INTEGRATED ICHNOLOGY & SEDIMENTOLOGY FOR FACIES ANALYSIS

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INTRODUCTION

Ichnology is the study of plant and animal traces. Implicit to this definition is that the traces made by plants and animals reflect some sort of behavior. Ichnology as a science actually began in prehistoric period, when hunter-gatherer societies used the signs of animals (tracks, feces, and other indirect evidence) for acquiring tracking to track their prey. Ichnology is thus probably one of the first applied sciences in human history, born out of necessity for survival. Ichnology can be divided into two major subdivisions: paleoichnology (the study of ancient traces) and neoichnology (the study of modern traces). Most ichnologists are involved in paleoichnology but a considerable number also study neoichnology for the comparison of modern equivalents (and their trace makers) to ancient traces.

By name, ichnology is a relatively young science that reached its widespread international recognition in the second half of the 20th century. Probably, The first use of the term "ichnology" was in the title of a scientific publication in 1858, Ichnology of New England, by Edward Hitchcock, regarding the vertebrate tracks of Mesozoic strata in the Connecticut Valley, U.S. Paleoichnology, became known later in human history, including the observation of dinosaur tracks in Mesozoic strata by Native Americans and other aboriginal peoples and the first recognition of some coprolites as feces in the 17th century.

The first Dinosaur tracks were documented in 1802 by Pliny Moody in the eastern U.S. but were not studied in any detail until more than 30 years later by Edward Hitchcock. Neoichnology of invertebrate organisms in modern times may have actually started by Charles Darwin, who observed the effects of bioturbation by earthworms in his yard during the 19th century. Darwin measured the amounts and rates of soil overturn in his yard by using "worm stones," experiments that took him years to gather data.

Regarding to marine environments, the pioneering efforts of Rudolf Richter in the 1920's lead to a much better understanding of the uniformitarian principles required for understanding trace fossils. He studied modern traces left in the North Sea tidal flats and one of the most comprehensive works on invertebrate and vertebrate trace fossils, *Vorzeitliche Lebensspuren* was published by Othenio Abel in 1935, soon after Richter began his work. Other than works done by mainly German authors and a few scientists in other countries, relatively little was published in invertebrate ichnology from the 1930's nearly through the 1950's. During that time, Vertebrate ichnology was represented the work of Roland Bird in dinosaur track studies.

The naming of invertebrate trace fossils began early in the 19th century, when paleontologists mistook some trace fossils as fossil algae ("fucoids"), reflected in the suffix of many

an ichnogenus (i.e., *Zoophycos*, *Palaeophycus*, *Spirophycus*). In 1873, a Swedish paleobotanist, Alfred Nathorst, refuted the algal origin for most of these trace fossils and demonstrated their affinity to modern biogenic sedimentary structures, but his arguments were not readily accepted at the time. The difficult task of classifying invertebrate trace fossils became one of the most important life works of Walter Häntzschel, who published the first concise catalog of described and illustrated invertebrate trace fossils in 1962, in a volume of the Treatise on Invertebrate Paleontology. H.E. Reineck revisited quantification of bioturbation, a subject originally approached by Darwin. In 1963 he proposed semi quantitative categories for amounts of bioturbation in a vertical sequence of sediment.

Work in ichnology increased throughout the 1960's and 1970's and the efforts of British paleontologists Peter Crimes and James Harper, as well as American paleontologist Robert Frey, resulted in several trace fossil books that attempted to popularize the subject more amongst geologists. Ichnology in the 1980's was represented by a renaissance in vertebrate ichnology, especially with regard to dinosaur tracks and dinosaur eggs. Guiseppe Leonardi made a major contribution to vertebrate ichnology through his 1987 publication of the Glossary and Manual of Tetrapod Footprint Palaeoichnology. Quantification of bioturbation was revisited again by the work of Mary Droser and David Bottjer in the mid- to late-1980's and other marine invertebrate ichnologists, such as Richard Bromley and Tony Ekdale, began to incorporate this work into their concepts of ichnofabric analysis through the 1990's. Since then, invertebrate ichnology had matured enough that the ichnofacies concept became commonly taught in sedimentology and paleontology courses at universities worldwide. Gatherings and discussion of ichnofabric and other aspects of trace fossils have been facilitated by the Ichnofabric Workshops, which started in 1991 and have now become a biannual international event.

INTEGRATED ICHNOLOGY AND SEDIMENTOLOGY

The applicability of ichnology to the interpretation of depositional environments leads to its use in petroleum exploration. The continuing work of George Pemberton exemplified this branch of study. The importance of ichnology to the fields of stratigraphy, paleontology and sedimentology derived from the following characteristics displayed by trace fossils (Pemberton et al, 1992; Pemberton, 1998):

- Long Time Ranges - Certain trace fossils, made by similar organisms with similar behavior, have much longer time ranges than most body fossils. These trace fossils are useful as environmental indicators for broader periods of time and they are more likely encountered than some body fossils.
- Abundance - One animal, especially if mobile, can make many traces during its lifetime, whereas it may or may not have its body preserved in the fossil record. Trace fossils made by most organisms should be more abundant than body fossils of the organisms themselves.
- Common In-situ Occurrence - Unlike body fossils, trace fossils are very rarely transported out of their original substrate. In the majority of cases, trace fossils represent behavior that occurred exactly where they were found.

- Preservation Potential - Trace fossils are common in clastic sedimentary rocks that are normally lacking body fossils. This phenomenon is largely a result of poor preservation potential for body fossils in such a medium, whereas trace fossils are preserved or (in some cases) enhanced in these rocks.
- Excellent Environmental Indicators - Because behavior is often influenced by environmental factors, trace fossils provide important clues to the original conditions of ancient environments. Environmental factors reflected by trace fossils include salinity, oxygen levels, energy, organism interactions, and food supplies.

Disadvantages of trace fossils are relatively fewer than their advantages but mainly center on the fact that one trace maker can make many different traces or many different trace makers can make the same trace. Because of these considerations, most trace fossils have limited value for biostratigraphy.

Trace fossils are most commonly represented in the geologic record by features formed through animal activity in a substrate of some sort, such as sediment, rock, or wood. These features include burrows, tracks, trails, and borings. Burrows are excavations made into an unconsolidated substrate. Tracks are imprints on a sediment surface by an animal with legs.

Trails are imprints on sediment by a legless animal dragging its body across a surface. Borings are excavations made into a consolidated substrate, which could include rock or wood. Burrows, tracks, and trails are examples of biogenic sedimentary structures (structures made in an unconsolidated substrate); borings are example of bioerosion structures.

Seven ichnofacies and their distribution in some environment have been found so far. These ichnofacies, their general environmental association, and representative ichnogenera are systematically depicted on fig.1 while fig. 2 visualizes the ichnofacies and their association distributed in some environment.

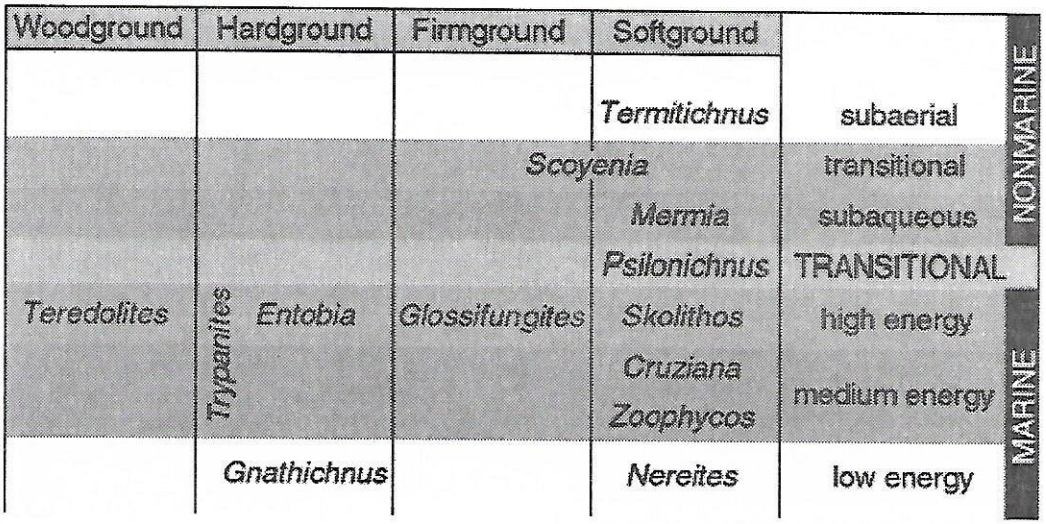


Fig. 1. Archetypical ichnofacies and their characteristic environments (adapted from Pemberton, Frey et al., 1992).

Development and refinement of the ichnofacies concept is still ongoing, especially with increased recognition of the diversity of nonmarine trace fossil assemblages (which will necessitate subdivision of the *Scoyenia* ichnofacies).

DEPOSITIONAL INTERPRETATION BY ICHNO-SEDIMENTOLOGY

The integrated ichnology and sedimentology has been applied to petroleum exploration as an aid to interpreting depositional environments. Trace fossil assemblages provide an excellent supplementary tool for facies analysis, especially when body fossils are lacking. In the case of the Parana Basin study by Buatois et al, (2001), evaluation of the ichnologic content allows to distinguish between restricted, brackish-water environments and regionally extensive fully marine settings. This study also indicates that the former fluvio-deltaic interpretation for the Rio Bonito Formation should be revised in favor of a tide-dominated estuarine model. Additionally, study of the uppermost part of the Rio Bonito Formation reveals that this interval represents a complex facies mosaic recording deposition in a lagoon environment. The overlying Palermo Formation reflects deposition in open marine, wave-dominated environments associated to a major transgression.

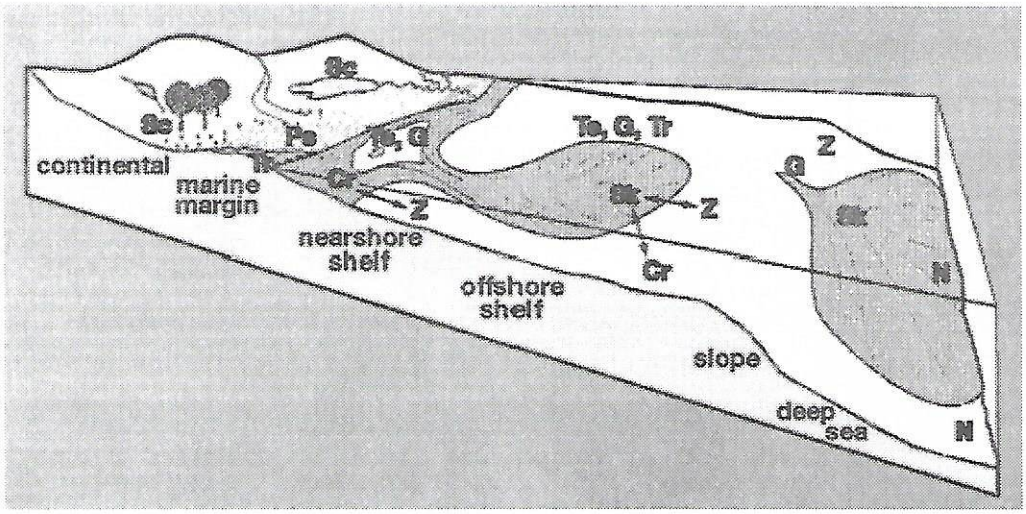


Fig. 2. Ichnofacies distribution in some environment. Sc: Scoyenia., Tr: Trypanites., Ps: Psilonichnus., Te: Teredolites., G: Glossifungites., Cr: Cruziana., Z: Zoopycos., Sk: Skolithos., N: Nereites. (Pemberton et al., 1992)

Identification of several successive suites of the *Glossifungites* ichnofacies aids in the recognition of ravinement surfaces within the lagoon complex and the open marine deposits, and points to an overall transgressive trend during deposition of the Rio Bonito and Palermo formations.

In Indonesia a contribution of ichnological data has used by Reksalegora et al, (1998). They showed how the integration of ichnology and sedimentology helped to interpret the depositional environment of Middle Miocene deposits offshore Java and contributed to the characterization of two different types of petroleum reservoirs. The integration of ichnology and sedimentology in sequence stratigraphy also allows detail correlation. The horizon of Glossifungites (Savrda, 1991a; Pemberton et al., 1992), Trypanites (Pemberton, et al., 1980), and Teredolites (Savrda, 1991) are the important bounding discontinuities and may be critical in the evolving concept of sequence stratigraphy. A promising area for future applications of ichnofacies in facies analysis is in hydrogeology and other aspects of environmental geology. Hydrogeologists often must approximate many of the same parameters (porosity, permeability, facies architecture) sought by petroleum geologists; hence ichnofacies present another important set of data for these geoscientists. While in environmental geology, the ichnology has been

applied as energy level indicator on recent sediment and applied on coastal engineering problem (Reineck, 1977).

APPLICATION ON FACIES ANALYSIS IN DELTAIC SETTING

Many authors believe that our knowledge of ancient deltaic reservoirs is still imperfect. It is an excellent opportunity to apply ichnofacies modeling on so readily in place delta like the Mahakam Delta, although ichnology has not been adequately applied yet. The study should comprise the most unique relationship between the Modern Delta setting and its equivalent Tertiary outcrops. In the modern Mahakam Delta, surface data (i.e. surface texture, bed form sedimentary structure, granulometric, type of ichnofacies, diversity and degree of ichnofacies, temperature, pH, and salinity) and shallow cores description (i.e. texture, sedimentary structures, ichnofacies types, diversity and degree of ichnofacies, stratigraphic contact, upward sequence profiles and mineral composition) are fundamental for neoichnology study. For this facies analysis study, these neoichnology data output could be analyzed along with ichnological and sedimentological data of the Tertiary outcrops. Environmental parameters in modern Mahakam Delta including temperature, pH, salinity analyses and number of ichnogenera in the Modern Mahakam Delta could be analyzed to get the relationships among ichnological data collected by depicting cross plot diagrams. With direct observation and comparison to modern pattern, deltaic setting can be uniquely identified in the stratigraphic Kutai Basin record and similar analogues can be identified. Ichnological and sedimentological data from outcrops will be analyzed along with their paleocurrent characteristics for facies modeling. The entire outcrops should be photographed for depicting detailed ichnofacies morphology and construction of a photo mosaic using the lateral profiles where the interpretations made from photo and outcrops examinations.

Distillation of Modern and Miocene Mahakam Delta data are extracted to result the deltaic facies model. This integrated ichnology and sedimentology study in Modern and Miocene Mahakam Delta is not only for detailed facies analysis and modeling but it is also provide crucial information for original environmental hazard indicator in recent Mahakam Delta.

CONCLUSION

The ichnology application has not been at maximum use despite its powerfulness as facies and stratigraphic analysis tool. Detail ichnological analysis and integrated with sedimentology could solve our imperfect knowledge of most ancient deltaic reservoirs. We have Mahakam Delta and their unique relationship with Tertiary Kutai Basin. Those are the excellent media for sedimentology and ichnology facies modeling to characterize deltaic reservoir. In Indonesia it had been used by Reksalegora et al, (1998) to help interpret depositional environment of Middle Miocene deposits offshore Java and contributed to the characterization of two different types of petroleum reservoirs.

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