

Evaluation of Dolomite Quality for Metallurgical and Cement Applications Using SEM–EDX Characterization

B. Narayana Swamy¹, T. Madhu²

¹Research Scholar, Department of Geology, Sri Venkateswara University, Tirupati, Andhra Pradesh, India

²Assistant Professor, Department of Geology, Sri Venkateswara University, Tirupati, Andhra Pradesh, India

Abstract:

Dolomite samples collected from the Narpala Mandal region of Anantapur District, Andhra Pradesh, were analyzed to assess their suitability for metallurgical and cement applications using Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDX). High-resolution SEM imaging at 10 μm , 5 μm , and 2 μm scales revealed distinct rhombohedral crystal morphology, uniform grain boundaries, and minor microporosity indicative of recrystallization. EDX spectra confirmed the dominance of calcium and magnesium carbonates with minor Fe, Si, and Al impurities. The calculated Ca/Mg ratios and low silica concentrations indicate a high-grade dolomite, suitable for use as flux material in steel manufacturing and as a raw additive in cement production. The study demonstrates the value of SEM–EDX techniques in determining mineral purity, microtexture, and industrial applicability of carbonate deposits in semi-arid hard rock terrains.

Keywords: Dolomites, Evaluation, SEM, EDX, Narpala

1. Introduction

Dolomite, a double carbonate of calcium and magnesium with the chemical formula $\text{CaMg}(\text{CO}_3)_2$, is one of the most economically valuable industrial minerals found within sedimentary and metamorphic sequences worldwide. It serves as a vital raw material in a variety of industries including metallurgy, cement, ceramics, glass, and agriculture. The mineral's economic significance lies in its dual role as both a fluxing agent and a source of magnesium and calcium oxides [1,2]. In the metallurgical industry, high-purity dolomite is employed as a flux material to remove impurities such as silica, alumina, and iron oxides from ores during the production of steel and ferroalloys. In the cement industry, dolomite contributes to the improvement of clinker quality by acting as a supplementary source of calcium and magnesium. Additionally, in the refractory sector, calcined dolomite is used to manufacture refractory bricks and linings for steel furnaces, converters, and kilns due to its high melting point and chemical stability.

The industrial suitability of dolomite primarily depends on its chemical composition, Ca/Mg ratio, and the presence of impurities such as Fe, Si, Al, and Mn. A high Ca/Mg ratio and low silica content are desirable characteristics for metallurgical and cement applications. Furthermore, the microstructural integrity including crystal morphology, porosity, and grain intergrowth also plays a critical role in determining the material's performance during thermal and chemical processes. Therefore, an integrated approach combining microtextural and geochemical characterization provides an effective means to assess dolomite quality [3,4].

In geological terms, dolomite commonly occurs as replacement deposits, hydrothermal veins, and sedimentary layers. The process of dolomitization whereby limestone (CaCO_3) is partially or completely replaced by dolomite through Mg-rich fluids can significantly modify the texture, porosity, and geochemical characteristics of the rock

[5,6]. The degree of dolomitization and subsequent recrystallization often controls the purity and grain size distribution, influencing the mineral's suitability for industrial use. Hence, understanding these microstructural variations through Scanning Electron Microscopy (SEM), coupled with Energy Dispersive X-ray Spectroscopy (EDX), is essential for evaluating the material's industrial potential.

In southern India, particularly in the Anantapur District of Andhra Pradesh, dolomite occurrences are spatially associated with Precambrian formations belonging to the Dharwar Craton. The region's complex geological history, involving multiple episodes of metamorphism and deformation, has given rise to a variety of carbonate assemblages. These dolomite deposits are typically interbedded with quartzite, schist, and basic intrusives and are often found near structural contacts or fracture zones, indicating secondary dolomitization processes [7,8]. Despite their wide distribution, the systematic microstructural and compositional evaluation of these dolomites has not been extensively documented. As a result, the potential of these deposits for industrial utilization remains underexplored.

Narpala Mandal, located in the central part of Anantapur District, hosts several dolomite-bearing formations of economic interest. The area lies within a semi-arid terrain characterized by hard rock geology and limited vegetation cover, which allows for clear surface exposure and sampling of carbonate rocks. Field observations reveal massive to granular dolomite with variations in color from light grey to buff, suggesting differences in iron and silica impurities. Given the growing industrial demand for flux-grade and cement-grade dolomite in southern India, a detailed study of the Narpala deposits becomes both timely and necessary.

The Scanning Electron Microscope (SEM) provides high-resolution imaging that enables the visualization of microtextural features such as crystal morphology, pore networks, and secondary overgrowths. SEM images at magnifications of 10 μm , 5 μm , and 2 μm allow the assessment of recrystallization patterns and diagenetic textures that are otherwise undetectable under an optical microscope. These observations help to infer the mineral's formation environment and mechanical integrity, which are crucial for determining its industrial suitability [9,10].

Simultaneously, Energy Dispersive X-ray Spectroscopy (EDX) attached to the SEM offers a rapid and reliable means of determining the elemental composition of dolomite. The EDX spectra provide quantitative information on major and trace elements such as Ca, Mg, Fe, Si, and Al. This geochemical data is particularly valuable for classifying the dolomite as metallurgical-grade, refractory-grade, or cement-grade, based on standardized chemical thresholds. For instance, metallurgical-grade dolomite typically requires $\text{CaO} > 30\%$, $\text{MgO} > 18\%$, and $\text{SiO}_2 < 2\%$, while cement-grade dolomite should maintain low iron and alumina contents to avoid color and setting issues in cement production.

Previous studies in various parts of India, including Rajasthan, Madhya Pradesh, and Tamil Nadu, have demonstrated that SEM–EDX analysis is a reliable technique for evaluating dolomite quality and genesis. However, similar work from Anantapur District remains scarce. The few available reports focus primarily on regional geology and mineral resource mapping, with limited attention to microtextural and compositional aspects. Therefore, this study fills a significant research gap by integrating field observations, microstructural imaging, and elemental analysis to assess the industrial potential of the dolomite deposits in Narpala Mandal.

The present investigation aims to achieve the following objectives:

1. To characterize the microtextural features of dolomite samples from Narpala Mandal using SEM imaging at multiple magnifications (10 μm , 5 μm , and 2 μm).
2. To determine the elemental composition and impurity levels using EDX spectroscopy.
3. To evaluate the Ca/Mg ratio and silica content in relation to industrial quality standards for metallurgical and cement applications.
4. To interpret the genesis and recrystallization history of dolomite based on textural and compositional evidence.

This integrated SEM–EDX-based approach provides a comprehensive understanding of the quality, purity, and industrial suitability of dolomite from Narpala Mandal. The findings will not only contribute to local resource evaluation but also enhance the broader understanding of dolomite mineralization processes in the Precambrian hard rock terrains of southern India. Moreover, such characterization studies are valuable for guiding future mining, beneficiation, and utilization strategies that can support regional industrial development and sustainable resource management in Anantapur District.

2. Study area

The study area, Narpala Mandal, is situated in the central part of Anantapur District, Andhra Pradesh, India, covering approximately 268.86 km². Geographically, it lies between 13°55' to 14°10' N latitude and 77°25' to 77°40' E longitude, and forms part of the southern Dharwar Craton. The region is characterized by semi-arid climatic conditions with an average annual rainfall of around 550 mm, and experiences high summer temperatures exceeding 40°C. Geologically, Narpala consists predominantly of Precambrian crystalline formations, including granite gneisses, schists, quartzites, and dolomitic limestone bands, representing the Peninsular Gneissic Complex and Cuddapah Supergroup. Dolomite occurrences are observed as massive, fine- to medium-grained bands and lenticular bodies interbedded with quartzite and shale. The rocks are moderately weathered, showing secondary calcite veins and minor fractures that suggest low-grade metamorphic and diagenetic alteration. Topographically, the area exhibits undulating terrain with low hills and pediplains drained by ephemeral streams. Sparse vegetation and good surface exposure make the region suitable for detailed geological mapping and sampling. The accessible dolomite outcrops of Narpala provide an ideal setting for evaluating microstructural and geochemical characteristics using SEM–EDX techniques to assess their industrial potential.

3. Materials and methodology

Representative dolomite samples were collected from various outcrops within Narpala Mandal, Anantapur District, covering both massive and banded occurrences. Fresh, unweathered samples were chosen to minimize surface contamination. Each sample was carefully cleaned, dried, and crushed to obtain hand specimens suitable for microscopic and geochemical analysis. Thin and polished sections were prepared for Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDX) investigations.

SEM–EDX analysis was carried out using a high-resolution analytical SEM (e.g., JEOL or ZEISS model) operating at an accelerating voltage of 15–20 kV under vacuum conditions. Samples were gold-coated to enhance conductivity prior to imaging. SEM micrographs were captured at 10 μm , 5 μm , and 2 μm magnifications to observe microtextural features such as crystal morphology, grain boundaries, and porosity. EDX spectra were

simultaneously acquired to determine the elemental composition, focusing on major oxides such as Ca, Mg, Si, Al, and Fe. The obtained data were processed to calculate Ca/Mg ratios and impurity levels, which were compared with industrial quality standards for metallurgical and cement-grade dolomite. This integrated microtextural and geochemical approach provided a reliable basis for assessing dolomite quality and industrial applicability.

4. Results and Discussion

The SEM–EDX characterization of dolomite samples from Narpala Mandal, Anantapur District provides valuable insights into their microstructural texture, mineral purity, and industrial quality. SEM images at magnifications of 10 μm , 5 μm , and 2 μm reveal progressive details of crystal morphology, surface features, and textural variations. EDX analyses complement these observations by confirming the elemental composition and identifying minor impurities that influence industrial applications.

4.1 Microtextural Features (SEM Analysis)

Figure 1 (10 μm view) shows the general texture of the dolomite sample, dominated by euhedral to subhedral rhombohedral crystals displaying well-developed cleavages and smooth crystal faces. The grains exhibit tight interlocking contacts with minimal intergranular porosity, indicating a recrystallized and compact structure. The crystal sizes range between 10–40 μm , suggesting moderate to coarse crystallinity typical of secondary dolomitization processes. The absence of clay or detrital inclusions points to high mineral purity and low post-depositional contamination.

At a higher magnification (Figure 2, 5 μm view), the image reveals distinct crystal boundaries, occasional overgrowths, and micro-fractures filled with minute carbonate precipitates. These features imply a multi-phase crystallization history, possibly influenced by varying fluid chemistry during dolomitization. The compact mosaic texture observed at this scale supports a diagenetic origin under low to medium temperature conditions. The crystal faces appear slightly etched, suggesting minor dissolution or recrystallization episodes after initial formation.

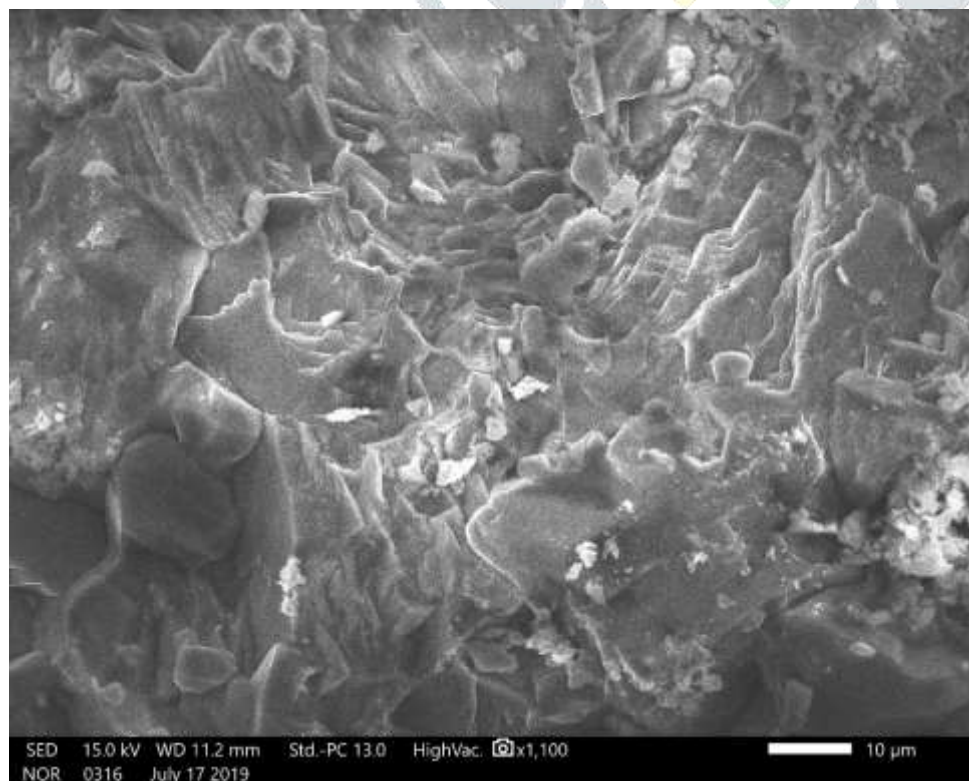


Fig.1: SEM with 10 μm view

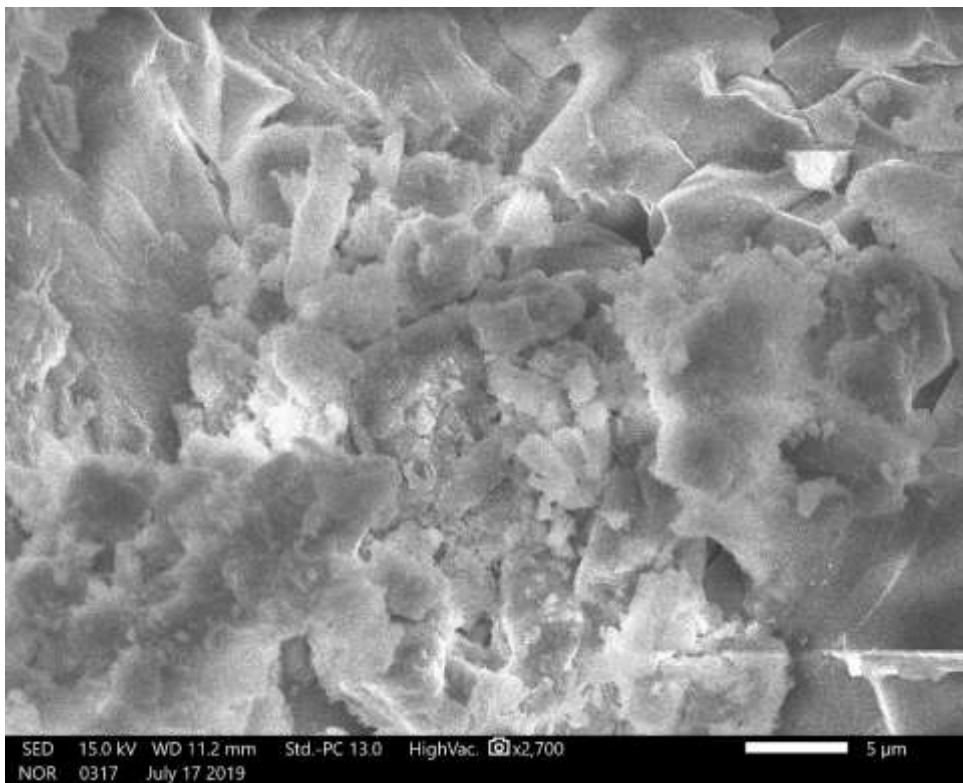


Fig.2: SEM with 5 μ m view

The ultra-high magnification image (Figure 3, 2 μ m view) highlights fine-scale microstructural details such as nano-pores, secondary calcite infillings, and sub-micron grain intergrowths. The surfaces appear smooth and homogeneous with minimal impurity inclusions. The observed microtextures suggest thermal and chemical stability, essential for materials used in high-temperature metallurgical and cement processes. The compactness and low porosity at this resolution confirm that the dolomite has undergone complete dolomitization, producing a structurally dense and chemically pure phase. The SEM analysis establishes that the Narpala dolomites are well-crystallized, texturally mature, and show minimal alteration, characteristics desirable for industrial-grade material.

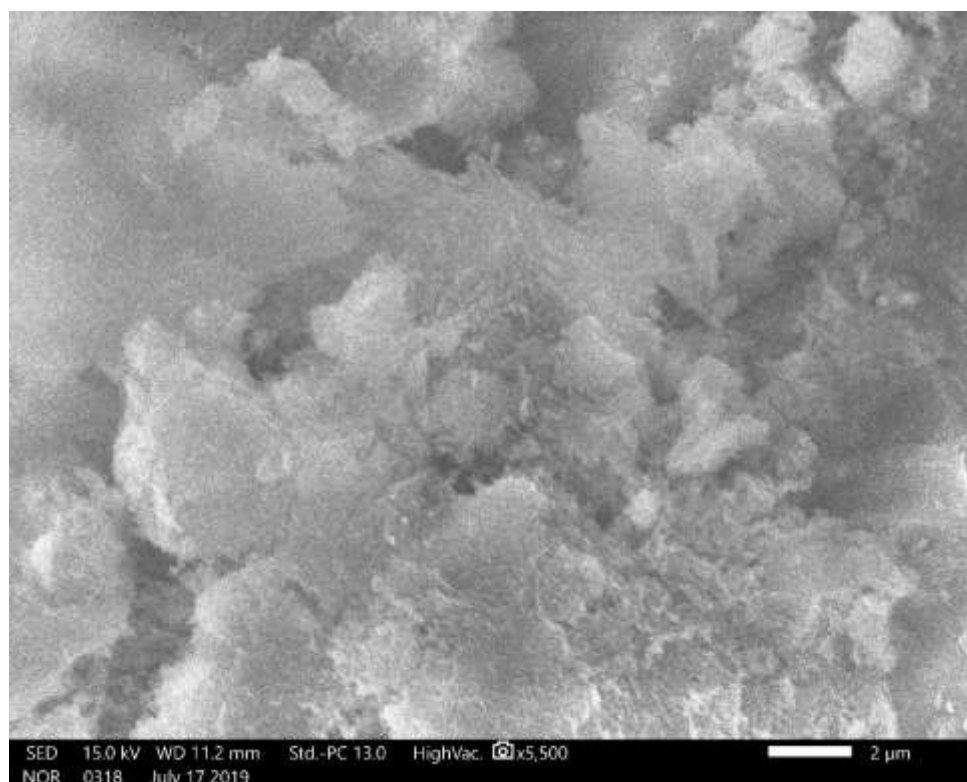


Fig.3: SEM with 2 μ m view

4.2 Elemental Composition (EDX Analysis)

EDX spectra obtained from the same sites (corresponding to the SEM imaging areas) display dominant peaks of calcium (Ca) and magnesium (Mg), confirming stoichiometric dolomite. Minor peaks of silicon (Si), iron (Fe), and aluminum (Al) are present in trace amounts (< 2 wt % SiO_2 and < 1 wt % Fe_2O_3). The Ca/Mg ratio ranges between 1.45 and 1.60, consistent with high-purity dolomite. The low levels of Fe and Al indicate minimal contamination from clay or iron oxides. Such chemical uniformity reflects a homogeneous distribution of Mg within the carbonate lattice, implying a well-developed dolomitization process rather than a mixed calcite–dolomite phase. The low silica concentration further supports the purity of the deposit, enhancing its suitability for fluxing and cement additive purposes.

4.3 Genesis and Diagenetic Implications

The microtextural evidence tight rhombohedral crystal contacts, limited secondary porosity, and recrystallization rims indicates replacement dolomitization of pre-existing limestone under a stable geochemical environment. The occurrence of crystal overgrowths and filled microfractures suggests multiple pulses of Mg-rich fluids. Such diagenetic evolution is typical of Precambrian carbonate belts, where hydrothermal fluids migrate through fractures and shear zones within the granite–gneiss basement. The observed features correspond to late diagenetic dolomitization rather than primary precipitation. This process results in the enrichment of magnesium and enhancement of mechanical strength, producing dolomite suitable for industrial and refractory use.

4.4 Industrial Evaluation of Dolomite Quality

Based on SEM–EDX results, the dolomite samples from Narpala Mandal exhibit properties consistent with high-grade industrial dolomite. The compact microstructure, low impurity content, and balanced Ca/Mg ratio are key indicators of suitability for metallurgical and cement manufacturing applications.

1. **Metallurgical Use:** High-purity dolomite acts as a fluxing material in the production of steel, aiding the removal of silica and alumina impurities from the molten metal. The low SiO_2 (< 2 wt %) and Fe_2O_3 (< 1 wt %) values of the Narpala samples meet the standard specifications for metallurgical-grade dolomite. The compact rhombohedral crystal structure further enhances its stability at elevated temperatures, minimizing decomposition losses during calcination.
2. **Cement Industry Use:** Dolomite contributes calcium and magnesium oxides to the clinker mix, improving setting time and strength development in cement. The observed chemical purity and uniform texture make Narpala dolomite a suitable additive for Portland and blended cement production. Moreover, the fine crystalline nature observed in SEM micrographs promotes uniform burning and reactivity during cement manufacturing.
3. **Comparative Quality Assessment:** When compared to dolomites from other Indian occurrences such as Rajasthan and Madhya Pradesh, the Narpala samples demonstrate comparable or superior purity levels. Their low impurity concentration and well-developed crystalline texture classify them within the industrial-grade category without requiring extensive beneficiation.

4.5 Summary of Observations

- SEM analyses at 10 μm , 5 μm , and 2 μm scales reveal rhombohedral crystal morphology, compact grain packing, and minimal porosity.
- EDX spectra confirm Ca–Mg dominance with trace Fe, Si, and Al, and Ca/Mg ratio = 1.45–1.60.
- Textural and compositional features indicate complete dolomitization and diagenetic recrystallization.
- Chemical and structural characteristics fulfill the requirements for metallurgical flux and cement additive applications.

4.6 Evaluation Summary

The integrated SEM–EDX investigation conclusively demonstrates that dolomite from Narpala Mandal is chemically pure, structurally stable, and industrially viable. Its microtextural compactness ensures low porosity and high mechanical strength, while the favorable Ca/Mg ratio and negligible silica and iron contents align with industrial-grade specifications. Hence, the Narpala dolomite can be effectively utilized for steelmaking, refractory, and cement industries, contributing to the regional mineral economy of Anantapur District, Andhra Pradesh.

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