Geol. Bull. Punjab Univ. 44, 2009.

MICROFACIES ANALYSIS AND DIAGENETIC SETTINGS OF THE MIDDLE JURASSIC SAMANA SUK FORMATION, SHEIKH BUDIN HILL SECTION, TRANS INDUS RANGES-PAKISTAN

BY

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Abstract: *A detailed study on the microfacies analysis and diagenetic settings of the Middle Jurassic Samana Suk Formation exposed at the Sheikh Budin Hill Section, Marwat Range, Trans Indus Ranges, was conducted. The Samana Suk Formation is mainly comprised of limestones and dolomitic limestones along with some dolomite and intercalations of marl and shale at different levels. The investigation was carried out after collecting systematically a total of 210 rock samples and studying selected 140 thin sections from 136 individual beds. The petrographic study of unstained and stained thin sections have been carried out to investigate its sedimentology, microfacies assemblages and diagenetic sequence. Detailed work in the field and in the laboratory revealed that it contains microfacies forming SMF zones and exhibits frequent oolitic, peloidal and skeletal grainstone microfacies along with presence of dolomite at various horizons. The grainstone microfacies constitute a predominant part in this section in comparison to other sections towards east of Sheikh Budin Hill. A variety of cement morphologies and diagenetic features have been elaborated. Dolomitization has developed at various levels as cement as well as replacement and as stylocumulates. The incorporation of iron into calcite and dolomite at some later diagenetic stage has been recorded. The dedolomitizatioin has, also, been noted. The Samana Suk Formation is widely exposed in various sedimentary basins of Pakistan. The detailed microfacies analysis and its diagenetic settings show that this formation was deposited in an environment of shallow shelf with open and restricted marine conditions as carbonate platform depositional product.*

INTRODUCTION

The Samana Suk Formation is a distinctive stratigraphic unit recognizable over a wide area of northern Pakistan. It is the most prominent lithological package of carbonates in the Mesozoic strata of Trans Indus Ranges, Cis-Indus Salt Range, Hazara Mountains, Kohat Tribal Range, Samana Range and Kala Chitta Range. Further towards the west the Chiltan Formation, exposed at a number of sections in the Sulaiman Range and Kirthar Range, is taken as an equivalent carbonate rock unit of the Samana Suk Formation. In Sheikh Budin Hill Section the Samana Suk Formation presents strata sets, comprising thin bed, medium to thick beds and massive limestone beds. Within the vertical stacking of beds at places the bedding thickness is uneven to wavy. The most part of the formation consists of relatively larger number of coarse grained limestone horizons. The Sheikh Budin Hill Section is located near Pezu Pass, District Laki Marwat at a distance of 7 km (Fig. 1). The approximate location of this section is at Latitude 32º 17′ 11″ N and Longitude 70º 43′ 51″ E (Toposheet No. 38 L/15 of Survey of Pakistan). The Pezu Pass could be approached from Dera Ismail Khan in south and Laki Marwat in northwest via Indus Highway. Field work was carried out in the Sheikh Budin Hill area, Marwat Range during March, 2006 and a total of 210 rock samples were collected from136 individual beds and 140 thin sections were selected for present research work. The thickness of this formation at the studied section is 87.57m. The paper demonstrates the investigations on the sedimentology, microfacies analysis and diagenetic settings of this formation. The research work presented here is extracted from the doctoral dissertation of the first author.

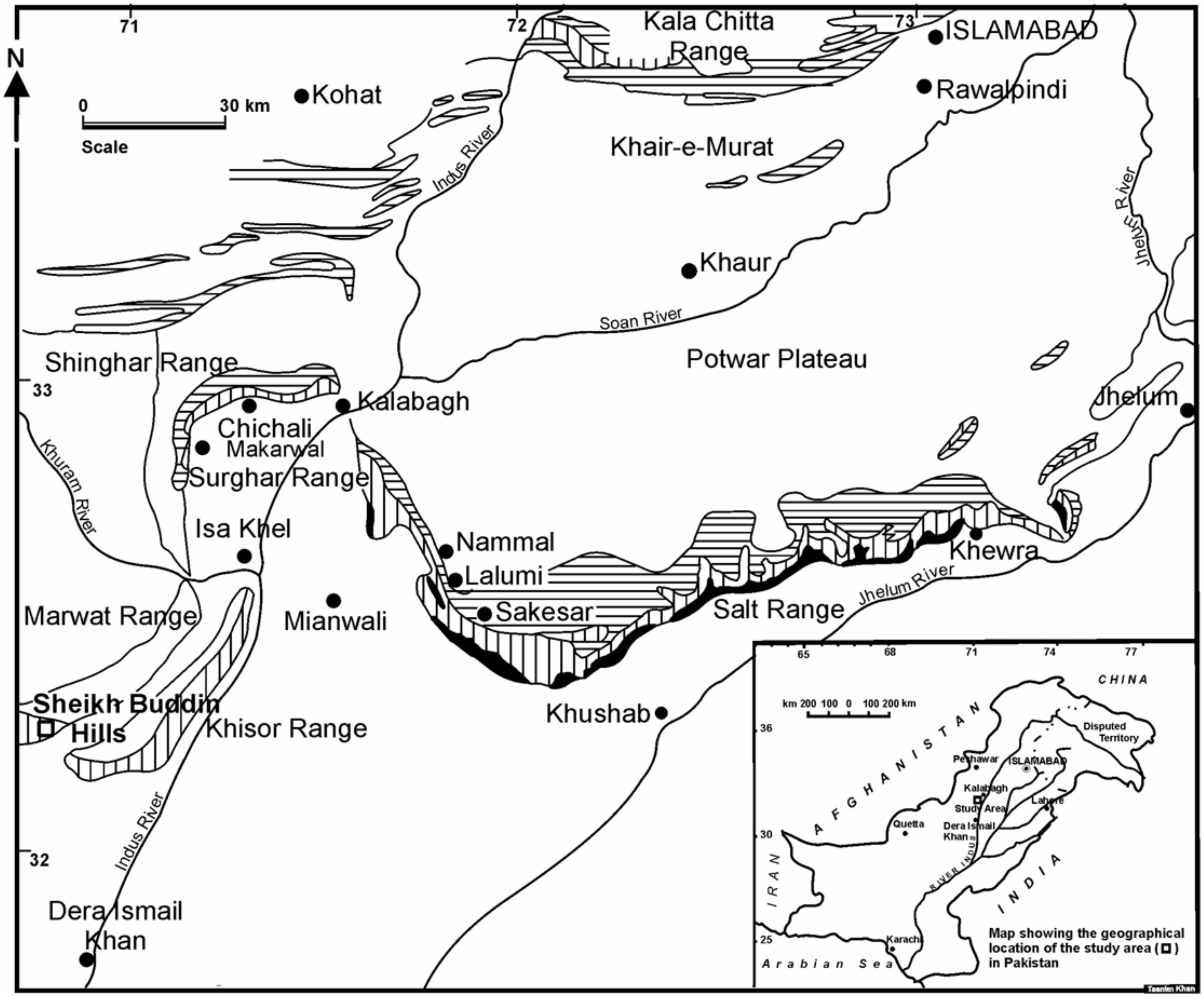


Fig.1. Map showing the location of Sheikh Buddin Hills Section (□) in the Trans Indus Ranges (Modified after Gee,1989)

PREVIOUS INVETIGATIONS

Previously this formation was named as Kioto Limestone by Cotter (1933) and Gee (1947), Samana Suk Limestone by Davies (1930) and Baroch Limestone by Gee (1947). In 1974 the name, Samana Suk Formation, was formalized by Fatmi et al., 1990. According to Shah (1977) in the Upper Indus Basin, where the Surghar and Marwat Ranges are situated (Anwar, et al., 1992 and Gee, 1989), the Jurassic sequence contains Datta Formation, Shinawari Formation and Samana Suk Formation. Bender and Raza (1995) added that the lower part (relatively much thinner) of Chichali Formation is part of this Jurassic sequence. Fatmi, et al. (1990) indicated that the upper part of Jurassic sequence is represented by the Samana Suk Formation and it is a shallow water marine carbonate rock. Mensink, et al. (1988), Fatmi, et al. (1990) and Mertmann and Ahmad (1994) described that the rocks of the Jurassic sequence are exposed at a number of localities in the Trans Indus Ranges, particularly in the Surghar and Marwat Ranges. A commendable work has been done on the various aspects of Samana Suk Formation of Jurassic age, Trans Indus Ranges, by Mensink, et al. (1988), Fatmi, et al. (1990) and Ahmad, et al. (1997) on its microfacies and depositional environments in a broad spectrum. Hemphill and Kidwai (1973) gave an account on the stratigraphy of Bunnu and Dera Ismail Khan including the geology of Sheikh Budin Hill and that of the Samana Suk Formation as well. From above it is obvious that no detailed work on sedimentology of the Samana Suk Formation was carried out in the area of Sheikh Budin Hill, Marwat Range. Therefore a detailed microfacies analysis and diagenetic interpretation of the Samana Suk Formation were undertaken.

The following parameters have been taken into consideration for this research work: Outcrop observations and field study, section measurement, field photography, laboratory investigations including thin sections studies using petrographic microscope, chemical staining with Alizarin Red S and Potassium Ferricyanide and digital photomicrography.

SAMANA SUK FORMATION

The Samana Suk Formation exposed at the Sheikh Budin Hill in the Marwat Range is mainly composed of limestones, dolomitic limestones and dolomites with interbedded calcareous shales/marls, which are present at various levels and are the result of periodic influxes of clay due to small scale and distant tectonic uplift and erosion or climatic change on a distant land mass. The limestones are mostly hard, compact, grey and yellowish grey and at places dark grey in colour, micritic, oolitic and dense to coarse grained. Generally the topographic impression of limestone is a ridge former, however it also forms steep slopes and impassable cliffs in the host area. Here it comprises limestone as a dominant lithology with dolomite, marl and shale intercalations. The Samana Suk Formation conformably overlies the Shinawari Formation and disconformably underlies the Chichali Formation (Table 1). The lower contact with Shinawari Formation is transitional one. The top most sandstone bed of the Shinawari Formation is marked here as the lower stratigraphic contact (Akhtar, 1983 and Mertmann and Ahmed, 1994). The upper contact with the Chichali Formation is sharp and is marked by hard ground with lateritic encrustation (Mertmann and Ahmed, 1994 and Sheikh, 1991). The shale/marl breaks and intercalations present at different levels do not show any regular or alternative cyclic deposition. Three well developed hard ground surfaces were found and recorded. These surfaces mark the presence of regressive cycles and periods of non erosion-non deposition. Mostly the bed forms are planar, however few beds exhibit uneven thickness. In Trans Indus Ranges the age of this formation was determined Late Jurassic (Late Callovian) on the basis of cephelopod fauna described by Spath (1939), however, Fatmi (1972) considers its age to be Early to Middle Callovian (Middle Jurassic) on the basis of Middle Callovian Ammonites that occur in richly fossiliferous sections of the Datta, Punnu Nala, Landa Nala, Mallakhel and Makarwal areas, Surghar Range. This formation is co-related with the Mazar Drick Formation and Chiltan Formation in the Sulaiman Fold and Thrust Belt and Murree Brewery Gorge near Quetta, Balochistan, Pakistan.

MICROFACIES

For the microfacies analysis of the Samana Suk Formation the microfacies classification scheme suggested by Dunham (1962) has been followed. To interpret coquinal limestone facies Embry and Klovan (1971) scheme has been adopted, who further subdivided the boundstone microfacies of Dunham into two categories: Autochthonous limestones and allochthonous limestones. Allochthonous limestones are classified as floatstones, in which component bioclasts are matrix-supported, larger than 2mm in dimensions and more than 10% in numbers whereas rudstones have grain-supported texture with bioclasts larger than 2mm as well (Scoffin, 1987). The Samana Suk Formation as measured in this section is dominated with bioclastic microfacies from bioclastic mudstone to bioclastic grainstone and floatstone/rudstone facies along with peloidal and ooidal grainstones. Ten microfacies have been identified and compared with the Dunham classification and Embry and Klovan extended scheme. The interpreted microfacies include bioclastic, peloidal, cortoidal and ooidal grainstones, grapestones, bioclastic rudstone and floatstone, bioclastic and peloidal packstones, bioclastic wackestone, bioclastic mudstone and mudstone. In the following pages details of microfacies and Standard Microfacies (SMFs) recorded from this section are presented:

Table 1
Stratigraphic successin of the Sheikh Budin Hill area, Marwat Range, Trans Indus Ranges, showing the position (**bold**) of Samana Suk Formatiom

ERA	AGE	GROUP	FORMATION
CENOZOIC	PLIOCENE-PLEISTOCENE	SIWALIK GROUP	Dhok Pathan Formation
			Nagri Formation
UNCONFORMITY			
MESOZOIC	CRETACEOUS	SURGHAR GROUP	Lumshiwal Formation
			Chichali Formation
	UNCONFORMITY		
	JURASSIC	BROACH GROUP	**Samana Suk Formation**
			Shinawari Formation
			Datta Formation

Grainstones

The petrographic analysis revealed the following microfacies of grainstone. Diversity of bioclastic grains has commonly been observed in all grainstones. An excellent display of grainstone assemblages is present in this section, which is estimated up to 32% and it is a higher value relative to the other studied sections of the Samana Suk Formation towards east in the Surghar Range (Nizami and Sheikh, 2007).

Bioclastic grainstones: This type of grainstone consists of skeletal shells, tests and fragments of different organisms sometimes in association with intraclasts (Plates 2a and d). These shells and grains mostly belong to foraminifera, algae and sponges.

Peloidal grainstones: The frequency of appearance of peloidal grainstones is relatively higher in this section and is found at a number of levels. It is commonly composed of faecal pellets and peloidal grains, having micritic composition (Plates 3a, 6d and 7b). These grainstones are also found in associations with foraminifera (Plate 3a).

Cortoidal grainstones: The cortoids are one of types of coated grains and are covered by micritic envelope only. These grains actually constitute a type of non-laminated coated grains (Tucker and Wright, 1990). This microfacies of grainstone has been recorded in (Plate 1d). The frequency of their appearance in other microfacies is relatively low.

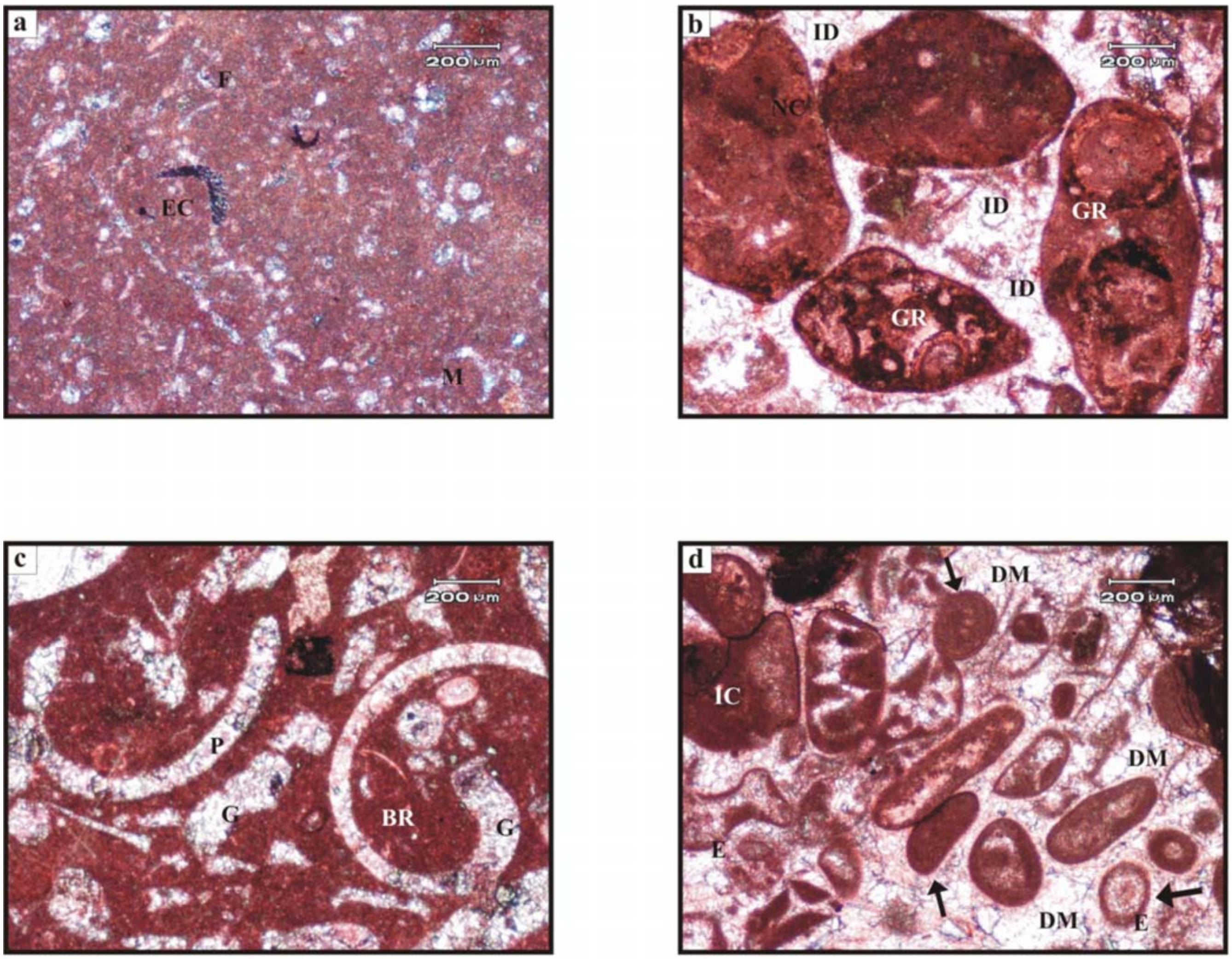
Ooidal grainstones: The ooids found are generally of concentric and radial concentric type (Plates 2b and c). The chemical compaction has intensely affected this microfacies. The boundaries between ooides are mostly sutured and embayments of one ooide into the other are present (Plate 7c). Due to over burden pressure brittle deformation has been noted in the form of broken and spalled off ooids (Plate 4a). In connection with the late void and micro fracture filling spars some calcareous spars related to the deep burial environments are precipitated between these spalled off cortices of ooids.

Grapestone grainstones: Grapestones are actually aggregate grains and are commonly encountered in the grainstone microfacies of Samana Suk Formation at this section. The grainstones comprised entirely of grapestones has been recorded in Plate 1b. The grapestones are also found in other microfacies, however the frequency of their appearance is not very high.

Bioclastic rudstones

According to Embry and Kalovan (1971) rudstone is mainly composed of more than 2mm larger shells and grains of organisms and is a grain supported sub-microfacies of allochthonous (derived) limestones. The rudstones found in this section are composed predominantly of bioclasts of mollusks and bryozoans shells, tests and their fragments with more than 3mm in length and 2mm in

Plate 1



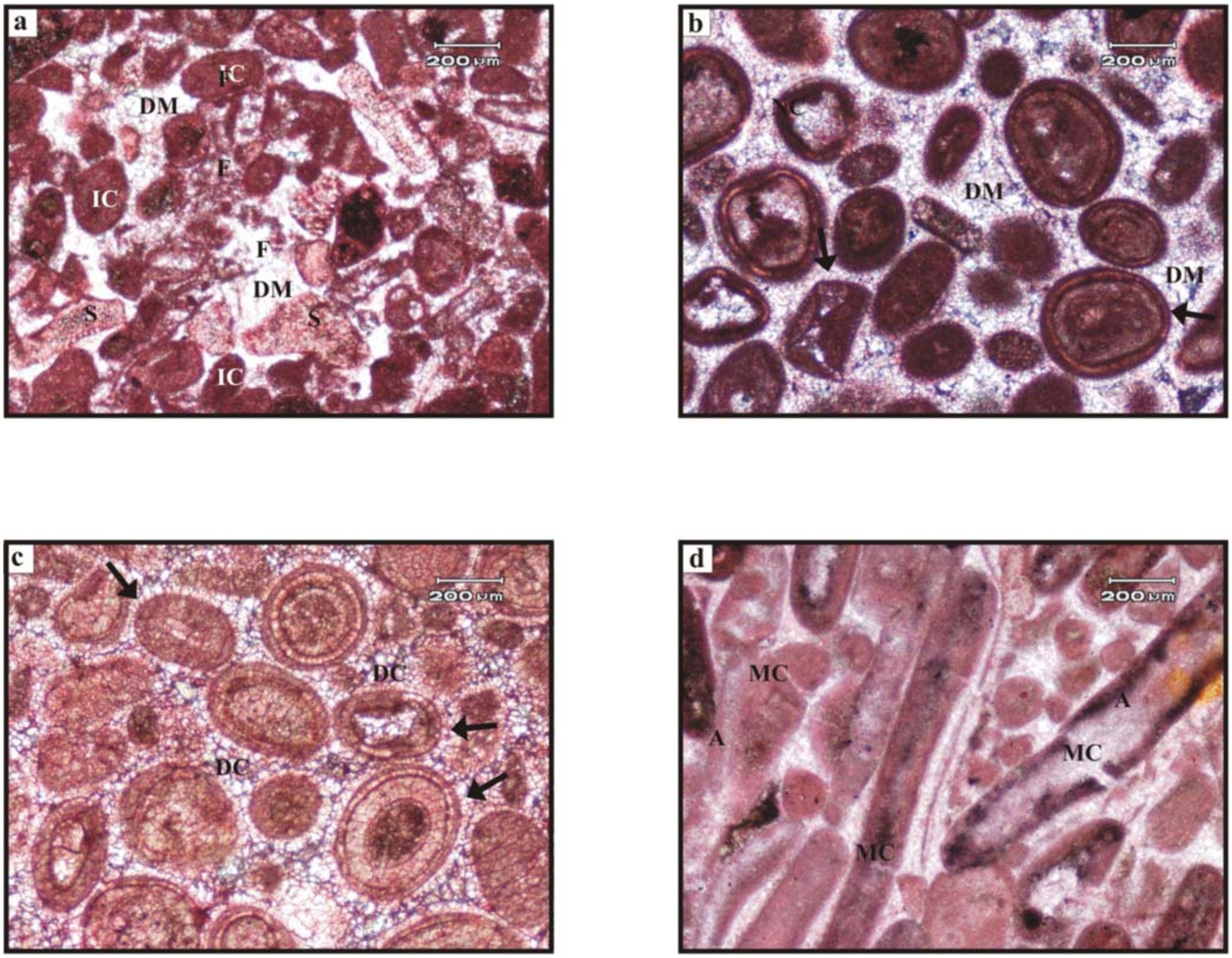
a. Photomicrograph showing peloidal packstone, wherein skeletal grains of echinoderm **(EC)** and mollusks **(M)** in association with peloids are present. (XN, stained) **Sample No. SBH-23B**

b. Photomicrograph showing a grainstone composed of grapestones **(GR)** cemented by intergranular dolomite **(ID)** cement. (PPL, stained) **Sample No. SBH-24T**

c. Photomicrograph exhibits bioclastic wackestone with well preserved shells and fragments of brachiopod **(BR)**, gastropod **(G)** and pelecypod **(P)**. (PPL, stained) **Sample No. SBH-42L**

d. Photomicrograph displays cortoidal grainstone with circumgranular columnar **(arrowed)** cement and intergranular drusy mosaic **(DM)** cement. The skeletal grains have lost internal structure due to dissolution-precipitation phenomenon and now possess micritic envelopes **(E)**, occasional intraclasts **(arrowed)** are present. (PPL, stained) **Sample No. SBH-42U**

Plate 2



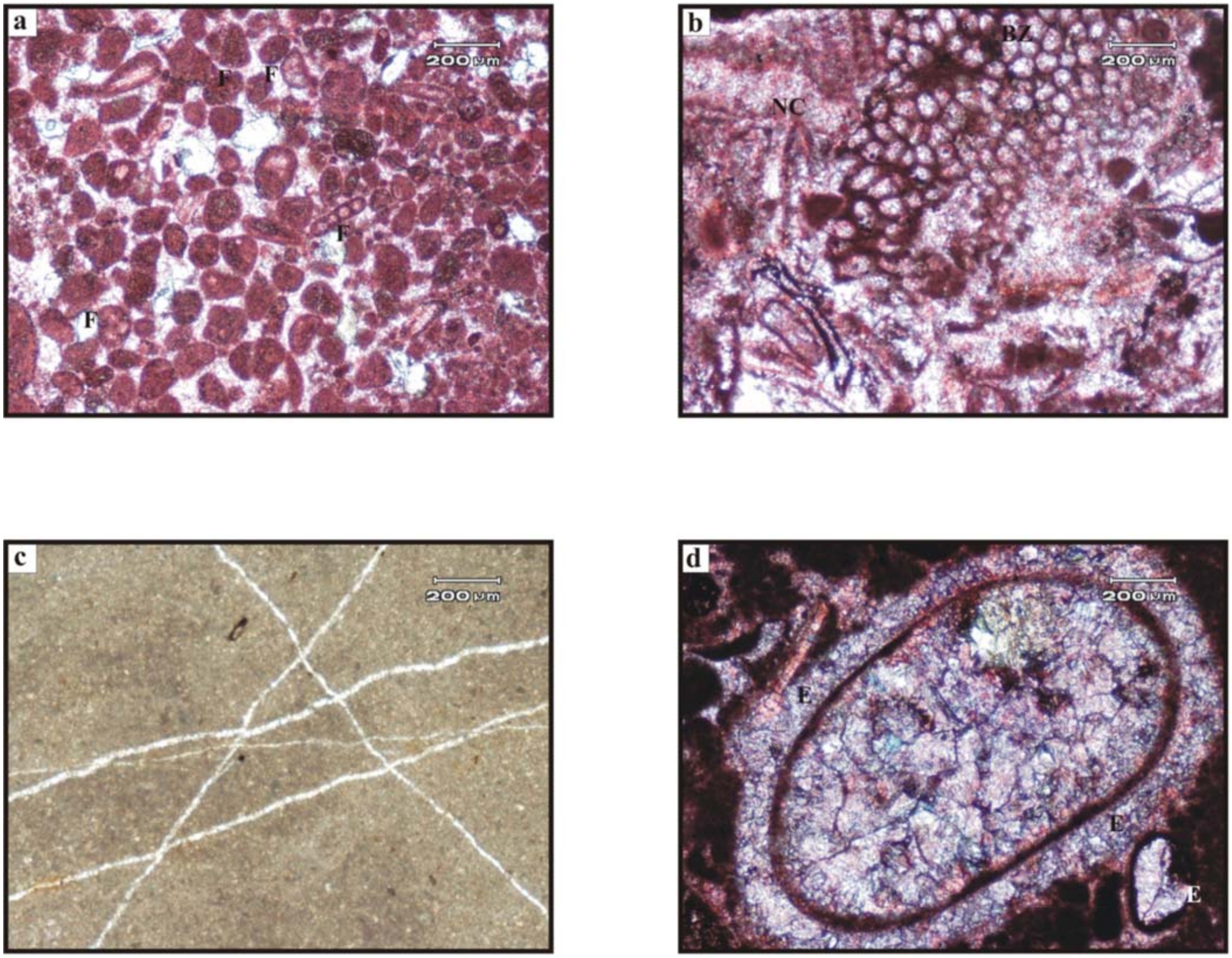
a. Photomicrograph showing a bioclastic grainstone. Several shells of sponge **(S)** and a few shells of foraminifera **(F)** are present along with intraclasts **(IC)** cemented by drusy mosaic cement **(DM)**. The signatures of mechanical compaction **(MC)** are present as well. (PPL, stained) **Sample No. SBH-46**

b. Photomicrograph showing an ooidal grainstone cemented by dolomite having drusy mosaic **(DM)** of crystals. Ooids are concentric. Dogtooth cement **(arrowed)** has nucleated few ooids. (PPL, stained) **Sample No. SBH-49**

c. Photomicrograph showing an ooidal grainstone with pervasive dolomitization attacking matrix and allochems (ooids). Ooids are concentric and are retaining morphology. Intergranular dolomite cement **(DC)** with partial incorporation of Fe and circumgranular columnar **(arrowed)** cement is present. (PPL, stained) **Sample No. SBH-49**

d. Photomicrograph exhibiting signatures of mechanical compaction **(MC)** in a bioclastic grainstone, shown by broken bioclasts of algae **(A)**. (PPL, stained) **Sample No. SBH-71B**

Plate 3



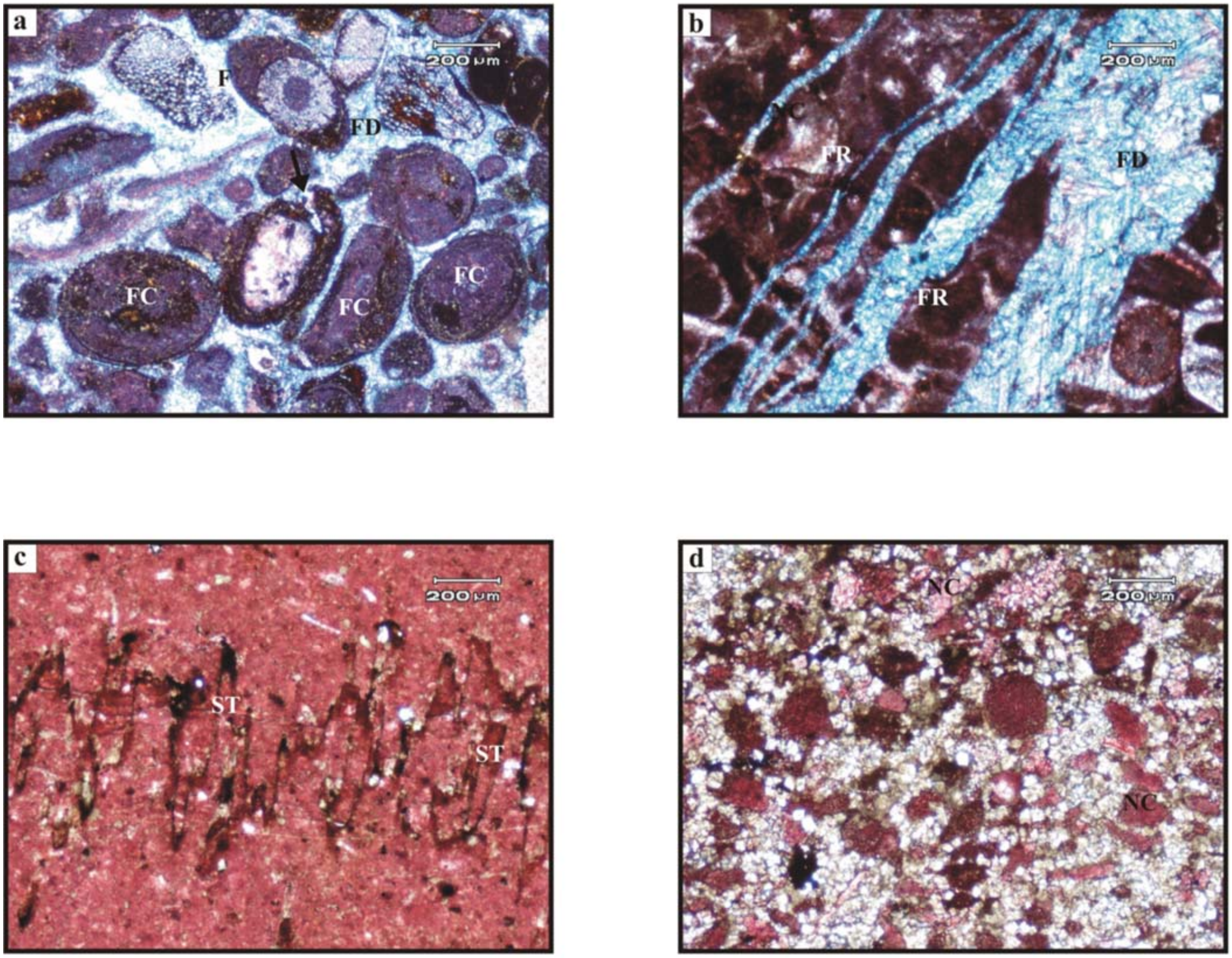
a. Photomicrograph displaying a peloidal grainstone with associated foraminiferal **(F)** tests. The intergranular drusy mosaic **(DM)** cement has partially altered into ferroan calcite with light royal blue stain colour. (PPL, stained) **Sample No. SBH-74B**

b. Photomicrograph displaying a bioclastic packstone. Bryozoan **(BZ)** colony is prominently present. (PPL, stained) **Sample No. SBH-89**

c. Photomicrograph showing a highly fractured mudstone bearing the multi-stage fracturing, well displayed by cross cutting relationship of these fractures. (PPL, unstained) **Sample No. SBH-96L**

d. Photomicrograph displaying a large and a small micritic envelope **(E)** in a bioclastic floatstone. (XN, stained) **Sample No. SBH-93**

Plate 4



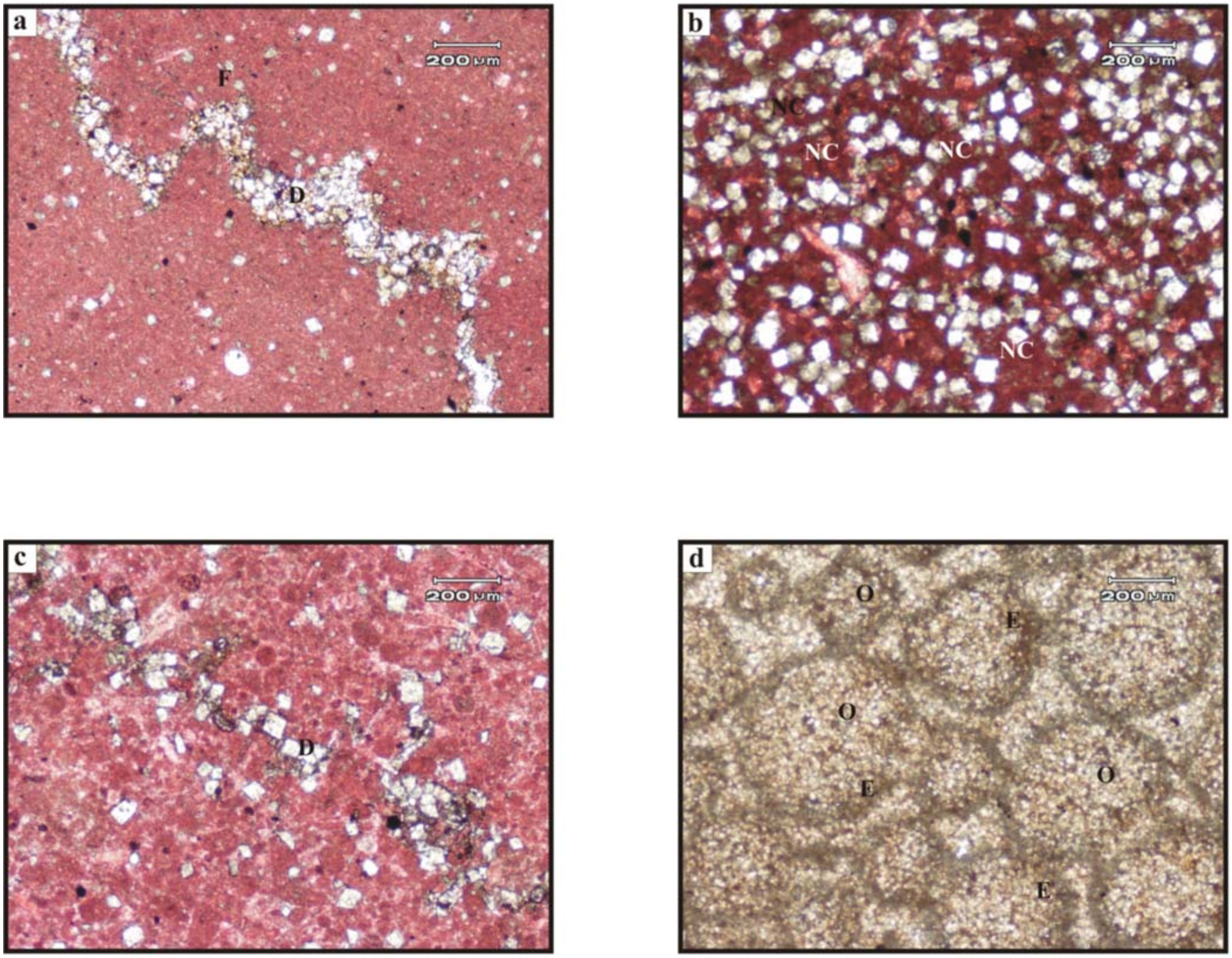
a. Photomicrograph displaying spalled off cortices **(arrowed)** of ooids in an ooidal grainstone. Incorporation of iron in calcite **(FC)** is shown by maroon stain colour of ooids. Iron also partially incorporated in the intergranular dolomite **(FD)** cement with turquoise stain colour. (PPL, stained) **Sample No. SBH-122B**

b. Photomicrograph displaying ferroan dolomite **(FD)** with turquoise stain colour precipitated along fractures in a bioclastic packstone. (PPL, stained) **Sample No. SBH-12**

c. Photomicrograph displaying a bioclastic mudstone. A high amplitude stylolite **(ST)** is cutting across the slide. (PPL, stained) **Sample No. SBH-1L**

d. Photomicrograph showing initially fabric selective dolomitization which after wards changed into pervasive dolomitization in a bioclastic grainstone, wherein bioclasts are indeterminate due to this replacement phenomenon. Some dolomite crystals have been dedolomitized **(NC)** with pink stain colour. (PPL, stained) **Sample No. SBH-5T**

Plate 5



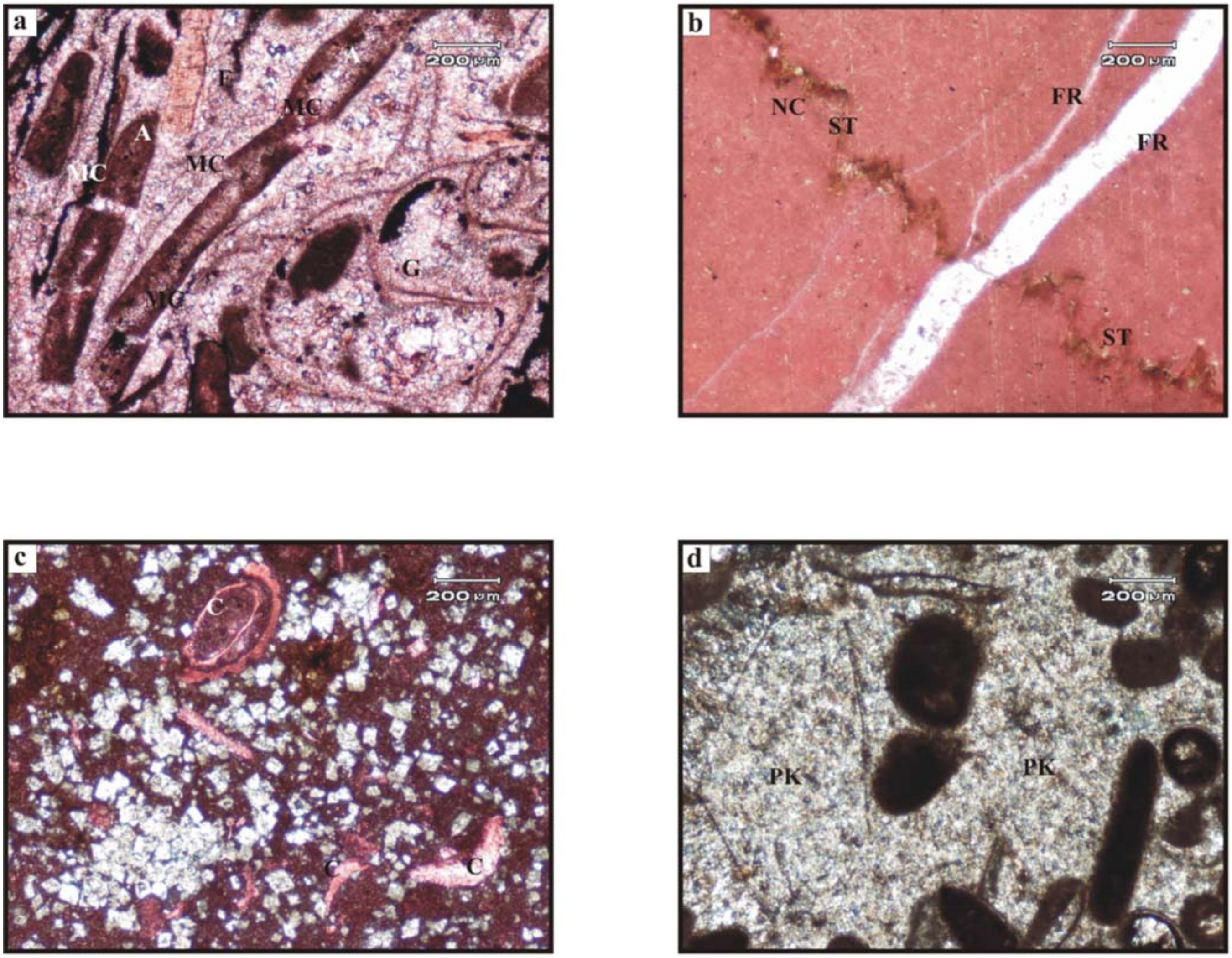
a. Photomicrograph showing stylolite along with dolomite stylocummulate **(D)** in a partially dolomitized mudstone. (PPL, stained) **Sample No. SBH-13B**

b. Photomicrograph showing dolomitization and dedolomitization **(NC)** with pink stain colour in a bioclastic grainstone. (PPL, stained) **Sample No. SBH-18L**

c. Photomicrograph showing dolomite stylolcumulate **(D)** in a partially dolomitized peloidal packstone. (PPL, stained) **Sample No. SBH-19T**

d. Photomicrograph showing pervasive dolomitization in ooidal grainstone converting it to microdolomite. The ghosts of ooids **(O)** are identifiable due to present micritic envelopes **(E)**. (PPL, stained) **Sample No. SBH-24B**

Plate 6



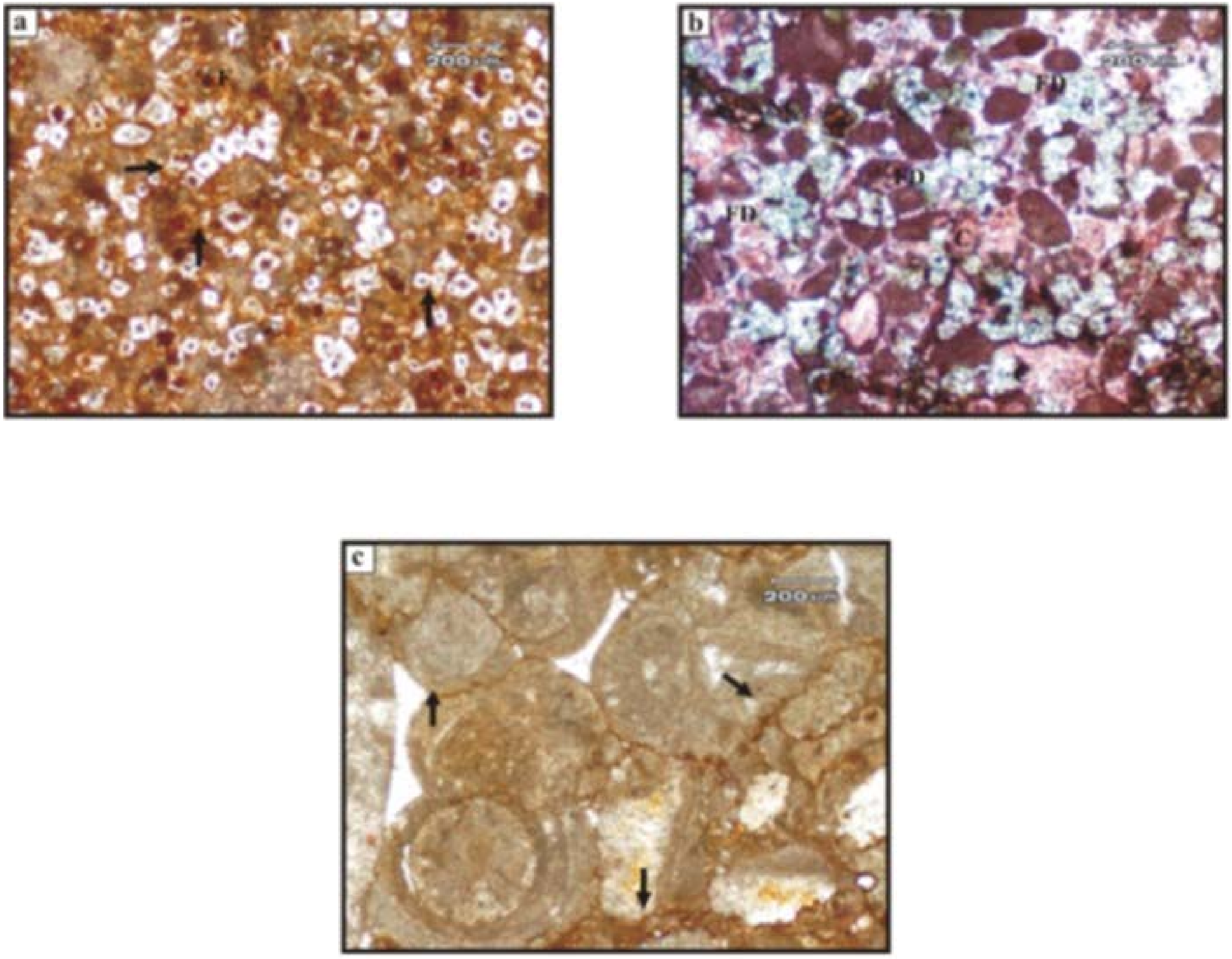
a. Photomicrograph showing a bioclastic rudstone, wherein mechanical compaction **(MC)** prior to cementation is exhibited by broken algal **(A)** shells. A large gastropod **(G)** shell is present too. (PPL, stained) **Sample No. SBH-31**

b. Photomicrograph displaying fractures **(FR)** and a low amplitude stylolite **(ST)** in mudstone. Stylolite is cutting across fractures and thus postdating these ones. (PPL, stained) **Sample No. SBH-56T**

c. Photomicrograph displaying matrix selective dolomitization in a bioclastic mudstone. The skeletal grains are composed of calcite **(C)** with pink stain colour. (PPL, stained) **Sample No. SBH-63L**

d. Photomicrograph displaying poikilotopic **(PK)** cement with characteristic large calcite crystal developed in a peloidal grainstone. (PPL, unstained) **Sample No. SBH-92**

Plate 7



A. Photomicrograph displaying zoned dolomite in a mudstone. The zoning **(arrowed)** in dolomite indicates changes in the geochemistry of formation fluids during the course of crystallization. (PPL, unstained) **Sample No. SBH-115B**

b. Photomicrograph showing ferroan dolomite **(FD)** with turquoise stain colour and calcite **(C)** with pink stain colour in a peloidal grainstone. (PPL, stained) **Sample No. SBH-124T**

c. Photomicrograph displaying a chemically compacted ooidal grainstone. The tightly compacted facies exhibits sutured grain contacts **(arrowed)** approaching to pressure solution seams. (PPL, unstained) **Sample No. SBH-130**

width. It is found only at one horizon in the studied formation (Plate 6a).

Bioclastic floatstones

Floatstone is a matrix supported sub-microfacies of allochthonous (derived) limestones. It consists of shells and grains of organisms more than 2mm in size (Embry and Kalovan, 1971). This microfacies is also found at only one horizon in the studied section (Plate 3d). Shells and bioclasts of mollusks and sponges have mostly been recorded.

Packstones

The follwing microfacies of packstone have been identified.

Bioclastic packstones: This sub-microfacies of packstone is commonly composed of skeletal grains of different species (Plates 3b and 4b). However at only one horizon a bioclastic packsone comprised of bryozoans is shown in Plate 3b.

Peloidal packstones: It has been recorded at few levels in the investigated section as shown in Plates 1a and 5c. Peloids are found in association with skeletal grains of echinoderm and mollusks in Plate 1a. Peloids in association with other grains in various microfacies are found with low frequency of appearance.

Wackestones

The carbonate microfacies with more than 10% skeletal/nonskeletal grains are categorized as wackestones (Dunham, 1962).

Bioclastic wackestones: The wackestones are found at various levels in the Samana Suk Formation. The interpreted bioclastic wackestones are mainly composed of bioclasts of gastropods and pelecypods (Plate 1c).

Mudstones

Mudstones, without any component grain have been found in the studied formation and are highly fractured (Plate 3c). Subsequently these fractures got filled with calcite. A highly fractured mudstone with a small amplitude stylolite, which is cross cutting these fractures and hence, postdating these fractures, is shown in Plate 6b. Such mudstones are present at few horizons in the investigated formation. Partially dolomitized mudstones have also been recorded (Plate 5a and 7a).

Bioclastic mudstones: Bioclastic mudstones are present at a number of levels in the measured section. Representatively the bioclastic mudstones are shown in Plates 4c and 6c.

STANDARD MICROFACIES (SMFs)

The recorded microfacies from this studied section have been compared with the Standard Microfacies (SMFs) of Wilson (1975) and Flugel (1982). The SMF No. 8, 9, 11, 15, 16, 17, 23 and 24 have been documented here.

DIAGENETIC SETTINGS AND SEQUENCE

The following diagenetic features, developed in this section, have been observed. A detailed account of the sequence of various diagenetic phases and their products depending on time hierarchy is presented here:

Micritic envelopes

It is the first diagenetic phase, which takes place in the marine diagenesis of limestones. Micritic envelopes develop around fauna which have original aragonitic mineralogical composition. Such grains are very much prone to develop these envelopes. As aragonite is a metastable carbonate mineral. It is dissolved in the very early phase of diagenesis of carbonate sediments and is subsequently replaced by calcite. These envelopes serve to define and preserve the outline and morphology of the carbonate grains over which these envelopes develop. These envelopes may be found on skeletal and non-skeletal grains in different microfacies. The micritic envelopes found here are shown in Plates 1d, 3d and 5d. These envelopes, recorded in the Samana Suk Formation of studied section, are similar to those described by Kendal and Skipwith (1969) from the recent carbonate sediments and resemble with those illustrated by Bathurst (1964) from the Jurassic and Carboniferous limestone. However, according to Sheikh (1992) fossil micritic envelopes found in the Shinawari and Samana Suk formations from Kalachita Ranges are different from the recent micritic envelopes.

Dissolution of aragonite

In the second phase the aragonite dissolves in the faunal grains having aragonitic mineralogy and is precipitated as sparite. Sometimes the internal structure of the skeletal grains is totally destroyed and no relict structure is observed at all. However, the outline and morphology of these grains is preserved.

Cements

Cement endows strength and stability to the carbonate microfacies and sediments. The well developed cement, always, resists physical, as well as, chemical compaction and fracturing episodes. Hence, the cementation of carbonate sediments is taken as an important diagenetic process. Early diagenetic cement precipitates as fibrous aragonite, while dog tooth cement (circumgranular equent cement), dolomite cement, drusy mosaic cement and poikilotopic cement precipitate as late diagenetic cements. Interagranular cement is the next phase of carbonate diagenesis. The sparry calcite cement with drusy mosaic of crystals is product of meteoric phreatic environment (Tucker, 1988). The following cement types have been recorded at different levels and in different microfacies:

Circumgranular cements: The documented two types of this cement are elaborated here:

Dog tooth cement: The dog tooth cement precipitates as late diagenetic cement as do dolomite cement and poikilotopic cement in a late diagenetic phase. It is circumgranular equant cement and has been recorded in Plate 2b.

Columnar or prismatic cement: It commonly precipitates in the mixed meteoric/marine phreatic environments (Tucker, 1988). This circumgranular cement found in the studied formation is shown in Plate 1d.

Drusy calcite cement: It is a pore filling cement and commonly precipitates in grainstones. It might be composed of sparry calcite or dolomite. Its crystals are of small size at margins and gets larger towards the centre of pore as per available accommodation space. It has been recorded in Plate 1d.

Poikilotopic cement: The diagnostic texture of poikilotopic cement is elucidated as that the coarse cement crystals enclose component allochems, which look like specks in crystals mosaic. It develops after the phase of pervasive dolomitization and development of intergranular cements and precipitates in phreatic environment, commonly, in burial regime. It has been found at various horizons and is shown representatively in Plate 6d.

Mechanical compaction

Mechanical compaction of the carbonate sediments is the next diagenetic event. Under this diagenetic process the inter-grain and interstitial space reduces, which results in the overall reduction of porosity of the rock. In case of poorly cemented sediments the component grains may break due to increased mechanical compaction (Plate 2d and 6a). This and other factors produce fractures and ultimately enhance the porosity and permeability of the rock.

Fractures: The presence of different types of fractures, veins and broken allochems display the imprints of both tectonic stresses and overburden pressure pre-and-post cementation phases. Fractures are commonly found at various horizons in the measured section. Different phases of fracturing, sometimes along with stylolitization, filled with one or more episodes of calcite/ferroan calcite and dolomite/ferroan dolomite have been identified here (Plates 3c, 4b and 6b). The stylolites developed in the lime mudstone microfacies have been noted disrupting the fractures (Plate 6b). Mudstones particularly bear fractures, which at places are highly fractured with several phases of fracturing sometimes (Plate 3d). Fractures have been recorded in other microfacies too (Plate 4b). The effective porosity and permeability is thought to be enhanced in the presently investigated section due to the occurrence of various phases of fracturing, which cause to provide interconnectivity. More over during and after uplifting of the host area most probably the creation of additional porosity took place by dissolution and fracturing. The signatures of mechanical compaction have been noted in Plate 2d.

Chemical compaction

In this late stage diagenetic phase as a result of increasing compaction due to over burden and tectonic stresses first the grain to grain contacts take place and then simple grain contacts developed into planar and sutured grain contacts. Later on dissolution of grains starts at these contacts. Sometimes the embayment of one grain into the other is, also, observed (Plate 7c).

Stylolites: The stylolites develop in the last diagenetic events. These are actually manifestation of a diagenetic phenomenon, named as pressure-dissolution or chemical compaction. The continued dissolution of compacted grains at planar and sutured contacts results in the formation of stylolites or so called dissolution seams/pressure solution seams. The recorded point, planar and sutured grain contacts, pressure solution seams and stylolites all are indicators of chemical compaction due to both tectonic stresses and overburden pressure. The observed stylolites at various levels of this formation range from low amplitude (Plate 6b) to high amplitude stylolites (Plate 4c) and are found mostly in mudstones, however these have been recorded in other microfacies as well (Plate 5c and 7c). The stylolites have also developed in association with different episodes of fracturing. The stylolites, developed in mudstone microfacies, have cross cutting relationship with calcite filled fractures and postdate these fractures (Plate 6b). The Plate 7c shows the sutured grain contacts approaching to pressure solution seams.

Dolomitization

The matrix selective, in other words, texture preserving dolomitization is the next phase of the diagenetic history of limestones, in which only the dolomitization of matrix takes place and component grains/allochems are not dolomitized. The diagenetic process of dolomitization results in the formation of dolomite of secondary nature. It is a common feature of carbonate sediments, particularly that of limestones, during the continuation of various diagenetic phases. In the investigated section the dolomitization is relatively fairly extensive and has developed at its different horizons. Dolomite has also been recorded as stylocummulate along microstylolites (Plates 5a and c), while dolomite as cement has been found in Plate 2b and c. The following types of dolomitization have been observed in the studied section:

Texture preserving dolomitization: It has been documented in the studied formation at a few horizons. It is a texture preserving non-mimic dolomitization process and remains restricted to the matrix. It attacks the matrix and destroys it (Plate 6c), that is why it is referred to as matrix selective dolomitization.

Pervasive dolomitization: It is an extensive dolomitization process in limestones, in which the dolomitization is not texture selective and attacks the fabric of rock, hence whole of the rock gets dolomitized with the passage of time (Plates 2c, 4d and 5d).

Microdolomitization: Microdolomitization is such a type of diagenetic process, in which crystals of dolomite develop in a very small size. Microdolomite is noted in Plate 5d.

Zoned dolomitization: It has developed in the upper part of this formation at a number of levels. The zoning in dolomite is indicative of changes in the geochemistry of formation fluids during the growth of dolomite crystals. The noted zoned dolomitization has partially affected the concerned microfacies (Plate 7a). It is related to uplift of the basin and/or to the unconformity surface.

Dedolomitization

Dedolomitization is also among the last diagenetic events, during which the dolomite is calcitized under the prevailing diagenetic conditions, such that, the dolomitization is reversed and dolomite is converted into calcite. This diagenetic process is also termed as calcitization. It is a common phenomenon in carbonate rocks and is thought to be a recent phenomenon, most probably related to the Holocene age. The recorded dedolomitization in the Samana Suk Formation is shown in Plates 4d and 5b.

Incorporation of iron into calcite and dolomite

It is the last diagenetic setting in which the leached out iron from various sources gets incorporated into calcite (rendering it into ferroan calcite) and dolomite (rendering it into ferroan dolomite) as per demand of the prevailing environmental conditions. This setting is related with the late stage uplifting and/or unconformity surface. It is the post uplift diagenetic phase. The leached out iron is incorporated in calcite and renders it into ferroan calcite (Plate 4a). The ferroan dolomite (Plates 4a and b and 7b) is formed by the same diagenetic process.

DISCUSSION

The Samana Suk Formation was deposited as significant carbonate litho-package comprised of limestones, dolomitic limestones and dolomites along with some siliciclastic contents in the form of shale/marl breaks. The limestones range from lime mudstones (unfissiliferous and poorly fossiliferous) to grainstones and are dolomitized at several horizons. The found dolomites are micro to macro and dedolomitized at a number of stratigraphic levels. The formation is predominantly composed of course grainstone microfacies, wherein a variety of diagenetic settings has been documented. These settings are represented by different cement types, neomorphic mineral products, mechanical and chemical compaction, stylolites and by the incorporation of iron in calcite and dolomites. The formation experienced a number of episodes of fracturing during its geologic history, in which swarms of fractures of different nature and size were produced. Latter on these fractures were filled by secondary calcite/dolomite. This sequence of carbonate sediments is highly fossiliferous at certain levels and contains very large faunal and floral tests, shells and bioclasts approaching to coquinal lithofacies. The main character of this formation exposed at the measured section is determined to be the porous and permeable course grained carbonate unit.

CONCLUSIONS

The conclusions drawn are given as under:

The Samana Suk Formation at this section is comprised predominantly of dolomitized limestones and dolomites frequently fractured and stylolitized along with minor shale and marl component.

The noted microfacies include bioclastic rudstones and floatstones, bioclastic, pelloidal, ooidal, cortoidal and grapestone grainstones, bioclastic and pelloidal packstones, bioclastic wackestones bioclastic mudstones and unfossiliferous mudstones.

The component skeletal grains of the bioclastic microfacies are predominantly shells, tests and particles of benthonic foraminifers, echinoderms, mollusks, brachiopods, corals, sponges, bryozoa and algae.

The diagenetic settings were prone to produce a variety of features, like, cements from early marine to late diagentic cements, micritization, neomorphism, different types and phases of dolomitization and dedolomitization, incorporation of iron to calcite/dolomite, compaction features and dissolution fabric.

Three hard ground surfaces have been recorded in this section at different levels. These surfaces represent the periods of non erosion/non deposition and mark regressive cycles during deposition of this formation.

The analytical studies of depositional texture and microfacies exhibit that the Samana Suk Formation was deposited in the shallow shelf open marine environments in outer and inner shelf and in lagoon.

The formation’s course grained texture, larger dolomitic contents, highly fractured horizons and dissolution fabric point towards its reservoir potential.

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