The application of ichnofabrics towards bridging the dichotomy between siliciclastic and carbonate shelf facies: examples from the Upper Jurassic Fulmar Formation (UK) and the Jubaila Formation (Saudi Arabia)

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GOLDRING, R., TAYLOR, A.M. & HUGHES, G.W. 2005. The application of ichnofabrics towards bridging the dichotomy between siliciclastic and carbonate shelf facies: examples from the Upper Jurassic Fulmar Formation (UK) and Jubaila Formation (Saudi Arabia). *Proceedings of the Geologists' Association*, **116**, 235–249. An initial study of the ichnofabrics of the Upper Jurassic (Kimmeridgian) Jubaila Formation of Saudi Arabia shows that the ichnofabrics are closely matched to the relatively well-described ichnofabrics of the contemporary Fulmar Formation of the UK Continental Shelf (North Sea), in respect of the lower shoreface/offshore transition facies to offshore facies. The ichnology and ichnofabrics of the Lower Jubaila Formation show that deposition took place on an open-marine platform on the Arabian craton subject to periodic storm activity, but under a persisting equilibrium between sediment accumulation and subsidence. This is consistent with the moderately deep-marine foraminiferal assemblages and the presence of calcareous nannofossils. Cyclicity is absent, though storm beds may be grouped, in contrast with the genetic sequences present in the rift and halokinetic scenario of the North Sea. In contrast with the siliciclastic setting hardgrounds (with *Gastrochaenolites*), more common firmground omission surfaces, and micritic mudstones with *Chondrites* and *Zoophycos* are notable features of the carbonate facies. In siliciclastic successions (parasequences) the latter ichnotaxa are generally regarded as having been deposited in rather deeper water, but in the carbonate Jubaila Formation are interpreted as being associated with local areas of lower turbulence. Likewise, the hardgrounds and firmgrounds, which have not been traced laterally, are tentatively regarded to be of local significance.

Key words: ichnology, siliciclastic, carbonate facies, ichnofabrics, Upper Jurassic, Fulmar, Jubaila, Saudi Arabia

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1. INTRODUCTION

Trace fossil analysis is an integral part of the description and interpretation of bioturbated clastic successions in terms of facies analysis and the recognition of key stratal surfaces. The ichnotaxa are well preserved in heterolithic sand/mud facies as sole traces, as well as hosted within individual beds. In contrast, as discussed by Curran (1994), trace fossil studies of carbonates tend to highlight features such as borings (e.g. on hardgrounds, intraclastic material and coral colonies), or filled burrows (e.g. mazes and boxworks) within limestone beds where the ichnology has been diagenetically enhanced. Hypichnia of limestones are frequently obscured by 'underbeds' where calcification has extended into the underlying micritic/clay layer. Similar diagenetic processes can also hide epichnia on upper surfaces. As a result, particularly with respect to the ichnofabrics, the ichnology of carbonates has received less attention than their siliciclastic counterparts. There are notable exceptions such as the study of calcareous turbidites (Powichrowski, 1989); Ordovician carbonates of eastern Canada (Pickerill *et al.*, 1984); Triassic mixed carbonate and siliciclastic marginal marine sediment of British Columbia (Zonnefeld *et al.*, 2001); Upper Jurassic mixed carbonate–siliciclastic sediments of Europe (Fürsich, 1974, 1975; Fürsich & Schmidt-Kittler, 1980; Schlirf, 2000); Lower Jurassic cycles (Sellwood, 1970;

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†This paper is an invited contribution in memory of the life and work of Douglas James Shearman (1918–2003). The set of papers was commissioned by Professor Graham Evans, who has also been Guest Editor for the manuscripts which are now published in the *Proceedings*. It is with great regret that we learnt that Roland Goldring, who joined the GA in 1959, died on 30 August 2005, while revision of this paper was underway; it has been completed by Andrew Taylor.

Moghadan & Paul, 2000); the detailed work on Cretaceous chalks (Ekdale & Bromley 1983, 1984, 1991; Bromley & Ekdale, 1986) and limestone–marl cycles in the USA (Lockair & Savrda, 1998a, b).

With the establishment of sedimentology as a distinct discipline over the past half century, a dichotomy of interests has tended to divide the subject into siliciclastic and carbonate branches, with several texts specifically devoted to each. This is in many respects surprising if one considers the bedforms of primary oolites and sand waves and the dynamic processes involved in their formation. This split in research along lithological grounds has not happened in ichnology as the emphasis has always been placed on the facies interpretation of clastic sediments. The ichnofacies scheme of Seilacher (Frey *et al.*, 1990) was drawn almost entirely from siliciclastic facies, with only the *Trypanites* ichnofacies and, to a lesser extent, the *Glossifungites* ichnofacies (in practice both are surfaces) having their origin mainly in limestones. The study of ichnofabrics ('texture of bioturbation at all scales') was pioneered on chalks and marls by Ekdale & Bromley (1983) and has been applied successfully to the interpretation of clastic sediments (Goldring *et al.*, 1991, Taylor & Gawthorpe, 1993).

The similarities between clastic shelves and epeiric carbonate platform/shelves have been noted by Tucker (1985) and Tucker & Wright (1990) because the dominant (autocyclic) processes are the same, namely storms and fair-weather processes. As Tucker & Wright (1990) emphasized, it is the hydraulic structures that should be used for environmental interpretation. To complement this, an understanding of ichnofabrics can provide the detailed information on benthic colonization which will also aid facies interpretation (Taylor *et al.*, 2003).

In order to compare trace fossil colonizations in both clastic and carbonate shelves, two Upper Jurassic (Oxfordian–Volgian) examples are discussed. The first is a clastic shelf-shoreline succession of Upper Jurassic age, the Fulmar Formation (Humber Group), recorded from borehole cores in the UK Continental Shelf (Figs 1, 2) (Gowland, 1996; Fraser *et al.*, 2003). The second example is from the Upper Jurassic Jubaila and Hanifa formations, seen in borehole core and in outcrop along the motorway section at Diplomatic Quarter, to the west of Riyadh at Tuwaiq Mountain and below the motorway on the south side of Wadi Leban (Figs 3–9). In addition, some comparisons are made with published accounts of the ichnology of shelfal siliciclastic sediments from Cretaceous deposits of the Western Interior of North America and southern England, the Miocene of the Suez area (Egypt), and Miocene pelagic carbonates (*Globigerina* Limestone) of the Maltese Islands.

2. SHELF (PLATFORM) MODELS

There are four major differences between the shoreline-shelf profiles of carbonate and siliciclastic sediments (Table 1). Perhaps the principal difference is in the type of 'barrier' that may be situated at various distances from the shoreline, separating the lagoon, where sediments accumulate under quite different hydraulic and ecological controls, from those operating on the seaward side of the barrier. In the carbonate realm, barriers are more common and diverse, with reef, carbonate mound, oolitic shoal, skeletal shoal or sandy shoal types which may or may not be emergent. In both clastic and carbonate settings, as sedimentation and subsidence continue, the 'barrier' may advance or retreat with time relative to the shoreline, resulting in a complex set of relationships and preservation potentials of the barrier, lagoon and shelf facies.

The second difference is in the source and origin of the sediment. On siliciclastic shelves sediment is mainly land derived and then distributed by various processes across the shelf. In contrast, on carbonate shelves sediment is sourced '*in situ*' and then redistributed by hydraulic processes, including tidal currents and storm processes. As a result shoreline-attached, siliciclastic shelf aggradation is largely determined by fluvial and deltaic input, and hence shoreline progradation and coarsening-upward successions are characteristic. Aggradation of carbonate shelves is influenced by biogenic productivity (temperature/illumination), and cyclicity, determined by the interaction between productivity and subsidence.

The third difference is in the propensity of the skeletal-building epifauna to construct edifices irregularly distributed across the shelf and thus stabilize the sedimentary surface. Such structures may be of a size that is outside normal hydraulic influence. In siliciclastic shelves the shelly epifauna/infauna is relatively minor and dominated by centimetre-size bivalve shells, which play little role in substrate stabilization. However, algal mats clearly helped stabilize sandy substrates in the Precambrian and seagrass undoubtedly played a significant role in the Cenozoic, in sediment production and in substrate stabilization.

The fourth essential difference between the carbonate and siliciclastic realms is in the lithification processes that operate in each. In both, compaction tends to increase firmness at the sediment–water interface and below, but it is the likelihood of diagenesis progressing deeper and more thoroughly in the carbonate realm to a hardground state that is particularly significant. Thus, hardgrounds (as distinct from rockgrounds) are confined to carbonate successions. They can be on a local scale, associated with tectonic processes, or on a regional scale due to fluctuations in oceanic chemistry (Gruszczynski, 1998). In both, the effect on the aspect of the sediment is high, with the presence of bored and encrusted surfaces, which are potentially correlatable.

For the Fulmar Formation, the shoreline is for the most part attached to the coast, with barriers/lagoon complexes rare (one well-documented occurrence is in the Curlew embayment Quad 29, UK Continental Shelf; Gowland, 1996). Sedimentation rates can often