Trace fossils in Middle to Late Triassic fluvial redbeds, Pranhita-Godavari Valley, south India

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Several morphological varieties of trace fossils abound in Middle and Late Triassic fluvial redbeds in the Pranhita-Godavari Valley, south India, including *Skolithos*, *Palaeophycus*, *Taenidium*, escape burrows, and a type of trace very similar to 'small stuffed burrows' from the Triassic of Greenland. Burrow morphology was influenced by local hydrodynamic conditions. The distribution of burrows was facies controlled; some forms are restricted to channel deposits whereas others occur only in floodplains. Vertical dwelling burrows (*Skolithos*) occur in both channel and floodplain deposits. Horizontal structures representing deposit feeding (*Taenidium*) are confined to nondepositional surfaces within parallel-laminated sandstones having parting lineations that represent catastrophically emplaced sand-sheets in channels and proximal floodplains. Vertical escape burrows are confined to what were slowly but continually accreting parallel-laminated sands of channel bars. Horizontal dwelling burrows (*Palaeophycus*) and 'small stuffed burrows' are virtually restricted to the smaller sandsheets of floodplain drainage systems.

The burrow assemblages do not occur as recurrent associations throughout the redbed sequence, and variations in different stratigraphic levels seem to be controlled by minor differences within a broadly similar environment. The entire assemblage has components of both the *Scoyenia* and *Rusophycus* ichnocoenoses reported from East Greenland but may be considered as the *Scoyenia* ichnofacies characteristic of redbeds deposited in extensive floodplains dissected by small streams, even though no *Scoyenia* individuals are present.

Key Words: trace fossil, fluvial sequence, redbed, Triassic.

INTRODUCTION

Holocene records document considerable diversity of tracemaking animals as well as recent trace morphologies in nonmarine wet or humid settings (Frey et al., 1984b; Frey and Pemberton, 1987). Nonmarine trace fossils, by contrast, are of remarkably low diversity, and many are not sufficiently diagnostic for the delineation of different nonmarine facies and environments. Low diversity and absence of well-defined environmentally sensitive assemblages also contrast nonmarine forms with marine ones (Savage, 1971; Hanley et al., 1971; Stanley and Fagerstrom, 1974; Pollard and Lovell, 1976; Bromley and Asgaard, 1979; Ratcliffe and Fagerstrom, 1980; Bown, 1982; Bown and Kraus, 1983; Maulik and Chaudhuri, 1983; D'Alessandro et al., 1987). The dichotomy is an indication of low preservation potential of traces in ephemeral non-marine environments, insufficient studies of those forms, or both.

Trace fossil assemblages in continental redbeds and similar deposits were grouped into a single *Scoyenia* ichnofacies by Seilacher (1967), and the term was subsequently expanded to include traces of any type from almost any kind of nonmarine deposit. Frey and Seilacher (1980) recognized seven ichnofacies, but the elements of the *Scoyenia* ichnofacies were not substantially elaborated. Evaluation of the ichnofacies came later, in a series of papers showing the association to be related primarily to streamside or overbank conditions (Frey et al., 1984b; Frey and Pemberton, 1984, 1985, 1987). Water availability seems to have been a major constraint on the original community of tracemakers (e.g., Gierlowski-Kordesch, 1991).

Bromley and Asgaard (1979) demonstrated the occurrence of several mutually exclusive, recurring nonmarine ichnocoenoses, and Chamberlain (1975) suggested that distributions of lebensspuren from deep lakes may exhibit bathymetric zonations similar to those from marine environments. These studies point to the potential value of ichnocoenoses in characterizing nonmarine environments.

Trace fossils are abundant locally in a fluviatile redbed sequence, ranging in age from Middle to Late Triassic (Kutty et al., 1987), of the Gondwana deposits of the Pranhita-Godavari Valley, south India (Tab. 1, Fig. 1A, B). Maulik and Chaudhuri (1983) reported the ichnofossils from the basal part of the redbeds. In the present paper we describe the trace morphologies, interpret the ethologic and environmental significance of traces from middle and upper parts of the redbed sequence, and examine the characteristics of an ichnofacies of a fluvial redbed sequence.

GEOLOGIC SETTING

The thick sequence of Gondwana rocks in the Pranhita-Godavari Valley (Fig. 1A), representing a fairly contin-

Tab. 1. Permo-Triassic (upper Gondwana) stratigraphic sequence in the Pranhita-Godavari Valley, south India. (After Jain et al., 1964; Chatterjee, 1967; Kutty, 1969; Sengupta, 1970; Anderson and Cruickshank, 1978; Kutty et al., 1987; Kutty and Sengupta, 1989.)

	Formation	Main Lithologies	Facies	Age
upper Gondwana	Dharmaram	coarse to medium quartz arenite and quartz wacke; red clay	channel and floodplain	Late Triassic (Rhaetian to late Norian)
	Maleri	red clay; medium to fine calcareous quartz arenite, fine quartz wacke; peloidal calcirudite/calcarenite	floodplain, ephemeral channel-fill	Late Triassic (early Norian to Carnian)
	Bhimaram	medium to coarse, pebbly, ferruginous feldspathic quartz wacke with thin intercalations of red clay	channel/point-bar, floodplain	Middle Triassic
	Yerrapalli	purple and red clay; medium to fine calcareous quartz arenite, fine quartz wacke; calcirudite/calcarenite	floodplain, ephemeral channel-fill	Middle Triassic (Anisian)
lower Gondwana	Kamthi	coarse to medium quartz wacke, locally pebbly; abundant clasts and lenses of purple siltstone at certain levels; thin sheets of claystone	channel/point-bar, floodplain	Late Permian to Early Triassic

uous succession of continental deposits spanning late Palaeozoic to late Mesozoic time, is considered to have been deposited primarily under fluviatile conditions (Pascoe, 1959; Robinson, 1970). Middle to Upper Triassic tracts in this sequence, represented by clay-dominant redbeds intercalated with thin sheet and lenticular sandstones, were classified by King (1881) as the Maleri Group. The group has subsequently been divided into four formations, the Yerrapalli Formation, Bhimaram Sandstone, Maleri Formation, and Dharmaram Formation, in ascending order (Jain et al., 1964; Chatterjee, 1967; Kutty, 1969; Kutty et al., 1987) (Tab. 1), having gradational and intertonguing formational contacts (Sengupta, 1970).

Triassic rocks of the Pranhita-Godavari Valley are very similar to redbeds of the Late Triassic Chinle Formation and Dockum Formation of the southwestern United States (Blakey and Gubitosa, 1984; Dubiel, 1987), and they were developed as deposits on an extensive floodplain dissected by small ephemeral streams. A hallmark of the coarse fraction is the ubiquitous calcareous peloids, a major component. The peloids were derived intrabasinally, through reworking of immature caliche profiles that formed in periodically stable geomorphic levels on alluvial plains having low to moderate rates of alluviation (Sarkar, 1988).

The Bhimaram Sandstone is represented mainly by a thick, ferruginous/calcareous, pebbly to medium-grained quartz wacke and arenite and subordinate amounts of red clay and calcarenite/calcirudite. The Maleri Formation is dominated by red clay intercalated with several sandbodies of varying dimensions and shape; the coarser fraction in the formation is represented mainly by medium- to fine-grained, calcareous quartz wacke and arenite and subordinate amounts of calcirudite/calcarenite. The Dharmaram Formation is quite similar to the Maleri Formation except for a slightly higher sand/mud ratio and slightly larger size of sandstone bodies. Dharmaram sandstones

are generally coarser than Maleri sandstones, and peloidal calcirudites/calcarenites are rather scarce.

Coarse fractions in the redbed sequence occur either as thin sheets or small lenses of the order of decimeters in thickness or as parallel-sided units on the order of 2 to 5 m thick and hundreds of meters long, measured along strike. Detailed mapping of the sandbodies and examination of sections reveal that these relatively larger sandstone units developed as multistory sandbodies through vertical and lateral superposition of lenticular fills of shallow, wide channels. Most channel-fill sequences exhibit a fining-upward trend (Sarkar, 1988, fig. 2) and are dominated by horizontal to slightly inclined, parallel-laminated sandstones, many displaying parting lineations. These larger sandbodies constitute channel deposits and were formed either as channel bars or high-energy sheet-flood deposits filling the shallow channels and spilling over the banks and proximal floodplain areas (cf. McKee et al., 1967) or through the combined activity of normal and catastrophic events.

Thin sheets of thinly bedded sandstone/calcarenite, many with parting lineations, and smaller lenses of cross-bedded calcarenite/sandstone intercalated with red clay, constitute the sandstone of the floodplain deposits. These thin sheets are inferred to be high-energy flood deposits emplaced from waning currents of sheet flows associated with the episodic overbank flooding of the larger channels. The smaller sand lenses commonly exhibit fining-upward sequences and apparently are the fill of small channels and gullies of the floodplain drainage system.

Robinson (1970, 1971) and Chatterjee (1978, 1980) suggested that the redbeds were deposited in the oxidizing environment of a hot monsoon-type climate in which dry seasons were intervened by periods of heavy rains. Paucity of plant fossils, however, may suggest a semiarid setting (Collinson, 1978). A semiarid climate was advocated by Maulik and Chaudhuri (1983), and Sarkar (1988) sug-
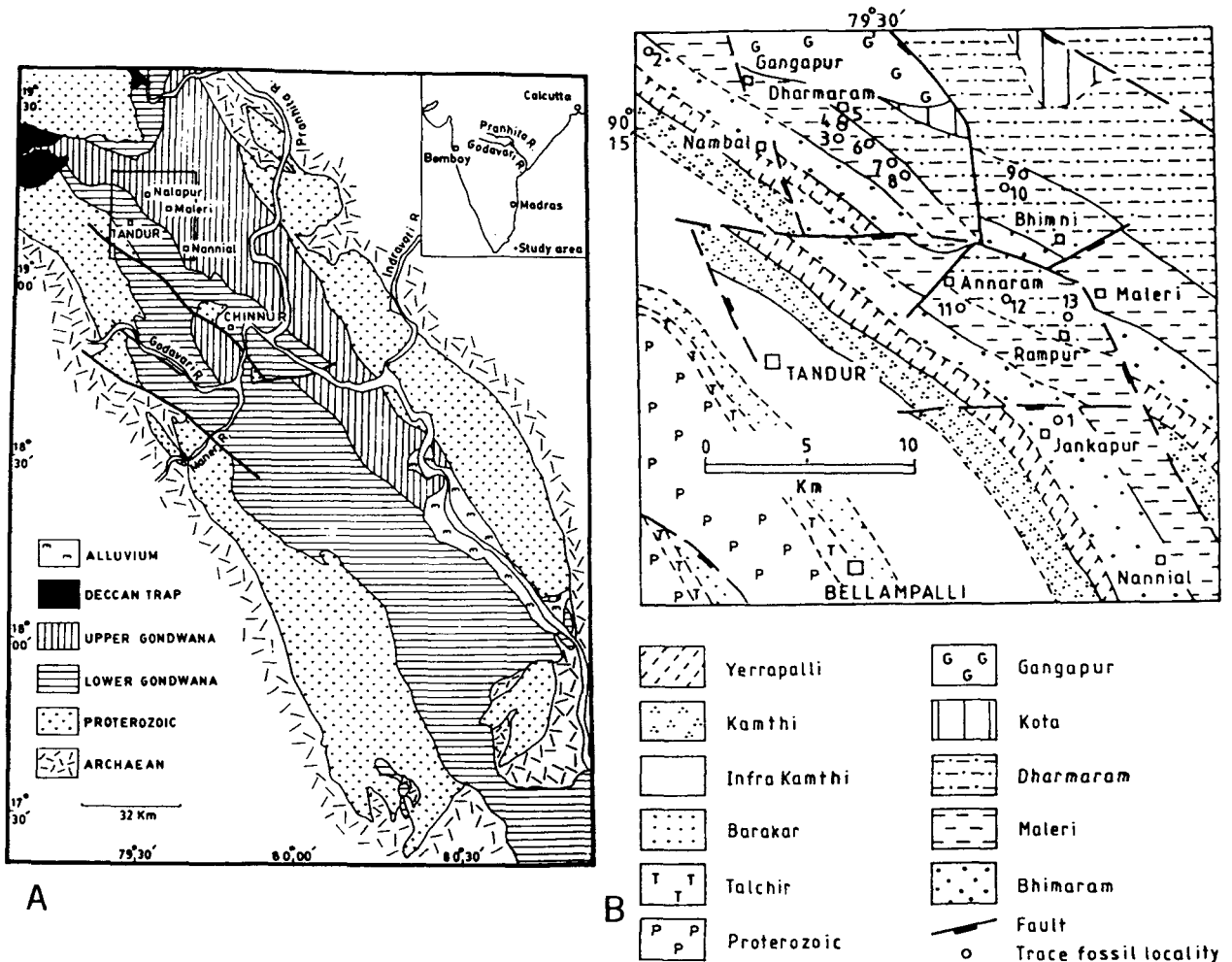
Fig. 1. Geologic maps of study area. (A) Part of the Pranhita-Godavari Valley (modified after King, 1881). (B) Closeup map of the square area in A, showing trace fossil localities (after Kutty et al., 1987). Regional dip of beds is generally about 10 to 15° to the northeast.

gested a relatively drier hot climate with low seasonal rainfall to account for the profusion of intrabasinal caliche-derived calcareous peloids in Maleri sediments.

DESCRIPTION OF TRACE FOSSILS

The traces can be grouped into several morphological types largely on the basis of shape, orientation, presence or absence of a distinct wall lining or sculpture, and characteristics of the burrow fills.

Ichnogenus *Skolithos*

Description: The burrows are vertical to subvertical, straight to slightly curved, tubular, nonbranching and relatively smooth walled (Fig. 2A). Width of most burrows is uniform throughout their length, and the burrows

appear as circular to semicircular holes or knoblike protuberances on exhumed bedding planes (see Fig. 4). Some of the vertical burrows become inclined to subhorizontal toward their lower end and appear as J-shaped structures (Fig. 2B). Maximum preserved length is about 9 cm, and diameters range from 1 to 15 mm with a major mode at 8 to 10 mm. Burrow fills are massive and most are dissimilar to the host lithology; in heterolithic units, burrows are filled with either sandstone or mudstone, whereas in sandy host rock, many sandstone fills are relatively poorly cemented and slightly more muddy and loosely packed than the host sediments (Fig. 2A). The burrows are generally unlined, though a poorly developed lining defined by preferential concentration of reddened clay pellets was noted in a few.

Discussion: Morphologically similar burrows have been described either as *Skolithos* or *Cylindricum*, which sometimes are considered as synonyms (Alpert, 1974; Bromley and Asgaard, 1979). Our forms, in contrast to
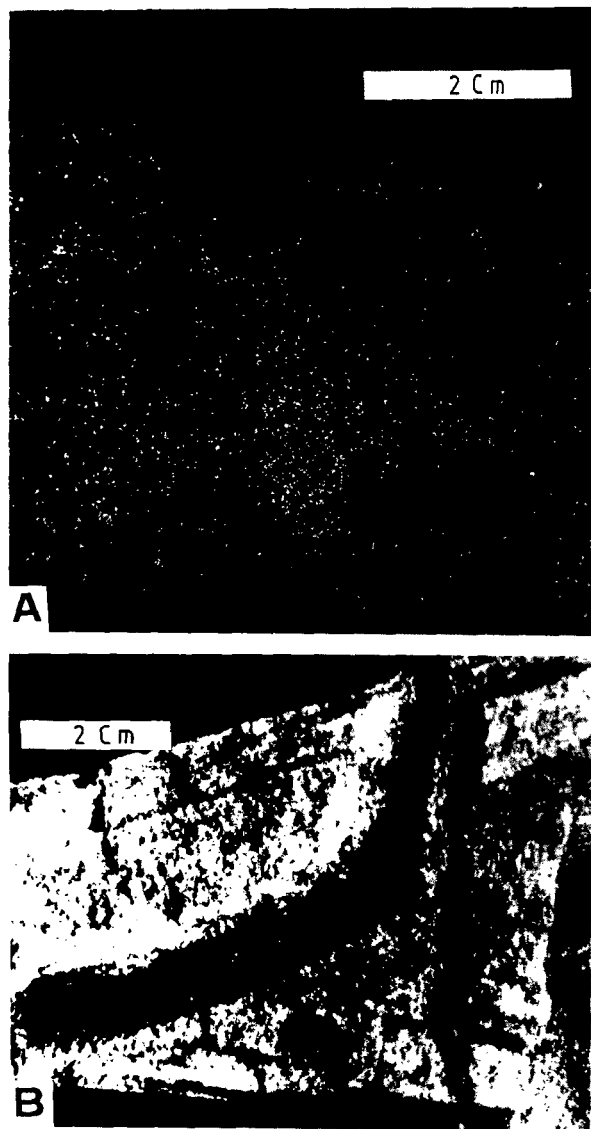
Fig. 2. *Skolithos*-like burrows. (**A**) *Skolithos* with massive fill, in medium-grained sandstone, illustrating the difference in texture between the burrow fill and host rock. Location 13, Dharmaram Formation. (**B**) J-shaped *Skolithos*- or *Macanopsis*-type burrow in scour-filling cross-bedded medium sandstone; vertical *Skolithos* 'pipes' are visible on the right side. Location 1, Bhimaram Sandstone.

typical vertical dwelling burrows (Frey and Pemberton, 1985), are generally unlined. Many authors have described morphologically similar, unlined burrows from nonmarine sequences and assigned them to *Skolithos* (Bromley and Asgaard, 1979) simply because of the preferentially vertical orientation of the burrows (D'Alessandro et al., 1987). Many workers, however, prefer to reserve the name *Cylindricum* for unlined, vertical dwelling burrows made by insects in nonmarine sediments (Pollard and Lovell, 1976; J. E. Pollard, 1990, written communication), in contrast to typically lined *Skolithos*. It

seems that the criterion of a lining may be important in the distinction, if any, between *Skolithos* and *Cylindricum* and needs to be tested by more case studies.

Pending well-established morphologic criteria for such distinction, we have assigned our forms to *Skolithos*, following Alpert (1974), Bromley and Asgaard (1979), and D'Alessandro et al. (1987). The arcuate to J-shaped burrows (Fig. 2B) may be intergradational with *Macanopsis* (cf. Frey et al., 1984a, tab. 2), although terminal chambers or basal cells of the *Macanopsis* type have not been observed here.

Interpretation: The traces were constructed as dwelling burrows. Many other domiciles have discretely lined walls (Frey and Seilacher, 1980; Frey and Pemberton, 1985). However, unlined dwelling burrows similar to these structures are common and have been described from several nonmarine occurrences (Stanley and Fagerstrom, 1974; Pollard and Lovell, 1976; Bromley and Asgaard, 1979; Maulik and Chaudhuri, 1983; Bracken and Picard, 1984). Absence of a wall lining in the present dwelling structures, and absence of deformed laminae in the host rock at burrow interfaces, apparently point to a high consistency of the host substrate into which the burrows were dug.

Lithological dissimilarities between host sediments and the burrow fillings may point to active sediment manipulation by the burrowers (cf. Pemberton and Frey, 1982), though absence of any internal structure suggests passive filling (Pollard and Lovell, 1976, p. 220). Hallam (1975) has shown that lithological dissimilarities may not everywhere be related directly to active filling by the burrowers, but may also be dependent on the lithological association of the substrate. *Skolithos* in the present study was constructed mostly on subaerial omission surfaces. The burrows were preserved as open structures that acted as sediment traps and were filled by gravity-induced sedimentation primarily during postconstructional periods (Stanley and Fagerstrom, 1974). In this scenario of a discontinuity between emplacement of the substrate and burrow filling, the lithology of the filling is dictated by the lithology of overlying beds, but not by the lithology of host beds. Vuggy filling in many *Skolithos* from the Triassic redbeds of East Greenland, quite different from the surrounding sandstone, prompted Bromley and Asgaard (1979) to infer a terrestrial (insect) origin of the burrows.

Ichnogenus *Palaeophycus*

Description: These burrows are straight to curvilinear, unbranched, horizontal to subhorizontal, and generally smooth walled (Fig. 3A); a segmented or annulated structure was noted only in one example (Fig. 3B). The traces occur either singly or in groups. Most are exhumed in concave or convex epirelief. Preserved hyporeliefs are

Fig. 3. *Palaeophycus.* (**A**) Two intersecting burrows with massive fills, exposed on bedding plane as convex epireliefs. Location 13, Dharmaram Formation. (**B**) Segmented appearance of a burrow, although lacking internal structure in the sawed part (left side). Location 1, Bhimaram Sandstone.

rather uncommon, and in rare instances epichinial burrows may grade into endichnial burrows. Endostratal burrows in transverse section are circular to nearly circular. These burrows generally do not exhibit a wall lining in hand specimens, although well-developed linings marked by the concentration of iron oxides were noted in one thin-section. All burrow fills are massive; the lithology is similar to that of the host, though in a few samples the burrow fills seem to be more muddy and poorly cemented than the host rocks. Maximum length recorded is 30 cm; diameters range from 2 to 10 mm and are concentrated around a mode at 8 to 9 mm.

Interpretation: The ethological significance of hori-

zontal burrows having massive fillings is not clear. Presence of a lining, and the broad similarity of the filling with the host lithology, point to passive sedimentation within open dwelling structures. The burrows were identified as *Palaeophycus* on the basis of morphology and characters of the internal filling (Pemberton and Frey, 1982). The specimen exhibiting an annulated exterior (Fig. 3B) may be a *Palaeophycus 'annulatus'* (*ibid.*, p. 853).

Ichnogenus *Taenidium*

Description: The burrows are straight to slightly curved, horizontal to subhorizontal, cylindrical, unlined, meniscate structures (Fig. 4); they commonly occur as hypichnial or epichnial features, though endichnial tubes having nearly circular transverse sections are fairly common. *Taenidium* occurs either singly or more commonly in groups, and many are associated with *Skolithos*. Branching was not noted, but interference and crossovers between burrows are common; interference structures may give the impression of branching. Maximum recorded length is 25 cm; the diameter ranges from 1.5 to 16 mm, with a modal value at 10 to 11 mm. Burrow fills are generally similar to the lithology of the host rocks, but show well-developed, gently arcuate, alternating menisci of well-sorted, medium-grained sand and reddish brown mud, 0.5 to 2.0 mm thick (Fig. 4B). The muddy menisci have a higher amount of iron-oxide pigment and are poorly cemented compared to the sandy menisci. The meniscate structure is best revealed by differential weathering. In a muddy host sediment, most finer grained menisci are thicker than coarse-grained menisci, whereas in a sandy host, coarse-grained menisci are much thicker and the burrow fills are dominantly sandy.

Discussion: Width, thickness, and curvature of the menisci remain uniform throughout the length of many burrows, particularly the smaller ones having a smooth boundary, and thus would seem to resemble *Ancorichnus*; but many are highly variable, particularly the larger ones, in which many menisci extend into the host rock, giving rise to a serrated margin (Fig. 4B). These structures, in contrast to *Ancorichnus*, lack a definite wall lining and therefore resemble *Taenidium*.

Unlined meniscate burrows have been assigned to several ichnogenera, many of which are synonymous. The present structures were identified as *Taenidium* (D'Alessandro and Bromley, 1987; R. W. Frey, 1988, written communication). The structures, however, differ from the ichnogenus *Taenidium* as reported by Häntzschel (1975, p. W112, 113) in several aspects, namely the lack of an umbellated pattern, absence of primary branching, and a downward radiating pattern in a rootlike system, though the principal taxonomic criteria support the classification as *Taenidium* (D'Alessandro and Bromley, 1987, p. 751).

Fig. 4. *Taenidium*. Location 1, Bhimaram Sandstone. (A) Burrows in parallel-laminated medium to fine sandstone; also visible are exhumed holes and knobby protuberances (fills) of *Skolithos*. (B) Bedding plane exposures of unlined burrows exhibiting irregular margins and the extension of certain menisci into the host rock (arrow).

The virtual absence of branching distinguishes these burrows from *Cladichnus* (*ibid.*, p. 759).

Interpretation: The menisci are very similar to those in internal fillings of *Scoyenia* and *Ancorichnus*, and they were probably formed through the combination of sediment sorting by the animal's body movement and sedi-

ment ingestion and sorting within the animal's digestive tract (Bromley and Asgaard, 1979; Frey et al., 1984b). The proportion of bypassing and ingestion was dependent on the texture of the sediment manipulated by the animal.
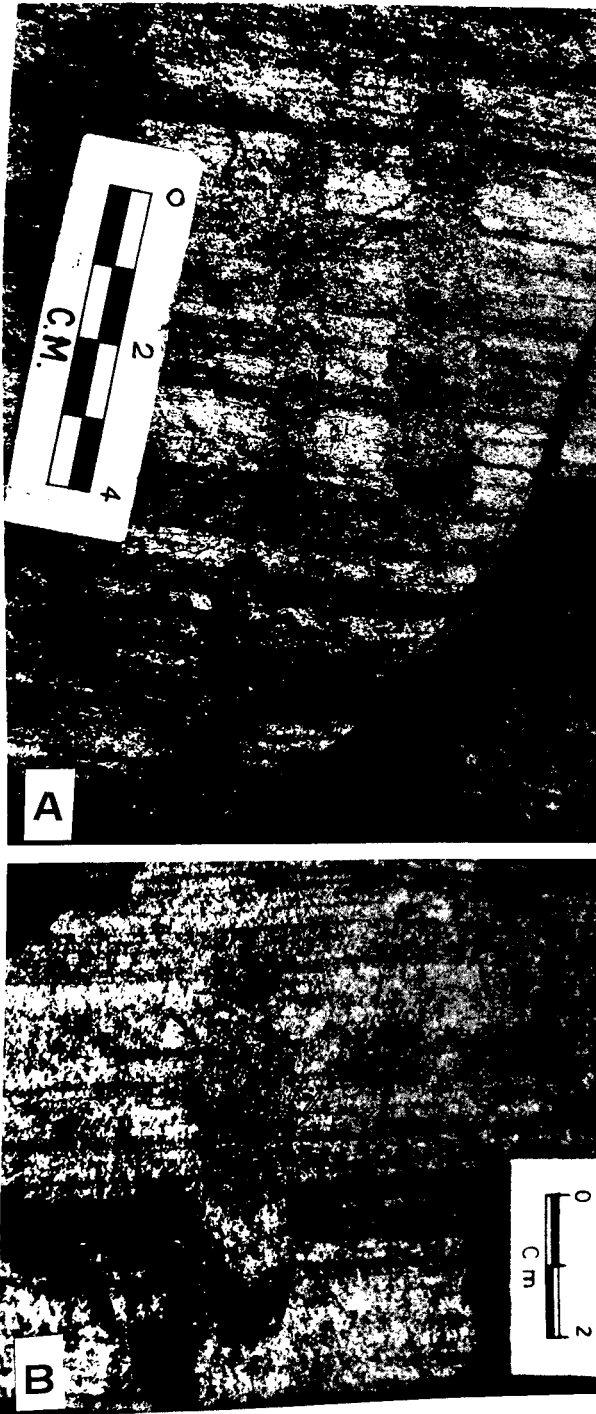
Escape Burrows

Description: The burrows are tubular, vertical to subvertical, straight to slightly curved and nonbranching. They sharply truncate the host laminae but do not deform them. The walls are unlined and sharp, exhibiting both regular and serrated margins (Fig. 5A). Maximum recorded length is 18 cm; the diameter ranges from 4 to 15 mm, with a modal value of 9 to 10 mm. The burrow fills are grossly similar to the host lithology in composition and are either meniscate throughout the length of the burrows or are partly meniscate and partly massive (Fig. 5B). Size differentiation between adjacent menisci is not pronounced, and the menisci are less well defined than those in horizontal burrows (Fig. 4); many menisci show lateral variations in thickness and composition. Thickness ranges from 0.5 to 1.5 mm, and the spacing is irregular. In most burrows the menisci are convex downward, though in a few they are convex upward (Fig. 5A). The massive fills are characterized by high porosity and chaotic fabric (Fig. 6). In some traces, a few host-rock laminae continue across the burrows with slight downward curvature, conforming to the curvature of the menisci, and in places, the host-rock laminae project slightly within the burrows as overhangs (Fig. 5B).
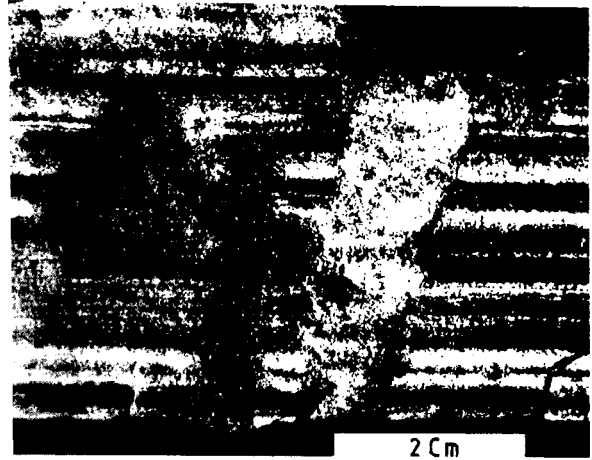
Discussion: These burrows do not seem to resemble *Beaconites*, as described by Allen and Williams (1981), Bradshaw (1981), and Graham and Pollard (1982). The burrow types described herein are much smaller than *Beaconites* (e.g., Gevers et al., 1971; Ridgeway, 1974; Pollard, 1976). Moreover, our varieties lack well-developed menisci and any sort of wall lining, which are reported to be present in many samples of *Beaconites* (Gevers et al., 1971, pl. 18, fig. 3; Bradshaw, 1981, p. 630). Also, the present structures are oriented dominantly vertically, in contrast to those described by Bradshaw (1981) and Graham and Pollard (1982).

Interpretation: Some of the structures closely resemble burrow-type 3B of Maulik and Chaudhuri (1983, fig. 12) from redbeds of the underlying Yerrapalli Formation. They may have served as temporary shelters for the animals near the depositional surface (*ibid.*), which moved upward or downward to maintain a specific distance relative to the substrate position in response to sediment aggradation or degradation (cf. Goldring, 1964; Frey and Seilacher, 1980). The downward movement of the animal could also be in response to dehydration of the surficial layers (Pryor, 1967; Maulik and Chaudhuri, 1983).

The meniscate internal structure, or the fabric of the

Fig. 6. A vertical escape burrow having irregular menisci (right-center). On the left are vertical to high-angle burrows with massive fillings. Parallel-laminated medium to fine sandstone (darker laminae are rich in mud). Location 1, Bhimaram Sandstone.

Fig. 5. Escape burrows, in parallel-laminated medium to fine sand. Location 1, Bhimaram Sandstone. (A) Unlined, vertical meniscate burrows in which the menisci are poorly developed and are oriented in opposite directions in the two burrows. (B) Vertical escape structure exhibiting poorly developed menisci in the lower part; one sediment lamina continues across the middle part of the structure (open arrow), followed by a massive fill in the upper part; solid arrow indicates host lamina that projects out into the burrow as an overhang.

massive fill, suggests active sediment processing by the animals; but the processing in these vertical structures, in contrast to that in the horizontal structures, appears more as a response of escape than of deposit-feeding activity (D'Alessandro and Bromley, 1987). Continuation of host laminae across the burrows points to multiple phases of burrow construction and shallow depths of burrowing. The burrows represent multiple behavioral traits, namely, shelter cum feeding cum escape, escape being the major functional mode, and they seem to be similar to the multi-behavioral burrows described by Frey and Pemberton (1985).

Vertical meniscate structures have often been assigned to the same ichnogenus as the horizontal meniscate structures (Frey et al., 1984b; Bracken and Picard, 1984; D'Alessandro et al., 1987). This classification is based primarily on the assumption that all these structures represent deposit feeding. However, identification of the structures as escape burrows or attributing multiple ethological significance distinguishes them from the horizontal feeding burrows, and Frey and Pemberton (1985) considered that escape burrows per se are not yet amenable to separate ichnogenus and ichnospecies names.

Small Stuffed Burrows

Description: This type trace consists of small burrows of highly variable shape. Many are spindle shaped, whereas others are small tubular structures (diameter: 1.5 to 10 mm), having both meniscate and massive fillings (Fig. 7). The burrows may occur at any angle to the substrate, horizontal to vertical, and are preserved mostly
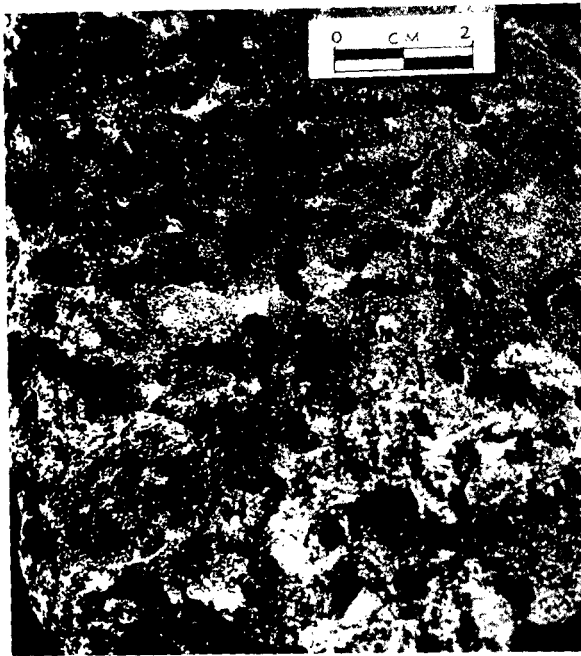
Fig. 7. Bedding plane exposure of small stuffed burrows, predominantly horizontal. Slightly meniscate internal structures occur in a few burrows. Location 5, upper Maleri Formation. (The dark holes are parts of unidentified vertical or inclined burrows exhumed by weathering.)

continental Triassic redbeds of East Greenland, and Pollard (1981) from the Triassic of Cheshire. We use the name "small stuffed burrows" for these Maleri traces.

Interpretation: The burrows seem to represent activities of small infaunal deposit feeders that penetrated randomly along and across sand-mud interfaces during exploitation of the sediment (cf. Pollard, 1981, p. 580).

DISTRIBUTION OF THE BURROWS AND THEIR ENVIRONMENTAL SIGNIFICANCE

Occurrences of the burrows are restricted mainly to sandstones and calcarenites of both channel and floodplain deposits. In the Bhimaram Sandstone and in the middle part of the Maleri Formation, the burrow population is dominated by those of channel deposits (*Skolithos, Taenidium,* and escape burrows). Burrows of floodplain deposits (*Skolithos, Palaeophycus,* and small stuffed burrows) abound in the upper part of the Maleri Formation and in the Dharmaram Formation (Tab. 2).

Burrows in Channel Deposits

Bhimaram Sandstone

Skolithos, Taenidium, and escape burrows occur profusely in a multistory channel-fill sandbody comprising several fining-upward sequences. The burrows are restricted mainly to scour-fill crossbeds and parallel-laminated units in one such fining-upward sequence (Fig. 8B) and are absent in the basal conglomerate and associated sand-streaked mudstones. Swarms of scours filled with sandy and heterolithic foresets possibly record the deposits of small anabranches developed on deposits of episodic flows, on small exposed bars during low-flow stages or in the floodplain muds. The parallel-laminated interval is dominantly sandy, but toward the lower part it is heterolithic. This interval is about 1.25 m thick and consists of bundles several decimeters thick truncated by low-angle

as epichnial full relief structures, either as ridges or grooves. A highly variable morphology, small size range (burrow diameter 1.5 to 10 mm), and the size-distribution pattern of the burrows clearly distinguishes them from other types of Maleri burrows. Compared to scattered size distributions of other types of burrows, the small stuffed burrows are characterized by a high degree of size consistency and unimodal distribution, which a highly peaked mode around 3 to 5 mm.

Discussion: These burrows are closely similar to those illustrated by Trewin (1976, fig. 4F) from the Old Red Sandstone, Bromley and Asgaard (1979, fig. 6C) from

Tab. 2. Distribution of burrows in mid-Upper Triassic redbeds of the Pranhita-Godvari Valley, India. Depositional settings (channel versus floodplain) are given for the three principal stratigraphic units. Trace fossil locality numbers (Fig. 1B) are given in parentheses.

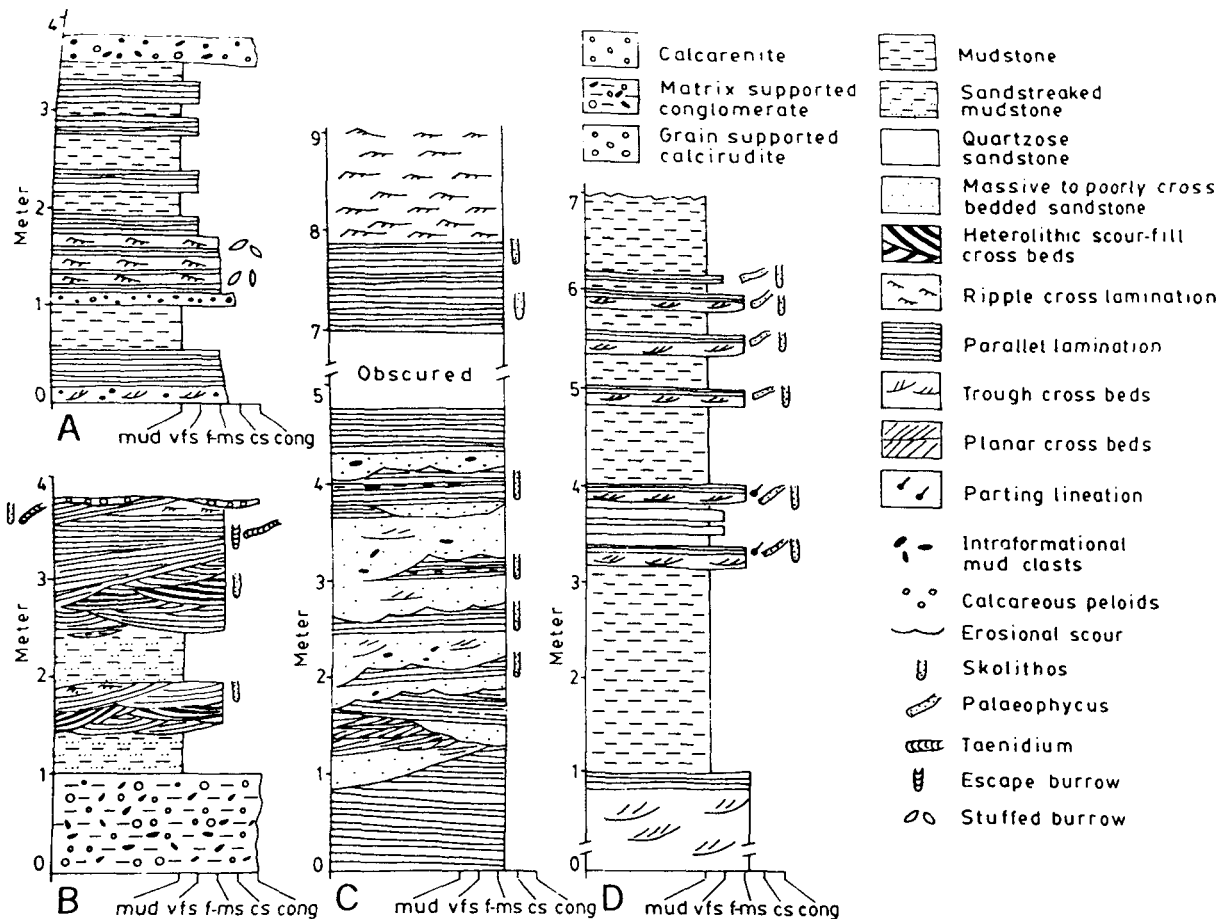| Trace Fossils	Bhimaram Sandstone			Maleri Formation		Dharamaram Formation
	Channel (1)	Floodplain		Channel (10)	Floodplain drainage system (3 to 9, 11)	Floodplain drainage system (12, 13)
		Proximal (1)	Distal (2)			
Skolithos	Profuse	Common	Uncommon	Profuse	Rare	Common to Uncommon
Palaeophycus	Rare	Rare	Uncommon	Rare	Rare	Common to Uncommon
Taenidium	Profuse	Common	Rare	—	—	—
Vertical escape burrows	Profuse	—	—	—	—	—
Small stuffed burrows	—	—	—	—	Profuse	—

Fig. 8. Some of the trace fossil bearing sequences. (**A**) Maleri Formation, upper part, Location 11. (**B**) Bhimaram Sandstone, Location 1. (**C**) Maleri Formation, middle part, Location 10. (**D**) Dharmaram Formation, Location 12.

planar discordance surfaces. A few bundles in the upper part show well-developed parting lineations. The parallel-laminated sandstones grade laterally into a zone of red mud with several closely spaced sheets of parallel-laminated, sandy, heterolithic rocks a few centimeters thick, exhibiting parting lineations. Laminae with parting lineations record high-energy sheet-flood deposition in the upper flow regime, which occasionally spilled over the channel banks onto the proximal floodplains, depositing thin sheets of sand intercalated with red clays.

Escape structures occur only in parallel-laminated sandstones lacking parting lineation, and most are uniformly distributed throughout the unit. *Taenidium* is abundant in uppermost parts of the bundle of parallel-laminated rocks having parting lineation and in thin sheets of sandstone having parting lineations that are intercalated with red clay. *Skolithos* is common in sandstone having parting lineations, in association with *Taenidium*, and also in the scour-filling crossbeds.

The mode of distribution of the escape burrows suggests that the burrower moved upward to keep pace with vertical aggradation through normal depositional processes. The animals backfilled the burrows as they moved upward. However, diffused menisci and poor sorting of grains in menisci suggest that the rate of sediment manipulation and upward movement to keep pace with aggradation were too rapid for construction of uniform menisci consisting of well-sorted grains. Further, development of partly meniscate and partly massive fillings probably suggests different rates of escape in response to fluctuations in the rate of sediment accretion. The burrowers must have maintained a critical balance with environmental conditions and manipulated the sediment near or at the sediment-water interface. Most escape burrows are oriented vertically, though in certain beds they coexist with horizontal burrows. The situation seems to be similar to that described by Bracken and Picard (1984). The horizontal structures are morphologically similar to the vertical es-

cape burrows and also are of similar size, suggesting that all the structures were formed by the same population of organisms.

Taenidium occurs only in the parallel-laminated sandstone having parting lineations. Planar erosional surfaces at low angles to the lamination attest to discontinuous accretion and removal of an unknown thickness of strata from the upper part of each bundle; these surfaces provide the most favored site for profuse development of *Taenidium*. The animals could colonize the upper layers of the flood-deposited interval during stable conditions of the following nondepositional stage.

Skolithos also was constructed on the exposed nondepositional surfaces, or in the low-energy, scour-filling crossbeds. Shifting granular sands seemingly are not the most favorable sites for the development of *Skolithos* in a fluvial redbed situation, as in shallow marine environments.

Maleri Formation

Burrows are profuse in the uppermost fining-upward sequence of a multistory sandbody in the middle part of the formation (location 10, Fig. 1B). These assemblages are restricted to parallel-laminated rocks in two different levels of the sequence (Fig. 8C). In contrast to burrows of the Bhimaram Sandstone, only *Skolithos* was developed in this formation.

The lower burrowed interval comprises decimeter-thick units of alternating thinly laminated sandstone/mudstone and massive to poorly cross-stratified sandstone, where each sandstone bed exhibits an eroded base and passes upward into parallel-laminated units. Burrows are virtually confined to the parallel-laminated units, and only in rare instances do they extend into the overlying massive sandstones. In the upper interval, an 80-cm thick, parallel-laminated sandstone, burrows are fairly uniformly distributed throughout the unit (Fig. 8C, 7–8 m).

The mode of occurrence suggests that slowly accreting, low-stress environments of bars or periodic breaks in deposition favored the development of dwelling burrows. The burrowing organisms could not withstand high-stress environments and were destroyed periodically during deposition of massive/cross-stratified sandstones succeeding or accompanying substrate erosion. A similar mode of occurrence of burrows was reported by Smith and Hein (1971) and Stanley and Fagerstrom (1974) from modern fluvial sediments and their ancient analogs.

Burrows in Floodplain Deposits

Bhimaram Sandstone

Skolithos and *Palaeophycus* were noted in thin (10–30 cm) sheets or lenses of fine-grained muddy sandstone

enclosed in thick red clay (location 2, Fig. 1B). Meniscate burrows are extremely rare. Low frequency of the burrows suggests that the extremely low-stress environment of the distal floodplain was not a particularly suitable habitat for the burrowers. Burrows in the proximal floodplain, represented by thin sandsheets having parting lineations intercalated with red clay (location 1), in contrast, provided a more favorable site for inhabitance by the burrowers.

Maleri Formation

Small stuffed burrows occur at many places (locations 3 to 9, 11; Fig. 1B), in small lenses and sheets of parallel- or cross-stratified sandstone enclosed within red clays. These burrows have been recorded from the middle part of the formation but are profuse in a thin zone in the uppermost part (locations 4 to 9, Fig. 1B). The burrows are so characteristic of this zone that it can be used as a stratigraphic marker over the study area. The burrowed beds occur as components of decimeter- to meter-thick heterolithic intervals, which grade upward into red clay and are underlain by massive to crossbedded calcirudite and calcarenite (Fig. 8A). The fining-upward sequences are inferred to have been deposited from sediment-laden surges in small channels and gullies of the floodplain drainage system.

Both structureless and meniscate burrows are common, but their relative frequency varies from place to place. The burrow distribution seems to have been controlled largely by environmental dynamics and lithology. The parallel-laminated zones provided the most favorable sites for the tracemakers, presumably during quiet interludes between episodes of high-energy deposition. The high-stress environments of massive or crossbedded calcirudite/calcarenite at the base of the fining-upward sequences, or the mud above the parallel-laminated sandy deposits, was inhospitable for the growth of the burrowing organisms.

Dharmaram Formation

Small fining-upward sequences representing sheetflood deposits (Fig. 8D) are characterized by profuse but local development of *Skolithos* and *Palaeophycus* (locations 12, 13; Fig. 1B). *Skolithos* is concentrated mainly in crossbedded rocks, whereas *Palaeophycus* is more common in parallel-laminated rocks. The facies specificity of burrow types, as in the Maleri Formation, suggests strong influence of environmental dynamics on burrow morphology. The vertical burrows provided shelter in high-energy shifting sands, whereas the horizontal burrows were made mostly along interfaces of parallel-laminated units in post-depositional low-energy environments.

DISCUSSION

Burrow/Lithofacies Relationships

In both channel and floodplain deposits, burrows are essentially confined to original shallow pools of slow sedimentation or exposed nondepositional surfaces. The *Skolithos* ichnofacies is considered to be archetypal of clean, well-sorted particulate substrates of nearshore environments having relatively high levels of wave or current activity and abrupt changes in rates of deposition, erosion, and physical reworking of sediments (Frey and Seilacher, 1980; Howard and Frey, 1985; Frey and Pemberton, 1985). *Skolithos* specimens in continental Triassic redbeds of the present study, on the other hand, are confined to slowly accreting, parallel-bedded sands on bar tops, scour-filling crossbeds formed during low-flow stages, crossbedded sands in small floodplain channels, or on wet, exposed nondepositional surfaces of high-energy deposits. Similar environmental control on the occurrence of *Skolithos* was described by Stanley and Fagerstrom (1974).

Skolithos in shallow-marine environments tends to exhibit discrete wall linings, originally a reinforcement against substrate instability (Frey and Pemberton, 1985, p. 97). Wall linings of this sort are conspicuously absent or are poorly developed among burrows in low-energy mud-dominant fluvial environments. *Skolithos* specimens lacking wall linings were described by Bromley and Asgaard (1979) from the Triassic of Greenland and Maulik and Chaudhuri (1983) from Middle Triassic redbeds of the Pranhita-Godavari Valley. Burrows without wall linings seemingly are typical of low-energy settings.

Presence or absence of discrete linings in *Skolithos*-type burrows may be a reflection of differences between producers in marine and freshwater environments (e.g., worms versus insects; J. E. Pollard, 1990, written communication). Freshwater *Skolithos* without any lining, described from Miocene deposits of ponded areas of abandoned braided river channels of western Nebraska, are reportedly made by beetles (Stanley and Fagerstrom, 1974). Different types of beetles also make unlined vertical dwelling burrows in the broad, exposed river bar sands and abandoned channels during low stages of discharge on the Platte River today. However, whether because of differences between producers or differences in environmental dynamics, the presence or absence of discrete linings may be used as a distinguishing criterion between two forms of *Skolithos*, one typical of shallow-marine sediments and the other of low-energy, mud-dominant, ephemeral fluvial deposits.

Distribution of the burrows is strongly facies-dependent, on both the outcrop level and the formation level. Within each formation, channel and floodplain deposits are characterized by mutually exclusive ichnofossil assemblages.

Horizontal meniscate burrows occur in both channel and proximal floodplain deposits of the Bhimaram Sandstone. In both cases, burrows of deposit feeders formed after deposition of the substrates on wet, exposed beds. Environmental stress conditions were essentially similar in both situations. Moreover, meniscate structures in the two separate facies may differ on the ichnospecies level. Poor preservation of meniscate burrows in proximal floodplain deposits of the Bhimaram Sandstone did not permit detailed morphologic analysis, although they appear to be similar to horizontal meniscate burrows of channel facies of the underlying Yerrapalli Formation (Maulik and Chaudhuri, 1983), tentatively identified as *Ancorichnus* by Frey et al. (1984b).

In channel deposits of the Bhimaram Sandstone, escape burrows are confined to what were continually accreting parallel-laminated bar sediments, whereas *Taenidium* and *Skolithos* are found exclusively in upper parts of the catastrophically emplaced sheet-flood deposits. Concentration of *Skolithos* in crossbedded facies of small channel-fill deposits of the Dharmaram floodplain, and of *Palaeophycus* in the more stable substrates of the parallel-laminated facies, point to the influence of different environmental factors on burrow morphology.

Ichnofacies

Despite the facies specificity of burrow distributions, none of the burrow assemblages manifests itself as a recurrent ichnofacies throughout the redbed sequence. The small stuffed burrows in floodplain deposits of the Maleri Formation (early Norian to Carnian), in contrast to the assemblage of *Skolithos* and *Palaeophycus* in floodplain sediments of the Yerrapalli Formation (Anisian), Bhimaram Sandstone (Middle Triassic), and Dharmaram Formation (Rhaetian to late Norian), possibly point to slight differences in the broad facies at different stratigraphic levels.

Bromley and Asgaard (1979) identified four recurring, mutually exclusive trace fossil assemblages in the Triassic nonmarine redbeds of Greenland: the *Arenicolites*, *Fuersichnus*, *Scoyenia*, and *Rusophycus* ichnocoenoses. Each ichnocoenose occupies a well-defined stratigraphic interval reflecting specific depositional conditions. The *Arenicolites* and *Fuersichnus* ichnocoenoses were developed in lacustrine environments of fresh or only slightly saline water, whereas the *Rusophycus* ichnocoenose developed in a shallow fluviatile environment. The *Scoyenia* ichnocoenose was considered to represent an intermediate environment marked by "temporary periods of partial or complete drying out of shallow water" (Bromley and Asgaard, 1979, p. 78). Recognition of ichnocoenoses representing different distinctive nonmarine environments enhances

the possibility of grouping nonmarine traces into different ichnofacies.

In contrast to the Greenland Triassic sequence, all four Triassic formations of the Pranhita-Godavari Valley represent essentially similar depositional environments: a muddy floodplain dissected by small ephemeral streams. Facies-controlled burrow assemblages in different stratigraphic levels appear to have components of both the *Scoyenia* and *Rusophycus* ichnocoenoses of Bromley and Asgaard (1979), and they may be considered as subsets of an ichnofacies (Bromley, 1990, p. 187) representing the redbed sequence. The assemblages are characterized by low diversity and are dominated by terrestrial, shallow burrows of deposit feeders and shallow aquatic dwelling burrows. The animals preferentially colonized moist or wet substrates of muddy fine to medium sands, either low-lying subaerial deposits periodically inundated by water or shallow aquatic deposits periodically exposed to air. The environmental setting shares many features in common with several better documented floodplain deposits characterized by *Scoyenia gracilis* and *Ancorichnus coronus* (Frey et al., 1984b, tab. 1). The association may be referred to the *Scoyenia* ichnofacies in the sense intended by Seilacher (1963, fig. 7; 1967, fig. 2) and redefined by Frey et al. (1984b), where the lined meniscate burrows have been replaced largely by ethologically similar, albeit unlined, *Taenidium*.

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