JOURNAL INDIAN ASSOCIATION OF SEDIMENTOLOGISTS ISSN NO 2582 – 2020
Vol. 38, Issue 1, 2021, pp. 33-40
DOI: 10.51710/jias.v38i1.154

Facies Evaluation and Depositional Environments of Carbonates of the Bagh Group, Dhar District, Madhya Pradesh, India

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Abstract:

A significant event of marine transgression took place in Central India during Late Turonian-Coniacian. Fossiliferous marine succession of Bagh Group is one of the few carbonate successions exposed in peninsular India which was in focus of the current study for understanding this event. The signatures of this event were identified in the carbonate succession. The carbonates of Bagh Group are composed of two formations: the lower part is represented by Nodular limestone Formation which is overlain by Bryozoan limestone Formation at the top. On the basis of grain size variation and sedimentary structures, the Nodular limestone is divisible into three facies: facies 'A', facies 'B' and facies 'C'. A hardground exists between facies B and facies C. Lack of sedimentary structures and high mud content indicates low energy depositional setting for the Nodular limestone Formation. Similarly, Bryozoan limestone Formation is divisible into five facies: facies 'D', facies 'E', facies 'F', facies 'G' and facies 'H' based on grain size variation and sedimentary structures. All of these five facies are fossiliferous. Glauconites are present within facies 'G' and have two modes of occurrence - as infilling within Bryozoan limestone and as altered feldspar. Presence of both small- and large-scale cross-stratification in Bryozoan limestone with lesser mud content are indicative of high energy shallow marine conditions. Large-scale cross-stratifications are possibly representing tidal bars while the small scale cross stratifications are formed in inter bar setting. Presence of reactivation surfaces within facies 'E' also supports their tidal origin. Increase in depositional energy condition is also evident from dominated by packstone facies.

Keywords- *facies, bryozoan limestone, nodular limestone, wackestone, packstone, marine transgression, tidal origin*

Introduction

The Bagh Group of rocks is generally exposed in isolated inliers within the Deccan Traps in the West Central India covering an area of 4000 sq. km. (approx). The exposures are mainly on the northern flank of the river Narmada. It is generally believed that the trend of the Narmada represents a tectonic lineament of mid continental rift (Biswas, 1999) which was associated with the Karoo rift system of Africa (Boselini, 1989). It was later reactivated during separation of India and Madagascar. The rifting guided the present configuration of the western margin of India along relatively straight coastline representing the rifted passive margin (Gombos et al., 1995). Rock succession of the Bagh Group is highly fossiliferous (Contains fossils of bivalves, gastropod, bryozoan, etc). This is one of the few carbonate successions, exposed in peninsular India. Its fossil content always has drawn attention of the experts in fields of paleontology, palaeoecology, biostratigraphy, etc. The Bagh Group is well exposed in and around Dhar district, Madhya Pradesh (Survey of India toposheet no. 46N/3, 46J/15), especially along the river banks of River Man. Deccan volcanics occur on top of the Mesozoic outcrops in many places. Extensive mining activities have exposed workable sections of the Bagh Group. The deposition took place in this intra-cratonic basin as the eastern arm of the Tethys transgressed (Chiplonkar et al., 1976; Jafar, 1982). Thus the carbonate succession is the product of Late Turonian-Coniacian transgression (Bardhan, 2002).

Numerous works on fossils in this group warranted a detailed study on its sedimentological aspects to supplement paleontological observations. Hence, a detailed microfacies analysis of the carbonates of the Bagh Group was attempted in Ratitulai, Rampura, Man river section, Zirabad and Mohi in Dhar district incorporating field observations as well as petrographic study.

Geological Setting

The carbonates of the Upper Cretaceous Bagh Group of Central India represent a fossiliferous shallow marine sequence. It consists of the lower Nodular limestone and upper Bryozoan limestone formations. However, Kennedy et al. (2003) showed alternations of Nodular limstone and Corallline limestone (Bryozoan Limestone of the present case) in the Hatni *nala* section. The Nodular limestone Formation is underlain by the fluvio-marine siliciclastic Nimar Formation which, in turn rests on the Precambrian crystalline rocks (Sarkar, 1973). However, at Karondia (lat. 22^0 22' 30" N, long. 75^0 4' 00" E) and Man River section, the Nodular limestone rests directly over the Precambrian granitic basement with a non-conformable contact. The beds in the Man River section are almost sub-horizontal whereas, in the area around Bagh Cave, these beds dip at 12^0-15^0 due north. One of the noteworthy feature of the Bagh Group is the occurrence of several hardgrounds in the carbonate succession (Ruidas et al., 2020). Bose, et al. (1982), proposed the name 'Bryozoan Limestone' instead of 'Coralline Limestone' because of paucity of corals and the dominance of Bryozoans.

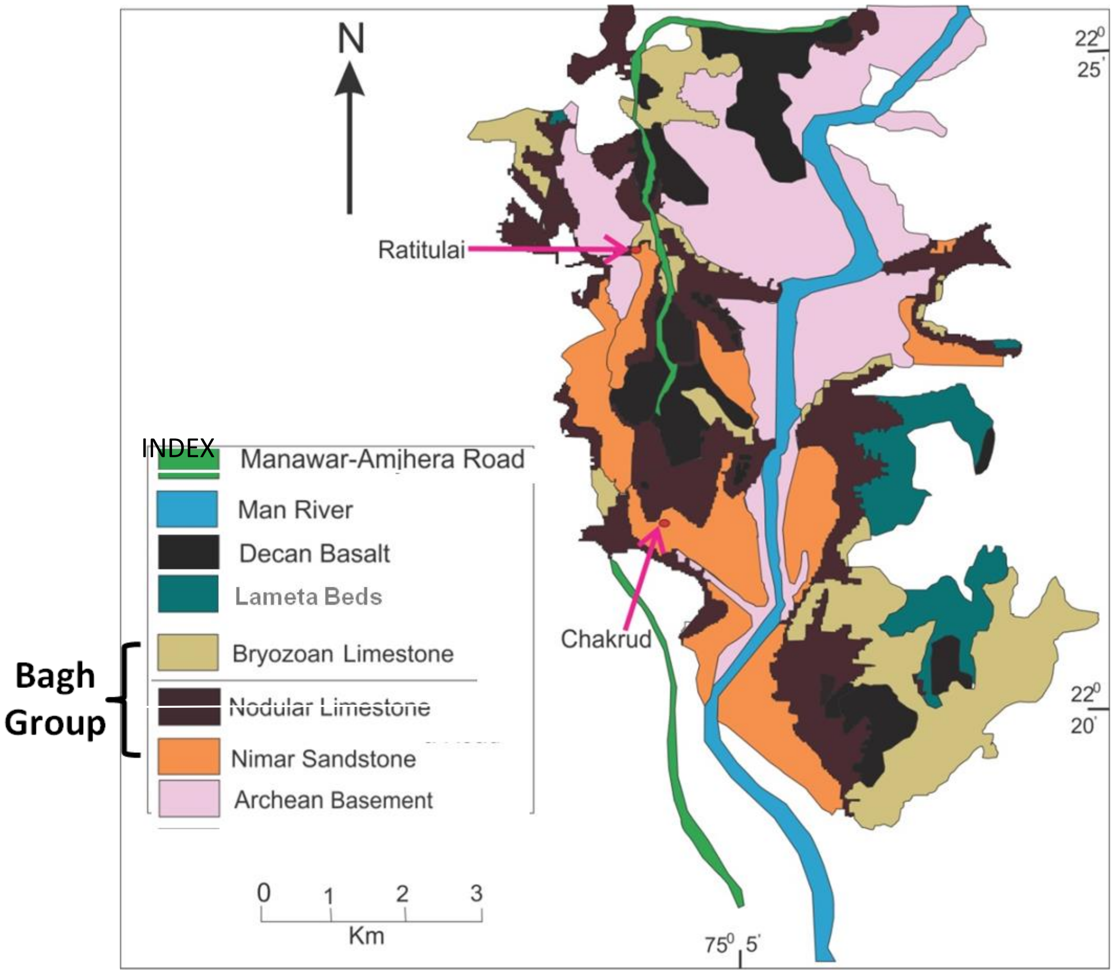

Fig. 1: Geological map of the study area (adapted from Khosla & Kapoor, 2003)

Materials and Methods

Detailed facies analysis through field observations and sampling of the Bryozoan Limestone of the Bagh Group at Ratitulai, Rampura, Chak road, Man River section, Zirabad, Mohi, Baria, Kosdana, Karondia, have been done. Litholog of the Bryozoan limestone from Baria (Fig-2) was prepared by taking traverse along the Man River (Fig-2). Grain size variation, different sedimentary structures, presence of burrows, etc. were minutely observed during the field work. As the beds dip very gently (~ 3°), care was taken to record the vertical sedimentary succession. Fresh samples were collected for petrography. Spot samples were collected for carrying out sedimentological and mineralogical analysis of glauconite. Thin sections were prepared using IsoMet Precision Saw (Buehler; 280-250; 0-300 rpm; 35cutting capacity; gravity feed weight system with diamond cutting wheel). For Polishing EcoMet 3000 Slow Speed Precision GrinderPolisher (Buehler) was used. Petrographic observations were carried out using Leica DM 4500P polarizing microscope at the Department of Earth Sciences, IIT Bombay using both transmitted and reflected light with external stage micrometer (Scale: 1 mm/0.01 mm; Cole-Permar product).

XRD investigations were carried out using EMPYREAN diffractometer. Operating conditions were 40 mA, 45 kV with nickel filtered Copper Ka radiation and a 3-D Pixel detector. Samples were continuously scanned in a 2θ range of 60° with scan step size of 0.0260/ 100s. The samples were scanned in three modes, initially air dried mode, subsequently scanned in glycolation mode (after treating with ethylene glycol for 2 hours) and finally scanned in heating mode (after heating at 400°C for 30 minutes).

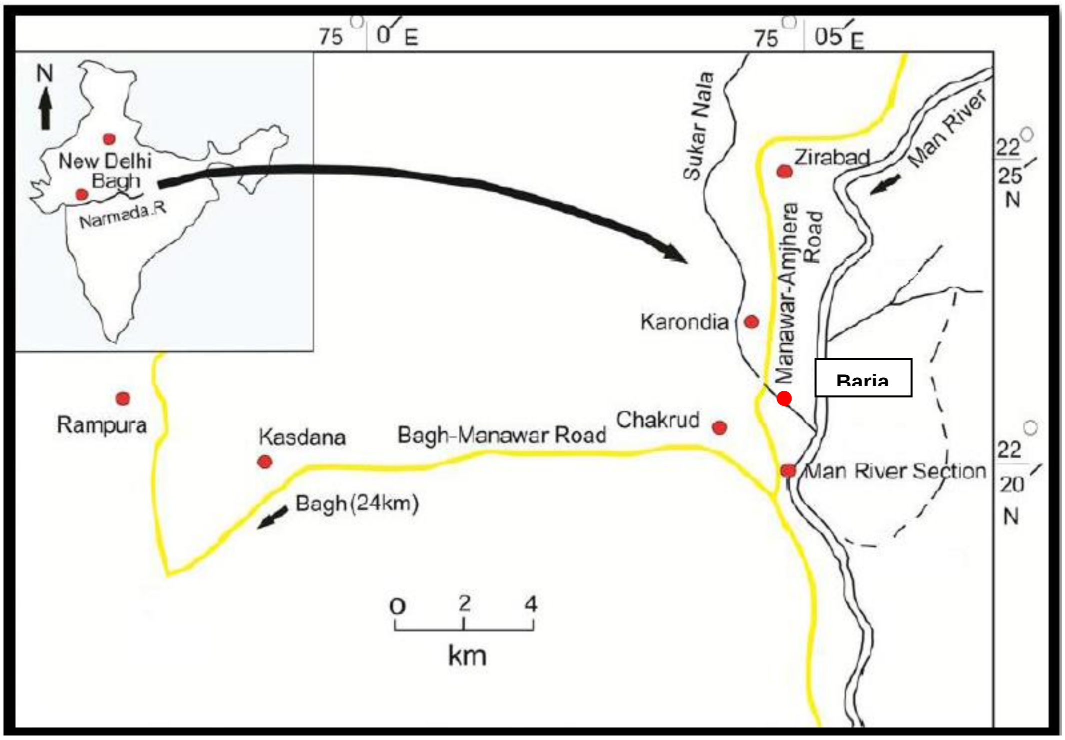

Fig. 2: Location map showing different study areas

Facies Description

Nodular Limestone

The Nodular limestones are exposed in Ratitulai, Rampura, Karondia, Chak road, Zirabad, Kosdana and Baria with maximum thickness of 7 m at Karondia and overlain by Bryozoan limestone. The strata below this Nodular limestone is Nimar Sandstone, which is exposed in only one place (Near Bagh Cave). Nodular limestone is divisible into three facies- facies A, facies B and facies C (Fig-3,4)

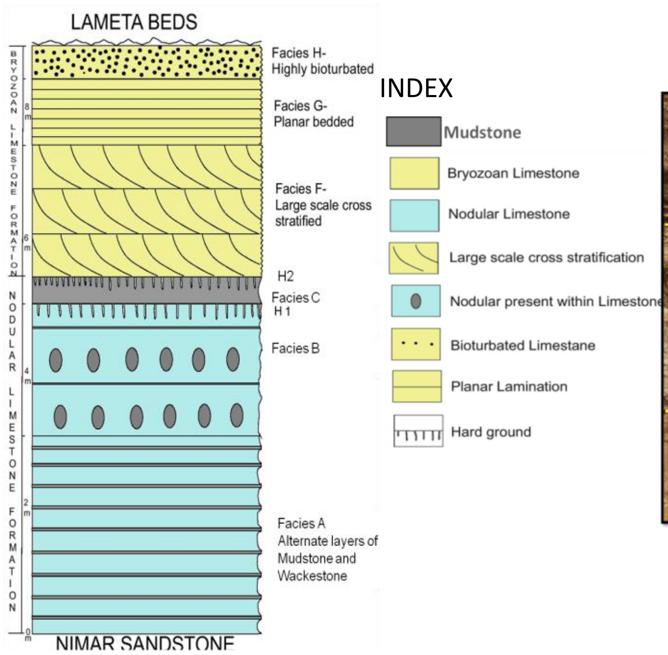

Fig. 3- Representative litholog (9m) of the Nodular limestone and the Bryozoan Limestone Formation of Bagh Group from Baria.

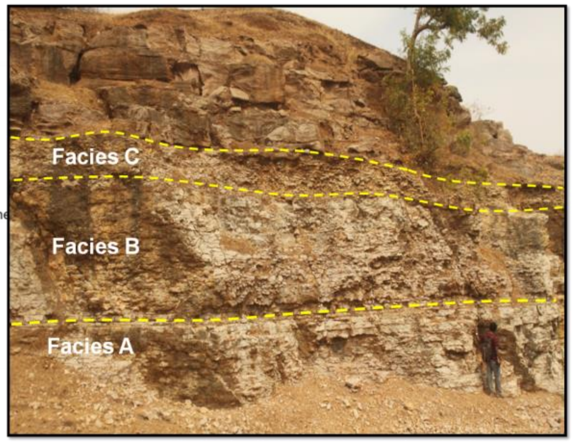

Fig. 4: Field photograph showing facies A, B & C

Description of Facies 'A': Mudstone-Wackestone Alternations. This facies is represented by alternate layers of mudstone and wackestone (Fig-5a). It attains a maximum thickness of 3m. The thickness remains more or less uniform laterally. Continuous beds are present at all the places. Bioturbation is rare. Ripple marks are present within thin mudstone layer. In the mudstone layer, micrite content is >95% (Fig-5b) and spar content <5%. In places, this mudstone is truncated by calcite veins (Fig-5b). In the wackestone layer, sorting is poor. Bioclasts (shells of gastropods, bivalves, foraminifers, etc. of varying sizes) are present as major allochems (Fig- 5c).

Description of Facies 'B': Highly Bioturbated Wackestone. In this facies bedded nature disappears and thickness of the mud layer decreases. This facies is nodular dominated (Fig-6a), formed due to chemical compaction, (Ruidas, et al., 2018). Size and shape of nodules are highly variable. The length: width ratio varies from 0.5 to 1.0 (Ruidas, et al., 2018). It is highly bioturbated and burrows are filled with silt sized particles (Fig-6b). Burrows are of both inclined as well as horizontal nature. Load casts are present at the base of this facies (Fig-6c). Pressure solution features are also found at many places. Within this facies, some patches, with high concentrations of Turritella shells are observed (Fig-6d). Shells of gastropods, bivalves and few foraminifers of varying sizes are present as bioclasts (Fig-6e). Sorting is poor. In some samples dissolution features are present. Bioclasts are mostly intact with few showing compaction features.

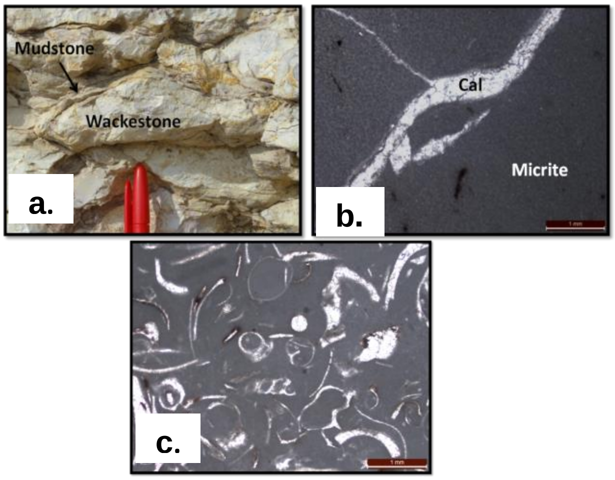

Fig- 5: a) Field photograph showing mudstone-wackestone alteration (scale = 3 cm),
b) Photomicrograph of mudstone layer, PPL, 1N
c) Photomicrograph of wackestone with bioclasts, PPL, 1N. Cal = Calcite

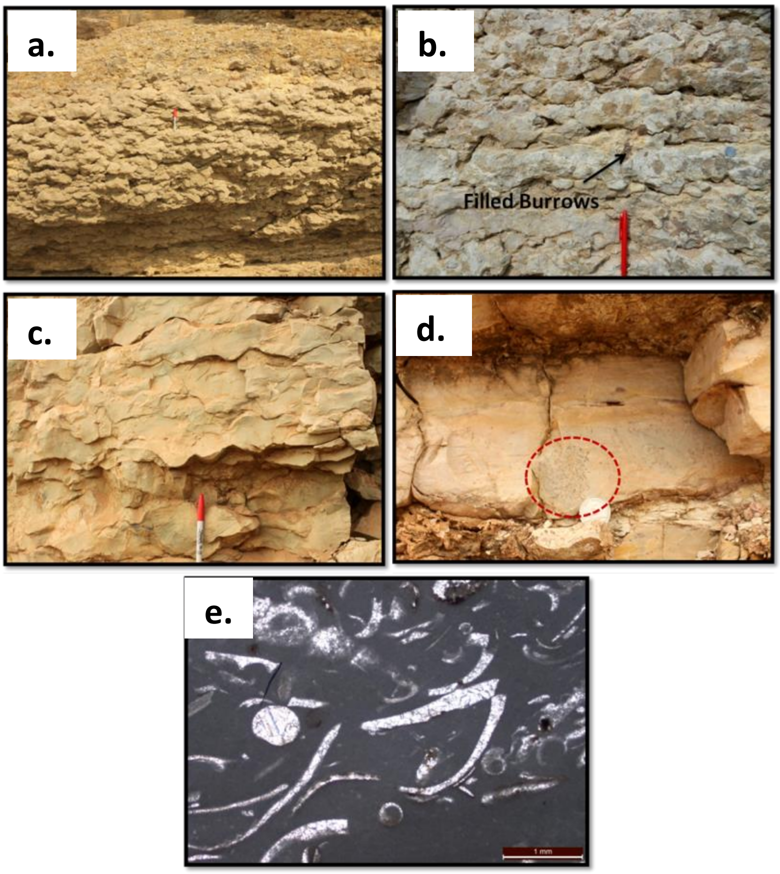

Fig-6: a) Field photograph showing nodular character of limestone, (scale= 14 cm) b) Bioturbated Nodular limestone; burrows filled with spar (scale= 14 cm), c) Load Casts in Nodular limestone (scale= 14 cm), d) Patches of Turritella shells, (scale= 2.5 cm), e) Photomicrograph of Wackestone, PPL, 1N.

Description of Facies 'C': Mudstone: This facies is locally developed and composed of mudstone (Fig-7a). This layer has a maximum thickness of 1.5m at Karondia. It is devoid of bioclasts (Fig-7b). A hardground occurs between facies B and facies C (Fig-7c). Burrows are present within this hardground (Fig-7d).

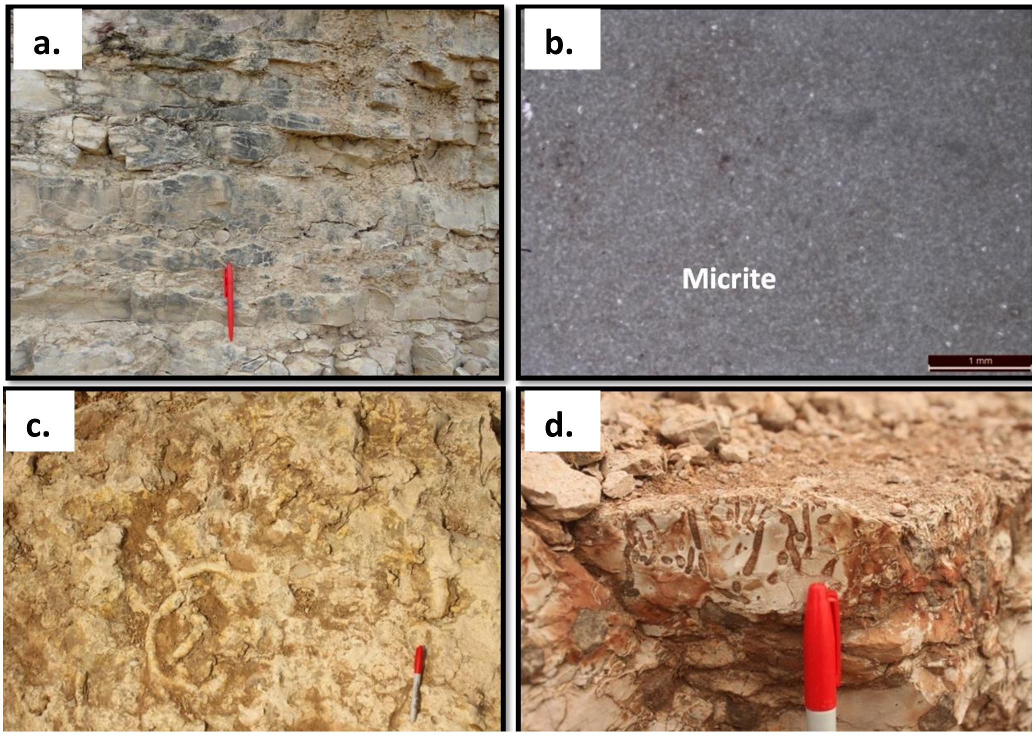

Fig-7: a) Field photograph of Mudstone, b) Photomicrograph of mudstone PPL, 1N, c) Field photograph of hardground, d) Burrows within hardground. (Scale= 14 cm).

Bryozoan Limestone

The Bryozoan Limestones (Fig-8a) are exposed in Ratitulai, Rampura, Karondia,Chak road, Zirabad, Kosdana, Baria. Maximum thickness of 4.5 meter was measured at Kosdana. At places, the Bryozoan Limestone is overlain by Deccan Trap, whereas at other places, like in Chak road, this is overlain by fluvial Lameta Formation. A highly bioturbated hardground having a maximum thickness of 50cm exists between the Nodular limestone and the Bryozoan limestone formations (Fig-8b). Dominant bryozoa are *Cyclostome* sp. and Cheilostome sp. From bottom to top, micrite content decreases. Samples from different locations were collected at an interval of 30 cm and out of these 9 samples were studied under the microscope.

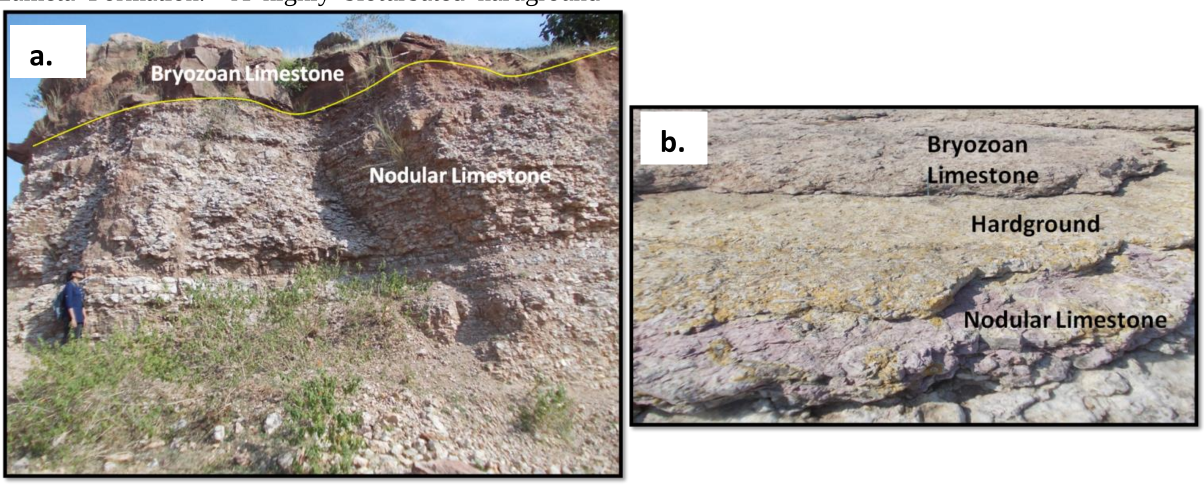

Fig-8: a) Field photograph of Bryozoan limestone overlying Nodular limestone, b) Field photograph of hard-ground between Nodular limestone and Bryozoan limestone. (Scale = 14.5 cm

Description of Facies 'D': *In situ* wackestone. This is the lowermost facies, lying above Nodular limestone. This facies consists of bryozoan fossils of variable sizes (Fig-9a). Branching of bryozoa is preserved, thus indicates negligible reworking. Sorting is poor. This is a mud supported rock but contains >20% bioclasts (bryozoa). It gradationally passes upward to facies 'E'.

Description of Facies 'E': Small-scale cross-stratified grainstone. This facies is exposed at Rampura and Mohi. Maximum thickness of this facies is 1 meter, exposed at Rampura. Bryozoans in this layer are reworked. Small scale cross stratification have a dip of nearly 30^0 (Fig-9b). Cross-stratified beds are wavy, indicating dissolution. Reactivation surfaces are present at Zirabad. Ripples are asymmetric. Under the microscope, this is a grain supported rock with mud content <10% (Fig. 9). Skeletal particles include Bryozoa (~80%), and very few fragments of gastropods and echinoid spines are present (10-20%) and forming 90% of rock (Fig- 9c). Stylolites and sutured grain boundaries of bryozoan fossils are present at places. Sorting is poor.

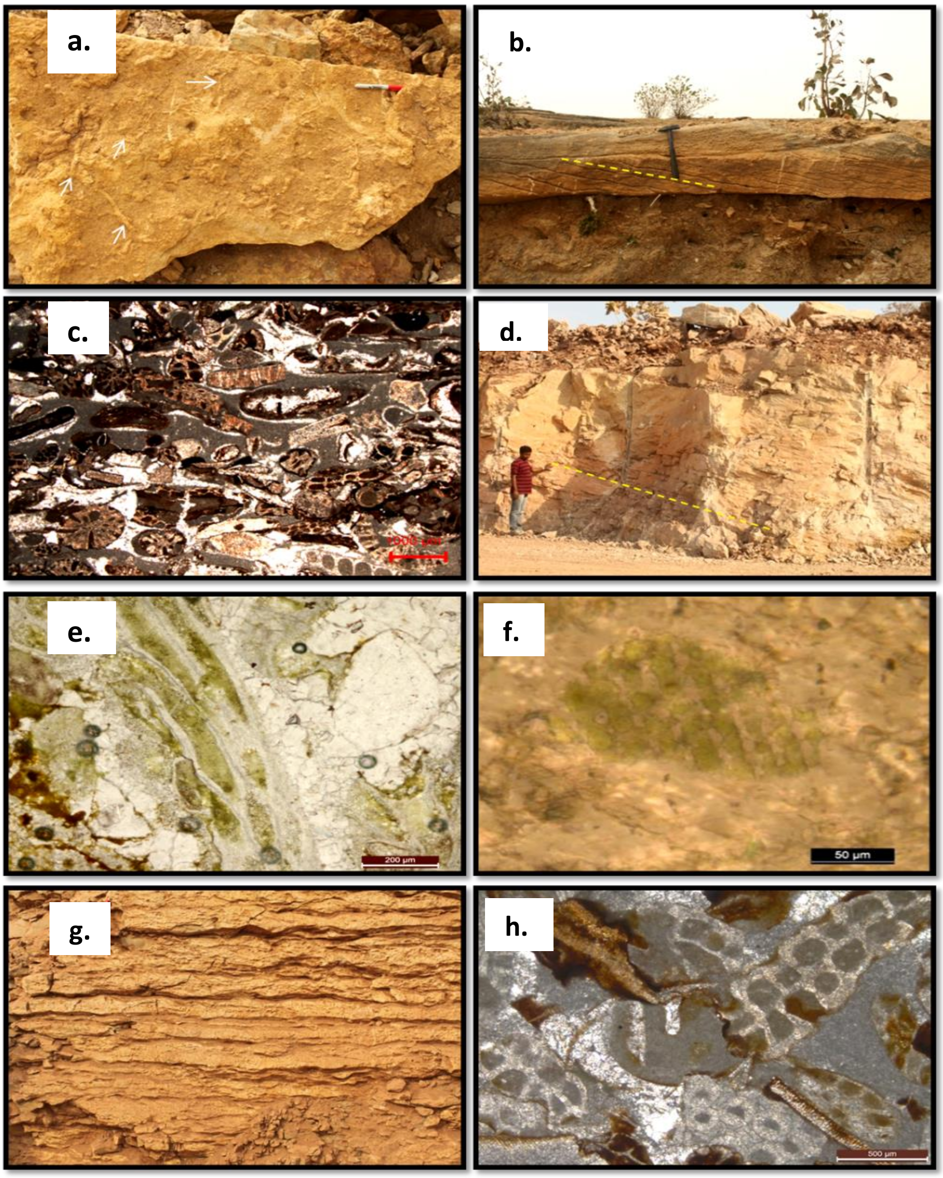

Fig- 9: a) *Insitu* wackestone with bryozoa (scale = 14 cm), b) Field photograph of small scale cross stratification with reactivation surface (yellow trend line) (scale= 38 cm), c) Photomicrograph of grainstone PPL, 1N, d) Field photograph of large scale cross stratification (yellow trend line), e) Photomicrograph of Glauconite as infilling within bryozoa fossil, PPL, 1N, f) Photomicrograph of Glauconite as altered feldspar. PPL, 1N, g) Field photograph of planner laminated Wackestone, h) Photomicrograph showing boring in bryozoa fossil PPL, 1N.

Description of Facies 'F', Large-scale cross-stratified grainstone. This facies overlies on Facies E and is exposed at Karondia, Zirabad, Baria, Chak road, Kosdana area with maximum thickness of 2.5 meter at Kosdana. This is a large-scale cross-stratified grainstone, composed of highly reworked bryozoan fossils and large-scale (max. thickness of foreset 2.5m) cross-stratification (Fig-9d). Bryozoa, present in this layer are highly reworked. Sorting is moderate.

Description of Facies 'G', Planar laminated wackestone. This facies is well exposed in Karondia, Zirabad, Baria, Chak road, Kosdana, Ratitulai with a maximum thickness of 2 meter at Zirabad. This layer consists of planner laminations (Fig-9e). Glauconite is present in this layer at Ratitulai. Glauconite (Fig- 9 e & f) has two modes of occurrence - as infilling within bryozoa and as altered feldspar (Bansal et al., 2019). Sorting is moderate.

Description of Facies 'H', Highly bioturbated packstone. This facies is exposed at Kosdana, Baria, Karondia with maximum thickness of 1 meter. This layer has profuse borings (Fig-9 g & h). It is a well sorted rock with lesser micrite content and >60% allochems. Allochems are bioclasts out of which 70% are of bryozoa, rest is bivalves and echinoids.

Chemical Analysis of Glauconite

According to Odin & Matter (1981) and Odom (1984) prominent peak between 10Å-14Å (001) basal reflections are characteristic of glauconite. The samples of Ratitulai exhibit characteristic peaks of glauconite at 9.8Å (001) (Fig-10) basal reflection, (020) reflection at 4.23 Å and (003) reflection at 3.05Å. Thus this confirms the existence of Glauconite in the analysed samples.

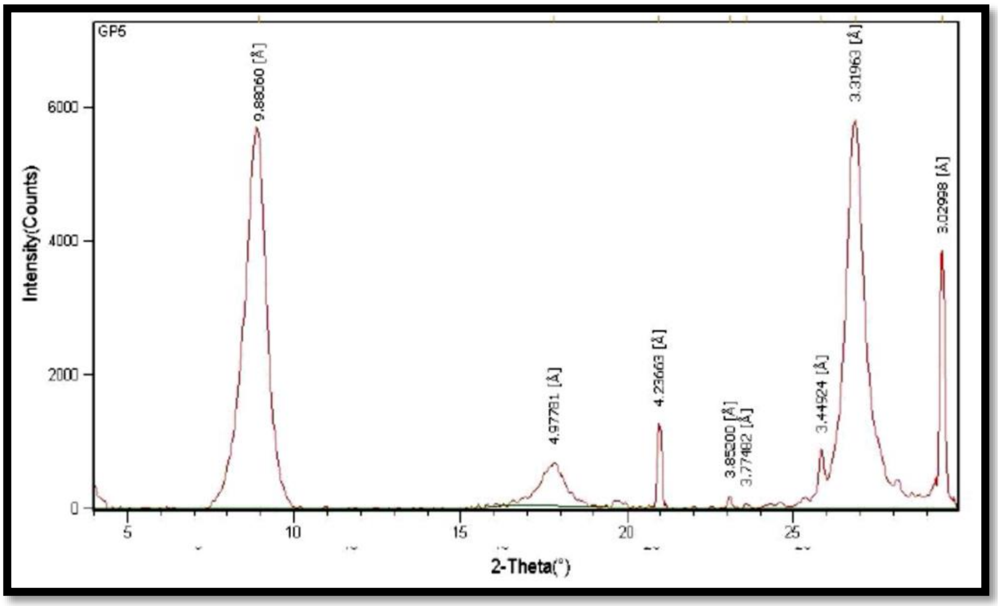

Fig.10 X-Ray diffactogram of sample collected from Ratitulai showing characteristic peak for glauconite

Discussion on Depositional Settings and Paleogeographic Shifts

The Nimar Formation at the base of the Bagh Group consists of shallow marine sandstone (Bhattacharya and Jha, 2014). The Nimar Formation is overall fining upward, exhibits transgressive trend at the upper part and gradationally passes over to the Nodular limestone in response to rise in relative sea level (Bhattacharya et al., 2014). The transgressive trend continued within the Nodular limestone and curtailment of clastic supply would have facilitated deposition of carbonate sediments. Carbonates are mostly mudstone, indicating low-energy depositional setting.

The facies A of the Nodular limestone is completely devoid of primary sedimentary structures indicating its deposition at a low energy depositional setting, possibly in the outer shelf. The deepening trend continued during the deposition of the facies B as carbonates are frequently dissolved forming nodules and dissolution seams. Primary sedimentary structures are almost absent within it. Lack of sedimentary structures and dissolution of carbonates suggest increase in depositional depth during the deposition of facies B. The deepening of the sea continued till the deposition of facies C containing mudstone. Hardground at the top of this facies is the result of extremely low rate of sedimentation. The Bryozoan limestone exhibits both large and medium-scale cross-stratification. This is indicative of deposition of sediments in shallow marine conditions. Large scale cross stratification within Bryozoan limestone is possibly reflection of tidal bars while the medium-scale cross-bedding may have in inter bar setting. Presence of reactivation surfaces within the cross-stratified sets of the Bryozoan limestone indicates their tidal origin. Increase in depositional energy condition is also reflected in the microfacies, which is dominated by packstone. The highly bioturbated packstone indicates significantly low sedimentation rate. Formation of glauconite corroborates the low rate of sedimentation.

Conclusions

The major conclusions of this study are as follows: The Nodular limestone is divisible into three facies: facies A - planar laminated alternate layers of mudstone and wackestone, facies B - bioturbated wackestone and facies C - entirely consists of mudstone. Lack of sedimentary structures and high mud content of these facies suggests deepening of sea during its formation. A hard-ground exists between facies B and facies C. Formation of this hardground corresponds to a low rate of sedimentation.

Bryozoan limestone is divided into 5 facies. Lower most facies D consists of insitu bryozoa. Followed by facies E - small-scale cross-stratified limestone with reactivation surfaces, facies F- large-scale cross-stratified limestone, facies G - planar laminated and facies H- highly bioturbated limestone at the top. Moving from bottom to top of this Bryozoan limestone layer show decreasing micrite content indicating increase in depositional energy. Large-scale cross-stratification and presence of reactivation surfaces indicate tidal origin. The presence of sedimentary structures and micro facies analysis indicate deposition of Bryozoan limestone in a shallow marine environment with high-energy condition.

Acknowledgements

Authors are indebted to their host institute IIT Bombay and the Department of Earth Sciences for providing the opportunity to carry out the study and for providing all the necessary facilities. Authors would like to express deepest gratitude towards their supervisor Prof. Santanu Banerjee for his guidance in every way possible. Authors are thankful to reviewers from Atomic Minerals Directorate for Exploration and Research (AMD) for their constructive suggestions and criticisms. We place on record sincere thanks to the anonymous reviewers for their critical comments on the MS.

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(Received on 29 October, 2020; Revised Accepted on 4 February, 2021)