

The role of early lithification in development of chalky porosity in calcitic micrites: Upper Cretaceous chalks, Egypt

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ABSTRACT

Petrological and geochemical examination of Upper Cretaceous chalks from the Abu Roash area and Bahariya Oasis (Egypt) provide insights into factors which control porosity development in fine-grained calcitic carbonates.

Petrological studies indicate that primary skeletal fabrics of coccoliths and foraminifera in micrites of Abu Roash are well preserved. In contrast, primary skeletal fabrics of the Bahariya Oasis chalks are pervasively altered. Geochemical analysis of these chalks reveals a striking contrast in composition. The high porosity chalks at Bahariya Oasis have depleted isotopic values ($\delta^{13}\text{C} = -5.0\text{‰}$, $\delta^{18}\text{O} = -8.9\text{‰}$ PDB) and low concentrations of trace elements (Sr and Na). In contrast, the low porosity chalks at Abu Roash are less depleted in terms of their isotopic values ($\delta^{13}\text{C} = 1.0\text{‰}$, $\delta^{18}\text{O} = -4.0\text{‰}$) and possess elevated concentrations of Sr, Na, Fe and Zn. Importantly, fracture and collapse veins, present only at Abu Roash, are filled with calcite whose $\delta^{18}\text{O}$ value is coincident with that of altered micrites at Bahariya Oasis. The lithic fragments cemented by this calcite, however, retain compositions identical to other lithified limestones at Abu Roash.

Differences in fabric and chemistry of the pelagic marine micrites observed between Abu Roash and Bahariya Oasis reflect the degree of early lithification and compaction prior to exposure and meteoric diagenetic alteration associated with regional Late Cretaceous/pre-Eocene subaerial unconformity.

1. Introduction

Previous studies (e.g. Wise, 1973; Schlanger and Douglas, 1974; Scholle, 1974, 1977) have demonstrated a systematic progression of micro-fabric alteration of pelagic carbonate in response to burial compaction and recrystallization processes. Such changes in fabric reflect the mechanical reduction of intergranular pore space, and the chemical redistribution of carbonate from more soluble phases to overgrowth cements. A significant exception to this orderly progression has been observed in overpressured sequences where mechanical reduction of porosity is inhibited by hyperpressured fluids which prevent

chemical recrystallization from proceeding. Most notable of such settings is the Cretaceous chalk sequence of the North Sea, Ekofisk field (Byrd, 1975; Hancock and Scholle, 1975; Van der Bark and Thomas, 1981; Feazel et al., 1985). The pattern of porosity preservation in North Sea chalk hydrocarbon reservoirs is a function of the composition of the chalk, overpressuring history, and the timing of hydrocarbon migration (Maliva and Dickson, 1992). Scholle (1974, 1977) has documented a progressive alteration of chalk micro-fabric in which recrystallization occurs without accompanying compaction. This process produces a characteristic diagenetic microfabric marked by rhombic subcrystallites with high residual porosity (Hancock and Scholle, 1975; Scholle et al., 1983). While little geochemical data for chalks exhibiting such fabrics exist, this chalk microfabric is apparently diagnostic of burial recrystallization in overpressured sequences.

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The purpose of this study is to examine the petrofabric and geochemistry of Upper Cretaceous chalks from northern Egypt to evaluate the environmental factors which alternatively either lead to the destruction, or local preservation, of porosity. Importantly, a wide spectrum of microfabrics is present in these chalks, ranging from well-indurated limestones in which nannofossil microstructure is preserved, to pervasively recrystallized chalks which possess extensive open intercrystalline porosity. In the context of the depositional and burial history of this sequence, an overpressured origin for such microfabric is unlikely. Therefore, this study will propose an alternative mechanism to generate regional variations in diagenesis of calcitic chalks.

2. Geologic setting

Upper Cretaceous rocks in the Western Desert of Egypt are the most extensive of all Mesozoic strata (Soliman and El-Badry, 1970; Issawi, 1972). Lithologically, they consist of sandstone and shale of the Nubian Sandstone facies in the southern part of the Western Desert. These terrigenous clastic facies are progressively replaced by limestone basinward toward the north as depositional depths increase. This overall pattern of deposition prevailed until after the Turonian when regression produced a regional unconformity between Turonian and Coniacian strata (Sestini, 1984). Following subsequent marine transgression, open marine chalk deposition was established and persisted from Santonian through Maastrichtian time over large parts of northwestern Egypt. The southern flank of the basin is characterized by relative shallowing, decreased stratigraphic thicknesses, and increased introduction of terrigenous clastics (Said, 1962; Bartov and Steinitz, 1977).

Deposition of chalk was terminated by tectonic deformation during Campanian to Maastrichtian time. This deformation, part of the Syrian Arc system of folds, is reflected structurally as a gentle anticlinal fold at Bahariya Oasis and as a faulted anticlinal structure at Abu Roash. The tectonic activity is reflected, in these areas, by a widespread unconformity between Maastrichtian

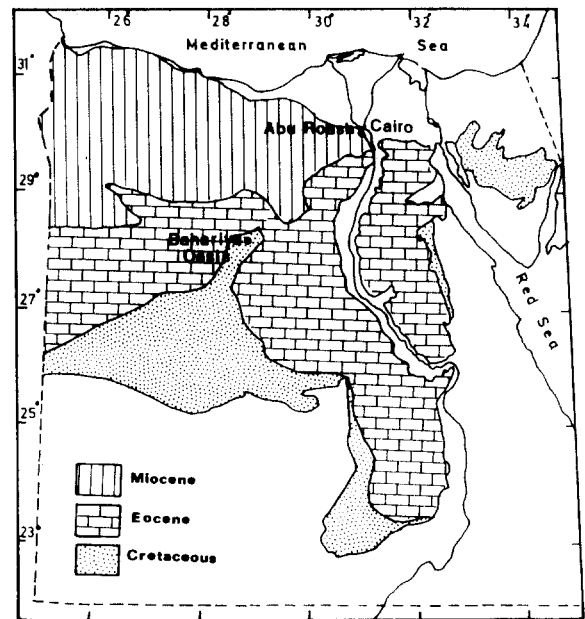


Fig. 1. Location map showing the distribution of major carbonate rocks in Egypt, scale 1:10,000,000. After El-Hinnawi and Loukina (1971).

and Middle Eocene strata (Hume, 1911; Faris, 1948; Said, 1962).

The material studied consists of 60 samples from the following two outcrop sequences encompassing Maastrichtian chalks: (1) Bahariya Oasis which is located at the central plateau of the Western Desert; and (2) Abu Roash, located at the northeastern corner of the Western Desert (Fig. 1).

The chalk formation at the Bahariya Oasis is formed of snow-white beds exposed on the western side of the oasis as an escarpment. The water depth at the time of deposition of these chalks was not more than 200 m (LeRoy, 1953; Said and Kerdany, 1961; El-Akkad and Issawi, 1963). However, the chalk formation at Abu Roash shows a comparatively thick sequence of relatively deep water facies dominated by planktonic foraminifera. Osman (1955a, b) suggested a water depth not less than 900 m for this sequence. However, association of *Thalassinoides* burrow systems with the chalk at the top of the sequence (Maastrichtian) indicates shallow depositional depths of less than 900 m for that part of the section (Strougo and Haggag, 1983).

3. Methods and results

3.1. Petrography

Sixty samples were examined and macroscopic textures and microfibrils of Maastrichtian chalk compared at these two localities. The fabric analysis was performed on thin sections utilizing a petrographic microscope and on fractured chips using a scanning electron microscope. Polished thin sections were examined under cathodoluminescence.

The Abu Roash chalks can be classified as wackestone with abundant well-preserved planktonic foraminiferal tests and coarser bioclasts consisting of prismatic layers of *Inoceramus*. Although evidence of compaction is present in many samples, chalks at this locality are marked by overall preservation of primary depositional fabric suggesting early lithification. Sparry calcite commonly infills unbroken foraminiferal tests.

Calcite veins, which have developed after lithification with no preferential orientation, constitute an important secondary feature in Abu Roash chalks. Scholle (1974) suggested that the calcite veins present in many European chalks were formed by in-situ recrystallization along possible microfractures rather than by void filling of open fractures. Fig. 2 illustrates this recrystallization phenomenon and shows the zoning of the sparry calcite cementing the chalk lithic fragments.

In contrast, the Bahariya Oasis chalks are mudstones with a homogeneous microcrystalline

calcite matrix of poorly preserved skeletal components. In this case, primary depositional fabrics are extensively altered. The matrix is highly porous and vuggy due to dissolution of the larger skeletal components. Foraminiferal tests exhibit extensive dissolution and are preserved by sparry calcite infillings.

Scanning electron micrographs reveal distinctive differences in microfabric and texture between chalks of Abu Roash and Bahariya Oasis. The Abu Roash chalks exhibit progressive diagenesis in response to burial (Fig. 3). Chalks show well-preserved coccoliths with extensive secondary calcite overgrowths developed on both coccoliths and other carbonate grains. There is non-uniform orientation of carbonate grains. Whole skeletons are occasionally intact but are usually disaggregated, producing plate or lath-shaped crystals. The combination of primary grain types within the Abu Roash chalk gives it a polymodal grain size distribution. Initial porosity within foraminiferal tests has been partially or completely filled by sparry low-magnesium calcite cement (Mapstone, 1975). This cement is believed to be derived internally through solution transfer (e.g. Durney, 1972). However, the absence of Paleocene and Lower Eocene rocks and the presence of surficial brecciation and extensive dissolution supply the evidence for subaerial exposure at Abu Roash chalks. This suggests a possibility that fluid flow has introduced additional carbonate cement from an external source, despite the low permeability of the Abu Roash

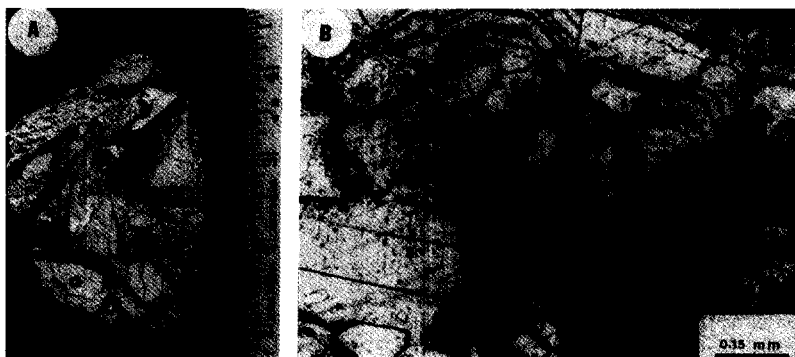


Fig. 2. A partly developed solution in the Abu Roash chalks. (A) Polished slab, presenting sparry calcite (b) cementing lithic fragments of chalk (a). (B) Photomicrograph showing the zoning of the sparry calcite cement of the same slab (crossed polarized light).

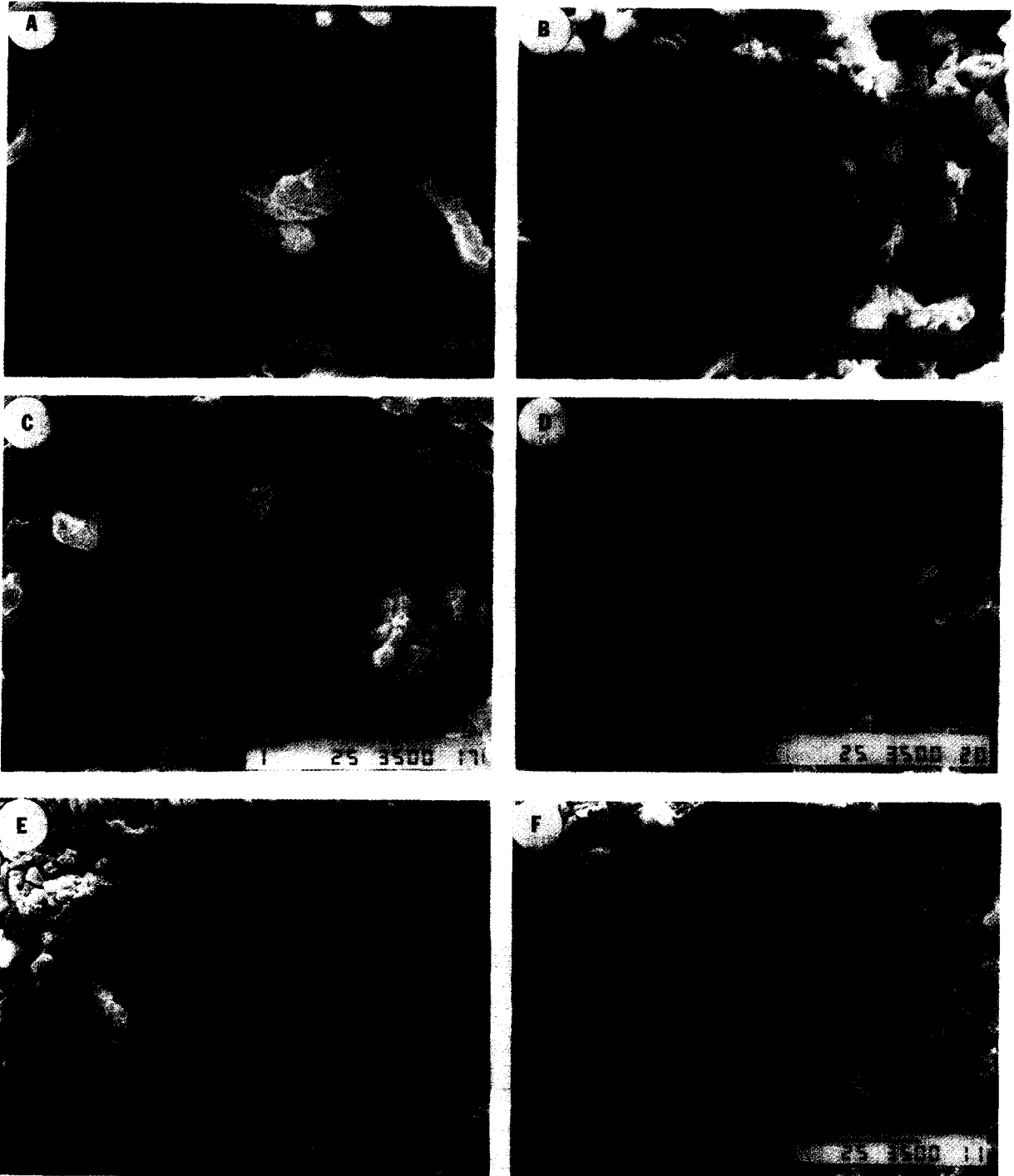


Fig. 3. Scanning electron micrographs of Maastrichtian chalks from Abu Roash area showing a sequence of pelagic diagenesis. (A, B) Relatively well-preserved coccoliths with scattered anhedra to subhedra grains of calcite which are the disintegration of some coccoliths and foraminifera tests. Note the overgrowth cement (B). (C, D) Remnant of corroded coccoliths in a matrix of coccolith fragments. (E, F) The transition from chalks to limestones with no coccoliths preserved. Note the secondary calcite crystals in matrix of much smaller calcareous bioclasts.



Fig. 4. Scanning electron micrograph of Maastrichtian chalks from Bahariya Oasis.

chalk matrix. Calcite cement began as overgrowths on coccolith elements and on the interior walls of foraminiferal tests (Fig. 3). The cementation of the sediment has considerably reduced the original pore volume, but Abu Roash chalks still retain a significant intercrystalline porosity.

In contrast, Bahariya Oasis chalks are pervasively recrystallized to equigranular (2–7 μm), polygonal calcite crystals with planar intercrystalline contacts (Fig. 4). Identifiable coccolith skeletal fragments are virtually absent. In addition, compaction features are rare with a dominance of open intercrystalline porosity (Fig. 4). In general, the Bahariya Oasis chalks exhibit a unimodal grain size distribution.

3.2. Geochemistry

Patterns of chemical variation were considered to assess the degree of diagenesis and recrystallization of carbonate rocks and to determine the conditions under which these changes occurred. Concentrations of Ca, Mg, Fe, Sr, Na, Mn, and Zn in thirty whole rock chalk samples and in eight separates of the fracture calcites were determined by neutron activation analysis.

Carbon and oxygen isotopic contents were measured for four components: *Inoceramus*, vein calcite, fracture calcite, and micrite matrix. Microsamples of 0.2–0.3 mg of powdered carbonate were mechanically separated from polished chips

using a microscope-mounted drill with a 500 μm diameter bit. All samples were roasted under vacuum at 380°C for one hour to remove volatile contaminations and subsequently reacted with anhydrous phosphoric acid at 50°C in an “on line” extraction system connected to a VG Micro-mass 602 E ratio mass spectrometer. After measuring the isotopic composition of the released CO_2 gas against that of a known CO_2 reference gas which was calibrated to PDB using the NBS-20, all enrichments were corrected for ^{17}O according to the procedure of Craig (1957) and then converted to the PDB scale. Precision of data was determined by daily analysis of a laboratory standard (NBS-20) and through the duplication of at least 10% of the samples, and it was maintained at better than 0.1‰ for both carbon and oxygen.

3.2.1. Major and trace elements

All samples exhibit high calcium carbonate contents similar to the analyses given by Hancock (1975). Mg^{2+} contents indicate low-magnesium calcite as the dominant mineral phase. Neither aragonite nor dolomite were detected in X-ray powder diffraction analysis of 60 whole rock samples. The pattern of variation of major and trace elements shows excellent correlation with microfabric differences observed for both localities.

The Abu Roash chalks are enriched relative to Bahariya Oasis chalks in Sr, Na, Fe, and Zn with averages of 990, 430, 225, and 23 ppm, respectively. The Sr concentration which ranges from 900 to 1200 ppm, approaches typical marine carbonate values (Land, 1980). Similarly, the concentrations of other trace elements are close to marine values. In contrast, there are significant differences in the chemistry of Bahariya Oasis chalks which are uniformly depleted in Sr, Na, Fe, and Zn averaging of 102, 152, 127, and 10 ppm, respectively. The most striking feature is that trace element values of the fracture sparry calcite of Abu Roash chalks show distinct trace element values as intermediate between the Abu Roash and Bahariya Oasis chalk values with averages of Sr = 450, Na = 260, Fe = 130, and Zn = 13.0 ppm (Fig. 5).

This preservation of chemical differences imposes constraints on the diagenetic system in-

volved and the degree of diagenetic alteration of chalks at both localities. While the relatively high trace element values of the Abu Roash chalks are offset from primary marine concentrations, the marked contrast with the Bahariya Oasis chalks values suggests leaching of trace elements by interaction with dilute fluids.

3.2.2. Carbon and oxygen isotopic compositions

The carbon and oxygen isotopic values (Fig. 6) of the Abu Roash micrite chalks are higher (with an average of +1.0 and -4.0‰ PDB, respectively) than those of high porosity Bahariya Oasis chalks (with an average of -5.1 and -8.9‰ PDB, respectively). These values, in general, are relatively uniform regardless of depth. The oxygen isotopic composition of Abu Roash micrite chalks is relatively constant indicating that the isotopic re-equilibration process is increasingly influenced by rock-introduced isotopic change in the composition of the recrystallized fluids.

The carbon and oxygen isotopic values of *Inoceramus* skeletons in Abu Roash chalks show little variation (with an average of +0.7 and -4.8‰ PDB, respectively) relative to the iso-

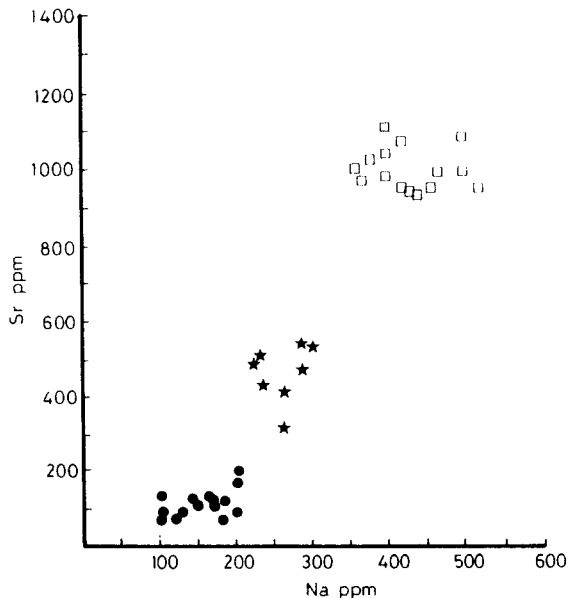


Fig. 5. Relation between Na^+ and Sr^{2+} values for chalks at the two studied localities. Squares represent Abu Roash micrite values, stars are fracture-filling sparry calcite from Abu Roash chalks, and dots are the Bahariya Oasis chalks.

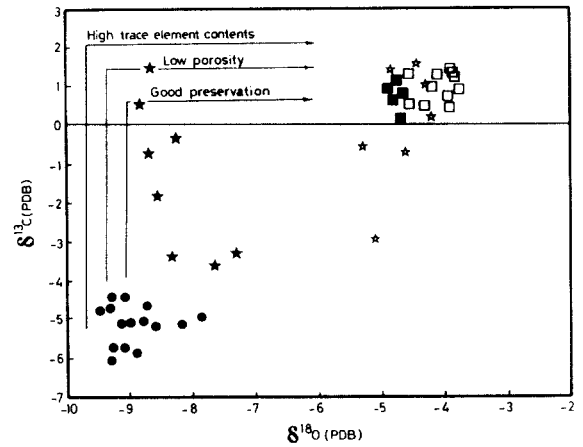


Fig. 6. Isotopic composition of Upper Cretaceous chalks from the two studied localities with the trends of trace element, porosity, and the microfabric preservation. Abu Roash micrite chalks (open squares), *Inoceramus* skeletal (solid squares), vein calcite (open stars), fracture-filling sparry calcite (solid stars) and Bahariya Oasis chalks (dots).

topic values of the micrite matrix of the same sample. Moreover, carbon and oxygen isotopic values are similar to those of vein calcites (with an average of +0.1 and -4.2‰ PDB, respectively). Importantly, the oxygen isotopic composition of the Abu Roash fracture sparry calcite is coincident with the oxygen isotopic composition of Bahariya Oasis chalks, whereas the carbon isotopic values range from -3.5 to $+1.5\text{‰}$ PDB. Such variation in carbon and oxygen values may reflect variation in the degree of water-rock interaction. This suggests a presence of a late diagenetic phase such as sparry calcite formed in a pore-water-controlled isotopic re-equilibration system at relatively high water/rock ratio.

4. Discussion

Chemical properties and the diagenetic history of chalk are assumed to be strongly dependent on primary composition, texture, and depositional setting. Therefore, if the effects of these parameters in the Maastrichtian chalks in the two studied localities are to be discriminated, it is first necessary to estimate the original starting composition, texture, and the paleogeography of the marine chalks. In this context, the best estimate of original prediagenetic composition and texture

of the chalks should be relatively close to those of the pelagic micrite of Abu Roash chalks which show microfabric preservation with high trace element concentrations (Sr and Na).

Petrographic work indicates that primary skeletal fabric of coccoliths and foraminifera of Abu Roash micrite chalks are well preserved. In contrast, primary skeletal fabrics of the Bahariya Oasis chalks are pervasively altered showing non-to poor-preservation. The trace element values confirm the above illustrative petrographic work. However, the concentration of these elements in the micrite of Bahariya Oasis chalks are anomalously low with averages of 110, 150, 90 and 10 ppm, respectively (Fig. 6). The differences in the Sr and Na contents (Fig. 5) between the chalks of the two localities, apart from the petrographic evidence, suggest that lithification, compaction and diagenetic history of these chalks took place in different environment settings and is of different magnitudes. Furthermore, the chemical data suggest that the calcite filling in the Abu Roash chalk fractures was formed from a dilute pore-water re-equilibration system at relatively high water/rock ratio.

Based on the geologic history of northern Egypt, the geochemical and petrographic evidence suggests that alteration of the Upper Cretaceous chalks in the two studied localities is a response to a common fluid. This alteration fluid was likely related to the exposure which resulted in the erosional unconformity during post-Maastrichtian to pre-Eocene times. In this scenario, the interaction of the Upper Cretaceous chalks with meteoric water is likely. However, the degree of alteration of these chalks might be different and related to the degree of early lithification and compaction. Therefore, in order to evaluate the difference in the diagenetic history of the studied localities from isotope and trace element data, it is also necessary to estimate the composition of pelagic marine carbonate during Upper Cretaceous time. Based on the estimates of Scholle and Arthur (1980) and Holail et al. (1988), Cretaceous marine carbonates are isotopically depleted in oxygen relative to present pelagic oozes, with values of -2.0‰ $\delta^{18}\text{O}$. The isotopic composition and the trace element values of the

Abu Roash chalks have been little shifted from the original marine values due to mechanical compaction and chemical compaction and cementation. However, these values are still higher than those reported for the Ekofisk chalks which are characterized by burial crystallization in overpressured sequences. In contrast, the Bahariya Oasis chalks show lower isotopic and trace element values, even lower than of the Ekofisk chalks (Mimran, 1977, 1978; Jorgensen, 1986; Kunzendorf et al., 1986). Therefore, in this context, an overpressured origin for such depletion of the isotopic and trace element values of the Bahariya Oasis chalks is unlikely.

A conclusion, based on Cretaceous paleogeography and stratigraphic reconstruction, is that pelagic micrites of Abu Roash, which accumulated near the depocenter, underwent early and pervasive marine burial lithification. This later hampered diagenetic processes, which are the response primarily to fresh water alteration and recrystallization of skeletal materials. In contrast, the micrites at Bahariya Oasis were deposited and buried only to shallow depths. These chalks underwent extensive recrystallization and chemical equilibrium during the formation of their distinctive, highly porous and finely crystalline microfabrics.

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References

- Bartov, R. and Steinitz, G., 1977. The Judea and Mt. Scopus groups in Negev and Sinai with trend surface analysis of the thickness data. *Isr. J. Earth Sci.*, 26: 119–148.
- Byrd, W.D., 1975. Geology of the Ekofisk field, off-shore Norway. In: A.W. Woodland (Editor), *Petroleum and the Continental Shelf of North-West Europe*. John Wiley and Sons, New York, pp. 439–445.
- Craig, H., 1957. Isotopic standards for carbon and oxygen and

- correction factors for mass spectrometric analysis of carbon dioxide. *Geochim. Cosmochim. Acta*, 12: 133–149.
- Durney, D.W., 1972. Solution transfer an important geological deformation mechanism. *Nature*, 235: 315–317.
- El-Akkad, S. and Issawi, B., 1963. Geology and iron deposits of the Bahariya Oasis. *Egypt. Geol. Surv. Pap.*, 18: 301.
- El-Hinnawi, E. and Loukina, S., 1971. Petrography and chemistry of some Egyptian carbonate rocks. *Neues Jahrb. Geol. Paläontol. Abh.*, 138: 284–312.
- Faris, M.E., 1948. Contribution to the stratigraphy of Abu Rouwash and the history of the Upper Cretaceous in Egypt. *Cairo Univ., Faculty Sci. Bull.*, 27: 221–239.
- Fazeel, C.T., Keany, J., and Peterson, M., 1985. Cretaceous and Tertiary chalk of the Ekofisk field area, Central North Sea. In: P.O. Roehl and P.W. Choquette (Editors), *Carbonate Petroleum Reservoirs*. Springer-Verlag, New York, pp. 495–510.
- Hancock, J.M., 1975. The sequence of the facies in the Upper Cretaceous of northern Europe compared with that in the Western Interior, in the Cretaceous System in the Western Interior of North America. *Geol. Assoc. Can., Spec. Pap.*, 13: 83–118.
- Hancock, J.M., and Scholle, P.A., 1975. Chalk of the North Sea. In: A.W. Woodland (Editor), *Petroleum and the Continental Shelf of North-West Europe*. John Wiley and Sons, New York, pp. 413–425.
- Holail, H., Lohmann, K.C. and Sanderson, I., 1988. Dolomitization and dedolomitization of Upper Cretaceous carbonate, Bahariya Oasis, Egypt. In: V. Shukla and P. Baker (Editors), *Sedimentology and Geochemistry of Dolostones*. *Soc. Econ. Paleontol. Mineral., Spec. Publ.*, 43: 191–207.
- Hume, W.F., 1911. The effect of secular oscillations in Egypt during the Cretaceous and Eocene Periods. *Geol. Soc. London Q.J.*, 67: 118–148.
- Issawi, B., 1972. Review of Upper Cretaceous–Lower Tertiary stratigraphy in central southern Egypt. *Am. Assoc. Pet. Geol. Bull.*, 56: 1448–1463.
- Jorgensen, N.O., 1986. Chemostratigraphy of Upper Cretaceous chalk in the Danish subbasin. *Am. Assoc. Pet. Geol. Bull.*, 70: 309–317.
- Kunzendorf, H., Gwozdz, R., Hansen, H.J. and Svendsen, N., 1986. Trace elements in a North Sea drill core. *Appl. Geochem.*, 1: 383–394.
- Land, L.S., 1980. The isotopic and trace element geochemistry of dolomite: the state of art. In: D.H. Zenger, J.B. Dunham and R.L. Ethington (Editors), *Concepts and Models of Dolomitization*. *Soc. Econ. Paleontol. Mineral., Spec. Publ.*, 28: 87–110.
- LeRoy, L.W., 1953. Biostratigraphy of the Maqfi section, Egypt. *Geol. Soc. Am.*, 54: 1–37.
- Maliva, R.G. and Dickson, A.D., 1992. Microfacies and diagenetic controls of porosity in Cretaceous/Tertiary chalks, Eldfisk, Norwegian North Sea. *Am. Assoc. Pet. Geol. Bull.*, 76: 1825–1838.
- Mapstone, N.B., 1975. Diagenetic history of a North Sea chalk. *Sedimentology*, 22: 601–613.
- Mimran, Y., 1977. Chalk deformation and large migration of calcium carbonate. *Sedimentology*, 24: 333–360.
- Mimran, Y., 1978. The induration of Upper Cretaceous Yorkshire and Irish Chalks. *Sediment. Geol.*, 20: 141–164.
- Osman, A., 1955a. Microstratigraphy of the Upper Cretaceous formations of Abu Roash. *Bull. Inst. Egypt*, 36: 181–191.
- Osman, A., 1955b. Facies analysis of the Mesozoic surface and subsurface formations of Abu Roash based on percentage of characteristic microfaunal families and general. *Bull. Inst. Egypte*, 36: 177–180.
- Said, R., 1962. *The Geology of Egypt*. Elsevier, Amsterdam, 377 pp.
- Said, R. and Kerdany, M.T., 1961. The geology and micropaleontology of Farafra Oasis. *Micropaleontology*, 28: 41–49.
- Schlanger, S.O. and Douglas, R.G., 1974. Pelagic ooze–chalk–limestone transition and its implications for marine stratigraphy. In: K.J. Hsu and H.C. Jenkyns (Editors), *Pelagic Sediments: on Land and under the Sea*. *Sep. Publ. Int. Assoc. Sedimentol.*, 1: 117–148.
- Scholle, P.A., 1974. Diagenesis of Upper Cretaceous chalks from England, Northern Ireland, and the North Sea. In: K.J. Hsu and H.C. Jenkyns (Editors), *Pelagic Sediments: on Land and under the Sea*. *Spec. Publ. Int. Assoc. Sedimentol.*, 1: 177–210.
- Scholle, P.A., 1977. Chalk diagenesis and its relation to petroleum exploration: Oil from chalks, a modern miracle? *Am. Assoc. Pet. Geol. Bull.*, 61: 982–1009.
- Scholle, P.A. and Arthur, M.A., 1980. Carbon isotope fluctuations in Cretaceous pelagic limestones: potential stratigraphic and petroleum exploration tool. *Am. Assoc. Pet. Geol. Bull.*, 64: 67–87.
- Scholle, P.A., Arthur, M.A., and Ekdale, A.A., 1983. Pelagic environment. In: P.A. Scholle, D.C. Bebout, and C.H. Moore (Editors), *Carbonate Depositional Environments*. *Am. Assoc. Pet. Geol. Mem.*, 33: 620–691.
- Sestini, G., 1984. Tectonic and sedimentary history of the NE African margin (Egypt–Libya). In: J.E. Dixon and A.H.F. Robertson (Editors), *The Geological Evolution of the Eastern Mediterranean*. *Spec. Publ. Geol. Soc. London*, 832 pp.
- Soliman, S.M. and El-Badry, O.A., 1970. Nature of Cretaceous sedimentation in Western Desert, Egypt. *Am. Assoc. Pet. Geol.*, 54: 2349–2370.
- Strougo, A. and Haggag, M.A., 1983. The occurrence of deposits of Paleocene age at Abu Roash, West of Cairo, Egypt. *Neues Jahrb. Geol. Paläontol. Mt.*, 11: 677–686.
- Van der Bark, E. and Thomas, O.D., 1981. Ekofisk; first of the giant oil fields in Western Europe. In: M.T. Hallouty (Editor), *Giant Oil and Gas Fields of the Decade 1968–1978*. *Am. Assoc. Pet. Geol. Mem.*, 30: 195–224.
- Wise, S.W., 1973. Calcareous nannofossils from cores recovered during leg 18, Deep Sea Drilling Project: biostratigraphy and observations of diagenesis. *Init. Rep. Deep Sea Drill. Proj.*, 18: 569–615.