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Microfacies and depositional environment of the Bathonian Jhurio Formation at the Jumara Dome, Kachchh, western India

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Abstract : The Kachchh Basin is a pericratonic rift basin situated at the western margin of the Indian plate. The Jumara Dome is one of the important exposures of Bathonian sediments among the Kachchh Mainland exposures. A rigorous facies analysis using the microfacies approach for the reconstruction of the depositional environment and setting of carbonate sedimentation with correlation of basin components had been lacking. Thus an important Kachchh Mainland outcrop of the Bathonian sediments (Jhurio Fm.) *viz.* the Jumara Dome was taken up for the present study. In accordance with the above-mentioned objectives detailed stratigraphical sections of the Jhurio Formation have been measured. Macrofacies were recorded for corroborating the microfacies data. Microfacies analysis has been carried out by studying thin-sections of rock samples under the microscope with the aim to interpret the depositional environment and setting. The study helped in the reconstruction of the depositional environment and setting at the Bathonian times represented by the Jhurio Fm.

The Jhurio Fm. at the Jumara dome is characterized by well-bedded limestone-marl/marlstone alternations and massive limestones (packstones and grainstones). The sections have several units where the limestone show nodular feature. Various microfacies types are present in the Jhurio Fm. at the Jumara dome. The MF types are associated into two MF associations at the dome.

A carbonate ramp setting seems to have been prevalent at the time of sedimentation of the carbonates during the Bathonian. In general, the depositional environment seems to have been a marine, open sea, mid to outer (deep) ramp environment. Depositional environment was largely low energy just below storm wave base which had seen phases of slight influence of storm-events. Reworked sediments of the transgressive phase witnessed relatively higher energy depositional environment.

Key words : Microfacies, Depositional Environment, Bathonian, Jurassic, Pericratonic Basin, Kachchh.

Introduction

The Kachchh Basin is a pericratonic rift basin situated at the western margin of the Indian plate (*e.g.* Biswas, 1987). The Jurassic sedimentary sequence in the Kachchh Basin outcrops in three east-west trending fault-bounded anticlinal ranges and in an isolated area in Wagad. The southern and middle ranges to the south and north of Bhuj in western Kachchh include many irregular elliptical quaquaversal units, which, in the middle range are termed "domes" (Rajnath, 1932). The two ranges together constitute the Kachchh Mainland (Fig. 1). The Mainland exposures consist of the Jara, Jumara, Nara, Keera, Jhura and Habo

Fig. 1. Location map of study area (Kachchh)

domes and Fakirwari, Walakhawas and Ler areas. The four isolated landmasses viz. Pachchhm (earlier spelt as Patcham), Khadir, Bela and Chorad are surrounded by vast plains, which remain submerged under water during monsoon and hence have been described as "islands". The Kachchh Mainland, the four "islands" and the isolated area of Wagad are the six "uplifts" (Biswas 1991). The domal structures are thought to have formed due to Deccan Trap volcanism. Erosion of younger sediments on and adjacent to the domes have exposed the Jurassic rocks.

The Kachchh area forms a classic area for Jurassic rocks in India and has been attracting the attention of geo-scientists. These sediments have provided ample opportunity for stratigraphical, sedimentological, palaeoecological and taxonomic studies due to their vast exposures and rich and highly diverse well preserved fauna.

The whole area, in general, constitutes a potential site for petroleum exploration. Scientists have worked on the prospects of hydrocarbon in the Kachchh Basin (Biswas and Deshpande, 1983). Significant oil shows have been noted in some wells drilled in the area.

Review of stratigraphical and sedimentological work

The geological study of the strata and fossils began about more than 160 years ago. Since then much work has been done on various geological aspects of the Kachchh Jurassics, such as biostratigraphy, sedimentology, lithostratigraphy, description and illustration of macrofossils and microfossils (including palynoflora) etc.

The Mesozoic sequence of the Kachchh Basin has been classified by various workers. Wynne (1872) divided the Jurassic rocks into a lower marine and an upper non-marine units which were termed by him respectively as Lower and Upper Jurassic (at the time the Cretaceous rocks were not recognized and included in the Jurassic). By the terms Lower and Upper Jurassic, he did not mean the rocks of Lower and Upper Jurassic age. It was the earliest litho-stratigraphic classification. Stolizcka (Waagen, 1875) created a classification for the Jurassic sediments which included Patcham, Chari, Katrol and Umia "groups" in ascending order based upon 'mineralogical and palaeontological characteristics'. Waagen adopted the classification and defined the units using 'ammonite assemblage zones' which were correlated with the European zones to assign their ages. This classification has been followed till now and has been modified by later workers mostly on the basis of their palaeontological findings. He correlated Patcham to Bath Group, Charee and Lower Katrol to Oxford Group, Upper Katrol to Kimridge Group and Umia to Tithon Group. Spath (1924, 1927-33) subdivided units of Stolizcka (Waagen, 1875) by ammonite zones which he referred to as *Macrocephalus* "Beds", *Rehmani* "Beds", *Anceps* "Beds" etc. This was a biostratigraphic classification although the units were termed "group", "beds" etc. Rajnath (since 1927) worked out detailed stratigraphy of the Jumara Dome. On the basis of his detailed work in Jumara Dome, Rajnath (1932) described 26 beds from Chari and Patcham series. He placed Bathonian-Callovian (time) boundary between his bed nos. 22 and 23 on the evidence of fossils (above the lower *Macrocephalus* Beds) and slight unconformity between the beds. He put the Patcham-Chari boundary between bed nos. 21 and 22 on the basis of lithology. Agrawal (1955) replaced the terms 'Chari Series' and its topmost unit 'Dhosa Oolite' with 'Habo' Series and 'Mebha Oolite', respectively. Poddar (1959,64) followed Rajnath's classification but used the term 'Formation' (lithostratigraphic term) instead of 'Series' and presented a brief geological history of the formations and their structural and tectonic framework. Mitra and Ghosh (1964) carried out purely biostratigraphic work in the Jhura Dome and produced a biostratigraphic map. They stated that assemblage zones, instead of ammonite index fossil, should be considered in correlation and classification. Biswas (1971, 1977) proposed for the first time a rock-stratigraphic classification using the recommendations of the International Subcommissions on the Stratigraphic Classification and described the units proposed. Three main lithologic provinces have been recognized by him, viz. Kutch Mainland, Pachham "Island" and Eastern Kutch (Wagad, Khadir and Bela "islands" and Chorar Hill). He divided the stratigraphic sequence of Kachchh Mainland into four formations formally named as the Jhurio (Jhura), Jumara, Jhuran and Bhuj Formations in ascending order. He recognized two rock units in the Jurassic rocks of Pachchham 'Island', a lower Kaladongar Formation and an upper Goradongar Formation, and Khadir and Washtawa formations and Wagad Sandstone in Eastern Kachchh. The lithostratigraphic framework given by Biswas (1977, 1981) served as the basis for reconstructing the depositional history of the basin (*e.g.* Biswas 1987, 1991). Agrawal (1982) broadly reviewed the classification of the Mesozoic sediments of Kachchh. He on the basis of *Laptosphinctes* Buckman found to (Jaitly, 1980; Singh *et al*., 1982) in lower part of the succession at Kaladongar in Pachchham 'Island' described the oldest sediments in Kachchh exposed at Kaladongar, belonging to Bajocian age. In his text book Krishnan (1968) adopted the classification given by Rajnath (1932, 1942) but with modification of age as per Arkell (1956). He maintained the earlier four-fold classification but included Rajnath's Bhuj Series as 'Bhuj Stage' within his Umia Series. Lately a collaborative team of scientists has started working systematically on an integrated approach using sedimentology and interplay of taphonomy, palaeoecology and ichnology to decipher the depositional history of the basin (Fürsich *et al*. 1994 a,b). Fürsich *et al*. (1994a), revised the classification of the Khavda and the Patcham Formations. Sedimentary succession and faunal content are described in detail. Fürsich *et al*. (2001), discuss the marker beds in the Jurassic of Kachchh with respect to their depositional environment and sequence-stratigraphic significance and put forward a new lithostratigraphic classification for Mesozoic sediments of Kachchh Basin.

Objectives and Scope of Present Work

From the review of the previous works on the Kachchh basin it is apparent that although much work exists, a rigorous facies analysis with a sufficiently detailed sedimentological description of the various formations is not available.

The present research work deals with rigorous facies analysis using the microfacies approach for reconstruction of the depositional environment of carbonates and has the ultimate aim at basin analysis with correlation of basin components. For this, an important Kachchh Mainland outcrop of the Bathonian sediments (in the Kachchh Basin carbonate sediments are mainly present in the Bathonian) *viz*. the Jumara Dome was taken up for the present study.

It puts up a model of the depositional conditions prevalent in the Kachchh Basin during the Bathonian times represented by the Jhurio Fm. at the area of the Kachchh mainland represented at the Jumara Dome.

Geology and Tectonic Evolution

The Kachchh basin has a comprehensive Mesozoic package. It has about 3000m of sediments ranging in age from the Late Triassic to Lower Cretaceous. The basin was inundated by sea by the Middle Jurassic (Bajocian) times (Biswas, 1981; Singh *et al*., 1982). The sediment package is predominantly siliciclastic with the carbonate sediments being mostly confined to the Bathonian. The siliciclastic sediments range from nearshore coarse-grained sands and conglomerates to storm-influenced shallow shelf silts and clays and silts of the mid-shelf situated below the storm wave base. Whereas, the carbonate sediments, represented by shallow-shelf skeletal, oolitic or intraclastic pack- to grainstones, mid-shelf argillaceous micrites punctuated by distal storm layers and shelly packstones formed as a result of reworking processes during transgressive events, are confined to the Bathonian (Fürsich *et al*., 1992; Fürsich and Oschmann, 1993).

The Mesozoic sediment package overlies the Precambrian basement. In the Mainland the Deccan Traps (Upper Cretaceous- Lower Tertiary) unconformably overlie the Mesozoics. The Tertiaries overlie unconformably either on the Mesozoics, as observed at places in the Mainland, or the Deccan Traps. At places the older rocks are covered by sub-recent sandstones and alluvium.

Oldest exposed strata are of Jurassic Period although Koshal (1975) reported Rheatic-Liassic palynoflora from sub-surface sediments in a well in Banni south of Pachchham Island.

The Kachchh Basin formed a segment of the embayment which extended from the southern margin of the Tethys in the southeasternly direction during the Jurassic Period. The basin evolved due to sequential rifting and repeated movements along Precambrian tectonic trends and it took place in relation with the Indian plate's northward drift after the break up from the Gondwanaland in the Late Triassic-Early Jurassic (Norton and Sclater, 1979; Biswas 1982, 1987, 1991; Boccaletti *et al*., 1988).

India's western continental margin can be classed as an Atlantic-type passive margin. The structural fabric of western India is dominated by the three Precambrian orogenic trends viz. the NNW-SSE Dharwar trend, the NE-SW Aravalli trend and the ENE-WSW Satpura trend. The northern component of the Aravalli orogen is the trend of the Delhi fold belt and this component swings to E-W and continues into the Kachchh region. The Kachchh basin got rifted along this trend (Biswas, 1982).

Kachchh rifting was initiated in the Late Triassic as indicated by continental Rhaetic sediments in the northern part of the basin (Koshal, 1975). In the early stages of India's northward drift away from Gondwanaland, during Jurassic time, the Kachchh basin was formed by subsidence of a block. The first occurrence of marine sediments in the Middle Jurassic indicates that this graben became a fully marine basin during that time.In the Early Cretaceous time, the basin was filled up (Biswas, 1987).

The basin is characterized by highlands, which are the areas of uplift and the plains, which are the basins between the uplifts. The uplifts are oriented E-W along five principal faults (Biswas, 1987).

The basin platform slopes towards the southwest, the direction in which the embayment opens up. The platform features a Median High across parallel fault ridges and demarcates the hinge of the basin in the Late Jurassic-Early Cretaceous time. The Precambrian terrain now exposed in Rajasthan, Gujarat and Pakistan define the margins of the basin (Biswas, 1987).

Microfacies

Microfacies of a carbonate sequence are identified by the study of thin-sections of rocks/ sediments and this chiefly comprises determination of the composition and texture of limestones. It is is the aggregate of all the sedimentological and palaeontological criteria. Differentiation of genetically interpretable microfacies (MF) types form an essential part of facies analyses. The features or elements whose existence and frequency are dependant on a few environmental factors or which are associated with certain sedimentary environments, are preferably the criteria for defining the MF types. Characteristics of the matrix, cement and grains (or particles) are used for the purpose. For differentiating MF types the frequency of the grains is often an essential criterion. Qualitative criteria such as the presence or absence, or quantitative criteria such as the relative abundance/ frequency of some features are used to differentiate most MF types. Depositional fabrics are generally documented as thin-section microphotographs or computer scans. Such classifications are very helpful in genetic interpretations.

Standard Microfacies Types (SMF types) are established by combining microfacies types of limestones of various ages so that they reflect the depositional and ecological conditions in a certain sedimentary environment. Limestones can be studied by comparing them with the SMF types, which is a system put forward by Wilson (1975) from Flügel's (1972) concept. Wilson (1975) identified 24 SMF types based upon the Phanerozoic limestones, and put a generalized model of carbonate sedimentation assignable to nine standard facies belts. Distinctive composition of each facies indicate towards a particular environment. This diagnostic feature of each facies is often applicable but many exceptions are there, moreover, some of the SMF types may not be restricted to only one facies belt (Wilson, 1975; Flügel, 1982). The 24 SMF types are ascribed to the carbonate types classified by Dunham (1962). Description of the microfacies criteria using the Dunham's classification scheme, is the basic requirement for recognizing SMF types, as designated by Wilson (1975). Some of the SMF types seem to be too generalized. Thus, specific details for microfacies type designation becomes important. The model basically pertains to carbonate shelf sedimentation. With the coming up of the ramp model as an alternative to the shelf model, a unique generalized facies model is not applicable to all the ancient carbonate sequences.

Methods

In accordance with the objectives of the present research work, detailed stratigraphical sections of the Jhurio Fm. have been measured and rock samples collected at the Jumara Dome after a thorough geological reconnaissance of the area. Macrofacies were recorded for corroborating the microfacies data. Thin-sections were prepared for each rock sample and studied for microfacies analysis. Microfacies analysis has been done by studying thin- sections of rock samples with the aim to interpret the depositional environment. Dunham's (1962) classification scheme has been used to describe the microfacies criteria. Comparison charts for visual estimates have been used for estimating percentages of grains to matrix, relative percentages of various grain types, sorting, roundness etc. Comparison charts (in Flügel 1982, after Baccelle and Bosellini 1965 and Schäfer, 1969) have been used for frequency estimations of intraclasts, bioclasts, peloids, ooids, oncoids and for estimating the shell fragment content. Frequency is expressed in terms of % of the portion of rock's thin-section visible under the microscope. Comparison chart (Flügel, 1982 after Anstey and Chase, 1979) has been used for describing particle sorting *i.e.*, poor, moderate, good and very good. Comparison chart (Flügel, 1982; Pilkey *et al*., 1967) has been used for describing the roundness of bioclasts i.e. classes I to IV (class IV is most rounded). Interpretation part involves reconstruction of the depositional environment at Bathonian times represented by the Jhurio Fm. using microfacies analysis.

The Jhurio Fm.

The Jhurio Fm. at the Jumara Dome is characterized by well-bedded limestone-marl/ marlstone alternations and massive limestones (packstones and grainstones). The sections have several units where the limestone show nodular feature.

For the present work the reference litho-stratigraphic classification used is the one given by Fürsich *et al*. 2001 (Table 1). In this classification the Bathonian sediments at the Jumara Dome (Kachchh Mainland) have been classified into the following formations and members in descending order.

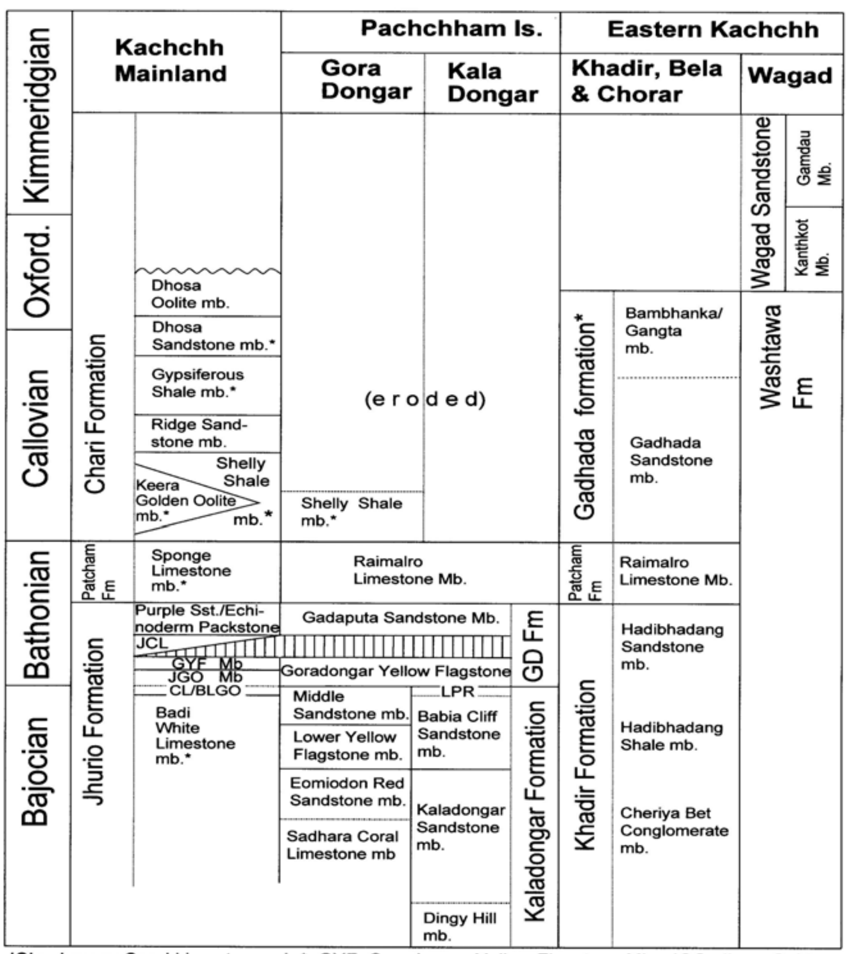
The Patcham Formation: This formation is represented by the Sponge Limestone mb. (informal member).

The Jhurio Formation: This is represented by the Echinoderm Packstone and the Jumara Coral Limestone (JCL) mb. (informal member), in descending order.

In this classification the Bathonian-Callovian boundary is taken as the boundary between the Patcham and the overlying Chari formations.

The Jumara Coral Limestone mb. corresponds to Rajnath's (1932) bed nos. 24-26; the Echinoderm Packstone

Table 1. Stratigraphic succession of Jurassic rocks of Kachchh Basin (after Fürsich *et al*. 2001)



JCL: Jumara Coral Limestone mb.*; GYF: Goradongar Yellow Flagstone Mb.; JGO: Jhura Golden Oolite mb.*; CL/BLGO: Canyon Limestone/Badi Lower Golden Oolite; LPR: Leptosphinctes Pebbly Rudstone corresponds to Rajnath's (1932) bed no. 23; and the Sponge Limestone mb. corresponds to Rajnath's (1932) bed no. 22.

Macrofacies description

The Echinoderm Packstone is overlain by the Sponge Limestone mb. (Patcham Fm.). The Echinoderm Packstone is brown to purple coloured ferruginous pack- to grainstone. Its thickness at the Jumara Dome is about 16m. Bioclasts are chiefly contributed by echinoderms, bivalves, brachiopods, gastropods, foraminifers, corals.

The Echinoderm Packstone is underlain by the Jumara Coral Limestone mb. The Jumara Coral Limestone mb. consist of well-bedded limestone-marl/marlstone alternations. The mb. is represented chiefly by bioclastic mudstone, bioclastic packstone and bioclastic float- to rudstones. Several tempestite units and units with mm thick cross laminations are present. The section has several units where the limestone shows nodular feature. At the upper parts of the section, the limestone contains traces of *chondrites*. The exposed thickness is about 23m. The colour in general is grey. The lower 4m has a few hard shell-beds which contain sand-sized quartz grains and some ooids. These are bioclastic pack- to grainstones and bioclastic rudstones. These beds have yellow to dark brown colour. Bioclasts have been contributed chiefly by corals,bivalves, brachiopods, echinoderms, and foraminifers.

Fig. 2 (a to e) and table 2 depict the lithological logs of the Bathonian sediments of the Jumara Dome.

Microfacies description

Jumara Coral Limestone (JCL) mb.

Bioclastic mudstone, bivalve packstone, bivalve rudstone and bioclastic floatstone are the major facies types present in the Jumara Coral Limestone mb. Echinoderm pack- to grainstone and bioclastic rudstone represent minor ones. The last two also contain some sand-sized quartz grains and some ooids.

Bioclastic mudstone

The bioclastic mudstones contain very thin bivalve shell fragments which are about 1% and have the average size of 0.5mm. Some of them contain both articulated and disarticulated bivalve shells with their size ranging from 2mm to 4mm and occasional foraminifer. Matrix is homogeneous micrite (Plate 1 [a], Slide 1-B1), (Plate 1 [c], Slide 2-B13), (Plate 1 [e], Slide 2-B67 & Slide 3-B15).

Bivalve packstone

The bivalve packstones contain very thin bivalve shells (about 50% and of average size of about 0.8mm) making somewhat criss-cross pattern within the general horizontal disposition. Sorting of the grains is good to moderate. Some granular sparite cement is present. The bivalve packstones have erosive base and overlie the mudstones. The bottom part of bivalve packstones contain relatively bigger (upto 7mm across) disarticulated and articulated but broken brachiopod shells, bivalve shells and peloids (average diameter 0.05mm). This part has much more granular sparite cement as compared to the upper part and is poorly sorted.

These graded units i.e. packstones with erosive base, overlying mudstones, represent storm beds (tempestite shell-beds) (Plate 1 [d], Slide 2-B39).

Bivalve rudstone

The bivalve rudstones are packed with disarticulated bivalve shells which are disposed

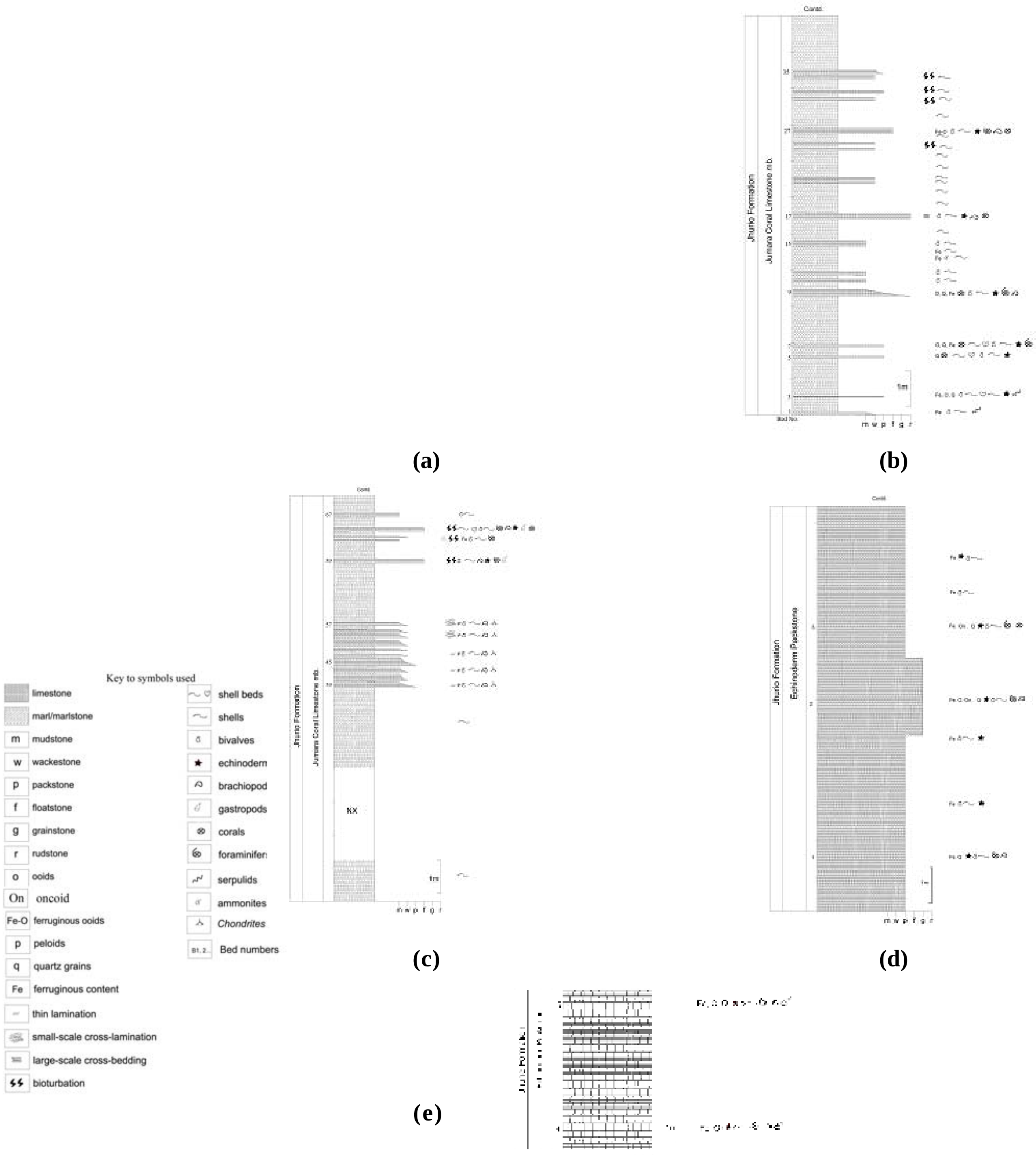


Fig. 2 (a to e) : Lithological log of the Bathonian of Jumara Dome.

Table 2. Litholog of the Bathonian sediments of the Jumara Dome
(Measured in the northern flank of Jumara Dome, North of Jumara village)

Echinoderm Packstone

Jumara Coral Limestone mb.

Bed no.	Description	Thickness (cm)
68	Marl	35
67	Mudstone;contains a few intraclasts,bioclasts	12
66	Marl	30
65	Brachiopod floatstone; grey; contains bioclasts. It is a shell-bed	10
64	Marl	15
63	Bioclastic mud- to wackestone; contains bioclasts; bioturbated bed; thin parallel laminations	5
62	Marl	5
61	Bioclastic mudstone; contains bioclasts, bioturbated bed; thin parallel laminations	6
60	Marl	37
59	Bioclastic floatstone; contains bioclasts, bioturbated bed	10
58	Marl	185
57	Bioclastic mud- to wackestone, contains peloids, bioclasts, small-scale cross laminations	10
56	Marl	10
55	Bioclastic mud- to wackestone, contains peloids, bioclasts, small-scale cross laminations	10
54	Marl	5
53	Bioclastic mud- to wackestone, contains peloids, bioclasts, *chondrites* , small-scale cross laminations	10
52	Marl	10
51	Bioclastic mud- to wackestone, contains bioclasts, *chondrites*	15
50	Marl	10
49	Bioclastic mud- to wackestone, contains bioclasts	5
48	Marl	10

47	Bioclastic mud- to wackestone, contains bioclasts	5
46	Marl	5
45	Bioclastic mud- to packstone, contains peloids, bioclasts, *chondrites* , parallel laminations	25
44	Marl	5
43	Bioclastic mud- to wackestone, grey; contains peloids, bioclasts, *chondrites* , parallel laminations	15
42	Marl	5
41	Bioclastic mud- to wackestone, contains peloids, bioclasts, small-scale cross laminations	20
40	Marl	5
39	Bioclastic mud- to bivalve packstone, contains peloids, bioclasts, *chondrites* , thin parallel laminations	15
38	Marl	250
37	Poorly exposed to not exposed	285
36	Marl; containing shell fgragments	270
35	Bioclastic wacke- to packstone, grey, contains bioclasts, bioturbated bed	10.5
34	Marl	3
33	Bioclastic wackestone, grey, contains bioclasts, bioturbated bed	10
32	Marl; containing sparse shell fgragments	25
31	Bioclastic packstone, grey, contains bioclasts, bioturbated bed	10
30	Marl; containing sparse shell fgragments	10
29	Bioclastic wackestone, grey, contains bioclasts, bioturbated bed	10
28	Marl; containing sparse shell fgragments	70
27	Bioclastic floatstone, grey, contains ooids, bioclasts (bivalve shell fragments, echinoderm, foraminifers, coral),	15
26	Marl; containing sparse shell fgragments	25
25	Bioclastic wackestone, grey, contains bioclasts, bioturbated bed	5
24	Marl; containing sparse shell fgragments	10
23	Bioclastic wackestone, grey, contains bioclasts, bioturbated bed	5
22	Marl; containing sparse shell fgragments	75
21	Bioclastic wackestone, grey, contains bioclasts	5
20	Marl; containing sparse shell fgragments	5
19	Bioclastic wackestone, grey, contains bioclasts	5
18	Marl; containing sparse shell fgragments	90
17	Bivalve rudstone, grey, contains bioclasts(coral, bivalve shell fragments, echinoderm, foraminifers), thinly laminated	15
16	Marl; containing sparse shell fgragments	60
15	Bioclastic mudstone, grey, contains bioclasts	15
14	Marl; containing sparse shell fgragments	70
13	Bioclastic mudstone, grey, contains bioclasts	10
12	Marl; containing sparse shell fgragments	8
11	Bioclastic mudstone, grey	10
10	Marl; containing sparse shell fgragments	15
9	Bioclastic wacke- to rudstone, yellow to brown coloured; contains intraclasts, ooids, corals, bivalve shells etc. and sand sized quartz grains	20
8	Marl; white; containing sparse shell fgragments	147
7	Echinoderm grainstone, brown; contains ooids, corals, echinoderm,bivalve shells etc.It is a shell-bed	4

almost horizontally. The bivalve shells are about 50% with an average size of about 1.5mm. Echinoderm and braschiopod debris also constitute the bioclasts. Sorting of the grains is moderate. Cement is granular sparite (Plate 1 [d], Slide 1-B17).

Bioclastic floatstone

Bioclastic floatstones contain disarticulated bivalve shells with an average size of 2.2mm, echinoderm debris, coral fragments, brachiopod shell fragments and foraminifer debris. Bioclasts range from about 20% to 45% and consist of sparite. A few tangential and radial ferruginous ooids (with an average diameter of 0.7mm) are present.

The brachiopod floatstones contain disarticulated brachiopod shells (about 20% and upto 1cm in size) and gastropod shell debris. Sorting of grains is moderate to poor and roundness fall under class III. These bioclastic floatstones contain some fibrous cement (Plate 1 [e], Slide1-B65).

Echinoderm packstone

The echinoderm packstone contains ooid- and sand-sized quartz-bearing intraclasts. The quartz grains within the intraclasts have an average diameter of 0.07mm and are angular to subangular. The average diameter of the intraclasts is 0.7mm and they are about 20%. Echinoderm debris (upto 2.5mm in size) are about 40%. Bivalve shell fragments are also present. A few radial and tangential ooids with an average diameter of about 0.6mm (nucleus has diameter of 0.25mm) are also present. Sorting is moderate to poor and roundness fall under class III. Cement is sparse. Some fibrous cement "A"(forming rims) and some medium grained granular sparite are present (Plate 1 [a], Slide 2-B3).

Echinoderm grainstone

These contain echinoderm debris which are upto 2mm in size and are about 20-25%. Echinoderm spines (a spine about 5mm in length), bivalve shell debris and foraminifer (about 2%) are also present. A few radial and tangential ooids with about 0.6mm diameter (nucleus about 0.2mm in diameter) are also present. A few quartz grains, about 0.1mm in diameter, are present. Granular sparite cement is dominant, with the average crystal diameter of 0.1mm. Several of the echinoderm debris show development of syntaxial "rim cement". In some cases development of fibrous cement (forming rim) is also seen. Sorting of grains is moderate to good and roundness fall under class III (Plate 1 [a], Slide 3-B5), (Plate 1 [b], Slide 1-B7).

Bioclastic rudstone

These contain about 10% intraclasts with an average diameter of 1mm. The diameter is upto >2mm. Some of the intraclasts contain sand-sized quartz grains. These enclosed quartz grains have an average diameter of 0.1mm and are subangular. Disarticulated bivalve and brachiopod shells are about 25% and these are upto 10mm in size. Average size of bivalve shells is about 1mm. Echinoderm debris with an average size of 0.8mm are also present. Radial and tangential ooids with an average diameter of 0.4mm are about 5%. Some of the ooids are broken. Angular to subangular quartz grains are present. These are about 2.5% with an average diameter of 0.1mm. Cement is predominantly medium grained granular sparite. Some fibrous cement (forming rims) is present. Some of the echinoderm debris also show development of syntaxial "rim cement". Sorting of the grains is poor to moderate and roundness falls under class III (Plate 1 [b], Slide 2-B9), (Plate 1 [c], Slide 1-B9).

Echinoderm Packstone (EP)

The Echinoderm Packstone is represented by ferruginous echinoderm packstone, ferruginous intraclastic packstone and echinoderm grainstone. All of them contain some sand-sized to granule-sized quartz grains. In the first and the third one, intraclasts are also dominant.

Ferruginous echinoderm packstone

In the ferruginous echinoderm packstone, intraclasts (ferruginous) are about 10% and have the average diameter of 0.5mm. In some cases the diameter is upto 1.8mm. Ooid-bearing intraclasts are also present. Echinoderm debris (average size is 1mm and size is upto 1.5mm and their abundance is about 10%), echinoderm spines, foraminifers, disarticulated and broken brachiopod and bivalve shells (average diameter 0.5mm and size upto 6mm), gastropod debris, constitute the bioclasts. Bioclasts are about 20%. In some cases both tangential and radial ooids are present. These are about 1% with average diameter of 0.7mm and have relatively large nuclei. Quartz grains are about 1% with the average diameter of 0.15mm. Cement is granular sparite and some fibrous cement is also present. Matrix shows ferruginisation. Sorting of grains is moderate to poor. In some cases sorting is good. Roundness falls under class III (Plate 1 [f], Slide 1-B1).

Ferruginous intraclastic packstone

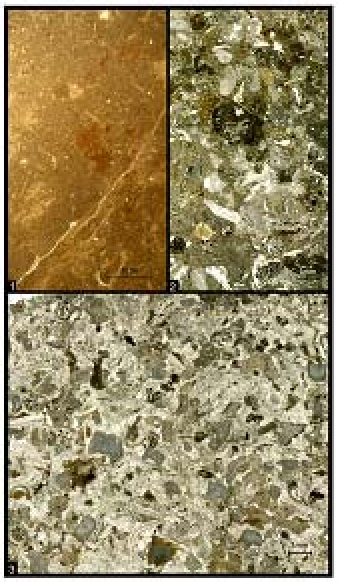
In ferruginous intraclastic packstone, intraclasts are about 35 to 40% with an average diameter of about 0.6mm. They are upto 1.5mm across. A few intraclasts contain several feldspar grains. Some intraclasts containing radial ooids are also present. Echinoderm debris (average diameter of 0.5mm), echinoderm spines, articulated and disarticulated bivalve shells (about 3.5mm across), foraminifer shells, coral debris, gastropod debris constitute the bioclasts. In some cases ooids are about 1.5%. Both radial and tangential ooids are present. The average size of ooids is 0.7mm and the average size of nucleus is 0.15mm. Some broken ooids are also present. A few oncoids with the average diameter of 0.5mm are also present. Quartz grains are about 1% with an average diameter of 0.15mm. Cement is predominantly granular sparite with some fibrous sparite. Micritic matrix show high ferruginisation. Sorting of grains is moderate to poor and roundness falls under class IV (Plate 1 [f], Slide 3-B3 & Slide 4-B4).

Echinoderm grainstone

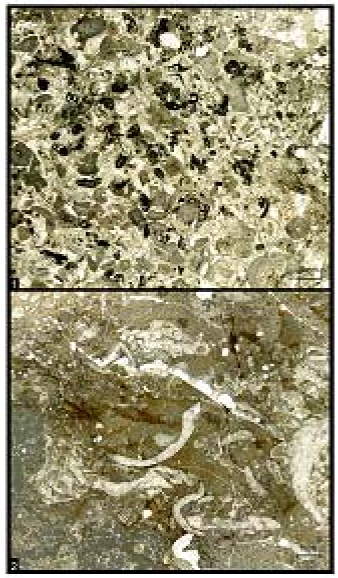
In these, erchinoderm debris, echinoderm spines, brachiopod shell debris (upto 2mm in size), bivalve shell debris and foraminifer shell debris constitute the bioclasts. The intraclasts have the average diameter of 1mm and are about 20%. Some of them contain several quartz grains (about 0.3mm in diameter) and echinoderm spines. Some contain ooids and quartz grains. A few ooids, upto 1mm in diameter, with tangential-radial and radial structure are present. These are complete ooids. A few oncoids are also present. Quartz grains are about 1% with average diameter of 0.25mm. Cement is granular sparite and some fibrous sparite. A few echinoderm debris show syntaxial "rim cement". Sorting of grains is good to moderate and roundness falls under classIV (Plate 1 [f], Slide 2-B2).

Microfacies Analysis

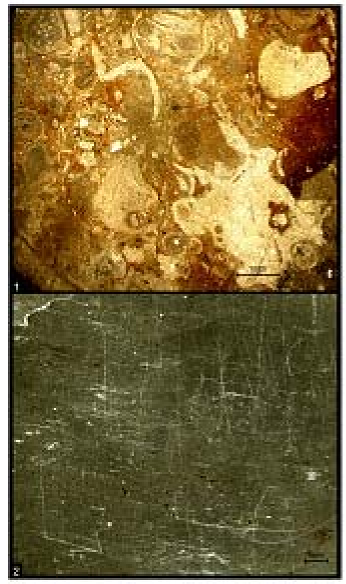
Carbonate platform is a very general



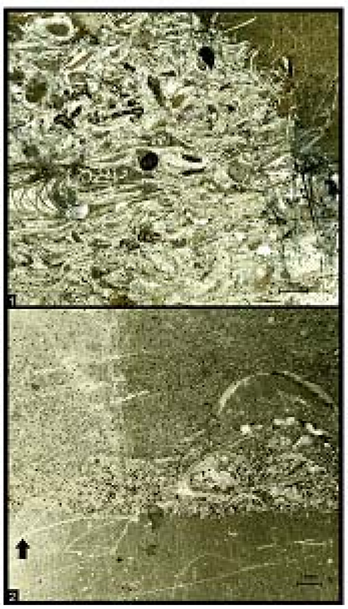
(a)



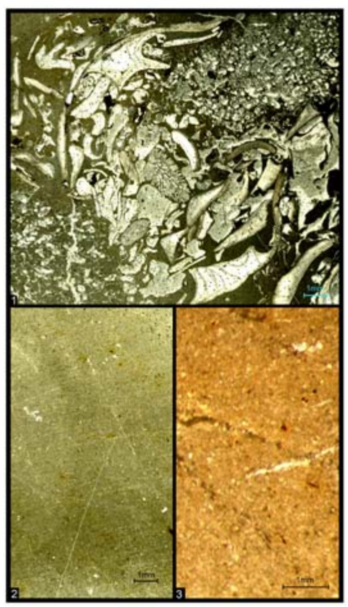
(b)



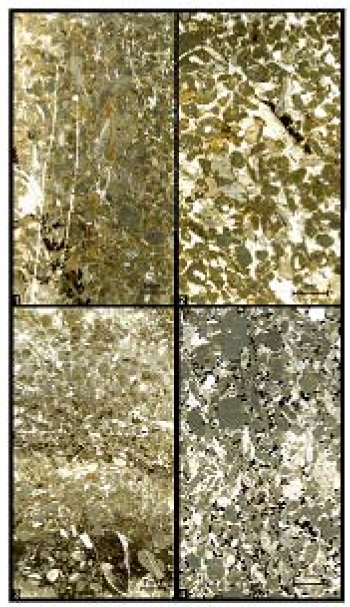
(c)



(d)



(e)



(f)

Plate 1 [a] Slide 1 Bioclastic mudstone *of the JCL mb. (B-1).* ***Slide 2*** **Echinoderm** packstone *of the LCL mb. (B-3).* ***Slide 3*** **Echinoderm grainstone** *of the JCL mb. (B-5).* ***[b] Slide 1*** Echinoderm grainstone *of the JCL mb. (B-7).* ***Slide 2*** **Bioclastic rudstone** *of the JCL mb. (B-9).* ***[c] Slide 1*** **Bioclastic** rudstone *of the JCL mb. (B-9).* ***Slide 2*** **Bioclastic mudstone** *of the JCL mb. (B-13).* ***[d] Slide 1*** Bivalve rudstone *of the JCL mb. (B-17).* ***Slide 2*** **Bivalve packstone** *of the JCL mb. (B-39).* **These graded units i.e. packstones with erosive base, overlying mudstones, represent storm beds (tempestite shell-beds).** ***[e] Slide 1*** Bioclastic floatstone *of the JCL mb. (B-65).* ***Slide 2*** **Bioclastic mudstone** *of the JCL mb. (B-67).* ***Slide 3*** **Bioclastic** mudstone *of the JCL mb. (B-15).* ***[f] Slide 1*** *Ferruginous echinoderm packstone of the EP (B-1).* ***Slide 2*** **Echinoderm grainstone** *of the EP (B-2).* ***Slides 3 & 4*** **Ferruginous intraclastic packstone to grainstone** *of the EP (B-3 & B-4, respectively).*

term used for a thick sequence of largely shallow-water carbonates. Carbonate platforms develop in a wide range of geotectonic settings. They particularly develop along passive continental margins, in intracratonic basins to failed rifts, and back-arc basins to foreland basins. Rimmed shelf, ramp, epeiric platform, isolated platform and drowned platform, are the various categories of carbonate platforms. A carbonate ramp is a gently sloping surface (slope generally less than 1o) on which the nearshore wave-agitated sandy facies pass offshore into more muddy facies of the deeper-water. Ramps are chareterized by gentle slope from intertidal to basinal depths without major change in gradient. Seaward progradation of the inner sand belt and storm transport of shoreface sand to the deep ramp constitute the important depositional processes. Geotectonics and relative sea-level are the major factors determining the carbonate platform type (Tucker and Wright 1990).

Microfacies associations

At the Jumara Dome, following two microfacies associations are present, representing the Jhurio Fm.

Microfacies association 1

This contains bioclastic mudstone, bioclastic wackestone, bivalve packstone and bivalve float- to rudstone. The Jumara Coral Limestone mb. is represented by this association. The association forms well-bedded limestone-marl/marlstone alternations and represents a largely low-energy depositional environment which had seen phases of slight influence of storm events.

Microfacies association 2

This contains *ferruginous echinoderm/ bioclastic packstone*, *ferruginous intraclastic packstone* and *echinoderm grainstone*. The Echinoderm Packstone is represented by this association. In this association the well-bedded limestone-marl/ marlstone intercalations are absent and it represents reworked sediments of the transgressive phase with relatively higher-energy depositional environment.

Depositional environment

Based upon the overall carbonate facies pattern, a *carbonate ramp* setting seems to have been prevalent at the time of sedimentation of the carbonates during the Bathonian (*e.g.* Misra and Pandey 2000, Misra 2002).

The Echinoderm Packstone probably represents reworked sediments of the transgressive phase (Fürsich *et al*. 2001) with relatively higher energy depositional environment as compared to the underlying Jumara Coral Limestone mb. In these units, the well-bedded limestone-marl/marlstone alternations, as those found in the underlying Jumara Coral Limestone mb., are absent. This unit is represented by the MF association 2, containing ferruginous echinoderm/bioclastic packstone, ferruginous intraclastic packstone and echinoderm grainstone. Sorting of grains is variable. High degree of ferruginisation, appreciable terriginous (sand-sized quartz grains) influx, presence of ooids (with a few broken ones) and oncoids, and relatively higher percentage of intraclasts, almost throughout the unit, is a characteristic feature.

The Jumara Coral Limestone mb. underlies the Echinoderm Packstone. In the Jumara Coral Limestone mb., which consists of well-bedded limestone-marl/marlstone alternations, mainly bioclastic mud- to wackestone, with intercalations of bivalve packstone and bioclastic float- to rudstone beds are present (MF association 1). This sequence represents a largely low-energy depositional environment just below storm wave-base, which had seen phases of slight influence of storm events. The lower 4m of the mb. contain some thin shell-beds which show ferruginisation and increased content of terrigens (sand-sized quartz grains) and ooids (broken ooids are also present). This part of the mb. represents episodic relatively higher energy conditions.

Fine grained packstones containing peloids and small sized bioclasts and intercalated with wackestones containing peloids and having mm cross- laminations, indicate towards a marine, open sea, mid to outer (deep) carbonate ramp environment. This is corroborated by the presence of well-bedded and nodular nature of the beds which are interbedded with marl/marlstone (literature on carbonate ramp *e.g.* Tucker 1985, Ahr 1973, Tucker and Wright 1990). Bioclastic packstones containing winnowed horizons represented by rudstones, indicate reworking by storm waves. Graded units, packstones with erosive base, overlying mudstones, represent storm beds (tempestite shell-beds). In general, the energy condition seems to have been low as major cross-bedding is absent.

Presence of bioclastic limestones containing diverse fauna in good quantities indicate good organic productivity and is in accordance with such depositional settings.

The presence of granular sparite cement alongwith fibrous cement and syntaxial "rim cement", the grain-sorting characteristics, and the bioclastic content of the sediments, support the prevalence of such environments.

Thus, a carbonate ramp setting seems to have been prevalent at the time of sedimentation of the carbonates during the Bathonian. The presence of a carbonate ramp setting is in coherence with the structure and tectonic evolution of the basin.

Conclusion

A carbonate ramp setting seems to have been prevalent at the time of sedimentation of the carbonates during the Bathonian. In general, the depositional environment seems to have been a marine, open sea mid to outer (deep) ramp environment. Depositional environment was largely low energy just below storm wave base which had seen phases of slight influence of storm-events. Reworked sediments of the transgressive phase witnessed relatively higher energy depositional environment.

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