Biostratinomic signature of Penarth Group (Upper Triassic) shell concentrations (Severn Estuary, South-West England): A preliminary account

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The principal characters of Penarth Group (Upper Triassic) marine shell concentrations are described and briefly interpreted from sections in the Severn Estuary area of south-west England. Concentrations encountered to date are thin, demonstrate predominantly simple biofabrics and are of archaic aspect. These features at least partly reflect the small size and morphologically conservative nature of Penarth Group bivalve shells, and their predominance in thinly-bedded to laminated lithofacies.

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Introduction

Since the Lower Palaeozoic, shell concentrations within shallow-marine successions have generally increased in thickness, complexity, faunal diversity, and probably, general abundance. Kidwell (1990) and Kidwell and Brenchley (1994, 1996) attributed these trends to essentially phylogenetic factors including the increasing strengths, architectural complexities, size and abundance of shells, and ultimate radiation of shelled benthos into habitats above fair-weather wave-base, characterised by extensive reworking and time-averaging. Kidwell (1990) defined archaic shell concentrations as a thin, essentially two-dimensional and typically brachiopod-dominated biostratinomic style that typifies Palaeozoic strata. This mode demonstrates simple internal biofabrics (*sensu* Kidwell *et al*., 1986) that are taken to reflect the semi-infaunal to epifaunal life modes of shell producers in predominantly low-energy, offshore marine habitats; their low reproductive rates, and low post-mortem durability of the high-organic brachiopod shell microstructure.

In post-Palaeozoic marine successions, thin accumulations are augmented by the thicker, mollusc-dominated 'modern' concentrations that demonstrate relatively complex internal stratigraphies and biofabrics and commonly, relatively durable shell microstructures (Kidwell, 1990; Simões *et al*., 2000; Boyer *et al*., 2004). This style of shell concentration reflects a greater range of physical and biotic processes including event-bed amalgamation, taphonomic feedback, input from diverse shell producers, bioerosion and bioencrustation (Kidwell, 1990). A 'transitional' mode has been defined from the Lower Triassic by Boyer *et al*. (2004), comprising successions dominated by mollusc-dominated concentrations that are nevertheless essentially archaic in terms of thickness and fabric.

In addition to these changes in shell concentration style, shallow-marine environments have witnessed increased infaunal tiering and bioturbation through the Phanerozoic (Bottjer and Ausich, 1986; Sepkoski *et al*., 1991). This has resulted in widespread overprinting and homogenization of poorly-sorted, laminated, and/or thinly-bedded sediment (Kidwell *et al*., 1986; Sepkoski *et al*. 1991). This factor has also influenced the decline of archaic concentrations, through an overall decrease in the preservation of thin event-beds (Brett and Allison, 1998; Kidwell *et al*., 1986). Palaeoenvironmentally 'stressed' conditions in post-Palaeozoic shallow-marine settings, characterized by reduced bioturbation rates and tiering, are commonly marked by resurgences of thinly-bedded and/or laminated lithofacies (Sepkoski *et al*., 1991; Wignall and Hallam, 1991). These commonly enclose thin shell concentrations of archaic aspect that demonstrate intrinsic biogenic or sedimentological fabrics (*sensu* Kidwell *et al*., 1986).

The Penarth Group (late Triassic) of the Severn Estuary area, South-West England, is well exposed in natural cliff sections, as well as inland quarries, cuttings and streams. The Penarth Group yields a rich macrobiota including the fish and reptile remains of the Westbury Formation (lower Penarth Group) bone beds, and shelly faunas throughout (Swift and Martill, 1999; Benton *et al*., 2002 and references therein). The Triassic Period was a critical interval for the development of shell concentrations, heralding the mid-late Mesozoic rise of modern-style concentrations (Kidwell, 1990; Boyer *et al*., 2004). For this reason the geometry and biostratinomic aspects of Penarth Group shell concentrations in the Severn Estuary area is being examined. This report provides an outline of observations and interpretations to date.

Palaeoenvironmental framework

Following deposition of arid continental and playa-lake red-beds (Mercia Mudstone Group), the Penarth Group of southern Britain marks marine transgression and the establishment of a shallow epicontinental sea in latest Triassic times (Warrington and Ivimey-Cook, 1992). The Penarth Group seaway was subject to regressive-transgressive pulses and is therefore characterised by rapid vertical facies changes (Hesselbo *et al*., 2004). Facies developments in the Severn Estuary area range from the storm-influenced, shallow-marine mudrock-dominated strata of the Westbury Mudstone Formation (Macquaker, 1999) up into calcareous mudstones, siltstones, fine-grained sandstones and micritic carbonates of the Lilstock Formation, locally demonstrating shallow-water settings with emergence and stromatolite developments (Hesselbo *et al*., 2004; Benton *et al*., 2002; Gallois, 2009). Shallow-tier bioturbation is locally widespread among the Westbury Formation mudrocks (Swift and Duffin, 1999; Allington-Jones *et al*., 2010).

The essentially low-diversity molluscan macrofauna of the Penarth Group (Ivimey-Cook *et al*., 1999) has been attributed to abnormal and/or fluctuating salinities (e.g. Hallam and El Shaarawy, 1982; Swift, 1995; Allison and Wright, 2005). However, widespread occurrences of stenohaline marine macrofossils such as corals, brachiopods and echinoderms (Swift and Martill, 1999) indicate that salinity fluctuations were at most only slight (Wignall 2001). Other limiting factors on Penarth Group benthic biodiversity would have included periodic low oxygenation (Westbury Formation; Macquaker, 1999; Allington-Jones *et al*., 2010), localised emergence (Lilstock Formation; Hesselbo *et al*., 2004) and possibly, fluctuations in nutrient supply, against the backdrop of the end-Triassic mass extinction (Barras and Twitchett, 2007; Mander *et al*., 2008; Wignall and Bond, 2008).

Shell concentrations

Concentrations (*sensu* Kidwell *et al*., 1986) of thin-shelled, predominantly small bivalves occur throughout the Penarth Group of the Severn Estuary area, typically among laminated mudrock and carbonate developments (Ivimey-Cook *et al*., 1999; Benton *et al*., 2002). To date, cliff and intertidal foreshore sections have been investigated at Blue Anchor Point (ST 033435 - 056434) and St Audrie's Bay (ST 907433 - 112432), Somerset; and Aust Cliff (ST 565895 - 572901), Manor Farm, Aust (ST 574896) and Garden Cliff, Westbury-on-Severn (SO 719129), Gloucestershire. Shell concentrations have been described and classified using terminology adapted from that of Kidwell *et al*. (1986) and Kidwell and Holland (1991). In some instances, hand specimens of thicker bioclastic limestones have been collected to reveal skeletal content and biofabric. The principle concentration styles encountered so far are summarized and interpreted below.

Shell pavements

Predominantly densely packed, two-dimensional pavements (*sensu* Kidwell *et al*., 1986) of disarticulated, mainly convex-up, small thin-shelled bivalves have been widely encountered, for example within the Westbury Formation (e.g. at Aust Cliff) and within the Lilstock Formation (e.g. *Pseudomonotis* Bed of Richardson, 1903, 1911 at Garden Cliff; Fig. 1). Shell pavements are frequently associated with shelly limestone beds which they commonly cap. Shells within pavements are often partly crushed within Westbury Formation mudrock lithofacies but are often relatively uncrushed in association with coquinas, or when occurring as seams within fine-grained limestone units (e.g. *Pseudomonotis* Bed; see above and Figure 1). Shells are typically unfragmented and unabraded, indicating generation of pavements largely or wholly through winnowing of intervening sediment, probably by weak storm currents and/or wave

Figure 1. *Pavement of small bivalves (*Oxytoma fallax*) in thinly bedded micritic limestone (*Pseudomonotis Bed*). Lilstock Formation, Garden Cliff, Westbury-on-Severn, Gloucestershire. Field of view is 105 mm wide.*

activity (Kidwell and Holland, 1991; Brett and Allison, 1998). Wave or current orientation of small elongate bivalve shells has been noted in loose blocks of fine-grained limestone from the Westbury Formation at Blue Anchor Point (probably the *Pleurophorus* Bed of Richardson, 1911; Figure 2), and in thin pyritic sandstones of the Westbury Formation at Manor Farm, Aust (Radley and Carpenter, 1998).

Shelly limestone beds ('coquinas')

These are matrix to bioclast supported shelly limestone beds, up to approximately 20 cm thick, characterising the Westbury Formation. Examples encountered to date are sharp-based, tabular and dominated by small, densely packed, thin-shelled bivalves, within argillaceous, arenaceous and/or shell-fragmental matrices. Some beds (e.g. Upper Pecten Bed at Aust Cliff and Manor Farm, Aust; Radley and Carpenter, 1998) are highly compacted. In contrast, some beds at Blue Anchor Point preserve uncompacted biofabrics (*sensu* Kidwell *et al*., 1986) of stacked, nested and variably-oriented bivalve shells (Figure 3). At least one unit demonstrates multiple-event deposition, revealed by subtle vertical changes in biofabric.

The sharp-based, tabular nature of the Westbury Formation bioclastic limestones indicates an origin through hydraulic concentration (Aigner, 1985). Internal biofabrics of variably oriented, stacked and nested shells indicate turbulent reworking of densely packed shells in shallow-water settings (Kidwell and Bosence, 1991; Kidwell and Holland, 1991). Comparable units and biofabrics were recorded from the Westbury Formation by Macquaker (1999). A significantly thicker (*c*. 1 m) oyster-dominated unit ('*bristovi* Beds') has been recorded from the base of the Westbury Formation at St Maryís Well Bay, South Glamorgan (see for instance Warrington and Ivimey-Cook, 1995) and deserves further investigation.

Shell lags within gutter casts

Fine sandstone gutter casts, up to a few centimetres deep, have been encountered among Westbury Formation mudrock lithofacies, notably at the Aust Cliff and Manor Farm sites and at Garden Cliff. Bivalve-rich lags occur, dominated by disarticulated, convex-up bivalves (Figure 4). These sedimentary structures are interpreted as waning-storm and/or fair-weather infills of storm-generated scours (Brett and Allison, 1998).

Interstitial fills

Radley and Carpenter (1998) recorded interstitial concentrations of small, fully articulated bivalves among clasts within the Ceratodus Bone Bed (basal Westbury Formation) and 'crazy' Cotham Marble developments (Cotham Member of the Lilstock Formation) at Manor Farm, Aust. The Ceratodus Bone Bed is a vertebrate-rich conglomeratic unit that most likely represents a transgressive lag (Martill, 1999). In contrast, 'crazy' Cotham Marble comprises intraformational calcareous mud-flake breccia, occupying channels between stromatolitic heads (Hamilton, 1961).

Discussion

Penarth Group shell concentrations are dominated by thin (<20 cm thick) units made up mainly of small bivalve shells, and are reminiscent of the 'transitional' shell concentration mode described from Early Triassic marine successions by Boyer *et al*. (2004). The thicker, oyster-rich accumulation reported from South Glamorgan is potentially of 'modern' aspect (cf. Kidwell, 1990).

Figure 2. *Pavement of wave or current-oriented bivalves (?'*Permophorus*' sp.) in fine-grained bioclastic limestone. Westbury Formation, Blue Anchor Point, Somerset. Specimen is 135 mm wide.*

Figure 3. *Weathered section through shelly limestone bed. Westbury Formation, Blue Anchor Point, Somerset. Note internal biofabric dominated by stacked and nested thin-shelled bivalves. Branching structure on the right side of the block is part of a calcite vein network. Thickness (height) of unit is 103 mm.*

Figure 4. *Underside of fine sandstone gutter cast exhibiting basal lag of small convex-up bivalve shells. Westbury Formation, Garden Cliff, Westbury-on-Severn, Gloucestershire. Specimen is 237 mm long.*

The thin, archaic aspect of the Penarth Group concentrations encountered to date partly reflects the small, morphologically conservative nature of constituent bivalves, and their inferred epifaunal to shallow-infaunal life modes (Ivimey-Cook *et al.*, 1999; Mander and Twitchett, 2008). Additionally, concentration character is considered to be due partly to their occurrence within thinly bedded and locally laminated lithofacies in which bioturbation is scarce and/or dominated by occurrences of shallow-tier ichnotaxa (Swift and Duffin, 1999; Barras and Twitchett, 2007; Allington-Jones *et al.*, 2010). Among the observed biofabrics of the shell concentrations, widespread sedimentological signatures (*sensu* Kidwell *et al.*, 1986) indicate the considerable potential of Penarth Group shell concentrations in palaeoenvironmental interpretation.

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