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# Assessment of Tertiary (Oligocene and Miocene) Limestone for their Suitability as Dimension Stone, Sona Pass Area, Karachi Pakistan

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**Abstract**

Geochemical and geotechnical characterization of Pir Mangho limestone, Halkani limestone unit Talawa limestone and Turitela bed of Tertiary age was carried out for their suitability as dimension stone. For this purpose, limestone samples (n = 8) were collected from Sonapass area. Petrographic properties reveals that all the collected samples are fine grained allochemical limestone enrich with fossil fragments as frame work grain. As per Dunham (1962) classification, Pir Mangho and Talawa limestone are classified as boundstone while Halakni limestone and Turitela units are classified as grainstone. According to Folk (1959) classification Pir-Mangho and Halkani limestone unit is classified as biosparitic limestone while, Talawa limestone is bio-micritic limestone. As per Munsell color chart most of the samples are reddish yellow followed by pinkish white and yellowish red in color. CaO and MgO content varies in the order of Lp (49.9%) > Lt (47.40%) >, Lh (30.81) > Lm 25.45% and Lm (2.20%) > Lh (1.30%) > Lt (0.84%) > Lp (0.72%) respectively. In Lp and Lt limestone samples, the average $SiO_2$ content is < 6%. On the other hand, Lh is found to contain 32.59% silica. Likewise, the mean content of $Na_2O$ and $K_2O$ varies in the order of Lh (0.47%) > Lm (0.44%) > Lt 0.06% > Lp (0.05%) and Lh (1.25%) > Lm (0.69%) > Lt (0.23%) > Lp 0.215% respectively. On the other hand, Al2O3 content in all studied samples varies in the order of Lh (5.94%) > Lm (4.76%) > Lt (1.28%) > Lp (1.15%). The average iron oxide content in collected samples is found to be 1.36% (Lp), 2.99% (Lt), 3.67% (Lh) and 14.90% (Lm) respectively. Absorption data of present study reveal that except sample Lm-8, all samples are classified as high density rocks where mean absorption values of all samples varied in the order of 3> 1.42 > 2.66

for Lh, Lt, and Lp respectively. On the other hand, sample Lm-8 is classified as medium density rock with high degree of absorption (5.27%). Collected samples have shown variable bulk density where average values are 2545.673 kg/m$^3$, 2289.44 kg/m$^3$, 2326.33 kg/m$^3$3 and 1990.80 kg/m$^3$ for Lp, Lh, Lt and Lm respectively so these rocks are classified as high to medium density rocks. The average compressive strength of collected samples are 42.21, 41.93 and 42.16 Mpa for Lp, Lh, and Lt respectively suggesting that these are medium density rocks and results are comparable with ASTM C 568. The Lt, Lp and Lh have acceptable range of modulus of rupture, with the average value varying in the order of 23.7 > 22.61 > 22.48 and comparable with ASTM C568. Absorption has negative relationship with compressive strength and density. While, density has positive relationship with compressive strength. Hence, these results indicate that except sample Lm-8 all the collected limestone samples of Nari and Gaj formations are suitable for the purpose of medium grade dimension stone.

**Keywords:** Limestone, Tertiary age, dimension stone, geochemical and geotechnical properties.

## Introduction

All natural rock materials that are quarried or mined for construction or industrial uses is termed as "stone" (Currier, 1960). The two main categories of construction stone among wide variety of its use namely, (a) crushed and broken stone and (b) dimension stone (Currier, 1960). As per Dolley (2004) dimension stones (DS) are rock material which can be cut, polished and used for making slabs or blocks of specific size for interior/exterior decoration of buildings. It is one of the oldest and most durable building materials. The Egyptian pyramids were built from quarried stone in about 2800 B.C. and the Babylonians used cut stone in 3600 B.C. to build the renowned Hanging Gardens, one of the Seven Wonders of the World. In nature wide variety of dimension stones, (marble, granite, limestone, travertine, and sandstone) with thousands of shades and colors, are present. The term marble is used for all calcareous rocks capable of being polished. The average use of DS increases by ~6.86% per annum of the total (Akber, 2009). About 60 million tons of DS are produced worldwide annually, out of which more than 50% contribution of China, Italy, Spain and India (Akber, 2009). In contrast Pakistan's share its production only 0.58% (Akber, 2009).

The limestone horizons of dimension quality occur in B and C units of Lakhra Formation of Paleocene age in and around Sonda and Chillia areas of Thatta district. The dimension quality limestone of Kirthar Formation of Upper Eocene age is exposed mainly in the Bado Jabal, Bhago Thoro, Thano Ahmed Khan and Tikku Baran areas. It is cream to creamy white and in places it becomes white. Geologically, the western Sindh consists of hilly terrain and largely comprises of sedimentary rocks. In most cases, limestone of the dimension and cut stones quality occur in geological horizons ranging in age from Upper Paleocene to Miocene (MMDD UnPub). Huge deposits of dimension and cut stones are found in Sari Singh area of Thano Bula Khan Taluka. The yellow-colored limestone of Nari Formation and pink colored limestone of the Gaj Formation are the main varieties used for making blocks, designed bricks and rock and split faced small slabs (MMDD UnPub). The deposits of Tertiary age rocks occur in Mattar, Gidari, Purkani, and Mol areas. The stones from this area are being used locally and supplied to the markets of Karachi and Hyderabad. Fortunately, exposures of limestone unit of Nari and Gaj formations occur on the southwest of Karachi which are assumed to be the good source of dimension stone. However, no work has been carried out so far to assess their suitability as dimension stone. Therefore, present study is aimed is at evaluating the suitability of limestone beds of Nari and Gaj formations exposed in southwest of Karachi for dimension stone where a large number of limestone units are exposed.

**Study area**

Study area is located near Sonapass area to Mubarak village on the southwest of Karachi city. It is located on the western flank of Cap Monze anticline at the southern end of Kirthar fold belt, west of Karachi (Fig.2). Hub River is present on the northwest while Sona Pass fault occurs on northeast. It lies between 24051/ 17.3267// to 24055/48.4185//N and 660 41/5.4442// to 660 52/23.9345// in south of Hub-River (Fig. 1).

The study area is accessible from Kemari town and it is located about 6-7 km from Hawks Bay where Nari and Gaj formations of Oligocene and Miocene age are exposed which are mainly comprised of siliciclastic rock with subordinate limestone.

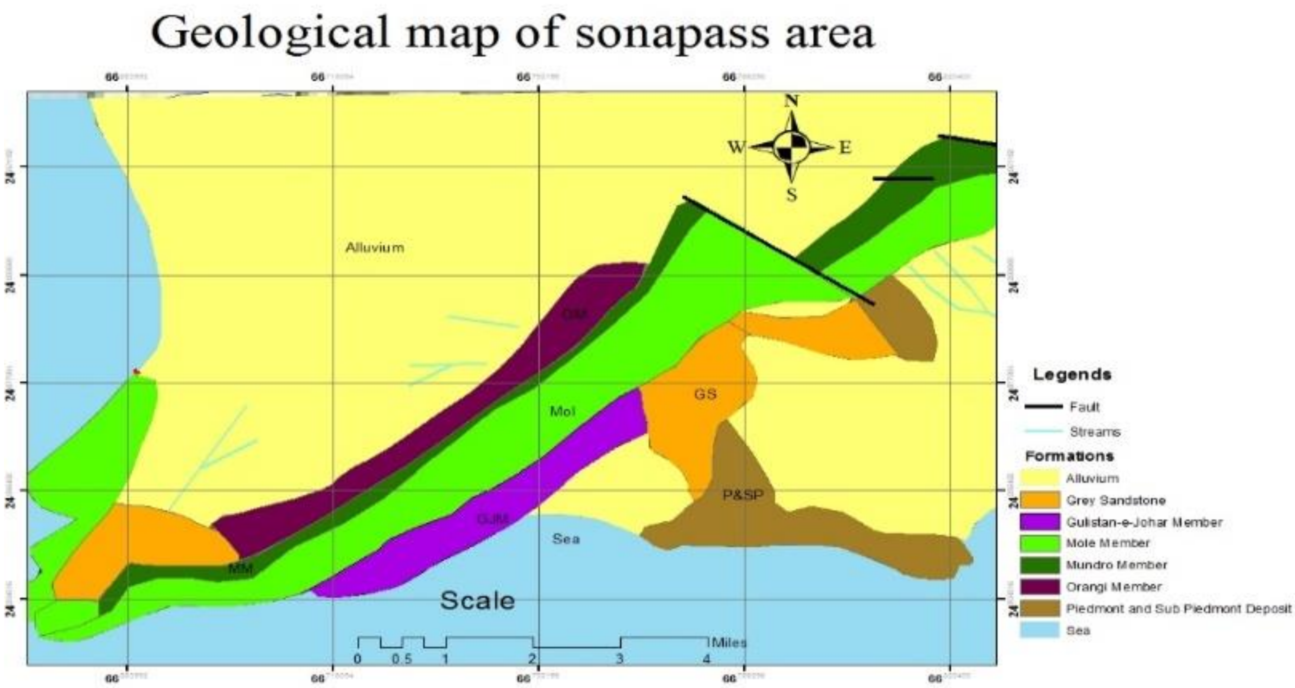



Fig.1 Geological map of study area

## Material and Methods

### Sampling

Field work was carried out to collect samples (n=08) from Pirmangho, Halkani, Metan and Talawa members of Nari and Gaj Formations cropping out along Sonapass fault, blocks of 15×15×15 inches were collected from Nari and Gaj formations.  The samples were tagged with number and carried to the laboratory for analysis. The field coordinates of collected samples were noted by using Global Positioning System (GPS) and plotted on google earth map (Fig. 2). The cementing material were tested in situ by using HCl (10%).

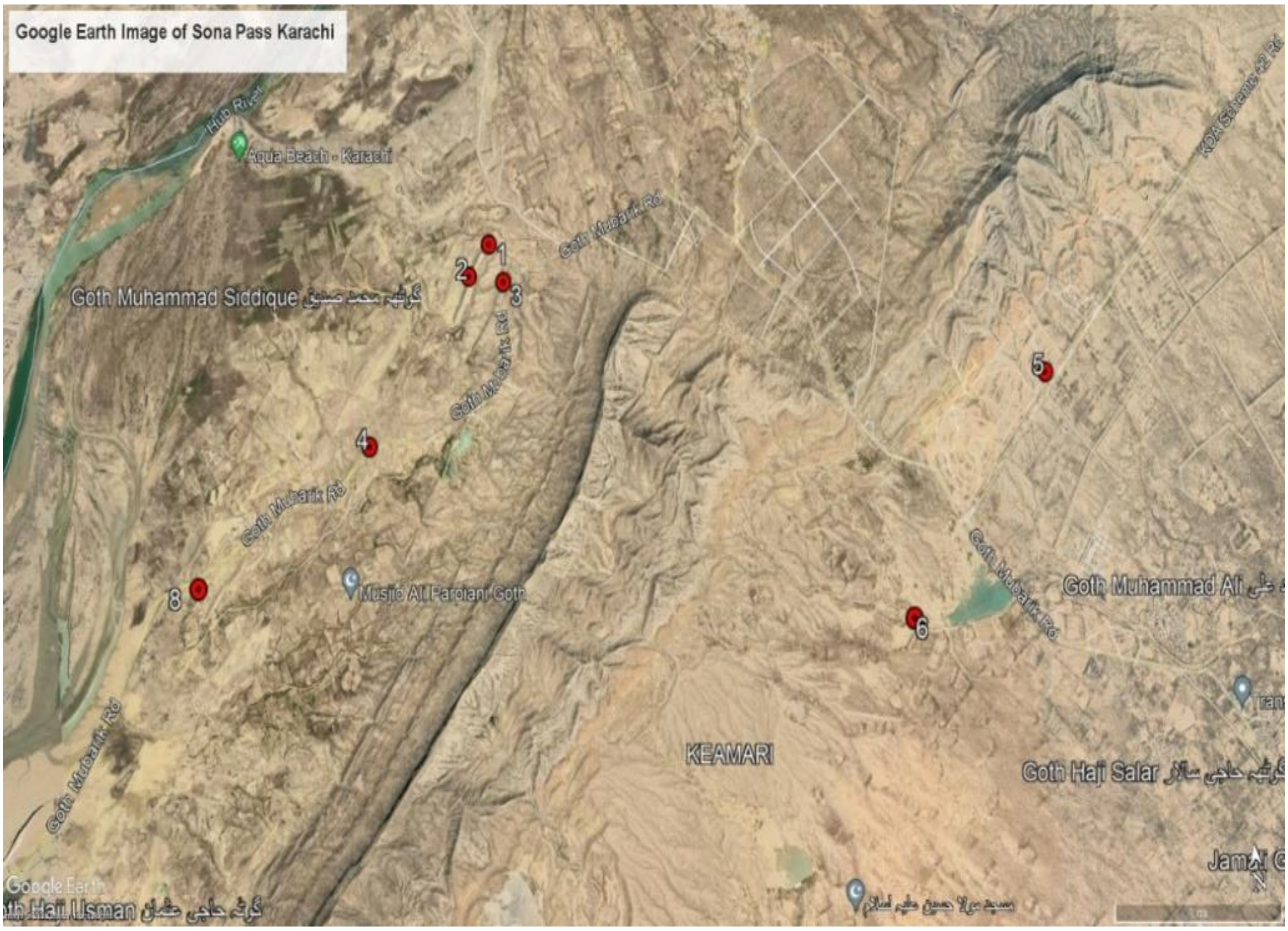



Fig.2 Google Earth image showing the samples location.

## Sample Analytical Techniques

Petrographic study of rock samples (n=8) were carried out using thin sections was examinant carried out under optical microscope. About 3 thin sections of each limestone samples were prepared to determine the fossils type, mineral composition, grain texture and grain matrix. The colors were determined using Geological rock color chart with genuine Munsell color chips (2009). The color of the studied samples is determined by spinning a small plate of the rock sufficiently to blend the colors of the constituent minerals and comparing the blended color with a standard rock color chart, such as that prepared by Munsell color chart (2009). Major oxides of the studied rocks samples were determined by using XRF technique. On the other hand, geotechnical properties including bulk density and water absorption of rigid and massive samples of limestone was determined according to ASTM C 97 (2003). While, compressive strength and rupture modulus for all the specimen were measured as per ASTM C 170 (1999) and ASTM C 99 (2000) respectively.

**Results and Discussion**

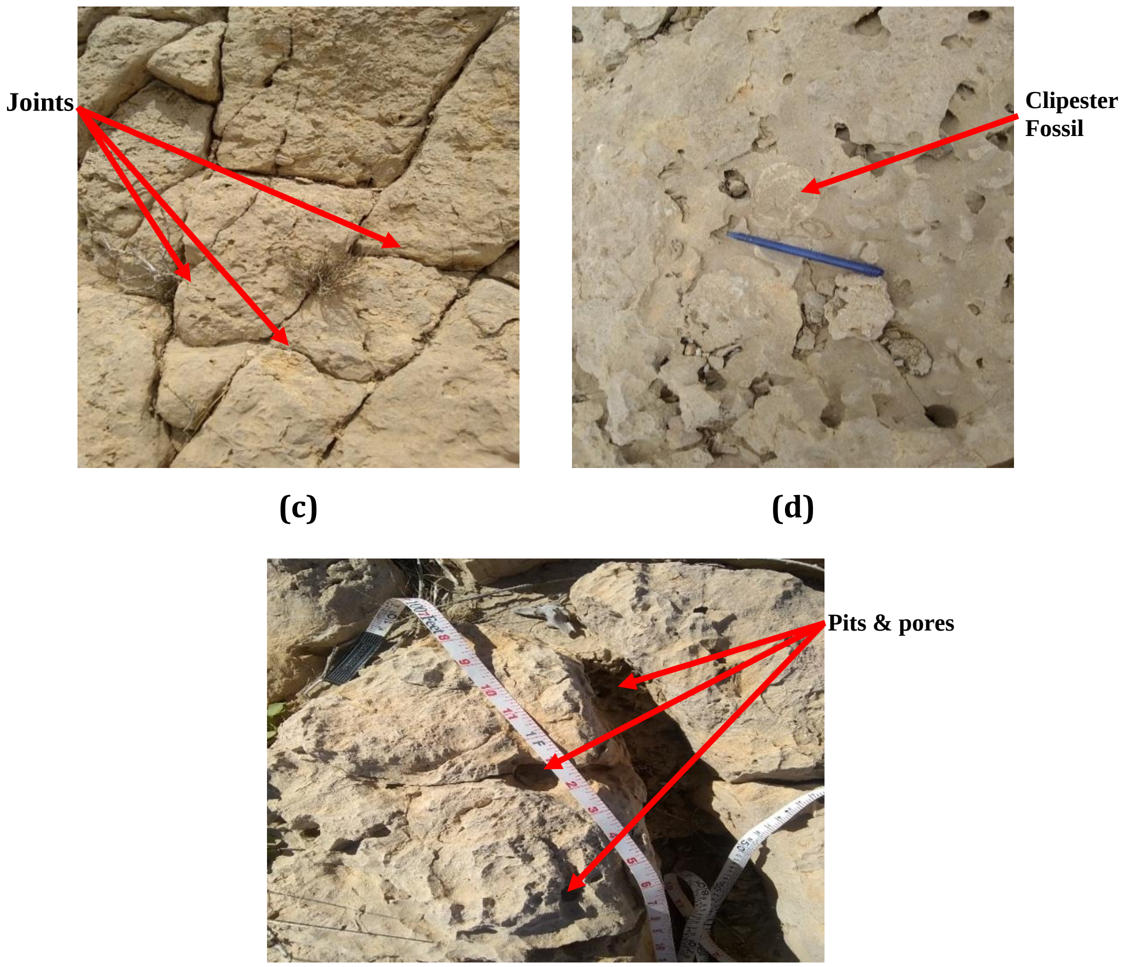
Limestone samples collected from four units (Pir mangho, Halkani, Talawa and Turitela bed of Metan Clay) of Nari and Gaj formations were analyzed for their substantial exposure, lithological uniformity, density of joint and fractures, durability, absence of deleterious materials and attractiveness as described by Awadh et al (2016). Other factors such as cost of quarrying, transportation, processing and the availability of alternative sources of supply have also been compared with the specifications described by Harrison and Bloodworth (1994).

**Characterization of Pir-Mangho Limestone (PML)**

Pir Mangho limestone is the unit of Tobo member which is basal part of Nari Formation. Tobo is grayish green shale with subordinate siltstone which contains few beds of fossiliferous, hard, compact, brownish cream color, fine grained nodular and shallow marine limestone which is grading into Pir Mangho Limestone unit (Fig.4b). This unit under the Tobo member and overlain by Halkani member. PML is highly fractured and contains 1 to 2 feet long jointed blocks expressing the impact of tectonic stress (Fig. 4c). Dense distribution of spherical pores (0.5 to 5 inches) were also observed indicating dissolution activity due to chemical weathering (Fig. 4d). Petrographic study reveal that PML is allochemical limestone containing gastropods and clypeaster fossils as frame work grain (Fig.4d). As per Dunham (1962) classification, PML is classified as boundstone.

**(a)**

**(b)**




(e)

Fig. 4 Surface features of the Pir Mangho limestone outcrop in study area. (a) Fine grain brown color fresh surface with lime mud and dull earthy color weathered surface, (b), Joint spacing (c) Jointed and fractured limestone (d) Echinoderm fossils (e) Pits and pores due to chemical weathering

## Halkani Limestone Unit (HLS)

Halkani limestone lies on the basal part of Halkani member. It is brown, hard, compact, crystalline limestone. Generally, the texture of rock is fine grained spheroidal blocks. Spheroids are the result of physical weathering on jointed blocks. Halkani limestone unit is densely fractured with inter joint spacing of 2 to 6 feet wide which is due to regional compressive forces (Fig. 5c). Thin (1.5inches) to thick (6 inches) bedding of limestone suggests fluctuation in energy of depositional environment due to sea level changes (Fig. 5a and 5b). Large calcitic veins (1 to 5 feet long) and small iron veins (1 to 1.5 inches) have also been observed indicating the hyper oxidation condition due to shallow depth and high energy environment (Fig. 5d and 5e). Petrographic study reveal that it is allochemic limestone containing gastropods fossils as frame work grain (Fig.8b). HLS classified as grain stone as per Dunham classification (1962).

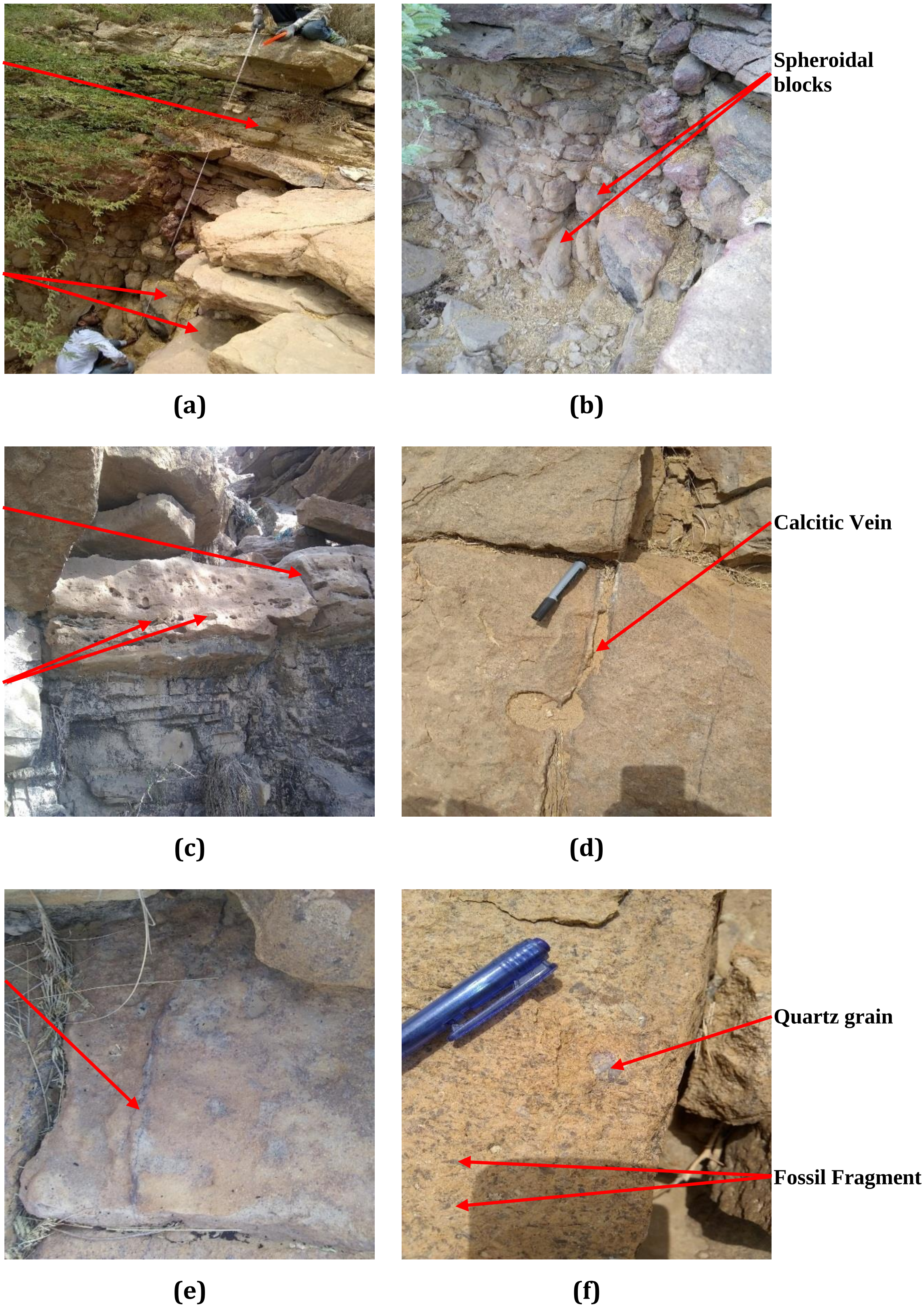


Fig. 5 Surface features of the Halkani limestone member outcrop in the studied area. (a) Thinly to thickly bedded limestone, (b) Nodules due to mechanical weathering, (c) Jointed and fractured limestone with 1-2 inches pore spaces (d) Calcitic vein (e) Iron vein (f) Fossil fragments.

**Turitela Limestone bed (TB)**

This thin to medium (1- 1.5 feet) bedded limestone is part of Metan clay member of Gaj Formation. It is exposed sporadically the form of thin layers (1-1.5 feet) or small pockets (Fig 6a). It is mainly consist of thin layer of limestone intercalated with shale suggesting shallow marine environment. Texturally, it is fine grained, allochemical limestone containing gastropode fossils (Fig. 6c). Turitela bed is redish brown and friable due to the presence of clay (Fig. 6b). It is mechanically weak limestone because clay content influences the mechanical behavior and strength of rock (MIA, 2016).

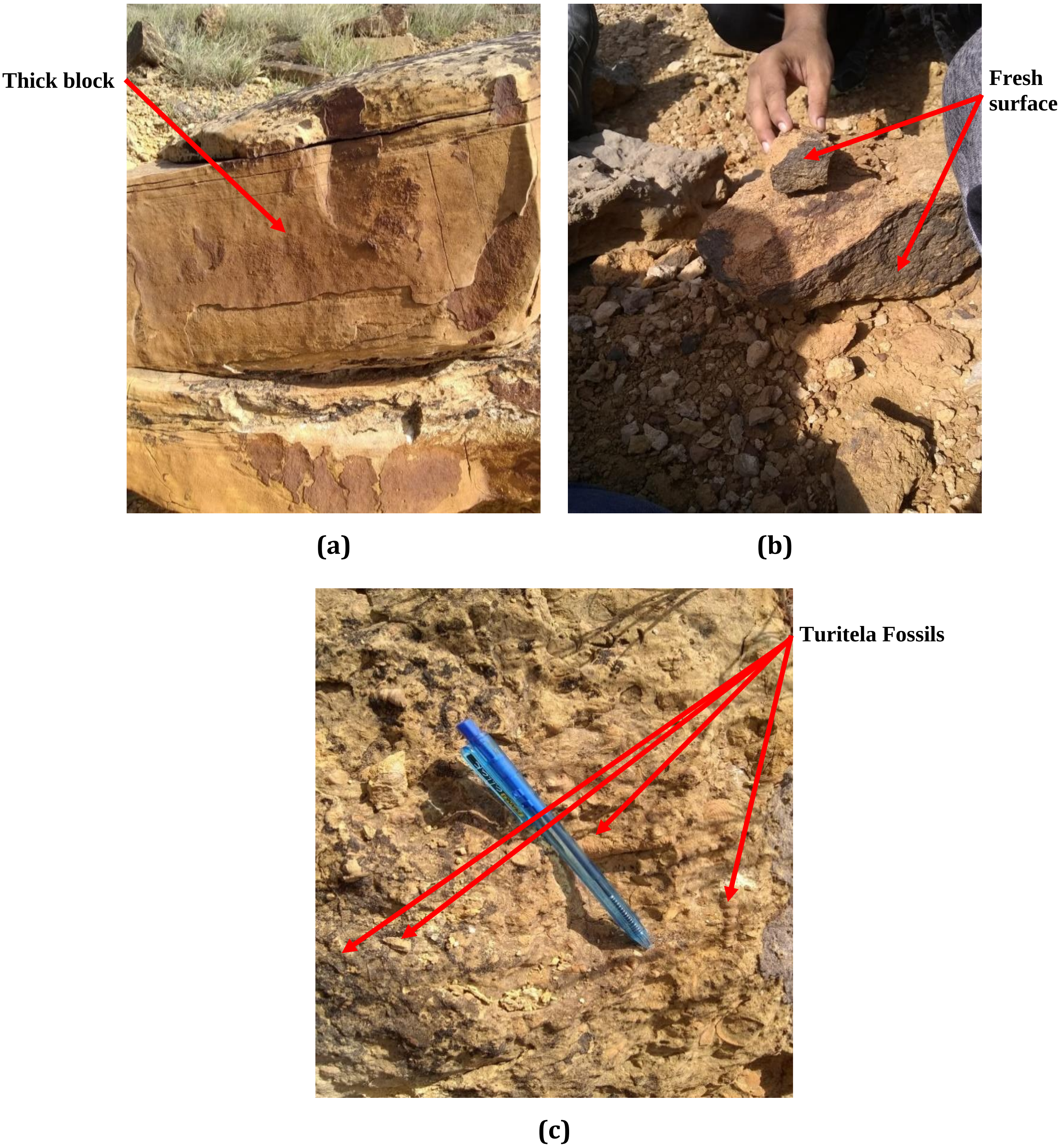
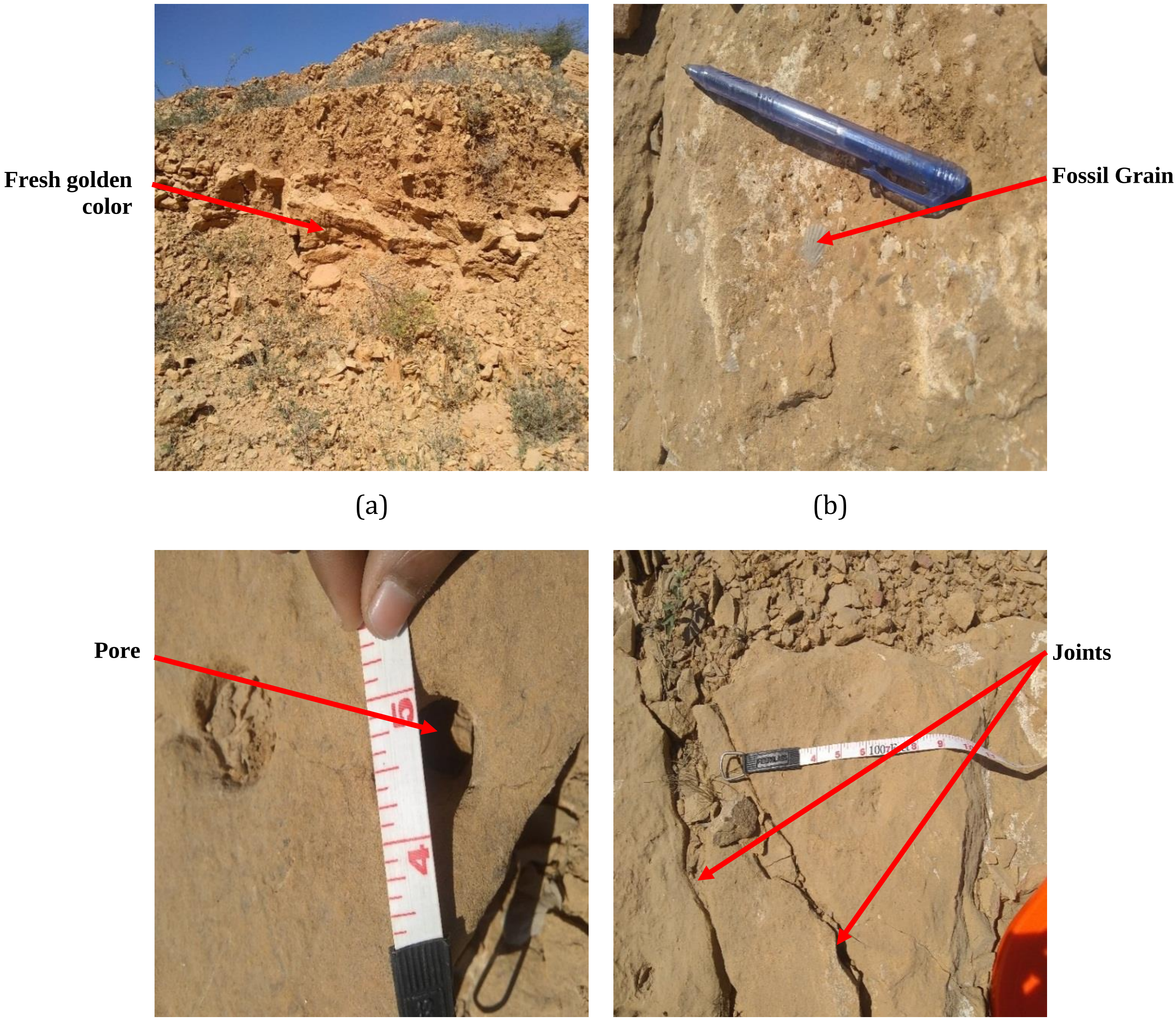



Fig. 6 Surface features of the Turitela limestone outcrop in the studied area. (a) Small pockets of limestone intercalated with shale, (b) Fresh surface of limestone shows redish brown in color with light brown weathered surface (c) Gastropode fossil fragments

**Talawa Limestone (TL)**

Talawa limestone overlain by the Jhill member of Gaj Formation and underlaine by Drig Clay. The texture of rock in study area is characterized by fine grain, fossiliferous containing microfossil of gastropodes (Fig. 7b). As per Dunhum (1962) classification TL classified as boundstone. Field observation reveals that it is hard, compact and brittle limestone manifesting fractures and joints of about 1 to 2.5 feet wide (Fig. 7a). Its fresh surface is golden yellow with dull brown weathered surface (Fig.7b and 7c). About 0.5 to 1 inches spherical pores have also been observed indicating dissolution of calcareous part due to acidic rainfall (Fig. 7b).

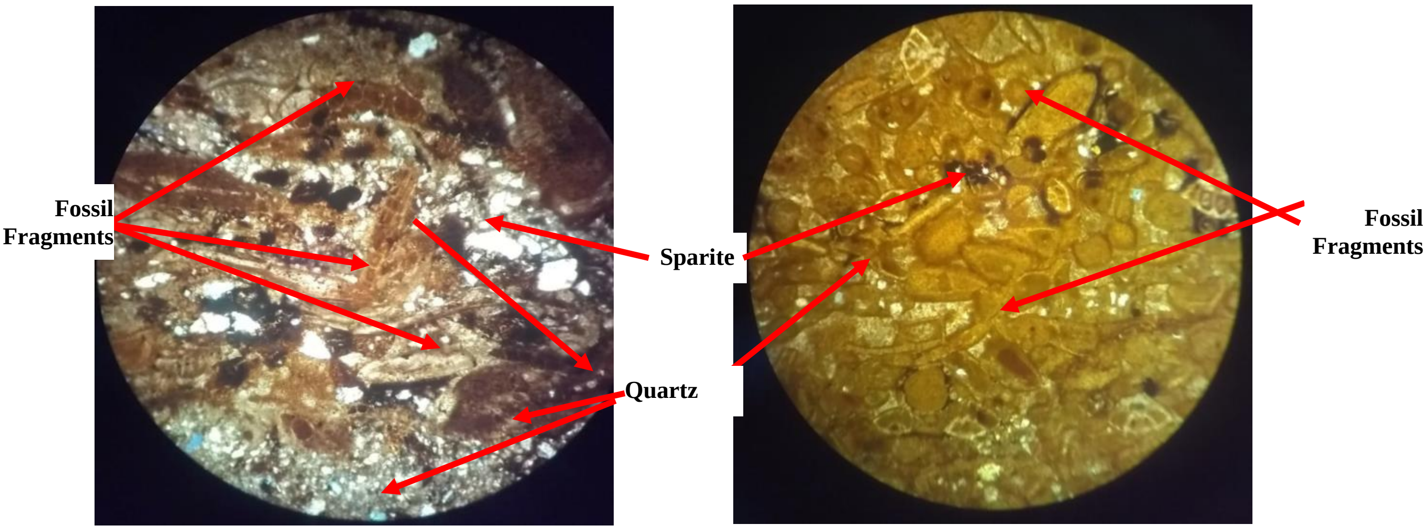


(c) (d)

Fig. 7 Surface features of the Talawa limestone outcrop in the studied area. (a) Jointed and fractured limestone and fresh surface golden yellow in color (b) Weathered surface dull brown in color and Fossil grain (c) Pores (d) Joints

## Petrography

Carbonate rocks are made up of depositional products (include grain and matrix) affected by diagenesis (Flugel, 2004). The physical, chemical and biological alteration occurred after deposition suggest diagenetic processes. This process can change many of the petro-physical properties of carbonate rock. Therefore, the understanding these processes and their product has high economic importance. (Flugel, 2013). Micrographs of thin sections reveal that all the collected samples of Nari and Gaj formations are fine grained, allochemical limestone enriched with fossil fragments as frame work grains (Fig. 3 a,b &c). As per Dunhum (1962) classification, Pir Mangho and Talawa limestones are classified as boundstone. On the other hand, about 80% grains and 20% matrix reported in Halkani limestone units are classified as grainstone. According to Folk (1959) classification all collected samples Pir Mangho and Halkani limestone are classified as biosparitic limestone (Fig. 3 a and b.). While Talawa limestone can be classified as biomicritic limestone (Fig 3c). Impact of compressional forces seems insignificant to form sparite in case of these limestones.



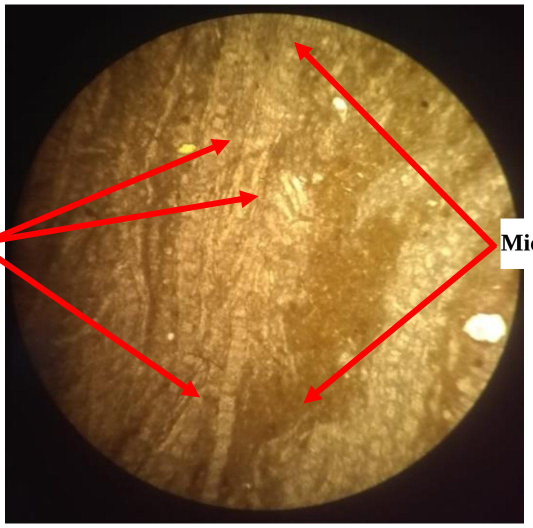



Fig. 8 a, b, and c Show the view of sample Lp, Lh and Lt under cross nicols mode.

### Color

Color of the studied limestone samples have been summarized in Table 1 are compared with Munsell color chip (2009). Color is an important property of rock used for building and ornamental stone. If surfaces are to be mark, vigorous contrast between polished and tooled surfaces is generally desired. Thus, a color classification must be based, on the type of surface as well as its use. According to Munsell color chart Lp-3 and Lm-8 of the collected limestone samples are yellowish red in color (Fig 9 c & h). The slight change of the color in studied samples can be attributed to the oxidation of organic matter and ferrous Fe-oxides (Currier, 1960). While color of sample Lp-1, Lp-4, Lp-5, Lp-6 and Lp-7 are reddish yellow. On the other Hand, Lp-2 is pinkish white. As per Pereira et al (2015), color indicates the occurrence of deleterious minerals supported by oxides that influence the textural integrity, durability, or strength of the stone.

Table 1 Color of the studied limestone sample using geological rock color chart with genuine Munsell color chips version 2009

| Sample Code | Color Code | Color Name According to Rock Color Chart (2009) |
|---|---|---|
| **Lp-1** | 5YR 7/6 | Reddish Yellow |
| **Lp-2** | 5YR 8/2 | Pinkish white |
| **Lh-3** | 5YR 5/6 | Yellowish Red |
| **Lp-4** | 5YR 7/6 | Reddish Yellow |
| **Lt-5** | 5YR 6/8 | Reddish Yellow |
| **Lt-6** | 5YR 7/6 | Reddish Yellow |
| **Lt-7** | 5YR 7/6 | Reddish Yellow |
| **Lm-8** | 5YR 5/6 | Yellowish Red |

**Geochemical Properties**

Oxides of the rock sign about weathering condition and provenance (Ben et al., 2016). Oxides of the rock give sign about weathering start and provenance (Ben et al, 2016). All the sedimentary rocks including limestone contain impurities that affect their properties and appearance. Mean CaO and MgO varies in the order of Lp (49.9%) > Lt (47.40%) >, Lh (30.81) > Lm (25.45%) and MgO% Lm (2.20%) > Lh (1.30%) > Lt (0.84%) > Lp (0.72%). Results indicate that CaO content in both Pir Mangho and Talawa limestone is higher than the reference value (42.32%) for carbonate rocks (Turekian and Wedepohl, 1961).. Whereas low content of CaO is reported in sandy limestone (Lh) and Turitela bed (Lm) (Table 2). In Lp and Lt the average $SiO_2$ content is < 6% (Table 2). On the other hand, On the other hand, silica content of Lh and Lm is found to be 32.60% and 14.60% respectively, both rock units are classified as sandy limestone. Likewise, the mean content of $Na_2O$ and $K_2O$ in all collected samples varies in the order of Lh (0.47%) > Lm (0.44%) > Lt 0.06% > Lp (0.05%) and Lh (1.25%) > Lm (0.69%) > Lt (0.23%) > Lp 0.215% respectively. On the other hand, $Al_2O_3$ content in all studied samples varies in the order of Lh (5.94%) > Lm (4.76%) > Lt (1.28%) > Lp (1.15%). $Al_2O_3$, $Na_2O$ and $K_2O$ are attributed to the occurrence of clay minerals in the rock (Erlström et al, 2009 and Jennerheim, 2016).. Hence, the low content of $Al_2O_3$, $Na_2O$, and $K_2O$ reflects the low clay mineral content in the limestone samples. Iron, (expressed as $Fe_2O_3$), is commonly found in studied samples rich in clay mineral, such as marl, where it can reach upto 3 %, as compared to other pure carbonate rocks (Jessica, 2016). The average iron oxide content in collected samples are found to be 1.36% (Lp), 2.99% (Lt), 3.67% (Lh) and 14.90% (Lm) respectively. The high content of iron reflects the occurrence of clay minerals in the studied samples (Table 2). It is consistent with the fact that all limestone of Tertiary age have been deposited on the clay substrate at the onset of shallow but stable environmental condition.

Table 2 Major oxide distribution of studied limestone samples

| Geochemical Properties Of Limestone | | | | | | |
|---|---|---|---|---|---|---|
| **Major Oxides** | **Lp-1** | **Lp-2** | **Mean** | **Lh-3** | **Lt-5** | **Lm-8** |
| **$SiO_2$** % | 4.75 | 4.14 | 4.45 | 32.95 | 5.87 | 14.59 |
| **$Al_2O_3$**% | 1.18 | 1.05 | 1.15 | 5.94 | 1.28 | 4.76 |
| **$Fe_2O_3$**% | 1.99 | 0.73 | 1.36 | 3.67 | 2.99 | 14.90 |
| **CaO**% | 49.02 | 50.78 | 49.02 | 25.45 | 47.40 | 30.81 |
| **MgO**% | 0.92 | 0.52 | 0.72 | 1.30 | 0.84 | 2.20 |
| **$Na_2O$**% | 0.06 | 0.05 | 0.05 | 0.47 | 0.06 | 0.44 |
| **$K_2O$**% | 0.23 | 0.20 | 0.215 | 1.25 | 0.23 | 0.69 |

**Geotechnical Properties**

Physical properties of carbonate rocks collected from Nari and Gaj formations, have been compared with the ASTM C568-03 (2006) for dimension stone (Table 3). These include density, water absorption, modulus of rupture and compressive strength. This ASTM standard specifies the minimum requirements for limestone to be used as dimension stone.

Table 3 Geotechnical properties of limestone samples

| **Geotechnical Properties of Tertiary age Limestones** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Physical Properties** | | | | **Strength** | | | |
| **Sample code** | **Absorption** | **Specific Gravity** | **Density** | **Compressive Strength** | | **Modulus of Rupture Strength** | |
| **-** | **%** | **-** | **Kg/m³** | **PSI** | **N/mm²** | **PSI** | **N/mm²** |
| **Lp-1** | 1.69 | 2.63 | 2632.08 | 6833 | 47.12 | 2963 | 20.43 |
| **Lp-2** | 2 | 2.6 | 2612.14 | 6139 | 42.34 | 3556 | 24.52 |
| **Lp-4** | 4.3 | 2.4 | 2392.8 | 5390 | 37.17 | 3319 | 22.89 |
| **Average** | **2.66** | **2.54** | **2545.673** | **6120.67** | **42.21** | **3279.33** | **22.613** |
| **Lh-3** | 3 | 2.3 | 2289.44 | 6080 | 41.93 | 3259 | 22.48 |
| **Average** | **3** | **2.3** | **2289.44** | **6080** | **41.93** | **3259** | **22.48** |
| **Lt-5** | 2.4 | 2.4 | 2392.8 | 6080 | 41.93 | 3233 | 22.30 |
| **Lt-6** | 1.149 | 2.2 | 2278.47 | 6000 | 41.38 | 3464 | 23.89 |
| **Lt-7** | 0.722 | 2.3 | 2309.33 | 6261 | 43.18 | 3615 | 24.93 |
| **Average** | **1.42** | **2.3** | **2326.33** | **6113.667** | **42.16** | **3437.33** | **23.7** |
| **Lm-8** | 5.27 | 2 | 1990.80 | - | - | - | - |
| **Average** | **5.27** | **2** | **1990.80** | - | - | - | - |
| **ASTM C 568** | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **High** | 3 | 2560 | 55 | 8000 | 55 | 1000 | 6.9 |
| **Medium** | 7.5 | 2160 | 28 | 4000 | 28 | 500 | 3.4 |
| **Low** | 1.2 | 1760 | 12 | 1800 | 12 | 400 | 2.9 |

### Absorption

Results of Geotechnical properties of collected limestone samples (n=08) have been summarized in Table 3. Water absorption refers to the amount of liquid that a stone will absorb upon immersion (Aurangzeb, 2009). According to ASTM C568, the rock with maximum absorption up to 3, 7 and 12% are classified as high, medium and low density rocks respectively (Table 3). Data of present study reveal that except sample Lm-8, all are classified as high density rocks where mean absorption values of all samples varied in the order of 3> 2.66> 1.42 for Lh, Lp, and Lt respectively. It suggests that these rock have low water absorption ability. As per (Jacobsen and Aarseth (1999) building stones exhibit low water absorption values are relatively more durable. Hence, low water absorption values in studied samples make these suitable for dimension stone in terms of absorption. On the other hand, sample Lm-8 is classified as medium density rock with high degree of absorption (5.27%) as compared to other samples. It is due to the presence of clay content, small pits and pores and micro-fractures (Fig. 6). with low content of water absorption on building material's surface will have little or not effect by weathering agents; such as wind or rainfall, which are considered as one of the factors for the assessment of appearance of rock that use as dimension stone (Jacobsen and Aarseth, 1999: Pereira et al. 2015).

### Density

Density data is important for and calculating the weight of flooring, walling or cladding panels used in the design of foundations, buildings and transportation (Spry., 1989). Collected samples of carbonate rock have shown variable bulk density where average values are 2545.673 kg/m$^3$, 2289.44 kg/m$^3$, 23263 kg/m$^3$3 and 1990.80 kg/m$^3$ for Lp, Lh, Lt and Lm respectively. As per ASTM C568-03, Pir Mangho limestone(Lp) samples are classified as high density rock while sandy limestone of Halkani Member (Lh) and Talawa limestone (Lt) are medium density rocks (Table 3). Data reveal that Lp, Lh, and Lt are suitable for use as dimension stone. On the other hand, sample Lm-8 is classified as low density rock which qualify to be used as DS.

### Compressive Strength

The average compressive strength of collected limestone samples is 42.21, 41.93 and 42.16 Mpa for Lp, Lh, and Lt respectively. Compressive strength of three studied rocks units suggest that these are medium density rocks and results are comparable with ASTM C 568 (Table 3). Strength of the rock depends on composition, degree of absorption and structure (Currier, 1960). Compressive strength of stratified sedimentary rocks (limestone and sandstone) is quite lower than those of crystalline rocks (granite, marble and quartzite). Compressive strength of Lm-8 could not be measured because it is friable, porous, and contain high clay content which render this rock unit to be considered as of low compressive strength stone. Kessler et al. (1940) gave compressive strength range (17.926 – 193.053 MPa) for limestone to be used as a dimension stone. Hence, the collected samples fall within this range and are of medium density, which confirm their suitability as dimension stone.

### Modulus of Rupture

Modulus of rupture measure the flexural strength of stones placed in position of unequal pressure or bedding such as sills and caps for doors and windows so that it has more tangible value than those for compressive strength (Currier, 1960). Data reveal that the Lt, Lp and Lh have acceptable range of modulus of rupture, with the average value varying in the order of 23.7 > 22.61 > 22.48 and comparable with ASTM C568 (Table 3), The modulus of rupture range for limestone reported by Bureau of standard is 3.447 – 1.379 MPa (Kessler et al., 1940). Hence, modulus of rupture of Lp, Lt and Lh further confirm their suitability as dimension stone. On the other hand, modulus of rupture of Lm was not measured because it was texturally and mechanically weak due to the occurrence of excessive amount of clay and, high degree of water absorption (Table 3). According to Currier (1960), the textural characteristics of a stone direct bearing on modulus of rupture.

### Interrelationships among Geotechnical Properties

## Density and Absorption

Absorption and density data shows negative relationship with each other where increasing degree of absorption it decreases density of the rock (Fig. 11). Absorption is a measure of how much a liquid the stone can contain in its pores. Water is one of the major factor which involved in most of weathering process (Siegesmund, 1996). Hence high degree of absorption and low density rock is not feasible for dimension stone.

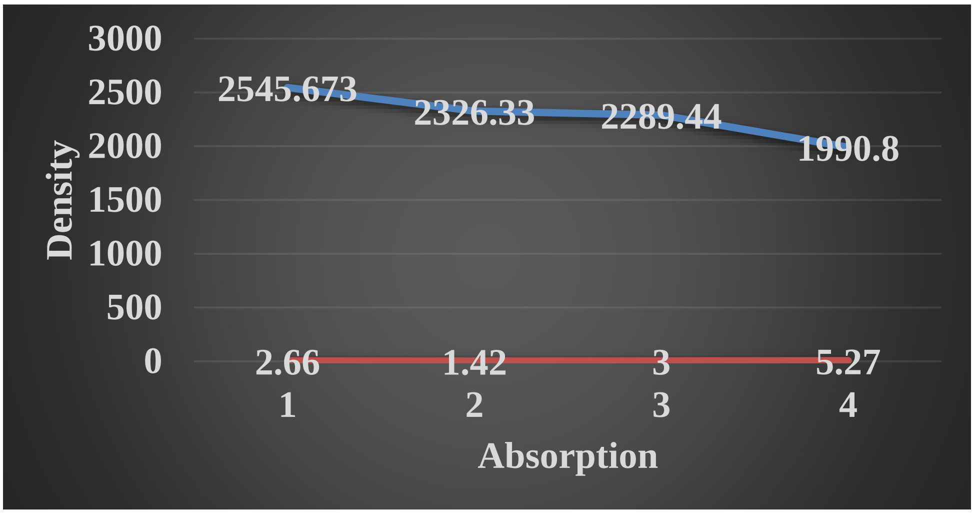



Fig. 11 Interrelationship between density and absorption

## Absorption and Compressive Strength

Negative relationship has been observed between absorption and compressive strength data where absorption increases with decreasing rock strength (Fig.12). High degree of absorption directly influences the strength and durability of the rock due to chemical weathering (Currier 1960). Those rocks which contains high degree of absorption and low value for compressive strength are not recommended as dimension stone as in the case of sample Lm-8

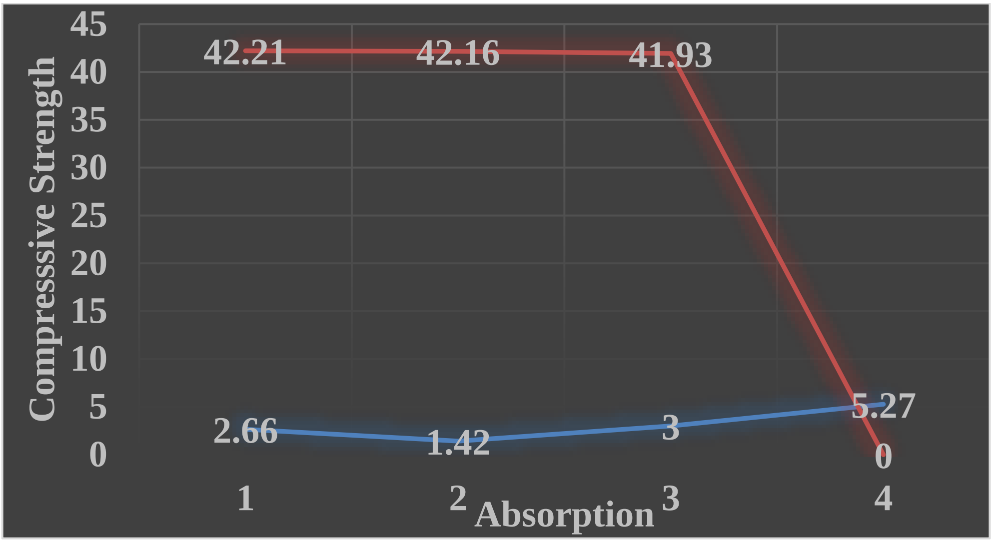



Fig. 12 Interrelationship between absorption and compressive strength

**Density and Compressive Strength**

All the studied samples show positive relationship between density and compressive strength. It is observing that density increases compressive strength which is consistent with the petrographic results that show interlocked texture due to strong tectonic compressions (Fig 13). Hence, except sample Lm-8 all the studied samples are qualifying for their use as dimension stone.

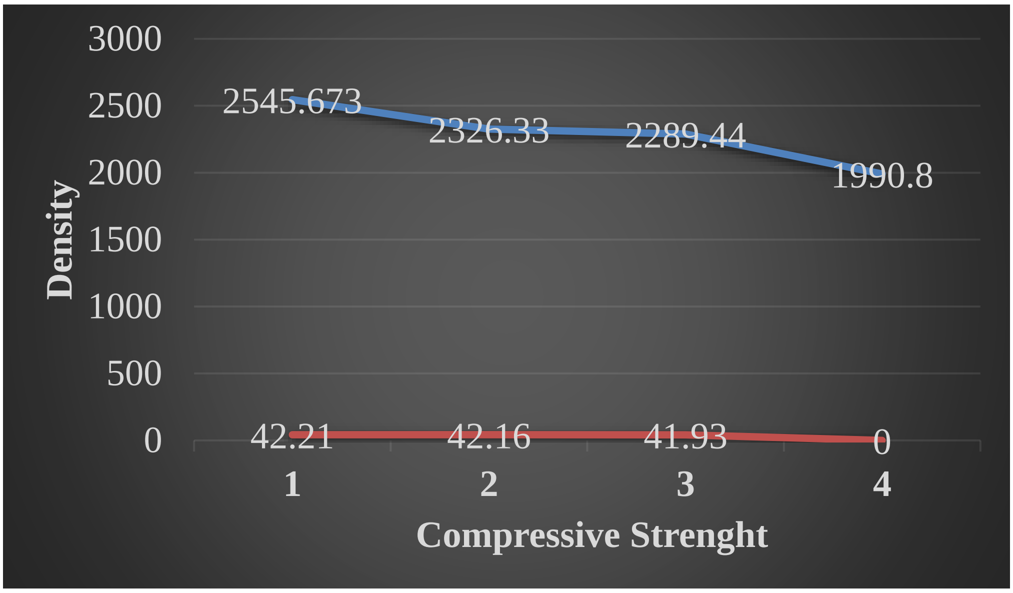



Fig. 13 Interrelationship between density and compressive strength

## Conclusion

It has been concluded from this study that the carbonate rocks of the Nari and Gaj formations cropping in sonapass area, are mainly composed of limestone. Except sample Lm-8, all the limestone units are allochemical, fine grain, hard, compact, and brittle limestone. Heterogeneity in color reveals enrichment of deleterious material which may affect their appearance. Geochemical results revealed that all the studied limestone samples consist of $CaCO_3$ followed by SiO2 and other chemicals due to the intercalation of sand and clay. Geotechnical properties, including water absorption and bulk density, for the tested rocks are very relevant to the specifications of dimension stones, as these exhibit moderate bulk density, and low water absorption (except samples Lm-8). Compressive strength and rupture modulus also lies within the range of medium density rock. The comparison of the measured values of the geochemical and geotechnical properties of the studied samples with those specified in ASTM C568-03 (2006) shows that the carbonate rocks of the Nari and Gaj formations are suitable for its use as dimension stone except sample Lm-8. Further studies are needed in other areas where Nari and Gaj formations are exposed to characterizing and estimate the reserves of these sources of D.S.

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