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Explore the Geochemical and Petrographic Characteristics of Low-Grade Limestone of Sidhi, M. P.

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Abstract

The growing depletion of high-grade limestone resources has necessitated the exploration and utilization of low-grade limestone deposits for industrial applications. This study investigates the geochemical and petrographic characteristics of low-grade limestone from the Majhgawan and Hinauti Extension areas of the Vindhyan Basin, Central India. Field-based stratigraphic analysis, borehole litholog interpretation, petrographic examination, and geochemical investigations (XRD and XRF) were conducted.

The results reveal significant compositional variability across stratigraphic horizons, influenced by shale intercalations and dolomitization processes. Petrographic analysis indicates dominance of micritic calcite with minor dolomite and quartz, while geochemical results show variations in CaO (38–48%), MgO (3–12%), SiO_2 (5–20%), and Al_2O_3 (1–6%). These variations directly affect industrial suitability, particularly for cement manufacturing. The study highlights that selective mining, blending, and beneficiation strategies can enhance the usability of low-grade limestone.

Keywords: Low-grade limestone, petrography, geochemistry, XRD, XRF, Vindhyan Basin

1. Introduction

Limestone is a fundamental raw material for cement, steel, and construction industries, with its chemical composition playing a critical role in industrial performance (Bieniawski, 1989; Goldscheider et al., 2020, Dixit and Mishra 2024, 2025). With increasing demand and depletion of high-grade reserves, attention has shifted toward the evaluation and utilization of low-grade limestone deposits (IBM, 2011; Noor & Jagoo, 2025).

The Vindhyan Basin of Central India hosts extensive carbonate formations, particularly within the Rohtas Limestone of the Semri Series (Ramakrishnan & Vaidyanadhan, 2010). However, these deposits often exhibit compositional heterogeneity due to depositional variations, diagenesis, and structural controls (Naqvi & Rogers, 1987; Bianco, 2021).

Recent advancements in geochemical characterization, including XRF, XRD, and machine learning-based mineral classification, have significantly improved the assessment of limestone quality and variability (Liu et al., 2025; Schuster & Feng, 2025). Additionally, remote sensing approaches have enabled large-scale mapping of carbonate deposits (Heriansyah et al., 2025).

This study aims to:

- Evaluate the petrographic characteristics of limestone
- Analyze geochemical variability across stratigraphic horizons
- Assess industrial suitability for cement manufacturing
- Suggest beneficiation strategies for low-grade deposits

2. Study Area

Sidhi District is one of the tribal districts in Madhya Pradesh, India. Sidhi is the district headquarters. Sidhi District reflects the great history of Madhya Pradesh. Sidhi district preserves natural, historical, and cultural history. The Sone River drains this district, which is well-known for its natural riches. On one side of the spectrum of its socio-cultural diversity and tribal ethnic past, the district enjoys a panoramic view of the Kaimur, Kehejua, and Ranimunda hills, ablaze with woodland blossoms and intoxicated by the sweet smell of mahua flowers.

Sidhi is located at 24.42°N, 81.88°E, with an average elevation of 272 metres (892 feet) and a geographical area of 10,526 km^2. Chandela Rajputs, originally from Khajuraho, live in this state. Sanjay Tiger Reserve, also known as Sanjay National Park, is located in the vicinity. Which demonstrates the majesty of the Lions here. Son Ghariyal Sanctuary was established in 1981 under the Wildlife Protection Rule under Section 18 (1) of Gazette Notification No. 14-47 80(2).

The district serves as the state's north-east boundary. There is a well-known resort called Parsili. Ghoghra Devi Temple, located in Gopad Banas Tehsil, hosts an annual Navaratri fair. Birbal, one of Akbar's nine diamonds, is believed to have been born here as well. Baanbhatta is thought to have been born in the district's Bhanwarsen region.

Aditya Birla Group was awarded the title of 'AON Best Employer' for the year 2018. It is the third time the Aditya Birla Group has received this title in the past 7 years. The Aditya Birla Group was also ranked fourth globally and first in Asia Pacific in the 'Top Companies for Leaders' study 2011 conducted by Aon Hewitt, Fortune Magazine, and RBL - a strategic HR and leadership consulting firm. The Aditya Birla Group was also awarded the title of 'No.1 Corporate' under the 'Corporate Image Monitor 2014-15' conducted by Nielsen. It was also awarded the title of 'No.1 Corporate', 'Best in Class', for the third consecutive year under the 'Corporate Image Monitor 2014-15' conducted by Nielsen. Ultra Tech is a brand that stands for 'Strength', 'Reliability', and 'Innovation'. It is these attributes that motivate engineers to push the boundaries of their imagination and create homes, buildings, and structures that reflect the New India.

The limestone in the Majhgawan Extension lease area is part of the Rohtas stage of the Semri Series in the Lower Vindhyan System of Indian Stratigraphy. Figure 1.3 shown the limestone from the Rohtas Stage and the overlying Kaimur sandstone are the only rock types visible along the hill slopes. The valley and hilly area are covered with mixed soil and talus. There are no signs of structural disturbances like folds, faults, or unconformities in the area. The usable limestone found during exploration is usually grey to dark grey and fine-grained with a banded appearance. In terms of quality, high MgO limestone is typically light grey, and its primary beddings are often not visible. The number of shale bands tends to increase towards the bottom of the horizon. Thin shale partings within the limestone have reduced its quality. Based on this behavior, the limestone horizon can be divided into two sections: the Upper limestone horizon and the Lower limestone horizon.

The mining lease covers parts of the villages Hinauti, Dengraha, Biharganj, and Jurmani, which are located in forest land Compartment No. R-725 and 726 of the Mukundpur Extension Forest in Satna District. The mine is accessible via a concrete road that starts at the Toll Plaza, about 35 km south of Rewa City, the district headquarters of Rewa District, and 55 km from Sidhi, the district headquarters of Sidhi District.

The area lies directly south of the Kaimur Hills, which feature a steep scarp that rises up to 600 m RL. The land covered by the Mining Lease is elevated and consists of spurs or hill slopes, with the ground level ranging from 333 m to 518 m MSL. The general terrain slopes gently to the south and east. Limestone and high magnesian limestone outcrops can be seen along the hill slopes shown in figure 1.4. The area included in the Mining Lease has no inhabitants, and the villages are located outside the ML boundary.

The main drainage feature in the area is a perennial nala called Marhwal, which flows from west to east at a distance of around 2.5 km due south. The nala flows into the Son River in Bhawarsen village, which is roughly 15 kilometers east of the ML area. The area covered by the mining lease is forest terrain, and the villages are located a considerable distance away. The Bansagar Canal, a concrete irrigation canal, runs west-east through the southern half of the ML area. The canal has little impact on the local drainage pattern. Figure 1.2 is a photo plate illustrating the general physiography of the ML area.

Sidhi District in Madhya Pradesh is a tribal-rich region known for its natural beauty, cultural heritage, and resources, drained by the son River and surrounded by hill ranges like Kaimur. The area hosts important ecological sites such as Sanjay Tiger Reserve and Son Ghariyal Sanctuary. Geologically, the region contains limestone of the Rohtas Stage (Lower Vindhyan), with distinct upper and lower horizons affected by shale partings. The Majhgawan Extension mining lease area lies in forest terrain with no habitation inside, featuring hilly topography and limestone outcrops.

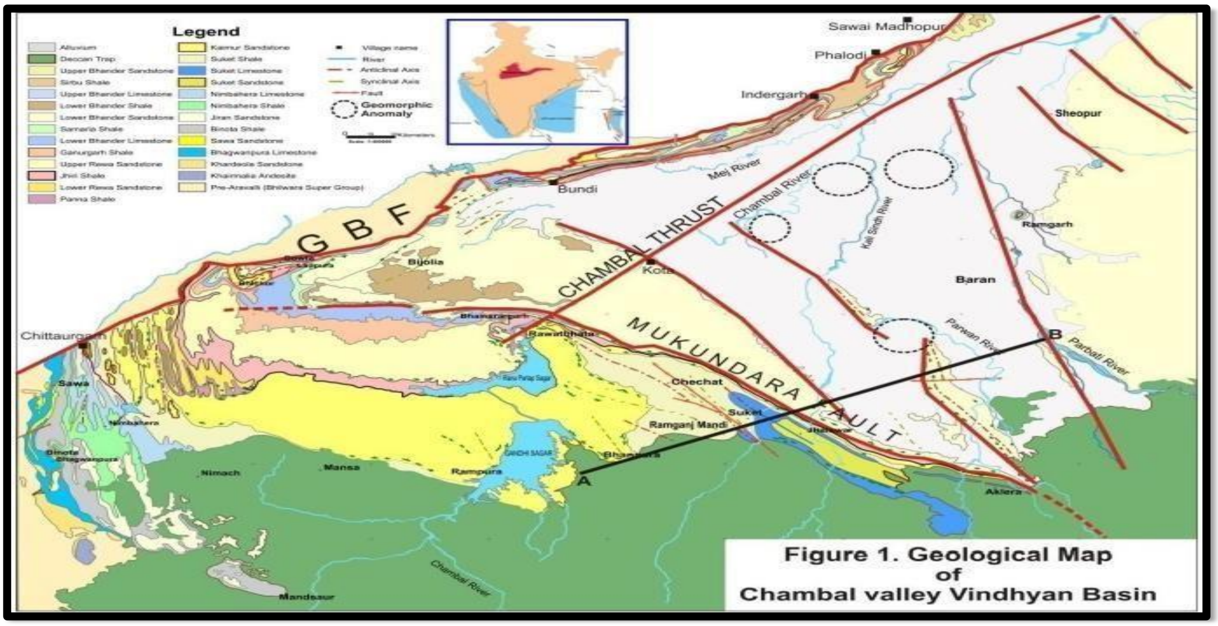


Figure 1: Geological Map of the study area

Figure 2: General Physiography of the Mining Lease area

Figure 3: Field Sample collections of Majhgawan and Hinauti Extension Mines.

The study area lies within the Vindhyan Supergroup, covering parts of Satna and Sidhi districts of Madhya Pradesh. The limestone belongs to the Rohtas Formation of the Semri Series and extends along the Kaimur escarpment (IBM, 2011; UltraTech Cement Ltd., 2023).

Geologically, the formation is characterized by:

- ENE–WSW strike with gentle dip (10°–15°)
- Alternating limestone, shale, and dolomite layers
- Shallow marine depositional environment

Such stratigraphic variability is typical of carbonate platforms and significantly influences geochemical composition (De Waele & Gutiérrez, 2022).

3. Methodology

3.1 Field Investigation

Fieldwork involved borehole litholog analysis, stratigraphic profiling, and systematic sampling across different horizons. Lithological variations were interpreted using borehole data .

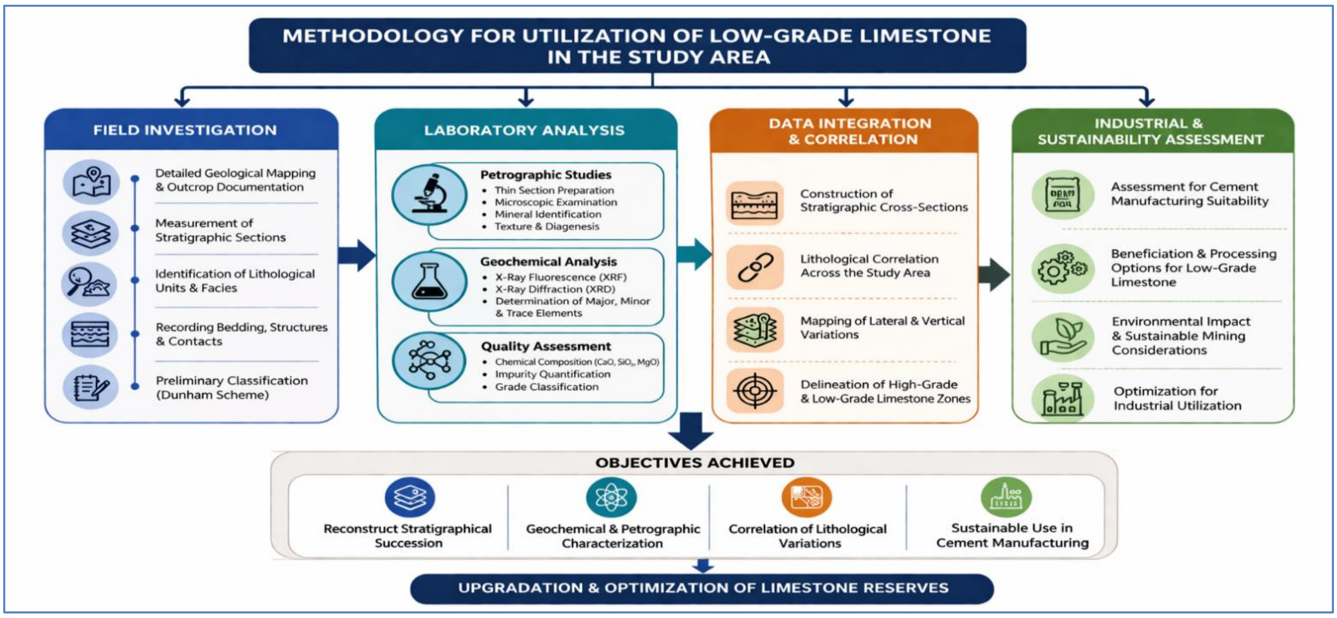
3.2 Laboratory Analysis

The following techniques were used:

- **Petrography:** Thin section microscopy
- **XRD:** Mineralogical phase identification
- **XRF:** Major oxide composition

These methods are widely used in carbonate rock characterization (Bianco, 2021; Adams et al., 2020).

Figure 4: Flow Chart of Methodology for Utilization of Low-Grade Limestone



4. Stratigraphic Characteristics

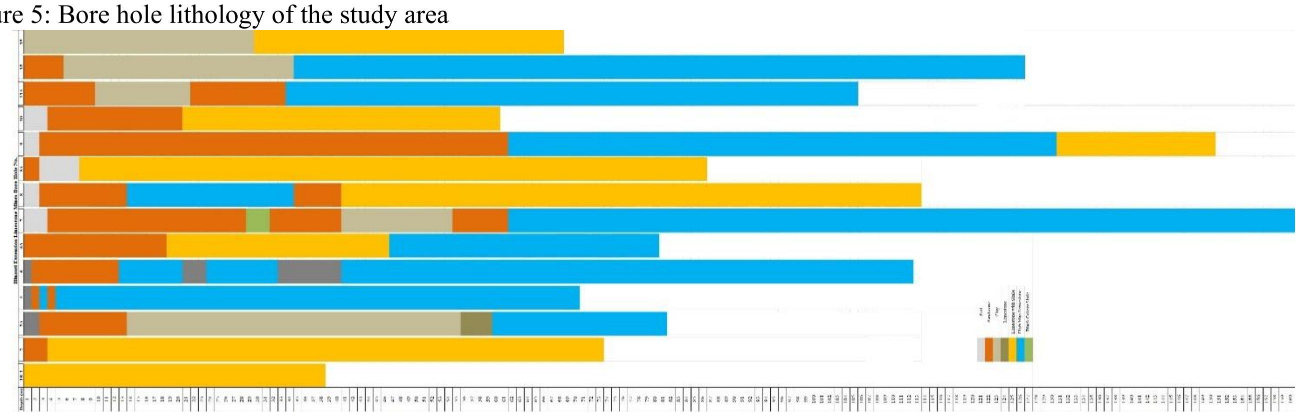
The limestone sequence is divided into following type shown in table 1:

Table 1 Limestone deposits quality and sequence

Horizon	Description	Quality
Upper Horizon	Massive limestone, low impurities	High grade
Lower Horizon	Shaly, dolomitic limestone	Low grade

Higher silica and alumina in the lower horizon reduce its industrial suitability (IBM, 2011; Sympa et al., 2025).

igure 5: Bore hole lithology of the study area



The presented figure 5 is a multi-borehole litholog of the Hinati Extension Limestone Mines, illustrating the vertical and lateral distribution of different rock types with depth across several boreholes. Each column represents an individual borehole, while the vertical axis indicates depth. The color coding highlights variations in lithology, including soil at the top, followed by sandstone, limestone, clay, limestone with shale, high MgO (dolomitic) limestone, and occasional black shale bands. This graphical representation provides a clear understanding of subsurface geological variability within the study area.

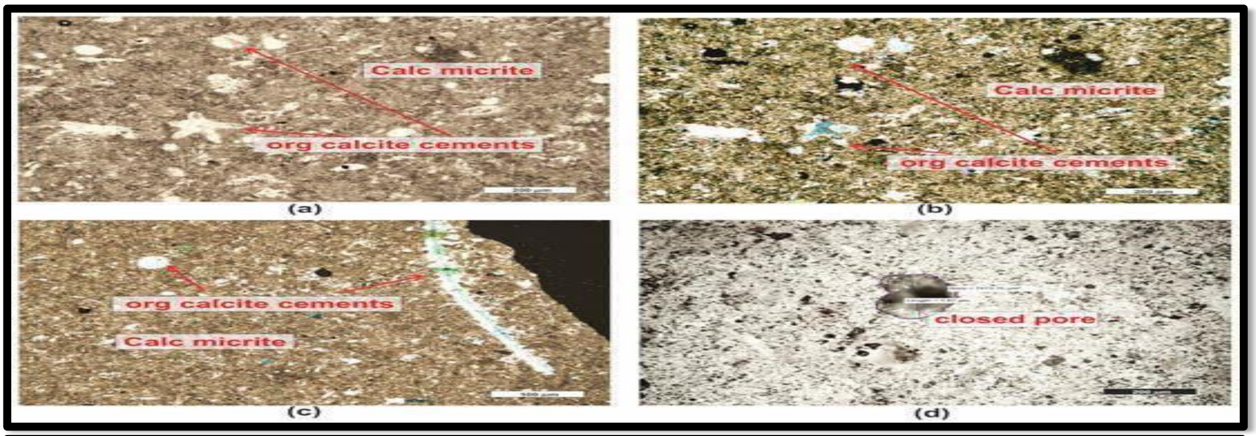
The litholog reveals a high degree of heterogeneity in the limestone deposit. Limestone, which is the primary mineral of interest, occurs in discontinuous bands of varying thickness across different boreholes. In some boreholes, such as TR-1 and 8A, relatively thick and continuous limestone zones are observed, whereas in others, limestone is either thin or interbedded with clay and shale. This irregular distribution indicates variations in depositional conditions as well as post-depositional processes, making the deposit non-uniform in nature.

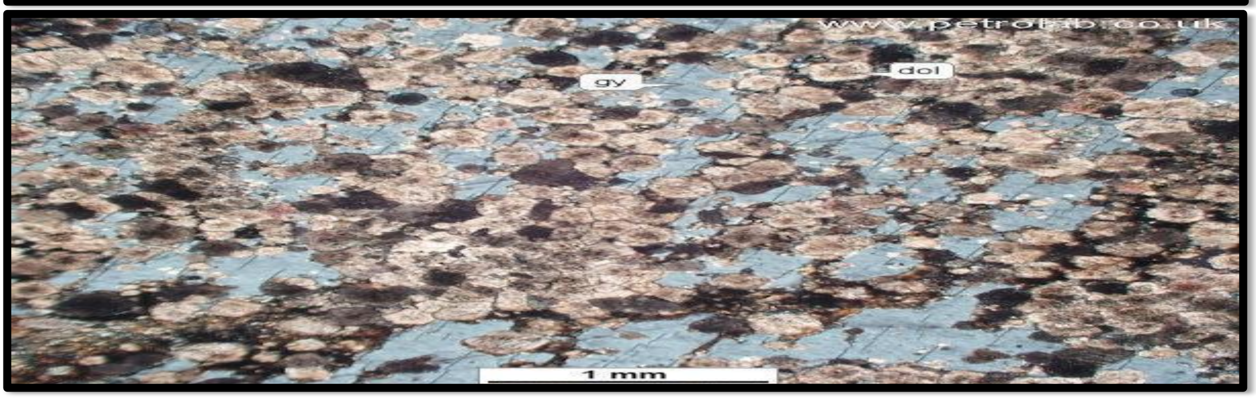
A significant feature of the litholog is the widespread occurrence of high MgO limestone (dolomitic limestone), particularly in the deeper sections of most boreholes. These blue-colored zones dominate the lower depth intervals, suggesting that dolomitization has affected the limestone at depth. From an industrial perspective, this is important because high MgO content reduces the suitability of limestone for cement manufacturing, thereby limiting its direct utilization without blending or beneficiation.

The presence of clay and shale intercalations further complicates the deposit. These layers occur both as thin interbeds and thicker zones, interrupting the continuity of limestone horizons. Such impurities adversely affect the chemical composition, especially by increasing silica and alumina content, which lowers the grade of limestone. Additionally, sandstone units appearing mainly in the upper to middle sections indicate changes in depositional environment, possibly reflecting periods of higher energy conditions during sedimentation.

Overall, the depth-wise distribution suggests a general trend of mixed lithology in the upper and middle portions, transitioning to predominantly dolomitic limestone at greater depths. This vertical variation, combined with lateral inconsistencies across boreholes, highlights the complex geological nature of the deposit. From a mining and industrial standpoint, the deposit requires careful planning, including selective extraction, grade control, and blending strategies to optimize the utilization of available limestone resources.

5. Petrographic Characteristics





5.1 Mineral Composition

The limestone predominantly consists of:

- Calcite (major phase)
- Dolomite (secondary phase)
- Quartz and clay minerals (impurities)

These findings align with global carbonate studies (Bianco, 2021; Yacouba et al., 2024).

5.2 Texture and Structure

Observed features include:

- Fine-grained micritic texture
- Laminations and banding
- Stylolites and microfractures

These indicate low-energy marine deposition and post-depositional compaction (Ramakrishnan & Vaidyanadhan, 2010; Laurent et al., 2021).

5.3 Diagenetic Features

Dolomitization and silicification are common in lower horizons, altering mineral composition and reducing

CaO content (Naqvi & Rogers, 1987; Chen et al., 2022).

6. Geochemical Characteristics

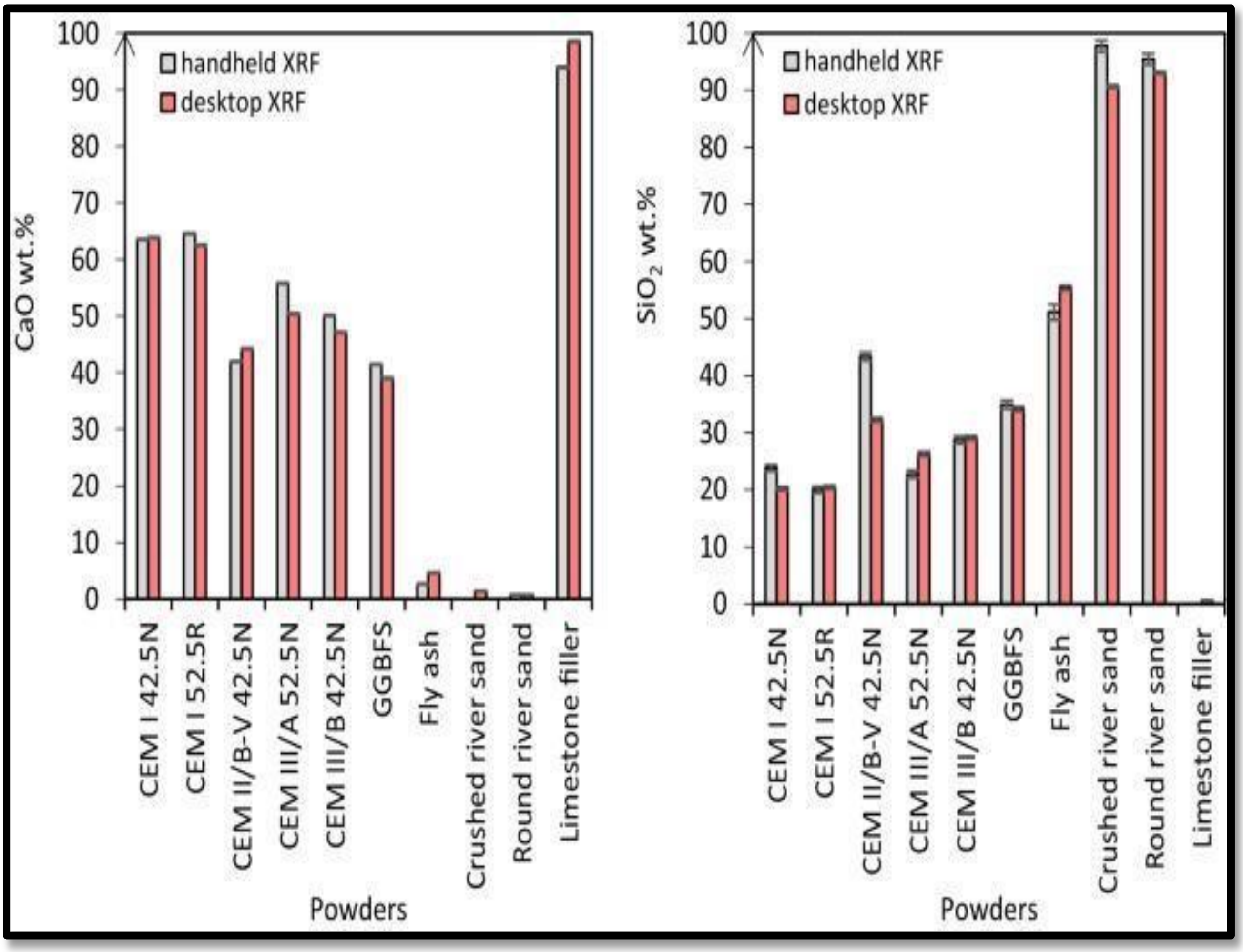
6.1 Major Oxide Composition

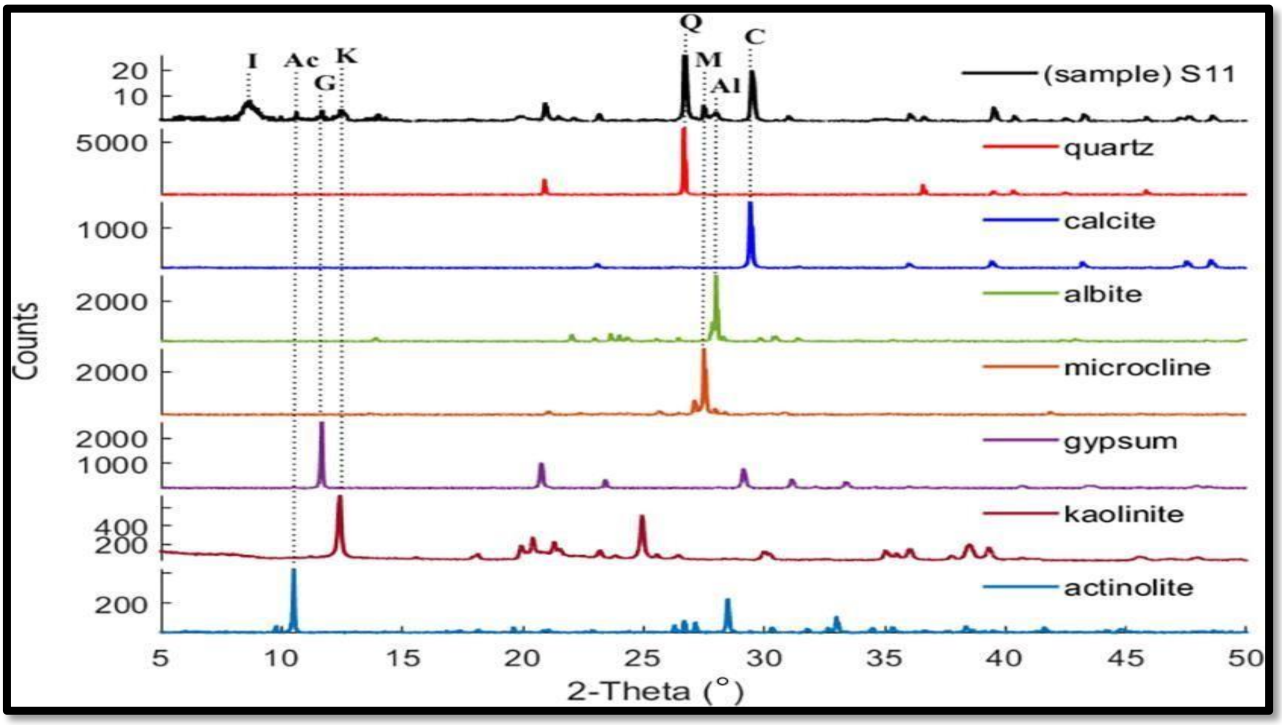
Table: Oxide compositions in the limestone

Oxide	Range (%)	Significance
CaO	38–48	Cement suitability
MgO	3–12	Dolomitization indicator
SiO_2	5–20	Impurity from shale
Al_2O_3	1–6	Clay contamination

High CaO improves clinker quality, while MgO and silica negatively affect cement properties (Noor & Jagoo, 2025; Sympa et al., 2025).

6.2 Geochemical Trends

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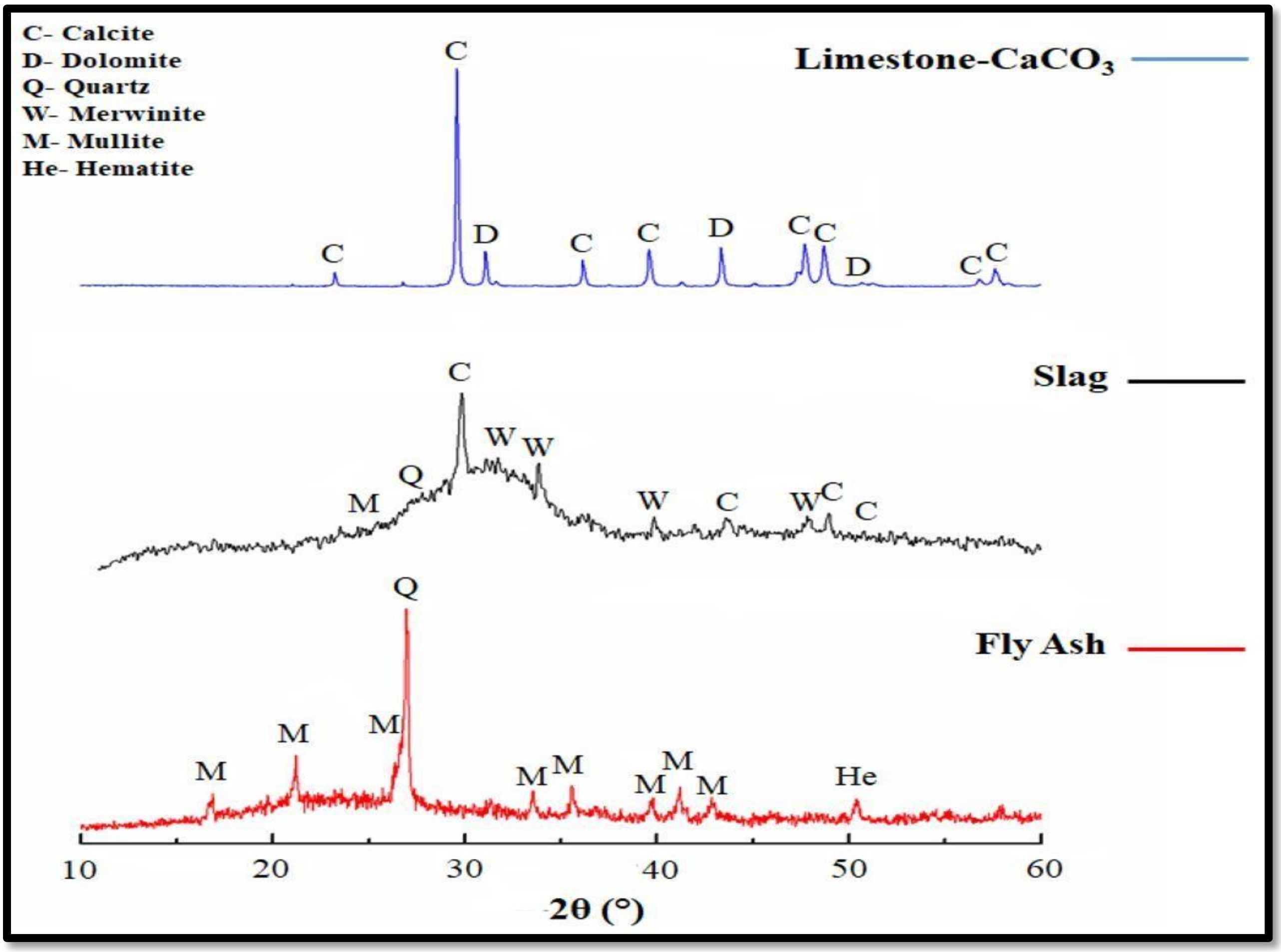
2-Theta (°)


C- Calcite
D- Dolomite
Q- Quartz
W- Merwinite
M- Mullite
He- Hematite
Limestone-CaCO3
Slag
Fly Ash
2θ (°)

Observed trends:

- Decreasing CaO with depth
- Increasing SiO_2 and Al_2O_3 in lower horizons
- Variable MgO indicating dolomitization

Machine learning-based studies confirm similar geochemical variability patterns (Liu et al., 2025).

6.3 XRD and XRF Interpretation

- XRD confirms calcite dominance with dolomite and quartz phases
- XRF highlights chemical heterogeneity across layers

Such variability necessitates blending strategies for industrial use (Schuster & Feng, 2025).

7. Correlation of Lithology and Geochemistry

Lithological variations strongly control geochemical properties:

- Upper horizon → High CaO, low impurities
- Lower horizon → High silica and MgO

This correlation is consistent with carbonate sedimentation models (Goldscheider et al., 2020).

8. Results and Discussion

The limestone deposit exhibits pronounced heterogeneity, primarily controlled by variations in depositional environments and subsequent diagenetic processes. These variations include fluctuations in energy conditions, episodic influx of terrigenous material, and changes in carbonate productivity during sedimentation. As a result, the lithological sequence shows irregular distribution of calcitic limestone interbedded with shale, marl, and occasional dolomitic horizons. Diagenetic alterations such as recrystallization, dolomitization, compaction, and pressure solution further enhance this heterogeneity by modifying original textures, porosity, and mineral composition.

Such heterogeneity is a common characteristic of carbonate basins worldwide, as documented by Parise & Trocino (2020) and more recent studies by Dixit and Mishra (2024, 2025), where lateral and vertical facies variability significantly impacts resource quality and mine planning. In the present deposit, the presence of shale intercalations contributes to increased silica (SiO_2) and alumina (Al_2O_3) content, while dolomitization leads to elevated magnesium oxide (MgO) levels. These compositional variations adversely affect the chemical suitability of limestone, particularly for cement manufacturing, where strict limits on MgO, SiO_2, and other impurities must be maintained to ensure clinker quality and kiln efficiency (Sympa et al., 2025).

Moreover, the heterogeneity influences physical properties such as hardness, grindability, and bulk density, which in turn affect mining operations, crushing efficiency, and raw mix design. High variability in CaO content (e.g., 38–40%) coupled with elevated silica (16–18%) indicates sub-grade to marginal quality limestone, necessitating careful grade control during extraction.

Despite these limitations, the industrial usability of such heterogeneous limestone can be significantly enhanced through modern beneficiation and raw material management techniques. Selective mining, optical sorting, and sensor-based ore sorting can help segregate high-grade limestone from impurity-rich zones. Additionally, blending strategies—both pre-blending in stockpiles and controlled raw mix proportioning—can homogenize feed quality to meet plant specifications. Advances in beneficiation methods such as washing, flotation, and selective crushing have also shown promising results in reducing silica and other deleterious components (Heriansyah et al., 2025).

Therefore, while geological heterogeneity poses challenges to direct utilization, it can be effectively managed through integrated approaches combining detailed geological modeling, geochemical characterization, and modern processing technologies. This not only improves resource utilization but also supports sustainable mining practices by enabling the use of low-grade and marginal limestone resources.

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