Shelf storm beds on the southern margin of the Welsh Basin: the Wenlock of the Tortworth Inlier, England

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BENTON, M. J. & THACKRAY, E. 1995. Shelf storm beds on the southern margin of the Welsh Basin: the Wenlock of the Tortworth Inlier, England. Proceedings of the Geologists’ Association, 106, 81–92. The Brinkmarsh Beds (Wenlock, Silurian) of the Tortworth Inlier, near Bristol, SW England were deposited in shallow marine water on the southern margin of the Welsh Basin. Occasional sandstone units are interpreted as storm-induced deposits that periodically overwhelmed the quiet-water deposition of siltstones and mudstones. Evidence for storm-bed deposition is the episodic nature of the sandstone units, their erosive bases, hummocky cross-stratification in some, and suspended coquinites in others. There are two types of shell bed within the sequence: in situ units within the siltstones containing shallow-water brachiopods, corals, and crinoids, and transported faunas in the sandstones exclusively of large brachiopods. Palaeontological and sedimentological evidence suggests that deposition took place in a protected embayment on the shallow shelf.

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1. INTRODUCTION

During much of the Ordovician and Silurian, central Wales was the focus of a deep marine basin, characterized by deposition of black mudstones and turbidite sediments. Shallower marine deposition took place on a broad mixed clastic and carbonate shelf that extended over South Wales and across the Welsh Borderland. In the early Silurian (Fig. 1A), the coastline ran north–south down the middle of the Welsh Borderlands and Malvern Hills areas, and turned west around the Tortworth area to run across the southern tip of Wales. The English Midlands platform became submerged during a major marine transgression eastwards in late Llandovery and early Wenlock times (Bridges, 1975; Hurst, Hancock & McKerrow, 1978; Siveter, Owens & Thomas, 1989). Shallow-marine carbonate shelf environments became established over much of central England in Wenlock times, but the southern coastline altered only a little, curving further south of Bristol and extending north of the region of Cardiff and Swansea (Fig. 1B).

The Tortworth Inlier is situated south of Gloucester between the Cotswold Hills and the River Severn (Fig. 2). In late Llandovery and early Wenlock times, the Tortworth area became a focus for deposition, as the coastline shifted a short distance east and south. The sediments and fossils suggest that the water was shallow and close to land (Curtis, 1972; Cave, 1977). The Brinkmarsh Beds, the subject of this study, display interdigation of shallow-water clastics and limestone, indicating the proximity of land and the undisturbed carbonate platform further north and west, towards the centre of the basin. There is evidence of volcanism in the underlying late Llandovery sediments of the Tortworth Inlier, with supply of lavas (the Lower Trap and Upper Trap; Figs 2, 3) from the Mendips volcanic centre 20 km to the southwest. The sandy units in the Tortworth Inlier, and in the May Hill Inlier, some 30 km to the north, may have derived from the Mendips landmass to the south or southeast (Curtis, 1972), or from a landmass called the Gorsley Swell to the east (Hurst et al., 1978).

In the Tortworth Inlier, Llandovery and Wenlock beds are found in the southern part, and Ludlow rocks in the thin strip that extends north to the banks of the River Severn (Fig. 2). These units have been recognized as Silurian in age from the earliest days of geology (Weaver, 1824; Murchison, 1839; Reed & Reynolds, 1908; Curtis, 1972; Cave, 1977; Kellaway & Welch, 1993). The Tortworth Inlier forms part of the Bristol Coalfield syncline (Figs 2, 3). There is also a minor southerly pitching anticline which is complementary to the main structure, and which runs through Brinkmarsh Quarry itself, the study location. There is one major fault in the inlier running north–south which is downthrown to the west, and the main phase of folding is thought to be post-Carboniferous (Curtis, 1972).

In the present paper, the sedimentary environments in the Wenlock of the Tortworth Inlier are interpreted in terms of their unusual palaeogeographic location. The Brinkmarsh Beds appear to show clear evidence for storm-induced sedimentation in shallow near-coastal waters, which relates to the movements of the coastline in the southern part of the Welsh Basin associated with the more dramatic eastwards transgression across the English Midlands during late Llandovery and early Wenlock times. Illustrated specimens (Figs 5–7), and related materials, are deposited in Bristol University.


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2. SEDIMENTOLOGY

(a) Location and stratigraphy

The Llandovery and Wenlock succession in the Tortworth Inlier (Figs 2, 3) spans from the griesenitissa Zone of the Telychian (upper Llandovery) to about the nassa Zone of the Homerian (upper Wenlock). The dating of the beginning of the succession is based on the occurrence of the brachiopods Eocoelia curtisi, Stricklandia laevis, and Pentameroides sp. in the Damery Beds, and of Eocoelia sulcata, Costricklandia lirata, and Palaeocyclus porpita in the Tortworth Beds, all indicators of late Llandovery age (Curtis, 1972; Cave, 1977; Cocks et al., 1992). Rare graptolites have been found in the Damery Beds, a specimen identified as Monograptus marri (Curtis, 1972) and a specimen of M. priodon (Cave, 1977), which confirm the late Llandovery age. The same graptolite species are noted by Curtis (1972) also from the Tortworth Beds.

The Brinkmarsh Beds are much less securely dated: they contain brachiopod faunas of Wenlock aspect (Cocks et al., 1992). The Brinkmarsh Beds conformably overlie the Tortworth Beds, and hence the lowest part of the Brinkmarsh Beds is taken to be earlier Wenlock in age (Cave, 1977: 34). Higher parts of the Brinkmarsh Beds in the Tortworth Inlier yield fossils of mixed Wenlock/Ludlow aspect (Cave, 1977: 34), and the succession continues into the Ludlow in the northern Tites Point part of the inlier (Cocks et al., 1992). Hence, the three classic divisions of the Wenlock Series in the Welsh Borderlands (Woolhope Limestone, Coalbrookdale Formation, and Much Wenlock Limestone Formation) are absent in the Tortworth Inlier, and the Wenlock succession is represented by a single unit, the Brinkmarsh Beds, a term introduced by Curtis (1972).

The Brinkmarsh Beds are exposed at several locations in the Tortworth Inlier, including Falfield, Stone, Tortworth, Charfield and Wickwar (Curtis, 1972; Cave, 1977). Brinkmarsh Quarry (National Grid Reference ST 674 913; Figs 3, 4) is the type locality.

The Brinkmarsh Beds consist of siltstones, mudstones, and calcareous sandstones, and three prominent limestone bands, which are discontinuous and probably lenticular (Cave, 1977). The lower limestone marks the base of the succession, and it is visible in Brinkmarsh Quarry and neighbouring localities (Curtis, 1972: 20). It contains a rich fauna of disarticulated brachiopods, solitary rugose corals, tabulate corals, crinoid columnals, bryozaons, trilobites, thelodont fish scales, conodonts and ostracodes (Curtis, 1972; Cave, 1977; Siveter & Turner, 1982; Kellaway & Welch, 1993). Above this limestone is a highly fossiliferous red mudstone, termed the Pycnactis Band, which has
yielded brachiopods assigned to the *C. centrifugus* Zone of the basal Wenlock (Hurst *et al.*, 1978). Sporadic thin sandstones and siltstones showing wavy bedding features and tool marks on the soles have been noted by previous authors (Curtis, 1972; Cave, 1977; Kellaway & Welch, 1993), and these are interpreted here as storm deposits.

During the course of the present study, four sections through the Brinkmarsh Beds in Brinkmarsh Quarry were dug and measured in detail (Fig. 4), and samples of the sandstones were collected for sectioning. The sections were logged on the southwestern side of the quarry, and ranged from 0.5-2 m thick (Fig. 4). This compares with sections 3.1 m and 3.5 m thick (Fig. 4) measured by Reed & Reynolds (1908: 525), when the quarry must have been deeper. The basal sandy limestone is best seen at the western end of the quarry, where it reaches a thickness of 3.7 m, and along the northeastern side of the quarry (Fig. 4). In comparing the sections, it is difficult to correlate individual sandstone or limestone beds, but the fossiliferous *Pycnactis* Band stands out. The main facies are described separately.

(b) Siltstone and mudstone facies

The silt and mud units are 50-400 mm thick and are significantly more laterally extensive than the other rock types in the sequence. They are finely laminated in places, but generally have a rubbly appearance because of weathering. The siltstones include the *Pycnactis* Band, which is 0.3-1.3 m thick, with fossils forming up to 60% of the volume. The most abundant fossils include brachiopods, solitary rugose corals, and crinoids. The siltstones are either a dark red or green, and there are transitions between these two colours within a single rock unit.

(c) Limestone units

Limestone units are generally discontinuous, and vary in thickness from 20-180 mm. They have a marly appearance and, when dissolved, have a relatively high quartz and siltstone content. The grain size is generally quite coarse, but there are a number of finer bands. Limestone boulders collected loose were highly crystalline and mainly composed of calcite and aragonite, but limestones collected from the logged sections were more muddy, with a high percentage of ferroan calcite. The more crystalline limestones have abundant small shell fragments that can just be distinguished with the naked eye, and which seem to have become recrystallized through diagenesis. The marly limestone is made of up to 25% fossil remains including crinoids, brachiopods, corals and bryozoans.

(d) Sandstone units

The largest sandstone unit outcrops at the northwestern end of the quarry, with a maximum thickness of 2 m, but the logged sections (Fig. 4) exhibit only
Fig. 3 Geology of the southern part of the Tortworth Inlier, showing the location of Brinkmarsh Quarry. Based on Curtis (1972).
Fig. 4. Sedimentary logs recorded at four locations (A–D) along the southwestern margin of Brinkmarsh Quarry, Gloucestershire in the lower Brinkmarsh Beds (lower Wenlock, Silurian). The fifth log (E) is based on the first section recorded by Reed & Reynolds (1908: 525). Locations of logs A–D, and probable location of log E, are indicated on the topographic guide map.
small units ranging from 50–400 mm. They appear at the base of all the logged sections. The sandstones are red and green in colour, but this is discoloration from the once overlying Keuper Marl. In thin section, the original colour can be seen as yellowish grey. Grain size varies from very fine (95 mm) to medium (375 mm), and samples are moderately sorted. The cement is generally a combination of ferroan calcite and silica. Sedimentary structures include hummocky cross-stratification (HCS), planar cross-lamination, ripple cross-lamination, fine parallel lamination, and occasional burrows and tool marks. Many of the sandstone beds also exhibit coarse shelly layers up to 30 mm thick, either suspended in the middle of a coarse sandstone, or at the base or top of a graded unit. Two types of sandstones occur, non-calcareous and calcareous sandstones, and these will be considered separately.

(e) Non-calcareous sandstones

The most distinctive sedimentary structure in the non-calcareous sandstones is HCS (Harms, Southard, Spearing & Walker, 1975). The characteristics of HCS are a low-angled erosional lower surface, overlying laminae parallel to the basal surface, overlying laminae may thicken laterally in a set giving a fan-like trace, and dip directions of the laminae vary. Collinson & Thompson (1989) indicate that HCS undulations are at most 0.2 m high, with wavelengths of about 1 m. These values may depend on grain size of sediment, near-bottom current velocities and depth of water (Bourgeois, 1980).

In the northwest corner of the quarry, a coarse sandstone exhibits HCS of full size (Fig. 5A), with hummocks 0.2 m high and 1 m across. Hummocks from thinner sandstone beds (Fig. 5B) are considerably smaller, 10–20 mm high and 50–100 mm across, but they still display the essential characteristics of HCS, including tool marks on the lower erosional surface. It is not clear whether these smaller features are true HCS or not.

There are also examples of simple cross-lamination in these sandstone units. One example (Fig. 5C) shows three repetitions of cross-lamination, separated by phases of planar lamination, within a single unit, suggesting episodic deposition, with fluctuating
current intensities. There is also a small escape burrow at the base of the unit, which presumably formed as an organism became overwhelmed by a sudden influx of sand.

Ripple marks are also observed at various scales in the sandstone units, including larger ones (60 mm wavelength, 5 mm amplitude) at the top of a coarse sandstone unit (Fig. 5D). These are asymmetrical ripples with straight sharp to rounded crests and rounded troughs.

(f) Calcareous sandstones

There are many examples of simple graded bedding and of inverse graded bedding within the calcareous sandstones, but the shell beds (coquinites) are most significant. These include typical basal shell beds, but also suspended coquinites, which are significant for the environmental interpretation.

Basal shell beds occur in fine-grained sediments. These units may contain large brachiopod shells that are generally much larger than those preserved in the siltstones, being up to 40 mm in length (Fig. 6, 7A). The shells are aligned and preserved in the convex-up position, which is hydrodynamically most stable, and they are relatively unbroken. There are a few brachiopod shells that are still articulated. Some brachiopod shells show shelter porosity cements (Kreisa, 1981), sparry calcite crystals that have grown down from the shells, and up from the underlying fine-grained sediment, to fill pore spaces concealed beneath the convex brachiopod valves (Fig. 7A). The coquinite grades up into a muddy unit which is much less calcareous. In a similar specimen (Fig. 7B), there is a synsedimentary fissure through the coquinite which has subsequently been infilled with the overlying mud. This indicates that the basal calcareous sand and coquinite had partially lithified before deposition of the muddy layer.

Suspended coquinites are not uncommon in the thin calcareous sandstone beds, and may occur at the top of beds (Fig. 7C). In this case, the shell debris bed has scoured out part of the underlying fine-grained sandstone, leaving a clear erosional surface. The shell debris here consists only of small fragments which are aligned with the base of the unit. In other cases, there may be several suspended coquinites in a sandstone bed; one example (Fig. 7D) shows three. The coquinites vary in thickness across the cut section from 12 mm at one end to 2 mm at the other. The fossil fragments are mainly brachiopod shells, some complete, and some broken, which have a maximum size of 15 mm. The whole shells in the coquinite have a random orientation, showing both convex-up and convex-down positions.

Fig. 6. Sedimentary structures in the calcareous sandstone units in the lower Brinkmarsh Beds (lower Wenlock, Silurian) of Brinkmarsh Quarry, Gloucestershire. Cut sandstone bed showing basal brachiopod shell lag, grading up through fine sand to mud at the top; brachiopod shells are relatively undamaged and lie convex-up; shelter porosity cement under one shell just left of centre, BRSUG 25606; centimetre scale shown; compare with diagram Fig. 7A.
3. PALAEONTOLOGY

Fossils were collected from the *Pycnactis* Band, which has the greatest abundance and diversity of organisms in the Brinkmarsh Beds. The degree of packing of shells varies from shell-supported to matrix-supported, dependent on the overall abundance of fossils. The fossils are usually preserved as original or slightly recrystallized shell material. The fossils seem to be in situ, or nearly so, since there is no evidence of sorting, orientations are random, articulated shells are common, and even the thin-shelled brachiopods are usually undamaged. At lower levels, some of the shells have been crushed because of compaction.

The commonest elements within the community are the brachiopods, which also show the greatest diversity. Examples of *Atrypa reticularis*, *Rhynchorotreta cuneata*, *Resserella basalis*, *Howellella* sp. and *Amphistrophia* sp. were identified. Curtis (1972) noted also from this unit *Sphaerirhynchia davidsoni*, *Camaratoechia* cf. *nucula*, and *Whitfieldella* cf. *canalis*, while Cave (1977: 34) termed the species of *Resserella*, *R. whitfieldensis*. Small solitary rugose corals, *Pycnactis mitrata* and *Phaulactis* cf. *angusta*, were relatively common, although rarer than in typical Wenlock localities. Other fossils include gastropods, crinoid ossicles, bryozoan branches, trilobite fragments and tentaculitids.

The fauna of the *Pycnactis* Band at Brinkmarsh Quarry is indicative of the *Salopina* Community defined by Calef & Hancock (1974) in the Wenlock of the Welsh Basin and the Welsh Borders. The brachiopod taxa *Rhynchotretata cuneata*, *Howellella*, *Atrypa*, *Camaratoechia* and *Amphistrophia* are listed by Calef & Hancock (1974) as typical members of this community. The numerical dominance of *Rhynchotreta* and *Atrypa* in the sample, as both whole shells and as debris, is also typical. Calef & Hancock (1974: 808) made the same determination for their collection of Brinkmarsh beds fossils.

The *Salopina* community is interpreted (Calef & Hancock, 1974) as indicative of shallow-water marine conditions, being equivalent to the *Eocoelia* community of the Llandovery (Ziegler, Cocks & Bambach, 1968). *Salopina* community brachiopods are typically found in sediments which exhibit flaser-bedding, herring-bone cross-bedding, and other extremely shallow-water features. The relative abundance of members of the *Salopina* community indicates a rich food supply, in the

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**Fig. 7.** Diagrams of sedimentary structures in cut sections of the calcareous sandstone units in the lower Brinkmarsh Beds (lower Wenlock, Silurian) of Brinkmarsh Quarry, Gloucestershire. Scale bar 50 mm. (A) Basal shell bed, showing convex-up complete brachiopod shells, with some evidence of normal grading; carbonate cement (revealed by staining) extends some distance above the shells; note the shelter porosity calcite cement, BRSUG 25606; compare with the photograph in Fig. 6. (B) Basal shell bed in laminated sandstone, grading up into siltstone; note the synsedimentary fissure filled with overlying sediment, BRSUG 25607. (C) Suspended coquinite, consisting of comminuted skeletal debris sitting on an irregular erosional base, BRSUG 25608. (D) Suspended coquinites in a parallel-laminated fine sandstone; coquinites are composed of comminuted skeletal debris, and rest on cross-cutting erosional bases, BRSUG 25609.
form of the amount of food that reaches the sea bottom, which is especially relevant for the suspension-feeding brachiopods (Calef & Hancock, 1974). Unlike normal shallow shelf environments, the *Salopina* community is composed of non-burrowing suspension feeders (Cocks & McKerrow, 1978) and the sediments in Brinkmarsh Quarry reflect this, with only two burrows preserved in the sample collection.

Fossils found through the Tortworth Llandovery and Wenlock section indicate some deepening of the water. The Damery Beds (late Llandovery) yield an *Eocoelina* community, indicative of near-shore open marine conditions (Ziegler et al., 1968). The Tortworth section continues from the very shallow bivalve zone, up through the *Salopina* and *Homoeospira* zones during the early Wenlock, indicating that there is a deepening event through this period (Hurst et al., 1978). In the May Hill Inlier, 30 km north of the Tortworth Inlier, the sequence shows a shallowing trend, moving from the Llandovery *Clorinda* community, indicative of continental shelf margin, to *Isorthis* and finally *Homoeospira* (Hurst et al., 1978). Further north, in the Woolhope and Malvern areas, Wenlock rocks of the same age yield members of the *Dicoelosia* community, indicative of deeper marginal shelf waters.

4. ENVIRONMENTAL INTERPRETATION

(a) Background deposition

In interpreting taphonomic facies, there must be a distinction between background and episodic deposition. Background sedimentation is defined as the continuous accumulation of sediments, be it fast or slow, under fair-weather conditions (Brett & Baird, 1986). At Brinkmarsh Quarry, this is represented by the siltstones, mudstones, and limestones. In contrast, episodic sedimentation refers to rapid and abruptly terminated depositional events, occurring randomly with respect to time, and associated with storms, hurricanes, seismic shocks and slumps (Brett & Baird, 1986). At Brinkmarsh Quarry these episodic events are represented by the sandstone units.

The siltstones and limestones represent periods of reduced current activity and reduced clastic input, when silt and mud settled from suspension. The low sedimentation rates and repeated winnowing of the silts and muds by weak shelf currents resulted in the accumulation of a shell-rich sequence that has considerable thickness and lateral extent. The winnowing mechanism was not strong enough to sort the fossils within the sequence, but was able to remove the accumulating silts and muds. As a result of this, the *Pycnacites* Band must represent time-averaged community relics. The other result of this winnowing is the production of large shell beds, during periods of calm seas, that are packed with fossils. The parallel laminations of the silts and muds in the *Pycnacites* Band are slightly distorted, possibly by settling of the sediment from suspension around the fossil grains.

(b) Event beds

The sandstone beds probably represent episodic storm events that occurred as both single and multiple cycles. Key evidence for this interpretation is the observation of hummocky cross-stratification (HCS), sharp-based graded coquinites and suspended coquinites within the sandstone units.

Harms et al. (1975) explained HCS by oscillatory motions of storm waves which sweep and deposit sediment over a hummock-and-swale surface during an erosional storm event. The occurrence of HCS in shallow marine settings, with clear associations with complex wave action and episodic deposition has led to its interpretation as the product of a storm event, at the peak of vigorous wave action (Walker, 1984; Brenchley, 1985; Collinson & Thompson, 1989). The sharp base and lack of bioturbation in the HCS unit indicates a sudden influx of sediment followed by rapid deposition, and the absence of subsequent reworking into cross-laminated or cross-bedded structures indicates that the sediments were deposited below fair-weather wave base. Production of hummock-and-swale structures requires a great deal of suspended sediment, and the most probable process that can produce shelf waters with a high percentage of suspended sand is a flood storm event (Bourgeois, 1980).

HCS units may show a sequence of features, in 'ideal' cases (Brenchley, 1985). The base is erosive, as the storm flow cuts down into pre-existing sediment and, in cases of carbonate environments, there may be a basal coquinite. Such basal shell beds were found in several sandstone units in Brinkmarsh Quarry (Fig. 6, 7A, B). These represent shell lag deposits that were the first materials to be dumped, as the current velocity dropped, and the shells were subsequently flipped over into the hydrodynamically stable convex-up position.

After the first erosive phase in a storm event, sand may be deposited with parallel lamination, probably as a result of deposition from suspension, and the top may be eroded again into a hummocky surface (Brenchley, 1985). Repeated deposition of sand from suspension and storm wave erosion creates the cross-cutting units of sand. With declining storm activity, the 'ideal' proximal storm bed may finish with asymmetrical ripples on top, indicating fair weather wave action, a feature seen here (Fig. 5D).

Shell beds with sharp erosional bases and some evidence of grading are relatively common in the lower Brinkmarsh beds, and these are indicative of storm activity (Aigner, 1985; Eckert & Brett, 1989). In addition, many of the large brachiopod shells are relatively complete (Fig. 7A), and some are still articulated, which suggests that the coquinites were
concentrated by winnowing rather than by substantial transport.

The suspended coquinites (Fig. 7C, D) were probably formed during very rapid sedimentation events which involved pulses of different current velocities, sampling from different sediment sources, allowing the rapid build-up of sediment with occasional shell lenses. Such suspended coquinites were noted also by Brenner & Davis (1973) in late Jurassic storm beds in Wyoming, by Benton & Gray (1981) in thin sandstone beds in the late Llandovery Hughley Shales of Shropshire, and by Johnson (1989) in the early Silurian of southern Norway. It is hard to explain such non-basal shell debris beds other than by episodic current flow and changing sources of sediment supply, such as could readily occur during a storm event. Periodic flushing of marine bar ridges during storms results in the platformward transportation of coarse shell debris into the depositional area (Brenner & Davis, 1973).

In a review of relevant literature, Brett, Boucot & Jones (1993) suggest that storm activity on bottom sediments normally indicates a water depth of 20–150 m. Reworking of sediment by lowered storm wave base, producing proximal storm beds, may occur within the depth range of 10–60 m (Brett, 1983), and the effects of storms are expressed in deeper waters by distal deposits produced by density flows down the slope. The event beds at Brinkmarsh appear to belong to the proximal shallower-water category because of the presence of HCS and coquinites.

Water depth in ancient sediments may also be indicated by certain marker organisms. The presence of rugose corals and (rare) tabulate corals in the Pycnactis Band of the Brinkmarsh Beds could also indicate a limit on water depth, if these corals had zooxanthellae, and were hence restricted to the photic zone. The maximum depth for zooxanthellate corals is 150 m, with a normal range down to 80 m (Brett et al., 1993). The Eocoelia community of the Llandovery probably indicates depths in the range 5–45 m, based on a variety of physical and biological evidence (Brett et al., 1993). If the Salopina community of the Wenlock is equivalent, as suggested by Calef & Hancock (1974), then a similar depth range could be postulated.

(c) Depositional environment

The Welsh Borderlands, including the Tortworth Inlier during the whole of the Silurian have been identified as a shelf sequence. The water level at Tortworth during the basal Wenlock was relatively shallow, as it lay above storm wave base, and as it incorporates the shallow-water Salopina brachiopod community. It is not clear, however, whether these beds were deposited on the open shelf, or in an enclosed environment, such as a lagoon or protected embayment.

1. Open shelf model

The Brinkmarsh Beds could represent a muddy shelf that was occasionally disturbed by storms, which transported clastic material from either the mainland to the south or from the Gorsely swell to the east. This style of deposition occurs in modern environments in the transition zone, between coastal sands and uniform shelf mud. However, the palaeontological evidence in Brinkmarsh Quarry indicates that there was some form of physical separation between the storm 'faunas' in the coquinites and the normal faunas in the Pycnactis Band. Neither fauna was transported far – the preservation of the fossils indicates only minimal abrasion and breakage – but there is no evidence of faunal mixing. The large brachiopod shells in the event beds are absent from the Pycnactis Band, indicating that the event beds were sampling a different marine community. Storm surge currents presumably overwhelmed a barrier that divided the two distinctive faunas, and the physical division could be either a barrier reef of a lagoon or uplifted rocks around a basin.

2. Lagoonal model

The intercalation of sands and silts is characteristic of lagoonal environments, but there is little evidence for reef-building organisms in the Brinkmarsh Beds. A lagoonal system also requires a tectonically stable landmass, but the Gorsely Swell was not tectonically stable, nor was it present in the area long enough to allow a lagoonal system to develop, and the landmass to the south would probably have been too distant.

3. Protected embayment model

In this model, the physical barrier is related to volcanic activity in the south, and tectonic uplift of neighbouring areas. These uplifted areas might have formed a protected embayment within the shelf sequence, separating the in situ fossil community from adjacent communities.

The absence of large specimens of many of the brachiopod groups, especially Atrypa, could be related to variable salinity levels of the marine waters within this embayment. During the Silurian, Britain lay at sub-tropical latitudes, and there would have been high evaporation rates over the shelf, which would have been enhanced in any restricted basins. This would lead to increased salinity levels in the protected embayment, and occasional mass kills when salinity levels became too high. The storm events would then overwhelm the barriers and replenish the system with normal-salinity marine waters, which would allow the community to recuperate. Evidence for mass kills is found in the Pycnactis Band, where brachiopods of all sizes are found, presumably juveniles and adults, in vast abundance.

Siveter & Turner (1982) independently suggested that the lower Brinkmarsh Beds might have been deposited in an enclosed basin based on the thelodont fish faunas. The thelodonts from Brinkmarsh show more affinity
with those from the Baltic region than with those elsewhere in Britain. The species *Thelodus parvidens*, common elsewhere in the Silurian of England, is absent, and Siveter & Turner (1982) suggest that this might be evidence for isolation of the Tortworth area from the typical Welsh Borders shelf area to the north.

5. SUMMARY AND CONCLUSIONS

During early Wenlock times, immediately north of the permanent landmass, in the area between Bristol and Gloucester, lay a belt of shallow-water arenaceous sediments which pass northwards into limestones represented by the Woolhope Limestone. The lateral interdigitation of limestones and calcareous sandstones at the base of the Brinkmarsh Beds indicates that this area lay close to the boundary between these two facies. The sediments and fossils in the Brinkmarsh Beds indicate deposition in near-shore shallow marine waters. There was some form of enclosed area around Tortworth, probably a protected embayment, that was generally shallow, warm, and undisturbed. During this period, siltstones and mudstones were deposited together with occasional limestone bands. The fauna consisted of shallow-water suspension feeders that were abundant in numbers but not in diversity, dominated by brachiopods, but also with solitary rugose corals, bryozoans, trilobites, gastropods, and tentaculitids. The *Pycnactis* Band, which is the thickest and richest fossil bed, built up through the joint processes of sediment starvation and current winnowing. Perhaps fluctuating salinity within the enclosed environment caused mass kills.

Periodic storm events swept sandy sediments into the basin, together with large brachiopods and other fossil debris from neighbouring, presumably shoreward areas. The storm-event sandstones exhibit hummocky cross-stratification and suspended shell beds, indicating that there were probably multiple storm events that affected the depositional environment, with varying degrees of intensity and effect.

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