

Geological engineering description of the exposed surface rocks in wadi Dawa'an, Hadramout Governorate, Republic of Yemen

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Abstract

The present study deals with engineering geological characteristics of the rock mass encountered in and on sides of Wadi Dawa'an, Hadramout governorate.

During the present investigation, detailed studies were carried out on lithology, discontinuities, etc. and basic Geotechnical Description (BGD) of rock mass. The results revealed that, the Limestone (Umm erRhaduma Formation) has been classified into three zones (Zone I to Zone III), and the exposed parts of Sandstone (Mukalla Formation) into two zones (Zone I and Zone II).

The Limestone (very steep cliff) varies from dark brown and moderately weathered in bottom, to dark grey and fresh in the upper most layer. Further, the exposed parts of Sand stone Rocks vary from highly and completely weathered, very low compressive strength to moderately weathered and low compressive strength.

Keywords: Rock mass; Engineering geological characteristics; BGD; Wadi Dawa'an; Hadramawt Governorate; Yemen.

Introduction

Wadi Dawa'an, is located in SE Yemen mainly in Dawa'an district about 185km northwest of Mukalla city (Capital of Hadramawt governorate)(Figure 1). Wadi Dawa'an is the largest southern tributaries of Wadi Hadramawt and has catchment area of about 3394 km² and mainly comprises two wadis that identified as the wadi Dawa'an right and left (Liemen and Lieser at Hadramawt parlance) and sub wadis (Wadi Qaydoun, Wadi Alghabr, etc.). The Wadi is more than 60kms long and ranges in width from 102m and 2kms at some sections. The study part bounded by north latitudes of 1666800 to 1733418 and east longitudes of 201802 to 230971 (Figure 1). Most archaeological, tourist towns and highly populated areas are occupied along the sides of the valley and on the surrounding terraces and plateaus.

Cretaceous to Paleogene sedimentary rocks are exposed on both side of the Wadi Dawa'an. These rocks are characterized with different engineering geological behavior.

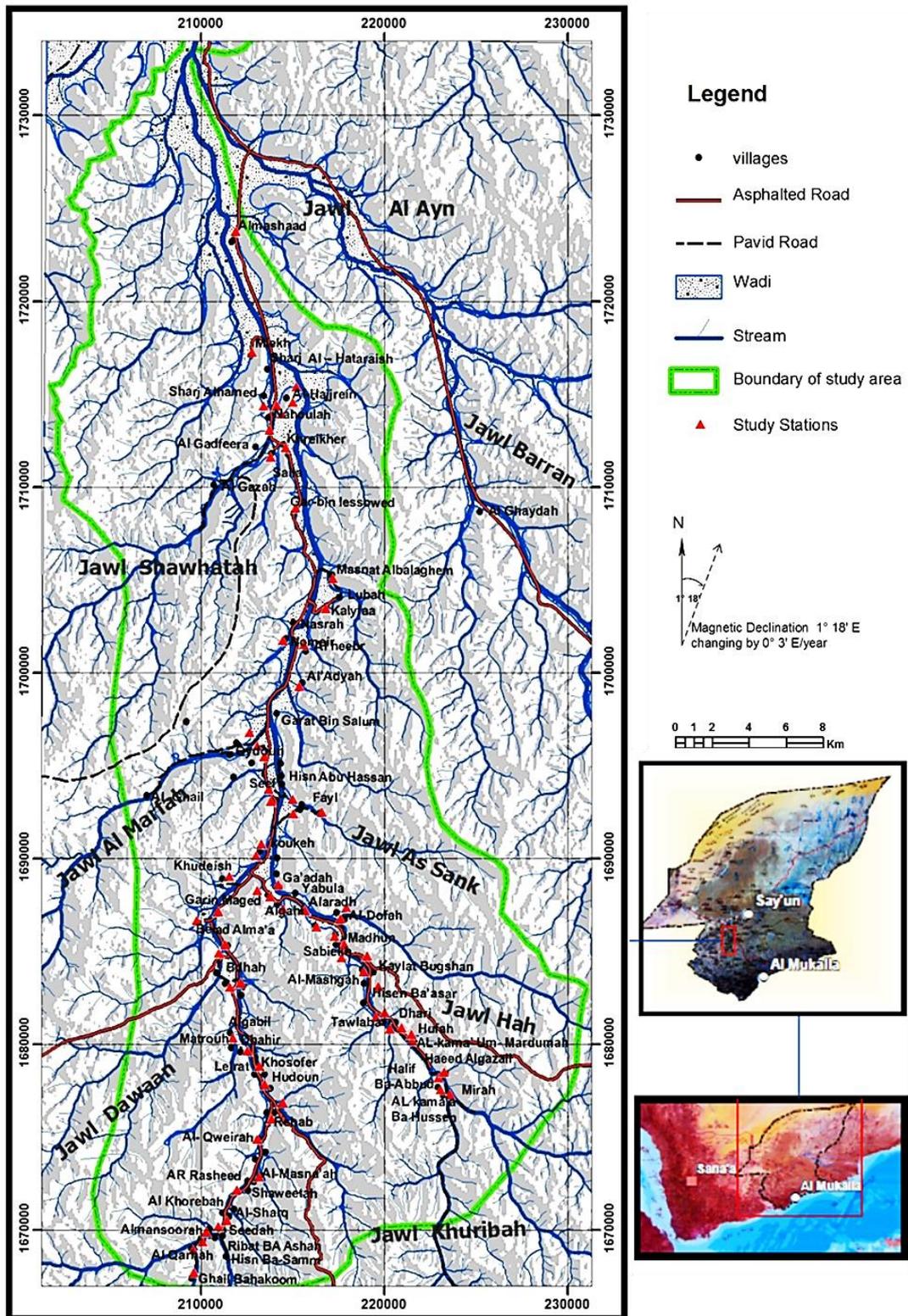


Figure1. Location map of the study area.

The geotechnical and engineering geological investigation and mapping mainly focus towards understanding the interrelationships between the geological environment and the engineering situation; the nature and relationships between the geological components, the active geodynamic processes and the prognosis of processes likely to result from the changes being made [19].

Due to complexity of rock mass with varying physico-mechanical in situ properties, numerous classification systems have been developed for the characterization, classification as well as to gain the knowledge on the rock mass properties and also to provide a quantitative valuation of rock mass [2,3].

The Basic Geotechnical Description of rock mass (BGD) technique introduced by the International Society of Rock Mechanics (ISRM) [14], was one of the major rock mass classification systems used for general geotechnical applications [18] including geotechnical conditions of exposed surface rocks.

From the geotechnical point of view, the rock masses in the Wadi Dawa'an has not been studied in the past. The present study was aimed at assessing and evaluating the preliminary engineering geological and geotechnical conditions and to provide important engineering geological data that may help to plan, design and maintain engineering projects and stability of slopes for the safety of the study area.

In order to accomplish these, 72 field stations from both sides of Wadi Dawa'an were selected, for geological mapping, discontinuity surveying and rock sampling for laboratory tests .

Topography

Wadi Dawa'an represents one of the southern tributaries of Wadi Hadramawt that forms deeply cut water course through Paleocene limestone in the eastern plateau region (Figure 2). It runs from south to north, in the south mainly consisted of right and left wadis (Liemen and Lieser at Hadramawt parlance) and begins about 102 m width at the upper part reaches Wadi Lieser and 112 m in the upper part reaches Wadi Liemen. It becomes progressively wider toward the north until it is about 2 km nearby AL-Mashhad area and the catchment area covers an area of about 3394 km². Many sub wadis reach their inflow to the main wadi. The range of the bed Wadi Dawa'an being from 763 m above the sea level in Al-Mashhad area in the north to 1024 m in Wadi Lieser and 1076 m at Wadi Liemen in the south. The highlands of the wadi are a rather broad, barren and pebbly plateau which named (Jawl Dawaan, Jawl Khuribah, Jawl Hah, etc), averaging at about 965 m to 1480 m above sea level. Contour banks on top of the plateau will gently direct the runoff water towards the wadi top head cut (Figure 3).

Geomorphologically, the drainage pattern system can be classified as dendritic, flat-topped cliffs that drop vertically to the wadi bottoms. This causes the runoff to be extremely rapid and may become flood. Especially in the spring and autumn seasons when heavy rain falls dominate. At times, the floods can cause enormous devastation to crops and buildings; and many people may get killed.

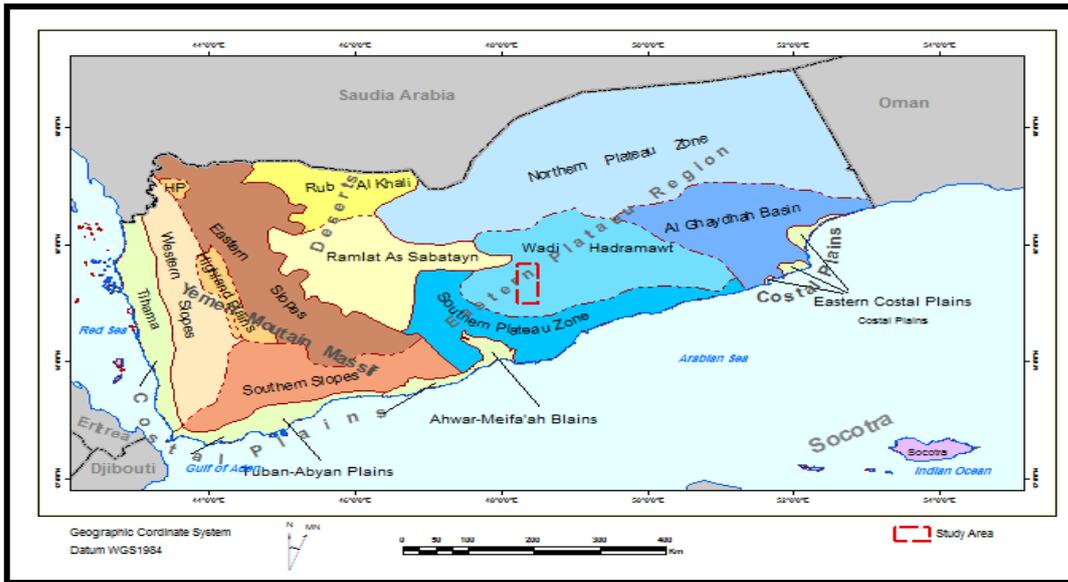


Figure2 a.. Physiographic province in Yemen showing the study area (modified after, Robertson[6] in WRAY[17]).

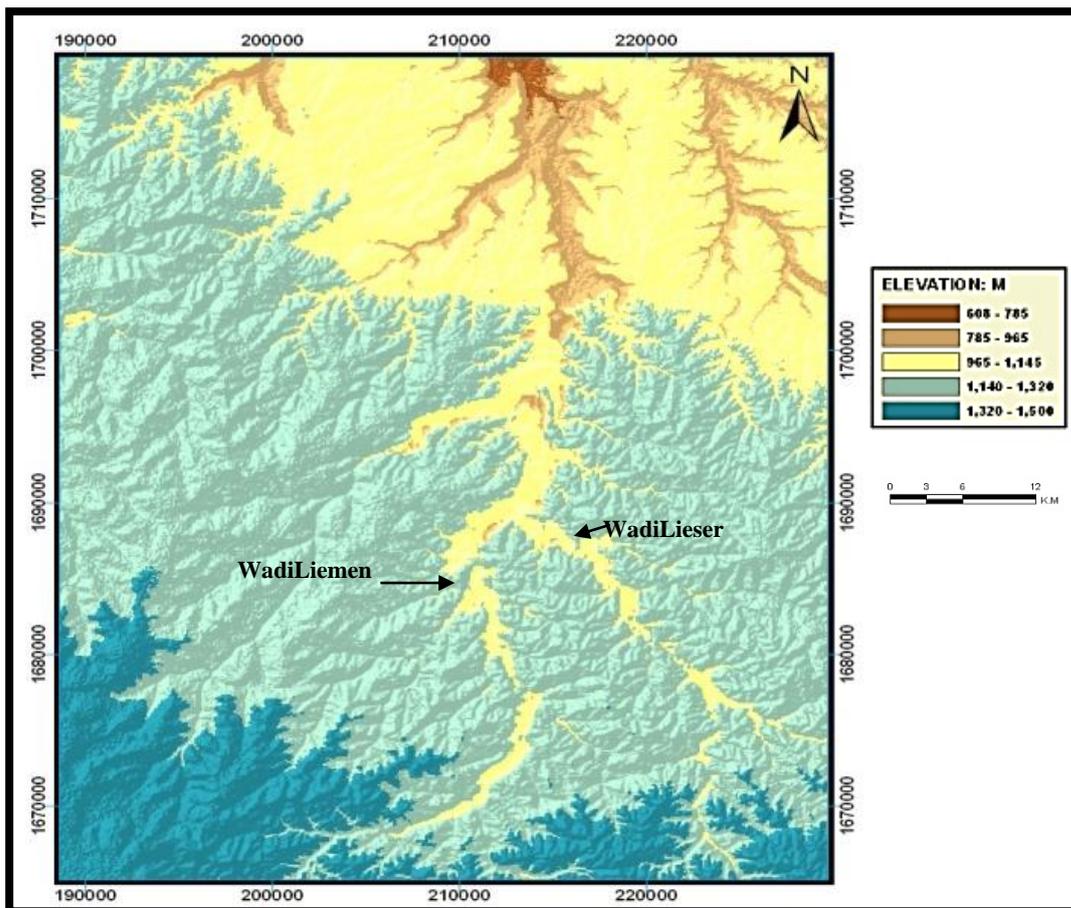


Figure 3. Digital Elevation Model (DEM) of the study area

Climate

Wadi Dawa'an is U-shape Wadi in a mountainous area at Hadramawt plateau with hot dry climate. The annual average temperature ranges from 9°- 43°c, the annual average of relative humidity range from 30 – 50% and the annual precipitation ranges from 50 to 125 mm/year [1,7] covered with considerable vegetative cover.

The monthly average of wind speed was (0.9 m/s) for the period 1980 - 2004 and the maximum monthly average is 1.1 m/s in July, while the minimum was 0.7 m/s in November and December[1].

Geological setting

Geological mapping with a scale of 1:100000 was conducted for the study area (Figure 4). The exposed surface rocks on either side of Wadi Dawa'an are very steeply dipping Tertiary rocks underlain by gently dipping Cretaceous rocks covered with scree. The exposed surface rocks range in age from Upper Cretaceous to Upper Paleocene. These rocks are represented (1) Mukalla Formation, (2) Umm erRadhuma formation [6].

(1) Mukalla formation is the deepest formation encountered in the subsurface at Al-Hajjrein Well-1 (within the study area) with 1164 m thickness [15]. It generally consisted of Sequence of Clastics primarily of coloured, friable, and current bedded sandstones, with pebbly horizons and with subordinate marls and siltstones.

This formation is outcropping in limited area few meters in height and mostly covered with scree.

(2) Umm erRadhuma formation rests conformably above the Mukalla formation and overlain conformably by the Jiza formation.

This formation consists of a basal dolomite overlain by paper shale's and nodular limestone, succeeded by a thick sequence of massive, dark-brown and dark grey commonly dolomitic limestone. Toward the top of the formation, a thick zone of white and grey, with dolomitic, chalky, nodular and cavernous limestone, due to scaly disintegration and exfoliation slumped sections, are common.

In the study area, the Umm erRhaduma formation is underlain unconformably by the upper Cretaceous Mukalla formation clastics, where the Sharwayan formation is absent [15].

Structural setting

The study area is located to the east of the Arabian shield as a part of Arabian shelf [6;5]. It lies in Say'un Sector, that part of Say'un-Almasila basin, that is one of sedimentary basins, which was formed at Mesozoic period in Yemen. The Mesozoic rift basins were formed due to the breakup of Gondwana and separation of India/Madagascar from Africa-Arabia during the late Jurassic/early Cretaceous [4].

The dominant structures in the study area are faults, joints and bedding planes. The faults are interpreted from aerial photographs (verified in the field), while the other structures are observed and measured. The study revealed NNW-SSE, ENE- WSW and NNE-SSW with minor NE-SW, NW-SE and E-W striking faults (Figure 5). The joints represent the second common structures in the study area. The strikes of the joints are generally parallel to the faults of the area. Most of the joints are vertical. Figure 5, shows rose diagram of joints measured in the study area. Mainly two major joint sets are observed (NNW & ENE trending) with some minor sets (NE & NW and E-W strike). The third geological structure is bedding plane, which is predominantly horizontal.

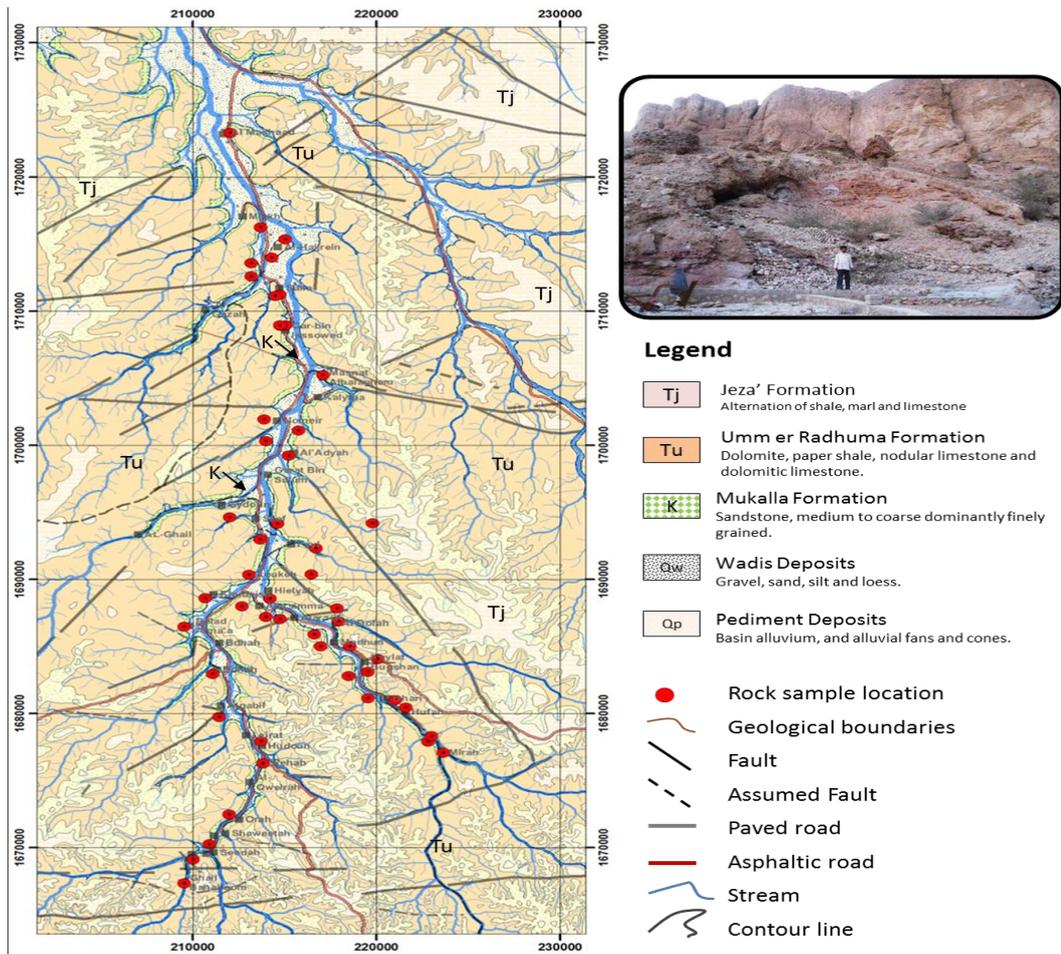


Figure 4. Geological Map of the study area with scale(1:100000) and photograph showing the exposed surface rocks.

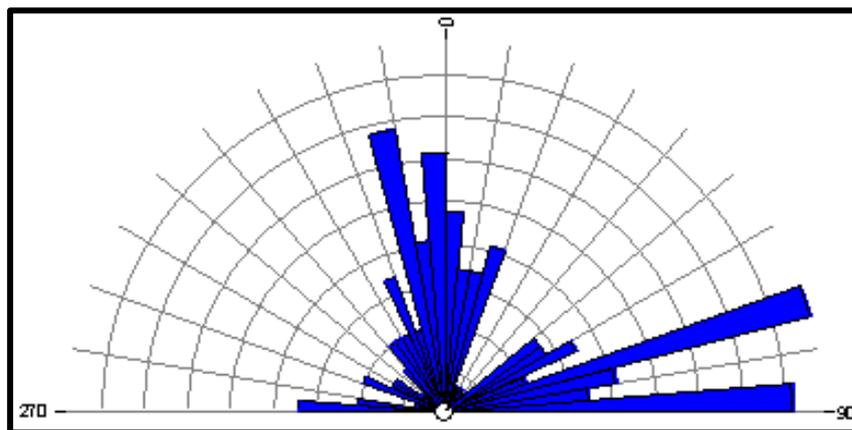


Fig. 5. Rose diagram for structure of the study area

Methodology

The present work was initiated by preliminary investigation (desk study) that include data collection and extensive literature survey. This work was followed by reconnaissance stage to gather more knowledge on the lithology, topographic features, and land-use of the study area, in order to prepare work plan for field and laboratory studies. Firstly, 72 field stations on either side of Wadi Dawa'an were selected.

The preliminary engineering geological study includes the detailed engineering geological studies and geotechnical study of the exposed surface rocks along the study area. Equipments used for this purpose are Brunton compass, Schmidt hammer, geological hammer, measuring tape, geological and topographical maps, GPS instrument, etc.

The engineering properties of the exposed rocks were noted down on both sides of the WadiDawaan. Detailed studies on lithology (rock type, color, grain size, and texture), discontinuities (joint-orientation, spacing, aperture, persistence, roughness and infilling materials), block size and shape, and seepage were carried out. Rock samples were collected from the rock outcrops.

In the present study, the BGD classification systems [4] were applied for the evaluation of engineering geotechnical properties [18]. The BGD classification system is based on a number of parameters that are combined to give acceptable judgments to provide the general picture of the geotechnical properties of the rock mass zones of the study area. Each zone is provided with its rock name, followed by the standard symbols for rock strength, discontinuity spacing and grade of weathering.

Engineering geological properties and classification of the exposed surface Rocks

The engineering geological properties of the exposed surface rocks in Wadi Dawa'an were determined based on the field observations, measurement, and laboratory tests which has been carried out for the first time. The description of rock material and mass characteristics were based on [13].

Field investigation and data collection

After the recognition of the lithological units in the area, discontinuity surveys from different rock masses were performed in seventy two selected field stations to determine the rock mass characteristics and for the purpose of the classification according to [13]. Some of the field examinations included using Schmidt rebound hammer and geological hammer for estimating compressive strength.

A total of 51 samples were collected from the field for laboratory testing and location of samples are plotted on a geological map of scale (1: 100,000);Figure4.

Physical and mechanical properties of the exposed rocks

Physical and mechanical properties include bulk density, water absorption, specific gravity, uniaxial compressive strength; shear strength parameters of the material within the discontinuities by direct shear tests and tensile strength test were tested in the laboratory for Paleocene limestone only. The result range values of physical and mechanical properties are illustrated in Table (1).

Determination of Physical and mechanical properties of the sandstone rock mass (Mukalla Formation) during geotechnical examination works in situ was disabled because of the sandstone rock mass friable behavior. It was difficult to get undisturbed samples because of rock mass disintegration in highly (W4) to completely weathered (W5) sandstones with thin siltstone; the significant is also a sudden degradation and disintegration of moderate weathered (M3) sandstone, after removing of geostatic loads and exposed to air and water during preparation. Small number of undisturbed samples from moderately weathered sandstone for density was tested in laboratory by using wax treatment. The unconfined compressive strength of moderately weathered sandstone was estimated in the field by geological hammer and described according to As-saruri et.al. [13]. The

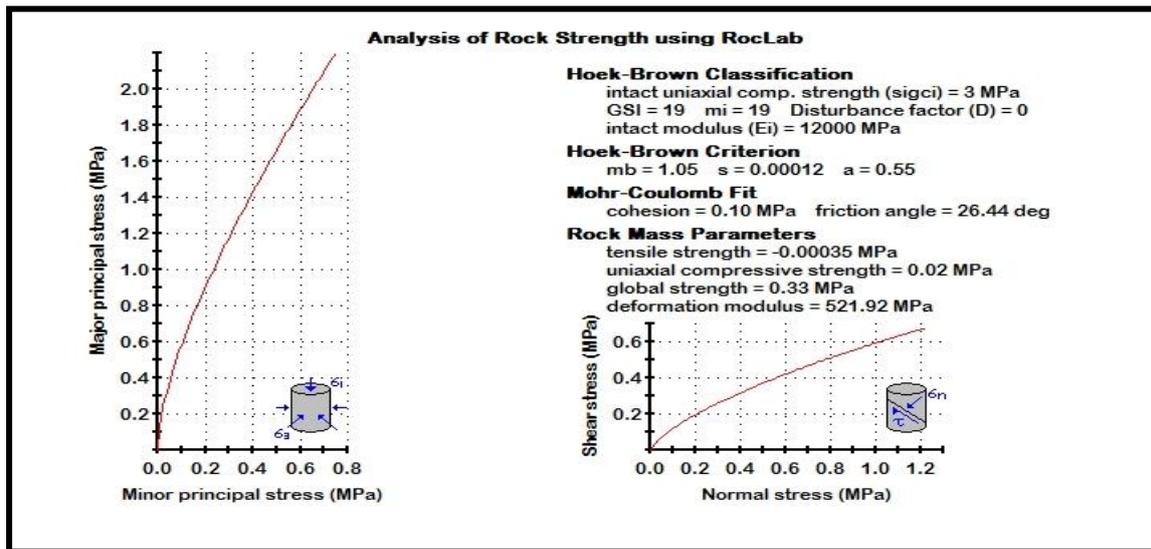


Figure7. Analysis of rock strength for highly and completely weathered sandstone (Mukalla Formation), using RocLab program

Engineering classification of the rock mass

Numerous rock mass classification systems have been developed for special purposes such as tunneling, mining, etc. The BGD classification system is one of the important systems, it intent to characterize the various zones that constitute a rock mass in a simplified form.

In the present study, a preliminary geotechnical investigations on the exposed surface rocks in 72 selected field stations along sides of Wadi Dawa'an using the technique (BGD) of ISRM [14] was performed.

Based on the results of BGD, the Limestone (Umm erRhaduma Formation) has been classified into three zones, and the exposed part of the Sandstone (Mukalla Formation) has been classified into two zones (Table 2, Figure8). Each zone is provided with rock name followed by standard symbols.

Table 2, summarized the average of the geotechnical characteristics of these rock formations at the surface, besides some general comments are given in the following paragraphs.

The uniaxial compressive strength was determined from Laboratory tests (dimensions of rock samples 5x5x5cm³) for limestone and, estimated by Schmidt hammer hardness readings through the approximate correlations of [9]. For Sandston the uniaxial compressive strength was estimated by geological hammer and approximated based on ISRM [13] and also estimated by Schmidt hammer.

The friction angle values for limestone was determined by direct shear test for material within the discontinuities, and also using Inclined Plane method (the rock samples in dimension 5x5x2.5cm³). For Sandstone, using the Rock Data program (Rock Science group) [11].

Table 2: The averages of geotechnical characteristics of the exposed rock units in either side of Wadi Dawa'an.

Rock Name And Grain Size	Color	Weathering	Joint Parameter's				L (cm)		F (cm)		S MPa		A (°)	
			N. of Joint sets	Roughness	Aperture (cm)	Persistence (m)	Av. Value	Sy.						
LIMESTONE, very fine grained	Dark grey	W1	Two to three	smooth planar	Closed To open	--	>200	L1	>200	F1	99.23	S2	34	A3
LIMESTONE, medium to fine grained	Light yellowish brown and White	W2 - W3	Two to three	rough undulating	Closed To open	--	101	L2	635	F1	60.25	S2	34	A3
LIMESTONE, medium to fine grained	Dark brown	W3	Two to three	rough undulating	Closed To open	--	>200	L1	259	F1	72.9	S2	34	A3
SANDSTONE, fine to coarse grained	yellow and pink	W3	Two to three	rough planar	Closed	Low. <3	<6	L5	35	F3	15	S4	25.38	A3
SANDSTONE, medium to coarse grained	white, yellow and pink	W4 - W5	-	-	-	-	<6	L5	-	F0	3	S5	26.44	A3

L= Layer thickness, F= Fracture intercept, S= Uniaxial compressive strength, A= Friction angle

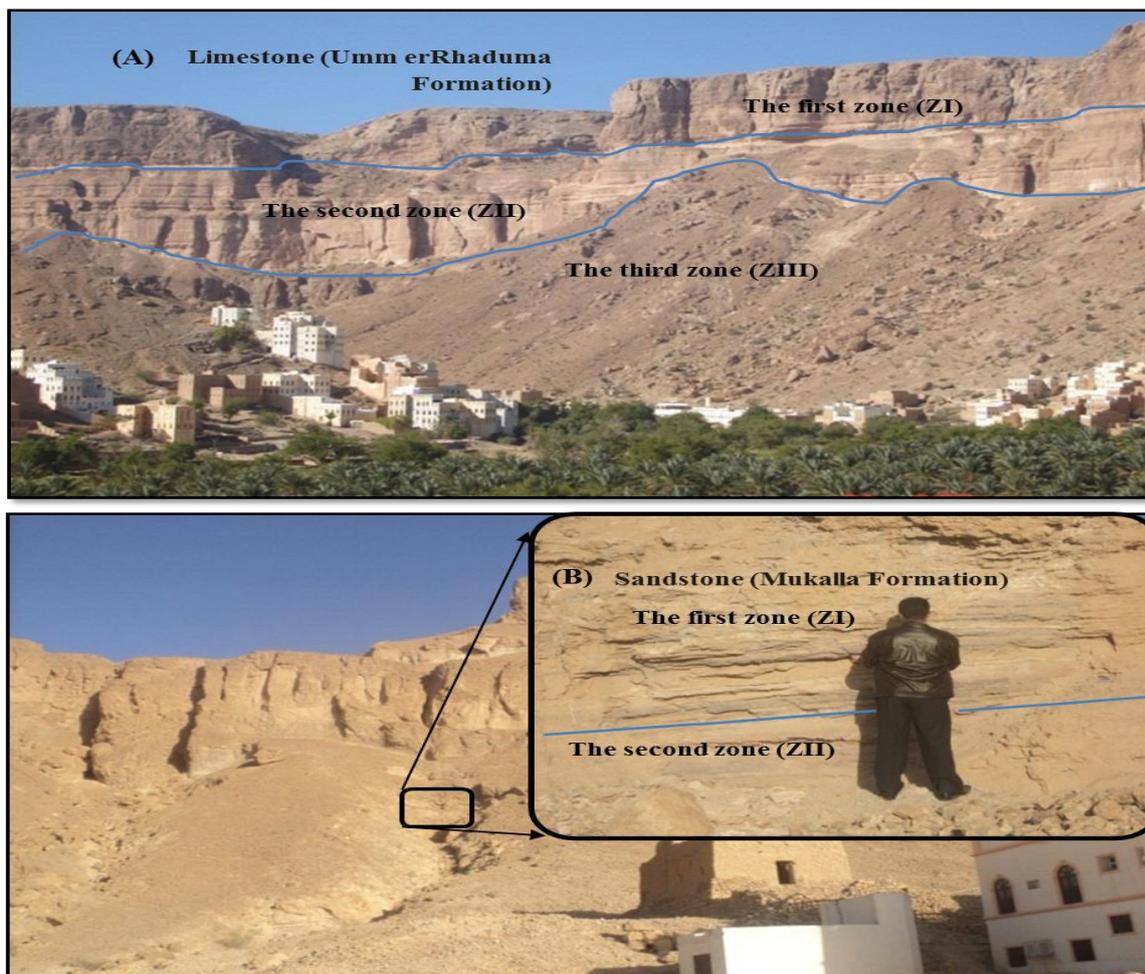


Figure 8. Photographs showing Basic geotechnical description of exposed surface rocks: (A) Limestone (Umm erRhaduma Formation)& (B) Sandstone (Mukalla Formation)

Limestone (Umm erRhaduma Fn.)

Limestone is the most widespread rock mass in study area. This rock unit has variable properties that resulted from nature structural discontinuities (Joints), bedding planes and weathering status. According to BGD classification system, this rock unit has been classified into three distinguished zones. These zones are found along sides of Wadi Dawa'an with variety of their thickness (Figure8) These zones are classified from up downwards as follows:

The first zone (Z1): Dark grey and Fresh, nodular LIMESTONE (L₁, F₁, S₂, A₃).

This rock represents the topmost of the steep cliff of the limestone rock mass (Umm erRhaduma Formation) along the wadi, It is dark grey, very fine grained, fresh (W1) and the layer thickness (L1) is more than 200 cm. Two sets of joints are dominant. The joints are closed in the bottom and open towards the top, generally without filling material, occasionally contain little of soil and litho-fragments rocks; mostly with smooth planar surface; very widely spaced joints (F1). The average of uniaxial compressive strength is 99.65 MPa which indicates high compressive strength (S2). The average of friction angle is 34° which indicated high friction angle (A3),

The geotechnical description of this rock subunit in study area can be assigned as:

Dark grey and fresh, nodular LIMESTONE L1, F1, S2, A3.

The second zone (ZII): Light Yellowish Brown and White, slightly to moderately weathered Limestone (L₂₋₃, F₁, S₂, A₃)

This engineering geological subunit is underlying the subunit of zone I at steep cliff on either side of Wadi Dawa'an, consisted of hard and soft layers. The hard layers have Light Yellowish Brown colour (outer), medium to fine grained; slightly weathered (W2), and the soft layers located in upper and lower part at this zone, have white colour, moderately weathered (W3) and deeply cut. The soft and hard layers have thickness estimated in average between (0.25 - 1.85 m) respectively, which indicates moderate (L3) to large thickness (L2). These layers are intersected by two main joints sets, but limited areas may have three main joints sets, closed from the bottom to the top, but some are open towards the top. Generally; without filling materials, occasionally contain little of soil and litho-fragments; mostly with rough undulating surface. very wide in fracture intercept (F1). Joints noted in zone I do not continue through this zone. The average of uniaxial compressive strength is 60.25 MPa which indicates high compressive strength (S2). The average of friction angle is 34° which indicates high friction angle (A3).

The general geotechnical description (BGD) of this subunit in the study area can be designated as:

Light Yellowish Brown and White, slightly to moderately weathered nodular LIMESTONE L2-3, F1, S2, A3.

The third zone (ZIII): Dark Brown and moderately weathered nodular Limestone (L₁₋₂, F₁, S₂, A₃)

This rock represents the base of the steep cliff of limestone rock (Umm erRhaduma Formation) along the study area, covered by sediments in most places. Its Dark brown in colour, medium to fine grained, moderately weathered (W3) and the layer thickness (L2) is between (60 – 200 cm), in some places the average thickness is >200 cm (L1).

Two sets of joints are dominant, with exceptional three sets of joints in some sites. The joints are closed in the bottom and open towards the top, generally without filling material, occasionally contain little of soil and litho-fragments rocks; mostly with rough undulating surface. The fracture intercept is very wide in average (F1). The averages of Schmidt hammer hardness and the density of this rock type are 72.9 MPa and 30.1 KN/m³ (3.07 gm/cm³) respectively which indicate high compressive strength (S2). The averages of friction angle is 34° which indicated high friction angle (A3). This rock contains numerous of cavern cavities and noticed the drops of water are falling from ceiling of caves.

The general geotechnical description (BGD) of this type in the study area is:

Dark Brown and moderately weathered nodular LIMESTONE (L1-2, F1, S2, A3)

Sandstone (Mukalla fn.)

This rock unit is covered by cemented materials which a mix of soil and litho- fragments rock. In limited areas this unit outcrops appear for few meters because of slope cutting by road and building constructions or by streams erosion, Figure.8. The crops out parts of this rock unite has variable properties. According to BGD classification system, the exposed parts of this unit has been classified into two zones, as follows:

First zone (ZI): Highly (W4) to Completely weathered (W5) Sandstone L₄₋₅, F₀, S₅, A₃

This subunit is varying in color ,white, yellow and pink, medium to coarse grained in size, highly(W4) to completely(W5) weathered; small (L4)to very small bedded (L5) generally loosely cemented, soft and don't show any fracture (F0), the rock wall strength is estimated between(1-5MPa) this indicates very low compressive strength(S5), The friction angle is 25.38° which indicates moderate friction angle (A3)Friable silty SANDSTONE.

The general geotechnical description (BGD) of this subunit in the study area is:

Highly to completely weathered and loose cemented SANDSTONE L₄₋₅, F₀, S₅, A₃.

Second zone (ZII): Moderately weathered (W3) Sandstone L₅, F₀₋₃, S₄, A₃

This subunit is yellow and pink in color, fine to coarse grained, moderately weathered (W3) and the layer thickness is very small bedded (L5). These layers are nearly horizontal; a little locations don't show any joints (fracture) (F0), but in most places Three main joints sets are dominant, the joints are closed; rough planar surfaces; the fracture intercept is moderate (F3) in average. The rock wall strength is estimated between (5-25MPa) this indicates low compressive strength (S4), the friction angle is 26.44° which indicated moderate friction angle (A3).

The general geotechnical description (BGD) of this subunit in the study area is:

Moderately weathered SANDSTONE L₅, F₀₋₃, S₄, A₃.

Discussion

The BGD of the rock units shows slight difference between the suggested subunits in the study area. The significant features recognized these units are the physical properties (table 2). That meansthe limestone could be divided into three subunits primarily due to its geological setting and inherited physical properties, and secondly due to its geotechnical properties.The same classification words can be supposed for the geotechnical characteristics of the Sandstone subunits.

Conclusions

Engineering geological features of rock masses and Geotechnical characteristics of the exposed surface rock onboth side of Wadi Dawa'anhave been studded by engineering geological rock mass description and BGD classification system.

Based on the results of the present study it can be concluded that, the Limestone Rock(Umm erRhaduma Formation) can be classified for engineering purposes into three zones (The first Dark grey and Fresh, nodular LIMESTONE (L₁, F₁, S₂, A₃), the second Light Yellowish Brown and White, slightly to moderately weathered Limestone (L₂₋₃, F₁, S₂, A₃) and third zone Dark Brown and moderately weathered nodular Limestone (L₁₋₂, F₁, S₂, A₃)), and the exposed part of Sandstone Rock (Mukalla Formation) can be classified into two zones (Highly to Completely weathered (W₄ - W₅) Sandstone L₄₋₅, F₀, S₅, A₄ and Moderately weathered (W₃) Sandstone L₅, F₀₋₃, S₄, A₃).

Further specific studies, for foundations, slope stability and site selectionis necessary and required for safety of the future engineering projects.

The results show that, the Limestone (Umm erRhaduma Formation) has been classified into three zones (Zone I to Zone III), and the exposed parts of Sandstone (Mukalla Formation) has been classified into two zones (Zone I and Zone II).

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الوصف الجيولوجي الهندسي للصخور المنكشنة في وادي دوعن، محافظة حضرموت،

الجمهورية اليمنية

عدنان عبدالعزيز بارحيم، خالد أحمد السباعي و عبدالكريم سيف البريهي

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الملخص

الدراسة الحالية تتعامل مع الخواص الجيولوجية الهندسية للمكاشف الصخرية المتواجدة خلال وادي دوعن وعلى جانبيه.

خلال التحري الموقعي الحالي، عُمِلت دراسات تفصيلية للصخرية، الانقطاعات، الوصف الجيوتقني الأساسي (BGD) للكتلة الصخرية بالحقل. النتائج أظهرت أن الصخور الجيرية (تكوين ام الرضومة) قُسمت إلى ثلاثة نطاقات (النطاق I إلى النطاق III)، و الأجزاء المنكشنة من الصخور الرملية (تكوين المكلا) تم تقسيمها إلى نطاقين (نطاق I و نطاق II).

الصخور الجيرية (منحدرات شاهقة شديدة الانحدار) تتباين من اللون البني الداكن و التجوية المتوسطة في الأسفل إلى اللون الرمادي الغامق الداكن و منعدمة التجوية في الأجزاء العلوية. بالمقابل الأجزاء المنكشنة من الصخور الرملية تنوعت من شديدة إلى كاملة التجوية، ذات مقاومة انضغاطية منخفضة جداً، إلى متجوية باعتدال و مقاومة انضغاطية منخفضة.

الكلمات المفتاحية: الكتلة الصخرية الجيولوجية، الصفات الجيولوجية الهندسية، الوصف الجيوتقني الأساسي، وادي دوعن، محافظة حضرموت، اليمن.