Depositional history of the early part of the Jurassic succession on the Rajasthan Shelf, western India

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Abstract Part of the lowermost deposits of the Triassic to Early-mid Jurassic up to Bajocian sedimentary succession spread across the Rajasthan shelf on the western part of the Indian craton is found in the Jaisalmer Basin east of Jaisalmer with the best exposed sections along the Jodhpur-Jaisalmer Highway. Based on lithostratigraphic characteristics, the succession is divided into four Odhau and Tharit members of Lathi Formation and Hamair and Jayan members of Jaisalmer Formation. Six facies are defined from microfacies sedimentary structures, biotic components and depositional environments: 1) ferruginous pebbly, cross-bedded sandstone—high-energy fluvial, 2) cross-bedded, poorly sorted, fossil wood-bearing sandstone—high-energy terrestrial, with high influx of sediment and warm and humid climate, 3) cross-bedded, rarely bioturbated, alternating silt to fine-grained sandstone—fluctuating sedimentation rates and energy—nearshore, mesohaline embayment to lagoonal, 4) partly bioturbated, storm-dominated, mixed siliclastic-carbonate facies—fully marine, 5) low angle cross-laminated silt to fine-grained sandstone—nearshore, shallow water, above fair weather wave base, and 6) thick mudstones with mega-ripples and reworked coral heads—storm deposits representing the peak of first major marine transgression across the basin.

Keywords Jaisalmer Basin, sediments, basal Jurassic-Bajocian, microfacies, depositional environment.

The Rajasthan Shelf on the western part of the Indian craton forms the easternmost part of a large tectonic unit, the "Indo-Arabian geological province". Tectonically, the shelf is situated to the west of the Aravalli Range and has been divided into four Lathi, Bikaner-Nagaur Basin, the Pokhuran-Nachana High, the Jaisalmer Basin, and the Barmer-Sanchor Basin. Fig. 1.

1 Geological setting

The sedimentary sequences of the shelf can be divided broadly into two geological cycles, Late Palaeozoic and Permoo-Carboniferous to Triassic and Triassic and late Jurassic continental sediments are widespread on the Rajasthan Shelf and occur in all three basins. Similarly, Paleogene sediments are present in all three. The term Jaisalmer Basin has been hitherto restricted to the area west of the Bikaner-Nagaur Basin and the Pokhuran-Nachana High and north of the Barmer-Sanchor basins as well as to known Jurassic-Quaternary sediments exposed in the area around Jaisalmer. This definition is no longer tenable because of the possible continuity of the sedimentary strata beyond the present tectonic limit of the basin. Thus, "Jaisalmer Basin" should be used more in a geographical sense. Lithostratigraphically, the lower part of the Jurassic sequence exposed east of Jaisalmer city is the Golden City of Rajasthan has been grouped into two Lathi and Jaisalmer formations in ascending order, ranging from Triassic to Early Jurassic Bajocian to Oxfordian, Fig. 1, Table 1.

Here we concentrate on this lowermost part of the sedimentary succession. Although widespread in the Rajasthan shelf, a complete section is exposed only between kilometers 20 to 6 along the Jodhpur-Jaisalmer Highway National Highway No. 15 east of Jaisalmer.

2 Early Jurassic succession east of Jaisalmer

Lithostratigraphically, the early part of the Jur-
Fig. 1. Location map and structural elements of western Rajasthan a modified after Pandey and Davé and geological map of Jurassic formations of western Rajasthan b modified from Das Gupta.

Jurassic succession has been grouped into the Odania and Thait members of the Lathi Formation and the Hamira and Joyan members of the Jaisalmer Formation. The name Lathi Formation representing the earliest Jurassic sediments was given by Oldham after the village of Lathi 71°32′E 27°03′N on the Pokaran to Jaisalmer Road. The Jaisalmer Formation represents predominantly carbonate sediments overlying the continental siliciclastic sediments of the Lathi Formation. The original name of this formation, Jaisalmer Limestone, used by Oldham and Blanford was subsequently redefined as the Jaisalmer Formation by Swaminath et al. It has been divided lithostratigraphically into the Hamira, Joyan, Fort, Badabag, Kuldhar, and Jaiya members in ascending order. In the

studied section the youngest member of the Lathi Formation Thaïat Member is directly overlain by the Hamira Member of the Jaisalmer Formation □ Table 1 □.

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<th>Age</th>
<th>Index Guide Fossil</th>
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<td>Mokal Dungar Member</td>
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<td>Continental deposits</td>
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<td>Thaiit</td>
<td>Triassic Lower Jurassic</td>
<td>gymnosperm wood fossils</td>
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Older Formations

a Dr. Surendra Pras● pers. comm. to DKP of the Geological Survey of India collected one specimen of the Bathonian ammonite Clydoniceras from the basal beds of the Bada bag Member Jaisalmer Formation.


2.1 Odania Member

This member is typically exposed in the Lathi Odania 71°43'E 26°58'N section and starts with pebbly sandstone seen N and SE of Odania. The lithic units are low to high angle cross-bedded well cemented poorly sorted ferruginous sandstone with pebbles to poorly cemented and poorly sorted medium- to coarse-grained mica-bearing cross-bedded calcareous to ferruginous sandstone. Wood fragments and tree trunks are commonly found in this member for example at the Akal National Park 17 km E of Jaisalmer on the Jaisalmer-Barmer road.

2.2 Thaiit Member

Succeeding the Odania Member the sediments of the Thaiit Member are best exposed on the scarp to the W and NW of Thaiit village 71°04'E 26°56'N. The section consists of a sequence of white to gray poorly cemented fine-grained often calcareous sandstone variegated sandy siltstone and a red siltstone bed at the top persistently seen along the contact with the overlying Jaisalmer Formation. The upper part is also exposed along the Thaiit ridge which crosses the Jodhpur-Jaisalmer Highway about 16 km E of Jaisalmer and along the basal part of an outlier which is a southward extension of the Thaiit ridge best approached from the Jaisalmer-Barmer road 3 km N of the 13 km-milestone E of Jaisalmer. The outlier is truncated by a NW-trending fault.

2.3 Hamira Member

The member defined by Das Gupta and named after the village Hamira 71°05'E 27°00'N is characterized by yellow arenaceous limestone with fragmentary bivalves. It succeeds the Thaiit Member exposed along the upper part of the Thaiit ridge. According to him the Hamira Member a basal member of the Jaisalmer Formation has "inter-tonguing" relationship with the underlying Lathi Formation.

2.4 Joyan Member

Narayanan et al. defined this member which consists of mixed siliciastic and carbonate sediments with a maximum thickness between Sata-ki-Dhani and Soran-ki-Dhani WSW and NE of Joyan village 71°55'45'E 26°48'45"N. The part of the member is also exposed along the left side of the Jodhpur-Jaisalmer road between 15 km E of

Jaisalmer and Jaisalmer city. Here the deposits are predominantly poorly-to well cemented low angle cross-bedded occasionally bioturbated ferruginous to calcareous silt to medium-grained sandstones overlain by an approximately 70 cm-thick rudstone with a megarrippled surface and reworked coral heads of *Isactrea bernardiana* d’ Orbigny. The biotic components are shell pavement nuculids Trigonia corals *Rhizocorallium jenense* etc.

Kachhara and Jodhawa based on the bivalve fossil assemblage mentioned that in all probability the Joyan Member is Bajocian. The occurrence of the characteristic Bajocian coral *I. bernardiana* in the topmost bed of the member also refines the upper limit of the Joyan Member as Late Bajocian.

3 Depositional history

Based on the fine silty arkosic nature of the sandstones and the plant remains a stable continental environment of deposition has been deciphered by earlier workers for the lower part of Lathi Formation whereas based on the transitional relationship with the overlying marine Jaisalmer Formation a littoral environment of deposition has been suggested for the upper part of the Lathi Formation.

Microfacies sedimentary structures and biotic components of the sedimentary units in this early part of the Jurassic succession on the Rajasthan shelf exposed east of Jaisalmer are broadly distinguished into six facies the depositional environment of which are as follows.

3.1 Facies 1—Ferruginous pebbly cross-bedded sandstone

The beds of this facies are exposed in patches about 9 km SW of Pokhara best approached from the Pokhara-Jaisalmer Road from a left hand cut about 1 km from Pokhara. This is the oldest unit which consists of an about 40 cm-thick yellowish-ochre to different shades of brown low angle cross-bedded well cemented well sorted medium-grained ferruginous sandstone and a brown high angle cross-bedded well cemented poorly sorted ferruginous sandstone with pebbles of quartzite and chert up to 11.5 cm in diameter. Fig. a b c the angular to subangular quartz grains are densely packed.

Low and high angle cross-bedding suggests a high-energy depositional environment. The well-sort-
ed sandy components also suggest a high-energy condition and probably long transportation. However the arkosic nature of the sediments of this facies mentioned by earlier workers suggests immature sediments not transported long distance. The outcrop pattern sedimentary structures and mineral composition of the facies suggest for fluvial depositional environment near to the hinterland.

3.2 Facies 2—Cross-bedded poorly sorted fossil wood bearing sandstone

The facies is a low to high angle cross-bedded moderately cemented medium-to coarse-grained mi-
ca-bearing ferruginous\ calcarceous sandstone with
subangular to subrounded grains widely exposed in
Akal National Park\ see above\]. The estimated
thickness of the sandstone facies is more than 10 m.
Several pieces of gymnosperm fossil wood\ up to 13.4
m long with a diameter of 0.4 m\ have been found in
this facies\ Fig. 2 c\ d\ e. Often\ calcium carbonate
is concentrated as thin film over the surface of the
beds.

Like the previous one\ this facies also exhibits
low and high angle cross-bedding and suggests a
high-energy depositional environment. Poor sorting
and mixing of mica flakes surely indicate very high influx of
sediment\ with no time for sorting. Absence of
body fossils and the unknown origin for its ferrugi-
nous and calcareous nature open a Pandora’s Box regard-
ing this facies. The occurrence of large pieces of
fossil wood supports the nearness of land where gi-
gantic gymnosperm trees existed. The carbonate con-
centrations in the form of a thin film or concretions
suggest mobilization of carbonate during diagenesis.
Based on the cross-beddings\ poor sorting\ a common
occurrence of wood fossils and the absence of any oth-
er guiding evidence for the marine condition it can be
safely suggested for now that this facies represents a
high energy fluvial depositional condition with high
influx rate of sediments.

3.3 Facies 3—Cross-bedded\ rarely bioturbated\ al-
ternating silt and fine-grained sandstone

The facies is best exposed along the base of an
outlier\ exposed 3 km N from the 13 km stone from
Jaisalmer on the Jaisalmer-Barmer National Highway
NH15\ bed Nos. 1—13\ Figs. 3 and 4 a\b. It is also
exposed along the Thait ridge section at 16 km
E of Jaisalmer on the Jaisalmer-Jodhpur Road\ Figs.
3 c\d\ e\f\ a\b\ 6—9\ and along the base of three
scarp\ 6\ 11 and 15 km\ respectively\ E of
Jaisalmer on the right hand side of the Jaisalmer-
Jodhpur Road\ NH15\.

The facies is about 11 m thick unit of alternating
siltstones and fine-grained sandstones. A yellowish\ reddish-brown colour predominates\ Figs. 4 c\ d\ e
f\ a\b\ c. Except for bed No. 7\ outlier section\ which is a wedge-shaped\ high angle cross-bedded
fine-grained calcareous sandstone bed\ all the units
are either thinly laminated or bedded\ low angle
cross-bedded or bioturbated\ Fig. 5 a\b. Bed No. 2
Thait section\ shows convolute bedding\ Fig. 5
b. Individual beds can be easily recognized on the
basis of a sharp base and top. The beds are generally
poorly cemented. Only bed Nos. 2 and 5 in the outli-
er section and bed Nos. 5 and 6 in the Thait ridge
section are fossiliferous. The dominant body fossils in
order of abundance are nerineid gastropods\ fossil
wood\ up to 60 cm long\ Trigonia\ fossil bones and
other articulated bivalve shells\ oysters etc. Trace fossils in this facies are Thalassinoidea\ Gyro-
chorte and burrow tubes.

Predominance of ferruginous siliciclastic sedi-
ments\ wedge- and lensoid-shaped bodies\ occurrence of
mono-specific shallow infaunal nerineid gastropods
in association with fossil wood fragments\ fossil bones
and the very low biodiversity suggest nearshore\ shal-
low-\ mesohaline embayment to lagoonal conditions.
The low angle cross-bedding\ bioturbation and alter-
nation of silt and fine-grained sandy sediments and
sharp bases to the units suggest a fluctuating rate of
sedimentation and rapid change in water energy be-
tween low and moderate\ with water depth oscillating
rapidly between above and below the fair-weather
wave base. The wedge-shaped\ high angle cross-bed-
ded fine-grained sandstone suggest for a high energy
fluvial channel depositional environment for a short
interval.

3.4 Facies 4—Partly bioturbated\ storm-dominat-
ed\ mixed siliciclastic-carbonates

This facies\ bed Nos. 14—25\ about 6.60 m thick
overlies directly facies 3 in all four localities but
gradually diminishes in thickness towards the west
and southwest\ bed Nos. 14—25\ Figs. 3 a\b c
7—9. The facies begins with an intra-formational
conglomerate\ then follow\ in ascending order\ well-
cemented\ fine- to coarse-grained\ ferruginous con-
glomeratic sandstone\ silty wacke- to packstone with
an interbed of coarse-grained to gravelly gritstone
10 cm thick\ about 25 cm below the top of the unit.
The pebbles in this bed consist of siltstone showing cracks
filled with ferruginous material. The upper and lower
surfaces of the bed are sharp and uneven. The overly-
ing beds consist of bioturbated to low angle cross-lam-
inated\ hummocky cross-bedded silty calcareous mud-
stone to sandy packstone with silty calcareous mud-
stone interbeds\ with sharp and uneven bases\ Fig. 10 b
storm and inter-storm intercalations. The facies is
richly fossiliferous in the lower part. The biotic
components are Trigonia\ Orthotrigronia\ shallow
infaunal suspension feeders\ oysters epifaunal cem-
Fig. 3. Lithological section of Thalat Member facies 3 and Hamira Member facies 4 at outlier on Thalat Ridge 3 km north from 13 km milestone from Jaisalmer on the Jaisalmer-Bumrer National Highway NH15.
Fig. 4. a Panoramic view of the outlier section on Thaat Ridge [see Fig. 3]. The arrow marks the boundary between the Thaat Member[] Lathi Formation[] below[] with facies 3[] and the Hamira Member[] Jaisalmer Formation[] above[] with facies 4[] b Close-up of rootlets in grainstone in facies 4[] Hamira Member[] Jaisalmer Formation[] exposed along the base of a scarp 6 km E of Jaisalmer on the Jaisalmer-Jodhpur Road[] NH15[] c Thaat ridge section showing succession of cross-bedded[] alternating silt and fine-grained sandstone[] facies 3[] Thaat Member[] Lathi Formation[] exposed along the base of a scarp at 16 km E of Jaisalmer on Jaisalmer-Jodhpur Road[] NH15[]. Note the red siltstone near the base of the sequence[] arrowed[].

Fig. 5. a Close-up of Thaat Ridge section showing facies 3[] Thaat Member[] Lathi Formation[] exposed 16 km E of Jaisalmer on the Jaisalmer-Jodhpur Road[] NH15[]. Note the sharp base of the overlying bed of silt to fine-grained sandstone with small pits arrowed[] these are holes spaces left by silicified wood fragments and horizontal and inclined cylindrical burrow[] b Convolute bedding in bed No. 2 of the Thaat Ridge section[] at 16 km E of Jaisalmer on the Jaisalmer-Jodhpur Road[] NH15[] near the base of facies 3[] Thaat Member[] Lathi Formation.

Fig. 6. Section at Thaat scarp[] 16 km E of Jaisalmer[] exposed along a ridge crossing the Jaisalmer-Jodhpur Road[] NH15[] for key of symbols see Fig. 3.

Fig. 7. Section at 15 km E of Jaisalmer[] along the right hand side of the Jaisalmer-Jodhpur Road[] NH15[] for key of symbols see Fig. 3.
Fig. 8. Section at 11 km E of Jaisalmer along the right hand side of the Jaisalmer-Jodhpur Road NH15 for key of symbols see Fig. 3.

Fig. 9. Section at 6 km E of Jaisalmer along the right hand side of the Jaisalmer-Jodhpur Road NH15 for key of symbols see Fig. 3.

ented suspension feeders crinozoan arms with pinules crinoid ossicles Grammatodon Pseudolina and rhyhnchonellids epi- and endobysseate suspension feeders. Also rich are the ichnospesies Rhizocorallium irregulare Taenidium Fig. 10 a and Planolites.

The basal bed of the facies is an insipient intra-formational conglomerate which records subaerial exposure evidenced from cracks of the pebbles filled with ferruginous material followed by at least three storm-induced inundations of the basin that partly winnowed cemented siltstones of the underlying facies and redeposited them together with marine biotic components. The sharp erosive base and top corroborates the action of erosion due to storm activity providing evidence of the early transgression after a period of subaerial exposure. The characteristic features of the overlying sediments i.e. beds of bioturbated silty calcareous mudstone to sandy packstone and silty calcareous mudstone interbeds with sharp erosional bases and storm-beds suggest alternations of low energy conditions and storm events. In this facies the carbonate component is greater than the siliciclastic. Although the biotic components fossils are not as
common as one would expect they suggest a fully marine environment. Possibly the facies represents a mixed silicilastic-carbonate protected ramp. The upper section of this facies and increasing silicilastic input towards the west and southwest bed Nos. 2—4 Fig. 9 suggest fine-grained offshore sandy shoals.

3.5 Facies 5—Low angle cross-laminated silt to fine-grained sandstone

The facies about 6 m thick is exposed along the cliff-section of a scar about 6 km E of Jaisalmer on the right hand side of the Jaisalmer-Jodhpur Road NH15. This facies bed Nos. 6—10 Fig. 9 is comparable to the underlying facies No. 3 in terms of the alternation of siltstone and fine-grained sandstone units except for its homogeneous low angle cross-laminated bedded character which is in contrast to the partly bioturbated nature of facies 3. The individual beds in general are well-sorted siltstone or fine- to medium-grained sandstone with sharp bases. No fossils have been recovered.

Exclusive low angle cross-bedded well-sorted silicilastic sediments suggest a nearshore shallow water above the fair-weather wave base possibly sheet sands on a silicilastic ramp where because of wave action or currents the coastal sediments were redistributed. Except for the alternating change in grain size that suggests fluctuating water energy no other distinctive features can be discerned.

3.6 Facies 6—Storm-dominated thick rudstone with mega ripples and reworked coral heads

This is the youngest unit observed in the present study exposed as a bed all around to the east and south-east of Jaisalmer best seen about 4 km E of Jaisalmer on the right hand side of the Jaisalmer-Jodhpur Road NH15. Stratigraphically this is the oldest occurrence of the facies in the Jaisalmer Basin the facies consisting of an about 65—100 cm thick yellowish to red-brown well-cemented hard ferruginous bioclastic unit when weathered exhibiting to bedding and directly overlying the sandstone of facies 4. The individual units within the rudstone are a lower part with fining-upward shells 11.5 cm topped by a sharp uneven erosional surface a thin shell-bearing unit 1 cm also with an erosional top a uniform concave-upward shell-bearing unit 20 cm a middle part with a thick shell concentration with irregular pattern 8 to 15 cm and with iron concentration along the erosional surface which secondarily impregnated fractures and an upper part the top of which shows megaripples and reworked abraded and bored coral heads 5 to 46 cm in diameter as well as abraded cobbles. The shells are more or less arranged parallel to the bedding surfaces. As noted above the characteristic Bajocian coral *Isastraia bernardiana* was found in this unit.

The characteristic features of the unit such as a rudstone microfacies reworked coral heads erosional surfaces graded bedding and mega-ripples suggest for amalgamated storm deposits. The unit can be assigned to a high-energy sediment of a late transgressive system tract. The facies represents the peak of first major marine transgression across the Jaisalmer Basin.

4 Conclusions

The oldest sediments exposed east of Jaisalmer display a continental to marine succession that starts with the terrestrial conglomerate and sandstone of facies 1 and sandstone of facies 2 Odania Member Lathi Formation and such as is commonly seen in any shelf basin with rise of sea-level. During this early Jurassic period the climate was warm and humid.

Deposition of facies 4 Hamira Member Jaisalmer Formation indicates an increase in the intensity of the transgression. There was yet another phase of stillstand when the periodic wave and current action redistributed the sediments and then facies 5 was deposited. The last facies 6 with its storm-dominated rudstone is the topmost bed of the Joyan Member Late Bajocian of the Jaisalmer Formation deposited at the peak of this first major marine transgression across the Jaisalmer Basin.

Of these six facies of the lower sedimentary succession exposed east of Jaisalmer described here for the first time only the upper four are the result of marine inundation and have been recorded only around east and south of Jaisalmer they have not been recorded elsewhere on the Rajasthan Shelf. Consequently the oldest sediments of the Jaisalmer Basin i.e. the area west of the Bikaner-Nagaur Basin and the Pokhara-Nachna High and north of the Barmer-Sanchor basins belong to Thaat Member of the Lathi Formation facies 3 which overlie the Odania Member of the Lathi Formation facies 2 of wide lateral extension on the Rajasthan Shelf.
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