Geotechnical Assessment of Dimension stone Resources in Oman

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Abstract — In this research we report the result of a study carried out to identify rocks that might be used for the production of dimension stone based on knowledge of the geology of Oman**.** The resources selected as the targets for the dimension stone assessment were the carbonate and ophiolite rock sequences in the Oman Mountains.

The suitability of different rock type was assessed based on the possibility of extracting large blocks, the mechanical properties of the stone, the appearance of the stone when cut and polished, and the accessibility of the site. The porosity, water absorption and saturation coefficient are used to indicate the durability of the rock. Strength values, used with rock mass data such as discontinuity information, are used to identify the most appropriate methods to extract building stone.

Of the sites assessed, the exotic limestone rocks were classified as having the highest potential for producing dimension stone. The compressive stress and geological features are found to be the controlling factors in the classification of dimension stone. The exotic limestone occur as dense, white to beige to yellowish polishable non crystalline limestone. These Omani limestone "marbles" occur in a large number of places as “exotic blocks” within the allochthonous Hawasina formation and are thought to represent former coral reefs rising from the deeper sea. These rocks are used extensively as ornamental stone tiles and slabs in the Oman building industry and is also exported to nearby countries. Omani exotic limestone marble has a sound economic standing with inexhaustible reserves. Other marble / limestone deposits in Oman show intense fracturing, which makes their use as ornamental stone difficult. The sites with low potential for dimension stone production are a mixture of limestone, gabbro, harzburgite and dunite rock units. Mostly these sites are a low priority because they do not have the potential to produce large blocks and rock samples do not have an attractive appearance and do not meet the engineering property criteria.

Keywords---Oman, dimension stone, geology, geotechnical properties.

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I. Introduction

The term ‘dimension stone’ covers a wide variety of naturally occurring stones used for the external and internal decoration of buildings (e.g. limestone, marble, sandstone, gabbro, granite, serpentine, and gneiss) [1].

The demand for industrial rocks and minerals in Oman is largely met by exports of construction and building materials (dimension stone and crushed rock aggregate).

Oman has impressive verities of geological terrains, each offering a diverse assemblage of stone colors and textures. This diversity provides a solid framework for the Oman dimension stone industry. The potential dimension stone resources of Oman are found mainly in the Mesozoic and Cenozoic platform limestone as well as the igneous and metamorphic rocks of the Oman ophiolite and the Proterozoic Arabian basement. However, rocks that have been faulted, fractured and chemically altered may not be suitable for dimension stone as such features may constrain the size of blocks that can be extracted for slab and tile production.

Geological and geotechnical characterization of dimension stone is essential for construction industry and will help in selecting the appropriate use of these building stones. The aim of this work is to study selected areas in Oman which are typical of certain lithologies and have the potential for use as dimension stone based on the geology of Oman. The potential dimension stone resources in some parts of Oman will be assessed, based on i) the possibilities of extracting blocks larger than 1 meter square, which can be determined from the density of discontinuities such as bedding planes, joints, fractures, faults and any other planes of weakness that may lead to the breakup of the stone when extracted; ii) their appearance when polished, iii) their technical properties, and include compressive strength, density, water absorption and porosity iv) the accessibility of the resource location the accessibility of the site, and v) the likelihood of quarrying

II. Geological Background

Three study areas have been given priority for geological and geotechnical assessment (Fig.1);

(1) Marble "Exotic limestone" of the Hawasina nappes.
(2) Harzbhurgite and gabbro of the Semail Ophiolite nappes
(3) Late Cretaceous-Tertiary limestone.

1. MARBLE "EXOTIC LIMESTONE"

Though marble in geological terms is restricted to crystalline metamorphic limestone, in Oman the term “Marble” is rather used for dense, white to beige to yellowish crystalline limestone. These Omani marbles occur in a large number of places as “exotic blocks” within the Hawasina formation (Fig. 2) and are thought to represent former coral reefs rising from the deeper sea [2]. Oman marbles comprise a fossil bearing dense and polishable limestone. During geological reconnaissance exploration in the northern Oman Mountains, it was found, that the overall grade of marble metamorphism is low to moderate, resulting in crystalline limestone, which closely resembles true metamorphic marbles. Oman Marble is used extensively as ornamental stone tiles and slabs in the Oman building industry. Oman marble is exported to more than 20 countries, hence Omani marble has a sound economic standing and given the almost inexhaustible reserves of this resource it is most likely, that the marble quarrying industry will be around in Oman for a long time to come.

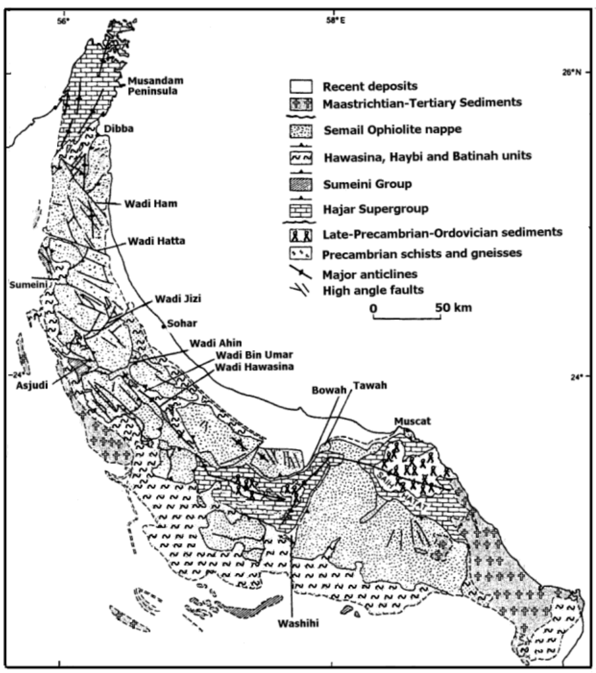

Fig.1 Location map of the studied areas.

2. HARZBURGITE AND GABBRO OF THE SEMAIL OPHIOLITE NAPPES

The ophiolite resources contain several bodies of gabbro, coarse grained igneous rocks (dunite and harzburgite). The Semail Ophiolite represents a slice ~20km thick of oceanic crust (gabbro, basalts and deep see sediments) and upper mantle (harzburgite, dunite, pyroxenite) formed during Late Cretaceous at the expanding Neo-Tethys oceanic ridge [3]. The ophiolite is a major feature of Oman geology and are potentially an extensive resource of dimension stone and contain several bodies of gabbro, and coarse grained igneous rock (dunite and harzburgite). Structurally, the ophiolite can be divided into areas several tens of kilometres in size that are separated by major shear zones. These shear zones, and other major structural features, are responsible for the intense fracturing, faulting and alteration of these rocks and control the size of blocks that could be extracted for use as dimension stone.

Fig.2. Quarried outcrops of the exotic limestone "marble"

Harzburgite has an extensive outcrop that forms steep jagged peaks, and characteristically have a deeply weathered surface layer which can be up to two metres thick (Fg.3). The thickness of the harzburgite is up to several kilometres. Weathering discolours and weakens the rock. The weathered layer would have to be avoided for dimension stone applications. When polished the rock tends to have a dark grey-black homogeneous appearance with anastomosing areas of serpentine alteration. Serpentine carbonate minerals, closely spaced joints and cleavages are common features of the harzburgite. The presence of these features is one of the most inhibiting factors for the use of this lithology as a dimension stone.

Fig. 2. Outcrop representing serpentinized harzburgite/dunite

In general terms, there are several types of gabbro intrusions in the Semail ophiolite, all of which are potentially suitable for dimension stone. They vary in grain size and texture but are typically massive, coarse- to medium-grained, and have an attractive green-grey colour when polished

(Fig.4). However, many sills, dykes and localised serpentinisation and chloritisation decrease the potential for dimension stone. At outcrop the gabbro is often massive with a 'speckled appearance' caused by the coarse grain size and the mixing of dark pyroxene crystals and pale coloured plagioclase crystals.

Fig. 3. Gabbro outcrop showing jointing and dyke intrusions

3. LATE CRETACEOUS-TERTIARY LIMESTONE

The post-emplacement units of Oman include a late Cretaceous assemblage unconformably resting on the Allochtonous units. The Tertiary limestone is exposed in foothills of Hajar Mountains, and form largest extension of the Dhofar Mountains in southern Oman [3],[4]. The outcrops of individual units are extensive, relatively homogenous and are interbeded with clay, silt and stone, chert (Fig.5) . In general, these rocks are tectonically undisturbed with low dip values and few tight folds. However, they are cut by several major shear zones, adjacent to which closely spaced fractures greatly decrease the potential for dimension stone extraction.

Fig.4. Extensive outcrop of Tertiary limestone

III. METHODOLOGY

Field program and collection of stone samples have been designed to identify sites having recoverable resources of dimension stone suitable for large block extraction. In this work, selected physical properties of samples were determined as a first evaluation of their usefulness as dimension stone, and will provide information on the physical characteristics of their potential. Multiple tests were carried out on each sample The specimens tested were cubes approximately 60 mm in dimension. The porosity and water absorption are used to indicate the durability of the rock. The compressive strength, water absorption and density of the rock samples was determined based on the American Society of Testing and Materials [5],[6]. This standard specifies the minimum requirements for a stone to be used as dimension stone (Table 1). Stone with properties that meet these specifications can be considered for dimension stone production.

TABLE I
SPECIFICATION REQUIREMENTS FOR DIMENSION STONE

American Society for Testing and Materials (ASTM specifications (2005)	Compressive strength Mpa (minimum)	Water absorption % (minimum)	Density Mg/m^3 (minimum)
Marble, calcite	52	0.2	2595
Limestone	55	0.3	2560
Harzburgite	69	0.20	2560
gabbro	131	0.40	2560

IV. RESULTS AND DISCUSSION

The desirable criteria for potential dimension stone prospects are: substantial exposure, lithological uniformity, low density of joint and fractures, durability, absence of deleterious materials and attractiveness [7]. Low water absorption or porosity values generally indicate rocks that are more durable. Water is one of the main agents of weathering. Water would be less able to penetrate non-porous stone types and, therefore, less able to cause damage [1]. Density data is important for transportation and calculating the weight of flooring, walling or cladding panels used in the design of foundations and buildings. The compressive strength is the basic measure of the load that a stone can withstand without being crushed. Strength values, used with rock mass data such as discontinuity information, are used to identify the most appropriate methods to extract building stone. A summary of the test results on the collected samples is given in Table 2.

Fig 2a-b show that there is a negative correlation between absorption, porosity and compressive strength, while Fig. 2c shows a positive correlation between density and compressive strength. Limestone samples present a low value for compressive strength and high absorption and porosity values that does not recommend their use as dimension stone. The rest of the samples (marble, gabbro and harzburgite) reach the minimum physical requirements, where higher compressive strength values are associated with lowered porosity and absorption values. This correlation is significant because a first approach to the possibilities of.using these rocks for ornamental purposes could be tested using the absorption study, which is easy, quick before carrying out further tests.

TABLE II
GEOTECHNICAL PROPERTIES OF THE STUDIED SAMPLES

#	Area	Rock type	CS Mpa	WA%	D g/m^3	P %
1	Sohar	Marble	167	0.55	2.61	0.66
2		Marble	155	0.7	2.58	0.72
3	Asjudi	Marble	140	0.93	2.51	0.88
4		Marble	145	0.81	2.54	0.82
5	Wadi Jizi	Marble	182	0.55	2.69	0.64
6		Marble	179	0.52	2.65	0.62
7	Muscat	Limestone	55	2.74	2.51	1.51
8		Limestone	81	2.01	2.73	0.95
9	Saih Hatat	Limestone	68	2.52	2.62	1.32
10		Limestone	71	2.41	2.65	1.22
11	Tawah	Limestone	58	2.61	2.53	1.35
12		Limestone	62	2.66	2.59	1.45
13	Bowah	Harzburgite	179	1.05	2.85	0.93
14		Harzburgite	175	1.15	2.87	0.89
15	Wadi Hawasina	Harzburgite	155	1.45	2.77	0.98
16		Harzburgite	163	1.25	2.74	0.94
17	Wadi Ahin	Harzburgite	185	0.88	2.91	0.84
18		Harzburgite	205	0.72	2.95	0.75
19	Bowah	Gabbro	220	0.42	2.91	0.35
20		Gabbro	217	0.44	2.93	0.38
21	Wadi Hawasina	Gabbro	230	0.25	2.89	0.25
22		Gabbro	248	0.31	2.88	0.28
23	Wadi Ahin	Gabbro	215	0.47	2.84	0.48
24	Bowah	Gabbro	223	0.46	2.83	0.45

CS: compressive strength, WA: water absorption, D: density, P: porosity.

Dimension stone assessment focused on 24 sites where these rocks occur at the surface. Based on an assessment of the presence of discontinuities such as bedding, faults, fractures and joints, only the marble sites have the potential to produce blocks one meter square or larger. All marble samples have compressive strength, water absorption and density properties that meet the specification requirements for dimension stone. The samples provided polished blocks with an attractive appearance.

Field studies indicate that the Tertiary and upper Cretaceous limestone of Oman are affected by brittle deformation, which has resulted in faults and fractures, joints, and contain discontinuities associated with bedding. These are the primary control on the size of the blocks that can be extracted. Joints are generally widely spaced, and most of them intersect the bedding at 90 degrees, rendering the rocks suitable for extraction as large blocks As these limestones are often interbedded with sandstones, siltstones mudstones, cherts, they are not regarded as potential dimension stone targets due to their thin and variable nature.

The harzburgite samples consist of serpentinised olivine and pyroxene with a dark grey to black appearance. The alteration degree of the rock is generally correlated to the absorption value. Harzburgite samples present a highly weathered aspect (carbonation and serpentization) in hand specimen, and show high absorption values, clearly outside the requirement values.

The studied gabbro consists of generally medium- to coarse-grained gabbro, with variable textures and veining and intruded by several dykes of different thickness. Despite that the harzburgite and gabbro samples have high compressive strength and relatively low absorption, these rocks have low potential to produce blocks of attractive dimension stone greater than 1 meter square. Of the 18 gabbro, harzburgite and limestone sample sites assessed, neither is considered to be suitable for the production of blocks of attractive dimension stone larger than 1 metre square.

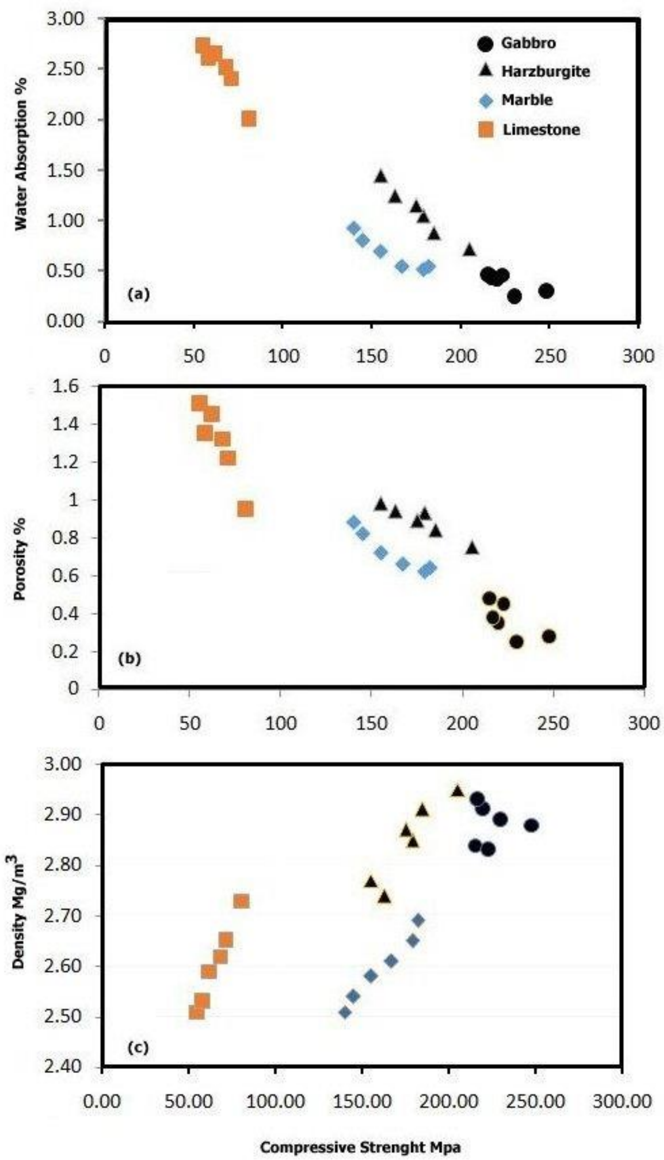

Fig. 5a-c. Compressive strength v.s. water absorption % (a), porosity (b) and density (c).

V. CONCLUSION

The compressive stress, physical and geological properties are found to be the controlling factors in the classification of dimension stone The sites with low potential for dimension stone production in Oman are a mixture of limestone, Gabbro and harzburgite rock units. Mostly these sites are a low priority because they do not have the potential to produce blocks larger than 1 metre square.

Samples from these sites do not have an attractive appearance and/or did not meet the field and engineering property criteria.

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