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Petrographic Analysis and physico-mechanical Properties of Nikanai Ghar Formation, Swabi, North-western Pakistan

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Abstract

The petrographic analysis and physico-mechanical assessment of the Nikanai Ghar Formation, exposed in the vicinity of the Bando Obo marble, near Swabi Town, north-western Pakistan, were carried out to assess and look into its prospects to serve as a building stone for engineering projects. Nine fresh bulk samples representing different textural types were chosen to investigate petrographic properties, as well as the physical and mechanical behaviour of the Nikanai Ghar Formation. A series of geotechnical tests and petrographic analyses were carried out to assess the material's suitability for construction applications. These geotechnical tests included measurements of unconfined compressive strength (UCS), Unconfined tensile strength (UTS), specific gravity (SG), shear strength (SS), porosity, and water absorption. The obtained physical qualities were then compared to standard specifications to evaluate their appropriateness for use in construction. The analysed samples are divided into different textural and mineralogical categories based on a careful microscopic examination of three representative thin sections. Four of the samples, JTN-1, JTN-2, JTN-4, and JTN-7, have a striking mineralogical similarity, both consisting primarily of calcite with only traces of opaque ore minerals. However, their textures are different, i.e., shape, grain size, and grain boundaries. JTN-2, JTN-9, and JTN-8 samples are medium-grained and sub-equi-granular while JTN-1, JTN-4, and JTN-5 are predominantly fine-grained and equi-granular. The JTN-3, JTN-6, and JTN-7 Samples are coarse-grained and sub-equi-granular to granular and contain trace amounts of muscovite, rutile, and ilmenite. The analysis showed that the Nikanai Ghar Formation can be used as aggregates by the domestic building sector because it falls within the parameters of standard specifications.

Keywords: Physico-mechanical properties; Petrographic Analysis, water absorption; Aggregate; Nikanai Ghar Formation; Specific Gravity.

1. Introduction

The research region is located in the northeast of the Peshawar Basin, exposed in the vicinity of the Bando obo marble, near Swabi Town, north-western Pakistan. The research region is located between the longitudes 72° 10′ 09″ to 72° 38′ 50″ E and latitudes 34° 05′ 17″ to 32° 36′ 13″ N and is accessible through Swabi-Mardan Road (Fig. 1). Marble resources have been the subject of much research and exploitation worldwide, mainly because of its economic significance and aesthetic worth in architecture and art. Considerable investigation has been devoted to the geology, extraction techniques, and industrial applications of marble. For example, Carrara marble, which has been famous in Italy since the Roman era, is still one of the best sources of marble (Poli, 1992). Research has also shown Turkey's vast marble reserves, especially in the areas of Afyon and Iscehisar, which are renowned for their abundant reserves and for producing a variety of marble varieties that are sold around the world (Török and Szücs, 2013). As the Makrana marble deposits in India provided the marble for the Taj Mahal, they have been the subject of much historical research (Chatterjee et al., 2015). Furthermore, contemporary methods like petrographic research and isotopic analysis have been used to comprehend the formation mechanisms and evaluate the quality of marble deposits in a number of locations, including Greece, Brazil, and the United States (Moufti and Nazzal, 2017).

In recent studies, Ullah et al. (2020, 2021) investigated the physico-mechanical properties of limestone units from the Permian Wargal Limestone and the Paleocene Lockhart Limestone, respectively. Their work focused on determining the suitability of these limestone formations as construction aggregates by conducting various laboratory tests. The results demonstrated that both limestone units possess favourable engineering properties, making them suitable for use in road construction and other civil engineering projects. These studies provide valuable insights into the potential of these formations as reliable aggregate sources in construction. Marble deposits in Khyber Pakhtunkhwa exhibit significant variation, with some deposits having been extensively studied for their petrographic features and mechanical characteristics. However, there remains a gap in detailed research on the Bando Obo marble, a potentially valuable resource within the region. This study aims to address this gap by conducting a comprehensive investigation of Bando Obo marble samples. The primary objectives are to thoroughly analyse the modal composition and textural properties of these marbles, and to evaluate their mechanical and physical properties. By doing so, this study seeks to provide a deeper understanding of the Bando Obo marble's suitability for various applications in construction and industry, contributing valuable data to the broader knowledge of marble resources in the region.

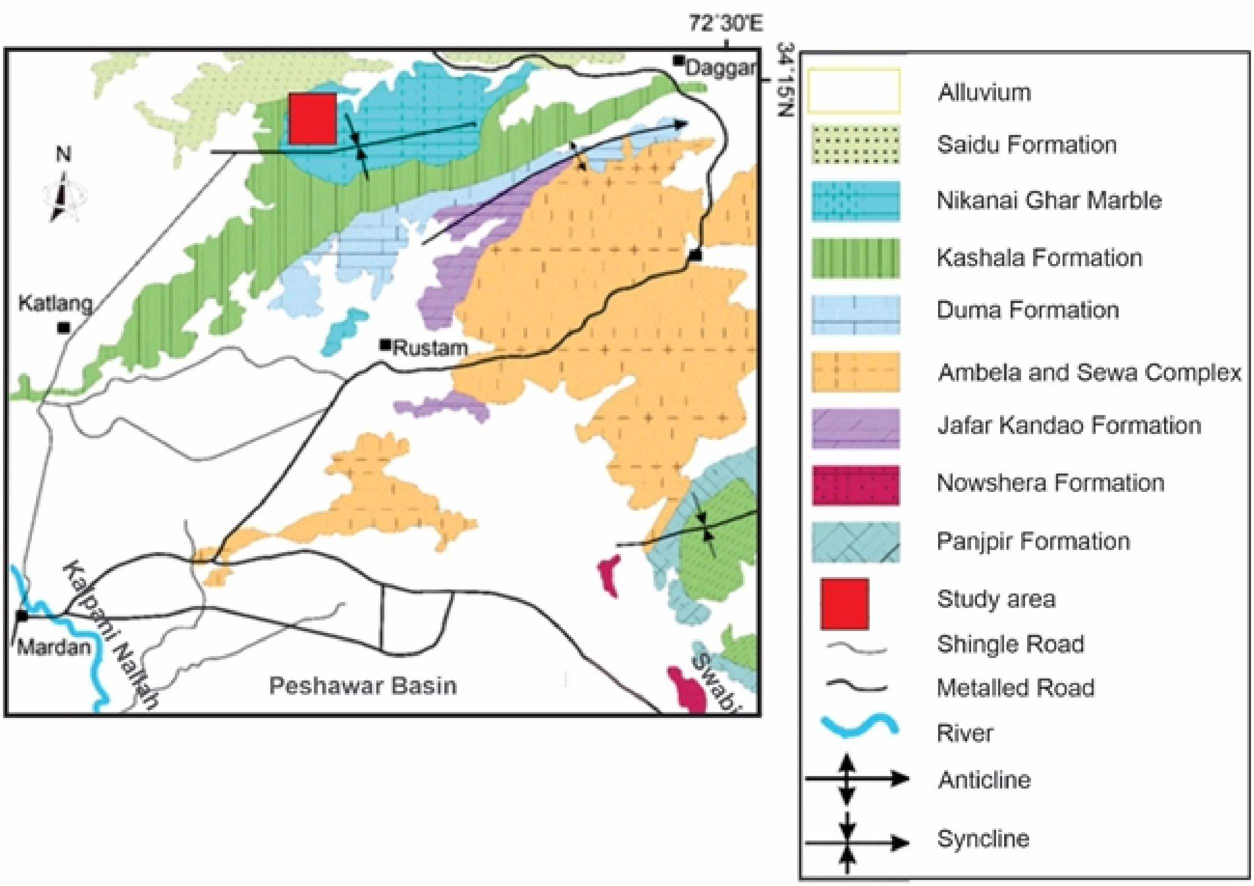

Fig. 1. Map showing geology and location of the study area (modified after Hussain., 1992).

2. Tectonic Setup

Tectonically, the study area is enclosed by the region of active thrusting and folding in the foreland of the 2489 km long Himalayan highland in Pakistan, therefore, showing a complex structural configuration (Yeiats and Hussaein, –12987). The Attoeck-Chearat Range (ACR) is sandwiched across the Peshawar Basin to the north and the Kala Chitta Rang (KCR) e to the south, with the boundary delineated by the Hissartang Thrust in the Nizampur Basin (Burbank and Johnson, 1982). This thrust fault separates the southern part of the ACR from the Kala Chitta Range, causing deformation in both ranges (Yeats and Hussain, 1987; Ghauri et al., 1991; Rehman et al., 2016; 2017).

The ACR features outcrops of sediments that range from the Precambrian to the Paleocene. It encompasses the Lesser Himalayan metasedimentary rocks and borders the region to the north. The region to the south is bounded by the Kala Chitta Range's foreland basin rocks (Hashmei et al., 20218). The area around the Main Boundary Thrust Fault (MBT) has undergone significant deformation and shortening, resulting in the formation of thrust faults and a number of large and small-scale folds (Rehman et al., 2024). The rocks at the Kahi Gorge and those that occurred in the ACR exhibit extensive folding. Kahi Gorge is situated in the Himalayan foothills within the Nizampur Valley of Khyber Pakhtunkhwa, northwest Pakistan. The KCR is a component of the active Himalayan Foreland Fold-and-Thrust Belt, which has gradually shifted southward through a sequence of southward-verging thrust imbricates along the MBT, contributing to the regional fault system of northern Pakistan (Wadood et al., 2019). The Peshawar Basin, a piggyback basin, has been passively transported on the back of shallowly dipping detachment faults and thrust sheets (Ori and Friend, 1984). It contains small to massive outcrops of Paleozoic and earlier strata. As one moves from north to south across the Peshawar Basin, the degree of metamorphism and the severity of deformation steadily decrease (Pogue et al., 1992). The study site is located in the southeast corner of the Peshawar Basin (Fig. 2). This region's geological complexity and structural features provide valuable insights into the tectonic evolution of the Himalayan foreland.

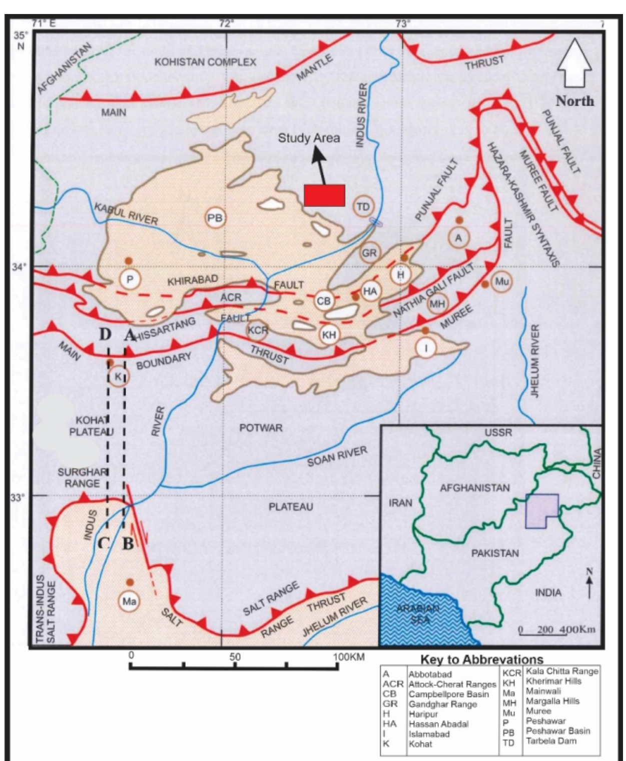

Fig. 2. Tectonic map of northern Pakistan highlights major structural boundaries and geographic locations in the region. Inset marks the location of the research region (After Rehman, et al. (2022a, –b).

Stratigraphy

The study area forms the north-eastern flank of the Peshawar Basin and comprises a sequence of sedimentary and metamorphic rocks, spanning in age from the Proterozoic to Paleozoic eras (Fig. 3). Within the study region, the oldest rock formations are attributed to the Proterozoic era, notably the Tanawal Formation mainly comprises of medium-grained quartzite and fine-grained mica schist. The Proterozoic rocks are succeeded by the Ambar Formation of Cambrian period, dolomitic limestone, calcareous quartzite, and subordinate argillite make up the majority of the Amber formation's lithology. The Cambrian sequence is trailed by the Ordovician rocks of Misri Banda Quartzite which is followed by the Panjpir Formation of the Silurian age. The Panjpir formation mainly consists of argillite and phyllite, with crinoidal limestone, meta-stone, and argillaceous and calcareous quartzite interbeds. The Silurian succession is overlaid by the Devonian limestone and dolomite of the Nowshera Formation. The Nowshera Formation is proceeded by the Jafar Kando Formation belonging to the Carboniferous age, mainly comprised of argillite with limestone lenses, argillaceous quartzite, conglomerate, calcareous quartzite, sandy limestone. Overlying the Carboniferous sequence are the Permian age rocks, primarily represented by the Karapa Formation in the research region. The Carboniferous sequence is succeeded by the Kashala Formation of Triassic age comprising of thick series of interbedded marble and phyllite. In the study area, the Triassic rocks are overlain by the Nikanai Ghar Formation, which ranges in age from Late Jurassic to Early Triassic. Ahmed et al. (1987) designated Nikanai Ghar for the extensive dolomite and marble found there. In southern Swat, the Nikanai Ghar Mountain serves as a type section. White to grey marble with thick bedding and dolomitic marble, ranging from finely to coarsely crystalline in texture make up the Nikanai Ghar Formation (Fig. 4) (DiPietro et al., 1999). Additionally, it has thin layers of quartzite, schistose marble, and calcareous schist. DiPietro et al. (1999) identified the Nikanai Ghar Formation as being from the Late Triassic period. This conclusion was made based on its position above the Late Triassic Kashala Formation and the occurrence of Palaeniscoid fish teeth within the formation.

3. Methodology

Extensive fieldwork was carried out in the region to collect samples and observe outcrop-defining features. Nine representative bulk samples of the Nikanai Ghar Formation were collected during geological fieldwork in the study area. These samples represent different textural varieties, including variations in colour and grain size, to determine their petrographic and geotechnical properties. Each sample has its geographic coordinates recorded using GPS (Table 1).

Three bulk rock samples collected in the field were analyzed at the National Centre of Excellence in Geology (NCEG) laboratory, University of Peshawar (UoP) for the petrographic and geotechnical studies. With a core drilling machine, five cores were drilled out of each bulk sample as per the ASTM, (American Society for Testing and Materials) specifications. Two chip samples were also acquired to prepare the thin section. Selected samples were analysed for their mechanical characteristics such as UCS, UTS, and SS tests in the NCEG, Peshawar University. For petrographic examination, a single thin section from each core was prepared. Specific gravity (SG) and water absorption tests were also performed on the samples in the Geochemistry lab of the NCEG

Results

A petrographic study, based on thin section analysis, reveals the textural context and modal mineralogy of a rock (Hussain et al., 2022). This study involves both field observations and microscopic analysis of thin sections. Thin section analysis is essential for understanding the origins of rock. The Nikanai Ghar formation, which consists of marble, dolomitic marble, and schist intercalation, was chosen for comprehensive petrographic and engineering examination. Nine bulk samples (JTN-1, JTN-2, JTN-3, JTN-4, JTN-5, JTN-6, JTN-7, JTN-8 and JTN-9) were collected during fieldwork for petrographic and physio-mechanical investigations. In the field study, two important features, a) dikes of apparently basic composition and b) calcite vein deposits were observed. Calcite veins/fracture fills of various thicknesses (1-15cm) can be found in Bando obo marble in certain locations. Such fissures may be generated by stresses occurring inside the earth crust, or they may be formed and increased by the intrusive forces of mineralizing solution during mineralization (Betman, 1967). Calcite crystals with a coarse grain are seen in these veins.

Table 1. Showing geographic coordinates/locations of the bulk samples.

Sr. No.	Samples	Samples locations/Coordinates
1	JTN-1	$34^{o}\ 12^{/}\ 38.5^{//}$ N $72^{o}\ 25^{/}\ 11.8^{//}$ E
2	JTN-2	$34^{o}\ 12^{/}\ 39.9^{//}$ N $72^{o}\ 25^{/}\ 09.5^{//}$ E
3	JTN-3	$34^{o}\ 12^{/}\ 45.6^{//}$ N $72^{o}\ 25^{/}\ 09.5^{//}$ E
4	JTN-4	$34^{o}\ 12^{/}\ 47.5^{//}$ N $72^{o}\ 25^{/}\ 17.2^{//}$ E
5	JTN-5	$34^{o}\ 12^{/}\ 50.4^{//}$ N $72^{o}\ 25^{/}\ 15.3^{//}$ E
6	JTN-6	$34^{o}\ 12^{/}57.2^{//}$ N $72^{o}\ 25^{/}\ 20.1^{//}$ E
7	JTN-7	$34^{o}\ 12^{/}48.3^{//}$ N $72^{o}\ 25^{/}\ 21.7^{//}$ E
8	JTN-8	$34^{o}\ 12^{/}\ 49.00^{//}$ N $72^{o}\ 25^{/}\ 29.5^{//}$ E
9	JTN-9	$34^{o}\ 12^{/}35.8^{//}$ N $72^{o}\ 25^{/}\ 28.4^{//}$ E

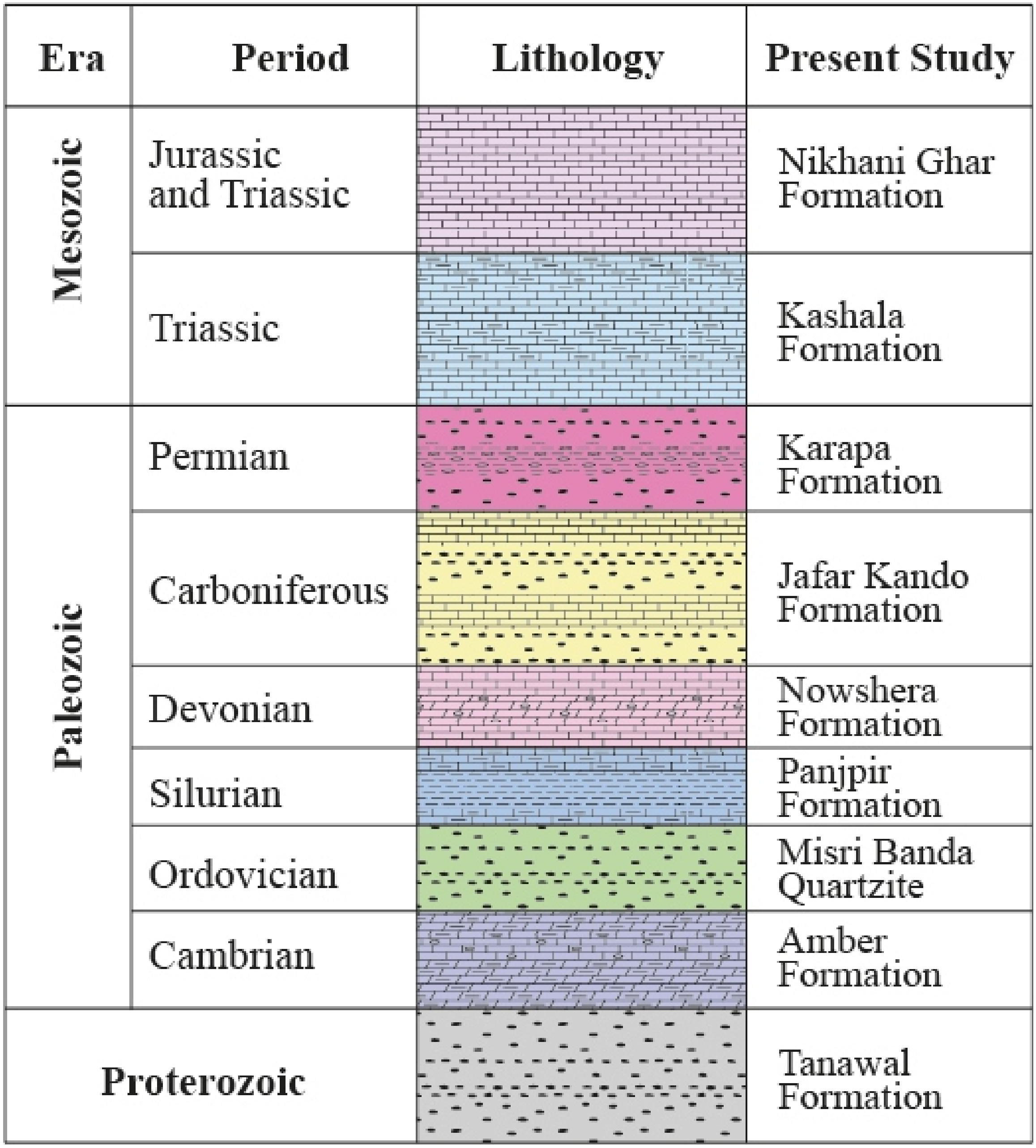

Fig. 3. Palaeozoic and Mesozoic stratigraphic chart of the Peshawar basin, (Pogue et al., 1992).

Three thin sections were prepared from each bulk sample in order to analyze the petrographic features and establish a correlation with their physico-mechanical properties. The modal mineralogy and textural characteristics of the thin sections were investigated using cross-polarized and plane-polarized light.

Based on visual estimation, the average model composition of each of the tested thin sections was established (Table 2). A comprehensive study of the texture is carried out, noting details such as cleavages, twinning, geometry, and grain size.

The bando obo marble was categorised into the following varieties after a careful petrographic analysis of nine sample thin sections.

Fig. 4. Photographs showing outcrops of the Nikanai Ghar marble (Swabi), NW Pakistan.

Table 2. Showing the average modal mineralogical compositions of the thin sections stylolites, grains contacts, cement, and matrix.

S. No	1	2	3
Nomenclature	JTN-1, JTN-4 & JTN-5	JTN-2, JTN-8, & JTN-9	JTN-3, JTN-6 & JTN-7
	Fine grained	Medium grained	Coarse grained
Calcite	98%	98%	98%
Ore Minerals	1%	1%	1%
Muscovite	0.5	0.3	0.6
Rutile	0.2	0.5	0.4
Ilmenite	0.3	0.2	-

5.1 Fine- Grained Marble

The Sample JTN-3 obtained from fine-grained marble has considerable differences from that of the other two bulk samples. The dominant mineral is calcite which exhibits very fine-grained texture. all the calcite grains show non-sutured or normal grain boundaries. The studied thin section is widely equi-granular; however, the various calcite grains are extraordinarily larger. A small amount of opaque minerals can also be found (Fig. 5).

5.2 Medium-Grained Marble

The petrographic analysis of bulk sample JTN-2 reveals that calcite is the most common mineral in these rocks, with traces of an opaque ore mineral present. Calcite is identified by two sets of cleavage and a strong varied relief. The rock-thin sections are mostly equi-granular, with fine to medium-grained grains. Inter-granular boundaries can also range from regular to irregular (sutured) (Fig. 6).

5.3 Coarse- Grained Marble

The thin sections studied, which represent the bulk sample, are mostly coarse-grained and primarily composed of abundant (96 model %) calcite with only a trace of rutile, ilmenite, and muscovite. A trace amount of opaque ore mineral in the form of tiny grains was also found. In this coarse-grained variety, the mineral grain boundaries are primarily sutured (irregular) (Fig. 7).

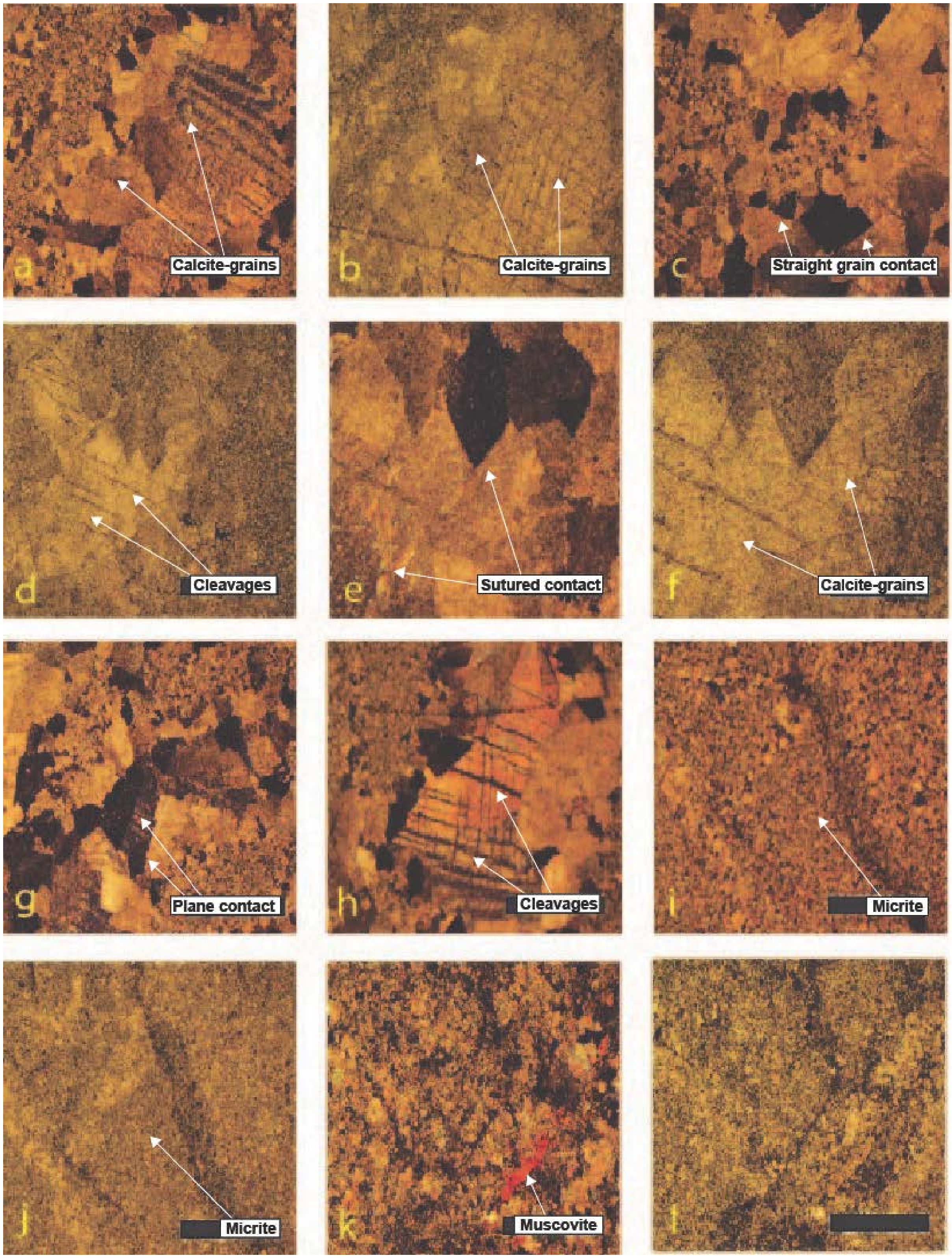

Fig. 5. Photomicrographs of thin sections: **a)** showing (XPL) calcite grains, **b)** showing same grain in (PPL), **c)** showing straight grain contact, **d)** showing calcite grain with prominent cleavages in (PPL), **e)** same grain in (XPL) showing straight and sutured contact between grain boundaries, **f)** showing same view in (PPL), **g)** showing plane contact, **h)** showing 2 sets of cleavages in calcite, **i)** showing (XPL) fine grain variety (micrite), **j)** showing same as in (PPL), **k)** shows pink elongated grains of muscovite, **l)** (PPL) view of fig k.

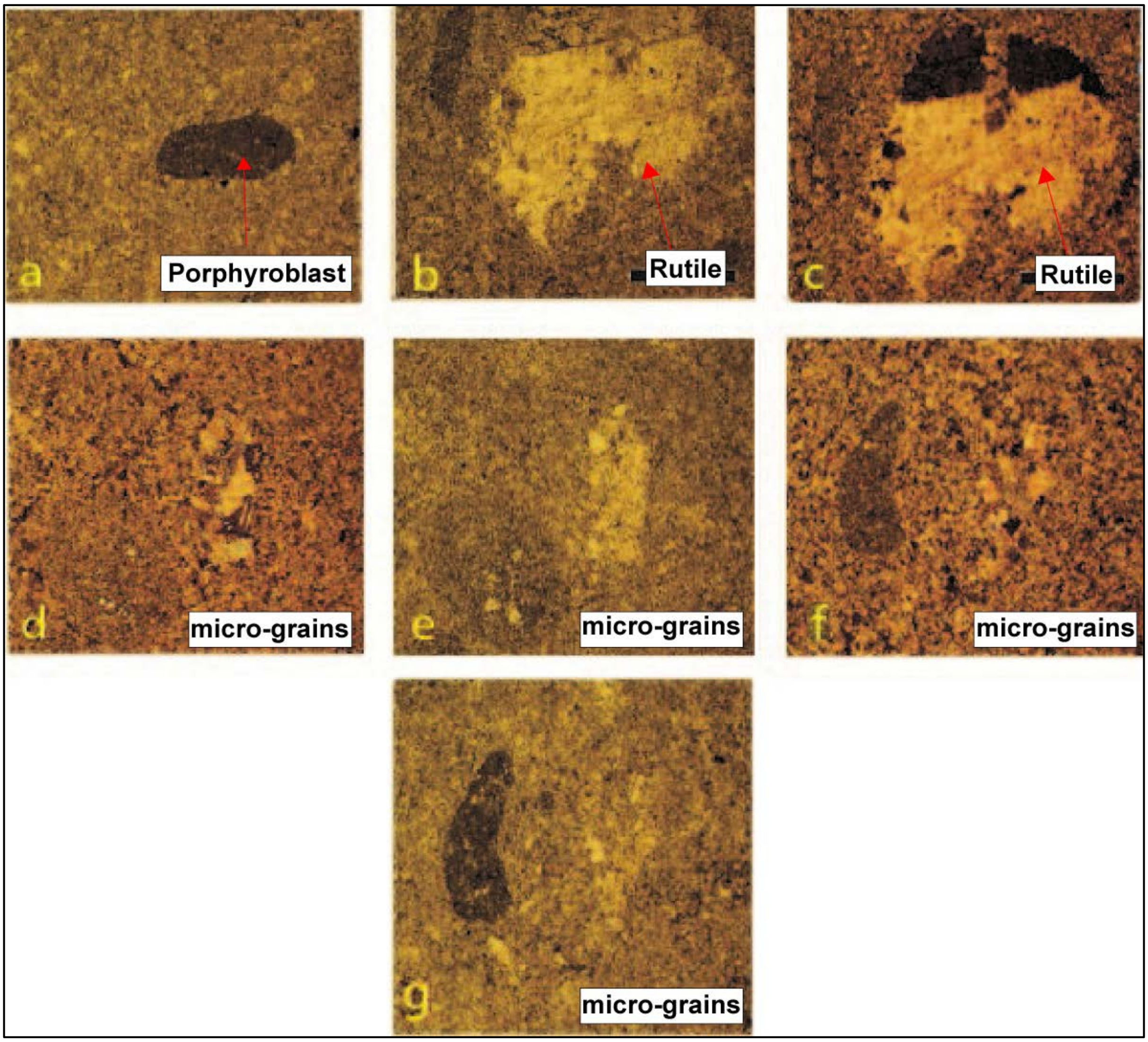

Fig. 6. Photomicrographs view of thin sections: **a)** showing prophyroblastic texture (XPL), **b)** showing same (PPL), **c)** showing Rutile (PPL), d) showing Rutile (XPL), **e-l)** showing micro granular texture (XPL) and (PPL) respectively.

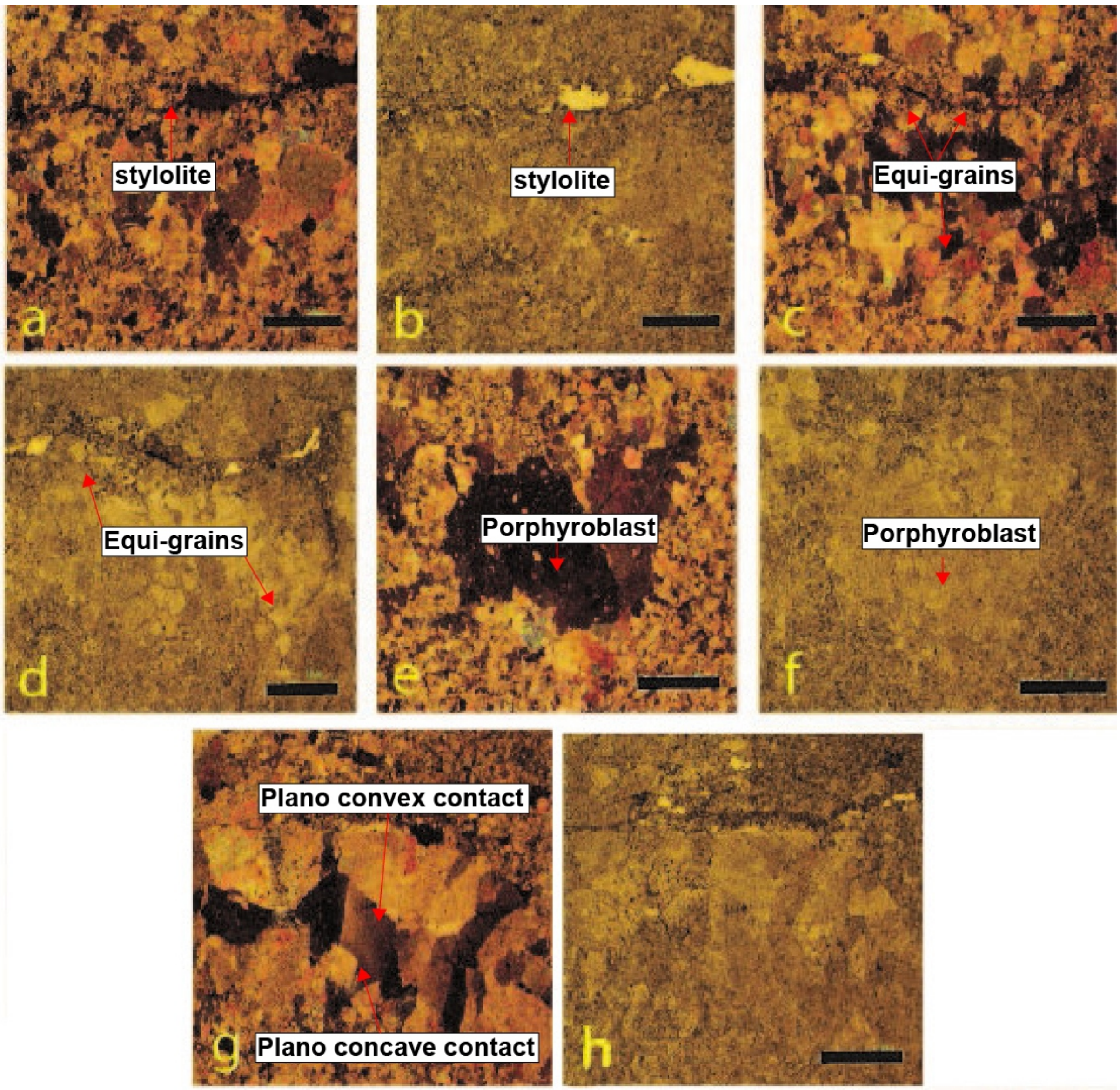

Fig. 7. Photomicrographs view of thin sections: **a & b)** showing stylolite microfracture in XPL and PPL respectively, **c & d)** showing equi-granular texture in XPL and PPL, **e & f)** showing porphyroblastic texture in XPL and PPL, **g-l)** showing sutured Plano-convex, Plano concave and plan contact in XPL and PPL respectively.

5.4 Mechanical properties

Rocks are a natural collection of mineral grains that are tightly linked by cohesive forces (Karl et al., 1996). Mechanics of artificial and natural materials, particularly their response under stress, are of interest to engineers. The study of rock's mechanical properties is important for a variety of engineering applications e.g., deep wells, repositories, designing of mines. In seismology, tectonics, and geophysics they also have many applications. In comparison to metals, rocks show anisotropic behavior. Rocks have a mechanical problem because of the uneven distribution of stress and strain on both small and large scales (Crisetern and Hunscshe, 12988). Weathering and erosion are the primary factors that contribute to the changes in rock quality (Bell, 2007). The resistance of a material to an externally applied burden is its strength.

The texture and mineralogical composition of a rock determine its strength. By in-situ testing (by penetrometer) in the field or experiments performed in the laboratory, we can find out the strength of the rock. As rock strength is experimentally determined in the lab using undamaged and undisturbed samples, lab tests yield more accurate and satisfactory results than field tests. These are some of the physical and strength tests that were conducted in the laboratory.

5.4.1 Uniaxial or Unconfined Compressive Strength (UCS) ASTM D-2938

The highest axial compressive stress that a specimen may tolerate under zero confining tension is known as unconfined compressive strength (UCS). With the help of UCS, one can make comparisons between rocks (Tsiambaos and Sabatakakis, 2004). The ASTM D-2938 standards are followed as the standard procedure for UCS (ASTM International, 1992). Three cores from each bulk sample were extracted using a core drilling machine, and the rock was then cut to ASTM specifications using a rock-cutting machine. At 90-100c samples were dried, and their end surfaces were polished by a grinding machine. For measuring UCS value of the core samples the universal strength testing machine was used in the rock mechanics laboratory. The core samples were placed in universal strength testing equipment, where a constant load was given devoid of any shock (Fig. 8). The UCS values can be determined using the following formula (Table 3).

UCS = P/A (KN/m^2)

where

$A = \pi/4 * D^2$

P= Pressure at failure (KN= Kilo-Newton)

A= Cross-sectional area of the rock core sample in m^2

Table 3. showing UCS values for selected samples.

Sample No	Area $(m)^2$	Load	Strength (Psi)	Strength (Mpa)
JTN-1	3.8	28158	7410	51.1
JTN-2	3.8	26581	6980	47.8
JTN-3	3.8	27499	7237	49.9
JTN-4	3.8	28268	7345	48.6
JTN-5	3.8	28359	7250	47.9
JTN-6	3.8	27453	7289	50.5
JTN-7	3.8	27967	7480	51.2
JTN-8	3.8	29121	7325	49.7
JTN-9	3.8	28170	7413	48.4

Fig. 8. Showing the loading process of a core sample in UCS machine for a compressive test.

The computed results were subsequently compared to international UCS classification standards (Table 4).

Table 4. Standard classification table of UCS (after Bell, 2007)

Geological Society (Anon, 1977)		**IAEG*(Anon,1979)**		**ISRM** (Anon, 1981)**	
Description	**UCS (MPa)**	**Description**	**UCS (MPa)**	**Description**	**UCS (MPa)**
Very weak	<1.25	Weak	<15	Very low	<6
Weak	1.25-5.00	Moderately strong	15.00-50.00	Low	6.00-10.00
Moderately weak	5.00-12.50	Strong	50.00-120.00	Moderate	20.00-60.00
Moderately strong	12.50-50	Very strong	120.00-230.00	High	60.00-200.00
Strong	50.00-100.00	Extremely strong	Over 230.00	Very high	Over 200.00
Very strong	100.00-200.00				
Extremely strong	Over 200.00				

Many different scales for comparing UCS values and grading rocks based on their compressive strength have been presented in Table 5 that contains three of these scales. According to these scales, all of the Bando Obo Marble samples analysed fall into the moderately strong category.

5.4.2 Unconfined Tensile Strength (UTS)

UTS is applied to determine the tensile strength by imposing a vertical load to generate tension across the diameter of a compressed rock disc. According to Bell, 2007, compressive strength of the rock is significantly greater than its tensile strength. The maximum amount of pressure that a disk-shaped sample can take without shattering after stretching is specified as the UTS. The UTS test can be completed in one of two ways. One way is direct, while the other is indirect. The direct method is more challenging than the indirect method because gripping the specimen with no bending stress is difficult (Beill, 20017). The indirect method, commonly known as the "Brazilian way," is not only more convenient but also less costly. To determine the UTS of the analyzed samples, the indirect technique was applied. In accordance with the specifications, a disc-shaped specimen from the core was picked, having a thickness to diameter ratio of about 0.50 inch (Fig. 9). The load at the moment of the specimen's failure was recorded. After that, the UTS values for all of the tested samples were determined using the following formula (Table 5).

$$UTS=2P/\pi DT$$

Where,
P = Load (lbs.); D = diameter of the rock core (inch); T = thickness of the rock core (inch).

Table 5. Showing UTS results of selected samples.

Sample No	Area (n)^2	Load	Strength (Psi)	Strength (Mpa)
JTN-1	3.4	2671	786	5.4
JTN-2	3.3	2409	730	5.0
JTN-3	3.4	3097	911	6.3
JTN-4	3.5	2520	826	5.8
JTN-5	3.4	2574	790	6.2
JTN-6	3.3	2670	845	5.9
JTN-7	3,5	2490	905	5.7
JTN-8	3.4	2667	780	5.6
JTN-9	3.5	2450	820	6.1

Fig. 9. Showing the loading process of a core sample in UTS machine for Tensile Strength test.

5.5 Shear Strength

A rock's shear strength is defined as its maximum resistance to distortion caused by persistent shear displacement under shear stress (Sajid et al., 2009). Typically, this property is measured in the laboratory using torsion tests. However, in this research, shear strength was not measured directly; Instead, it was inferred indirectly using Uniaxial Compressive Strength and Uniaxial Tensile Strength values (Sajid et al., 2009).

To achieve this, the UCS value for the particular rock type was plotted on the + x-axis, while the UTS data was plotted on the __ x-axis. Mohr circles were then constructed for each measurement, and a common tangent was established between the two resulting circles. Shear strength was calculated using two factors: cohesion (C) and the angle of internal friction (Φ).

In this study, the shear strength of the collected samples was calculated indirectly from the UCS and UTS data (Tables 2 & 5). A common tangent was plotted between the two Mohr circles. The angle of the tangent with the horizontal axis yielded the value of Φ, while the distance between the intersection points on the x and y axes and the point where the tangent crosses the y-axis gave the value of C (Fig. 10). The values of cohesion and internal friction varied based on different UCS and UTS values. The average values calculated for the analyzed samples are presented as C = 3.45, and ϕ = 31.5°.

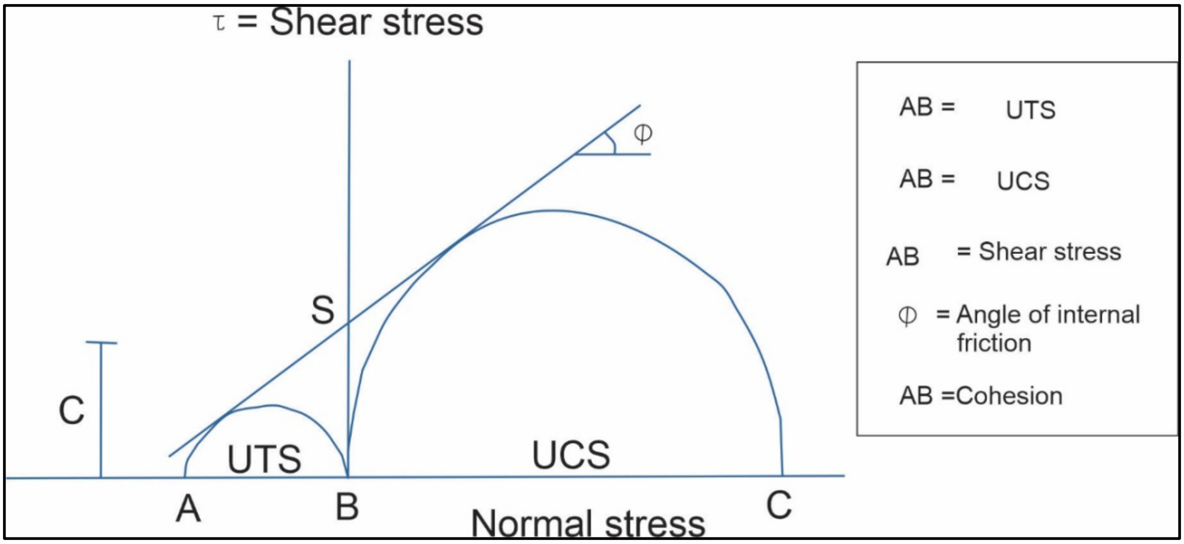

Fig. 10. Shear strength evaluation utilizing UCS and UTS.

5.6 Porosity

The term "porosity" describes a rock's ability to hold pores. The mineralogical composition of a rock, especially the presence of clay minerals, as well as its grain size and shape, determine its porosity (Bell, 2007). Porosity and rock strength have an inverse relationship. The saturation method was applied (Tsivilis et al., 2003), for assessing the porosity of the rock samples under examination. The samples' dry weights were first measured in open air. Then, using a thread, the samples were suspended in water to calculate their volume. The formula below is used to calculate porosity. The porosity International Standard Values are listed in Table 6.

$$P = \frac{(\text{wt. in air}) - (\text{dry wt.})}{(\text{wt. in air}) - (\text{wt. in water})} \times 100$$

5.7 Water Absorption Test

Water absorption is the amount of water that a sample may absorb in a certain amount of time (24 hours). The mechanical disruption of a tiny part of rock adjacent to an exposed surface caused by repeated hydration and dehydration enables water into the rock, increasing the degree and rate of weathering (Bell, 2007). As a result, rocks must be examined for their ability to absorb water. For the water absorption test, cuboidal samples were made from each of the three bulk samples, dried in an oven at 105-110°C, weighed as W1. To test their water absorption capacity, for twenty-four hours, the dry samples were immersed in distilled water.

After cleaning these wet samples with tissue paper, they were weighed once more as W2 on a sophisticated electronic balance (Table 8). The following formula was applied to determine the sum of water ingested by the samples.

Amount of water absorbed (%) = (W2-W1/W1) *100

Where, W1= Dry weight; and W2 = Wet weight

5.8 Specific Gravity Test

A rock's specific gravity is defined as the weight of the sample divided by its weight in water. Values that are greater than or equal to the sample's weight in air indicate greater strength, while smaller values indicate lower strength or lower quality. Rocks that have a specific gravity of 2.55 or higher, remain appropriate for construction (Blyth et al., 2017). The test was executed in compliance with ASTM C 127-12 (Sajid et al., 2009).

For a rock, the standard specific gravity is

≥2. A digital weight balance, thread, distilled water, and a beaker were used to determine the specific gravity. After being weighed initially, the samples were heated to between 105 and 110 degrees Celsius for 24 hours, and then they were weighed once more (Hussain et al., 2022). The samples were then placed in water, and the sample's total volume specific gravity was calculated using the formula below (Table 7).

$$\text{Specific gravity} = W1 / (W1 - W2)$$

Where,

W1=Weight in air

and

W2=Weight in water

According to Blyth and DE Freitas (1974), rocks with a high specific gravity≥2.25 is better for heavy construction. All the studied have specific gravity values greater than 2.25. So, the marble of Bando Obo area is suitable for construction purpose.

Table 6. Showing the International Standard Values for porosity and dry density (Anon, 1979).

Sr. No.	Dry Density	Description	Porosity	Description
1	<1.80	Very low	Over 30.00	Very high
2	1.80 - 2.20	Low	30.00 – 15.00	High
3	2.20 - 2.550	Moderate	15.00 – 5.00	Medium
4	2.550 - 2.750	High	5.00 – 1.00	Low
5	Over 2.750	Very high	<1.00	Very low

Table 7. Showing samples' specific gravity and water absorption test results

Sample No.	Weight in air in gm	Weight in water in gm	SSD weight	Oven dry weight in gm	Absorption	% Absorption	Specific gravity
JTN-1	766.7	497.34	766.91	766.31	0.39	0.05	2.849
JTN-2	766.07	496.56	766.27	765.75	0.32	0.04	2.845
JTN-3	751.13	486.23	751.32	750.41	0.72	0.10	2.841
JTN-4	752.08	477.15	749.28	751.50	0.49	0.08	2.839
JTN-5	762.03	483.45	763.27	749.07	0.33	0.07	2.852
JTN-6	749.3	472.33	766.28	750.23	0.66	0.09	2.833
JTN-7	759.21	489.23	763.24	753.39	0.52	0.06	2.841
JTN-8	763.38	473.37	759.35	765.27	0.42	0.09	2.849
JTN-9	758.63	489.23	761.11	759.28	0.52	0.08	2.832

6. Discussion and Conclusion

A comprehensive petrographic examination of representative samples reveals that the mineralogical composition of the Bando Obo marble is relatively consistent; however, there is significant textural variation. These marbles are divided into (a) fine-grained, (b) medium grained and (c) coarse grained marbles based on texture. Whereas fine grained variety is distinctly in equi-granular, and medium and coarse-grained samples are largely equi-granular to sub-equi-granular.

Rocks also behave differently in term of their strength having deferent textural features and composition. Mechanical properties of rocks include (a) modal mineralogical composition, (b) grain shape, (c) grain size and the extent of its variation, (d) the overall abundance of accessory minerals is control by the most important petrographic characteristics and more importantly, the degree of their orientation (Willard and Mcwilliams, 1969; Farmer, 1983; Howarth, 1986; Tugrul and Zaif, 1999; Bell, 2007; Lindqvist et al., 2007).

In the studied samples, the sample JTN-1 which is fine grained has the greatest UCS value (averaging 21.8 MPa) this is because of the two reasons (i) predominantly fine grain size and (ii) the in-equi-granular nature of the tested sample. This is in line with the explanation provided by Lindquist et al. (20037), which states that "a large size distribution enhances strength and improves resistance to disintegration when compared to a rock with more uniform grain size." The variation in grain size significantly influences the mechanical behaviour of rocks. Rocks with higher concentrations of physically powerful minerals are, of course, more durable (Tugrul and Zarif, 1999). Rocks with coarse grain sizes are weaker than those with finer grain sizes but identical model mineralogy (Bell, 2007). However, the UCS value of the medium-grained sample (sample averaging 15.09 MPa) is lower than that of the coarse-grained variety, according to the current experiment (Sample JTN-3 averaging 18.86 MPa). The coarse grain sample's higher strength is most likely owing to the finer irregularity, or sutured quality, of the boundaries of the constituent minerals grain. As a result, the medium grained sample's UCS value is low, most likely due to the greater regularity of the intergranular contacts. This observation is consistent with Shakoor and Bonelli's (1991) finding that the type of grain contact is more critical in influencing rock strength. Regularly structured mineral grains in rock are weaker than randomly shaped constituents. In addition to strength testing, tests for water absorption and specific gravity were carried out to ascertain the marble's porosity and specific gravity. The examined samples from the Bando Obo area has very little water absorption value. As a result, all of the tested samples have a high specific gravity value, i.e., greater than 2.25. Hence the bando obo marble are good for using construction.

Authors contribution

Acquiring data and composing a draft, Afrasiab and Ishtiaq Zaman; this study's conception, methodology, management of the project, resources, software, monitoring, collecting data writing, and draft writing- the manuscript's appraisal and revision, Nazir ur Rehamn and Abdul Hakim Shah.

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Conflict of Interest

There are no conflicting interests mentioned by the researchers.

References

Anon, O. H. (1997). The description of rock masses for engineering purposes. Engineering Group Working Party Report, Quarterly Journal of Engineering Geology, 10, 43-52.

Anon, O. H. (1979). Classification of rocks and soils for engineering purposes: Engineering geological mapping, part 1: Rock and soil materials. Bulletin of the International Association of Engineering Geology, 19, 364-371.

Anon, O. H. (1981). Basic geotechnical

description of rock masses. International Society of Rock Mechanics Commission on Classification of Rocks and Rock Masses. International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, 18, 85-110.

Asrarullah, & Hussain, A. (1985). Marble deposits of Northwest Frontier province, Pakistan. Geological Survey of Pakistan Information Release, 128.

ASTM International. (1992). ASTM D2938-92, Standard test method for unconfined compressive strength of intact rock core specimens. ASTM International.

Bateman, A. M. (1967). Economic mineral deposits (2nd ed.). John Wiley & Sons.

Blyth, F. G. H., & De Freitas, M. H. (1974). A geology for engineers (6th ed.). Edward Arnold Ltd.

Bell, F. G. (2007). Engineering geology (2nd ed.). Elsevier.

Blyth, F. G. H., & De Freitas, M. H. (2017). A geology for engineers (7th ed.). CRC Press.

Burbank, D. W., & Johnson, G. D. (1982). Intermontane-basin development in the past 4 Myr in the northwest Himalaya. Nature, 298(5873), 432-436.

Calkin, J. A., Offield, T. W., & Ali, S. T. (1996). Geology and mineral resources of southern Hazara District. Geological Survey of Pakistan.

Chatterjee, B., Banerjee, S., & Sarkar, A. (2015). Provenance and geochemical study of the Makrana marble, Rajasthan, India. Journal of Asian Earth Sciences, 111, 98-110.

Cristern, N. D., & Hunsche, U. (1998). Time effect and rock mechanics, experimental foundation. Rock Mechanics and Rock Engineering, 31(4), 225-236.

Diepetro, J. A., Pogue, K. R., Hussain, A., & Ahmed, I. (1999). Geological map of Indus Syntaxes and surrounding areas, NW Himalaya, Pakistan. Geological Society of America Special Paper, 328.

Farmer, I. (1983). Engineering behaviour of rocks (2nd ed.). Chapman & Hall Ltd.

Ghauri, A. A. K., Pervez, M. K., Riaz, M., Rehman, O. U., Ahmad, I., & Ahmad, S. (1991). The structure and tectonic setting of Attock-Cherat and Kalachitta ranges in Nizampur area, NWFP, Pakistan. Kashmir Journal of Geology, 8-9, 99-109.

Howarth, D. F. (1986). Experimental study on the relationship between rock texture and mechanical performance. Transactions of the Institute of Mining and Metallurgy, 95, 41-44.

Hussain., A. (1992). Paleozoic and Mesozoic stratigraphy of the Peshawar basin, Pakistan: Correlations and implications, Geological Society of America Bulletin.

Hussain, K., et al. (2022). Engineering geological and geotechnical investigations for design of oxygen plant. International Journal of Geosciences, 13, 303-318.

Hashmi, I. S., Jan, U. I., Khan, S., & Ali, N. (2018). Depositional, diagenetic, and sequence stratigraphic controls on the reservoir potential of the Cretaceous Chichali and Lumshiwal formations, Nizampur Basin. Pakistan Journal of Himalayan Earth Sciences, 51(2A), 44-65.

Hylland, M. D., & Riaz, M. (1988). Stratigraphy and structure of the southern Gandghar Range, Pakistan. Geological Bulletin of the University of Peshawar, 1, 15-24.

Lindquist, J. E., Akesson, U., & Malanga, K. (2007). Microstructures and functional properties of rock materials. Materials Characterization, 58, 1183-1188.

Moufti, M. R. H., & Nazzal, J. M. (2017). Marble quarrying: An energy and waste-intensive process. Energy Procedia, 141, 136-141.

Pogue, K. R., Wardlaw, B. R., Harris, A. G., & Hussain, A. (1992). Paleozoic and Mesozoic stratigraphy of the Peshawar Basin, Pakistan: Correlations and implications. Geological Society of America Bulletin, 104, 915-928.

Poli, G. (1992). Genesis and evolution of Carrara marble: The role of CO2-rich fluids. Journal of Geology, 100(1), 73-86.

Rehman, U. N., Ahmad, S., Faisal, S., Ullah, S., Khan, A. M., & Fakhrul, I. (2024). Structural modeling of the southern Kohat Basin and frontal ranges: Implications for tectonic evolution and hydrocarbon play. Journal of Solid Earth Sciences, 9(2).

Rehman, U. N., Ahmad, S., Faisal, S., Asghar, A. A., Azeem, W. M., Afrasiab, ... & Javed, S. (2022). Geological mapping and neotectonics studies of the Eocene limestone distributed over Mala Khel Anticline, Trans Indus Ranges, Northwest Himalayas, Pakistan. Arabian Journal of Geosciences, 15, 1281.

Rehman, U. N., Ahmad, S., Faisal, S., Ullah, S., Azeem, W. M., Afrasiab, ... & Jabir, N. (2022). Structural refinement of the southern Kohat Basin and adjoining areas: Implications for hydrocarbon potential of the Kohat Basin, Pakistan. Bahria University Research Journal of Earth Sciences, 7(1), 8-19.

Rehman, U. N., Ahmad, S., Ali, F., Alam, I., & Shah, A. (2017). Joints/fractures analyses of Shinawah area, District Karak, Khyber Pakhtunkhwa, Pakistan. Journal of Himalayan Earth Sciences, 50(2), 93-113.

Rehman, U. N., Ahmad, I., Ahmad, S., & Waheedullah. (2016). Structural analysis of the Kharthop and Kalabagh Hills area, Mianwali District, Punjab, Pakistan. Journal of Himalayan Earth Sciences, 49(2), 63-74.

Sajid, M., Arif, M., & Muhammad, N. (2009). Petrographic characteristics and mechanical properties of rocks from Khagram-Razagram area, Lower Dir, NWFP, Pakistan. Journal of Himalayan Earth Sciences, 42, 25-36.

Shakoor, A., & Bonelli, R. E. (1991). Relationship between petrographic characteristics, engineering index properties, and mechanical properties of selected sandstones. Environmental & Engineering Geoscience, 28, 55-71.

Török, Á., & Szücs, C. (2013). The geology and significance of Afyon marble, Turkey. Geological Journal, 48(3), 266-278.

Tsivilis, S., Tsantilas, J., Kakali, G., Chaniotakis, E., & Sakellariou, A. (2003). The permeability of Portland limestone cement concrete. Cement and Concrete Research, 33, 1465-1471.

Tsiambaos, G., & Sabatakakis, N. (2004). Considerations on strength of intact sedimentary rocks. Engineering Geology, 72, 261-273.

Tugrul, A., & Zarif, I. H. (1999). Correlation of mineralogical and textural characteristics with engineering properties of selected granitic rocks from Turkey. Engineering Geology, 51, 303-317.

Ullah, R., Ullah, S., Rehman, N., Ali, F., Asim, M., Tahir, M., ... & Muhammad, S. (2020). Aggregate suitability of the Late Permian Wargal Limestone at Kafar Kot Chashma area, Khisor Range, Pakistan. International Journal of Economic and Environmental Geology, 11(1), 89-94.

Ullah, S., Ullah, R., Rehman, N., Turab, S. A., Ahmad, S., Khan, M. A., ... & Rehman, T. U. (2021). Physio-mechanical properties of the Lockhart Limestone aggregate at Kohala Bala, South Eastern Hazara, North Pakistan. Bahria University Research Journal of Earth Sciences, 6(1), 1-7.

Wadood, B., Awais, M., Bilal, M., Ishaq, M., Ahmad, L., & Zafar, Z. (2019). Reservoir characterization and modeling with diagenetic trends of carbonates of the Kawagarh Formation: A section exposed in the Kala-Chitta Range, Pakistan. International Journal of Economic and Environmental Geology, 10(2), 105-111.

Willard, R. J., & McWilliams. (1969). Microstructural techniques in the study of physical properties of rocks. International Journal of Rock Mechanics and Mining Sciences, 6, 112.

Yeats, R. S., & Hussain, A. (1987). Timing of structural events in the Himalayan foothills of northwestern Pakistan. Geological Society of America Bulletin, 99, 161-176.