DIAGENETIC HISTORY OF THE HARUR FORMATION, EARLY CARBONIFEROUS (TOURNAISIAN), NORTHERN IRAQI KURDISTAN REGION

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ABSTRACT

The main diagenetic processes affected the Harur Formation of Early Carboniferous (Tournaisian) in Nazdur area, Northeast of Zakho town, Northern Iraqi Kurdistan are studied. Harur Formation is exposed in the Northern Thrust Zone of Iraq. One surface section, near Nazdur village, far north of Iraqi territory, was chosen for the purpose of this study.

Harur Formation has various lithologies, consisting of thin to medium bedded, black, organic limestone, dolomitic limestone, with black micaceous shale mainly in its lower and upper parts. A sum of 35 thin sections of limestones were petrographically studied. The formation had been affected by different diagenetic processes, which belong to three diagenetic stages; early (shallow burial), middle and late (deep burial and subsequent uplifting). Processes belonging to early stage are hardly preserved; those of middle stage are common, while late processes are dominant. The described diagenetic processes are; micritization, dolomitization, neomorphism, cementation, solution, compaction, silicification, and others.

التاريخ التحويري لتكوين هارور، الكربوني المبكر (التورنازي) شمال أقليم كوردستان العراق

سردار محي الدين بالكي

المستخلص

تمت دراسة العمليات التحويرية المؤثرة على صخور تكوين هارور ، الكربوني المبكر (التورنازي) في منطقة نازدور شمال شرق مدينة زاخو ، اقليم كوردستان العراق. يتكشف تكوين هارور في نطاق الزحف الشمالي، حيث تم اختيار مقطع سطحي قرب قرية نازدور في أقصى شمال العراق لغرض الدراسة. تتألف صخارية تكوين هارور من طبقات رقيقة الى متوسطة السمك من الصخر الجيري العضوي الاسود و الصخر الجيري الدولوميتي المتداخل مع السجيل الاسود في الأجزاء العليا والسفلى. اظهرت الدراسة البتروغرافية المعتمدة على 35 شريحة رقيقة، بان تكوين هارور تأثر بعمليات تحويرية مختلفة تعود الى ثلاث مراحل تحويرية: المبكرة (الدفن الضحل) و المتوسطة والمتأخرة (الدفن العميق وعملية الرفع اللاحقة). وكانت العمليات التى تعود الى المراحل المبكرة غير شائعة بينما العمليات التي تعود الى المرحلتين المتوسطة والمتأخرة فقد تراوحت من شائعة الى سائدة على التوالي. تشمل العمليات التحويرية التي أثرت على التكوين : المكرتة، الدلمتة ، التشكل الجديد، السمنتة، الاذابة، الانضغاط، وغيرها من العمليات.

INTRODUCTION

The Paleozoic rocks are exposed in some patches in Northern Iraq, and Western Desert, in addition to their presence in some subsurface sections such as Khlessia well 1, Kifl 1, KH5/1, and Akkas 1. The Harur Formation was first

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recognized and described from the Ora fold, Amadia district, of Northern Thrust Zone of Iraq by Wetzel and Morton, 1952 in (Bellen et al., 1959). Lithologically, Harur Formation consists of thin to medium bedded black, organic limestone, dolomitic limestone, and black micaceous shale mainly in its lower and upper parts. The total thickness of the formation, in the type section is about 62 meters; while in the studied section is about 49.5 meters. Based on the evidence of fossils, the age of Harur Formation has been determined as Early Carboniferous (Tournaisian).

Aiming to fill the large gaps in the geology of Paleozoic units in Northern Iraq, the present study and other studies are expected to highlight details of the Paleozoic formations in Northern Iraq. The sum of all such studies would integrate to establish comprehensive correlation of Paleozoic units among outcrops and subsurface sections. The objective of this paper is to study the main diagenetic processes that affected Harur Formation, giving some clues to its post depositional history.

LOCATION AND METHODS

Nazdur village which is chosen for the purpose of this study, is located in far north of Iraqi territory, about 45 Km to northeast of Zakho town, Duhok Governorate (Fig.1). The studied section is located approximately on Lat.37°18' 45" N and Long. 43° 15' 46" E, nearly 1 Km to northeast of Nazdur village, just on the main road to the village. During field survey, the general geology and structural relations of the Paleozoic units in the surroundings were studied. This was executed to choose the most appropriate locality for the study. Sampling had focused on the main lithologies (limestones). The total number of collected samples is 35. The same number of thin sections were prepared and stained with the Alizarin Red S (ARS) solution following the procedure of Fridman (1959) for detecting the calcite and dolomite.

GEOLOGIC SETTING AND STRATIGRAPHY

The Harur Formation is exposed as isolated patches in some eroded cores and limbs of anticlines in the Thrust Zone of Northern Iraq. Nazdur area, which was chosen for present study, is the name of a village with the same name that is located within the Zone of Imbrication of the foreland basin, (according to Numan, 2000). Several reported E–W trending thrusts, had given rise to repetition or interruption of strata in the exposed succession. At this locality, the Paleozoic rocks crop out within the limb of one of the thrusted folds. Additionally, numerous normal and reverse faults and secondary folds within the existing formations characterize the area. All distortion in the stratigraphic succession of the area. The general trend of structural features is E – W.

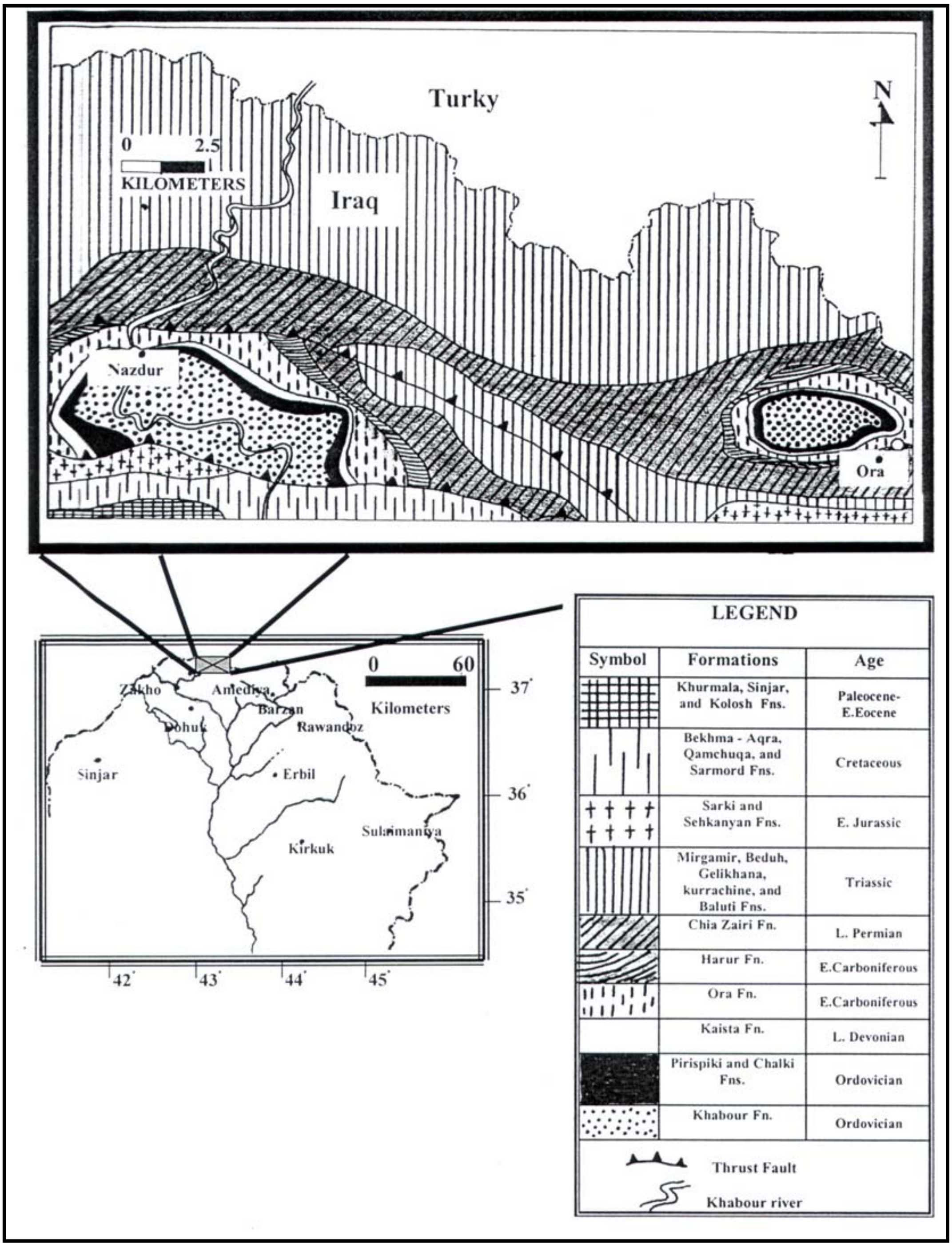


Fig. (1): Location and Geological map of the area of the studied section
(Modified from Sissakian, 2000)

In respect to topography, Nazdur area lies in a rugged terrain, extending along narrow and steep–sided long valley of consequent type. The main stream course in the area is Khabour River, which has tributaries or (drainage lines) of dendritic pattern.

In respect to stratigraphy, the investigated section includes stratigraphic succession, starting with oldest rock; Khabour Formation (Ordovician), which underlies Pirispiki Formation (Ordovician). The latter is, in turn, overlain by the younger Kaista Formation (Late Devonian), with Ora Formation (Early Carboniferous) overlying them. Followed by Harur Formation (Early Carboniferous) that overlies Ora Formation. The section terminates by the youngest Chia Zairi Formation (Late Permian) (Fig. 1). The nature of the boundaries of Harur Formation is not uniform; the lower boundary is conformable and gradational with underlying Ora Formation, while the upper boundary is unconformable with overlying Chia Zairi Formation.

PREVIOUS STUDIES

The Paleozoic rocks had, generally remained for along period of time away from geologic research, especially in outcrops, except for very few. Similarly, with several Paleozoic units the Harur Formation was first recognized and described from the Ora fold, Amadia district, of Northern Thrust Zone of Iraq by Wetzel and Morton, 1952 in (Bellen et al., 1959). Based on the fossils evidence, the age of Harur Formation has been determined as Early Carboniferous (Tournaisian) (Bellen et al., 1959). Buday (1980), in a general review of the formation, had described the depositional environment as marine neretic (mostly reef and fore–reef). Nader and Mustafa (2005), in a subsurface study pointed out that the age of Harur Formation is more likely to be Late Tournaisian. Lately, Shirwani et al. (2006), has contributed in a detailed study of microfacies and environmental analysis of Harur Formation in Nazdur area, they concluded that the depositional environment is shallow marine environment, mostly reef and reef flanks.

PETROGRAPHY

The lithologic composition of Harur Formation in the Northern Thrust Zone consists of thin to medium bedded, black, organic limestone, dolomitic limestone, intercalated with black micaceous shale mainly in its lower and upper parts. Using polarizing microscope, 35 thin sections of limestone samples were examined. The petrographic study shows that skeletal grains include: brachiopods, echinoderms, bryozoans, corals, in addition to ostracods. Nonskeletal grains include peloids only. Further petrographic details of Harur Formatin are presented in Sherwani et al. (2006).

DIAGENESIS

Diagenesis of carbonate rocks is more varied than that of clastic rocks particularly, because of metastable nature of carbonate minerals (Bathurst, 1975). Diagenetic processes include physical, chemical, and biological changes affecting sediments since their deposition, then lithification and emergence on ground surface under normal pressure and /or temperature (Larsen and Chilingar, 1979). These processes are either destructive diagenesis, caused by solution and pressure, or constructive diagenesis, caused by cementation and neomorphism.

Several diagenetic processes had affected Harur Formation through three main stages (paragenesis); early, middle, and late (Fig. 2). The descriptions of the most important processes are herein cited:

1- Micritization

This is the earliest diagenetic process taking the form of micritic rim (or envelope) (Fig. 2) due to borer organisms such as endolithic algal activity or fungi in carbonate deposits (Bathurst, 1975) in stagnant marine phreatic zone (Longman, 1980). The present study shows that micritization preferentially affected shells (valves) of brachiopods (Figs. 3.1, 3.5, 3.6, 4.6 and 4.7), bryozoans, (Fig. 3.2) and ostracods (Fig. 3.1). This process seems more active in lower and middle parts of the formation.

2- Dolomitization

Dolomite is commonly recognized in rocks of all ages by its typically rhombic crystal form. However, in many ancient rocks, dolomites can often be found as mosaic of anhedral crystals with irregular intercrystalline boundaries and undulatory extinction (Gregg and Sibley, 1984). Dolomitization requires rise in Mg /Ca ratio in saline water that enter pores and interstices of carbonate rocks (Folk and Land, 1975).

Dolomite Texture

The most important controls affecting dolomite texture are; mineralogy of the material being replaced, whether or not the dolomitizing solution is saturated with respect to the replaced mineral and the availability of nucleation sites (Sibley, 1982). The dolomite texture of Harur Formation, in the studied section, is of fine crystalline which is mostly of early diagenetic origin, in form of floating rhomb fabric (texture). This texture consists of either scattered euhedral dolomite rhombs within an affected micrite matrix (Fig. 3.3) or rhombs that are accumulated (or juxtaposition) along stylolite surface with considerable insoluble materials (Fig. 3.4). Such fabric type was also suggested by (Randazzo and Zachos, 1984) as early stage of dolomitization.

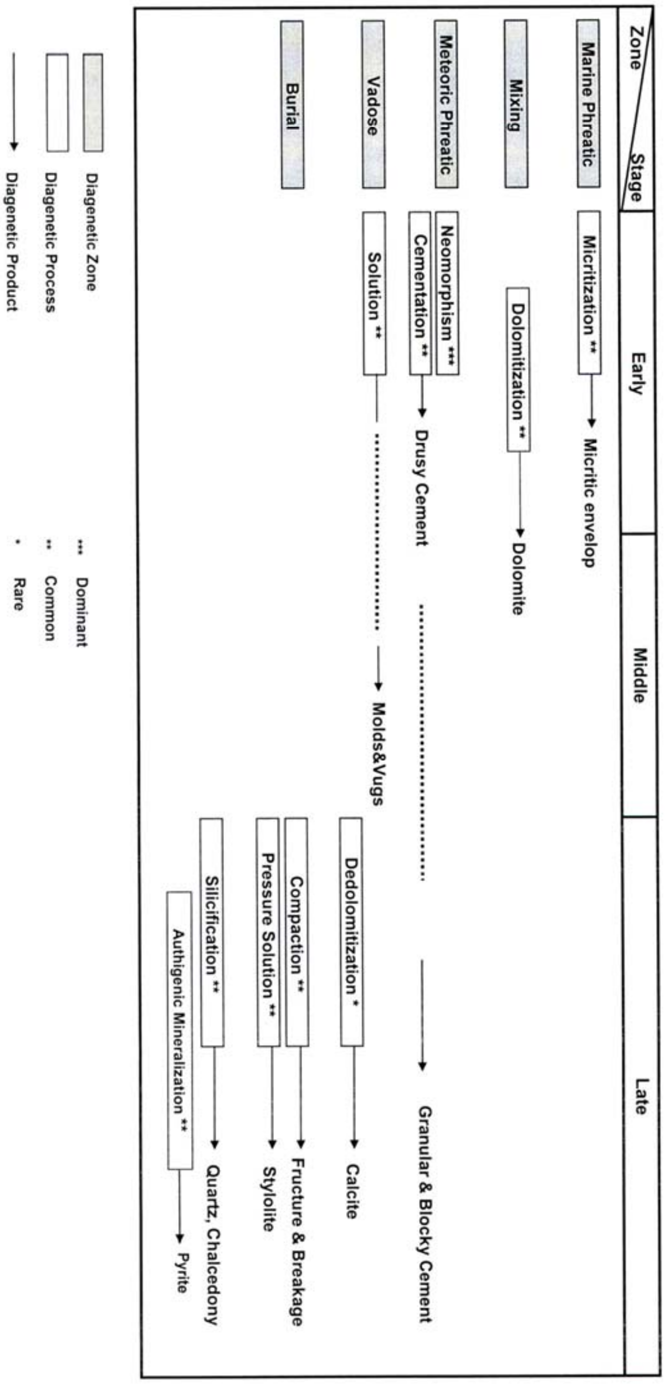


Fig. (2): Main diagenetic zones , stages , processes and products of Harur Formation (Early Carbonifereous) , Nazdur area,northern Iraq

3- Neomorphism

The term neomorphism was first introduced by Folk (1965) to include all transformations between both recrystallization and inversion. Neomorphism of marine sediments is attributed to meteoric phreatic conditions (Longman, 1980).

Neomorphism effect was obvious on rocks of Harur Formation particularly on shells of brachiopods (Figs. 3.7, 3.8, 5.4 and 6.2), corals (Fig. 4.5), and bryozoans (Fig. 5.1). This effect has extended to the micritic matrix of the formation. Consequently, the neomorphism processes are merely an alteration of microcrystalline calcite (micrite) to microspar and pseudospar (Figs. 4.1 and 5.8).

4- Cementation

Cementation is chemical deposition of calcium carbonate from saturated solutions, between or inside grains or in pores and cracks resulted by solution, all leading to growth of sparry calcite in these cavities (Larsen and Chilingar, 1979).

Cementation in Harur Formation is not a dominant process especially in the studied section. However, several types of cement are recognized including the following, in order of dominance:

a- Drusy Cement

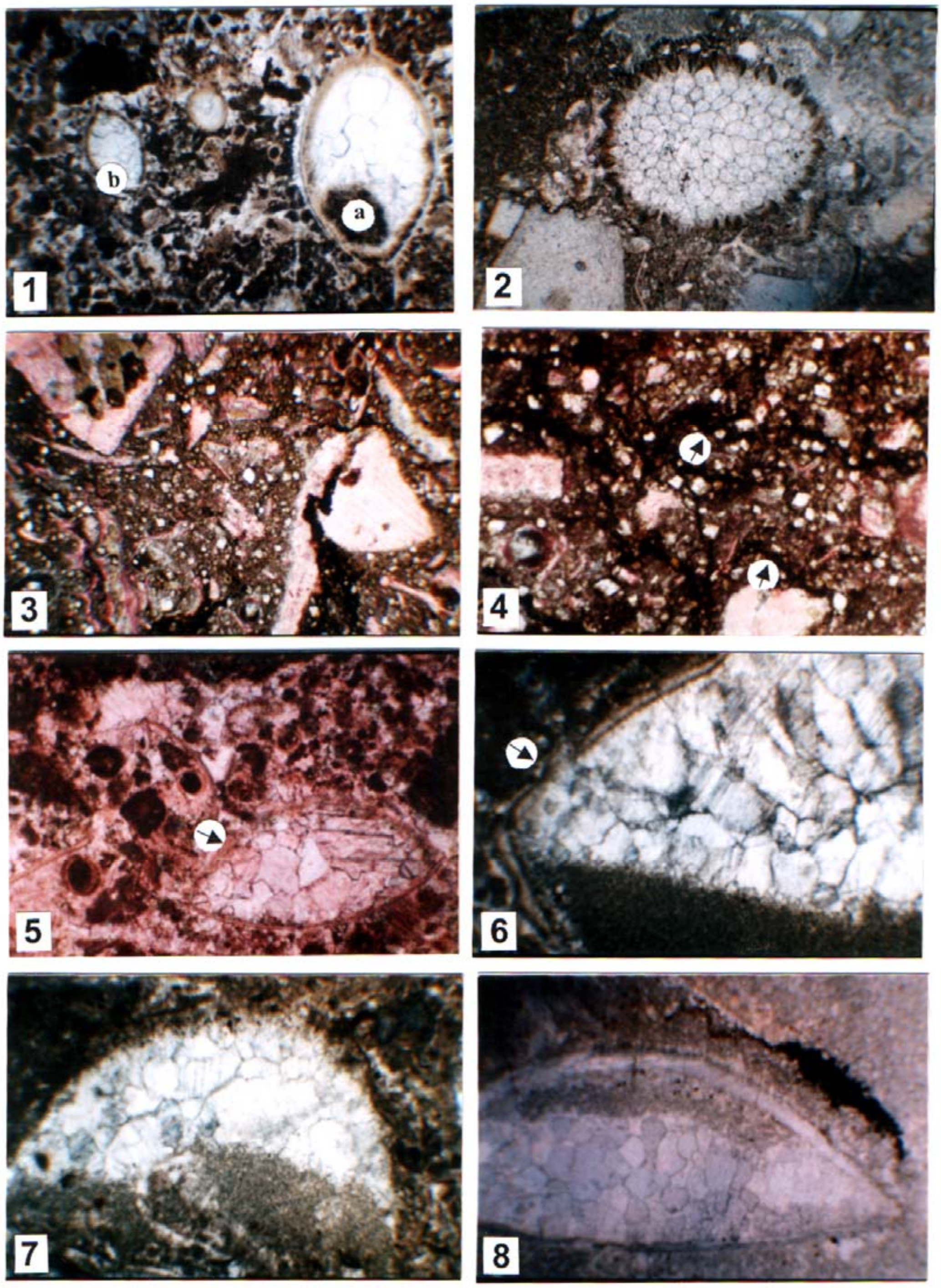
Drusy cement consists of anhedral to subhedral calcite crystals, usually greater than 10 µm and crystal sizes increase from pore walls to center of cavities (Flugel, 1982). Drusy cement was found to be common in a studied section of Harur Formation. It was observed filling the chambers of articulated brachiopods (Fig.1.6) or sheltered primary pores (Fig. 1.7).

b- Granular Cement

Granular cement seems to be the second most common in the studied samples of Harur Formation.This cement type is observed infilling articulated brachiopods (Figs. 3.1, 3.5 and 3.8) and brachiopod spines (Figs. 4.1 and 4.7) , compaction related fractures (Figs. 4.2 and 6.1), sheltered primary pores (Fig. 4.6), and intergrains (Fig. 4.3). According to Longman (1980), granular cement occurs under fresh water phreatic conditions. This presumption supports the late diagenetic origin of this cement type.

c- Blocky Cement

This cement type owns large euhedral – subhedral crystals. The presence of this type is limited in section of Harur Formation. It is only found in fractures and cracks (Fig. 4.4) that confirms its late diagenetic origin. Similar to granular cement, the blocky type is believed, by Longman (1980), to have formed in fresh water phreatic zone.



Figs. 3.1 – 3.8

Figs. 3.1 – 3.8

3.1 Micrite envelope (rim) surrounding a brachiopod shell (a), and ostracods (b), both filled with granular cement, in a micritic matrix. H. 29, P.P., 32X.

3.2 Micrite envelope (rim) surrounding a bryozoan shell, in a neomorphosed micrite matrix. H. 21, P.P., 32X.

3.3 Floating rhombs fabric, showing scattered dolomite rhombs floating in micritic matrix. H. 13, P.P., A.S., 32X.

3.4 Scattered dolomite rhombs concentrated along stylolite surface (arrows), along which local Mg – rich solution is moved for dolomite formation. H. 14, P.P., A.S., 63X.

3.5 Articulated brachiopod filled with drusy cement (arrow). Note micrite envelope surrounding the valves. H. 30, P.P., A.S., 32X.

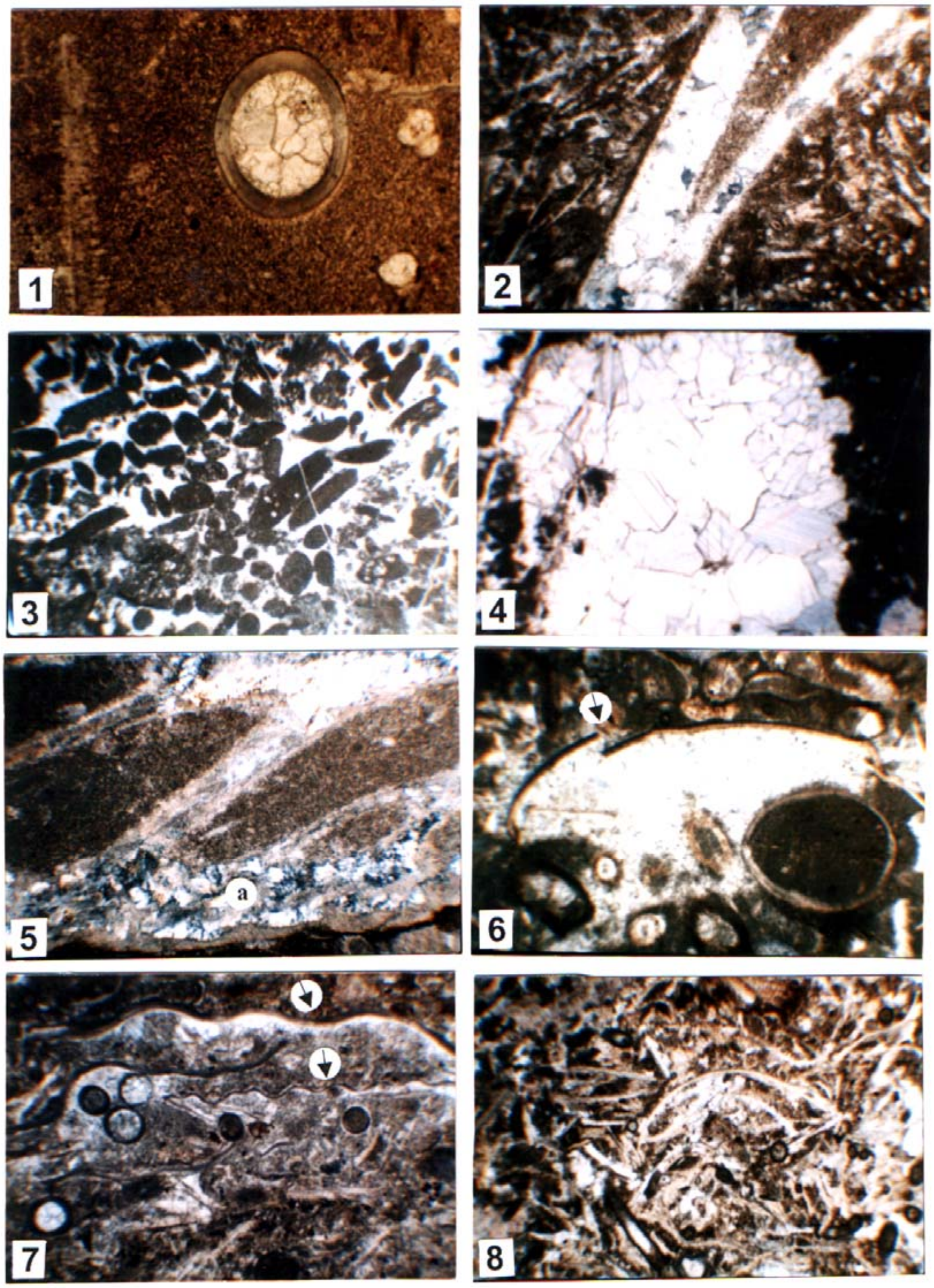
3.6 Drusy cement filling an articulated brachiopod. Note sparite crystal coarsening inward, and micrite envelope (arrow). H. 4, P.P., 32X.

3.7 Cementation (drusy cement) filling sheltered space under micritized (micrite envelope) brachiopod valve. H. 5, P.P., 32X.

3.8 Articulated brachiopod filled with granular cement. H. 6, P.P., 32X.

Key Words

H. Harur Formation
P.P. Plane Polarized
X.N. Crossed Nicols
A.S. Alizarin Stained
X. Magnification power



Figs. 4.1 – 4.8

Figs. 4.1 – 4.8

4.1 Cementation (granular cement) filling brachiopod spine in a neomorphosed micritic matrix. H. 2, P.P., 63X.

4.2 Fracture porosity, reduced by cementation (granular cement). H. 24, X.N., 32X.

4.3 Cementation (granular cement) filling spaces between peloids. H. 31, P.P., 32X.

4.4 Blocky cement filling a fracture (vein). The matrix is organic rich lime mud (micrite). H. 32, P.P., 32X.

4.5 Selective silicification affecting corals (a). Note micrite matrix not affected by silicification. H. 12, X.N., 32X.

4.6 Breakage of skeletal grain (brachiopod valve) (arrow) due to weight of overburden. Note the valve acts as an umbrella to form shelter porosity that is later reduced by cementation (granular cement). H. 22, P.P., 32X.

4.7 Plastic bending of micritized brachiopod valves showing wavy appearance (arrows). Most of them are oriented parallel to the bedding plane due to compactional effect. H. 28, P.P., 32X.

4.8 Over close packing of brachiopod valves due to compactional effect. H. 27, P.P., 32X.

Key Words

H. **Harur Formation**
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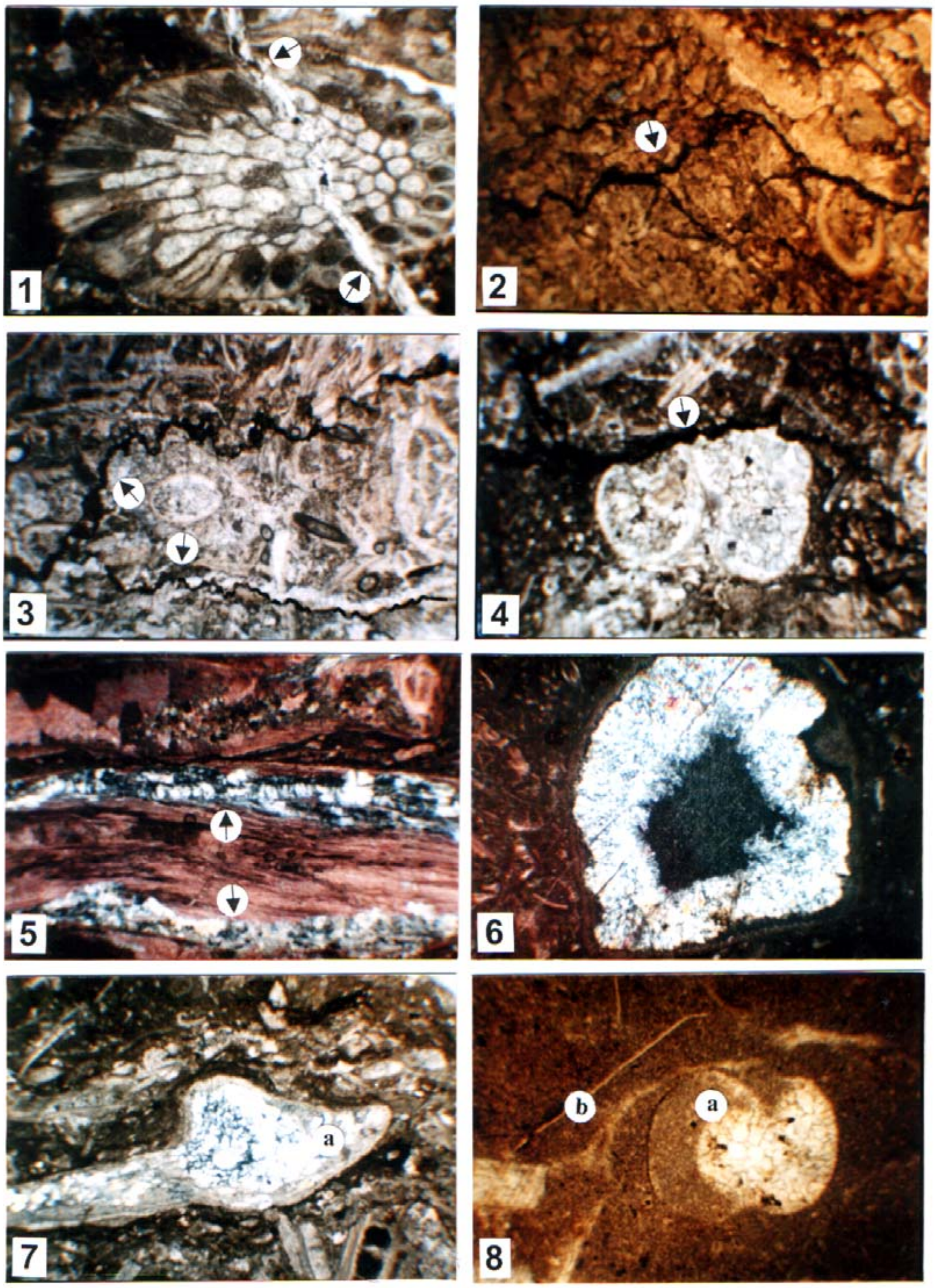

Figs. 5.1 – 5.8

Figs. 5.1 – 5.8

5.1 Bryozoan shell cut by a cement – filled fracture (arrows). Both filled with granular cement. H. 26, P.P., 32X.

5.2 Sutured seam stylolite, irregular type with peaks of low amplitude (arrow). H. 5, P.P., 32X.

5.3 Non–sutured seam stylolite (anastomosing stylolite) (arrows). Note insoluble material concentrated along stylolite surface. H. 27, P.P., 32X.

5.4 Sutured seam stylolite (arrow). Fossils seen partly missing or (bisected) on stylolite surface. H. 26, P.P., 32X.

5.5 Selective silicification affecting brachiopod shells (arrows). H. 26, X.N., 32X.

5.6 Echinoderm plate , selectively silicified within unaltered micritic matrix. H. 15, X.N., 32X.

5.7 Large brachiopod shell (a), selectively silicified. Note surroundings are not affected. H. 17, X.N., 32X.

5.8 Moldic porosity, brachiopod mold (a), partly filled by granular cement. Note matrix and other brachiopod valves (b) are neomorphosed. H. 2, P.P., 32X.

Key Words

H. **Harur Formation**
P.P. **Plane Polarized**
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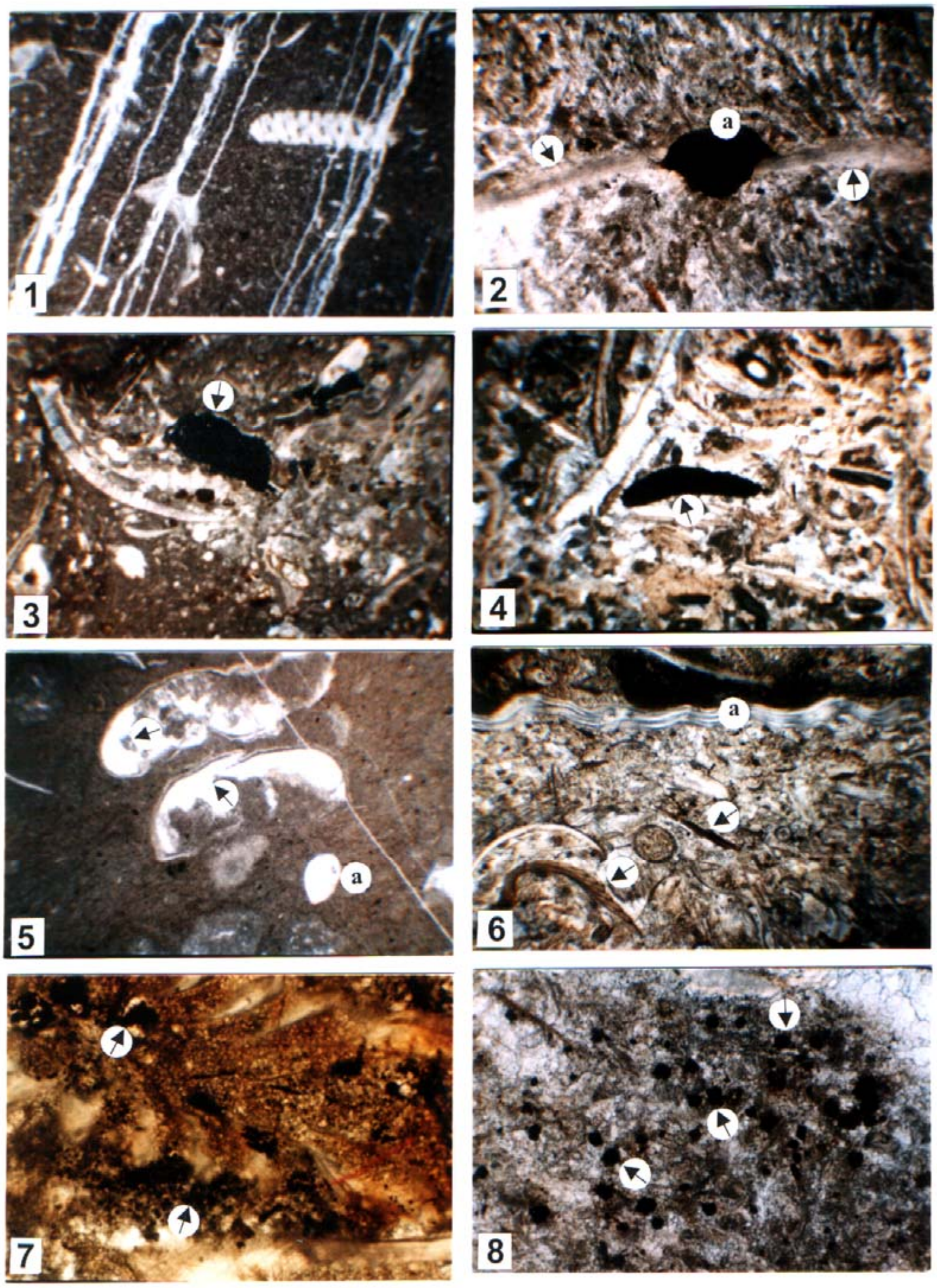

Figs. 6.1 – 6.8

Figs. 6.1 – 6.8

6.1 Fracture porosity, several sets of fracturing caused by either tectonic activity or compaction, all of them are filled or reduced by cementation. H. 19, P.P., 32X.

6.2 Vuggy porosity (a), filled with black organic material. Note brachiopod valve strongly neomorphosed (arrows). H. 25, P.P., 32X.

6.3 Vuggy porosity (arrow), produced by solution enlargement of brachiopod valves. H. 17, X.N., 32X.

6.4 Solution (leaching) of brachiopod valve (arrow). H. 27, P.P., 32X.

6.5 Shelter porosity (arrows), reduced by cementation, and moldic porosity (a), produced from solution of ostracod shell. H. 28, P.P., 32X.

6.6 Phosphatic shell (arrows). Phosphatization, affecting brachiopod valves. Note plastic bending of brachiopod valve (a). H. 4, P.P., 32X.

6.7 Framboidal pyrite (arrows) in a neomorphosed micritic matrix. H. 5, P.P., 63X.

6.8 Small cubic pyrite (arrows) in a neomorphosed micritic matrix. H. 25, P.P., 63X.

Key Words

H. Harur Formation
P.P. Plane Polarized
X.N. Crossed Nicols
A.S. Alizarin Stained
X. Magnification power

5- Solution (Leaching)

This process is greatly enhanced by fresh water rather than marine water (i.e. during early to middle diagenetic stage) (Fig. 2). Solution had imprints on rocks of Harur Formation in the studied section and had affected most of shells of brachiopods, and ostracods, (Figs. 6.4 and 6.5). According to Longman (1980), this process occurs under fresh water (phreatic and vadose) environments.

6- Porosity

Porosity is lost or reduced through cementation, compaction and gained through solution, dolomitization and tectonic fractures. The petrographic examination of rocks of Harur Formation had shown that the available porosity (even low in value) is mainly of the secondary type. Basically, the porosity classification of Choquette and Pray (1970) is followed:

I- Fabric – Selective Porosity

Three types of porosity were recognized:

a- Moldic porosity

This type is formed by the selective removal of primary constituents from sediments or rocks. Molds of fossils, such as those of brachiopods (Fig. 5.8) were recognized. They are generally formed by the effect of fresh water on their initial susceptible mineralogy, and are often infilled by equant calcite cement.

b- Shelter porosity

It is also called umbrella voids (Reeckmann and Friedman, 1982), and is found bellow large particles such as skeletal fragments (large molluscan shell or brachiopod valves) (Figs. 3.7, 4.6 and 6.5), which act as umbrellas protecting the pore space beneath them from downward movement of fine material. This type is found in studied section of Harur Formation and is always infilled by later spary calcite cement.

c- Interparticle porosity

This kind of porosity represents the space between grains, and is modified by later compaction (Reeckmann and Friedman, 1982). Interparticle porosity is recognized in the upper part of formation (Figs. 4.2 and 4.3).

II- Non Fabric – Selective Porosity

Two types of this division were recognized in rocks of Harur Formation:

a- Fracture porosity

This type is caused by either tectonic activity or compaction process. Several stages of fracturing can be recognized in Harur Formation throughout the studied section (Figs. 4.2 and 6.1); all of them are filled or reduced by granular and blocky cement.

b- Vuggy porosity

This kind is less common in Harur Formation. It results from dissolution and may have no relationship to initial rock texture (Reeckmann and Friedman, 1982). Many vugs may be solution – enlarged molds and fractures. According to Longman (1980), this type of porosity generally forms at the vadose zone of fresh phreatic environment. Vuggy porosity, traced in the upper part of Harur Formation, is often filled with organic materials (Figs. 6.2 and 6.3).

7- Dedolomitization

This term was first introduced by Vonmorlot (1848, in Al-Hashimi and Hemingway,1973) to indicate the process of calcite replacing dolomite.Back et al (1983) have considered the dedolomitization as near surface or surface diagenetic phenomenon. It is believed to have taken place while the beds were exposed. This process is not common in Harur Formation and is restricted, when found, in the upper parts of the studied section, possibly post uplifting of sediments (Telodigaenetic origin).

8- Compaction

Compaction of sediments resulted in reduction of sediment thickness and intergranular porosity (Meyers, 1980). Additionally, Tucker (1981) divided compaction into two types:

i - Mechanical Compaction
ii- Chemical Compaction

i- Mechanical Compaction

Mechanical compaction is the process that decreases the bulk volume of single grains or that result in closer packing of grain, i.e., grain deformation and reorientation (Meyers, 1980). The common criteria for recognizing mechanical compaction in Harur Formation are mentioned below:

1. Fractures usually filled with sparry calcite cement (Figs. 4.2 and 4.1).
2. Breakage of grains (Fig. 4.6).
3. Orientation and plastic bending or (waving) of particles particularly the valves of brachiopods (Figs. 4.7 and 6.6).
4. Overclose packing (Figs. 4.8 and 6.4).
5. Veins penetrated fossils (Fig. 5.1).

ii- Chemical Compaction (Pressure Solution)

This process is well noticed by grains which undergo dissolution under applied stress (overburden) giving rise to pressure solution effect (Bathurst, 1975). The main result of chemical compaction is stylolites, which are pressure solution features along seams that are laterally extensive on the scale of hand specimen (or greater) and that cut numerous grains, mud, and cement.

Stylolites

Stylolites result from pressure solution, dissolution of the limestone along planes as a result of overburden or tectonic pressure (Wanless, 1979). Stylolites seem to be common phenomenon in Harur Formation. Among stylolite types described by Wanless (1979), only two of them can be recognized:

i- Sutured – Seam Stylolite

This type forms within units having structural resistance and little or no platy insoluble minerals (Wanless , 1979). The current study shows that the most common stylolites in the studied thin sections are of irregular type (a subdivision of sutured seam stylolites), mostly with peaks of low amplitude (Fig. 5.2). Some fossils are often observed partly missing or bisected, adjacent to stylolites (Fig. 5.4). It was observed that stylolites were parallel to bedding and according to Tucker (1981) they are formed due to load of overburden.

ii- Non – Sutured Seam Stylolite

Occurs in limestones that have significant amount of clay and platy silt (Wanless, 1979). They show low relief and are thinly undulated. Anastomosing type of non–sutured seam stylolites is noticed to be present in rocks of Harur Formation (Fig. 5.3).

9- Silicification

Silicification in Harur Formation is a common diagenetic process, which occurs particularly within the lower and middle parts of the formation.The petrographic study shows that there is a selective silicification, which affected valves of brachiopods (Figs. 5.5 and 5.7), echinoderms (Figl. 5.6), and corals (Fig. 4.5) either completely or partially without affecting the groundmass.

10- Phosphatization

Phosphatization affects bones and other skeletal parts in phosphorus – rich medium, a process promoted by upwelling currents which are vital for P–enrichment in sea water (Slansky, 1986). Phosphatized bioclasts were noticed in rocks of Harur Formation belonging to the lower and middle parts (Fig. 6.6).

11- Authigenic Mineral

• Pyrite

Pyritization, producing different crystal forms of pyrite, is formed under reducing conditions, probably promoted by decay of organic matter, which, inturn, is induced by anaerobic bacteria, or solution of sulfate by reducing bacteria (Hudson, 1982). Reducing conditions, necessary for pyritization, are available during early burial stages when anaerobic bacteria become active (Larsen and Chilingar, 1979). The most common pyrite forms noticed in the studied section are framboidal pyrite (Fig. 6.7), and small cubic pyrite (Fig. 6.8).

SUMMARY AND CONCLUSIONS

- The diagenetic processes belong to three diagenetic stages; early (shallow burial), middle, and late (deep burial and subsequent uplifting).
- Processes of early stage are hardly preserved; those of middle stage are common, while late processes are dominant.
- Diagenetic processes, arranged in order of chronology, include; micritization, dolomitization (early stage), neomorphism, cementation, solution, dedolomitization, compaction, authigenesis (pyritization).
- Neomorphism is the most common process, and had affected considerable skeletal grains and groundmass.

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