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CLAY AND CARBONATE MINERALOGY OF THE REEF SEDIMENTS NORTH OF JEDDAH, WEST COAST OF SAUDI ARABIA

By

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ABSTRACT

Clay and carbonate mineralogy of the modern and Quaternary reef sediments in the coastal plain north of Jeddah, west coast of Saudi Arabia has been studied by X-ray diffraction analysis. Abundant kaolinite, mixed layer chlorite-vermiculite and illite are the clay mineral assemblage in almost all the samples. The alluvium derived from the low grade metamorphic rocks and volcanic basalts of the Jeddah group forms the source of the clay material in the coastal sediments. Mixed layer chlorite-vermiculite is considered to have been developed during the post-depositional diagenesis of chlorite and volcanic material.

The modern reef carbonates are composed of high Mg-calcite and aragonite with traces of low Mg-calcite and dolomite. However, in the Sharm Abhur, the content of aragonite increases relative to Mg-calcite possibly due to more inorganic precipitation of carbonates. In the Quaternary reef sediments low Mg-calcite, that is considered to have been formed by the meteoric diagenesis of high Mg-calcite and aragonite, is the dominant mineral with varying proportions of aragonite. The intensity of the meteoric diagenesis gradually decreases seawards leaving more and more aragonite unaltered.

INTRODUCTION

Quaternary emergent reef limestones, varying in width from 0.5 to 10 Km and attaining a maximum height of about 3 mts. above the mean sea level, occur all along the west coast of Saudi Arabia. They are almost flat and gently sloping towards the sea with a thin cover of terrigenous sediment. However, the eastern part of the coralline limestone is overlain by alluvial deposits derived from the adjacent high fringing mountains consisting mainly of crystalline rocks. The western margin, which forms the present coastline, is traversed at some places by tidal creeks that extend several kilometers inland. These creeks are considered to be drowned river valleys formed during lowered sea levels and at a time when the rainfall was greater in the region (Chapman, 1978).

Though the reef carbonates occupy a vast area of the coastal plain and treasure valuable information on the Quaternary climatic variations in the western Saudi Arabia, no study has yet been made on these sediments.

Therefore, a systematic investigation has been undertaken by the author to study the sedimentological, mineralogical and chemical constitution of the carbonate sediments in an area 30 Kms north of Jeddah. In order to understand the process of subaerial lithification and the accomplished changes in the Quaternary carbonates, modern reefs that are actively building up in the nearshore marine environment and in Sharm Abhur, a tidal creek, have also been investigated. In the present paper, the mineralogical composition of the carbonates and the associated clay fraction and their variation within the known stratigraphic framework are discussed.

GEOLOGY OF THE AREA

The coralline limestones of the Quaternary age in the study area overlie a bed of conglomerate with argillaceous cement, which in turn is underlai by the volcanic Basalt of the Trap series. However, such bedded sequence is not noticed in the 670 meter thick Plio-Pleistocene limestone encountered in an offshore well near Jeddah. Further, Shanti and Sultan (1966) observed in the coastal plain of Umm Lajj, about 400 Kms north of Jeddah, that the 150 mts thick pinkish chalky reef limestone overlying the Tertiary sediments is only slightly interbedded with sandstone and shale. But, in the western Red Sea coastal plain, Akkad and Dardir (1966) classified four coral reefs alternating with gravel bands in the Pleistocene deposits. A similar succession has been reported by Carella and Scrapa (1962) in the coastal region of Sudan. In the light of the above, the coralline limestone in the Jeddah area may be considered to be late Pleistocene and associated with the last period of higher sea level in the west coast of Saudi Arabia (Skipwith, 1973).

In the area under investigation, the reef limestone extends from the coastline about 10 Kms east, where it is covered by the alluvium (Fig. 1) derived from the weakly metamorphosed sediments and volcanics of Jeddah group occuring further inland. Jeddah group, that is regionally metamorphosed to the green schist facies, is described in detail by Jackaman (1972) and Greenwood et al (1976). Another important geological formation in the area is the alkali olivine Basalt of the Trap series. At Al Kura these Basalts occur at the base of the Quaternary sequence and are overlain by the conglomerates and coralline limestones (Skipwith, 1973). Fine to medium sands with coral fragments and salt occasionally cover the reef sediments.

Sharm Abhur was the ancient mouth of Wadi Al Kura and presently is in restricted communication with the Red Sea through a narrow opening. The depth of the water at the mouth is about 60 meters and gradually decreases towards the landward margin of the Sharm, where depths less than 10 meters are reached. The Sharm has a broad and reasonably flat bottom that gradually becomes narrower towards the sea. The cross-sectional profile of the Sharm indicates two stages in the development of the valley. Probably the river stood at about 5 mts for sometime and later cut down its valley deeper with further lowering of the sea level. Very little terrigeneous material is supplied to the lagoon from the adjacent land and most of the sediments in the Sharm are indigenous carbonates mixed with clastic material in various proportions.

The nearshore shelf is an active carbonate depositional region with wide spread fringing coral reefs. As there are no rivers draining the area and as the rainfall is scanty, the shelf receives very little terrigenous material and therefore the deposits on the shelf are mainly skeletal sands. Binocular observation has revealed that the shelf sediments are composed mostly of fragments of coral, coralline algae and mollusks. Though the corals both as solitary and colonial forms are widespread, the number of genera and species are rather limited. The branching Acropora, Stylophora, Platygira, Porites,

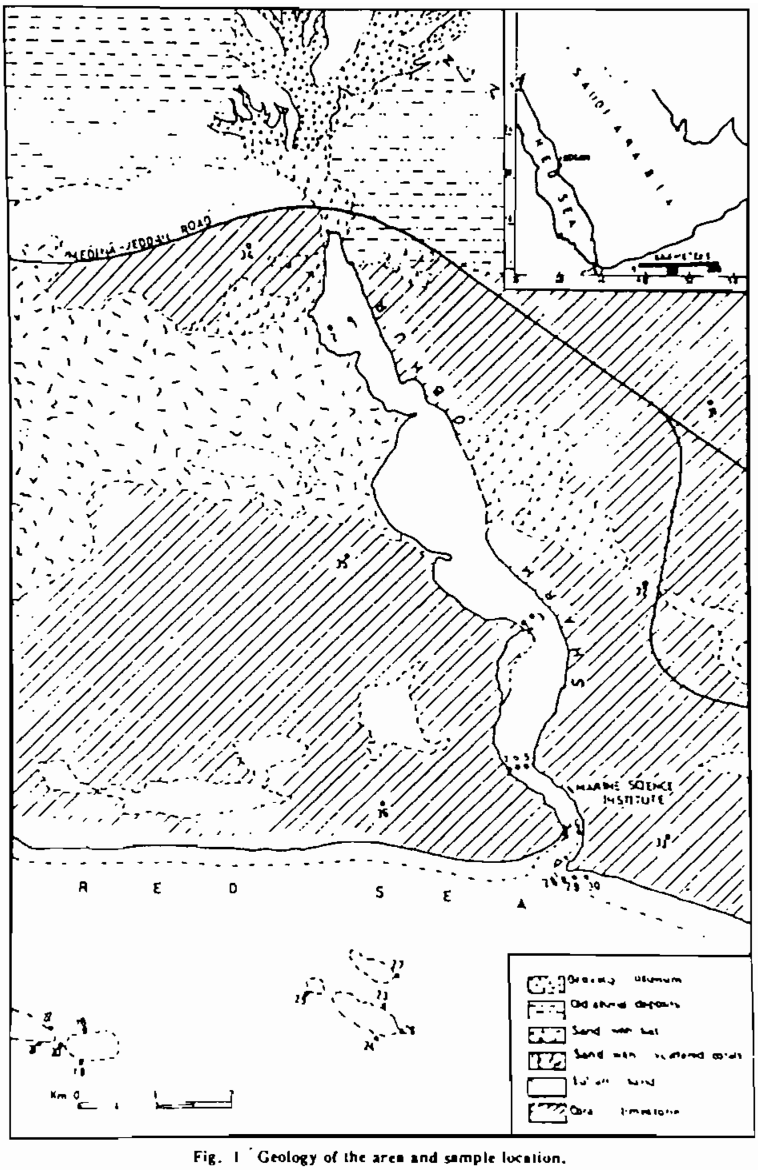

Fig. 1 Geology of the area and sample location.

Millepora, Sarcophyton, Dendronephtya, Xenia and Seriatopora are the commonest types. The eolian activity contributes some fine clay-sized sediments to the shelf from the adjacent landmass. However, during most part of the year the wind blows from N or NNW and so the eolian transport is to a greater extent landwards.

SAMPLE COLLECTION AND METHODS OF STUDY

Thirteen bottom sediments from the nearshore shelf and seventeen samples from Sharm Abhur were collected by a grab sampler. Sample recovery was poor because of the hard surface of the floor in many areas. From the Pleistocene reefs on the land, six sediment samples were collected at depths of 10-20 cm from the surface with an auger.

The mineralogy of the carbonates and the Mg contents of the calcites were determined by X-ray diffraction. The powdered samples were mounted on alluminum holders and scanned at ½° interval. Uniform powdering time and gentle grinding are maintained for all samples keeping in view the effects of increased grinding time and overgrinding on the mineralogy of the carbonates. The relative amounts of calcite, Mg-calcite and aragonite were determined by estimating the peak areas (Milliman, 1974). When the peaks are not clear and show only a slight hump on one side, the mineral is recorded as traces.

The non-calcareous fraction of the sediments, obtained after treating the sample with dilute HCL is dispersed in jars and less than 2 microns fraction is seperated by sedimentation technique basing on the settling velocities. Oriented specimens were prepared by filtering 15 mg of the clay in suspension under suction through membrane filters. Simultaneously, the well dispersed clay sediment is pipetted on glass slides and dried at room temperatures. X-ray analysis of the clays was carried out using Ni filtered Cu radiation, on a Philips X-ray diffractometer with a scanning speed of 1°/min and with setting at 30 MA and 40 KV. The time constant is 4 sec. and the chart speed 600 mm/hour. In addition to the untreated samples, the clays were glycolated at 60°C for 12 hours, heated to 350°C and 550°C for 2 hours and treated with warm, dil HCL and were then subjected to X-ray analysis. The clay minerals were identified from the diffraction charts basing on the values given in powder diffraction data file (1977) published by the International Centre for Diffraction Data, Pennsylvania. The following features were used in the identification of the clay minerals present in the oriented mounts.

(1) Material having a 10A° (001) peak in the untreated sample which was relatively unaffected by either glycolation or heating was assigned to illite.

(2) Material having a 7A° (001) peak which was unaffected by glycolation but which was destroyed at a temperature of 550° was taken as indicating the presence of kaolinite.

(3) Material having a peak at 14°A (001) which expands to about 16 A° on glycolation and which shows high peak intensities on heating to 550°C was taken as indicative of swelling chlorite.

The identification of kaolinite and chlorite is also based on the diffraction pattern obtained after treating the material with warm, dilute HCL. The 14A° chlorite peak disappears, whereas the 7A° and 3.5A° peaks of kaolinite persists.

Organic Carbon determinations were made using potassium dichromate-Ferrous ammonium sulphate titration method of Wakeel and Riley (1957).

RESULTS

The clay mineral composition of the sediments from the Pleistocene reef, Sharm Abhur and from the nearshore marine environment is virtually identical with dominant kaolinite, swelling chlorite and illite. Typical X-ray diffraction patterns of the clay fractions are presented in figures 2a, b & c. Peterson (1961) observed that the compositional variation of the expandable chloritic mineral component was between the composition of vermiculite and that of corrensite. Dixon & Jackson (1962) described chlorite expandible layer silicates in soils with properties intermediate between true chlorite and true vermiculite and (or) montmorillonite. Wu (1974) considers the swelling chlorite noticed in shales as mixed-layer chlorite-montmorillonite. Weaver and Pollard (1975) state that the swelling chlorites, which are common in marine sedimentary rocks are the regularly interstratified chlorite-vermiculite and it appears that the expanded layers are probably some form of smectite. In view of the above observations, the 14 A° spacing that expands slightly on glycol treatment and does not collapse on heating to 550°C is considered to be mixed layer chlorite-vermiculite.

The non-clay minerals frequently encountered are feldspars, quartz and occasionally Amphiboles

Table 1. Mineralogical and chemical composition of the representative carbonate sediments:

Sample No.	Depth (mts.)	Aragonite %	Calcite %	Mg-Calcite %	Dolomite %	O.C. %	Insoluble Residue%
1.	8.0	60.70	trace	38.60	trace	0.461	23.2
2.	0.8	67.60	trace	31.8	trace	0.299	16.3
4.	0.7	70.60	trace	29.0	trace	0.409	7.0
5.	8.0	42.0	—	58.0	—	0.265	6.7
6.	12.0	46.0	—	54.0	—	0.331	4.5
8.	0.4	32.0	—	68.0	—	0.494	27.0
12.	38.0	30.0	—	70.0	—	0.713	18.6
16.	0.5	35.0	trace	64.6	—	0.394	22.0
20.	14.0	30.0	trace	69.8	—	0.284	7.4
21.	13.0	32.0	trace	67.50	trace	0.349	9.3
23.	35.0	10.5	—	64.8	trace	0.263	4.8
25.	23.5	41.7	trace	58.0	—	0.175	4.4
26.	12.5	38.0	trace	61.6	trace	0.253	1.8
28.	45.0	24.0	trace	75.05	trace	0.276	2.2
31.	—	1.0	99.0	—	—	0.153	20.3
32.	—	18.0	82.0	—	—	0.164	21.6
33.	—	56.0	44.0	—	—	0.250	15.2
34.	—	2.0	98.0	—	—	0.165	22.4
35.	—	21.0	79.0	—	—	0.160	15.6
36.	—	36.0	64.0	—	—	0.215	16.8

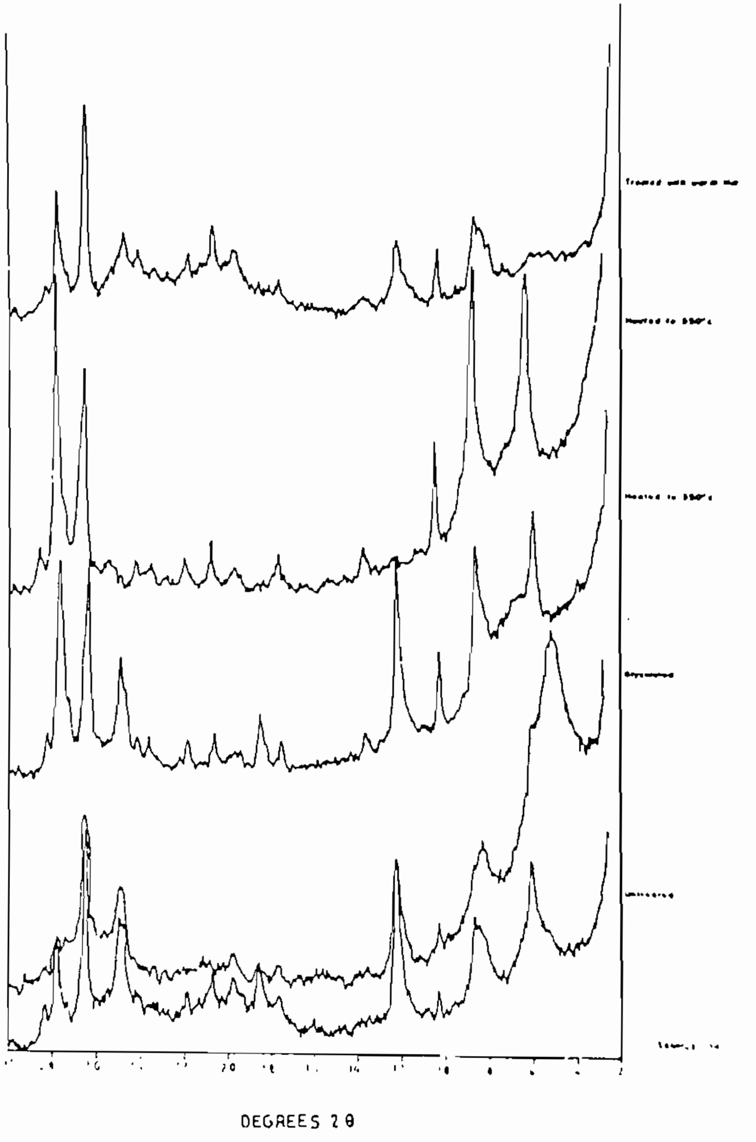

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Fig. 2a Typical X-ray diffraction pattern of clay fraction from Sharm Abhur.

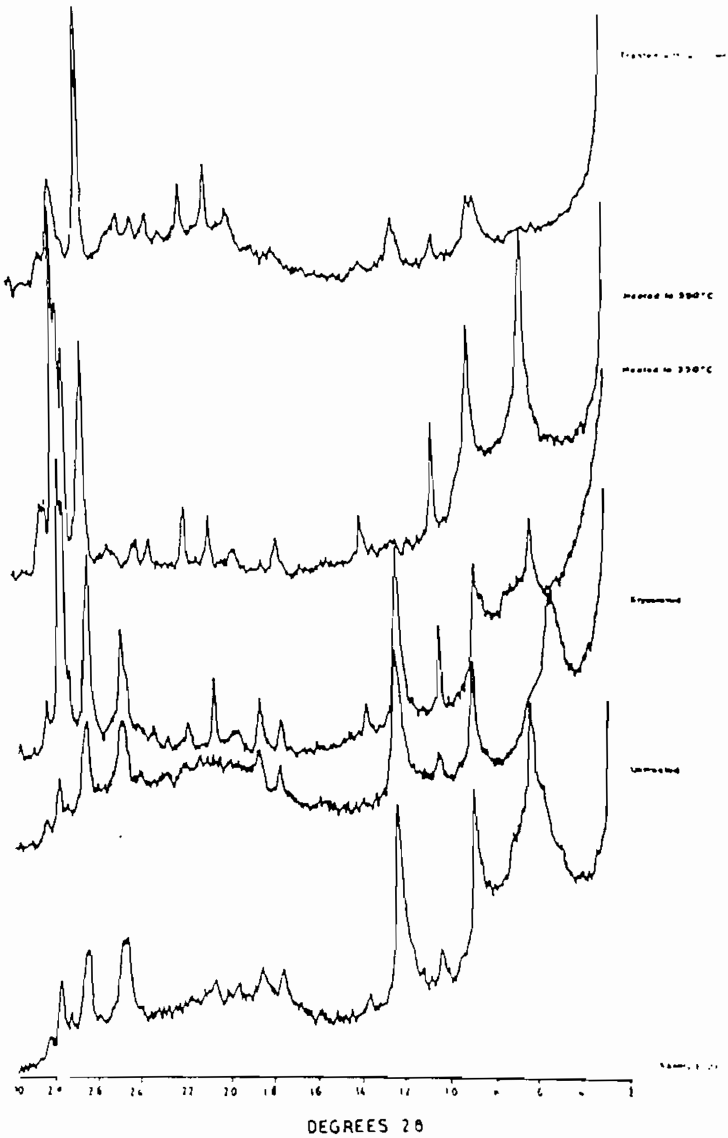

Fig. 2b Typical X-ray diffraction pattern of clay fraction from nearshore marine environment.

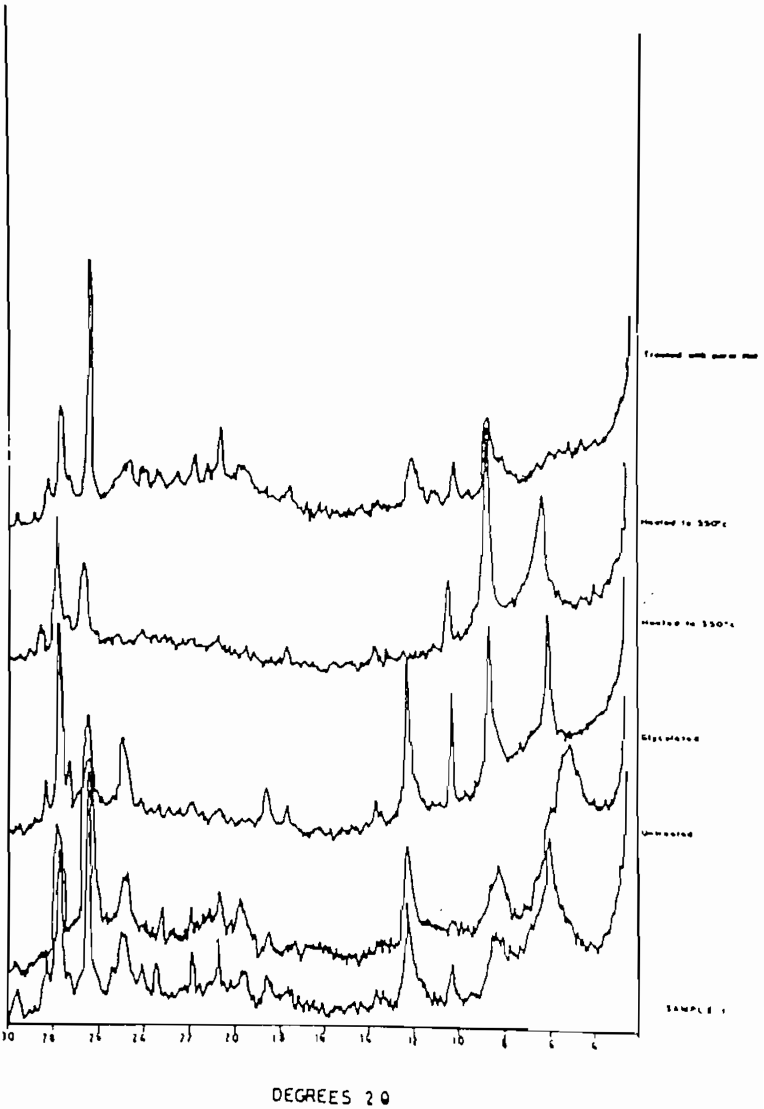

Fig. 2c Typical X-ray diffraction pattern of clay fraction from Quaternary reef limestone.

There is a considerable variation in the mineralogical composition of the carbonate sediments in the study area. Fig. 3 shows the characteristic X-ray diffraction patterns of the carbonates from nearshore shelf, Sharm Abhur and from the landward and seaward margins of the Pleistocene reefs. The quantitative data on the carbonate minerals are summarised in table 1. High Mg-calcite with a peak at 2.997 A° and corresponding to 12 mole % $MgCO_3$ (Goldsmith et al, 1958) is the dominant mineral with subordinate aragonite in the nearshore marine environment and in the seaward margin of the Sharm Abhur. Traces of low Mg-calcite and dolomite are present in almost all the samples. In the Sharm Abhur, the high Mg-calcite gradually decreases landward with concomitant increase in the aragonite concentration. Quaternary reefs are characterized by low Mg-calcite with a systematic variation in the proportions of aragonite. The content of aragonite gradually decreases landward, where it falls as low as 1 percent from the high value of 56 percent in the seaward samples.

The Mg-calcites with 12 mole % $MgCO_3$ in the nearshore marine environment and in the Sharm Abhur are comparable to the Mg-calcites in the deep Red Sea sediments reported by Milliman et al (1969). On the other hand, though the bulk mineralogical composition of the deep-sea carbonates in some of the Red Sea cores studied by Herman and Rosenberg (1969) is the same as observed in the nearshore carbonates, the concentrations of individual minerals and their distribution patterns in various coastal environments differ considerably.

In general the organic carbon is low in the Pleistocene reef sediment. But no distinct pattern in the distribution of organic carbon is noticed in the nearshore shelf and in the Sharm Abhur.

DISCUSSION

The clay mineral composition of the sediments in the coastal region of Jeddah indicates two different climatic conditions and thereby two different weathering environments in the source areas from which they are derived. Kaolinite generally forms under intense chemical weathering conditions in tropical to sub-tropical humid climates with proper leaching of alkalies (Grim, 1968 and Keller, 1970). Walker (1974) found abundant kaolinite and little illite-montmorillonite in the alluvium derived from the humid tropic regions unlike that in the arid regions of the deserts characterized by abundant mixed layer illite-montmorillonite and little kaolinite. In the present arid climate of the Era, due to high evaporation the prevailing water movement in the weathering zone is upward and the decay constituents are not being removed from the decay zone. Further, because of the scanty rainfall there is no downward leaching of the alkalies and the possibilities for the development of kaolinite in such an environment are meagre. Therefore, the Kaolinite in the coastal sediments is considered to have been formed during the humid phases in the geological past. Hotzl and Zotl (1978) found evidences indicating humid conditions with greater amount of precipitation and stronger surface runoff of Wadis during early the middle Holocene in the central and eastern Saudi Arabia. Even in the Pleistocene and late Pliocene, existence of extensive runoff and humid conditions is indicated by the intense lateritic weathering and deeply furrowed dissection of the basalt flow 3.5 million years old, though the later phases.

Fig. 3 Typical X-ray diffraction patterns of carbonates.

were marked mainly by arid conditions. Further, investigations on the marine sediments in Gulf of Aden (Olaussen and Olsson, 1969) and in the northeastern African area (Degens and Hecky, 1974) have also revealed multiple changes of humid and arid phases during Holocene. In the light of the above, it is inferred that such humid phases with relatively greater runoff existed in the western Saudi Arabia also favouring the formation of Kaolinitic clays. However, data on the vertical variation of the clay minerals is awaited to correlate the periods of climatic changes in the western Saudi Arabia with those found in the central and eastern Saudi Arabia.

The low grade metamorphic rocks of the Jeddah group form the main source of the chlorite, though a little might have been derived from the basic volcanics. Due to the mechanical breakdown of the metamorphic green schists in the source area under arid conditions, chlorite might have been passed into the alluvium and from there is transported into the coastal sediments. Grim (1968) states that in temperate regions chlorite may pass through unaltered from rock to soil and to the transported sediments. In the sediments of the Atlantic and the adjacent seas, Biscaye (1965) noticed that chlorite is relatively lower adjacent to the same continental landmasses, where kaolinite is comparatively high and considered it as a characteristic mineral of high latitudes and temperate regions (Griffin et al, 1968 and Behairy et al, 1975). Gorbunova (1966) attributed the abundance of chlorite and illite in the sediments of the northern Indian Ocean to desert and semi-arid soils of the surrounding landmass, where they are predominant clay minerals.

Kaolinite and illite in the clay sediments of the reef limestone are detrital, while the mixed layer chlorite-vermiculite seems to be a diagenetic product. Supporting the inference is the clay mineral composition of the inland sediments (Technical reports of DGMR, Jeddah), which are characterized by kaolinite, chlorite, montmorillonite and illite with no mixed layer clay minerals. In addition, earlier investigations (Peterson, 1961 and Wu, 1974) have shown that swelling chlorite-like mineral is a diagenetic product in a hypersaline evaporite environment. Weaver (1961), who found mixed layer chlorite-vermiculite as the pre-dominant clay mineral in the limestones and dolomites, concludes that this mineral forms fairly easily in a Mg-rich environment either from the volcanic source material or montmorillonite or chlorite. It might be that the chlorite and the volcanic material, derived from the mechanical breakdown of the volcanic basalts, have been subjected to post-depositional alteration in the marine environment.

The observed mineralogical changes in the Pleistocene reef limestones indicate a diagenetic alteration of the carbonates by meteoric or meteoric-marine hydrologic regime. By analogy with the modern carbonates from the nearshore marine environment and the Sharm Abhur, the Pleistocene reefs are considered to be composed of high Mg-calcite and aragonite when originally deposited. During the subsequent subaerial exposure, meteoric process in which all the metable Mg-calcite and aragonite have been transformed to calcite. Investigations on the Pleistocene and Late Tertiary limestones (Friedman, 1964, Land et al, 1967 and Land, 1970) have shown that Mg-calcites were the first phases to be altered to calcite and were followed by the later alteration of aragonite. Gavish and Friedman (1969) noticed in the carbonate sediments along the Mediterranian coast that aragonite and Mg-calcite in the modern carbonates have been partially eliminated in the late glacial carbonates and almost completely in the older carbonates. It took 10 thousand years or less to eliminate all the Mg-calcite and 70 or 100 thousand years or less for the aragonite to disappear. However, in the carbonate sediments of Jeddah, though the diagenetic alteration of Mg-calcite may be comparable with that of the above, aragonite transformation seems to be more dependent on the intensity of the diagenetic process rather than on the time factor. This is evidenced by the gradual increase in the aragonite concentration seaward, in which direction the influence of the meteoric water decreases.

As there is no significant variation in the types of carbonate producing organisms in the nearshore environment and in the Sharm, the landward increase in the aragonite content in the Sharm Abhur is attributed to the varying hydrographical conditions. Both temperature and salinity increase in the Sharm waters from the mouth towards the landward margin. Though the high salinities resulting from the high evaporation rates facilitate more inorganic precipitation of carbonate in the form of aragonite, the observed salinity variations (10‰) does not seem to be totally responsible for the additional aragonite in the Sharm. Milliman (1974) states that, if the salinities are not extreme, the inorganic precipitation is more dependent upon the lack of skeletal deposition. With the decreasing depths landward, the waters probably become more turbid and lower the skeletal carbonate precipitation. In addition, the increased temperatures favour the precipitation of more aragonite in the species with mixed mineralogies (Lowenstam, 1964). Finally, it is inferred that high salinity, high temperature and low skeletal precipitation cumulatively increased the aragonite content in the landward margin of the Sharm relative to the nearshore marine environment.

CONCLUSIONS

The clay mineral assemblage in the carbonate sediments of the Jeddah area constitute kaolinite, mixed layer chlorite — vermiculite and illite, and reflects the climatic conditions in the adjacent source region. Abundant kaolinite is considered to have been formed in the humid climatic phases in the geological past. The humid climatic conditions noticed during the Holocene and Pleistocene periods in the central and eastern Saudi Arabia probably existed in the western Saudi Arabia also. The mixed layer chlorite-vermiculite in the clays is a diagenetic product formed from the alteration of chlorite and the volcanic material derived from the source area.

The meteoric diagenesis altered the metastable Mg-calcite and aragonite in the subaerially exposed Pleistocene reef carbonates to stable calcite. However, the transformation of aragonite decreases seaward due to the decreasing influence of the meteoric waters. In the Sharm Abhur more inorganic precipitation takes place leading to the higher concentration of aragonite than in the nearshore marine environment.

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دراسة معادن الطين والكربونات فى رسوبيات الشعب المرجانية شمال جدة على الساحل الغربى السعودى

د · عبدالقادر بحيرى

كلية علوم البحار – جامعة الملك عبدالعزيز – جدة

تمت دراسة معادن الطين والكربونات الموجودة فى الشعب المرجانية من العصرين الحديث والرباعى فى السهل الساحلى لشمال جدة بواسطة الاشعه السينية · وضح من هذه الدراسة وجود معدن الكاولينيت بكثرة مع وجود خليط طبقى من معدنى الكلوريت – الفرميكيوليت مع الالليت فى معظم العينات · وتعزى وفرة الكاولينيت إلى الرطوبة العالية التى كانت سائدة خلال عصرى الهولوسين والبليستوسين فى وسط وشرق المملكة ·

ويعتبر الطرين الناتج من الصخور المتحولة المنخفضة الدرجة وصخور البازلت البركانية لمجموعة جدة المصدر الرئيسى لطمى الرسوبيات الساحلية ·

وقد وجد ان الكربونات المكونة للشعب المرجانية الحديثة تتركب من معادن كالسيت عالى المغنسيوم واراجونيت يزداد بالنسبة الى الكالسيت المغنسيومى وقد يرجع ذلك الى زيادة الترسيب غير العضوى المتزايد للكربونات · اما فى الشعب رباعية العصر فقد كان الكالسيت منخفض المغنسيوم هو المعدن السائد مع كميات مختلفة من الاراجونيت · ويعزى تكون هذا الكالسيت إلى تاثيرات مائية بعد الترسيب ·

Saudi Governorates; The Saudi Network. Trade and business information and links to saudi arabia, arabian gulf and middle east area. member of Nova Stars Information Services.Â The capital of the region is Hail. Its important towns are Al Rawda, Al Ghajala. Eastern Region Governorate. Capital city is Dammam. This region is the best of the Kingdom's oil industry. The important cities of this region are Qatief, Mobriz, Ugair, Jubail, Al Khobar, Dhahran, Rass Tanoura and Beqiq. This work discusses the composition and characteristic of the surficial sediments in the southern corniche of Jeddah, Saudi Red Sea coast, in an attempt to infer the surficial distribution pattern of minerals and provenance of sediments. Twenty-six superficial sediments samples were collected from backreef and forereef areas and were analyzed for grain size, $CaCO_3$ content, and mineralogy.Â However, on the contrary the percentage of carbonate minerals were low in the backreef-flat area, which could be attributed to the supply of non-carbonate terrigenous materials. The terrigenous material contains quartz, k-feldspar, plagioclase and amphibole minerals and are dominant in backreef-flat area with averages of 12.7%, 7.13%, 2.93% and 0.65%, respectively. Introduction The western coastal plain of Saudi Arabia has been cut through by numerous drowned estuariesor sharms,whichextendonto the inner part of the shelf. One such sharm, Sharm Obhur, is located about 35 km north of Jeddah(Fig. 1). It extends about 10km inland through coralline limestone, and attains a maximum width of 1.5 km. It isconnectedwith the Red Seathrough a narrow mouth.