Trace Fossils - A Different View of the Rocks

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Introduction

The study of fossilized tracks, trails, tubes and burrows associated with organisms that burrow into and live in, or near the bottom deposits of an ocean is called Ichnology. First studies of trace fossils date from 1823 to 1881 when they were originally assigned to the plant kingdom as fossil algae, "fucoids" (Osgood, 1975). During those early examinations, the gross morphology of the "fucoids" was thought to resemble plants thus supporting the assignment. In 1880, evaluation of previous work raised questions of validity. Many "fucoids" were determined to be traces of invertebrate activity and others were sedimentary structures. Discussions continued to 1927, when "fucoids" were disproved and the study of trace fossils all but ceased. Little progress was made in the study of trace fossils from 1927 to 1960. Three reasons are cited for this lack of progress: 1) problems related to taxonomy (the classification of organisms), 2) there was no statement as to the value of trace fossil studies to paleontology, zoology, and sedimentology, and 3) there was limited interest by sedimentologists and paleontologists in paleoecology (the interaction between ancient organisms and their environment) and the use of trace fossils to help determine past environments. Since that time a classification of trace fossils has been developed using sedimentological and behavior methods. Trace fossils have proven useful in many aspects of geology including facies analysis, animal behavior, and morphology. This paper is intended to be an introduction to trace fossils, not an extensive report with all the details.

Trace Fossils versus Body Fossils

Trace fossils represent behavior or activity by organisms rather than the actual body parts of the organism itself (Frey, 1975). Trace fossils ("facies fossils") are significantly different from body fossils in that they extend over longer periods of time and have more restricted geographical distribution. Particular assemblages of trace fossils reflect particular environments of deposition thus making them very useful for environmental reconstruction and extending those environments to strata of significantly different ages. The traces are not necessarily formed penecontemporaneously with sedimentation, their presence indicating the sediment had become more stable allowing for mobile feeders. The abundance of different types of trace fossils appears to be linked with energy conditions at the time of sedimentation (larger diversity is associated with quieter waters).

Body fossils comprise the primary record of ancient life. Trace fossils record the expression of that life. Soft-bodied organisms are primarily represented by traces. Traces include:

1) Tracks — impressions left by a moving individual's appendage (walking or running);
2) Trails — continuous groove produced during locomotion (sliding or slithering);
3) Burrows — more or less permanent structures excavated within the sediment; and,
4) Bioerosion structures — organisms mechanically or biochemically boring into a rigid substrate (Angulo and Buatois, 2009).

There is a great deal of difficulty in relating the traces back to the trace maker. The trace maker is rarely, if ever, found in or near the trace. Understanding is gained by interpreting the behavior that led to the formation of the trace, was it resting, crawling, grazing, feeding, dwelling, or escaping. These behavioral responses may also be related to environmental changes in salinity, oxygenation, temperature and water turbidity (Gingras et al. 2009). Features that indicate the environmental changes listed above include:

1) Unburrowed – indicator of fresh water
2) Distribution of the types of traces
3) Size of the trace – for example, the size of the trace in a marine environment would be an indicator of oxygen content and food supplies; small traces might indicate a stress environment; and high diversity would result from abundant food, oxygen, and normal salinities.

This leads to a simple, practical classification based on the morphology of their trace (fig. 1). There is not a direct correlation between ichnofacies and depositional environments; instead they represent a set of environmental factors (Angulo and Buatois, 2009). These can be split into 4 main categories (fig.2):

1) Softground marine - *Psilonichus*, *Skolithos*, *Cruziana*, *Zoophycos*, *Nereities*
2) Substrate-controlled – *Glossifungites*, *Trypanites*, *Teredollites*
3) Continental invertebrate
4) Vertebrate

Subsurface studies in the Williston Basin focus on the top two categories, the softground marine and the substrate controlled. These are the traces that are encountered when working with cores from the basin (fig. 3).

Ichnofabric Analysis

Ichnofacies analysis starts by determining the discrete and the poorly defined traces in cross-section view. Emphasis is placed on cross-cutting relationships. This view allows for tiering, where there is a vertical partitioning of the habitat due to changes in the environment including physical, chemical, and biological parameters (Angulo and Buatois, 2009). There are three factors that are the most important in controlling tiering. The first changes the consistency of the sediment by compaction due to vertical accretion and progressive burial and dewatering. The second relies on the abundance of organic matter. The greatest amount of organic matter is at the sediment-water interface. The number of organisms present can be directly related to the abundance of food. The number of feeders decreases away from the food source. The third factor shows a similar trend regarding the oxygen content of the sediment. Sorting all of the trace fossils into a tiering structure can be difficult especially in areas of intense bioturbation.

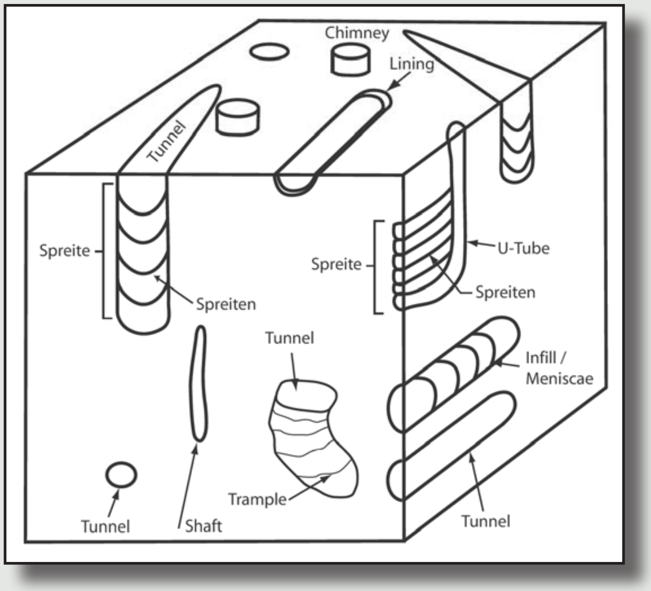


Figure 1. Three dimensional diagram displaying morphological classification of burrows and their associated names (from Gingras et al. 2009)

To assist in the analysis of trace fossils, the degree of bioturbation is assigned a number (bioturbation index) that represents the percent of the sediment that is disturbed (table 1, fig. 4). This can be plotted visually alongside the tiering diagram and other parts of the analysis to aid in the determination of the sedimentary environments (fig. 5).

A collection of the information can then be used to determine the sedimentary environment. Gingras et al. (2009) developed a flow chart (fig. 6) that aids in the interpretation of common bioturbate textures.

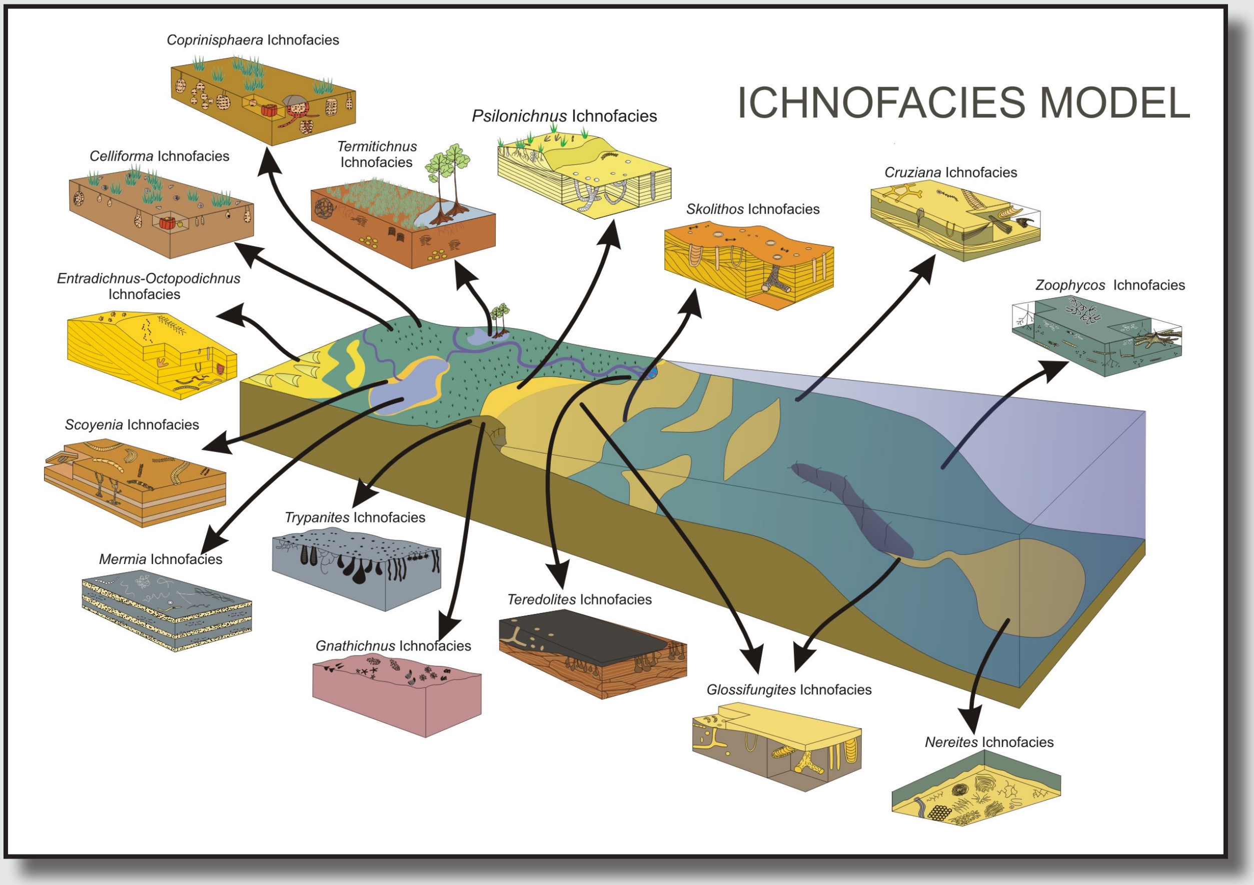
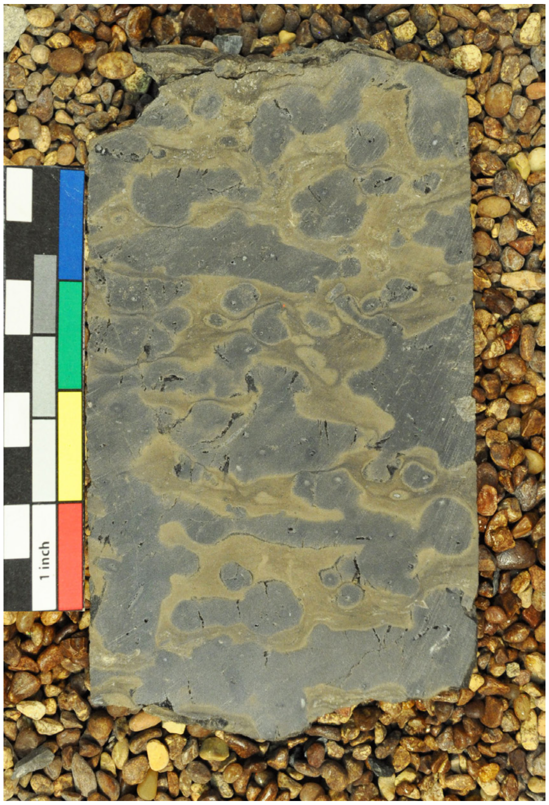


Figure 2. Ichnofauna model of the soft-ground and substrate controlled trace fossil assemblages and how they relate to marine environment. Each is comprised of a series of traces that reflect environmental factors which, in association with sedimentary and hard body fossils, assist in the determination of the sedimentary environment. Diagram from Angulo and Buatois (2011).



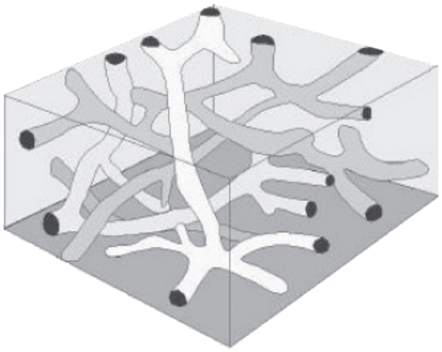
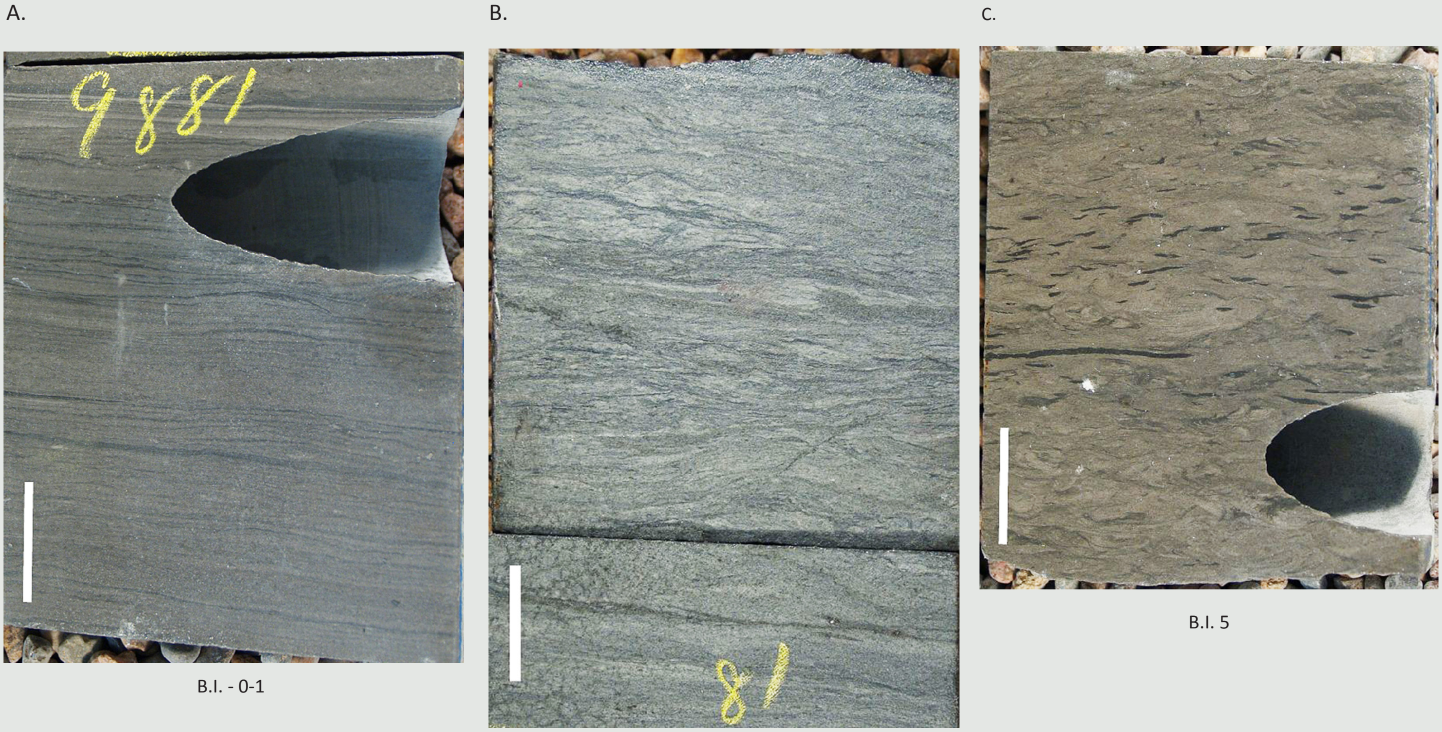


Figure 3. Example of *Thalassinoides* burrows from the Ordovician Red River Formation from the Terra Resources, Inc. – BNRR #1-17 (NWSW Sec. 17, T145N., R103W; API: 33-053-00955-0000; depth 12,963.1 ft) well with an diagrammatic 3D representation of the boxwork of the burrows. Preferential dolomitization of the burrow over the rock matrix causes the burrows to standout. It also comprises the reservoir for the formation. Diagram from Gerard and Bromley (2008).



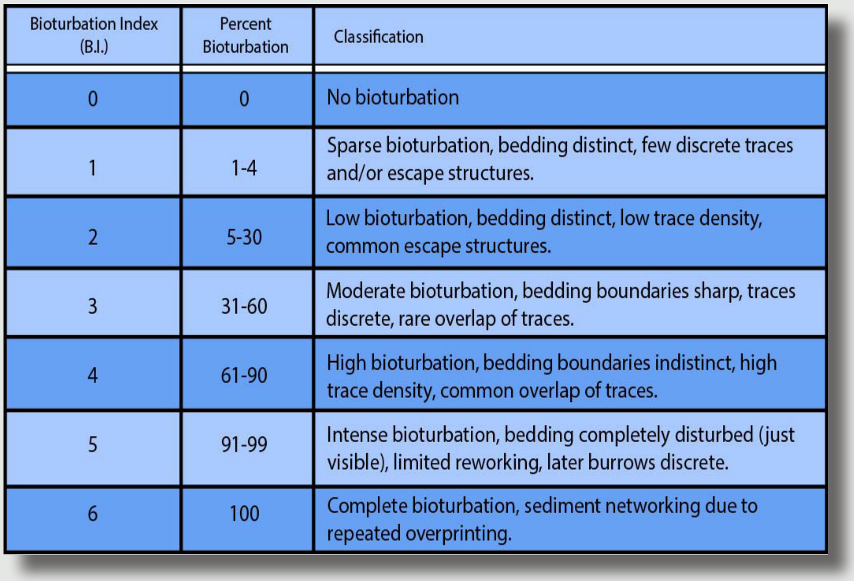
B.I. - 0-1

B.I. 3

B.I. 5

Figure 4. Examples of variations in Bioturbation Index within the Middle Member of the Bakken Formation in North Dakota. A and C are from the Whiting Oil and Gas Corp. – Braaflat #11-11H (NWNW Sec. 11, T153N, R91W; API #33-061-00641-0000; depths – 9,881 ft and 9,901 ft). The core sample that is shown in B is from the EOG Resources, Inc. – Fertile #1-12H (SESE Sec. 12, T151N, R90W; API #33-061-00557-0000; depth – 9,382 ft). Core sample A has limited burrowing with laminations that are virtually undisturbed. Core sample B is moderately bioturbated while still retaining some of the original laminations. Core sample C is extensively bioturbated. All of the sediment has been displaced by the burrows. Scale bar in white is one inch.

Table 1. Criteria for the determination of the Bioturbation Index. See Figure 4 for the visual display of this type of data.



Bioturbation Index (B.I.)	Percent Bioturbation	Classification
0	0	No bioturbation
1	1-4	Sparse bioturbation, bedding distinct, few discrete traces and/or escape structures.
2	5-30	Low bioturbation, bedding distinct, low trace density, common escape structures.
3	31-60	Moderate bioturbation, bedding boundaries sharp, traces discrete, rare overlap of traces.
4	61-90	High bioturbation, bedding boundaries indistinct, high trace density, common overlap of traces.
5	91-99	Intense bioturbation, bedding completely disturbed (just visible), limited reworking, later burrows discrete.
6	100	Complete bioturbation, sediment networking due to repeated overprinting.

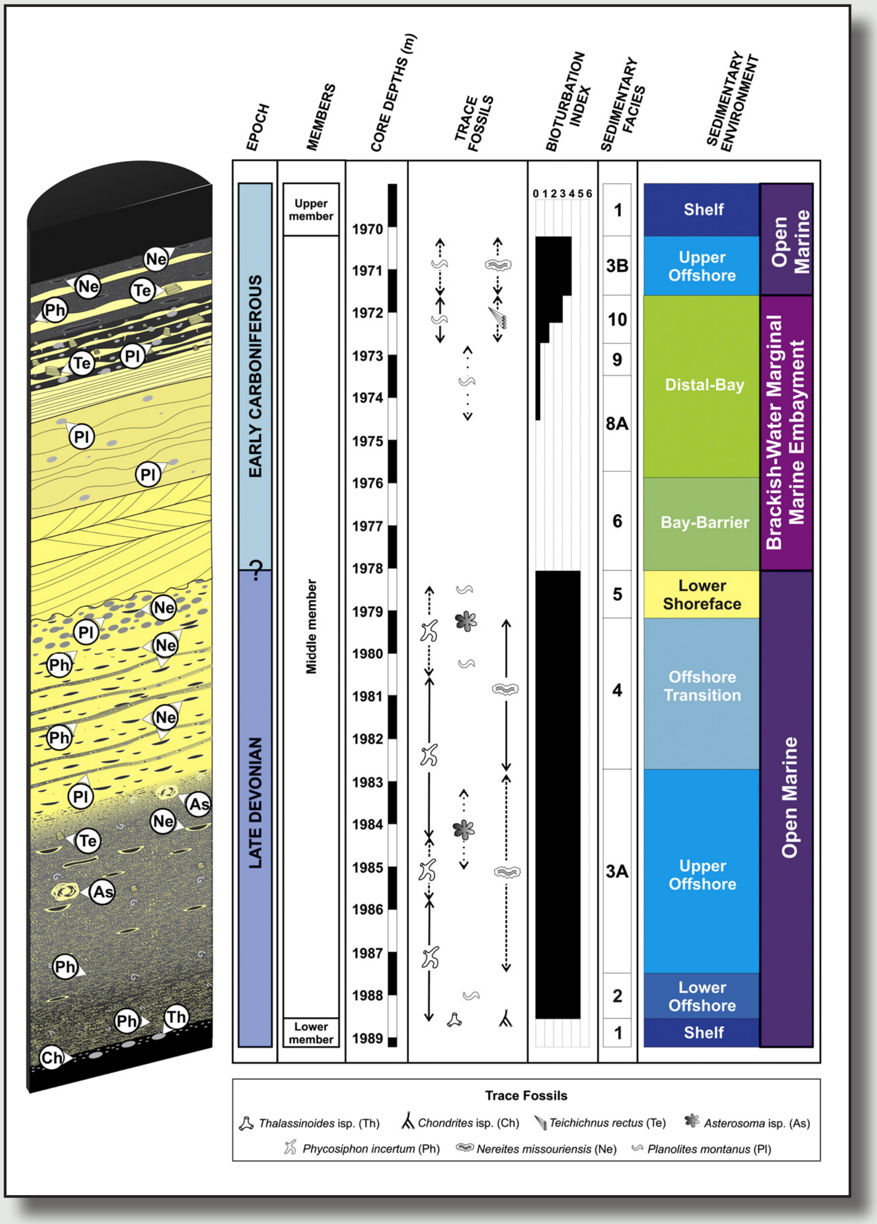


Figure 5. Example of a core log from Bakken well 15-31-03-11W2 showing the result of applying the ichnofabric approach. Illustration on the left represents the described core displaying the burrows and sedimentary structures. This is followed by the age, nomenclature, depth, bioturbation index, and ultimately the sedimentary facies and environments. Diagram from Angulo and Buatois, 2012.

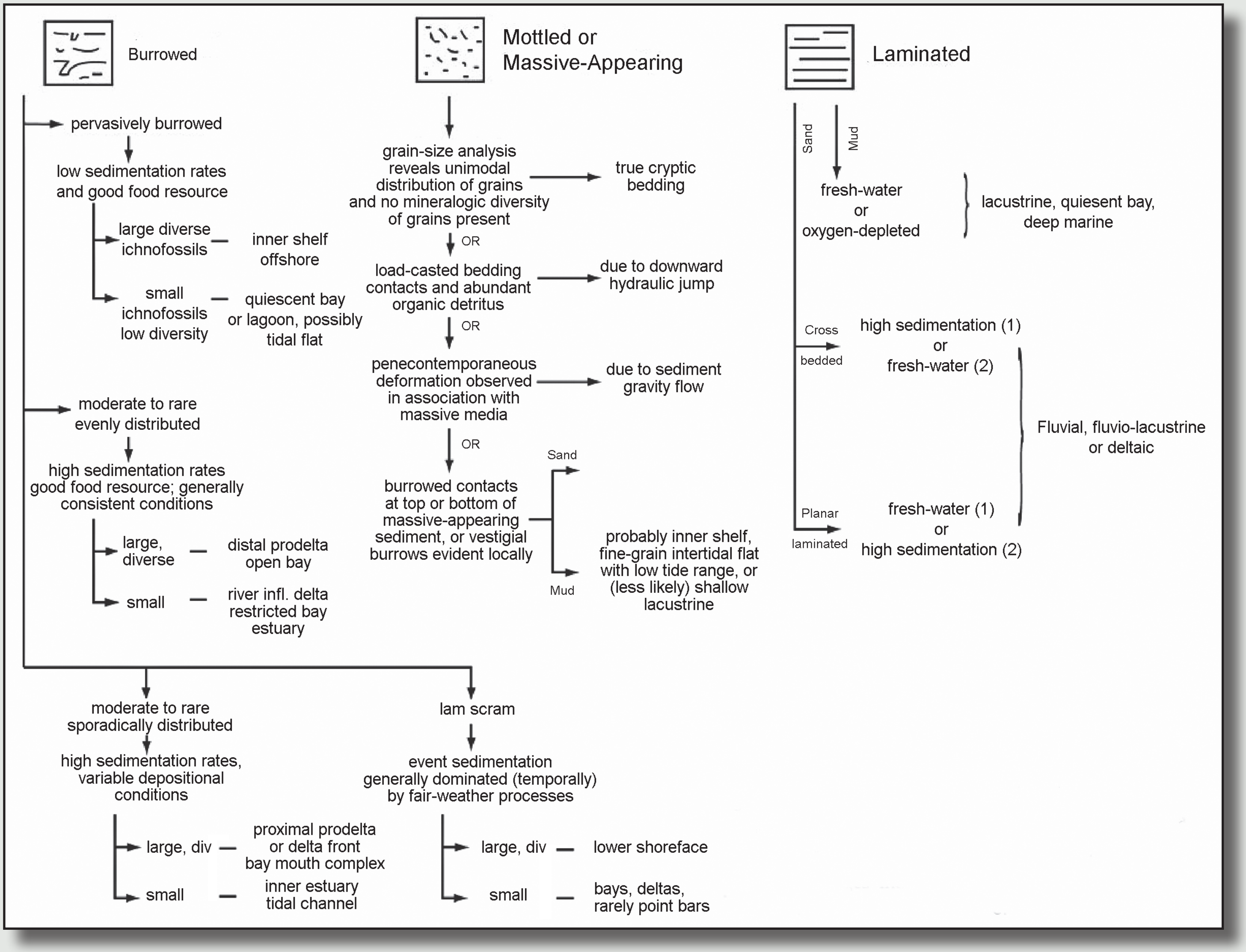


Figure 6. Flow chart developed by Gingras et al. (2009) demonstrating the process of interpreting ichnological fabrics.

Conclusions

Trace fossils are an additional tool that assists the geologist in determining the environment of deposition. Multiple factors contribute to the absence or abundance of trace fossils in the rocks. Attention to detail, in addition with hard body fossils and sedimentary structures, add to our knowledge of past environments.

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