Ichnology of an incised valley-fill: their recognition and significance in the 'Beta' Field, Coastal Swamp Depobelt of the Niger Delta.

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Abstract

Integration of high resolution biostratigraphy, wireline logs and core samples from 'Beta' field in the Coastal Swamp depobelt of the Niger Delta revealed a tripartite arrangement of facies typical of an incised valley system. The stratigraphic succession penetrated in the field consists of a basal conglomerate unit that reflects a fluvial system that progressively becomes influenced by tidal process; a medial sandstone and mudstone unit that represents deposition in the central part of an estuary and, a cross stratified sandstone unit at the top, representing the progradational filling of the bay-head of the estuary. The trace fossil assemblages recognised in the succession were the *Skolithos* ichnofacies which include *Skolithos*, *Ophiomorpha, Diplocraterion*, *Conichnus*, *Palaeophycus, Planolites* and *Arenicolites*; the *Cruziana* ichnofacies which comprises *Thalassinoides*, *Teichichnus*, *Chondrites, Rhizocorallium*, *Asterosoma* and *Zoophycos* ichnofacies that consists of *Phycosiphon*, *Zoophycos, Neonereites, Helminthoida*. Abundance, diversity and the rate of bioturbation of these trace fossil suites differ within the tripartite succession. *Skolithos, Cruziana* and *Zoophycos* ichnofacies characterise the prograding bay-head of the estuary due to the interplay of fluvial, marine and tidal processes while the *Skolithos* ichnofacies dominate the tidal-influenced fluviatile basal unit of the incise valley.

Index Term- Bay-head delta, Coastal Swamp Depobelt, central estuary, incised valley-fill, ichnofacies, systematic ichnology.

Introduction

Numerous research areas such as the hydrocarbon habitat of the Niger Delta, the stratigraphy, biostratigraphy, structural and petroleum potential have received increased attention since the discovery of commercial hydrocarbon in the basin [1], [2], [3], [4], [5], [6], [7], [8], [9]. Though the

ichnology of estuarine/incised valley-fill depositional systems is becoming a focus of research globally [10], [11], [12], little of such study has been published the Niger Delta. Incised valley estuarine fills are known to host reservoirs that produce economically significant quantities of hydrocarbon [13], [14]. This has therefore awakened interest in recognizing and interpreting the depositional systems of the ancient incised valley deposits in the Niger Delta, using ichnology. Ichnology, which is the study of organism-sediment interactions has been significantly useful in sedimentology, paleoecology and environmental reconstruction. It act as potential indicators of bathymetry, currents, food supplies, aeration, rate of sedimentation, depositional history and substrate stability [15].

The main purpose of this study is to identify and document the types of trace fossils (ichnofossils) present in the core samples of the incised valley fill from the 'Beta' field of the coastal swamp depobelt and note the pattern and styles of bioturbation. This paper also intends to discuss the relevance of trace fossils for facies delineation in an incised valley-fill.

Stratigraphic Setting and Location of the Study Area

The Niger delta is situated on the continental margin of the Gulf of Guinea in equatorial West Africa. The subaerial portion of the delta covers about 75,000km^2 with regressive wedge of clastic fill of about 12 km. The 'Beta' field lies within the Agbada Formation (the hydrocarbon rich lithostratigraphic succession of the Niger Delta) in the Coastal Swamp II depobelt of the Niger delta. It is situated approximately 90km Southeast of Port Harcourt and straddles the shoreline (Fig. 1).

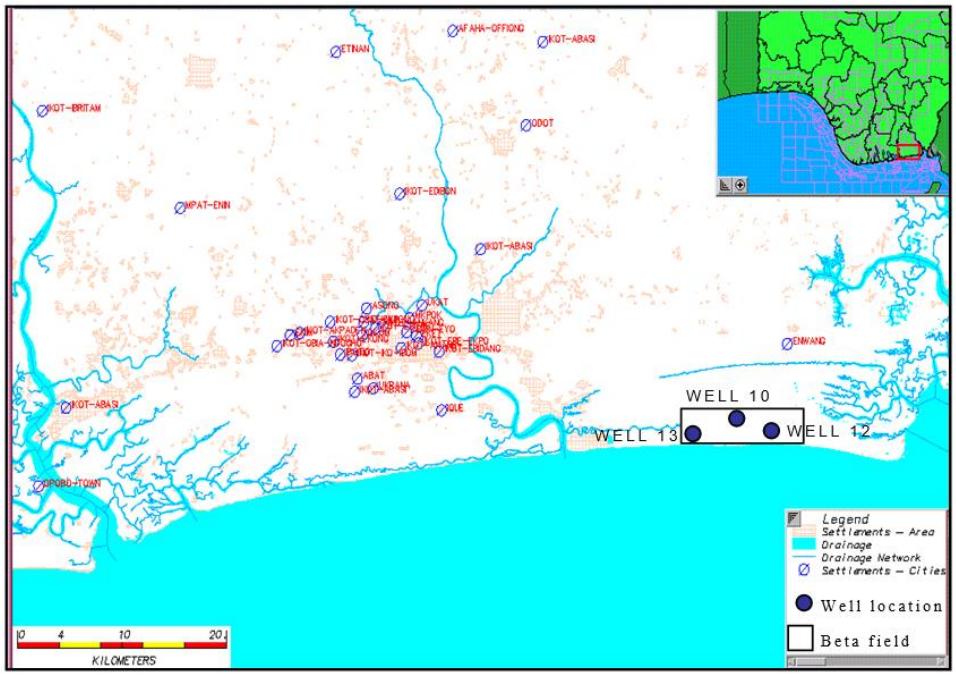


Fig. 1 Map showing the studied field and well locations

Methods

The study focuses on core samples of about 175ft (at 8651.8-8595ft; 10835.1-10773ft; and 11748-11691ft intervals) from a representative well (well-13) that penetrated the 'Beta' field, Coastal swamp depobelt. The core samples were sedimentologically and paleontologically described for lithofacies and ichnofacies interpretations in the laboratory of Location Sample Services (LSS), Port-Harcourt Nigeria. Core diameters of 7.5cm were slabbed into one-third and two third sections. The one-third section was permanently mounted in core boxes (3 ft in each box) and studied for sedimentological and paleontological description while the two third section was digitally photographed (under white and ultra- violet light prior to description) to obtain improved visualization of chosen ichnofabric features.

Analysis of ichnofacies in cores has its advantages, the cores provide vertical continuity and the core material (rock) is completely fresh with detailed and well persevered ichnological data. Although the cores are narrow and can only be viewed in two dimensions, recognizing the ichnotaxa of the trace fossils was made possible by observing the nature of the burrow boundary or wall structure/ material and the details of the fill. The branching characteristics were fairly determined. The full-relief

structures observed on the cores are recognized and compared with the schematic model modified from MacEachern et al. [16].

Sedimentology of "Beta" Field Incised Valley-fill

The sedimentary succession of the study area is characterised by a tripartite zonation of an incised valley-fill deposit. It begins with a basal conglomerate unit which is dominated by multi-storey conglomerate and coarse sandstone. Each sandstone is defined by basal erosion surface followed by poorly sorted pebbly sandstone, interpreted as fluvial channel deposit based on facies analysis and the blocky nature of GR log motif (Fig.2,3a) [17]. A tidal influenced fluvial deposit characterised by alternation of sandstones and mudstones (Fig. 3b), with mud drapes foresets and flaser bedding occur in the sandy units. The tidal sands characterized by flaser, wavy, and lenticular bedding are part of a continuum of tidal influenced deposition [18]; between sand-dominated sedimentation (flaser bedded) and more mud dominated sedimentation (wavy to lenticular bedded). These bedding types occur as a result of alternating current action and slack water [18]. The presence of mud-draped foresets indicate alternation periods of high energy that led to migration of ripples and a slack water episode that deposited mud from vertical accretion. Mud drapes are commonly deposited over dunes during slack water conditions of high tide. Dominant trace-fossil assemblage is the *Skolithos* ichnofacies.

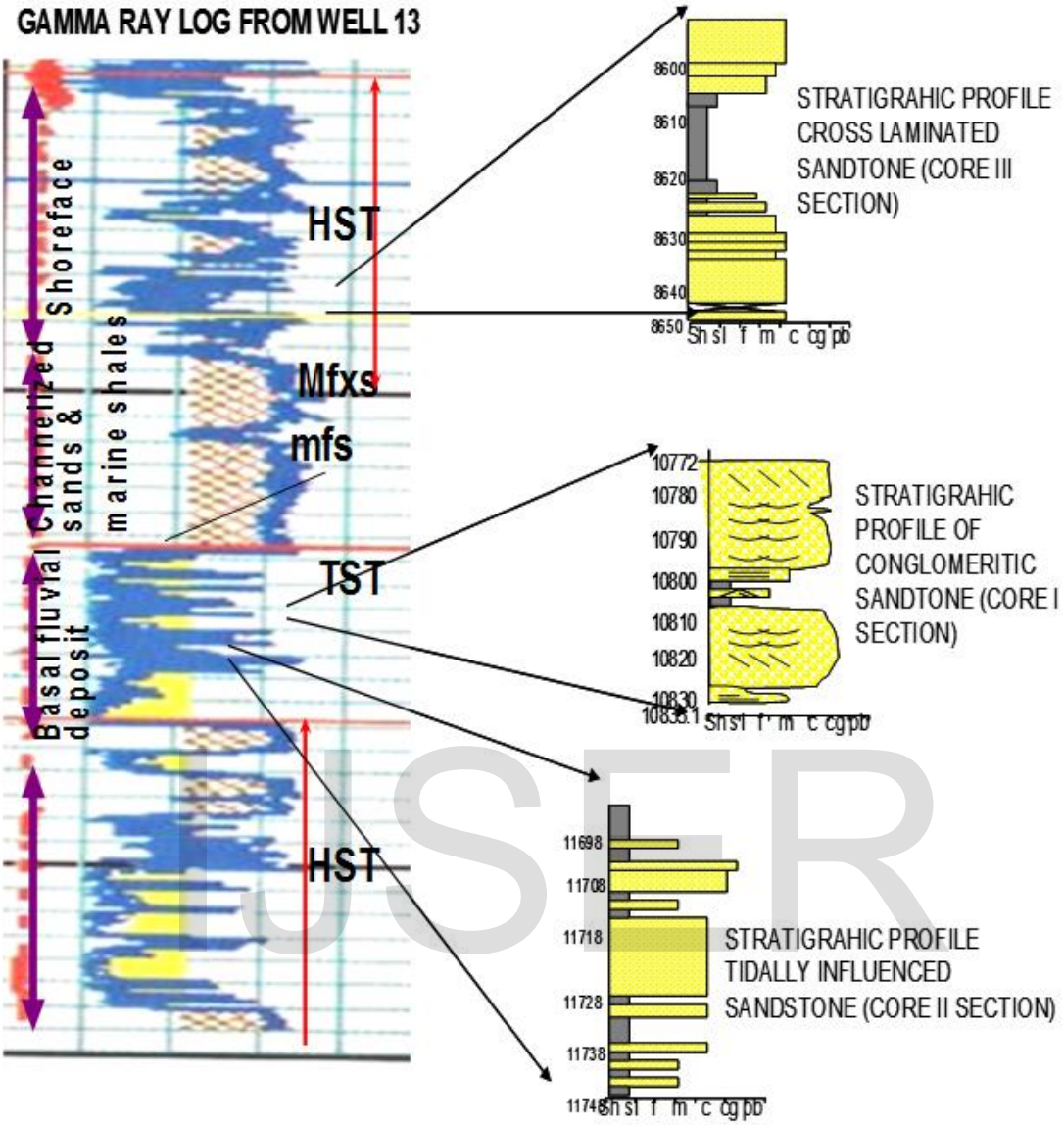


Fig. 2. Wireline log for well-13 showing the lithologic units and the cored intervals within the 'Beta' Field, Coastal Swamp Depoabelt of the Niger Delta.

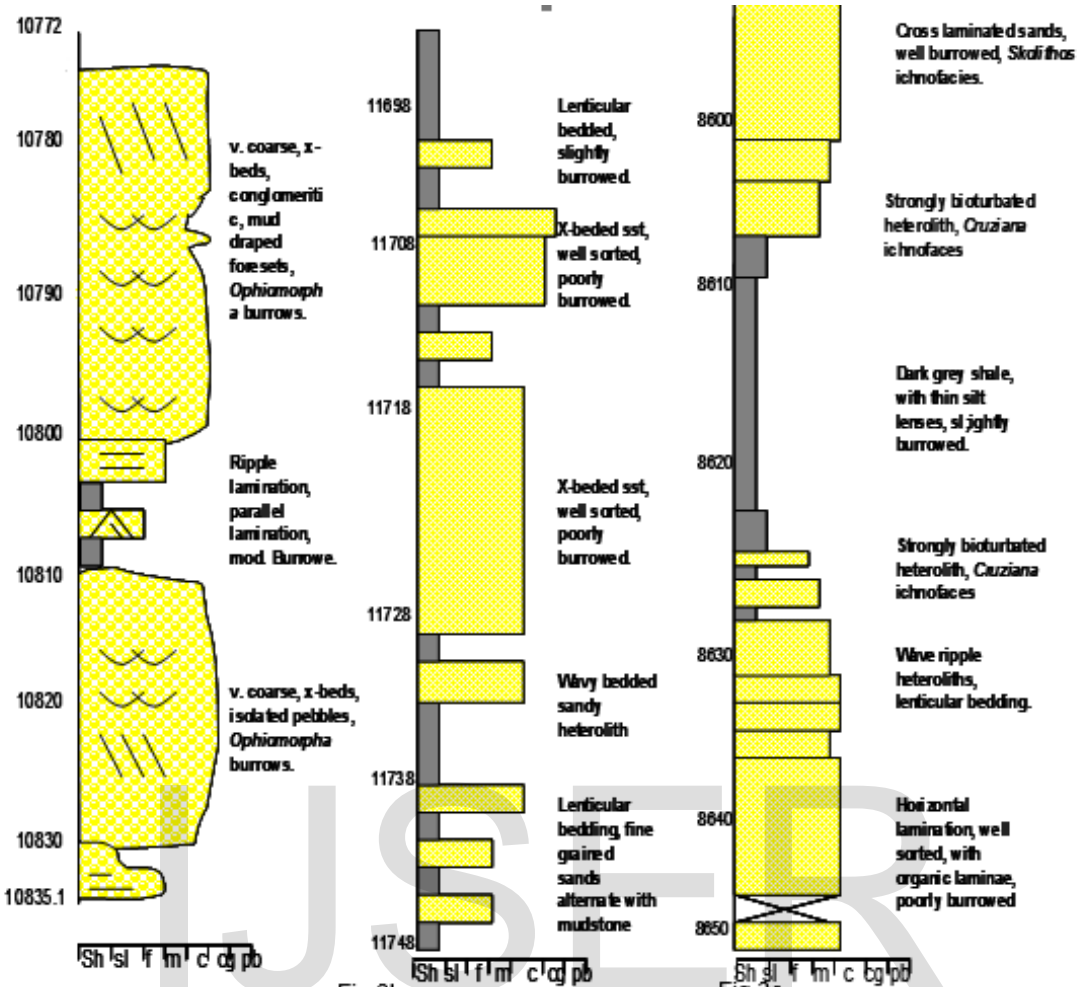


Fig.3a
STRATIGRAHIC PROFILE OF CONGLOMERITIC SANDTONE (CORE I SECTION)

Fig.3b
STRATIGRAHIC PROFILE TIDALLY INFLUENCED SANDSTONE (CORE II SECTION)

Fig.3c
STRATIGRAHIC PROFILE CROSS LAMINATED SANDTONE (CORE III SECTION)

The central part of the estuary is a zone of interference between marine (waves and tides) and fluvial processes [11]. The central unit is described mainly from the wireline logs. Core sample was not obtained from this interval probably due to low net to gross ratio. The GR log pattern of the sandstone/mudstone unit is characteristically serrated whereas the neutron/density log shows variation in separation. It is dominated by mudstone and corresponds to the area occupied by the drowned-valley estuary at the end of transgression [14]. The Cross-laminated sandstone unit consists of fine to medium grained sandstone, sandy heteroliths and mudstone that exhibit a general coarsening and thickening upwards pattern (Fig. 3c). The sand body occur as well sorted fine grained cross-laminated

sandstone, wave ripple-laminated heteroliths and bioturbated heteroliths. Thin beds of coarse sand occur at various levels. This unit is interpreted as shoreface deposits based on the established models of Walker and James, [19]. The wave ripple heterolith and cross-laminated sandstone suggest proximal lower to upper shoreface deposits, which reflect sedimentation under conditions of alternating storm (sands), and quite water (heteroliths) conditions. This unit is characterised by *Cruziana* and *Zoophycus* ichnofacies.

Ichnology of "Beta" Field Incised Valley-fill

The trace fossil assemblages recognised in the succession were the *Skolithos, Cruziana* and *Zoophycos* ichnofacies. Their abundance and diversity differ within the tripartite succession. The *Zoophycos*, *Cruziana* and *Skolithos* ichnofacies characterise the central and prograding bay-head of the estuary due to the interplay of fluvial, marine and tidal processes while the *Skolithos* ichnofacies dominate the fluviatile basal unit of the incise valley.

Systematic Ichnology

The *Skolithos* ichnofacies include *Skolithos, Ophiomorpha, Palaeophycus, Planolites, Arenicolites,* and *Diplocraterion,* while the *Cruziana* ichnofacies are *Thalassinoides, Rhizocorallium, Teichichnus, Scolicia,* and *Chondrites. Asterosoma*. *Neonereites*, *Zoophycos, Phycosiphon* and *Helminthopsis* belong to the *Zoophycos* ichnofacies. A systematic description of these trace-fossils is outlined below:

Ichnogenus: *Arenicolites* Salter [20]

Diagnosis: Commonly an unbranched U-shaped burrow, with or without burrow lining and it is passively-filled [21].

Description: *Arenicolites sp*. occurs as vertical J-shaped burrow, with thin mud lining, and passively-filled (Fig.4A). Bioturbated texture is observed around the burrow lining. The burrow is less than 2 cm in length and mm-scale in diameter.

Discussion: *Arenicolites* is typical of dwelling (domichnial) activity of a suspension-feeding organism. In the area of interest, it occurs as an

isolated burrow in association with *Ophiomorpha*, *Planolites*, *Palaeophycus* and *Siphonichnus* in a fined grained laminated sandstone unit, interpreted as proximal lower to upper shoreface environment.

Ichnogenus: *Asterosoma von Otto* [22]

Diagnosis: Star-shaped burrow system consisting of radial bulbous arms. The arms are circular to irregular in cross-sections and consist of very fine concentric laminae of silt and clay packed around a sand-filled central shaft.

Description: *Asterosoma* is observed as a circular structure consisting of concentric laminae of silt and clay packed around a central tube (Fig.4B). The width of the burrow is 3cm and 1cm in height.

Discussion: *Asterosoma* represents a specialized feeding structure and it is commonly associated with fully marine conditions. It is observed in the muddy substrate of the cross laminated sandstone unit. *Asterosoma* are excellent indications of lower shoreface setting.

Ichnogenus: *Bergaueria* Prantl, [23]

Ichnospecies: *Bergaueria perata*

Diagnosis: Hemispherical to shallow cylindrical, vertical burrow with a rounded base [24]. Burrow walls are smooth and unornamented, with or without lining and usually with shallow central depression and radial or biradial ridges at the burrow base [24], [25].

Description: The observed trace fossil occurs as a single lined burrow, with passive infill similar to the host rock, and it appears as a gentle convex hyporelief on the core. The burrow is about 4 mm in depth and 1.5 cm in diameter.

Discussion: The burrow is regarded as the dwelling or resting trace (domichnion or cubichnion) of sea anemones [26]. It occurred in a sandy laminated heterolith, which is moderated burrowed with bioturbation index of 3.

Ichnogenus: *Chrondrites* von Sternberg [27]

Ichospecies: *Chrondrites* isp.

Diagnosis: Simple root-like burrow system of regularly branching feeding tunnels of uniform diameter which never interpenetrate, nor cut across one another. In core, they appear as array of tiny elliptical dots. *Chrondrites* represents a complex deposit feeding strategy.

Description: Two modes of occurrence of *Chrondrites* were observed. In sand starved mudstone, they occurred as tiny white elliptical dots (Fig.4C, D). The burrow fill is silt and it differs from the host rock. The branching tunnels were not observed on cores. *Chrondrites* also occurred in association with other *Cruziana* ichnofacies in muddy horizon of bioturbated muddy heteroliths.

Discussion: *Chrondrites* systems occur more or less persistent in the muddy and mudstone subfacies of the cross-laminated sandstone facies, interpreted as prograding shoreface environment. The subfacies represent offshore to lower shoreface subenvironments which reflect to low oxygen conditions. *Chondrites* probably represent tunnels produced by deposit-feeding sipunculids, which worked from a fixed centre on the substrate surface and created the tunnels by extending its proboscis.

Ichnogenus: *Diplocraterion* Torell, [28]

Ichnofossil: Diplocraterion parallelum, Torell, [28]

Diagnosis: Vertical U-shaped spreiten burrows; the spreiten may be retrusive, protrusive or a combination of both. Classified as the dwelling of a suspension-feeding organism.

Description: *Diplocraterion parallelum* appears as a U-shaped spreiten burrow with retrusive spreiten (Fig.4E). Menisci consist of fine laminae of very fine grained sand and clay. The burrow is more than 4 cm thick and more than 4 cm in long.

Discussion: *Diplocraterion* occur in associated with the *Skolithos* ichnofacies in the Cross laminated sandstone unit interpreted as shoreface deposit.

Ichnofossil: Diplocraterion habichi Lisson [29] *(Fig. 4F)*

Diagnosis: Small in size, with commonly discontinuous spreite and divergence of arms, which can be missing due to erosion. Also classified as dwelling burrow of a suspension feeder.

Description: Structures referred to as *D. habichi* are characterised by straight, retrusive, vertical U-shaped burrow. It is about 2 cm long and oriented normal to the bedding plane. The shafts are thinly lined with argillaceous materials (Fig 4F).

Discussion: *D. habichi* has been recognised in the low angle cross stratified sandstone beds of the central estuary. Its presence suggest high-energy conditions for sedimentation.

Ichnogenus: *Helminthopsis* Heer, [30]

Diagnosis: Irregularly meandering, smooth-walled burrows that never branch, interpenetrate or cut across one another. Classified as a grazing structure produced by systematic grazing polychaete (or other worm-like organism).

Description: *Helminthopsis* occur as swarms of worm-like organism. The burrows are sub-circular and are horizontal. Burrow fill is dissimilar from the surrounding matrix, commonly of dark argillaceous material (Fig. 4G) and the individual burrows are small (1 to 2 mm in length). They appear as dark, curved lines.

Discussion: *Helminthopsis* is observed in a strongly bioturbated cross laminated sandstone, obliterating the structures. Although it is a common element of *Zoophycos* ichnofacies, it is found in association with *Planolites, Paleophycus* and *Neonereites* in the proximal lower shoreface environment.

Ichnogenus: *Neonereites* Seilacher, [31]

Ichnospecies: *Neonereites uniserialis* Seilacher, [31]

Diagnosis: *Neonereites* sp. is horizontal, gently curved to slightly sinuous traces constituting uniserial rows.

Description: The burrows occur as straight to curved and sinuous with crescentic menisci. Burrow fill is dissimilar from the surrounding matrix, commonly of dark argillaceous material (Fig. 4G) and the burrows are relatively small (5 to 8 mm) in length.

Discussion: *Neonereites uniserialis* also occurred in the strongly bioturbated cross laminated sandstone. It is a facies-crossing trace fossils that is commonly associated with *Cruziana* and *Zoophycos* ichnofacies. In

the area of interest, *Neonereites* occurs in association with *Helminthopsis*, *Planolites* and *Paleophycus* in the proximal lower shoreface environment. *Neonereites* is indicative of shallow and deep marine environments.

Ichnogenus: *Ophiomorpha* Lundgren, [32]

Ichospecies: *Ophiomorpha annulata* Ksiazkiewicz, [33]

Diagnosis: Burrow walls of evenly spaced transverse rows of elliptical pellets; end–to-end pellets from more or less continuous rings or annulations around burrow segments.

Description: *Ophiomorpha annulata* is recognised by its poorly developed pelletoidal exteriors (Fig.4H), the wall is iron stained, and the burrow diameter ranges from 1cm to 3 cm. Horizontal tunnels were observed.

Discussion: *Ophiomorpha annulata* is observed in the conglomeritic facies as mono-specific trace fossil and indicates conditions of moderate to high sediment influx in a high energy marine environment in which suspension feeders flourish [29].

Ichospecies: *Ophiomorpha nodusa* Lundgren [32]

Diagnosis: Burrows walls predominantly of a mosaic of dense, regularly to irregularly distributed discoid, ovoid or polygonal pellets.

Description: The *Ophiomorpha nodusa* observed has vertical to inclined shafts and horizontal tunnels, and distinctly lined with agglutinated pelletoidal sediments (Fig. 4A, I). Burrow length varies between 1cm to 4cm long and burrow diameter ranges from 0.5cm to 1 cm. The burrow wall varies from 1mm to 1cm thick with dark mud pelletal lining.

Discussion: The pellitoidal or nodular walls, and the horizontal to vertical tunnels/shafts are characteristic of high energy environment of beaches, tidal flats and tidal delta.

Ichospecies: *Ophiomorpha irregulaire*

Diagnosis: Burrow walls predominantly of sparse, irregularly distributed, flame-like pellets or pelletal masses.

Description: *Ophiomorpha irregulaire* occur in sandy substrate as vertical shafts and horizontal tunnels. The pelleted walls are elongate, irregularly conical and made up of organic matters (Fig. 4A). The horizontal segments observed in the core range between 2 and 2.5cm long. The burrow

diameter varies from 1 to 2 cm. *Ophiomorpha irregulaire* is filled with structureless sands similar to host sediment.

Discussion: The burrow occurs in fine grained sandstone facies of the conglomeritic unit. The bioturbated nature suggests deposition from waning currents which probably reflect high flow velocity during flood stage. *Ophiomorpha irregulaire* is commonly associated with sand waves in high energy marine and marginal marine environments. Its presence also suggests tidal shoal setting and particularly marine influence in the fluvialite sediment.

Ichnogenus: *Palaeophycus* Hall, [34]

Ichospecies: *Palaeophycus tubularis* Hall, [34]

Diagnosis: Smooth-walled, unornamented, predominantly horizontal, straight to sinuous cyclindrical burrows, thinly but distinctly lined.

Description: *Palaeophycus tubularis* is observed as horizontal to inclined and circular burrows with thin, dark argillaceous wall lining (Fig. 4D). Fills are of the same composition as the surrounding sediments. These fills represent passive, gravity-induced sedimentation [35].

Discussion: *P. tubularis* is associated with *Skolithos* ichnofacies and commonly found with, *Planolites, Ophiomorpha* and *Siphonichnus* (Fig.4A, D, E) in the sediments interpreted as shoreface deposits. It also cut-cross *Diplocraterion* as observed in Fig. 4E.

Ichnogenus: *Planolites* Nicholson, [36]

Ichospecies: *Planolites montamus* Richer, [37]

Diagnosis: Small, smooth-walled, rarely branched, typically curved to undulant or contorted burrows.

Description: Burrows recognised as *Planolites montamus* has unlined walls and the burrow fills are structureless, differing from the enclosing sediment. The burrows vary in sizes from very small (4 mm in diameter) to large circular to elliptical shaped burrows of 3.5 cm in diameter.

Discussion: *P. montamus* are obvious in the cross-laminated bioturbated sandstone of the shoreface deposit (Fig 4D, G) and the muddy heteroliths of the lower shoreface-upper offshore deposit (Fig. 4A).

Ichnogenus: *Phycosiphon* Fischer-Ooster 1858 [38]

Ichnospecies: *Phycosiphon incertum* von Fischer-Ooster, 1858

Diagnosis: Horizontal, irregular shaped and gently inclined sinuous burrows. Burrow central core is filled with dark material surrounded by lighter substrate. Classified as feeding wormlike deposit feeders (39).

Description: *Phycosiphon* occurs as small straight to sinuous burrow, with dark organic-rich worm-like burrow infill and a light silty or clayey surrounding. The surrounding material may be bioturbated or with a texture different from the host rock. The burrow varies from 2 mm – 1 cm in diameter.

Discussion: *Phycosiphon* is common in mudstones and muddy heteroliths of the lower shoreface-upper offshore deposit (Fig. 4C, D). The presence of Phycosiphon suggests of reduced-oxygen conditions and organic-rich substrates (39).

Ichnogenus: *Rhizocorallium* Zenker, [40]

Ichnospecies: *Rhizocorallium*

Diagnosis: Straight to sinuous, horizontal, U-shaped spreiten-burrows. In core, *Rhizocorallium* is discerned by two circular burrows (tube arms) joined by horizontal band (spreite). Classified as dwelling/feeding burrow of a deposit-feeder.

Description: *Rhizocorallium* is recognised by one circular burrow (referred to as tube arm) and its horizontal band (spreite) (Fig.4J), the second circular burrow was not well observed. Burrow infill is nearly identical to the matrix. The circular burrow is appears collapsed; it is 5 mm thick and 4 cm in diameter.

Discussion: It is found in association with *Thalassinoides*. *Rhizocorallium* is associated with the distal *Cruziana* ichnofacies that characterises fully marine offshore environments [11].

Ichnogenus: *Scolicia* de Quatrefages [41]

Ichnospecies: *Scolicia* de Quatrefages [41]

Diagnosis: It is a large, unbranched, meandering to coiling, or subhorizontal burrow with meniscate lamellae that may be divided into two

concave sets (42). In cores, the burrows longitudinal and oblique sections may show a densely meniscate or lamellar backfill (43).

Description: *Scolicia sp*. appear as a simple meandering to coiling burrow with lamellar backfill. Burrows are long, with about 3.5 mm in diameter and more than 7.8cm in length (Fig. 4K). The burrows posse active fills that differ from the enclosing substrate.

Discussion: *Scolicia* occurs as a monospecific ichnofossils within a muddy heterolith, which has been interpreted as lower shoreface to offshore environment. *Scolicia* is referred to as the deposit-feeder (fodinichnial) of irregular echinoids (42).

Ichnogenus: *Siphonichnus* Stanistreet, Le Blanc Smith and Cable [44]

Ichnospecies: *Siphonichnus eccaensis* Stanistreet

Diagnosis: It is typically a vertical burrow with a central vertical tube or pairs of tube and either concave downwards or convex downwards backfill laminae. *Siphonichnus* is characterized by a laminated meniscate (active fill) mantle, which is breached by a (passive fill) homogeneous core (43).

Description: *S. eccaensis* is characterised by a single passive filled central siphon trace (up to 2.5 cm in length and 5 mm in diameter). The siphon trace is preserved in coarser grained (similar to the host rock), better-sorted sediment than the rest of the burrow fill (Fig. A, E). The dark muddy, carbonaceous burrow lining or mantle is up to 2 cm thick and the length may be more than 8 cm long.

Discussion: *Siphonichnus* indicates a dwelling trace (domichnion) of a suspension- and deposit-feeder, such as a bivalve (43). It is typical of shallow-marine and marginal-marine environments, but may indicate fluctuating salinity and freshwater influx (45).

Ichnogenus: *Teichichus* Seilacher, [31]

Ichospecies: *Teichichus rectus*

Diagnosis: Long, straight, planar to slightly irregular or zigzag, retrusive spreiten structures oriented at various angles with bedding planes.

Description: Structures referred to here as *Teichichus sp* appear as vertical to slightly inclined, circular to subcircular concave up and concave down

burrow (Fig.4C) and actively filled with darker sands than the enclosing sediments. Spreite is characterised by vague to well-defined retrusive crescentric laminae. The burrows are 2.5cm to 3.5cm in diameter and are 1cm to 2cm long. They are possibly produced by smaller vermiform animals. This *Teichichnus* -producing organism seems to be a deposit-feeder that migrated upward or downward in its burrow to keep up with sedimentation.

Discussion: *Teichichnus* is associated with the *Cruziana* ichnofacies and occurs commonly in lower shoreface to offshore environment. It is also found in brackish-water lagoon/bay environments [11].

Ichnogenus: *Thalassinoides* Ehrenberg [46]

Diagnosis: Relatively large burrow systems consisting of smooth-walled, essentially cylindrical components. Classified as dwelling-feeding burrows of deposit feeding crustaceans.

Description: The burrows referred to as *Thalassinoides* occur as cylindrical components (Fig. 4J). The fills are structureless, light coloured and different from the enclosing sediments. The burrow wall is unlined. The burrow is 1cm thick in diameter.

Discussion: *Thalassinoides* is observed mainly in the muddy substrate along with other Cruziana ichnofacies and it is typical of lower shore to offshore environments [37].

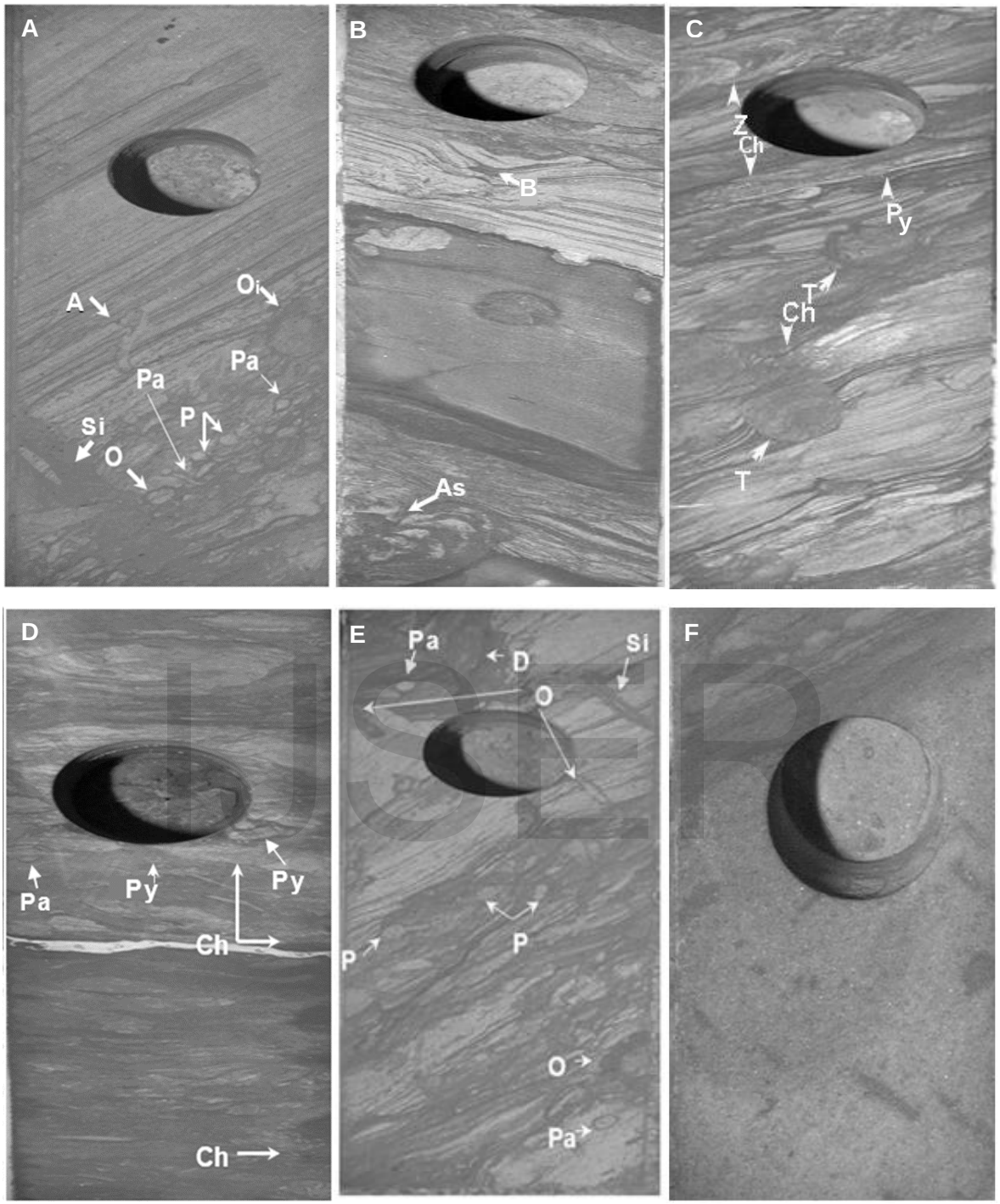
Ichnogenus: *Zoophycos* Massalongo [47]

Ichospecies: *Zoophycos isp*

Diagnosis: circular to lobate sheetlike spreite structures, horizontal to slightly oblique with respect to bedding; spreiten may be laminated or structureless internally.

Description: *Zoophycos sp* occurs in association with *Cruziana* ichnofacies (Fig.4C). Spreiten are well developed in a more or less horizontal orientation to bedding and correspond to the feeding spreite part of the structure. Although they contain sediment that is paler than the surrounding sediment, dark laminae are observed. The lateral extent of spreite observed is more than 7cm, and a thickness of about 4.2mm.

Discussion: *Zoophycos* occur within bioturbated wavy laminated sandy heterolith which is interpreted as lower shoreface to upper offshore environments.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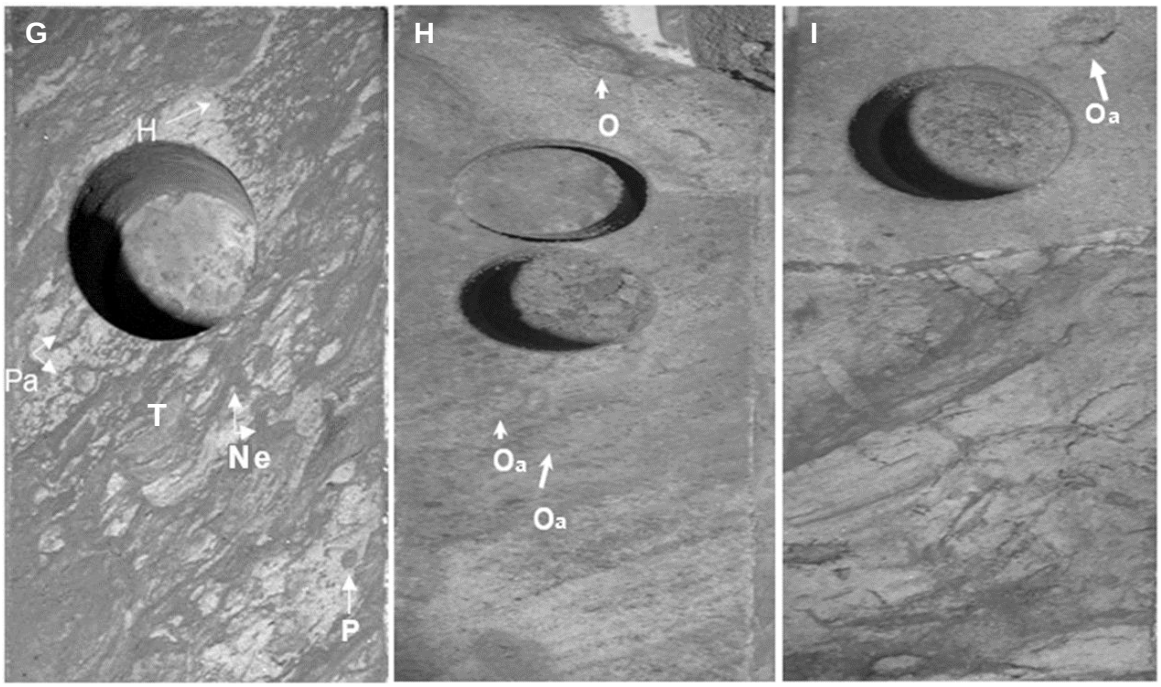

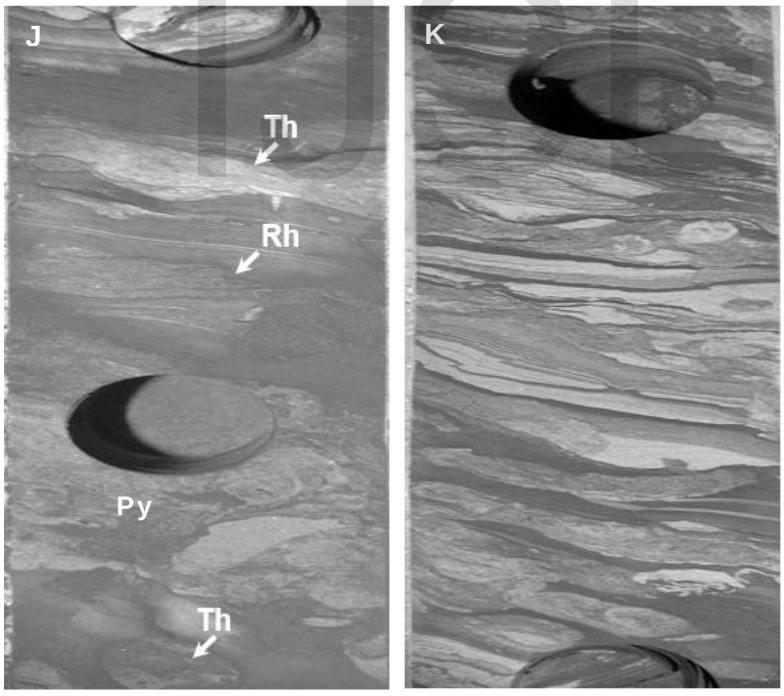

Fig. 4. Selected trace fossils found in the area of interest [width of core 7.8 cm]. **A.** The trace fossil suites are *Ophiomorpha nodusa* (O), lined with agglutinated pelletoidal sediments; *O. irregulaire* (Oi), characterised by flame-like burrow lining; Siphonichnus (Si), distinctly lined by thick muddy mantle and pierced by a passive siphon trace; *Planolites* (P); *Paleophycus* (Pa) and J- shaped Arenicolites (A) sp. [Depth: 08598 ft]. **B.** Isolated burrows such as *Asterosoma* (As) and *Bergauria* (B) occurred. [Depth: 08625 ft]. **C.** Mixed *Cruziana* and Zoophycos ichnofacies consisting of *Teichichus rectus* (T), *Phycosiphon* (Py), *Zoophycus* (Z), and *Chondrites* (Ch) in a bioturbated sandy heterolith. [Depth: 08610ft]. **D.** Dominantly *Chondrites* (Ch), with *Phycosiphon* (Py) and *Palaeophycu*s (Pa) in sand starved mudstone, with the presence of *Phycosiphon* (Py) and Palaeophycus (Ph). [Depth: 08616ft]. **E.** Moderately diverse trace fossil suites which include *Ophiomorpha nodusa* (O) is distinctly lined with agglutinated pelletoidal sediments. *Planolites* (P), *Paleophycus* (Pa), Siphonichnus (Si) and Diplocraterion (D) commonly occur. [Depth: 08600 ft]. **F.** *Diplocraterion habichi,* with retrusive spereite in a sandy substrate suggesting rapid sedimentation [Depth: 1170 ft]. **G.** Strongly burrowed muddy heterolith comprising *Helminthopsis* (H),*Neonereites* (Ne) *Planolites* (P), *Teichichnus* (T) and *Paleophycus* (Pa) [Depth: 08600.5 ft]. **H.** *Ophiomorpha annula* recognized by its poorly developed pelletoidal exteriors. The wall is iron stained. [Depth: 10770 f]. **I.** *Ophiomorpha irregulaire.* The pelleted walls are elongate, irregularly conical and made up of organic matters. **J.** *Thalassinoides* (Th), *Phycosiphon* (Py) and *Rhizocorallium* (Rh). [Depth: 08623 ft]. **K.** Strongly bioturbated and dominated by monospecifc *Scolicia sp.* [Depth: 08622 ft)

Trace fossil assemblages and bioturbation textures

The sedimentary units within the incised valley fills show a remarkably high trace-fossil diversity [11]. The degree of burrowing, its uniformity, and the distribution of individual species varies.

Overall, the *Cruziana* ichnofacies characterised by *Thalassinoides, Rhizocorallium, Teichichnus, Chondrites, Scolicia* and *Asterosoma* dominate the muddy substrate. *Zoophycos, Helminthopsis, Physicophon* and *Neonereites* are the dominate *Zoophcos* ichnofacies observed and they occur in association with the *Cruziana* trace fossil suite. Whereas, the *Skolithos* ichnofacies which include *Skolithos, Ophiomorpha, Palaeophycus, Planolites, Arenicolites,* and *Diplocraterion* are dominant in the sandy substrate.

The sporadic distribution and variable abundance in the sedimentary units are interpreted to reflect fluctuations in salinity within the estuary [16], which may have repeated ranged from brackish to fully marine. *Rhizocorallium, Teichichnus, Chondrites,* and *Asterosoma* probably occurred in the incised valley-fill deposits when conditions approached

fully marine condition. Their absence is pronounced in the conglomeritic sandstone and central estuary, probably due to low overall salinities.

The conglomeritic sandstone shows monospecific *Ophimorpha* burrows and possesses one of the weakest degrees of burrowing. The representative core for the central estuary demonstrates a very low degree of burrowing. This probably suggests a high-energy deposition for the sandstone units and a low salinity and anoxic conditions for the deposition of dark mudstone.

The prograding bayhead delta is dominated by opportunistic organism, with generally high degrees of burrowing, which although reduces upwards. The sporadic distribution of trace fossils in this zone demonstrate salinity fluctuation, ranging from nearly marine condition to brackish water condition.

Conclusion

Sediments which penetrated the “Beta” field Coastal Swamp depocentre of the Niger delta have been interpreted as incised valley fill deposit based on the physical and biogenic sedimentary structures in cores and signatures of the wireline logs, along with biostratigraphic information. The application of ichnology to sedimentological interpretation is important, as it contributes not only to the interpretation depositional environments, but also gives insight to reservoir implication of sandstone bodies. A low-diversity *Skolithos* ichnofacies characterizes the basal conglomeritic unit that has been interpreted as tidal-influenced fluvial deposit**.** Interconnectivity of channel sands can be possibly improved by vertical burrows. A high-diversity *Cruziana* and *Zoophycos* ichnofacies occur in the prograding bay-head fill which has been interpreted as shoreface. Burrows with sandy infills will act as conduits and enhance porosity and permeability in reservoirs.

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