Terrestrial trace fossils as tools for sequence stratigraphy in marginal settings: examples from Alberta and Wyoming

Jennifer J. Scott [1] and Rochelle A. Bank [2]
[1] Department of Earth Sciences, Mount Royal University; [2] Cenovus Energy

Summary

The correlation between marine and non-marine depositional systems is a difficult task. Nevertheless, models for the application of terrestrial trace fossils to solve this problem remain underdeveloped. Recent research has focused on the application of terrestrial ichnology for recognizing sequence stratigraphic surfaces and progradational systems tracts in the marginal settings of both marine and lacustrine basins. Case studies include the Campanian Belly River Group of southern and central Alberta and the Eocene Green River Formation of Wyoming, which despite disparate facies assemblages, show similarities in the stratigraphic significance of terrestrial trace fossil assemblages. Surfaces bioturbated by air breathing organisms demonstrate subaerial exposure and may help to recognize the subaerial portions of sequence boundaries. Additionally, certain types of burrows (e.g., insect-produced meniscate backfilled burrows) can be used to identify well drained substrates, where water tables are below the land surface. The traces mark the tops of progradational successions in both lowstand (in lacustrine basins) and highstand systems tracts (in marine and lacustrine basins) because they represent the basinward movement of shorelines and lowering of base levels. Depending on the relationship between accommodation and sediment supply as controlled by allogenic factors (e.g., tectonics), the terrestrial trace fossil assemblages also appear to reflect cycles of base level rise and fall at different frequencies in different areas of a basin. Analyses of terrestrial trace fossils can improve our ability to correlate between marine and non-marine environments, as well as our ability to interpret basin evolution and lateral variability in the relationship between accommodation and sediment supply in basins that preserve non-marine sediments.

Introduction

The correlation of stratigraphic surfaces that represent lowered base levels in non-marine and marine deposits remains challenging. Models to apply trace fossils to this problem are presently under development. This research incorporates examples from several field areas and depositional settings, from continental to marginal marine, to develop a model for the application of terrestrial trace fossils to the sequence stratigraphic correlation between non-marine and marine environments. The traces help to map horizons that represent lowered base levels. Examples from the Basal Belly River of central Alberta, for example, show the preservation of meniscate backfilled burrows (Hansen and MacEachern, 2007) in point bar deposits along horizons that underlie regionally mappable flooding surfaces (Power and Walker, 1996).

Results to date show that some types of terrestrial trace fossils produced by air-breathing organisms such as insects, described as "meniscate backfilled burrows", represent the first colonization of sediments that were deposited underwater and were then subaerially exposed. The bioturbated substrates often do not preserve other evidence of subaerial exposure, although they may be associated with roots and paleosols where base level remained low for greater lengths of time. In other cases, these burrows, which are relatively "deep-tier" and can be up to 2 m in depth (e.g., Buatois et al., 2007), may be the only evidence of subaerial exposure due to either the erosion of the uppermost exposed sediments, or lack of other indicators when base level in that location remained low for a short period of time. The depths and vertical orientation of meniscate backfilled burrows produced by terrestrial organisms (e.g., known as *Taenidium barretti*, or, *Naktodemasis bowni/Taenidium bowni*), along with the presence of "sediment aggregates" in the burrow fill, are key features that can be used to distinguish the burrows from those produced in marine environments (e.g., *Scolicia*, *Taenidium* isp.). The terrestrial traces are typically part of low-diversity or monospecific assemblages.

Mappable horizons containing this assemblage appear to represent the most basinward position of the shoreline at the top of progradational stratigraphic successions. These patterns are recognized at a variety of time-scales and relate to different frequencies in cycles of base level rise and fall, depending on factors that control accommodation in marginal areas (e.g., gradient, sedimentation rate, water levels). In the examples studied to date, the burrows represent the first terrestrial colonization of soft and/or firm substrates once the sediments are subaerially exposed and base level has decreased sufficiently for air-breathing organisms to survive in the substrates.

Methods

Marginal marine – Field research to date has focused on the deltaic and coastal plain deposits of the Campanian Belly River Group in southern Alberta, at Redcliffe, Sandy Point, and Dinosaur Provincial Park (e.g., Eberth, 2005). Core studies focused on the Basal Belly River of central Alberta (e.g, 12-22-46-2W5), and the Foremost and Oldman formations of southern Alberta (e.g., 1-2-20-12W4; Hamblin and Abrahamson, 1993).

Marginal lacustrine – Fieldwork focused on the Green River Formation of southwestern Wyoming, and on environments ranging from saline lacustrine lake margin mudflats to deltaic, coarsening upwards wedges (Scott, 2010).

Recognition of terrestrial meniscate backfilled burrows

Although meniscate backfilled burrows can be produced by a variety of organisms living in terrestrial and marine settings, several criteria appear to be useful for distinguishing those produced by terrestrial, air-breathing organisms (i.e. insects) from those produced by marine organisms (e.g., *Scolicia*, produced by heart urchins). Several different names have been used to describe these traces including, "Adhesive Meniscate Burrows", *Beaconites barretti* (e.g., Draganits et al., 2001), *Taenidium barretti* (e.g., Buatois et al., 2007), *Naktodemasis bowni* (Smith et al., 2008), and *Taenidium bowni* (Krapovickas et al., 2009). The key features of these burrows are as follows: (1) the burrows typically have vertical, horizontal, and oblique orientations, and (2) the backfilled material contains sediment aggregates ~1-2 mm in diameter that were packed into the burrow by the organism's mouth-parts and forelegs (Smith et al., 2008). "Packets" of backfilled material can also be recognized (Smith et al., 2008), although they are not always present. The burrow margins are typically sharp because the burrows are produced in sediments that were deposited in aqueous environments (e.g., point bars, littoral areas) but which were later exposed. The burrows are also typically cross-cut by burrows produced by the same or different individual organisms, and they may exhibit secondary successive branching, or false branching, that is, the apparent branching of the burrow due to its later reuse.

Examples of the terrestrial meniscate backfilled burrows recognized to date from several field areas and different formations (e.g., Green River Formation; Oldman Formation; Basal Belly River) are all present in very low diversity assemblages, typically with only one to two other ichnogenera (e.g., *Planolites*). This pattern may be present in marginal facies as early as the late Silurian and early Devonian (e.g., Old Red Sandstone), when these terrestrial meniscate backfilled burrows were first produced (e.g., Davies et al., 2006).

Examples

The examples to be displayed as core and field samples include: the Basal Belly River (12-22-46-2W5; 8-22-46-2W5) southwest of the Pembina field in central Alberta; the uppermost Foremost Formation and the Oldman Formation of southern Alberta (1-2-20-12W4); and the Eocene Green River Formation from Wyoming.

Conclusions

Meniscate backfilled burrows produced by terrestrial organisms can be used to recognize the uppermost portions of progradational successions in both continental and marine basins at different scales. The successions coarsen upwards and mark the tops of regressive cycles of higher frequency (~4-5th order) and lower frequency (~3rd order). The presence or absence of the meniscate backfilled burrows appears to depend on factors controlling local and regional base level (i.e., sediment supply, gradient, accommodation in the water body). Their presence or absence in time-equivalent units in the same basin may help to interpret variability in accommodation in different areas, and be applied to the characterization of basin physiography.

The traces are typically found along discrete horizons that signify relatively low water tables and subaerial exposure, and are typically produced in sediments originally deposited in aqueous environments (e.g., delta front, delta plain, littoral, and point bars of deltaic and coastal plain fluvial systems), but which were subaerially exposed when base level dropped. In examples such as the Basal Belly River, the recognition of these horizons has the potential to help map stratigraphic surfaces that correlate to the most basinward occurrences of shoreline-detached sand bodies deposited during forced regression. In lacustrine oil shales, the recognition of these surfaces has the potential to help map "lean zones" into more basin central areas.

Future work will focus on identifying more examples in the Green River Formation oil shales of Utah and Colorado, as well as on the more landward facies associations of the Spirit River, Peace River, and Viking formations of the Cretaceous of Alberta, to better understand how the horizons relate to regressive and transgressive cycles at several scales.

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