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Palynofacies of the early Cretaceous Pariwar Formation, Jaisalmer Basin, Rajasthan, India: Palaeoenvironmental interpretation

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Palynofacies analysis of the Early Cretaceous Pariwar Formation exposed near the Serawa village, Jaisalmer Basin, Rajasthan, western India has been carried out. Palynofacies data indicate that the Pariwar Formation are rich in degraded organic-matter. Based on the quantitative composition of the sediementry organic matter three distinct palynofacies associations are recognized (PF–1 to PF–3). PF–1 (predominance of the phytoclasts) is inferred as proximal suboxic to dysoxic shelf, PF–2 (dominated by AOM) is interpreted as distal dysoxic-anoxic shelf and PF–3 (predominated by phytoclasts alongwith AOM) is interpreted as shelf to marginal transition. Based on the distribution of palynofacies, it is inferred that the deposition of the Pariwar Formation took place in marginal to distal shelfal region in the marine setting. Recently discovered rich plant megafossil impressions, calcareous nannofossils and bioturbations in the successive horizons of the studied succession also indicate the presence of shallow marine condition at the time of deposition of the rock unit.

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INTRODUCTION

The western Rajasthan shelf is a distinct tectonic province in the northwestern part of India. It contains four distinct sedimentary basins, *viz.,* Bikaner-Nagaur, Jaisalmer, Barmer and Sanchore, housing marine sediments deposited over the Banded Gneissic Complex, Malani Igneous Suite and Erinpura Granite (Coulson, 1933; Heron, 1953; Gupta *et al*., 1980; Roy and Jakhar, 2002). Among these, the Jaisalmer Basin covers a major part of the Rajasthan shelf and occupies an area of about 50,000 km^2. Blanford (1876) laid the foundation of the stratigraphy of Jaisalmer Basin.

The occurrence of well-developed exposures consisting plenty of well-preserved fossils in the Jaisalmer Basin have been of the prime significance for its refined palaeontological, sedimentological and stratigraphic studies undertaken by many workers (Oldham, 1886; Das Gupta, 1975; Krishna, 1980, 1987; Kachhara and Jodhawat, 1981; Garg and Singh, 1983; Kalia and Chowdhury, 1983; Kalia and Chakraborty, 1985; Mahender and Banerji, 1989, 1990; Pandey and Fürsich, 1994; Dave and Chatterjee, 1996; Pandey and Krishna, 1996, 2002; Khosla *et al*., 2006; Pandey *et al*., 2006, 2007; Singh, 2006). Besides, the sedimentary basin is also significant for its promising hydrocarbon reserves in the Cretaceous successions (Das Gupta, 1975; Biswas, 1991; Mitra *et al*., 1993; Singh, 2006). Much attention has been given to the composition of palynofacies association with different sedimentary rock categories through quantity, composition and the maturity (colour) of associated organic matters to determine the source rock potential. In the present paper we document palynofacies of the Pariwar Formation of the Jaisaler Basin.

GEOLOGY OF THE STUDY AREA

The geology and stratigraphy of Jaisalmer Basin has been recorded by several workers (Oldham, 1886; La Touche 1902; Ghosh, 1952; Swaminathan *et al*., 1959; Narayanan, 1964; Das Gupta, 1975; Pareek 1981, 1984; Krishna, 1987; Singh, 1996; Bhandari, 1999; Pandey and Krishna, 1996, 2002). The pericratonic Jaisalmer Basin is tectonically divisible into four geostructural zones *viz.,* Kishangarh Sub-basin, Jaisalmer Mari High, Shahgarh Sub-basin and Miyajlar Sub-basin. This basin is filled with sediments ranging from Precambrian to Quaternary in age. The Late Proterozoic to Early Cambrian and Triassic sediments have been recorded in the boreholes only, while surface outcrops along the raised Mari-Jaisalmer Arch in the basin show sedimentary records ranging from Early Jurassic to Quaternary in age (Das Gupta, 1975; Misra *et al*., 1996; Pandey and Bahadur, 2009). The well exposed Mesozoic rocks in this basin are lithostratigraphically organised in to Lathi, Jaisalmer, Bhadasar (encompassing Baisakhi Formation of Swaminathan *et al*., 1959), Pariwar and Habur formations in ascending order (Table 1). The

Parihar beds of Oldham (1886) and Parihar Formation of Swaminathan *et al*. (1959) is originally used for Parihar Sandstone, exposed in the Trigonometric Hill 858, due south of the village Pariwar, south of Habur and northeast of Kanoi village and comprises of medium grained, quartzitic, calcareous and ferruginous sandstones. Till the exploration drilling started in Jaisalmer-Mari Arch, the Pariwar Formation was considered unfossiliferous and of Jurassic age. Sigal and Singh (1967) reported an arenaceous foraminiferal assemblage and assigned Neocomian age to this formation. Das Gupta *et al.* (1958) proposed two subdivisions of this formation as Lower and Upper Members based on lithology. Das Gupta *et al.* (1973) redefined its limits by restricting it to his earlier defined Lower Member, which is rich in plant fossils. As the name Parihar Formation is no longer tenable, Das Gupta (1974) has, therefore, designated this Lower Cretaceous sequence as Pariwar Formation after Pariwar village (27°14′30″N; 70°44′30″E).

The exposures of Pariwar Formation, though, widespread but are mostly covered by aeolian deposits. The Pariwar Formation is exposed as detached outcrops of about 350 meters thickness (Das Gupta, 1975) but in the subcrops, the estimated maximum thickness is 850 meters. In outcrops, the base of the formation showing disconformable relationship with underlying Bhadasar Formation is suspected south west of Pangli by Narayanan *et al.* (1961). In the subsurface, this contact is conformable. The upper boundary in outcrops is unconformable with overlying Habur Formation. The contact is marked between arenaceous limestone of Habur Formation and brown current-bedded sandstone of the Pariwar Formation. In subsurface, it has conformable relationship with the overlying Goru Formation. The Goru Formation is recorded only from the subsurface borehole data, is found homotaxial with Habur Formation. In outcrops, the Pariwar Formation is basically an arenaceous unit without any body fossil except plant impressions (Fig. 1). However, in the subsurface, rich microfossil assemblages *viz.,* arenaceous foraminifera with rare calcareous benthic foraminifers (Sigal *et al*., 1970; Singh and Sigal, 1980), ostracodes (Singh, 1997; Bhandari, 1999; Andreu *et al.,* 2007) and palynomorphs (Luckose, 1977) have been recorded and used for age determination. The base of the formation comprises chiefly of intercalation of sandy siltstone and calcareous sandstone, the middle part is represented by arenaceous clay, whereas the top of the formation composed of medium grained to pebbly sandstone and siltstone with yellow to brown sandy siltstone intercalation contains fossil leaf impression.

MATERIALS AND METHODS

For the present investigation, four samples (SR-1 to SR-4) have been collected from rock succession of Pariwar Formation exposed near the Serawa village (27°12′36.5″N: 70°36′10″E) about 20 km southwest of Pariwar village (Fig. 1). The sedimentary beds of this formation at the above site are almost horizontal with very low dips with ~ 2°. The succession is approximately 1.5 m thick and lithofacies comprises mainly of medium to coarse-grained sandstone.

Processing of the samples for palynofacies analysis was done by using the standard non-oxidative procedure (Faegri and Iversen, 1989; Tyson, 1995; Prasad *et al*., 2013). The sieved organic residue with polyvinyl alcohol (PVA) was spread and dried on a coverslip, and the prepared coverslip was mounted on a slide using Canada balsam. The quantitative studies comprised of at least 300 counts of organic particles per sample at various magnifications (20X/40X/63X). In order to attain a better resolution, five to eight mounted slides from each sample were observed under the microscope (Leica DM 2000 LED). The sedimentary organic matters were classified into three main categories: 1) phytoclasts, 2) palynomorphs and 3) amorphous organic matter (AOM) (Table 2). Phytoclasts includes translucent phytoclasts (poorly preserved woody material, cuticles and tracheids) and Opaque phytoclasts (opaque black remains) (Traverse 1994). Palynomorphs in this study include mainly trilete spores, fungal spores and zooclasts. Amorphous organic matter (AOM) includes degraded organic matter (DOM) which is formed as a result of bacterial and fungal activities on structured phytoclasts and structureless, porous/ spongy, dark or slightly translucent amorphous mass formed due to fungal and bacterial activities on partly degraded structured phytoclasts. The prepared slides are deposited in the museum of Birbal Sahni Institute of Palaeosciences, Lucknow (Slide nos. 16645–16652).

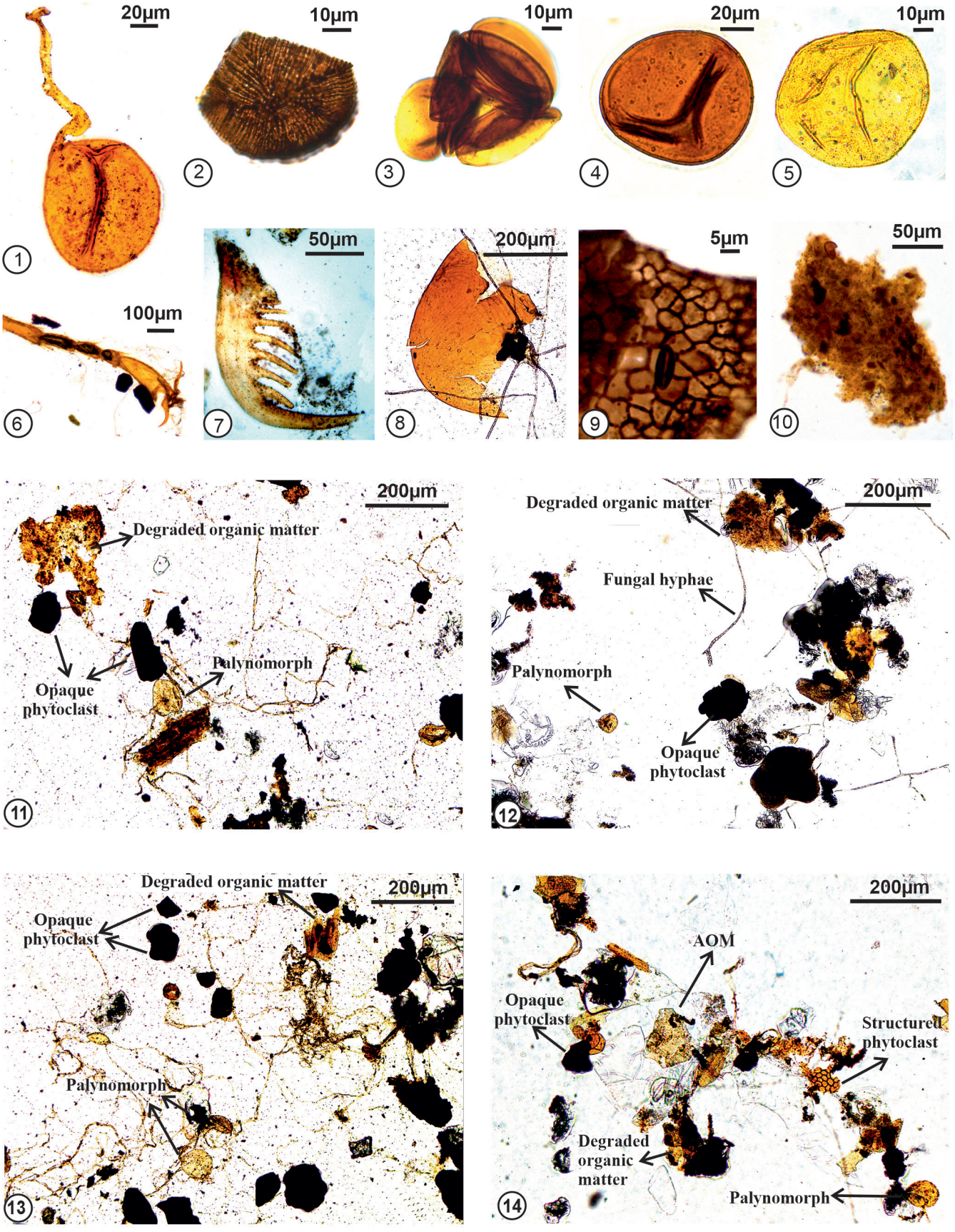
PALYNOFACIES ANALYSIS

On the basis of the recovered data, three distinct palynofacies have been identified:

EXPLANATION OF PLATE I

Palynofacies recovered from the sequence of Serawa village of Pariwar Formation. Fig. 1. Fungal spore with hyphae (M-33/1 BSIP slide 16647); Fig. 2. Fungal thalli (O-54/3, BSIP slide 16646); Fig. 3. Cluster of fungal spores (R-40/2, BSIP slide 16652); Fig. 4. Fungal spore (U-51/2 BSIP slide 16648); Fig. 5. Palynomorphs (J-38/2 BSIP slide 16645); Fig. 6. Zooclast (D-36, BSIP slide 16651); Fig.7. Zooclast (M-44/1, BSIP slide 16647), Fig. 8. Egg remain (K-52/3, BSIP slide 16649); Fig. 9. Structure phytoclast with stomata (N-27/4/ BSIP slide 16647); Fig. 10. Degraded organic matter (M-32/4, BSIP slide 16647); Fig. 11. Degraded organic matter along with opaque phytoclast and palynomorphs. (H-41, BSIP slide 16650); Fig. 12. Degraded organic matter along with palynomorphs, fungal hyphae and opaque phytoclast (P-34/3, BSIP slide 16649); Fig. 13. Opaque phytoclast along with palynomorphs and degraded organic matter (M-52/4, BSIP slide 16650); Fig. 14. Palynomorph, structured phytoclast along with amorphous organic matter, degraded organic matter and opaque phytoclast (H-43, BSIP slide 16645).

Plate I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Fungal hyphae
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13
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AOM
Opaque phytoclast
Structured phytoclast
Degraded organic matter
Palynomorph
14

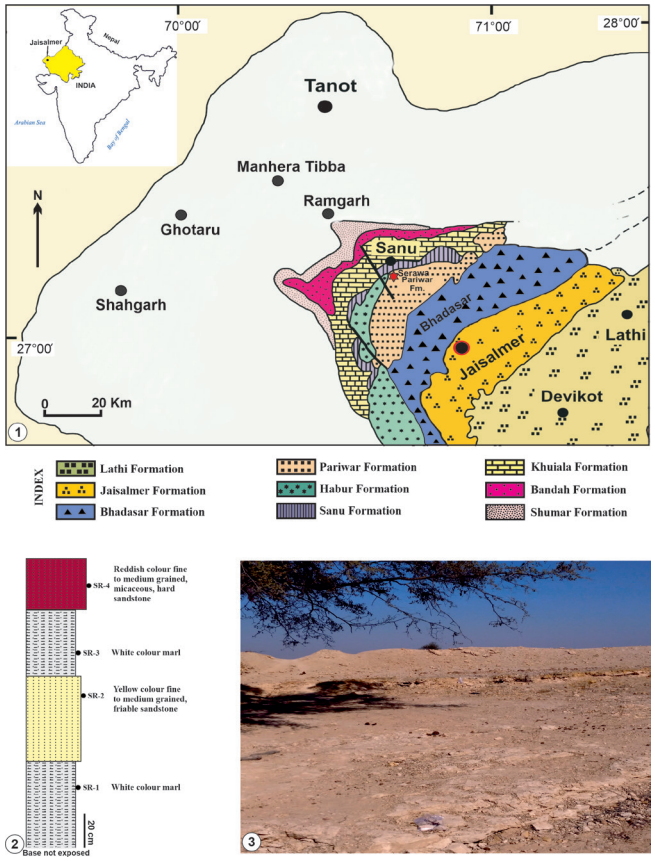

Fig. 1. 1) Generalised geological map of the Jaisalmer Basin. 2) Measured lithosection of Pariwar Formation exposed near Serawa village. 3) Photograph of the sample locality at Serawa village.

Palynofacies–1 (PF–1)

PF–1 is characterized by the abundant occurrence of the phytoclasts (50.34–53.89%), including structured phytoclasts and opaque phytoclasts (16.08–25.89%). Amorphous organic matter is the sub-dominant component of this palynofacies (41.97–44.64%) including degraded organic matter (25.17–38.39%) and structureless organic matter (6.25–16.8%). Scanty presence of palynomorphs has also been documented (1.78–6.99%). Lithologically, this palynofacies assemblage has been recorded from white colour marl (Sample no. 1 and 3). The increased phytoclasts content and decreased amorphous organic matter directly corroborate to a high terrestrial influx in the marine realm.

Palynofacies–2 (PF–2)

PF–2 is characterized by the dominance of amorphous organic matter (52.36%) including degraded organic matter (39.86%) and structureless organic matter (12.5%) and sub-dominance of the phytoclasts (33.1%) including opaque phytoclasts (22.63%) and structured phytoclasts (10.47%). Reduced content of palynomorphs (14.52%) has also been recorded. Based on the litho unit, the palynofacies occur in yellow coloured fine to medium-grained sandstone (Sample no. 2). Abundance of AOM along with dominant occurrence of opaque phytoclasts signify that the transportation of phytoclasts occured in the stagnant water settings for the degradation of the organic matter in AOM.

Palynofacies–3 (PF–3)

PF–3 is characterized by the dominance of phytoclasts (40.2%), including structured phytoclasts (23%) and opaque phytoclasts (17.2%) along with amorphous organic matter (34.51%) including degraded organic matter (25.22%) and structureless organic matter (9.29%). A moderate percentage of palynomorphs has also been recorded (24.33%). The palynofacies is reported in reddish colour, fine to medium-grained, micaceous hard sandstone lithology (Sample no. 4). Abundance of phytoclasts alongwith AOM influenced by mainly terrestrial palynomorphs denote that this palynofacies may have been deposited in marginal marine settings.

PALAEOENVIRONMENTAL INTERPRETATION

The composition of palynofacies components of the Pariwar Formation are plotted in AOM–Phytoclasts–Palynomorphs (APP) ternary diagram of Tyson (1995). The plot shows the three distinct assemblages of deposition for Palynofacies (1–3). White coloured marl (Sample no. 1 and 3) is located in the field VI, which indicates proximal suboxic to a dysoxic shelf (Fig. 2). While yellow coloured fine to medium-grained sandstone (Sample no. 2) and fine to medium-grained, micaceous friable sandstone (sample no. 4) are located in the feild VII and IV, respectively. Feilds VII and IV denote distal dysoxic-anoxic shelf and shelf to marginal transition, respectively (Fig. 2).

So, the ternary diagram suggests three different types of palaeoenvironments:

Proximal suboxic to dysoxic shelf

As the PF–1 is characterized by the dominance of the terrestrially derived brown woody particles, tracheids and cuticles which represents the deposition of this palynofacies from the fluvio-deltaic source (Kholeif, 1998) towards the proximity. The moderate occurrence of the degraded and structureless organic matter suggests reducing conditions for the basin and indicates suboxic to dysoxic environments that may extend to anoxic conditions (Batten, 1983; Tyson, 1995). The increased phytoclasts content and decreased amorphous organic matter directly corroborate to a high terrestrial influx in the marine realm. The present depositional environment may be deciphered as a regressive phase in the shelfal region of facies (Țabără *et al*., 2015).

Distal dysoxic-anoxic shelf

PF–2 is characterized by the dominance of amorphous

Table 1. The Mesozoic lithostratigraphic framework in the Jaisalmer Basin (modified after Das Gupta, 1974; Krishna, 1987).

Formation	Gross Lithology
Habur Formation	Marine coquinoidal limestone and sandy limestone
Unconformity	
Pariwar Formation	Sandstone and shale alternation with plant fossils and fossilised tree trunk
Unconformity	
Bhadasar Formation	Medium to fine and even coarse-grained sandstone, alternating with shale yieldind ammonites
Unconformity	
Jaisalmer Formation	Alternation of marine arenaceous limestone and calcareous sandstone with a fossiliferous oolite bed at the top
Lathi Formation	Terrestrial to deltaic sandstone with fossil wood, tree trunk

organic matter (AOM) and sub dominance of the phytoclasts. Increased amorphous organic matter and decreased phytoclasts directly corroborate with the lowered terrestrial influx (Ţabără *et al*., 2015). The change in palynofacies content from PF–1 to PF–2 also corroborates with the lithological setting (Fig. 1) *i.e.,* change in the sediments from white colour marl to yellow colour, fine to medium grained friable sandstone. A higher percentage of opaque phytoclasts along with dominant AOM in this region signifies that the transportation of phytoclasts took place followed by stagnation conditions making conducive environment for degradation under organic matter and converting them to AOM. The depositional setting can be inferred to higher sea level probably due to higher water level and distal shelf part.

Shelf to marginal transition

In the PF–3 the abundance of phytoclasts along with sub-dominance of AOM along with a moderate percentage of the palynomorphs indicates a high freshwater regime of the continental and marine domain. In this deposition, palynomorphs are common and dominated by terrestrial sporomorphs. The higher value of woody material, cuticles and tracheids, terrestrial sporomorphs and lower percent of opaque phytoclasts suggests a quiet saline environment due to its proximity to continental setting and active fluvio-deltaic sources during the depositional time. The palynofacies data exhibit a clear proximal/marginal terrestrial dominated setting (Ţabără *et al*., 2015) for the deposition of this palynofacies matter.

DISCUSSION AND CONCLUSIONS

The tectonism in the west Rajasthan shelf in different geological periods are concomitant with the widespread marine transgressions and subsequent regression. The Pariwar Formation is one of the important stratigraphic units in the Jaisalmer Basin and represents a regressive phase of sedimentation. The Pariwar Formation was initially believed to be an unfossiliferous sequence, but subsequently, it has yielded some plant megafossils *viz., Pterophyllum*, *Anomozatites*, *Actinosporites*, *Elactocladus* and *Cladophlebis*

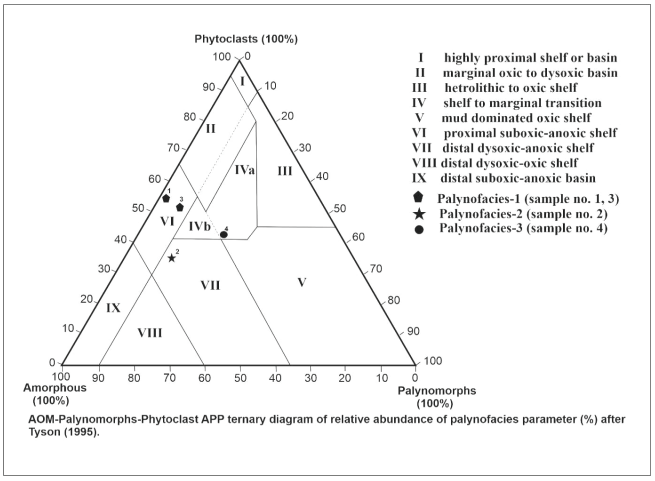

Fig. 2. AOM-Palynomorphs-Phytoclast APP ternary diagram of relative abundance of palynofacies parameter (%) (after Tyson, 1995).

Table 2. Classification of sedimentary organic matter of Pariwar Formation (modified after Tyson, 1995; Bombardiere and Gorin, 2000; Mendonça Filho *et al.*, 2002; Carvalho *et al.*, 2006; Ţabără *et al.*, 2015).

Group	Subgroup		Origin
Phytoclast	Opaque	Equidimensional Lath	Derived from the ligno-cellulosic tissues of terrestrial higher plants or fungi
	Structured/ Transluscent	Cuticle	Leaf-epidermal tissue of higher plants
		Woody remains	Gymnospermous and angiospermous woody tissues
	Fungal remain	Fungal hyphae	Derived from fungi
Palynomorphs	Sporomorph	Spores	Terrestrial palynomorph produced by pteridophyte, bryophyte and fungi
	Zooclast	Scolecodonts	Mouth and body parts of some polychaete worms (mostly marine)
Amorphous Organic Matter (AOM)	Structureless material	Derived from phytoplankton or degradation of bacteria (fluorescent AOM) or degraded higher plant debris (non-fluorescent AOM). Structureless material with no morphology or form	
	Degraded organic matter	Derived as an effect of fungal and bacterial activities, brown and homogeneous. Various states of preservation partial to completely degraded have been observed	

(Das Gupta *et al*., 1974). Maheshwari and Singh (1976) and Bose *et al*. (1982) also reported a rich assemblage of plant megafossils which include *Glechenia* sp., *Phlebopteris* sp., *Pachypteris haburensis*, *Pachypteris* sp., *Taeniopteris* spp., *Pterophyllum* sp., *Ptilophyllum acutifolium*, *Otozamites imbricatus*, *Ginkgo* sp., *Araucarites* sp., *Coniferocauon* sp., *Elatocladus* sp., *Pagiophyllum* sp. Wood fossils *viz., Mesembrioxylon* spp., *Podocarpoxylon haburensis*, are also reported from this formation (Das Gupta *et al*., 1974; Guleria and Shukla, 2008). Recently, authors also reported a rich plant megafossil of bennettitalean flora from the present seccession (Das *et al.,* 2021, in press). Besides, Das *et al.* (2018) have also reported 11 nannofossil taxa belonging to moderately diversified, reasonably well-preserved calcareous nannofossils assemblage from the present studied part of the Pariwar Formation.

Based on rich plant fossils assemblage, Das Gupta (1975) suggested a continental to deltaic environment of deposition and assigned an Early Cretaceous age for the

Pariwar Formation. However, Luckose (1977), on the basis of palynofossil assemblage, interpreted shallow marine, brackish water to continental environment and considered the Early Cretaceous age for Pariwar Formation. Sigal *et al*. (1970) and Sigal and Singh (1980) recorded an assemblage of arenaceous foraminifera with several species of *Ambaculites* and *Haplophragmoides* along with rare calcareous foraminifera and dated Pariwar Formation as Neocomian to Aptian age and considered near shore to inner neritic conditions for deposition. Rai *et al.* (2013) assigned early to middle Albian age on the basis of the presence of *Predisosphaera columnata* nannofossils.

On the basis of the palynofacies studies on Pariwar Formation of the Jaisalmer Basin following inferences has been drawn:

1. Based on the distribution of palynofacies, it is evident that the deposition took place in marginal to distal shelfal region in the marine setting.
2. The deposition of palynofacies suggests the varying degree of suboxic to anoxic environments based on the degradation of organic matter.
3. The reconstruction of transgressive and regressive environments can also be evidenced as suggested by high terrestrial and marine palynofacies matter.

In conclusion, the presence of foraminifera (Sigal *et al*., 1970; Singh and Sigal, 1980) calcareous nannofosils and bio-turbation (Rai *et al.*, 2013; Das *et al.*, 2018; Das *et al.*, 2021, in press) are indicative of shallow marine environment, together with wood fossil and plant fossil impressions, preserved in ferruginous sandstone suggests a continental to paralic environmental conditions prevailed during the deposition of Early Cretaceous of Pariwar Formation in this basin. Further, the present palynofacies evidence suggests that during the deposition of this formation, which was basically a regressive phase of sedimentation, the deposition took place in marginal to distal shelfal region in the marine setting and short pulses of marine transgression occurred intermittently. The global eustatic rise coupled with the local tectonics *viz.,* westward tilting in Early Cretaceous was possibly responsible for these transgressive episodes.

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