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TRACE FOSSILS FROM CONTINENTAL TRIASSIC RED BEDS OF THE GONDWANA SEQUENCE, PRANHITA—GODAVARI VALLEY, SOUTH INDIA

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ABSTRACT

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Three types of trace fossils, (a) horizontal burrows, (b) inclined passageways between successive galleries of horizontal burrows and (c) vertical to slightly inclined burrows, occur in the Triassic red beds of the Gondwana sequence in the Pranhita—Godavari Valley, South India. As is the case with marine trace fossils, morphologies of these continental burrows are found to vary with the sub-environments of the fluvial domain, i.e., channels and flood plains. Whereas the traces tend to be vertical in the shifting conditions of the channel facies, those in more stable parts of the flood plain facies are generally horizontal. Trace fossils in the continental environment are as effective as those of the marine environments in the recognition of the various environmental parameters.

INTRODUCTION

The nature, distribution and environmental significance of non-marine trace fossils are still poorly understood, although Seilacher (1967) has assigned a number of associations of trace fossils from the non-marine clastics to distinct ichnocoenoses. Most information concerning trace fossils is derived from marine environments but studies of non-marine occurrences are relatively rare. Studies of locally varied trace fossils from different non-marine facies, glaciofluvial to semi-arid floodplains, that range in age from Palaeozoic to Recent (Seilacher, 1963; Pryor, 1967; Daley, 1968; Hanley et al., 1971; Savage, 1971; Smith and Hein, 1971; Stanley and Fagerstrom, 1974; Bromley and Asgaard, 1979; Kar and Chaudhuri, 1981), however, indicate that the present state of knowledge of non-marine traces may partly be due to a strong bias towards studies of marine occurrence rather than actual scarcity of traces in continental settings.

Trace fossils were noted to occur in profusion in a number of formations of the continental Gondwana deposits in the Pranhita—Godavari Valley, South India. Though an impressive array of vertebrate body fossils has been

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described from this sequence (Kutty and Roy Chowdhury, 1970), trace fossils seem to have been generally overlooked.

The present paper reports trace fossils from the Middle Triassic red beds, the Yerrapalli Formation, developed around Bhimaram (18°51′N, 79°41′E; Figs.1 and 2) in the Adilabad district, Andhra Pradesh. Our purpose is to describe the trace morphologies and to interpret the palaeoecologic significance of the trace fossils.

GEOLOGICAL SETTING

A thick sequence of Gondwana rocks, representing a fairly continuous continental deposits spanning the Late Palaeozoic to Late Mesozoic, occurs in a NW—SE-trending linear outcrop belt following the trend of the present-day Pranhita—Godavari river valley in South Central India (Fig.1). The Gondwana sequence is generally considered to have been deposited under fluviatile (locally, exclusively lacustrine) conditions (Pascoe, 1959, p. 911).

Triassic red beds of the Gondwana sequence, the Maleri beds of King (1881), have recently been classified into three units (Table I, Jain et al., 1964; Sengupta, 1970). The Yerrapalli Formation that contains the trace fossils considered here represents, according to Sengupta (1970), an inter-channel flood plain deposit of the Gondwana river system. The Yerrapalli Formation is comprised of extensive but thin deposits of red and purple clay and interbedded sandstone occurring either as thin sheets or as small, isolated lenses.

Thin sheets of sandstones interbedded within the flood plain clays and silts are characterised by parallel laminations and parting lineations. These sandstones are fine-grained, poorly sorted and calcareous with abundant clay matrix. These rocks closely resemble the high-energy flood deposits described by McKee et al. (1967) and Tunbridge (1981), and were probably deposited from waning currents of sheet flows associated with episodic overbank flooding of ephemeral streams.

Sandstones occurring as small lenses within the red clays and siltstones are, in general, fine grained, well sorted and low in clay matrix, and are characterised by a large calcareous component and well-sorted, dark-brown fecal pellets. The sandstones are dominantly cross-bedded and have also well-developed, thin parallel laminations in places. Though Sengupta (1970) interpreted these sand bodies as cut-off meanders abandoned in the inter-channel flood plains, they appear to be quite unrelated to the coarse clastics of the overlying Bhimaram sandstones and the underlying Kamthi sandstones, the channel-bar and point-bar deposits of the major Gondwana streams. Instead of being cut-off meanders these sand bodies may rather represent fillings of small ephemeral channels within an extensive flood plain.

It has been suggested that the Yerrapalli and Maleri red beds were deposited in the oxidizing conditions of a hot monsoon-type climate characterised by dry seasons alternating with periods of heavy rainfall (Robinson, 1967, 1971).

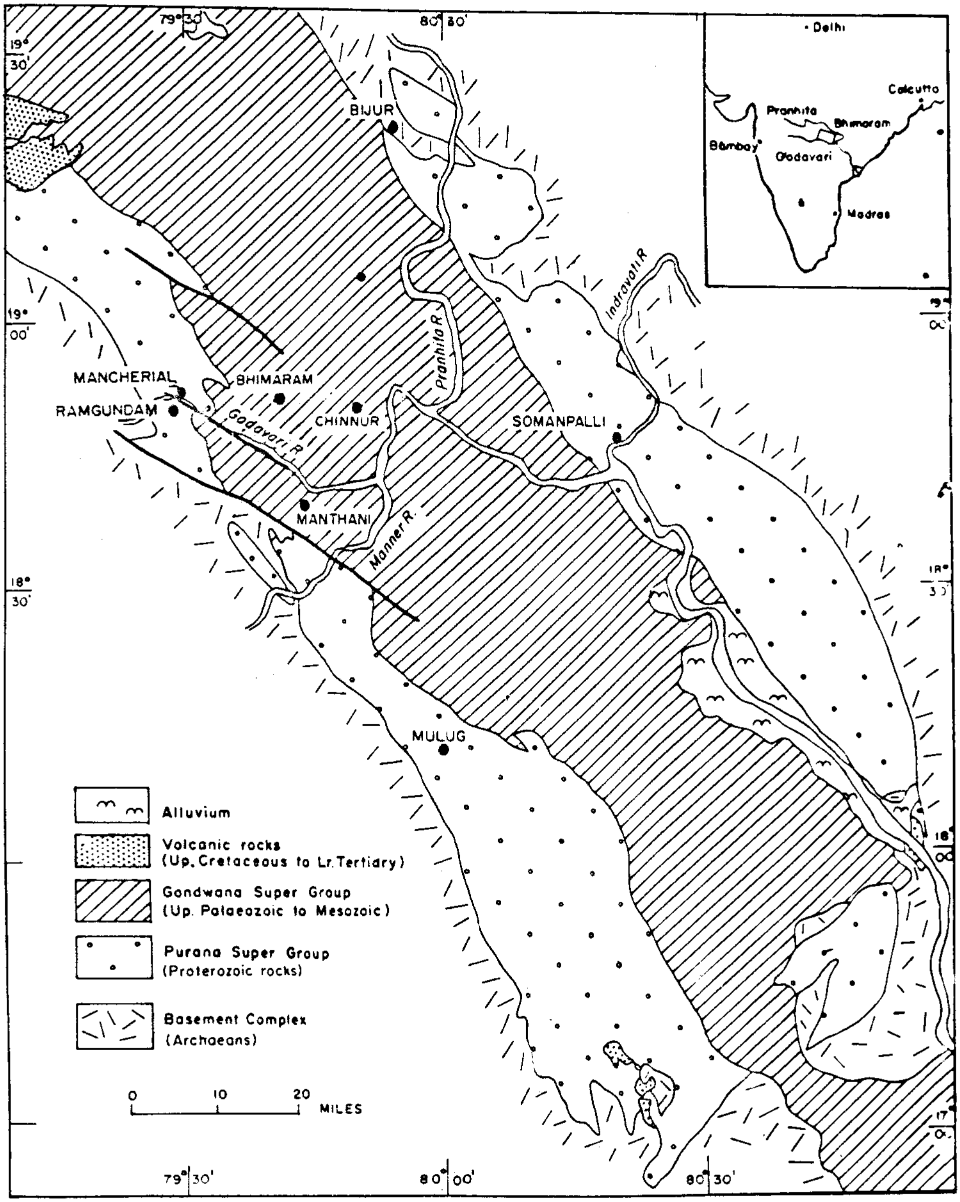

Fig.1. Geological map of the Pranhita—Godavari valley (after King, 1881).

TABLE I

Stratigraphic classification of the Permo-Triassic Gondwana rocks around Bhimaram (after Jain et al., 1964; Sengupta, 1970)

Formation	Main lithologies	Facies	Age
Maleri	red clays, fine-grained sandstones, and "lime-pellet" rock	inter-channel flood plain facies	Upper Triassic
Bhimaram	coarse, pebbly sandstones with intercalated red clays	channel bar/point bar facies	
Yerrapalli	red clays, fine-grained calcareous sandstone/siltstone to fine sandy pelletiferous limestone	inter-channel flood plain facies	Middle Triassic
Kamthi	sandstone and siltstone		Permian

Paucity of plant fossils, however, suggests a more semi-arid setting (Collinson, 1978). Low seasonal rainfall is also suggested by Sarkar (1980) to explain the origin of pellets of calcium carbonate that occur in profusion in certain horizons.

TRACE FOSSIL OCCURRENCE

Trace fossils reported here were studied at one locality, about 6.5 km SSE of Bhimaram (Fig.2). Many of the specimens occur as float but a number were studied and collected in-situ, in sections exposed along creeks. Traces occur in the fine sandstones and siltstones, both thin sheets interbedded with the clays and channel-fill lenses, and wherever found, they occur in profusion.

TRACE FOSSILS

Trace fossils in the Yerrapalli sediment include full-relief burrows displayed on horizontal bedding surfaces, as sub-horizontal to vertical tubes through the bedding and as button-like bodies. Bioturbated layers are rare. The traces can be grouped into three types as follows: (1) horizontal burrows formed by infaunal deposit feeders; (2) low-angle to vertical passageways joining different bedding surfaces, mined by the deposit feeders; (3) vertical to slightly inclined burrows (Table II).

Type 1: Horizontal burrows

Horizontal burrows lie on bedding plane surfaces and may transect a few laminations. The burrows are straight to curvilinear, and individual traces

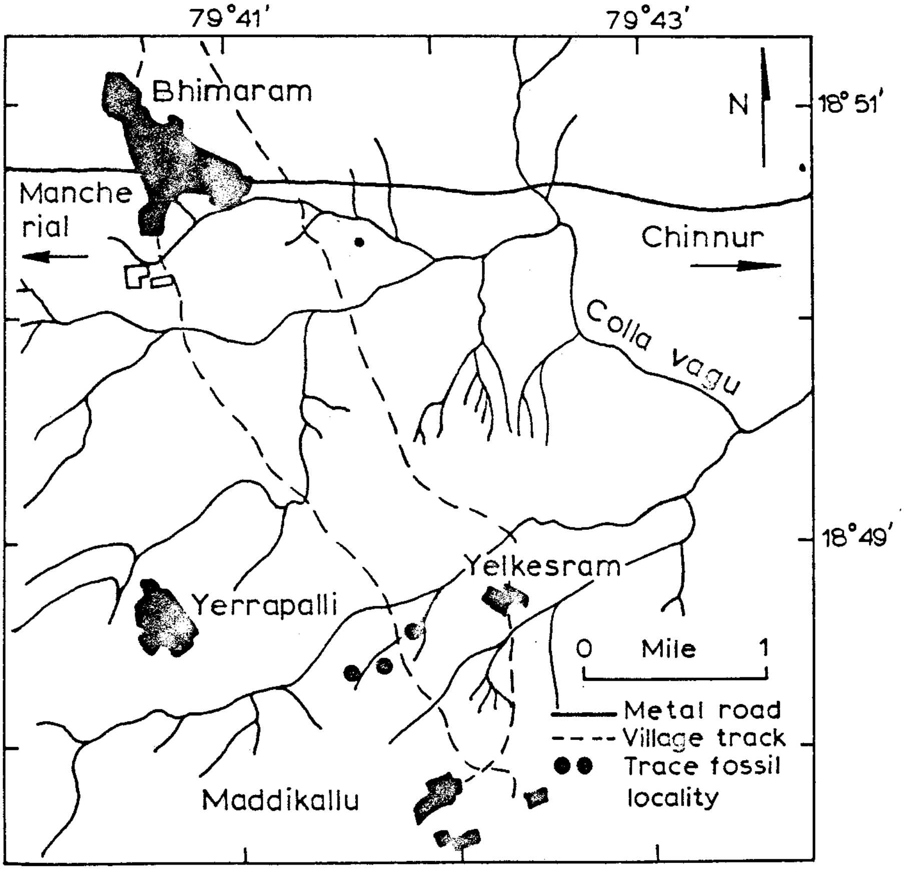

Fig.2. Trace fossil locality map.

maintain fairly uniform width throughout their lengths (Fig.3). The structures are non-branching, but may intersect. Contact with the host rock is well defined; no evidence of deformation or collapse has been observed. Burrow diameters vary widely from 1.2 mm to 9 mm and have modal diameter of about 1 mm, 5 mm, or 9 mm. Maximum length preserved, in a straight 8 mm wide burrow, is 130 mm.

Horizontal burrows can be separated into two groups; those confined to the flood plain deposits and the others restricted to channel-fill facies. Horizontal burrows in the flood plain sands are internally massive and filled with red, muddy sand similar to the host rock. Internal menisci, where developed, tend to be diffused. These structures are closely associated with the inclined passageways (type 2). Horizontal burrows in the channel-fill deposits occur in association with small vertical burrows in the parallel-laminated units. These burrows, in contrast to those in the flood plain deposits, are generally

TABLE II

Summary of lithology, primary structures, and sedimentary facies in relation to trace fossil assemblages

Facies	Lithology and sand body geometry	Major sedimentary structures	Trace fossils
Flood plain facies	thin sheets of fine-grained, poorly sorted sandstone with abundant clay matrix; interbedded with flood plain clays and silts	parallel lamination, parting lineations	(a) horizontal burrows, Type 1; without clear internal structure (b) inclined to vertical passageways, Type 2; often terminal extensions of associated horizontal burrows
Channel-fill facies	small lenses of fine-grained calcareous sandstone	cross-bedding, parallel laminations	(a) horizontal burrows, Type 1; with well-developed internal structure (b) vertical to slightly inclined tubular structures, dwelling burrows, Type 3A; may be internally massive or with menisci (c) short vertical burrows, make knobbly protuberances on the underside of the beds
			shelter burrows, Type 3B; sets of menisci separated by downward convex host-rock laminae passing across the burrows

internally meniscate. Menisci are smoothly arcuate in shape, and comprise alternating coarse and fine laminae (Fig.3). In some specimens the menisci are grouped together to give rise to "megamenisci" (similar to that described by Bromley and Asgaard, 1979, fig.9A), about 1 mm thick, and these are responsible for the gentle peristaltic undulations on the walls (Fig.3) which are absent in traces lacking internal structure. Material filling the burrows does not differ significantly from the host sediments. Sorting of the fill, however appears to be slightly better, and the grains composing the coarse menisci are coarser than the average size of the grains in the host rock.

The trace maker evidently was a deposit feeder, and the menisci were formed as active back-fill structures (Seilacher, 1964). It is difficult to ascertain the exact mode of origin of the meniscate structure, though preservation

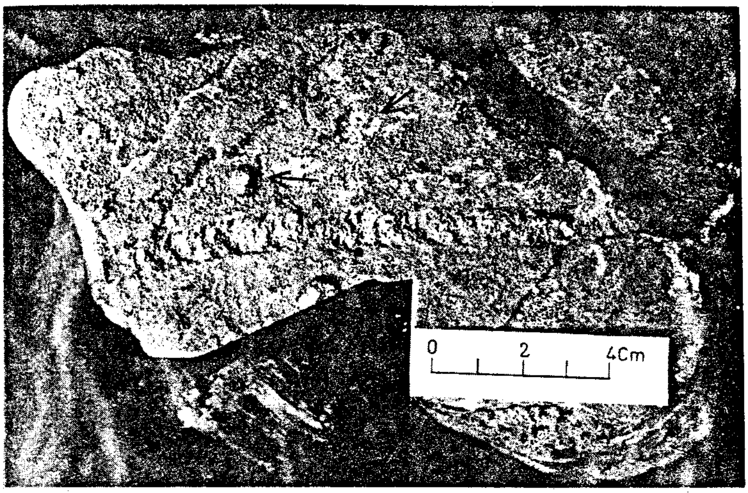

Fig.3. Horizontal feeding burrow on bedding plane (under surface) of the calcareous, laminated fine-grained sandstone of the channel facies. Note rectilinear nature of the burrow and well-preserved meniscate structure within it. The arrow points to the button-like protuberances of the associated shelter burrow. Length of the specimen is 15 cm.

of fecal pellets indicates that at least some of the material was ingested and passed through the digestive tract of the animals.

Horizontal burrows in the Yerrapalli Formation closely resemble the horizontal deposit-feeding burrows recorded by Stanley and Fagerstrom (1974) and the *Scoyenia gracilis* described by Bromley and Asgaard (1979) from ancient continental sediments. Stanley and Fagerstrom (1974) argued that the meniscate burrows from Pliocene braided river deposits were constructed in moist sand without any water cover. However, according to Bromley and Asgaard, similar burrows in the Triassic red beds of the Carlsberg Fjord were constructed under very shallow water. The Yerrapalli structures, by themselves, do not throw any light on the conditions of their origin, i.e., subaqueous or subaerial. Horizontal structures in the flood plain facies, however, are unlikely to develop in highly agitated conditions such as during floods. It appears more plausible that they formed during quieter interludes of dehydration between floods. This contention is favoured by the red coloration of the sediments and of the material filling the burrows as well. The meniscate burrows in the channel-fill deposits, on the other hand, might have formed under very shallow water conditions.

Type 2: Inclined to vertical passageways

Traces constructed by animals moving up and down through the Yerrapalli flood plain sands produced straight, cylindrical (full relief) burrows with modal diameters of about 4—6 mm, 8—10 mm and 12 mm; the maximum observed length being 22 mm. The burrows are mostly inclined (Fig.4) at low angles to the bedding, a few may be vertical (Figs.5 and 6). Inclination of the burrows generally remain constant along their length (Fig.5).

Sediments filling the burrows are almost the same as the host rock. However, the depositional fabric of the host rock, i.e., alternate iron-enriched and iron-depleted parallel laminations (apparently primary), have been completely destroyed and the material within the burrow thoroughly churned up. The structures are internally massive (Fig.6).

Contact of the burrows with the host rock is irregular, but sharp. Polished sections of the vertical burrows show two concentric zones; a central canal comprised of fine-grained, reddish-brown clayey material, surrounded by an outer greyish-white zone about 2 mm thick (Fig.5). The outer zone is dominantly sandy and was probably formed by selective segregation of coarser sand grains by the burrowers during movement through the sediments. Host-rock laminae are almost invariably deformed near the burrow wall, and the zone of deformation may be 2—3 mm wide. Generally the laminae exhibit downward buckling (Figs.5 and 6), though a few of them may develop second-order contortions along a narrow zone adjacent to the burrow (Fig.5).

Fig.4. Inclined passageway in vertical section in clayey sandstone of the flood-plain facies. Note constancy of width of the burrow. Width of the passageway is 1.5 cm.

Fig.5. Vertical passageway-burrow in clayey sandstone of the flood-plain facies. Note deformation of the laminations along the burrow walls. The central part of the burrow is filled up with fine, clayey reddish-brown material, and is surrounded by the greyish-white zone of coarser sand, about 2 mm wide. An inclined passageway is in the left corner of the specimen. Width of the burrow is 0.8 cm.

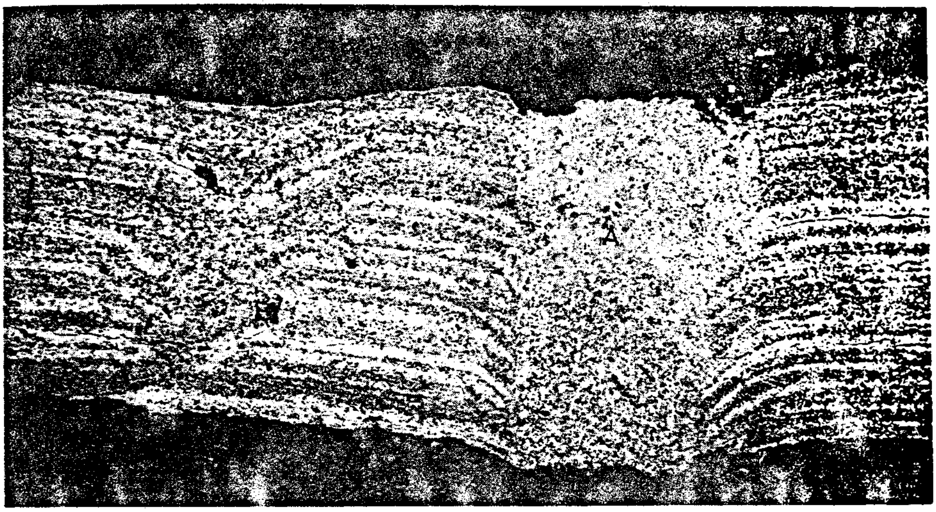

Fig.6. The massive fill of a vertical passageway (A). Note the disturbance in the host-rock laminae around the burrow. The disturbed zone (B) is the marginal part of another burrow on the plane of the vertical section. Negative print from a thin section. Length of the specimen is 7.5 cm.

The inclined to vertical burrows are confined to the flood plain deposits and in several examples are terminal extensions of the horizontal traces. Thus, both types of structures were evidently formed by the same trace maker, reflecting a change in behavioral mode of the animal. Absence of back-filling structures indicates that burrows were not formed as a result of feeding activities, but rather represent connections between galleries at successive bedding surfaces.

Structures of similar shape and orientation have been variously identified as *Tiggilites*, *Cylindricum* or *Skolithos* by earlier workers, depending upon difference in size and structure of the terminal end (Frey and Chowns, 1972; Bromley and Asgaard, 1979).

Type 3: Vertical to slightly inclined burrows

Based on the geometry of the internal fill in relation to the host rock, the burrows may be divided into two sub-types: In one type, the burrows are marked by downward convex laminae (menisci) all along their length, and those of the second type, on the other hand, comprise downward convex laminae (menisci) with occasional interference by the host laminae passing across the burrow. Burrows of the second type are generally shorter than the first.

Sub-type A

Vertical to slightly inclined tubular structures of sub-type A form the characteristic burrow system of the channel-fill sand bodies. Burrows are locally abundant and cut through different types of primary sedimentary structures of variable flow conditions (Fig.7).

These burrows occur in full relief on bedding plane surfaces, and are mostly circular in cross-section. Most of the burrows are straight (Fig.8), though a few, particularly the larger ones are slightly sinuous (Fig.9). The straight burrows normally maintain uniform width throughout their lengths. Sinuous burrows, in contrast, may show changes in width in different parts of the structure (Fig.9). All are non-branching single tubes but where they crowd together in a small area, they may interfere with one another. The burrows do not deform the host-rock laminae, but truncate them sharply (Figs.8, 9). Only in one example do the host-rock laminae bend slightly downward at the burrow wall, but the bending is quite uniform and contortions are absent. Burrow lining is rare, though fecal materials are concentrated along the margins of a few structures (Fig.10).

Diameters of the burrows range from 3 mm to 12 mm, the maximum concentration being in the range of 6 mm to 8 mm. Complete burrows with lower and upper termini are rare, and lengths of as much as 90 mm are preserved.

Fig.7 Vertical dwelling burrow (marked by dashed line) cutting through cross-laminated (middle of the photograph) and underlying parallel-laminated zones. Length of the specimen is 6.5 cm.

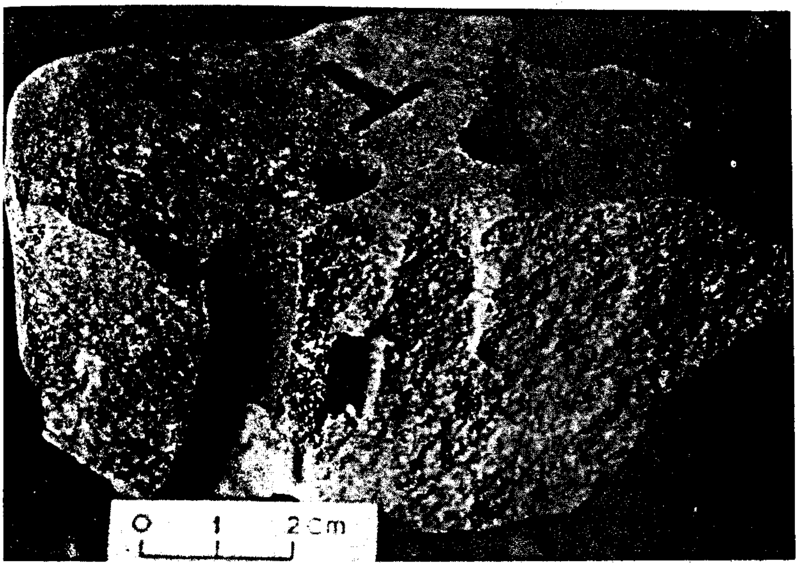

Fig.8. Vertical to slightly inclined dwelling burrows in the calcareous sandstone of the channel facies. Sharp truncation of the host rock by the burrows. Nearly circular section of the burrows on the bedding plane.

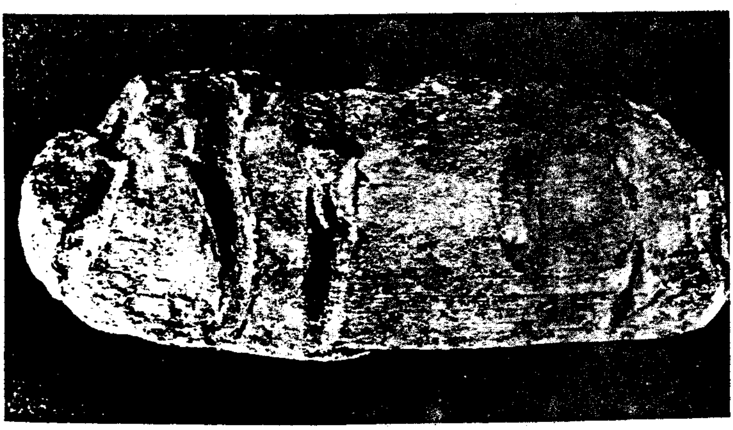

Fig.9. Straight to slightly sinuous dwelling burrows in the calcareous sandstone of the channel facies. Note slight variation in width along the length of a burrow (marked by dashed line). Length of the specimen is 15 cm.

Fig.10. Vertical dwelling burrows in the fine-grained calcareous sandstone of the channel facies. Note concentration of dark fecal pellets along the burrow margin. Length of the specimen is 0.7 cm.

Internal structures in these burrows are not as well developed as in the horizontal burrows and are recognisable only on etched polished sections or in radiographs. The burrows are generally internally massive. A few, however, are partly massive and partly meniscate. In a radiograph of a few closely spaced burrows it is noted that the burrows are massive for the most part of their lengths, with diffused contacts with the host rock, while menisci have developed either towards the top or towards the bottom of the bed. Convexity of the menisci in different burrows may be in different directions. Interestingly, while the convexity of the menisci at the underside of the beds are upward, those towards the top point downwards (Fig.11). Such orientations of menisci in different burrows indicate that the burrows were formed in response to both upward and downward movements of the animals through the burrowed beds.

The major constituents of the burrow fills are similar to that of the host rock. There are, however, a few significant differences: (a) the burrows are characterised by higher concentrations of fecal pellets, and some of the burrows contain significant amounts of brownish, presumably organic material; (b) some burrows contain crustacean shells, probably ostracods, and (c) the carbonates within the burrow system are much less recrystallised.

The structures are similar to the *Cylindricum* or *Skolithos* burrows described by Alpert (1974) and were probably used as dwelling burrows as suggested by Stanley and Fagerstrom (1974) and Miller (1979).

Sub-type B

Burrows of sub-type B occur in association with horizontal traces of the channel-fill facies. These burrows are short, 5 mm to 10 mm, vertical tubular

Fig.11. X-ray radiograph of a polished slab (2 mm thick) of calcareous sandstone from the channel facies showing vertical closely spaced burrows. Note that burrows are massive for most of their lengths with diffuse contacts; menisci have developed only at the terminal parts. Menisci towards the upper end of the burrows (on the right) are convex downward and those at the lower end of another burrow (on the left) are convex upward. Length of the specimen is 8 cm.

bodies, nearly circular to slightly ovate in cross section. Where preserved, lower terminations are hemispherical and make knobbly protuberances on the under surfaces of the beds (Fig.3). Burrow margins are sharp and often delineated with a lining of fine, black pellets, of probable fecal origin. The contacts are zig-zag and irregular. Some of the structures appear to be internally massive, but a few exhibit a poorly defined meniscate structure (Fig.12). The burrow fill is similar to the host rock, except for a larger proportion of pellets. Selective concentrations of fecal material within the burrows and along the burrow margins help to differentiate the structures from the host rocks in fresh or polished surfaces.

The host-rock laminae that continue through the burrows show slight downward curvature within the burrowed area (Fig.7). Maximum concentrations of pellets along these surfaces indicate that these planes may be the surfaces of non-deposition. Continuation of these planes through the burrows suggest that the burrows were probably constructed in phases.

The burrows resemble those from the Tully clastic equivalents of the Catskill deltaic complex in external morphology (Miller, 1979), and may

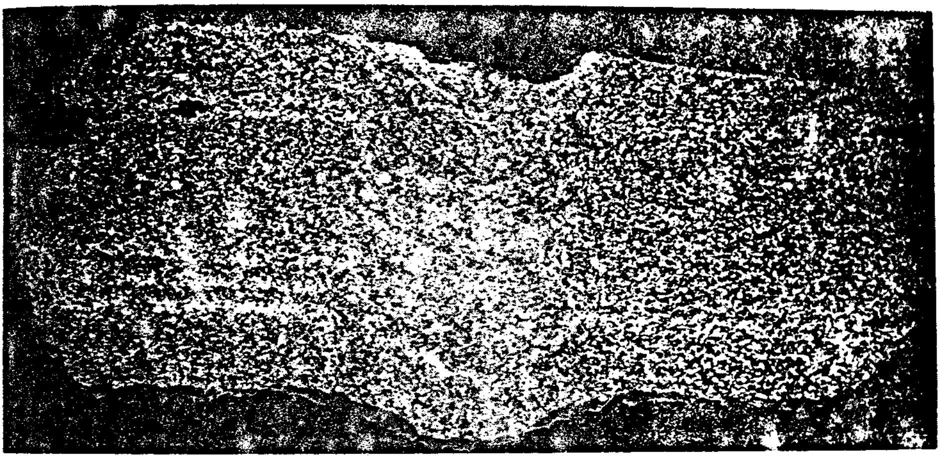

Fig.12. Vertical section of a shelter burrow in a parallel laminated calcareous sandstone of the channel facies. Note the poorly developed meniscate structure within the burrow and also the continuity of some of the host-rock laminae across the burrow with downward curvature conforming with the menisci. Diffused contact between the burrow fill and the host. Negative print from a thin section. Length of the specimen is 4 cm.

represent dwelling burrows. Multiple phases of burrow construction and short depth of each phase of burrowing, however, suggest that they might have served as temporary shelters of the burrow makers close to the depositional surface.

DISCUSSION

Yerrapalli trace fossils can be classified in two distinct assemblages according to their interpreted environment of origin. The two environments are profoundly different with respect to the substrate characters and different physical attributes, and consequent to this, the behavorial patterns of the trace makers also differ. The assemblages of trace fossils are mutually exclusive and demonstrate well-defined facies specificity, as follows:

(a) Horizontal burrows without any clear internal structure and associated inclined burrows, the passageways (Fig.6), developed only in the red, muddy siltstones and fine-grained sandstones interbedded in the red clays of the Yerrapalli flood plain.

(b) Horizontal traces with well-defined internal menisci, (Fig.3) shelter burrows making knobbly traces (Figs.3 and 5) and vertical and high-angle dwelling burrows (Figs.7 to 12) are characteristic of the fine-grained calcareous sandstones and arenaceous limestones of the channel-fill lenticular bodies. Within the channel-fill deposits traces can be grouped into two sub-assemblages; horizontal traces and the shelter burrows are restricted within the parallel-laminated rocks whereas dwelling burrows are restricted to the cross-stratified units.

Analysis of the trace fossil assemblage and facies relationship in the Yerrapalli Formation attest that factors controlling the trace morphology are primarily environmental, and are in close agreement with the observations from the shallow marine areas. Horizontal burrows have developed in those facies that were subjected to least environmental stresses and the conditions remained fairly constant over long intervals between successive phases of sedimentation. Vertical burrows, on the other hand, are characteristic of the facies deposited in relatively unstable environments marked by rapid fluctuation in hydrologic conditions, temperature and rate of deposition.

As suggested earlier, lenses and small sheets of thinly laminated muddy sandstones within the red clays were probably products of overbank flooding. The horizontal trace makers burrowing in the sands and feeding on the entrapped organic material established themselves shortly after the floods. In a semi-arid condition the hydrological realm of the flood plains is likely to remain undisturbed for long periods. The flood plain is rarely inundated, the most frequent overbank flooding interval is between one and two years (Wolman and Leopold, 1957; Collinson, 1978). The undisturbed condition of the exposed flood plain areas and the fine muddy sands therein apparently provided a favourable niche for the growth of an extensive population of deposit-feeding organisms (cf. Purdy, 1964). The trace makers probably operated at different levels, on the sediment surface and along bedding surfaces close to the sediment-air interface. Changes in level of burrowing probably reflect a response to the dehydration of the surficial layers under rigorous climatic conditions; animals moved downwards to escape from the surficial heat. Downward movement of the animals consequent to dehydration on the surface has been demonstrated by Pryor (1967) from Recent environments.

Horizontal trace makers were also active in the thinly laminated calcareous siltstones associated with the cross-stratified channel-fill deposits. These parallel-laminated silts with evidence of grain movement were formed within the channels during high discharge periods (cf. McKee et al., 1967), and probably were environmentally less disturbed than the cross-stratified deposits. The burrows must have been dug in these high-discharge deposits during low-discharge periods when these sediments were not covered with water. Though the burrows were formed in exposed conditions (without any water cover), presence of linings in some of the burrows, particularly the passageways, suggests that the substrate was moist and soft (Frey, 1970). The consistency of the substrate, however, was quite high as is clearly indicated by the plastically deformed laminae of the host rock (Fig.5) along a zone extending several grain diameters around the burrows (cf. Rhoads et al., 1972; Rhoads, 1975).

The channel facies evidently was subjected to relatively high environmental stresses in contrast to the products of overbank flooding, and was colonised by the vertical burrows. Behavior of the trace makers must have been similar to the behavior of the burrowers operating in the fluctuating conditions of the intertidal areas, and the vertical burrows were constructed for protection against environmental variabilities. Also the truncated sets of sands suggest an environment of shifting sediments. The shifting substrate and relatively clean sand precludes the presence of deposit-feeding infauna. Organic detritus trapped in the sediments was apparently not sufficient to support an abundant detritus-eating community, as is true of the muddy sediments in the adjoining flood plains. Instead, only filter-feeders, burrowing vertically or at high angle into the substrate, could successfully inhabit this environment (cf. Walker and Laporte, 1970; Howard, 1972). The presence of ostracod shells, both broken and unbroken, within some of the burrows points to the filter-feeding character of the burrow makers.

Crowding of the burrows in certain beds and their paucity in the adjoining areas similar to the burrowed horizons in texture, composition and sedimentary structures suggest high variability in the rates and condition of sedimentation. Concentrations of well-developed burrows along single bedding horizons indicate that the rate of sedimentation was negligible during certain intervals (Seilacher, 1964; Frey, 1968). A slow rate of sedimentation in the channel facies is also suggested by the abundance of pellets (Rhoads, 1967).

General absence of burrow lining, in contrast to the flood plai burrows, points to the high consistency of the substrate (Frey, 1970). Absence of deformation in the host rock around the burrows also corroborates that the substrate was firm. High consistency of the substrate in the present case was probably achieved through syndepositional lithification of the highly calcareous sediments under conditions of frequent emergence and submergence in hot climates with low precipitation.

It is difficult to state which specific organisms were the originators of the Yerrapalli burrows. Stanley and Fagerstrom (1974) considered beetles as the originators of the vertical burrows from the braided-bar sands of the North Platte River. Vertical Yerrapalli burrows resemble the Platte River burrows and beetles could have been one of the trace makers. Interestingly, in the present case also Chatterjee (1980) observes that beetles probably were quite abundant during the Yerrapalli time.

CONCLUSION

The foregoing description of the trace fossils and the discussion clearly brings out close similarity of the behavioral modality of the continental trace fossils with those in the shallow marine environments. Trace fossils in combination with other primary structural and textural features may act as keys to the interpretation of continental facies. The Yerrapalli trace fossils provide, besides the information on the abundance of the bottom-dwelling organisms, significant clues in identifying the subenvironments and their ecological parameters in the complex milieu of fluvial environments. This remains true even when other fossil evidence does exist.

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