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# Diagenesis of Jurassic Tuwaiq Mountain Limestone, Central Saudi Arabia

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**Abstract.** Outcrops of the Jurassic Tuwaiq Mountain Limestone in central Saudi Arabia was diagenitically studied in detail. This formation has been divided into lower and upper parts purely on lithologic grounds. Several microfacies can be distinguished. Mudstone, wackestone and packstone are the most common microfacies. Grainstone is less encounterd and floatstone and boundstone are rare. A slight change in the limestone facies is interpreted as a reflection of depositional shelf environment; it is a normal marine carbonate sequence.

The Tuwaiq Mountain Limestone shows various diagenetic features. These include cementation, micritization, dolomitization, dedolomitization and recrystallization. Many of the examined samples of the Tuwaiq rocks of limestone and dolomitic limestone are dedolomitized as evidenced by the presence of partially or completely calcitized dolomite crystals.

Dolomite is dominant in many of the lime mudstone, wackestone and packstone facies. Leaching of packstone and lime mudstone (micrites), and dedolomitization of dolomite and dolomitic limestone, followed by recrystallization, are common processes of diagenesis.

## Introduction

Diagenesis is the term used to define all the changes which occur in sediments during the interval between deposition and lithification. These diagenetic changes may take place in the submarine, subaerial fresh water and subsurface environments. The various diagenetic processes usually reduce the primary pore volume of the original limestone fabric and produce mineralogical changes, dissolution, precipitation and textural modification. The evidence for these diagenetic changes in the resultant limestone fabric is shown by cementation, mineral replacement, recrystallization, leaching and cavity infilling.

The diagenetic processes which affected the outcrop of the Tuwaiq Mountain Limestone rocks are slightly similar to those of the subsurface at the eastern region. The upper most Tuwaiq Mountain Limestone is generally equated with the level of the

Hadriya Reservoir [1, 2]. The dedolomitization process is a common phenomenon at the outcrop [3-7].

Cementation, micritization, dolomitization, dedolomitization, and recrystallization are common diagenetic phenomena in the Tuwaiq Mountain limestones. These diagenetic processes might have taken place soon after deposition or some shorter or longer time after deposition and after burial as late diagenetic processes.

## Previous Study

The cementation process is a common phenomenon at the outcrop of the Tuwaiq Mountain limestones. Also, dolomitization and dedolomitization are still common phenomena, but less than cementation. The occurrence of dolomite in some Arabian carbonate rocks usually affects the primary porosity of these rocks [8].

The diagenetic processes had taken place contemporaneously during deposition or at later time after deposition (primary dolomitization), and after or post-burial as a late diagenetic process (secondary dolomitization). Carbonate diagenesis is discussed in details by many workers [3, 6, 7, 9-21].

## Stratigraphy

The Tuwaiq Mountain limestone rocks form a west facing cliffs (Fig. 1), which extend for more than 1200 km from south to north in central Saudi Arabia [22]. The area of study is located between latitudes 24˚ 31´and 24˚ 35´N and between longitudes 46˚ 20´ and 46˚ 24´E. Figure 2 is a generalized stratigraphic section of Tuwaiq Mountain Formation and parts of the underlying Dhruma Formation and the overlying Hanifa Formation. It shows the main microfacies of the studied rocks. The total thickness of this sequence of Tuwaiq Mountain Limestone is 186.5 m. Okla [23] divided the Tuwaiq Mountain Formation into lower and upper part. Vaslet and others [24] divided the formation into three parts and call them (T1, T2 and T3). In this study, the Tuwaiq Mountain Formation is subdivided on lithologic grounds into two parts, the lower Tuwaiq Mountain Limestone and the upper Tuwaiq Mountain Limestone. The Lower Tuwaiq Mountain Limestone corresponds to the two lower units (T1 and T2) of Vaslet and others [24], and the upper Tuwaiq Mountain Limestone corresponds to their uppermost unit (T3) .

The most prominent microfacies in the Tuwaiq Mountain limestone rocks are mudstone, wackestone and packstone. Grainstone is less encounterd and floatstone and boundstone are rare. Few limestone units are partly dolomitized.

## Diagenesis

The study of the diagenetic aspects was mainly undertaken under the light microscope on thin sections cut from representative rock specimens which were systematically collected from the successive bed units of the Tuwaiq Mountain Limestone. The diagenetic aspects in the Tuwaiq Mountain limestone rocks of outcrops in central Saudi Arabia (Fig. 1) are described as follows:

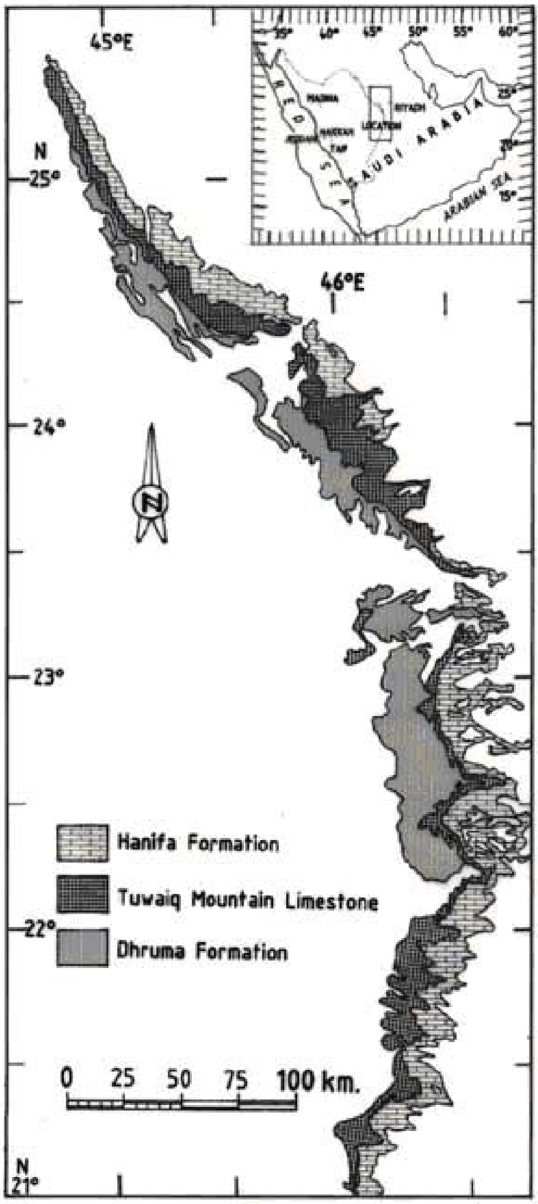

**Fig. 1. Geologic map of the Tuwaiq Mountain Limsetone and adjacent formations (after Basyoni, 2003).**

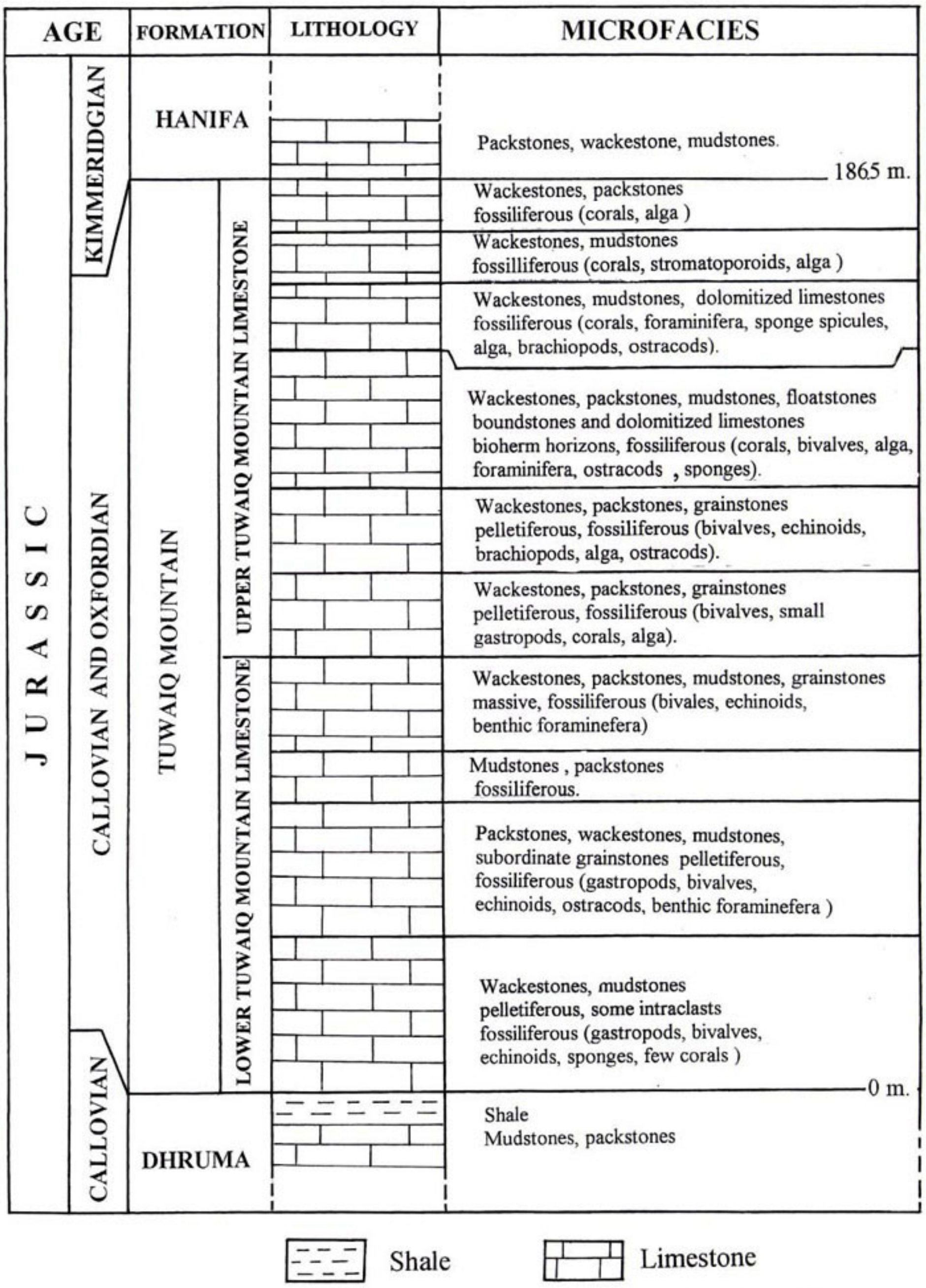

**Fig. 2. A generalized stratigraphic section of Tuwaiq Mountain Formation and parts of the underlying and overlying formations, showing the main microfacies.**

### 1) **Cementation**

Cementation, in general, is defined as a diagenetic process of cavity filling or open-space filling through chemical precipitation of material from a solution on a free surface (substrate).

In the absence of any evidence showing that the carbonate sediments of Tuwaiq Mountain Formation were deposited in the intertidal or supratidal environments or that they were brought into the subaerial environment shortly after deposition; it would be fair to assume that the early cement was precipitated under the influence of submarine environment at or just below the sediment-water interface.

Early cement may appear around the carbonate sand grains of the Tuwaiq Limestone as a thin layer of either fibrous or scalenohedral calcite crystals which all have grown normal to the grain surface in isopachous distribution (Figs. 3, 4 & 5). The dominant form of early cement, however, is found to consist of equigranular calcite crust around the carbonate grains (Figs. 6 & 7). The early diagenetic cement is present, not only as lining to the primary intergranular pores around the free surfaces, but also as lining to the primary intragranular pores within fossil structures (Figs. 8 & 9 ) of many skeletal grains on the shallow sea floor [25]. The skeletal grains belong generally to fossils such as gastropods, algal nodules, ostracods and stromatoporoids (Fig. 10). The internal walls of cellular chambers within a stromatoporoid colony are lined by microspar crystals, some of which show dentate pointing toward the pore center.

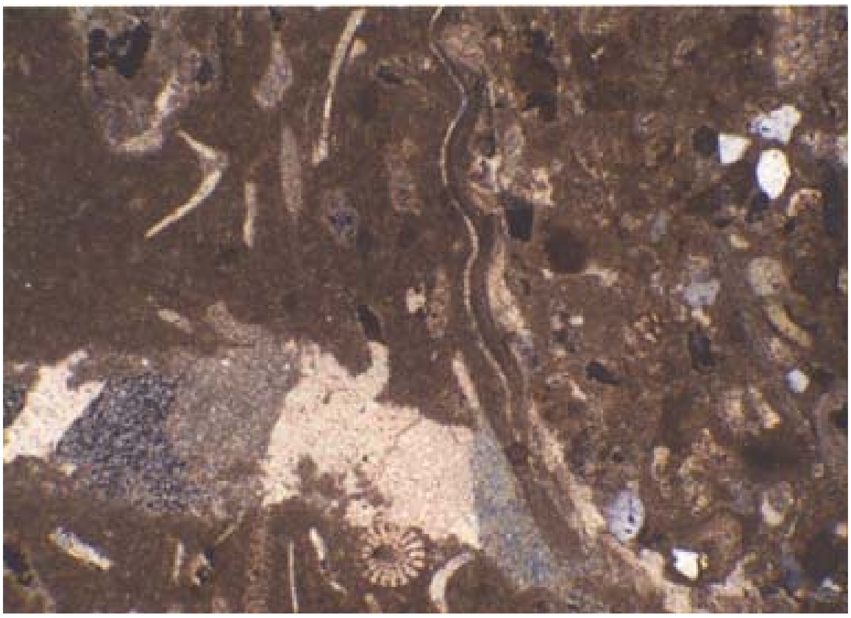

**Fig. 3. The fibrous cement around the right side of a large bivalve shell and pore microfracture filled with sparry calcite. Sample No. 9 , XPL. X 6.3.**

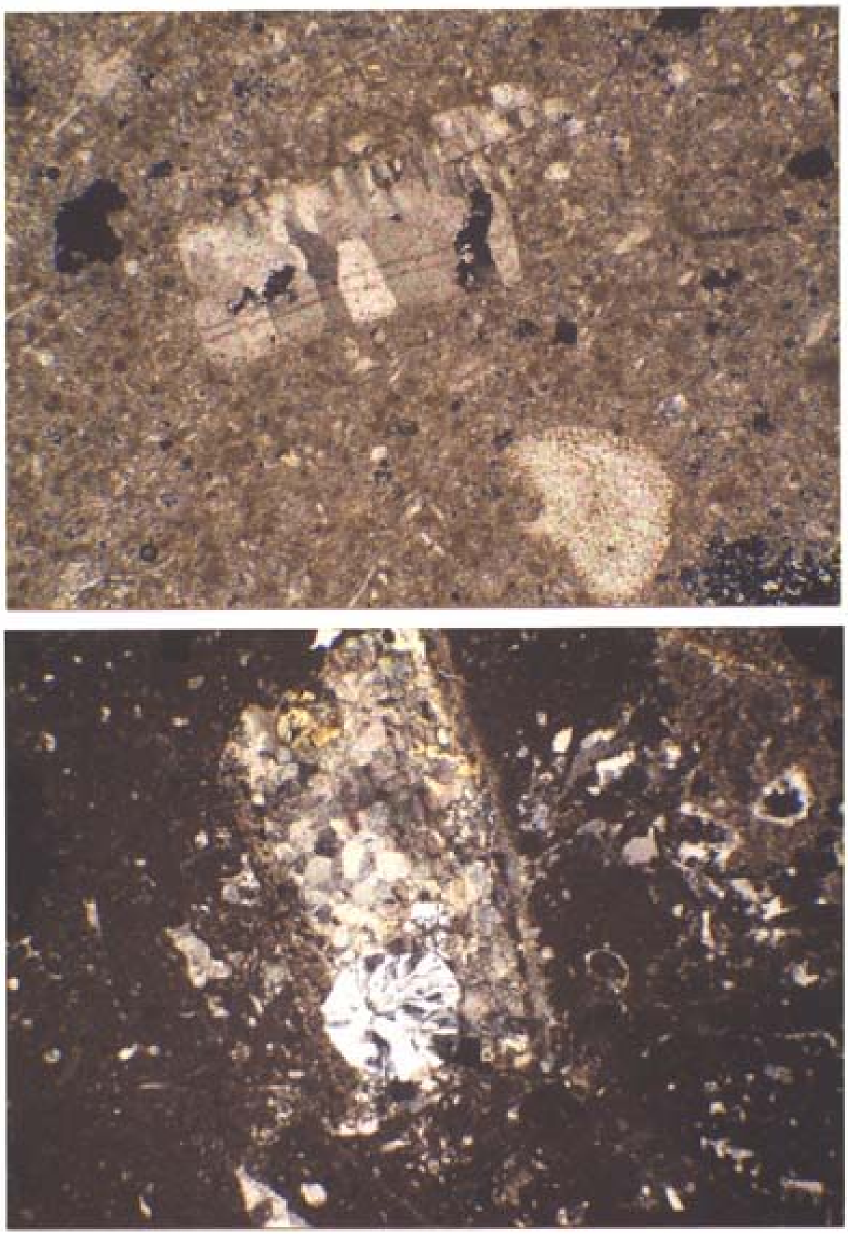

**Fig. 4. A punctuated clear fibrous brachiopod fragment appears at the center. Note the partial and preferential replacement by the microcrystalline calcite. Sample No. , XPL. X 6.3 (upper), and the same replacement of a large prismatic molluscan pelecypod fragment by microcrystalline calcite & quartz aggregates with the destruction of the primary shell structure of the sites of the chert (microcrystalline quartz) replacement. Sample No. 4, XPL. X 2.5 (lower).**

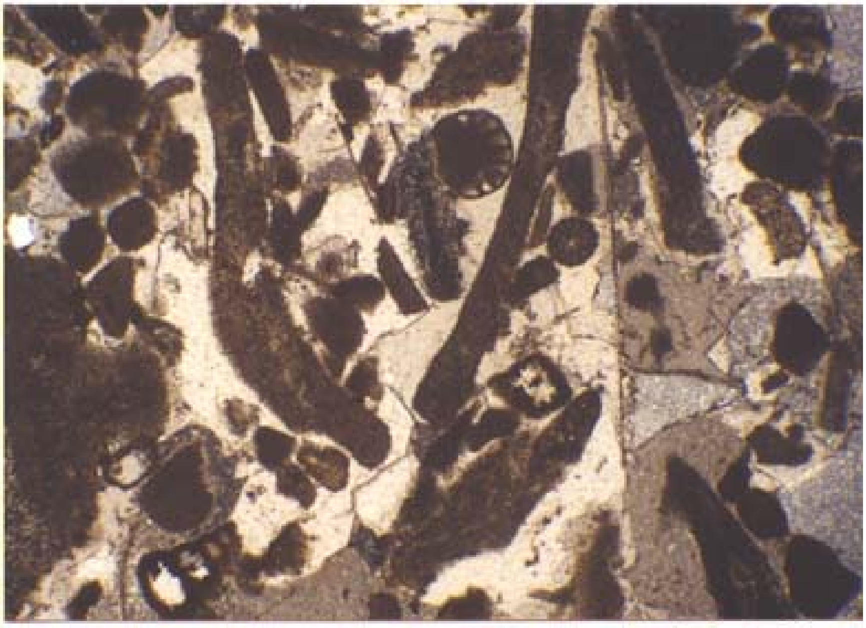

Fig. 5. Peloidal-foraminiferal grainstone; scalenohedral calcite crystals filled the spaces around the carbonate grains. Note the large echinoderm plate at the left side and the inter & intraparticle cementation. Sample No. 9, XPL. X 6.3.

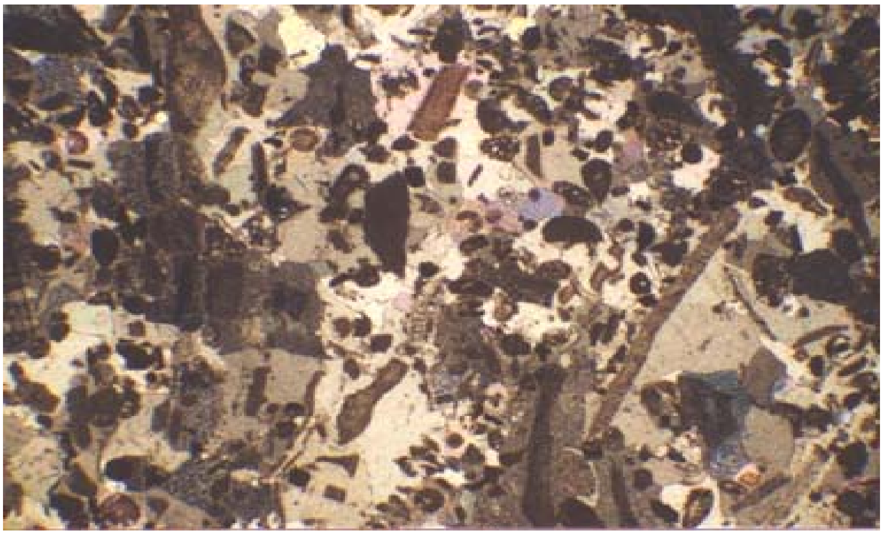

Fig. 6. Nearly equigranular calcite crystals filled the pore spaces between the bioclastic carbonate grains. Sample No. 9, XPL. X 2.5.

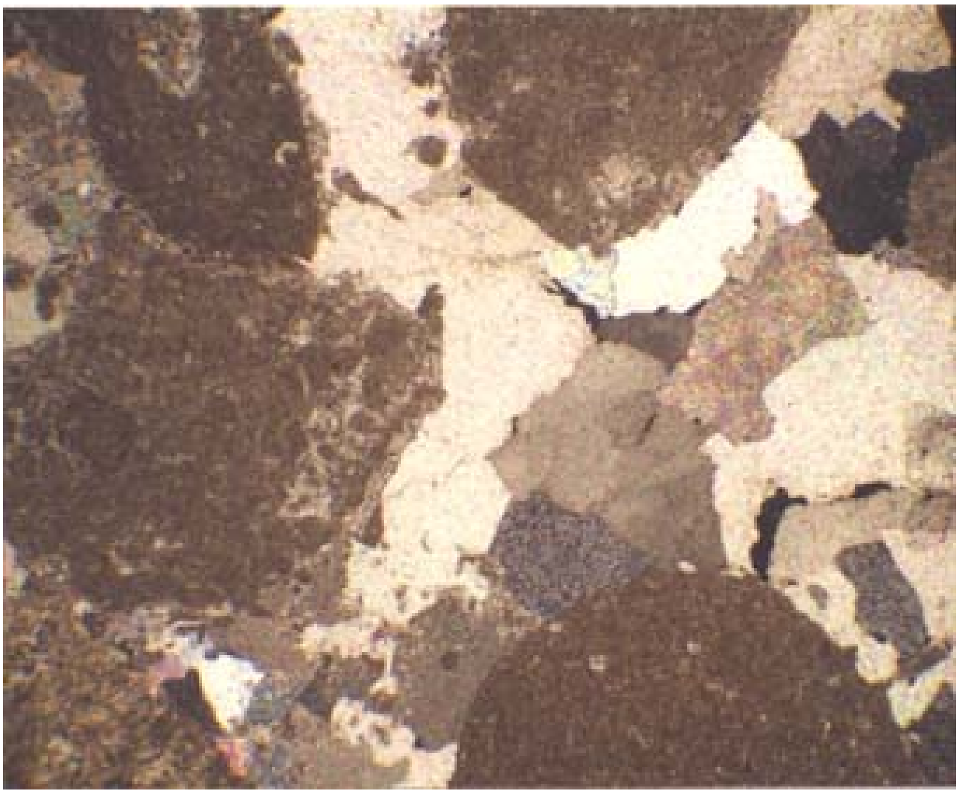

**Fig. 7. Peloidal-foraminiferal grainstone. Most of the peloids are intensely micritized. Note the presence of early rim cement around the free grain surface and along contacts between mutually pressed grains. Drusy calcite fills partially and completely interparticle spaces (as complete regeneration of the parts of sparry calcite). Sample No. 47B, XPL. X 2.5.**

The present calcite mineral of the early cement must be the result of polymorphic transformation and recrystalization of the original aragonite or high-magnesian calcite through subsequent neomorphism because the growth of low-magnesian calcite is inhibited by the presence of Mg++ ions in sea water.

It has been observed throughout the Upper Jurassic limestone of the Tuwaiq Formation that the early cement is generally present in the packstone facies. The fine calcite fringe, lining either the free surfaces of grains or the internal cavities of fossils, represents the first generation of cement; while the coarsely crystalline blocky calcite filling the remaining pore volume represents the second generation of cement in the carbonate rocks [26].

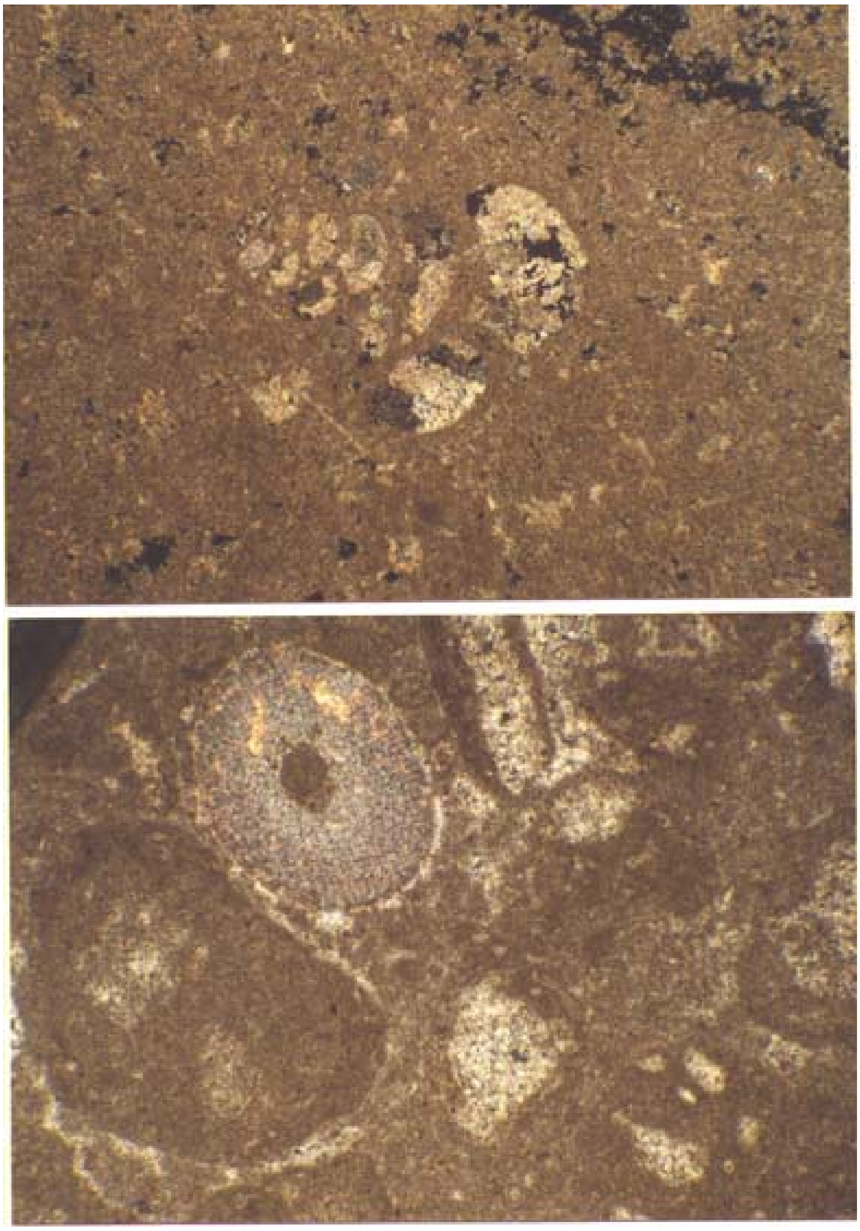

**Fig. 8. Beautiful cross section in foraminifera of a lime mudstone facies, sample No. 58 (upper), and algal nodules with the presence of algal filaments within the thick and vaguely laminated micritic coat, whereas the inner surface is irregular due to micritization of former skeletal nucleus and echinoid spine with a central canal which have the same extinction with the calcite cement surrounding it (calcite overgrowth) in bioclastic wackestone, (lower). Note the intragranular pores which are filled by sparry calcite. Sample No. 47B, XPL. X 6.3.**

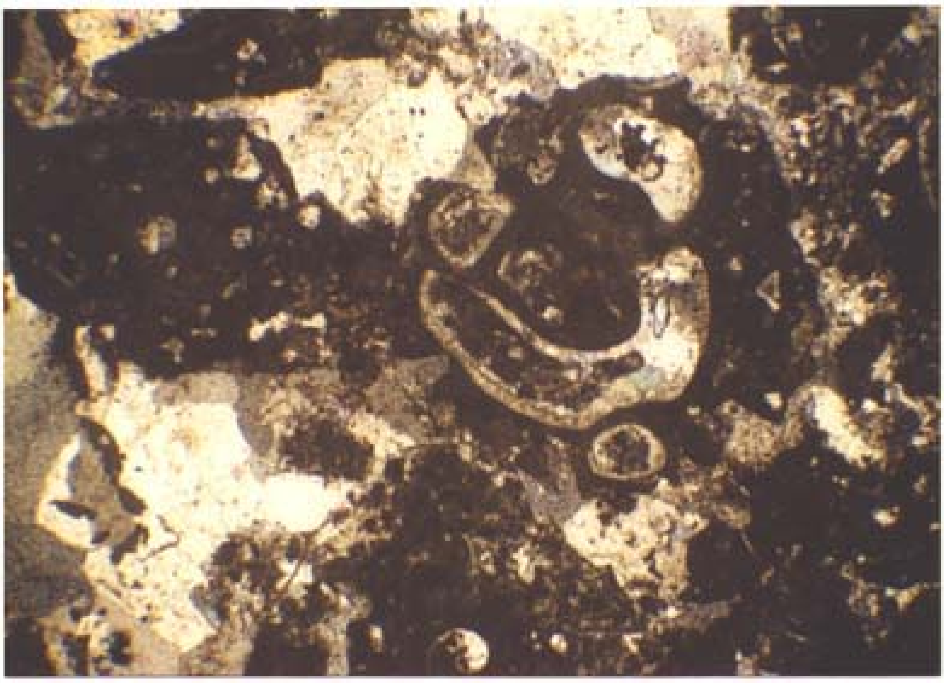

**Fig. 9. The growth of dolomite crystals within the sparry calcite cement; it infills intergranular porosity and intragranular pore in calcarenitic limestone facies. Note the cross section in a gastropod shell at the center. Sample No. 64, XPL. X 2.5.**

### 2) Micritization

The majority of the skeletal grains in the Tuwaiq Mountain Limestone appear to have been replaced to some degree by micrite. It is evident from the partly micritized grains that the replacement process starts from the outer margins to produce a micrite envelope enclosing a residual core of unaltered skeletal carbonate or its cast, if leached, and later infilled with sparry calcite (Figs. 7, 8 & 11).

The term micritization is now used for the process which causes the transformation of skeletal grains into cryptocrystalline carbonate. X-ray diffraction analysis of micritized grains in several recent sediments has proved that micrite of the envelope consists of aragonite in one place and high-magnesian calcite in another. Both of these unstable carbonate polymorphs are bound to be replaced later by low-magnesian calcite during subsequent diagenesis [27]. Two possible mechanisms are believed to be responsible for the precipitation of calcium carbonate in the tubes of algal bores. The first process is an inorganic precipitation promoted by the presence of special physico-chemical microenvironment within the bores [28, 29]. The second process of precipitation is caused by the metabolism of algae through bacterial growth [30].

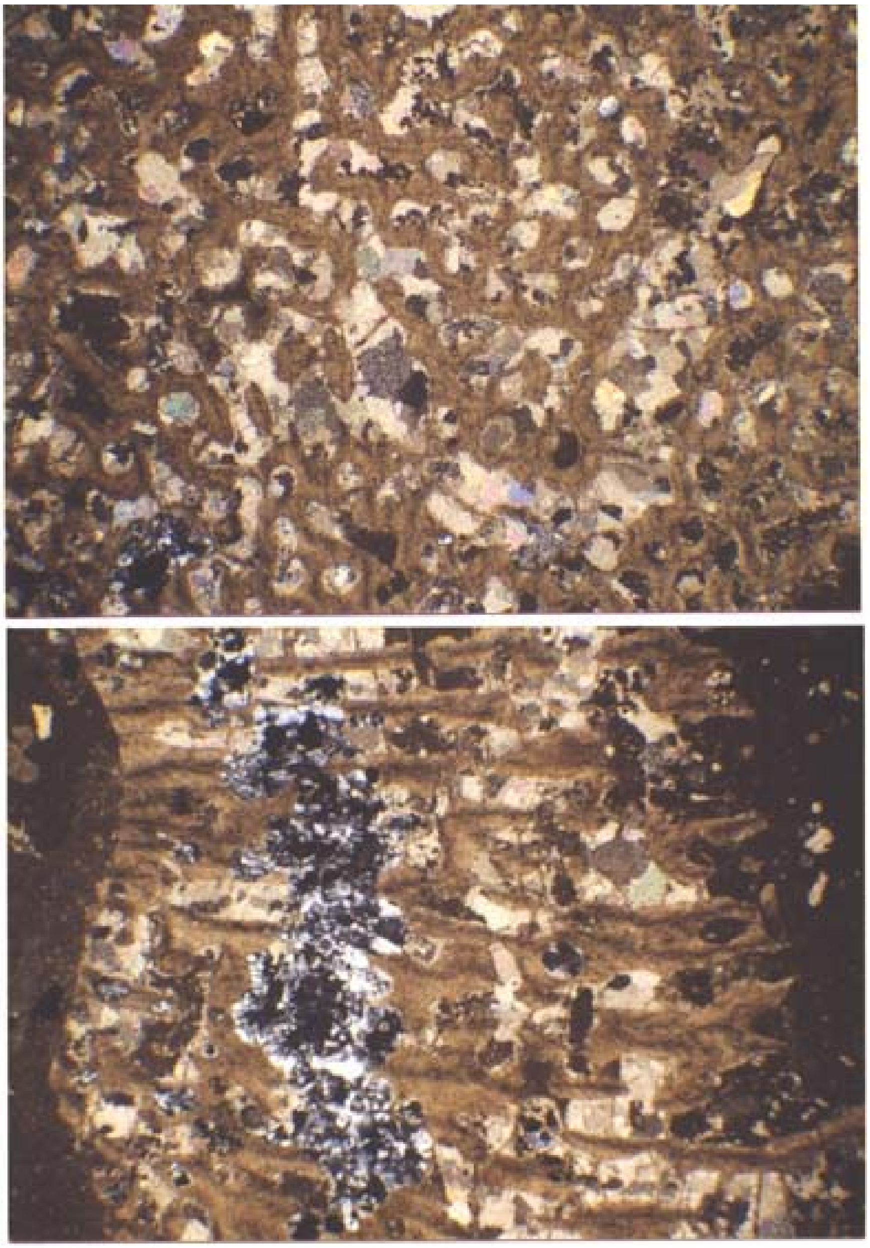

**Fig. 10.** **Stromatoporoid fragment with some idiotopic dolomite rhombs; note the development of early cement of dentate microspar lining the primary cellular voids within the stromatoporoid. The remaining intragranular pore space is filled with relatively coarse sparry calcite cement (upper); note the microcrystalline quartz aggregates and the destruction of the primary structure at the sites of chert replacement and sparry calcite (lower). Sample No. 39A, XPL. X 2.5.**

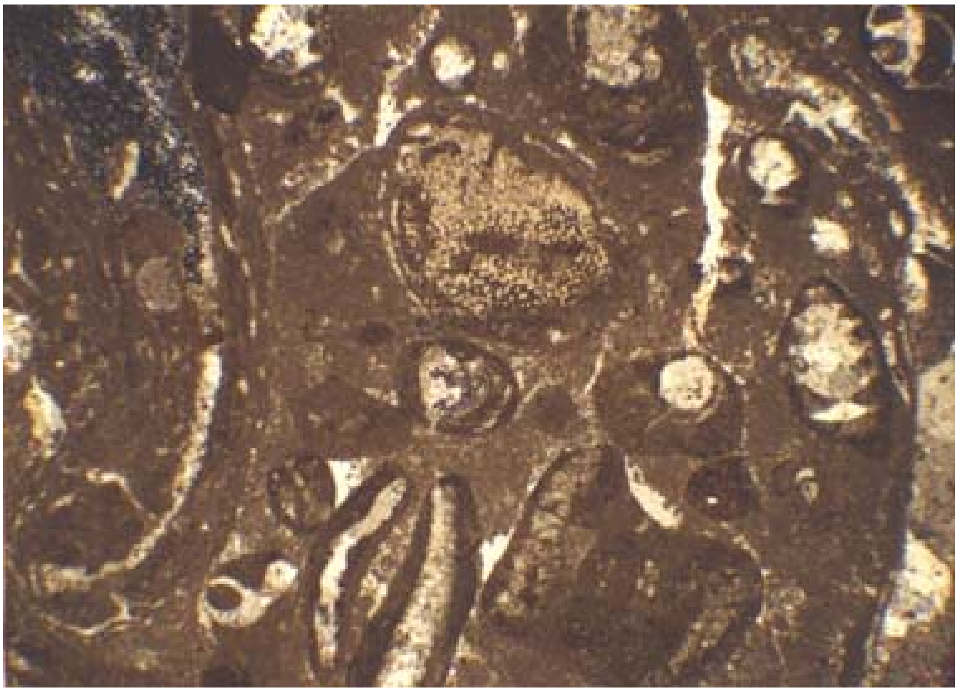

**Fig. 11. An echinoderm plate at the center with reticulate network filled partially with micrite with marginal micritization; also algal nodules at the bottom center, built of calcite, filled skeletal mold. Note the thick accretionary micritic coat showing vaguely concentric laminae. The presence of peloids in this bioclastic packstone is mainly of foraminiferal origin. Sample No. 46B, XPL. X 2.5.**

The occurrence of algal-bored grains can be used as a water depth indicator. Because of the photosynthetic growth requirements of algae, the abundance of these grains in sediments indicates that deposition took place at less than 40 meters, probably at less than 15-18 meters [31]. This bathymetric criterion is valid unless the sediment in question has been reworked or carried to greater depth after an early stage of accumulation.

### 3) Dolomitization

The condition of dolomitization in the Tuwaiq Mountain Formation will be discussed in the light of the stratigraphic distribution of dolomite and its textural features. These textural features of dolomite were investigated in the successive rock units of the Tuwaiq Mountain Limestone. The relationship between the original dolomite content and the amount of allochems and micrite matrix in the carbonate rocks is also determined.

The distinction between limestone and dolomite can be made on the basis of difference in size and shape of the carbonate crystals. Most dolomites are relatively coarsely crystalline compared with the dense micritic limestones. Dolomites in the Tuwaiq Formation generally consist of fine to medium crystalline crystals. The micritic limestones, which form the dominant rock type, have cryptocrystalline texture with micron-size crystals, though occasionally showing recrystalized texture.

The analysis is intended to study the tendency for the dolomite replacement with respect to the various rock types of limestone, and the vertical and lateral trend of dolomite development throughout the formation as well.

The dolomite in the Tuwaiq Mountain Limestone rocks is originated through the replacement of original calcium carbonate sediments. The dolomitization occurred during post-depositional processes in semi or wholly consolidated sediments. This is indicated by the growth of dolomite crystals within the sparry calcite cement that infills intergranular porosity in clcarenitic limestones (Fig. 9). This secondary dolomitization resulted more likely from Mg rich brine water from which the dolomite crystals grew larger between the pores and microfractures (Fig. 12) or even in moldic pores (Fig. 13).

The dolomite matrix consists of anhedral to subhedral crystals (Figs. 14 & 15) set in interlocking mosaic with little inter-crystalline porosity. This indicates that dolomitization had probably taken place in a coherent carbonate matrix. The majority of dolomites in the Tuwaiq limestones seem to be of burial diagenetic origin. Early dolomitization in soft sediments, though limited, might have also occurred. The dolomite replacement of the Tuwaiq limestone has induced by lateral down dip or vertical downward flow of dense Mg++ rich brines passing from the above sediments through permeable limestone since these carbonate sediments deposited in a normal marine environment.

### 4) Dedolomitization

Dedolomitization has become a widely recognized feature in many carbonate rocks in Saudi Arabia, especially at surface exposures. De Groot [28] have shown, according to his experimental work, that dedolomitization can only take place at or near the earth's surface. Goldberg [32], Katz [33], Folkman [34] and Al-Hashimi [35] have also contributed to the study of dedolomitization texture, and proposed different mechanisms for the replacement of dolomite by calcite.

Petrographic study of the Tuwaiq Mountain Limestone in the outcrops of central Saudi Arabia shows evidence of the presence of dedolomitization in the dolomitic limestones and dolomites. Rhombohedral pores proved very common in association with dedolomitic limestones. The dedolomitization phenomenon varies from one bed to another, as well as from one locality to another. Calcite replacement of dolomite is not only confined to the Tuwaiq rocks, but it also occurs in adjacent parts of the carbonate formations. Although, the dedolomitized limestones are irregularly distributed throughout the Tuwaiq rocks, the evidence for dedolomitization is revealed by the following characteristic textures:

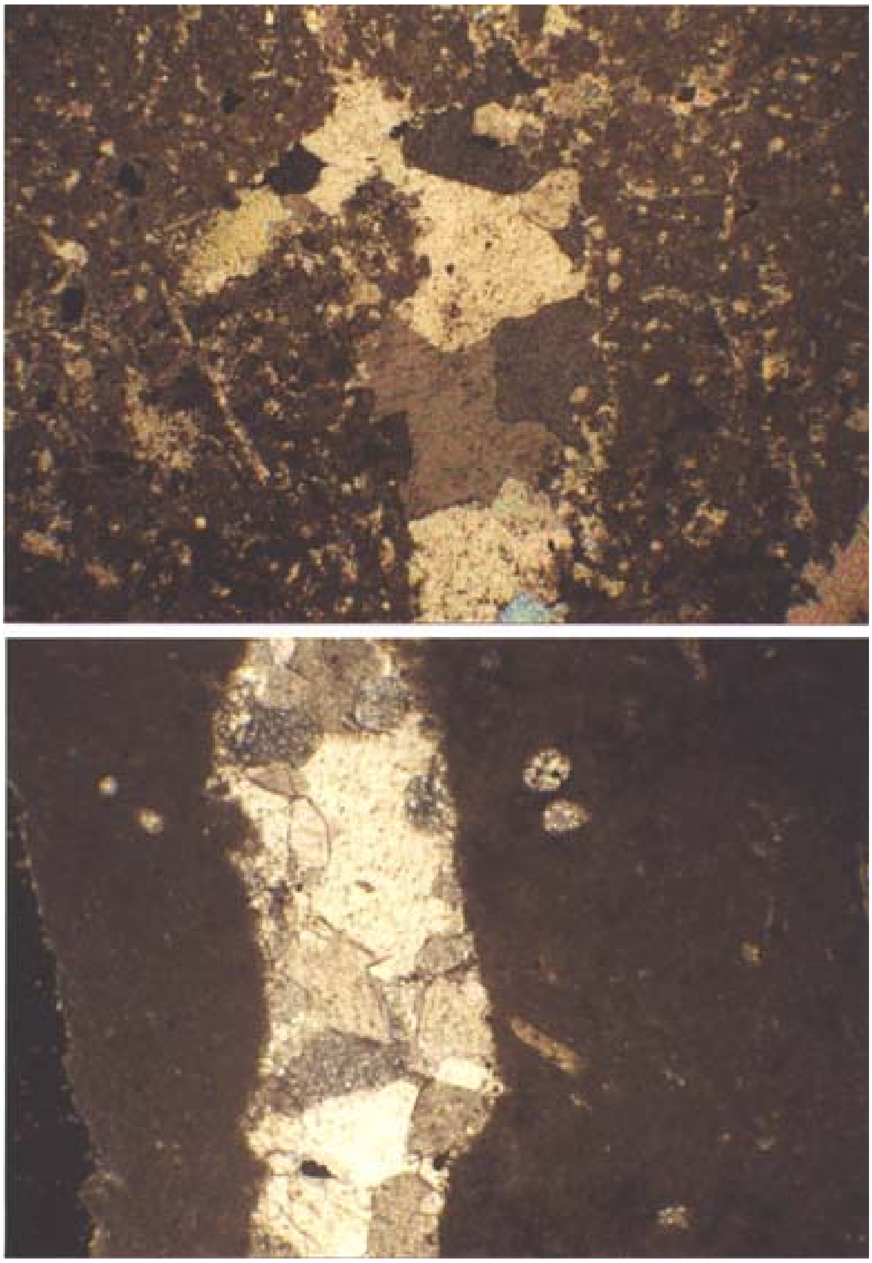

**Fig. 12. Photomicrograph showing the pore microfractures filled with dedolomitized calcite cement. Sample no. 60, XPL. X 2.5 (upper), and sample No. 66, XPL. X 6.3 (lower).**

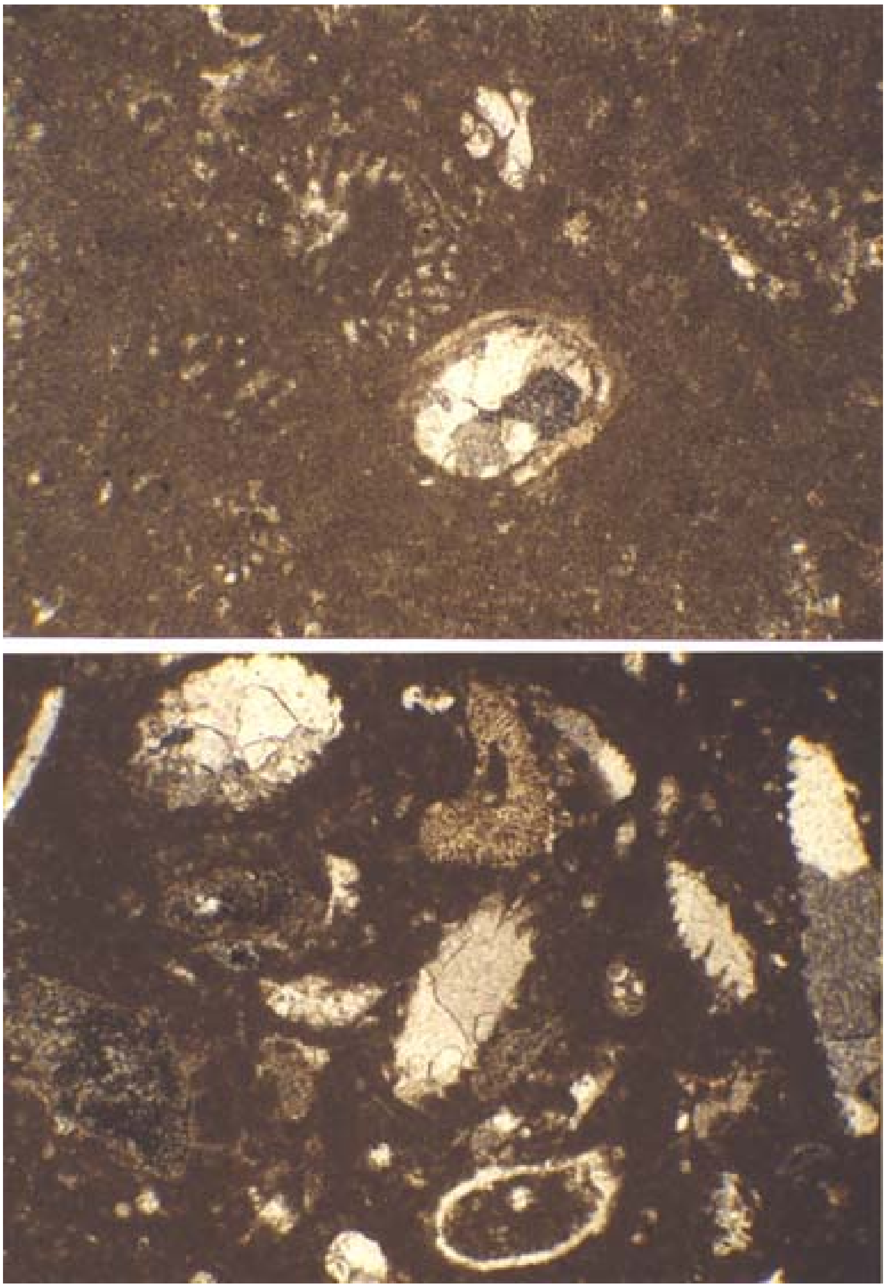

**Fig. 13. Foraminiferal wackestone with the association of few ostracods filled by dedolomitized calcite cement. Note the ostracod at the center affected by recrystallization; the calcareous walls regenerated the fibrous calcite. Sample No. 73, XPL. X 6.3 (upper), and sample No. 44, XPL, X 6.3 (lower).**

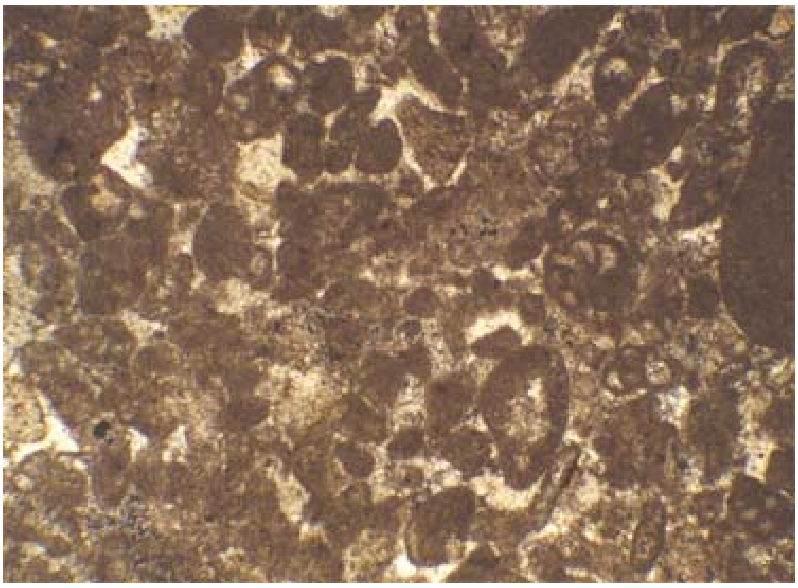

Fig. 14. Foraminiferal-peloidal dolomitic packstone. Note the preservation of depositional fabric in the dolomite matrix. The clear dolomite between the self-supported calcarenite relics is a presumptive evidence for dolomite replacement of earlier sparry calcite cement. Coated bioclasts, forams and echinoderm grains are recognized after complete dolomitization. Sample No. 54, XPL. X 6.3.

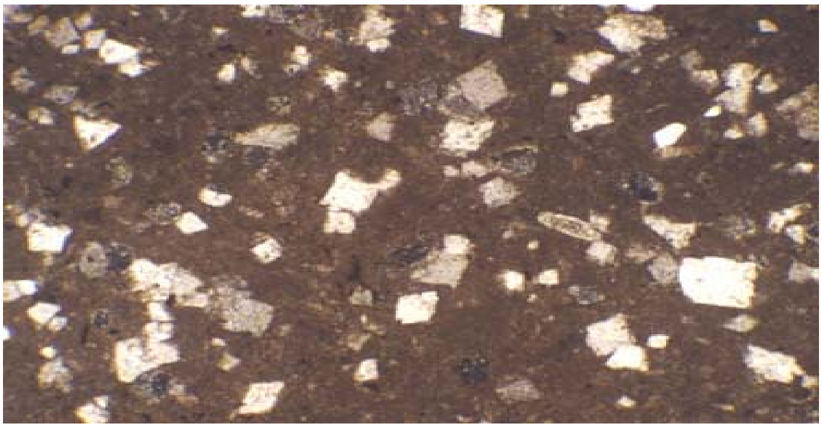

Fig. 15. Moderately dolomitized wackestone with complete dedolomitization. Note the occurrence of rhombohedra composed of less equant calcite crystals. The absence of ferric oxide rhombs structures defines earlier dolomite within the micrite matrix. Sample No. 32, XPL. X 6.3.

1. The common occurrence of incompletely calcitized dolomite crystals (Fig. 16).
2. The presence of well-defined composite calcite rhombohedra as pseudomorphs of calcite after dolomite crystals (Fig. 17).

**Fig. 16. Dedolomitized lime mudstone where the very fine dolomite crystals are incompletely calcitized. Note the dolomitization and subsequent dedolomitization which affected the ostracod carapace (at the center). Sample No. 65, XPL. X16.**

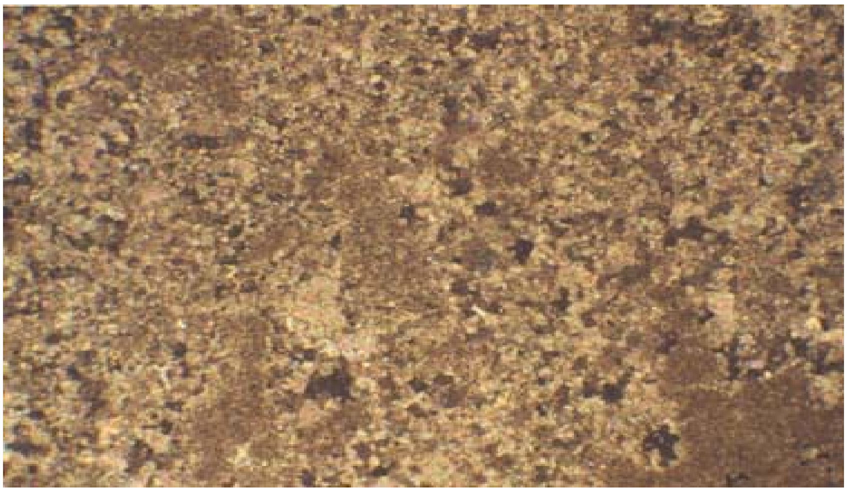

**Fig. 17. Strongly dolomitized lime mudstone with complete dedolomitization. Note the fine microspar patches imparting a patchy recrystalization texture to the micrite matrix. Sample No. 60, XPL. X 6.3.**

3. The common development of rhombohedral pores is considered as an indirect evidence for dedolomitization in limestones (Fig. 18).

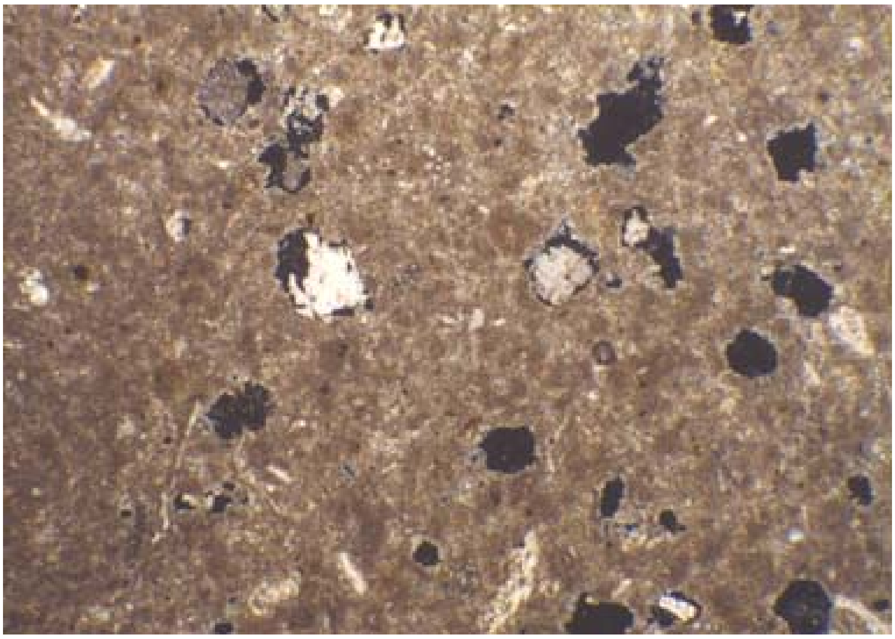

**Fig. 18. Dolomitized wackestone with complete dedolomitization. Note the occurrence of open rhombohedra (leached idiotopic dolomite rhomb) lined with fine calcite microspar representing remnant of undissolved dedolomite grains; this is another evidence for the dedolomitization origin of the grumeleuse texture in the micrite matrix, filled partially or completely with sparry calcite. Sample No. 30, XPL. X 6.3.**

The well-defined rhombohedra texture is composed of equicrystalline mosaics of subhedral calcite crystals (Fig. 19). This distinctive and widely recognizable texture, known as the composite calcite rhombohedra or the pseudomorphs of calcite after dolomite, has evidently resulted from the replacement of earlier individual crystals of dolomite by multi-crystalline calcite during dedolomitization.

In the Tuwaiq Mountain limestones, more evidence of the dedolomitization origin of composite calcite rhombohedra is provided by dolomite crystals which contain rhombic cores of polycrystalline calcite as seen in Fig. 17. Shearman and others [36], Evamy [37], Zeidan [4], Zeidan and Basyoni [21], Basyoni [5-7] and other workers described similar composite calcite rhombohedra and dolomite rhombs with calcite cores in carbonate rocks from Saudi Arabia and distant parts of the world. Most of the workers interpreted this phenomenon as dedolomitization (or calcitization). The new generation of calcite within the rhombohedra is often easily distinguished from the groundmass of the limestone on textural basis. This is mainly because the micrite constituent inside the rhombohedra appears slightly more coarsely crystalline than outside.

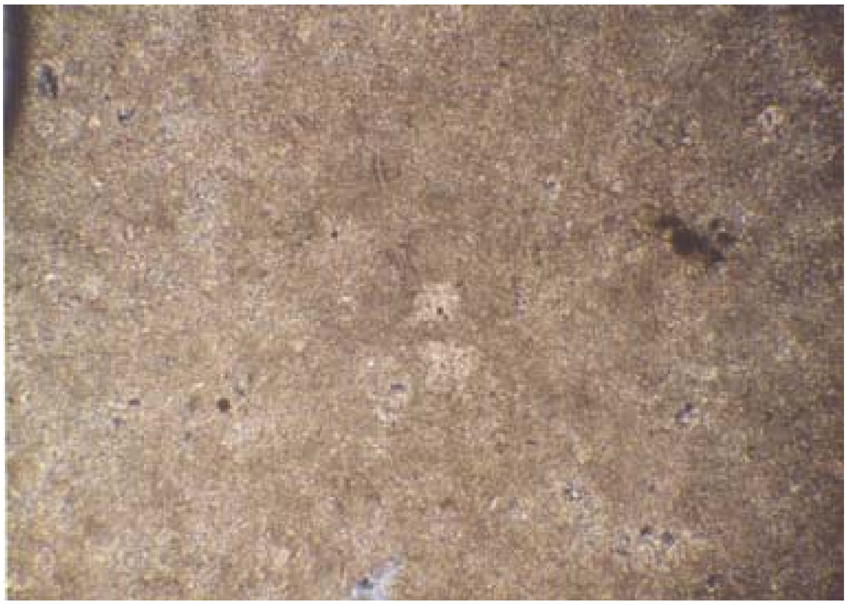

**Fig. 19. Well-defined composite calcitized dolomite crystals. The dedolomitization origin for grumeleuse texture in the micrite is certain; it is indicated by the presence of some definite calcite rhombohedra. Sample No. 65, XPL. X 16.**

Dedolomitization, therefore, produces calcite rhombohedra composed of equi-crystalline crystals which are slightly coarser than the original limestone texture. These microcrystalline calcite crystals seem to replace the former dolomite in the Tuwaiq rocks. Dedolomitization thus seems to have partially reproduced the original texture of limestone.

In rare cases, the worker can observe a special type of composite calcite rhombohedra characterized by relatively clearer and coarser microcrystalline crystals increasing in size porewards with drusy fabric. This drusy texture of calcite crystals within rhombohedra could suggest a calcite growth by cementation in earlier-formed rhombohedral pores rather than by direct replacement as pointed out by Evamy [37]. These rhombohedra appear to be partly or completely filled with drusy calcite in the present rocks. The calcite cement is, therefore, an end product of successive diagenetic changes which have apparently involved dolomitization, dedolomitization, selective leaching and finally calcite cementation.

The fine recrystallization texture is quite common in homogeneous lime mudstone facies which make up the dominant rock type of the Tuwaiq Mountain Formation. It generally consists of uniformly-distributed patches of fine microspar crystals within a micrite matrix, and form grumeleuse texture. These microspars patches are in many limestones to be part of composite calcite rhombohedral boundaries. These patches can appear either as well-defined or as ill-defined rhombohedra (Figs. 19-21).

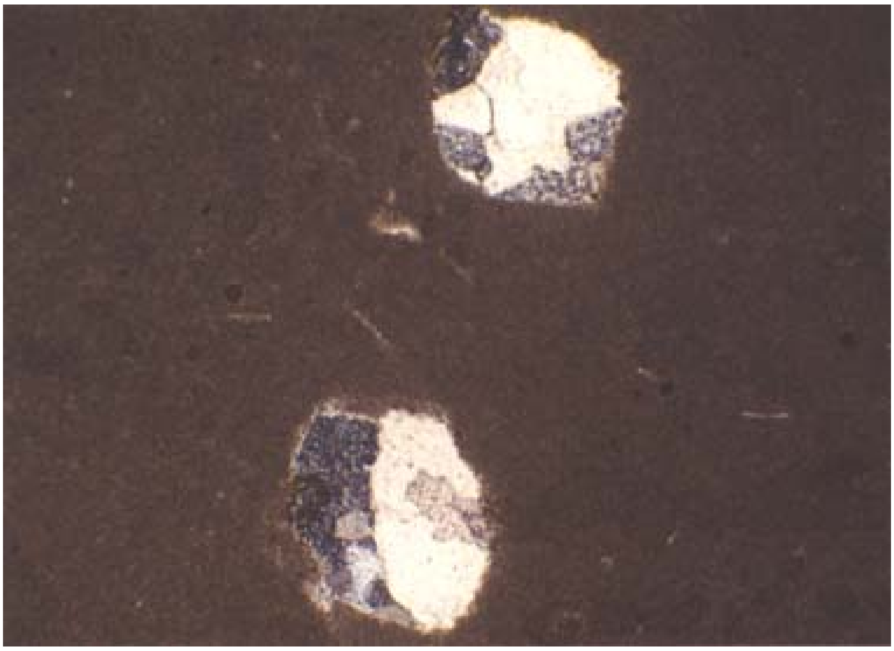

**Fig. 20. Shapes of dolomite crystals; they contain rhombic cores of polycrystalline calcite probably a replacement of dissolved dolomite rhombs in a lime mudstone. Sample No. 6 , XPL. X 6.3.**

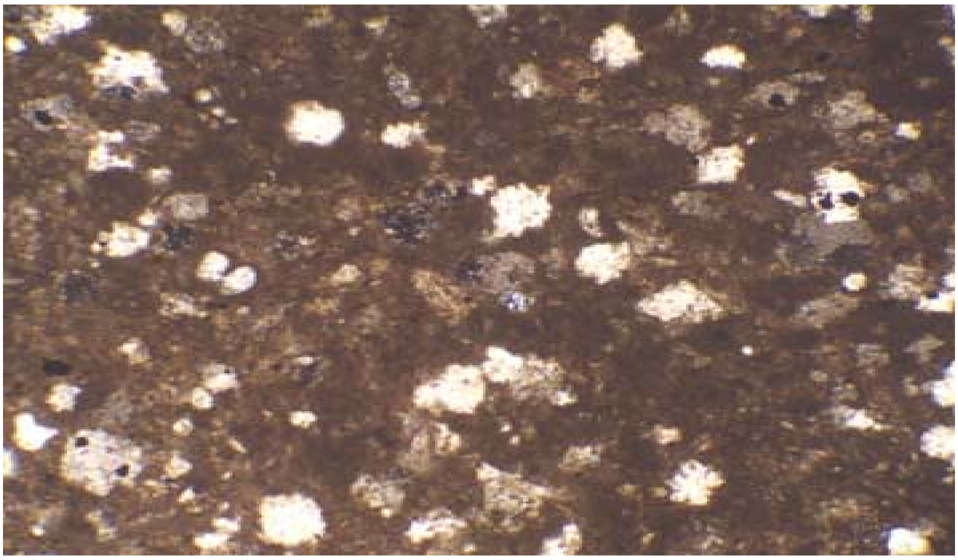

**Fig. 21. Patches of well-defined or ill-defined dolomite rhombs having a microspar composite calcite in a wackestone facies. Sample No. 37, XPL. X 6.3.**

The grumeleuse texture, produced by the dedolomitization process, is very similar to that produced by recrystallization of original lime mudstone. Evidently the criteria for the dedolomitization origin of such texture is based on the presence of rhombohedral structure often with ill-defined outlines, serrated contact between micrite and microspar, ferric oxide inclusions, and sometimes rhombohedral pores. However, in the absence of such evidence, it would be extremely difficult to decide whether grumeleuse texture have originated through dedolomitization or recrystallization.

In some instances, the limestone of presumably original micrite composition appears to be completely replaced by a uniform and clear microcrystalline calcite mosaic with no evidence as to the origin of its newly formed texture. In such cases, the field occurrence of such limestone with a reasonable degree of certainty indicates a dedolomitization origin rather than a neomorphic recrystallization origin.

Dolomitization of the sparry calcite cement, present as intergranular pore cement and infillings to cavities, is slight common in the Tuwaiq Mountain limestones. The replacing dolomite rhombs may grow within larger or smaller anhedral calcite crystals and across the boundaries between these calcite spars and allochems or micrite. The unaltered dolomite is generally free of both the ferrous and the ferric forms of iron, though it preferentially replaces the ferron sparry calcite host. Dedolomitization of these crystals has invariably regenerated the original sparry calcite.

Ghosts and outlines of replaced fossils and peloids can still be seen within the matrix of many dolomite rocks. The fine texture of micritic envelopes and the internal structure of bioclastic debris are frequently preserved in detail after complete dolomitization. This preservation of fabrics and primary structures of pre-existing allochems as ghosts within the replacement dolomite crystals is produced by impurities and relict calcite inclusions [38]. These inclusions could eventually form centers for the growth of calcite crystals during dedolomitization.

Evidence of the regeneration of some fossils is found in dedolomitized packstones and grainstones of the Tuwaiq Mountain Limestone. Echinoderm debris are among these fossils and their optically continuous calcite overgrowth is frequently regenerated by dedolomitization (Figs. 8, 14 & 22).

In the Tuwaiq Mountain limestones, dedolomitization is found to affect the inner portion of dolomite crystals, thus creating a calcite core enclosed by a dolomite rim. The dedolomitized core often consists of a calcite mosaic which is composed of equant subhedral microspar, similar to that found in composite calcite rhombohedra. This observation seems to indicate that dedolomitization has generally started from the center and proceeded towards the edges of the dolomite crystals.

The rhombohedral pores in the Tuwaiq Mountain limestones are often lined with relicts of dolomite or granular calcite and occur in association with dolomite and

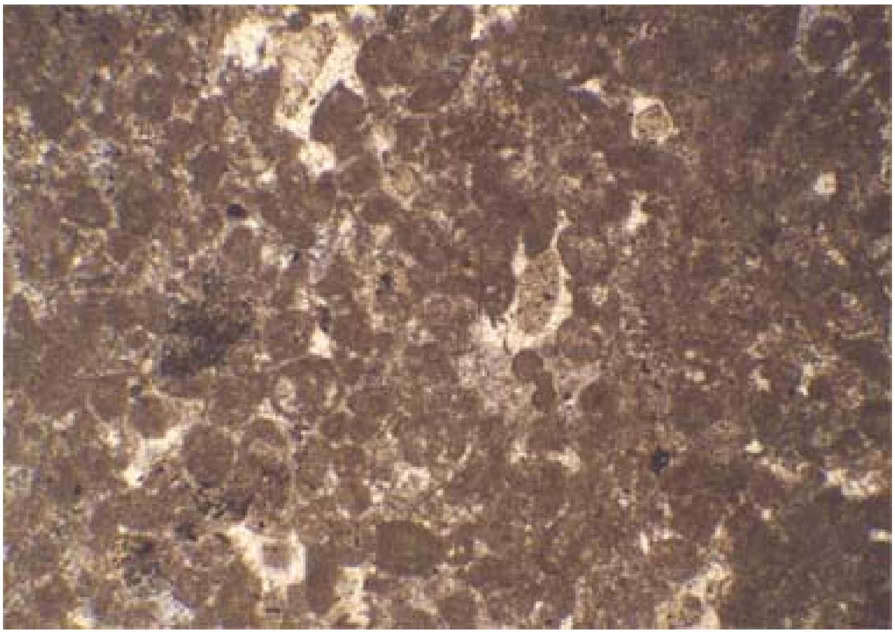

**Fig. 22. Peloidal-foraminiferal packstone. Many peloids of foraminiferal origin. Some of these forams are slightly altered, while others are in their midway to complete alteration by micritization. Note the echinoderm debris (at the center) with its optically continuous calcite overgrowth which is regenerated by dedolomitization. Sample No. 72, XPL. X 6.3.**

dedolomite rhombohedra (Figs. 18 & 20). These pores can be partly or completely destroyed by later calcite cementation distinguished by its drusy texture and the lack of relict dolomite. This interpretation is based on the following criteria:

1. The intimate association of rhombohedral pores with dedolomite rhombohedra and the common presence of relict calcite lining the pores.
2. The rhombohedral pores are found to be a surface or near surface phenomenon, just as that of dedolomitization.
3. If rhombohedral pores are considered as intermediate stage in the near surface process of dedolomitization, then any relict inclusions from the original limestone would be eliminated, and no trace of the predolomitization texture could be regenerated by dedolomitization. Besides, composite calcite rhomnbohedra would always be secondary to rhombohedral pores and, therefore, they should all exhibit cementation mosaics.

The regional dedolomitization, that affected the Tuwaiq rocks and adjacent formations, resulted more likely from a replacement process. It seems certain that this replacement process has been brought about by sulphate solutions reacting with dolomites as proposed by Shearman and others [36] and De Groot [28]. The source of these sulphate solutions is evidently the dissolved deposits of massive anhydrite of the Arab and Hith Formations, sometime before their erosion. Only such mechanism of dedolomitization does explain the widespread occurrence and extensive lateral distribution of dedolomites over a distance of hundreds of kilometers.

This conclusion is further supported by the concentration of massive dedolomite beds in the Tuwaiq Mountain limestones.

### 5) Recrystallization

This phenomenon is formed by crystal enlargement in lime mudstone facies which change from very fine to coarser crystals. Recrystallization and clotted textures are mostly found in the lime mudstone rocks and they probably formed and resulted from dedolomitization (Figs. 17, 23 & 24). Most of the lime mudstone rocks are crystallized into microspar and pseudospar within the lime mudstone facies.

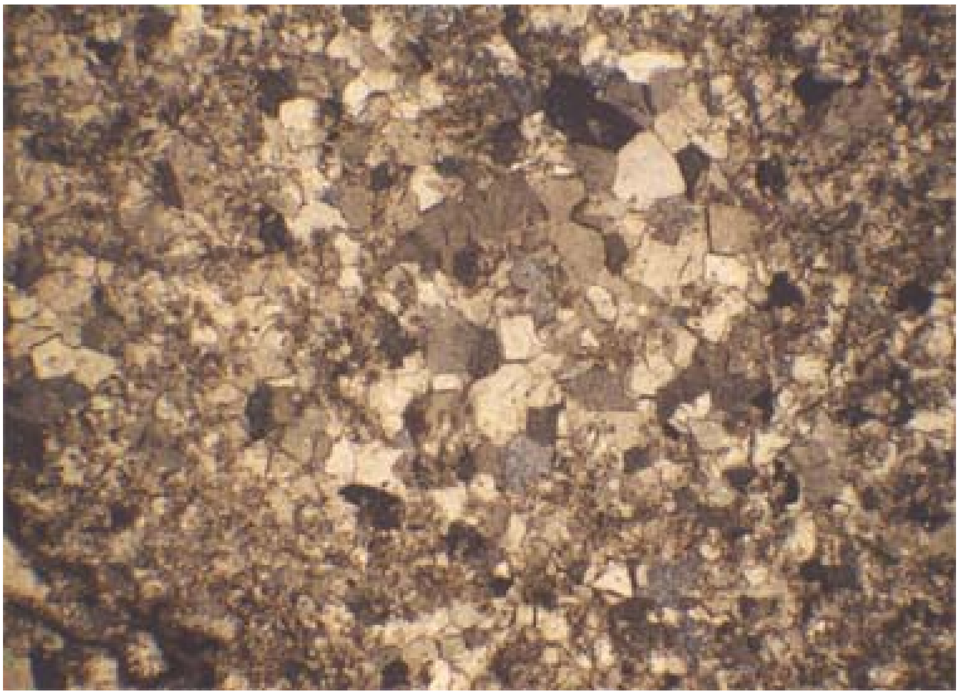

**Fig. 23. Recrystallized sparry calcite and the crystal enlargement in the lime mudstone forming recrystalized and clotted textures. Sample No. 36, XPL. X 2.5.**

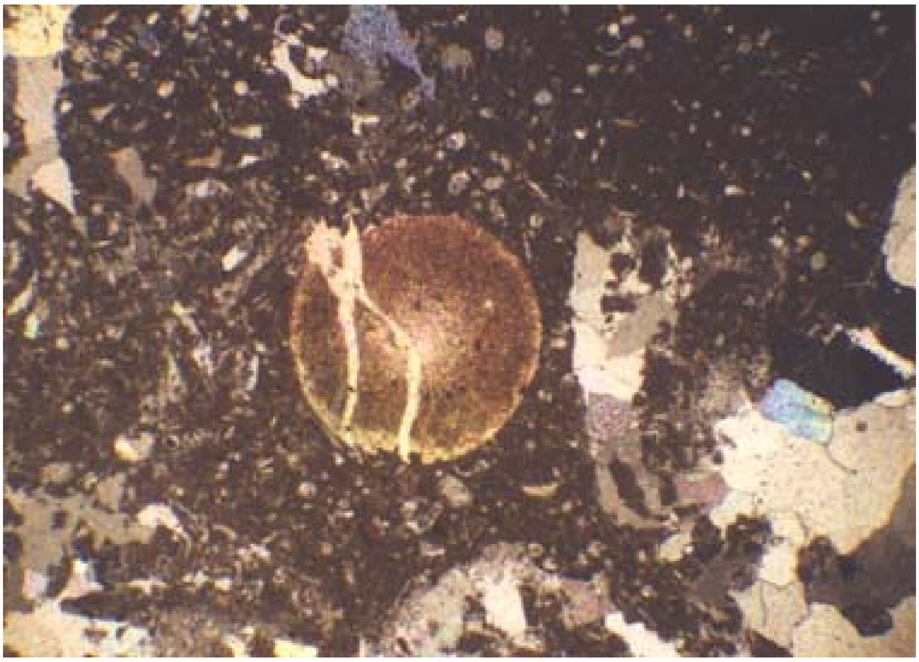

**Fig. 24. Beautiful cross section in an echinoid spine in bioclastic packstone. Note the crystal enlargement to form recrystallized and clotted textures. Sample No. 41, XPL. X 2.5.**

Porosity is present in all limestone facies of the Jurassic Tuwaiq Mountain limestones. Their presence is essential for petroleum accumulation in many Jurassic reservoirs. Abu Hadriyah is an oil reservoir in the Tuwaiq Formation units. Both primary and secondary porosities are present in the Tuwaiq Mountain limestones. Moldic, intercrystalline, intergranular and intragranular porosities are present. The intercrystalline porosity, though minimal, has more likely resulted from dolomitization which caused an increase of pore spaces when limestone changed to dolomite. Rhombohedral pores are also present. Although the above porosity types are present, some porosity is totally or partly destroyed by overgrowth and mineralization.

## Conclusions

The conclusions drawn from the petrographic study of Jurassic Tuwaiq limestone rocks in central Saudi Arabia, are as follows:

1. The lime mudstones and the wackestones forming the bulk of the Tuwaiq Mountain rocks were deposited in normal marine conditions.
2. Occasional and laterally persistent packstone and grainstone beds represent temporary turbulent water conditions; they contain various bioclasts mostly of foraminiferal, echinodermal, bivalve and molluscan debris; they also contain

peloids, algal nodules and some intraclasts as well.

3. The examined limestone formation can be vertically divided, purely on lithologic grounds, into lower and upper.
4. Dolomitization is widespread in the Tuwaiq limestone and all dolomites are of secondary replacement origin. Dolomite shows a replacement of lime mud matrix, thus being common in mudstones and wackestones and relatively rare in packstones and grainstones. The majority of dolomites are of post-depositional (burial) origin, while a minority of dolomites might be of early penecontemporaneous origin. The dolomite porosity is insignificant because syntaxial dolomite overgrowth and younger calcite cement destroy the intercrystalline and mold voids.
5. Dedolomitization is another important diagenetic alteration that affected the exposures of the carbonate rocks in central Saudi Arabia after dolomitization. This phenomenon, resulting from the replacement of dolomite by calcite, is recognized in several textural forms in the affected rocks, such as composite calcite rhombohedra, microcrystalline and coarsely crystalline calcite.
6. The Tuwaiq Mountain limestone rocks are characterized by their high indurance. This is apparent in the lime packstones and occasional grainstones where the pore system is completely filled by calcite spar cement. Calcite cementation is evasive in the Tuwaiq limestones with complete destruction of primary and most secondary porosity.
7. Recrystallization textures, resulting from dedolomitization and not from neomorphism, are recognized in the Tuwaiq limestones.
8. Rhombohedral pores in the Tuwaiq limestones are created by the selective dissolution of dolomite rhombohedra.
9. Micritization of bioclasts is quite common and most of the peloids in the examined packstones are the products of intensive micritization of former skeletal grains especially small forams, fine mollusks and echinoderm debris.

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# عمليات النشأة المتأخرة لحجر جير متكون جبل طويق من العصر الجوراسي بوسط المملكة العربية السعودية

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(قدم للنشر في ٤/١/١٤٢٦هـ؛ وقبل للنشر في ٢٤/١٠/١٤٢٦هـ)

**ملخص البحث.** تمت دراسة عمليات النشأة المتأخرة لحجر جير متكون جبل طويق من العصر الجوراسي بوسط المملكة دراسة تفصيلية، ولقد قسمت صخور هذا المتكون إلى جزء سفلي وجزء علوي على أساس خصائصها الليثولوجية.

أمكن تمييز سحنات دقيقة متعددة في صخور هذا المتكون. السحنات الغالبة في هذه الصخور هي سحنات الوحل الجيري والواكستون والباكستون، وتتواجد سحنة الجير الحبيبي بشكل أقل أما سحنتا الباوندستون والفلوتستون فهما نادرتان.

هذا وقد أبرز حجر جير متكون جبل طويق العديد من مظاهر عمليات النشأة المتأخرة و التي تضمنت السمنتة والمكرتة والتدلمت وفقد التدلمت وإعادة التبلور.

وتميزت صخور المتكون الجيرية والجيرية المتدلمتة بظاهرة فقد التدلمت التي يستدل عليها بوجود بلورات الدولومايت التي تغيرت جزئيا وكليا إلى كالسايت نتيجة عمليات النشأة المتأخرة. وعلى الرغم من انتشار معدن الدولومايت في أغلب سحن المتكون كدليل على عملية التدلمت إلا أن عمليات الإذابة وفقد التدلمت وعمليات إعادة التبلور تعتبر مظاهر مميزة لهذه الصخور.