

The Industrial Uses of Middle Eocene Limestone in the Northern Part of Al-Ghaydah District, Al-Mahrah Governorate, Yemen

الاستخدامات الصناعية للحجر الجيري من العصر الإيوسيني الأوسط في الجزء الشمالي من مديرية الغيضة،

محافظة المهرة، اليمن

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ABSTRACT:

Keyword

- Limestone
- Al-Ghaydah
- Industrial uses
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- Yemen

Large quantities of high-quality limestone are found in various regions of Yemen, particularly in Al-Mahrah governorate. Samples of Middle Eocene limestone from the Northern Part of Al-Ghaydah District, southeastern Yemen, were studied to evaluate their industrial potential. Petrographic analysis revealed that these limestone rocks are of the foraminiferal packstone type. Geochemical analysis using X-ray fluorescence (XRF) revealed a high calcium carbonate (CaCO_3) content, averaging 97.57%. Major oxide analysis indicated that CaO content ranges from 52.01% to 56.00%, with an average of 54.64%, while other oxides were present in trace amounts. The loss on ignition (LOI) ranged between 43.04% and 45.30%, confirming the high purity of the limestone (CaCO_3 content of 92.88%–100%). Correlation analysis showed a strong negative relationship between CaO and LOI and moderate negative correlations with MnO, Al_2O_3 , and MgO. Trace element concentrations were measured in ppm, with Zn (10.21–18.92), Pb (<7.50), Cr (10.46–14.69), and As (16.54–30.32). These results confirm that the high-purity limestone in the study area is suitable for various industrial applications, including steel production, paper manufacturing, fillers, pottery and porcelain, bleaching powder, soda ash, caustic soda, calcium carbide, sugar refining, textile production, adhesives, sealants, agriculture, and animal feed.

الملخص:

توجد كميات كبيرة من الحجر الجيري ذي النوعية الجيدة في مناطق مختلفة من اليمن، خاصة في محافظة المهرة. تمت دراسة عينات من الحجر الجيري من عصر الأيوسين الأوسط في الجزء الشمالي من مديرية الغيضة، جنوب شرق اليمن، لتقييم إمكاناتها الصناعية. أظهرت نتائج التحليل البتروجرافي أن هذه الصخور هي من نوع الحجر الجيري الفورمينيفري. وكشفت التحاليل الجيوكيميائية باستخدام تقنية الأشعة السينية الوميضية عن نسبة عالية من كربونات الكالسيوم (متوسط 97.57%)، وأظهرت تحاليل الأكاسيد الرئيسية أن محتوى أكسيد الكالسيوم يتراوح بين

الكلمات المفتاحية

- الحجر الجيري
- الغيضة
- الاستخدامات الصناعية
- المهرة
- اليمن.

52.01-56.00% بمتوسط مقداره 54.64%، في حين وجدت الأكاسيد الأخرى بكميات ضئيلة. وكان فاقد الحرق من 43.04 إلى 45.30%، مما يؤكد نقاء الحجر الجيري (إذ تراوحت نسبة كربونات الكالسيوم ما بين 92.88 و 100%). أظهرت نتائج التحليل وجود علاقة سلبية قوية بين أكسيد الكالسيوم مع فاقد الحرق، وعلاقة سلبية متوسطة مع كل من: أكسيد المنجنيز وأكسيد الألومنيوم، أكسيد الماغنيسيوم. أما تركيزات العناصر النادرة (جزء من المليون) فكانت النتائج على النحو التالي: الزنك (10.12-18.92)، الرصاص (أقل من 7.5)، الكروم (10.46-14.69)، والزرنيخ (16.54-30.32). تؤكد هذه النتائج أن الحجر الجيري النقي في منطقة الدراسة مناسب للاستخدام في عدد من التطبيقات الصناعية، مثل: صناعة الصلب، تصنيع الورق، المواد الملائمة، الخزف، الفخار، مسحوق التبييض، رماد الصودا، الصودا الكاوية، كبريد الكالسيوم، تكرير السكر، إنتاج المنسوجات، المواد اللاصقة والمواد المانعة للتسرب، الزراعة، وتغذية الحيوانات.

Introduction

The limestone and lime are prehistoric and among the oldest materials used by mankind. Limestone is a sedimentary calcareous rock, mostly composed of calcite with some gangue minerals such as quartz and feldspar. It comprises approximately 10% of all sedimentary rocks exposed on the earth's surface and is primarily biological in origin.

Limestone is an extremely valuable raw material and is one of the most versatile of all industrial rocks and minerals. A wide range of industries has been made from limestone and its by-products, such as metallurgy (iron and steel making), manufacturing (pharmaceutical, food processing, sugar refining, cosmetics, glass, paper, fillers, cement, ceramics, paints, leather, rubber, plastic, adhesives, calcium carbide, sealants, water purification, waste water treatment, flue gas desulphurisation, insulation, coal dust fire dampener and pH control), agriculture (fertilizers, fungicides, animal feed, poultry, liming of soil and fish ponds), construction (mortar, cement, plaster, whitewash, silica bricks and building stone) purposes [1-14] and removal of heavy metals and Cr from water and mitigation of poisonous and dangerous gases emission [15,16]. In addition, waste materials of limestone can be used in stabilization of swelling soil [17]. Limestone is a versatile material, which can support a wide range of chemical and other industries in Yemen. Any limestone with CaCO_3 in excess of 75% can find some industrial use or another, and therefore warrants geological prospects to make an assessment of reserves and quality and to determine the industrial possibilities [4]. High-purity limestone is defined as a carbonate rock that contains greater than 97% CaCO_3 . It is often referred to as industrial limestone [1].

In Yemen, limestone deposits are widespread and are often well documented in geological research, reports and maps. It is widely extracted as building stones, coarse aggregates and cement raw materials, often by poorly-regulated open-pit quarrying. There are 44 reported pure limestone occurrences in Yemen. The estimated reserve in these locations is about 3.4 billion m^3 [18] and the potential reserve of limestone in the study area is about 30,800,000 m^3 [19]. There is an increasing awareness of the need for geological resource studies to guide strategic mineral planning and development plans. There is often no factual basis to assess their quality, and to inform the planning process. The sector of industrial rocks

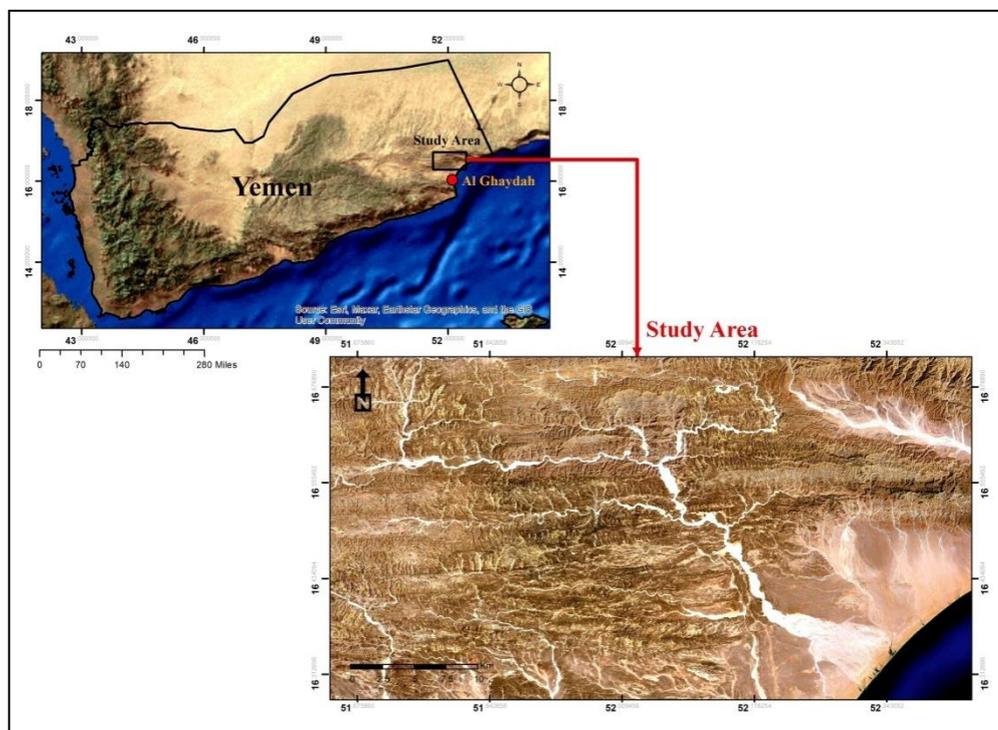
is considered an economic and social driver for Yemen. It largely contributes to the improvement of infrastructure and the absorption of large numbers of the Yemeni labor. However, the development of this sector is dependent on the quality and quantity availability of useful rocks in the different areas of the country.

The purpose of this work is to make a preliminary study for geochemical assessment of Middle Eocene limestone in the Northern part of Al-Ghaydah district, southeastern Yemen for industrial uses.

Study Area

The study area is located in the northern part of Al-Ghaydah district, Al-Mahrah governorate, southeastern Yemen, about 50 km from the coastline and 110 km west of Oman (Fig. 1). It is characterized by an arid climate condition and a very rare vegetation.

Fig. 1 Location map of study area

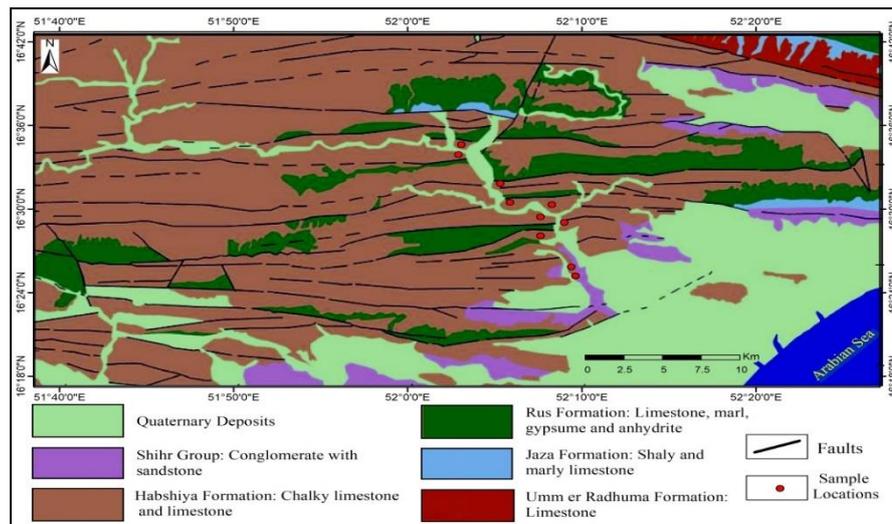


Generally, the study area is characterized by small hills topography due to the presence of low to moderate hills (< 1000 m above sea level). The limestone rock outcrops covers extensive areas in Al-Mahrah governorate. In general, the topography of study area is subdued and does not offer major obstruction to quarry sites. At many places, a large quarry can be operated with a minimum of heavy equipment, so that large tonnages of rock can be produced at a minimum cost. Therefore, specific attention was not given in this investigation to mining methods, costs, and reserves.

Geological setting

The main exposed rock unit in the investigated area is Middle Eocene limestone (Habshiyah Formation) (Fig. 2). This formation is a part of Hadramawt Group. The microfacies of the Habshiyah Formation include a foraminiferal alveolin packstone and is

Fig. 2: Geological map of study area [21]



characterised by the very low content of siliciclastic materials. This is considered as Middle Eocene on the basis of its fossil assemblages and its formation is apparently conformably underlain by the Rus Formation; contact is transitional, occurring at the top of the powdery gypseous chalk bed of the Rus and the base of the yellow gypseous marls of the Habshiyah (Figs. 3 and 4).

The study area contains sedimentary rocks that ranges in age from late Paleocene (Umm Er Radhuma) to recent time, and is dominated by a thick Habshiyah formation. Habshiyah formation is a marine succession that outcrops extensively in the eastern part of Yemen [20] and in the study area consisting of shallow marine limestone and chalky limestone.

According to megascopic observation, the limestone samples have shown no alterations and weathering evidence in hand specimen. The rock is easily workable due to systematic four joint sets. There are three main uses of limestone in Al-Ghaydah area. They are used in construction of structural concrete, road pavement, and as filling materials. Many tectonic structures such as faults are clearly visible in the study area as well as numerous structures to small dimension such as fractures and joints.

Fig. 3: Contact between Rus and Habshiyah formations in the study area

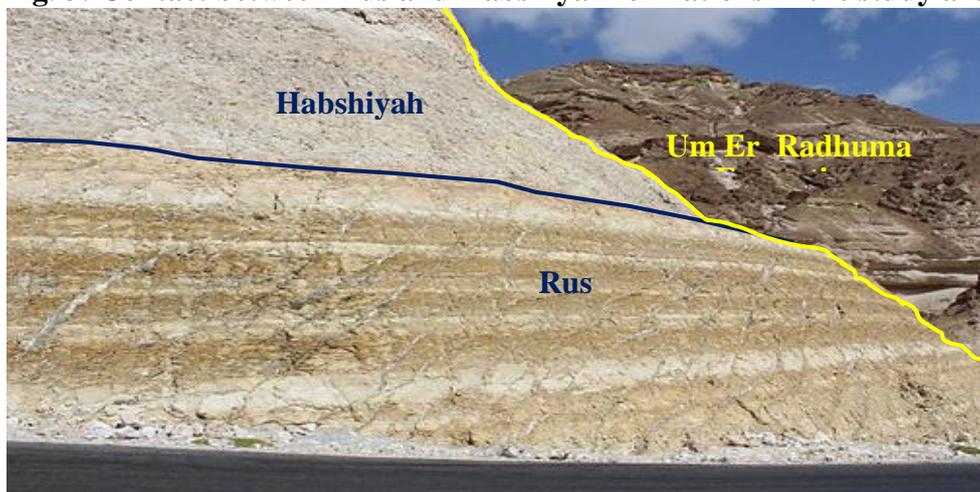


Fig. 4: Chalky limestone of Habshiyah Formation in the study area



Materials and Methods

To determine the quality of Middle Eocene limestone in the study area, geochemical analysis and petrographical were made, 25 representative samples were collected for preliminary field identification, geochemical analysis and petrographical examination of thin sections.

Geochemical analysis of the collected samples was carried out by X-ray fluorescence spectrometry (XRF) using AxiosPANalytical machine at Faculty of Earth Science, King Abdulaziz University, Jeddah, Saudi Arabia. LOI was determined by heating powdered samples for 50 min at 1000 °C. The determination of the content of sulphur trioxide (SO₃) was carried out by a gravimetric technique. The concentration of major oxides were expressed as a weight percentage (wt.%). Brightness was measured according to ISO 2470 [22], using a reflectance spectrophotometer in Saudi Geological Survey (SGS), Jeddah.

Results and Discussion

Petrography

Petrographical studies of limestone samples from the studied area indicated that the samples are dominantly composed of calcite (Fig. 5). These limestone rocks have fine to medium grained granular mosaics with fossils. The medium- to coarse- grained calcite crystals are generally interlocked.

Geochemistry

The limestone rocks used in this research were tested for determination chemical composition by using XRF test. The major elemental chemistry of the randomly hand-picked limestone samples from the study area is presented in Table 1. Chemical analyses revealed that the limestone samples contain lime (CaO) as the major constituent, followed by LOI (Table 1). Other oxides are present in traces concentration (<0.37%). The CaO content varies between 52.01 to 56.00% with an average of $54.64 \pm 1.23\%$ and is due to the calcite present in the limestone (>92.88%). LOI varies from 43.04 to 45.30% with an average of $43.82 \pm 0.73\%$ (Table 1). High LOI value is indicative of high volatile content and this suggests a high

carbonate content since it is synonymous with the evolvement of CO₂ after heating at 1000 °C [23].

The content of Al₂O₃ varies from 0.04 to 0.07% with an average of 0.05% confirming no presence of clay minerals in this limestone. The Fe₂O₃ values range from 0.02 to 0.06% with an average of 0.05%. The SiO₂ values range from 0.20 to 0.32% with an average of 0.25%.

Table 1: Geochemical composition of limestone samples

Sample No.	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	MnO	SO ₃	P ₂ O ₅	LOI	Total	CaCO ₃
1	0.25	0.05	0.05	0.05	55.00	0.32	0.21	0.09	0.05	0.35	0.05	43.71	100.18	98.21
2	0.25	0.05	0.05	0.05	52.95	2.34	0.05	0.06	0.05	0.07	0.05	44.04	100.01	94.55
3	0.25	0.05	0.05	0.05	55.30	0.21	0.11	0.05	0.05	0.05	0.05	43.62	99.84	98.75
4	0.25	0.05	0.05	0.05	55.20	0.31	0.16	0.20	0.05	0.60	0.05	43.04	100.01	98.57
5	0.25	0.05	0.05	0.05	55.20	0.22	0.26	0.15	0.05	0.08	0.05	43.35	99.76	98.57
6	0.25	0.05	0.05	0.05	54.70	0.37	0.37	0.29	0.05	0.09	0.05	43.73	100.05	97.68
7	0.20	0.05	0.05	0.05	56.00	0.30	0.09	0.21	0.05	0.05	0.05	43.04	100.14	100.00
8	0.22	0.04	0.02	0.04	54.50	0.24	0.05	0.06	0.05	0.05	0.03	44.80	100.10	97.32
9	0.32	0.05	0.02	0.03	55.53	0.24	0.01	0.02	0.04	0.05	0.03	43.60	99.94	99.16
10	0.26	0.07	0.06	0.04	52.01	0.40	0.05	0.03	0.06	0.05	0.01	45.30	98.34	92.88
Min.	0.20	0.04	0.02	0.03	52.01	0.21	0.01	0.02	0.04	0.05	0.01	43.04	98.34	92.88
Max.	0.32	0.07	0.06	0.05	56.00	2.34	0.37	0.29	0.06	0.60	0.05	45.30	100.18	100.00
Ave.	0.25	0.05	0.05	0.05	54.64	0.50	0.14	0.12	0.05	0.14	0.04	43.82	99.84	97.57
STD.	0.03	0.01	0.01	0.01	1.23	0.65	0.11	0.09	0.00	0.18	0.01	0.73	0.54	2.20

The CaO content in this limestone shows a strong negative correlation with that of the LOI (-0.81) (Table 2) which may be due to the reason that LOI is contributed mainly by the carbonate content (calcite, CaCO₃).

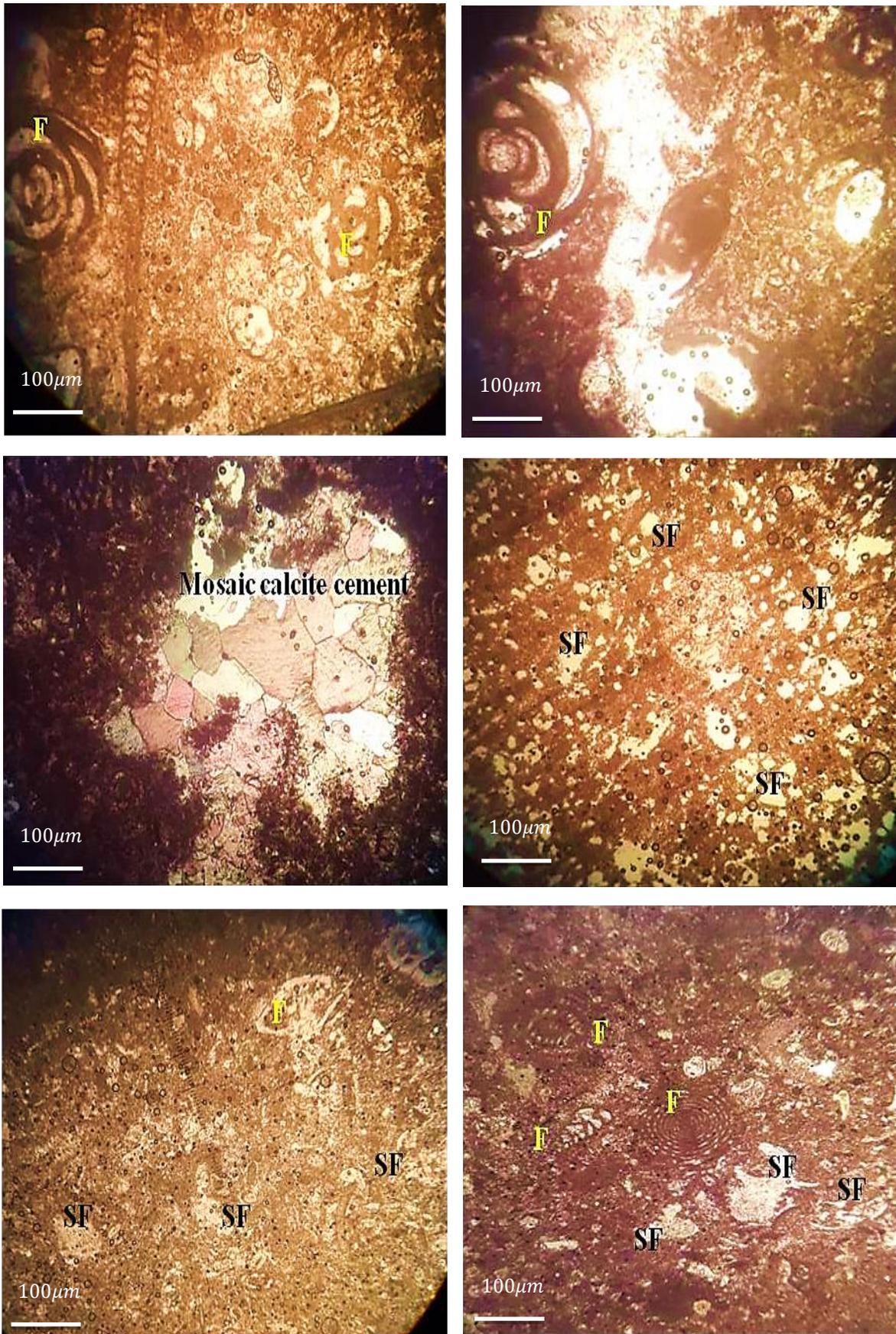
The CaO exhibits moderate negative correlation with MnO, Al₂O₃ and MgO (Table 2). Fe₂O₃ has a significant positive correlation with Al₂O₃, TiO₂ and MnO, whereas it does not have any significant correlation with SiO₂ (Table 2). This indicates that contents of these elements do not relate to the detrital input. The chemical composition of the limestone reflects its mineralogical composition.

Table 2: Correlation coefficient values of constituents of limestone samples

	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O	MnO	SO ₃	P ₂ O ₅	LOI
SiO ₂	1.00											
Al ₂ O ₃	0.25	1.00										
Fe ₂ O ₃	-0.30	0.61	1.00									
TiO ₂	-0.62	-0.13	0.70	1.00								
CaO	-0.08	-0.63	-0.33	0.13	1.00							
MgO	-0.01	0.02	0.18	0.21	-0.53	1.00						
Na ₂ O	-0.15	-0.11	0.40	0.59	0.25	-0.24	1.00					
K ₂ O	-0.42	-0.19	0.33	0.58	0.39	-0.18	0.76	1.00				
MnO	-0.46	0.64	0.70	0.34	-0.67	0.06	0.08	0.03	1.00			
SO ₃	0.00	-0.08	0.21	0.32	0.20	-0.12	0.25	0.30	0.00	1.00		
P ₂ O ₅	-0.31	-0.56	0.23	0.77	0.58	0.17	0.54	0.56	-0.34	0.32	1.00	
LOI	0.05	0.41	-0.09	-0.44	-0.81	0.14	-0.36	-0.55	0.55	-0.40	-0.81	1.00

Bold emphasis indicate the significant positive and negative correlations

Fig. 5: Microphotograph of Limestone rocks from the study area (F=foraminifera; SF= replaced bioclastic grains)



Trace Element

The trace elemental composition reported in ppm (Table 3) has the concentration of Zn ranging from 10.21–18.92 ppm with an average of 13.78 ppm. Pb is less than 7.50 ppm. Cr and As vary from 10.46-14.69 ppm and 16.54–30.32 ppm with mean values of 12.57 ppm and 24.95 ppm respectively. These results show low levels and indicate the high degree of purity of the limestone in the study area.

Table 3: Trace elemental concentrations of Tanhalen limestone (in ppm) [19]

Sample No	Zn	Pb	Cr	As
1	18.92	< 7.50	12.56	30.32
2	10.21	< 7.50	14.69	16.54
5	12.21	< 7.50	10.46	27.99
Average	13.78	< 7.50	12.57	24.95

Classification of limestone

The chemical classification of limestone in the study area is made according to Todd [24] (Table 4). The standard Ca/Mg ratio varies from 26.82 to 312.07, while the reciprocal ratio Mg/Ca ranges from 0.003 to 0.037. This result reveals that the limestone deposits in the study area is pure limestone type except sample 2, magnesian limestone type (Table 5).

The Ca/Mg ratio also corresponds to stability condition during the formation of carbonate rock [25]. He pointed out that the degree of salinity increases with decrease in Ca/Mg ratio. Higher values of Ca/Mg ratio of the studied limestone indicates comparatively less evaporation of sea water and low paleo-salinity conditions which prevailed during the formation of limestone in general.

Table 4: Chemical classification of limestone [24]

Descriptive term	Standard ratio Ca/Mg	Reciprocal ratio Mg/Ca
Dolomitic limestone	1.41-12.30	0.08-0.18
Magnesian limestone	12.30-39.00	0.03-0.08
Pure limestone	39.00-100.00	0.00- 0.03

The low values of Mg/Ca ratio indicate that the studied samples are not dolomitized (except sample 2), because dolomitization would necessarily cause a marked increase in the Mg/Ca ratio of the limestones [26].

The average content of CaCO₃ in the studied samples are 97.57%, CaO 54.64%, MgO 0.05%, SiO₂ 0.25% and Fe₂O₃ 0.05% (Table 1), which is called high purity limestone according to Cox et al. [27] and Harrison et al. [28] (Table 6).

Brightness and whiteness

Brightness was measured according to ISO 2470 [22] using a reflectance spectrophotometer. The percentage reflectance being directly proportional to the whiteness and to some extent, the purity of the sample. Brightness values should be greater than 80% for high purity limestone samples [1].

Table 5: Chemical classification of studied limestone from the study area

Sample No.	CaO (%)	MgO (%)	Ca (%)	Mg (%)	Ca/Mg	Mg/Ca	Nomenclature [24]
1	55.00	0.32	39.31	0.19	203.68	0.005	Pure limestone
2	52.95	2.34	37.85	1.41	026.82	0.037	Magnesian limestone
3	55.30	0.21	39.53	0.13	312.07	0.003	Pure limestone
4	55.20	0.31	39.46	0.19	211.02	0.005	Pure limestone
5	55.20	0.22	39.46	0.13	297.35	0.003	Pure limestone
6	54.70	0.37	39.10	0.22	175.20	0.006	Pure limestone
7	56.00	0.30	40.03	0.18	221.21	0.005	Pure limestone
8	54.50	0.24	38.96	0.14	269.11	0.004	Pure limestone
9	55.53	0.24	39.69	0.14	274.20	0.004	Pure limestone
10	52.01	0.40	37.18	0.24	154.09	0.006	Pure limestone

Table 6: Limestone purity classification [27, 28]

Purity classification	CaCO ₃ (wt %)	CaO (wt %)	MgO (wt %)	SiO ₂ (wt %)	Fe ₂ O ₃ (wt %)
Very high Purity	> 98.5	> 55.2	< 0.8	< 0.2	< 0.05
High Purity	97.0 - 98.5	54.3 - 55.2	0.8 - 1.0	0.2-0.6	0.05 – 0.1
Medium Purity	93.5 - 97.0	52.4 - 54.3	1.0 - 3.0	0.6 – 1.0	0.1 – 1.0
Low Purity	85.0 - 93.5	47.6 - 52.4	> 3.0	< 2.0	> 1.0
Impure	< 85.0	< 47.6		> 2.0	

Analysis of brightness of limestone revealed a brightness index range between 82-86%. High purity limestone that has been ground to a fine powder is called whiting. Whiting is used in the paint and allied industries chiefly as a pigment, diluent, reducer or extender for other pigments, primer, and an ingredient in putty [29]. It must be white, free of abrasive material and free of coloring agents, particularly Fe₂O₃. Analysis of whiteness of the study area limestone ranged between 94-96%.

Industrial potentials uses

Limestone samples analyzed were subjected to study their suitability for industrial utilization. The general requirements of limestone for use in industries uses are shown in Table 7. Limestone apposite for cement industry must contain at least 42% CaO, less than 6% SiO₂, less than 5% Al₂O₃, less than 3% Fe₂O₃ and less than 3% MgO with minor quantities of Na₂O, K₂O, P₂O₅ and SO₃[30,31] (Table 7). Limestone from the study area meets this requirements (Table 1).

Limestone suitable for steel industry should contain at least 51% CaO, less than 6% SiO₂, less than 1.3% Al₂O₃, less than 1% Fe₂O₃ and 2% MgO with trace amounts of P₂O₅ and SO₃ [32-34] (Table 7). The limestone from the study area meets these specifications (Table 1).

Chemical requirements of limestone, as raw materials for paper industry include; high CaCO₃ 96%, other maxima include 0.40% SiO₂, 0.50% Al₂O₃, 0.10% Fe₂O₃, 0.45% MgO, and excellent brightness (>93%) [6,35] (Table 7). In paper industry the high brightness is preferred to produce the high quality paper. Limestone from the study area is suitable for paper manufacturing (Table 1). Specific chemical requirements of limestone, as raw materials

for fillers in paints, rubber and plastic manufacturing include; high CaCO₃ 96% content; other maxima include SiO₂ 1.2%, Al₂O₃ 0.30%, Fe₂O₃ 0.08%, and MgO 0.72% [36-38] (Table 7). The Limestone in the study area is suitable for this purpose (Table 1).

High purity limestone as whiting is used as a flux for pottery and porcelain ware. It should be at least 96% CaCO₃, less than 2 % SiO₂, less than 0.30 % Fe₂O₃, and less than 0.50% MgO [35,39] (Table 7). The limestone in the study area is suitable for this purpose (Table 1).

For the manufacture of bleaching powder, limestone containing more than 54% CaO is required. Less than 0.75% SiO₂, less than 0.15% Fe₂O₃, less than 2% MgO [32,40] (Table 7). The limestone from the study area meets these specifications (Table 1).

Limestone for the manufacture of soda ash and caustic soda should be contain at least 53% CaO, less than 1% MgO and total SiO₂+Al₂O₃+Fe₂O₃ should be less than 3% [32,40] (Table 7). So the limestone in the study area is suitable for this purpose (Table 1). Limestone specifications for manufacture of calcium carbide must contain at least 97% CaCO₃, less than 1.2% SiO₂, less than 0.8% MgO, less than 0.50% Al₂O₃+Fe₂O₃, and a trace of P₂O₅ [32,35,37,40] (Table 7). The limestone from the study area meets these specifications (Table 1). Limestone for manufacture of sugar must contain more than 50% CaO, less than 2% SiO₂, less than 1% MgO, and less than 1.5% Al₂O₃+ Fe₂O₃ [36,40] (Table 7). The limestone from the study area meets these specifications (Table 1).

In glass industry, high purity limestone is used 98% CaCO₃, less than 0.30% SiO₂, 0.40% Al₂O₃, 0.83% MgO and less than 0.10% Fe₂O₃ for glassware manufacture [34,36,42,43] (Table 7). For colourless glass, limestone should contain 98.5% CaCO₃, Fe₂O₃ less than 0.05% [42]. The limestone of the study area is not suitable for this industry (Table 1).

Table 7. Specifications of limestone for industrial uses

Industrial uses	Compounds (% by mass)						Brightness, (min.)
	CaCO ₃ (min.)	CaO (min.)	SiO ₂ (max.)	Al ₂ O ₃ (max.)	Fe ₂ O ₃ (max.)	MgO (max.)	
Cement (OPC)[30,31]	75.00	42	25.00	5.00	2.00	3.00	-
Steel industry [14,32-43]	91.00	51.00	6.00	1.30	1.00	2.00	-
Paper [7,35]	96.00	53.76	0.40	0.50	0.10	0.45	93.30
Filler [36-38]	96.00	53.76	1.20	0.30	0.08	0.72	75.00
Pottery & Porcelain ware [35,39]	96.00	53.76	2.00	-	0.30	0.50	-
Bleaching powder [14, 31,32,40, 41]	96.60	54.00	0.75	-	0.15	2.00	-
Soda ash & caustic soda [32,40]	94.60	53.00	3.00			1.00	-
Calcium carbide [14,31,32,35,37,40]	97.00	54.00	1.20	0.50		0.80	-
Sugar [14,36,40]	89.29	50.00	2.00	1.50		1.00	-
Glassware [34,36,42,43]	98.00	54.85	0.30	0.40	0.10	0.83	-
Ceramic [7,32]	97.00	54.32	0.12	-	0.30	3.00	95.50
Textile production [14,31,32,37]	94.00	52.64	2.50	2.00		3.00	-
Food & pharmaceutical [7]	97.00	54.35	0.12	-	0.10	0.42	90.00
Adhesive & sealants [7]	92.00	51.55	4.50	-	0.10	1.20	75.00
Agriculture & animal feed [7,14,32]	92.00	51.55	4.50	-	0.10	0.96	81.00
This Study	97.57	54.64	0.25	0.05	0.05	0.50	94.00

In ceramic industry, high purity limestone is used more than 97% CaCO₃, less than 0.12% SiO₂, less than 3% MgO, less than 0.30% Fe₂O₃ and excellent brightness (>95%) [6,32] (Table 7). The limestone of the study area is not suitable for ceramic industry (high values of SiO₂, 0.25% (Table 1).

Limestone specifications for textile production must contain at least 94% CaCO₃, less than 2.50% SiO₂, 3% MgO and 2% Fe₂O₃+Al₂O₃ [32,37] (Table 7). The limestone from the study area meets these specifications (Table 1).

In food and pharmaceutical industry, high purity limestone is used; at least 97% CaCO₃, less than 0.12% SiO₂, less than 0.42% MgO, less than 0.10% Fe₂O₃ and high brightness (>90%) [6] (Table 7). The limestone of the study area is not suitable for food and pharmaceutical industry (SiO₂ ≥ 0.20%, Table 1).

In adhesive and sealants industry, limestone should contain more than 92% CaCO₃, less than 4.5% SiO₂, less than 1.2% MgO and less than 0.10% Fe₂O₃[6] (Table 7). The limestone from the study area meets these specifications (Table 1).

For agriculture and animal feed, limestone should contain more than 92% CaCO₃, more than 51.55% CaO, less than 4.5% SiO₂, less than 0.10% Fe₂O₃, 0.96% MgO and good brightness (>81%) [6] (Table 7). The limestone of the study area meets specified requirements for agriculture and animal feed (Table 1).

The impure limestone which could not meet the requirement for chemical and other applications earlier stated can be used in the liming of soils or in stabilization of swelling soil. It is therefore, apparent that the use of limestone for cement production only may not be entirely beneficial to the industrial growth of other sectors, such as, steel industry, chemical, fertilizer and lime production.

Conclusion

Limestone is one of the important and common uses industrial rocks. It is quarried for cement production in some parts of Yemen. However, the suitability of limestone production depends on its chemistry. This helps in the prediction of its purity. In this study, the chemical composition of Middle Eocene limestone from the Northern Part of Al-Ghaydah district, southeastern Yemen is presented. The results obtained indicated that the limestone from the study area exhibits high purity, high CaO content (average 54.64%), trace amounts of other oxides and the trace element contents are very low. Hence, it is suitable for industrial uses such as; steel industry, paper, filler, pottery and porcelain ware, bleaching powder, soda ash and caustic soda, calcium carbide, sugar, textile production, adhesive and sealants, agriculture and animal feed.

Extensive deposits of limestone occur in Al-Mahrah governorate has not been examined carefully. These locations cover large areas of the governorate and the potential markets are closer. Uses of limestone rock should be oriented to the beneficial industries instead of using it as a building material (coarse aggregates and building blocks) or cement production. This study is only a preliminary effort to spotlight the possible industrial uses of the rocks available in this area. It will help to understand the properties of limestone from the study area for various industrial applications; however more detailed studies should be undertaken to launch economic projects.

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