Qatar Univ. Sci. J. (1994), 14 (1): 146-152

DIAGENESIS OF THE MIDDLE EOCENE "NUMMULITE BANK" OF THE GIZA PYRAMIDS PLATEAU, EGYPT: PETROLOGIC AND $^{18}O/^{16}O$ EVIDENCE

By

HANAFY HOLAIL
Department of Geology, Faculty of Science, University of Qatar, Doha, Qatar

تغيرات ما بعد الترسيب « ضفة النيموليت » لعصر الأيوسين الأوسط في هضبة أهرامات الجيزة بمصر : أدلة بتروجغرافية ونظائرية

حنفي هليل

تعرضت « ضفة النيموليت » التابعة لعصر الأيوسين الأوسط في هضبة أهرامات الجيزة بمصر إلى تغيرات كبيرة بعد ترسبها . وتتضمن الدراسة الحالية عدة جوانب عن البتروجرافيا ، الوميض الكاثودي ، تحليل نظائري للأكسجين والكربون حيث وفرت نتائجها معلومات عن مصدر وطبيعة سوائل ما بعد الترسيب وكذلك مدى وفترة مراحل التغيرات التي حدثت بعد الترسيب .

وقد أوضحت المظاهر البتروجرافية والخواص الجيوكيميائية أن سوائل ما بعد الترسيب قد تدرجت من بحرية إلى جوية ، فقد تغير التركيب النظائري لأرضية الصخور دقيقة الحبيبات من تركيب بحري أولي (-٢,٩ أكسجين -١٨ ، +٠,٥ كربون -١٣) عبر اتجاهات معينة تعكس تغيرات بسيطة بعد الترسيب بفعل المياه بين الحبيبات. أما حبيبات النيموليت فقد أوضحت تركيباً نظائرياً يتراوح بين التركيب البحري في هضبة أهرامات الجيزة (-١,٨ أكسجين -١٨ ، +١,٩ كربون -١٣) إلى تركيب مياه عذبة (-١٠,٦ أكسجين -١٨ ، -٢,٧ كربون -١٣) في منطقة الفيوم والواحات البحرية . وقد تلى هذا التغير الأولي في أرضية الصخر إحلال دولوميتي لأرضية الحجر الجيري وحبيبات النيموليت ، كما ترسبت بلورات كاملة الأوجه من الدولوميت فيما بين فراغات الحبيبات ومساميتها وذلك بعد الإحلال الدولوميتي ، وتتراوح نسب نظير الأكسجين في الدولوميت الإحلالي بين -٠,٦ إلى +١,٢ جزء في الألف بينما نسب نظير الكربون تتراوح بين +٠,٨ و+٣,٠ جزء في الألف . وتشير هذه النسب إلى أن عملية الدلمته قد تمت في مياه مختلطة سادت فيها المياه البحرية وتحت درجة حرارة منخفضة . وفي المرحلة الختامية ترسب كالسيت كتلي لاحم وأوضحت النسب النظائرية للأكسجين والكربون (-٩,٦ أكسجين -١٨ ، -٤,٢ كربون -١٣) به أنه قد ترسب في نطاق للمياه العذبة .

Key Words: Nummulites, Dolomites, Isotopes, Eocene, Giza pyramids plateau.

ABSTRACT

The Middle Eocene "nummulite bank" of the Giza Pyramids Plateau has been extensively altered diagenetically. The result of a study involving petrography, cathodoluminescence, and $^{18}O/^{16}O$ and $^{13}C/^{12}C$ data, provide information about origin and nature of the diagenetic fluids, as well as magnitude and timing of the diagenetic stages.

A sequence of petrologic features coupled with the geochemical characters suggests a progression of diagenetic fluids from marine to meteoric. The micrite rock matrix isotopic compositions depart from an initial marine composition (-2.9‰ $\delta^{18}O$ and +0.5‰ $\delta^{13}C$ PDB) along covariant trends that reflect slight alteration by diagenetic pore waters. The nummulite grains show isotopic composition close to the isotopic composition of marine carbonates (-1.8‰ $\delta^{18}O$ and + 1.9‰ $\delta^{13}C$ PDB). The early diagenetic alteration of the rock matrix was followed by partial to complete dolomitization of the limestone matrix and nummulite grains. The oxygen isotopic ratios of the matrix-replacive dolomites range from -0.6 to +1.2‰ PDB, whereas the carbon isotopic ratios range from +0.8 to +3.0‰ PDB. These isotopic ratios suggest that dolomitization occurred in marine-dominated mixed waters at low temperatures. The final diagenetic phase involve the precipitation of a blocky calcite spar cements (ave. -9.6‰ $\delta^{18}O$ and -4.2‰ $\delta^{13}C$ PDB).

INTRODUCTION

Studies of the processes and products of diagenesis in carbonate rocks have proven an effective tool in paleoenvironmental reconstructions and interpretations of diagenetic sequences. The oxygen and carbon isotope technique has been utilized extensively to trace the source of, and to constrain the timing of, the generation of diagenetic carbonate phases.

A key factor needed for the use of stable isotope geochemistry in dolomites, and dolomitization process, is an understanding of what isotopes can tell us about the original composition as well as the later diagenetic fluids which modified the original compositions [1-3]. Diagenetic modification of the early dolomites complicates evaluation of ancient dolomites because the modification could have occurred in different environments from those in which the dolomites initially formed or the same [4]. Moreover, many models of dolomitization process have been proposed, but no single criterion allows a geologist to place an ancient dolomite into a single dolomitization model [1, 5, 6].

This paper presents a detailed petrographic and isotopic compositional study of the Middle Eocene carbonate succession from the Giza Pyramids Plateau, Egypt. The purpose of this study is to integrate the existing geological and stratigraphic data into a comprehensive petrographic and isotope geochemical characterization which will improve our understanding of the diagenetic history of Middle Eocene carbonates.

GEOLOGICAL SETTING

The study area is located west of Cairo, in the northeastern part of the Western Desert, Egypt (Fig. 1), which is a basin containing up to 600 m of combined Mesozoic and Tertiary sediments. The stratigraphic and sedimentological framework for the Middle Eocene rocks of the Abu Roash area has been reviewed in Aigner [7-9].

During Middle Eocene time, the study area was a carbonate platform on which nummulite packstones and wackestones of the Mokattam Formation accumulated. The depositional facies of these carbonates is characterized by a single shallowing-upward sequence (Fig.1). Aigner [10] recognized that the nummulites have been found to occur in three facies associations: 1- "nummulite bank" facies; 2- "shoal-bank" facies; and 3- "back-bank" facies. Nummulite banks at Giza Pyramids Plateau are composed of nummulite packstones up to 30 m thick. They are highly bioturbated throughout, and contain a variety of sedimentary structures such as erosion surfaces and both "contact" and "isolate" imbrications.

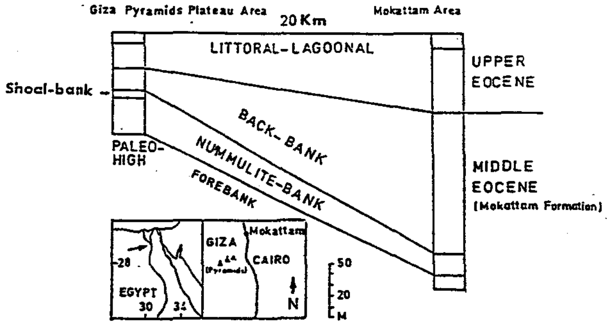

Fig. 1: Location map of the study Giza Pyramids sequence showing the Eocene facies around Cairo, Egypt. After Aigner [8].

RESEARCH METHODS

Limestone and dolomite samples for this study were collected from the Middle Eocene carbonate which exposed at the Giza Pyramids Plateau, north of Egypt (Fig. 1). Rock samples and individual nummulite grains were studied both in hand specimen and polished thin section using conventional petrographic, staining with Alizarin red-S and potassium ferricyanide [11] and SEM techniques. Cathodoluminescent (CL) petrography was used to determine crystal zonation growth in dolomite and calcite and to evaluate preservation of nummulite skeletons. CL analysis was conducted on Nuclide ELM-2B Luminoscope at 16 Kv and 0.5 Ma, with a 5 mm spot size.

Carbonate mineralogy was determined by means of powder X-ray diffractometry (XRD, using Cu Kα). The mole percentage of $MgCO_3$ was determined by XRD using a silicon standard and the calibration curves of Goldsmith & Graf [12].

Microsamples of individual diagenetic phases for isotopic analysis were milled from polished rock chips and nummulite grains using a microscope-mounted drill assembly. All samples consisted of a single phase and other phases did not affect the isotopic compositions. All powdered samples were roasted in vacuo at 380°C for one hour to remove volatile contaminations. Samples were reacted at 73°C with 3 drops of anhydrous phosphoric acid in individual reaction vessels of an on-line, automated carbonate reaction device (Kiel Device) coupled to a Finnigan-MAT 251 mass spectrometer. Isotopic ratios were corrected for ^{17}O contribution as described by Craig [13] and are reported in per-mil relative to the PDB standard. A correction for phosphoric acid fractionation was applied to dolomite analyses. Precision on lab standard powders was better than 0.1‰ for both ^{18}O and ^{13}C isotope compositions.

RESULTS AND DISCUSSIONS

Petrography

The Middle Eocene succession largely consists of fossil packstones and wackestones containing an open-marine biota. There is no evidence of evaporite minerals or their former presence. The fossils in this succession consist of nummulite grains mainly of the *Nummulites gizehenesis* group. Based on sizes, Aigner [10] classified nummulites into small "A-forms" and larger "B-forms". The smaller nummulite forms dominate over the larger forms (Fig. 2). Other fossils are relatively sparse and include mostly gastropods and bivalves. The shells have often been broken as a result of compaction (Fig. 2D).

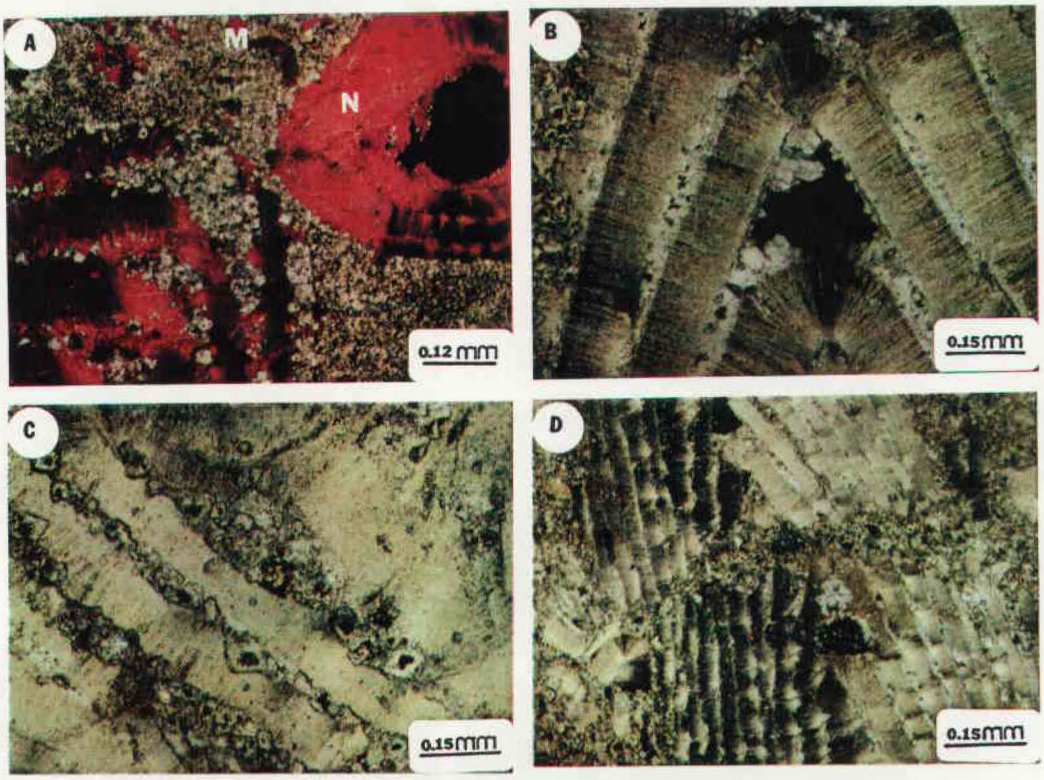

Fig. 2: Crossed nichols photomicrographs of Middle Eocene "nummulite Bank" carbonate succession. A. Nummulite grains (N) are partially dissolved and dolomitized. Note the relict of the original limestone matrix (M) in the dolomite matrix. B. Nummulite shell shows thick wall. The intraparticle pores were partially filled by calcite cement. C. Dolomite selectively replacing nummulite shell. D. Broken nummulite grain.

Nummulites shell structures are generally well-preserved (Figs. 2B and C). The shells showing thick walls which have a radial fibrous structure in which the original LMC fibers are aligned at right angles to the shell wall (Figs. 2B and 3A). Under cathodoluminescence (CL) the nummulite shells show irregular variation in luminescence, ranging from very luminescent to non-luminescent (Fig. 4B).

Replacive dolomite occurs in the Middle Eocene succession, partially- to completely replacing limestone matrix, and selectively replacing nummulite grains. A volumetrically significant proportion of these dolomites occurs as matrix-replacive dolomites. The abundance of dolomite, therefore, is primarily a function of original limestone matrix. The non-ferroan dolomite rhombs of nummulite grains are euhedral to subhedral and typically are 40 to 150 mm in size. Inclusion density is variable and no zoning was observed in individual rhombs (Fig. 2C). The presence of dark rhomb cores and clear rims is very characteristic. This phenomenon is commonly interpreted as resulting from dolomites that replace precursor calcitic sediments rather than precursor aragonite sediments [14]. Moreover, the presence of such textures might suggest dolomite precipitation from progressively less saline water, resulting from mixing of freshwater and seawater [5]. Under cathodoluminescence (CL) the inclusion-free rim of dolomite rhombs shows fine-scale luminescent zoning, while the cloudy core is non-luminescent (Fig. 4). The rim zonation consists of non-luminescent, dull red and bright red concentric bands that range in thickness from few micrometers to tens of micrometers (Figs. 4B and C).

Nummulite grains are partially replaced by medium-grained, non-ferroan dolomite rhombs (Fig. 2C). Relics of the original LMC nummulite are concentrated near dolomite cores (Figs. 3C and D). Dolomite rhombs have cloudy cores and clear rims (Fig. 2C). Under CL the rhombs exhibit sharply defined zonation (Fig. 4C). The luminescence varies from red to non-luminescent within a single rhomb, and zone width also varies. The non-luminescent cores show irregular luminescent patches (Fig. 4C). In general, CL zonation is usually

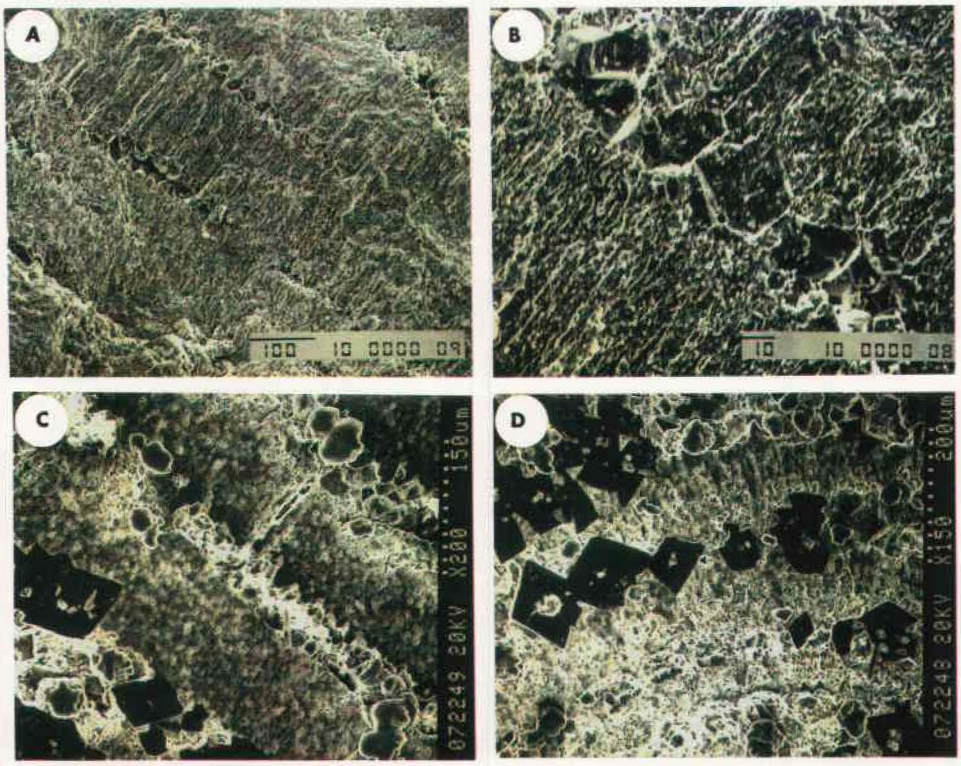

Fig. 3: SEM micrographs of fractured and polished surfaces of nummulite grains. A. Thick wall of original LMC radial fibrous structure. B. Enlargement of the radial fibrous structure showing calcite cement. C and D. Distribution of the replacing dolomite rhombs (black) and calcite cement in the nummulite grains.

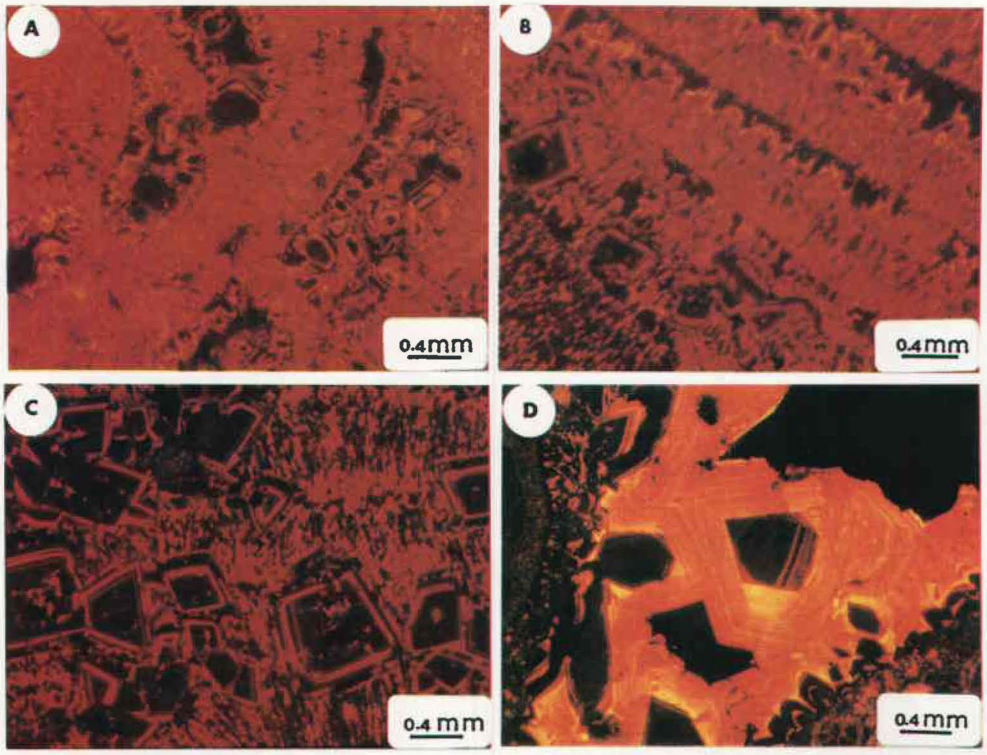

Fig. 4: Photomicrographs showing cathodoluminescent characteristics of nummulites. A. Calcite crystals filled the intraparticle pores. B. Partial dissolution of nummulite and precipitation of calcite cement. C. Enlargement of dolomite rhombs which selectively replacing nummulite grains. D. Late-stage sparry calcite cement.

interpreted to result from dolomite precipitation in fluids of fluctuating redox potential [15].

Finally, medium- to coarse-crystalline, equant calcite spars occur as cement in secondary pores. They lack typical petrographic characteristics of shallow marine cements, such as columnar or prismatic crystal morphologies and microdolomite inclusions. Calcite spar post-dates dolomitization. Under CL this calcite cement exhibits sharply luminescent zones (Fig. 4D), which suggests a meteoric origin for the calcite cement.

Mineralogy

X-ray diffraction analyses of samples taken from the matrix of the Middle Eocene succession indicate that dolomite is the major mineral phase present with minor original LMC matrix present. The dolomites are near-stoichiometric, with a well-ordered crystalline structure.

Oxygen-carbon isotopic compositions

Nummulite grains and limestone matrix: The texturally well-preserved non-dolomitic nummulite grains from the Giza Pyramids succession were originally calcitic and have $\delta^{18}O$ values range from -0.8 to -2.1‰ PDB and $\delta^{13}C$ values range from +0.4 to +2.8‰ PDB (Fig. 5). In the original limestone, $\delta^{18}O$ values range from -2.0 to -3.6‰ PDB, and $\delta^{13}C$ values range from -0.5 to 2.0‰ PDB (Fig.5). Average $\delta^{18}O$ in the nummulite grains is 1.1‰ higher than that of the limestone matrix and differences in $\delta^{13}C$ between nummulite grains and the limestone matrix are less distinct (Fig. 5). The nummulite grains and the limestone matrix samples appear to preserve a primary $\delta^{13}C$ signature. The relative depletion of $\delta^{18}O$ values of the limestone matrix suggests some degree of diagenetic alteration of the matrix under the influence of ^{18}O-depleted pore-waters.

In order to evaluate the degree of diagenetic alteration of the Middle Eocene rocks, it is necessary to estimate isotopic composition of marine carbonate during Eocene time. In general, the heaviest $\delta^{18}O$ and $\delta^{13}C$ values of nummulite grains may approximate such a composition (Fig. 5). These isotopic values are similar to the values of $\delta^{18}O$ and $\delta^{13}C$ for modern shallow seawater carbonate [15] and can be used to estimate the isotopic composition of the Eocene marine carbonates. Moreover, $\delta^{18}O$ values of these nummulite grains (-0.8 to -2.1‰ PDB) do not show much depletion in ^{18}O relative to estimates for Eocene marine carbonates ($\delta^{18}O \approx -1.0$ to -2.0‰ PDB; [16, 17]).

Dolomites: Oxygen isotopes of the matrix-replacive dolomites ($\delta^{18}O \approx -0.6$ to 1.2‰ PDB) are significantly enriched, and carbon isotopes ($\delta^{13}C \approx 0.8$ to 3.0‰ PDB) are similar to the marine Eocene values (Fig. 5). Heavy oxygen is characteristic of neither freshwater nor high temperature dolomites [1, 6, 18]. Both of these would be lighter, not heavier, than the marine values. Heavy oxygen occurs when there is either marine or significant evaporitic water involved in dolomitization [19, 20]. Evidence for evaporitic influence on the study of Middle Eocene succession has not been observed.

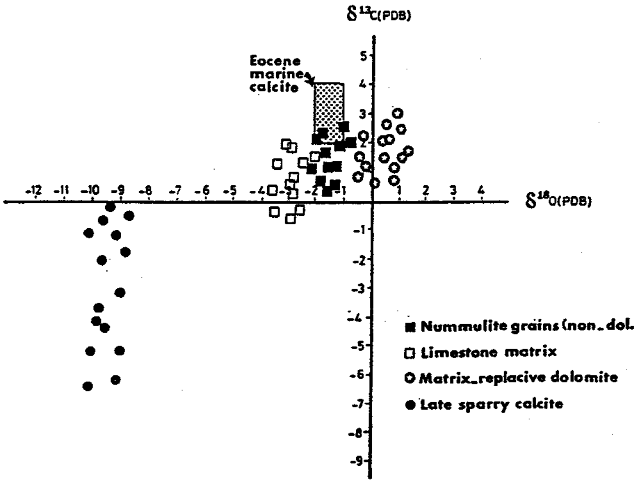

Fig. 5: Carbon vs. oxygen stable isotope compositions for all carbonate components of the Middle Eocene succession.

In this study, the $\delta^{18}O$ compositions of the matrix-replacive dolomite fall between values of dolomite expected if precipitation had been from these precipitating the modern evaporitic dolomites ($\delta^{18}0 \approx 3.5$ to 7.5‰ PDB, [4, 19]) and Eocene marine carbonates. Recrystallization to the less calcic, well-ordered compositions of ancient dolomites could alter isotopic compositions to those of the fluid-phase in which recrystallization occurred [1, 2, 3, 21]. The most distinctive features of the isotopic data in Figure 6 is the enriched $\delta^{18}O$ values of the Middle Eocene dolomites relative to values of the Middle Eocene mixing-zone dolomites from the Bahariya Oasis, Egypt [22]. Meanwhile, These values are depleted relative to the $\delta^{18}O$ values of the Eocene mixing-zone dolomites from Florida, U.S.A. [23] and the Eocene seawater dolomites from Enewetak Atoll [20].

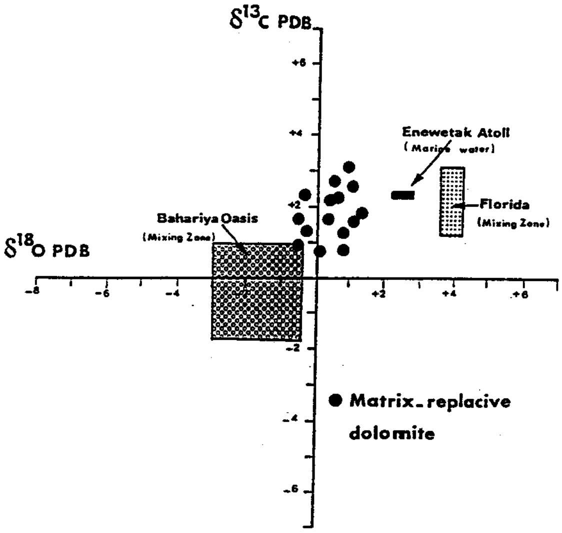

Fig. 6: Carbon vs. oxygen stable isotope compositions for Middle Eocene matrix-replacive dolomites analyzed in this study (solid circles) and the Eocene dolomites interpreted to have a mixing-zone origin from Baharyia Oasis, Egypt and from Florida, U.S.A. (Land et al., 1975; and Randazzo and Cook, 1987). Normal seawater Eocene dolomites are also shown (Saller, 1984).

Late calcite cements: Isotopic data can be used to supplement petrographic interpretation of the origin of the late calcite cements. These calcite spars have highly depleted isotopic signatures and are far removed from the isotopic compositions of marine-derived components. The isotopic compositions show distinctive depletion of ^{18}O and ^{13}C relative to the isotopic compositions of other carbonate components of the Middle Eocene succession (Fig. 5). The wide range of the $\delta^{13}C$ values (from -0.1 to -6.1‰ PDB) observed for these calcite spars may simply reflect precipitation from fluids which have undergone different degrees of water/rock interaction [24]. The greatly depleted ^{13}C values probably reflect the addition of isotopically light soil-gas CO_2 [25] and an open system was developed during the formation of these calcite spars.

The precipitation of calcite spars with distinctive low ^{18}O results from the involvement of isotopically light fluids (freshwater), from formation at elevated temperatures, or a combination of both factors [26]. Thermal fractionation is unlikely to have caused these depleted $\delta^{18}O$ values (about -10.0‰ PDB) which could require precipitation temperature of more than 75°C. Such elevated temperatures are not consistent with the known burial history of the Middle Eocene succession of the Giza Pyramids [27]. Therefore, the depleted ^{18}O content suggests fairly low temperatures of formation consistent with freshwaters origin of these calcite spars.

Paleotemperatures: The $\delta^{18}O$ values of the nummulite grains is not only related to the oxygen ratio of the seawater but also to its formation temperature. The ambient seawater temperature during the formation of nummulite grains can be calculated using the $\delta^{18}O$ composition of the texturally well-preserved nummulites that precipitated calcitic shells in isotopic equilibrium with the surrounding water and the following equation:

$$T^{o}C = 16.9 - 4.2(\delta^{18}O_c - \delta^{18}O_w) + (\delta^{18}O_c - \delta^{18}O_w)^2$$

where the δc is the $^{18}O/^{16}O$ of the well-preserved nummulite grains (PDB) and δw is $^{18}O/^{16}O$ of the seawater (SMOW), which is assumed to be 0‰ [28]. Paleothermometry yield temperatures of 21°C to 26°C of formation of these nummulite grains. Therefore, the oxygen isotope characteristics of the Middle Eocene nummulite grains are consistent with precipitation originally from a relatively warm marine fluids.

POROSITY AND DIAGENETIC HISTORY

Porosity in the Middle Eocene succession in the study area varies and is a function of diagenetic overprint, which in turn is a function of depositional environment. Pores include interparticle and intraparticle primary spaces (Figs. 2A and B), molds of leached nummulite grains, and intercrystal voids between dolomite rhombs (Fig. 2A). Although the primary porosity still exists, the vast majority of pore spaces have originated as secondary porosity. Diagenetic events that have controlled porosity development are (1) post-depositional leaching of some nummulite grains, and (2) complete to partial dolomitization of matrix and nummulite grains (Fig. 4). Although both moldic porosity and dolomitization are a result of diagenesis in mixing-zone, the solution pathways allowing diagenetic fluids to flow through the study succession were first created at the time of deposition. Therefore, diagenetic stages, are in large part controlled by the porosity trends in the original setting of the Middle Eocene rocks.

Three diagenetic stages are recognized in the study of Middle Eocene succession: marine-phreatic, mixing-zone, and shallow-meteoric. The marine-phreatic stage, affected the sediment-water interface to a meter or so below the surface. Mixing-zone dolomitization had produced good intercrystalline porosity and was the dominant process at the mixing-zone stage. A mixing-zone model best explains the distribution of dolomite in the studied succession. The necessary Mg is supplied by seawater, which is considered as the primary agent of massive dolomitization [1 & 28]. The proposed shallow dolomitization by mixing waters is consistent with (1) the selective dolomitization of nummulite grains, (2) replacement of the micrite matrix and supply of Mg to the site of dolomitization, and (3) oxygen isotope values that have been depleted with respect to $\delta^{18}O$ values of modern evaporite dolomites and enriched relative to $\delta^{18}O$ values of the Eocene marine carbonates.

CONCLUSIONS

Isotopic composition of the texturally well-preserved nummulite grains from the Giza Pyramids succession was examined to estimate the initial isotopic composition of the Eocene marine carbonates. These data suggest that Eocene seawater was isotopically similar in oxygen and carbon to the modern seawater.

Integration of dolomite distribution, timing, petrographic and isotopic characteristics suggest that dolomite formed in seawater-freshwater mixing environment and the Mg was mainly derived from seawater. The distribution pattern of the carbonate minerals through the studied succession indicates that dolomitization process had been affected by fluctuation in the mixed-water zone caused by rising sea level and permeability controlled flow patterns of dolomitizing fluids. Dolomitization and diagenetic leaching enhanced original depositional porosity. Late-stage sparry calcite cements occluded some of the early depositional and diagenetic porosity.

AKNOWLEDGEMENTS

I am deeply grateful for the many suggestions, interpretations, points of guidance, and cooperation provided by Drs. A. Selim, A. El Bouseily, M. Abdel Kireem, Alexandria University, Egypt. Drs. K.C. Lohmann, B. Wilkinson, The University of Michigan, U.S.A.

REFERENCES

[1] **Land, L.S., 1985.** The origin of massive dolomite. Jour. Geol. Education, 33: 112-125.

[2] **Gao, G.** and **L.S. Land, 1991.** Early Ordovician Cool Creek dolomite, Middle Arbuckle Group, Slick Hills, SW Oklahoma, U.S.A.: origin and modification. Jour. Sed. Petrology, 61:161-173.

[3] **Mazzullo, S.J., 1992.** Geochemical and neomorphic alteration of dolomite: a review. Carbonates and Evaporites, 6: 21-37.

[4] **Gregg, J.M., S. A. Howard, and S.J. Mazzullo, 1992.** Early diagenetic recrystallization of Holocene (<3000 years old) peritidal dolomites, Ambergris Cay, Belize. Sedimentology, 39: 143-160.

[5] **Morrow, D.W., 1982.** Diagenesis II, dolomite - part II: dolomitization models and ancient dolostones. Geoscience Canada, 9: 95-107.

[6] **Hardie, L.A., 1987.** Dolomitization: A critical view of some current views. Jour. Sed. Petrology, 57: 166-183.

[7] **Aigner, T., 1982.** Event-stratification in nummulite accumulations and in shell beds from the Eocene of Egypt, In: Einsele, G. and Seilacher, A. (eds.), Cyclic and event stratification. Berlin, Springer-Verlag, 248-262.

[8] **Aigner, T., 1985.** Biofabric as dynamic indicators in nummulite accumulations. Jour. Sed. Petrology, 55: 131-134.

[9] **Strougo, A., 1985.** Eocene stratigraphy of Giza Pyramids Plateau. Middle East Res. Cent. Ain Shams Univ., Egypt, 5: 79-99.

[10] **Aigner, T., 1983.** Facies and origin of nummulitic buildups: an example from the Giza Pyramids Plateau (Middle Eocene, Egypt): Neues Jahrb. Geol. Palaont. Abh., 166: 347-368.

[11] **Dickson, J.A.D., 1966.** Carbonate identification and genesis as revealed by staining. Jour. Sed. Petrology, 36: 491-505.

[12] **Goldsmith, J.** and **D. Graf, 1958.** Relation between lattice constraints and composition of the Ca-Mg carbonates. Am. Miner., 43: 84-101.

[13] **Craig, H., 1957.** Isotopic standards for carbon and oxygen and correction factors for mass spectrometric analyses of carbon dioxide. Geochim. Cosmochim. Acta, 12: 133-149.

[14] **Sibley, D.H., 1982.** The origin of common dolomite fabrics: clues from the Pliocene. Jour. Sed. Petrology, 52: 1087-1100.

[15] **Frank, J., A. Carpenter** and **T. Oglesby, 1982.** Cathodoluminescence and composition of calcite cement in the Taum Sauk Limestone (Upper Cambrian), southeast Missouri. Jour. Sed. Petrology, 52: 631-638.

[16] **Kropinck, P.M., 1985.** The distribution of ^{13}C of CO_2 in the world oceans: Deep-Sea Research, 32: 57-84.

[17] **Hudson, J.D.,** and **T.F. Anderson, 1989.** Ocean temperatures and isotopic compositions through time. Royal Society of Edinburgh Transactions, Earth Sciences, 80: 183-192.

[18] **Machel, H. and E.W. Mountjoy, 1986.** Chemistry and environments of dolomitization: A reappraisal. Earth Sci. Rev., 23: 175-222.

[19] **Mckenzie, J.A., 1981.** Holocene dolomitization of calcium carbonate sediments from the coastal sabkhas of Abu Dhabi, U.A.E.: a stable isotope study. Jour. Geology, 89: 185-198.

[20] **Saller, A.H., 1984.** Petrologic and geochemical constraints on the origin of subsurface dolomite, Enewetak Atoll: An example of dolomitization by normal seawater. Geology, 12: 217-220.

[21] **Gao, G., 1990.** Geochemical and isotopic constraints on the diagenetic history of a massive stratal, Late Cambrain (Royer) dolomite, Lower Arbuckle Group, Slick Hills, SW Oklahoma, U.S.A. Geochimica et Cosmochimica Acta, 54:1979-1989.

[22] **Land, L.S., R. Salem,** and **D. Morrow, 1975.** Paleohydrology of ancient dolomites: Geochemical evidence: Am. Assoc. Petroleum Geologists Bull., 59: 1602-1625.

[23] **Randazzo, A.F.** and **D.J. Cook, 1987.** Characterization of dolomitic rocks from the coastal mixing zone of the Floridan aquifer, Florida, U.S.A. Sedimentary Geology, 54: 169-192.

[24] **Meyers, W.J. and K.C. Lohmann, 1985.** Isotope geochemistry of regionally extensive calcite cement zones and marine components in Mississippian limestones, New Mexico, In Schneiderman, N. and Harris, P.M., (eds.), Carbonate cements. SEPM Spec. Publ. 36: 223-240.

[25] **Allan, J.** and **R.K. Matthews, 1982.** Isotope signatures associated with early meteoric diagenesis. Sedimentology, 29: 797-817

[26] **Anderson, T.F.** and **M.A. Arthur, 1983.** Stable isotopes of oxygen and carbon and their application to sedimentological and paleoenvironmental problems. In: M. Arthur,T,Anderson, I. Kaplan, J. Veizer, and L. Land, (eds.), Stable isotopes in sedimentary geology. SEPM, Short Course No. 10: 1-151.

[27] **Holail, H., 1987.** Stable isotopic composition and its relation to origin and diagenesis of some Upper Cretaceous dolomites and dolomitic limestones from Egypt. Ph.D. Thesis, Purdue University, USA, 284 p.

[28] **Craig, D.H., 1965.** The measurement of oxygen isotope paleotemperature. Symp. on Isotopes in Hydrology and Paleoclimatology, Spoleto, Lab. Geol. Nucl. Pisa, 161-182.