The ichnology of shallow-marine and transitional environments

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Abstract: The ichnology between marine and non-marine environments is a key field of work concerning the understanding of the variation of environmental parameters in inland-to-offshore transitional environments. In order to understand the geological and palaeobiological processes at these locations, this Special Publication attempts to discuss records in shallow-marine and transitional environments throughout the Phanerozoic, including topics such as ichnotaxonomy, ichnofacies analysis, ichnofabric analysis for records from both shallow-marine and transitional environments, and neoichnological aspects. The volume includes 14 papers in total: one focused on aspects of neoichnology in rock iguanas in coastal settings, nine concerning various shallow-marine palaeoenvironment topics and four addressing issues about dinosaur tracks in transitional environments.

The interface between the marine and non-marine realms is critical for studying a wide range of phenomena ranging from ecology evolution and palaeobiology through to nutrient flux and hydrocarbon reservoirs. The ichnology of shallow-marine and transitional environments provides an important perspective, enabling us to better characterize many environmental parameters in inland-to-offshore transitional environments. Ichnological approaches towards improved understanding of this critical interface come from neoichnological studies of modern coastal settings and studies of the ichnology, ichnofacies and ichnofabrics of both the shallowest-marine and terrestrial coastal deposits.

In many cases, the palaeoenvironmental interpretations that can be determined from the study of physical sedimentary structures alone can be greatly augmented by the addition of biological data. Animals and plants in marginal-marine settings experience a lot of environmental stressors, ranging from fluctuating temperature and salinity to dehydration, that are difficult to assess using sedimentological proxies. While the study of marginal-marine settings is of fundamental interest, the sedimentary rocks that are deposited in these settings are highly significant to the hydrocarbon and mining industry as sites of important economic resources.

The most commonly used ichnological paradigm to assess the depositional setting is the ichnofacies concept (Seilacher 1953*a*, *b*, 1967). In recent years, the original bathymetrically focused approach has been refined through the addition of many new ichnofacies and subfacies (MacEachern and Bann 2022), as well as the integration of sedimentological and ichnological assemblage data on a case-by-case basis, using the ichnofabric method (e.g. McIlroy 2004), such that in recent years the two methods have become conceptually very close (McIlroy

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2008). With the increased interest in marginal-marine deposits, there has been a growth in the sophistication of integrated ichnological sedimentological studies, including the integration of invertebrate and vertebrate ichnology.

This volume was originally conceived as a means of including, in a single compilation, state-of-the-art studies across a range of disciplines and palaeoenvironments to provide insights and advances in this complex topic, incorporating new contributions and approaches alongside reviews to provide an up-to-date synthesis of the field. This Special Publication attempts to discuss records in shallow-marine and transitional environments through the Phanerozoic. It includes topics such as ichnotaxonomy, ichnofacies analysis, ichnofabric analysis for records from both shallow-marine and transitional environments, and neoichnological aspects, in order to gain a better understanding of geological and palaeobiological processes.

In attempting to bridge the gap between biology and ichnology, it is important to employ neoichnological techniques in coastal settings. The work of **Buynevich *et al.* (2021)** presents a geophysical dataset of rock iguana burrows in carbonate substrate using ground-penetrating radar, demonstrating its potential as a rapid, non-invasive and practical method for visualizing burrows for ichnology, but also for conservation ecology. Ichnological analyses commonly rely upon interpretation of the mode of life/feeding of burrowing taxa and, as such, palaeoenvironmental inferences are only as good as the palaeobiological understanding. A paper by **Neto de Carvalho and Paredes (2022)** exemplifies this through the study of fossil anemone burrows from the Jurassic of Portugal, showing possible surficial feeding by comparing these with modern cnidarian taxa based on the burrow morphology. The work of **Curran and Glumac (2021)** importantly identifies that the trace fossil *Dactyloidites ottoi* is present in the shallowest-marine facies in the Pleistocene of the Bahamas, making this an environment of critical importance for understanding sea-level change. The trace fossils *Psammichnites* and *Olivellites* are commonly recognized in shallow-marine deposits; a detailed morphological and palaeobiological review by **Pazos and Gutiérrez (2022)** has concluded that post-Cambrian examples are all *Olivellites* and probably result from the activity of a burrowing bivalve.

The behaviour of organisms with respect to relative sea-level change is of fundamental importance to sequence stratigraphy and correlation. The fossilized Cretaceous log-grounds of Cuba described by **Villegas-Martín *et al.* (2022)** are an excellent example of how trace fossils can help to identify marine incursions in stratigraphic successions, with the authors exploring the life histories, ecology and taphonomy of the deposits. Another expression of marine flooding surfaces is the *Glossifungites* ichnofacies, which forms on firm muddy substrates, often as eroded tubular tempestites that record conditions during a time of flooding that are otherwise missed. Classic examples of this from core-based ichnofabric studies in the Devonian of Brazil are presented by **Sedorko *et al.* (2022)**, showing the utility of ichnology in the study of marginal-marine facies in core. The integration of ichnology and palaeoenvironmental analysis is well demonstrated by the study of the shallow-marine Wilcox Formation, Mexico, by **Hernández-Ocaña *et al.* (2022)**, whose work ranges from thin sections and classic taxonomic ichnology/ichnodiversity studies through sedimentology to facilitate basin-scale stratigraphic understanding. Similarly, **Benzina *et al.* (2022)** present a diverse ichnological assemblage produced by arthropods, annelids and bivalves, from late Miocene marginal-marine deposits of the Tafna Basin, Sikkak area, Algeria. The work of **Bayet-Goll *et al.* (2022)** links the occurrence of exotic facies and the resurgence of microbialites with trace fossils to extraordinary palaeoceanographic conditions in the Mila Group (late Cambrian) in the Alborz Basin, northern Iran. The ichnofacies approach is discussed by **MacEachern and Bann (2022)** with regard to their new *Phycosiphon* and *Rosselia* ichnofacies, documenting animal–sediment relations in prodeltaic and delta-front deposits, being archetypes based on mixed wave- and river-influenced delta deposits.

This volume includes several contributions that address issues in transitional environments. **Heredia *et al.* (2022)** show a fascinatingly graphic case of small sauropod slipping tracks preserved in a surface with evidence for microbial matgrounds on a tidal flat developed in a mixed carbonate–siliciclastic environment, from the Lower Cretaceous Agrio Formation, northern Patagonia, Argentina. Dinosaur and invertebrate trace fossils are also identified in a braid delta system from the Iberian Peninsula by **Díaz-Martínez *et al.* (2022)**, one of the few worldwide localities where Albian dinosaur tracks have been found in deltaic facies. An area with periods of crevasse sub-delta progradation is where the dinosaurs are thought to have been roaming. New dinosaur tracksites are also reported herein from the Middle Jurassic of Madagascar by **Wagensommer *et al.* (2022)** in marginal-marine environments, which is one of the most laterally extensive records of dinosaur tracks in the Southern Hemisphere. In a literature review of the main vertebrate 'megatracksites', **Lockley and Meyer (2022)** found that they are mainly associated with coastal plains; this allowed them to characterize and subdivide the sites into three types depending on the frequency of horizons and their lateral continuity.

We hope this volume will accomplish many goals in further years. From one side, the scientific

community will benefit from this compendium of valuable and updated data. Additionally, we believe that students and young scholars will surely find useful tools here to develop their careers.

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