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Sedimentological and palaeoecological significance of the trace fossils of the Jurassic rocks of the Jhura Dome, Mainland Kachchh, western India

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Key words: Jurassic, ichnoassemblages, ichnoguilds, ichnofacies, depositional environment, Kachchh, India.

Abstract. The Middle to Late Jurassic succession of the Jhura Dome (Jhurio and Jumara formations) of the Mainland Kachchh, western India, comprises a ~500 m thick succession of clastic carbonates and mixed siliciclastic-carbonates, intercalated with shales. The sequence, as based on sedimentological characteristics, exhibits six sedimentary facies and four subfacies. Certain exceptional bands of the ripple-marked calcareous sandstone, shale and oolitic limestone facies are rich in ammonites, belemnites, brachiopods and bivalves. Thirty four ichnogenera were also identified and analysed paleoecologically. These trace fossils represent five ethological categories and six ichnoassemblages. Seventeen ichnoguilds are demonstrated based on space utilization for characterising the ecological complexity of ichnoassemblages. Bathymetric control of the trace fossils resulted with development of Skolithos, Cruziana and Zoophycos ichnofacies type conditions. The sedimentological and ichnological data analysis revealed seven distinctive depositional regimes ranging from offshore shelf below storm wave base to middle shoreface.

INTRODUCTION

This integrated study of the sedimentology and ichnology of this shallow marine succession helped to delineate and differentiate the various environmental conditions necessary for the deposition of the sediments. The Mesozoic of Kachchh contains succession of shallow marine deposits and is an incredibly famous region amongst geologists for its rich fossil content and spectacular outcrops. The northern part of the Kachchh Mainland contains a series of domes, and amongst them is the Jhura Dome, wherein crop out the oldest Mesozoic successions on the Kachchh Mainland. The highly bioturbated successions of the Jurassic of Kachchh have attracted many ichnologists (Howard, Singh, 1985; Shringarpure, 1986; Ghare, Kulkarni, 1986, Kulkarni, Ghare, 1989, 1991; Fürsich, 1998; Desai *et al*., 2008; Patel *et al*., 2012; Patel *et al*., 2008, 2009, 2012, 2014; Joseph *et al*., 2012) to work in the different parts of Kachchh. A few attempts have also been made for sequence stratigraphic analysis based on ichnology (Patel *et al*., 2010, 2013; Bhatt *et al*., 2012; Patel, Joseph, 2012) and shell concentrations (Fürsich, Pandey, 2003) within the Mesozoic succession.

The objective of this paper is to record the sedimentological characteristics and trace fossil contents of the Jurassic successions (Bajocian to Oxfordian) of the Jhura Dome. To achieve the goal, the stratigraphic successions were measured at different locations with systematic stratigraphic sampling. Physical and biological sedimentary structures (trace fossils) were also recorded and examined. The lithologs were prepared along with their lateral and vertical continuity. Sedimentary facies and ichnofacies analysis were attempted in order to interpret the depositional environment.

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LOCATION AND STRATIGRAPHY

Amongst the domes of Kachchh Mainland, the Jhura Dome contains the oldest exposed sediments and provides information vital to the understanding of the stratigraphy and lateral and vertical facies changes within the basin. The study area, Jhura Dome (Fig. 1) is situated in the northern part of the Mainland Kachchh stretching from 23°30' to 23°40'N latitudes and 69°30' to 69°40'E longitudes.

The Mesozoic successions of the Jhura Dome have been studied by many palaeontologists and stratigraphers. Rajnath (1932) divided the succession into the Patcham and Chari series, but the lithostratigraphic divisions of Biswas (1971, 1977, 1991) have been used in the present study. According to this author, the successions of the Jhura Dome contains two formations, namely the lower Jhurio Formation and the upper Jumara Formation (Fig. 1); both the formations are further divided into informal members (Table 1). The core part of the Jhura Dome contains the oldest rocks, the Jhurio Formation being an inlier surrounded by the Jumara Formation (Fig. 1). The Jhurio Formation mainly comprises well bedded limestones in the lower and upper part, while the middle part of the sequence mainly consists of thick bands of Golden Oolite Limestone intercalated with calcareous shales (Biswas, 1991). The Jumara Formation comprises shales in the lower part, a mixed siliciclastic-carbonate sequence in the middle part, and is capped by the Dhosa Oolite Limestone at the top, which is the most conspicuous marker horizon of the Kachchh Basin.

LITHOFACIES DESCRIPTION WITH ASSOCIATED TRACE FOSSILS

According to Miall (1984), the word facies is used in two senses, a descriptive facies that include certain observable attributes of sedimentary rock bodies and in an interpretive sense, in terms of depositional processes. For detailed inves-

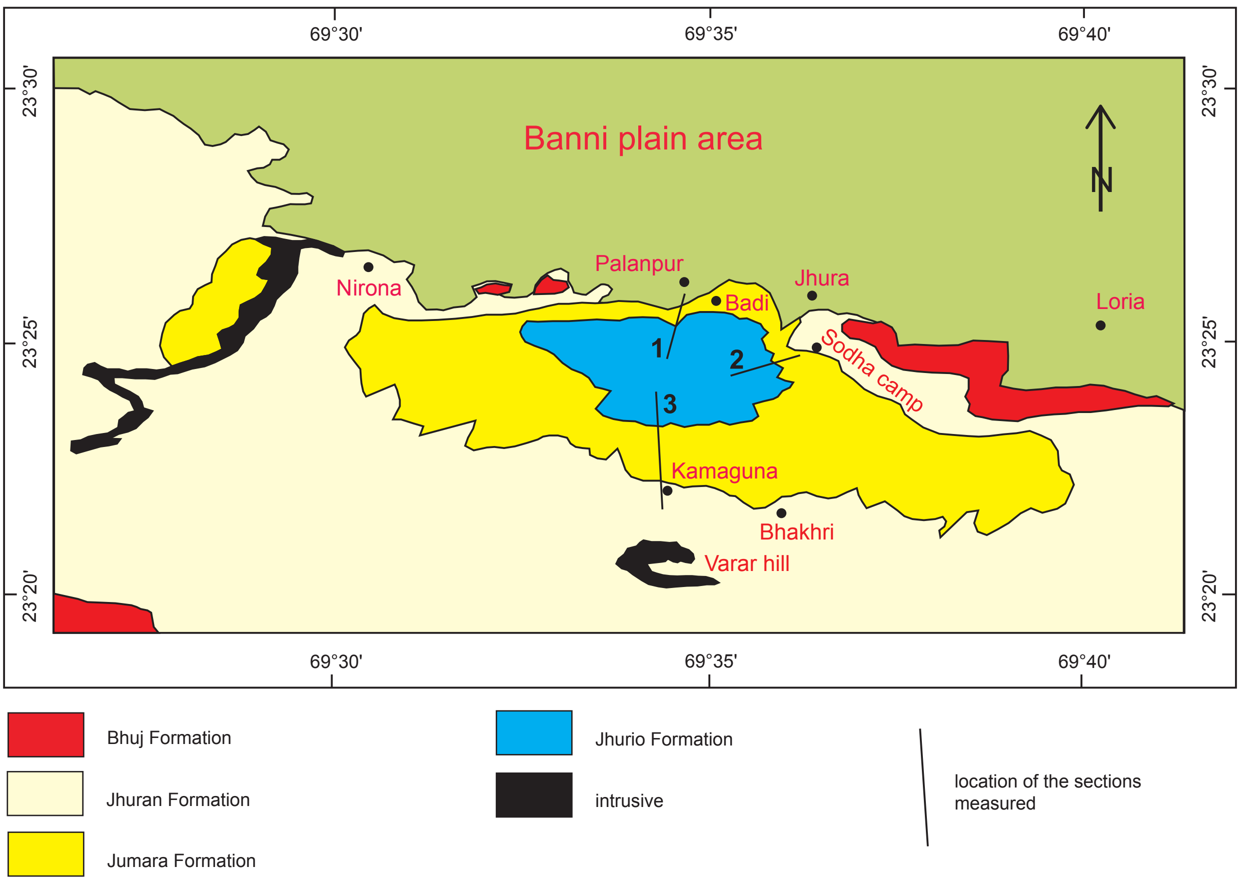


Fig. 1. Location and geological map of the study area (after Biswas, Deshpande, 1970)

Table 1

Lithostratigraphic divisions of the Jhura dome section (Biswas, 1977)

Formation	Member	Description
Jumara	IV (20 meter)	Dhosa Oolite Member: Green oolite marlite bands alternated by beds of green shale and topped by conglomeratic band
	III (106 meter)	Green, gypseous shale with fossiliferous marlite ferruginous and white marlite bands
	II (50 meter)	Green, gypseous shale with fossiliferous white marlite & red ferruginous bands. Green, hard, sandy fossiliferous marlite
	I (90 meter)	Thick greenish to yellow grey, laminated, gypseous, clayey shale with thin red nodular hematite bands and numerous grey marlite and yellowish white limestone bands
Jhurio	Member G (72 meter)	Well bedded and jointed white, grey, cream colored limestone
	Member F (20 meter)	Thick golden oolite bands are intercalated with thinly bedded yellow limestone
	Member E (45 meter)	Golden oolite – thick beds
	Member D (40 meter)	Khaki colored laminated calcareous shale with lenses of crystalline calcite
	Member C (15 meter)	Golden oolite – thick beds on weathered brick red colored
	Member B (25 meter)	Grey, khaki colored, calcareous, laminated silty shales
	Member A (19 meter)	Limestone and minor shale

tigation purpose, the ~500 m thick Mesozoic succession of the Jhura Dome (Fig. 2A–C) was divided into number of lithofacies. These subdivisions were based on the distinctive lithological features, including composition, textures, structures, biological character, bedding characteristics, colour, physical and biogenic sedimentary structures present at different stratigraphic positions. The study of the sequence is mainly focused on vertical facies relationships exhibited in six lithofacies with four subfacies:

1. Limestone Lithofacies – LL (subfacies: Badi Limestone Subfacies – BLs and Nodular White Well Bedded Limestone Subfacies – NWWLs),
2. Conglomerate Lithofacies – CL,
3. Calcareous Silty Shale Lithofacies – CSSL,
4. Oolitic Limestone Lithofacies – OLls (subfacies: Golden Oolite Subfacies – GOs and Dhosa Oolite Subfacies – DOs),
5. Ripple Marked Calcareous Sandstone Shale Lithofacies – RMCSSL and
6. Greenish Grey Shale Lithofacies – GGSL,

each composed of genetically related sediments.

LIMESTONE LITHOFACIES (LL)

Badi Limestone Subfacies (BLs)

Description: This subfacies is defined on the basis of the predominance of carbonate material over the fine silty and clayey argillaceous components (Fig. 2A). It is about 19 m thick and is found to be well developed at the base of Jhurio Formation, underlain by CSSL, and exposed at the core of the Jhura dome (Pl. 1: 1). Rocks of this subfacies consist of thick, white-coloured, hard, compact limestones alternating with thin bands of shales (0.5 to 15 cm). The limestones are white, pale brown and grey, and are fine textured. The shales are greenish and grey, massive, fine textured and quartzose. Some limestones (mostly in the upper part) are oolitic with small golden ooids and some are ‘lump sparite’ containing streaks and lenticles of fine golden-oolite aggregates. This facies is fossiliferous and mainly yields the colonial coral *Lochmaeosmilia trapeziformis*? (Pandey and Fürsich, 2001: 490), bivalves (*Alectryonia*), and brachiopods (rhynchonellids). The deposits are moderately bioturbated and contain

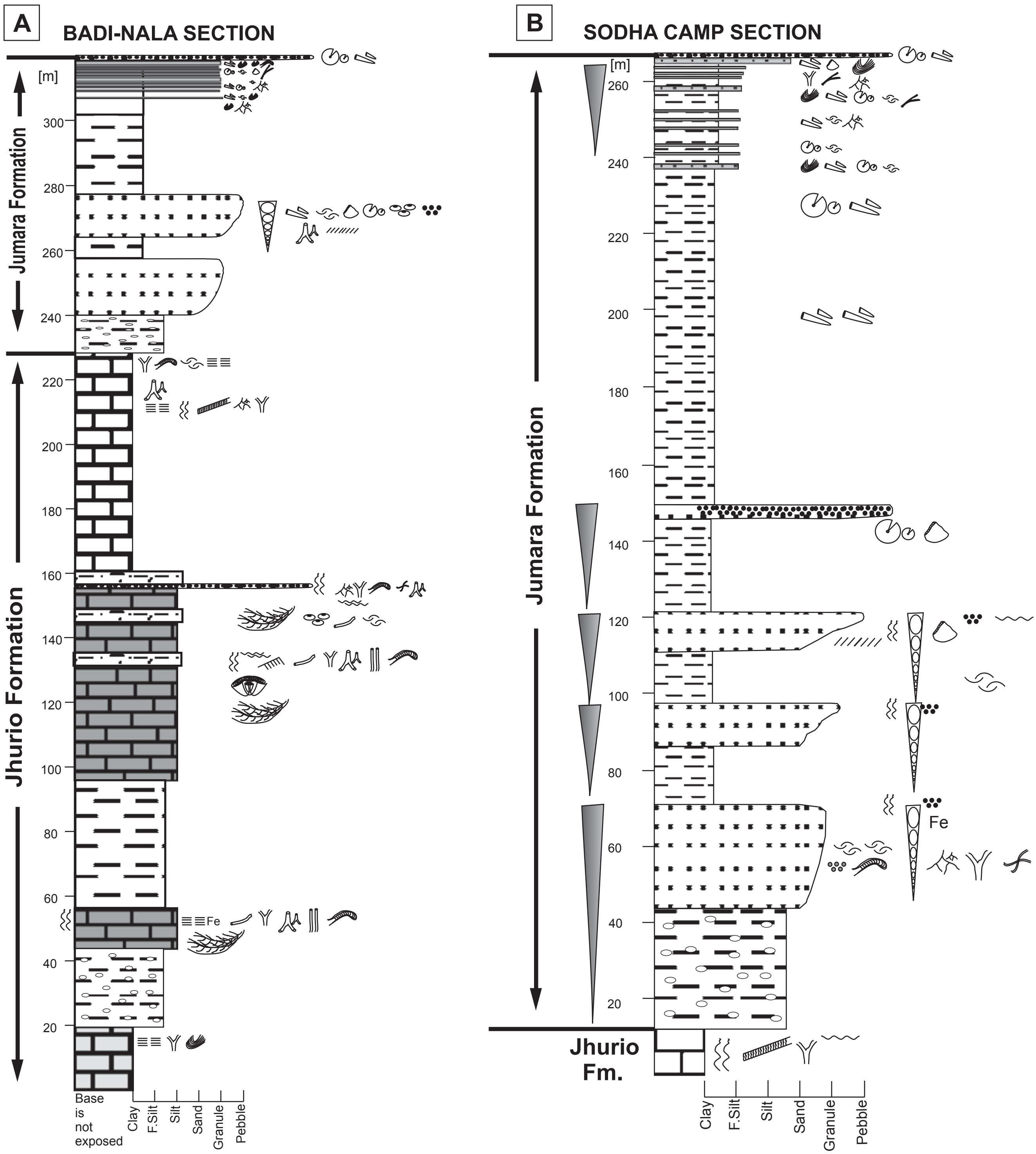
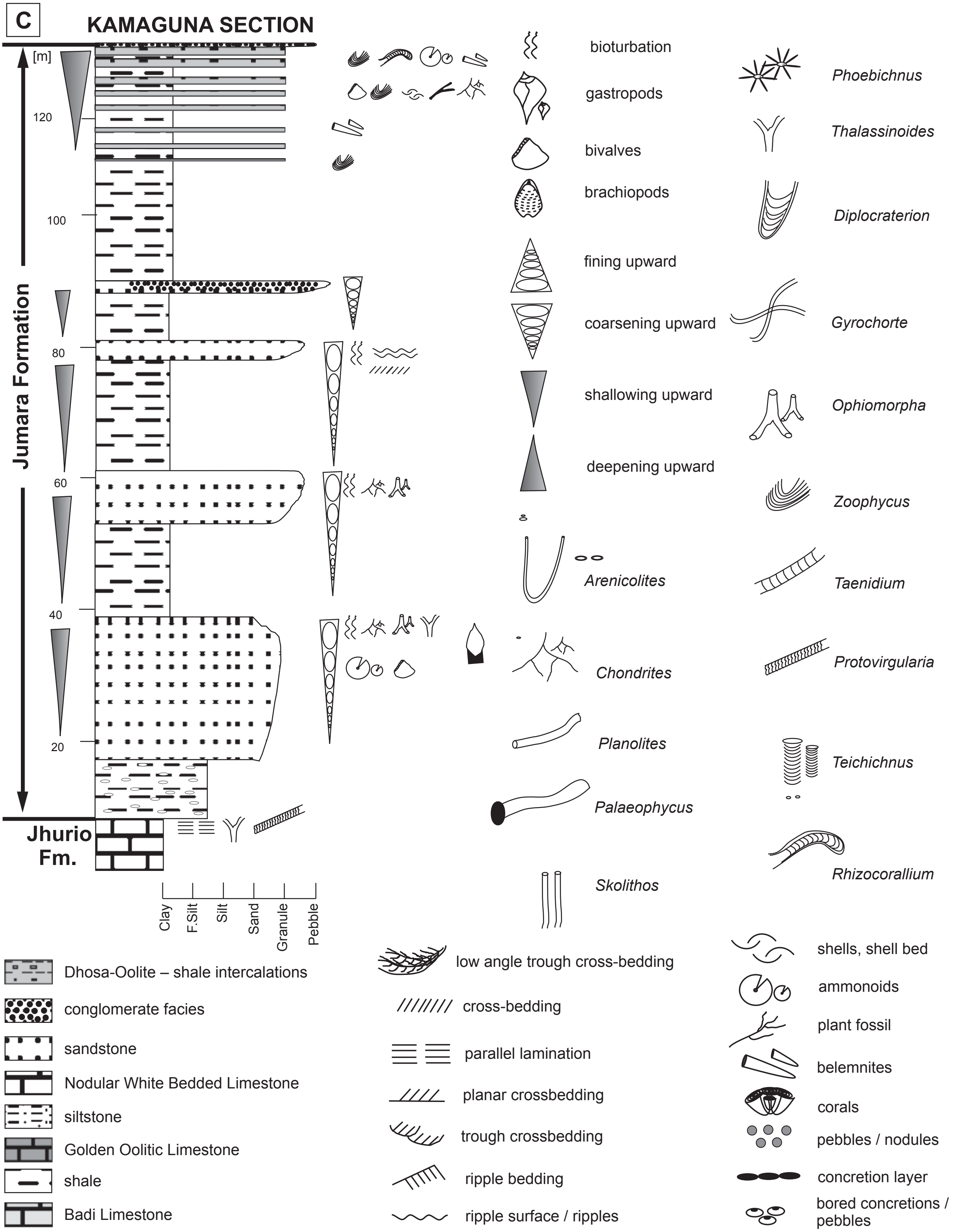


Fig. 2. Measured stratigraphic sections: (A) Badi-Nala outcrop section, (B) Sodha Camp outcrop section and (C) Kamaguna outcrop section of the Jhura Dome, Kachchh Mainland


C
KAMAGUNA SECTION
[m]
120
100
80
60
40
20
Jumara Formation
Jhurio Fm.
Clay
F.Silt
Silt
Sand
Granule
Pebble
bioturbation
gastropods
bivalves
brachiopods
fining upward
coarsening upward
shallowing upward
deepening upward
Arenicolites
Chondrites
Planolites
Palaeophycus
Skolithos
Phoebichnus
Thalassinoides
Diplocraterion
Gyrochorte
Ophiomorpha
Zoophycus
Taenidium
Protovirgularia
Teichichnus
Rhizocorallium
Dhosa-Oolite – shale intercalations
conglomerate facies
sandstone
Nodular White Bedded Limestone
siltstone
Golden Oolitic Limestone
shale
Badi Limestone
low angle trough cross-bedding
cross-bedding
parallel lamination
planar crossbedding
trough crossbedding
ripple bedding
ripple surface / ripples
shells, shell bed
ammonoids
plant fossil
belemnites
corals
pebbles / nodules
concretion layer
bored concretions / pebbles

the following trace fossils: *Zoophycos*, *Thalassinoides*, *Rhizocorallium* and *Ophiomorpha*.

The limestones contain commonly fragments of bivalve and gastropod shells (Pl. 1: 2–5), foraminiferal tests, bryozoans, echindoderm spines, intraclasts, pellets, as well as clay aggregates, and silt size detrital quartz grains (Pl. 1: 6). It has been observed that the micrite is replaced by sparite cement and there is an overall increase in fossil content, ooids, peloids and intraclasts from bottom to top. In general, the limestones are classified as intrasparite (Pl. 1: 2, 4), biosparite (Pl. 1: 3), biomicrite (Pl. 1: 5); and intramicrite (Pl. 1: 6) as defined by Folk (1962).

Interpretation: The lithology of the Formation comprises predominantly biomicrite at the base and biosparite to biointramicrite with a few peloids at the top. The lithofacies contains allochems and terrigenous materials in subordinate amounts at the bottom whereas the orthochemical grains increase in number towards the top. The lithological associations indicate offshore deposition under relatively stable conditions, occasionally influenced by storm events which have supported the preservation of large bioclasts in the middle part of the succession.

Nodular White Well Bedded Limestone Subfacies (NWWLs)

Description: This facies consists of a 65 m thick, hard and compact, well bedded and nodular limestone (Pl. 2: 1, 2) alternating with thin bands of shales at the top (Fig. 2A–C). The limestones from the upper part of the succession are white, grey and cream-coloured, well bedded, jointed and nodular in appearance. Some terrigenous matter is invariably present as thin silt and/or clay beds showing thin parallel laminations (Pl. 2: 3). These thin beds are underlain and overlain by greenish shaly partings along the smooth sharply-defined bedding planes. The lower part of the succession is represented by white to grey and brownish-grey limestone (clayey pelmicrite); this part is very distinctive for its chalky appearance and brick-like structure produced by the intersection of bedding planes and closely spaced vertical joints. This subfacies is highly fossiliferous and yields rhynchonelids, terebratulids, belemnites and crinoids as well as a few small ammonites (?macrocephalitids). This lithofacies is highly bioturbated and contains abundant trace-fossils: *Ancorichnus*, *Beaconites*, *Chondrites*, *Cochlichnus*, *Cosmorphaphe*, *Lockeia*, *Palaeophycus*, *Phoebichnus*, *Protovirgularia*, *Scolicia*, *Taenidium*, *Thalassinoides* and *Zoophycos* (also see Fürsich *et al*., 2013).

Thin-sections show the presence predominantly of peloids and bioclasts (Pl. 2: 4–9) preserved in sparite or microsparite. The size of the peloids is more or less similar, rounded to subrounded and they are closely packed; fragments of shells of bivalves, brachiopods and gastropods are present (Pl. 2: 4–9).

Interpretation: The limestones were deposited with a low influx of terrigenous sediments from the nearshore zone. The alternations of micrite and sparite indicate fluctuating low and high energy conditions, respectively; the micrites generally deposited below the average wave base and the sparites during the interventions of higher energy such as perhaps during the repeated storm cycles or tempestite (Fürsich *et al.*, 2013).

The abundance of fossils, especially benthonic forms like brachiopods, corals and annelids, together with epipelagic nektonic forms like ammonites and belemnites, indicates deposition in the lower offshore to shelf environment within the photic zone. The latter extends from the shoreline and down to 180 m depth, but the rhynchonellids do not live at depths less than 25 m (Woods, 1958). This restricts the environment of deposition within the lower offshore zone below the 25 m bathymetric level.

CONGLOMERATE LITHOFACIES (CL)

Description: The facies is observed at three different stratigraphic levels; on top of the GOs (Fig. 2A), DOs (Fig. 2A–C), and within the RMCSSL (Fig. 2B, C), with a sharp scoured base. The thickness varies from 7 to 55 cm, the maximum being in the upper part of GOs (Pl. 3: 1). The conglomerate unit within the RMCSSL (Pl. 3: 2) and above the DOs (Pl. 3: 3) has an average thickness of 45 cm. The clasts vary in size from 2.0 to 7.0 cm in diameter. On the surface of many pebbles subaqueous dehydration cracks are observed, suggesting dehydration under water at the time of diagenesis.

The lithofacies can be distinguished into two types of conglomerate: intraformational and extraformational. The former is observed above the GOs and DOs while later is observed within the RMCSSL. The intraformational conglomerates mainly contain gravel and pebble sized clasts of limestones with peloids, ooids and quartz grains, with a red, white or yellowish coloured silty micromicrite or biomicrite to ferruginous matrix. (Pl. 3: 4, 5) Large ammonites (PL. 5: 3), abundant belemnites, brachiopods and bivalves are observed in upper part of DOs. Often small sub-angular to well rounded pebbles are seen coated with golden yellow films. The extraformational conglomerate with the RMCSSL represents an oligomictic and polymictic orthoconglomerate consisting of gravel and pebble sized quartz and huge bioclasts in a mixed siliciclastic-carbonate matrix.

Interpretation: The alignment of pebbles and the absence of wave-induced structures like symmetrical wave ripples and migratory, ripple-generated cross stratification is evidence of the exhumation of concretionary pebbles under stormy conditions in the upper shoreface. The sharp contact of the facies, mostly scoured at the base, is most likely due to erosional episodes during storms (Ball, 1967; Aigner, 1985). During the storms, pebbles of micritic and ferruginous mud along with quartz and other detrital grains have been produced. The relative proportion of pebbles to bioclasts embedded in the conglomerate indicates a storm generated deposit within the RMCSSL and above the GOs, whereas a storm flow dominated deposits above the DOs. The presence of intraclasts and bioclasts (Pl. 3: 4, 5) is also characteristic of a storm-generated facies.

CALCAREOUS SILTY SHALE LITHOFACIES (CSSL)

Description: This facies occurs throughout the Jhurio and Jumara Formations (Fig. 2A–C). It attains thickness of ~40 metres in association with GOs, and at the base of the Jumara Formation it unconformably overlies the NWWLs and is a major component of the Jumara Formation. This facies consists of an association of grey to greenish calcareous, quartzose shales, khaki coloured, laminated, silty shales and laminated calcareous shales.

This facies yields only a few species of belemnite and ammonite and abundant trace fossils: *Rhizocorallium*, *Thalassinoides*, *Scolicia*, *Planolites*, *Pilichnus*, *Phycodes*, *Palaeophycus*, *Monocraterion*, *Margaritichnus*, *Laevicyclus*, *Gyrochorte*, *Diplocraterion*, *Calycraterion*, *Chondrites*, *Biformites*, *Bergaueria* and *Arenicolites*.

Interpretation: The silty shale forms the dominant rock type in the succession and occurs as alternations with the golden oolitic rocks in the lower part. Thus, the quieter conditions of shale deposits were periodically interrupted by the higher energy states. The shales were deposited by reworking of the residual clays. This facies was deposited in stable, calm, offshore conditions where terrigenous fine grained sediments input/supply were negligible.

OOLITIC LIMESTONE LITHOFACIES (OLL)

Golden Oolite Subfacies (GOs)

Description: This facies occurs in association with the CSSL of the Jhurio Formation and consists of three thick beds of golden-oolitic rocks (Fig. 2A). Two thin golden oolitic beds are also observed to be intercalated with well bedded limestone near the base of the NWWLs of the Jhurio Formation: the lower bed is hard and dull green to reddish in colour whereas the middle bed consists of a massive bed of golden-oolitic limestone with a thin bed of limestone; moreover, some upper beds represent intercalations of brown and grey coloured bedded limestones with golden oolitic beds. The middle band has a brick red colour and also shows the presence of physical sedimentary structures like current ripples; thus, it contains wave ripples (Pl. 4: 1), trough cross-laminations (Pl. 4: 2), large corals (Pl. 4: 3) and is highly bioturbated (Pl. 4: 4) at places. The lower part of each of these bands consists of reddish brown coloured pebbles of lateritized rocks and sub-angular fragments of a greenish marly rock and sub-angular to well rounded pebbles coated with golden yellow films. Microscopically, the golden-oolitic beds are sandy sparites and usually the upper and lower part of each bed contains few ooids. Beds are highly fossiliferous and show the presence of bivalve, brachiopod, gastropod, cephalopod, crinoid, bryozoan, ostracod, foraminifer and echinoderm bioclasts. The bioclasts (<20%) are crushed and well rounded, sometimes coated by a thin ooidal cortex (superficial ooids). Detrital quartz grains are rather common (up to 20%) and large (average 0.3 mm in diameter). A few oncoids/oncolites and small oolite debris are also present. Flat clay-silty pebbles, up to several millimetres in size frequently contain an admixture of quartz grains and ooids, often completely micritized.

The subfacies also contains entire, well preserved ooids; mostly ellipsoidal in shape, ranging between 0.2 and 2.0 mm in length and 0.2–0.5 mm in diameter. The nuclei of the ooids are quartz grains, peloids or bioclasts. The types of ooids observed are single ooids that are micritic (Pl. 4: 5, 9, 10) or radially-fibrous (Pl. 4: 5) in nature, and compound ooids in sparitic cement (Pl. 4: 5–8). The ooids are frequently flattened and deformed as *spastoliths*. The concentric layers of ooids were composed initially of chamosite which on oxidation gave 'the golden yellow' colour. The cement is mainly sparite; occasionally a clayey-muddy micritic matrix is preserved.

Overall, the lithofacies shows the presence of ooids (up to 60%) and oncoids (5–10%), terrigenous material, mainly sand and silt grade quartz (less than 20%) in the micritic matrix. In the process of diagenesis, the micritic matrix present at the time of deposition was converted into coarser calcite crystal grains, which interpretation is supported by the floated nature of the ooids and bioclasts.

This facies contain fossils such as oysters – *Alectryonia*, brachiopods- rhynchonellids and terebratulids, small ammonites and corals *Montlivaltia*, *Microsolena*, *Lophosmilia* (Pandey and Fürsich, 2001). The trace fossils identified are: *Arenicolites*, *Beaconites*, *Chondrites*, *Calycraterion*, *Didymaulichnus*, *Diplocraterion*, *Gordia*, *Margaritichnus*, *Monocraterion*, *Ophiomorpha*, *Palaeophycus*, *Phycodes*, *Phymatoderma*, *Pilichnus*, *Planolites*, *Rhizocorallium*, *Skolithos*, *Taenidium*, *Thalassinoides.*

Interpretation: The golden oolite beds indicate higher energy conditions when compared with the quieter conditions during deposition of the intervening shale deposits. Subsequently, the golden colour of the chamosite in the golden oolite rocks and the prevailing light colouration of the biomicrites and biosparites indicate conditions of oxidation. These suggest a shallow, open shelf environment where free circulation and aeration predominated. Moreover, highly bioturbated golden oolite rocks and the biogenic traces of mixed suspension and deposit feeders indicate the range of variation in the environment of deposition from lower-shoreface to transition zone.

Dhosa Oolite Subfacies (DOs)

Description: The Dhosa Oolite Subfacies occurs in the Dhosa Oolite Member at the top of the Jumara Formation (Pl. 5: 1, 2) and comprises a 23 m thick sequence of alternating beds of oolitic limestones and shales (Fig. 2A). The lower part of the subfacies is characterised by thick greenish grey gypsiferous shale with a few-centimetre thick, hard, non-bioturbated ferruginous/calcareous sandstone beds. The upper part consists of 0.2 to 1.5 m-thick hard, resistant, yellowish to greenish brown, oolitic beds (Pl. 5: 1, 2), whereas the uppermost bed of the oolitic limestone is represented by an intraformational conglomerate which consists of large size of boulders of oolitic limestones, ammonites (Pl. 5: 3) and belemnites (Pl. 3: 3). There are twenty-three oolitic limestone bands intercalated with shale present in the south river's flow Nala-section near village Kamaguna, south of Jhura Dome.

The facies contains varied types of lithology, which range from oolitic, bioclastic, calcareous sandstone to oolitic, micritic or sparitic limestone. The overall petrographic study reveals that the subfacies comprises fine-grained, well sorted, ferruginous, silty, intramicrudite and/or sandy micritic oolitic fossiliferous limestones, containing elongated to sub-rounded ooids (up to 70%), quartz (15–30 %) and also bioclasts up to 70% at places (Pl. 5: 4, 5, 9). Isopachous and irregular (gravitational?) rim cements around ooids and reworked micritized nuclei in the ooids are observed (Pl. 5: 6). The ooids represents the neomorphosed micritic type; the concentric type and the radially fibrous type of cortex is observed. The bioclasts are usually of a large size (typically 2 to 3 mm). The diameter of the detrital quartz varies from 0.1 to 0.15 mm. The presence of numerous well preserved ooids in a micritic matrix (Pl. 5: 6) and larger bioclasts (Pl. 5: 4, 5), as well as the presence of intraclasts of oolites, are characteristic features. Most of the intraclasts are identical to the host rocks of the succession. Additionally calcareous siltstones with microsparite cement, showing the presence of a few ooids, are recognized.

The oolitic limestone bands are highly bioturbated (Patel *et al.*, 2009) and contain abundant trace fossils, such as *Chondrites*, *Palaeophycus*, *Rhizocorallium*, *Thalassinoides*, *Gyrochorte*, and *Zoophycos.*

Interpretation: The non-bioturbated ferruginous/calcareous sandstone beds in the lower part indicate anaerobic and dysoxic conditions. This suggests an environment far away from terrigenous input in a relatively uniform offshore setting, below fair weather wave base, within the reach of singular storms. The Oolitic Limestone Subfacies is indicative of prolonged phases of omission and frequent erosive intervals leading to a very slow rate of net sedimentation. The uniform conditions and the negligible sediment input most likely reflect slow sedimentation within a transgressive phase (Singh, 1989) which persisted throughout the deposition of the facies and the subfacies. The dominance of *Zoophycos* and *Chondrites* and other feeding traces suggests generally low energy conditions within an oxygenated substrate (Patel *et al.* 2009).

RIPPLE MARKED CALCAREOUS SANDSTONE SHALE LITHOFACIES (RCMSSL)

Description: The facies is dominantly characterised by the wave ripple marks (Pl. 6: 1) on the top and the presence of cross-stratification along with abundant mega-fossils. It consists of four hard calcareous sandstone beds intercalated with shales (Fig. 2B, C). At places, two hard calcareous sandstone beds are prominent and form a cliff-like appearance called the Ridge Sandstones (Biswas, 1971, 1991; Fürsich *et al.*, 2001) which mark the periphery of the Jhura dome (Pl. 6: 2). The rocks are massive, well bedded to cross bedded, graded to inverse graded and consist of up to 3 m thick bands. The topmost bed is characterized by straight to gently sinuous ripple crests which are locally bifurcated. Locally the facies appear as conglomeratic in nature, showing a poorly graded nature as well as internal scouring and reactivation surfaces. It also contains flat pebbles of red to brown, ferruginous, argillaceous material and dirty white to yellow-coloured marl. The facies is highly bioturbated which results in the obliteration of the planar and cross-stratification; additionally it shows numerous erosional surfaces which indicate fluctuations in the sedimentation rate.

Thin section studies show that the grain size of the rock varies from fine sand to coarse and gravely sand (Pl. 6: 3–9). The sand grains are poorly to moderately sorted, and angular to sub-rounded in nature. Sand size quartz grains mainly show straight light extinction, but a small number of grains show undulose extinction. Gravelly grains show either undulose extinction or the polycrystalline nature of the rock. The rock also contains 10–15% feldspar grains of microcline, orthoclase and plagioclase (Pl. 6: 9) and at places it also shows the presence of peloids (5 to 10%) or scattered dolomitic to ankeritic crystals. A few beds contain 15 to 60% of argillaceous matrix and are also rich in fossils (Pl. 6: 4–6, 8). The overall matrix is mainly micritic but ferruginous cement also occurs in small patches or in disseminated form. The matrix composition, isolated bioclasts and high proportions of quartz grains (Pl. 6: 7, 9) indicate texturally immature micritic sandstone (Mount, 1985).

The facies is characterized by the presence of abundant bivalves (*Trigonia*, *Astarte*, and oysters) and other fossil groups such as gastropods, brachiopods, cephalopods, bryozoans, foraminifers, echinoids, algal filaments. This facies is highly bioturbated and contains abundant trace fossils which include, *Ophiomorpha*, *Thalassinoides*, *Rhizocorallium*, *Planolites*, *Pilichnus*, *Phycodes*, *Parahentzscheliana*, *Palaeophycus*, *Monocraterion*, *Margaritichnus*, *Laevicyclus*, *Gyrolithes*, *Gyrochorte*, *Gordia*, *Diplocraterion*, *Calycraterion*, *Chondrites*, *Bergaueria*, *Arenicolites*, *Ancorichnus.*

Interpretation: The cross-stratification, which is planar to trough in nature, depicts the origin of the facies by movement migration of sediment in the form of bed load. The presence of intrabasinal grains and flat pebbles suggest exhumation from the foreshore and near shoreface (Hart and Plint, 1989). The erosional and reactivation surfaces within a single bed suggest the activity of short-timed erosional events like storms. The storm generated nature of the deposit is also depicted by the presence of mega-wave ripples, the unsorted nature of the deposits (with the occurrence of smaller to larger detrital grains and bioclasts, as well as the occurrence of intraformational pebbles normally at the base), and the overall gradational nature of the deposits. The final phase within the storm deposits is characterized by symmetrical ripples which point towards oscillatory waves commonly occurring in the intertidal-subtidal zones. The upper part of facies shows less intense burrowing than the lower part (Miller, Knox, 1985). The overall facies characteristics suggest that deposition took place in a high wave and current energy environment above the fair weather wave base of the shoreface zone.

GREENISH GREY SHALE LITHOFACIES (GGSL)

Description: The Greenish Grey Shale facies (Pl. 3: 7) is characterised in part by a 20 m thick greenish brown, yellow, red and brown to black coloured shale succession, containing varying shapes and sizes of abundant gypsum crystals, and forms a part of the Jumara Formation (Fig. 2A–C). This lithofacies also includes 15 m sequence of shale with thin green glauconite and yellow limonitic layers, red ferruginous layers and a few layers of calcareous concretions with sideritic nodules. The rocks are massive to laminated, ferruginous, clayey to carbonaceous. The shale often contains silt-size quartz grains with glauconite, and fragments of plants.

Some hard siltstone layers are observed in the succession, each shale unit showing variation in thickness ranges from 0.1 to 2.0 m. Each unit shows a rapid gradational character from siltstone below, and an abrupt erosional contact above. Body fossils are represented by fragments of scattered belemnites and ammonites, leaf impressions and plant fragments also occur. Trace fossils are moderate to rare in number, which may partly result from the poor preservational potential of burrows in a fissile rock. The lithofacies grades into siltstones which in places show trough and planar cross-stratification and symmetrical to asymmetrical ripple marks on top of the beds.

Interpretation: The paucity of physical sedimentary structures and the fine grained nature of the facies suggest that the sediments were deposited in quiet water of low wave and current energy; the predominance of argillites with ferruginous layers indicate deposition in a shallow marine environment. The well-developed gypsum crystals indicate that the environment was separated from the main sea, and that precipitation has taken place in supersaturated saline environments (Bock, 1961), suggesting the overall development in a protected environment, *e.g.*, lagoon. The dark colour of the black shale and the high degree of dark mottling within the shale indicates post-depositional modification. Nodular siderite in the shale indicates brackish water or fluctuating salinity condition and moderately low pH and oxygen content (Woodland, Strenstrom, 1979). Owing to the presence of evaporite deposits, very little bioturbation and abundant leaf impressions, a lagoon to shoreface origin for the shales can be postulated.

PALAEOECOLOGICAL SIGNIFICANCE

The Jhurio and Jumara Formations of the Middle Jurassic of the Jhura Dome contain different bioturbated units of carbonates, mixed siliciclastic-carbonate and calcareous shale sediments within a ~500 m thick succession. 34 ichnogenera were identified (*cf*. Książkiewicz, 1977; Uchman, 1995; Schlirf, 2000), and their ethological category and toponomical aspects are considered in relation to ichnoassemblage, ichnoguild and ichnofacies units.

ETHOLOGY

Ethology has the advantage of grouping similar assemblages of traces/lebensspuren according to the life habits or behavioral patterns of an animal (Seilacher, 1953). The trace fossils observed in the present study area were classified into the five classical behavioral/ethological categories of Frey and Pemberton (1985). The relative abundance of the ethological category corresponding to the lithofacies is displayed in Figure 3. These structures are preserved at the sediment-sediment interface at very shallow depth (*Pilichnus*, *Planolites*), on the surface (*Rhizocorallium*) or at relatively greater depth (*Chondrites*, *Thalassinoides*). Fodinichnial structures predominate in all the lithofacies, indicating the dominance of infaunal elements over the epifaunal elements. In the calcareous silty shale lithofacies the numbers of fodinichnial and pascichnial traces are equal in number which suggest conducive conditions for the infaunal and epifaunal elements. The overall dominance of feeding structures (fodinichnia and pascichnia) as compared to other behavioural groups in all lithofacies indicates exploitation of a highly organic-rich sea floor. Further, all the facies show the moderate occurrence of dwelling burrows which indicates less diversity and abundance in animals using the suspension feeding mode. Crawling traces are present almost in all the lithofacies but are fewer in number, while resting traces are limited and observed in the BLs, NWWLs, GOs and RMCSSL. The ethological analysis of the trace fossils of the Jurassic succession of the Jhura Dome indicates that the deposit-feeding animals were abundant as compared to suspension-feeding and carnivore animals.

ICHNOASSEMBLAGES

The term ‘ichnoassemblages’ is used, in the present work, as an association of traces that can be related to one definite stratigraphic level (*i.e.* bed) or which may have been emplaced simultaneously as a single ecologically related group or which may represent several overprinted events of bioturbation (Bromley, 1996).

Protovirgularia–Lockeia assemblage

This assemblage is observed in the NWWLs and BLs of the Jhurio Formation. *Protovirgularia* (Pl. 7: 1) is the most abundant trace fossil and mainly occurs in association with *Lockeia*. *Lockeia* is the typical resting trace (cubichnia) of bivalves associated with *Protovirgularia* and *Cochlichnus*, giving a clear representation of deposit-feeding bivalves that are living in calm and stable conditions. Together with these, the feeding/dwelling traces (*Thalassinoides* and *Cosmorhaphe*), and the feeding traces (*Phoebichnus*) prove the presence of a good oxygenated environment at the time of deposition. They are mid-tier deposit feeder structures indicating good oxygenation, nutrient supply, and a comparatively low water energy level. As a whole, *Protovirgularia–Lockeia–Cochlichnus–Cosmorhaphe* represents shallow-tier and *Thalassinoides–Phoebichnus* signify to mid-tier traces.

Zoophycos–Chondrites assemblage

This is associated with the DOs of the Jumara Formation and occurs in the BLs of the Jhurio Formation. Both *Zoophycos* (Pl. 7: 2) and *Chondrites* (Pl. 7: 3) represent feeding activities at deeper tiers and the associated *Thalassinoides*, *Rhizocorallium*, *Palaeophycus* and *Gyrochorte* represent shallow-tier. It indicates the opportunist’s assemblage of the deeper tier cutting across the shallower tiers. Bromley (1996) considers that *Zoophycos* occur in low resource, inhospitable, oxygen depleted environments. These specimens most probably represent offshore carbonate platforms, where the assemblage occupying the deepest levels in the sediment constituted the depleted zone of the substrate. It has been characterized as representing oxygen- depleted sea floor. But, there may be other structures in the upper levels which could have been eroded away, leaving the *Zoophycos* assemblage alone. This postulation is based on the occurrence of *Thalassinoides*, *Rhizocorallium*, *Gyrochorte* and *Palaeophycus* at the same horizon.

In general, the trophic and behavioral characteristics of the assemblage indicate a gradient in bottom water agitation. The deposit-feeding *Rhizocorallium* and *Thalassinoides* assemblage reflects progressively lower energy conditions. On the other hand the *Chondrites* and *Zoophycos* assemblage are characterized by extremely low energy conditions, where a low rate of deposition and less erosion prevailed. Finally, the trophic diversity of the trace fossil data reflects different types of substrate conditions, varying rates of sedimentation, salinity differences and different degrees of wave agitation. Many of these factors, individually or collectively, must have been responsible for the overall distribution of the animal communities in the DOs.

Rhizocorallium–Pilichnus assemblage

Plentiful *Rhizocorallium* (Pl. 7: 4) species were observed in association with *Pilichnus* (Pl. 7: 5), *Palaeophycus*, *Diplocraterion*, *Chondrites* and *Planolites* in the clastic deposits of the CSSL of the Jhurio and Jumara Formations. All are shallow to mid-tier deposit-feeder structures. Buckman

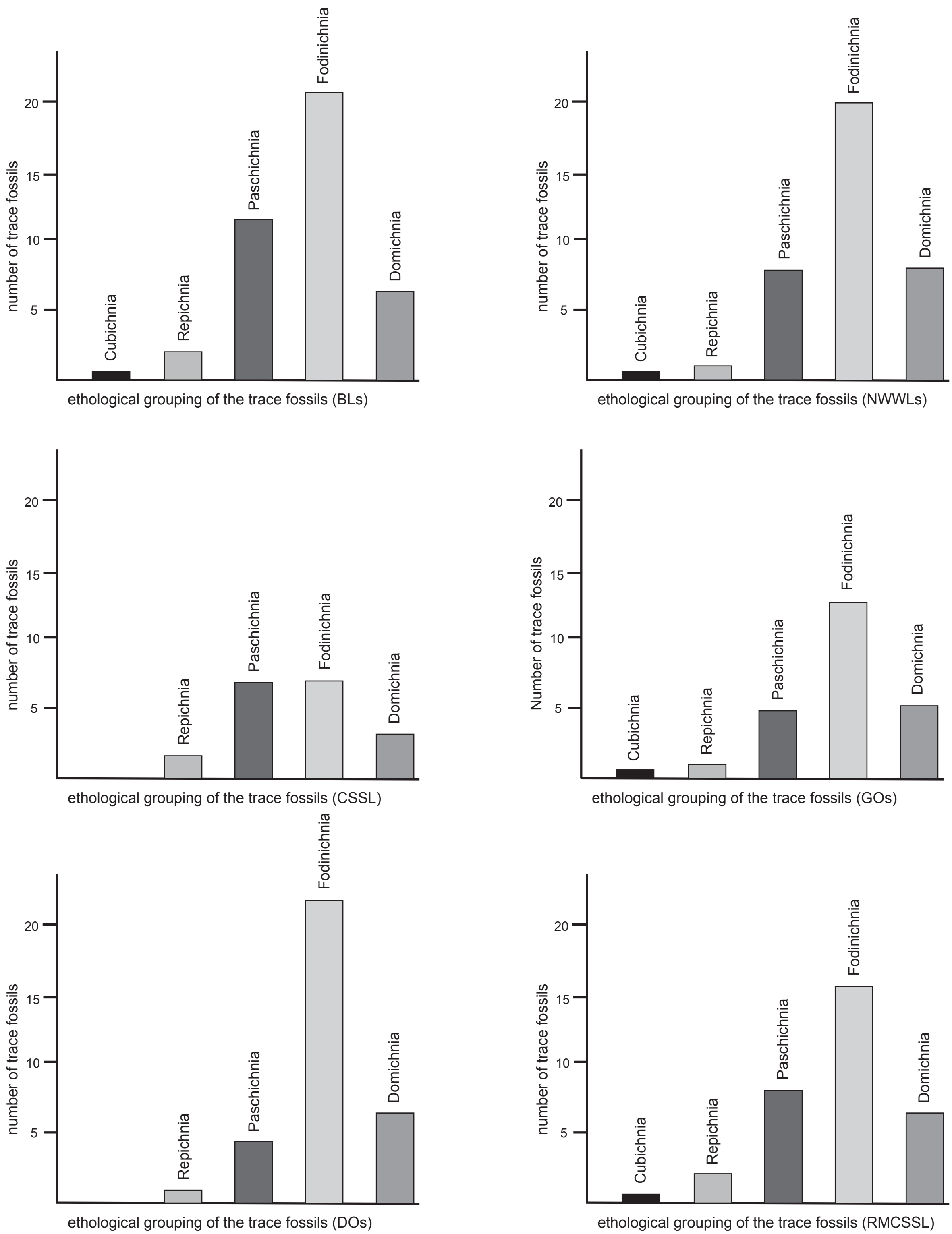


Fig. 3. Graphical representation of ethological categories showing the relative abundance of the trace fossils in different lithofacies

(1990) suggested that *Rhizocorallium* indicates shallow marine conditions and also a sediment feeding mode of life. A high degree of bioturbation in the shallow-tier specifies good oxygenated conditions with high nutrient supply at a low sedimentation rate and the presence of *Chondrites* indicate deep-tier in relatively deeper offshore environment.

Ophiomorpha–Arenicolites assemblage

The assemblage consists of stationary, deep suspension-feeder and dwelling structures at shallow- to mid-tier, is mainly associated with the GOs of the Jhurio Formation and the RMCSSL of the Jumara Formation. The assemblage is of unstable sand substrates in hydrodynamically higher energy environments (Bromley, 1996). In this setting, the high energy and frequent turbulence inhibited the biogenic activity that was reduced to a few ichnotaxa typical of shifting substrates in a high energy environment, supported by the coarse clastic nature of the GOs and RMCSSL. The low ichnodiversity and moderate density of ichnospecies suggest abundance of the opportunistic suspension feeding community. Considering the above facts it is postulated that the depositional environments varied from upper–middle shoreface under moderate to relatively high energy conditions. Such conditions normally are formed in slightly muddy to clean, well sorted, shifting sediment subjected to abrupt erosion or deposition (Pemberton *et al*., 2001).

Taenidium assemblage

This assemblage (Fig. 4) is present in the GOs (*Taenidium*, *Beaconites*, *Thalassinoides*) and NWWLs (*Thalassinoides*, *Beaconite*) of the Jhurio Formation. These show active back-filled feeding activity structures at mid- to deep- tier. The ripple marked, cross-stratificated, ooidal nature of the lithofacies along with mid- to deep-tier feeding activities indicate moderate to high energy conditions between middle shoreface to upper offshore depositional environment. This ichnoassemblge is also observed in the NWWLs, where it shows the environmental gradient and is developed in low energy offshore regimes.

Thalassinoides–Palaeophycus assemblage

This assemblage is characterized by the presence of shallow-tier, subsurface deposit feeders. It is observed in the CSSL, GOs, and RMCSSL. The occurrence of this assemblage (Fig. 4) is in a wide range of substrates. The predominant occurrence of the horizontal structures and fine grained nature of the sediments indicates low wave and current energy. Furthermore, the association with different ichnogenera at different stratigraphic levels indicates that it was formed in a variety of lower shoreface to upper offshore environmental conditions, irrespective of the normal wave base or storm wave base, but it was formed in quiet-water conditions, so that finer food particles were deposited on the sea floor.

ICHNOGUILDS

An ichnoguild is a group of ichnospecies that expresses a similar sort of behaviour, belonging to the same trophic group and occupying a similar tier or location within the substrate (Bromley, 1996). It is a term embracing species having similar feeding behavior. The characteristic ichnoassemblage thus define the guild, which is named after its characteristic ichnogenus. Bambach (1983) has defined the ichnoguild as including three major aspects of the species groups: (1) structural plan of the body (bauplan) (2) food source and (3) space utilization. Considering the space utilized by the trace producers and their mode of life, seventeen ichnoguilds are identified and described in the subsequent paragraphs. The tiers occupied by the ichnoguilds are shown in Table 2.

ARENICOLITES ICHNOGUILD

This guild has vertical U-shaped burrows, lacking spreite (*Arenicolites*, Pl. 7: 6) and occurs in the CSSL of the Jhurio Formation and the RMCSSL of the Jumara Formation; other ichnogenera such as *Skolithos*, *Diplocraterion*, *Ophiomorpha*, *Calycraterion*, *Bergaueria* (Pl. 7: 11) and *Monocraterion* are also observed. The burrows were probably made by annelids or crustaceans for permanent domicile purpose at distinct stratigraphic levels, suggesting the opportunistic behaviour of tube-dwelling suspension-feeding organisms (Dam, 1990). This is a low diversity assemblage that had adapted to a well-aerated high-energy environment where food was available in chiefly in suspension mode. This ichnoguild represents the behaviour of shallow to deep tier suspension feeding organisms in argillaceous to sandy shifting substrates of the upper shoreface environment.

CALYCRATERION ICHNOGUILD

This includes stationary, mid- to deep-tier suspension feeding structures similar to the *Arenicolites* ichnoguild. It shows a moderate diversity and is represented by the common occurrence of *Calycraterion* (Pl. 7: 9) together with *Arenicolites*, *Margaritichnus* and *Ophiomorpha.* This ichno-

Table 2

Space utilization by the organisms which produced trace fossil and their mode of life

Level of tiering/ Space utilization	Ichnoguilds	Palaeoecological comments
Surface tier	*Calycraterion* IG, *Gyrochorte* IG, *Margaritichnus* IG, *Protovirgularia* IG, *Rhizocorallium* IG	Suspension and deposit feeders. Sediment – water interface
Shallowest tier	*Chondrites* IG, *Gyrochorte* IG, *Parahentzscheliana* IG, *Planolites* IG, *Taenidium* IG, *Thalassinoides* IG	Deposit feeding animals are abundant. Dominance of feeding structures indicates good oxygen availability; nutrient supply and comparatively low energy level within sediment
Mid tier	*Arenicolites* IG: *Chondrites* IG, *Diplocraterion* IG, *Ophiomorpha* IG, *Palaeophycus* IG, *Zoophycos IG; Parahentzscheliana* IG; *Phoebichnus* IG; *Planolites* IG, *Skolithos* IG; *Taenidium* IG; *Thalassinoides* IG	
Deep tier	*Arenicolites* IG: *Chondrites* IG; *Diplocraterion* IG; *Ophiomorpha* IG; *Palaeophycus* IG; *Phoebichnus* IG; *Skolithos* IG; *Thalassinoides* IG; *Zoophycos* IG	Suspension feeders prevail over deposit feeders, high to low energy conditions; oxic or dysoxic substrate

guild, known from the RMCSSL, indicates the presence of dwelling burrows of opportunistic suspension feeders in an upper shoreface high-energy depositional setting.

CHONDRITES ICHNOGUILD

This ichnoguild consists of different ichnospecies of *Chondrites* (Pl. 7: 3) along with frequent occurrences of *Planolites*, *Palaeophycus*, *Pilichnus*, *Rhizocorallium*, *Thalassinoides* and *Zoophycos* in BLs, DOs, CSSL, RMCSSL and GOs. The ichnoguild represents branching shafts in vertical, oblique and horizontal orientations, at deep-tier, constructed by endobenthic deposit – feeding organisms of unknown taxonomic affinity, where the burrows are emplaced well below the water-sediment interface, *i.e.* found deep in the sediments. The nature of the structures indicates that the burrow was kept open by its inhabitant and had later on been filled passively by the overlying sediments. The *Chondrites* organism is considered as an opportunist and its presence indicates very low oxygen levels in the interstitial waters within the sediment at the site and time of burrow emplacement (Bromley, Ekdale, 1984; Ekdale, 1985). It thus may occur alone (Bromley, Ekdale, 1984; Vossler, Pemberton, 1988a), and its presence in different lithofacies suggests an environmental tolerance of low oxygen level, deep within the sediment. It can also be associated with other trace fossils, representing a fully marine, low energy regime, with quiet water conditions, developed in upper offshore to shelf conditions with poor water circulation and typically occurring in mud or muddy sands rich in organic matter but somewhat deficient in oxygen (Frey *et al*., 1990). Offshore sites are below storm wave base to deep water, in an area free from turbidity flows or significant bottom currents. Bromley (1996) described the ichnoguild as non-vagile, deep deposit feeder structures.

Chondrites species occur in BLs and DOs facies of the Jhurio and Jumara Formations, respectively, and appear to indicate sediments deposited in the offshore region or below storm wave base, where areas are free from significant bottom currents or turbidity flows. In case of the GOs and CSSL of the Jhurio Formation and RMCSSL of the Jumara Formation, however, it seems to occur in association with sediments deposited in the shoreface zone above the fair weather wave base, because these sediments occasionally contain cross-bedding and a variety of ripple marks including mega wave-ripples. *Chondrites* mostly occurs in fine argillaceous and calcareous silty rocks where water circulation was poor and content of carbonate cement (originally lime mud-micrite).

DIPLOCRATERION ICHNOGUILD

This ichnoguild is observed in GOs and CSSL of the Jhurio Formation and RMCSSL facies of the Jumara Formation; it is characterized by the shallow- to moderately deep-tier structures of suspension feeders. *Diplocraterion* (Pl. 7: 7) consist of two parallel tubes or two circular tubes joined by retrusive spreite on the bedding plane surface. The ichnoguild represents a community dominated by suspension feeding (domichnia) organisms, which inhabited calcareous, ferruginous, and arenaceous substrates during the deposition of the RMCSSL facies of the Jumara Formation, and the GOs and CSSL of the Jhurio Formation. Physical reworking appears to be frequent, as indicated by the presence of erosional surfaces in horizons of RMCSSL. The monodominant nature and moderate occurrence of *Diplocraterion* suggest the presence of opportunistic ichnotaxa. The depositional features (sedimentary structures, erosional and reactivation surfaces) indicate that the burrows were produced over a short period of time and also that the depositional environment was inhospitable to most life forms due to the high rate of sedimentation and shifting substrate. Considering the above facts it is postulated that the depositional environments varied from upper shoreface to lower shoreface under moderate to relatively high energy conditions.

GYROCHORTE ICHNOGUILD

This ichnoguild is characterized by the dominance of horizontal, crawling and feeding structures, such as *Gyrochorte* and *Planolites*, *Palaeophycus* and *Thalassinoides*, respectively. It is also characterized by the presence of shallow- to mid-tiers of deposit feeders, observed in DOs and the upper part of the RMCSSL facies of the Jumara Formation. The guild generally shows a high degree of bioturbation indicating relatively slow sedimentation and little physical reworking. The very good preservation of crawling trails, mostly in the form of epirelief and intrastratal preservation suggests low energy conditions, with a moderate rate of sedimentation. The guild occurs in the lower shoreface, below daily wave base but not storm wave base, in somewhat quieter conditions. From a taphonomic viewpoint, this situation profoundly increases the preservational potential of the guild. It normally occurs in well sorted sands which are moderate to intensely bioturbated and depicts a rather slow rate of sedimentation.

MARGARITICHNUS ICHNOGUILD

The *Margaritichnus* (Pl. 7: 10i) ichnoguild is a domichnia of a soft-bodied organism. The burrow is vertically plugged, slightly inclined to the bedding, and shows high density. These represent shallow- to mid-tier, mainly associated with *Thalassinoides*, *Laevicyclus* and *Skolithos* in CSSL of the Jhurio Formation. It normally occurs in silty shale and corresponds to relatively moderate energy of the lower shoreface environment.

OPHIOMORPHA ICHNOGUILD

The suspension feeding-dwelling structure *Ophiomorpha* (Pl. 7: 8) ichnoguild was observed in the BLs, NWWLs, GOs of the Jhurio Formation and the RMCSSL of the Jumara Formation. This ichnoguild is characterized by stationary, deep-tier, suspension feeder structures of mobile, opportunistic organisms, exploring the substrate for dwelling purposes. Moreover, its presence shows that sedimentation was periodic, causing a successive upward extension of shafts. This is an ichnoguild of unstable sandy and oolitic substrate in hydrodynamically energetic environments. The ichnotaxa represented are *Arenicolites*, *Skolithos*, *Calycraterion*, *Parahentzscheliana*, *Margaritichnus* and *Monocraterion*. This ichnoguild is characteristically found occurring in the coarse to medium grained sandstones of the RMCSSL, GOs and BLs facies.

The density of *Ophiomorpha* burrows varies in different lithofacies, but the maximum population can be observed in RMCSSL and GOs, present in mostly clean sand but also in muddy sand, indicating moderate to instantaneously high sediment influx. A low rate of reworking seems to be a precondition for the construction of the structures, since the delicate clay-ball lined walls in *Ophiomorpha* are wholly preserved. On the other hand, the regular nature of the tube swellings along certain bedding planes reveals that these were brought about by some events affecting all the burrowing individuals at the same time. It is considered that this ichnoguild, of unstable sandy, oolitic substrates (RMCSSL and GOs) in foreshore to upper shoreface hydrodynamically energetic environments, is mainly found in the form of shafts (Bromley, 1996). The occurrence of *Ophiomorpha* alone in amalgamated sandstone beds of RMCSSL of Jumara Formation indicates physically unstable high storm frequency conditions which favour opportunistic behaviour (Frey *at el*., 1978; Rhoads *et al*., 1985; Vossler, Pemberton, 1988b).

PALAEOPHYCUS ICHNOGUILD

This ichnoguild is characterized by the presence of shallow-tier, subsurface deposit feeders. It has been observed in the GOs, DOs, RMCSSL, CSSL and BLs facies. This ichnoguild is represented by different species of *Palaeophycus* (Pl. 8: 1) and other forms which include *Anchorichnus*, *Chondrites*, *Cochlichnus*, *Phycodes* (Pl. 8: 2), *Phymatoderma* (Pl. 8: 3), *Pilichnus*, *Rhizocorallium*, *Taenidium*, *Thalassinoides*, and *Planolites*.

This ichnoguild is characterized by a palaeo-community of mobile, shallow to mid-tier, subsurface deposit feeders and occurs in wide range of substrates. The range of species diversity of this ichnoguild has been interpreted as being produced by the complex behaviour of deposit feeders seeking food as well as shelters. It is mainly associated with horizontal structures and the fine grained nature of the sediments. It indicates low wave and current energy. Furthermore, the association of shallow water marine environments with the different ichnogenera at different stratigraphic levels indicates that it is formed in quiet water in upper shoreface to offshore environmental conditions, irrespective of the normal wave base or storm wave base, so that finer food particles were deposited on the sea floor.

PARAHENTZSCHELIANA ICHNOGUILD

The *Parahentzscheliana* (Pl. 8: 4) ichnoguild is characterized by the presence of mid- to deep-tier, subsurface, deposit/suspension feeders, and is observed in the RMCSSL of the Jumara Formation, and is also observed in association with *Arenicolites*, *Skolithos*, *Calycraterion*, *Margaritichnus*, *Monocraterion* and *Ophiomorpha*. The radiating inclined burrows originating from vertical to oblique central shafts indicate that the structures were made in a shifting substrate. It is considered to be the ichnoguild of unstable sandy substrates of RMCSSL in moderately energetic environments. The presence of such structures in sandy facies indicates high energy conditions with a moderate to high rate of sedimentation, with an unstable sea floor, signifying an upper shoreface to middle shoreface environmental setting.

PHOEBICHNUS ICHNOGUILD

This ichnoguild is characterized by the complex burrow *Phoebichnus* associated with *Protovirgularia*, *Lockeia*, *Cochlichnus*, *Thalassinoides*, etc. found to occur in moderate density in NWWLs of the Jhurio Formation. This fodinichnia trace was produced by an infaunal deposit feeder, systematically mining the sediment for food in one particular place (Bromley, Asgaard, 1972). This ichnoguild generally shows a moderate degree of bioturbation indicating slow rate of sedimentation and physical reworking. The occurrence of an exclusively deposit feeding organism is indicative of a very quiet environment in which organic materials were deposited (Heinberg, Birkelund, 1984). This stationary fodinichnia guild probably exemplifies an oxygen-limited environment that was exploited thoroughly by a population of opportunistic organisms (Ekdale, Mason, 1988).

PLANOLITES ICHNOGUILD

This ichnoguild embraces different species of *Planolites* (Pl. 8: 5) representing deposit feeding activity at shallow- to mid-tier. The traces were produced by in-faunal organisms combining the activity of deposit-feeding and locomotion, thus producing endostratal pascichnia burrows (Dam, 1990). They occur in most of the lithofacies *i.e*. BLs, GOs and CSSL facies of the Jhurio, and DOs and RMCSSL facies of the Jumara Formations. The low diversity in the BLs facies suggests a limitation of oxygen and nutrient supply within the sediment (Ekdale, Mason, 1988). The wide range of occurrence in different lithofacies and the association with shallow marine ichnogenera like *Palaeophycus*, *Pilichnus*, *Thalassinoides*, *Rhizocorallium*, *Ophiomorpha* and *Taenidium* suggest a wide range of environmental conditions from middle shoreface to lower offshore.

PROTOVIRGULARIA ICHNOGUILD

This ichnoguild is observed only in NWWLs of the Jhurio Formation and chiefly consists of infaunal traces of a keel-like trail – *Protovirgularia* (Pl. 7: 1) with associated resting structures – *Lockeia*, and feeding structures – *Phoebichnus* and *Thalassinoides*. *Cochlichnus* and *Palaeophycus* are in low abundance. It contains semi-vagile to vagile, surface-tier deposit feeder structures found in interbedded successions of shale and limestone. This indicates extremely quiet water condition with little physical reworking, where organic matter was being deposited along with the sediment. The sedimentary characteristics and ichnological parameters suggest that these beds were formed in an offshore environment well below storm wave base.

RHIZOCORALLIUM ICHNOGUILD

The ichnoguild characteristically consists of abundant species of *Rhizocorallium* (Pl. 7: 4). This has been observed in CSSL of the Jumara Formation. It also occurs in BLs and GOs of the Jhurio Formation and RMCSSL and DOs of the Jumara Formation. It is characterized by horizontal to oblique U-burrows with active back-filled surface-feeding spreiten structures. The other shallow-tier feeding structures also observed include *Palaeophycus*, *Pilichnus*, *Planolites* and *Thalassinoides*. Most elements of this association are shallow burrowing deposit feeders, found in the thinly bedded calcareous silty shale/limestone of the Jhurio Formation. Wherever the *Rhizocorallium* ichnoguild is observed in CSSL, the sediments are fine grained and do not exhibit any sedimentary structures, which indicates a very low rate of deposition. The *Rhizocorallium* traces studied here indicate marine conditions and also possibly a sediment feeding mode of life in the well lit, clear water, photic zone of the lower shoreface to offshore.

SKOLITHOS ICHNOGUILD

This includes stationary, shallow- and mid-tier suspension feeding structures primarily consisting of *Skolithos*

(Pl. 8: 6) with other characteristic elements including mainly dwelling burrows observed in the GOs facies of the Jhurio Formation and the RMCSSL and DOs facies of the Jumara Formation. The *Skolithos* ichnoguild chiefly represents suspension feeding organisms living in a high energy hydrodynamic setting with shifting substrate, subject to abrupt erosion and deposition (Bromley, 1996). According to Vosslar and Pemberton (1988b), the opportunistic ichnotaxa are commonly heavily dominated by *Skolithos linearis*, and generally indicate high energy levels of the beach, foreshore and shoreface settings (Frey *et al*., 1990).

According to Bromley (1996), the slow moving suspension feeders that inhabited the shifting sand environment sought security through burrowing deeply and remaining stationary for longer periods, and have a good chance of preservation. In rapidly accreting sands such as migrating sand waves or ripples, there may be no erosional loss of the upper parts, yet the ichnological result is the same – low density *Skolithos* assemblages. Thus, the opportunistic vertical burrows of the *Skolithos* ichnoguild appear as being the shallow- to mid-tier structures of suspension feeders indicating unstable sandy (RMCSSL) and oolitic (GOs and DOs) substrates in the hydrodynamically energetic environments of shoreface and upper offshore environments, respectively.

TAENIDIUM ICHNOGUILD

These straight or sinuous, dominantly horizontal, meniscate backfilled burrows occur as shallow- to mid-tier, crawling-feeding structures and consist of various ichnospecies of *Taenidium* (Pl. 8: 7). The ichnoguild shows moderate diversity and density. It is associated with *Planolites*, *Palaeophycus*, *Protovirgularia*, *Phoebichnus* and *Chondrites* in the NWWLs and GOs facies of the Jhurio Formation. The occurrence of *Taenidium cameronensis* and *T. serpentinum* in the GOs facies indicates that it was restricted to the shelf during Jurassic times (Keighley, Pickerill, 1994), but other sedimentary features like cross-stratification, mega-ripples and ooidal facies indicate the relatively energetic environment of the protected lower shoreface to upper offshore zone where both types of the food particles (deposit and suspension) were available.

THALASSINOIDES ICHNOGUILD

The *Thalassinoides* (Pl. 8: 8) ichnoguild contains Y- and T- shaped, unlined burrows with passive fill, and comprises dwelling and feeding structures produced by decapod crustaceans. It is widely distributed stratigraphically and observed in the BLs, NWWLs, CSSL, GOs and DOs facies. This ichnoguild is commonly in association with active and passive back-filled horizontal feeding structures, which include *Ancorichnus*, *Taenidium*, *Phycodes*, *Rhizocorallium*, *Planolites*, *Palaeophycus*, *Pilichnus*, *Protovirgularia*, *Lockeia*, *Cochlichnus* and *Chondrites*. Bromley (1996) considered it as semivagile and vagile, middle level deposit feeder structures which are intermediate to equilibrium or climax trace fossils, present in oxygenated situations. It has been observed also in thick sandstones, but in low density. The large, semi-permanent, mainly horizontal tunnel systems-exhibiting exclusively deposit feeding traces and their very low diversity is indicative of extremely quiet water conditions with little reworking where organic matter was being deposited along with the sediments. This guild probably represents the lowest energy levels (Fürsich, Heinburg, 1983). It is usually found in interbedded limestones-shales deposited in quieter conditions of middle shoreface to lower offshore settings.

ZOOPHYCOS ICHNOGUILD

This ichnoguild (Pl. 7: 2) is observed in the BLs and DOs facies of the Jhurio and Jumara Formations, respectively, in association with *Chondrites*, *Rhizocorallium*, *Thalassinoides*, *Taenidium*, *Skolithos*, *Ophiomorpha*, *Gyrochorte* and *Palaeophycus* etc. *Zoophycos* mainly consists of ‘U’ and ‘J’ shaped structures which are efficiently executed feeding traces, with spreiten typically planar to gently inclined, distributed in delicate sheets, ribbons or spirals.

Bromley (1996) considers *Zoophycos* as an opportunistic trace, which can appear together with *Chondrites* in the opportunistic situation of low resource, inhospitable, oxygen depleted environments. The *Zoophycos* of the DOs is characterized by horizontal lobate structures that indicate low to moderate energy conditions in shallow water marine environments. However, the abundance of *Zoophycos* in the oolitic limestone bands indicates a well aerated zone which is thoroughly bioturbated by infaunal elements. This postulation is based on the co-occurrence of abundance traces of shallow- to deep-tier structures such as *Thalassinoides*, *Phycodes* and *Palaeophycus* at the same horizon.

In general, the trophic and behavioural characteristics of the guild indicate a gradient in bottom water agitation. The suspension feeding *Skolithos* ichnospecies represents the highest energy level, and the deposit feeding *Chondrites*, *Rhizocorallium*, *Thalassinoides*, *Palaeophycus*, *Planolites* reflect progressively lower energy conditions, where slow deposition and less erosion prevailed. Finally, the trophic diversity of the trace fossil data reflects different types of substrate conditions, oxygen availability, nutrient supply, varying rates of sedimentation, salinity differences and different degrees of wave agitation. Many of these factors, individually or collectively, must have been responsible for the overall distribution of the animal communities in the sedimentary units of DOs. *Zoophycos* species have an extremely broad bathymetric range and depositional gradient and may vary from one part of the stratigraphic column to the next (Pemberton *et al.*, 2001). They are usually reported at greater depths in Mesozoic and Cenozoic deposits as compared to Paleozoic deposits (Frey, Pemberton, 1984). The presence of the other ichnospecies with this ichnoguild indicates upper offshore, quiet water conditions, with poor water circulation, typified by nearly thixotropic muds or muddy sands rich in organic matter but somewhat deficient in oxygen.

ICHNOFACIES

Seilacher (1964, 1967) introduced the term ichnofacies for recurring associations of trace fossils through the Phanerozoic on a global scale, and recognized six ichnofacies, Skolithos, Cruziana, Zoophycos, Nereites, Glossifungites and Scoyenia, related to sedimentary facies and depositional environmental conditions like bathymetry, salinity, substrate consistency, food supply, oxygen level and temperature. Frey and Pemberton (1984) argued that this idealized ichnofacies succession works well in most ‘normal’ situations. MacEachern *et al.* (2007) considered the deposition system to be a complex interaction of numerous physical, biological, and chemical processes; and ichnofacies to be reflecting specific combinations of organisms responses to these environmental conditions. Today, these ichnofacies remain valuable in environmental reconstructions, but paleobathymetry is only one aspect of the modern ichnofacies concept (Frey *et al*., 1990). The distribution pattern of trace fossils in the Jhura Dome exhibits a clear relationship to the hydrodynamic conditions, and secondarily, to bathymetry, and follows the classic ichnofacies concept of Seilacher (1967) and Bromley (1996) exhibiting three ichnofacies (i) Skolithos, (ii) Cruziana, and (iii) Zoophycos.

SKOLITHOS ICHNOFACIES

This ichnofacies is indicative of relatively high levels of wave and current energy and is typically developed in clean, well-sorted, loose or shifting particulate substrates (Seilacher, 1964; Pemberton *et al*., 2001). Abrupt changes in rates of deposition, erosion and physical reworking of sediments are frequent. Such conditions commonly occur on the foreshore (bar) and upper shoreface environments (Fig. 4) The associated energy levels are represented by fine, parallel to sub-parallel, gently seaward-dipping sedimentary laminae, with large and small scale trough cross beds. The most common ichnogenera of such conditions especially include *Skolithos* and *Ophiomorpha* with *Parahaentzscheliana*, *Arenicolites*, *Diplocraterion*, *Monocraterion* and *Rhizocorallium* with resting traces.

The Skolithos ichnofacies is very well developed in RMCSSL of the Jumara Formation and moderately developed in GOs of the Jhurio Formation and consists of the different trace fossil genera in varying proportions. Wave ripples in GOs and RMCSSL and large size cross-bedding in RMCSSL indicate high wave and current energy in the shallow marine environment, above the fair weather wave base. Mostly suspension feeding animals were abundant and they constructed deeply penetrating, more or less permanent domicile structures, like *Ophiomorpha* and *Skolithos* and the unusual large burrow systems of *Thalassinoides*. The conglomeratic nature and high fossil content towards the top of RMCSSL suggests storm events and the subsequent rapid transgression giving intercalated siltstones. The GOs shows mega-ripple surfaces, low angle cross and trough stratification, and graded bedding, with abundant *Skolithos* and *Ophiomorpha*, *which* indicates upper shoreface to lower shoreface environments. The presence of vertical and U-shaped burrows indicates high energy conditions and an unconsolidated shifting sandy substrate located in the shoreface zone. The Skolithos ichnofacies also appears in the slightly to substantially deeper water deposits like NWWLs, where energy levels, food supplies and hydrographical and substrate characteristic were suitable.

CRUZIANA ICHNOFACIES

The Cruziana ichnofacies is typically associated with poorly sorted, unconsolidated marine substrates lying below fair weather wave base and above storm weather wave base in the middle-lower shoreface to offshore (littoral to sublittoral) depositional environment (Pemberton *et al*., 2001). The ichnofacies is typically associated with vertical, inclined and horizontal structures. The traces have high diversity and abundance; mostly feeding and grazing structures constructed by deposit feeders, except where crawling traces are predominant constructed by mobile organisms.

This ichnofacies is observed in the storm-influenced ramp and also represents the classical gradation from *Skolithos* to *Cruziana* in many different types of substrates as indicated either by a change in hydrodynamic conditions, depositional dip or bathymetry in the basin (Fürsich, 1974a, b; Frey, Howard, 1985). This ichnofacies consists of abundant horizontal structures which recur in all facies BLs, NWWLs, CSSL, GOs and DOs of the Jhura Dome succession indicating favourable conditions for its development. The diversity of the trace fossils is appreciable, but the population density differs in different lithofacies. However, mixed *Skolithos–Cruziana* associations do occur at various stratigraphic levels. They consist mainly of *Rhizocorallium*, *Chondrites*, *Beaconites*, *Gordia*, *Didymaulichnus*, *Megagrapton*, *Phymatoderma*, *Phycodes*, *Planolites*, *Palaeophycus*, *Pilichnus*, *Protovirgularia*, *Thalassinoides*, *Taenidium* and *Zoophycos*. The BLs, CSSL, GOs and NWWLs of the Jhurio Formation have shown a well developed Cruziana ichnofacies, while to some extent the RMCSSL and DOs also contain a development of such an ichnofacies along with the Skolithos ichnofacies. The most conspicuous trace fossil *Zoophycos* occurs abundantly in the DOs of the Jumara Formation and shows a wide range of variation in morphological features and dimensions (Patel *et al*., 2009).

The abundance of horizontal structures in the Cruziana ichnofacies indicates a low energy environment of deposition on an unconsolidated substrate and the repeated appearance of the Skolithos ichnofacies in the stratigraphic record indicates either shallowing of the basin or high energy conditions, as found in subtidal zones above storm wave base. A change in energy levels and allied parameters during the deposition of RMCSSL, with the temporary excursion of *Skolithos*–type conditions into a *Cruziana* –type setting, is also seen. This indicates poorly sorted sediments and typically forms in either moderate energy condition in shallow water below the fair weather wave base and above storm wave base, to low energy levels in the deeper, quiet water.

In the DOs, a sudden change in environmental conditions is noticed when a temporary incursion of large sized and morphologically conspicuous burrows of the *Zoophycos* species appeared and sedimentation changed into a *Cruziana* type setting. The overall bedding style association is a *Cruziana* type and consists of abundant burrows of *Thalassinoides*, *Phycodes*, *Planolites*, *Palaeophycus*, *Rhizocorallium* and *Taenidium*¸ which are the members of the Cruziana ichnofacies (Patel *et al.*, 2009).

Overall, the lithofacies of the Jhura Dome area consists of poorly sorted, fine grained sediments indicating low to moderate energy conditions and contains both suspended and deposited food components. The grazing, feeding and dwelling activities of the animals characteristically indicates both suspension and deposit feeders. Mobile carnivores and scavengers were also abundant. Because of the lowered energy and abrupt shifts in temperature and salinity, burrow structures tend to be constructed horizontally rather than vertically (Pemberton *et al*., 2001) in the different facies of the Jhura Dome sequence.

ZOOPHYCOS ICHNOFACIES

The Zoophycos ichnofacies represents the circa-littoral to bathyal, quiet-water conditions, more or less deficient in oxygen (Frey, Seilacher, 1980; Frey, Pemberton, 1985; Pemberton *et al.*, 2001). Rocks of the Zoophycos ichnofacies usually show total bioturbation. The quiet accumulation of mud allows climax communities to develop, spread over many levels, the *Zoophycos-Chondrites* ichnoguild occupying the deepest tier (Bromley, 1996). The ichnogenus *Zoophycos* may also be abundant in the Cruziana and Nereites ichnofacies under normal oxygen levels. In popular bathymetric schemes (Frey, Pemberton, 1985; Pemberton *et al*., 2001), the Zoophycos ichnofacies typically represents an intermediary between the Cruziana and Nereites ichnofacies. The Zoophycos ichnofacies is interpreted as relatively simple to moderately complex, containing efficiently executed grazing traces and shallow feeding structures (Walker, James, 1992; Pemberton, MacEachern, 1995).

The Zoophycos ichnofacies occurs in the BLs of the Jhurio Formation and is characterized by two species of *Zoophycos* with isolated occurrences of such traces as *Thalassinoides* and *Rhizocorallium*. The fine grained nature of the sediments and presence of the *Zoophycos* association indicates thixotropic conditions, low oxygen content and low nutrient supply. The sudden appearance of elements of the *Cruziana* association indicates a change in environmental condition from lower offshore to upper offshore conditions during the deposition of sediments of the BLs.

The upper and lower surfaces of the oolitic limestone beds of DOs are intensely bioturbated and contain a number of trace fossils. A variety of large sized *Zoophycos* species are observed in three to five oolitic limestone beds, with moderately diverse and fairly abundant species of the Cruziana ichnofacies (Patel *et al*., 2009). Most species of *Zoophycos* are lobe-shaped. The large size of the structure and their abundance indicates aerobic conditions, organic rich sediments and calm conditions below storm wave base. The sediments are thoroughly bioturbated by the *Zoophycos* producer and their dominance is to be considered as largely a preservational artifact (Patel *et al.*, 2009) in *Cruziana* ichnofacies type conditions.

ICHNO-SEDIMENTOLOGICAL MODEL

The sedimentological and ichnological data are synthesized in the 3-D ichno-sedimentological model (Fig. 4) that shows the variation of carbonate and siliciclastic facies in seven depositional regimes: 1) shelfal below storm wave base, 2) lower offshore to shelf, 3) upper offshore to lower offshore, 4) upper offshore, 5) transition to lower shoreface, 6) lower shoreface above fair weather wave base and 7) lower shoreface to middle shoreface. The significant variation in composition of the carbonate rocks, which consist of micrites and/or, sparites, with various kinds of bioclasts, ooids,

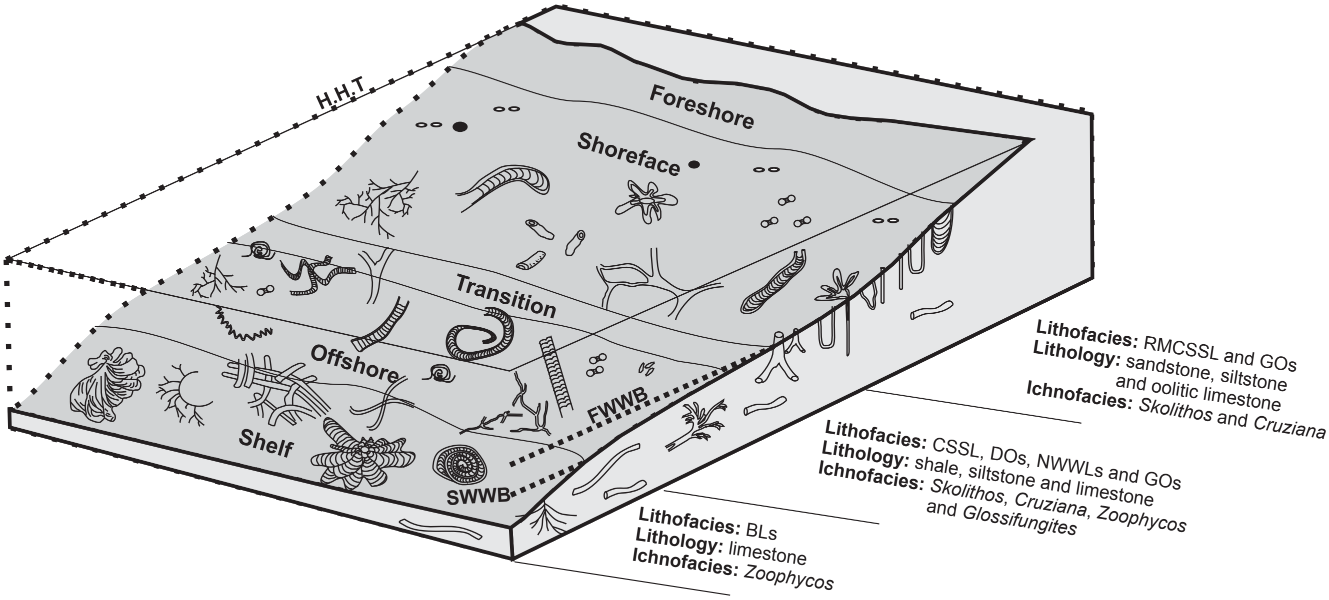


Fig. 4. A schematic three dimensional model of depositional environments showing distribution of trace fossils in recognized lithofacies and corresponding ichnofacies

and other physical parameters, reflects fluctuation in the depositional regime characterized by complex ecological conditions reflecting the diversity in biogenic structures. The Jurassic depositional phase is marked by transgressive and regressive episodes including storm generated events, controlled by eustatic sea level changes, regional tectonic movements, and physiographic and biologic responses.

The Jhurio Formation mainly comprises carbonate facies sediments deposited in the relatively stable conditions of shallow shelf settings during a gradual transgression of the sea. The presence of the BLs, GOs, and NWWLs facies, and CSSL, marked the transgressive and regressive phases respectively, frequently interrupted by waves, storms and calm conditions. The shallow shelf sedimentation is responsible for development of the intercalated sequence of bedded limestone and calcareous siltstones. On the other hand, lower shoreface to offshore sedimentation has been inferred for the development of the cross-bedded golden oolitic limestone with its mega-wave rippled surface and intrabasinal conglomerate. This episode is characterized by typical body (coral) and trace fossils (Fig. 4).

Lower shoreface to offshore conditions continued during the deposition of the lower Jumara Formation and the basin was filled by the intercalated finer mixed clastic and nonclastic sediments. The basin was, in all possibilities, shallowing and the finer clastic sequence was gradually being shifted towards a coarser clastic sequence to form either barriers or blanket sand bodies. This shoreface sedimentation was such that it developed quick intercalations of shales, siltstones and sandstones, with or without ripple marks. In the shoreface environment, as pointed earlier, mixed siliciclastic-carbonate rocks dominated, characterized by the lateral extension of individual beds with more or less uniform thickness, and showing massive to horizontal stratification with cross bedding structures. Calm conditions in the shoreface environments were distinguished by intercalations of siltstones/shales in the RMCSSL, GGSL and the lower part of the DOs. The fluctuating supply of argillaceous and arenaceous sediment has been recorded in the quick alternations within the RMCSSL facies in a shoreface environment. The sedimentary structures often indicate a wave dominated environment (shoreline conditions), while the trace fossil associations suggest high energy conditions.

The beds of DOs shows much less terrigenous sediment supply and the generation of basinal authigenic sediments and the development of the *Cruziana* ichnofacies in transition-offshore conditions have resulted in production of a deepening upward oolitic limestone sequence. The topmost facies, the DOs of the Jumara Formation, comprises a thin intraformational conglomerate with abundant large ammonites, belemnites and the rare occurrence of reworked pebbles or slabs of limestone (Alberti *et al*., 2013), indicating high wave and current energy conditions. The sedimentological and ichnological characteristics of the Jurassic succession of the Jhura Dome indicate the finer deposition settings in the shallow marine environments (Fig. 4).

CONCLUSIONS

Palaeoecological analysis of the trace fossils of the Jurassic of the Jhura Dome succession has revealed fluctuation of wave and current energy, substrate consistency, rate of sedimentation, mode of food supply, feeding diversity, level of feeding, and bathymetry during the deposition of the different facies.

Jhura Dome succession shows a marked diversity and density of ichnotaxa which was controlled by the changing environmental conditions. Six ichnoassemblages were distinguished on the basis of their occurrence and association in particular horizons.

Seventeen ichnoguilds are recognized based on similar feeding behaviour and occupancy in the substrate.

Three Seilacherian ichnofacies have been identified: Skolithos; Cruziana and Zoophycos.

The sedimentological and ichnological analysis of the Jurassic succession of the Jhura Dome indicates a wide range of environmental settings for the deposition of the sediments. The palaeoecological information of the Jurassic sediments of the Jhura Dome of the Mainland Kachchh, western India has revealed seven distinctive depositional settings: shelfal below storm wave base, lower offshore to shelf, upper offshore to lower offshore, transition to lower shoreface, lower shoreface above fair weather wave base, lower shoreface to middle shoreface and upper offshore.

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Plates

PLATE 1

Limestone Lithofacies: Badi Limestone Subfacies

Fig. 1. Bedded limestone exposed at the core of the Jhura dome

Fig. 2–4. Abundant bioclasts of bivalves and foraminifers

Fig. 5. Oriented bioclasts with fine to medium grained quartz

Fig. 6. Carbonate matrix with poorly sorted quartz grains and bioclasts

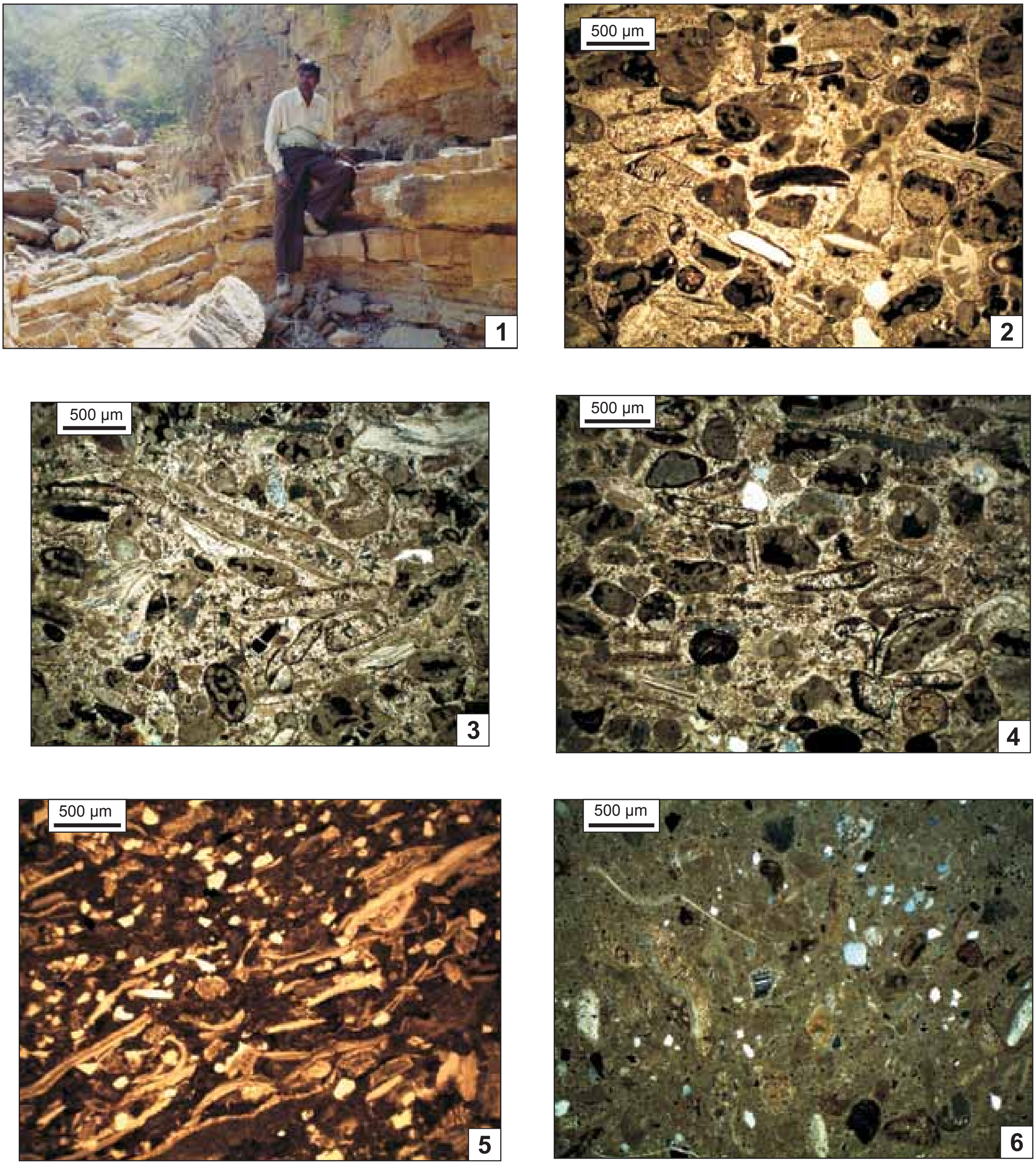

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PLATE 2

Limestone Lithofacies: Nodular White Well Bedded Limestone Subfacies

Fig. 1, 2.	Thin beds of limestone
Fig. 3.	Parallel lamination in limestone
Fig. 4–6.	Rounded and elongated micritic faecal pellets; sparsely rod shaped pellets with isolated large bioclasts and isolated medium size quartz grains
Fig. 7.	Bioclasts and matrix with isolated faecal pellets
Fig. 8.	Elongated and rounded faecal pellets in very fine micrite matrix with isolated large bioclasts of algae and echinoid

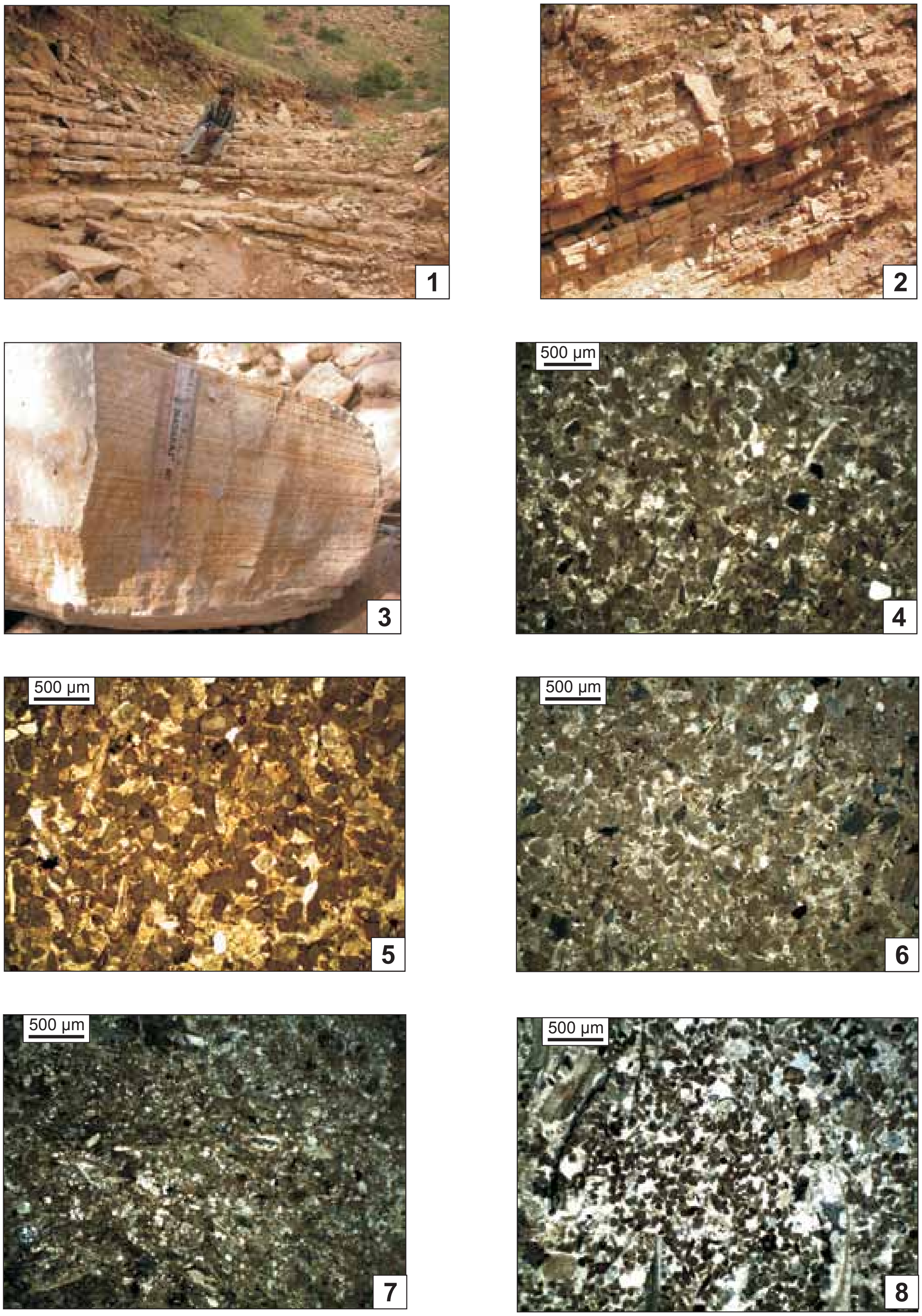

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PLATE 3

Conglomerate Lithofacies

Fig. 1. Clay pebbles in GOs

Fig. 2. Clay pebbles in RMCSSL

Fig. 3. Large boulder of oolitic limestone with abundant belemnites and ammonites in DOs

Fig. 4. Large size of limestone clasts, quartz grains; thin section of Dos

Fig. 5. Bioclasts; thin section of Dos

Fig. 6. Thick massive siltstone bands intercalated with thin calcareous silty shales

Fig. 7. Greenish grey shale facies showing thin siltstone bands

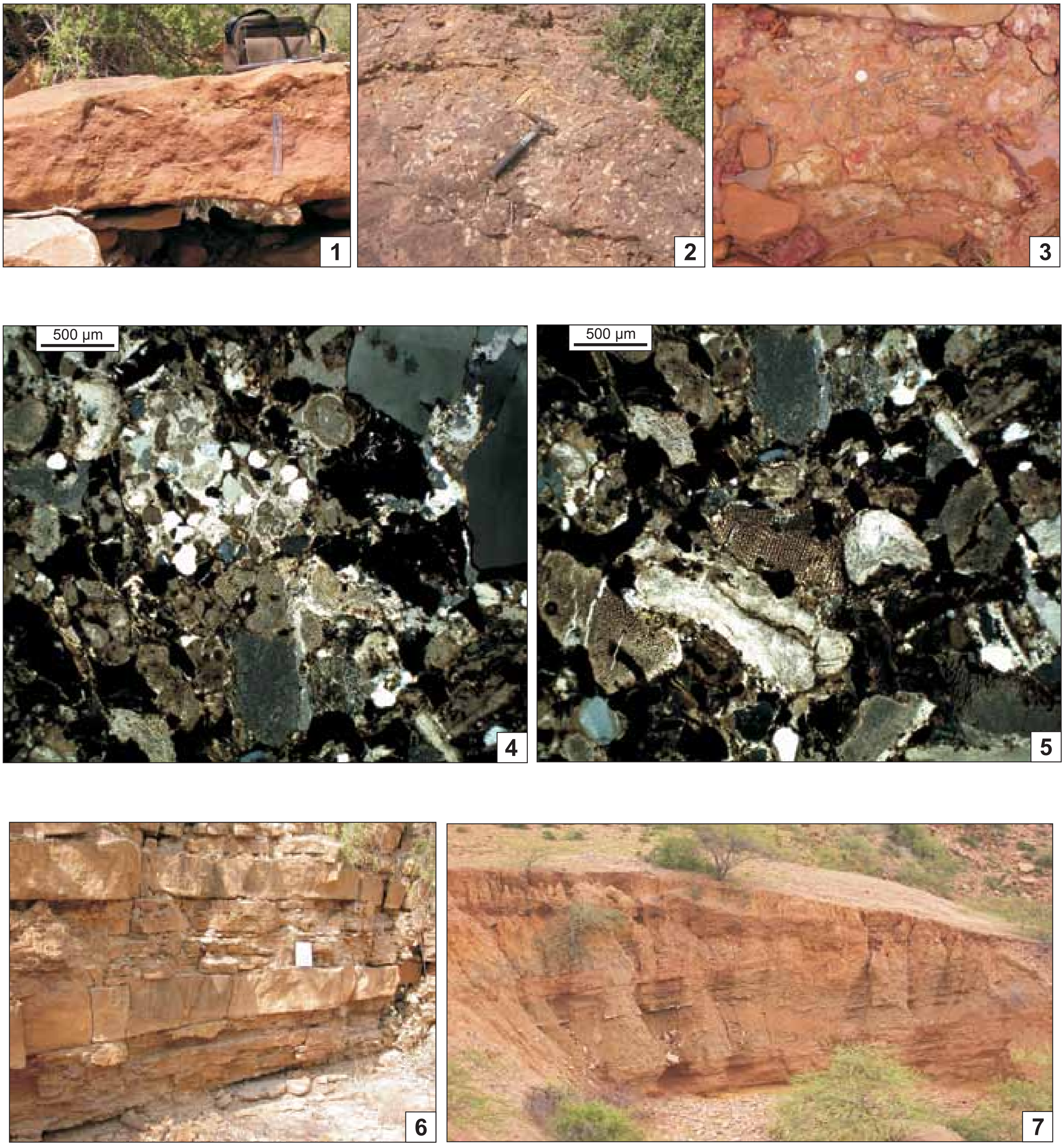

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PLATE 4

Oolitic Limestone Facies: Golden Oolite Limestone Subfacies

Fig. 1.	Mega wave-ripple on top of the golden oolitic limestone
Fig. 2.	Planer and trough cross stratification
Fig. 3.	Large size coral embedded in oolitic band
Fig. 4.	Highly bioturbated golden oolitic band
Fig. 5–8.	Large size rounded to elongated pellets and occasional quartz grains and bioclasts
Fig. 9–11.	Abundant rounded to oblong pellets
Fig. 12.	Radial fibrous oolite, with rounded to elongated pellets in the recrystallized micritic groundmass

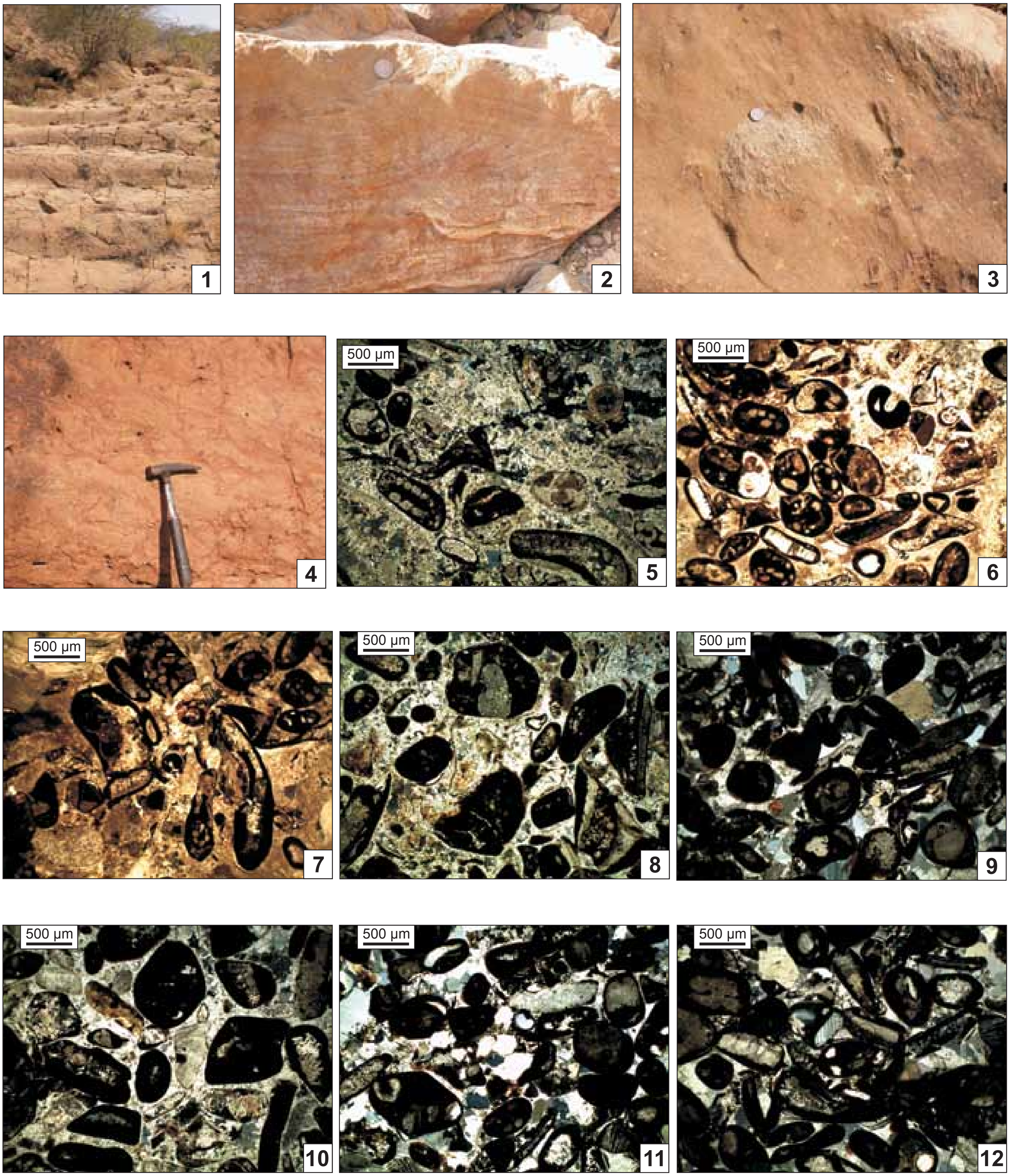

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PLATE 5

Dhosa Oolite Subfacies

Fig. 1. Oolitic limestone bands

Fig. 2. Hard bands of oolitic limestone above the greenish grey shales; proportion of shale decreases upwards

Fig. 3. Large ammonite in oolitic limestone band

Fig. 4, 5. Highly fossiliferous; bioclasts are mainly belemnites, bivalves, ammonites and brachiopods

Fig. 6. Isopachous and irregular (?gravitational) rim cements around ooids and reworked micritized nuclei in the ooids

Fig. 7, 8. Calcareous siltstone with microsparite cement; note presence of rare ooids

Fig. 9. Bioclasts in microsparitic cement

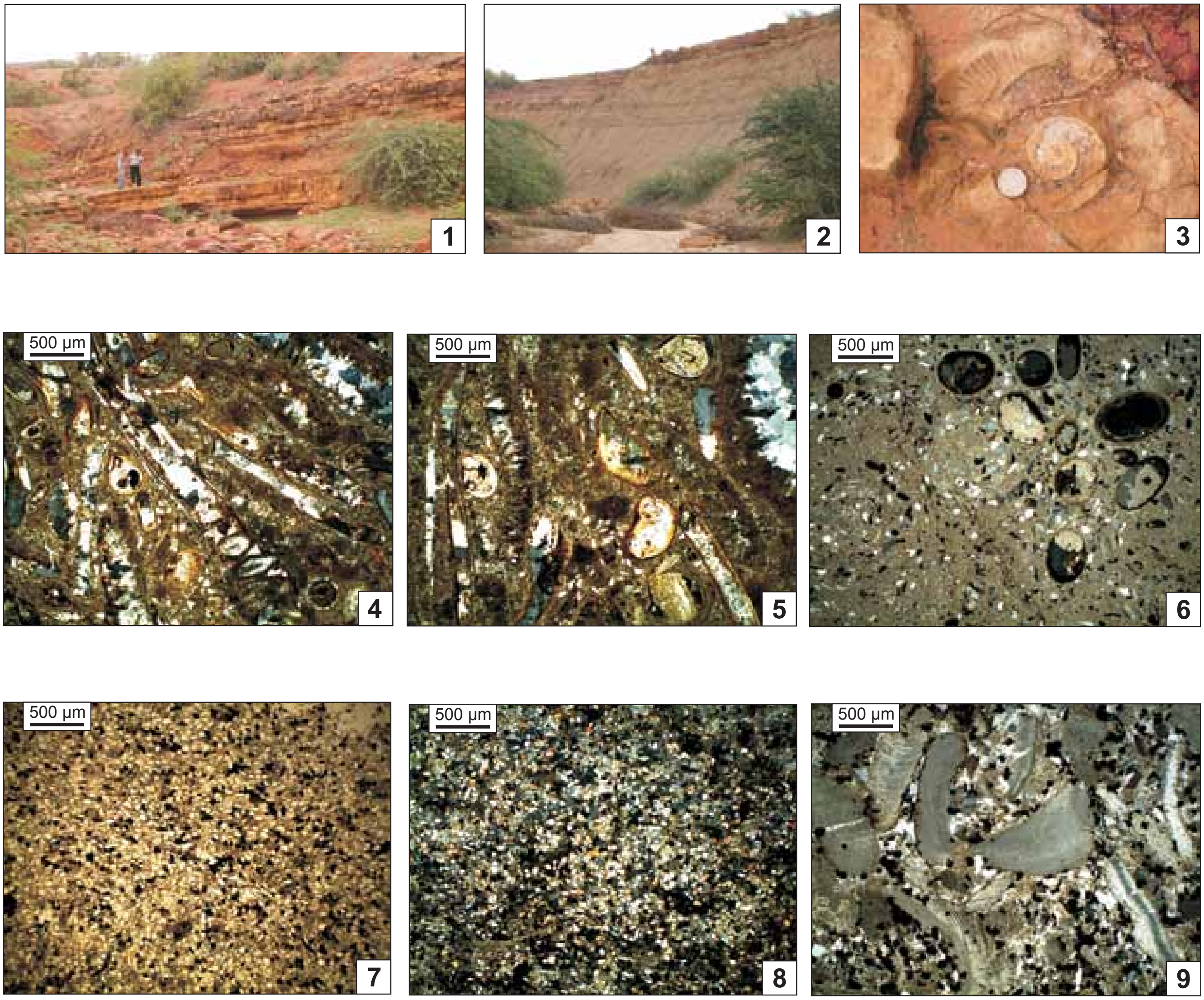
1
2
3
500 µm
4
500 µm
5
500 µm
6
500 µm
7
500 µm
8
500 µm
9

PLATE 6

Rippled Marked Calcareous Sandstone Lithofacies

Fig. 1.	Wave ripple marks on the top of the cross stratified micritic sandstone
Fig. 2.	Wall-like structure of the sandstone marks the periphery of the dome
Fig. 3.	Micritic sandstone consisting of high proportion of well sorted quartz grains
Fig. 4–6.	Grain supported thin-sections showing the variation in siliciclastic bioclast proportions
Fig. 7–9.	Siliciclastic dominated thin-section with isolated bioclasts, grain size of the quartz varies from fine to coarse. Isolated grains of feldspar are also observed (9)

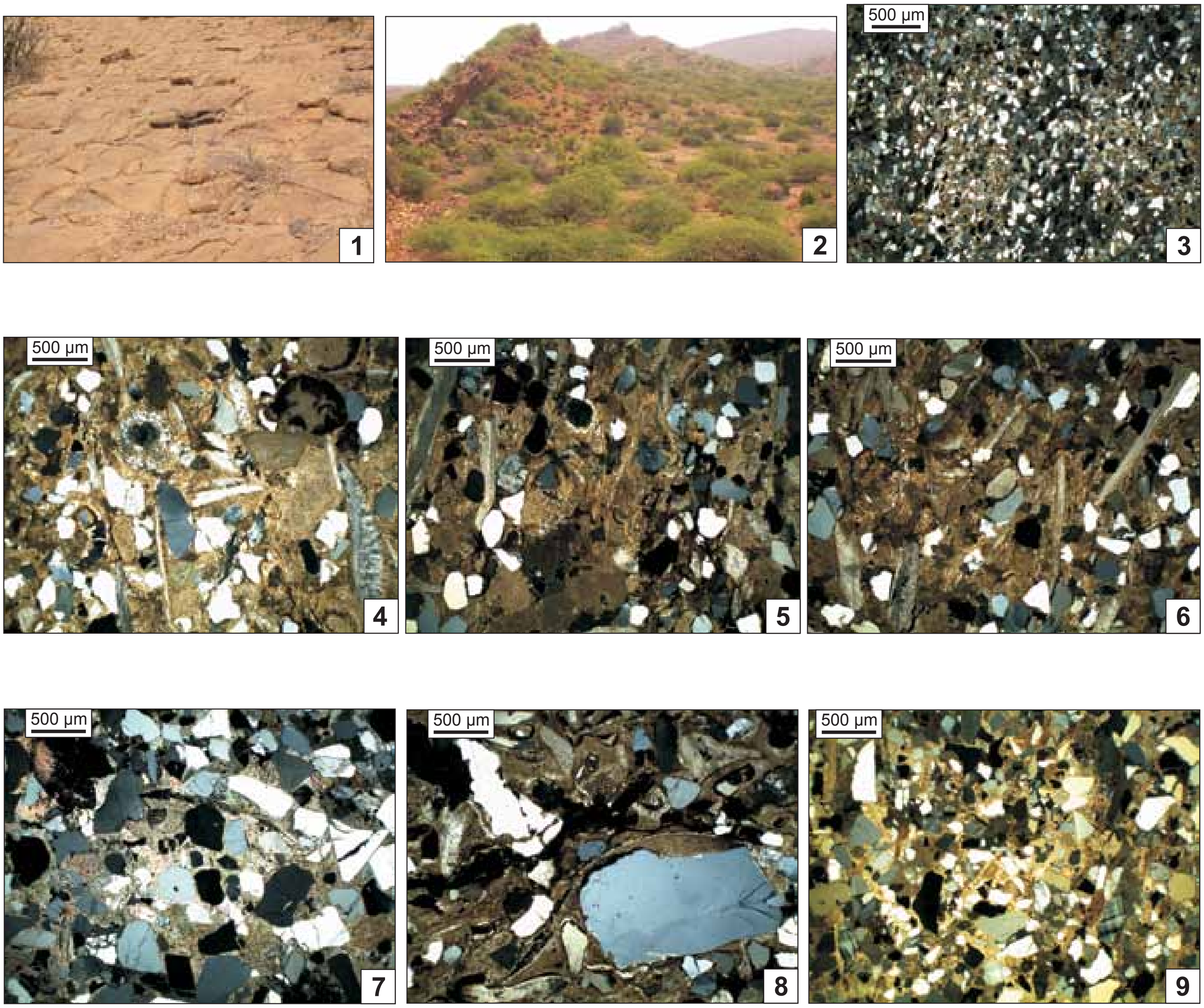

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PLATE 7

Fig. 1. *Protovirgularia*, NWWLs, Jhurio Fm. (coin diameter = 2.5 cm)

Fig. 2. *Zoophycos*, DOs, Jumara Fm. (coin diameter = 2.5 cm)

Fig. 3. *Chondrites*, DOs, Jhurio Fm. (coin diameter = 2.5 cm)

Fig. 4. *Rhizocorallium*, GOs, Jhurio Fm. (coin diameter = 2.5 cm)

Fig. 5. *Pilichnus*, GOs, Jhurio Fm. (coin diameter = 2.5 cm)

Fig. 6. *Arenicolites*, CSSL, Jhurio Fm. (coin diameter = 2.5 cm)

Fig. 7. *Diplocraterion*, RMCSSL, Jumara Fm. (bar length= 2 cm)

Fig. 8. *Ophiomorpha*, RMCSSL, Jumara Fm. (coin diameter =2.5 cm)

Fig. 9. *Calycraterion*, RMCSSL, Jumara Fm. (coin diameter =2.5 cm)

Fig. 10. i) *Margaritichnus* and ii) *Thalassinoides*, CSSL, Jhurio Fm. (coin diameter =2.5 cm)

Fig. 11. *Bergaueria*, RMCSSL, Jumara Fm. (coin diameter =2.5 cm)

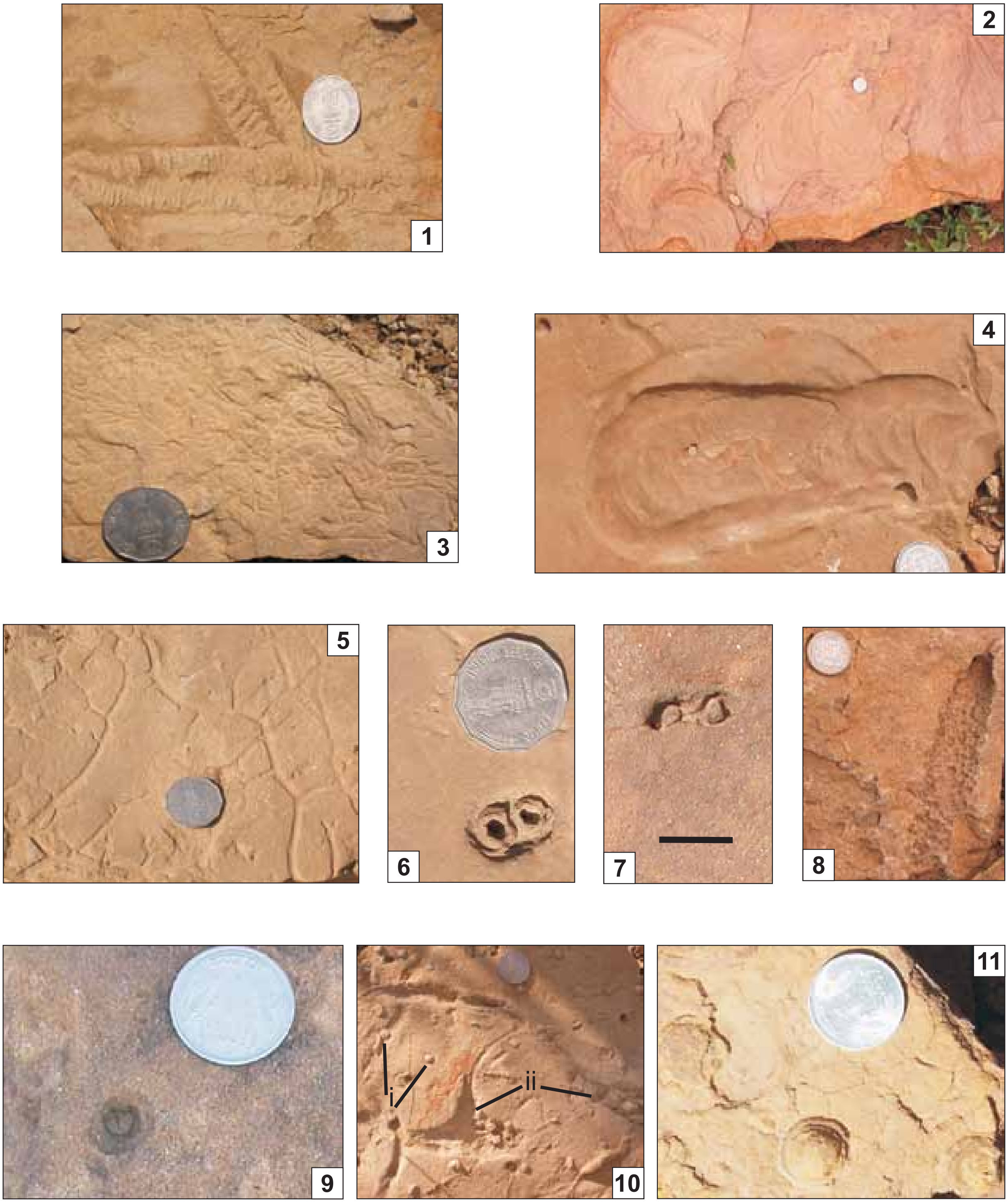

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PLATE 8

Fig. 1. *Palaeophycus*, GOs, Jhurio Fm. (coin diameter = 2.5 cm)

Fig. 2. *Phycodes*, RMCSSL, Jumara Fm. (coin diameter = 2.5 cm)

Fig. 3. *Phymatoderma*, CSSL, Jumara Fm. (coin diameter = 2.5 cm)

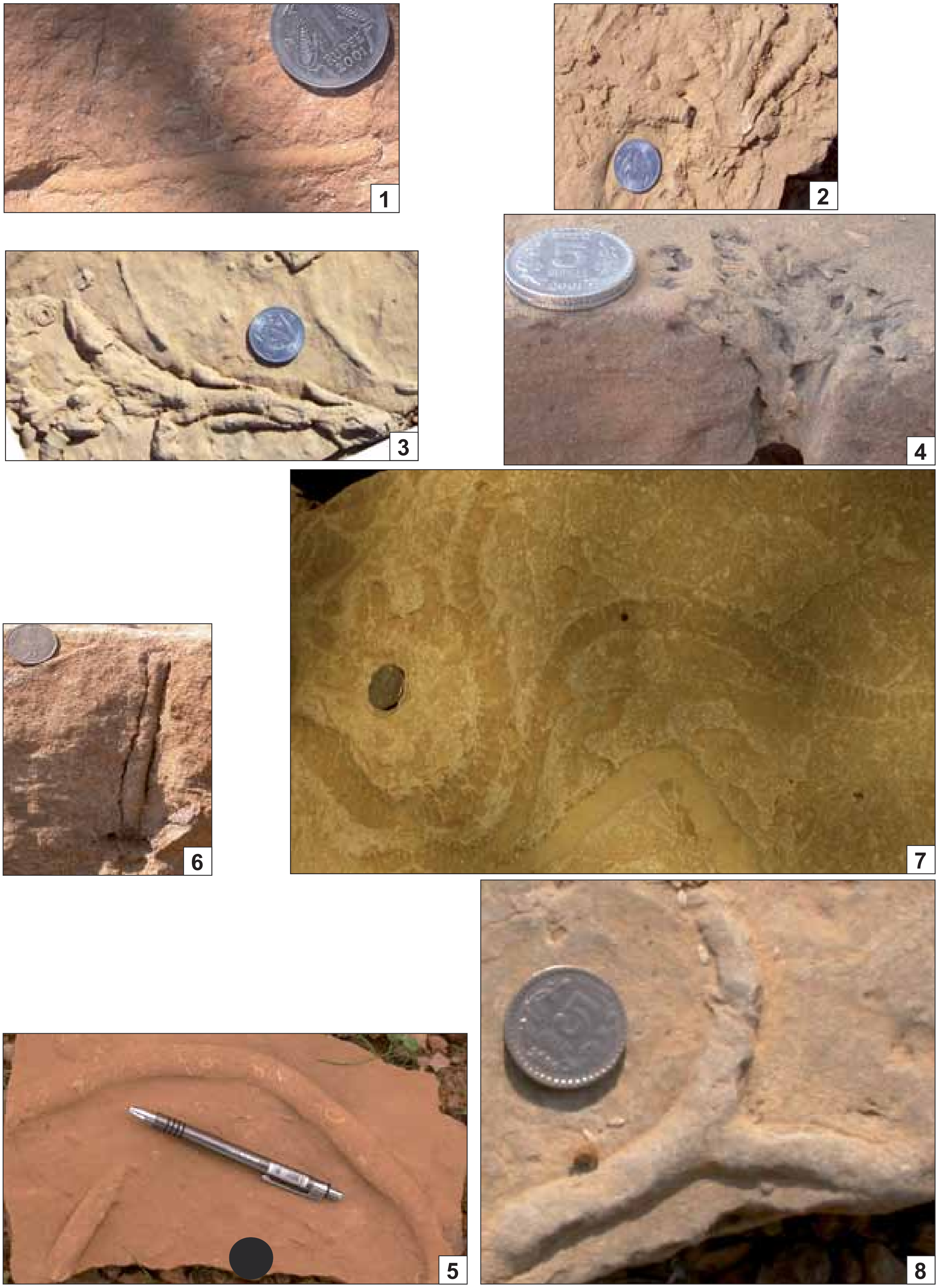
Fig. 4. *Parahentzschelinia*, in vertical section RMCSSL, Jumara Fm. (coin diameter = 2.5 cm)

Fig. 5. *Planolites* RMCSSL, Jumara Fm. (pen length =14 cm)

Fig. 6. *Skolithos*, GOs, Jhurio Fm. (coin diameter = 2.5 cm)

Fig. 7. *Taenidium*, NWWLs, Jhurio Fm. (coin diameter = 2.5 cm)

Fig. 8. *Thalassinoides*, NWWLs, Jhurio Fm. (coin diameter = 2.5 cm)



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