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Bathymetric Significance of the Ichnofossil Assemblages of the Kulakkalnattam Sandstone, Ariyalur Area, Cauvery Basin

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Abstract: Well preserved ichnofossils were found in Kulakkalnattam sandstone exposed at Kulakkalnattam stream in Ariyalur area, Cauvery Basin. It consists of infaunal structures of both suspension and deposit feeders. Five ichnofossils are present in a fine to coarse grain sandstone which includes *Ophiomorpha*, *Palaeophycus, Planolites Skolithos,* and *Thalassinoides.* The study infers that ichnofossils *Skolithos* and *Ophiomorpha* are infaunal colonization of the suspension feeders in high energy condition in shifting substrate, whereas *Thalassinoides* and *Planolites-Palaeophycus* ichnofossils indicate infaunal deposit feeders living at the sediment-sediment interface in low to moderate energy conditions. Furthermore, the abundance and diversity of the trace fossils indicates there was alternatively fluctuations in energy conditions which lead to development of *Skolithos* and *Cruziana* ichnofacies type condition during the deposition of Kulkkallanattam sandstone in foreshore-shoreface environments.

Keywords: Ichnofossils, Kulakkalnattam Sandstone, Ariyalur area, Cauvery Basin.

INTRODUCTION

Biogenic sedimentary structures record the vital information for environmental interpretation, in terms of water depth, salinity, energy level, oxygenation variations (Ekdale, 1988). The ichnofossils are indicators of depositional environment (Savrda, 1995) and help to record sedimentation rate; intensely bioturbated horizons and beds with well preserved, complex feeding and grazing traces would reflect slow rates of sedimentation; bored surfaces indicate a break in sedimentation allowing sea-floor cementation to take place. Intense bioturbation may occur immediately below a flooding surface. U-Shaped burrows and escape structures reflect more rapid sedimentation. Trace fossils directs to assess the sediment consistency. If the sediment is soft, then tracks made on a lamina can be transmitted through to underlying lamina. Where burrows are either filled with coarser sediment of preferentially lithified during early diagenesis, surrounding sediments are commonly compacted around the burrow fills if the sediment was a soft ground. In firm grounds the burrow show little compaction, and hard grounds are recognized by the presence of borings and encrusting organisms. Ichnofossil assemblages have immense utility in determining paleobathymetric conditions especially when sediments are devoid of body fossils.

The Kulakkalnattam sandstone in Ariyalur area is generally pauperate in body fossils and hosts rich assemblage of ichnofossils. This sandstone is exposed along Kulakkalnattam stream. Considering the utiiity of ichnofossils in reconstructing paleobathymetry an attempt is made to record and illustrate well preserved ichnofossils from Kulakkalnattam sandstone.

GEOLOGY AND STRATIGRAPHY

The Cauvery Basin is a pericratonic basin located along the south east coast of India. It was developed as a consequence of the breakup of Gondwana land during the Late Jurassic (Rangaraju et al. 1993).The outcrop area comprises part of the western margin of the basin from Pondicherry in the north to Sivaganga to the south. It includes major outcrop areas at Ariyalur, Pondicherry, Virdhachalam, and Sivaganga and relatively small Thanjavur area at the central part.

The Albian to Maastrichtian sediments is exposed around Ariyalur area. These rock sequence have been divided into three groups, Uttatur, Trichinopoly and Ariyalur

(Blanford, 1862), consisting of seven formations in ascending stratigraphy order viz. Dalmiapuram, Karai, Garudamangalam, Sillakkudi, Kallankurchchi, Ottakkovil and Kallamedu (Tewari et al. 1996a,b; Sundaram et al. 2001).

The Trichinopoly Group consists of Garudamangalam Formation, comprises of three members; Kulakkalnattam sandstone, Anaipadi sandstone and Saturbhagam sandstone Members. The Coniacian-Santonian Kulakkalnattam sandstone unit of Garudamangalam Formation unconformably overlies Karai Shale. This sandstone is highly bioturbated and consists of abundant dwelling burrows of suspension and deposit feeding animals. The Kulakkalnattam sandstones are mineralogical and texturally immature, poorly sorted and the grains are enriched in calcite cement. The petrography of the Kulakkalnattam sandstone reveal that the grains are poorly sorted; free floating, angular to sub angular, bimodal distribution of grains. The feldspar grains are more than quartz and low population of lithic fragments. The grain boundary is corroded and early calcite cementation is present. Besides, some sedimentary section shows that the calcite population is higher than quartz and feldspar; the shell fragment present is more than the detrital grains. This unit vertically grades into calcarenite. The overlying Saturbhagam sandstone unit (Fig.1) of the Garudamangalam Formation characterized by cross laminations point to fluvial channel origin, revealing sea level drop at the end of Santonian (Nagendra et al. 2010).

DESCRIPTION OF ICHNOFOSSILS

Five ichnofosssils, *Ophiomorpha*, *Palaeophycus, Planolites, Skolithos* and *Thalassinoides* are described in detailed in the alphabetical order.

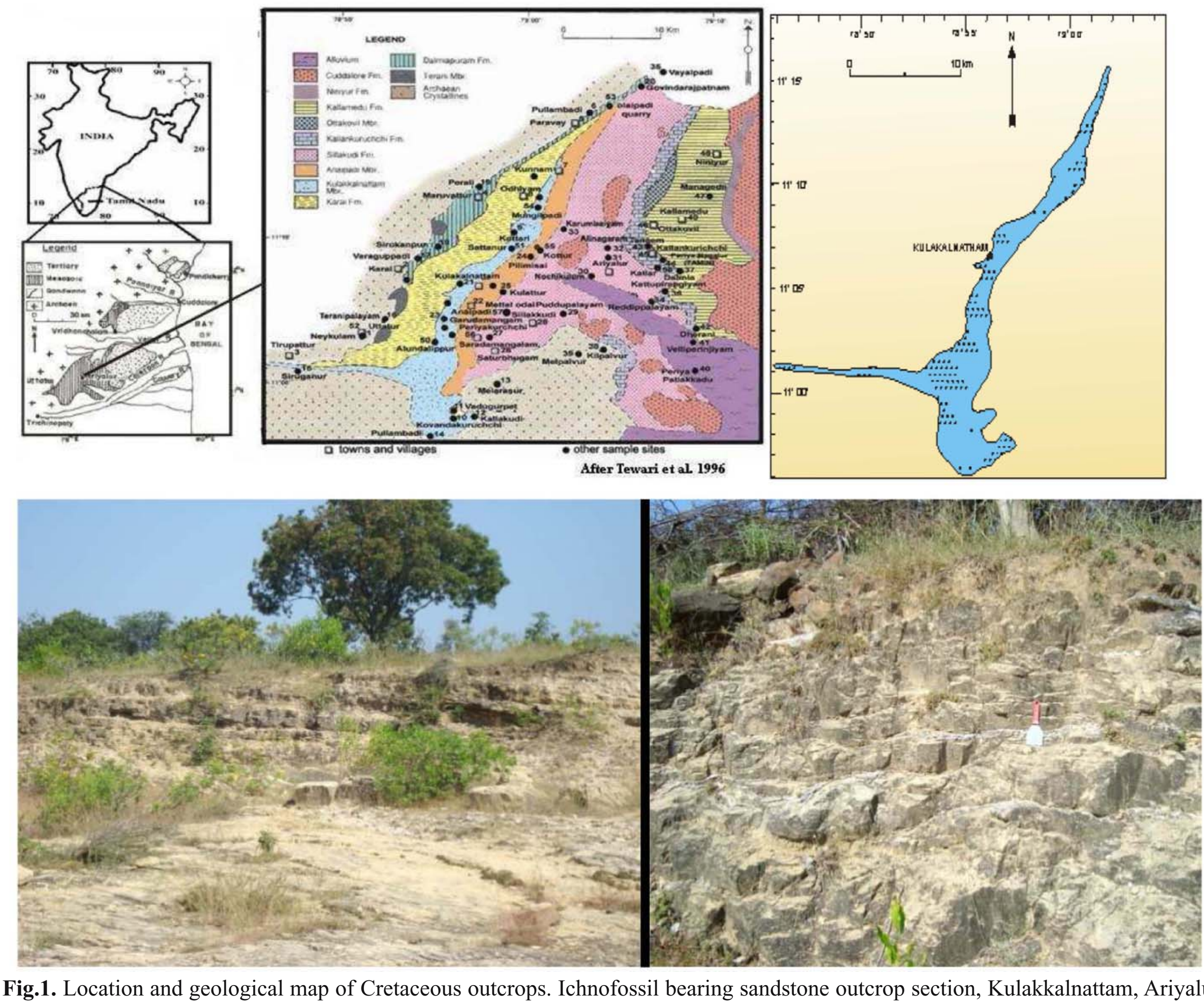

Fig.1. Location and geological map of Cretaceous outcrops. Ichnofossil bearing sandstone outcrop section, Kulakkalnattam, Ariyalur area.

Ichnogenus: *Ophiomorpha* Lundgren, 1891

Diagnosis: Simple to complex burrow systems distinctly lined with agglutinated pelletoidal sediments. Burrow lining more or less smooth interiorly; densely to sparsely mammilliated to nodose exteriorly. Individual pellets or pelletal masses may be discoid, ovoid, mastoid, bilobate, or irregular in shape. Burrow systems three dimensional, vertical and horizontal, cylindrical, tunnels dichotomy, and simple to complex burrow systems (Howard and Frey, 1984).

Ichnospecies: *Ophiomorpha nodosa* Lundgren, 1891
(Fig.2a-d)

Diagnosis: Three-dimensional burrow systems, vertical and horizontal cylindrical tunnels, generally at acute angles; with local swellings. Burrow walls consisting predominantly of dense, regularly distributed ovoid pellets, internal wall smooth.

Description: Endichnial large burrow system, branched or unbranched, straight to gently curved and varying angles to the bedding plane. The internally burrow is smooth, but outer surface of burrow lining characteristically mammilliate, most often with a single pallet form of construction. Collapsed burrows are very common and usually represented by thick, dark, irregular circular outer tube like structure around the inner shaft in the vertical burrows. While in the inclined and horizontal burrows the outer lined structures are weathered and eroded and appears like beaded and furrows Fig.2b) like structures. In few ichnospecies, small branches were also emerge from main burrow at short distance and perpendicular in downward direction or inclined to bedding plane. Burrow dimensions are constant in the given burrow system but there lengths and penetrations are vary in the different burrow populations and diameter is of 3-5 cm. Burrows fill is identical to host sediments.

Remarks: *Ophiomorpha nodosa* is identified by the diagnosis followed by Frey et al, (1978). *Ophiomorpha* usually occurs in near shore deposits (Weimar and Hoyt, 1964; Frey et al. 1978) and are considered to be made by Callianasids shrimps. Patel and Desai (2001, 2010) have also observed *Ophiomorpha nodosa* like burrows which were made by Stomatopodean (Squillidean) crustaceans, especially *Oratosquilla striata* in the runnels of the intertidal zone of the Mandvi area. The presence of the *O. nodosa* is indicating the foreshore-shoreface environments.

Ichnogenus: *Palaeophycus* Hall, 1847

Diagnosis: Cylindrical or sub cylindrical burrows, usually sinuous, oriented more or less obliquely to bedding. Commonly unbranched, though may be branched occasionally. Surface of walls smooth or rarely with faint longitudinal striae. *Palaeophycus* is distinguished from *Planolites* by having a distinct wall lining and sediment fill typically different from the lithology of the host rock.

Ichnospecies: *Palaeophycus heberti* Saporta, 1872
Fig.3d

Description: Burrow occur as endchinial or convex hyporelief, cylindrical to sub cylindrical, straight to gently curved, horizontal to inclined, thickly, distinctly lined which marked as dark line in collapsed burrow and rarely branched. The length is about 9 to 13 cm and diameter of the burrow is constant throughout the length of the burrow and is being of 2.5 cm. Burrow fills are resistant to weathering and tends to stand out as relief and is typically of same lithology and texture as the host stratum.

Remarks: Pemberton and Frey (1982), clearly distinguished *Palaeophycus* from morphologically similar *Planolites* by the presence or absence of distinct wall lining and nature of fill. It is interpreted as dwelling trace of predaceous vermiform animals (Pemberton and Frey, 1982).

Ichnospecies: *Palaeophycus tubularis* Hall, 1847
Fig. 3c(ii) and e

Diagnosis: Straight to slightly curved or more or less smooth walled, unornamented, burrows variable, thinly but distinctly lined.

Description: Trace fossils occur as convex hypo relief; horizontal, smooth, cylindrical, straight, unbranched, straight to gently curved, distinctly lined burrows. The burrows crowded and either overlapping or criss-crossings are very common. The diameter of the burrow is constant and being of 2.5 cm, length is highly variable in different burrow population, maximum observed length is of 12 cm on bedding plane and it is appear as thick dark circular ring with in filled hard material which is identical to host sediments.

Remarks: P. tubularis is distinguished from *P. heberti* by having smooth, thick lined which is usually collapsed in exposed part of the burrows while burrow fills are resistant to weathering and tend to stand out as relief. This is interpreted as dwelling structures of predaceous vermiform animals (Pemberton and Frey, 1982).

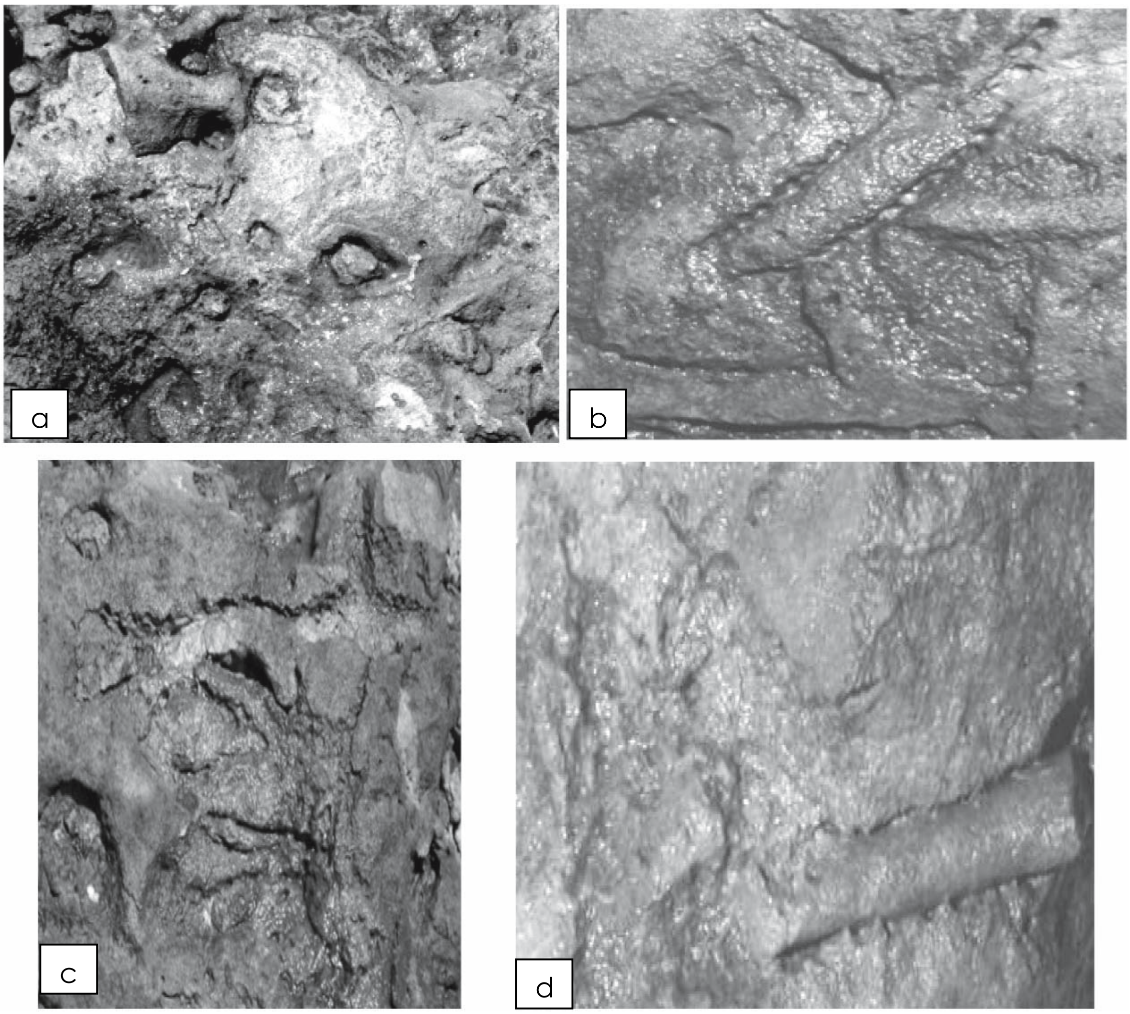

Fig.2. *Ophiomorpha nodosa* burrow in sandstone, Kulakkalnattam, Ariyalur area. **(a)** *O. nodosa* burrow exposed as irregular circular ring on bedding plane with burrow fill material appear as rod like structures. **(b)** Inclined burrows; collapsed wall appear as beaded and furrow structures. **(c)** Branched burrow system of *O. nodosa* and **(d)** Horizontal component of collapsed burrow. Note: Wall lined is eroded.

Ichnogenus: *Planolites* Nicholson, 1873

Diagnosis: Unlined, rarely line, rarely branched, straight to tortuous, smooth to irregularly walled or annulated burrows, circular to elliptical in cross-section, of variable dimensions and configurations, fill essentially structureless, differing in lithology from host rock (Pemberton and Frey, 1982; Fillion and Pickrill, 1990).

Ichnospecies: *Planolites beverleyensis* Billings, 1862
Fig.3c (ii)

Diagnosis: Relatively small, smooth, straight to gently curve or undulose cylindrical burrows.

Description: Preserved as endichnial and hypichnial ridges, predominantly cylindrical, smooth-walled, unbranched burrows typically oriented more or less parallel to bedding plane. Burrows occur as crowded masses in which crossovers interpenetrations and reburrowed segments are common. Dimension varies from different burrows population. Length of burrow is varied from 8 to 12 cm and diameter of 0.7 to 1.2 cm.

Remarks: *Planolites* is identified by using criteria as discussed by Pemberton and Frey (1982). *Planolites* is generally regarded as the fodinichnia/pascichnia, product of vermiform deposit feeders, actively back-filling their burrows (Uchman, 1995).

Ichnogenus: *Skolithos* Haldeman, 1840

Diagnosis: “Ordinary pipes”, straight tubes or pipes perpendicular to bedding and parallel to each other, subcylindrical, unbranched.

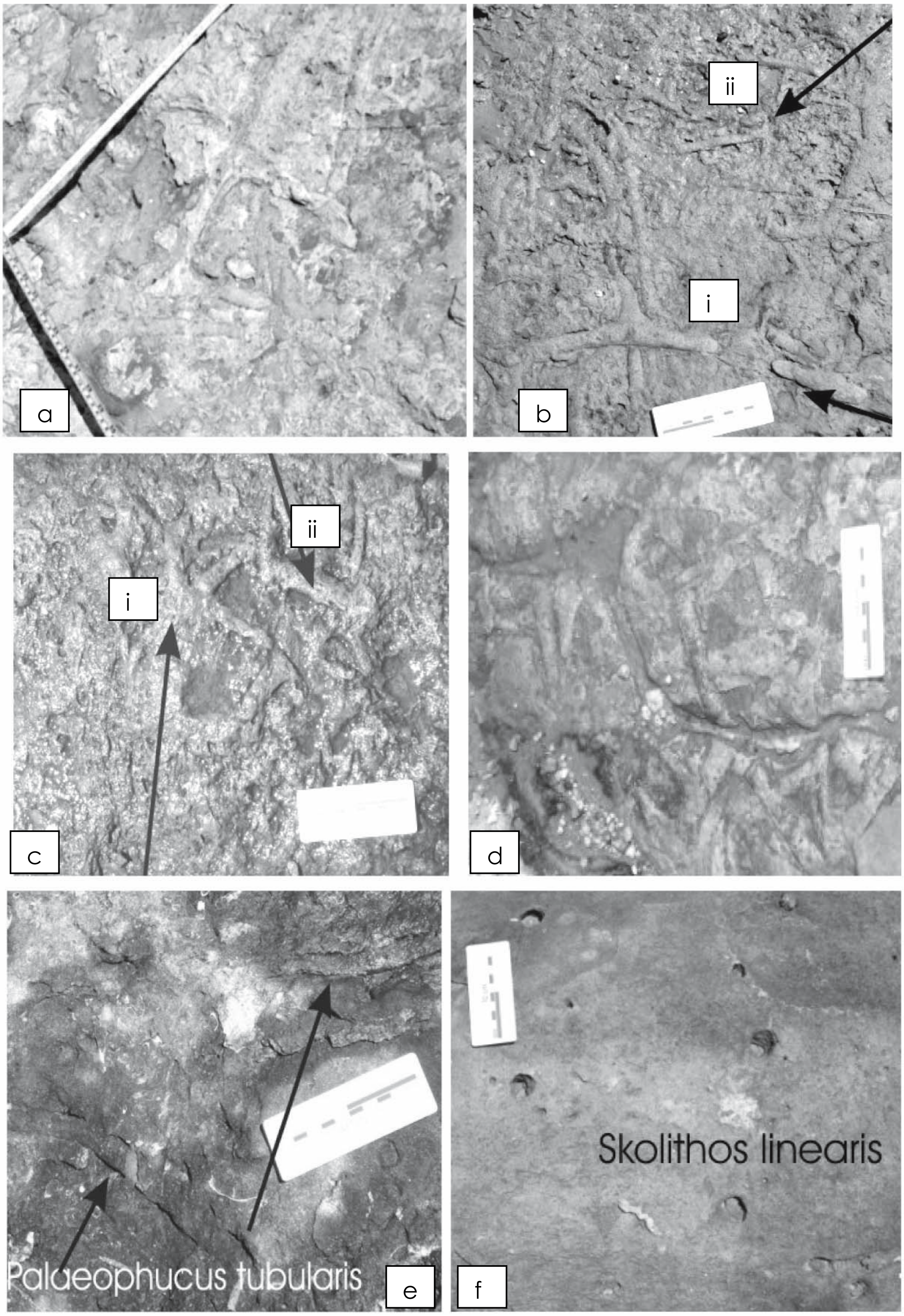

Fig.3. Ichnofossils in Kulakkalnattam sandstone, Ariyalur area. **(a)** Large, horizontal, branched polygonal burrows of *Thalassinoides horizontalis,* **(b)** (i) Large, horizontal to inclined burrows with enlargement at point of bifurcation in the *Thalassinoides suevicus,* and (ii) horizontal crowded burrows of *Planolites beverleyensis,* **(c)** (i) *Thalassinoides horizontalis* (ii) *Palaeophycus tubularis*, **(d)** Large, thick lined represent as dark line in *Palaeophycus heberti,* **(e)** Large, horizontal, burrows of *Palaeophycus tubularis*, **(f)** Vertical cylindrical holes of *Skolithos linearis* on bedding plane.

Ichnospecies: *Skolithos linearis* Haldeman, 1840
Fig.3f

Diagnosis: Cylindrical burrows, straight or slightly curved, and vertical to inclined, wall smooth or rarely corrugated.

Description: Endichnial, cylindrical to sub-cylindrical, vertical to slightly inclined, straight to slightly curved, unbranched, wall distinct, with variable diameter of the tube. Collapsed structures are very common and it appears as vertical cylindrical hole on the bedding plane. Burrow depth/ penetration is difficult to determine but ring like structure on the bedding planes appears to be of 20-25 mm in diameter. Burrow fill is also identical to surrounding materials.

Remarks: *Skolithos linearis* burrows are generally large, vertical, and thickly lined as compared to *Skolithos verticalis* which is usually display shorter, smaller and more commonly inclined and curved shaft. *S. linearis* is a facies crossing species and is found throughout the Phanerozoic time. It is interpreted to be a domichnion of suspension feeding polychaetes like *Amphinome rostrata* and *Nereis costoe* (Patel and Desai, 2009). *Skolithos* is widely recognised in shallow water, intertidal deposits (Seilacher, 1967) and in various shallow marine environments (Fillion and Pickerill, 1990; Alpert, 1974) and is probably thought to be produced by annelids or phoronids (Alpert, 1974).

Ichnogenus: *Thalassinoides* Ehrenberg, 1944

Diagnosis: Cylindrical burrows forming three dimensional branching systems consisting of horizontal network connected to surface by more or less vertical shaft. Regularly branching, Y to T-shaped bifurcations in horizontal system is forming polygons, typical swelling at points of branching or elsewhere.

Ichnospecies: *Thalassinoides horizontalis* Myrow, 1995
(Fig.3a and c ii)

Diagnosis: Predominately horizontal, cylindrical more or less regularly branched, unlined burrow system with smooth wall. The diagnostic characteristic are (1) an entire bedding parallel oriented network, (2) absence of vertical oriented offshoots from polygon framework (3) diameter of the both inner and outer burrow wall is constant within the specimen, including lack of swellings at the junctions (Mayrow, 1995).

Description: Relatively large, smooth, essentially unlined to very thinly lined, three dimensional horizontal burrow systems and usually branched perpendicular or T shaped. Branches typically lack swelling at points of bifurcation and parallel to bedding plane and form polygonal network. Lengths of the tunnels are variable and diameter of 3 to 6 cm. Burrows are circular in cross-section and fills representing passive gravity induced sedimentation within fine grained coherent substrates.

Remarks: The specimens differ from the type material of Myrow (1995) only in diameter. *T. horizontalis* resembles *T. bacae* but differs from it in entirely lacking the presence of vertical shafts. *T. horizontalis* was also observed to be formed at the under-surface or within the bedding plane. The isolated branches of *Thalassinoides* burrows are morphologically similar to *Planolites* except for enlarged junction points and nature of fill. In case of *Thalassinoides* the fill is gravity induced in nature and shows the alimentary canal of animal.

Ichnospecies: *Thalassinoides suevicus* Kennedy, 1967
Fig.3b

Diagnosis: Predominantly horizontal, more or less regularly branched, essentially cylindrical burrow system consisting of a horizontal network connected to the surface by a more or less vertical shaft; dichotomous bifurcations are more common than T-shaped branches (Howard and Frey, 1984). Burrows form three dimensional branching systems; Y-shaped bifurcations in horizontal system forming polygons; typical swelling at points of branching or elsewhere.

Description: Endichnial, full relief, large, horizontal to slightly oblique three-dimensional burrow system, Y shaped bifurcations on bedding plane forming polygons and typically swelling at point of bifurcations. The whole burrow system is very large but the arms showing the uniform diameter and being of 5.5cm. The burrows fill commonly has the same colour and texture as host rock.

Remarks: *Thalassinoides* is a facies-crossing form, most typical of shallow-marine environment, and is produced mainly by crustaceans (Frey et al. 1984). The enlarged junction points are often used as turning points for the organism**.**

DISCUSSION

Considering the utility of ichnofossil assemblages in reconstructing paleobathymetry (Seilacher, 1967) in marine environments, Kulakkalnattam sandstone of the Ariyalur area provide an excellent opportunity. Utilizing the typical trace fossil associations, Frey and Pemberton (1985) have constructed ichnofacies which are representative of environmental gradients and illustrated eight inchofacies occurring from rocky coast to abyssal zone. The abundance of vertical burrows represented by both smooth and reinforced wall, 'U' shaped, 'J' shaped, 'Y' and 'T' shaped structures are commonly reported from semi consolidated substrate (Frey and Pemberton, 1985) and are characteristic of foreshore, moderate to high energy conditions (Seilacher, 1967; Frey and Pemberton, 1992; Reddy et al.1992; Satyanarayana et al.1999).

The present study on Kulakkalnattam sandstone revealed the dominant occurrence of vertical burrows in association with horizontal burrows. The vertical burrows are predominantly represented by *Ophiomorpha nodosa* and *Skolithos linearis* are produced by the suspension feeding animals are preserved as full relief. These structures are the member of the *Skolithos* ichnofacies (Frey and Pemberton, 1992). Abundance of the biogenic structures and sediment characteristic indicates the relatively moderate to high energy conditions and shifting substrate have been exploited by the opportunistic animals in the foreshore/shoreface environments.

Alternatively Kulakkalnattam sandstone is fine grained which is mineralogical and texturally immature and highly bioturbated and shows the good preservation of horizontal structures of deposit feeding communities. It is dominated by the cylindrical, branched, large size three dimensional horizontal burrows of *Thalassinoides horizontalis* and *Thalassinoides suevicus* with unbranched horizontal burrows represented by *Planolites beverlyensis,* and *Palaeophycus tubularis*. The horizontal structures of Kulkkallanattam sandstone is typical members of the *Cruziana* ichnofacies (Seilacher, 1967) which colonized in reduce energy conditions in the shallow marine environments. *Planolites* and*, Palaeophycus* are essentially horizontal structures and occur few centimeters below the sediment-sediment interface, suggesting unconsolidated substrate experiencing relatively moderate to low energy sub tidal conditions. The degree of bioturbation is very high and completely obscures the physical sedimentary structures.

The ichnofossils of the Kulakkalnattam sandstone is represented development of two ichnofacies, *Skolithos* and *Cruziana*. The ichnofossils present in both the ichnofacies were probably made by crustaceans and polychaetes of the shallow marine environments. The *Skolithos* ichnofacies is indicates the relatively moderate to high energy conditions and unconsolidated shifting substrate. While *Cruziana* ichnofacies type condition was developed in the shallow protected zone which indicates sudden change in environmental conditions. The petrography characters reveal that the grains are poorly sorted, free floating, angular to sub angular, bimodal distribution. Sediment characteristics and biogenic (feeding/dwelling) activity suggests normal salinity in the fully marine foreshore-shoreface environment during the deposition of the Kulakkalnattam sandstone of the Ariyalur area.

CONCLUSIONS

1 Kulakkalnattam sandstone represented by *Ophiomorpha nodosa, Palaeophycus tubularis, Planolites beverleyensis, Skolithos linearis, Thalassinoides suevicus* and *Thalassinoides horizontalis*.
2 These ichnofossils assemblages display development of the *Skolithos* and *Cruziana* Ichnofacies indicating deposition of the Kulakkalnattam sandstone under moderate to high energy conditions.
3 The integration of both ichnofossils, textural and mineralogical characteristics conclusively infer that the Kulakkalnattam sandstone was deposited in foreshore-shoreface environments.

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