BULLETIN OF CANADIAN PETROLEUM GEOLOGY
VOL. 58, NO. 2 (JUNE, 2010), P. 97–99

A historical perspective on applied ichnology in Western Canada

Murray K. Gingras
Department of Earth and Atmospheric Sciences
University of Alberta
1-26 Earth Science Building
Edmonton, AB T6G 2E3
mgingras@ualberta.ca

John-Paul Zonneveld
Department of Earth and Atmospheric Sciences
University of Alberta
Edmonton, AB T6G 2E3
Canada

James A. MacEachern
Department of Earth Sciences
Simon Fraser University
8888 University Drive
Burnaby, BC V5A 1S6
Canada

Ichnology emerges as a discipline

The study and application of ichnology, or trace fossils, have evolved substantially since trace fossils were first recognized (as such) in the late 19th century. Trace fossils were, in fact, initially interpreted as fossilized remains of marine algae (i.e. fucoids). This notion was not dispelled until A.G. Nathorst (1881) reinterpreted several fucoids — for example *Chondrites*, *Zoophycos*, and *Palaeophycus* — as the burrows of marine invertebrates. Both during the "age of fucoids" and for several decades thereafter, trace fossils were collected with the aim of determining diversities and temporal ranges of ichnofossil types, and the use of trace fossils as paleoecological indicators was not well developed. In the early part of the twentieth century, the ethologic and ecologic significance of ichnofossils was gradually recognized. In 1929, Rudolf Richter, an early leader in trace-fossil analysis, established the Senckenberg Vorschungstelle für Meeresgeologie und Meerespaläontologie at Wilhelmshaven which was later known as "Senckenberg am Meer" (Senckenberg by the Sea). The purpose of this research station was to study animal-sediment relationships in modern depositional settings, in order to apply the actualistic concepts of Lyell to the ichnological record.

An important abstraction needed to be embraced before trace fossils could be employed to aid in the identification of sedimentary environments. That is, a trace fossil represents a "behavior" employed by an animal to live in a sedimentary environment, and that the behavior is a physical response to chemical and physical depositional conditions. Conversely, ichnofossils can be used to interpret some sedimentary and chemical parameters of the depositional setting. Richter's (1928) work established this concept through the observations of modern burrowing animals in "Psychische reaktionen fossiler tiere" (free translation: Psychological reactions of fossil animals). This conceptualization made possible the modern Applied Ichnological framework we use today.

Ichnological studies along the Wadden Sea persisted for several decades after the research station's establishment, and key workers such as Walther Häntzschel, Wilhelm Schäfer, and Hans-Erich Reineck established Germany as the unchallenged leader of ichnological research and shallow-water marine sedimentology. However, no efforts have been as influential to the field of ichnology as those of Adolph Seilacher. Seilacher proposed an ethologic classification of trace fossils (1953) and, in 1964, used recurrent ethologically united suites of trace fossils (ichnofacies) to infer a link between the character of bioturbation and bathymetry. Seilacher's concepts were the first broadly accepted demonstration that trace fossils could be used to extract highly evolved interpretations of depositional conditions. Seilacher's models and interpretations propelled ichnology into the 'modern era', and they are still widely employed today.

In the 1960s and 70s, research on (modern) animal sediment interactions continued, but focused along the southeast coast of the USA. Robert Frey and James Howard led intensive efforts aimed at establishing the distribution of characteristic animal traces in marginal-marine settings. Their body of work represents a range of high-resolution ichno-sedimentological studies that still have substantial use today (e.g. Howard et al., 1972; Frey, 1973; Howard et al., 1973). This work influenced S.G. Pemberton, who applied many of Frey and Howard's characterizations and observations to Cretaceous rocks in Western Canada.

Ichnology as a tool in sedimentological analyses

Although the roots of an Applied Ichnology extend back into the 1920s, ichnological characterizations were not commonly included in sedimentological studies until the last decades of the 20th century. A key to the expansion of ichnology into standardized geological studies hinged strongly on developing a set of criteria for the identification of trace fossils in drill core. Trace fossils, after all, are formally identified on the basis of their 3-D morphology. Identifying ichnofossils from 2-D views of drill core requires determination of ichnogenera without having all of the diagnostic criteria. However, the amount of core available for research purposes expanded greatly in the 1970s, owing to increased petroleum exploration and an expanding need to understand the physical and depositional characteristics of reservoir intervals. In Canada, drill cores obtained for petroleum exploration and exploitation purposes are the property of the provincial jurisdiction in which the well was drilled (with core from wells in the northern territories under the authority of the federal government). Thus, these cores provide an ever-increasing, publically available dataset.

Additionally, the Deep Sea Drilling Project (DSDP), as well as increases in offshore oil and gas drilling, provided extensive datasets that warranted detailed scientific scrutiny. Trace fossil studies associated with the DSDP, for example, led to some of the earliest systematic identification of trace fossils from core (Ekdale, 1973; Chamberlain, 1975; Ekdale, 1977).

Evolution of the "Canadian School of Ichnology"

Given the amount of drill core available and the overall interest in understanding stratigraphic and sedimentological complexities in the Western Canadian Sedimentary Basin (WCSB), it is not surprising that Applied Ichnology blossomed in Alberta, Canada in the 1980s and 90s. Through the efforts of S.G. Pemberton (University of Alberta) and his colleagues and students, the WCSB has become one of the world's premier laboratories for testing ichnological hypotheses and developing models and applications. Among the many, now widely used applications developed in Alberta are: 1) the brackish-water ichnological model (Pemberton et al., 1982); 2) the recognition of omission suites and their application to sequence stratigraphy (MacEachern et al., 1990; MacEachern et al., 1992; Gingras et al., 2001; 2004); 3) the detailed characterization of shoreface, delta, bay and estuary deposits (Moslow and Pemberton, 1988; MacEachern and Pemberton, 1992; Gingras et al., 2002); 4) application of ichnological analysis to reservoir porosity and permeability distribution (Pemberton and Gingras, 2005); and 5) continued expansion and characterization of the ichnofacies concept. Students of the "Alberta School of Ichnology" have continued to develop a broad range of ichnological models in a broad range of strata, including delta studies (e.g. MacEachern et al., 2005; Bann et al. 2008), coarse-grained clastic shorelines (MacEachern and Hobbs, 2004; Dashtgard et al., 2008), estuaries and bays (Gingras et al., 1999; Hauck et al., 2009), mixed siliciclastic-carbonate shorelines (Zonneveld et al., 1997; Zonneveld, 2001; Zonneveld et al., 2004) and arid coastal successions (e.g. Zonneveld et al., 2001). Trace fossils have also been recognized as primary tools in assessing ecosystem health and system recovery in the aftermath of major biotic perturbations such as the end-Permian extinction (e.g. Beatty et al., 2008; Zonneveld et al., 2010) and thus are crucial tools in analyses of lower Triassic 'tight gas' successions.

The success of the Alberta work has hinged on the recognition that a high-quality sedimentological characterization is required to produce an exceptional ichnological characterization. Thus, the aforementioned work is broadly multidisciplinary. Note that as the focus of this summary is the *Applied Ichnology in Western Canada*, we have omitted some contemporaneous efforts from Europe. It is worth mentioning, however, that other workers have developed similar principles and applications using ichnofabric analysis of core (e.g. Bockelie, 1991; Taylor and Goldring, 1993; Taylor et al., 2003; McIlroy, 2004): much of that work is summarized in Taylor and Goldring (1993) and discussion of the common ground between ichnofacies and ichnofabric analyses is provided in McIlroy (2008).

Today, an "applied" ichnological characterization of core has become an almost universally expected aspect of any comprehensive study. Several centers in Canada offer high-level ichnological expertise, including (west to east) Simon Fraser University (J. MacEachern and S. Dashtgard), the University of Calgary (S. Hubbard and M. Spila), the University of Alberta (M. Gingras, S.G. Pemberton and J-P. Zonneveld) the University of Saskatchewan (L. Buatois and G. Mángano), the University of New Brunswick (R. Pickerill and D. Keighley), and Memorial University (D. McIlroy). Notably, over half of this group are former students of Dr. S.G. Pemberton to whom this volume is dedicated. The "Canadian School of Ichnology" has now reached the forefront of this rapidly developing discipline.

References

Bann, K.L., Tye, S.C., MacEachern, J.A., Fielding, C. and Jones, B.G. 2008. "Ichnological and sedimentologic signatures of mixed wave- and storm-dominated deltaic deposits; examples from the Early Permian Sydney Basin, Australia; Recent advances in models of siliciclastic shallow-marine stratigraphy". *Special Publication - Society for Sedimentary Geology,* v. 90, p. 293–332.

Beatty, T.W., Zonneveld, J-P. and Henderson, C.M. 2008. Anomalously diverse Early Triassic ichnofossil assemblages in northwest Pangea: a case for a shallow marine habitable zone. Geology 36, p. 771–774.

Bockelie, J.F. 1991. Ichnofabric mapping and interpretation of Jurassic reservoir rocks of the Norwegian North Sea: 13th International Sedimentological Congress, Ichnologic Symposium. Palaios, v. 6, no. 3, p. 206–215.

Chamberlain, C.K. 1975. Trace fossils in DSDP cores of the Pacific. Journal of Paleontology, v. 49, no. 6, p. 1074–1096.

Dashtgard, S.E., Gingras, M.K. and Pemberton, S.G. 2008. Grain-size controls on the occurrence of bioturbation. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 257, no. 1-2, p. 224–243.

Ekdale, A.A. 1973. Burrowing patterns of abyssal infauna in Deep Sea Drilling Project cores (Cretaceous to Pleistocene): a preliminary report. Abstracts with Programs - Geological Society of America*,* v. 5, no. 7, p. 609–610.

________ 1977. Abyssal trace fossils in worldwide Deep Sea Drilling Project cores: trace fossils 2. Geological Journal, Special Issue*,* no. 9, p. 163–182.

Frey, R.W. 1973. Concepts in the study of biogenic sedimentary structures. Journal of Sedimentary Petrology, v. 43, no. 1, p. 6–19.

Gingras, M.K., MacEachern, J.A. and Pickerill, R.K. 2004. Modern perspectives on the Teredolites Ichnofacies: observations from Willapa Bay, Washington. Palaios 19, p. 79–88.

________, Pemberton, S.G. and Saunders, T. 2001. Bathymetry, sediment texture and substrate cohesiveness: their impact on modern Glossifungites trace assemblages at Willapa Bay, Washington. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 169, p. 1–21.

________, ________, ________ and Clifton, H.E. 1999. The ichnology of modern and Pleistocene brackish-water deposits at Willapa Bay, Washington: variability in estuarine settings. Palaios*,* v. 14, no. 4, p. 352–374.

________, Raesaenen, M. and Ranzi, A. 2002. The significance of bioturbated inclined heterolithic stratification in the southern part of the Miocene Solimoes Formation, Rio Acre, Amazonia Brazil. Palaios 17, p. 591–601.

Hauck, T.E., Dashtgard, S.E., Pemberton, S.G. and Gingras, M.K. 2009. Brackish-water ichnological trends in a microtidal barrier island-embayment system, Kouchibouguac National Park, New Brunswick, Canada. Palaios, v. 24, no. 8, p. 478–496.

Howard, J.D., Frey, R.W. and Kingery, F.A. 1973. Physical and biogenic characteristics of sediments from outer Georgia continental shelf. The American Association of Petroleum Geologists Bulletin*,* v. 57, no. 4, p. 784.

________, ________ and Reineck, H. 1972. Georgia Coastal Region, Sapelo Island, U.S.A., sedimentology and biology: I, Introduction. Senckenbergiana Maritima, v. 4, p. 3–14.

MacEachern, J.A. and Hobbs, T.W. 2004. The ichnological expression of marine and marginal marine conglomerates and conglomeratic intervals, Cretaceous Western Interior Seaway, Alberta and northeastern British Columbia. In: Marine Conglomerate Reservoirs: Cretaceous of Western Canada and Modern Analogues – Part 2. T.F. Moslow and J-P. Zonneveld, (eds.). Bulletin of Canadian Petroleum Geology, v. 52, p. 77–104.

________ and Pemberton, S.G. 1992. Ichnological aspects of Cretaceous shoreface successions and shoreface variability in the Western Interior Seaway of North America: applications of ichnology to petroleum exploration - a core workshop. SEPM Core Workshop*,* v. 17, p. 57–84.

________, Bann, K.L., Bhattacharya, J.P. and Howell, C.D. 2005. Ichnology of deltas: organism responses to the dynamic interplay of rivers, waves, storms and tides. In: River Deltas: Concepts, Models and Examples: L. Giosan and J.P. Bhattacharya (eds.). SEPM Special Publication 83, p. 49–85.

________, Pemberton, S.G., Raychaudhuri, I. and Vossler, S.M. 1990. The *Glossifungites* Ichnofacies and discontinuity surfaces: applications to sequence stratigraphy. 13th International Sedimentological Congress: abstracts, posters. International Sedimentological Congress, v. 13, p. 140.

________, Raychaudhuri, I. and Pemberton, S.G. 1992. Stratigraphic applications of the *Glossifungites* Ichnofacies: delineating discontinuities in the rock record. In: Applications of Ichnology to Petroleum Exploration - a core workshop. S.G. Pemberton (ed.). SEPM, Core Workshop 17, p. 169–198.

McIlroy, D. 2004. Some ichnological concepts, methodologies, applications and frontiers: the application of ichnology to palaeoenvironmental and stratigraphic analysis. Geological Society Special Publications, v. 228, p. 3–27.

________, 2008. Ichnological analysis the common ground between ichnofacies workers and ichnofabric analysts: biotic-sediment interactions. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 270, no. 3-4, p. 332–338.

Moslow, T.F. and Pemberton, S.G. 1988. An integrated approach to the sedimentological analysis of some Lower Cretaceous shoreface and delta front sandstone sequences: sequences, stratigraphy, sedimentology - surface and subsurface. Memoir - Canadian Society of Petroleum Geologists*,* v. 15, p. 373–386.

Nathorst, A.G. 1881. Om spâr af evertebrerade djur m. m. oc deras paleotologiska betydelse (with abridged French translation: Mémoire sur quelques traces d'animaux sans vertèbres etc. et de leur portée paléontologique p. 61–104). Kongliga Svenska Vetenskaps-Akademiens Handlingar, v. 18, p. 1–104.

Pemberton, S.G. and Gingras, M.K. 2005. Classification and characterizations of biogenically enhanced permeability. AAPG Bulletin*,* v. 89, no. 11, p. 1493–1517.

________, Flach, P.D. and Mossop, G.D. 1982. Trace fossils from the Athabasca Oil Sands, Alberta, Canada. Science, v. 217, no. 4562, p. 825–827.

Richter, R. 1928. Psychische reaktionen fossiler tiere. Palaeobiologica, Emil Haim and Co.

Taylor, A.M. and Goldring, R. 1993. Description and analysis of bioturbation and ichnofabric: organisms and sediments - relationships and applications. Journal of the Geological Society of London, v. 150, no. 1, p. 141–148.

________, ________ and Gowland, S. 2003. Analysis and application of ichnofabrics. Earth-Science Reviews, v. 60, no. 3-4, p. 227–259.

Zonneveld, J-P. 2001. Middle Triassic biostromes from the Liard Formation, British Columbia, Canada: oldest examples from the Mesozoic of NM Pangea. Sedimentary Geology, v. 145, p. 317–341.

________, Carrelli, G.G. and Riediger, C. 2004. Sedimentology of the Upper Triassic Charlie Lake, Baldonnel and Pardonet formations from outcrop exposures in the southern Trutch region, northeastern British Columbia. In: Central Foreland NATMAP: Stratigraphic and Structural Evolution of the Cordilleran Foreland - Part 1. L.S. Lane (ed.). Bulletin of Canadian Petroleum Geology, v. 52. P. 343–375

________, Gingras, M.K. and Beatty, T.W. 2010. Diverse ichnofossil assemblages from the Lower Triassic of northeastern British Columbia: evidence for shallow marine refugia on the northwestern coast of Pangaea. Palaios, v. 25, p. 368–392.

________, ________ and Pemberton, S.G. 2001. Depositional framework and trace fossil assemblages in a mixed siliciclastic-carbonate marginal marine depositional system, Middle Triassic, NE British Columbia. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 166, p. 249–276.

________, Moslow, T.F. and Henderson, C.M., 1997. Lithofacies associations and depositional environments in a mixed siliciclastic-carbonate depositional system, upper Liard Formation, Triassic, northeastern British Columbia. Bulletin of Canadian Petroleum Geology, v. 45, p. 553–575.