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Depositional sequences and sea level changes during Bathonian-Oxfordian, Kutch (Kachchh) Basin, Gujarat, India

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ABSTRACT
The Kutch sedimentary basin is situated at extreme west of Indian Peninsula is an excellent example of cyclic sedimentation in Mesozoic shallow marine regime. The Bathonian to Santonian shallow marine rocks crops out in the Kutch Mainland extending for ~ 193 km from Habo in the east to Lakhpat in the west. Based on detail field studies in the Jhura dome, Kutch Mainland and laboratory investigations of 43 carbonate rock samples, the 370 m succession of carbonate-dominated rocks is stacked into three depositional sequences of regional importance. The 84 m Transgressive sequence-I of Bathonian age consisting of four microfacies assemblages represents an upward deepening facies succession. The 130 m regressive sequence of Callovian age composed of five microfacies assemblages showing upward shoaling facies succession. It was deposited during stillstand period followed by gradual increase in sediment supply. The 155 m transgressive sequence II of Early Oxfordian age consists of four microfacies assemblages that deposited during highstand of sea level in the basin together with episodic and less sediment supply. The relative sea level curves indicate high-order sea level variation during whole sequence before to major drop in sea level at the end of the transgressive sequence-II. The microfacies study reveals that these high order sequences are regionally comparable and might have been controlled by an active tectonic mechanism together with global sea level change.

Keywords: Microfacies, Depositional sequences, Sea level curve, Bathonian-Oxfordian succession, Kachchh basin.

INTRODUCTION

Geoscientific study of Kutch basin has an applied aspect (e.g., Lohani et al., 2022; Shaikh et al., 2020, 2022; Dhawale et al., 2023) to comment on hydrocarbon prospect of the terrain. The Kutch basin is located on the prime hydrocarbon belt of the western part of Indian subcontinent and it has been classified as category-II based on the degree of hydrocarbon perspectivity (Dwivedi, 2016). Following the geodynamic classification of Indian sedimentary basins, Kutch basin is a pericratonic rift basin (Biswas et al., 1993). Mesozoic shallow marine rocks of Kutch basin have been continuous focus of Oil and Natural Gas Corporation Ltd (ONGC) of India since its inception in the mid-1950. Recent hydrocarbon discoveries in the offshore and onshore of Kutch basin have presumed greater importance (Patil et al., 213). In this context is here delineated high order depositional sequences (transgressive-regressive facies) that can help to map the distribution of source and reservoir rocks in sequence stratigraphic framework. Occurrence of hydrocarbon is well known in Cenozoic high order sequences in Gulf of Mexico and Niger Delta (Amodu et al., 2022; Rassi, 2002). The distribution and heterogeneity of source rocks are well connected to various orders of depositional cycles identified in Paleozoic to Mesozoic successions (van Buchem et al., 2005).

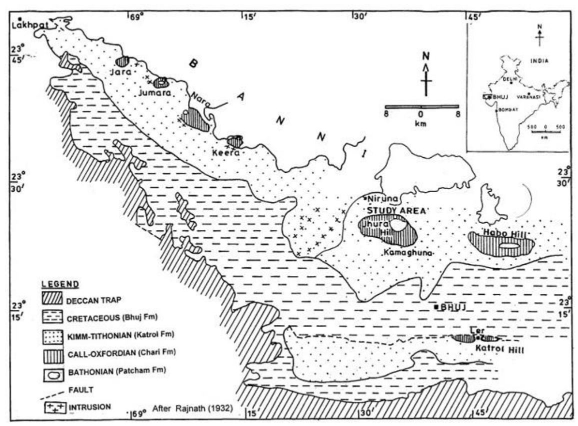

Figure. 1 Geological map of Mainland along with location of the studied section. Map modified after Rajnath (1932).

Middle Jurassic to Upper Cretaceous sedimentary successions of Kutch basin are exposed extensively in the Kutch Mainland, Wagad, the 'Islands' of Pachcham, Bela and Khadir, and the Chorar hills. The Mesozoic sedimentary successions of Kutch basin were divided into four 'Groups' namely Patcham, Chari, Katrol and Umia in ascending order by Stoliczka (Waagen, 1873), and Jhurio, Jumara, Jhuran and Bhuj formations in Mainland by Biswas (1971, 1977). Continuous succession from Bathonian to Santonian is exposed in various outcrops of Kutch Mainland. The succession is composed of most conspicuous ridge extending for about 193 km from Habo in the east to Lakhapat in the west. Geological map of Mainland along with location of studied section is shown in Figure 1 (Rajnath, 1932) and lithostratigraphic framework of Middle Jurassic rocks of Kutch mainland in Table 1.

Table 1. Lithostratigraphic framework of Middle Jurassic rocks of the Kutch/Kachchh Mainland.

Age	After (Krishna, 2002 integrated to Stoliczka (In Waagen 1873)		After Biswas (1977)
	Formation	Member	Formation
Callovian – Middle Oxfordian	Chari Oolite	Dhosa	Jumara
Bathonian	Patcham		Jhurio

The review of the previous literature (Biswas, 1981, 2016) reveals two distinct megacycles (second order cycles) in the Kutch basin: a transgressive cycle comprises Jhurio and Jumara formations (Patcham and Chari formations of Stoliczka, 1873) followed by a regressive cycle (Jhuran and Bhuj formations). These two lower order cycles include several high orders fluctuations of sea level. Bajocian to Oxfordian was a period of major sea level rise in Kutch graben (Krishna et al., 1983), followed by major drop in sea level till Neocomian.

Present investigation includes Patcham and Chari formations deposited during major rise in sea level and it would help in developing high order sequences in well resolve time frame (Bathonian to Early Oxfordian) which reflect regional relative sea level fluctuations. Identification of high-order tectonic sequences based on vertical facies change is a major criterion for regional correlation (Abbott and Sweet, 2000). The sequences of < 3 Ma duration are found throughout Phanerozoic would be globally correctable (Haq et al., 1988). There are four scales of sequence development in stratigraphic record related to range of time. The third order cycle varies from < 1 to ~ 10 Ma (Vail et al., 1977a). Most of the geologists assume the time durations between 0.5 and 3-5 Ma for the third order eustatic cycles. By knowing the pattern of third order depositional sequences through lithofacies analysis along with existing biostratigraphic data is providing finer stratigraphic details that recognizable across the basin. These 3rd order sequences are helpful in formulation of outcrop-based sequence stratigraphic model for Patcham and Chari formations and hydrocarbon exploration (van Buchem et al., 2002).

Previous geological studies did not distinguish microfacies in well resolve time frame of the carbonate dominated Patcham and Chari formations of Mainland of the Kutch basin**.** There is much scope for developing high order depositional sequences with support of biostratigraphic and genetic sedimentological principles. Existing lower order (2nd order) Transgressive – Regressive model in the basins can be improved by considering microfacies analysis of carbonate-dominated succession. The study also attempts to document the fine stratigraphic details by establishing high order Transgressive-Regressive sequences during Bathonian to Early Oxfordian.

METHODOLOGY

This study includes detailed field and lab investigations of a single section (Badi section) of the Jhura hill. I present a stratigraphic column that shows all sedimentary features (Fig. 2). Around 43 rock samples were collected according to change in lithology. Petrographic characters of all the rocks were observed and examined under a polarizing microscope. Additionally, modal percentage of different allochems, orthochems and associated detritals were identified and counted using point counter, which helped in their classification of facies. In order to know the mineral composition of mudrocks, three samples were examined by x-ray diffraction available in the laboratory of Oil and Natural Gas Corporation Ltd. (ONGC) Dehradun, India.

RESULTS

MICROFACIES DESCRIPTION OF GRAINSTONES (A):

This is the most abundant and frequently occurring lithofacies in the Patcham Formation and is interbedded with calcareous mudstone and well observed in Badi section. It is characterized by grain-supported fabric and on the basis of types of allochems, orthochems and their relative abundances Dunham (1962), this lithofacies has been divided into four microfacies which are described below:

Oolitic fossiliferous grainstone (A_1):

It is very thickly bedded and contains well preserved fossils and ooids. Fossils are mostly mollusks and foraminifera. These fossils are commonly coated with ferruginous material. Good preservation of few mega fossils has also been noticed. Spherical to elliptical shaped ooids having 0.2 to 0.4 mm diameters are commonly present. Few ooids with quartz nucleus are well preserved. (Plate 1A). Fossils and ooids are cemented by spiritic materials. Modal analysis of this microfacies was carried out to identify the precise percentage of framework grains. The result is as follows: fossils – 64.9%, ooids – 10.8%, intraclasts – 3.8 %, peloids – 1.5 %, spars 17.8 % and terrigenous clasts – 1.3% (Table 2).

Intraclastic grainstone (A_2):

The main components of this microfacies are micritic intraclasts and larger foraminifers. Bioturbations are frequently observed. Micritic

Table 2. Modal Composition of grainstones (% by vol.)

S.No	Sample No.	Allochems					Orthochems		Total	Dunhm's nomenclature
		Ooid	Fossil	Intraclast	Peloid	Sand	Micrite	Spar		
1	S-99/124	11.3	64.5	3.4	1.5	1.8	-	17.5	100	Oolitc Fossiliferous Grainstone (A_1)
2	S-99/143	10.2	62.7	4.0	3.0	1.0	-	19.1	100	
3	S-99/144	10.8	67.5	4.5	0.0	1.4	-	16.8	100	
	Average	10.8	64.9	3.8	1.5	1.3	-	17.8	100	
4	S-99/104	-	7.1	45.0	-	1	-	46.7	100	Intraclastic Grainstone (A_2)
5	S-99/105	-	6.5	45.7	-	-	-	47.6	100	
6	S-99/111	-	7.0	46.5	-	-	-	46.0	100	
	Average		6.82	45.7	-	1.28		46.16	99.72	
7	S-99/150	2.5	20.0	4.2	-	40.7	-	35.6	100	Bioclastic Grainstone (A_3)
8	S-99/149	6.0	32.4	10.5	-	9.0	-	42.1	100	
9	S-99/148	4.5	27.3	8.4	-	8.5	-	47.3	100	
	Average	4.3	26.5	7.7		19.4		41.6	99.9	
10	S-99/116	2.5	65.7	4.2	1.5	5.5	-	20.6	100	Fossiliferous Grainstone (A_4)
11	S-99/126	19.5	51.0	2.0	1.0	7.0	-	19.5	100	
12	S-99/137	1.5	67.5	4.8	5.5	2.0	-	18.9	100	
13	S-99/142	0.3	68.2	9.8	3.1	1.5	-	17	100	
	Average	5.9	63.1	5.2	2.7	4.0		19	100	

intraclasts are (sub)spherical. These allochems are bounded by microsparitic orthochems (Plate 1B). Modal analysis of this microfacies is as follows: 6.82 % fossils, 45.7 % intraclasts, 1.2% sand and 46.16% spar (Table 2).

Bioclastic grainstone (A_3):

It is characterized by mostly shell fragments and terrigenous materials and few percentages of ooids (Plate 1C). These fragments are cemented by coarsely crystalline carbonate materials. Fossil fragments are mostly mollusks and echinoids. Modal analysis exhibits fossil fragments – 26.5 %, sand – 19.4%, intraclasts – 7.7%, ooids- 4.3% and spars – 41.6 % (Table 2).

Fossiliferous grainstone (A_4):

It is thinly bedded, moderately bioturbated and contains well preserved megafossils (mollusks and echinoids) and coarser clastic materials of 0.5 cm to 2 cm diameter (Plate 1D). Few clastic materials of 2 to 5 cm diameter are present. However, well rounded pebbles are commonly noticed. Modal analysis reveals the percentages of the following: fossils - 63.1%, intraclasts - 5.2%, ooids - 5.9%, peloids - 2.7%, sand - 4% and spar - 19.0% (Table 2).

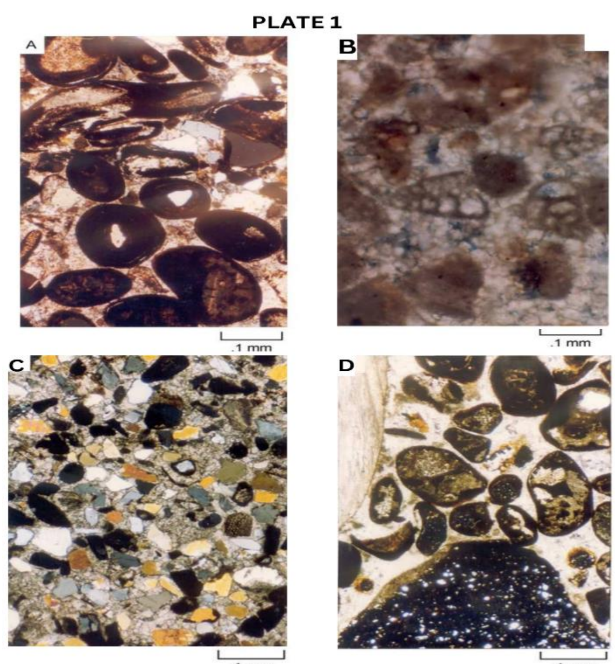

Plate 1. Photomicrograph showing petrographic types of grainstones: A - Oolitic fossiliferous grainstone, B - Intraclastic grainstone, C - Bioclastic grainstone, D-Fossiliferous grainstone.

Table 3. Modal Composition of packstones (% by vol)

S/N	Sample No	Allochems					Orthochems		Total	Dunham's nomenclature
		Ooid	Fossil	Int	Pel	Sand	Micrite	Sp.		
1	S-99/65A	53.65	-	-	-	-	46.34	-	100	**Oolitic Packstone: (B_1)**
2	S-99/65B	53.95	3.8	-	-	1.3	40	-	100	
3	S-99/67	46.95	1.0	-	-	6.4	45.5	-	100	
	Average	51.46	1.6	0	0	2.5	43.9		100	
4	S-99/68	33.9	11.9	-	-	8.7	45.4	-	100	Bioclastic Oolitic Packstone **: (B_2)**
5	S-99/70	44.6	9.1	-	-	11.2	37.1	-	100	
6	S-99/161A	32.5	9.2	-	-	9.2	47.27	-	100	
	Average	36.98	10.1			9.7	43.25		100	
7	S-99/76	1.0	24.9	-	-	19.0	55	-	100	Fossiliferous Packstone **: (B_3)**
8	S-99/79	2.2	37.4	-	-	10.3	50	-	100	
9	S-99/81	1.0	30.5	-	-	13.4	55	-	100	
	Average	1.4	30.9			17.6	53.3		100	
10	S-99/96	-	69.5	-	-	-	32.4	-	100	Bioclastic Packstone **: (B_4)**
11	S-99/97	-	66-5	-	-	-	33.4	-	100	
12	S-99/98	0.5	65.5	-	-	-	33.7	-	100	
13	S-99/99	7.5	38.8	-	-	4.3	49.2	-	100	
14	S-99/101A	4.6	44.3	-	-	4.9	45.8	-	100	
15	S-99/101B	3.5	45.5	-	-	3.5	47	-	100	
16	S-99/101C	7.5	42.0	-	-	3.3	47.2	-	100	
	Average	3.08	53.15			2.9	41.2		100	

MICROFACIES DESCRIPTION OF PACKSTONES (B):

This lithofacies are mainly confined to the upper part of the Chari Formation and normally interbedded with siltstone. It is distinguished by grain-supported textures and contains ~ 60-65% allochems consisting of ooids, shell fragments and terrigenous clasts of various size grade embedded in micritic matrix. Based on the present allochems and orthochems and their relative abundances (Dunham, 1962), this lithofacies has been divided into four microfacies as follows.

Oolitic packstone (B_1):

This microfacies is very thin and observed in the uppermost bed of Dhosa Oolite member exposed in Kutch Mainland. It contains boulders, cobbles and pebbles within the fine-grained calcareous sandstone/siltstone, mudstone and ironstone. These fragments are subangular to subrounded and embedded in an oolitic micritic matrix. This microfacies is composed of mostly allochems consisting of ooids and few shell fragments. On the basis of occurrence of various allochems, the rock can be named as oolitic packstone. The size of ooids varies from 0.25 to 1.0 mm and are mostly ellipsoidal. Ooids are highly ferruginised and their color varies from deep brown to light yellow. These are concentric and have heterogeneous nucleus. Shell fragments include mollusks, echinoderms, brachiopods and coated with iron oxide. Modal analysis reveals the presence of ooids-51.46%, micrite- 43.9%, fossil fragments-1.6%, terrigenous constituents-2.54% (Table 3).

Bioclastic oolitic packstone (B_2):

It is the most abundant and frequently occurring microfacies in the Dhosa Oolite Member. The Bioclastic oolitic packstone is hard and compact, generally of light yellow / yellowish brown in colour containing deep brown ooids. This microfacies shows rhythmic alternations with soft beds of siltstone (C_1). These are present just below the oolitic packsone microfacies in the Badi section. The Bioclastic oolitic packstone contains significant amount of shell fragments and sand size clastics and differs from normal oolitic packstone. It is a grain-supported oolitic carbonate rock and is made up of monocrystalline quartz, feldspars and ooids embedded in a microcrystalline carbonate matrix (Plate 2A). Modal analysis of bioclastic oolitic packstone was carried out to know the percentage distribution of various constituents. The study reveals the presence of ooids 36.98 %, micrite-43.25%, sand – 9.7% and shell fragments – 10.06 % (Table 3).

Fossiliferous packstone (B_3):

This microfacies is typically developed in the lower part of Dhosa Oolite member and interbedded with gypsiferous mudstone (C3). The Fossiliferous packstone countians appreciable number of well-preserved fossils and sand size clastics. Besides, ooids are also observed in few slides but their percentage is very less. The allochems are embedded in micritic matrix (Plate 2B). Modal analysis of sandy fossiliferous packstone reveals the presence of fossils-

30.9%, sand (quartz and feldspar) – 17.6 %, micrite- 53.33% and ooids – 1.4% (Table 3).

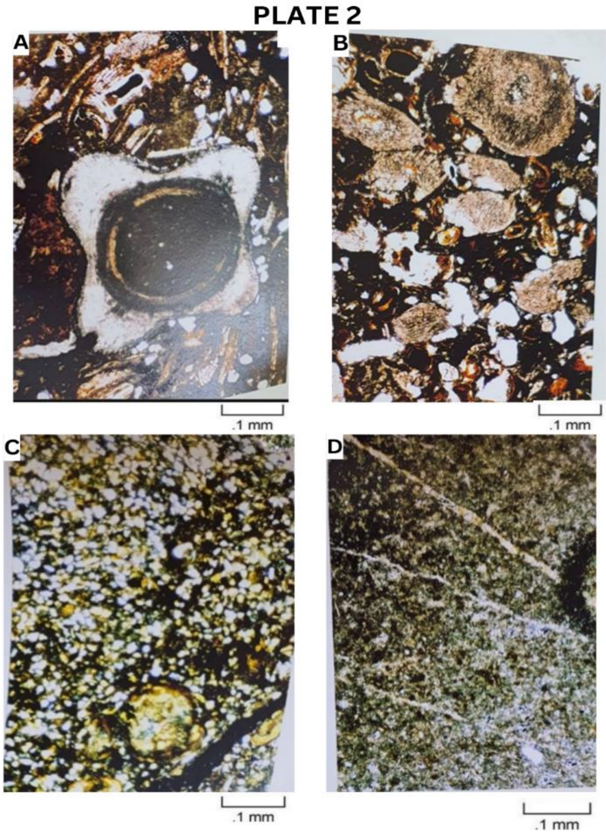

Plate 2. Photomicrographs exhibit packstone and mudrock types: A - Bioclastic oolitic packstone, B - Fossiliferous packstone, C - Siltstone, D - Calcareous mudstone.

Bioclastic packstone (B_4):

It is one of the significant microfacies of Dhosa Oolite member and interbedded with siltstone (C_1). Shell fragments and subspherical to elliptical, subrounded pebbles of ironstone, calcareous mudstone with ferruginous coating from the framework of the rock which are cemented by femicrite. Thin section study shows that this rock is rich in shell fragments, mostly of bivalves. Internal fabric of shell fragments is partially preserved and consists of micrite or microsparite. Thin section study of bioclastic packstone reveals the presence of fossil fragments- 53.15%, ooids- 3.08%, micrite – 41.2% and terrigenous clastics like quartz, feldspars- 2.28% (Table 3).

MICROFACIES DESCRIPTION OF MUDROCKS (C):

It is most abundant lithofacies in the Patcham and Chari Formations and occurs in association with different types of limestone and sandstone microfacies. This lithofacies is generally bioturbated except in the case of gypsiferous mudstone which are thinly bedded to laminated and nodular/concretionary in nature. Murdock's are mostly fragile weathered fine grained moderately compact to soft and variable in color e.g., earthy / yellowish brown / light and dark grey. In the present study classification of argillaceous rock proposed by Blatt et al. (1980) has been followed. The result of x-ray diffraction (XRD) shows that chlorite and illite-mica are dominant in siltstone and comparatively low in gypsiferous mudstone. Montmorillonite is present mainly in calcareous mudstone and as a minor constituent in siltstone. Identified minerals with their respective peak values obtained from the analysis are shown in Table 4. This lithofacies is divided compositionally into following three microfacies. The microfacies are described below:

Siltstone (C_1):

It is thinly bedded to laminated in lower part of the sequence and highly disrupted by biological reworking in the upper part. Siltstone is brown moderately compact weathered and contains calcareous nodules at places. The siltstones are fine-grained clastics dominating over clay and show moderate to poor sorting. Fine clastic materials are floated in clayey matrix. Muscovite is the common mica present in the rock (Plate 2C). Mineralogically it is composed of 65 to 70% silt-sized detritals like quartz, feldspars and some limestone clasts. Clay mineral (illite- mica, chlorite and montmorillonite) from 25 to 30%. Other accessories like iron oxide, shell fragments and heavy minerals constitute < 5% of the rock.

Calcareous mudstone (C_2):

This microfacies is bioturbated, greenish grey color, rich in micro- fossils and contains marly concretions. The calcareous materials are predominant over argillaceous materials. Micritic and pelletic material are homogenously distributed in the microfacies. Some fragments can also be observed (Plate 2D). Mineralogically, calcareous mudstone is composed of mainly calcite and little montmorillonite.

Gypsiferous mudstone (C_3):

This microfacies is yellowish brown to grey, massive and at places parallel laminated. Field observation reveals the interlayering of thinly bedded to laminated mudstone and gypsum. In Badi section, ~ 1 cm thick gypsum layer and ~ 7 cm laminated mudstone are distinctly observed in nala cutting. Gypsiferous mudstones at times contain calcareous and ferruginous nodules of various shape and sizes. Mineralogical composition of this microfacies indicates gypsum as the dominant constituent besides

Table 4. X-ray diffraction analysis of mudrocks (C)

Microfacies	Sample Number	Montmorillonite	chlorite	Illite-Mica	Calcite	Quartz	Gypsum
Siltstone (C_1)	S-99/99	15.09 (885)	7.008 (733) 3.55 (648)	9.92 (584) 4.92 (474) 4.42 (467)	3.01 (518)	3.31 (496) 4.16 (496)	
Calcareous mudstone (C_2)	S- 99/105	14.92 (448)			3.02 (1796) 3.82 (302)	3.32 (783) 422 (308)	
Gypsiferous mudstone (C_3)	S- 99/77B		7.04 (372) 3.54 (334)	4.42(346)		3.32 (1264) 4.24 (815)	7.47 (1726) 3.04 (720) 3.75 (524) 2.85 (400) 2.66 (435) 2.77 (258)

chlorite and illite- mica. The character of detritals is similar as in the siltstone. Only the occurrence of subhedral grains of gypsum and abundance of argillaceous matrix distinguishes this rock from siltstone. Gypsum is distinctly observed and its percentage is quite high. Ferruginised carbonate pellets are uniformly distributed in the rock (Plate 3A).

MICROFACIES DESCRIPTION OF SANDSTONES (D):

The sandstones are interbedded with siliceous mudrocks and occur in the Chari Formation. This lithofacies is thickly to thinly bedded, coarse to fine grained, hard and compact but at times highly weathered and fragile. The regular increase in thickness of the bed can be observed in the section. The petrographic description of various microfacies types is given below:

Medium to coarse grained sandstone (D_1):

This microfacies is thickly to thinly bedded, medium to coarse grained, hard and compact and exhibit a range of colors from dirty yellow to reddish brown and grey. Calcareous variety of sandstones predominate over argillaceous and siliceous. Fossil fragments are commonly present in the sandstones. Microscopic examination reveals that the dominant constituents of the sandstones are quartz, feldspars, rock fragments, mica, and shell fragments lithified by calcareous, argillaceous and ferruginous cementing material (Plate-3B). Thin section study reveals the presence of quartz 79.95%, feldspars 14.57% and rock fragments 5.30% (Table 5).

Fine-grained sandstone (D_2):

This microfacies is thinly bedded and mostly fine grained. The grains are moderately to poorly sorted except few samples which show well sorting. The detritals are mostly floating in the calcareous cement. In some of the samples, the cementing material is coarsely crystallized calcium carbonate (sparite). The dominant constituents of the sandstones are quartz, feldspars, rock fragments, mica, and shell fragments lithified by calcareous, argillaceous and ferruginous cementing material (Plate 3C).

Pebbly cherty calclithite (D_3):

This sandstone is thinly bedded, pebbly to very coarse grained and showing reverse grading. Among the rock fragments, chert, phyllite, quartzite, granite, limestone, dolerite and basalt are common

PLATE 3

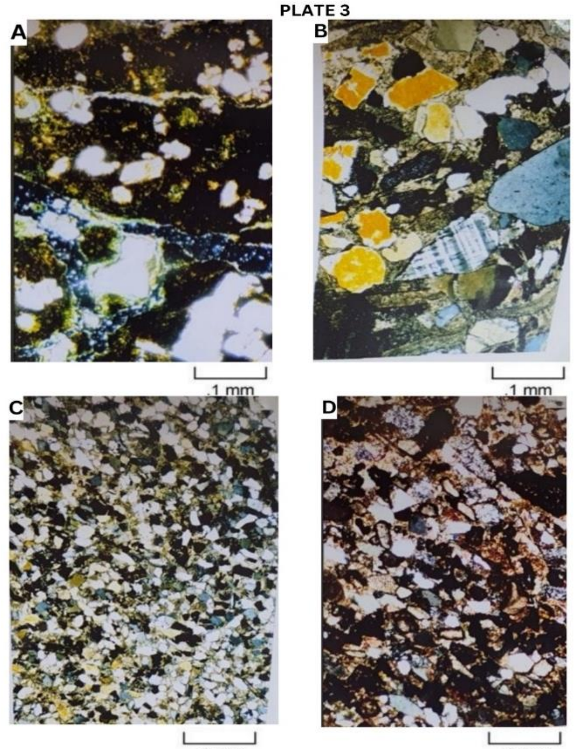

Plate-3 Photomicrographs: A - Gypsiferous mudstone and sandstone types: B - Medium to coarse-grained sandstone, C - Fine-grained sandstone, D - Pebbly cherty calclithite.

(Plate 3D). The size of igneous and metamorphic fragments varies from 0.8 to 2.5 mm whereas the average size of sedimentary rock fragments (limestone and chert) is 0.5 mm. The rock fragments are mostly subangular and subrounded. Modal analysis reveals the presence of quartz 28.05%, feldspars 10.55% and rock fragments 61.25% (Table 5).

Table 5. Modal composition of sandstones (excluding cement, micas and accessories) (% by vol) (D_1)

S/No	Sample No.	quartz	feldspar	Rock Fragments	Total	Maturity Index
1	S- 99/82	80.3	15.5	4.1	99.9	4.09
2	S-99/84	82.3	13.8	3.7	99.8	4.70
3	S-99/85	77.5	18.0	4.0	99.5	3.52
4	S-99/87	85.8	11.2	2.9	99.9	6.08
5	S-99/89	83.9	10.3	5.7	99.9	5.24
6	S-99/90	86.0	9.3	4.5	99.8	6.23
7	S-99/91	75.6	20.3	4.0	99.9	3.11
8	S-99/162	69.8	17.8	12.3	99.9	2.31
9	S-989168	78.4	15.0	6.5	99.9	3.60
Average		79.95	14.57	5.30	99.9	4.32

Pebbly cherty calclithite (D_3)

1	S-99/93	30.7	12.8	56.4	99.9	0.44
2	S-99/94	25.4	8.3	66.1	99.8	0.34
	Average	28.05	10.55	61.25	99.85	0.39

MICROFACIES ASSEMBLAGE:

On the basis of detailed field studies in Jhura dome, Kutch Mainland and lab investigation, the 370 m succession of rocks is stacked in to various microfacies assemblages that refers to the architecture of vertical succession of depositional sequences (fig.2). The total of 13 microfacies assemblages were identified: The lower 84 m consisting of four microfacies assemblages:

(i) oolitic fossiliferous grainstone - bioclastic grainstone (A_1-A_3),
(ii) oolitic fossiliferous grainstone - calcareous mudstone (A_1-C_2),
(iii) fossiliferous grainstone - calcareous mudstone(A_4-C_2),
(iv) intraclastic grainstone - calcareous mudstone (A_2-C_2). The middle 130 m composed of five microfacies assemblages: (i) fine grained sandstone - siltstone (D_2 – C_1), (ii) bioclastic packstone – siltstone (B_4-C_1), (iii) pebbly cherty calclithite microfacies (D_3), (iv) gypsiferous mudstone - fine grained sandstone (D_2 – C_3), (v) medium to coarse grained sandstone microfacies (D_1) and the upper 155 m consists of four microfacies assemblages: (i) gypsiferous mudstone-medium to fine grained sandstone (D_2-C_3), (ii) fossiliferous packstone - gypsiferous mudstone (B_3-C_3), (iii) bioclastic oolitic packstone – siltstone (B_2 –C_1), (iv) oolitic packstone microfacies (B_1).

DISCUSSIONS

Depositional Sequences and Relative Sea level changes

On the basis of detailed field studies, lab investigations, the succession of present area is stacked into three third order depositional sequences. The stacking pattern of microfacies assemblages comprises to the architecture of a vertical succession of depositional sequences. Transgressive sequence- I, Regressive sequence and Transgressive sequence-II stacking patterns can be recognized (Fig.2). In Transgressive sequence-I, the microfacies assemblage become more distal upward or representing an upward-deepening facies succession. In Regressive sequence, the microfacies assemblage become more proximal upward to or showing an upward-shoaling facies succession and in Transgressive sequence-II, the facies showing upward deepening facies succession. Based on lithofacies analysis together with existing biostratigraphic data, the local sea level curve derived in present investigation has been compared with global standard. Departure from global standard during regressive interval reveal local tectonic disturbances (Jacquine and de Graciansky, 1998) which may be considerable importance in regional correlation, however, transgressive intervals showing similar trend with global standard. This kind of global synchronization of these sequences suggests they have great potential as events having chronostratigraphic value. These transgressive and regressive sequences correlate reasonably well with 'anoxic' and 'oxic' events during which 'organic rich' and 'organic poor' facies may have been deposited (Miall, 1984; van Buchem et al., 2002; Soua and Chihi, 2014). The main source rocks for hydrocarbon in North African basins, West European and Russian platform basins are associated with short lived oceanic anoxic events that occurred during transgressive phases in Jurassic time (e.g., review in Soua, 2014; Mattioli et al., 2004). The Transgressive intervals (TS-I and TS-II) in present investigation may correspond to horizons of principal source rocks of hydrocarbons. Transgressive successions are commonly fine grained, thinly bedded and low permeability intervals that can act as seal rocks (Olsen, 1998). The interpretation of transgressive-regressive sequences is integrated with the existing biostratigraphic data available to make it regionally comparable. The description and interpretation of each sequence are given as follows (Fig.2).

TRANSGRESSIVE SEQUENCE-I (TS-I)

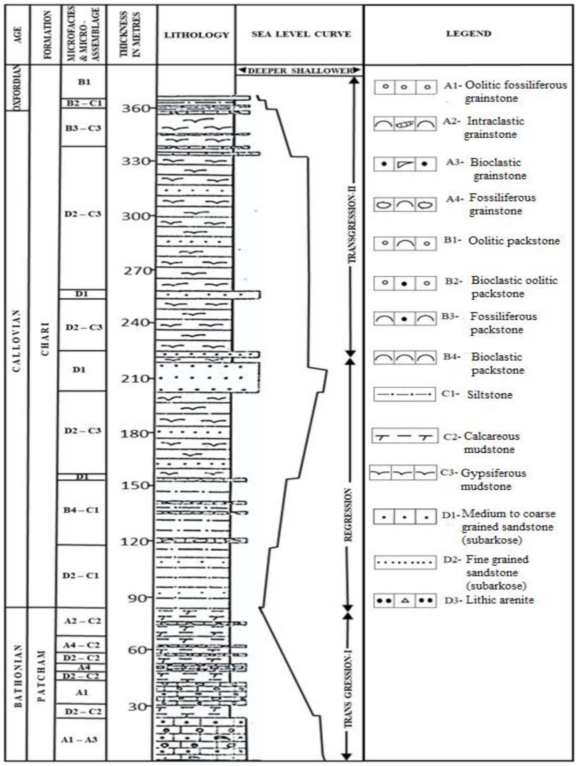

Figure 2. Litho-column showing sequences of microfacies assemblages, sea level curve and depositional sequences during the Bathonian to Oxfordian, Jhura dome, Kutch/Kachchh Mainland (modified after Mishra 2002).

(BATHONIAN):

The total thickness of TS-I is 84.34 m. It is composed of dominantly carbonate rocks and bounded below by coarse grained carbonate rocks and upper boundaries is conformable and characterized by change in lithofacies from nonclastic to clastic. TS-I of Bathonian age (Rajnath, 1932; Stoliczka, 1873) composed of mostly calcareous mudstone microfacies (C_2) and subordinately grainstone lithofacies (A). From bottom to top the sequence of four microfacies assemblage occurs in the fallowing order: (i) oolitic fossiliferous grainstone – bioclastic grainstone (A_1-A_3). (ii) oolitic fossiliferous grainstone – calcareous mudstone (A_1 – C_2), (iii) fossiliferous grainstone – calcareous mudstone (A_4- C_2), (iv) intraclastic grainstone- calcareous mudstone (A_2-C_2). There is general increase in the percentage of calcareous mudstone and decrease in coarse grained grainstone in upward direction. Each assemblage showing irregular contacts and varying number of clastic constituents occur as separate layers mixed with carbonate rocks.

Interpretation

An initial rise in sea level (Bajocian/Bathonian time) is marked by basal layer of coarse-grained carbonate grading upward into bioturbated, fine-grained calcareous mudstone with abundance of microfossils. These carbonate deposits are explained as transgressive deposits on a gently sloping carbonate shelf. Alternating calcareous mudstone and grainstone may indicate deposition from storms and fair-weather settling during net sea level rise (Mishra and Tiwari, 2006). These transgressive deposits are related to initial transgression phase in the basin and may contain organic rich anoxic facies. Most of the source rock intervals of the Tunisian basins North Africa are accompanied with initial transgression phase that occurred in early to middle Jurassic time (e.g., review in Soua, 2014). The regular fining upward stacking pattern of microfacies suggests that rise in sea level was continuous and comparable with the global rise of relative sea-level during Bathonian time (Vail et al., 1977b), but the rate of relative rise of sea level was slow as revealed by regular decrease in thickness of grainstone microfacies (A). Frequent tectonic episode is revealed by varying number of terrigenous materials occur as discrete lavers admixed with carbonate beds together with irregular contacts between the microfacies.

REGRESSIVE SEQUENCE (RS) (CALLOVIAN):

The preserved thickness of Regressive Sequence is 130 m. This sequence of Callovian age (Krishna and Ojha, 1996) is dominantly siliciclastic and consists of mostly mudrocks (gypsiferous mudstone microfacies and siltstone microfacies) subordinately with varying proportion of sandstone and carbonate microfacies (i.e. mudrock microfacies > sandstone microfacies > carbonate microfacies). Its lower and upper sequence boundaries are conformable and characterized by microfacies change. The lower boundary is marked by change in microfacies from nonclastic to fine grained clastic and upper is distinguished by very thickly bedded medium to coarse-grained clastics (D_1). From base to top, the sequence of five microfacies assemblage occurs in the following order: (i) fine grained sandstone (subarkose) – siltstone (D_2 – C_1), (ii) bioclastic packstone – siltstone (B_4-C_1), (iii) pebbly cherty calclithite 'D_3' microfacies, (iv) gypsiferous mudstone - fine grained sandstone (D_2 – C_3), (v) medium to coarse grained sandstone (D_1). The basal part of this sequence is marked by predominance of siltstone and fine-grained sandstone microfacies assemblage (D_2 – C_1), followed by siltstone - bioclastic packstone microfacies assemblage (B_4-C_1). The middle and upper strata are characterized by gypsiferous mudstone (C_3) interbedded with medium to coarse grained sandstones microfacies (D_1). There is general increase in bed thickness of clastic microfacies (D_2 – C_3) and (D_1) in upward direction.

Interpretation

Abundance of fine grained clastic (D_2 – C_1 assemblage) at the base of this sequence are interpreted to have been deposited in a relatively deep-water environment, possibly indicating a standstill or a relative lowering of sea level. Preservation of pebbly cherty calclithite microfacies 'D_3' (storm unit) indicate a shallowing upward trend during deposition of B_4-C_1 assemblage and is interpreted as low stand, relatively shallower water deposits as supported by coarse grained clastics and abundance of eroded rock fragments. Extensive erosion suggests a relative drop in sea level. (D_2 – C_3) assemblage is believed to have been deposited within standing body of water environment during maximum fall in sea level. (D_1) is a shallowest deposit and deposited during maximum sand supply in Middle Callovian. Upward stacking pattern of microfacies assemblage in the study area indicate regressive deposits and overall shallowing of the sea that is regionally correlative but not comparable with the global trend of relative sea-level rise during Middle Jurassic time (Vail et al., 1977b).

TRANSGRESSIVE SEQUENCE – II (TS-II) (EARLY OXFORDIAN):

The total thickness of this sequence is 155.8 m. Its basal boundary is marked by microfacies change from coarse grained clastic to fine grained clastic and upper boundary is characterized by conglomeratic horizon indicating condensed marine facies (hardground) of Oxfordian age and by basin- wide occurrence of condensation phenomena (Fursich et al., 1992). Transgressive sequence II of Early Oxfordian age (Krishna, 1990; Krishna et al., 1998) consists of four microfacies assemblages and occur from base to top in following order: (i) gypsiferous mudstone-fine grained sandstone (D_2-C_3), (ii) fossiliferous packstone - gypsiferous mudstone (B_3-C_3), (iii) bioclastic oolitic packstone – siltstone (B_2 –C_1), (iv) oolitic packstone microfacies (B_1). There is general increase in bed thickness of carbonate microfacies (B_3-C_3), (B_2 –C_1) and (B_1) in upward direction. Appreciable percentage of terrigenous materials like sand and gravel are admixed with carbonate beds, however varying number of carbonate rocks are present in clastic rocks (siltstone). All the carbonate assemblages exhibit erosional surfaces.

Interpretation

Initial rise in relative sea level is indicated by preservation of fossiliferous packstone microfacies (B_3) in the lower part of this sequence. Microfacies assemblages B_3-C_3 and B_2-C_1 has been regionally correlated and deposited during slow sea level rise as explained by abrupt change in detrital grain size, mixing of two lithology, plenty of siliciclastic in each microfacies, whereas oolitic packstone microfacies (B_1) exhibit its deposition during rapid sea level rise as supported by reduced thickness, erosive to irregular contact and presence of intraformational conglomeratic materials (Tiwari and Mishra, 2007). It is also justified by upward thickening of packstone microfacies. Upward stacking pattern of microfacies assemblage reveals transgressive deposits and overall deepening of the sea that is comparable with the global rise of relative sea-level during Early Oxfordian time (Vail et al., 1977b). It is maximum transgression in the basin covering large geographic area that results from combined effect of 2nd and 3rd order sea level variations. These transgressive maxima (B_2-C_1 assemblage and B_1 microfacies) may be associated with horizons of major accumulation of organic matter (van Buchem et al., 2002). Main European source rocks of petroleum are well related to transgressive maxima of Jurassic time (Cojan and Renard, 2002). Frequent tectonism is marked by erosional contacts between the microfacies assemblages and abundance of conglomeratic materials that characterizes the microfacies.

These 3rd order depositional sequences described above TS-1, Regressive and TS-II corresponding to Bathonian, Callovian and Early Oxfordian respectively are attributed to both regional tectonic mechanism and global sea level change Cloetingh (1986, 1988), Kauffman (1984), and (Yunbo et al., 2014). Shift in source area and transport direction from north-northwest to east -northeast during studied interval may have contributed significant influx of immature clastics (Mishra and Tiwari, 2005) that indicate short transport or tectonic instability condition or both. Alternate and mixed deposition of low to high energy siliciclastics and carbonates as reflected in each microfacies indicating different phases of tectonics.

CONCLUSIONS

Bathonian to Early Oxfordian succession having total thickness of 370 m is stacked in to three third-order depositional sequences. The 84 m Transgressive sequence-I, 130 m. Regressive sequence and 155 m. Transgressive sequence-II have been recognized. The stacking pattern of 13 microfacies assemblages refer to the architecture of vertical succession of depositional sequences. From the present study, it is inferred that the Transgressive Sequence-I was deposited during relative sea level rise and less sediment supply in Bathonian. Regressive Sequences was deposited during stillstand period followed by relatively high rate of sediment supply in Middle Callovian and Transgressive Sequence – II was deposited during highstand of sea level along with frequent and extremely low rate of sediment supply in Early Oxfordian. The relative sea level curves reveal sea level fluctuations during the deposition of whole sequence prior to major drop in sea level at the end of Transgressive Sequence- II. These high order sequences are regionally comparable and might have been generated due to regional tectonic mechanism together with global sea level change.

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