Original Research Paper

Volume - 16 | Issue - 08 | August - 2026 | PRINT ISSN No. 2249 - 555X | DOI : 10.36106/ijar

Geology

VARIATIONS OF MINERALOGICAL, GEOCHEMICAL AND PHYSICO – MECHANICAL PROPERTIES OF MARBLES OF RAJSAMAND DISTRICT, RAJASTHAN

S. N. Dodia	Research Scholar, Department of Geology, B.N. University, Udaipur
Hemant Sen	Assistant Professor, Department of Geology, B.N. University, Udaaipur
Vinod Agrawal	Retired Professor, Department of Geology, M.L. Sukhadia University, Udaipur

ABSTRACT The present study evaluates the geological setting, mineralogical, geochemical, and physico-mechanical properties of marbles from Rajsamand District, Rajasthan. Fifteen representative marble samples collected from major quarry belts were investigated through petrographic, whole-rock geochemical, and laboratory engineering analyses. The marbles are predominantly dolomitic, composed mainly of calcite and dolomite with minor quartz, amphiboles, biotite, muscovite, and iron oxides. Geochemical data indicate uniform CaO and MgO contents but variable SiO_2 concentrations. Physico-mechanical tests reveal high compressive strength, density, and specific gravity, with low porosity and water absorption. Most samples satisfy BIS and ASTM specifications, confirming their suitability as high-quality dimension and decorative stones.

KEYWORDS : Rajsamand marble, Petrography, Geochemistry of marble, Physico-mechanical Properties of marble.

INTRODUCTION

Geologically, marble is a metamorphic rock formed through the recrystallization of sedimentary carbonate rocks, most commonly limestone and dolostone (dolomite rock). In commercial terminology, however, marble refers to any relatively soft, compact rock that can be extracted in large blocks, sawn into slabs, and polished to obtain an attractive finish (IBM, 1993; Trivedi, 1998). According to the American Society for Testing and Materials (ASTM), commercial marble is defined as a crystalline rock composed predominantly of one or more minerals such as calcite, dolomite, or serpentine and is capable of taking a good polish.

Marble is one of the most valuable dimension and decorative stones owing to its excellent aesthetic appeal, durability, and versatility. Its attractive colours, intricate patterns, and superior polishing characteristics have made it a preferred material for architects, sculptors, and designers since ancient times. Historical monuments and modern architectural structures alike extensively utilize marble for flooring, wall cladding, monuments, sculptures, countertops, and ornamental purposes. The increasing demand for premium building materials in residential, commercial, and institutional construction has substantially enhanced the consumption of marble worldwide.

Rajasthan occupies a unique position as the leading producer of high-quality marble in India. Marble deposits are reported from 20 of the state's 33 districts (Dwivedi, 1991; DMG, 1996; DMG, 2001; Jha, 2003; DMG, 2014; IBM, 2015). These commercially important deposits were formed during different geological periods, ranging from the Archean to the Mesozoic (Middle Jurassic). However, the majority of commercially exploited marble deposits belong to the Aravalli and Delhi Supergroups of Palaeoproterozoic and Mesoproterozoic age, respectively (Sen et al., 2021). The state produces a wide range of marble varieties that differ in colour, texture, mineralogical composition, and physico-mechanical properties, making Rajasthan one of the most important marble-producing regions in the world.

Geological Setup of Rajsamand Marble Deposits

Rajsamand District, located in south-central Rajasthan, is one of the most important marble-producing regions in India. The marble deposits are mainly exposed in the northern and north-western parts of the twin towns of Rajnagar and Kankroli within the well-known "Hammer Head Syncline." Heron (1953) assigned these marble deposits to the Raialo Series, which he considered younger than the Aravalli System. Subsequent geological investigations, however, have established that these deposits belong to the Aravalli Supergroup of Lower to Middle Proterozoic age.

Based on lithostratigraphy, structural characteristics, metamorphism, depositional environment, and structural disposition, the Aravalli Supergroup has been subdivided into six major groups: the Debari Group (oldest), Udaipur Group, Bari Lake (Kankroli) Group, Jharol (Dovda or Nathdwara) Group, Lunavada Group, and the youngest Champaner Group. The Rajsamand marble deposits are mainly associated with the Dovda and Kankroli Groups of the Aravalli Supergroup (Sastry, 1992; Gupta et al., 1992).

On the basis of structural configuration and physical continuity, the marble deposits of Rajsamand are distributed into the following three major belts:

Jogi-Magra–Agaria–Lava–Sardargarh Belt: This belt includes the Jogi-Magra, Kotri, Agaria, Parvati, Lava-Sardargarh, and Saprav-ka-Guda mining areas. It is located in the eastern part of the district.

Tasol–Devra-ka-Khera–Devi-Khera–Binol Belt: This central belt comprises the Tasol, Devra-ka-Khera, Devi-Khera, and Binol mining areas situated to the east of National Highway (NH-8). Although these deposits occur as isolated bodies with limited structural continuity, they exhibit similar geological characteristics and are therefore grouped together.

Kelwa–Morwar–Janjar–Sapol Belt: This belt lies west of NH-8 and includes Kelwa, Nizarna, Umti, Morwar, Janjar, Sapol, Atma, Talai, Arna, Juni-Arna, Leva-ka-Guda, Dhameta, Khandiya, Dabkudiya, Koyal, and Dholikhan mining areas. This belt contains several of the most productive and commercially important marble deposits in the district.

Marble Resource Potentiality

Rajasthan occupies a dominant position in India with respect to the availability and production of high-quality marble resources. The state possesses a remarkable diversity of marble varieties distinguished by their colour, texture, mineral composition, and commercial value, making it the country's largest producer of dimension stone. Marble deposits are distributed across 20 districts of Rajasthan, reflecting their extensive geographical occurrence (Dwivedi, 1991; DMG, 1996; DMG, 2001; Jha, 2003; DMG, 2014; IBM, 2015).

According to the Department of Mines and Geology, Rajasthan (DMG, 2023–24), a total of 1,889 marble mining leases have been granted in the state. Of these, 1,683 leases are for white marble and 206 leases are for green marble (serpentinite). In addition, nearly 740 quarry licences have been issued for marble extraction. Rajsamand District alone accounts for 976 marble mining leases, representing approximately 51% of the total marble leases in Rajasthan, highlighting its overwhelming importance in the state's marble industry.

Marble quarrying in the Rajsamand region is predominantly carried out through open-cast, semi-mechanized mining methods (Figures 1 and 2). In this method, operations such as excavation, loosening, loading, and transportation of overburden and marble blocks are performed using a combination of manual labour and mechanical equipment. The mining method is selected according to the depth of the quarry, local topography, geological conditions, and the desired production capacity to ensure efficient extraction with minimum operational cost.

The semi-mechanized quarrying process generally comprises four major stages:

- Removal of overburden.
- Preparation of marble blocks through drilling and wire-saw cutting.
- Separation and extraction of dimension blocks.
- Transportation of the extracted blocks to processing and polishing units.

The Rajsamand marble industry plays a significant role in the economy of Rajasthan by generating employment, promoting exports, and supplying premium-quality marble for domestic and international markets. The district is particularly renowned for commercially important marble varieties such as Morwad White, Arna, Janjar, Dhameta, Nizarna, and Kelwa marbles, which are highly valued for their superior mineralogical characteristics, aesthetic appeal, and excellent physico-mechanical properties. Owing to these attributes, Rajsamand continues to be one of the foremost centres of marble production and processing in India.

Figure 1: Panoramic View of Agaria Marble Mining Area, Rajsamand

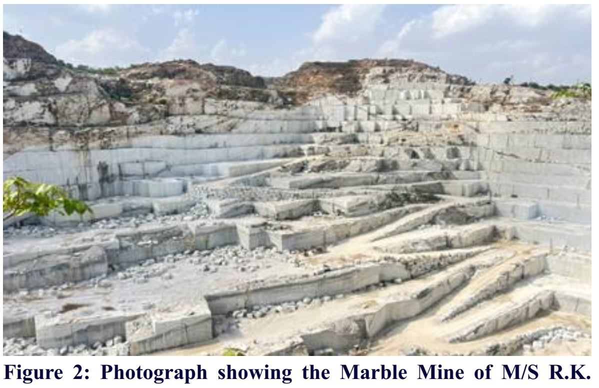


Figure 2: Photograph showing the Marble Mine of M/S R.K. Marbles at Morwad

METHODOLOGY

The present study was undertaken to evaluate the geological setting and to investigate the mineralogical, textural (fabric), geochemical, and physico-mechanical properties of marble deposits in the Rajsamand District of Rajasthan. Both secondary and primary data were utilized to achieve the objectives of the study. Secondary data pertaining to the regional geology, lithostratigraphy, structural framework, mining activities, and marble resources were collected from published literature, reports of the Department of Mines and Geology (DMG), Indian Bureau of Mines (IBM), Geological Survey of India (GSI), and other relevant scientific publications.

Primary data were generated through systematic field investigations and representative sample collection from the major marble-producing areas of Rajsamand District. Detailed field visits were conducted to several active marble mining areas, including Kelwa, Amet, Agaria, Sapro Ka Guda, Sapol, Morwad, Nijharna, and adjoining quarry belt. During field investigations, observations were made regarding the lithological characteristics, structural features, mining methods, colour variations, texture, and field relationships of the marble deposits. Representative fresh marble samples of different commercial varieties were collected from quarries (Figure 3) ensure their suitability for laboratory investigations.

The collected samples were subjected to detailed laboratory analyses for the determination of their mineralogical, petrographic, geochemical, and physico-mechanical characteristics. Mineralogical and petrographic investigations were carried out to identify the constituent minerals, mineral proportions, grain size, texture, and fabric using standard petrographic techniques. Geochemical analyses were performed to determine the major oxide composition and to assess chemical variations among different marble varieties. Physico-mechanical properties, including bulk density, water absorption, compressive strength, flexural strength, abrasion resistance, and other engineering parameters, were determined using standard laboratory procedures.

The analytical results obtained from the laboratory investigations were interpreted to evaluate the quality, durability, and commercial suitability of the marble varieties. Furthermore, the geochemical and physico-mechanical properties were compared with the specifications prescribed by the American Society for Testing and Materials (ASTM) and the Bureau of Indian Standards (BIS) to assess their conformity with national and international quality standards for dimension stones.

Petrography of Marble Samples

In the present study, a total of 15 representative marble samples from different quarry belts of the Rajsamand area were selected for detailed petrographic investigation. The samples were chosen to represent the variations in colour, texture, mineral composition, and field characteristics observed across the major marble-producing localities.

Megascopically, the majority of the Rajsamand marbles are white to off-white in colour, hard, compact, and massive in nature. They generally exhibit a coarse-grained, crystalline, granular texture with prominent mineral banding defined by the concentration of mafic minerals and other accessory constituents (Figures 3 and 4). Variations in colour and banding are primarily attributed to differences in the abundance and distribution of accessory minerals such as amphiboles, biotite, muscovite, quartz, and iron oxides.

Microscopic examination of thin sections reveals that the marbles are medium- to coarse-grained, inequigranular, and display a well-developed granoblastic texture, which is characteristic of recrystallized metamorphic carbonate rocks. The dominant mineral assemblage consists of calcite and dolomite, occurring as interlocking anhedral to subhedral crystals. These carbonate minerals exhibit well-developed rhombohedral cleavage, characteristic polysynthetic twinning, and straight to slightly curved grain boundaries. In several samples, the grain boundaries are irregular and sutured, reflecting recrystallization under metamorphic conditions. The coexistence of calcite and dolomite indicates that the marbles were derived from impure carbonate protoliths containing both limestone and dolostone components (Winter, 2010; Evans, 2004).

Accessory minerals identified in the thin sections include amphiboles, biotite, muscovite, quartz, and opaque iron oxides. Amphiboles generally occur as elongated prismatic crystals, whereas biotite and muscovite are present as fine to medium-grained flaky minerals aligned along weak foliation or concentrated within mineral-rich bands. Quartz occurs as anhedral, interstitial grains occupying spaces between carbonate crystals. The occurrence of these silicate minerals suggests that the original carbonate sediments contained varying proportions of silica- and clay-rich impurities, which recrystallized during regional metamorphism to form silicate-bearing marble (Yardley, 1989; Winter, 2010; Bucher and Grapes, 2011).

Iron oxides are present in minor amounts in several samples, commonly occurring as fine disseminations or concentrated along grain boundaries and microfractures. Their distribution indicates the mobilization and subsequent precipitation of iron during metamorphism or later hydrothermal alteration processes (Evans, 2004; Deer et al., 2013). In a few samples, the iron oxides impart light grey to brownish streaks and bands, contributing to the colour variation observed in hand specimens.

Overall, the petrographic characteristics indicate that the Rajsamand marbles have undergone extensive recrystallization under medium-grade regional metamorphic conditions, resulting in the development of a coarse crystalline granoblastic fabric with interlocking carbonate minerals. The mineralogical variations observed among different marble varieties primarily reflect differences in the composition of the original carbonate sediments and the nature of associated impurities. Representative photomicrographs illustrating the mineralogical and textural features of the studied marble samples are presented in Figures 5 to 10.

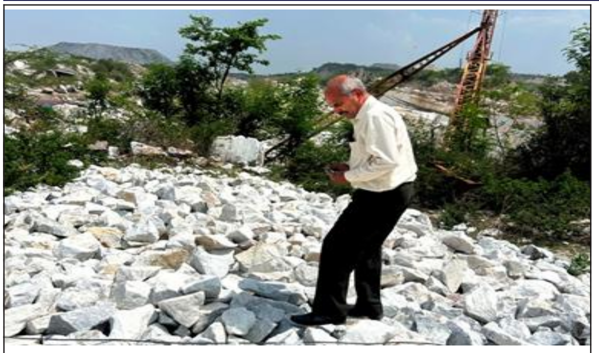


Figure 3: Collection of marble sample from the mine site

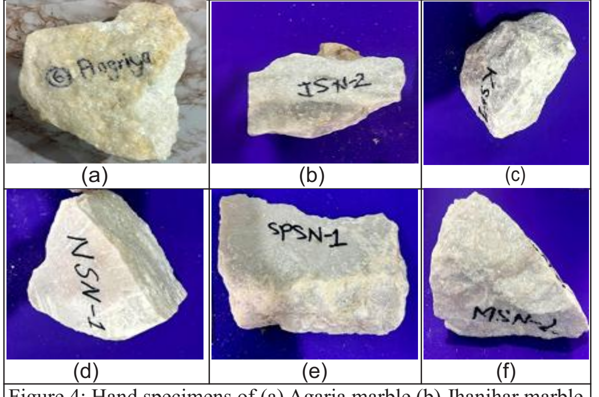


Figure 4: Hand specimens of (a) Agaria marble (b) Jhanjhar marble (c) Kelwa marble (d) Nijharna marble (e) Sapol marble and (f) Morward marble(c) Kelwa marble (d) Nijharna marble (e) Sapol marble and (f) Morward marble

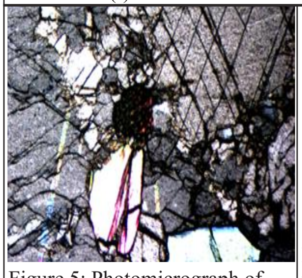


Figure 5: Photomicrograph of marble from Agaria, Rajsamand, showing medium to coarse grained, inequigranular granoblastic texture. Carbonate grains (calcite and dolomite) are the major constituents. Impurities of amohibole and muscovite are visible.

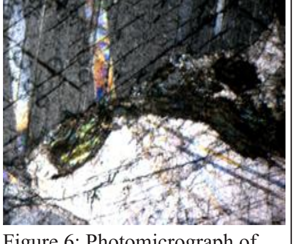
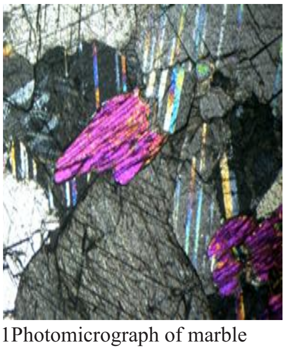


Figure 6: Photomicrograph of marble from Jhanjhar, Rajsamand, showing coarse grained, granoblastic texture. Carbonate grains (calcite and dolomite) showing well developed cleavages and characteristic twinning. Impurities of amohibole are invariably present.



1Photomicrograph of marble from Kelwa, Rajsamand, showing medium to coarse grained, inequigranular granoblastic texture. Carbonate grains (calcite and dolomite) are the major constituents. Impurities of muscovite are visible.

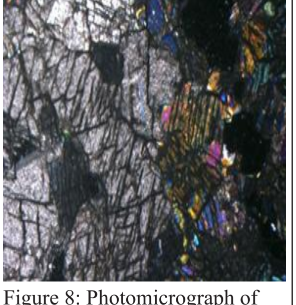


Figure 8: Photomicrograph of marble from Nijharna, Rajsamand, showing coarse grained, granoblastic texture. Carbonate grains (calcite and dolomite) showing well developed cleavages. Amohibole is invariably present as accessory mineral.

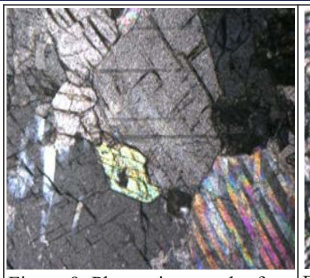


Figure 9: Photomicrograph of marble from Sapol, Rajsamand, showing coarse grained, granoblastic texture. Carbonate grains (calcite and dolomite) showing well developed cleavages and twinning. Muscovite is invariably present as accessory mineral.

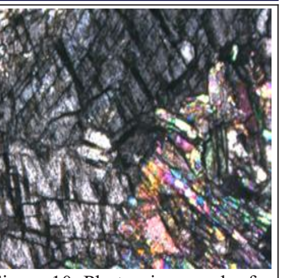


Figure 10: Photomicrograph of marble from Morwad, Rajsamand, showing coarse grained, granoblastic texture. Carbonate grains (calcite and dolomite) showing well developed cleavages. Muscovite is invariably present as accessory mineral.

Chemical Composition of Marbles

The chemical composition of marble is an important factor governing its quality, durability, aesthetic characteristics, and suitability for use as a dimension and decorative stone. The major chemical constituents influencing these properties include calcium oxide (CaO), magnesium oxide (MgO), silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), and Loss on Ignition (LOI). Variations in the concentration of these oxides reflect differences in the mineralogical composition, purity of the carbonate protolith, and the presence of silicate and other accessory minerals.

In the present investigation, 15 representative marble samples collected from different quarry belts of the Rajsamand area were subjected to whole-rock chemical analysis. The analytical results are presented in Table 1. The geochemical data indicate that the Rajsamand marbles are predominantly dolomitic in composition, with comparatively high contents of both CaO and MgO.

The CaO content varies from 28.91% to 31.50%, with an average value of 30.30%, whereas the MgO content ranges between 18.95% and 22.05%, averaging 20.71%. The relatively high MgO content, together with moderate CaO values, confirms the predominance of dolomite over calcite in most of the studied marble samples. The limited variation in these major oxides suggests broadly uniform carbonate mineralogy across the Rajsamand marble deposits.

The concentration of Fe_2O_3 ranges from 0.28% to 0.64%, with an average value of 0.42%. Although present in minor quantities, iron oxide plays an important role in influencing the colour and appearance of the marble. Slightly elevated Fe_2O_3 contents are responsible for the development of grey, cream, or brownish streaks and bands observed in some marble varieties. The Al_2O_3 content also exhibits only minor variation, ranging from 0.18% to 0.98%, with an average of 0.47%. The low concentration of alumina indicates that the marbles contain only small amounts of clay-derived aluminosilicate minerals.

In contrast, the SiO_2 content shows considerable variation, ranging from 0.55% to 15.77%, with an average value of 5.86%. The lowest silica content was recorded in the Saprao Ka Guda marble sample (SGSN-2), whereas the highest value was observed in the Kelwa marble sample (KSN-1). The wide variation in silica content reflects differences in the abundance of quartz and other silicate minerals, indicating variable amounts of non-carbonate impurities in the original sedimentary protolith. Higher silica content generally corresponds to the increased presence of quartz and silicate accessory minerals, which is also supported by petrographic observations.

The Loss on Ignition (LOI) values range from 32.72% to 46.51%, with an average of 41.79%. The relatively high LOI values are characteristic of carbonate rocks and represent the release of carbon dioxide (CO_2) during the thermal decomposition of calcite and dolomite. Variations in LOI largely correspond to differences in carbonate mineral content and the proportion of non-carbonate impurities within the marble.

Overall, the geochemical characteristics indicate that the Rajsamand marbles are predominantly dolomitic marbles with relatively consistent concentrations of CaO and MgO, while the observed variations in SiO_2, Fe_2O_3, and Al_2O_3 are mainly controlled by the abundance of accessory silicate and oxide minerals. These compositional differences influence the colour, texture, durability, and commercial quality of the marble, thereby determining its suitability for various architectural and decorative applications.

Table 1: Chemical Composition of Rajsamand Marbles

S.No.	Sample Number	Location	Compressive Strength (Kg/cm^2)	Water Absorption %	Specific Gravity	Density g/cc	Apparent Porosity %	Rock Hardness
1	ASN-1	Agaria	716.23	0.32	2.85	3.00	0.91	3.25
2	ASN - 2	Agaria	709.60	0.19	2.85	3.06	0.54	3.28
3	ASN - 3	Agaria	745.50	0.24	2.87	3.03	0.65	3.23
4	JSN - 1	Jhaanjhar	909.67	0.13	2.94	3.04	0.38	3.28
5	JSN - 2	Jhaanjhar	920.45	0.14	2.97	3.02	0.35	3.24
6	MSN -1	Morwad	797.30	0.24	2.85	2.95	0.69	3.26
7	MSN - 2	Morwad	982.58	0.09	2.86	2.98	0.26	3.26
8	SPSN - 1	Sapol	1098.01	0.17	2.85	3.07	0.49	3.27
9	SPSN - 2	Sapol	1095.64	0.16	2.83	3.01	0.45	3.28
10	KSN - 1	Kelwa	1104.43	0.09	2.94	3.10	0.26	3.80
11	KSN - 2	Kelwa	1110.20	0.11	2.96	3.05	0.24	3.67
12	SGSN - 1	Saprao ka Guda	1006.34	0.16	2.85	2.99	0.46	3.27
13	SGSN - 2	Saprao ka Guda	1002.45	0.17	2.83	2.96	0.35	3.16
14	NSN - 1	Nijaharna	1227.61	0.21	2.84	3.06	1.03	3.30
15	NSN - 2	Nijaharna	1111.57	0.09	2.78	3.05	0.25	3.35
AVERAGE	**969.17**	**0.17**	**2.87**	**3.02**	**0.49**	**3.33**		

Physico-mechanical Properties

The quality and commercial value of dimension stones depend not only on their aesthetic appearance, colour, and texture but also on their petrographic, physical, and mechanical characteristics. These properties govern the strength, durability, weathering resistance, and long-term performance of the stone in construction and architectural applications. Therefore, the determination of physico-mechanical properties is essential for evaluating the suitability of marble as a dimension stone (Ganesha et al., 2016).

In the present study, selected physico-mechanical properties of representative marble samples collected from the Rajsamand area were determined following standard laboratory procedures. The analyses were carried out at Rahul Engineering Laboratory, Udaipur, an ISO/IEC-accredited and ISO 9001:2008 certified laboratory recognized for geotechnical and construction material testing. The investigated parameters included compressive strength, water absorption, specific gravity, density, apparent porosity, and rock hardness. The analytical results are presented in Table 2.

The compressive strength of the marble samples ranges from 709.60 kg/cm² to 1227.61 kg/cm², with an average value of 969.17 kg/cm². The lowest compressive strength was recorded in the Agaria marble (ASN-2), whereas the highest value was observed in the Nijharna marble (NSN-1). According to the American Society for Testing and Materials (ASTM), the minimum permissible compressive strength for commercial marble is 527.30 kg/cm² (equivalent to 7,500 psi or approximately 52 MPa). All the investigated marble samples exhibit compressive strength values significantly higher than the ASTM requirement, indicating their excellent load-bearing capacity and suitability for structural, flooring, and decorative applications.

Water absorption is an important index of the porosity and durability of dimension stones. The water absorption values of the studied marble samples range from 0.09% to 0.32%, with an average value of 0.17%. According to the Bureau of Indian Standards (BIS), the maximum permissible water absorption for marble is 0.40%, whereas the ASTM specifies a more stringent limit of 0.20%. All the marble samples satisfy the BIS specifications. However, when evaluated against ASTM standards, three samples (ASN-1, ASN-3, and MSN-1) exhibit water absorption values exceeding the prescribed limit of 0.20%, indicating comparatively higher porosity in these samples.

The specific gravity of the marble samples shows very little variation, ranging from 2.78 to 2.96, with an average value of 2.87. According to Blyth and de Freitas (1974), rocks having a specific gravity of 2.55 or greater are considered suitable for heavy construction works. Similarly, the BIS (IS: 1122–1974) recommend a minimum specific gravity of 2.50 for dimension stones. All the studied marble samples exceed these standards, indicating their suitability for heavy-duty structural and construction applications.

The density of the marble samples varies from 2.95 to 3.10 g/cm³, with an average value of 3.02 g/cm³. The relatively high density reflects the compact and crystalline nature of the marble and indicates very low pore space. According to ASTM specifications, dolomitic marble should possess a minimum density of 2.80 g/cm³ (2800 kg/m³). All the analysed samples satisfy this requirement, confirming their excellent compactness and high-quality engineering characteristics.

The apparent porosity of the marble samples ranges from 0.24% to 1.04%, with an average value of 0.49%. The lowest apparent porosity was recorded in the Kelwa marble (KSN-2), while the highest value was observed in the Nijharna marble (NSN-1). The generally low porosity values indicate a compact crystalline fabric with minimal interconnected voids, contributing to the high durability and low water absorption characteristics of the Rajsamand marbles.

The rock hardness of the studied marble samples, determined on the Mohs hardness scale, varies from 3.16 to 3.80, with an average value of 3.33. The BIS recommends a minimum hardness value of 3.0 for commercial marble. All the analysed samples exceed this minimum requirement, indicating satisfactory resistance to abrasion and wear. The relatively uniform hardness values are consistent with the predominance of calcite and dolomite in the mineral assemblage and demonstrate the suitability of these marbles for flooring, wall cladding, staircases, and other architectural applications.

The physico-mechanical characteristics of the Rajsamand marbles demonstrate that they possess high compressive strength, high density, favourable specific gravity, low apparent porosity, low water absorption, and adequate hardness. Except for three samples that marginally exceed the ASTM limit for water absorption, all investigated marble varieties satisfy the relevant requirements prescribed by the American Society for Testing and Materials (ASTM) and the Bureau of Indian Standards (BIS). These results confirm that the Rajsamand marbles are durable, mechanically strong, and suitable for a wide range of structural, decorative, and dimension stone applications in both domestic and international markets.

Table 2: Physico-mechanical Properties of Rajsamand Marbles

S.No.	Sample Number	Location	CaO %	MgO %	Fe_2O_3%	Al_2O_3 %	SiO_2 %	LOI %
1	ASN-1	Agaria	31.39	19.99	0.47	0.50	5.13	41.71
2	ASN - 2	Agaria	31.50	20.68	0.31	0.60	1.72	44.29
3	ASN - 3	Agaria	31.25	20.20	0.36	0.55	2.21	45.43
4	JSN - 1	Jhaanjhar	28.91	20.79	0.32	0.20	11.06	38.73
5	JSN - 2	Jhaanjhar	29.05	20.98	0.28	0.18	10.95	38.56
6	MSN -1	Morwad	29.93	21.32	0.64	0.31	6.92	40.46
7	MSN - 2	Morwad	30.41	21.29	0.46	0.98	2.03	44.23
8	SPSN -1	Sapol	30.45	21.70	0.47	0.20	4.36	42.67
9	SPSN -2	Sapol	30.25	20.95	0.48	0.18	3.96	44.18
10	KSN - 1	Kelwa	29.88	19.52	0.43	0.63	15.77	32.72
11	KSN - 2	Kelwa	30.10	18.95	0.45	0.65	13.21	36.64
12	SGSN -1	Saprao ka Guda	30.33	21.40	0.48	0.51	0.56	45.94
13	SGSN -2	Saprao ka Guda	29.98	22.05	0.43	0.48	0.55	46.51
14	NSN - 1	Nijaharna	30.78	20.72	0.48	0.51	4.21	42.53
15	NSN - 2	Nijaharna	30.26	20.16	0.32	0.61	5.33	42.36
AVERAGE								

Discussion on Physico-mechanical properties, Chemical and Mineralogical Composition

The physical and mechanical properties of rocks are primarily controlled by their petrographic characteristics, including mineralogical composition, grain size and shape, textural relationships, preferred orientation of mineral grains, pore spaces, microfractures, and the degree of alteration. These intrinsic characteristics collectively influence the engineering behaviour, durability, and performance of dimension stones. According to Quick (2002), a comprehensive understanding of mineralogy, texture, and microscopic features provides a reliable basis for predicting the physical, chemical, and mechanical behaviour of rocks.

The results of the present investigation demonstrate a close relationship between the mineralogical composition, geochemical characteristics, and physico-mechanical properties of the Rajsamand marbles. Petrographic studies reveal that the marbles are predominantly composed of calcite and dolomite with varying proportions of quartz, amphiboles, biotite, muscovite, and iron oxides. Correspondingly, the geochemical analyses indicate relatively uniform concentrations of CaO and MgO, confirming the dolomitic nature of most of the studied marbles, whereas significant variations in SiO_2 reflect differences in the abundance of quartz and other silicate minerals.

The compressive strength of the marble samples exhibits considerable variation and appears to be strongly influenced by both mineral composition and texture. Several marble samples possess compressive strength values exceeding 1000 kg/cm², indicating excellent mechanical competence. The higher strength observed in these samples can be attributed to their comparatively higher silica content and the presence of quartz and other silicate minerals. Quartz, owing to its high hardness and mechanical stability, contributes significantly to the overall strength and resistance of the rock. In addition, fine- to medium-grained interlocking carbonate crystals provide strong grain-to-grain bonding, thereby enhancing compressive strength.

However, the relationship between silica content and rock strength is not always straightforward. The Jhanjhar marble samples (JSN-1 and JSN-2), despite containing relatively high SiO_2 content (greater than 10%), exhibit comparatively lower compressive strength. Petrographic observations indicate that these marbles possess a coarse-grained crystalline texture. The larger grain size reduces the cohesion between adjacent mineral grains and promotes the development of intergranular fractures under applied stress, thereby lowering the overall strength of the rock. This observation is consistent with the findings of Onodera et al. (1980), who reported that compressive strength generally decreases with increasing grain size because of reduced intergranular bonding and increased susceptibility to crack propagation.

Water absorption also shows a significant influence on the mechanical behaviour of the marble samples. In general, compressive strength exhibits an inverse relationship with water absorption, whereby an increase in water absorption is associated with a reduction in rock strength. Higher water absorption indicates greater pore connectivity and the presence of microfractures, both of which reduce the effective load-bearing capacity of the rock. The relationship between these two parameters is illustrated in Figure 11, which clearly demonstrates that marble samples with relatively higher water absorption values generally possess lower compressive strength. This inverse correlation agrees with the established understanding that porosity and microstructural discontinuities adversely affect the mechanical properties and durability of dimension stones.

The specific gravity and density of the Rajsamand marbles exhibit only minor variations, reflecting their compact crystalline fabric and relatively uniform carbonate mineralogy. Similarly, the low values of apparent porosity and water absorption indicate that most of the marble varieties possess a dense and well-recrystallized microstructure with limited interconnected pore spaces. These characteristics contribute to their excellent durability, weathering resistance, and polishing qualities. The uniform hardness values recorded for the studied samples further support the petrographic evidence of a mineral assemblage dominated by calcite and dolomite with minor silicate minerals.

A comparison of the physico-mechanical properties of the Rajsamand marbles with the specifications prescribed by the Bureau of Indian Standards (BIS) and the American Society for Testing and Materials (ASTM) indicates that the majority of the investigated marble varieties satisfy both national and international quality standards. The marbles from Jhanjhar, Sapol, Kelwa, Saprao Ka Guda, Agaria (ASN-2), Nijharna (NSN-2), and Morwad (MSN-2) comply with all the prescribed physico-mechanical requirements of both BIS and ASTM standards. On the other hand, the samples ASN-1, ASN-3, MSN-1, and NSN-1, although meeting all BIS specifications, exhibit water absorption values slightly exceeding the ASTM permissible limit of 0.20%. Consequently, these varieties may have limited suitability for applications requiring strict compliance with international specifications, although they remain suitable for most domestic construction and decorative purposes.

Overall, the integrated petrographic, geochemical, and physico-mechanical investigations indicate that the Rajsamand marbles are predominantly dolomitic marbles characterized by compact crystalline textures, low porosity, high density, and excellent mechanical strength. Variations in engineering properties are mainly controlled by differences in silica content, accessory mineral assemblages, grain size, and pore characteristics. With the exception of a few samples exhibiting marginally higher water absorption, the majority of the studied marbles conform to both BIS and ASTM standards, confirming their suitability as high-quality dimension stones for domestic as well as international markets.

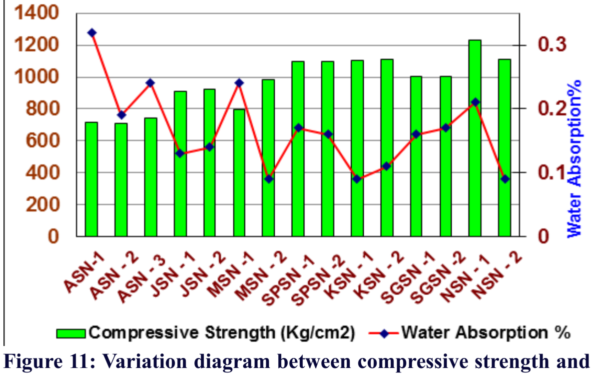


Figure 11: Variation diagram between compressive strength and water absorption values of Marble samples

Concluding Remarks

The present study provides a comprehensive evaluation of the geological setting, mineralogical characteristics, geochemical composition, and physico-mechanical properties of the commercially important marble deposits of Rajsamand District, Rajasthan. The integrated approach adopted in this investigation demonstrates that the quality and engineering behaviour of the marbles are closely controlled by their mineralogical composition, textural characteristics, and geochemical variations.

Overall, the study confirms that the Rajsamand marble deposits constitute an important source of high-quality dimension stone with excellent mineralogical, geochemical, and engineering characteristics. The findings provide valuable scientific information for resource evaluation, quality assessment, mine planning, and the selection of suitable marble varieties for specific engineering and architectural applications. The results will also be useful for the marble industry, researchers, and planners in promoting the sustainable utilization and value addition of Rajasthan's marble resources.

REFERENCES:

1. Blyth, F.G.H., de Freitas, M. H. (1974): Geology of engineers. ELBS and Edward Arnold,
2. London, 514 pages.
3. Bucher, K. and Grapes, R. (2011): Petrogenesis of Metamorphic Rocks (8th Edition), Springer Science and Business Media, 428 p.
4. D.M.G. (1996): Marble in Rajasthan. Mineral series No. 2, Department of Mines & Geology Rajasthan Publication, Udaipur.
5. D.M.G. (2001): Marble in Rajasthan. Department of Mines and Geology Rajasthan Publication.
6. D.M.G. (2014): Mineral Statistics, Department of Mines and Geology Rajasthan Publication.
7. D.M.G. (2025): Department of Mines and Geology Rajasthan Website: https://mines.rajasthan.gov.in
8. Deer, W. A., Howie, R. A., and Zussman, J. (2013): An Introduction to the Rock-Forming Minerals (3rd ed.), Mineralogical Society of Great Britain and Ireland, 498 p.
9. Dwivedi, C.S. (1991): Marble deposits of Rajasthan. Mining and Mineral world, May-
10. June issue, pp 105-111.

11. Evans, B.W. (2004): The serpentinite multisystem revisited: Chrysotile is metastable. International Geology Review, Vol. 46, pp479–506.
12. Ganesha, A.V., Prakash, Narshimha, K.N.P. and Krishnaiah, C. (2016): Petrographic and Physico-mechanical studies on Granitic rocks around Bidadi, Ramanagaram Taluka, Karnataka State, Int. Jour. Adv. in Mechanical and Civil Engineering, Vol. 3(2), pp 36-40.
13. Gupta, S.N., Mathur, R.K. and Arora, Y.K. (1992): Lithostratigraphy of Proterozoic rocks of Rajasthan and Gujrat A review. Rec. Geol. Surv. Ind. Vol. 117(7&8).
14. Heron, A. M. (1953): The geology of central Rajputana. Mem. Geol. Surv. India. 79, pp 1–389.
15. I.B.M. (1993): Marble – a market survey. Indian Bureau of Mines Market survey
16. series MS: 19, 135p.
17. I.B.M. (2015): Indian Mineral Year Book (Marble), Indian Bureau of Mines Publication.
18. Jha S. (2003): Studies on Geological, Physico-mechanical, Eco-environmental and Commercial characteristics of Decorative stones (Marble resources) from Southern districts of Rajasthan. Unpublished Ph.D. thesis. M.L. Sukhadia University, Udaipur
19. Onodera, T. F. and Kumara, A. H. M. (1980): Relation between texture and mechanical properties of crystalline rocks. Bull. Int. Asso. Eng. Geol., Vol. 22, pp 173-177.
20. Quick G. W. (2002): CSIRO building selective guide to the selection of dimension stone. Construction and Engineering, Highett, Vicotoria, Australia.
21. Sastry, C.A. (1992): Geochronology of the Precambrian rocks from Rajasthan and north-eastern Gujarat. Special Publication. Geol. Surv. Ind., Vol. 25, pp. 96.
22. Sen, Hemant, Agrawal, V. and Kapasya H. (2021): Commercial Marble Deposits of Rajasthan: Geology, Distribution, Resource Potentiality an SWOT Analysis. International Journal of Scientific Research, Volume – 10, Issue – 09.
23. Trivedi, L.L. (1998): Mineral economics and resource analysis of south Rajasthan. Unpublished Ph.D. thesis, ML Sukhadia University, 219 p.
24. Winter, J. D. (2010):Principles of Igneous and Metamorphic Petrology (Second Edition), Prentice Hall,, 745 p.
25. Yardley, B. W. D. (1989): An Introduction to Metamorphic Petrology, Longman New York, 248 p.