Investigating the Effects that Animals have on Sediment Properties

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Sediments are modified by the action of infaunal organisms in a number of different ways. Organisms use sediments as a place to live, but also as food. The modification of sediment texture by infaunal organisms, known as ichnofabric, changes the physical characteristics of the sediment itself. It has the potential to both increase and decrease connectivity between permeable horizons, to augment and destroy reservoir potential.

This study focusses on both the physical and bio-geochemical effects that organisms have on sediments through an experimental neo-ichnological approach. A number of modern taxa have been cultured in experimental tanks with known geochemisty and sediment-type. The experimental tanks are studied using a dedicated CT-scanning facility. Data collected includes pore volume calculations for bio-pores, geochemistry of clay-grade material, burrow morphology and organism-sediment interactions.

An Ichnological and Sedimentological Facies Model for Mud-Dominated Inner-Estuarine Deposits, Bay of Fundy, Canada

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Analysis of fine-grained clastic deposits associated with the macrotidal inner-estuarine mouth of Chignecto Bay, Bay of Fundy, New Brunswick, Canada concentrated on identifying the ichnological and sedimentological characteristics of tidally dominated point bars and their adjacent tidal flats. The aim of the study was to establish an ichnological model for application to the geological record.

Within the study area, the distribution of ichnological structures and sedimentary characteristics such as grain-size distribution and total-organic content are associated with bank bathymetry, tidal-bank slope, and the local hydraulic processes. The distribution of infaunal traces is influenced by the duration of intertidal exposure and sedimentation rates. The size and diversity of the burrowing fauna are affected by the chemistry of the depositional waters and by seasonal variations in the composition and temperature of those waters. The extreme seasonality of the depositional setting favors opportunistic fauna and thereby contributes to an impoverished, brackish-water trace assemblage.

Geomorphologically, the area is dominated by point-bar and tidal-flat deposits, which comprise rhythmic bedding, composed of interlaminated to thinly interbedded silty and sandy mud. Point-bar bedding dips channelwards and represents mud-dominated inclined heterolithic stratification (IHS). Bedding alternates between burrowed and laminated beds. Cyclic variations in laminae thickness are attributed to spring-neap variation in tidal-current strength. The burrowed interbeds exhibit high degrees of bioturbation that eradicate the preexisting lamination. The intercalation of laminated and burrowed beds represent seasonal variations in the depositional system: laminated beds characterize early winter and early spring sedimentation and the bioturbated beds represent late spring through fall deposits.

Ichnological Variability of Shallow Marine Strata within the Macedon Member: A Comparison of the Enfield and Laverda Depositional Systems, Exmouth Sub-Basin, Western Australia

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The Macedon Member forms the lowstand deposits of a 3rd order Upper Jurassic sequence. Detailed seismic, core and borehole image interpretation, and re-evaluation of biostratigraphic data enables further subdivision into higher frequency stratigraphic cycles. Two of these are penetrated at the Laverda and Enfield oilfields. This study illustrates the application of ichnology in restricting the depositional range of these deposits, historically inferred to have been deposited on the upper slope, to a distal inner shelf to upper shoreface setting.

Two phases of deposition are recorded in the Laverda field. The preliminary Laverda canyon system identified on seismic (SSW – NNE), is associated with earlier lowstand incision. The lower part of the canyon fill, seen in Laverda-1, consists of conglomerates interbedded with horizontal sandstones, deposited from traction carpets and high-density turbidites. These are unconformably overlain by siltstones and sandstones with *Chondrites* and *Phycosiphon*, representing deposition in a distal inner shelf setting. The section to the NW in Laverda-2 reveals the presence of sharp-based stratified sandstones alternating with highly bioturbated fine sandstones with diverse ichnofaunas. Trace fossils include *Teichichnus*, *Phycosiphon*, *Rhizocorallium*, *Chondrites*, *Skolithos* and minor *Ophiomorpha*. These reflect the deposition of alternating storm-generated event beds and suspension strata associated with fairweather periods. A series of non-bioturbated horizontally stratified and ripple cross-laminated sandstones punctuate the succession, derived from hyperpycnal flows on the shelf.

The Enfield study interval (wells Enfield-2 and Enfield-3) is dominated by highly bioturbated sandstones passing up into cross-stratified sandstones. The ichnofabrics in the basal section are comparable to those seen in Laverda-2, reflecting deposition on the inner shelf. The overlying cross-stratified sandstones comprise pervasive *Macronichnus* with local occurrences of *Ophiomorpha*, deposited in a shoreface setting. Shallow marine conditions were maintained in the Enfield area due to its location on a palaeohigh to the northeast of the Laverda canyon system.

Contrasting Ichnologic Signatures of Wave-Dominated Deltaic and Non-Deltaic Shallow-Marine Deposits in the Miocene Carapita and Capaya Formations, Tacata

Field, Eastern Venezuela

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Integrated ichnologic, sedimentologic, sequence stratigraphic and micropaleontologic analysis of cores from the Lower Miocene Carapita Formation and the Middle Miocene Capaya Formation (Tacata Field, eastern Venezuela) allows delineating deltaic and non-deltaic deposits in the subsurface. Sandstone wedges in these formations record progradation of a wave-dominated deltaic complex where periodic fluvial discharges alternated with storm events and suspension fallout in the delta front and prodelta. Tidal evidence is detected in the distributary plain. Deltaic facies grade vertically and laterally into non-deltaic nearshore deposits. Degree of bioturbation ranges from low to moderate in deltaic deposits. Prodelta and distal delta front deposits are dominated by *Phycosiphon* and *Chondrites*, commonly occurring as monospecific suites. Other components are *Terebellina*, *Arenicolites*, *Palaeophycus*, *Teichichnus*, *Planolites* and escape traces. Vertical *Ophiomorpha*, *Thalassinoides* and *Planolites* are dominant in delta front deposits; *Terebellina*, *Phycosiphon*, *Palaeophycus*, *Teichichnus* and *Planolites* are subordinate components. Distributary channel deposits contain *Ophiomorpha* and *Skolithos*. *Planolites*, *Palaeophycus* and root traces are the most common forms in interdistributary bay deposits. Large and deep synaeresis cracks and soft-sediment deformation structures are very common. Low ichnodiversity of individual suites reveals a stress factor due to reduced salinity and allows distinction from nondeltaic strandplain shoreface successions. However, the dominance of *Phycosiphon*, *Terebellina* and *Chondrites* suggests periods of normal marine salinity that alternated with dilution due to fluvial discharge. Non-deltaic deposits are commonly more intensely bioturbated and display an increase in ichnodiversity. In particular, the echinoid trail *Scolicia* is restricted to offshore deposits lacking any evidence of associated fluvial discharge, revealing normal marine salinity. Ichnologic data are extremely valuable to detect fluvial inputs in shallow marine clastic seas.

Trace Fossils and Palaeoenvironment in Shelf-Margin Clinoforms: An Example from the Central Basin of Spitsbergen

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Lower Eocene shelf-margin clinoforms in the Central Basin, Spitsbergen, have been well studied, but not previously from an ichnological point of view.

Forty six ichnotaxa have been recognized in the coastal plain – shoreline/shelf – slope segments of clinoforms, but only ten of them are common. Coastal-plain channel sandstones contain a few root structures, whereas supra-channel facies have the low diverse ichnoassemblage. *Helminthoidichnites*, *Steinichnus* and roots are common. *Cochlichnus* and bird footprints are rare. This ichnoassemblage belongs to the impoverished *Scoyenia* ichnofacies with contributions from the Mermia ichnofacies (*Cochlichnus, Helminthoidichnites*), typical of lakes. The coastal plain was probably inundated, swampy and vegetated, explaining the general lack of mammal footprints.

Tidal-flat sediments are poorly bioturbated, but rippled surfaces display *Haplotichnus* and *Kouphichnium*, rarely *Undichna, Archaeonassa* and *Limulicubichnus*. The assemblage is less diverse than in similar settings of older age, probably because these tidal flats were stressed by predator and scavenger activity, such as birds.

In the shallower parts of wave-dominated deltaic parasequences *Ophiomorpha nodosa*, *Arcusichnus*, and rare *Macaronichnus* occur. They belong to the *Skolithos* ichnofacies. The *Cruziana* ichnofacies is represented by *Thalassinoides*, *Asteriacites* and *Stelloglyphus*. Prodelta mudstones and fine-grained sandstones are dominated by *Phycosiphon incertum*, which strongly bioturbate the sediments. Bioturbation decreases gradually up the parasequences. Turbidites in slope channels and basin-floor fans are not colonized at all or contain abundant *Arenituba storvolensis*. In places it co-occurs with *Phycosiphon* and ?*Polykladichnus*. This trace fossil assemblage is dissimilar to the deepwater *Nereites* ichnofacies, possibly because the Spitsbergen turbidites were generated by hyperpycnal flows.

Ichnofabric Analysis, Event Stratigraphy and Paleoenvironmental Reconstruction: Late Miocene Strata, East Cape - Te Araroa, New Zealand

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A shallowing upward and coarsening upwards marine sequence of upper Miocene to lower Pliocene age strata is spectacularly exposed in broad shore platforms over a distance *c* 20km at East Cape, North Island, New Zealand. The setting was an active continental margin where background hemipelagic sediment accumulation was episodically punctuated by volcaniclastic gravity flows and tephra deposition. Intensive bioturbation destroyed small-scale sedimentary structures and obliterated minor event beds. Trace fossils are sharply defined by the strong contrast between dark grey, hemipelagic, background sediment and the light coloured ash horizons. The archetypal ichnofacies concept, focussing as it does on discrete and elite traces, lacked the resolution necessary to decipher paleoenvironmental changes associated with event bed deposition in this thoroughly bioturbated sequence. Our approach has used Taylor and Goldring's ichnofabric constituent diagrams (ICD's) and proportional bioturbation indices (BI's). It differed in that vertical ordering in ICD's followed stratigraphic sequence – older to younger rather than younger to older. The diagrams succinctly illustrate sedimentation history, key stratal surfaces, colonisation order, variation in bioturbation intensity, and organism response to event deposition. They also identified trace fossil-event bed deposition associations and highlighted ichnofaunal responses to changing environmental conditions. From 11 representative stratigraphic

sections, 16 discrete ichnofabrics were identified (*Zoophycos*, *Zoophycos-Chondrites*, *Chondrites-Phycosiphon-Scolicia*, *Teichichnus-Asterosoma*, *Asterosoma*, *Thalassinoides*, diffuse mottling, mixed, slump horizon, turbidite, fine ash, coarse ash, grain flow, vertical burrow, echinoid and hieroglyphic mudstone). There are two main categories of ichnofabric; those related to hemipelagites and those related to event beds. Of the archetypal ichnofacies, only *Zoophycos*, *Cruziana* and *Glossifungites* were recognised. ICD's/BI's provided far more detailed paleoenvironmental resolution than would otherwise be revealed by Seilacherian archetypal ichnofacies and is an approach yet to be fully exploited.