under cooler or drier conditions.

3. Environmental Monitoring

Clay minerals play a crucial role in environmental processes because of their high surface area and ion exchange capacity. XRD analysis contributes significantly to environmental monitoring studies in the Rann of Kutch.

Laser Diffraction Technique

Principle of Laser Diffraction

Laser diffraction is a modern and advanced technique used for particle-size analysis of sediments. It is based on the scattering of laser light by particles suspended in a medium.

When a laser beam passes through dispersed sediment particles:

- Large particles scatter light at small angles.
- Small particles scatter light at wider angles.

The scattered light pattern is measured by detectors, and particle-size distribution is calculated using:

- Mie Theory
- Fraunhofer Diffraction Theory

Laser diffraction provides rapid and precise measurement of particle sizes ranging from clay to sand fractions.

In the Rann of Kutch sediments, laser diffraction is particularly useful for studying:

- Grain-size distribution
- Sediment texture
- Transport mechanisms
- Depositional energy conditions
- Environmental changes

The integration of XRD and laser diffraction techniques provides comprehensive information regarding both mineralogical composition and sediment granulometry. Together, these techniques significantly enhance the understanding of sedimentary processes, paleoenvironmental conditions, and geological evolution of the Rann of Kutch region.

Application of Laser Diffraction in Rann of Kutch Sediments

Grain Size Analysis

Laser diffraction provides accurate measurement of:

- Clay fraction
- Silt fraction
- Sand fraction

This helps classify sediments and depositional environments.

RESULTS AND DISCUSSION

For analysis, only selected samples were taken from **India Bridge** in **Rann of Kutch.** The results of both the proxies are described in the details below. After performing Grain size analysis and X- Ray Diffraction analysis (clay mineralogy) following results are observed.

Grain size distribution analysis:

The percentage distribution of various fractions of grain size along with sedimentary profile:

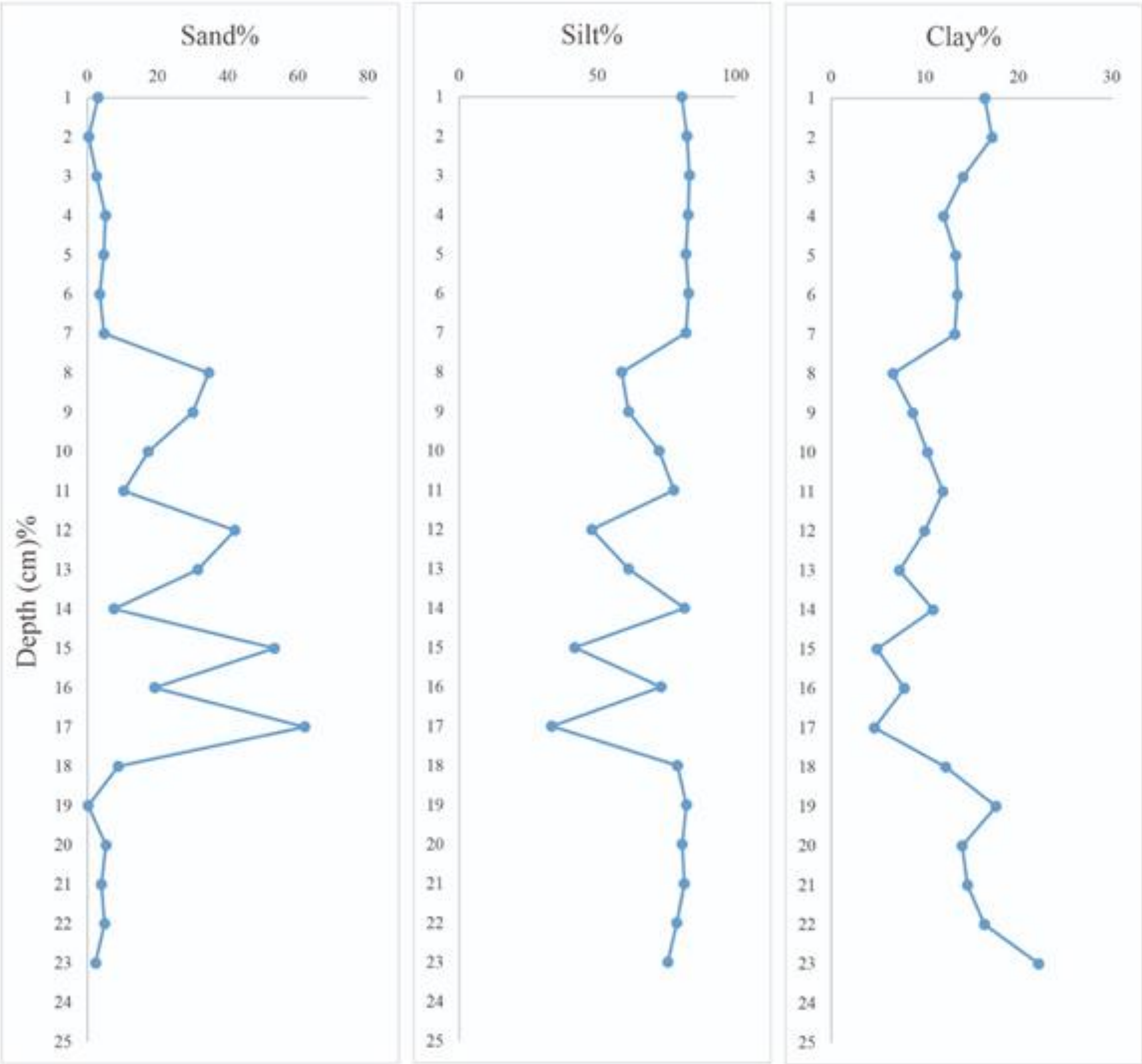
The grain size analysis of sediment samples collected from the Rann of Kutch was carried out using a **Laser Diffraction particle size analyser** method. The results indicate that the sediments consist of a mixture of sand, silt, and clay fractions, with silt and clay dominating in most samples.

The particle size distribution shows that the sand fraction (>63 µm) is present in smaller amounts, while the silt fraction (2–63 µm) constitutes a moderate portion of the sediment. The clay fraction (<2 µm) forms a significant percentage, indicating the fine-grained nature of the sediments.

Sample Number	Sand%	Silt%	Clay%	Depth cm
IB-1	3.0355658	80.54061	16.423843	1
IB-2	0.3839362	82.413129	17.202963	2
IB-3	2.6251674	83.29093	14.083909	3
IB-4	5.1588741	82.82871	12.012395	4
IB-5	4.6497574	82.0303	13.319902	5
IB-6	3.5046668	82.99783	13.497538	6
IB-7	4.7634656	82.04172	13.19484	7
IB-8	34.572957	58.807846	6.6191965	8
IB-9	30.028301	61.24825	8.7234054	9
IB-10	17.373885	72.336383	10.289729	10
IB-11	10.355433	77.697414	11.947144	11
IB-12	42.034802	47.969033	9.9961704	12
IB-13	31.469985	61.23733	7.2926532	13
IB-14	7.5547735	81.5396	10.905642	14
IB-15	53.323816	41.78008	4.8960744	15
IB-16	19.154863	73.03464	7.8104961	16
IB-17	61.910089	33.470798	4.6191114	17
IB-18	8.7714805	78.98802	12.240488	18
IB-19	0.188348	82.185079	17.626568	19
IB-20	5.3145657	80.68056	14.00487	20
IB-21	3.9856308	81.449477	14.564896	21
IB-22	4.9074304	78.694421	16.398151	22
IB-23	2.3336036	75.48736	22.179054	23

The data presented in the table shows the percentage composition of sand, silt and clay for different samples (IB-1to IB- 23) collected at varying depth. The **depth**(cm) represents the vertical position of each sample, which helps in understanding sediment variation with depth.

From the table, it is evident that most samples are **silt dominated,** with silt percentages generally higher than sand and clay. This indicates deposition under relatively low to moderate energy conditions, where fine particles can settle. The variation in sand content suggests occasional higher energy conditions, allowing coarser particles. The clay fraction, through comparatively lower, is significant for understanding chemical processes, adsorption properties, and paleoclimatic conditions. Higher clay content may indicate calm water conditions and longer suspension times.



Graph between sand, silt and clay percentage

The graph represents the variation of sand (%), silt (%), and clay (%) with depth (cm) for the studied sediment samples (IB-1 to IB-23). Each curve shows how the proportion of a particular grain size fraction changes vertically with increasing depth

Sand (%) Variation

The sand content is generally low in the upper layers (1–7 cm), indicating deposition under low-energy conditions where fine particles dominate.

Between 8–17 cm, sand percentage shows noticeable fluctuations with some peaks, suggesting intermittent high-energy conditions such as stronger water currents or episodic sediment input.

Below this zone (18–23 cm), sand content again decreases, indicating a return to quieter depositional conditions.

Silt (%) Variation

Silt is the dominant fraction throughout the profile, remaining consistently high across most depths.

- From 1–7 cm, silt content is very high, showing stable, low-energy depositional environment.
- Between 8–17 cm, slight variations occur, inversely related to sand content (when sand increases, silt decreases).
- From 18–23 cm, silt again becomes more stable, reinforcing the dominance of fine particles.

Clay (%) Variation

Clay content is moderate in the upper layers, with some fluctuations throughout the depth.

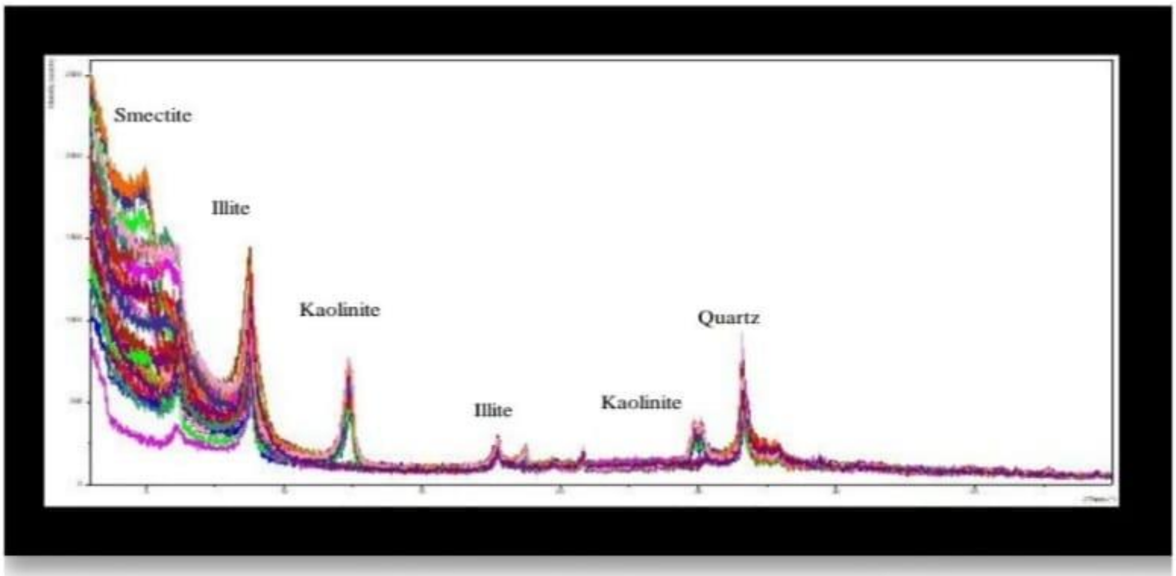
- A slight increase in clay at certain depths (e.g., around 18–23 cm) indicates very calm conditions, where the finest particles settle.
- Clay variation also reflects changes in suspension time and chemical conditions of the depositional environment.

The sediment profile is silt-dominated, indicating a low-energy depositional environment fluctuations in sand and clay suggest periodic environmental changes, possibly due to seasonal variations or changes in water flow.
The inverse relationship between sand and silt indicates sorting of particles based on energy conditions. This graph clearly shows that the depositional environment experienced variable energy conditions over time, but was predominantly calm to moderate, allowing finer particles (especially silt) to dominate.

XRD ANALYSIS
X-ray Diffraction (XRD) is one of the most important techniques in clay mineralogy for identifying different clay minerals and understanding their structural properties.

Treatments Used
Air-Dried Sample- The air-dried slide was analyzed using X-Ray Diffraction (XRD).
Glycolation (Ethylene Glycol Treatment)- The slide was glycolated in a desiccators for 10-12 hours, followed by analysis using X-Ray Diffraction (XRD). The resulting diffraction peaks were used for the identification of clay minerals.

Heating (e.g., 550°C in muffle furnace)- The prepared slide was heated in a metal furnace at 550°C for 2 hours. followed by analysis using X-Ray Diffraction (XRD). The resulting diffraction peaks were used for the identification of clay minerals.



Graph of air dried sample, glycolated sample and heated sample slide using XRD

Overview of the Graph
- At X-axis represents 2θ (diffraction angle, typically 2–60°)
- At Y-axis represents intensity

The multicolour peaks represents the diffraction patterns of the same sample under different treatments or conditions (such as air dried sample slide, glycolated sample slides and heated sample slides**).**

Interpretation
Strong Peaks at Low Angle (2θ ≈ 5–10°)
The peak appearing between **5**° and **10**° **(2θ)** on the graph represents the presence of **smectite.** This peak represents the basal spacing (d001) of smectite layers. The smectite peak appears in the low-angle region and show expansion after glycolation and collapse after heating, confirming the presence of expandable clay minerals.

Peak Around 2θ ≈ 8.8–9° (≈10°) (Peak 1) and 17-18°(Peak 2)
The most prominent **illite** peak is located on the left side of the graph, between the **Smecite** and **Kaolinite** peaks. Moving further to the right, a smaller secondary peak 2 labelled **Illite** is visible at 17-18° and near the centre of the X-axis. The illite peaks remain stable after Glycolation or heat treatment. The 10° (001) peak does not shift to a lower

angle, it stays exactly where it was in the air dried sample state. After the heating treatment, The peak at 10° remains visible and often becomes sharper or more intense.

Peak Around 2θ ≈ 12–13° (peak 1) and 24 - 25° (peak 2)
The first **Kaolinite** peak is located to the right of primary Illite peak. And second Kaolinite peak is located to the right of the secondary Illite peak. Kaolinite peaks remain stable after Glycolation but collapse after heating. The characteristics peaks at 7.16 Å and 3.58 Å do not shift. They remain at the same (2θ) position as seen in the air-dried sample. After the heating treatment the diffraction peaks at 7.16 Å and 3.58 Å completely disappear from the XRD pattern.

Peak around 2θ ≈ 26.6°
The intense peak is located on the far right side of the primary clay minerals peaks. This peak represent the presence of **Quartz** in the sample. Because Quartz is extremely stable and highly crystalline, this peak is typically very sharp and narrow as seen in graph. The peak remains unchanged even after heating treatment.
The smaller peaks near the Quartz peak represents the feldspar and calcite.

CONCLUSION

The grain size distribution and X-ray diffraction (XRD) analysis indicate that sediment core is composed of silt- and clay-sized particles, with less sand. This finr-grained nature of sediments suggests deposition under relatively calm hydrodynamic condition where low-energy conditions.

Mineralogical characterization through XRD reveals that illite is the dominant clay mineral across all samples, followed by Kaolinite, with smectite present only in trace amounts. The prevalence of illite is typically associated with the physical weathering of K-feldspar and mica-rich source rocks under condition of limited chemical alternation. However the presence of kaolinite indicates more intense chemical weathering under relatively humid conditions. The minor presence of smectite, an expandable clay minerals, may reflect limited alteration of primary minerals under alkaline and saline conditions.

Overall, the dominance of fine-grained sediments along with the clay mineral assemblage suggests deposition in a low-energy environment, most likely a saline mudflat or coastal system. These characteristics are consistent with environments such as the Rann of Kutch, where restricted circulation, high evaporation reates, and episodic influxes of sediments create conditions favorable for the accumulation of silty-clayey sediments and the formation of specific clay minerals assemblages.

The Rann of Kutch, with its complex sedimentary environment and tectonic significance, serves as an excellent natural laboratory for sedimentological and mineralogical research. The combined application of XRD and laser diffraction has significantly enhanced the scientific understanding of clay-rich sediments and their environmental implications. These techniques continue to play a major role in geological, environmental, and climate-related studies, contributing valuable knowledge for sustainable management and future research in the region.

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