THE USE OF TRACE FOSSILS IN DELINEATING AND INTERPRETING STRATIGRAPHIC DISCONTINUITIES

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Abstract: Trace fossils represent both sedimentological and palaeontological entities and as such, represent a unique blending of potential environmental indicators in the rock record. Trace fossils and trace fossil suites can be employed effectively to aid in the recognition of various discontinuity types and to assist in their genetic interpretations. Ichnology may be employed to resolve surfaces of stratigraphic significance in two main ways: 1) through the identification of discontinuities using substrate-controlled ichnofacies (*i.e.*, the firmground *Glossifungites* ichnofacies, the hardground *Trypanites* ichnofacies, and the woodground *Teredolites* ichnofacies), and 2) through careful analysis of vertical softground (penecontemporaneous) ichnologic successions (analogous to facies successions). Integrating the data derived from substrate-controlled ichnofacies (so-called omission suites) with palaeoecological data from vertically and laterally juxtaposed softground ichnological successions greatly enhances the recognition and interpretation of a wide variety of potentially significant stratigraphic surfaces.

INTRODUCTION

The importance of ichnology to the fields to stratigraphy, palaeontology, and sedimentology stems from the following characteristics displayed by trace fossils: (1) long temporal range - although a disadvantage in high-resolution biostratigraphy, it greatly facilitates palaeoecological comparisons of rocks differing in age; (2) narrow facies range - reflects similar responses by trace-making organisms to given sets of palaeoecological parameters; (3) little or no secondary displacement - biogenic sedimentary structures, where preserved intact, are closely related to the environment in which they were formed; (4) occurrence in otherwise unfossiliferous rocks - trace fossils are commonly enhanced by the very diagenetic processes that typically obliterate tests and shells, especially in siliciclastics; (5) creation by non-preservable soft-bodied biota - many trace fossils are formed by the activities of organisms that generally are not preserved because they lack hard parts ; such organisms, in many environments, represent the bulk of the biomass; (6) a particular structure may be produced by the work of two or more different organisms living together, or in succession, within the structure; (7) the same individual or species of organism may produce different structures corresponding to different behavior patterns; (8) the same individual may produce different structures corresponding to identical behavior but in different substrates (*e.g.* in sand, in clay, or at sand-clay interfaces); and (9) identical structures may be produced by the activity of systematically different trace-making

organisms, where behavior is similar (Ekdale *et al.*, l984). Such characteristics are very useful in facies analyses, including reconstruction of individual palaeoecological factors, sedimentary dynamics, and the documentation of local and regional temporal facies changes.

Trace fossil assemblages can be employed effectively to aid in the recognition of various discontinuity types, as well as to assist in their genetic interpretations. Ichnology can be utilized to resolve surfaces that may have stratigraphic significance in two main ways: 1) through the identification of discontinuities using substrate-controlled ichnofacies, and 2) through careful analysis of vertical softground (penecontemporaneous) ichnologic successions (accomplished by using either ichnofacies or ichnofabric analysis).

Though ichnological analysis is a valuable tool, it continues to remain highly under-utilized in most sedimentologically driven genetic stratigraphic studies. Integrating the data derived from substrate-controlled, omission-related ichnofacies with palaeoecological data from vertical ichnologic successions facilitates the recognition and interpretation of a wide variety of stratigraphically important surface types.

Trace fossils have proven to be one of the most important groups of fossils in assisting in the delineation of stratigraphically important boundaries related to genetic stratigraphy (*e.g.*, MacEachern *et al.*, 1991; 1992a,b; 1998; 1999a,b; Savrda, 1991a,b; Pemberton *et al.*, 1992a; Taylor and Gawthorpe, 1993; Pemberton and MacEachern, 1995; Savrda, 1995; Ghibaudo *et al.*, 1996; MacEachern and Burton, 2000; Savrda *et al.*, 2001; Pemberton, *et al.*, 2002; Taylor *et al.*, 2003; Pemberton *et al.*, in press). Genetic stratigraphy lies at the core of three main stratigraphic paradigms: genetic stratigraphic sequences (Galloway, 1989a,b), allostratigraphy (Walker and James, 1992), and sequence stratigraphy (Van Wagoner *et al.*, 1990). The recognition of stratigraphic breaks is essential in any genetic stratigraphic paradigm, but also, is commonly a difficult task, particularly in subsurface analysis. Interpreting the origin of the discontinuity, essential to sequence stratigraphy and to genetic stratigraphic sequences, is also vital in resolving the depositional environments of associated deposits, and in determining the allocyclic controls on the depositional systems. To accomplish this requires the integration of ichnofacies relationships (see Pemberton *et al.*, 2002) or ichnofabric analysis (see Taylor *et al.*, 2003), physical sedimentology and sequence stratigraphic techniques. Ichnofacies and reconstructed ichnocoenoses are part of the total aspect of the rock, imparted by the depositional environment and therefore, like lithofacies, are subject to Walther's Law. For example, isolated bored shells or clasts do not, in themselves, constitute the *Trypanites* ichnofacies. Rather, there must be some semblance of stratification, lateral continuity, and/or vertical succession before an ichnofacies can be applied.

SUBSTRATE-CONTROLLED ICHNOFACIES AND THE RECOGNITION OF STRATIGRAPHIC DISCONTINUITIES: THE USE OF OMISSION SUITES

One of the most important factors in the distribution of organisms in modern environments is substrate

type. In their recent review, Taylor *et al* (2003) summarized the different substrate types (Fig. 1) as: soupground (water-saturated mudrocks and micrites), softgrounds (muddy and micritic sediment with some dewatering); loosegrounds (sandy sediments where permanent burrows require stabilized margins); stiffground (stabilized sediment where burrows are unlined); firmground (firm, dewatered, commonly compacted sediment); and hardgrounds (lithified substrate surface; variations can be shellground, a cemented shell bed; and rockground, with tectonic omission.

discontinuities. Determining whether these discontinuities are autocyclically generated, or allocyclically generated and hence stratigraphically important, is considerably more problematic.

Substrate-controlled ichnocoenoses typically crosscut the pre-existing softground suites and, hence, reflect conditions that post-date both the initial deposition of the unit and the erosion of that unit. These omission suites actually correspond to the period of time between the erosional event (which exhumes the substrate) and final burial of the discontinuity beyond reach of the benthic

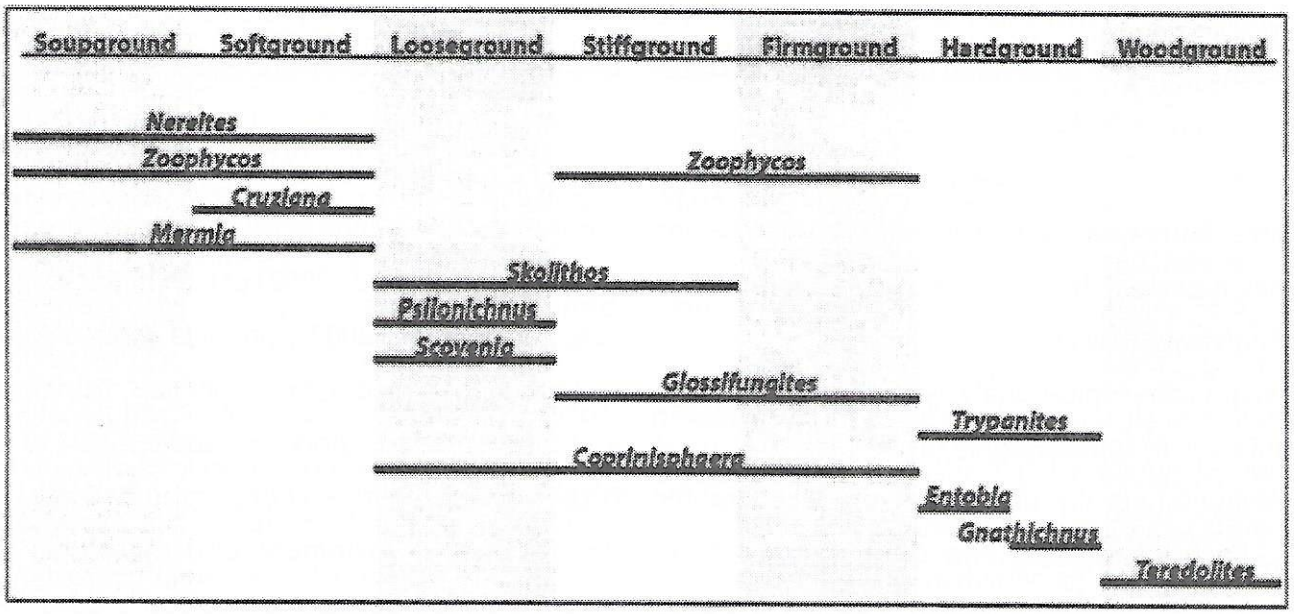


Figure 1: Relationship of substrate type and the distriction of the named ichnofacies.

To this list could also be added woodgrounds (xylic substrates) and the closely related log-grounds (substrates composed of distinct logs; see Bromley *et al.*, 1984; Savrda *et al.*, 1993). Three substrate-controlled ichnofacies have been established (Ekdale *et al.*, 1984): *Glossifungites* (firmground), *Trypanites* (hardground), and *Teredolites* (woodground). In clastic settings, most of these trace assemblages are associated with erosionally exhumed (dewatered and compacted or cemented) substrates, and hence, correspond to erosional

community of the overlying unit. During this hiatus, infaunal organisms are free to colonize those substrates, the specific characteristics of which are determined by the nature of the substrate, and the paleoenvironmental conditions prevailing during the hiatus. By observing (a) the underlying and cross-cut softground trace fossil suite (contemporaneous with deposition of the underlying unit), (b) the omission suite and ichnofacies associated with the exhumed substrate itself, and (c) the ichnocoenosis of the overlying

unit, it is possible to make some interpretation regarding the origin of the discontinuity, and the allocyclic or autocyclic mechanisms responsible.

The Trypanites *ichnofacies*

The *Trypanites* ichnofacies (Fig.2A) develops in fully lithified substrates such as hardgrounds, reefs, rocky coasts, beachrock and other omission surfaces (Pemberton *et al.*, 1980; Gryszeynski, 1986, 1998). As such, development of this ichnofacies also corresponds to discontinuities that have major sequence stratigraphic significance. Bromley and Asgaard (1993) subdivided the *Trypanites* ichnofacies into two ichnofacies; the *Entobia* ichnofacies for rocky shorelines (also see De Gilbert *et al.*, 1998) and the *Gnathichnus* ichnofacies for bored shells and boulders found further offshore. Bored shells and boulders, however, are not substrates that can be correlated because it is difficult to ascertain when the boring activity was initiated.

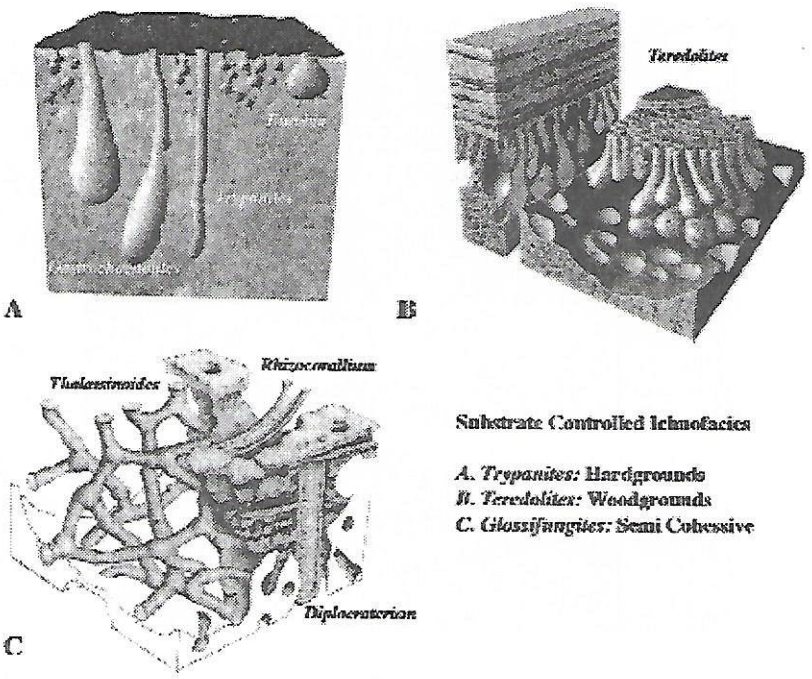


Figure 2: Substrate controlled ichnofacies; A. The Trypanites ichnofacies is indicative of fully cemented substrates like hardgrounds, disconformities, and beachrock; B. The Teredolites ichnofacies is indicative of a woodground like a peat deposit; and C. The Glossifungites ichnofacies is indicative of semi cohesive substrates like dewatered muds or compacted sands (Modified from Pemberton et al., 2002).

The traces in the *Trypanites* ichnofacies (Fig. 3A) are characterized by: (1) cylindrical to vase, tear- or U-shaped to irregular domiciles of suspension feeders or passive carnivores; (2) raspings and gnawings of algal grazers and similar organisms (mainly chitons, limpets, and echinoids); (3) moderately low diversity, although the borings and scrapings of individual ichnogenera may be abundant; and (4) borings oriented perpendicular to the substrate which may include large numbers of overhangs. In contrast to the *Glossifungites* ichnofacies, the walls of the borings cut *through* hard portions of the substrate rather than skirting around them.

The Teredolites *ichnofacies*

The *Teredolites* ichnofacies (Fig. 2B) consists of a characteristic assemblage of borings or burrows in woody or highly carbonaceous substrates. Woodgrounds differ from lithic substrates in three main ways: (1) they may be flexible instead of rigid; (2) they are composed of carbonaceous material instead of mineral matter; and (3) they are readily biodegradable (Bromley *et al.*, 1984). Such differences dictate that the means by which, as well as the reasons for which these two types of substrates are penetrated are also different. Since currents can raft woody substrates, it is important to determine whether the borings are autochthonous or allochthonous.

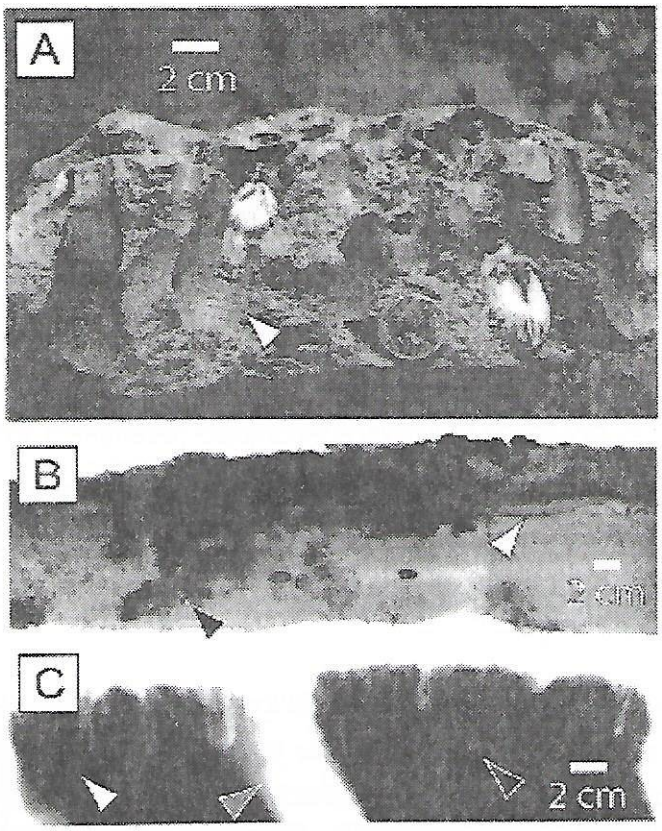


Figure 3: Substrate controlled assemblages; A. Modern Trypanites ichnofacies, Bay of Fundy, New Brunswick; Arrow shows Gastrochaenolites clavatus with bioglyphs. The trace maker is the bivalve Zirfea pslsbyri; B. Modern Teredolites ichnofacies, a bored Douglas Fir, Willapa Bay, Washington; white arrow points to a teredinid (Bankia sp.) and the black arrow points to encrusting barnacles (Balanus sp.); and C. Modern Glossifungites ichnofacies from a bored firmground in Willapa Bay, Washington. X-radiograph of the surface shows Arenicolites made by the amphipod Corophium (white arrow), Diplocraterion (spreite not visible) made by the polychaete Polydora (black arrow), and the top of a Thalassinoides system made by the mud shrimp Upogebia (gray arrow).

Only the autochthonous elements are true members of the *Teredolites* ichnofacies. These assemblages may also be important in defining sequence and parasequence boundaries (*e.g.* Savrda, 1991a). Although Savrda *et al.*, 1993 has successfully demonstrated a strong association between transgressive deposits and the occurrence of marine-bored wood clast accumulations the use of log grounds should be avoided, because it is very difficult to ascertain when the logs were bored. Such logs are clasts and should not be treated in the same manner as the *Teredolites* ichnofacies *sensu stricto.*

The *Teredolites* ichnofacies (Fig. 3B) is characterized by: (1) sparse to profuse, club-shaped borings; (2) boring walls that are generally ornamented with the texture of the host substrate (*i.e.* tree ring impressions and other xyloglyphs); (3) stumpy to elongate subcylindrical excavations in marine or marginal marine settings; and (4) shallower, sparse to profuse nonclavate etchings (isopod borings) in freshwater settings.

The Glossifungites *ichnofacies*

The *Glossifungites* ichnofacies is environmentally wide ranging, but only develops in firm, unlithified substrates such as dewatered muds or highly compacted sands. Dewatering typically results from burial and the substrates are made available to trace-makers if exhumed by later erosion (*e.g.*, Pemberton and Frey, 1985). Exhumation can occur in terrestrial environments, as a result of channel meandering or valley incision, in shallow-water environments as a result of meandering tidal channels, tidal scour erosion, erosive shoreface retreat associated with wave ravinement, or as a result of submarine channels cutting through previously deposited sediments. Such exhumed surfaces commonly correspond to stratigraphic discontinuities, and the specific characteristics of their colonization are critical to their sequence stratigraphic interpretation

(Saunders and Pemberton, 1986; MacEachern et al., 1992a; Pemberton et al., 1992; Pemberton and MacEachern, 1995; MacEachern et al., 1998, 1999a,b; MacEachern and Burton, 2000; Pemberton et al., 2002; Taylor et al., 2003; Pemberton et al., in press).

The Glossifungites ichnofacies (Fig. 2C) is characterized by: (1) vertical, cylindrical, U- or tear-shaped (Fig. 3C), commonly scratch-marked burrows and sparsely to densely branching dwelling burrows; (2) protrusive spreiten in some burrows that develop mostly through animal growth (funnel-shaped Rhizocorallium and Diplocraterion [formerly Glossifungites]); (3) animals that leave the burrow to feed (e.g. crabs) as well as suspension feeders; and (4) low diversity, but commonly abundant individual structures.

Firmground traces are dominated by vertical to subvertical dwelling structures of suspension feeding organisms (Fig.4). The most common structures correspond to the ichnogenera Diplocraterion, Skolithos, Psilonichnus, Arenicolites, and unnamed flask-shaped domichnia comparable to Gastrochaenolites. Dwelling structures of deposit feeding organisms are also constituents of the ichnofacies, particularly where exhumed substrates occupied more sheltered or distal settings during colonization, and include firmground Thalassinoides, Spongeliomorpha and Rhizocorallium. More recently, MacEachern and Burton (2000), and Savrda et al. (2001) have shown omission-related firmground Zoophycos associated with discontinuities colonized in very distal settings of the shelf and slope. Caution should be exercised in distinguishing firmground assemblages from stiffground assemblages (Wetzel and Uchman, 1998) that can be localized and can be related to deep tiers.

In proximal, high-energy settings, the assemblages attributable to the Glossifungites ichnofacies are dominated by vertical domichnia. The presence of vertical shafts within shaly intervals is anomalous, as these structures are not capable of being maintained in soft muddy substrates. *Glossifungites* ichnofacies elements are typically robust, commonly penetrating 20-100 cm below the bed junction. Many shafts tend to be large in diameter (e.g., 0.5-1.0 cm), in particular, Diplocraterion habichi and Arenicolites. This scale of burrowing contrasts markedly with the

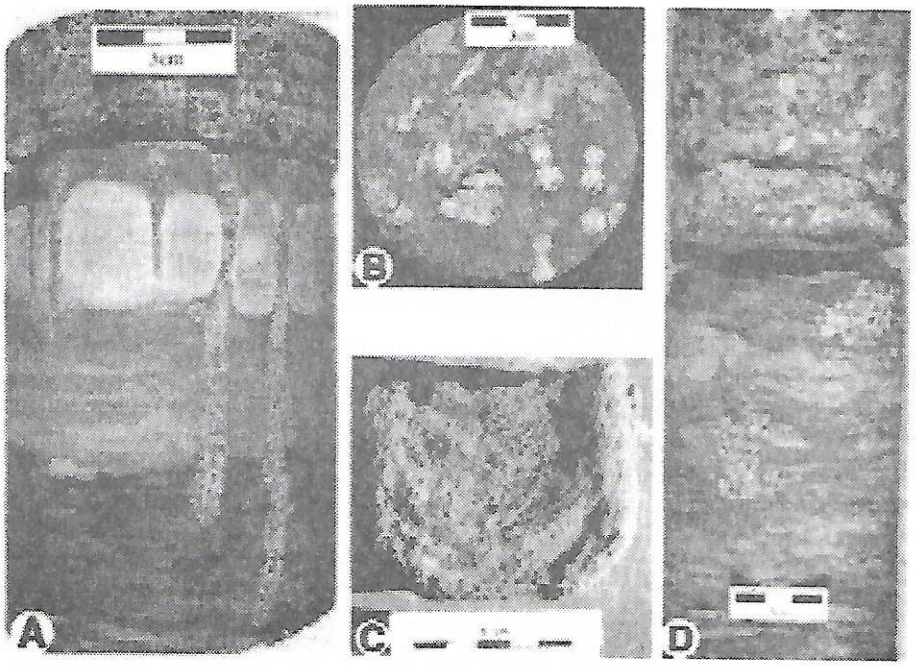


Figure 4: Characteristics of trace fossils that are associated with the Glossifungites ichnofacies. ***A.*** *The burrows tend to be robust, unlined domiciles,* ***B.*** *Are found in very high densities,* ***C.*** *Commonly display scratch marks; and* ***D.*** *Cross cut the original soft ground trace fossil assemblage. (Modified from Pemberton et al., 2002)*

predominantly horizontal and diminutive ichnogenera that typify the exhumed shaly intervals. The firmground traces are generally sharp-walled and unlined, reflecting the stable, cohesive nature of the substrate at the time of colonization and burrow excavation. Further evidence of substrate resilience, atypical of soft muddy beds, is the passive nature of most causative burrow fills. This demonstrates that the structure remained open after the trace-maker vacated the domicile, thus allowing material from subsequent depositional events to infiltrate the open tube.

The post-depositional origin of the *Glossifungites* ichnofacies is clearly demonstrated by the ubiquitous cross-cutting relationships with the previous softground assemblage. The final characteristic of the suite is the tendency to reflect colonization in large numbers (Fig. 3). In numerous examples, seven to fifteen firmground traces, most commonly *Diplocraterion habichi*, have been observed on the bedding plane of 9 cm (3.5 inch) diameter cores, corresponding to a density of between 1100 to 2300 shafts per m^2.

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FOSI EVENING TALK
MAY 21, 2004

The most recent FOSI evening talk was held on Friday, May 21, 2004 in Thamnak Thai Restaurant, Menteng. The talk took the topic of "Oligo-Miocene Carbonates of East Java Basin: Regional Facies Definition and Recent Significicant Discoveries" with Awang H. Satyana from BP Migas as the speaker. In his presentation Pak Awang gave a highlight of carbonate's potential of East Java Basin which is happen to be a very potential play which success ratio around 80%.

The talk drew many interests from G and G staff of some oil companies as well as services and private attenders. Questions raised are about the source rock, secondary porosity of the carbonate reservoirs regarding of its nature and the best reservoir type for carbonates. All questions were answered intelegently by Pak Awang, showing his broad knowledge on the topic he presented.

The very lively discussion was forced to end at 07:00 PM as time limited the eager crowd. Detailed composition of the attenders were 25 from oil companies, 4 privatees and 2 from service companies. The next gathering by FOSI that will focused more on the carbonate play topic would be the open discussion within the next few months.

is essentially money, a lot of shortcuts are taken to save costs and achieve a "fit-for-purpose" understanding of the reservoirs. The course instilled the importance of back to basics i.e. back to the rocks to understand the reservoirs more and therefore improve our understanding of the subsurface. At times, challenging the paradigms and established dogmas can turn the tide over for the better. This is a course that is highly recommended to all. The juniors or the experienced amongst the geoscientist community will gain from the tremendous learning. It definitely changed my view of trace fossils for the better. I now will try to decipher the code left by the organisms when I see one.

References:

Darman, H. & Damit, A. R, 2003, Structural Control on Sediment Distribution in Offshore Brunei Darussalam, South China Sea, IPA 29th annual convention proceedings.

Suggested Reading Materials:

AAPG Paper (Maori shales), SEPM (Sedimentary records, Charlotte Schreiber), AAPG 1998 (Use of trace fossils in recognizing bounding surfaces, George Pemberton), Sequence Stratigraphy (Blackwelder, 1090), IRG

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ICHNOLOGICAL APPLICATIONS TO GENETIC STRATIGRAPHY

The applications of ichnology to genetic stratigraphy are mainly two-fold. The most obvious use is in the demarcation of erosional discontinuities (Fig. 5). The second use is subtler, and is concerned with the palaeoenvironmental implications of the trace fossil suites, both with respect to the softground and the substrate-controlled assemblages.

Regressive Surfaces of Erosion (RSE) and Sequence Boundaries (SB)

Although subaerial exposure and/or erosion during relative sea level lowstand may produce widespread development of dewatered, firm or cemented substrates (corresponding to regressive surfaces of erosion and sequence boundaries) most are unlikely to become colonized by substrate-controlled trace fossil suites unless the surfaces are subsequently exposed to marine or marginal marine conditions prior to burial.

In most cases, deposition of significant thicknesses of nonmarine strata generally precludes development of these omission suites on the RSE or SB themselves. There are a number of scenarios, however, where such discontinuities may be preferentially colonized by tracemakers of substrate-controlled assemblages. Such settings include RSE developed beneath forced regressive shorefaces, SB underlying lowstand shorefaces, SB comprising submarine canyon margins, and SB lying at the estuarine mouths of incised valleys, prior to transgressive infill. All of these settings are conducive to colonization of the discontinuity, because the surfaces were excavated subaqueously in a marine or marginal marine environment.

Glossifungites ichnofacies can develop on subaqueously excavated sequence boundaries, such as those associated with incised lowstand submarine canyons (*cf.* Hayward, 1976), as well as forced regression (Fig. 5A) and lowstand shorefaces (*cf.* Plint *et al.*, 1988; Posamentier *et al.*, 1992; Pemberton and MacEachern, 1995; MacEachern *et al.*, 1999a). Forced regressive and lowstand shoreface basal discontinuities (RSE and SB, respectively) are probably excavated and introduced to the colonization window only to fairweather wave base (FWWB). Although erosion my persist as far seaward as storm-weather wave base (SWWB), such autocyclically generated scour surfaces are mantled by storm beds, and shielded from the colonization window. As such, seaward of FWWB, the RSE and the SB pass into non-erosional correlative conformities (CC), so far as sequence stratigraphic nomenclature is concerned. Such CC have a high preservation potential only in lowstand shorefaces of lowstand systems tracts (LST); continued fall of relative sea level during the falling stage systems tract (FSST) during forced regression facilitates the erosional removal of the CC outboard of the RSE (*e.g.*, MacEachern *et al.*, 1999a).

Transgressive Surfaces

Transgressive surfaces are manifest by 1) mainly non-erosional marine flooding surfaces (MFS) and 2) low relief, erosional (ravinement) surfaces. The ravinement surfaces are commonly referred to as transgressive surfaces of erosion (TSE).

Marine flooding surfaces (MFS) are typically abrupt contacts across which there is evidence of a relative increase in water depth. These surfaces are mantled with dispersed sand, granules or intraformationally derived rip-up clasts, indicating some erosion. The preservation of underlying markers indicates that the degree of erosion is minimal. MFS are typically characterized by the abrupt juxtaposition of offshore, shelf or prodelta mudstones on shallow marine sandstones and are easily identified on geophysical well logs.

Transgressive surfaces of erosion (*i.e.* ravinement surfaces) afford the most elegant manner of generating widespread, substrate-controlled assemblages, because the exhumed surfaces are produced within a marine or marginal marine environment (Fig. 5B). This favors firmground colonization by organisms while the ravinement surface is excavated, and prior to accumulation of significant thicknesses of overlying sediment. The recognition of discrete TSE is difficult on the basis of sedimentology alone, particularly where there exist abundant, sharp-based pebble stringers and thin, trough cross-stratified, coarse-grained sandstone, intercalated with interbedded sandstones, siltstones and shales (*e.g.* MacEachern *et al.*, 1992b; Pemberton and MacEachern, 1995). A few of these coarse stringers could reflect the veneer on transgressive ravinement surfaces, but due to their abundance, picking which ones have regional stratigraphic significance is difficult. However, virtually every TSE incised into, or ravined across, shaly sediments exhibits a *Glossifungites* suite. Many firmgrounds also appear to have been developed on siderite-cemented intervals within the shales. Whether the siderite is a consequence of the ravinement, a chemical response related to deep penetration by the trace-makers of the *Glossifungites* suite, or that pre-existing, siderite-cemented bands formed resistant layers through

which the TSE could not incise, is uncertain. In the latter case, soft-bodied fauna would presumably find it difficult or impossible to penetrate a cemented layer, and would produce, if anything, *Trypanites* ichnofacies elements.

In the Cretaceous of Alberta, Canada several (Albian) Viking Formation oil and gas fields in central Alberta produce hydrocarbons from NW-SE trending, sharp-based sandstones interpreted as incised shoreface deposits. Many of these shoreface deposits are believed to rest upon a transgressive surface of erosion, including Chigwell (Raychaudhuri *et al.*, 1992), Joffre (Downing and Walker, 1988; MacEachern *et al.*, 1998; 1999a), Gilby (Raddysh, 1988), and Giroux Lake (MacEachern and Pemberton, 1992).

The facies that comprise these Viking transgressive shoreface successions are virtually identical to those of the forced regression complexes. The main differences lie in the thickness of the offshore to upper shoreface succession; transgressive systems tend to be thicker due to the increased accommodation space available.

The other principal difference between the forced regression complex and the transgressively incised shoreface complex lies in the erosional extent of the basal discontinuity. In the transgressive scenario, lower and upper offshore deposits, reflecting deposition *below* fairweather wave base, can overlie the erosional component of the basal discontinuity. Transgressive ravinement permits the generation of an erosional discontinuity that ultimately lies seaward of fairweather wave base during subsequent shoreface progradation. This is because the modified surface was cut prior to shoreface progradation, and while sea level lay at a stratigraphically lower position (MacEachern *et al.*, 1999a). This contrasts markedly with the RSE and SB, which pass into non-erosional CC seaward of fairweather wave base. This difference facilitates discrimination of shorefaces and deltas generated during relative sea-level fall, from transgressively incised shorefaces and deltas deposited during relative sea-level rise.

A *Glossifungites* assemblage commonly demarcates the transgressive surface of erosion, even in positions where the overlying facies reflect deposition well below fairweather wave base. In these positions, a coarse-grained lag is also commonly associated with the discontinuity. The transgressive surface of erosion passes seaward into a non-erosional marine flooding surface (MFS). In settings characterized by intense burrowing, the contact may be obscured. Only the full integration of sedimentology, ichnology and stratigraphy permits the reliable recognition and interpretation of the discontinuity.

Amalgamated Sequence Boundaries and Marine Flooding Surfaces

Amalgamated sequence boundaries and transgressive surfaces are also commonly colonized by substrate-controlled trace-makers, and are widespread in many stratigraphic successions. The lowstand erosion event typically produces widespread firmground, hardground, and woodground surfaces, corresponding to RSE or SB. The following transgressive event, commonly accompanied by erosion, generates a TSE that typically removes most or all of the lowstand deposits, and exposes the original discontinuity to marine or marginal marine conditions. During this phase of transgression, organisms are able to

Ichnologically Demarcated Surfaces of Genetic Stratigraphic Significance

SEQUENCE BOUNDARIES

- Estuarine mouths of incised valleys
- Lowstand (forced-regresion) shorefaces
- Submarine Canyons

TRANSGRESSIVE SURFACES OF EROSION

- Wave or tidal ravinement surfaces
- Early transgressive/stillstand shorefaces

CO-PLANAR SEQUENCE BOUNDARIES & FLOODING SURFACES

- Ravinement across subaerial surfaces
- Some ravinement and floding surfaces within incised valleys

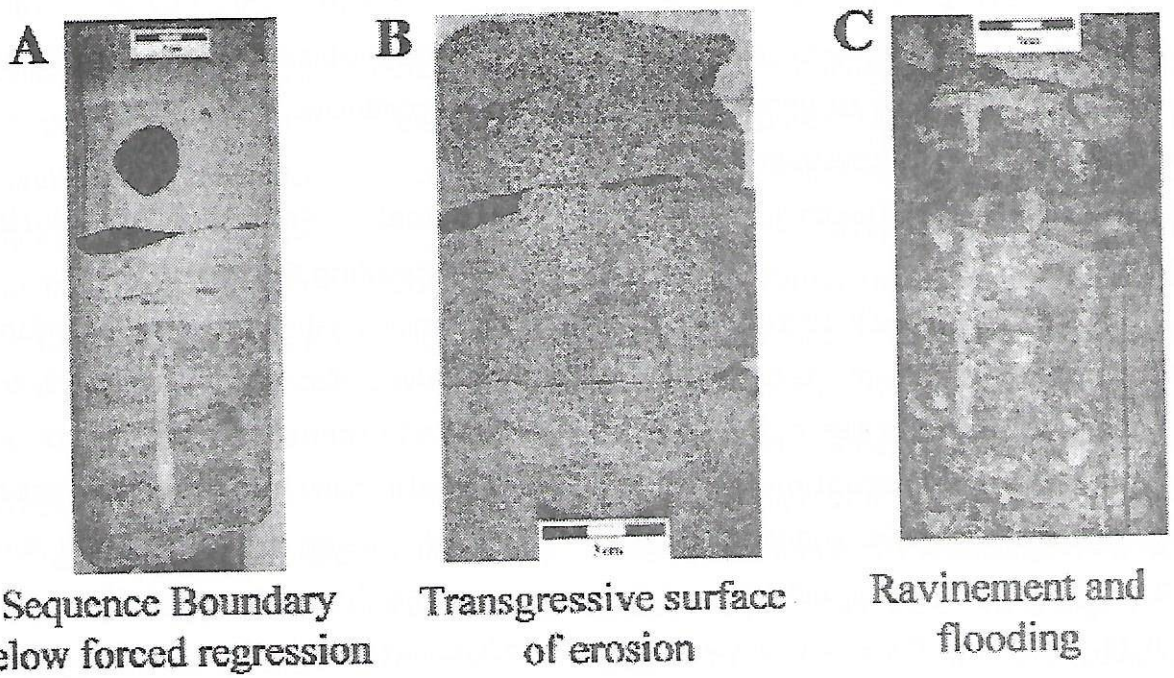


Figure 5 Types of genetic stratigraphic surfaces that can be recognized using substrate-specific ichnofacies. A. Sequence boundry at the base of an interpreted forced regression shoreface, Viking Kabob Core 11-35-61-20W5, 1759m; B. Firmground Arenicolites marking a transgressive surface of erosion (TSE), Cretaceous Viking Formation (Core 07-19-62-19W5, 1652m); and C. Sequence boundry/flooding surface at the top of the Viking interval at Cyn Pem Core 06-12-51-11W5, 1944.4m.

colonize the re-exhumed substrate. Although such surfaces may also include the discontinuities at the bases of some transgressively incised shorefaces (*e.g.*, E-T surfaces of Plint, 1988; Plint *et al.*, 1986; 1988; FS/SB of MacEachern *et al.*, 1992; 1998, 1999a,b), the majority are associated with incised valley systems. Incised valley discontinuities may correspond to subaerially exposed areas, such as delta plains, fluvial floodplains, interfluves, or to transgressively modified sequence boundaries within the estuarine valley fills themselves. Some reserve the term "FS/SB" for discontinuities developed on valley interfluves alone, where deposition did not occur until the valley was filled and the area transgressively ravined during ensuing relative sea level rise (*e.g.*, Van Wagoner *et al.*, 1990). Examples of co-planar or amalgamated sequence boundaries and marine flooding surfaces include:

(1) Transgressive surface of erosion across subaerially exposed surfaces. Numerous units in coastal margin (delta plain and coastal plain) settings display initially subaerial surfaces subsequently flooded and eroded during transgressive influx of brackish to marine waters. Such scenarios are conducive to the development of substrate-controlled ichnofacies demarcating the discontinuities (Fig. 5C); and

(2) The bases and margins of transgressively filled incised valley complexes or estuaries (Pemberton *et al.*, 1992b; MacEachern and Pemberton, 1994; Pemberton and MacEachern, 1995). For the most part, lowstand deposits rarely dominate incised valley complexes, since the system is largely a zone of sediment bypass during incision (Van Wagoner *et al.*, 1990). Much of the sediment accumulation in these systems occurs during late lowstand and transgression and is therefore characterized by estuarine (brackish-water) infill. The juxtaposition of facies into which the valley is incised, the presence of remnant fluvial deposits within the valley, accumulations of estuarine intervals during ensuing transgression, and the excavation of numerous internal discontinuities within the valley fill, results in highly complex facies architectures and vertical successions for which ichnology is ideally suited to help resolve. Ichnological suites are also effective in differentiating salinity changes and more specifically, salinity reductions, assisting in the differentiation of fully marine, brackish-water and freshwater deposits (*e.g.*, Wightman *et al.*, 1987; Beynon *et al.*, 1988; Beynon and Pemberton, 1992; MacEachern and Pemberton, 1994; Gingras *et al.*, 1999; MacEachern *et al.*, 1999b,c). This, coupled with the presence of substrate-controlled assemblages demarcating erosional discontinuities within the valley fill, allows detailed mapping of valley components, and assists in the resolution of the sequence stratigraphic history of valley excavation and infill.

CONCLUSIONS

The main applications of ichnology to applied stratigraphy are two-fold. The most obvious use lies in the demarcation of erosional discontinuities. Substrate-controlled ichnofacies have traditionally been under-utilized, but are fast becoming a popular means of recognizing and mapping these stratigraphically important surfaces both in outcrop and the subsurface. Locally, many surfaces are obvious on the basis of sedimentology alone; however, their appearance can change markedly across a study area, making correlations

difficult. The *Glossifungites* ichnofacies is important in both the recognition and genetic interpretation of erosional discontinuities in marine-influenced, siliciclastic intervals, as the many Cretaceous examples cited from the Western Canada Sedimentary Basin demonstrate (Pemberton and MacEachern, 1995). In many cases, the genetic interpretation of the discontinuity has come principally from the ichnological assemblage associated with the discontinuity and the overlying units. The continued integration of substrate-controlled ichnofacies with detailed stratigraphic and sedimentologic analysis will undoubtedly enhance and refine developing genetic stratigraphic paradigms.

The second use is subtler, and is concerned with trace fossil behaviors and their paleoenvironmental implications. Trace fossils, when used in conjunction with primary sedimentary structures, are useful in the delineation and interpretation of facies and facies associations. When these behavioral and substrate-controlled aspects of ichnology are integrated fully with other sedimentologic and stratigraphic analyses, the result is a powerful approach to the recognition and genetic interpretation of discontinuities in the rock record.

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