Ichnofacies and Facies Interpretation

ROLAND GOLDRING
Postgraduate Research Institute for Sedimentology, University of Reading, Whiteknights, P.O. Box 227, Reading, RG6 2AB, U.K.

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The use of archetypal ichnofacies in facies interpretation is criticized because it does not provide the resolution that can be obtained by using traditional methods of paleoecological analysis: analyzing the autecology and then moving to the synecology (including the ichnofabric) and synthesis.

It is eleven years since Byers (1982) gave a critical assessment of the ichnofacies concept (Seilacher, 1954, 1964, 1967; Frey and Seilacher, 1980; Pemberton et al., 1992). Perhaps the most important question that Byers posed was "Has the (ichnofacies) model reached the limits of its resolution?" Though Bromley (1990) expects the number of ichnofacies to increase there are still less than 10 archetypal ichnofacies; a fraction of the number of sedimentary facies that have been described. The original depth-controlled, or depth-related, factors for marine ichnofacies have long since gone and given way to an appreciation that ichnofacies relate to many ecological factors (Frey and Seilacher, 1980; Frey et al., 1989; Bromley, 1990; Pemberton et al., 1992). While the bathymetric model has been superceded, relative bathymetry is still most important in facies interpretation since coarsening-up and fining-up trends are frequently involved. There are two broad groups of archetypal ichnofacies: those related to substrate consistency (including *Trypanites* and *Teredolites* ichnofacies, and which are essentially surfaces) and those under wider ecological control and associated with soft substrates (including *Cruziana* and *Nereites* ichnofacies). It is particularly the latter group that concerns facies interpretation since this accounts for the bulk of the stratigraphy. Publication of the English-language papers on the ichnofacies concept (Seilacher, 1964, 1967) more or less coincided with publication of Ager's (1963) classic text *Principles of Paleoecology*. This explains why Ager included his entire discussion on trace fossils in chapters on autecology.

But what information do sedimentologists hope to obtain from studies of trace fossils? (1) Any information that will aid in the environmental interpretation of sedimentary facies to as specific a degree as possible (including chemical and hydraulic factors and wave climate), together with information relating to the nature of the original substrate and diagenetic changes that have occurred during burial history, (2) information relating to sedimentational history (basin analysis, sedimentation and erosion rates), stratigraphic correlation, and (3) information relating to porosity, permeability. Such information is best obtained by analyzing and assessing the ichnology with the sedimentology and paleontology: by integrating all aspects of the facies and its diagenesis. Ichnological analysis involves the standard methodology of autecology followed by synecology and synthesis as outlined by Ager (1963, following earlier literature), and includes analysis of the ichnofabric (Ekdale and Bromley, 1983; Taylor and Goldring, 1993) and the ordering and tiering of the trace fossils. Ichnofabrics result from all aspects of the texture and internal structure of a sediment that results from bioturbation at all scales (see Ekdale, 1992). They include the mottlings (biodeformational structures) as well as discrete and elite trace fossils. It is often useful to be able to indicate a grade of bioturbation, a Bioturbation Index (BI), at any early stage of analysis. Taylor and Goldring (1993) reviewed existing schemes and their drawbacks and introduced ichnofabric constituent diagrams to aid distinguishing between different ichnofabrics.

The resolution of the archetypal ichnofacies (an extraction of the facies) is insufficient for the fine resolution required today. Interpretation of the ichnology of deltaic, estuarine and lagoonal sediments (all important in facies analysis) is not readily resolved since these environments do not fall readily into the ichnofacies scheme. Ekdale (1988) mentions that not all sedimentary environments might be distinguished by trace fossils. But in an integrated study every trace fossil can help in facies interpretation. The ichnofacies concept is seriously flawed in respect of facies interpretation. Besides resolution being quite insufficient for modern studies the concept suggests that facies interpretation can be accomplished without first making autecological analysis.

The sedimentological value of the *Zoophycos* ichnofacies is still enigmatic (Ekdale, 1992). Attempts to resolve the question of the primary sedimentary structures and other trace fossils associated with *Zoophycos* have not resulted in any way that is significantly useful in facies interpretation. This is aggravated by the apparent change in facies of *Zoophycos* over geological time (Bottjer et al., 1987, 1988). For facies interpretation the *Zoophycos* ichnofacies is further confused by Wetzel (1991, p. 65) who describes deep tier occurrences of *Zoophycos* as *Zoophycos* ichnofacies in a situation where shallow tier *Nereites* and associated traces have been removed by erosion: a taphonomic accident. The *Zoophy-*

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cos ichnofacies (the black sheep of the family—Bromley, 1990) is best dispensed with and each occurrence of *Zoophycos* analyzed with its associated sediments and fossils. This, of course, leaves a "gap" between the *Cruziana* ichnofacies (shelf environments) and the *Nereites* ichnofacies (deep-water environments). Brackish water trace fossils (Pemberton et al., 1992) are linked together as a mixture of structures typical of both the *Skolithos* and *Cruziana* ichnofacies. This may be satisfactory in a general interpretation but closer inspection may show thin marine intercalations, or brief records of shore facies.

The most important environmental boundary is that separating the marine from the non-marine. The *Scoyenia* ichnofacies was proposed by Seilacher (1967), formalizing earlier work (Seilacher, 1963), as an attempt to discriminate between marine and non-marine trace fossil assemblages. This early generalization is gradually being resolved, and, for instance, Pollard (1988; see also Goldring, 1991, fig. 6.24) has refined the model distinguishing between the trace fossils associated with fluvial channel/levee, crevasse splay, alluvial plain and flood basin lake environments. Bromley and Asgaard (1991) rejected the salinity factor and proposed that non-marine ichnotaxa be redistributed amongst the marine ichnofacies according to their ethology. Of course, the shoreline may be difficult to define, especially in tidal environments, and in estuaries the salinity gradient may be more useful.

Bromley and Asgaard (1991) also proposed the Arenicolites ichnofacies (not italicized because *Arenicolites* does not have to be present) for opportunistic occurrences of *Skolithos* in storm deposits. Frey and Goldring (1992) criticized this because, (1) all previous ichnofacies have been named on the basis of a representative ichnogenus and *Arenicolites* in general is hardly known as an indicator of opportunistic colonization, and (2) it ignores the considerable variation and diversity of ichnofossils known to occur in hummocky beds (Frey, 1990).

There are many minor difficulties in using the archetypal ichnofacies in facies interpretation, including assessing the role of facies-crossing ichnotaxa, many of which have now been shown, when analyzed by traditional methodology to be of significant use. Freeing ichnotaxa from their confined associations with ichnofacies allows us to take greater advantage of the information about ancient environments they carry; for instance, *Chondrites* (and *Planolites*) as an oxygenation indicator (Savrda and Bottjer, 1991; Bottjer and Savrda, 1993), and *Planolites* in distinguishing the several ichnofabrics with *Ophiomorpha nodosa* (Pollard et al., 1993).

As Byers (1982) noted, not all authors have seen their ichnotaxa distributions in terms of Seilacherian ichnofacies, preferring to look for solutions from examination of all ecological factors. In recent years this indeed seems to be the case for the majority of ichnological studies. As there are many sedimentary depositional environments and facies sequences, so there are far more associations of trace fossils that are useful in facies interpretation than in the "limited number" (Pemberton et al., 1992) of archetypal ichnofacies.

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