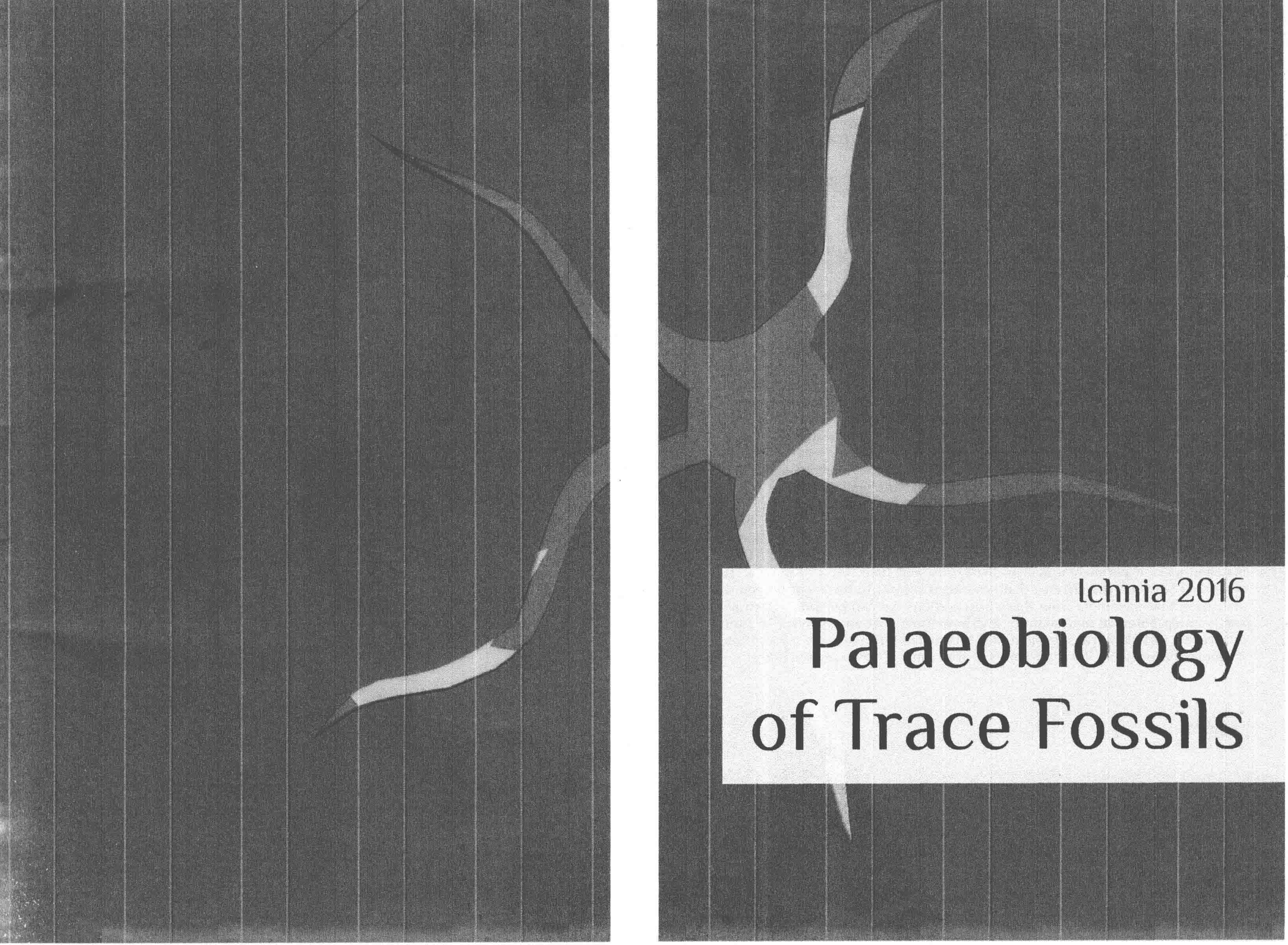
Palaeobiology of Trace Fossils

Spain
2016



Ichnia 2016

Palaeobiology of Trace Fossils

A doomed expedition? Exploring the concept of doomed pioneers using an annular flume tank and the polychaete, *Alitta virens*

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Keywords: Doomed pioneers, annular flume tank, *Alitta virens*, turbulent transport, allochthonous

Trace fossils provide *in situ* evidence for organisms and their activities and are widely applied as palaeoenvironmental indicators. But what if the organisms are allochthonous to the depositional environment? This is the concept behind the"doomed pioneers" hypothesis (Föllmi and Grimm, 1990); that organisms living in a well-oxygenated environment could be caught up in a turbulent flow and transported to a different, oxygen deficient, environment. These organisms are then able to colonize and create trace fossils in anoxic sediment, at least for a short time, before eventually succumbing. The feasibility of this occurring has important implications for interpreting trace-fossil material in deep-marine settings.

Using an annular flume tank, ethically-approved experiments have been designed to explore the survivorship potential and viability of the polychaete, *Alitta virens*, after being subjected to a turbulent transport regime (Fig-1). In a matched-pairs experimental design, the ability and time taken to burrow, is compared between polychaetes that have been subject to turbulent transport and those that have not. From these observations we can begin to constrain survivorship potential and quantify just how functional an organism is after undergoing turbulent transport and the likelihood of it forming any traces from its doomed expedition. Results from these experiments are discussed here.

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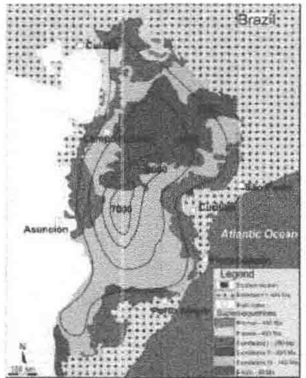

Fig. 1. Location of study area in the Paraná Supersequence, S Brazil.

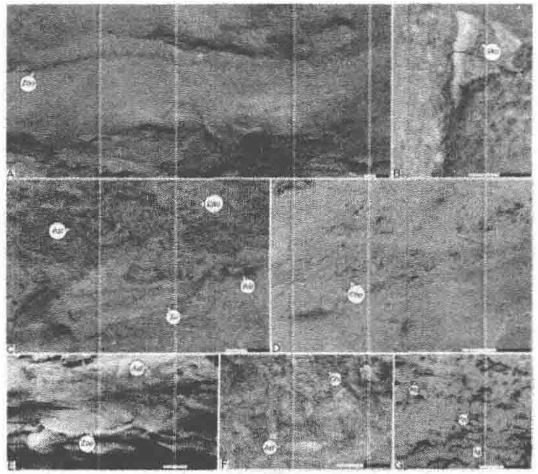

Fig.2. Ichnofabrics from the study area. A. *Zoophycos* ichnofabric. B. *Skolithos* ichnofabric. C. Composite ichnofabric of *Asterosoma-Teichichnus* with *Chondrites*. D. *Chondrites* ichnofabric. E. Composite ichnofabric of *Asterosoma -Zoophycos*. F. Composite ichnofabric of *Asterosoma - Chondrites*. G. Composite ichnofabric of *Planolites - Palaeophycus*. Scale bar 2 cm.

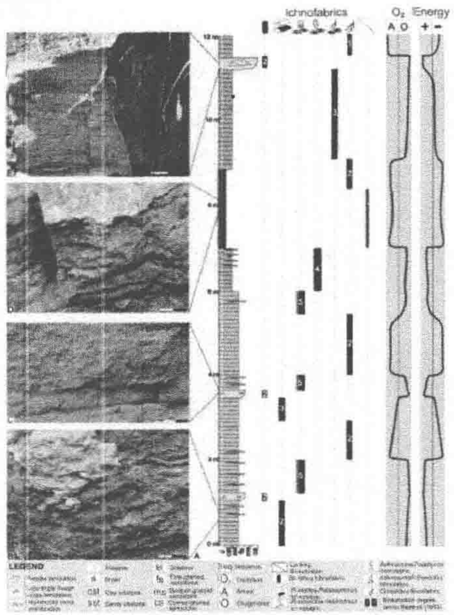

Fig. 3. Geological section of Ponta Grossa Formation at Tibagi region. A. Schematic profile, distribution of ichnofabrics and inferred paleoenvironments parameters of the study area. B. Sandy siltstones with parallel lamination interrupted by fine-grained sandstone lenses. C. Fine-grained sandstone beds with wavy ripples. D. Pyritiferous black shales. E. Medium to coarse-grained sandstone with hummocky cross stratification. Scale bar 2 cm.

Ichnofabrics of Devonian shales: a case study from Paraná Basin, southern Brazil

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Keywords: Devonian shales, Gondwana, anoxic events.

Six ichnofabrics present in Devonian shales from Ponta Grossa Formation (sensu Grahn et al., 2013) were analyzed in Tibagi region (Brazil, Fig. 1). The composite *Planolites-Palaeophycus* ichnofabric (Fig.2) reflects feeding behavior of detritivorous organisms in dysoxic upper offshore settings. The composite *Asterosoma-Teichichnus* is dominated by feeding burrows of detritivorous organisms but burrows produced by suspension-feeders are also present. It characterizes the relict preservation of the shallow tiers in the historical layer zone, representing optimum ecological conditions in lower shoreface to offshore transition zones. The composites *Asterosoma-Zoophycos* and *Asterosoma-Chondrites* ichnofabrics are dominated by feeding burrows that reflect activity of preferentially detritivorous and decomposers and represent colonization of dysoxic substrates to in offshore settings. The *Chondrites* ichnofabric shows the prevalence of decomposing activity and suggests abundant organic-rich content into oxygen-deficient offshore substrates. These ichnofabrics characterizes a fair-weather trace fossil assemblage of the distal *Cruziana* Ichnofacies, suggesting deposition below wave base affected by storms. *Skolithos* ichnofabric shows simple vertical burrows that express prevalence of suspension feeding behavior, represents the opportunistic colonization of the substrate during higher-energy events and characterizes the Skolithos Ichnofacies (Fig. 3). Uchman and Wetzel (2011) pointed that bioturbation is absent when organic carbon content is high (Corg >2%) and correlated beds express Corg near to 2%. *Chondrites* and *Planolites* are post-depostional burrowers and its presence at the top of the shale bed suggests that the substrate became hospitable for chemosymbiont animals after the reactivation of the bottom currents. Unbioturbed black shale beds reflects prevalence of anoxic conditions into the substrate.

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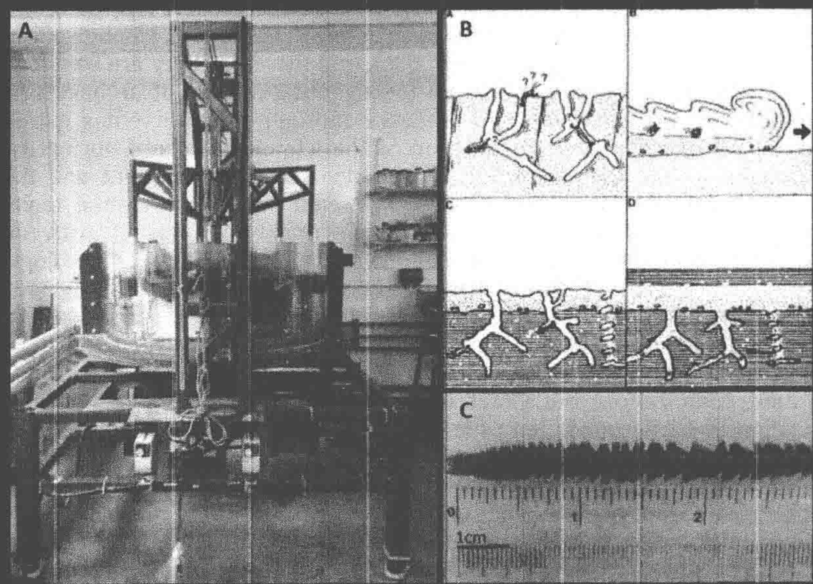

Fig. 1. A) Annular Flume tank utilized for these experiments B) An illustration of the doomed pioneer hypothesis (after Föllmi and Grimm 1990) and C) the polychaete, *Alitta Virens*.

Run, rabbit, run: Ichnodisparity and ichnodiversity trajectories during evolutionary radiations

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Keywords: evolutionary radiations, ecospace colonization, ichnodiversity, ichnodisparity, trace fossils

Organisms and their behaviors are in constant change as a result of colonization of new ecospace, environmental fluctuations, and extinctions. In order to explore the ichnologic record of evolutionary radiations, we compile changes in ichnodiversity and ichnodisparity of invertebrate trace fossils through time. Occurrences were compiled on a case-by-case basis, therefore summarizing actual occurrences. However, ichnodiversity and ichnodisparity curves were plotted as "range-through" data, and therefore they are based on lower and upper appearances for each ichnogenus/category of architectural design and then extrapolating their presence through any intervening gap in the continuity of its record. Comparison of the ichnologic record during the Cambrian Explosion, the Great Ordovician Biodiversification Event and the Mesozoic Marine Revolution as well as of events in the continental realm indicates that evolutionary radiations are invariably associated with an ichnodiversity increase. Analysis of ichnodiversity changes through geologic time supports Sepkoski's three-phase kinetic model, which was originally based on analysis of marine body fossils. In contrast, increases in ichnodisparity are not linked to evolutionary radiations *per se*, but to the colonization of empty ecospace, as illustrated by the Cambrian Explosion for softground colonization, the Great Ordovician Biodiversification Event for colonization of hardgrounds, and the colonization of paleosols by the end of the Mesozoic. This pattern supports analysis based on body fossils that indicates a "first disparity, then diversity" scenario. In spite of potential limitations of ichnodiversity and ichnodisparity, our study indicates that ichnologic information is highly useful as an independent line of evidence to understand paleobiologic megatrends.

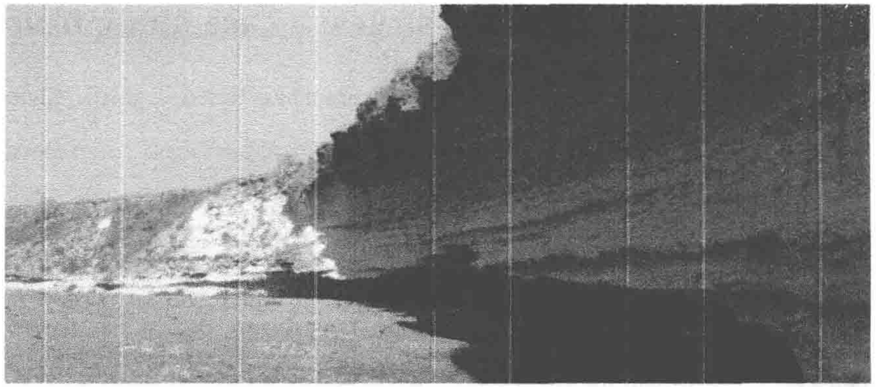

Fig. 1. Outcrop of Fulra Limestone Formation. Note highly bioturbated horizons within the limestone giving nodular appearance to the surface.

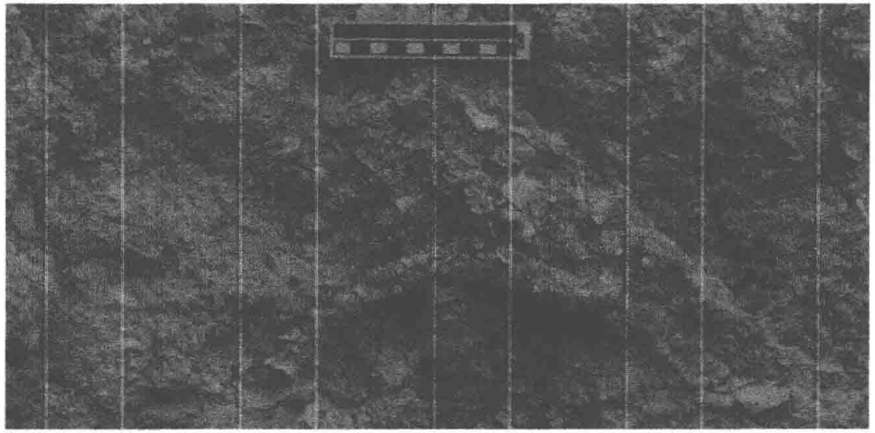

Fig. 2. *Thalassinoides*, wall showing presence of tests of larger benthic foraminfera.

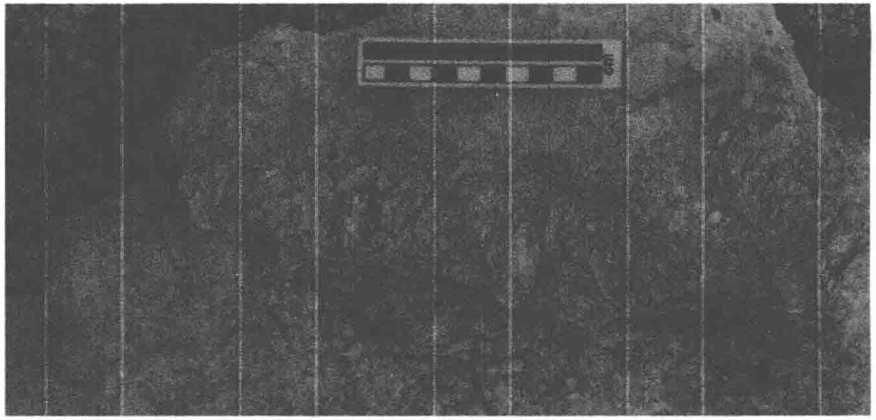

Fig. 3. Burrow wall showing arrangement of tests of larger benthic foraminifera perpendicular to the length of burrow.

Grain size? No issue for burrowing! An example from the Eocene of Kachchh, India

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Keywords: Fulra Limestone Formation, Foraminiferal limestone, bioturbation, Upper Eocene

Kachchh Basin, located in the western margin of Peninsular India is a rift basin holding an excellent record of sediments from Mesozoic to Recent. The Paleogene sediments are classified into five formations *viz.*, Matanomadh, Naredi, Harudi, Fulra Limestone and Maniyara Fort in ascending order. The current study encompasses Fulra Limestone Formation. This formation is more or less uniform in lithology and consists of thickly bedded, white to buff or ochreous yellow coloured biomicrite or biosparite, bearing abundant large saddle-shaped benthic foraminifera *Discocyclina* and ellipsoidal *Alveolina* bestowing a very coarse grained nature. The maximum grain size is to the order of 5 cm. The formation is bioturbated almost throughout its thickness, except for a few beds towards the base. The ichnoassemblage consists mainly of *Thalassinoides*, forming horizontal networks and mazes. *Bichordites* and *Planolites* occur occasionally. The burrows have been emplaced by tunneling through the coarse grained substrate, resulting in reorganisation of grains of the larger foraminifera. They have been arranged perpendicular to the length of the burrow thus modifying the original fabric. The present example rather deviates from the ichnological concept that traces are usually preserved in medium to fine grained clastics.The construction of burrows appear to be similar to the recent *Diopatra* tubes but the absence of wall and masonary work rules out the possibility of any comparison.

Neoichnology of the blue land crab *(Cardisoma guanhumi)*: indicative meaning of a Bahamian landscape engineer

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Keywords: Supratidal, Sea Level, Decapod, Georadar, Eleuthera, San Salvador

Neoichnological research in the Bahamas (Eleuthera, San Salvador; Fig. 1) demonstrates that the blue land crab (*Cardisoma guanhumi*) acts as a pervasive tracemaker in a number of transitional supratidal habitats. Open-ground and root/rock-sheltered large (entrance diameter >10 cm) and medium (5-10 cm) burrows occurr at densities of up to 4-5/m^2. Accompanied by massive spoil piles of sediment excavated from their *Macanopsis*-like shaft-tunnel-chamber systems (total length >1 aerial photography and geophysics (georadar). The substrate composition is modified with the introduction of organic matter by these semi-terrestrial omnivorous brachyurans, along with discarded exoskeletons from >50 moult cycles (triple of most land crab species) and exotic clasts (relict mollusc shells, artifacts). A sandy washover from a recent storm was devoid of bioturbation but contained rarely observed trackways of *C. guanhumi*, with tapered footprints identical to those on the floor of a chamber cast. In contrast to relatively steep J-shaped shafts through a thick mangrove peat, burrows at lower elevations exhibit gentler gradients, both designed to terminate just below the local groundwater table to sustain a shallow hydration pool. Proximity of the water table to tidal levels, high preservation potential of domichnia with habitat shift, and the radiocarbon-dating utility of enclosed vegetation remains, make blue crab burrows a prospective sea-level indicator. To complement their Neogene body fossil record, the identification of fossil *Cardisoma* sp. burrows and galleries will offer a valuable benchmark for paleoenvironmnetal reconstruction of Atlantic and Indo-Pacific supratidal successions.

sequence analysis, as the sedimentologist can split the sequences observed in core particularly or possibly in a section in the field too, in a series of recurring ichnofabrics. Ichnofabrics allow not only large third-order cycle recognition, but can also identify and correlate higher-frequency cycles by comparing the ichnofabric cycles and their vertical stacking. Furthermore, the stacking pattern of ichnofabrics leads to the identification of correlative bounding surfaces that are essential to understand the stratigraphy at basin scale or achieving description, correlation and prediction of reservoir architecture to constrain ultimately reservoir modelling.

Integration of ichnofabrics in depositional environment interpretation and sequence analysis

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Keywords: ichnofabrics, sequence analysis, depositional environment interpretation;

Ichnology provides useful information on the environmental conditions that prevailed during or shortly after sediment deposition. As such, recognition and interpretation of trace fossils are now integrated in advanced sedimentological studies. Like most other laboratory or field techniques, ichnology should not be used as a stand-alone tool. Ichnofabric information is best used in the full context of the sedimentary framework. Only then can ichnology provide detailed environmental information that can be related to depositional processes, relative palaeobathymetry, sequence stratigraphy and correlation.

The use of "ichnofabrics" has increased steadily since the ichnofabric concept was first developed by Bromley and Ekdale in 1984: "Ichnofabrics: all aspects of the texture and internal structure of a sediment that result from bioturbation at all scales". Globally recurring trace fossil associations or ichnofabrics are interpreted to be characteristic of bathymetric zones and/or depositional environments passing from onshore to deep offshore settings although the suite of ichnofabrics consists of a broad spectrum of palaeobathymetry with subtle but real changes of trace fossil associations along the depositional profile in response to local physical and chemical changes.

Identification of ichnotaxa and their grouping leads to the understanding of the vertical distribution of the endobenthic community in the sediment along a tiering profile which is mainly controlled by sediment grain size, texture, oxygenic content and redox boundary. Sediment aggradation results in an overprint of the shallow tier by the medium and deep tier. Therefore, the analysis of the cross-cutting relationship between tiers provides a key to the understanding of the relative adjustment of the endofauna to sediment aggradation with time although absolute duration cannot be assessed. Although identification of all ichnotaxa is not always achievable where the degree of bioturbation is high, ichnofabric technique helps splitting the stratigraphic record in recurring associations organized in half-transgressive and half-regressive cycles bounded by correlative geological surfaces.

In the case of low aggradation rate and even erosion associated to transgressive ravinement events, physical and chemical conditions prevailing for a fair amount of time lead to changes of the substrate and texture of the underlying sediments. Then, the sea floor is generally colonized by new ichnofauna more adapted to a firmer substrate. The analysis of ichnotaxa below this colonisation surface and the degree of bioturbation of the sediment provide additional constraints to the identification of significant geological surfaces of the stratigraphic record.

In fact ichnofabric techniques bear a fair potential for high resolution

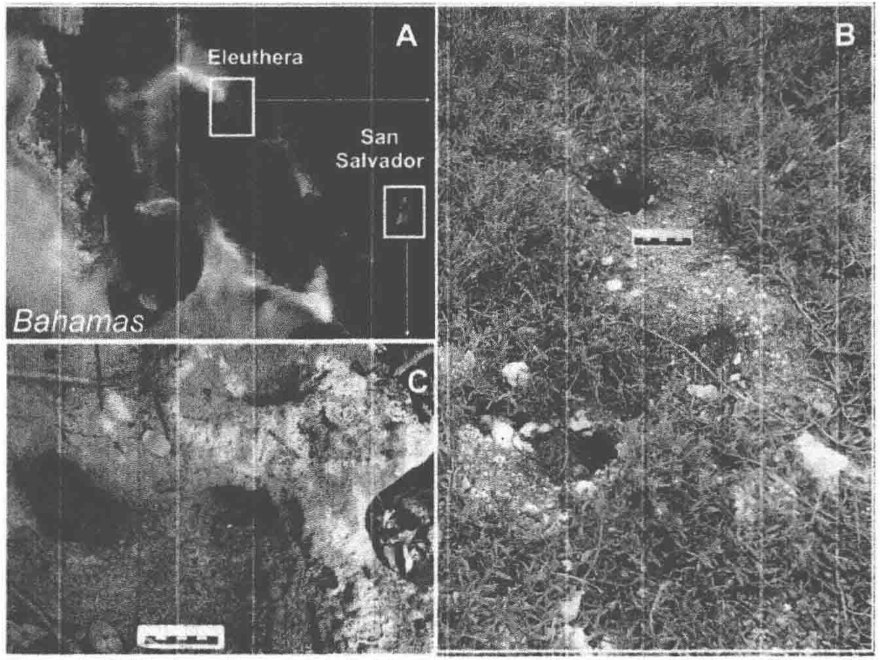

Figure 1. Field sites along the two islands in the Bahamian Archipelago (A) exhibit extensive bioturbation by the blue land crab in mangrove-fringe (B) and backdune (C) supratidal settings.

Mammal and avian tracksites from the Lower Oligocene in the North of Ebro Basin (Aragón, Spain)

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Keywords: Artiodactyl, Avian, footprints, continental facies, Cenozoic, Spain

The record of Oligocene vertebrate ichnites in the Iberian Peninsula is especially interesting because the fossils from this epoch are scarce worldwide (McDonald et al., 2007). In Aragón (NE of Spain), Hernández-Pacheco (1929) reported the first Cenozoic tracksite ("Playa Fósil", Peralta de la Sal locality, Peralta Formation) in the Iberian Peninsula. The author described two different morphotypes of avian footprints: one with, and another one without interdigital membrane. Later, Canudo et al., (2007) made a preliminary description of the Fondota tracksite (Abiego locality, "Calizas de Peraltilla Formation") where they distinguished 3 different morphotypes of artiodactyl tracks (*Anoplotheriipus*-like, Ellenberger, 1980). During last year, new fieldwork was carried out in these localities in order to obtain high spatial resolution point clouds with Terrestrial Laser Scanning (TLS, LiDAR technology) and photogrammetry techniques. Moreover stratigraphic profiles were made for providing a sedimentological interpretation of the deposits. A close-up examination of the ichnites and the photogrammetric models of the "Playa Fósil" tracksite allow to suggest that the described avian morphotypes might be produced by a single trackmaker walking in a detrital substrate with different water content. This is coherent in an environment like a shallow lake shoreline reached by detrital supplies or in a ponded area located in a flood plain. The TLS data and the photogrammetric models of "Fondota" tracksite allow us to characterize better the morphology of the three previous described morphotypes and distinguishing 26 lineations that represent individual trackways produced by the artiodactyls walking subperpendicular to the a lake shoreline.

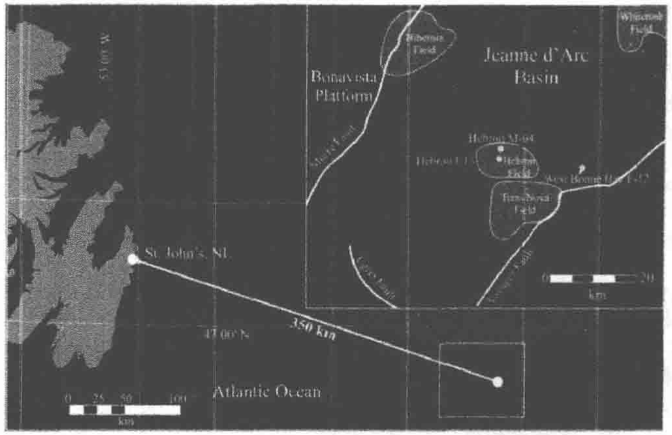

Figure 1. Geographic map indicating the location of the studied wells and nearby oil fields in the Atlantic offshore of Newfoundland, Canada.

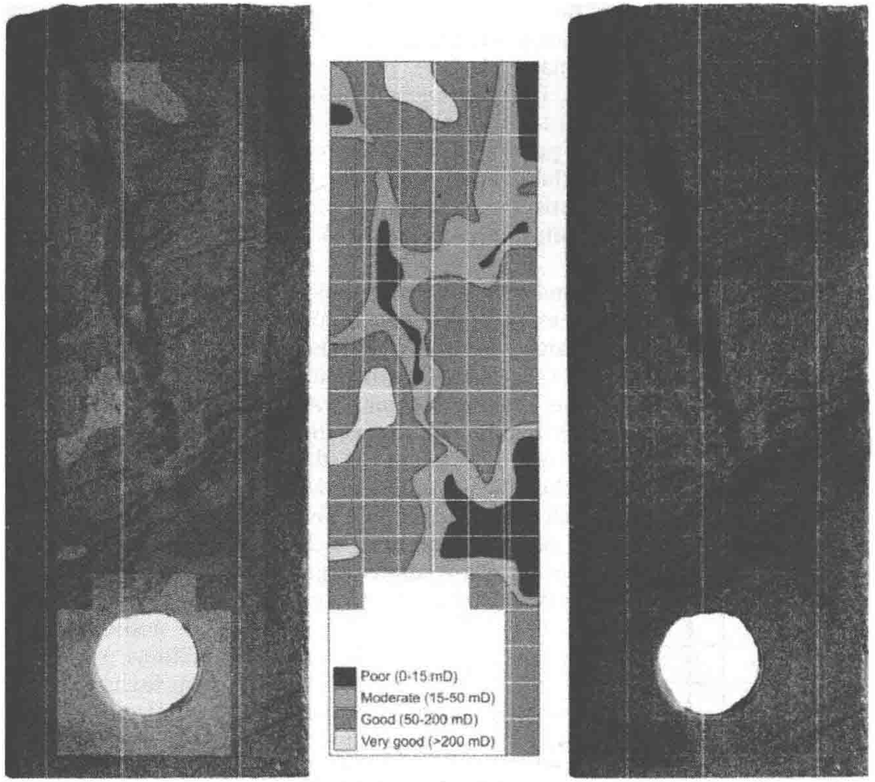

Figure 2. A contour map illustration of mini-permeametry results of sampling conducted on a slabbed core face from the West Bonne Bay F-12 core. Note the permeability difference between the Ophiomorpha burrow lining and the surrounding medium- to coarse-grained cross-bedded sandstone. Sampling grid is 6 cm by 19 cm.

Permeability and porosity characteristics of ichnofabrics and lithofacies from the Early Cretaceous Hibernia Formation, offshore Newfoundland, Canada

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Keywords: Early Cretaceous, Hibernia Formation, ichnofabric, permeability, porosity

The Early Cretaceous, upper Hibernia Formation in the southern Jeanne d'Arc Basin (Fig. 1), offshore Newfoundland in Canada is interpreted as a wave-influenced delta. Facies analyses show a transition from offshore marine in the Hebron area to more proximal shoreface and deltaic facies in the West Bonne Bay region. Hydrocarbon discoveries in the Hibernia Formation make it a potential target for the petroleum industry though little research has been conducted on the upper Hibernia Formation in the southern Jeanne d'Arc Basin. This study utilizes core samples taken through the Hebron Member, of the upper Hibernia Zone in the southern Jeanne d'Arc Basin to assess facies-specific trends in permeability and porosity related to the presence or absence of bioturbation. Minipermeametry analyses of slabbed core faces show a difference of 300 mD between mud-lined burrows and surrounding clean sandstones within the same 19 cm long core section (Fig. 2). Comparisons between thinly bedded sandstones and their cryptobioturbated equivalents display a difference in permeability of up to 20 mD. Core plug data indicates that parallel laminated storm-generated sandstone beds display higher permeability and porosity values than bioturbated fair-weather facies. Coarse-grained, cross-bedded sandstones with rare *Ophiomorpha* in the Hibernia Formation (Fig. 2) display the greatest permeability values (up to 900 mD), but bioturbated mudstones and very fine-grained sandstones containing *Phycosiphon* isp. are demonstrated, by petrography and core plug analyses, to have increased porosity and permeability. Facies distribution of isolated sandstone lenses and *Phycosiphon*-containing fair-weather deposits therefore strongly influence the potential for reservoir connectivity and thus should be factored into well planning.

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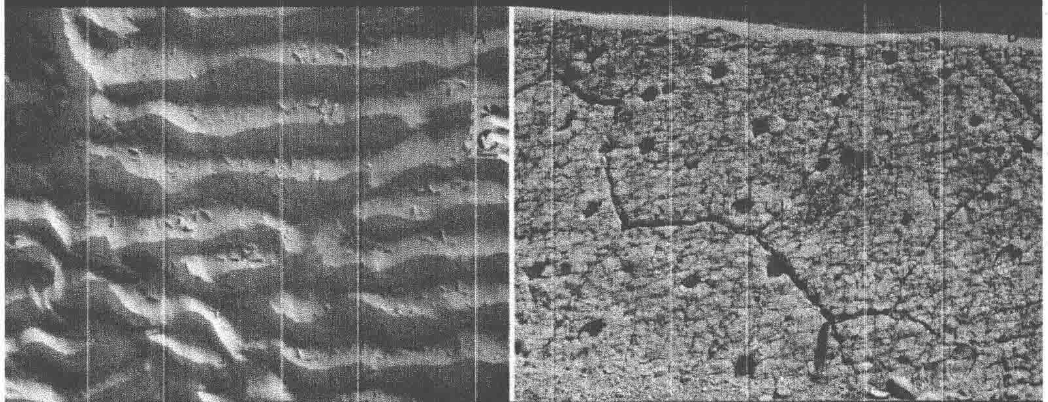

Fig. 1.Pictures of parts of the outcrops from the Playa fósil tracksite (A) and the Fondota tracksite (B) from the Lower Oligocene of the North of Ebro Basin (Aragón, Spain).

A stromatoporoid trace fossil from the Upper Ordovician of the Siberian Platform

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Keywords: *Stromatoporoids, trace fossils, Upper Ordovician, Siberia.*

Numerous specimens of a conical-shaped trace fossil similar to *Conichnus conicus* Männil, 1966 but usually larger (10–35 cm high and about 7–20 cm in diameter) were found in the Upper Ordovician (Katian) cool-water carbonate succession of the Tungus Basin in the Siberian Platform (Fig.1). The trace fossils are represented by vertically oriented conical or bulbous accumulations of bioclastic material (bioclastic packstone) surrounded by mudstone or wackestone with much lower concentrations of bioclasts. In several conical detrital accumulations, calcite tubes of stromatoporoid *Aulacera tenuipunctata* Yavorsky, 1955 were found in the axial or slightly tilted (axis-off) position in the cones (Fig. 2). During 2014, outcrops yielding numerous large tubes of *Aulacera tenuipunctata* were studied in detail. Where *in situ* the lower end of the tube is vertically oriented and surrounded by a detritic envelope of the conical shape. Detritic cones are thus closely connected with the calcite tubes and represent a trace fossil for which the aulaceratid stromatoporoids were the trace makers. It seems that the aulaceratid stromatoporoids could accumulate bioclastic debris around them as well as to penetrate into the sediment for at least 35 cm, probably by means of their weight and vibrations caused by hydrodynamic activity. Bioclastic debris probably passively filled an open space created by this vibration between the stromatoporoid tube wall and the firm surrounding sediment. They formed a kind of anchor, which prevented the animal from being plucked out by storms. In this respect, the trace fossils under consideration could be attributed to fixation/anchoring traces or the category fixichnia (Gibert et al., 2004).

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Stacking pattern analysis constrained by ichnofabrics

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Keywords: ichnofabrics, stacking-pattern, depositional environment interpretation, correlation

Detailed description including physical and biogenic sedimentary structures is mandatory to achieve comprehensive facies analysis of reservoirs in exploration projects complemented by the integration of all sort of data at different scales (petrography, biostratigraphy, chemostratigraphy, wireline log and seismic).
Identification of ichnotaxa and their grouping into ichnofabrics coupled with the analysis of physical sedimentary structures supports the recognition of half regressive and half transgressive cycles (Gérard and Bromley, 2008). Identification of the cyclicity from bed scale to bedset scale to parasequence scale (Campbell, 1967) is essential to identify the geologically significant surfaces bounding flow units at reservoir scale and sequences at the basin scale.
Recognition of the stacking pattern supports sequence analysis to achieve correlation of depositional sequences and geological surfaces between wells. Detailed stratigraphic analysis is essential for describing and understanding the reservoir architecture and more importantly for prediction of changes in reservoir architecture and quality in response to lateral facies changes as proposed by the Walther's law.
A series of case studies will exemplify the importance of combining physical sedimentary structures and biogenic structures to identify sequences and interpret depositional environments. Recurring ichnofabrics from classical prograding storm-dominated shelfs will be presented, but also incised valley fills and prograding river-dominated deltas controlled by floods where ichnofauna is sensitive to fresh water input will show the importance of recognition of the fining-upward and coarsening-upward cycles (1-5m) in defining the architectural elements and their correlation between wells.

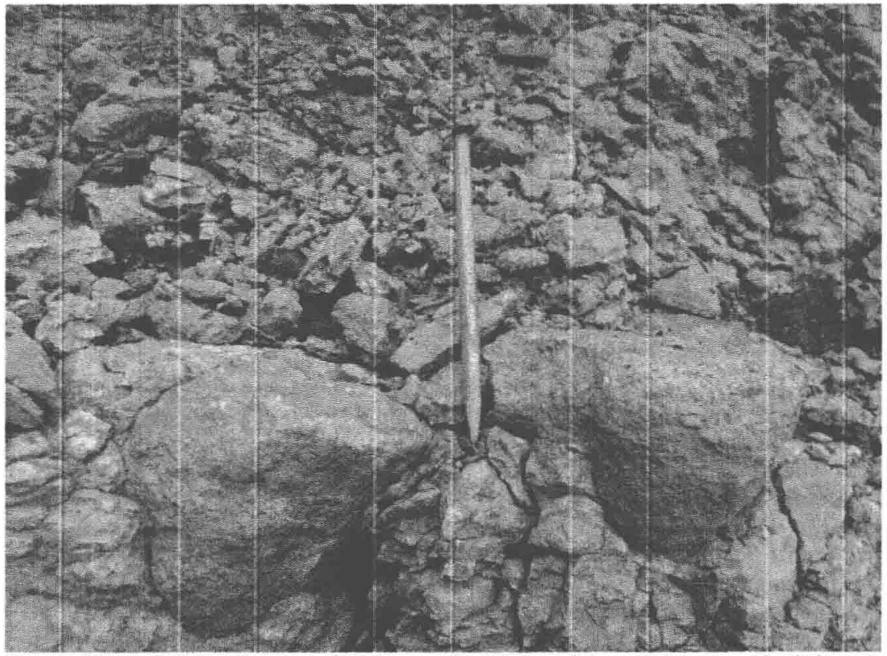

Fig. 1. Conical-shaped trace fossils produced by the stromatoporoid *Aulacera tenuipunctata* Yavorsky, 1955; Moyerokan River valley; Dzherom Formation. Upper Ordovician of the Siberian Platform.

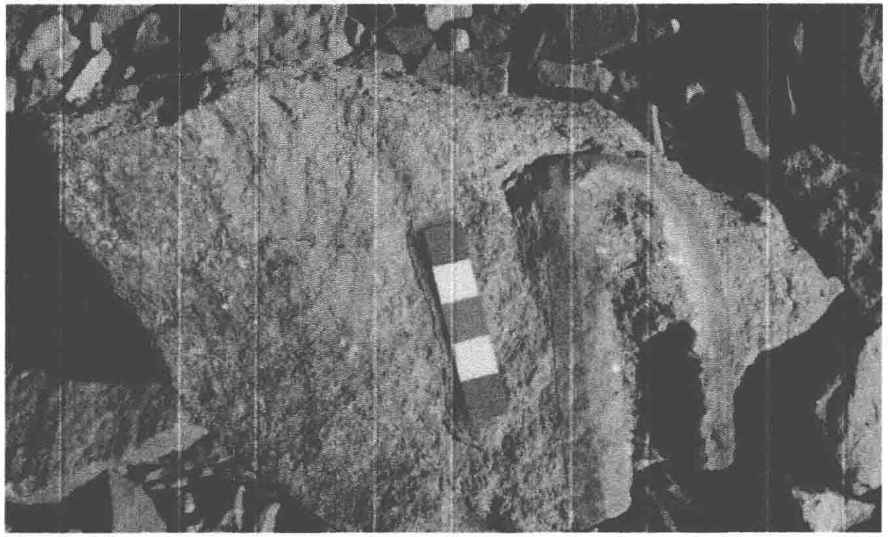

Fig. 2. Calcite tube of the stromatoporoid *Aulacera tenuipunctata* Yavorsky, 1955 within the conical detrital accumulation; Moyerokan River valley; Dzherom Formation. Upper Ordovician of the Siberian Platform.

Cruziana, Rusophycus and the record of arthropod limb evolution

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Keywords: Cruziana, Rusophycus, Gondwana, trace formation

The most iconic of all trace fossils, *Cruziana* and *Rusophycus*, have intrigued generations of ichnologists. While their stratigraphic significance and species diversity has been thoroughly documented (Seilacher, 1994), their modes of formation are still far from clear. The research community is divided in two regarding the formation of *Cruziana*. Major issues are the position of the organism in relation to the benthos and the limbs or parts thereof participating in the formation of the trace. The position of the trace maker as an epi- or endo- benthic organism is a crucial aspect for understanding the formation of *Cruziana* and *Rusophycus*. Here we discuss the mode of formation of *Cruziana* through interpretation of material from the Ordovician Sajir formation of Saudi Arabia. The material interpreted here indicates that Ordovician forms from Gondwanan outcrops did not have a differentiated endopod into an excavating mechanism and that it was retained as a relatively simple structure. Other specimens from the same locality indicate that the formation of the trace could not have been anything but at the interface between sand-mud layers, as overlapping traces could not be produced in an open burrow due to the absence of the casting substrate in the larger lobes of excavated sediment. In this report we wish to illustrate the difficulty of working with aspects of trace fossil formation and the importance of taphonomical processes in the preservation of trace fossil material and whether the evolution of arthropod limbs could be documented by the ornament of associated trace fossils.

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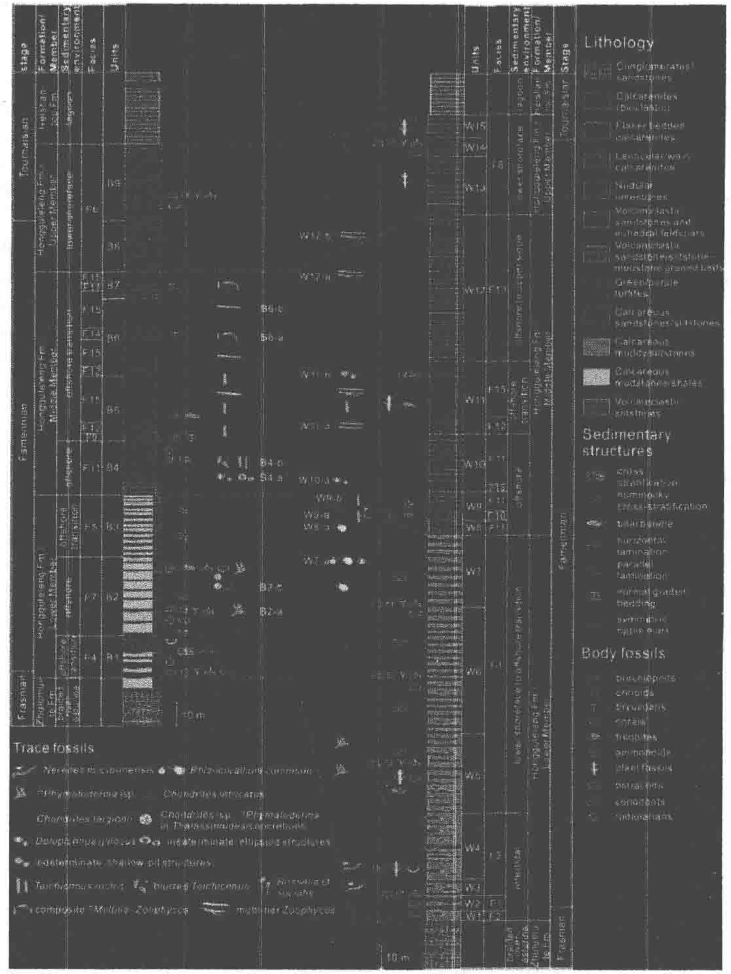

Fig. 1. Sedimentary columns of the Bulongguoer (left) and Wulankeshun (right) sections in western Junggar, recording sedimentary structures, body and trace fossils and their facies interpretations.

Ichnological and sedimentological features of the Hongguleleng Formation (Devonian–Carboniferous transition) from the western Junggar, NW China

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Keywords: Trace fossil, Late Devonian, Volcanic arc, Event sedimentation, Western Junggar

Two sections of the Late Devonian to Early Carboniferous Hongguleleng Formation in the Sha'erbuerti and Xiemisitai mountains of western Junggar, NW China were logged in detail. It is composed essentially of marginal- to shallow-marine deposits formed in a volcanic arc-related setting. Trace fossils include indeterminate ellipsoid structures, indeterminate shallow-pit structures, *Chondrites intricatus*, *Chondrites targionii*, *Chondrites* isp., *Dolopichnus gulosus*,*?Multina* isp., *Nereites missouriensis*, *Nereites* isp., *Palaeophycus tubularis*, *?Phycosiphon* isp., *?Phymatoderma* isp., *Rhizocorallium commune*, *Rosselia* cf. *socialis*, *Teichichnus rectus*, *Teichichnus* ispp., *Thalassinoides* isp., and *Zoophycos* ispp. These ichnofossils and related bioturbation structures constitute five distinct groups of ichnofabrics: *Chondrites–?Phymatoderma*, *Rhizocorallium commune*, anemone dwelling/burrowing, *Teichichnus*, and *Zoophycos* ichnofabrics, conforming to an upward trend from the *Cruziana* to *Zoophycos* ichnofacies. The volcanic arc setting provides a natural laboratory to investigate the colonisation styles of benthic faunas in event influenced strata during the Devonian. Simple and composite ichnofabrics have been distinguished. The simple ichnofabrics are typified by the indeterminate ellipsoid "ichnofabric" made by sea anemones, representing short colonisation event and in situ death and burial resulted from relatively high sedimentation rates even during the periods between volcanic explosions. The composite ichnofabrics are characterised by the *Chondrites–?Phymatoderma*, *?Multina–Zoophycos* and multi-tier *Zoophycos* ichnofabrics, representing vertical migration of benthic faunas in pace with either distal event deposition or steadily accreted sea floor. The colonisation window in the arc-related setting is closely related to sedimentation rates and frequency of depositional events, determining the completeness of burrow system structure and maturity of benthic communities.

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Life and death on the continental shelf 20 Ma: the interaction between predator and prey as reflected in trace fossils

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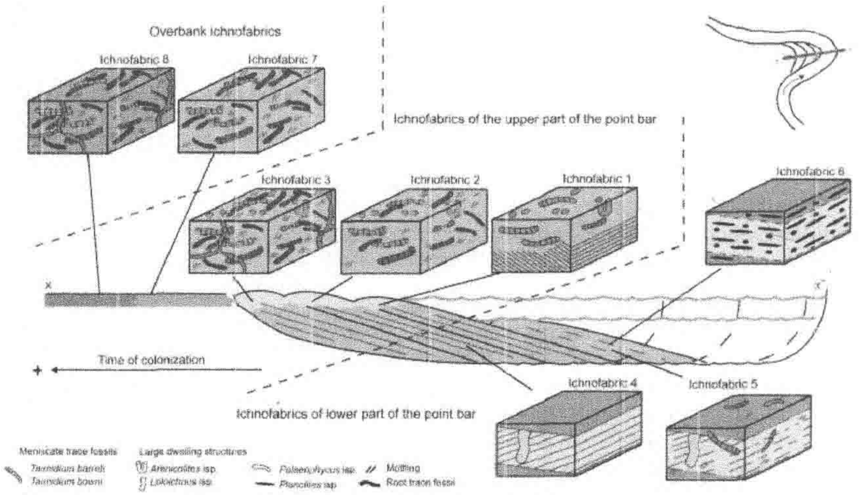
Keywords: Schaubcylindrichnus, Ophiomorpha, Piscichnus waitemata, Miocene, Taiwan

Before Taiwan formed in the late Miocene-Pliocene through the collision of a volcanic arc on the Philippine Sea Plate with the continental shelf of the Eurasian Continent, the environment was characterized by a wide shelf where cyclic deposits of offshore to deltaic sediment were laid down. Today these sand- and siltstones are exquisitely exposed along the northeast coast of Taiwan, allowing detailed observations on the relationship between the different organisms that inhabited the benthic environment. In particular, *Piscichnus waitemata* (stingray feeding traces) often contain broken pieces of wall material from *Ophiomorpha* and *Schaubcylindrichnus*, suggesting that the shrimps and worms constructing these borrow systems belonged to the favorite food of the stingrays. These observations are of special interest for our understanding of the trace fossil *Schaubcylindrichnus*. Is the sequential construction of lined tubes in the typical sheaves or bundles of wide, U-shaped tubes in *Schaubcylindrichnus* a response to attacks by stingrays?
Here data from two well exposed areas along the NE Coast of Taiwan are evaluated to determine whether there is a statistical correlation between the abundance of *P. waitemata* and the number of tubes in the *Schaubcylindrichnus* sheaves. The hypothesis being that increased predation pressure by stingrays would lead to more *Schaubcylindrichnus* systems being partly destroyed, in its turn resulting in higher numbers of repaired systems, as reflected by the number of tubes per sheaf.



Facies	Lithologies	Body fossils	Sedimentologic features	Other features	Depositional environment	
Non-channelized deposits	Yellowish sandy marly mudstone	Fragments of mollusc shell, planktonic foraminifera and calcispheres	Commonly massive Locally lenticular bedding Glauconite grains and locally authigenic glauconite	Ichnofabric 7	Proximal	Overbank mudflats
	Reddish sandy-marly mudstone	Commonly ostracods and charophytes	Massive	Ichnofabric 8 Locally carbonate nodules and paleosols	Distal	
Paleochannel deposits	Hybrid arenite	Fragments of bivalve shell and planktonic and benthonic foraminifera and calcispheres	Commonly massive	Ichnofabrics 1, 2, 3	Upper point bar	Tide-influenced meander loops
	Hybrid arenite and sandy-marly mudstone	Plant remains, including palm tree leaves Locally fragments of echinoderm and red algae and charophytes, ostracods, and vertebrate bones and eggshells	Inclined heterolithic stratification (IHS) with erosional and no erosional/reactivation surfaces. Large- and small-scale cross-bedding, climbing-ripple cross bedding, flaser bedding and parallel lamination Locally diffuse IHS and sedimentary structures	Ichnofabrics 4, 5, 6	Lower point bar	

Fig. 1. Ichnofabrics identified in tide-influenced meander loops of Tremp Formation (South-Central Pyrenees, Spain). The geometry of deposition of point bars controls, firstly, the ichnofaunal distribution.

Ichnofabrics in tide-influenced meander loop deposits: Underscoring the geometry of the colonization window

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Keywords: Ichnofabric approach, bioturbation controls, tide-influenced meander loop, colonization window

Studies dealing with the colonization window typically emphasize two major features, duration (short vs long time) and frequency (episodic vs continuous colonization). However, our understanding of tide-influenced meander loops requires considering an additional feature, the geometry of the colonization window. Tide-influenced meandering channels show an heterogeneous ichnofaunal distribution that reflects the variety of processes operating along the point bar and overbank surfaces. Ichnofabric analysis of tide-influenced meander loop deposit from the Upper Cretaceous Tremp Formation (Pyrenees, Spain) provides valuable insights to better understand the dynamic and ichnology of these marginal marine systems and to evaluate the importance of their paleomorphology controlling the colonization window. Eight ichnofabrics are identified in the point bar and associated overbank deposits. The ichnofabrics differ in bioturbation index (higher in upper part of point bars), preservation of primary sedimentary fabric (typically preserved in lower part of point bars), inferred behaviour and trophic types (dominance of dwelling or feeding structures in the lower and upper parts of point bars, respectively), depth of penetration, ichnotaxonomic composition (e.g. freshwater vs brackish water suites), presence or absence of root traces and/or mottling, and the number of superimposed suites. Moreover, the colonization windows inferred differ in duration, frequency and geometry (e.g. inclined vs horizontal). The key environmental factor controlling the nature and distribution of ichnofabrics is the paleomorphology of the point bar lateral accretion surfaces, which is directly linked to the geometry of the colonization window. Factors of subordinate importance are: helicoidal flow, water level changes, time of meander loop development, salinity fluctuations and early diagenesis (shallow dissolution and/or cementation).

Terror at the beach: huge theropod tracks on the Jura carbonate platform (Late Jurassic, Switzerland)

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Keywords: Dinosaur track, tridactyl, Theropoda, 'Megalosaurids', Jura Mountains

Excavations along Highway A16 (NW Switzerland) in Kimmeridgian tidal-flat deposits of the Jura carbonate platform revealed > 650 sauropod and tridactyl (mostly theropod) trackways with different morphologies and size classes. All trackways were carefully documented and partially collected and/or casted constituting a huge track collection and database. Several huge (pes length > 50 cm) tridactyl trackways were discovered. Some of these tracks are well preserved and morphologically distinct, characterized by a slightly larger pes length than width, a very small anterior triangle, weak mesaxony, three blunt ('fleshy') digits (II-III-IV) with pronounced claw marks of equilateral triangle-shape, and occasionally with heel impression. Some of these features are typical of very large theropod tracks. The blunt digits and sheer size of the largest tracks, some of which amongst the largest worldwide, suggests a 'megalosaurid' theropod as a trackmaker. The frequent presence of huge theropod tracks in tidal-flat deposits of the Jura carbonate platform and in (close) association with tiny to large sauropod tracks and minute to large tridactyl tracks, has important palaeoecological implications for the dinosaur population. Also this evidence is important for palaeo(bio)geographical reconstructions, as theropod tracks larger than 50 cm in length (and some of which of similar morphology) are also known from of the Late Jurassic of Northern Germany (Kaever & Lapparent, 1974), France (Cariou et al., 2014), Spain (Cobos et al., 2014), and Morocco, and tracks of similar morphology are also known from the Middle Jurassic of Portugal (under study).

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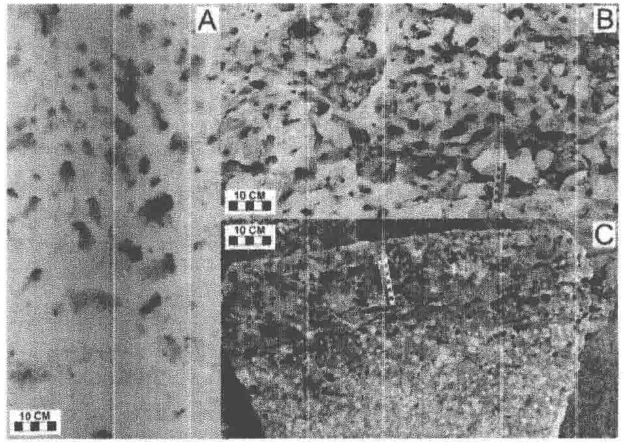

Fig. 1. Examples of dissolution-enlarged Thalassinoides- and Ophiomorpha-related megaporosity exhibited in Lower Cretaceous shallow-marine platform carbonate rocks in the subsurface and outcrops of Central Texas, USA. (A) Solution-enlarged permeable megaporosity formed by Thalassinoides or Ophiomorpha in the Glen Rose Formation that contributes to a groundwater production zone in a water well at depths below the surface between 93 and 94.2 m. (B) Solution-enlarged Thalassinoides that forms fabric-selective megaporosity in a lime packstone matrix (Thalassinoides-dominated Cruziana Ichnofacies) within of the Burrowed Member of the Fort Terrett Formation that crops out near Leakey, Texas. (C) Solution-enlarged Ophiomorpha that forms fabric-selective megaporosity in a lime grainstone matrix (Ophiomorpha-dominated Skolithos Ichnofacies) of the Glen Rose Formation that crops out at the Canyon Lake Spillway in Comal County, Texas.

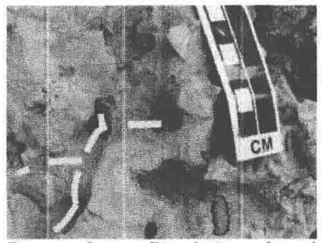

Fig. 2. Dissolution-enlarged megaporosity in a Thalassinoides-dominated lime packstone (Thalassinoides-dominated Cruziana Ichnofacies) within lagoonal platform carbonate rocks of Paleocene age at Monte Baio, northeastern Spain. The dashed yellow line emphasizes the hallmark branching morphology of the Thalassinoides. This megapore system has apparently resulted from overprinting of mixing-zone dissolution (Baceta et al., 2007) over a Thalassinoides-dominated ichnofabric. It is considered analogous to the interaction between mixing-zone dissolution and bioturbated strata presented by Todaro et al. (2016) for Triassic peritidal carbonate rocks in Sicily.

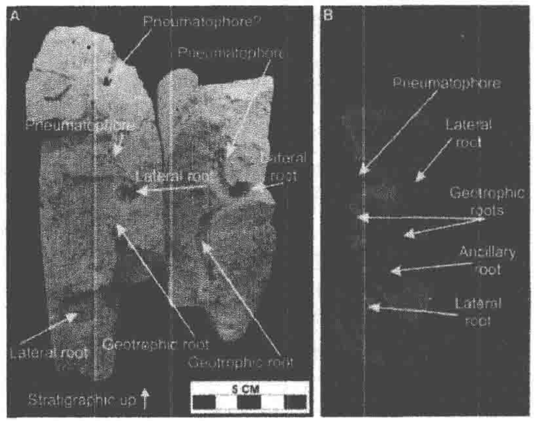

Fig. 3. Photograph (A) and rendering of X-ray computed tomography scans (B) of a rhizolith-dominated Psilonichnus Ichnofacies in a limestone core specimen acquired from a depth of 1175.1 m (top of specimen) below the surface in the G-2984 test corehole located in southeastern Florida, USA. (A) Dissolution-enlarged mangrove-root molds dominate the megaporosity of core specimen of middle Eocene tidal-flat benthic-foraminifer wackestone and packstone that caps a carbonate peritidal high-frequency cycle. This megaporosity type is a major contributor to groundwater flow detected by a borehole-fluid flowmeter. (B) Three-dimensional volume of X-ray computed tomography slices of core specimen in A. Acquisition and volume rendering of computed tomography data conducted at the University of Texas High-Resolution X-ray Computed Tomography Facility.