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Sedimentary cycles in the Callovian-Oxfordian of the Jaisalmer Basin, Rajasthan, western India

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Key words: cyclicity, Jaisalmer Basin, Jaisalmer Formation, Callovian–Oxfordian.

Abstract. The Callovian and Oxfordian marine sediments of the Jaisalmer Basin constitute the uppermost part of the Jaisalmer Formation, which comprises the Kuldhar and Jajiya members. In the present paper the authors illustrate retrogradational-progradational, more or less symmetrical cycles representing low- to high-energy marine environments. Despite an incomplete sedimentary record in a profile disrupted by a number of omission surfaces, it is possible to distinguish seven such sedimentary cycles in less than 24 m of sedimentary succession. The cycles, often bearing in their upper parts a thick-bedded well-cemented calcareous sandstone/pack- to rudstone, or hummocky cross-stratified beds indicative of storm events, are occasionally topped by hardgrounds. Hardgrounds provide well-defined boundaries useful for delineating correlative/bounding surfaces, identified here with sequence boundaries (3rd order cycles). Maximum flooding surfaces characterized by richly fossiliferous marly wackestones provide additional correlative horizons. Within these sequences, subordinate cycles can be tentatively distinguished, some of them may represent parasequences. The stratigraphical significance of correlative surfaces and sequences is tested by their fossil content, and these surfaces can be used for regional correlations with neighbouring basin.

INTRODUCTION AND GEOLOGICAL SETTING

During the Jurassic, the Jaisalmer Basin (a part of the Rajasthan shelf; Fig. 1), situated to the west of the Aravalli axis on the western part of the Indian Craton, formed the easternmost part of the "Indo-Arabean Geological Province", from the late Proterozoic to the early Cenozoic (*e.g.*, Rehman, 1963; Shrivastava, 1992). Within the Jaisalmer Basin, as revealed by geophysical investigations conducted by the Oil and Natural Gas Commission, four geostructural units, *viz*. the raised Mari-Jaisalmer Arch extending through the central part of the basin, the synclinal Shahgarh Sub-basin to the west and southwest, the Kishangarh Sub-basin to the north and northeast, and the Miajlar Sub-basin to the south have been recognized (Raghavendra Rao, 1972; Sinha *et al*., 1993; Singh *et al*., 2005). The Late Proterozoic to Early Cambrian and Triassic sediments have been recorded in boreholes, while surface outcrops along the raised Mari-Jaisalmer Arch in the basin (Fig. 2) show deposits ranging from Early Jurassic to Quaternary in age (Das Gupta, 1975; Misra *et al.*, 1996; Pandey, Tej Bahadur, 2009). These sediments have attracted the attention of geologists, palaeontologists and amatour collectors primarily for their rich and well preserved fossil contents, characteristic golden yellow coloured sediments and low lying, easily accessible outcrops. Later on, the basin was proved also to be potential for oil and gas reserves. Recently, several oil companies have carried out oil exploration work.

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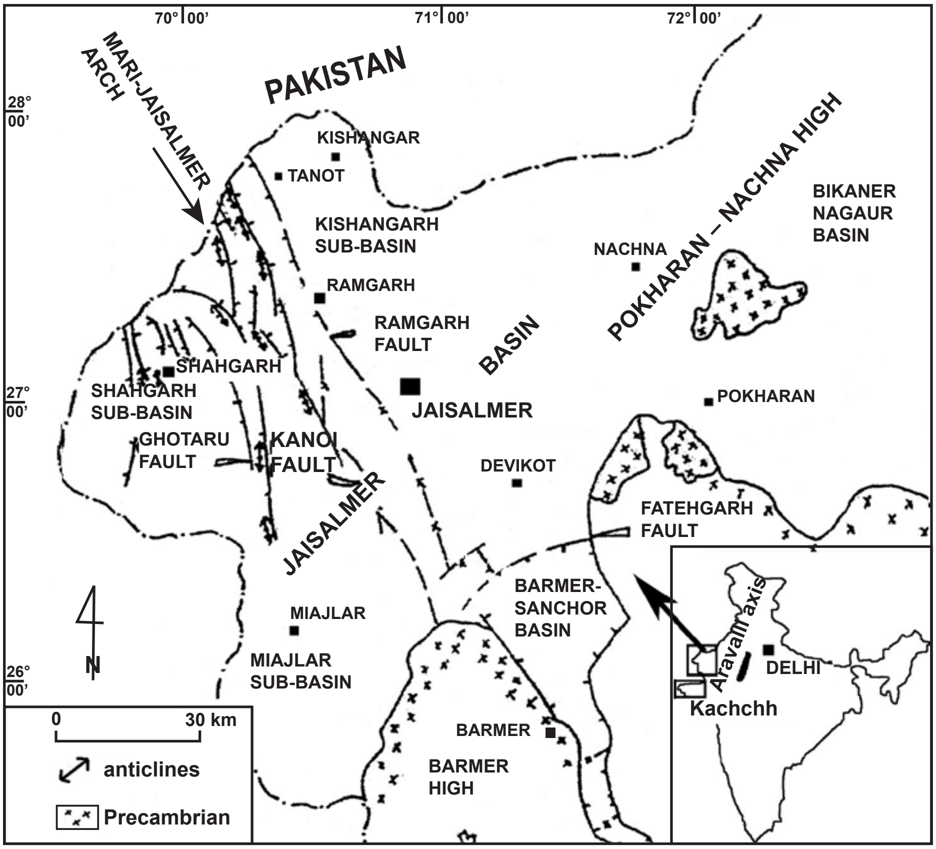


Fig. 1. Location map. Structural elements in western Rajasthan (modified after Misra *et al.*, 1993)

Lithostratigraphically, the Jurassic sediments have been grouped into the Lathi, Jaisalmer, Baisakhi and Bhadasar formations in ascending order (Das Gupta, 1975; Pandey *et al*., 2005, 2006a, b, 2009b). The thickness of individual formations ranges from 70 to 1000 m (Swaminathan *et al*., 1959; Narayanan *et al*., 1961; Das Gupta, 1975; Pareek, 1984). Study of the sections has revealed that there is cyclicity in the sedimentation. In general, sedimentary cycles can be observed in all the four formations, but they are particularly well displayed in the Jaisalmer Formation of Late Bajocian to Oxfordian age (Jaikrishna, 1987; Pandey, Fürsich, 1994; Pandey *et al*., 2006a, b, 2009). Lithostratigraphically, the formation has been divided, in ascending order, into the Hamira, Joyan, Fort, Badabag, Kuldhar and Jajiya members (Narayanan *et al*., 1961; Das Gupta, 1975; Kachhara, Jodhawat, 1981). The Callovian-Oxfordian sediments of the Jaisalmer Formation, grouped into the Kuldhar and Jajiya members, are predominantly carbonates deposited in the shoreface zone to offshore transition zone above storm wave-base. These are the only members of the Jaisalmer Formation yielding ammonites. In addition they show the maximum diversity of fauna of the entire Jaisalmer Formation. Recently, two specimens of *Clydoniceras* Blake, 1905 from the Bathonian part (Badabag Member) of the Jaisalmer Formation have been collected (Pandey *et al*., 2006b; Prasad *et al*., 2007).

In the Jaisalmer Basin the best outcrops of the Callovian and Oxfordian sediments are on the southwest and west of Jaisalmer City. The precise localities of the outcrops studied are: (1) Kuldhar River-section, 16 km southwest of the Jaisalmer City (Pls 1, 2), (2) the east-west transect section at 11 km milestone west of the Jaisalmer City (Pls 3–6), and (3) Jajiya River and cliff sections 6 km south of Damodara Village across the Damodara–Jajiya road (Pl. 7). Five lithological sections (S1–S5, see Fig. 2), which give a quite comprehensive picture of the Callovian-Oxfordian sediments of the Jaisalmer Basin, are described and discussed for recognition of sedimentary cycles. Due to regional syn-sedimentary tectonics, cyclicity is well-expressed in the more complete successions of the neighbouring rift basin of

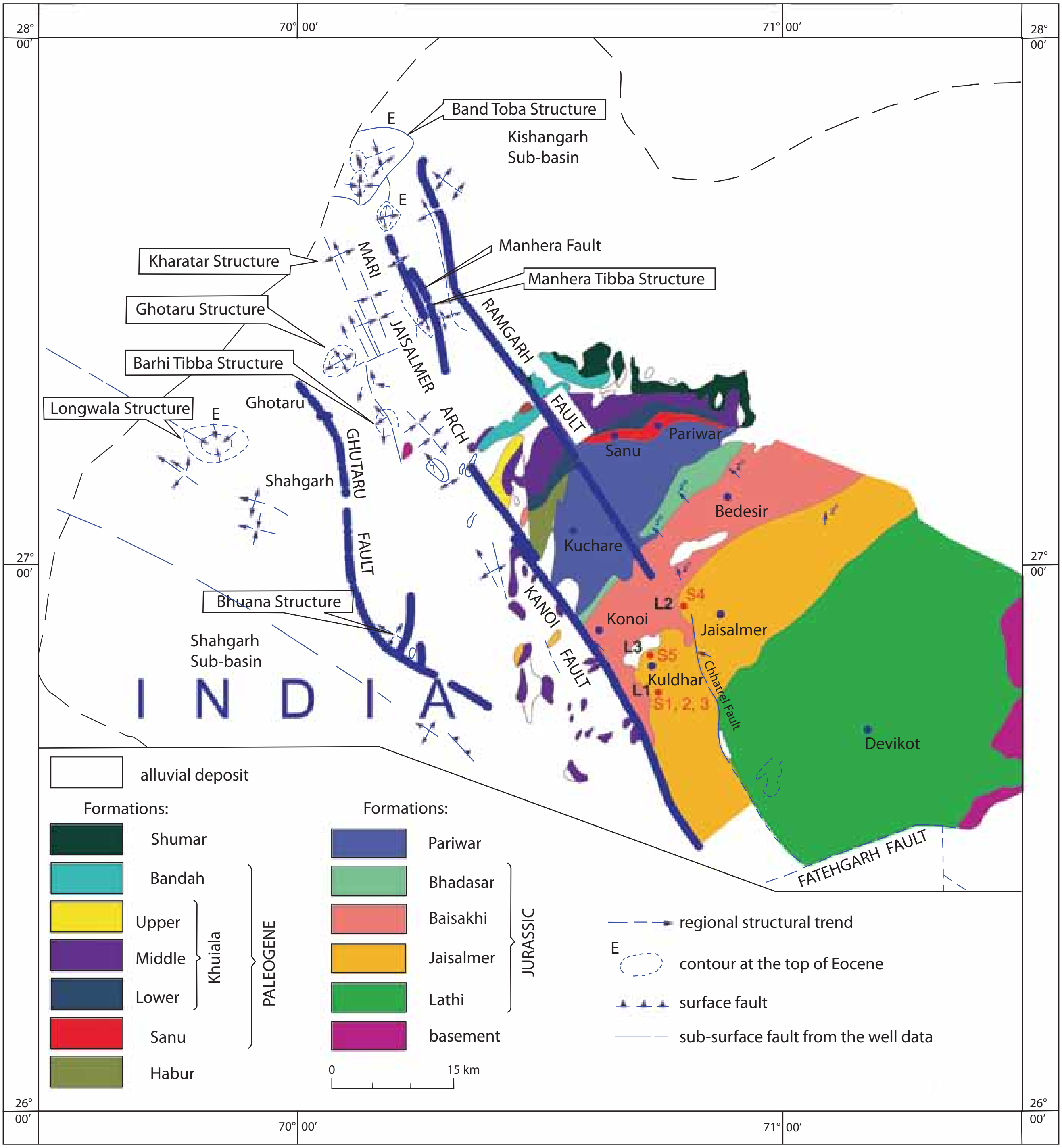


Fig. 2. Geological map of the Jaisalmer Basin (after Das Gupta, 1975) showing localities L1, L2, L3 and the location of sections (S1–S5) investigated in the present study

Kachchh (*e.g*., Fürsich *et al.*, 1991, 2001; Pandey *et al*., 2009b), while the Jaisalmer Basin, representing a northward sloping shelf basin, comprises a far less complete record, with number of omission surfaces (Pandey *et al*., 2009b). The aim of the present paper is the description of the Callovian-Oxfordian part of the section; the Early–Middle Jurassic section was described previously by Pandey *et al*. (2006 a, b; 2009b).

SEDIMENTARY FACIES AND PROFILE OF THE CALLOVIAN-OXFORDIAN SEDIMENTS OF THE JAISALMER BASIN

A study of the sections through the Callovian-Oxfordian sediments of the Jaisalmer Basin reveals rapid temporal changes in lithology, which are expressed in conspicuous beds (*i.e*. Pls 4: 3; 5: 1, 2). The lithological units (beds) are usually separated by sharp bounding surfaces (mostly of erosional character). The average thickness of an individual unit does not exceed 1 m, and some of them are only few cm thick (the minimum recorded thickness is 2.5 cm). In the hierarchy adopted herein, these beds represent the smallest lithostratigraphic units; they are bounded by sharp surfaces and internally show a uniform lithology. The high frequency of erosional surfaces points to frequent gaps (omission surfaces) in the sedimentary record. Possibly, the observed layers represent depositional events associated with the creation of accommodation space during transgressive pulses, while periods of prevailing standstill or regression are represented by omission (erosional) surfaces. These beds show more general changes upwards within the vertical profile, expressed in terms of microfacies, sedimentary structures and biotic components. These more general trends have allowed the authors to distinguish in the whole Callovian-Oxfordian sequence four general facies units, characterized by different sedimentary facies. The facies units described below in chronological order are as follows:

Facies unit 1. Fossiliferous, partly bioturbated and cross-bedded packstones with hardgrounds.

Facies unit 2. Fossiliferous bioturbated silty marlstones with interbeds of wacke- to packstones.

Facies unit 3. Low angle cross-bedded clayey, silty marlstones with interbeds of fine-grained calcareous sandstones to sandy packstones.

Facies unit 4. Partly bioturbated and low angle cross-bedded pack- to rudstones and fine- to medium-grained calcareous sandstones.

Individual beds, but also some units, are separated by hardgrounds, regarded as more prominent bounding surfaces. A hardground is defined as the surface of a bed formed slightly below the sediment–water interface due to synsedimentary lithification. Upon erosion (due to increased water energy) of the overlying sediments this surface is usually colonized by encrusting (*e.g*. oysters) or boring organisms.

FACIES UNIT 1
Fossiliferous, partly bioturbated and cross-bedded packstones with hardgrounds

The lower deposits of this oldest facies unit (latest Bathonian–Early Callovian) are exposed at locality 1 (L1 in Fig. 2) as a platform on the eastern side of the Kuldhar River, just southwest of the ruins of Kuldhar Village, whereas their upper part is exposed mostly along the western bank of the river (Figs 3, 4). Deposits showing similar facies also extend in a NNE direction and are exposed at locality 2 (L2 in Fig. 2) about 11 km west of Jaisalmer (S4 in Fig. 4). In the Kuldhar River--section, the basal bed (no. 1) (S1 in Fig. 3) is a fine-grained sandstone (20 cm), overlain by moderately to well cemented, fossiliferous, partly bioturbated and trough cross-bedded, ooid and intraclast-bearing grain- to packstone. Megaripples, iron crust and three very conspicuous hardground surfaces are present (Fürsich *et al*., 1992) (beds nos 2–11, S1 in Fig. 3; beds nos 1–8, S2 in Fig. 3). A few silty wackstone beds are also included in the facies. On the other hand, in the section 11 km west of Jaisalmer (L2 in Fig. 2) the deposits are more thinly bedded with sharp upper and lower surfaces of the beds and at least two hardgrounds (Fig. 4). The basal bed (no. 1) exposed in the latter section is a bioturbated packstone. Here the facies is predominantly packstone with subordinate wackestones, mudstones and a few levels of rudstones in the upper part. Intersecting oscillation ripples and hummocky cross-bedding have been recorded. The siliciclastic input is less significant in this part (less or 3–5%). Petrographically the beds in the Kuldhar River-section contain ooids (silt to coarse sand size up to 10%), coated grains (0.10–0.25 mm in size, up to 10%), a high percentage of quartz (up to 20%) and bioclasts (turreted gastropods, echinoderm plates and spines, algal filaments, bryozoans, sponges, foraminifers, ostracods, bivalve shells, *etc*., locally up to 10–40%), whereas the beds in the section 11 km west of Jaisalmer (L2) have remarkably no ooids and a low siliciclastic input (less or 3–5%), and instead show peloids, bioclasts and intraclasts up to 20%. The whole sequence is characterized by the upward increase in thickness of the beds (top bed no. 10 – 38 cm thick). Occasionally within this succession the sharp bases of the particular beds are followed by the parallel arrangement of shells, also the size of crushed shells shows a fining upward tendency (*e.g*. bed no. 3). Oscillation wave ripples (beds nos 1, 3) and bioturbation (beds nos 1, 9) have also been recorded. The biotic elements recorded from this sequence are: *Rhizocorallium irregulare* (very common), *Planolites*, turreted gastropods, oyster shells, *etc*.

Table 1

Comparison of attributes of the beds with top hardground surfaces of Facies unit 1 exposed in localities L1 (Kuldhar River-section Section) and L2 (section about 11 km west of Jaisalmer)

	Kuldhar River-section	Section about 11 km west of Jaisalmer
Individual beds	thick – range from 7 to 130 cm thick	thin – range from 3 to 95 cm thick
Total thickness	5.37 m (base sandy facies)	4.17 m (base not seen)
Siliciclastic input	conspicuously higher (up to 20%)	conspicuously lower (less or 3–5%)
Ooids	golden ooids common in the facies	no ooid recorded
Fossils	richly fossilifereous	poor diversity and number of fossils
Trace-fossils	*Zoophycos* and *Thalassinoides* (common)	*Rhizocorallium irregulare* (very common)
Megaripples	conspicuous	not recorded

Within the facies unit, three conspicuous coarsening upward trends (cycles) are observed. Either a thick bed, a hardground surface or rudstone/hummocky cross-beds tops the cycle. Out of four hardground surfaces recorded in the facies unit, the oldest one at both the outcrops can be compared well and used for correlation. It seems that it has a wider geographic extension in the basin. The spatial extension of other hardgrounds could not be confirmed, chiefly because of limited outcrops. Nevertheless, all the four beds with top hardground surfaces are described in Table 1.

Hardground I (of the highest correlative significance). This is the oldest hardground surface about 180 cm above the base of the Kuldhar River-section. It is characterized by wave megaripples, oyster shells encrustations (Pl. 1: 2–4), bivalve borings and partly with *Thalassinoides* burrows (the oldest, softground/firmground tier of a softground-firmground-hardground succession). The surface is topped with a thin lamina of iron crust (see Fig. 5A). The deposits below the iron crust vary from mudstones through pack- to grainstones (the latter with large scale trough cross-bedding) (beds nos 2–3, S1 in Fig. 3). Occasionally, the deposits are bioturbated. Limids, oyster shell fragments (*Liostrea*, *Nanogyra*), rhynchonellids and terebratulids occur in these sediments.

In the section 11 km west of Jaisalmer (L2) this hardground surface, which is characterized here by an uneven and eroded surface, bored pebbles, encrustation of oyster shells and long, branching *Rhizocorallium irregulare* (forming a pre-hardground tier occupied by a community of soft/firmground dwellers), tops a *c.* 1.18 m thick sedimentary sequence of thinly bedded packstones with sharp upper and lower surfaces (Pl. 3: 2, 3, beds nos 1–10; S4 in Fig. 4).

Hardground II. The surface is characterized by bivalve borings and cemented oyster shells. This surface, like hardground I, is also covered with iron crust, which laterally is replaced by stromatolitic crust (Fig. 5B). The 30 cm thick bed lying below this surface is wackestone (bed no. 4, S1 in Fig. 3). The bivalves *Homomya* and *Pholadomya* occur in life position in this bed. Other bivalves (*Nanogyra*, *Chlamys*), brachiopods (terebratulids), sponges, gastropods (*Pleurotomaria*), cephalopods (belemnites, ammonites), colonial corals, and older tier established in unconsolidated sediment with trace fossils (*Rhizocorallium irregulare*, *Chondrites*, *Thalassinodes*), *etc*., have also been recorded from these sediments. No hardground comparable to this could be observed in the section 11 km west of Jaisalmer (L2); its equivalent is rather indicated by an sharp, uneven omission surface. The deposits below this surface are partly bioturbated, thinly cross-bedded, predominately calcareous mudstones with a few erosional surfaces (beds nos 11 to lower part of bed no. 17, see S4 in Fig. 4).

Hardground III. This is the youngest hardground surface in the Kuldhar section. This surface is characterized by bivalve borings and reworked concretions. This surface is also covered with a stromatolitic crust (Fig. 5C). The bed (80 cm) is a wackestone consisting of intraclasts and ooids (beds nos 5–6, S1 in Fig. 3). It yields: bivalves (*Plagiostoma*, *Ctenostreon*, *Chlamys*, *Cosmetodon*, *Nanogyra*, *Entolium*, *Camptonectes*, *Pholadomya*, *Nicaniella*, *Vaughonia*, corbulids, neocresinids), rhynchonellids, terebratulids, belemnites, ammonite fragments and crinoid ossicles. An older tier (community) of unconsolidated sediments contains trace fossils such as *Chondrites*, *Planolites* and *Thalassinoides*.

The fossils in the upper part of the facies recorded above hardground III are bivalves (*Entolium*, *Camptonectes*, *Oxytoma*, *Pseudolima*, *Ctenostreon*, *Plicatula*, *Vaughonia, Nanogyra* and other oysters), belemnites, ammonites (*Reineckeia* – Pl. 2: 3), rhynchonellids, terebratulids (monospecific as shell-beds and occasionally as pavements), crinoids, bone fragments, trace fossils (*Thalassinoides*, *Scolicia*, *Cylindrichnus*), *etc*. (Pl. 2: 1, 2).

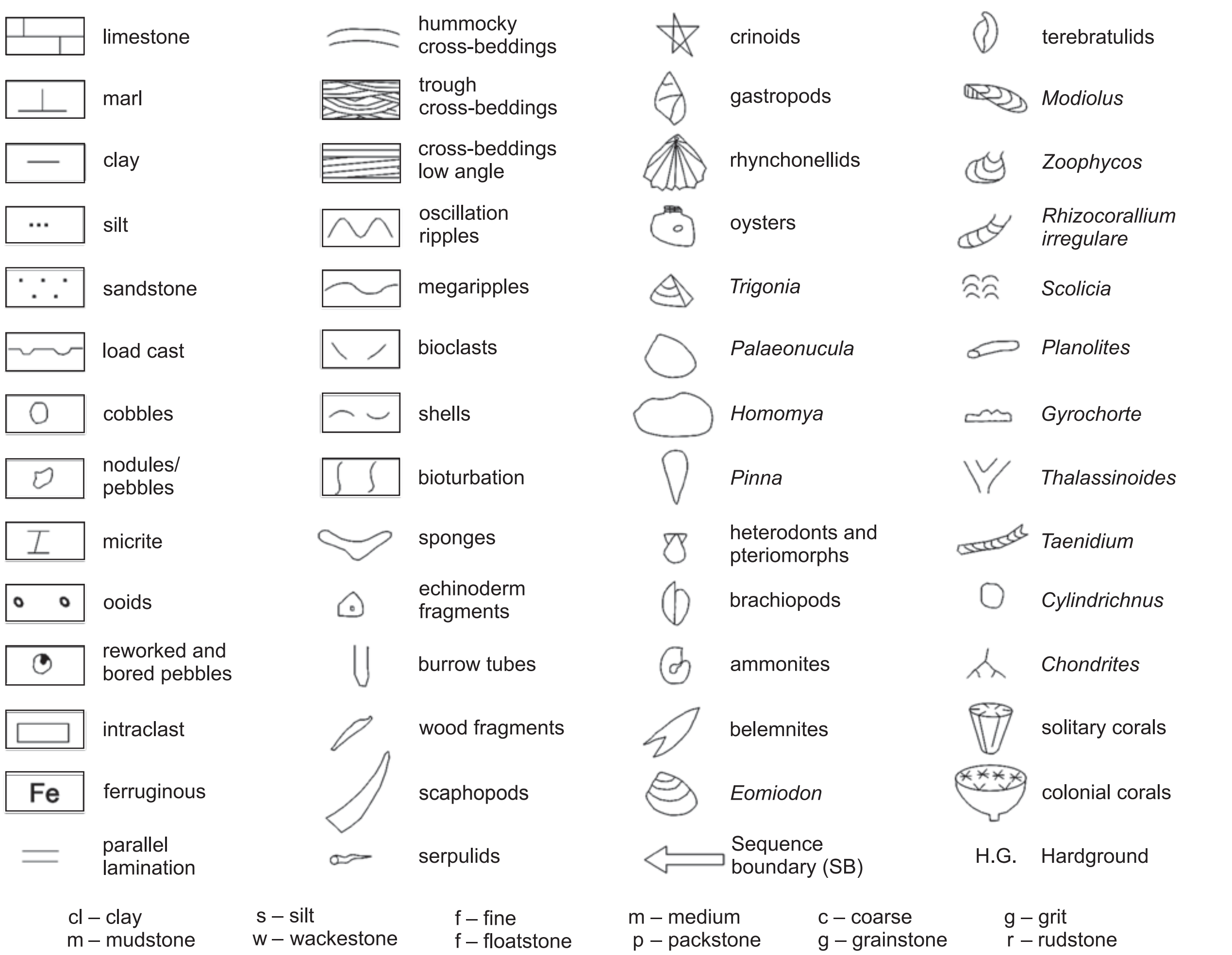
Petrographically, ooids (10%), intraclasts, micro-oncoids (0.72–0.92 mm) and bioclasts – echinoderm plates (common), crinoid spines, foraminifers, *etc.,* have been recorded.

Hardground IV. This is a second hardground in the outcrop section 11 km west of Jaisalmer (L2 in Fig. 2) and has no contemporary record in the Kuldhar Member at Kuldhar. In fact this was only traced for a short distance along the cliff. The surface is uneven and bored, encrusted with oyster shells and covered with a very thin layer of ferruginous, calcareous sandstone which fills the borings (Pl. 4: 2).

Discussion. At Kuldhar the facies with hardgrounds and monospecific shell beds, consisting of articulated shells, is interpreted as having been deposited in a high-energy storm-dominated environment, between the upper shoreface and the offshore transition zone above storm wave-base. The grainstone and packstone indicate conditions of the upper shoreface of a bar system, situated above storm wave-base. The megaripples and associated large-scale trough cross-bedding are indicative of strong waves. Before consolidation of the sediments, the soft to firm bottom was colonized by burrowing organisms, leaving a trace fossil assemblage (*Thalassinoides, Rhizocorallium, Planolites*, *Scolicia*, *Cylindrichnus*, *Chondrites* and others).

The dominance of cemented forms such as oysters including *Nanogyra* and sessile, pedically attached brachiopods (terebratulids and rhynchonellids), indicates a firm substrate. The grainstone of bed no. 2 (S1 in Fig. 3) suggests winnowing in a high-energy environment, either by current or by wave action.

Explanations for Figures 3 and 4



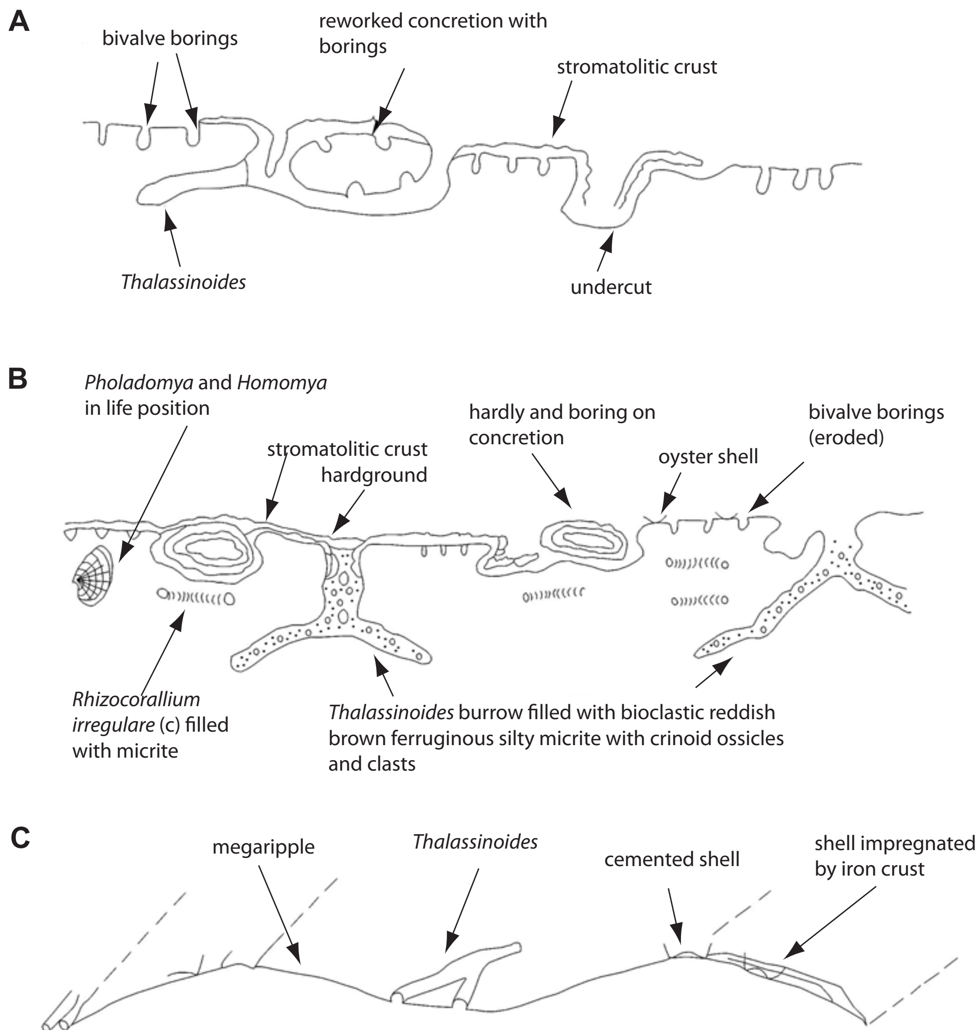


Fig. 5. Sketch diagram of hardground surfaces I, II and III in the Kuldhar Member at Kuldhar River-section (S1 in Fig. 3), south of the Kuldhar Village in the east of the Kuldhar River (locality L1 in Fig. 2), 16 km southwest of Jaisalmer City (Fürsich *et al.*, 1992)

The synsedimentary lithification, encrustation of oysters, serpulids, sponges and borings by bivalves at hardground surfaces suggest deposition in a carbonate rich environment with a break in sedimentation at the hardground surface. Since the formation of a hardground requires synsedimentary lithification taking place slightly below the sediment-water interface, erosion of some part of the sequence is evident. The wackestone beds nos 4, 6–7 (S1 in Fig. 3) suggesting the successive lowering of energy (grainstone of bed no. 2 – packstone of bed 3 – wackestone of beds nos 4, 6–7; S1 in Fig. 3) corresponds to the deepening of the basin. *Chondrites*, produced either by adeposit-feeder or by a chemosymbiotic organisms (Seilacher, 1990; Fu, 1991; Bromley, 1996), is suggestive of low oxygen conditions deeper in the sediment, whereas the iron crust or stromatolitic crust (Fig. 5) at the top of each hardground and micro-oncoids in beds nos 2 and 8 (S1 in Fig. 3; observed under microscope) indicates shallow, warm, well-lit conditions. The high diversity of the fauna indicates favourable condition for organisms. The four hardground surfaces represent at least four phases of non-deposition and/or omission of sediments.

The lateral change in facies (Tab. 2) suggests the general deepening and lowering of the energy of deposition in the NNE, *i.e.* from locality L1 to locality L2. The hardgrounds and storm-beds suggest the intermittent increase in current and energy level. Locality L2 (at the section about 11 km west of Jaisalmer), was further away from the source of siliciclastic influx, perhaps between the lower shoreface

Table 2

Biostratigraphy of the Callovian-Oxfordian sediments of the Jaisalmer Basin (modified after Jaikrishna, 1987; Callomon, 1993; Prasad, 2006; Jain, 2007; Jaikrishna *et al.*, 2009a, b)

Stage	Ammonites – Jaisalmer	Ammonites – Kachchh
Middle to Upper Oxfordian	*Dichotomosphinctes/Dichotomoceras* *Mayaites maya*	*Dichotomosphinctes/Gregoryceras/ Dichotomoceras* *Mayaites maya*
Lower Oxfordian	*Peltoceratoides semirugosus*	*Peltoceratoides semirugosus*
Upper Callovian	*Properisphinctes*	*Peltoceras athleta*
Middle Callovian	*Collotia gigantea*	*Collotia gigantea*
	Reineckeia anceps	*Reineckeia anceps*
Lower Callovian	*Subkossmatia opis*	*Subkossmatia opis*
	Macrocephalites semilaevis *M. madagascariensis*	*Macrocephalites semilaevis* *M. dimerus*
Upper Bathonian	*Macrocephalites triangularis* *Sivejiceras congener*	*Macrocephalites triangularis* *Perisphinctes congener*

and offshore transition zones. The substrate at locality L2 was not suitable for both epifaunal and infaunal organisms. The presence of *Chondrites* in the upper part may suggest oxygen deficiency.

FACIES UNIT 2
Fossiliferous bioturbated silty marlstones with inter-beds of wacke- to packstones

More than 8 m of the remaining part of the Kuldhar River-section (locality 1; L1 in Fig. 2) is represented by occasionally oolitic, fossiliferous, bioturbated silty marlstone with thin, moderately well cemented beds of wacke- to packstones (beds nos 12–17, S1 in Fig. 3; beds nos 9–19; S2 in Fig. 3; beds nos 1–7, S3 in Fig. 3, Pl. 2: 4), which occasionally change laterally to shell-beds. These thin beds seem to be persistent, but due to the soft nature of the facies and a few shear faults traversing through the section, most of the succession is covered with scree material and consequently beds cannot be traced laterally for more than 50 m. Secondly, because of similar microfacies, it is also difficult to trace a particular bed laterally. However, in a few cases the concentration of belemnite guards or well-sorted shell concentrations (shell-beds) can be used as a guide for correlation. That ammonites originally must have been abundant is evident from previous records (Prasad, 2006), but they have been rigorously collected in the past, so it is difficult to find any nowadays. Laterally, due to weathering towards the down-stream side, the deposit looses its stratified character and occurs as big blocks of shales with numerous terebratulids, small and large rhynchonellids (both isolated single valves and articulated double valves), oyster shells, fragmentary *Plagiostoma*, *Trigonia*, small fragments of belemnite guards and juvenile to large fragments of ammonites (*Hubertoceras*, *Hecticoceras*, *etc*.). From their lithological character it appears that these blocks correspond to the upper part of the deposit. The fossils in general are distributed throughout the deposit but they vary in individual number from bed to bed. These are: bivalves [*Palaeonucula*, *Presaccella*, *Mesosaccella*, *Indogrammatodon*, *Modiolus*, *Gervillela*, *Myophorella*, *Pinna*, *Nicaniella*, *Pecten*, *Eopecten*, *Camptonectes*, *Plagiostoma*, *Pseudolima*, *Oxytoma*, *Ctenostreon*, *Meleagrinella*, *Plicatula*, *Lopha*, *Nanogyra* and other oyster shells, *Entolium* (fairly large up to 2 cm high), *Bositra* (abundant), *Pholadomya*, *Bucardiomya*, *Pleuromya*, *Protocardia*, *Corbulomina*, *Trigonia*], brachiopods (rhynchonellids, terebratulids), echinoderms (*Pentacrinites*, echinoderm spines), scaphopods, *Cycloserpula*, *Tetraserpula*, *Donoserpula*, belemnites (occasionally showing a preferred orientation, at some levels encrusted by serpulids), ammonites (occasionally encrusted by serpulids), trace fossils [*Zoophycos*, *Planolites*, *Chondrites* (abundant), *Phycodes*, *Thalassinoides*], wood fragments, *etc.*

Petrographically, ooids, micro-oncoids (0.54–2.00 mm), echinoderm plates, foraminifers and other bioclasts, peloids, intraclasts, *etc*. have been recorded.

The sediment grain-size, composition, bioturbation and rich high diversity of fossil associations suggest a fully marine and carbonate rich depositional environment in the offshore transition zone above storm wave-base. The preferred orientation of belemnite guards and their abrasion and encrustation by serpulids suggest their transportation and long residence time in a sediment starved basin, and deposition in high-energy conditions under the influence of currents. The concentration of the shells forming shell beds, the occurrence of isolated single valves of rhynchonellids, and the erosional lower and upper bed surfaces suggest storm deposits followed by winnowing of sediments. The irregular concentration of ooids suggests a fluctuating energy level. The presence of an occasional bioturbated unit between two shell beds also suggests the intermittent lowering of energy level.

The presence of *Chondrites* may indicate temporary oxygen-depleted conditions (particularly, deeper in the sediment). Micro-oncoids suggest, at least periodically, warm and well-lit conditions of deposition. The overall picture presented by the facies suggests that it was deposited in fully marine, carbonate rich, sediment starved, low to high fluctuating energy region, alternating under the influence of currents in an offshore transition zone very near to storm wave-base.

FACIES UNIT 3
Low angle, cross-bedded, clayey, silty marlstones with interbeds of fine-grained calcareous sandstones to sandy packstones

This facies unit has been recorded 11 km west of Jaisalmer (locality 2; L2 in Fig. 2) overlying facies unit 1 (described above). It is one of the most unique facies in the sense of the gradual upward change of the succession from low angle cross-bedded clayey, silty marlstone with 2–12 cm thick interbeds of fine-grained calcareous sandstones (beds nos 25–27, S4 in Fig. 4) to low angle cross-bedded, fine-grained calcareous sandstone, and then to sandy packstone (beds nos 28–33, S4 in Fig. 4). The beds are poorly cemented and show gradational boundaries (Pl. 5: 1). The interbeds of fine-grained calcareous sandstone gradually become thicker, more calcareous and more cemented upwards and show distinct bedding surfaces in the younger deposits. The beds of the older deposits (*i.e.* clayey, silty marlstones) have not yielded any fossils, whereas due to the hard and indurate nature of the younger part of the succession, body fossils could not be collected. However, vertical burrows and *Taenidium* have been recorded from the lower surface of the topmost unit (Pl. 6: 1).

As revealed by ammonites in the overlying deposits (facies unit 4) discussed below and by the correlation of the underlying facies (facies unit 1), exposed both at the Kuldhar River-section (locality L1; S1–S3) and 11 km west of Jaisalmer (locality L2; S4), the older deposits of this facies (facies unit 3) correspond to facies unit 2 exposed in the Kuldhar River-section (locality L1) overlying facies unit 1.

The topmost *c.* 30 cm of the facies unit is exposed in the river-bed at the Damodra-Jajiya road crossing, 6 km south of Damodra Village (locality L3; L3 in Fig. 2; section S5, beds nos 1–2, S5 in Fig. 4). Here the topmost surface is a hardground surface (H.G.V), characterized by well-cemented rudstone with an upper bored and erosional surface (Pl. 7: 3) encrusted with oyster shells. The oyster shells are mostly abraded. Due to erosion, an abraded surface with large pebbles of the underlying bed of well cemented calcareous mudstone (bed no. 1, S5 in Fig. 4) is exposed as windows in the erosional surface (Pl. 7: 2). This erosional hardground surface has the appearance of a megarippled surface (Pl. 7: 1), however, a close look of the microfacies, which partly consists of micrite, does not allow its interpretation as megaripples. It has been interpreted as synsedimentary erosion of the hardground surface, which resulted in the formation of linear grooves and crests oriented parallel to the current direction. The crests are flat and the sides are steep with a sharp edge, rather with gently dipping curved sides as one expects in megaripples (Pl. 7: 3). The remnants of oyster shells also suggest strong erosion.

Quartz grains are silt to medium sand grain in size and subangular to subrounded in shape within fine-grained calcareous sandstone. A few ooids have also been recorded. Petrographically, the sandy packstone is a quartz biopelsparite. In general, echinoderm plates and spines, oyster shells, ostracods, sponges, algal mats, foraminifera, bivalve shells and microsparitic, sparitic, ferruginous cements have been recorded in the microfacies. Petrographically, the topmost unit with a hardground surface is an oobiomicrite to biomicrite. In this microfacies quartz grains are silt to fine sand grain sized, subangular to subrounded. Ooids and bioclasts are locally up to 40%. The fossil components recorded in the microfacies are bivalve shells, echinoderm plates and spines, and ostracods.

The clayey, silty marlstones with interbeds of fine-grained calcareous sandstones in the basal part suggest cyclicity in the depositional environment, perhaps due to climatic change. Keeping in mind the total time involved in the deposition of this part of the deposit (the time evaluation has been based on ammonites recorded from the overlying deposits of facies unit 4 and from the comparable conformable lateral sequence exposed in the Kuldhar section, locality L1, one might compare these cycles with the “Precession” cycle of Milankovich (*i.e.* of 21 ka duration). The persistent low angle cross-bedding in the facies suggest offshore and depth above fairweather wave-base. The gradual change from clayey, silty marlstone with interbeds of fine-grained calcareous sandstones in the basal part to sandy packstone in the younger part suggest an increase of the energy level upwards. The thick, massive, low angle cross-bedded, fine-grained calcareous sandstone/sandy packstone (bed no. 32) near the top of the facies suggests maximum water energy well above the fairweather wave-base. The vertical burrows (Pl. 6: 1) have not been fully understood; however, the *Taenidium* suggests a coastal depositional environment.

The upward thickening of beds, microfacies, biotic components, hardground surface and intensive erosional surface at the top suggest storm-dominated high energy fully marine conditions in the distal part of the basin, probably between the lower shoreface and the offshore transition zone, at or above the storm wave-base, very much similar to the conditions during the deposition of facies 1 (see above).

FACIES UNIT 4
Partly bioturbated and low angle cross-bedded pack- to rudstones and fine- to medium-grained calcareous sandstones

The best outcrop of the facies unit (maximum thickness 10.55 m) can be seen exposed in the riverbed, about 6 km south of Damodra Village crossing Damodra-Jajiya road, to Jajiya scarp near Jajiya Village (section S5 at locality L3, see Fig. 2 and beds nos 3–13 in S5 in Fig. 4). The facies is also exposed at the top of the section 11 km west of Jaisalmer (section S4; locality L2 see Fig. 2; and beds nos 34–39 in S4 in Fig. 4). The facies consists of ooid- and bioclast-bearing pack- to rudstone and ooid-bearing fine- to medium-grained calcareous sandstone. The limestone beds are bioturbated in the lower part whereas in the upper part they are cross-bedded (Pl. 5: 2). A single sandstone bed in the entire section is also cross-bedded. Occasional ripplemarks have also been recorded. This sandstone bed in S5 can be subdivided into two parts on the basis of primary sedimentary structure, degree of cementation, colour, presence/absence of shell fragments and an uneven and sharp planar surface between them (note beds nos 6–7 in S5, bed no. 37 in S4 in Fig. 4). Otherwise also erosional surfaces between the beds and within the beds are quite common (Pl. 7: 4). The facies in general is fossiliferous, and most fossils are confined to the bioturbated packstone beds. In general, the fossils are abraded, encrusted with oysters and bored (borings seen particularly in belemnites). They appear as a para-autochthonous assemblage. The fossil assemblage consists of bivalves: oyster shells, *Orthotrigonia*, *Sphaeara*, *Pseudolima*, *Ctenostreon*, *Plagiostoma*, *Plicatula*, pectinids, *Corbula* and other articulated bivalves, brachiopods: terebratulids (common), articulated and disarticulated dorsal valve large and small rhynchonellids (common), turreted gastropods (Pl. 5: 3), cephalopods: belemnites, ammonoids (*Hecticoceras*, *Epimayites*, *Dichotomosphinctes* and other perisphinctids), echinoderm spines (abundant), echinoid shell fragments, crinoids ossicles, corals (reworked): solitary (?*Epistreptophyllum*) and colonial (diameters 1.5–10.0 cm) (plocoid – *Stylina kachensis*; Pl. 5: 4; cerioid – monocentric to bicentric), serpulids and trace fossils representing the pre-consolidation/lithification stage: *Thalassinoides*, *Planolites* and *Zoophycos*.

Petrographically, the rudstones range from a quartz oobiosparite to a biooomicrite. Quartz grains are silt to medium-grain, subangular to subrounded, up to 30%. The bioclasts and ooids are up to 40%, whereas peloids are less than 5%. The biotic elements recognized in the thin sections are echinoderm plates and spines (abundant), bryozoans, solitary corals, ostracods, foraminifers, gastropods, bivalves (mostly oyster shells), dasycladacean algae, rhynchonellids and other brachiopods. In the sandstone the quartz grains are fine- to medium-grain, subangular to subrounded, with bryozoans, ostracods, echinoderm spines, ooids up to 20–30% and bioclasts up to 10%. The cement is microsparite.

The pack- to rudstone and fine- to medium-grained calcareous sandstone beds with sharp and uneven erosional surfaces, low angle cross-bedding, ripple surfaces, *etc*. suggest high-energy depositional conditions above fair weather wave-base dominated by storm action. The bioturbated beds suggest deposition at a depth below fair weather wave-base.

The mixing of ammonites (*e.g. Hecticoceras* and *Dichotomosphinctes*) in bed no. 34 of S4 and beds nos 3 and 4 of S5 suggests the condensed deposition of the sediments from the Late Callovian to the Middle Oxfordian due to sediment starving in the basin at the maximum flooding zone. The abrasion, borings and encrustations also suggest a long residence period of the shells before final burial. The rich fossil assemblage and high diversity of marine fauna suggest a fully marine environment for the organisms.

The only cross-bedded sandstone unit in the entire section with an uneven and erosional surface in the middle and a sharp base abruptly above ooid bearing packstone suggests regression, either due to sudden sea-level fall or due to sudden increase of terrestrial sediment influx. In brief, it can be interpreted that the environment during the deposition of facies no. 4 was very rapidly fluctuating between lower shore face and offshore transition zone above storm wave-base in continuation of facies unit 3.

BIOSTRATIGRAPHY OF THE CALLOVIAN AND OXFORDIAN SEDIMENTS OF THE JAISALMER BASIN

As mentioned above, the Callovian and Oxfordian sediments of the Jaisalmer Basin consists of both siliciclastic and carbonate sediments. The siliciclastic sediments are barely fossiliferous; however, bar a few, most of the calcareous beds are richly fossiliferous. The dominant, frequently recorded fossils groups are: bivalves, ammonoides, belemnites, brachiopods, gastropods, echinoderms, corals, foraminifers, ostracods, calcareous nannoplankton and trace-fossils (Sahni, 1955; Sahni, Bhatnagar, 1958; Lubimova *et al.*, 1960; Subbotina *et al.*, 1960; Srivastava, 1966; Singh, Jaikrishna, 1969; Bhatia, Mannikeri, 1976; Jaikrishna, 1979, 1980a, b, 1983, 1987; Kumar, 1979; Singh, Mishra, 1980; Kachhara, Jodhawat, 1981; Garg, Singh, 1983, 1986; Kalia, Chowdhary, 1983; Kalia, Roy, 1989; Chatterjee, 1990; Ghosh, 1990; Pandey, Jaikrishna, 1996, Pandey *et al*., 2005, 2006a, b; Khosla *et al*., 2006; Pandey *et al*., 2009a). An integrated correlation of ammonoid and foraminiferal biozones (Jaikrishna, 1979; Kalia, Chowdhury, 1983; Dave, Chatterjee, 1996) does not add any better precision to the ammonite biostratigraphy of the Callovian to Oxfordian sediments. The up-to-date summary of ammonite biostratigraphy of Callovian to Oxfordian sediments of the Jaisalmer Basin and its correlation with those of the neighbouring Kachchh Basin emerged from the pioneer works of Jaikrishna (1979, 1987) and subsequent works of Chatterjee (1990), Dave and Chatterjee (1996), and Prasad (2006) has been given in Table 2.

SEDIMENTARY CYCLES IN THE CALLOVIAN AND OXFORDIAN SEDIMENTS OF THE JAISALMER BASIN

Sedimentary cycles are broadly distinguished on the basis of repetition of beds or sets of beds. These changes have been interpreted as to corresponding to periodic changes in energy level, sediment supply, sediment composition, nutrition, *etc*. The four facies units described above represent the most general changes, but within these four facies units one can distinguish subordinate cycles, identified with seven depositional sequences (Figs 3, 4).

The Callovian and Oxfordian sediments of the Jaisalmer Basin display coarsening upward sedimentary cycles. The youngest part of most of the coarsening upward cycles usually represents a thick (up to 2 m in thickness) calcareous bed, predominantly pack- to rudstone, or hummocky cross-stratified beds or a hardground surface. As these cycles clearly represent the relative sea-level changes, the authors propose to introduce sequence stratigraphy terminology. In terms of sequence stratigraphy, these sedimentary cycles possibly correspond to a transgressive systems tracts and highstand systems tracts, building together depositional sequences. The Jaisalmer Basin being a shelf basin shows the sedimentary sequences consisting of TST and HSTs only. The LST time is represented by a stratigraphic gap at the sequence boundaries. The top of each HST (top of a calcareous thick bed) is a sequence boundary (in the same time boundary between HST and following TST). These sequences and systems tracts consist of parasequences. Totally, 35 parasequences have been grouped into seven depositional sequences. The stacking pattern of the parasequences and the absence of any major change in the tectonic setting of the basin suggest that eustatic changes have played a main role in the sediment supply and control of the relative sea level changes, possibly also involving climatic changes. Either sedimentary cycles or the sequence cycles can be easily traced and compared in all the three localities, each of which is about six to 10 km away from each other.

SEQUENCES 1 AND 2

The oldest parasequence (no. 1) of sequence 1 is recorded only partly at the base of the Kuldhar River-section (locality L1; see Figs 3, 4) about 1.30 m below the first hardground surface. It is a fine-grained calcareous sandstone with bioclasts and oyster shell fragments. A thin ooid and intraclast-bearing grainstone with a sharp base and a massive thick richly fossiliferous, trough cross-bedded bed of ooid, bioclast and quartz grain-bearing packstone (parasequence 2) with a hardground wave megarippled surface follow it. From this parasequence, Jain (2007, 2008) recorded the Late Bathonian association of *Sivajiceras congener* (Waagen) and *Macrocephalites triangularis* (Spath). This association in the adjoining Kachchh Basin also marks the Late Bathonian (Callomon, 1993). Based on their stratigraphic position above parasequence (no. 1), these two beds (beds nos 2–3, Figs 3, 4) have been interpreted here as a transgressive succession (TST) of sequence 2 lying on a transgressive surface/sequence boundary (sb). The positions of sequence boundaries (sb) merged with transgressive surfaces (ts) and maximum flooding surfaces (mfs). The comparable beds in the section 11 km west of Jaisalmer (locality L2) consist of thin, poorly fossiliferous, pack- to wackstone beds with sharp erosional surfaces (beds nos 1–10, Fig. 4). At this locality too, the top surface is a hardground, characterized by an uneven eroded surface encrusted with oyster shells, containing also an earlier trace fossil assemblage of vertical burrows and long, bifurcating *Rhizocorallium irregulare*. Occasionally erosional surfaces are followed by a bed of packstone with bored pebbles, which shows graded fining upward sand-sized (up to 2 mm) parallel layers of shell and argillaceous intraclasts suggesting of current action, caused possibly by a storm. As evident from the lithology and sedimentary structures the latter (locality L2) is distally located as far as water energy and siliciclastic input are concerned.

In the Kuldhar River-section, the stratigraphic sequence above parasequence no. 2 (*i.e.* HST, beds nos 4–17, see S1 in Fig. 3) shows facies typical of the storm-dominated near shore zone, characterized by thin beds of fossiliferous, bioturbated wackstones, packstones and silty marls, mostly with sharp surfaces (occasionally grading each into other), some with shell concentrations, reworked and bored clasts with two hardground surfaces near the base. The hardground surfaces are heavily bored and encrusted by large oyster shells and overlain by well-defined iron crusts, which laterally are surrounded by stromatolitic crust. Based on the flooding surfaces indicated in the Kuldhar River-section, more than 11 parasequences can be tentatively recognized (see parasequence nos 3–13 in Fig. 3).

At the locality 11 km west of Jaisalmer (locality L2), the comparable HST is characterized by two facies: (A) the older is poorly fossiliferous, low angle cross-laminated/bedded, partly bioturbated calcareous mudstones (bed no. 11 – lower part of bed no. 17) in the lower part, hummocky cross-bedded, mud- to pack- to rudstones with sharp, uneven upper surfaces and at least two erosional surfaces and graded bedding (upper part of bed no. 17 – bed no. 18; S4 in Fig. 4) in the middle part, and partially bioturbated mud- to packstones with a hardground surface at the top in the upper part (beds nos 19–24 in S4 in Fig. 4). The hardground surface is uneven with undercuts and bored, encrusted with oyster shells. A thin layer (up to 2 mm) of ferruginous sandstone forming a crust on the hardground and filling the borings occurs; (B) the younger facies is characterized by low angle cross-bedded clayey, silty marlstone with interbeds of fine-grained calcareous sandstones; each interbed has sharp and uneven upper and lower surfaces. The top beds have shell concentrations (see beds nos 25–28 in S4 in Fig. 4). At locality L2, within the HST, 17 parasequences have been recognized (see parasequence nos 3–19; S4 in Fig. 4). Broadly the HST at the two outcrops can be correlated, however it is difficult to compare the individual parasequences at both the localities, particularly when the individual storm beds in the upper part of the Kuldhar River-section are laterally not traceable due to the soft nature of the facies (Fig. 4). Further, the sandy nature of the younger part of the facies in locality L2, *i.e.* 11 km west of Jaisalmer, in comparison to Kuldhar River-section (locality L1) means that evidence of storm action in the beds is not very conspicuous except for the sharp upper and lower surfaces.

The oldest parasequence (no. 1) recorded only partly at the base of the Kuldhar River-section (locality L1; see Fig. 3) is the youngest parasequence preserved corresponding to the older sequence (Bathonian); it may be designated here as sequence 1. The two latter systems tracts discussed above correspond to a sequence (Upper Bathonian–Lower Callovian), designated here as sequence 2.

SEQUENCE 3

The following parasequence no. 20 (at locality 2), characterized by sandy packstone with shell concentration and loadcasts at the base (S4 in Fig. 4; Pl. 6: 2) in the lower part, and low-angle cross-bedded, well cemented, silt to grit-sized calcareous sandstone with shell fragments in the upper part (beds nos 29–30, S4 in Fig. 4), corresponds to the TST of the next sequence. The next parasequence no. 21, which is characterized by low-angle cross-bedded, well cemented, fine-grained calcareous sandstone with scattered shells in the lower part, and with well cemented, fine-grained calcareous sandstone (40 cm) with hyperrelief (Pl. 6: 1) plus vertical burrow tubes and *Taenidium* in the upper part, corresponds to the HST with a time interval when the basin was sediment starved, perhaps due to dry climatic conditions. These two system tracts have been designated as sequence 3. The sequence has been studied only in locality L2, 11 km west of Jaisalmer.

SEQUENCE 4

The sequence 4 (bed no. 32, parasequence no. 23; TST and bed no. 33, parasequence no. 24; HST, see S4 in Fig. 4) is the next sequence with a depositional setting more or less similar to those of sequence 3. Keeping in view the sharp bedding surfaces, the role of climate in changing the composition of the beds may be ruled out. This sequence too has been studied only in locality L2, 11 km west of Jaisalmer.

SEQUENCE 5

The sediments of the next sequence cycle are particularly well exposed in the Jajiya River and cliff sections 6 km south of Damodar Village across the Damodar–Jajiya road (locality L3 in Fig. 2). A well-cemented rudstone with a hardground upper surface characterizes a TST (parasequence no. 25, see bed no. 2, S5 in Fig. 4). The hardground surface is bored and encrusted with oyster shells. The surface shows conspicuous erosion. A thin bed of richly fossiliferous bioturbated, well-cemented, ooid-bearing, ferruginous, silty wackestone, characterizes the younger part of the cycle. This bed is interpreted as the MFZ of overlying the HST (bed no. 3, parasequence no. 26, see S5 in Fig. 4). The last two parasequences have been designated as sequence 5.

SEQUENCE 6

Sequence 6 is characteristically richly fossiliferous. The lower part is a bioturbated, moderately to well-cemented, ooid-, bioclast-, silt-sized quartz grain-bearing ferruginous grainstone (bed no. 4, S5 in Fig. 4), which has been designated here as a TST, whereas the upper part, characterized by bioturbated, poorly cemented, ooid- and bioclast- bearing packstone, concretionary in the upper part, has been referred to the MFZ of the following HST. The TST sediments are exposed only in the Jajiya River- and scarp-sections (mentioned above), whereas the MFZ part is represented at two localities: locality L3, *i.e.* at Jajiya River- and scarp-sections (bed no. 5, S5 in Fig. 4) and locality L2, 11 km west of Jaisalmer (beds nos 34–36, S4 in Fig. 4). At both the localities the MFZ sediments form a condensed zone as revealed by the ammonite assemblage (Fig. 4). The parasequence nos 26–28 could have been considered to belong to one MFZ, but the decease of energy from parasequence nos 27 to 28 has been interpreted as due to increase in accommodation, perhaps due to sea-level rise.

The overlying sediments in both the localities (L2 and L3) are low-angle cross-bedded to trough cross-bedded, moderately to well cemented, poorly sorted, fine- to medium-grained calcareous sandstone with shell fragments, occasional nodules and sharp upper and lower surfaces. This sudden change in lithology suggests lowering of the sea-level, *i.e.* a progradational HST. From the trend of the change of the facies discussed above it seems that this bed was deposited during forced regression, *i.e.* FSST. This has been assigned to parasequence no. 29 (beds nos 6–7, S5 in Fig. 4 and bed no. 37, S4 in Fig. 4; also see Fig. 4 for correlation). This parasequence corresponds to the upper part of sequence 6.

SEQUENCE 7

The overlying sediments (beds nos 38–39, S4 in Fig. 4 and beds nos 8–13, S5 in Fig. 4) have been deposited during the next transgressive event. The sediments do not represent a single bed, rather several thin beds of brownish yellow, fossiliferous, low-angle cross-bedded, occasionally bioturbated, well cemented ooid- and bioclast-bearing pack- to rudstones, each with a sharp base and top. This whole sequence has been divided into six parasequences (nos 30–35) on the basis of flooding surfaces, which together have been assigned to a TST of sequence 7. This sequence of parasequence tops the area around 11 km southwest and west of Jaisalmer city.

CONCLUSIONS

Cyclicity in sedimentary deposits is a well known phenomenon but as a tool which can be used to distinguish depositional sequences in the field, it can still be better demonstrated by adding information from several semi-explored sedimentary basins, such as the pericratonic basin of Jaisalmer situated to the west of the Aravalli axis on the western part of the Indian Craton. The Callovian-Oxfordian sequence of the Jaisalmer Basin examined in the present study displays very well shallowing upward sedimentary hemicycles. There are indicators whose exclusive or combined repeated occurrence determines sedimentary cyclicity. These indicators are: (a) thick-bedded, well cemented, medium to coarse-grain calcareous sandstones/pack- to rudstones at the top of the thinly bedded fine-grain sediments, (b) poorly cemented sediments overlain by well cemented sediments or the reverse (affect of diagenetic changes due to change in sediment composition), (c) alternate occurrence of carbonate and siliciclastic sediments or fine- and coarse-grain sediments, (d) hummocky cross-stratified beds at the top of the coarsening upward sequence and followed by low energy, bioturbated fine-grain sediments, (e) alternate occurrence of shell-beds and siliciclastic or carbonate sediments, (f) alternate occurrence of bioturbated and cross-bedded units, and (g) hardgrounds following thinly bedded bioturbated fine-grain sediments. These facies occur successively building sedimentary cycles of various orders, from parasequences to more general cycles, identified with depositional sequences. The boundaries of these cycles are of correlative significance. In particular, the hardground surfaces of regional extent can be useful in demarcating tops of sedimentary cycles, parasequences or sequences. The sediments demonstrate alternate low-energy and high-energy depositional environments. The beds deposited in low energy invariably are fine-grained and bioturbated, whereas those of high energy are coarser-grained and cross-bedded. The mineralogical composition, percentage of allochemical components, taphonomic and biostrationomic features in these beds depend upon their location in the basin profile and the events of deposition with which they are associated. A combined study of the sedimentary facies, their depositional environments and the sequence stratigraphy revealed that the lower beds of each shallowing upward hemicycle had been deposited either in the transgressive stage (including the maximum flooding zone) when the basin is sediment starved or in the low energy time intervals in between storm dominated TST or HST, whereas the uppermost bed is either a bed representing mostly the TST following the sequence boundary or the topmost bed of the HST. Sequence boundaries are identified with the tops of the high-energy deposits at the tops of HST's and they are immediately followed by transgressive surfaces, commencing the TST of the next sequence. In addition, coarse-grained, high-energy sediments are associated with erosional surfaces and sediments with graded bedding deposited during storm events during HST's. Terrigenous siliciclastic sediments are rare and deposited during progradational highstand system tracts in foreshore to shoreface environments. Bioturbated condensed units are very rich in fossils and deposited in sediment starved basins representing the TST and particularly maximum flooding zones.

The Callovian-Oxfordian sediments deposited in the Jaisalmer Basin during trangressive systems tracts consist of fossiliferous, cross-bedded packstones, grainstones and rudstones with erosional surfaces. The unit either mostly rests on a transgressive surface upon arenaceous facies or upon the finer grained calcareous sediments of the HST. The sediments of the highstand systems tract, wherever there is a complete sedimentary record, show a sequence with coarsening or increasing energy level upwards. A sudden shallowing of the basin due to regression (falling stage system tract; FSST) has also been observed (localities L2 and L3, parasequence no. 29, S5 in Fig. 4).

The Jaisalmer Basin sediments were laid down in a shelf environment, and the LST systems tracts are not represented as deposits in this area. This time is concealed within omission surfaces at the sequence boundaries. Generally, 35 fourth order parasequences bounded by flooding surfaces have been grouped into seven sequences of third order. The base of each transgressive unit and top of each HST is a sequence boundary merging with the transgressive surface commencing the next sequence. Seven sequences have been distinguished within four more general facies units, which are mere lithostratigraphical units. The character of the parasequences and absence of any major change in the tectonic setting in the basin suggest that eustatic changes (influenced possibly by climatic changes) have played a principle role in the relative sea-level change and sediment supply. Both depositional sequences and parasequences can be easily traced and compared in all three localities, each of which is about six to 10 km away from each other. On comparison with the global sea-level change during Callovian and Oxfordian stages and their 3rd-Order Sequences given by Haq *et al.* (1987) and Hardenbol *et al*. (1998) it can be inferred that sedimentary record of the Callovian-Oxfordian sediments of the Jaisalmer Basin is incomplete.

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Plates

PLATE 1

Fig. 1. Panoramic view of the ruined village of Kuldhar. In the center is an old temple of Kuldhar Village (near locality L1 in Fig. 2)

Fig. 2. Mega-rippled surface of packstone (S1, bed no. 3), exposed as a platform on the south of Kuldhar Village, eastern side of the Kuldhar River (locality L1), Kuldhar Member, Jaisalmer Formation (scale: height of the person – 167 cm).

Fig. 3. Oyster encrustations on the hardground surface of the packstone (S1, bed no. 3), locality same as above (scale: hammer – 32.5 cm)

Fig. 4. A close-up view of an oyster shell encrusted on the hardground surface of the packstone (bed no. 3), locality same as above (scale: ball pen – 14.0 cm)

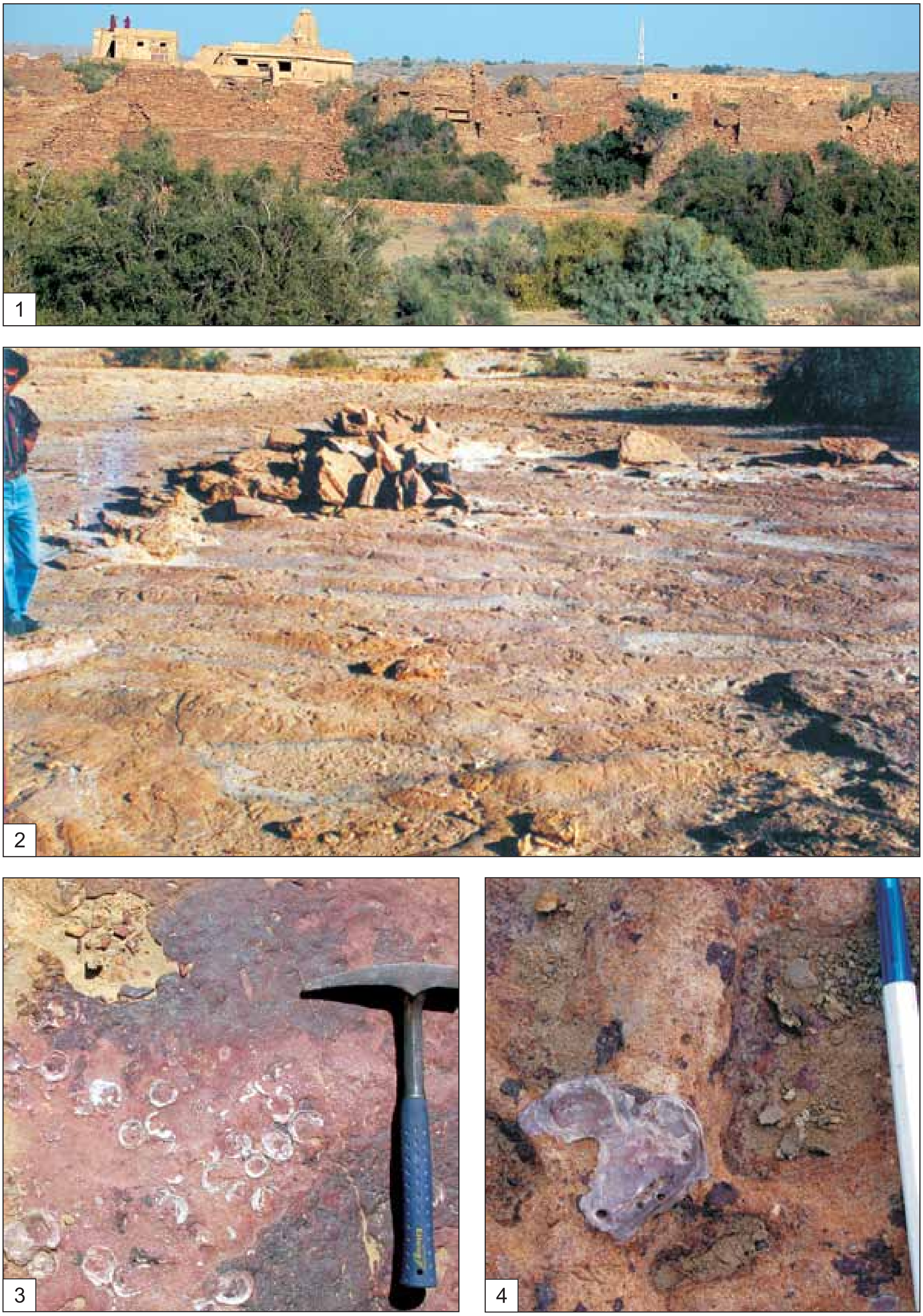

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PLATE 2

Fig. 1. Terebratulids in pavement on the upper surface of wackestone (S1, bed no. 6), exposed on the south of Kuldhar Village, on the eastern side and river bed of the Kuldhar River (locality L1), Kuldhar Member, Jaisalmer Formation (scale: ball pen – 14.0 cm)

Fig. 2. A bone fossil on the upper surface of the oopackstone (S1) exposed south of Kuldhar Village in the river bed of the Kuldhar River, Kuldhar River-section, locality same as above, Kuldhar Member, Jaisalmer Formation. Since the sequence here is interrupted by faults it was difficult to ascertain the bed number for this particular bed (scale: hammer – 32.5 cm)

Fig. 3. A close-up view of a bioturbated strongly iron oolitic packstone rich in fossils, showing the Middle Callovian ammonite genus *Reineckeia* occurring with belemnite guards, note the parallel arrangements of belemnite guards (arrowed); locality same as above, Kuldhar Member, Jaisalmer Formation, exposed about a kilometer southwest of the Kuldhar Village on the western side of the Kuldhar River. This bed can be compared laterally with bed no. 6 (S3 in Fig. 4) also exposed along the scarp on the western side of the river, but nearer to Kuldhar Village (scale: hammer – 32.5 cm)

Fig. 4. A complete section (S2 in Fig. 4) of poorly cemented silty marly beds with thin, occasionally oolitic, fossiliferous, ammonite bearing interbeds (upper part of Kuldhar Member, Jaisalmer Formation) across the Kuldhar River, just south of Kuldhar Village (scale: height of the person – 160 cm)

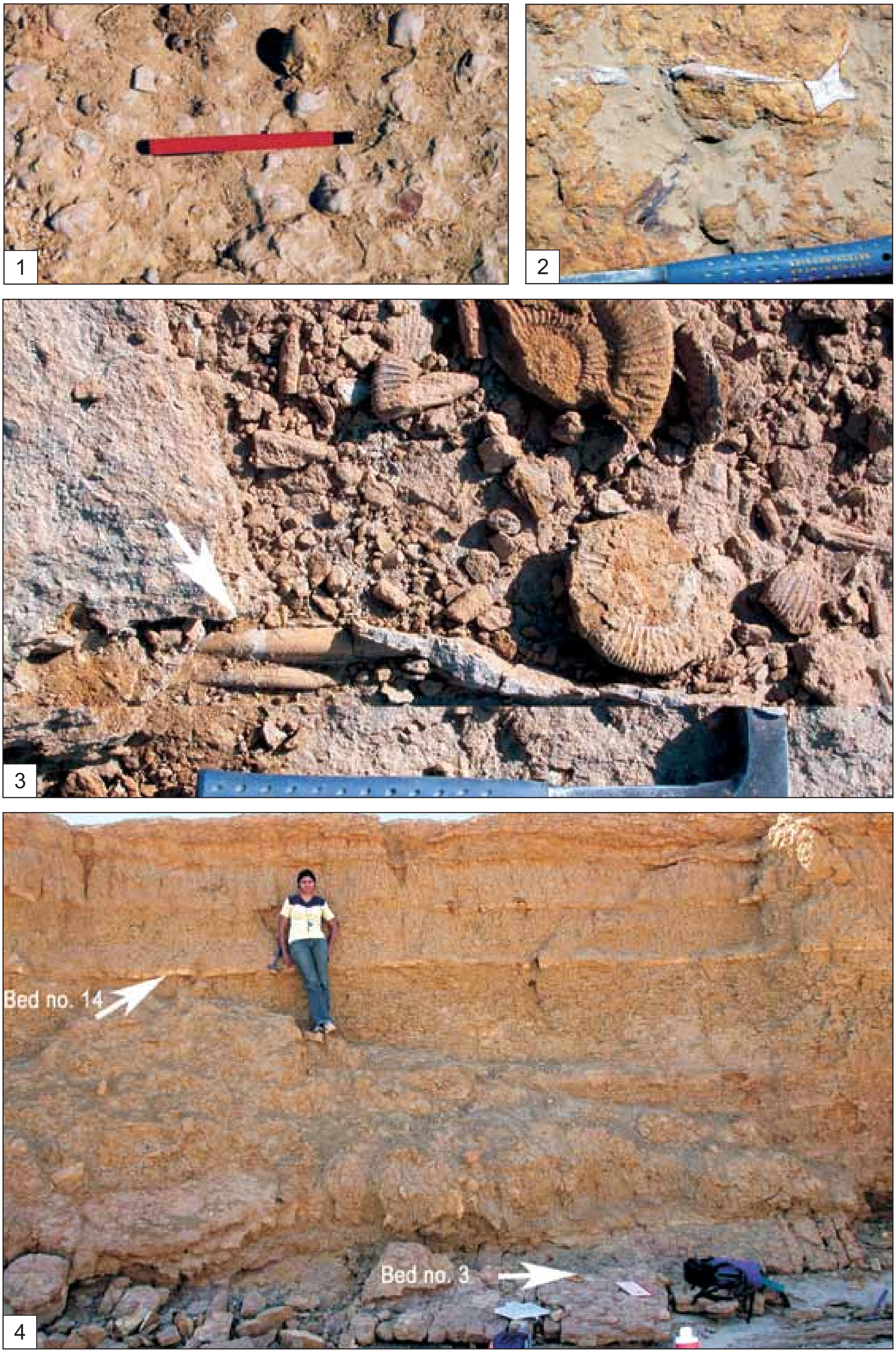
1
2
3
Bed no. 14
Bed no. 3
4

PLATE 3

Fig. 1. A panoramic view of the Kuldhar, Jajiya-section (S4, see Fig. 6) of the Kuldhar Member exposed 11 km west of Jaisalmer on the Jaisalmer-Sam Road (locality L2). Note the thinly bedded limestone beds at the base (light coloured, bed nos. 1–24) overlain by brownish thick sandstone. The lower part of the section beautifully displays at least three coarsening upward sedimentary hemicycles (scale: height of the person – 167 cm)

Fig. 2. A close up view of a hardground surface of packstone (S4, bed no. 10), which is bored and encrusted with oysters. Locality same as above (scale: hammer – 32.5 cm)

Fig. 3. A close up view of the bifurcated *Rhizocorallium irregulare* on the hardground surface of packstone (S4, bed no. 10). Locality same as above (scale: hammer – 32.5 cm)


1


2


3

PLATE 4

Fig. 1. A close-up view of a section showing at least two erosional surfaces and graded bedding (storm events) within mud- to wacke- to rudstone (bed no. 18), exposed at 11 km west of Jaisalmer on the Jaisalmer-Sam Road, Kuldhar, Jajiya-section (S4 at locality L2, Fig. 6), Kuldhar Member, Jaisalmer Formation (scale: hammer – 32.5 cm)

Fig. 2. Oysters encrusted on mud- to wackestone (hardground surface) (S4, bed no. 24). Locality same as above. Note remnants of a thin iron crust covering also the oyster shells (scale: cm scale)

Fig. 3. A close-up view of the lower part of the section (S4) showing its bedded nature, Kuldhar Member, Jaisalmer Formation. Locality same as above. Note lateral change in the thickness of the beds. The section very well displays hummocky cross-bedding (arrowed) (scale: height of the person – 160 cm)

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PLATE 5

Fig. 1. A section of silty marl to claystone beds (S4, bed nos. 25–27; Fig. 6) with thin interbeds (2–12 cm thick) of impersistent, rather variably thick, fine-grained calcareous sandstone overlain by a thick sandstone unit (S4, bed nos 28–33), exposed 11 km west of Jaisalmer on the Jaisalmer-Sam Road, Kuldhar, Jajiya-section (locality L2), Kuldhar and Jajiya members, Jaisalmer Formation (scale: average height of students – 175 cm)

Fig. 2. The low angle cross-bedded nature of the well cemented oobiopackstone to rudstone (S4, bed no. 38), Jajiya Member, Jaisalmer Formation. Locality same as above (scale: hammer – 32.5 cm)

Fig. 3. A close-up view of a turreted gastropod on the upper surface of rudstone (S4, bed no. 38). Locality same as above (scale: diameter of 5 Rupees coin – 2.2 cm)

Fig. 4. A close-up view of a reworked plocoid colonial coral, *Stylina kachhensis*, on the upper surface of oobiopack- to rudstone (S5, bed no. 13), Jajiya-section (locality L3), 6 Kilometers from Damodra Village, on the road from Damodar towards Jajiya Village (scale: diameter of 2 Rupees coin – 2.5 cm)

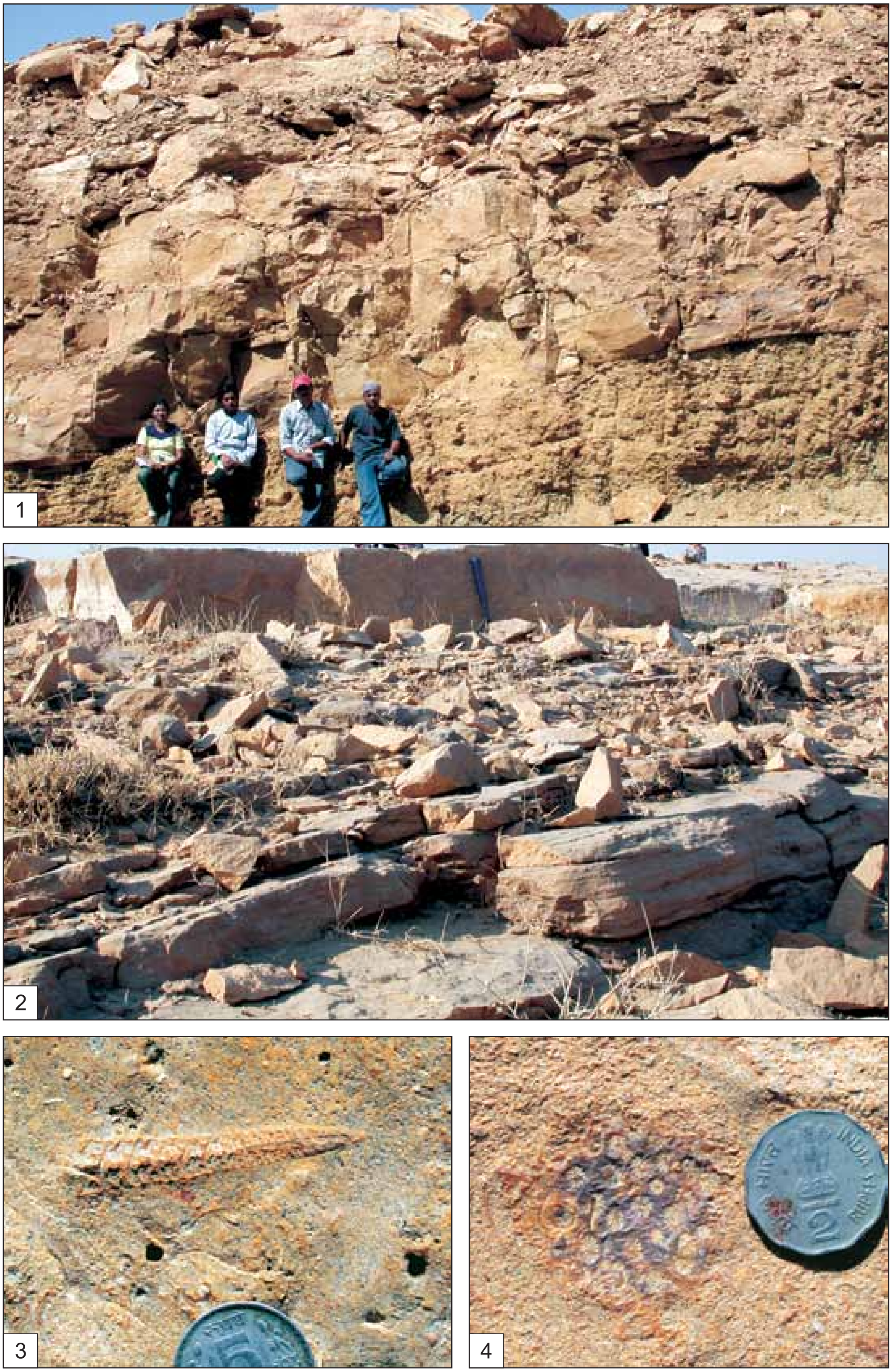

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PLATE 6

Fig. 1. A close-up view of the lower surface of bed no. 31 of S4 showing casts of vertical burrows and *Taenidium* (hyper-relief), seen at 11 km west of Jaisalmer on the Jaisalmer-Sam Road, Kuldhar, Jajiya-section (locality L2), Jajiya Members, Jaisalmer Formation (scale: hammer – 32.5 cm)

Fig. 2. A close-up view of the lower surface of bed no. 29 of S4 showing load casts. Locality same as above (scale: hammer – 32.5 cm)

1

2

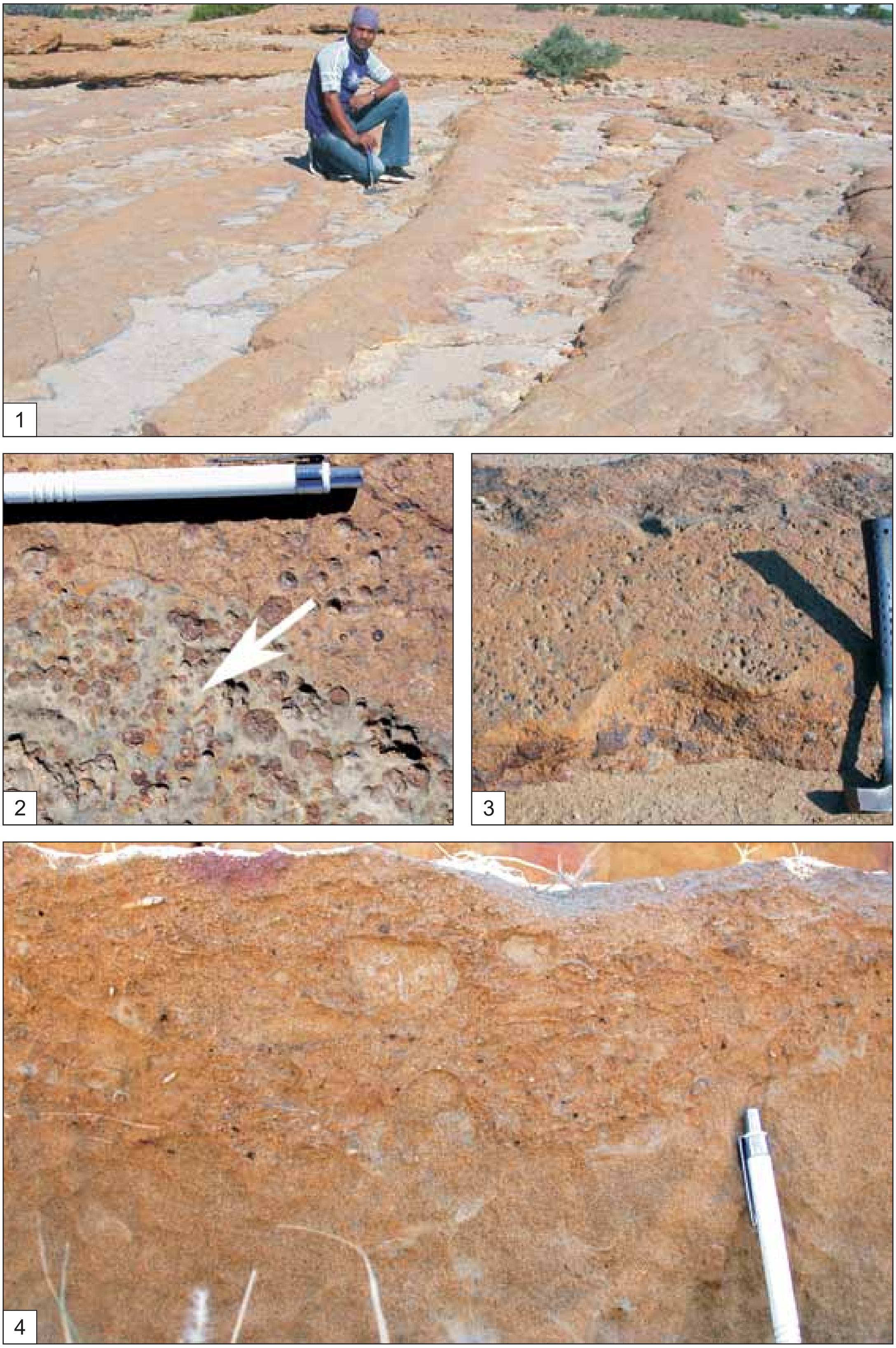
PLATE 7

Fig. 1. A view of a hardground surface (bed no. 2, S5 at locality L3) showing erosional lineaments. The feature gives the appearance of a megarippled surface. River bed outcrop, 6 km south of Damodar Village, on the road from Damodar towards Jajiya Village (scale: average height of the person – 175 cm)

Fig. 2. A close view of hardground surface (bed no. 2, S5) showing patches of the underlying bed of mudstone (S5, bed no. 1) as windows (arrowed). This has been formed due to uneven erosion of bed no. 1 before deposition of bed no. 2 and the subsequent erosion of much of the overlying rudstone (bed no. 2). Locality same as above (scale: ball pen – 14.0 cm)

Fig. 3. A close view of an eroded flat and bored hardground surface with steep sides. Note the sharp edge formed due to erosion during the Jurassic. Locality same as above (scale: hammer – 32.5 cm)

Fig. 4. A close view of a section of an erosional surface in the upper part of the Jajiya cliff-section (S5). Note the rudstone in the upper part with a sharp erosional base in the middle of the unit. 6 km south of Damodar Village, on the road from Damodar towards Jajiya Village (scale: ball pen – 14.0 cm)



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