Progressive Cementation in Pleistocene Carbonate Sediments Along the Coastal Area of Alexandria, Egypt

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ABSTRACT


One of the Pleistocene offshore carbonate rocky formations of Alexandria, the Miami Formation, was studied to trace the progressive sequence of cementation. Petrography, mineralogy and geochemistry of the collected samples were investigated by several techniques as thin sections, scanning electron microscopy (SEM), X-ray diffraction and atomic absorption spectrophotometry (AAS).

Calcite, aragonite, quartz and feldspar form the mineralogical constituents; high Mg-calcite was absent. A general increase in concentrations of Ca, Mg, Sr, Fe and Mn was observed from the topmost layers of the formation downwards. However, there is a limited application of the use of geochemical and mineralogical results as indicators of the progressive cementation. The common cement types are micrite, blocky sparry calcite and aragonite. The progressive sequence of cementation took place in the vadose, marine and mixed phreatic zone.

The precise age of the formation studied is uncertain from the results of the present study, and in the absence of reliable dating information. Earlier hypotheses connecting the offshore formations of Alexandria to one of the last interglacial bars are therefore questioned.

ADDITIONAL INDEX WORDS: Egypt, limestone, cementation, interglacial, Pleistocene, earthquakes, eustatic changes, offshore bars.

INTRODUCTION

The cementation of marine carbonates and their lithification take place in a variety of different depositional environments. Studies of carbonate cements provide visual gratification to carbonate petrographers, mineralogists and economic geologists (SCHNEIDERMANN & HARRIS, 1985).

The study of carbonate diagenesis also serves in the reconstruction of palaeoenvironmental sedimentary conditions. The Pleistocene carbonate deposits of the northern Egyptian littoral have been investigated by several authors (e.g. ZEUNER, 1950; SHUKRI, PHILIP, & SAID, 1956; BUTZER, 1960; EL-SHAZLY, SHATA, & FARAG, 1964; ISMAIL & SELIM, 1969). Interpretations of their origin and lithification were attempted by SELIM (1974) and SELIM & EL-BOUSEILY (1984) in the Salum and Alexandria regions, respectively.

ZEUNER (1950) proposed a sequence of bars and lagoons corresponding to some ten stages of Pleistocene Mediterranean transgressions. THIEDE (1978) recognized only that the Mediterranean coastlines had undergone some changes during the last glacial due to lowered sea levels.

The Alexandria region, the area of the present study, lies on a wide Pleistocene bar along the present shore of the Mediterranean, with a second one farther inland, both running in an E-W direction. Both sedimentary and tectonic influences governed the evolution of this zone.

Seawards, series of submerged offshore bars run in the same direction more or less parallel to the present shoreline of Alexandria (EL-WAKEEL & EL-SAYED, 1978). The former bars can thus be found anywhere from several meters below sea level to many meters above. These bars of Quaternary origin, are well developed as a result of the repeated violent earthquakes in the delta and around Alexandria during the last two millennia accompanied by the eustatic sea level changes during the same period (BUTZER, 1960).

One of these offshore bars of Alexandria was selected for the present study in order to trace...
progressive petrographic, mineralogical and geochemical changes. A limitation of the present work is the lack of any reliable dating or stratigraphic information regarding the offshore bars in the area.

Area of Study

The shoreline of Alexandria exhibits typical features of a young shoreline; it extends more or less straight with slight undulations forming small bays (Figure 1A). The area of study, Miami Bay (Figure 1B), is limited to the west by the promontory of Bir-Massoud, separating it from the Bir-Massoud Bay. A large island, Gabal El-Kor, is emerged at the northern side of the bay. The island is composed of about 10 m of indurated crossbedded calcareous sandstones (EL-HALABY, 1975). SELIM & EL-BOUSEILY (1984) defined these deposits as sandy pelloidal biosparite; they further defined the origin of this structure as interrupted weathered remnant parts of the “Main Monastirian”. Gabal El-Kor and its surrounding rocky formations were originally composed of coarse sand grains including remnants of mollusks and other bioclastics, and thus they are largely different from the other bars characterized by well-developed oolitic texture (SELIM, 1974; SELIM & EL-BOUSEILY, 1984).

A rocky outcrop west of Gabal El-Kor (Figures 1B and 2A, B) was selected for the present study. This formation reaches about 3 m above sea level, and is highly weathered and burrowed (Figure 2A). Similar coastal formations are well-known in other regions from the Mediterranean (GAVISH & FRIEDMAN, 1969).

MATERIALS AND METHODS

The various lithological units of the studied formation were examined in the field; stratification is almost invisible owing to the intensively eroded surface. However, samples were collected from the whole outcrop and as close as possible to the ill-defined bedding; the sampling intervals range from 30 to 50 cm (Figure 2B).

Thin sections were prepared from the samples and mineralogically examined after staining following the technique described by FRIEDMAN (1959). The fabric was observed, and a preliminary mineralogical study was checked in a quantitative manner by X-ray powder diffractometry PHILIPS PW 1050/75 goniometer using Ni-filtered Cu Kα radiation. A scanning electron microscope (JEOL JSM-35) was used to study the cement types. The method of ROBINSON (1980) was applied to determine Ca, Mg, Sr, Fe and Mn in the powdered samples. Measurements of the element concentrations were carried out by a UNICAM SP 90 Series 2A Atomic Absorption Spectrophotometer following the standard techniques.

RESULTS

Texture and Cements

These littoral and coastal dune sands were constituted mostly of marine bioclastics and detrital deposits, and then were diagenetically hardened by calcareous solutions. SELIM & EL-BOUSEILY (1984) defined them as sandy pelloidal biosparite or intrapelloidal sparite and biosparite. This formation is, however, devoid of ooid structures. The amount of cement varies widely from the topmost layers downwards to lower parts. This variation corresponds to the diagenetic processes affecting the area during the late Quaternary.

The study of the cements in the representative samples from the upper parts of the outcrop (Samples No. 1 & 2; Figure 2B) shows that the interparticle porespaces have been entirely cemented by blocky sparry cement (Figure 3A). This cement type is less abundant in sample No.3 (Figure 3B). Figure (4A) shows void-filling rhombic crystals (interpores). Altered Mg-calcite overlies the “probably” fresh water rhombic crystals; this cement type is clear in sample No.2 (Figure 4B). Boring by organisms is recorded in sample No.7 (Figure 4D), which represents the lowermost exposed area from the outcrop. Dissolution of cements occurs and crystal outlines are poorly defined as a consequence of leaching (Figure 4C). The abovementioned cement types and stages probably correspond to the vadose and mixed phreatic zone.

In the intertidal zone (sample No.8), marine cementation represents a later stage of diagenesis (Figure 3C), where micropar presents the first coating cement generation; this is followed by a second generation of blocky sparry calcite, and finally by aragonite cement generation (Figure 3C and Figure 5A). Aragonite needles are growing on calcite rhombs (Figure 5B).
These cement types are related to the marine mixed phreatic zone cementation.

The lower part of the formation which is generally covered by sea water and lies in the lower intertidal zone (sample No.9) shows intergranular marine cements. The cement shows a partly altered Mg-calcite (Figure 5C); the detailed structure of this cement type is shown in Figure 5D, where leaching features appear on the sharp-sided rhombic crystals.

Mineralogy

X-ray mineralogy reveals the presence of the following carbonate minerals: calcite, aragonite and low-Mg calcite; high Mg-calcite is
absent. Quartz and feldspars are also present (Figure 6). Similar mineralogical constituents were determined in the late glacial carbonates elsewhere in the Mediterranean (GAVISH & FRIEDMAN, 1969).

Aragonite is found in a nearly equal proportion to calcite in the studied formation. The relative abundance of the carbonate minerals in the different samples indicates the diagenetic sequence within the formation.

Geochemistry

GAVISH & FRIEDMAN (1969) mentioned that manganese, magnesium, strontium and iron have to be analysed because of their ability to substitute for calcium in the carbonate lattice, and their expected variability with mineralogical changes. The author has studied the hypersaline lagoon sediments from the Red Sea and found that magnesium and strontium are common elements in the metastable carbonate minerals, while strontium is common in aragonite; these findings agree with those of GAVISH & FRIEDMAN (1969).

Table (1) depicts the concentrations of CaO, MgO, SrO, Fe₂O₃ and MnO in the studied samples. In general, the concentrations of the various chemical types increase from the top layers of the studied formation towards the bottom (Table 1). This result is attributed to the weathering and leaching of some elements from the upper parts. The relatively high strontium concentration (average 5990 ppm) indicates the presence of marine skeletal remains, rich in strontium, through the whole formation; this finding may explain the dominance of aragonite despite the absence of ooids. The bioclastics are mostly coralline algae, calcareous algae and some mollusks.

Calcium and magnesium are highly correlated, where the coefficient of correlation (r) equal to +0.82. Manganese and strontium are also highly correlated (r = +0.71). Strontium is correlated with both calcium and magnesium (r = +0.57 and +0.66, respectively); while calcium only is moderately correlated with manganese (r = +0.58). On the other hand, iron shows a slight negative correlation with Mn, Sr, Ca and Mg.

Although the use of minor elements as geochemical indicators of diagenetic trends in carbonate sediments was noted by many authors (e.g. FRIEDMAN, 1964; HARRIS & MATTHEWS, 1968; SELIM, 1974), these indicators are not largely applicable to the present study except for the vertical variation in the chemical concentrations.

Figure 3. (A) Microsparry cement in micritic crust (sample No. 1). (B) Microsparry cement in micritic crust (sample No. 2). (C) Blocky microsparry calcite and aragonite cements (sample No. 8). (Facing page)
DISCUSSION AND CONCLUSIONS

The Quaternary carbonate sediments of the coastal area of Alexandria underwent several diagenetic processes. The progressive cementation in these sediments may be categorized in three stages.

Stage 1
The early stage of cementation occurred in a vadose, active phreatic zone. The cement is mostly intergranular between bioclastics and detrital fragments; the cementation process was accompanied by boring of organisms and the formation of micritic crust. Vadose cementation during this stage is proved by the formation of blocky cement of low-Mg calcite forming a micrite envelope; this cement type occurs at grain contacts as a consequence of the migration of supersaturated carbonate waters between the pores. LONGMAN (1980) describes

Figure 4. (A) SEM showing void filling rhombic crystals (interpores) in sample No 1. Crystal increases in size away from the substrate freshwater cement. (B) SEM showing altered Mg-calcite (bottom), fresh water rhombic crystals on top (sample No. 3). (C) SEM showing the dissolution of cements and crystal outlines (sample No. 7). (D) SEM presenting the boring by biological activity (sample No. 7).
Figure 5. (A) SEM showing blocky microsparry calcite and aragonite cements growing on quartz surface (sample No. 8). (B) SEM showing aragonite needles growing on calcite rhombs (sample No. 8). (C) SEM showing intergranular marine cement, partly altered Mg-calcite (sample No. 9), and (D) SEM showing the leaching features on the steep sides of the rhombs calcitic crystals (sample No. 9).
the process by which such types of cement occurred. Samples above the present high tide line are representative of this stage of cementation. The types of grains are pelleted and intrasparite, with no indication of any ooids or coatings. Formation of similar structure which has the same compositional constituents, despite a difference in elevation, is the oldest
Tyrrhenian limestone bar in the Salum area; concentric coatings are absent and most of the allochems of this structure developed micritic envelops of calcite (SELIM, 1974).

Stage 2

The second stage of cementation occurred during a marine regression and the subaerial exposure of the Quaternary deposits in the area. Karstification started during this stage which caused the dissolution of carbonates. It is assumed that the Mediterranean environment during this stage became infavourable for further carbonate deposition. The limestone which had been in the phreatic marine zone earlier started to become leached out, reflecting the instability of the Mg-calcite.

A further transgression occurred and the sea reached the lower part of the outcrop; this part is always affected by the splash of sea water in the intertidal zone. Aragonite cements are formed and have the needle shaped appearance; they are growing on previously formed Mg-calcite rhombs. The whole cementation sequence during this stage is presented by the first micritic envelope cement generation. The envelope is partly dissolved and Mg-calcite is precipitated. Aragonite presents the latest cement generation during this stage.

HARRIS et al. (1985) claimed that cementation in the intertidal zone occurs along beaches where a decrease in CO₂ occurs by degassing, due to tidal pumping, and may form beachrock. The cements are micritic, bladed or fibrous with variable mineralogy. Mg-calcite and aragonite cements appear related to marine water tables; calcite cement in contrast seem related to an influx of fresh water from and adjacent land area into the intertidal zone. They added that the diagenetic overprint is surprisingly uniform throughout the vadose and phreatic zone of Pleistocene limestones from the Barbados, the Bahamas and south Florida.

Stage 3

The last stage of cementation probably occurred below the low-tide line and in a mixed marine phreatic zone. Calcium carbonate is precipitated during this stage mainly in the form of blocky calcite cement. The common type of cement is the calcite palisade with indication of the presence of euhedral gypsum in micrite and microsparite calcite; halite is also shown during this stage.

The high strontium concentration anomaly does not correspond to ooid structure or aragonitic cements; it is primarily of biogenic origin or related to the process of vadose cementation. GAVISH & FRIEDMAN (1969) mentioned that the waters responsible for the formation of calcite cement in the carbonate rocks of Israel, were high in the strontium since they were derived from aragonitic dissolution. Two types of freshwater calcites are dominant, reflecting the origin of the water itself; these are the high-strontium calcites and the low-strontium calcites.

Origin of the Studied Carbonate Rocky Formation

The origin of the studied formation was previously defined as Quaternary by EL-HALABY (1975). However, this outcrop and similar pelleted and intrasparite limestones comprising the headlands, wave-cut benches and offshore islands near Alexandria are mostly detached parts of the second limestone ridge so-called “Main Monastirian”(SELIM & EL-BOUSEILY, 1984). The origin of these formations as “Main Monastirian” is debatable, since the studied formation is lacking any ooid structures, which is one of the main characteristic features of the Main and Late Monastirian formations (SELIM, 1974; SELIM & EL-BOUSEILY, 1984). It should be mentioned that the term “Monas-
tirian” was abolished by resolution of the INQUA Congress, Madrid 1957 (BUTZER, 1960). However, it is commonly used to define Late Pleistocene stratigraphy in Egypt.

The fluctuations in the level of the Mediterranean Sea have been important factors in the construction of the ancient shorelines of Egypt. The location of the many previous shorelines is shown by wave-cut terraces, sea cliffs, beach-rocks and dune rocks. Quaternary sea level history in the Mediterranean, particularly with respect to elevation and age precision during the last 10,000 years is still poorly understood.

Regarding the lithology, cementation and diagenesis of the studied formation, it seems likely that it corresponds to a detached offshore barrier formed in one of the local transgressions of the Mediterranean during the Late Pleistocene.

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LITERATURE CITED


Formation Alexandrias an einer der letzte intereiszeitlichen Sperre, sind dafür angezweifelt.—Stephen A. Murdock, Charlottesville, Virginia, USA

Pour reconstituer la progression des séquences de cimentation, étudie la formation de Miami, située au large d'Alexandrie et constituée de roches carbonatées d'âge pléistocène. Les constituants minéralogiques sont: calcite, aragonite, quartz et feldspath (pas de Mg-calcite). Les concentrations en Ca, Mg, Sr, Fe et Mn augmentent depuis la couche superficielle vers les plus profondes, mais l'utilisation de ces résultats comme indicateurs d'une cimentation progressive demeure limitée. Les types de ciment sont la micrite, la calcite (blocs de spath) et l'aragonite. La cimentation progressive s'effectue en zone de mélange des eaux phréatiques et marines. Les résultats de l'étude ne permettent pas de donner l'âge précis des formations étudiées. On doit interroger les hypothèses antérieures qui relèvent les formations au large d'Alexandrie à une des dernières barres glaciaires.—Catherine Bres- solier, EPHE, Montrouge, France.

Una de las formaciones rocosas marinas de carbonatos pleistocenos en Alejandria, la Formación Miami, ha sido estudiada con el objeto de seguir la evolución de su secuencia progresiva de cementación. Las muestras recogidas han sido investigadas petrográficamente, mineralógicamente y geoquimicamente sobre secciones de pequeño espesor, mediante diversas técnicas: SEM, rayos X y AAS. Los constituyentes minerales están formados por calcita, aragonita, cuarzo y feldespato, observándose ausencia de calcita con alto contenido de magnesio. Se observó un aumento general en las concentraciones de Ca, Mg, Sr, Fe y Mn al descender desde las capas más altas. Sin embargo, la aplacación de los resultados geoquímicos y mineralógicos como indicadores de la progresiva cementación es limitada. Los tipos comunes de cemento son micrita, calcita espática en masa y aragonito. La secuencia de cementación pregresiva tuvo lugar en la zona poco profunda, marina e interfreatática. La edad exacta de la formación es incierta, siguiendo los resultados del presente estudio, y en ausencia de información temporal fiable. Las primeras hipótesis que relacionaban las formaciones marinas de Alejandria con una de las últimas barras interglaciares son cuestionadas por ello.—Department of Water Sciences, University of Santander, Santander, Spain