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The Composition and Diagenetic Features of the Inland Quaternary Coralline Limestone, South-Sharm Obhur, Red Sea Coastal Plain of Saudi Arabia

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ABSTRACT. Low Mg-calcite, minor aragonite and less common dolomite, quartz and feldspar constitute the bulk composition of the inland Quaternary coralline limestone south of Sharm Obhur.

Two characteristic facies associations have been distinguished in this limestone: foraminiferal sandy biosparite and foraminiferal algal biosparite. They indicate deposition in regression sea under high energy conditions. Dissolution and precipitation processes indicate diagenesis under meteoric vadose sub-environment. High Mg-calcite was converted into low Mg-calcite and aragonite was partially dissolved. Sparites are developed within skelatal cavities of foraminiferal and mollusc chambers.

Geochemical investigation proved that Ca is associated with $CaCO_3$ and correlated negatively with Mg, Fe, Mn and Ba which are associated with the terrigenous materials drifted from the Tertiary mountains to the coast and enriched at the weathering zone. However, Sr is found to be the only element affected by the dissolution-precipitation process.

Introduction

Extensive investigations have been carried out on the Late Pleistocene reef limestone terraces and the unconsolidated sediments covering the hard reefal limestone in the eastern Red Sea margin. However, very little attention has been given to their petrography and microlithofacies. A series of transgressive and regressive cycles that formed the Quaternary coastal carbonates have been determined by Behairy (1983). Behairy (1980), Behairy and El-Sayed (1984), Dullo and Jado (1984) and Dullo (1986) studied the composition and diagenesis of the Pleistocene reef carbonate terraces. The carbonate and clay mineralogy of the near-shore shelf sediments north of Jeddah had been investigated by Durgaprasada Rao and Behairy (1986). Durgaprasada Rao *et al.* (1987) assumed that the dolomitization processes in the raised Pleistocene reef limestone of the western coastal plain of Jeddah have been affected by the fluctuating mixed-water zone associated with sea-level oscillations.

In this work an attempt is made to investigate the microlithofacies associations, the mineral and chemical constituents and the diagenetic features through the early meteoric process in the inland reef limestone. The data obtained from the present study have been correlated with the previous study of Durgaprasada Rao *et al.* (1987) on the littoral raised limestone terraces at Sharm Obhur.

Physiography of the Studied Area

Obhur is located on the western coast of Saudi Arabia approximately 35 km north of the port city of Jeddah (Fig. 1). Sharm Obhur is an elongated body of sea water which extends northeasterly for approximately 10 km inland through coralline limestone.

The investigated area lies to the south of Sharm Obhur and represents the lower part of the Red Sea coastal plain of Saudi Arabia (Tihama). It consists of a levelled or gently sloping flat surface of coralline limestone with thickness varying from 2.5 to about 10 m at different locations below the ground surface (Morris, 1975). It is covered with a thin layer (10-50 cm) of coralline and shelly silty sand. To the east of the studied area, lies the upper section of Tihama, which represents a pediment cut on Tertiary and Precambrian rocks. The basaltic lava covers most of the sedimentary sequence. On the other hand, the coastal strip on the northern part of Sharm Obhur is characterised by the Quaternary reef limestone raised terraces of about 0.5 km width. The presence of inland sabkha deposits in the raised coastal reefs in Obhur and the occurrence of al-Qasr and Sulman lagoons north of Obhur were associated with filling of lagoons inland of the reefs followed by sea regression and evaporation under subtropical to tropical climatic conditions (Ali and Hossain, 1988).

Material and Methods

Six Quaternary coralline limestone samples were collected vertically from various depths during foundation drilling, to a depth of about 4 m below the ground surface in the coastal plain at southern Obhur (Fig. 1).

Thin sections were petrographically examined under the polarizing microscope. A part of four representative samples rocks were ground into powder by agate mortar and used for bulk mineralogical, chemical and carbonate content analyses. The mineralogy was determined by X-ray diffraction using Philips X-ray diffractometer unit equipped with Ni filter, Cu-K radiation source. The scanning range was between 25 and 40° 2 Θ to include peaks of detrital and carbonate minerals.

Chemical analysis was performed by treating the powdered bulk samples with nitric and hydrofluoric acids (HNO_3/HF). Measurements of Ca, Mg, Fe, Mn, Sr and Ba were carried out using Perkin-Elmer model 400 Inductively Coupled Plasma Atomic Emis-

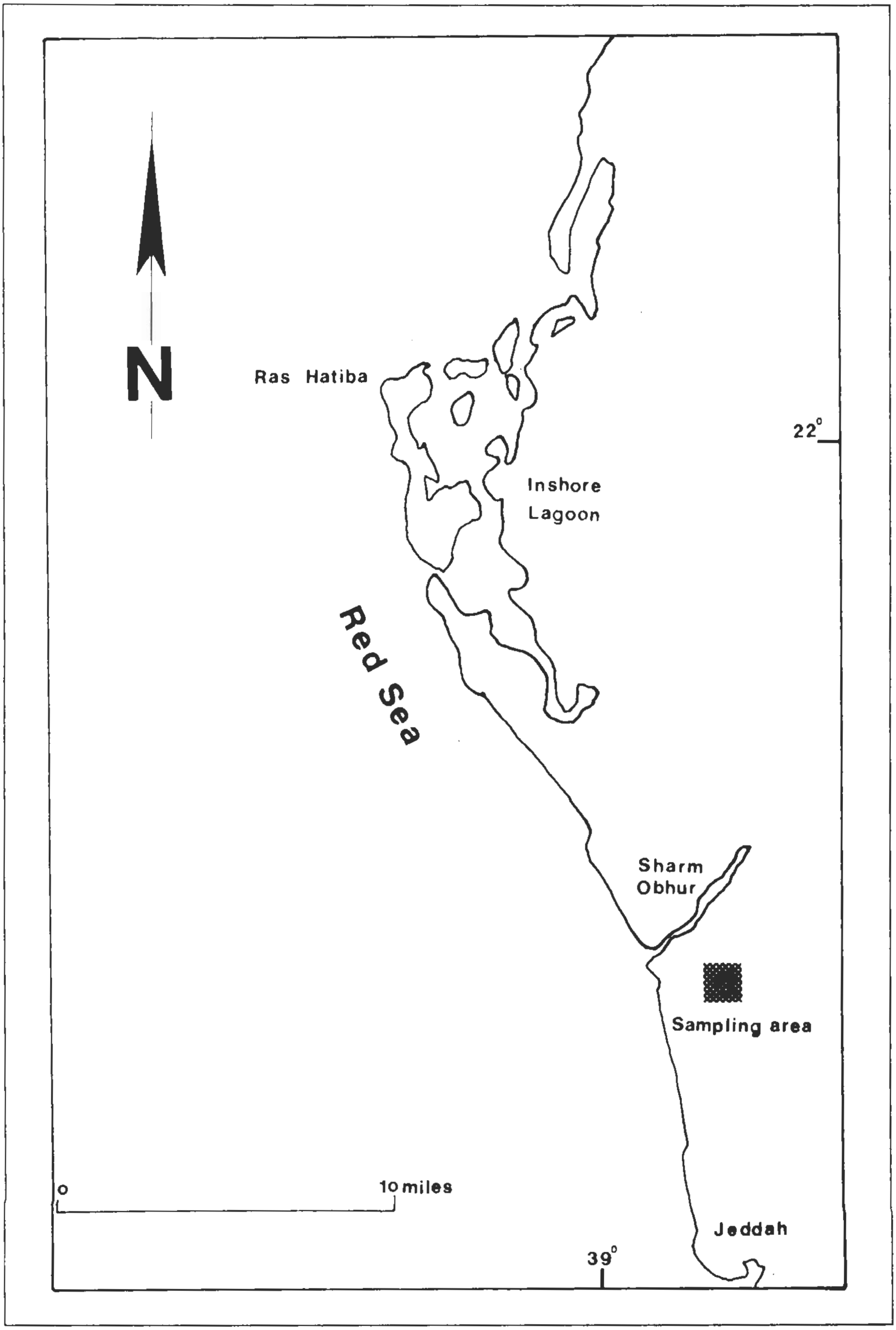

FIG. 1. Location map of the study area.

sion Spectrophotometry (ICP/AES). Carbonate content was determined by leaching the samples with cold diluted hydrochloric acid (lM HCl). The weight of acid soluble material ($CaCO_3$) is expressed as a percentage of the total weight of sample.

Results and Discussion

Facies associations

Thin section investigation of the six Quaternary coralline limestone samples showed similar petrographical and mineralogical characteristics and distinct faunal assemblages. The composition of these associations and the mineralogy as well as fabrics of their early formed marine cements are described. The palaeoecological conditions and the diagenetic history are interpreted. Following the limestone petrographic classification (Folk, 1959, 1962) two main facies were distinguished; foraminiferal algal biosparite characterizing most of the samples and foraminiferal sandy biosparite which is restricted to the top sample. The photomicrographs of the sections studied are shown in Figs. 2 & 3. The allochems are mainly composed of fossils which include benthonic foraminifera, algal grains, gastropods, bryozoa and echinoid spines. These skeletal components indicate deposition in a near-shore environment. Shell fragments, oolitic grains, pellets, quartz grains and heavy minerals are also embedded in a micritic matrix (Fig. 3a). The presence of detrital grains (quartz and heavy minerals) in the sample near the ground surface indicate a good supply of terrigenous materials derived probably from nearby Tertiary mountains common in the coastal plain by surface water run-off and aeolian transportations. These facies reflect littoral environment.

Evidence of diagenesis in the studied samples include partial recrystallization of the high Mg-calcite and replacement occurring after deposition. The original structure of foraminiferal and molluscan shell fragments show partial recrystallization and precipitation of equant blocky calcite cyrstals indicating diagenesis under meteoric vadose subenvironment. The dissolution and precipitation processes are shown in Figs. 2 a, b, c. Dissolution of the original high Mg-calcium carbonate is due to the concentration of CO_2 in the meteoric water and the precipitation of thin layer of micrite as fibrous or fine-grained crystals, coated the allochems by thick micrite envelope. Sometimes cementation appears in patches (Fig. 2b) and occurs as meniscus bridges binding the grains. The diversity in size of the framework of the rocks (allochems) indicates rapid accumulation and deposition in transitional environment under regression sea.

It has been known that in the meteoric environment, all the aragonitic elements, skeletal grains and cements are selectively dissolved and reprecipitated as sparry calcite mosaic consisting of equant low Mg-clacite crystals lining or completely filling the pores and replacing earlier aragonitic skeletal grains (Tucker and Wright, 1990). However, the distribution of the sparry calcite mosaic appears patchy in some thin sections, such precipitation may have occurred in phreatic subenvironments within the meteoric vadose zone (Beier, 1985). It is known that during selective diagenesis, the original high Mg-calcite skeletal grains and cements are inverted into low Mg-calcite (Tucker and Wright, 1990). In this inversion, nearly all Mg^{2+} ions have been removed through a

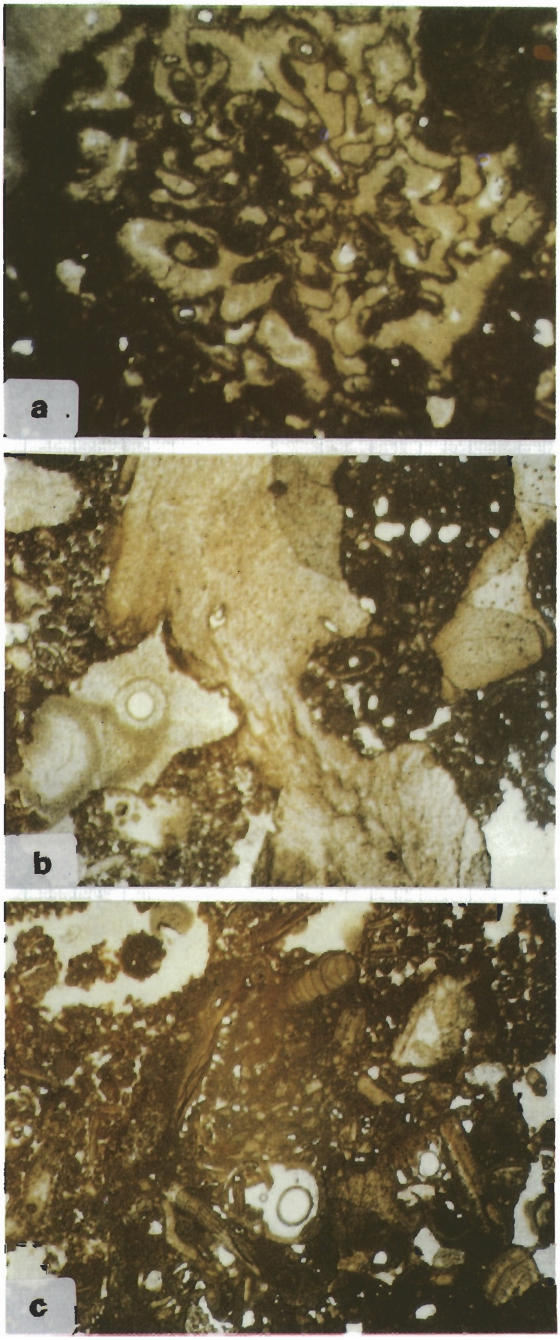

FIG. 2. Photomicrographs of the inland Pleistocene coralline limestones at southern Obhur.
(a) Partial dissolution and precipitation of micritic material in the resulted voids.
(b) Calcitic solutions reprecipitated as patches.
(c) Foraminiferal algal sparite with early diagenetic dissolution creating a lot of voids.

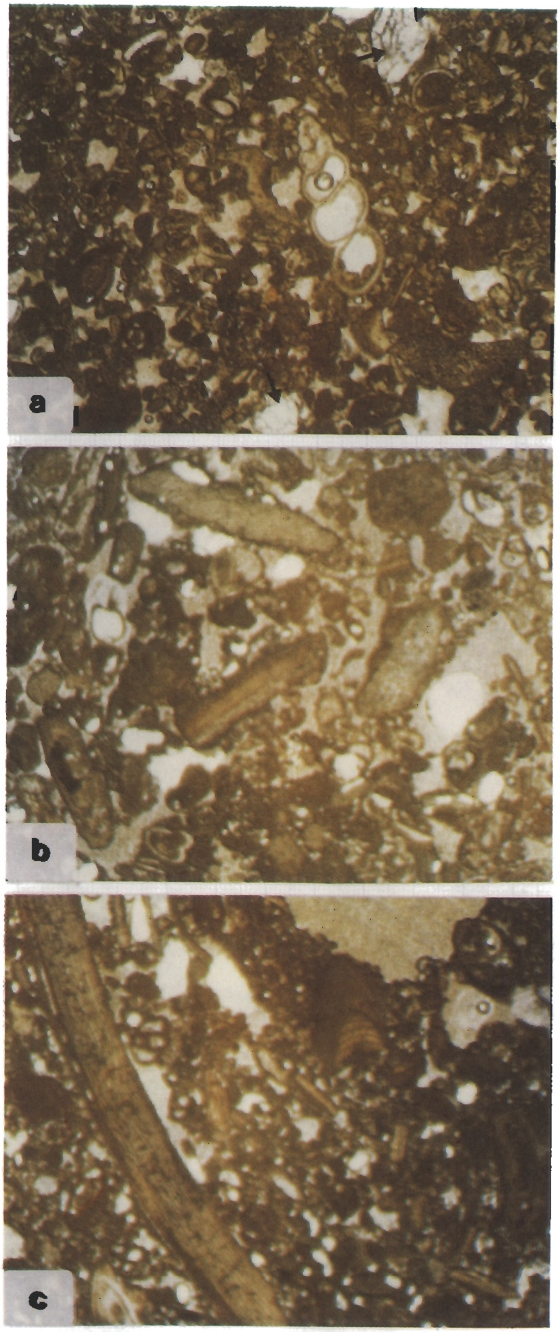

FIG. 3. Photomicrographs of the inland Pleistocene coralline limestones from southern Obhur. (a) Highly fossiliferous rock rich with allochems embedded in a micritic matrix. Notice the dissolution of intraskeletal cavities of shells with formation of equant low-Mg calcite crystal (arrows). (b) Large coralline algal grains with excellent preservation of their microstructure embedded in sparitic matrix. (c) Recrystallized shell fragment with micritic envelope embedded in foraminiferal and algal micritic matrix. The early diagenetic dissolution creates a lot of voids, while reprecipitation evolved low-Mg calcite patches.

process of exsolution. This mechanism is supported by the occurrence of a few dolomite crystals in the upper sample near the ground surface. They are restricted in distribution, suggesting an autochthonous source of the Mg^{2+} ions. According to Ross (1991), the presence of such dolomite inclusions indicates an original high Mg-calcite composition. However, Sibley (1980) believed that early solution or conversion of aragonite and high Mg-calcite to stable low Mg-calcite could inhibit dolomitization.

Mineralogy and Geochemistry

Four representative carbonate rocks have been analysed by X-ray diffraction and the patterns obtained are shown in Figs. 4 & 5. The relative abundance of the main mineral constituents together with acid soluble carbonate ($CaCO_3$) content and the concentration of the major elements (Ca, Mg, Fe, Mn) and trace elements (Sr, Ba) are presented in Table 1.

TABLE 1. Bulk mineralogy, chemical composition and carbonate contents of the inland Quaternary coralline limestones.

Sample No.	Depth (cm)*	Aragonite	Low Mg-calcite	Dolomite	Quartz	Plagioclase Feldspar	$CaCO_3$	Ca	Mg	Fe	Mn	Sr	Ba
								%				PPM	
1	20-30	5.1	40.5	5.1	36.9	12.4	43	17.35	2.55	2.43	371	1550	95
2	100-110	Trace	100	–	–	–	95	38.33	0.44	0.09	22	1450	14
3	250-260	10.0	90	–	–	–	90	36.25	0.58	0.26	47	2382	26
4	390-400	20.0	80	–	–	–	88	38.84	0.49	0.25	51	5840	40

* depth (0-20 cm) represents the unconsolidated sediment cover.

Mineralogical data indicates that the carbonate minerals of the investigated rock samples are represented by the dominance of low Mg-calcite over aragonite and dolomite. Dolomite is being recorded as a minor constituent (5%) together with the detrital minerals (quartz and plagioclase feldspar) in the upper sample which is located near the ground surface where the sediments have mixed carbonate-siliciclastic composition. The detrital minerals were transported from the Tertiary outcrops under arid climatic conditions where mechanical weathering prevails.

The diminishing of aragonite at the top of the sequence is due to its partial dissolution by fresh water and consequently precipitation of calcite downward (Table 1). This agrees with the findings of Behairy (1980) and Dullo and Jado (1984). They further noticed various stages of aragonite alteration to calcite. It can be concluded that after the eustatic drop in the sea level, both high Mg-calcite and aragonite in the reef limestone suffered from early diagenesis through meteoric processes. The inland Quaternary coral limestones in the coastal plain at southern Obhur are exposed to the fresh-water recharge and subjected to more vigorous alteration. Dolomitization seems to be confined to the unstable aragonite. Gaines (1980) assumed that aragonite is more readily dolomitized than the low Mg-calcite, accordingly, two fundamental stages may have led to the formation of dolomite: (1) an early penecontemporaneous replacement stage of

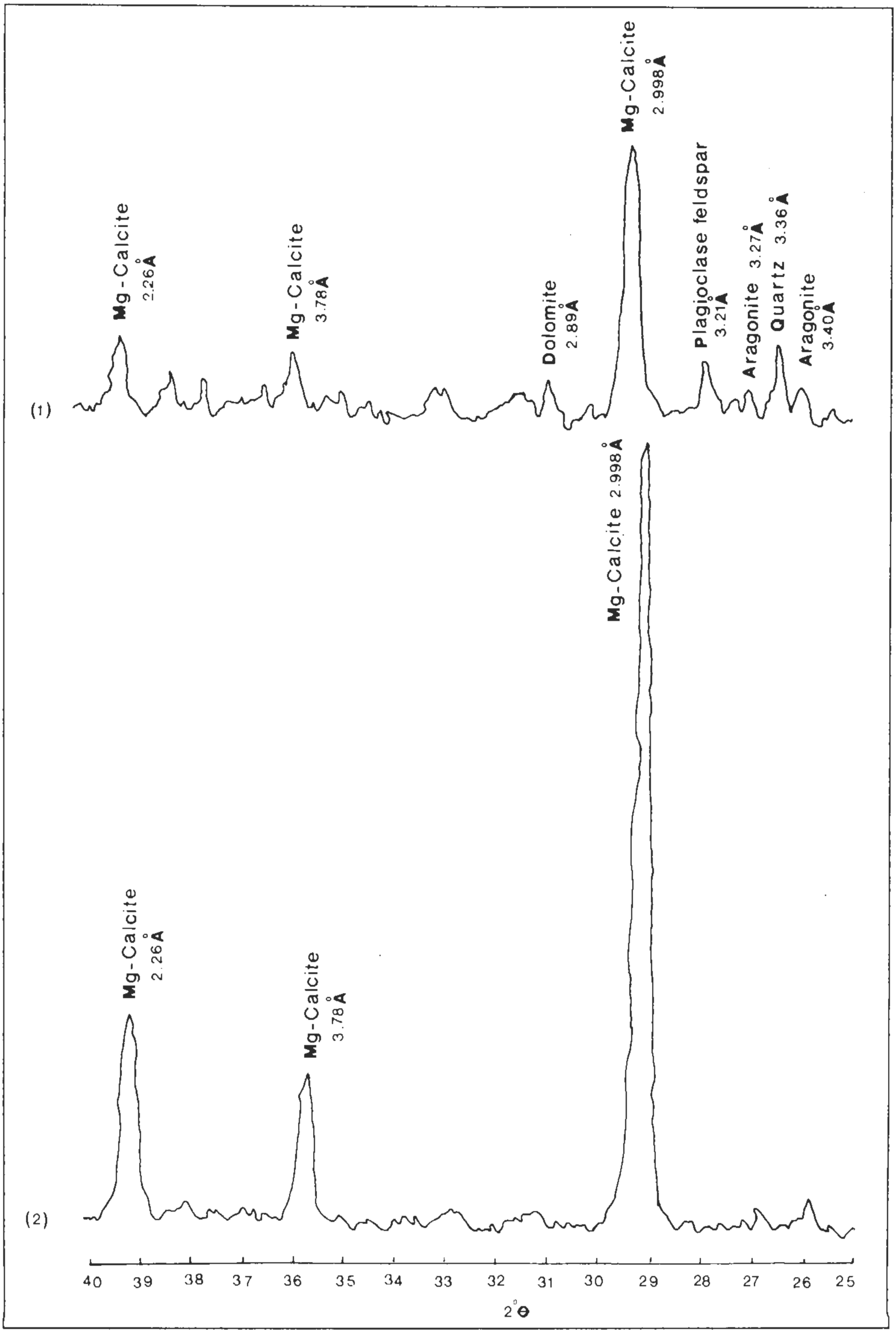

FIG. 4. X-ray diffrectograms showing the bulk minerals of whole rock for samples No. 1 and 2.

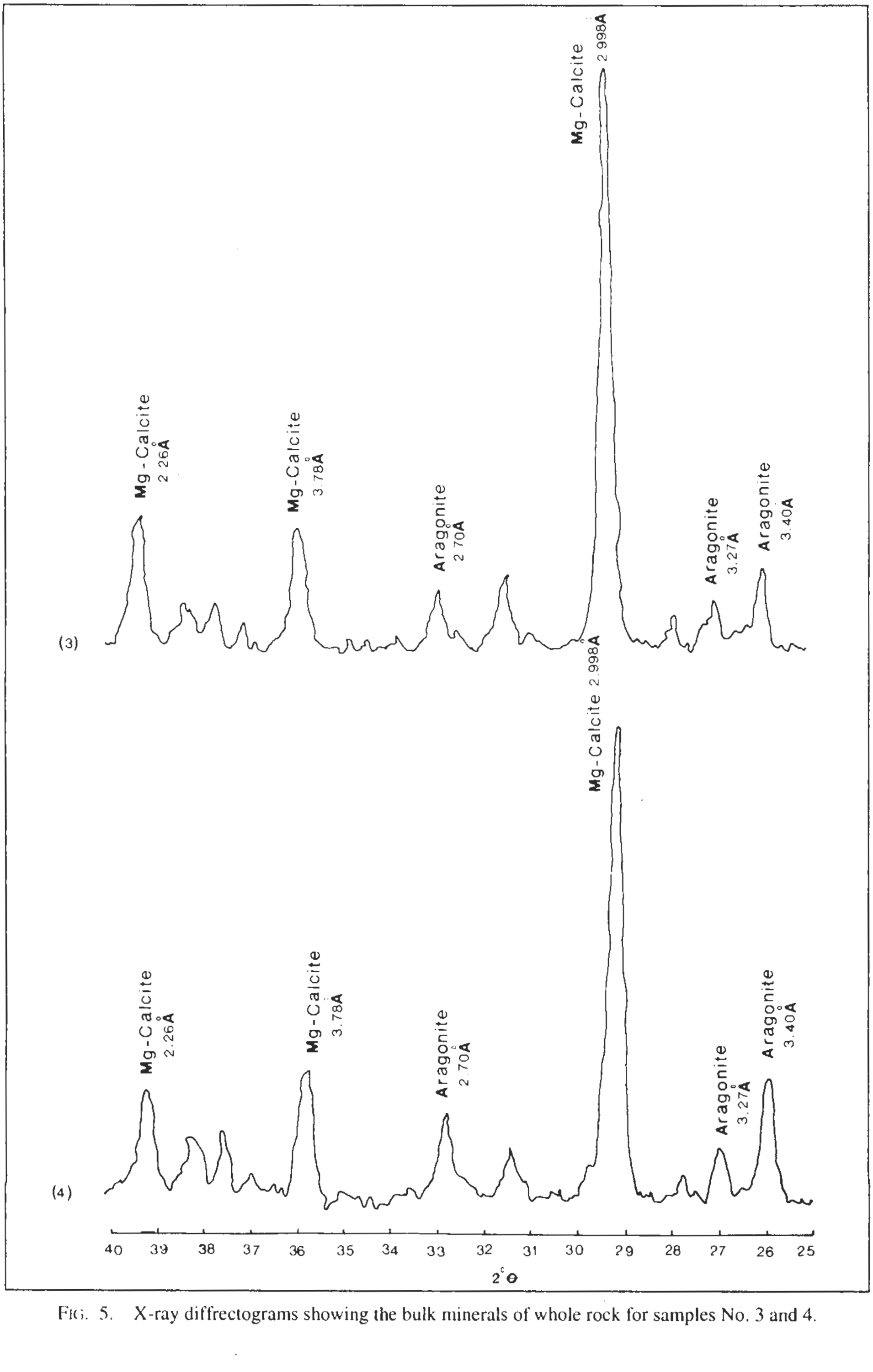

FIG. 5. X-ray diffrectograms showing the bulk minerals of whole rock for samples No. 3 and 4.

aragonite by dolomite and (2) a later diagenetic replacement stage.

On the other hand, the appearance of dolomite in minor amounts near the ground surface is possibly related to local dolomitization. Sediments in this zone are reworked and/or affected by the pedogenic processes acting on aeolian terrigenous material. These materials were transported by wind and accumulated during dry climatic phases. The Sahara dust is the most important parent material for soils of the Quaternary limestones especially coral reef. However, Behairy *et al.* (1984) related the presence of dolomite in an evaporite environment in the coastal plain of Jeddah to the possible dolomitization of the subaerially exposed coastal plain limestones. Durgaprasada Rao *et al.* (1987) reported that halite, trace of gypsum in addition to low Mg-calcite and aragonite are the bulk minerals formed on the littoral surface of the raised limestone terraces at Sharm Obhur.

It is known that the original chemical composition of a rock is influenced by the depositional environment and the post-depositional diagenetic processes. In general, calcium is the most abundant element in all analyzed coralline limestone rock samples (Table 1). It ranges between 17.35% at the top and 38.84% at the bottom of the studied sequence. Calcium is positively correlated with the diluted acid soluble carbonate ($CaCO_3$) fraction of the limestone rocks and negatively with Mg, Fe, Mn and Ba (Table 2). Correlation with the $CaCO_3$ and the mineralogical composition of the rocks confirms the association of calcium with the acid soluble calcium carbonate minerals; aragonite and calcite.

TABLE 2. Correlation coefficient between the determined chemical constituents.

	Ca	Mg	Sr	Ba	Fe	Mn	$CaCO_3$
Mg	–0.99						
Sr	0.45	–0.40					
Ba	–0.94	0.95	–0.12				
Fe	–0.99	0.99	–0.36	0.96			
Mn	–0.99	0.99	–0.33	0.97	0.99		
$CaCO_3$	0.98	–0.99	0.30	–0.98	–0.99	–0.99	
Residue	–0.98	0.99	–0.30	0.98	0.99	0.99	–1.0

The data presented in Table (1) also demonstrate that Mg, Fe, Mn and Ba show their highest concentrations in the sample at top of the studied sequence, where detrital and heavy minerals (augite, epidote, hornblende, olivine, zircon rutile and biotite) are common constituents in the insoluble residual fraction. On the other hand, the positive correlation of these elements with each other and with the residual, *i.e.* non-carbonate fraction (Table 2) ensure their association with the terrigenous materials present in the weathering zone under oxidizing conditions.

Mg has negative correlation with $CaCO_3$ and positive correlation with Fe, Mn and the insoluble residue indicating its main association with the terrigenous minerals and partially with the dolomite.

Sr concentration on the other hand, increases with depth (Table 1), probably due to the increase of aragonite content. Sr^{+2} substitutes for Ca^{+2} in the orthorhombic crystal lattice of aragonite (Goldschmidt, 1954). Harris and Matthews (1968) indicated that in vadose zone of Pleistocene reefal limestone in Barbados, most of the dissolved aragonite with high Sr content is precipitated locally as sparry calcite with low Sr content. Therefore, the dissolution-precipitation process plays an important role in the distribution of Sr in the inland coralline limestone. However, the negative correlation found between Sr and Mg (Table 2) indicates that Sr decreases as dolomitization proceeds. It can be concluded that the crystal structure of aragonite is much more receptive to large cations such as strontium and barium than is calcite. The conversion from aragonite to calcite is generally a solution-precipitation reaction that is greatly accelerated by movement of relatively fresh water through intergranular voids in the carbonate. Therefore, the presence of minor quantities of aragonite with depth suggests that: (*i*) fluctuations in the sea level, which control the location of meteoric-marine water mixing zones and left the unaltered aragonite in the lower layers resubmerged in marine environment, where it is less soluble, or (*ii*) the shell shapes of skeletal aragonite are preserved in the limestones because they are defined by micrite envelopes.

Conclusion

Petrographical, mineralogical and geochemical studies of the inland Quaternary coralline limestone in the coastal plain at southern Obhur, north of Jeddah indicate that these rocks were deposited under regression sea. The sediments were then subjected to early diagenetic trend through dissolution-precipitation process. Leaching of Mg from high Mg-calcite and the partial dissolution of aragonite led to the secondary calcite cement filling of the voids and solution channels show evidence of such process.

The composition of the framework elements within the recognized facies; foraminiferal sandy biosparite and foraminiferal algal biosparite indicate deposition in a littoral environment. The mineralogical and geochemical variations with depth are attributed to the early diagenetic trend under meteoric vadose subenvironment and partially to the deposition in areas receiving considerable continental siliciclastic influx.

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المكونات والظواهر التحويرية في صخور الحجر الجيري المرجاني الرباعية الساحلية ، جنوب شرم أبحر ، السهل الساحلي للبحر الأحمر – المملكة العربية السعودية

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المستخلص . يتكون المحتوى المعدني الكلي لصخور الحجر الجيري المرجاني المتكون على الساحل جنوب شرم أبحر من معادن الكالسيت منخفض في المغنسيوم ، ونسبة قليلة من الأرجونايت ، والدولوميت الغير شائع والكوارتز والفلسبار .

ولقد أمكن تمييز سحنتين صخريتين في صخور الحجر الجيري المرجاني هما : سباريت Sparite حيوي رملي منخربي ، وسباريت حيوي طحلبي منخربي . ولقد دلت هذه السحنات الصخرية على ترسبها تحت ظروف بحر متقهقر ثم تعرضها لتحورات جوية مبكرة ، حيث دلت عمليات الإذابة والترسيب على حدوث التحورات في نطاق الارتشاح الجوي ، فتحور معدن الكالسيت العالي في المغنسيوم إلى كالسيت منخفض في المغنسيوم بينما ذاب معدن الأرجونايت جزئيًا . كما نمت بلورات من السبارايت داخل تجاويف حجرات أصداف المنخربات والرخويات .

وقد برهنت الفحوصات الجيوكيمائية على مصاحبة عنصر الكالسيوم للكربونات حيث أظهر علاقة سالبة مع كل من عناصر المغنسيوم ، الحديد ، المنجنيز ، الباريوم ، المصاحبة للفتات الصخري المجروف من على جبال العصر الثلاثي الموازية للمنطقة الساحلية والمتركز في نطاق التجوية . أما الاسترونشيوم فهو العنصر الوحيد الذي تأثر بعمليات الإذابة والترسيب .