

PETROGRAPHIC AND CHEMICAL MICROHETEROGENEITY IN DOLOMITE, BAHARIYA OASIS, EGYPT

By

H. HOLAIL*, M. SHAABAN** and M. KHALIFA***

* Department of Geology, Faculty of Science, University of Qatar, Doha, Qatar

** Department of Geology, Faculty of Science, Alexandria University, Egypt

*** Department of Geology, Faculty of Science, El-Menoufia University, Egypt

دراسة بتروجرافية وكيميائية لصخور الدولوميت غير المتجانس الواحات البحرية - مصر

حنفي محمود هليل و محمد ناصر شعبان و محمد عبد الغني خليفة

أوضحت دراسة صخور الدولوميت للعضو السفلي بمكون الحفوف وجود عدم
تجانس في الخواص الصخرية والجيوكيميائية . وقد بينت الدراسة البتروجرافية أن صخر
الدولوميت يشتمل على ثلاثة أنواع هي :

١ - فتات الدولوميت الأساسي

٢ - أرضية دولوميتية

٣ - دولوميت رقائقي

وتتميز هذه الأنواع بوجود تفاوت في محتوى نظائر الأكسجين والكربون المستقر
وكذلك في نسبة تواجد العناصر الرئيسية (كالسيوم - ماغنسيوم - حديد) والعناصر
الشحيحة (استرانشيوم - صوديوم - منجنيز) . ويعزى هذا الاختلاف في التركيب
الصخري والكيميائي لأنواع الدولوميت سألقة الذكر إلى إختلاف نشأتها الأولية وكذلك
إختلاف الظروف الثانوية التي أثرت عليها وأدت إلى وجودها في حالة ثبات .

Key Words: Dolomite, Bahariya Oasis, dolomitization, El-Hefhuf Formation, stable isotope

ABSTRACT

Dolomite samples from the lower member of the El-Hafhuf Formation (Turonian-Santonian) possess noticeable petrographic and chemical heterogeneity among their fabric components. Petrographically, the study samples can be subdivided into three types of dolomite: 1) main dolomite intraclasts embedded in 2) dolomite matrix and bounded by 3) laminated dolomite. Dolomite intraclasts are the more stoichiometric having $\delta^{18}\text{O}$ values that range from (-0.5 to -3.2‰ PDB) and enriched $\delta^{13}\text{C}$ signatures (+2.0 to +6.0‰ PDB). They possess nonplanar crystal boundaries and polymodal crystal size distributions. The dolomite matrix shows the lowest Sr^{2+} (av. 80 ppm) and Na^+ (av. 320 ppm) values and the highest Mn^{2+} (av. 1150 ppm) content. They exhibit narrow $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ ranges (-3.5 to -4.7 and 0.0 to -1.8‰ PDB, respectively). Crystals comprising this matrix have dominantly euhedral planar forms possessing polymodal distribution. Laminated dolomites exhibit the highest Sr^{2+} (av. 230 ppm) and Na^+ (av. 470 ppm) values and depleted $\delta^{18}\text{O}$ (-5.1 to -6.4‰ PDB) and $\delta^{13}\text{C}$ (-2.5 to -5.1‰ PDB) signatures. Their crystal boundaries are nonplanar while crystal size distribution is polymodal. Such petrographic and chemical heterogeneity among the investigated dolomite types within the studied samples are related primarily to the variable origins of these dolomites and their diagenetic stabilization pathways.

INTRODUCTION

The dolomite riddle, in its general sense, is a complex one that requires the involvement of more than one interacting factor [1]. It is a matter of consensus that the idea of a "panacea" or a special water capable of dolomitization can not be viable anymore.

This paper, however, does not address the different origin and distribution of the various dolomite types covering a wide area at the Bahariya Oasis. Instead, it focuses on microscale petrographic and chemical heterogeneity on a specific dolomite samples from the lower member of the El-Hefhuf Formation exposed therein. This sort of heterogeneity in dolomites in general,

as will be illustrated in the present study, may cast some doubt upon the application of the wide spectrum of dolomitization models to ancient enigmas.

GEOLOGICAL SETTING AND STRATIGRAPHY

The Geology and stratigraphy of the Bahariya Oasis have been investigated thoroughly by many workers [2-7]. The oasis which has a general oval shape is highly irregular in its outline (Fig. 1). Topographically, it is strikingly characterized by a larger number of hills within the depression where it is subdivided into three regions; 1) the high escarpments that bound the depression, 2) the isolated hills within the depression, and 3) the floor of the oasis. The tectonic setting of the oasis lies along the contact between the stable and unstable shelves of Egypt. It marks a highly deformed anticline of considerable extent and magnitude where axis runs NE-SW [8]. Periods of tensional readjustment have resulted in the initiation of a fault zone that transects the axis of the anticline.

The exposed stratigraphic sections in and around the Bahariya depression range in age from Cenomanian to Late Eocene (Fig. 1). The Upper Cretaceous shallow marine sequence therein is composed of the El-Heiz Formation (Late Cenomanian), the El-Hefhuf Formation (Turonian-Santonian) and the Ain Giffara Formation (Campanian) which are overlain by the Khoman Chalk (Maastrichtian). Two regional unconformities are recorded; the

first separates the El-Hefhuf Formation from the underlying El-Heiz Formation and can be seen in the southern escarpment, while the second separates the Ain Giffara Formation from the overlying Khoman Chalk. The El-Hefhuf Formation can be differentiated into three members (Fig. 2). The lower member consists of siliceous massive to thin bedded dolostone with some chert nodules which attain an average thickness of 20 m. The middle member is comprised of intercalations of yellow dolostone and sandy clays, while the upper member consists entirely of claystone, with interbeds of glauconitic sandstones. The study samples were collected from the lower member of this formation along the SE escarpment of the Bahariya Oasis.

METHODS

An integrated petrographic methodology has been used to examine the heterogeneity of the different dolomite fabrics and textures exhibited by the study samples. Sixty polished thin sections in different directions were prepared for conventional and cathodoluminescence microscopic study. Small rock fragments were used for scanning electron microscopy (SEM).

Major elements (Mg, Ca, and Fe) were measured using an electron microprobe at Purdue University, U.S.A. Meanwhile, trace element (Sr, Na, and Mn) contents were determined using a Perkin Elmer atomic absorption. Sampling for stable isotopic analysis was carried out using a microscope-mounted microdrill. The drill assembly extracted around 0.5 mg of powdered dolomite. Extracted samples were then roasted in a vacuum at 380°C for one hour and then reacted with anhydrous phosphoric acid at 55°C. Samples were reacted off-line for 4-6 hours before being connected to the inlet of a VG 602 E ratio mass spectrometer at Stable Isotope Laboratory at the University of Michigan. All obtained values were converted to PDB. Precision was monitored through daily analyses of NBS-20 standard and was better than 0.08‰ for both oxygen and carbon.

PETROGRAPHY

Preliminary petrographic investigation reveals that each study sample having a yellow to brownish yellow color, is divided into two basic parts (Fig. 3A). The first exhibits a brecciated macrofabric being composed of large ill sorted subrounded to angular pebbles of dolomites which are best described as intraclasts. These latter are partly fragmented and show a faint brown hue. They are embedded in but have sharp contacts with a relatively dark brown iron-stained dolomite matrix. The second half of this sample is made up of laminated dolomite (Fig. 3A). It is quite obvious that laminites result primarily from the alternation of inclusion-rich and inclusion-poor dolomite bands. The dolomite crystals comprising the intraclasts range in size from fine to medium. They usually show polymodal crystal size distribution. Crystal boundaries are non planar (Fig. 3B), although euhedral to subhedral planar crystal boundaries may exist. Extinction varies from being even to wavy. Crystal cores are noticeably dark (Fig. 3). Inclusions are numerous and they are mainly composed of clay minerals and/or iron oxides. Some fractures that are filled with clear calcite crystals cut the dolomite intraclasts.

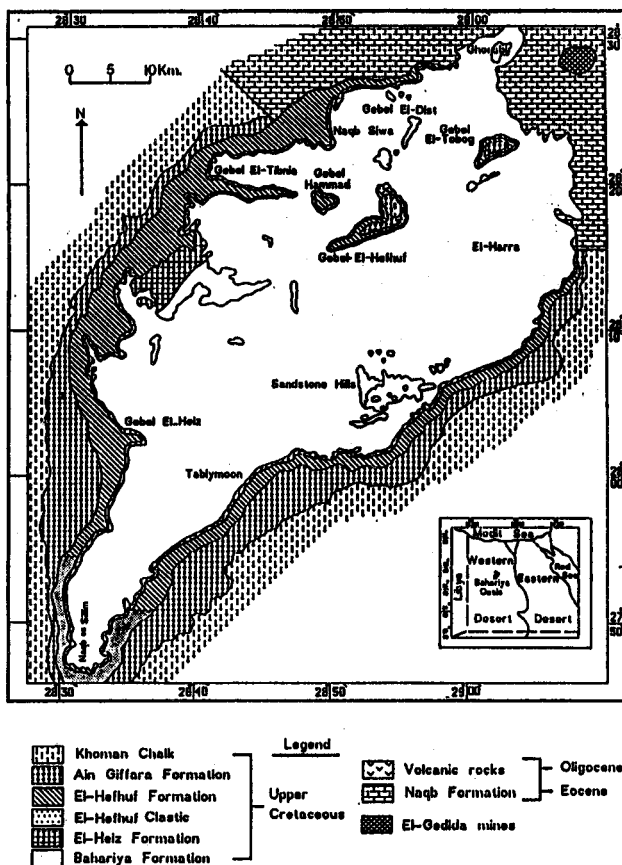


Fig. 1: Generalized geologic map of the Bahariya Oasis region.

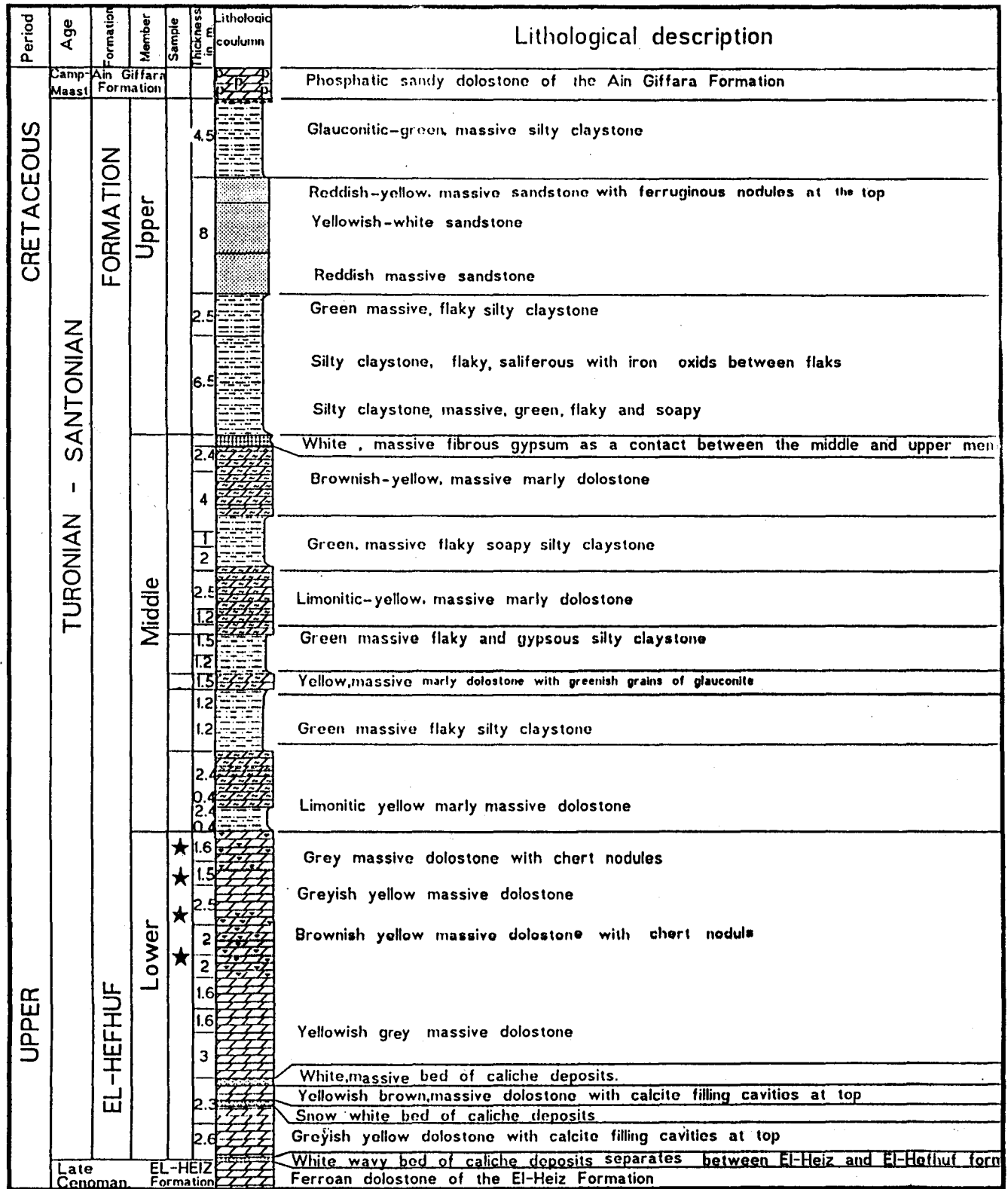


Fig. 2: The composite stratigraphic section of the upper Cretaceous sequence and the location of analyzed sample in this study.

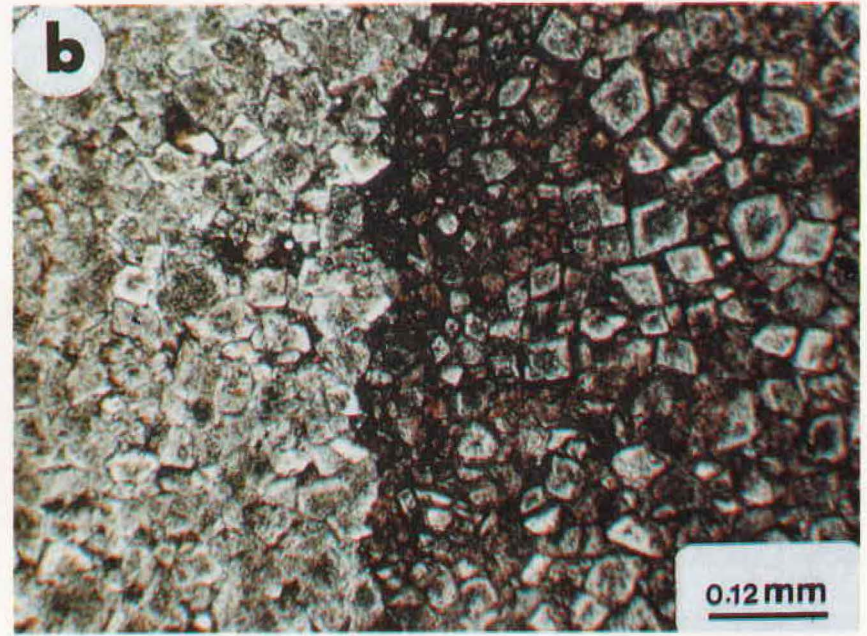
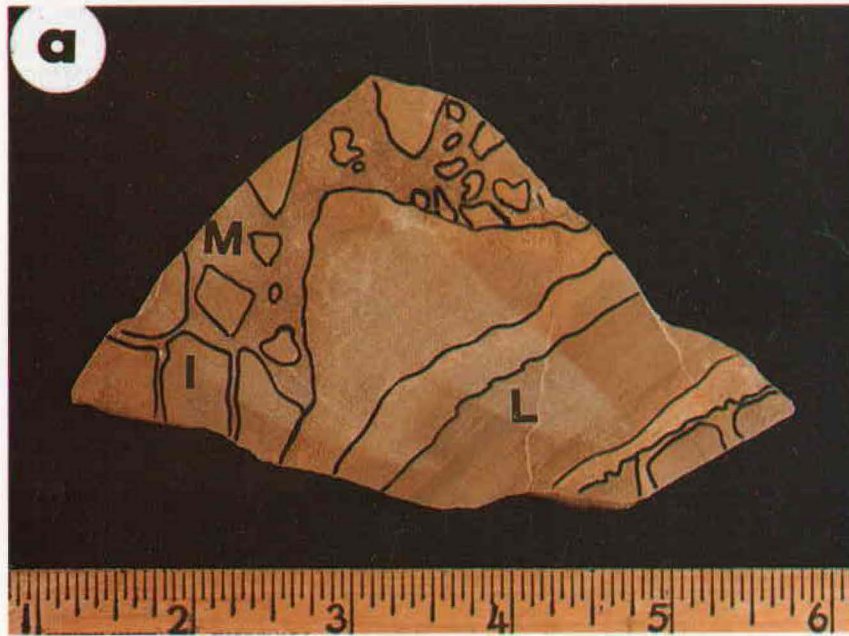


Fig. 3: A- Polish slab of the laminated dolomite (L), the dolomite matrix (M), and the dolomite intraclasts (I). B- Photomicrograph of breccia of microfabric dolomite. Note the difference in size and shape of the crystals between the dolomite intraclasts and the dolomite matrix. C- SEM image of dolomite matrix crystals. D- Numerous thin zones which range from brightly luminescent to non-luminescent and characterize the dolomite intraclasts type.

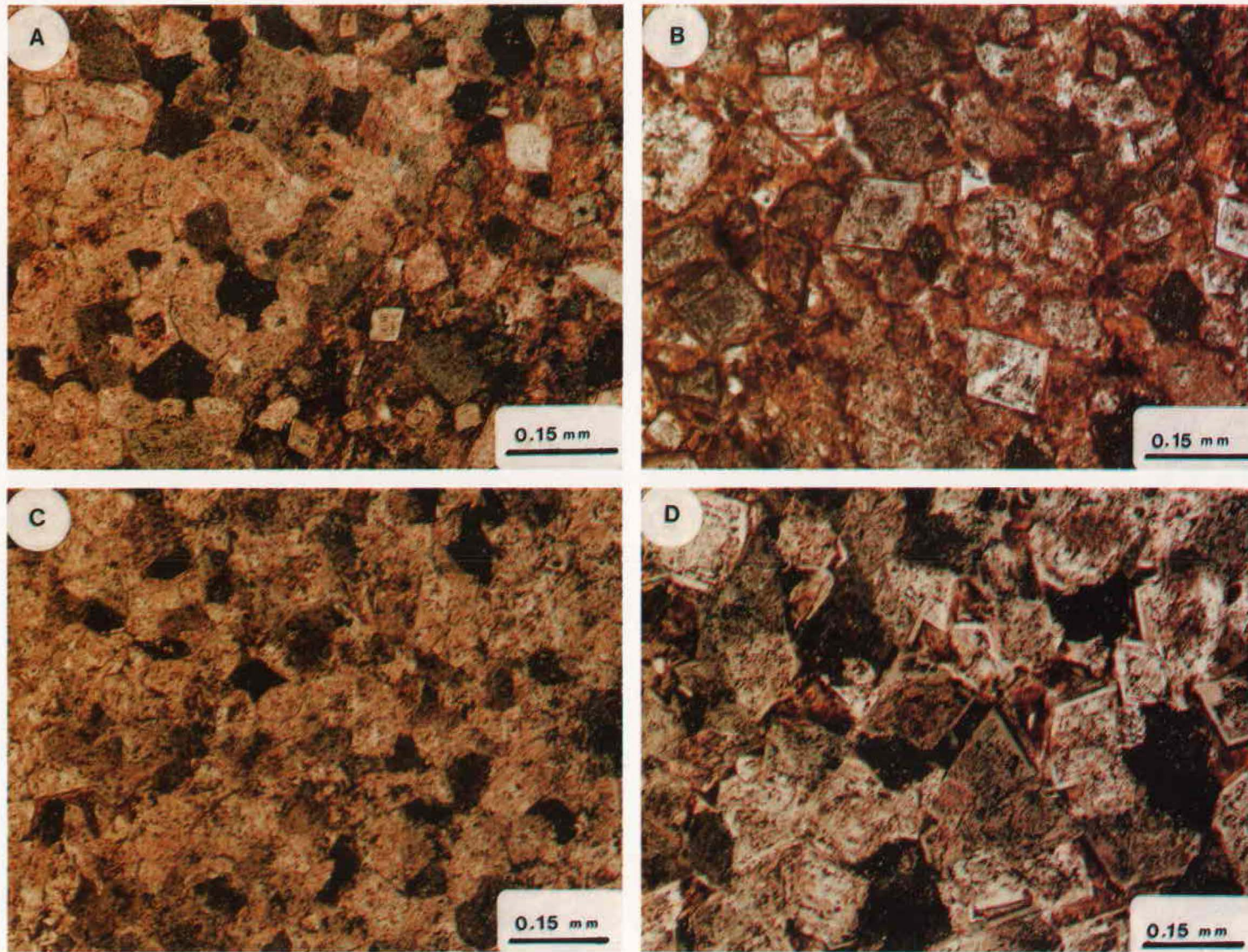


Fig. 4: Photomicrographs of the studied El Hefhuf Formation carbonates in which limestone has been totally replaced by dolomite (Plane polarized light). A- Brecciated dolomite composed of light clasts (I) distributed in a darker, iron-rich matrix (M). B- The matrix consists of euhedral dolomite rhombs stained by iron oxides. C- The lighter clasts consist of a mosaic of subhedral dolomite crystals. D- The original rocks consists of medium-grained, euhedral, distinctly zoned dolomite crystals.

The matrix surrounding the aforementioned intraclasts is made up of fine to medium, iron-stained dolomite crystals that show euhedral planar crystal boundaries (Fig. 4). Their crystal size distribution is polymodal and extinction is usually even. Inclusions are mainly arranged at zoning planes. Dissolution is frequently observed near cores of these dolomite rhombs.

Laminated dolomites are composed of fine to medium crystals that show polymodal crystal size distribution. Crystal boundaries are mainly non planar. Extinction is wavy and zoning is not an observable criterion. Pyrite and organic matter inclusions are frequently encountered.

GEOCHEMISTRY

It is evident that the three basic parameters that define and control the chemistry of dolomite are; 1) the degree of dolomite nonstoichiometry, 2) the concentration of some trace elements that show similarity to Ca²⁺ and Mg²⁺ ions, and 3) the stable oxygen and carbon isotopic contents of dolomite.

The studied dolomites exhibit different degrees of nonstoichiometry (Table 1). Dolomite intraclasts show the closest composition to stoichiometric dolomite, while the dolomite matrix and the laminated dolomites are far from the stoichiometric composition. None of the studied dolomite approach ankeritic composition (i.e. > 2 mole % FeCO₃) although they are of variable FeCO₃ composition. It is conceivable that tracing the behavior of trace elements in dolomite, in general, could monitor the principal factors that might control the dolomitization process itself (e.g. the kinetics that prevailed, the nature of the stoichiometric reactions, and the composition of the dolomitizing fluids). All of the studied dolomites were analyzed for their Sr²⁺, Mn²⁺, and Na⁺ contents. Strontium distribution exhibits a great variability among the study dolomite types, with the laminated dolomites having the highest values (av. 230 ppm) and the dolomite matrix showing the lowest (av. 80 ppm). In contrast, the dolomite intraclasts have an average Sr content of 103 ppm. Average Mn²⁺ values are relatively low in the dolomite intraclasts (720 ppm), whereas an increase in these values occurs in both the dolomite matrix (1150 ppm) and the laminated dolomites (950 ppm). Average sodium contents parallels those of the strontium, so that laminated dolomites exhibit the highest values

(470 ppm), the dolomite matrix shows the lowest (320 ppm) and dolomite intraclasts have the modest ones (425 ppm).

Isotopic composition of dolomites, in general, is controlled by the chemistry of the latest stabilization event and the chemistry of the precursor carbonate mineral [9]. The investigated dolomites are differentiated into three groups based on the cross relationship between their δ¹³C and δ¹⁸O contents (Fig. 5). Dolomite intraclasts are relatively enriched in both their δ¹³C and δ¹⁸O contents rather than the dolomite matrix and the laminated dolomite.

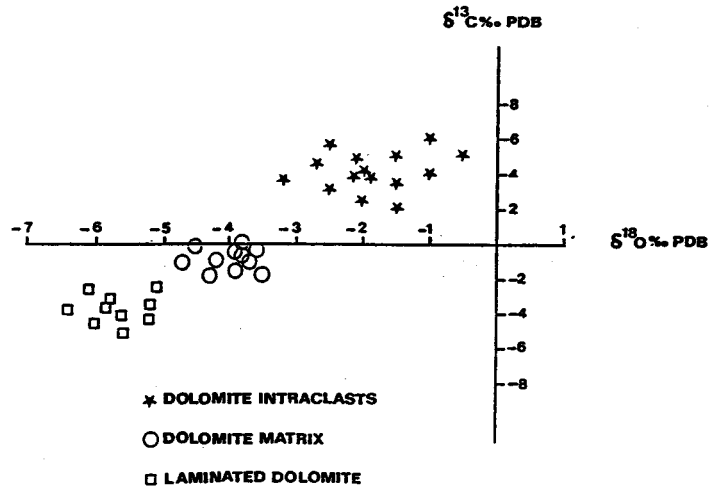


Fig. 5: Stable isotopic composition of the studied dolomite types.

DISCUSSIONS

Origin and stabilization events

Dolomite intraclasts

A synsedimentary origin could possibly be assigned for these dolomites since they comprise reworked intraclasts that were probably collapsed breccias, the product of evaporite dissolution. It is evident, however, that the noticeable increase in the abundance of nonplanar crystal boundaries and zones

Table 1
Average chemical composition of the studied dolomite types

Dolomite Types	CaCO ₃ %	MgCO ₃ %	FeCO ₃	Sr ppm	Na ppm	Mn ppm	δ ¹³ C ‰ PDB	δ ¹⁸ O ‰ PDB
Intraclasts dolomite	51.0	47.1	1.9	103	425	720	+2.0	-0.5
	-	-	-	-	-	-	-	-
	52.5		0.4				+6.0	-3.2
Dolomite matrix	53.4	44.9	1.7	80	320	1150	0.0	-3.5
	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-1.8	-4.7
Laminated dolomite	54.3	45.1	0.6	230	470	950	-2.5	-5.1
	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-5.1	-6.4

overgrowths (which are brightly luminescent, Ca-rich and Fe-poor) and the presence of corroded and/or dissolved relict cores in some crystals may argue for a stabilization trend "neomorphism" for the early planar dolomite phases developed during the initial dolomitization events [10]. Furthermore, it is obvious that the polymodal size distributions within these dolomite intraclasts may suggest the initiation of multiple periods of nucleation [11].

The broad range of the enriched $\delta^{13}\text{C}$ values (+2.0 to +6.0‰ PDB) of these dolomites does not necessarily reflect diagenetic changes of the original dolomite phase since these carbon isotope values are usually not affected by water/rock interactions. These enriched $\delta^{13}\text{C}$ values, instead, are believed to be either inherited from the original CaCO_3 precursor, or record the precipitation of these dolomites from evaporatively concentrated marine or mixed brines. The brecciated macrofabric of these dolomites may argue for a collapse structure related to the dissolution of the associated evaporites [12]. The lack of evaporite minerals in these dolomites does not mean that concentrated marine or mixed brines have been in existence. Evidence for vanished evaporites is suggested by the presence of some cherty nodules with relics of evaporite minerals. Solution collapse breccia and the abundance of curved nonplanar crystal boundaries which may be considered as a diagenetic criterion resulted from the precipitation of dolomites within highly supersaturated hypersaline conditions [11-13].

The depleted Sr^{2+} values and the broad range of $\delta^{18}\text{O}$ contents of this type of dolomite is attributed to further stabilization events that affected them. However, it is evident that the $\delta^{18}\text{O}$ contents (-0.5 to -3.2‰ PDB) are more depleted than expected for marine derived dolomites of the Upper Cretaceous considering these dolomites may be of syndimentary origin [12]. It is assumed that these stabilization events must have occurred in a fresh or mixed meteoric-marine setting. This environment has potential for the formation and stabilization of dolomite as it provides the necessary long term hydrologic system. In other words, it is proposed that the hydrologic pumping within this mixing zone must have exceeded the average rate of dolomite precipitation, and hence neomorphism, versus the residence time of this mixing zone in contact with the rock being dolomitized [14].

Dolomite matrix

The euhedral planar crystal boundaries exhibited by the dolomite matrix, along with its relatively high Fe contents, suggests a slower rate of precipitation from a less supersaturated solution for the dolomite crystals comprising this matrix [11 & 15]. These crystals were probably formed following the dissolution of the evaporites associated with the main dolomite intraclasts, concurrent with the first stabilization events of the latter. It is proposed that the relatively high Mn^{2+} and Fe^{2+} contents, lower Sr^{2+} values and depleted $\delta^{18}\text{O}$ signature of dolomite matrix, in addition to its limited aerial extent, are in accordance with the proposition that the precipitation of these dolomite crystals, as direct chemical precipitates, from a mixed meteoric-marine water within the interstices left between the dolomite intraclasts.

It seems possible that dolomitization was enhanced over calcification within this mixing zone. This appears related to the

arid conditions with limited soil development and lowering of Pco_2 . This undersaturation of calcite, however, is not a prerequisite factor for dolomitization at this mixed water site. It permits, instead, the precipitation of dolomite crystals at slower rates which overcome one of the major kinetic inhibitors for dolomite precipitation. The relative local variations in the growth rates of these crystals and/or heterogeneous distribution of nucleation sites might have resulted in the polymodal size distribution of these crystals [11].

Laminated dolomite

The laminated dolomites possess an identical chemical and petrographic character that differs dramatically from those of the other two dolomite types. The depleted wide range of $\delta^{13}\text{C}$ in these dolomites might inherited from the signature of the original CaCO_3 mineral precursor or they may reflect the precipitation from a ^{12}C -enriched fluid which is caused either by; 1) highly $\delta^{13}\text{C}$ -depleted meteoric water coincident with soil gas CO_2 within the zone of mixing or 2) the derivation of $\delta^{13}\text{C}$ -depleted CO_3 ions as the result of organic matter degradation, a precept supported by the presence of pyrite cubes and the iron-poor nature of these dolomites.

It is obvious, however, that the organic matter degradation which took place via the effect of sulfate reduction bacteria must have occurred within the zone of meteoric-marine water mixing. The relatively elevated Na and Sr values argue for their marine source while the depleted $\delta^{18}\text{O}$ signature and the high Mn values are indicative of fresh water involvement. The negative $\delta^{18}\text{O}$ values are not attributed to the effect of elevated temperature since the documented shallow burial history of the study sequence argues against this [12].

CONCLUSIONS

Dolomite samples from the lower member of the El Hefhuf Formation possess noticeable variations in their petrographic, chemical and isotopic characters. More than one dolomitization model needs to be used in the interpretation of the origin and the stabilization pathways of the different fabric components of these dolomite samples. The rock was dolomitized within a well developed paleomixing zone coupled to the effect of the time of exposure of this rock to the stabilizing fluids, which have a major impact on the petrographic and chemical heterogeneity of the dolomites in this study.

REFERENCES

- [1] **Hardie, L.A., 1987.** Perspective on dolomitization: a critical view of some current views: *Jour. Sed. Petrology*, 57: 166-183.
- [2] **El-Akaad, S. and B. Issawi, 1963.** Geology and iron ore deposits of the Bahariya Oasis, Western Desert, Egypt: *Geol. Surv., Egypt, Paper No. 18*, 301 pp.
- [3] **Said, R. and B., Issawi, 1964.** Geology of northern plateau, Bahariya Oasis, Western Desert, Egypt. *Geol. Surv. Egypt, Cairo, Paper No. 29*, 42 pp.

- [4] **Issawi, B., 1972.** Review of Upper Cretaceous-Lower Tertiary stratigraphy in central and southern Egypt, *Am. Assoc. Petrol. Geol. Bull.* 56: 1448-1463.
- [5] **Soliman, M.S. and O.A. El Badry, 1980.** Petrology and tectonic framework of the Cretaceous, Bahariya Oasis, Egypt, *Egypt. J. Geology*, 24: 11-51.
- [6] **Soliman, M.S. and O.A. El Badry, 1970.** Nature of Cretaceous sedimentation in Western Desert, Egypt, *Am. Assoc. Petrol. Geol. Bull.* 54: 2349-2370.
- [7] **Abou El-Hassan, M.M., 1994.** Geological and sedimentological studies of the Turonian-Santonian rocks, Bahariya Oasis, Western Desert, Egypt, Ph. D. Thesis, El-Menoufia University, Egypt, 240 p.
- [8] **Said, R., 1962.** *Geology of Egypt.* El Sevier, Amsterdam, 377 pp.
- [9] **Land, L.S., 1982.** Dolomitization: *Am. Assoc. Petrol. Geologists Educat. Course Ser. No. 24*, 20 pp.
- [10] **Montanez, I.P. and J.F. Read, 1992.** Fluid-rock interaction history during stabilization of early dolomites, upper Knox Group (Lower Ordovician), U.S. Appalachians, *J. Sed. Petrology*, 62: 753-778.
- [11] **Sibley, D.F. and J.M. Gregg, 1987.** Classification of dolomite rock textures, *J. Sed. Petrology*, 57: 967-975.
- [12] **Holail, H., K. Lohmann and I. Sanderson, 1988.** Dolomitization and dedolomitization of Upper Cretaceous carbonates: Bahariya Oasis, Egypt: In V. Shukla and P. Baker (Eds.), *Sedimentology and geochemistry of dolostones: SEPM Special Publ. No. 43*: 191-207.
- [13] **Friedman, G.M., 1980.** Dolomite is an evaporite mineral: evidence from the rock record and from sea-marginal ponds of the Red. Sea. *SEPM Spec. Publ. No. 28*: 69-80.
- [14] **Machel, H.G. and E.W. Mountjoy, 1990.** Coastal mixing zone dolomite, forward modeling, and massive dolomitization of platform margin carbonates. *Discussion. J. Sed. Petrology*, 60: 1008-1012.
- [15] **Ruppel, S.C. and H.S. Cander, 1988.** Dolomitization of shallow-water platform carbonates by seawater and seawater derived brines: San Andres Formation (Gaudalupian) West Texas: In V. Shukla and P. Baker (Eds.), *Sedimentology and geochemistry of dolostones: SEPM Special Publ. No. 43*: 245-262.