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## Submarine limestones in the nearshore environment off Kuwait, northern Arabian Gulf\*

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### ABSTRACT

Even with careful petrographic and mineralogic characterization of marine limestones, intertidally and subtidally lithified rocks are often difficult to differentiate, thus hindering an accurate delineation of the diagenetic environment. Limestones from water depths of 6 to 8 m off Kuwait vary in petrographic character from oosparite and biosparite (in which the cement is entirely aragonite) to oomicrite and biomicrite (in which at least some of the cement is microcrystalline magnesian calcite). Carbon-14 dates suggest that the oosparite may have lithified at depths shallower than at present (possibly intertidally) during a lower stand of sea-level. In contrast the biosparite, oomicrite and biomicrite appear to be contemporaneous and to have lithified subtidally.

### INTRODUCTION

Lithification of marine carbonates in water depths less than 100 m is well documented from many intertidal and subtidal areas throughout the world. Lithification results in formation of intertidal beachrock as well as subtidal hardgrounds, many of which can be underlain or interbedded with unconsolidated sand. Reports on the petrology and origin of such rocks proliferated in the late 1960's (e.g. Füchtbauer, 1969; Bricker, 1971); later summaries can be found in Milliman (1974) and Bathurst (1975). While mineralogical, compositional and petrographic data on various intertidal and subtidal limestones are plentiful, modes of origin are unclear. Presumably both types of limestone result from the inorganic precipitation of cement around and/or between immobile grains, but what triggers the actual precipitation and controls the mineralogy of the resultant cement is not known.

The similar appearance of many intertidal and subtidal limestones makes differentiating these two

limestone types particularly difficult. For example, submerged limestones from the North Carolina shelf break that were assumed to be relic beachrock (Milliman & Emery, 1968; Macintyre & Milliman, 1970) probably were lithified subtidally (Macintyre *et al.*, 1975). Conversely, in the Arabian Gulf, an area in which submarine lithification is particularly well-documented, several of the reported subtidally lithified limestones (e.g., Shinn, 1969; Stoffers & Ross, 1979) have sufficiently old C<sup>14</sup> dates to suggest they may have been lithified at shallower depths, perhaps even intertidally.

In this paper we report the occurrence of submerged calcareous hard layers off Kuwait, which occupies the western edge of the Mesopotamian shallow shelf in the Arabian Gulf (Fig. 1). An extensive study by the Kuwait Institute for Scientific Research has revealed the occurrence of submarine hard layers in several sites on a 5–10 m submarine terrace off Kuwait City. These hard layers generally are covered by a thin layer of pebbles, sand or muddy sand. Although samples of these hard grounds have been collected from other

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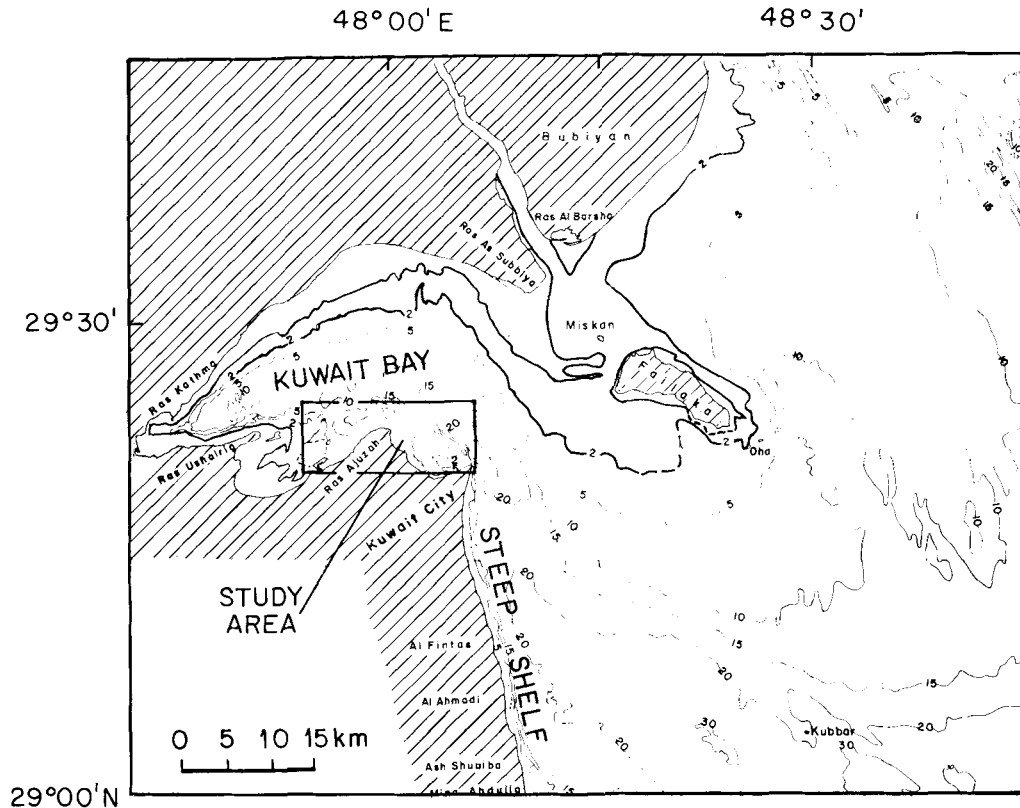


Fig. 1. Map of the northwestern Arabian Gulf, showing study area.

sites, the present study concentrates on the area off Kuwait Bay because of the availability of sufficient samples and information from several boreholes drilled in the area (Fig. 2). Our data, as will be seen, suggest that the hardgrounds may have undergone both intertidal and submarine lithification.

#### OCCURRENCE OF SUBMARINE HARD LAYERS

The study area is located along the southeast coast of Kuwait Bay, which is a shallow horn-shaped gulf protruding westward from the main Gulf (Fig. 1). The bay has a maximum depth near its entrance of about 20 m, but most of the area is less than 10 m deep. The southern part of the bay is relatively narrow and steep, mainly covered with sandy deposits (Khalaf *et al.*, 1979). Directly off Kuwait City, the seafloor is characterized by discontinuous hard layer(s) varying in thickness from a few ten's of cm to 3 m. The rock

layer dips seawards at approximately  $4 \text{ m km}^{-1}$  (Fig. 2). It is exposed near Ras Ajuza at 4 m water depth, locally covered by a few cm of coarse sand and rock fragments, most of which probably were eroded from the hard layer. With increased water depth, the hard layer becomes covered by recent sand and mud. Based on stratigraphic/lithographic logs of about 20 shallow boreholes drilled in the study area, overlying sandy and muddy sediments can reach up to 8 m in thickness (Fig. 2A). The lithic layer itself thickens offshore to 1.5–3.0 m (Fig. 2B).

The hard layer is underlain by an uncemented sand sequence about 9 m thick. Based on its petrographic characteristics, the sand contains an upper oolitic sand unit underlain by quartzitic sand. The oolitic sand, 2 to 5 m thick, has an elongated lenticular shape which suggests that it was deposited as an offshore sand bar. The lower sand layer is thicker and composed mainly of well-sorted quartz grains. Textural and mineralogical characteristics indicate that this sand is non-marine and can be correlated with the Mio-

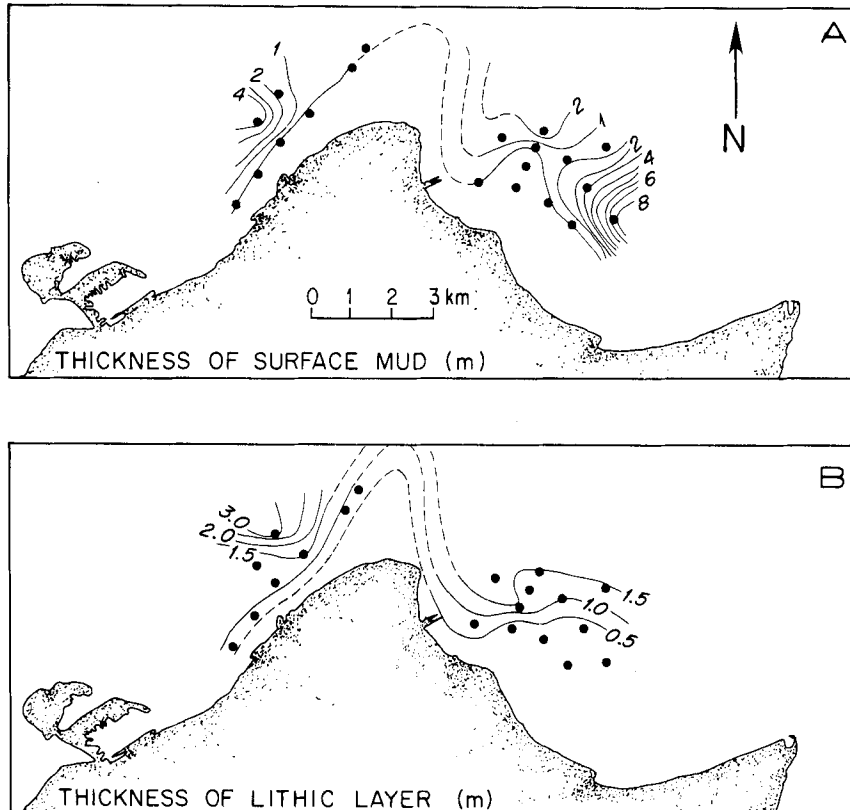


Fig. 2. Maps of the study area, showing thickness of overlying mud (a) and lithic layer(s) (b) as determined by various cores in the area.

Pliocene sands exposed in the southern coast of Kuwait Bay.

### PETROGRAPHY

The submarine hard layers are generally porous. They are composed of a well-cemented mixture of shells, shell fragments, pellets and ooids, the composition of the framework grains varying both laterally and vertically. Both exposed and buried surfaces of this hard layer usually have a pitted, fissured and honey-combed appearance (Fig. 3). Similar features occur in recently lithified Pleistocene oolitic limestones exposed along the Kuwait shoreline. The surfaces of some of the hard layers locally are penetrated by bivalve borings (Fig. 3). Extensive burrowing has largely destroyed bedding.

Based on the composition of framework grains and the cement-matrix ratio, four types of rock are

recognized: biosparite, biomicrite, oosparite and oomicrite. Biosparite is the most frequent rock type, whereas oolitic rocks are commonly restricted to the eastern side of the study area (Fig. 2).

*Biosparite* is composed chiefly of clean well-sorted fragments of molluscs, echinoids and bryozoans (Fig. 4A). Molluscan fragments constitute more than 65 percent of the framework grains; whole shells of small bivalves and gastropods also are present. Echinoid fragments, both plates and spines, form about 15 percent of the skeletal grains. Detrital quartz and feldspar comprise a few grains.

Random orientation of skeletal debris results in an initially high porosity for this rock type. The framework grains are cemented by clear acicular aragonite which occurs as an isopachous fringe. Small gastropods and bivalves are partially to completely filled with sparry aragonite cement, with clear acicular fringes on the internal surfaces. Some microcrystalline cement is present. Most of the studied biosparites are

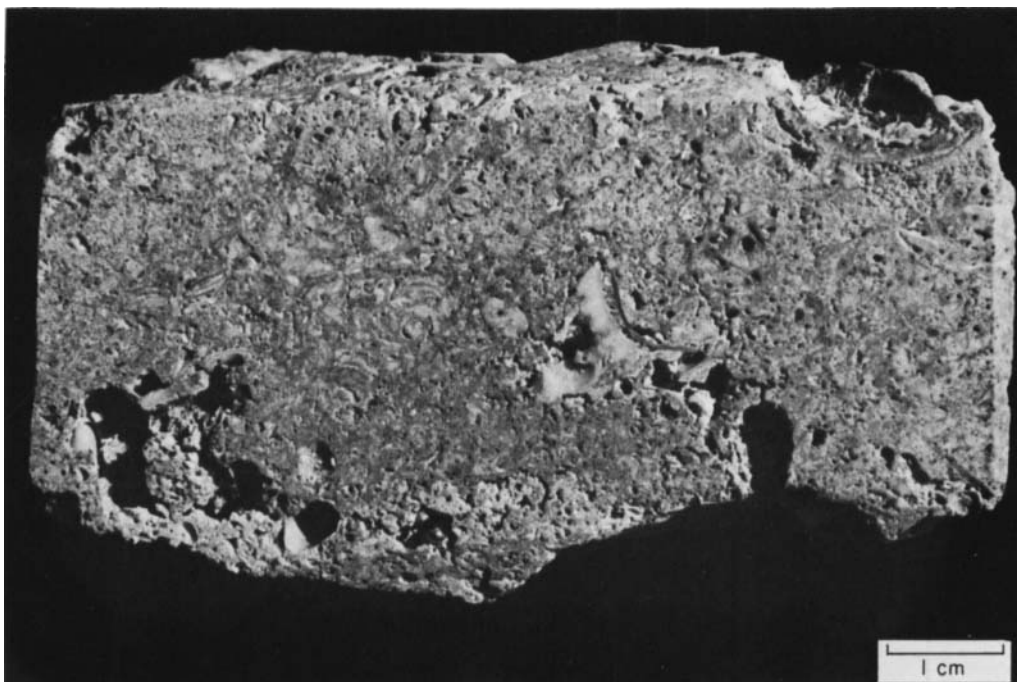


Fig. 3. Vertical section of core sample from the top of a hard lithic layer, showing extensive boring by molluscs.

dense due to almost complete filling of the intergranular pores.

*Biomicrites* occur mainly in the offshore of Ras Ajuza as less consolidated, porous rocks. They are composed of poorly-sorted mixtures of skeletal fragments, small gastropods and bivalves, and quartz grains within a micritic matrix (Fig. 4B). Cavities of gastropods and bivalves, as well as burrows, commonly are lined with a thin acicular aragonite cement. *Biomicrites* are characterized by superficial crusts of calcareous algae.

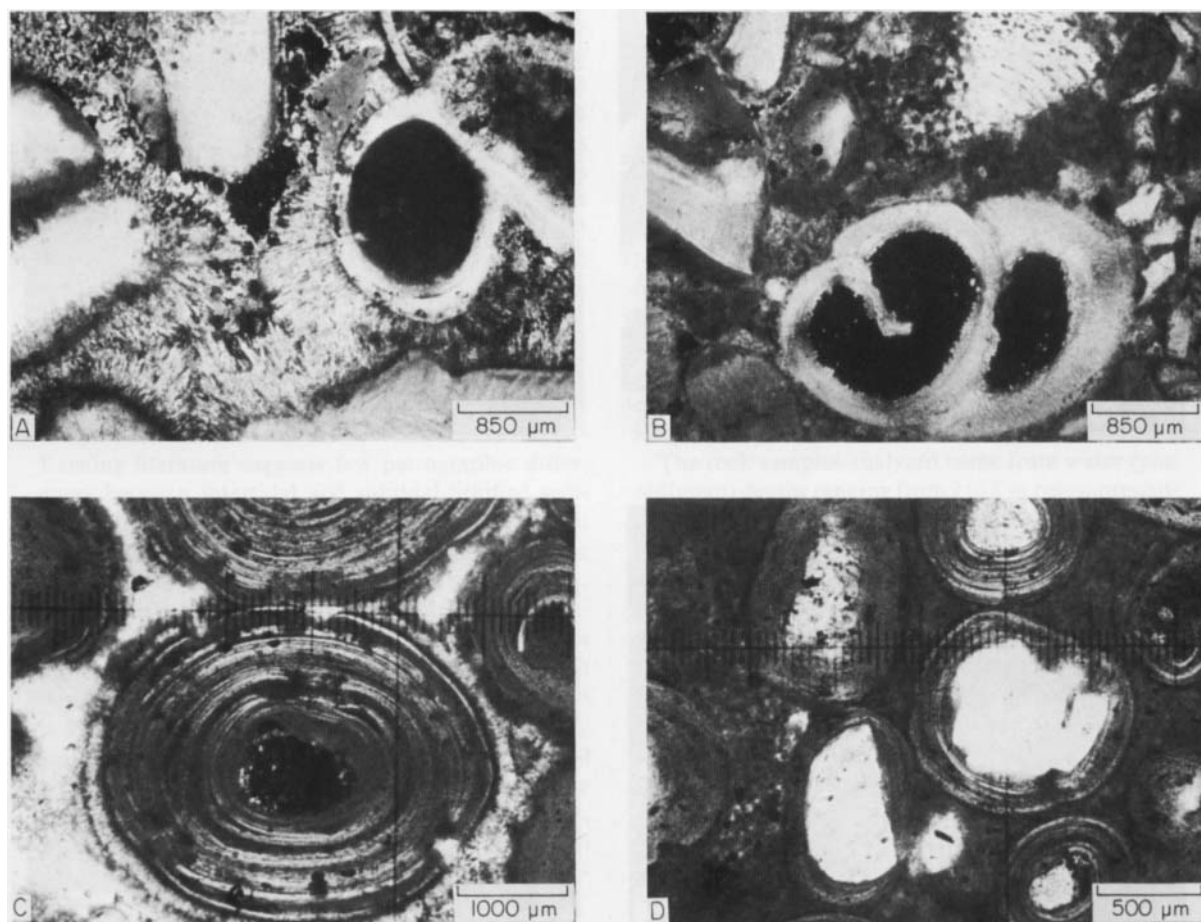
*Oosparites* are composed of well-sorted ooids of medium sand size, cemented with aragonite. Most of the ooids are spherical, although ellipsoidal ooids are frequent. Ooids generally contain nuclei of detrital skeletal fragments and (to a lesser extent) peloids of bivalves filled with microcrystalline carbonate. Composite nuclei of two or more detrital grains have been recognized. The ooid cortex is generally well developed (Fig. 4C).

Oolites are cemented by relatively thin fringes of clear acicular aragonite; small pores are completely filled. Microcrystalline grains (probably high Mg-calcite) are commonly scattered within the aragonite cement.

*Oomicrites* are composed of poorly-sorted, rounded ooids within a micritic matrix (Fig. 4D). About 60 percent of the ooids contain nuclei of detrital quartz. The micrite matrix, which contains some foraminifera and ostracodal shells, is grey in colour, presumably indicating the presence of pyrite. Locally, microcrystalline matrix is absent and clear acicular aragonite cement is developed.

## MINERALOGY

Carbonate content of the rocks ranges from 70 to 95 percent, with micro-crystalline rocks containing more non-carbonate material than the sparites. Quartz and feldspar are the dominant non-carbonate minerals. X-ray diffraction analysis reveals that the rocks are composed mainly of aragonite, high Mg-calcite, calcite, quartz and feldspar (Table 1). Dolomite is recorded in trace amounts. Aragonite is the most frequent mineral in all studied samples. However, it is relatively more abundant in the sparites. High Mg-calcite is relatively abundant in microcrystalline rocks.



**Fig. 4.** (a) Biosparite, biogenic grains cemented by clear acicular aragonite; (b) Biomicrite, skeletal fragments within a microcrystalline matrix; (c) Oosparite, with well-developed ooid cortex; (d) Oomicrite, ooids within a microcrystalline matrix.

## DIAGENESIS

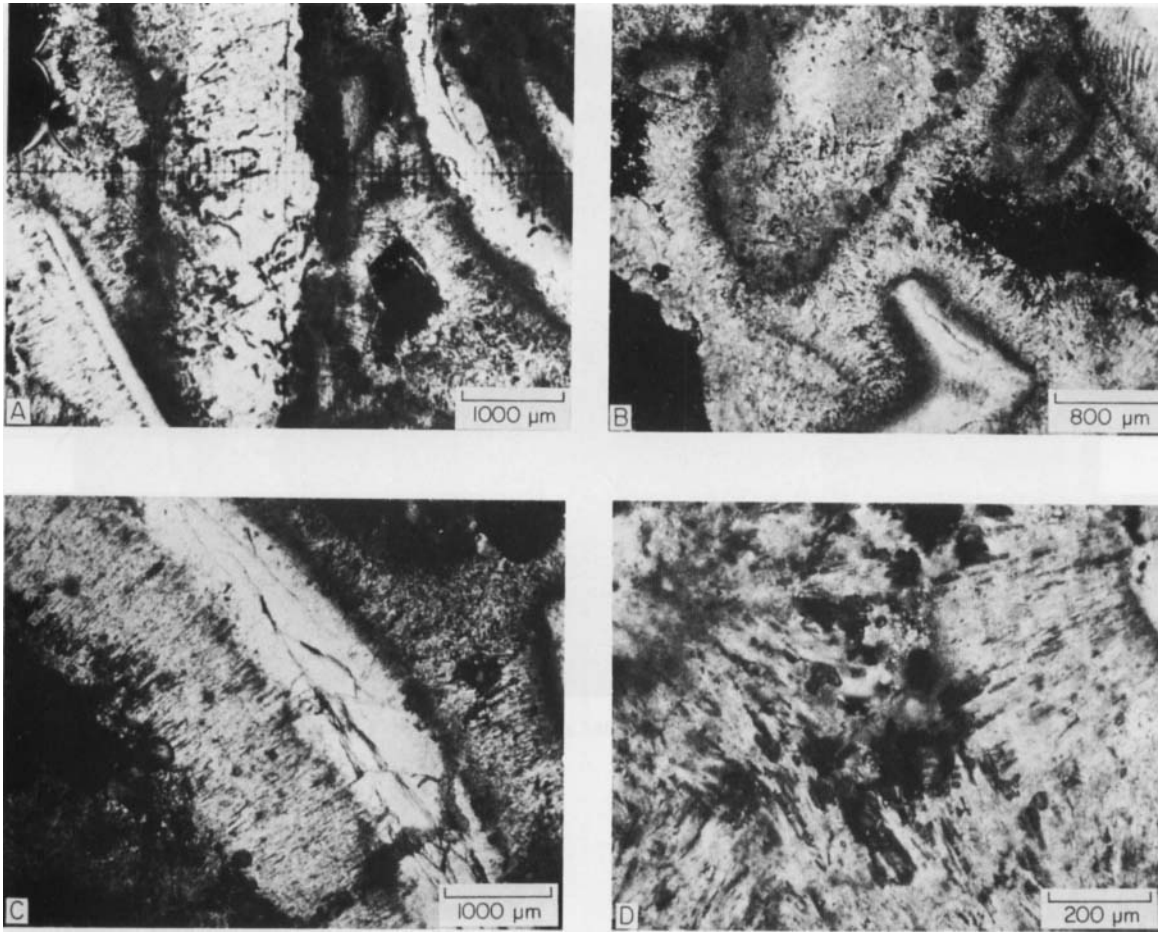
Diagenesis started during initial deposition and included biologic boring (mainly by algae) and algal

coating (cf. Bathurst, 1966). Most skeletal grains are at least partially micritized and some fine grains are almost completely micritized (Fig. 5A).

Two types of cement are recognized: a fine-grained

**Table 1.** Results of mineralogical and carbon-14 dating analyses on submerged limestones of Kuwait.

Sample No.	Litho Type	Percent Carbonate Mineralogy				Age (yr B.P.)
		CaCO <sub>3</sub>	Aragonite	Mg-Calcite	Calcite	
ALB 38-1	Biosparite	85	70	12	18	2070 ± 400
Shar 25-1	Biosparite	90	70	12	18	
ALB 25-1	Oosparite	95	72	11	17	6250 ± 120
ALB 25-2	Oosparite	85	72	16	12	5260 ± 90
Shar 35-2	Biomicrite	80	62	25	13	3360 ± 200
						3740 ± 250
Shar 34-1	Biomicrite	83	62	25	13	2910 ± 100
ALB 39-1	Oomicrite	70	65	21	14	4350 ± 300
ALB 39-2	Oomicrite	75	60	27	13	



**Fig. 5.** (a) Biosparite, partial algal micritization and development of relatively thick microcrystalline envelopes over skeletal fragments; (b) Biosparite: Skeletal fragments have a microcrystalline rind which is overlain by a fibrous aragonite cement which projects into the intergranular pores; (c) Inter-fringed aragonite needles growing from parallel sides of two grains; (d) Biosparite, interconnected aragonite needles growing from the surface of three grains forming a well-defined fringe; note micritic particles trapped between the aragonite crystals.

dark brown microcrystalline cement and a clear, acicular aragonite cement. In the biosparite, a microcrystalline rind coats the particles (particularly molluscan fragments), overlain by a fibrous cement whose crystals project into the intergranular pores and/or internal cavities of the shells (Fig. 5B).

Clear acicular aragonitic cement occurs as an isopachous fringe of laths perpendicular to the framework grains; the coating varies in thickness from 25 to 65  $\mu\text{m}$ . The fabric of the cement depends on the relation with the framework grains. In areas where cement fills a gap between two grains, aragonite laths grow on both sides and inter-fringe (Fig. 5C). In intergranular pores that occur between more than

three grains, aragonite cement is present as an isopachous fringe which is formed of interconnected laths grown from the surface of each grain towards the pore space. This fabric presumably is responsible for the hardness and denseness of the rocks. The state of cementation depends partly on the size of intergranular pores. Pores less than 100  $\mu\text{m}$  in diameter commonly are completely cemented, whereas larger pores are usually partially cemented.

In the biomicrites, acicular aragonite cement fringes intergranular pores and fills molluscan shell cavities. In most of the rocks, acicular cement appears to grow on a microcrystalline substrate (Fig. 5B). Although some of the microcrystalline cement/matrix may be

aragonitic (e.g., Shinn, 1973, p. 208), higher concentrations of magnesian calcite in these rocks (Table 1) suggest that the cement contains considerable amounts of magnesian calcite. During the development of the acicular aragonitic cement, microcrystalline particles are commonly trapped between the aragonite crystals (Fig. 5D). In some of the completely cemented intergranular pores, micritic (magnesian calcite?) particles accumulate along the contact between the various cement fringes.

### ORIGIN OF THE SUBMARINE HARDGROUNDS

Existing literature suggests few petrographic differences between intertidal and subtidal lithified sediments. Both beachrock and submarine limestone can have rim or matrix cements of either aragonite or magnesian calcite (Taylor & Illing, 1969; Bricker, 1971; Alexandersson, 1972). The degree of cementation in both beachrock and submarine limestone varies considerably and appears to be related to both age and porosity. Both types of rock tend to dip at angles coincident with local gradients. Often the only significant points of difference are the well-bedded nature of beachrock (gently dipping seawards), the presence of sub-tidal organisms within the rock (e.g., Macintyre *et al.*, 1975) or evidence of intertidal organisms and/or erosional features (such as phytokarst).

Present field and laboratory data are ambivalent as to the origin of the lithified sediments off Kuwait. The rocks are generally bioturbated and therefore lack bedding, suggesting sub-tidal lithification. However, many limestones are overlain by one meter or more of sediment: does this mean that the limestones are relic (e.g. beachrock), or does it mean that they are modern (subtidal) and have lithified under one metre or more of sediment? The deeper limestones appear to lie on a submarine terrace, possibly inferring formation during a prior lowstand of sea level. Otherwise, most data are inconclusive. Oolitic sands form in intertidal and very shallow subtidal conditions (Newell *et al.*, 1960; Milliman, 1974; Bathurst, 1975), but molluscs can grow in a wide variety of environments; thus an oolitic limestone could be intertidal (e.g. beachrock), but no such assumption can be made about a molluscan limestone without additional evidence.

Carbon-14 dates might help clarify the origin of the rocks. Young dates would indicate that the rocks formed at or near present water depths (submarine

lithification), whereas older dates might reflect lithification during a lower stand of sea level (intertidal?). Determining the age of lithification, however, is hampered by the presence of older carbonate grains, which give the rock a  $C^{14}$  age older than that of most of the grains or the cement. On the other hand, a strongly bored rock may contain fillings of younger sediment and cement, some of which might contain post-bomb  $C^{14}$ ; in this instance, the age of the rock may appear younger than it actually is. Where possible, we avoided secondary fillings when preparing the samples for dating. Moreover, with relatively young rocks (i.e. one half life or less) such as we are dealing with here, contamination with young  $C^{14}$  is less critical than it is in older rocks.

The rock samples analyzed came from water (plus sediment) depths ranging from 2 to 8 m below present-day low tide level. These rocks represent biosparite (ALB 38-1), biomicrite (Shar 34-14, 35-2), oosparite (ALB 25-1; 25-2), and oomicrite (ALB 39-1). Analyses were performed on bulk carbonate samples (constituents and cement). Carbon-14 results (Table 1) show that the biosparites and biomicrites have ages of 2070–3740 yr B.P., the oosparite have  $C^{14}$  age of 5260 and 6250 yr B.P., and the oomicrite has an age of 4350 yr B.P. In assessing these dates, we assume that except for unusual circumstances (e.g. methane cementation; Allen *et al.*, 1969), the cement within a limestone is either penecontemporaneous or younger than the constituent grains within the rock.

The biosparites and biomicrites come from water (plus sediment) depths of 2 to 8 m. Since sea level in the Arabian Gulf has remained more or less at present-day levels for the past 4000 to 5000 years (e.g. Taylor & Illing, 1969; Kassler, 1973; Shinn, 1973), the bulk ages of these rocks suggest they were lithified at or near present water depths, that is, subtidally. In fact, 2000 to 4000 years ago, sea level in the Arabian Gulf may have been 1–2 m higher than at present (Felber *et al.*, 1978), further supporting a subtidal origin for these rocks.

In contrast, the oosparite comes from a depth of 6 metres. At 5200 to 6500 yr B.P., sea level may have been 4 to 10 m lower than at present (Fairbridge, 1961; Curray, 1965; Milliman & Emery, 1968). Therefore, if the cement is penecontemporaneous with the grains, it may have lithified intertidally as beachrock or at shallow subtidal depths (1–3 m). However, we cannot rule out the possibility of lithification at a greater water depth: since the cement represents less than 20 percent of the rock, a more recent age for the cement (i.e. substantially younger



than 5260–6250 yr) could be masked by an older age for the ooids. Such an origin is evident for the oomicrite: the fact that its bulk age is significantly younger than the oosparite (4350 vs. 5260 and 6250 yr B.P.) suggests that the cement is younger, possibly penecontemporaneous. Clearly accelerator  $C^{14}$  dating (requiring only 8 mg of  $CaCO_3$ ) could actually date the age of the cement and perhaps future research will include this.

We conclude that the biosparites and biomicrites were lithified in water depths similar to today, 6 to 8 m beneath sea level; presumably the oomicrite lithified at similar depths. The probable importance of magnesian calcite in the microcrystalline cement of the oomicrite and biomicrite presumably reflects the nature of cementation rather than the water depth, since the biosparite (with an even younger  $C^{14}$  age) contains aragonitic cement. In contrast, the oosparite may have lithified as beachrock.

The wide range of dates plus varying petrography conflict with the preliminary field observations which suggested that a more or less continuous hard layer resulted from deposition and lithification of a time-transgressive sediment during rising Holocene sea level. Instead, the 'layer' appears to be discontinuous in composition, origin and age. Re-evaluating previous data from the Arabian Gulf, we find evidence to suggest different origins and ages for other submerged limestones. Shinn (1969), for instance, reported one limestone from a depth of 11–12 m, with a radiocarbon age of  $8390 \pm 260$  yr B.P. Given the admitted problem of bulk age versus time of lithification and the lack of a Holocene sea level curve for the Arabian Gulf, it is possible that this rock represents a submerged beachrock rather than a sediment lithified at present conditions.

Equally perplexing is the 1 to 8 m of unconsolidated sediment covering these submerged rocks. Although the possibility that lithification occurred within the sediment column (i.e., near or at present-day burial depths) cannot be ruled out, present consensus seems to suggest that shallow-water lithification occurs at or near the sea water–sea bed interface (e.g., Shinn, 1969; Milliman, 1974). If so, the minimal rates of sediment accumulation (assuming date of lithification equals bulk age of the limestones) have been 25 to 200 cm  $10^{-3}$  yr. More contemporaneous cementation, of course, would infer greater accumulation rates. If these high rates of accumulation are correct, then the source and transport paths of the sediment off Kuwait should be documented, as should the horizontal extent and continuity of the limestone layer(s).

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