Sedimentation across the Tywi Lineament, Mid Wales

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Sedimentation across the Tywi Lineament, mid Wales

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Along the southeast edge of the Welsh Basin, faults control sedimentation throughout the Lower Palaeozoic. Two important fault zones in the Llandovery area are the Myddfai Steep Belt and the Tywi Lineament, both of which show several phases of movement that are reflected by subtle changes of sedimentary facies.

The Myddfai Steep Belt consists of a relatively simple fault system that defined a palaeoshoreline in Ashgill time, only becoming fully overstepped by a basal Wenlock transgression. The Tywi Lineament, which lies further offshore, is a more complex structure. Facies variations across the lineament were controlled by a fine balance between the sedimentation and fault displacement rates, with the fault tip lines concealed beneath a blanket of shelf sediment. Coarse clastics were resedimented locally in response to rapid displacement on fault strands. Less dramatic fault movements are shown by *in situ* liquefaction of mudstones, together with a variety of small-scale soft sediment deformation features.

The Tywi Lineament was active from at least Ashgill to Pridoli time, and was probably originally an extensional fault, reactivated in a transpressive stress régime. Evidence for possible oblique slip during Ashgill time is found elsewhere along the Lineament.

1. Regional setting

The southeast margin of the lower Palaeozoic Welsh basin is defined by a suite of northeast–southwest trending lineaments, of which the Myddfai Steep Belt and the Tywi Lineament run through the Llandovery area (figure 1). The Myddfai Steep Belt trends northeast into the Clun Forest Disturbance, which cuts the northwest edge of the Builth–Llandrindod inlier. The lineament then traces on into the Pontesford–Linley Fault, which defines the southeast edge of the Shelve inlier (Woodcock 1984; Whittard 1979). To the south of Llandovery, the lineament swings to trend ENE–WSW at Red Roses, beyond which it merges with post-Carboniferous structures (figure 1).

The Tywi Lineament is less well constrained. The structure has an anticlinal outcrop pattern, closing to the northwest at Abbey Cwm-Hir (figure 1), where it is overlain by Silurian rocks (Roberts 1929). To the southwest of Llandovery, the lineament passes close to Llandeilo, and then gradually curves to trend E–W at Carmarthen (Evans 1906). Further west still, in north Pembrokeshire, the Tywi Lineament becomes NW–SE trending, possibly owing to passive rotation during Variscan deformation (figure 1). Separation of the effects of Variscan and Caledonian deformation is possible at Carmarthen, but becomes more ambiguous to the west (Cope 1979).

The object of this paper is to review the current evidence for the activity of the Tywi Lineament during the early Palaeozoic and to examine lineament control on sedimentary facies during Ashgill time.

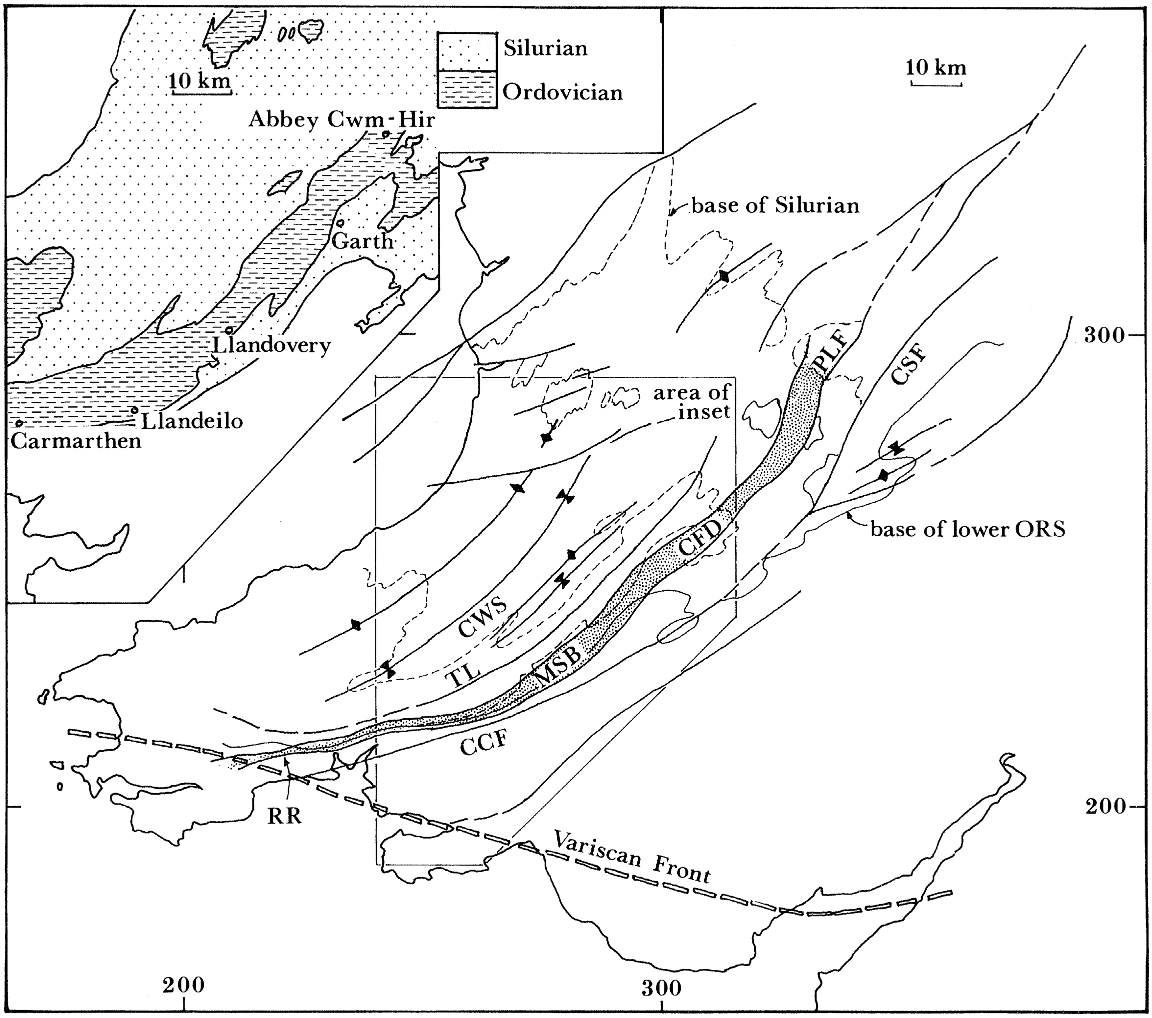

Figure 1. Outline map of Central Wales, showing major structural elements within the Lower Palaeozoic (modified after Woodcock 1984). CCF, Careg Cennen Fault; CFD, Clun Forest Disturbance; CSF, Church Stretton Fault; CWS, Central Wales Syncline; MSB, Myddfai Steep Belt; PLF, Pontesford–Linley Fault; RR, Red Roses Disturbance; TW, Tywi Lineament; ORS, Old Red Sandstone. Inset is location map of the Tywi Lineament. See text for details.

2. APPRAISAL OF LINEAMENT HISTORIES

(a) *The Myddfai Steep Belt*

The Myddfai Steep passes 3 km SE of the Llandovery area, where it is represented by a suite of NW downthrowing normal faults (Cocks *et al.* 1984). This fault strand located a palaeoshoreline in late Ashgill time, with deposition of shallow subtidal clastics to the west (Woodcock & Smallwood 1986). Ashgill to Middle Llandovery rocks thin towards the fault belt and are overstepped by transgressive Upper Llandovery littoral sandstones (Cocks *et al.* 1984). The fault belt was fully overstepped in Wenlock time, with deposition of laminated fine clastics in an open-shelf environment throughout the area. In the south of the Llandovery area, top Ordovician tidal delta sediments also show evidence of active faulting during sedimentation (Woodcock & Smallwood 1986). At Garth, 25 km northeast of Llandovery (figure 2), Llandovery rocks progressively thin onto the lateral equivalent of the Myddfai Steep Belt, which again is fully overstepped by Wenlock rocks (Andrew 1925). At Llandeilo, 15 km southwest of the Llandovery area (figure 2), Llandovery rocks are almost absent along the fault belt. Wenlock rocks overstep the Upper Llandovery to rest on middle Ordovician strata (Williams 1953), but there is not necessarily a simple progressive overlap within the Silurian rocks (Squirrel & White 1978).

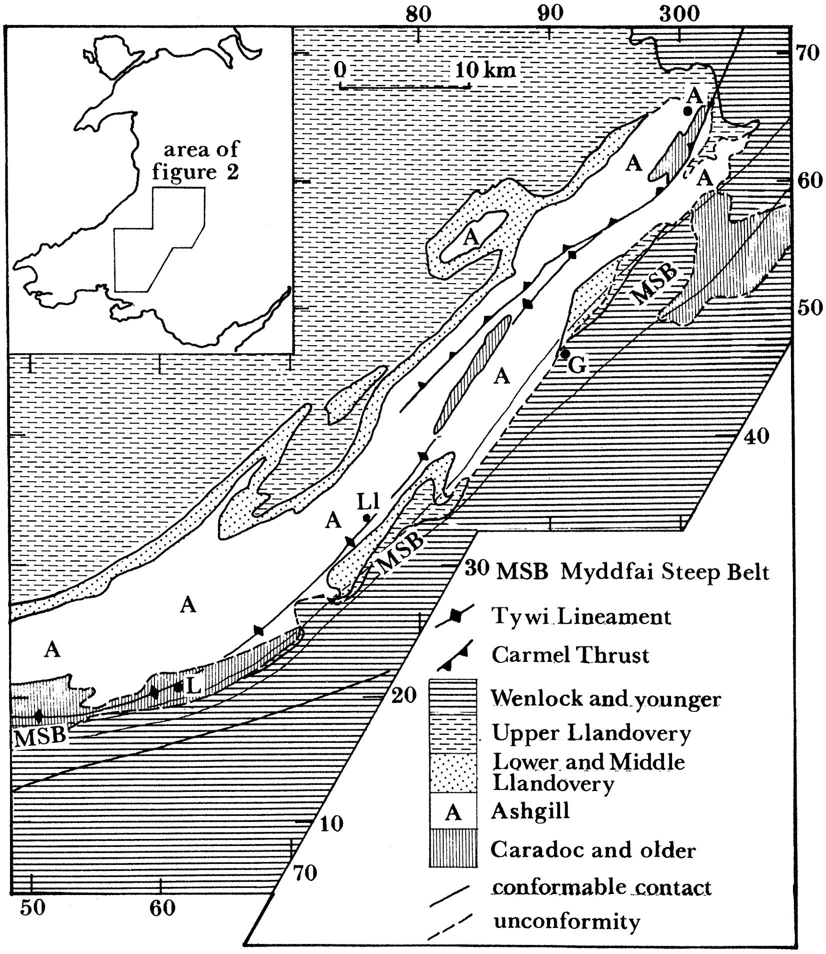

Figure 2. Stratigraphic map of the Tywi Lineament and Myddfai Steep Belt (modified after Jones 1938). A, Abbey Cwn-Hir; G, Garth; L, Llandeilo; Ll, Llandovery.

Thus, there is evidence for a long history of syndepositional tectonic activity along the Myddfai Steep Belt, extending from at least Ashgill through to Upper Llandovery time. The local fault activity is superimposed on overall eustatic variations, which have larger scale effects on facies distribution (James 1983). Clear evidence for strike-slip movement on the fault belt is absent in the Llandovery area, but has been reported further to the northeast on the Clun Forest Disturbance and also along the Pontesford Lineament during Ashgill–Upper Llandovery time (Woodcock 1984).

(*b*) *The Tywi Lineament*

The axis of the Tywi Lineament passes through Llandovery, where it is a fold-dominated structure with complex associated facies relations (figure 2). The lineament is classically regarded as representing the position of the shelf edge during Llandovery time (Jones 1912).

On the shelf to the southeast, bioturbated mudstones and shelly sandstones were deposited in coarsening upward cycles (Cocks *et al.* 1984). In the more basinal areas to the northwest, finely laminated graptolitic mudstones accumulated, with periodic influxes of coarser clastic material.

At Llandeilo, Middle Ordivician shallow subtidal and intertidal facies sediments are interbedded with volcanics, indicating the presence of a palaeohigh along the lineament (Williams 1953). Ashgill rocks are restricted to the northwest side of the lineament. Deposition may have taken place further to the southeast in the Ashgill, but the sediments must have been stripped off the lineament as a result of uplift before late Llandovery time. Another palaeohigh on the Tywi Lineament was at Llanwrtyd, where Llandeilo–Caradoc sediments show shallow-water facies associated with a volcanic centre (Stamp & Wooldridge 1923).

At Abbey Cwm-Hir, the lineament marks a southeast to northwest shelf to basin transition in Ashgill rocks. Upper Llandovery and Wenlock rocks overstep the lineament but thin markedly to the east (Roberts 1929). Further northeast, in Clun Forest, the lineament probably controlled the development of slumps in rocks of Ludlow–Pridoli age (Earp 1940).

Stratigraphic control on the periods of movement of the Tywi Lineament is relatively poor. However, it is clear that early widespread movement took place during Ashgill time, and the lineament continued to be tectonically active until latest Silurian time. Fault motions in the Llandovery area are either dip-slip or steep oblique-slip at outcrop. The steep regional cleavage transects fold axes at low angles in a clockwise sense, suggesting that Caledonian folding took place in a transpressive régime (Woodcock 1984; Soper & Hutton 1984). However, there is no clear evidence for strike-slip displacement along the Tywi Lineament during the Ashgill and Lower Llandovery.

3. Ashgill sedimentology of the Llandovery area

A thin belt of top Ordovician tidal facies sediments outcrops along the Myddfai Steep Belt. The Tywi Lineament passes 2–3 km to the northwest of this belt, offshore from the shoreline facies. The Ashgill sediments of the Tywi Lineament area were therefore deposited in a fully marine environment.

The sediments may be divided into background and slump facies.

(*a*) *Background facies*

The sediments are predominantly silty mudstones with intercalations of sandstones. The mudstones are finely laminated, with graded silt laminae and silt–mud couplets. The silt laminae often show rolling grain ripples, together with slight lenticularity and sharp tops. Rare thin, fine-sand laminae have starved current ripples with graded silty drapes. The mudstones frequently contain small vertical burrows, together with feeding tracks. However, bioturbation is not present in significant amounts.

Sandstones occur as lenticular packets within the mud-dominated sequence. The 'shelf' facies sand packets are composed of 5–30 cm thick, slightly lenticular, fine to medium sand layers, together with interbedded massive dark silty mudstones. The sands commonly show Bouma T_{bc} units, and the tops of the beds are sharp, often with superimposed straight-crested or combined flow ripples. Although some beds are graded, the sand source seems to have been very well sorted so that often little grading is present within a narrow grain-size distribution.

Conglomerate units up to 50 cm thick occur in the 'shelf' facies sandstones. The dominant clast types are well rounded vein quartz and quartzite, together with black shale clasts which are sometimes armoured. There are also non-comminuted bioclasts, mainly streptoplasmid corals and large articulated brachiopods.

'Tidal' facies sandstones occur in isolated patches across the Tywi Lineament area (figure 3). These are thin-bedded sandstones containing flaser and lenticular lamination, with very little grading.

This sequence accumulated in a quiescent open shelf or upper-slope environment. The finer grained sediments were deposited by low-energy traction currents. The 'shelf' facies sandstones were probably deposited by strong offshore directed storm return flows reworking well sorted

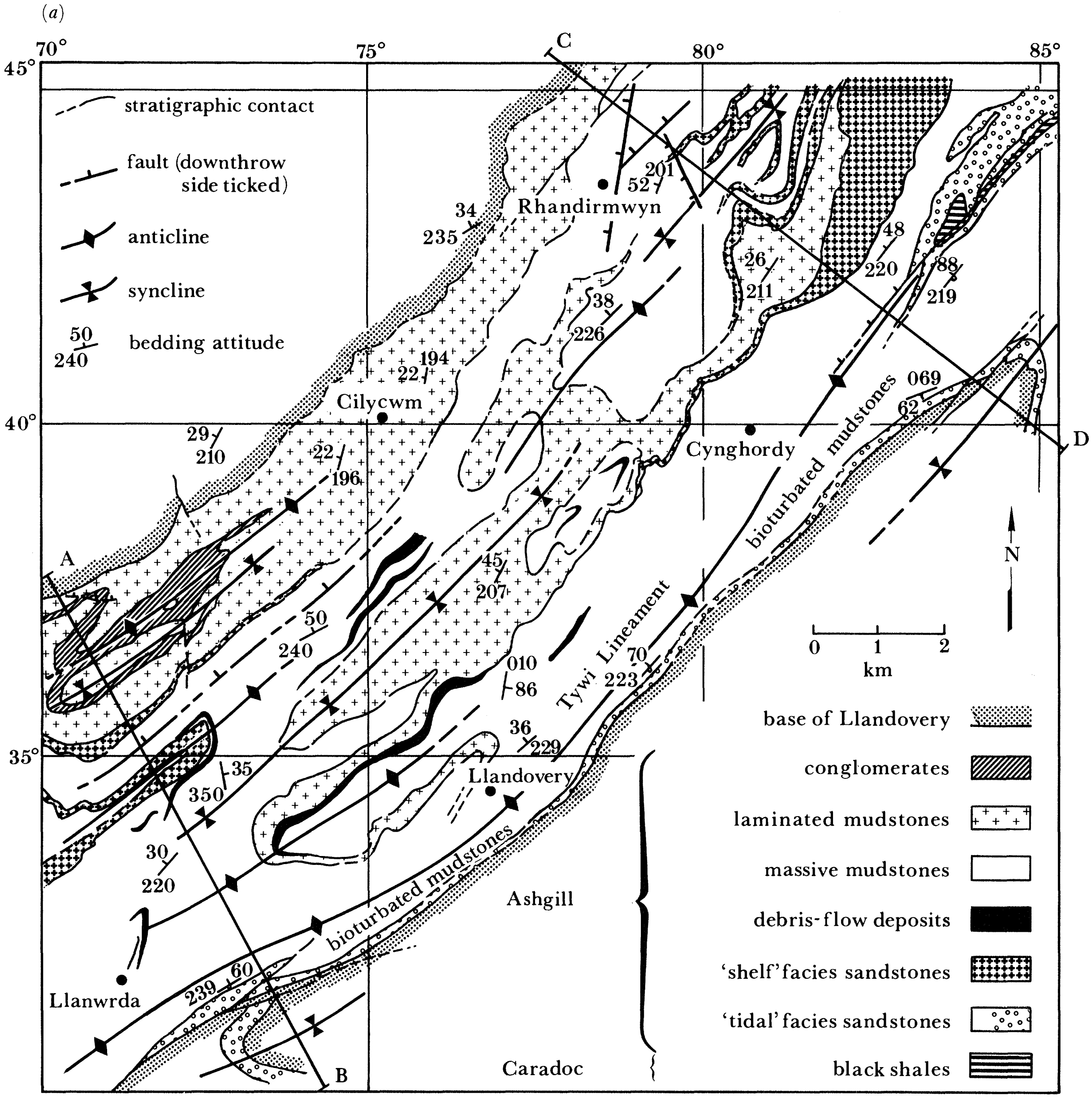

FIGURE 3 (*a*). For description see p. 284.

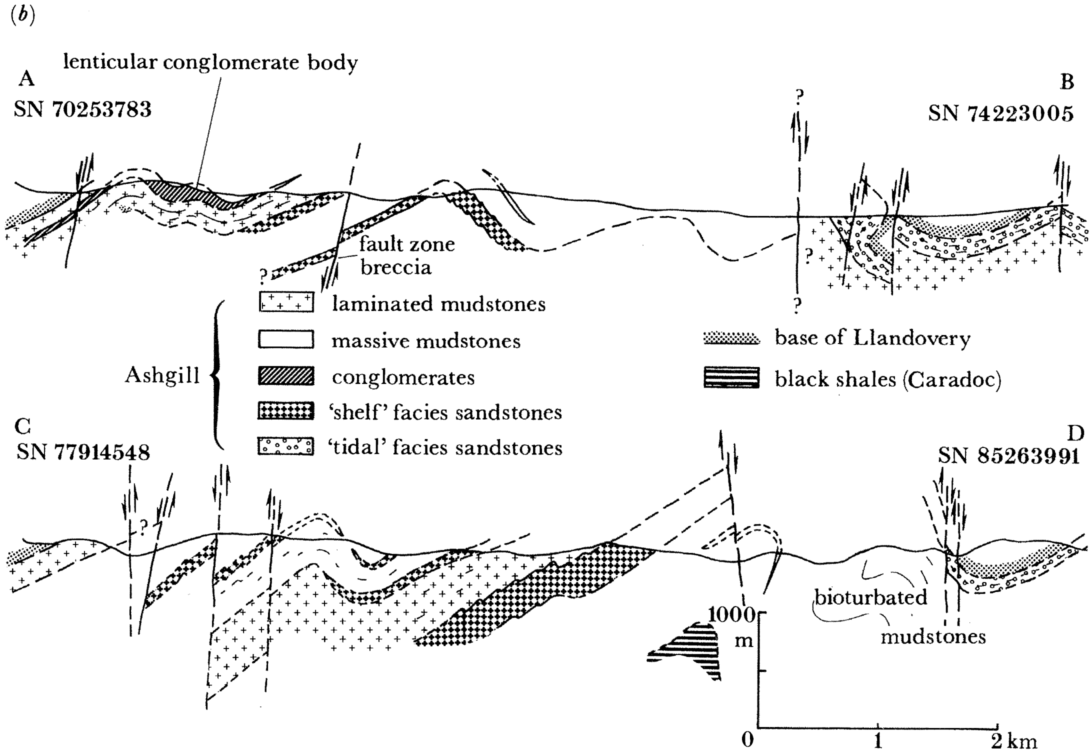

Figure 3. (*a*) Simplified map of the Llandovery area, mid Wales, showing main structural elements and major lithofacies units. (*b*) Sketch sections along lines shown in figure 3*a*.

nearshore sands. The 'tidal' facies sandstones show local wave or tidally influenced deposition on palaeohighs.

There are also marked facies changes along the length of the Tywi Lineament. Coarser grained sediments pass into mudstones in the centre of the mapping area (figure 3). A similar facies pattern in Ashgill and Llandovery age sediments has been reported from the area immediately to the southeast (Cocks *et al.* 1984; Woodcock & Smallwood 1986). The facies changes seem to be related to the syn-depositional development of periclinal structures trending parallel to the lineament. However, the control on pericline development is not clear.

(*b*) *Slump facies*

The slumped sediments in the Tywi Lineament area may be separated into two end-members, autochthonous slump sheets and allochthonous debris flows. These two slump facies are incorporated into a model with a primary tectonic control, which relates their formation directly to the syndepositional activity of buried faults along the Tywi Lineament.

(i) *Slump sheets*

The laminated mudstones can be traced laterally into the massive or slumped lithofacies mudstones on outcrop scale. The slumped muds consist of largely structureless silty mudstones in slump sheets up to about 10 m thick. The bases to the sheets are gradational. Laminated mudstones become more deformed upwards until only diffuse, silty wisps remain. Thin sand layers deform ptygmatically, but the laminae frequently remain intact, suggesting only minor displacements for the slump sheets. The tops of the sheets are fairly sharp and they are conformably overlain by laminated mudstones, indicating a lack of any substantial topography.

Sand volcanoes and convolute lamination are widespread in the sandstone packets, because of high pore pressures caused by rapid rates of sand deposition. Dewatering on a larger scale is shown by disaggregation of sand layers into separate lenses, which founder into the surrounding mudstones. This process is interpreted as liquefaction essentially *in situ*, and may be associated with slump-sheet movement. In one locality (SN 76193605), a 1.5 m thick pebbly sandstone unit has been fabricated down a local northwest-dipping palaeoslope to form a soft sediment duplex. The ramps are lubricated with a thin veneer of black shale, and black shale is also injected into incipient fractures in the sandstone horses. This deformation style suggests that the sandstones were better lithified and behaved as rigid rafts in the high-ductility muds. The sand unit is interbedded with slumped mudstones, which retain very little lamination, and show some isolated sand blocks.

These para-autochthonous slump deposits show localized sediment instability. The average sedimentation rates are low, and there is little evidence for a large-scale depositional slope from southeast to northwest through the Llandovery area. The variable preservation of laminated mudstones both laterally and stratigraphically suggests a local trigger for slump movement. The most likely cause is subdued fault activity along different fault strands on the Tywi Lineament. With fault tip lines buried beneath a thick blanket of sediment, seismic effects would radiate over a wide area, causing only minor deformation.

(ii) *Debris flows*

The pebbly mudstones usually consist of randomly distributed, well rounded quartz pebbles up to 7 cm in diameter, set in a massive silty mudstone matrix. The clast:matrix ratio varies from 5 % to 50 % clasts. Large irregular blocks and lenses of arkosic sandstone and conglomerate up to 2–3 m across are also present. The blocks often show ductile soft-sediment deformation as well as more visco-plastic brecciation, showing that the sediment was only partly lithified when it was incorporated into the mass flow.

The pebbly mudstone units are interpreted as matrix-rich debris-flow deposits. Debris flows are known to move on very low slope angles (see, for example, Prior *et al.* 1984), and so these deposits do not necessarily infer that fault tip lines were emergent above the sediment surface. However, the flows are fully allochthonous, and were probably more closely controlled by the location of active fault strands than the slump sheets. The debris-flow units are up to about 20 cm thick, but are likely to represent compound flows.

(iii) *Conglomerates*

The most direct evidence for localized fault activity comes from a lenticular conglomerate body on the northwest of the Llandovery area (figure 3*a*). The conglomerate body is up to 15 m thick, and extends for at least 10 km along strike. The unit thins to both northeast and southwest into fine-grained mud facies sediments. There is little evidence for erosion either within or below the conglomerates. The conglomerates are clast supported, with a bimodal grain-size distribution. Large, well rounded vein quartz and quartzite pebbles up to 6 cm in diameter are surrounded by coarse greenish subarkosic sandstone. Individual beds are 0.5–2 m thick and map out as discontinuous sheets thinning to the northwest. The units show inverse coarse tail grading at the base, together with concentrations of large, angular rip-up clasts of black shale and laminated calcerous sandstone. Rare pebble imbrication in the conglomerate units show a south or southeasterly source. Occasionally, the tops of the units may be normally graded, but sorting is generally poor through the middle part of the bed. The beds have flat bases and sharp tops and are usually overlain by fining and thinning upward cycles of parallel- and cross-laminated pebbly sandstone. These cross-bedded units show north or northeastward palaeocurrents.

The conglomerates were deposited as a clastic apron against the local fault strand which outcrops as a breccia zone to the southeast (figure 3*b*). It is possible that more fine-grained matrix material may have been present originally, but was flushed out by syndepositional fluidization. If the sediments were originally deposited by clast-supported grain flows however, very steep gradients are required (Lowe 1976). This implies relatively large, rapid displacements on a syndepositional fault so that the tip line emerged above the sediment surface. This local submarine scarp caused very rapid sedimentation to occur by tapping a shallower water mature clastic reservoir to the southeast. Following the mass flow deposition, the tops of the conglomerate units were reworked by high-density turbidity currents to deposit cross-bedded pebbly sandstones.

4. LIMITATIONS OF THE MODEL

Both fault displacement rates and sedimentation rates are likely to be nonlinear functions through time, and will show a very complex interrelation superimposed on overall subsidence. This relation may be viewed as a qualitative graph, with three fields defining sediment response to tectonic activity (figure 4). Field stability depends on sedimentation keeping pace with local fault displacement. Rapid fault displacement will be followed by a recovery period during which the topography is blanketed by sediment (figure 4, field C). The normal position for most environments will be above the equilibrium line, in field B, with net accretion compensating both for large-scale subsidence and local intrabasinal faulting. The finite fault displacement involved is dependent on the ratio of fault slip rate against tip propagation rate. With rapid fault tip propagation, only a small net displacement may occur for the tip to reach the sediment surface.

Deformation style is dependent on depth of burial and sediment induration, causing overlap between the different fields. Also, the biostratigraphic control is very poor, both at the top of the Ashgill and the top of the Caradoc, where a non-sequence may be present (Price 1984). This affects the estimation of average sedimentation rates through the Ashgill. The deformation styles described are not mutually exclusive, and will represent a progression through time. Cyclic loading and sediment instability cause thixotropy and fluidization. Loading may initiate fault and slump movement, giving rise locally to very rapid rates of deposition.

Tectonic activity along the Myddfai Steep Belt and the Tywi Lineament were probably linked, so that more rapid erosion rates associated with fault displacement to the southwest of the basin supplied sediment to newly formed perched tectonic traps over the basin margin, bypassing nearshore sediment traps. This situation is more complicated during the Hirnantian glacio-eustatic regression. A drop of up to 200 m in sea level caused rapid reworking of shallow-water deposits without any tectonic activity necessarily being involved (Brenchley & Newall 1980). After the basal Llandovery transgression, these palimpsest sediments were probably again reworked and transported further into the basin by turbidity and traction currents (Cave 1979).

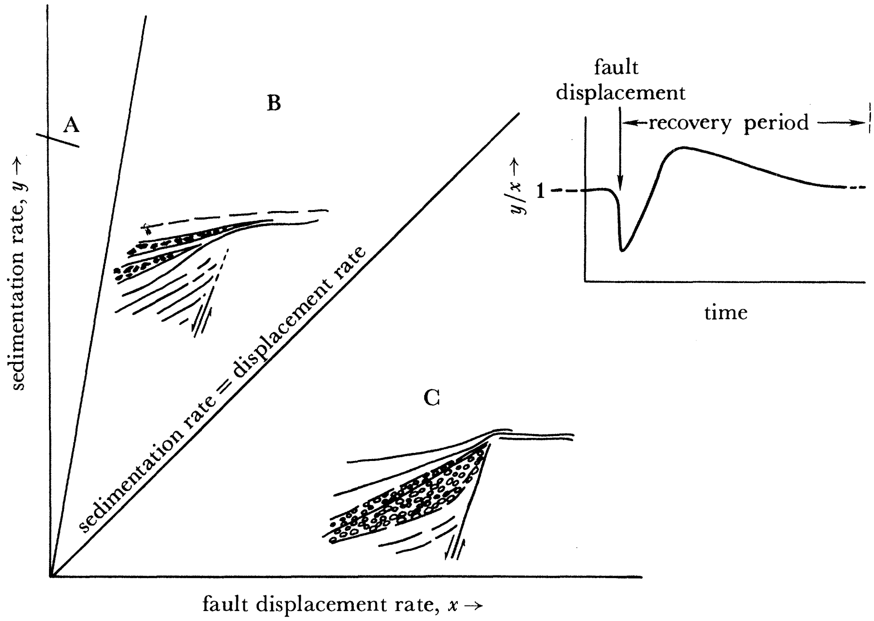

Figure 4. Qualitative model for the relation between sedimentation and fault displacement rates in the Llandovery area, mid Wales. Inset shows response of sedimentation to rapid fault movement through time. Initial topographic irregularity is infilled during a recovery period. In stable field A, sediment is deformed by loading and dewatering in response to subdued seismicity. Stable field B comprises locally irregular topography with sediment draped passively onto scarps; some mass flows are likely. In unstable field C, the fault tip propagates to the sediment surface rapidly, followed by resedimentation to infill topography.

This model may be applied only qualitatively in the Llandovery area. However, with more outcrop and a better constrained structural and biostratigraphic framework, a quantitative estimate of the model parameters could be derived.

5. Conclusions

Ashgill sediments around Llandovery are dominantly mudstones, together with coarser clastic material deposited periodically in an open-shelf–upper-slope environment. Local fault movement initiated sediment instability, with the type of slump facies developed dependent on the speed and scale of fault displacement. Generally, fault tip lines remained buried beneath the sediment cover so that only small-scale slump movement and *in situ* liquefaction occurred. However, when fault displacement rates were faster, shelf sediments were rapidly resedimented to form clastic aprons extending away from the fault tip lines. Rapid deposition continued to subdue the topography throughout a recovery period, after which background sedimentation resumed. The slump facies and the conglomerates provide the only evidence of Ashgill age tectonic activity on the Tywi Lineament in this area.

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