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Petrography and diagenetic history of the Kometan Formation (Upper Cretaceous) in the Imbricated Zone, Iraqi Kurdistan Region

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Abstract: The petrography and diagenetic history of Upper Cretaceous Kometan Formation is investigated from its type locality in Kometan Village, Imbricated Zone, Kurdistan Region, Northeastern Iraq. The formation comprised 44 m of white weathered, light grey, thin to medium bedded fractured limestones with chert nodules and lenses in the upper part. The petrographic study of the formation is based on 50 thin sections and showed that the majority of limestones microfacies are carbonate mud (micrite). The skeletal grains include planktonic foraminifera, oligostegina, calcisphers, ostracods, pelecypods, larvae ammonoids and echinoderms. Non-skeletal grains include peloids only. The Kometan Formation has been subjected to several diagenetic processes such as: micritization, dolomitization, cementation, neomorphism, compaction, silicification, solution, phosphatization, glauconitization and fracturing. All these occurred during marine phreatic shallow burial stage and activated during intermediate to deep burial and uplifting in the late stages. The paragenetic history of the Kometan Formation has passed through four diagenetic environments including; marine, meteoric, burial and uplifting.

Keywords: Petrography, diagenetic stages, Kometan Formation, Kurdistan, Northern Iraq

INTRODUCTION

The Upper Cretaceous Kometan Formation is a fractured carbonate petroleum reservoir in Northern Iraq, located in the lower portion of the AP9 (Late Turonian–Danian) tectonostratigraphic megasequence Arabian Plate (Sharland *et al*., 2001). The formation contributed to the forming of the huge oil fields situated in the western areas of the Zagros foreland basin, including Hamren, Taq Taq, Khabaz, Jambur, Kirkuk and Bi Hassan oil fields (Aqrawi *et al*., 2010). Kometan Formation is a part of the Turonian-Lower Campanian sub cycle and widely crops out in northeastern Iraq particularly in Sulaimaniyah Governorate in the Kurdistan region. lt is also found in the subsurface wells such as: Chamchamal 2 and Kirkuk 109 and 116 wells in addition to some wells of the Mosul Petroleum Company (Bellen *et al*., 1959). It is laterally equivalent to Khasib, Tanuma, and Saadi formations in the central and southern Iraq (Buday, 1980). Dunnington firstly recognized the formation in 1953 in Kometan village close to Endezah, NE of Rania town, northern Iraq (Bellen *et al*., 1959). Lithologically, the Kometan Formation comprises of white weathering, light gray, thinly to thickly bedded limestone with glauconite at the base and chert nodules in the upper parts of the formation.

The Formation have been studied by many researchers such as Bellen *et al*. (1959), Buday (1980), Al-Sayyab *et al*. (1982), Al-Jassim *et al*. (1989), Al-Khafaf (2005), Al-Barzinjy (2008), Karim *et al*. (2008), Karim & Taha (2010), Al-Ubaidy (2011), Al-Bassam & Fouad (2012), Asaad (2014), Jaff (2015) and Balaky *et al.* (2016). The study aims to determine the petrography and diagenetic processes of Kometan Formation in the studied section in order to understand the diagenetic history of the formation.

GEOLOGICAL SETTING

The High Folded and Imbricated Zones in Iraq are characterized by well exposures of Cretaceous rocks. Therefore, the Kometan type locality close to Kometan village in the Shahidan valley, about 7 km southeast to Endezah and 20 km northeast of Ranya city, approximately on lat. 36° 24′ 28″ N and long. 44° 48′ 18″ E was chosen for the purpose of this study (Figure 1). The studied area is located in the Balambo-Tanjero tectonic zone which exhibits tight belt (more than 25 wide) and had NW–SE trending in the imbricated zone. The zone exposed near the Iranian border from the SE and extended to the Turkish border from the NW in the northern edge of Arabian platform. It is characterized by intensive folding and faulting inside the unstable shelf of Iraq (Amin, 2009). The structural style of this zone is the outcome of two tectonic phases both Late Cretaceous obduction and Late Tertiary uplift (Jassim & Goff, 2006). This zone was tilted towards the northeast and thrusted by sheets of the Zagros Suture Zone during Late Miocene-Pliocene period. The Balambo-Tanjero zone is equivalent to the Zagros Imbricated Zone, which is distinguished from the thrusted Tethyan sheets of the Zagros Suture Zone by its parautochthonous origin of sedimentary rocks within the Arabian Plate margin. On the other hand, the intensive deformation and imbrication made it different from the Zagros Folded Zone (Al-Qayim

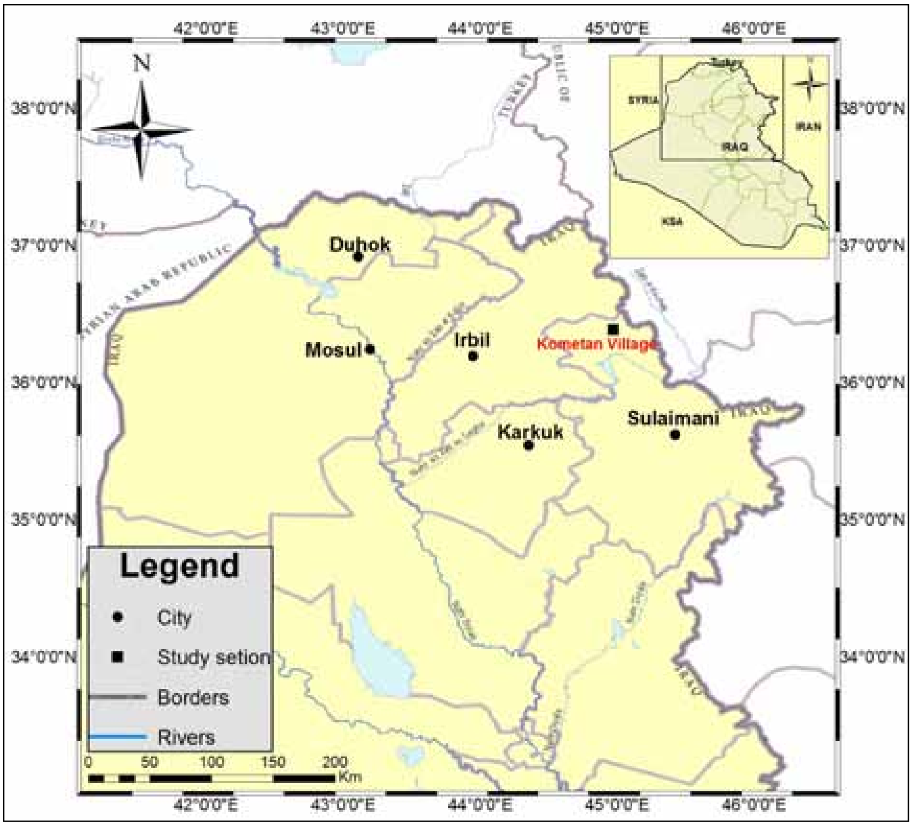

Figure1: Location map of the studied section.

et al., 2012). Accordingly, based on the tectonic division of Jassim & Goff (2006), the investigated area is situated on the site between the High Folded and the Imbricated Zones. Furthermore, from the field observations, several NW-SE trending thrusts are observed (Figure 2). These thrusts had created interruptions or repetitions of strata in the stratigraphic successions.

The studied section lies on the Ashkur stream in Gali-Duwaila and is characterized by a drainage line of dendritic pattern. In addition, the effect of tectonic movements is observed in the Kometan Formation by occurring minor folds in its upper part. On the other hand, the Kometan village is located in a long and narrow semi rugged terrain, existing along the Doli-Shahedan valley. Several high mountains surrounded the studied section, such as Qandil Series Mountain to the east and Milmant Mountain to the west.

The stratigraphy of the studied area includes Qamchuqa Formation (Lower Cretaceous) which is located in the High Folded Zone overlaid by Kometan, Shiranish and Tanjero formations (Upper Cretaceous). Consecutively, the latter is overlaid by Red Bed Series.

In the studied section, the Kometan Formation comprise of 44 m of white weathering, light grey, thin to medium bedded highly fractured limestone, brecciated in lower part and bearing chert nodules in the upper part (Figure 3a). It sets unconformably above the Cretaceous Qamchuqa Formation (Figure 3c) and disconformably below the Upper Cretaceous Shiranish Formation (Figure 3b).

MATERIALS AND METHODS

The work was done in two steps: firstly, field work which includes; the survey of general geology and structural relations of the Upper Cretaceous units in the surrounding area to choose the most suitable section for this work. The studied formation is described and measured in detail, including logging the lithology, mineralogy and sampling. 54 samples were collected. Secondly; preparing thin sections and staining with Alizarin red solution following the techniques of Friedman (1959) at the workshop of the Geology Department in Salahaddin University – Erbil. The prepared thin sections are examined for detailed petrographic study by polarizing microscope

RESULTS AND DISCUSSIONS

Petrography

The petrographic investigation of Kometan limestones was carried out on 50 thin sections. The recognized skeletal grains include: planktonic foraminifera (Figures 4a, b and c), oligostegina (Figure 4d), calcispheres (Figure 4d), ostracods (Figures 4e and 4f), pelecypods (Figures 5a and b), larvae ammonoids (Figure 5c), and echinoderms (Figure 5d) in addition to bioclasts (Figure 5e). Non skeletal grains are rare peloids only (Figure 5f). The groundmass mainly consists of carbonate mud (micrite) (Figure 4a) that transformed to microspar (Figure 8e) due to effective neomorphism.

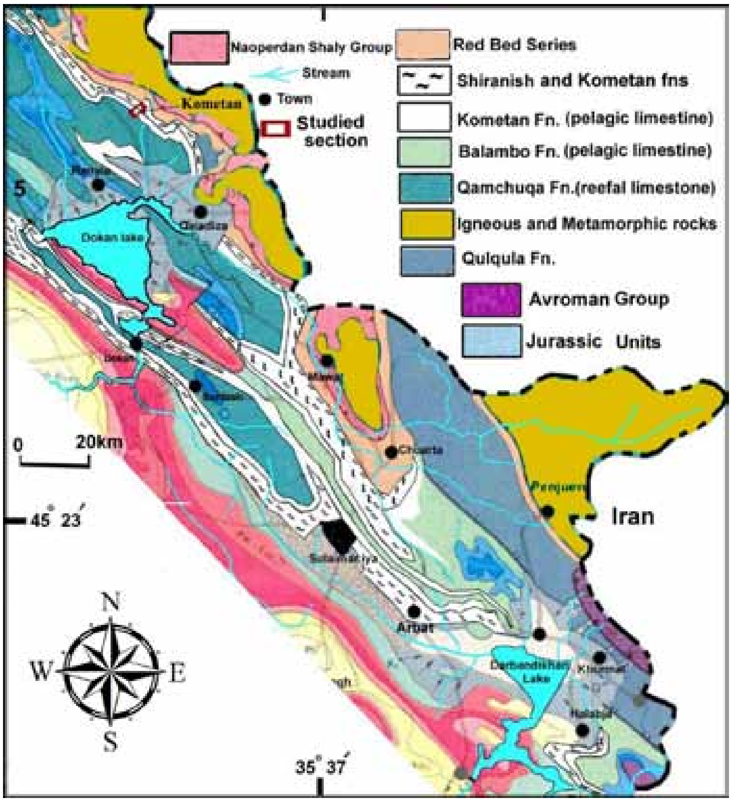

Figure 2: Geological map of the studied area (after Sissakian & Fouad, 2013).

Diagenesis

Diagenesis includes all modifications that take place at low temperatures and pressures in deposited carbonate sediment after deposition (Sellwood, 1994). Diagenesis in carbonate rocks are more varied than that of siliciclastic rocks due to their mineral's unstable nature (Bathurst, 1975). The limestones of Kometan Formation was subjected to different diagenetic processes which can be categorized into three main stages; early, middle, and late (Figure 10). These are as following:

Micritization

It is regarded as an early diagenetic process (Figure10) which exhibits as micritic envelope (or rims), as a result of boring organisms such as endolithic algae activity or fungi in a carbonate deposits (Bathurst, 1975). The early stage of micritization forms micritic rim, while in the advanced stages the skeletal grains are overturned to peloids (Blatt, 1982). It occurs in the marine phreatic zone (Longman, 1980). In this study, micritization discriminatorily influenced thin shells (valves) of pelagic pelecypods, ostracods and test of foraminifera (Figure -6a).

Dolomitization

Dolomitization is a process whereby limestone is entirely or slightly transformed to dolomite by the alteration of the original $CaCO_3$ to magnesium carbonate, by the influence of Mg bearing water (Flügel, 2004). Dolomitization process is classified into two types, early diagenetic dolomitization and late diagenetic dolomitization. Due to absences of late diagenetic dolomitization in the present study, only early diagenetic dolomitization is explained in detail.

A - Early diagenetic dolomitization

Early dolomitization happens before solidification of sediments which are still in touch with marine water and damage their textures (Tucker, 1981) that are due to the effect of Mg–rich marine water on newly precipitated carbonates (Fuchtbauer, 1974). Early dolomites possess crystals of fine size, which is abundant in most parts of the Kometan Formation, in forms of rhombs of dolomite crystals found floating in micrite matrix (Figure 6b). These crystals are believed to be early diagenetic in origin.

Cementation

It is defined as chemical precipitation of calcium carbonate from saturated solutions which precipitated among, within grains, or in pores and cracks produced by solution and lead to growth of spary calcite in these voids (Larsen & Chilingar, 1979). The following cement types are differentiated in the studied rocks according to their dominance:

A - Granular cement

Granular cement is characterized by pore-filling calcite crystals without a preferred orientation and no substrate control (Flügel, 2004). This type of cement seems to be

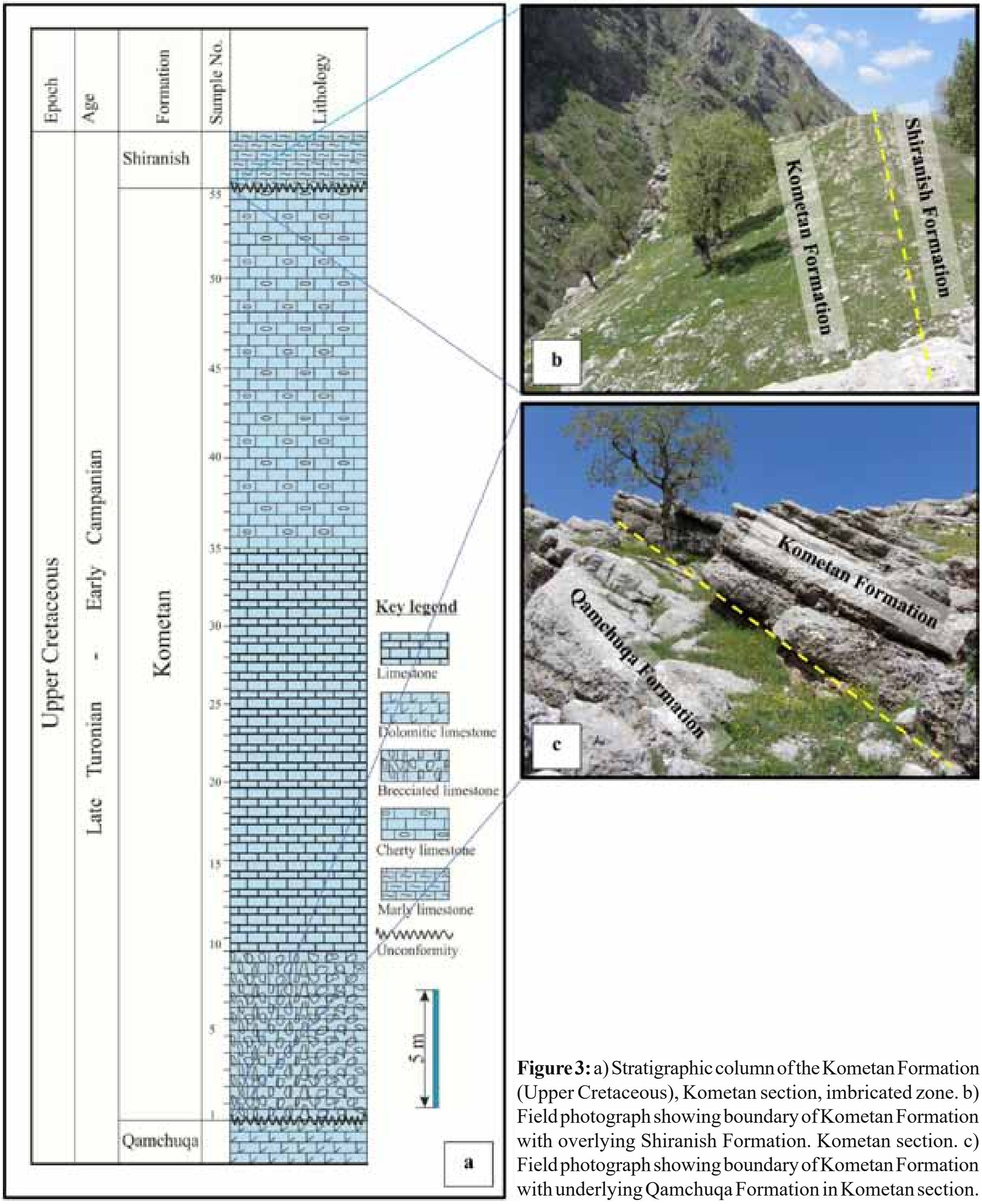

Figure 3: a) Stratigraphic column of the Kometan Formation (Upper Cretaceous), Kometan section, imbricated zone. b) Field photograph showing boundary of Kometan Formation with overlying Shiranish Formation. Kometan section. c) Field photograph showing boundary of Kometan Formation with underlying Qamchuqa Formation in Kometan section.

the most common in the Kometan limestones of studied section. Granular cement is noticed infilling shells of Foraminifera (Figure 6c), articulated ostracods (Figure 6d) and compaction-related fractures (Figure 6e).

B- Drusy cement

Drusy cement is second common in the studied samples of the Kometan Formation. This type of cement consists of anhedral to subhedral calcite crystals, commonly larger than 10 µm, which they increased in size from pore walls to center of voids (Flügel, 1982) (Figure 6f).

C- Blocky cement

It is that type of cement which its individuals take roughly the same diameter in all directions (Blatt *et al*., 1980). The presence of this type is rare in the studied rocks of the Kometan Formation and only found in fractures

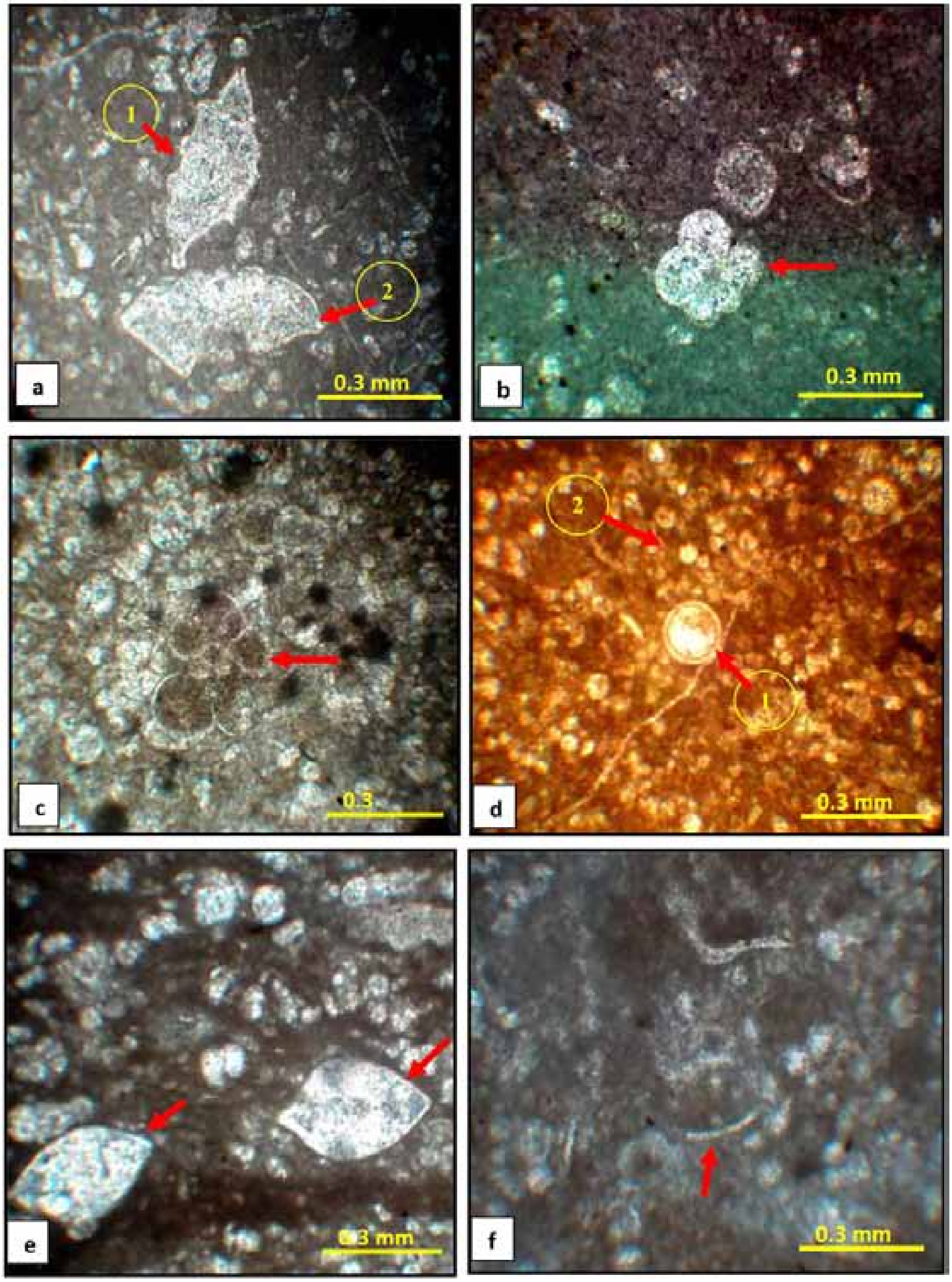

Figure 4: Photomicrographs showing petrographic components of Kometan limestone: a) Planktonic foraminifera, (1-*Marginotruncana* (arrow) & 2-*Globotruncana* (arrow)), in micritic ground mass. K11, P.P. b) Planktonic foraminifera (*Hedbergella*) (arrow), K41, A.S, P.P. c) Planktonic foraminifera (Whitinella*)* (arrow), K5, P.P. d) 1-Calsispher skeletal grain surrounded by 2-*Olegostegena* (small circular calcitic grains), K45, A.S, P.P. e) Articulated ostracods shells partially silicified (arrows), K27, P.P. f) Inarticulatedostracoda valve (arrow), K7, P. P5 Key: K: Kometan, P.P.: Plane polarized light, A.S.: Alizarin Stained.

(Figure 7a) that emphasized to be late diagenetic origin. The blocky cement type is believed by Longman (1980), to form in fresh water phreatic zone.

Neomorphism

It includes all transformations between one mineral and itself or a polymorph (Folk, 1965). In sediment, it is

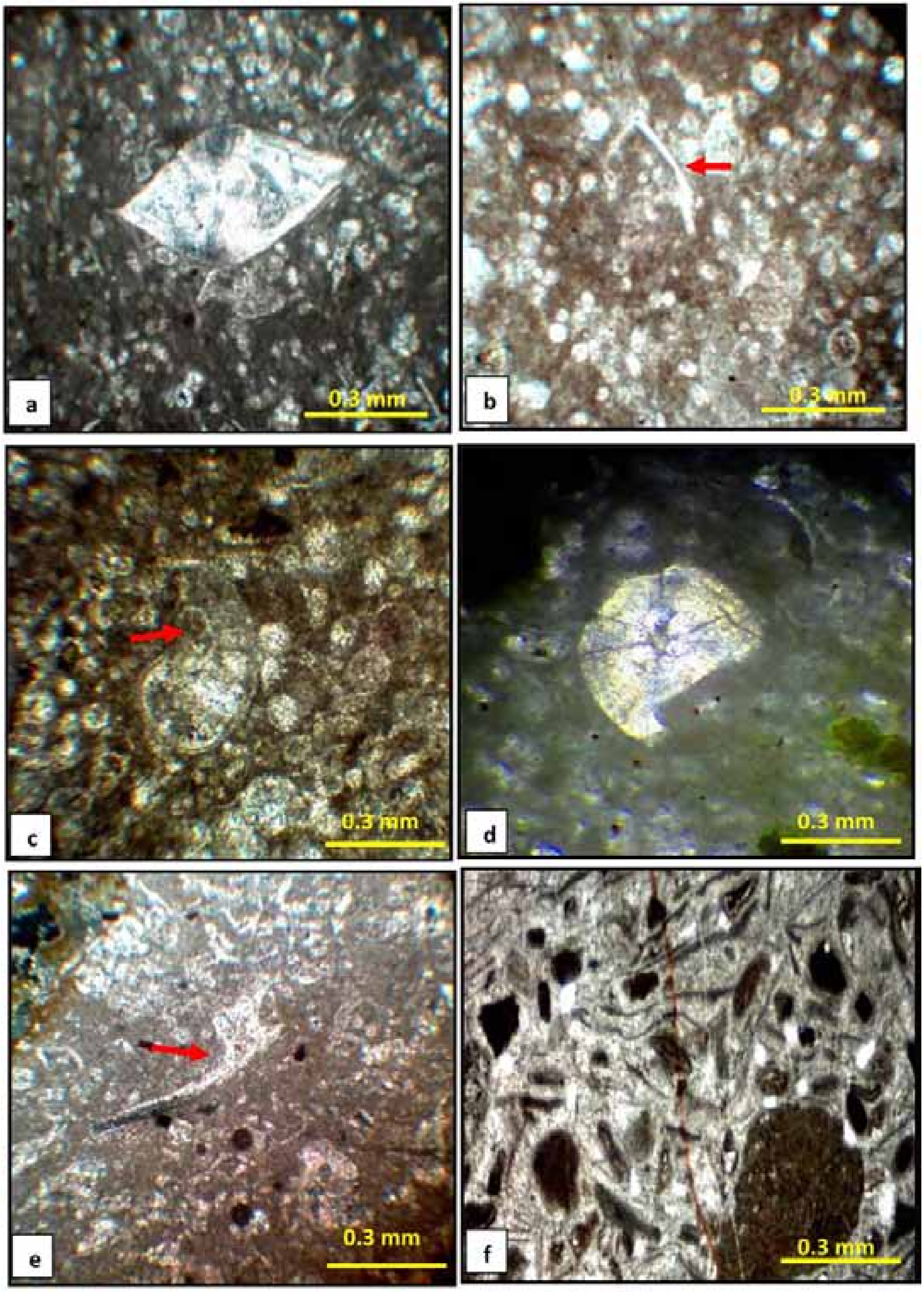

Figure 5: Photomicrographs showing petrographic components of Kometan Limestone a) Articulated Pelycepods shell, K12, P.P. b) Inarticulated Pelycepods valve surrounded by *Oligostegena* (arrow), K22, P.P. c) A larvae ammonoid shell strongly neomorphosed (arrow), K1, P.P. d) A larvae echinoderm shell partially broken, K14, P.P. e) Bioclasts possibly of mollusks origin (arrow), K13, P.P. f) Non-Skeletal grains (peliods), K12, P.P.
Key: K: Kometan, P.P.: Plane polarized light, A.S.: Alizarin Stained

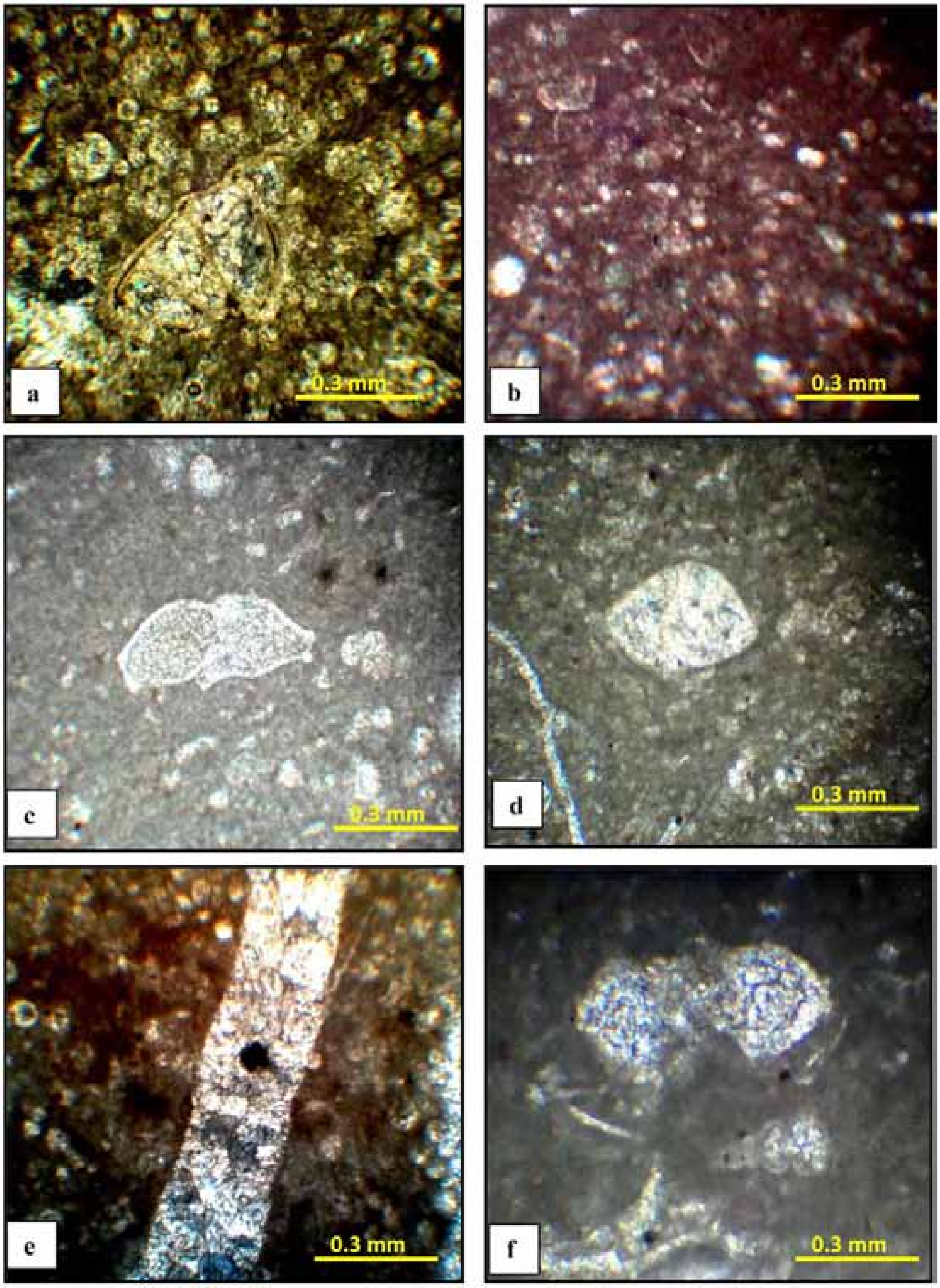

Figure 6: Photomicrographs micritization, dolomitization and cementation showing:
a) Micrite envelop (rim) surrounding foraminifera (*Marginotruncana*), K2, P.P. b) Early stage dolomitization. Note (unstained) very fine size dolomite crystals, K49, A.S.P.P. c) Planktonic foraminifera (*Marginotruncana*) filled by granular cement, K33, P.P. d) Articulated ostracoda filled by granular cement, K42, P.P. e) Compaction related fracture filled by granular cement, K3, P.P. f) Foraminifera (*Globigerinelliodes*) filled by drusy cement, K36, P, P.
Key: K: Kometan, P.P.: Plane polarized light, A.S.: Alizarin Stained

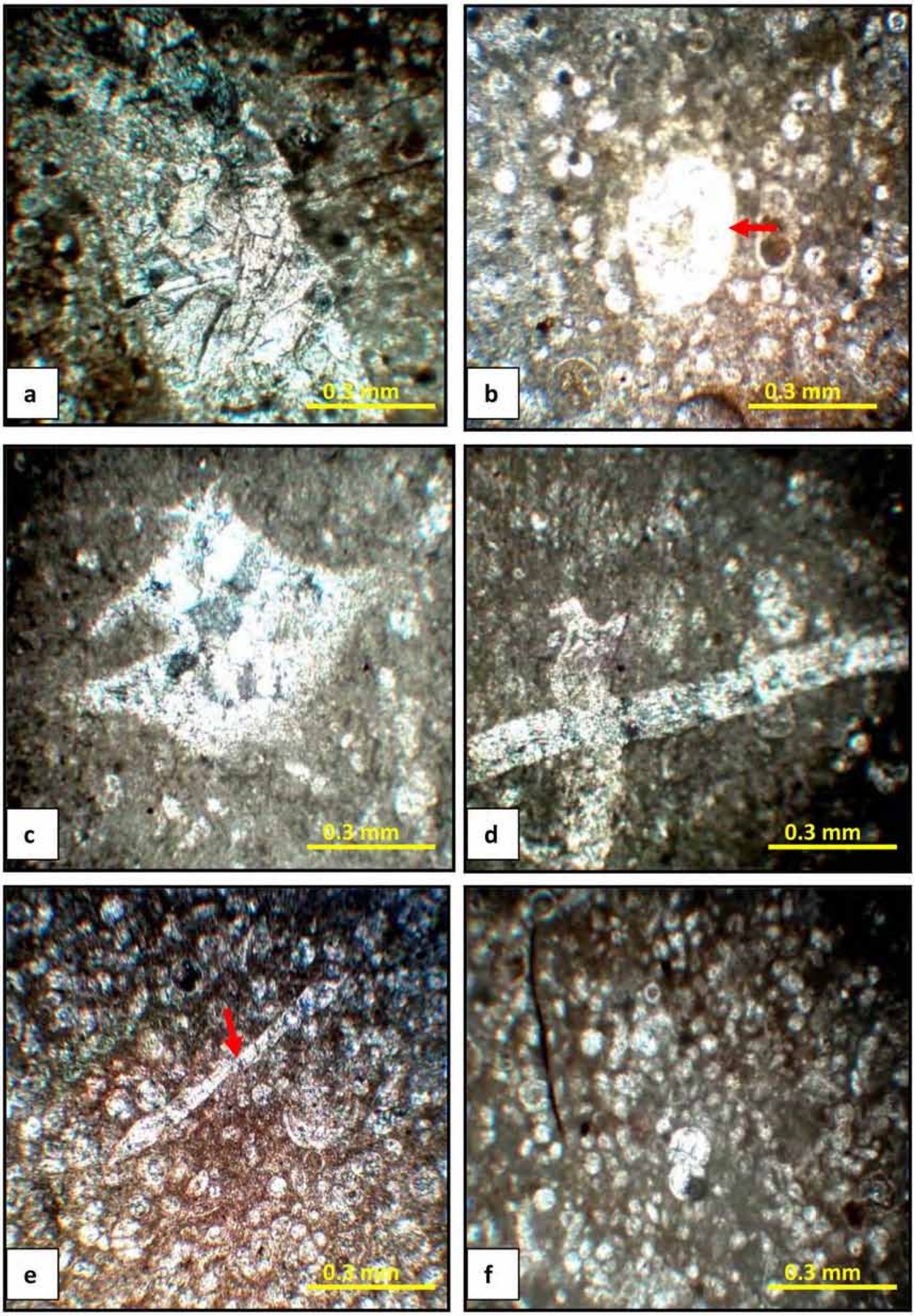

Figure 7: Photomicrographs of cementation, neomorphism and physical compaction showing: a) Blocky cement filling a fracture (vein), K1, P.P. b) Planktonic foraminifera test strongly neomorphised (arrow) K3, P.P. c) Neomorphism of micrite matrix, K43, P.P. d) Fractures filled with spary calcite cement, K43, P.P. e) Breakage of skeletal grain (pelycepods) (arrow) due to weight of overburden, K1, P.P. f) Over close packing of skeletal grains, K8, P.P.
Key: K: Kometan, P.P.: Plane polarized light, A.S: Alizarin Stained

attributed to meteoric phreatic conditions (Longman, 1980). In this study, neomorphism effect was manifested in the Kometan Formation. It affected the shells of most types of fossils (Figure 7b) and also extended to micritic ground mass of the studied samples (Figure 7c).

Compaction

It is a type of diagenesis which leads to reducing the bulk volume, thickness or porosity of the sediments by overloading material over it, or to the pressure producing within the crust by earth movements (Flugel, 1982 and Mclane, 1995). The compaction is divided into two types according to Tucker (1981); physical compaction and chemical compaction.

A- Physical compaction

It is also called mechanical compaction which began directly after deposition and is formed by the effective stress upon the sediments (Croize *et al*., 2010). The most common criteria dealing with mechanical compaction in the Kometan limestone in studied section are the following:

1 - Fractures; commonly filling by sparry calcite cement (Figure 7d).
2 - Breakage of grains (Figure 7e).
3 - Over close packing of skeletal grins (Figure 7f).

B- Chemical compaction (pressure solution)

The chemical compaction is well observed by particles which were subjected to dissolution under overburden stress, increasing pressure solution effect (Bathurst, 1975). The main product of this type of compaction are stylolites which are pressure solution features along incisions that are laterally expanded on the size of hand specimen (or greater) and that cut numerous grains, micrite and cement.

Stylolites

They are toothed sub- planar surfaces at which mineral material has been removed by pressure dissolution, resulting in a reduction in total volume of rock (Middleton, 2003). It appears to be dominant in the Kometan limestone in studied section. From the types of stylolites proposed by Wanless (1979); these were identified:

A-Sutured–seam stylolite

Generally, its formation is within beds characterized by structural resistance and few platy insoluble minerals (Wanless, 1979). The most common type found in the studied section are irregular types which commonly had peaks of low amplitude (Figure 8a), and others of high amplitudes (Figure 8b).

B- Non–sutured seam stylolite

This type is related to carbonates that involved considerable ratio of clay and platy silt (Wanless, 1979). It is characterized by low relief and thin undulation. The principal kind noticed in the studied section is anastomosing (Figure 8c).

Silicification

Silicification of carbonate rocks is either carbonate replacement by silica or silica cementation which filled the pores (Flügel, 2004). This diagenetic type is obvious in different parts of the studied section, particularly in the upper part which selectively affected the skeletal grains (Figure 8d) or ground mass (Figure 8e).

Solution (leaching)

Carbonate metastable minerals such as high-Mg calcite and aragonite show faster response to solution process as compared to low-Mg calcite (Friedman, 1964). Fresh water has more effect than marine water on this process. Solution process had imprints on the limestone of the studied formation and had affected the ground mass (Figure 9a) and most type of fossil shells (Figure 8f).

Authigenic mineral (Pyrite)

Pyritization is formed under reducing conditions, probably promoted by decay of organic matter, which is induced by anaerobic bacteria, or solution of sulfate by reducing bacteria and producing different crystal forms (Hudson, 1982). The most common pyrite forms noticed in the studied samples are small spherical pyrite (Figure 9b), and cubic pyrite (Figure 9c).

Phosphatization

Phosphatization affects the skeletal particles in phosphorus–rich medium. It is a process promoted by upwelling currents which are vital for phosphorus enrichment in sea water (Slansky, 1986). Phosphatized bioclasts were noticed in the lower and middle parts of studied rocks of the Kometan Formation (Figure 9d).

Fracturing

Limestones of the Kometan Formation is considerably fractured, which are commonly filled with calcite cements (Figure 9e).

Glauconitization

Glauconitization is the process by which a mineral is replaced by glauconite under slow sedimentation rates and at depths of 100 to 300 m (Abu El-Ghar & Hussein, 2005). In the Kometan Formation, glauconite is present at the base of the formation and also seen as scattered particles in most studied samples (Figure 9f).

Diagenetic Sequences

Based on the study of petrographic components, diagenetic history of the Kometan Formation in it is type locality section passed through four diagenetic stages: marine, meteoric, burial and uplift (Figure 10).

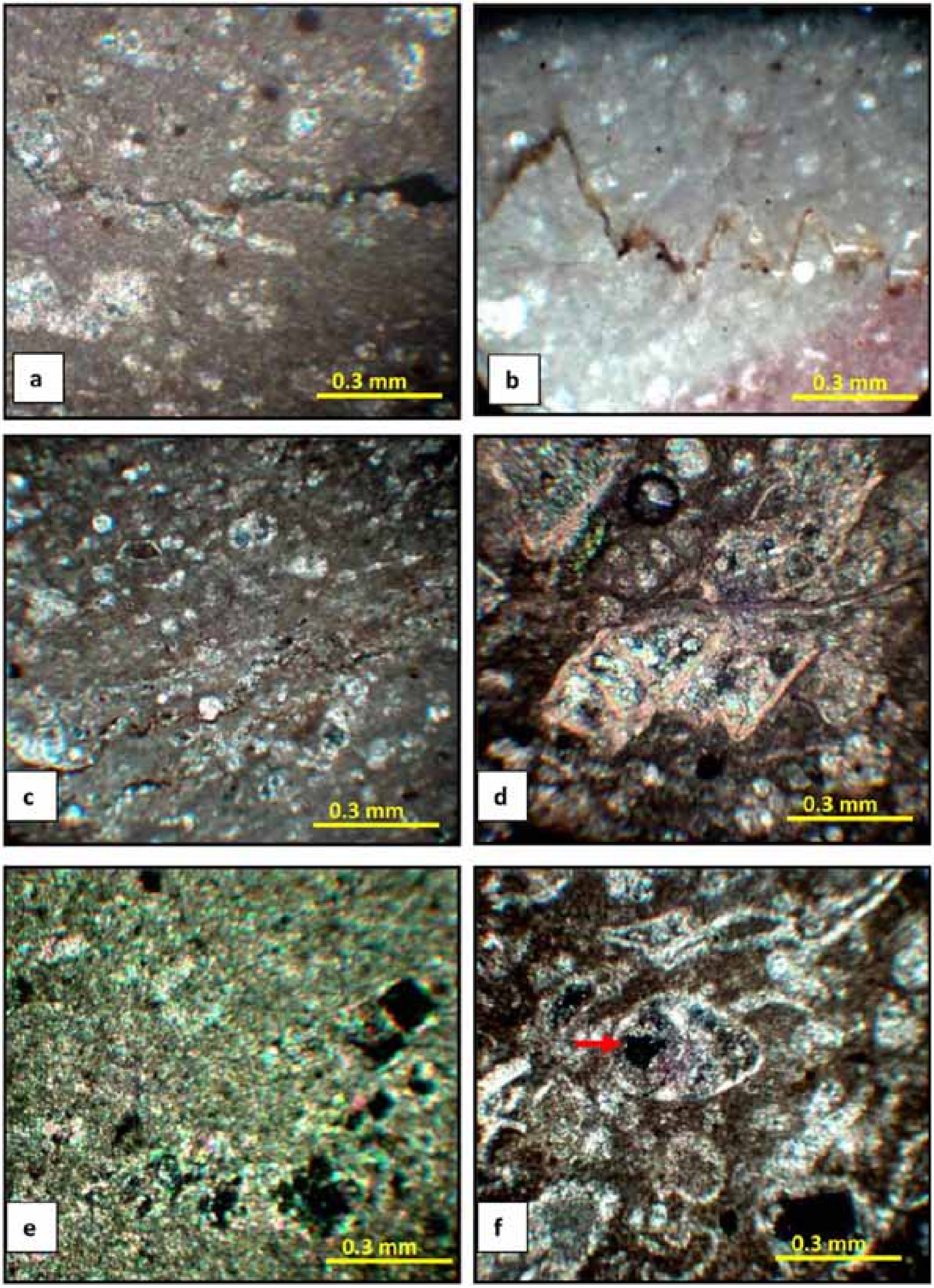

Figure 8: Photomicrographs of chemical compaction, silicification and solution:
a) Sutured seam stylolite, irregular type with peaks of low amplitude, K32, P.P. b) Sutured seam stylolite, irregular type with peaks of high amplitude (columnar stylolite), K30, P.P. c) Non–sutured seam stylolite (Anastomosing stylolite), K33, P.P. d) Silicification affected Planktonic foraminifera (*Globotruncana)* test, K12, P.P. e) Silicification affected the ground mass, K40, P.P. f) Solution of Ostracod shell (arrow), which partially affected by silicification, K22, P.P.
Key: K: Kometan, P.P: Plane polarized light, A.S: Alizarin Stained

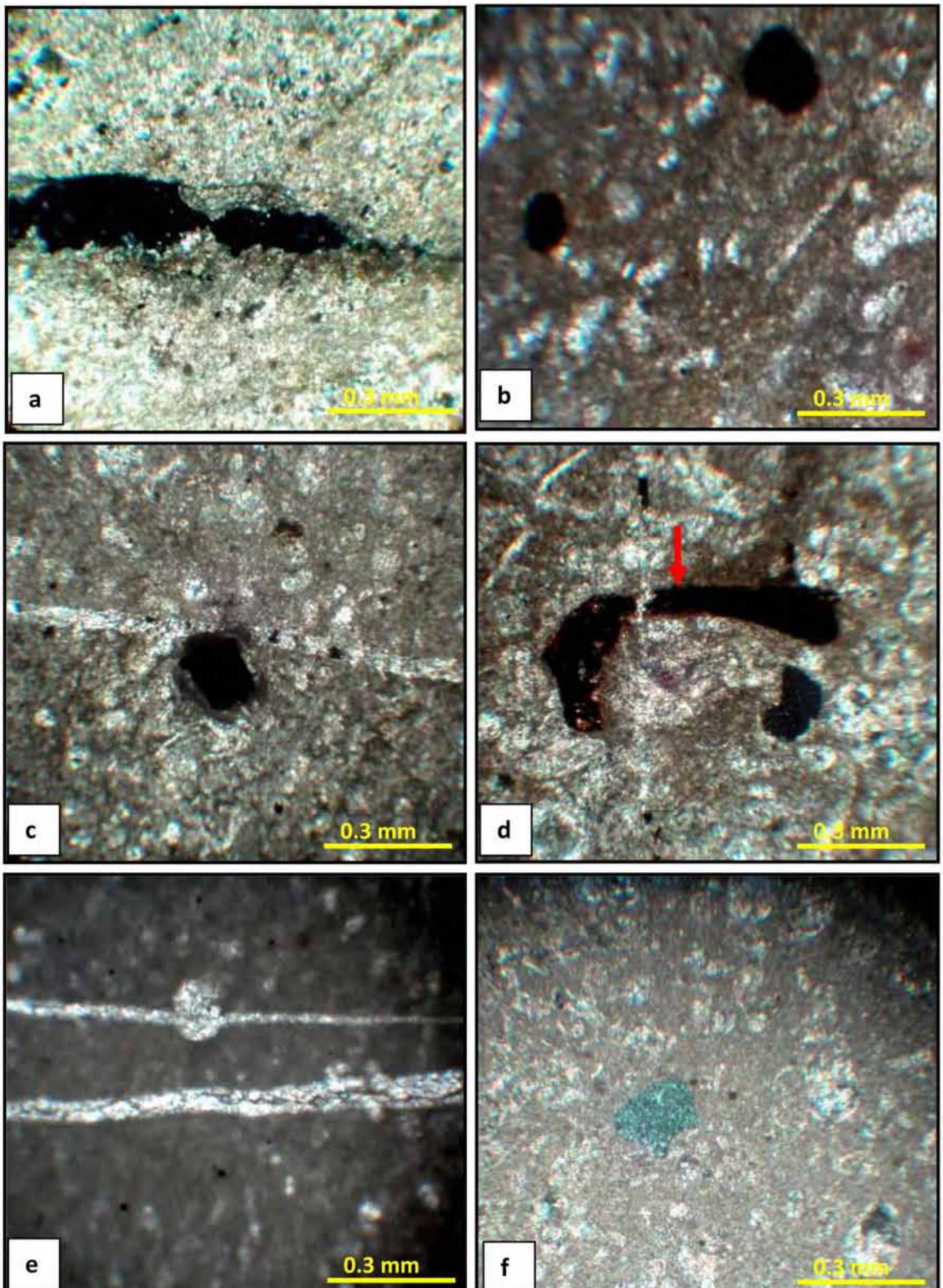

Figure 9: Photomicrographs of solution, pyritization, phosphatization, fracturing and glaouconitization showing: a) Neomorphosed micritic matrix subjected to solution, K6, P.P. b) Small spherical pyrites in micrite matrix, K50, P.P. c) Cubic pyrites in micrite matrix, K42, P.P. d) Phosphatization (arrow) affected unidentified bioclast, K26, P.P. e) Fracture porosity, reduced by cementation, K36, P.P. f) Glauconite nodules in neomorphosed micritic matrix, K1, P.P.
Key: K: Kometan, P.P.: Plane polarized light, A.S.: Alizarin Stained

1. Marine diagenesis

The early micritization of allochems in the Kometan Formation is an indicator of marine phreatic diagenesis. It can be seen by the developing of micrite envelops or rims around thin shells of planktonic foraminifera and calcispheres (Figure 6a). The early marine cementation (fibrous cement) is not observed within the Kometan limestone of the studied section which means it does not occlude primary porosity predominantly, but early compaction reduced it during this stage. Micritization is supposed to be formed in stagnant marine phreatic zone by boring algal activity, which occurs at the sediment–water interface to 1 m below the interface (Longman, 1980). Glauconitization also formed in the Kometan Formation limestone which can be regarded as an early diagenetic mineral precipitated either by replacing the particles or filling the pores in shallow to deep marine environments that characterized by high nutrient levels and low sediment rates (Scholle & Scholle, 2003). The early dolomitization represented by fine crystalline dolomites are also formed, which subsequent by marine diagenesis in the vadose zone and it supposed to be in meteoric-marine mixing zone. Both neomorphism and mechanical compaction is more effective in this stage (Figures 7c to 7e) and continuous from marine to meteoric stage is dominated by overclose packing of grains (Figure 7f).

2. Meteoric diagenesis

The stage is started with meteoric vadose phreatic diagenesis precisely with the vadose solution zone, which extends tens to hundreds of meters below the surface (Longman, 1980) and during it metastable skeletal and non-skeletal grains were dissolved. As a consequence of its secondary fabric- and non- fabric selective porosity were formed. Subsequently, phreatic diagenesis happened when pore spaces were filled by meteoric waters. Drusy mosaic, granular, and blocky cements were precipitated. These second-generation kinds of cements gradually reduce primary pore spaces.

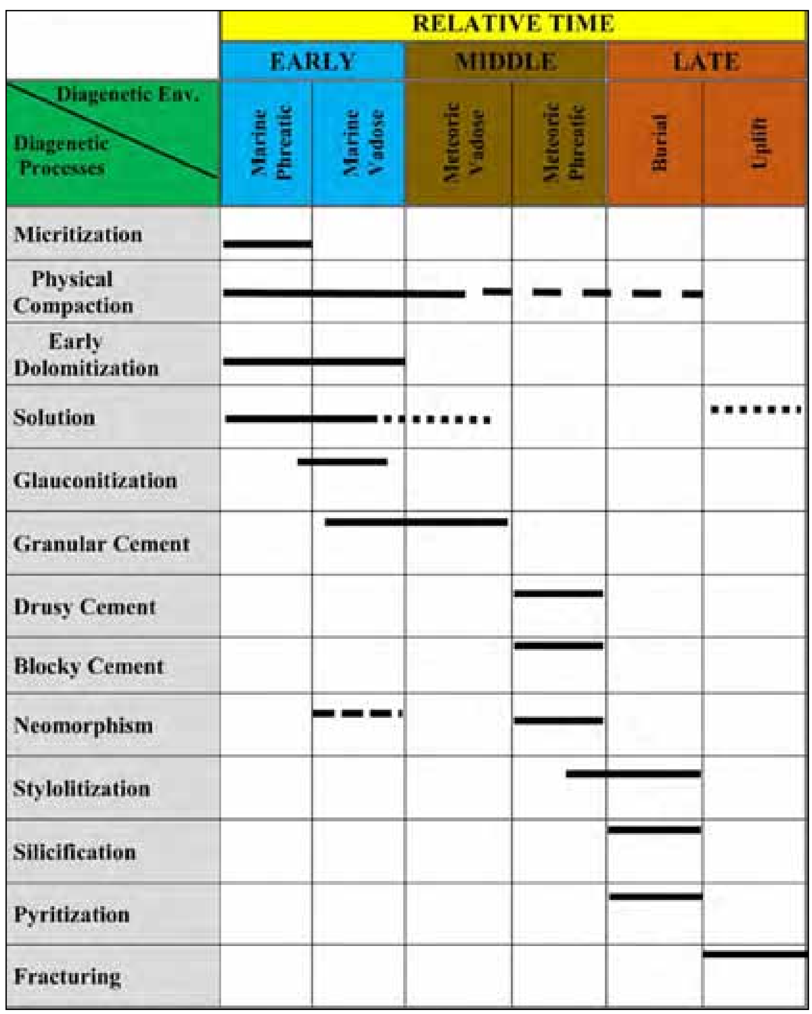

Figure 10: Paragenetic sequence of Kometan Formation (Upper Cretaceous) in Shahidan valley, Kurdistan Region-Northern Iraq.

3. Burial diagenesis

This diagenetic stage was happened when overburden stress increased. During this stage breakage, deformation, over close packing and bending of skeletal grains are occurred. Silicification also another diagenetic processes occur during this stage. On the other hand, primary and secondary porosity was reduced by compaction in the lack of cementation. The chemical compaction (stylolites) was being active and pyritization also formed.

4. Uplift

Late Alpine orogenies resulted in uplifting of upper cretaceous rocks, and caused folding and fracturing on the rocks of Kometan Formation too. Uplift with exposure to fresh water in younger periods made more dissolution and progressed vuggy porosity in the Kometan rocks.

CONCLUSIONS

The following conclusions are obtained from the present study:

1. Petrographic studies of Kometan Formation revealed that several types of skeletal grains include planktonic foraminifera, oligostegina, calcispheres, ostracods, pelecypods**,** larvae ammonoids, and echinoderms in addition to bioclasts, while, non-skeletal grains include peloids only. The groundmass of the studied formation is composed mainly of carbonate mud (micrite) and transformed into microspar.
2. The Kometan Formation subjected to different types of diagenesis processes include: micritization, dolomitization, cementation, neomorphism, compaction, silicification, solution, phosphatization, glauconitization and fracturing.
3. The diagenetic processes that affected the Kometan limestone in the studied section belong to three diagenetic stages; early (shallow burial), middle and late (deep burial). Processes belonging to early stage are rare, while those of middle stage are common, and late stage processes are common.
4. The diagenetic history of Kometan Formation was passed through four diagenetic environments which are: marine, meteoric, burial and uplift.

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