Llanvirn-Llandovery activity on the Llangranog Lineament in Southwest Ceredigion, Wales

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Abstract: A new course is proposed for the Llangranog Lineament between Corris and Strumble Head. Evidence of major contemporary down-to-northwest movement is lacking in the Arenig, fairly firm in the Llanvirn volcanic sequences and weak in the early Llandeilo. Further evidence is provided by both the presence and distribution of turbidites in the mid(?) Llandeilo-Caradoc west of Cardigan, which are absent across the Lineament to the southeast. Later, the Lineament footwall determines the northwestern limit of a non-sequence at the base of the Ashgill around Crymych. Recurrent movement on the Lineament together with movement on the Central Wales Lineament controlled the distribution of turbidites in the early Ashgill around Newcastle Emlyn and in the mid Llandovery around Pencader. Intensity of movement probably increased in the late Llandovery when the Llangranog Lineament controlled the eastern margin of the depotrough of the Aberystwyth Grits.

The Llangranog Lineament

In recent years it has been increasingly appreciated that a distinct zone of relatively high tectonic strain and rapid sedimentary facies changes extends along much of the coastal area of Ceredigion. Important structural elements of the zone include the Sarnau vergence divide south of Llangranog (Craig, 1985) and the Glandyfi vergence divide northeast of Aberystwyth (Cave and Hains, 1986). These were correlated by Craig (1987), on the basis of detailed structural studies, as elements within a major Llangranog Lineament, continuous from Cardigan to the Llyfnant valley. The Lineament was considered to represent the surface expression of a zone of tectonic adjustment between basement blocks. Indeed it overlies a possible deep-seated fracture, the Corris-Llangranog Fault, postulated by James and James (1969) largely on the basis of sedimentological studies in the Ashgill strata of the region.

The Lineament has been referred to variously as the Corris-Llangranog Lineament (Smith, 1987a; James, 1991) and, in the north, as the Glandyfi Lineament (Wilson *et al.*, 1992). Assuming physical continuity, it would be helpful to stabilise on one simple terminology, namely the Llangranog Lineament (e.g. Smith and Anketell, 1992). It has been suggested recently (Wilson *et al.*, 1992) that the Lineament is not continuous along the line suggested by earlier workers and thus a new synthesis of its location and continuity is needed, although not all workers accept the Lineament as a major structure (e.g. Pratt, 1992, fig. 1). This paper attempts to provide such a synthesis and to assess over what timespan the Lineament can be demonstrated to have exerted influence on sedimentation. The synthesis requires integration of sparsely distributed modern and classic published work with data from several unpublished postgraduate theses and with my own field work, much of which is of a reconnaissance nature in poorly exposed areas not studied this century. Parts of the synthesis are therefore speculative; however, they do fit within a self-consistent model which is offered for future testing.

Figure 1 illustrates the concept that the Lineament is continuous between Strumble Head and Corris and that its eastern margin is defined by major faults at the present day surface. In the north of the area these are the Corris Fault and, in agreement with Craig (1987), the Brwyno Fault. Inland from Aberystwyth, the Brwyno and Allt-y-Crib Faults of the Glandyfi tract (Cave and Hains, 1986) and possibly also the Dinas Mawddwy Lineament appear to merge with the major Bronnant Fault (Wilson *et al.*, 1992). Farther southwest, this in turn is here correlated with the Bwlch y Fadfa Fault mapped by Anketell (1987). This latter correlation arises from the coincidence of the Bwlch y Fadfa Fault and the incompletely mapped portion of the Bronnant fault system between SN 440 500 and 470 520. Moreover, the Bwlch y Fadfa Fault marks the southeastern margin of the regional fold vergence divide (Anketell, 1987) in obvious similarity to the Bronnant-Glandyfi fault system (Wilson *et al.*, 1992; Cave and Hains, 1986). Between Newcastle Emlyn and Eglwyswrw there is a gap in published mapping; however, the most plausible Lineament-bounding correlative fault would appear to be that defining the northern extremity of the Fishguard Volcanic Group around Newport (see Figure 1 and Lowman and Bloxam, 1981). The trace of the fault to the west of Fishguard is not clearly recognisable on published geological mapping. If present, its continuation probably lies southeast of the Fishguard Volcanic Group within the Arenig-Llanvirn sequence of the southeast limb of the Goodwick syncline in the Strumble peninsula, before entering Cambrian strata and passing out to sea immediately south of Abercastle (see map in Bevins *et al.*, 1989). A fault in this position could merge with the fault near Newport via a WNW-facing relay ramp, centred about 1.3km east of Fishguard, which contains the Carn Fran and Carn Gelli Faults (see Lowman and Bloxam, 1981, fig. 1).

Between Newport and Machynlleth the position of the Llangranog Lineament argued in this paper shows good to fair correlation with the zone of strong Euler gravity anomalies identified by

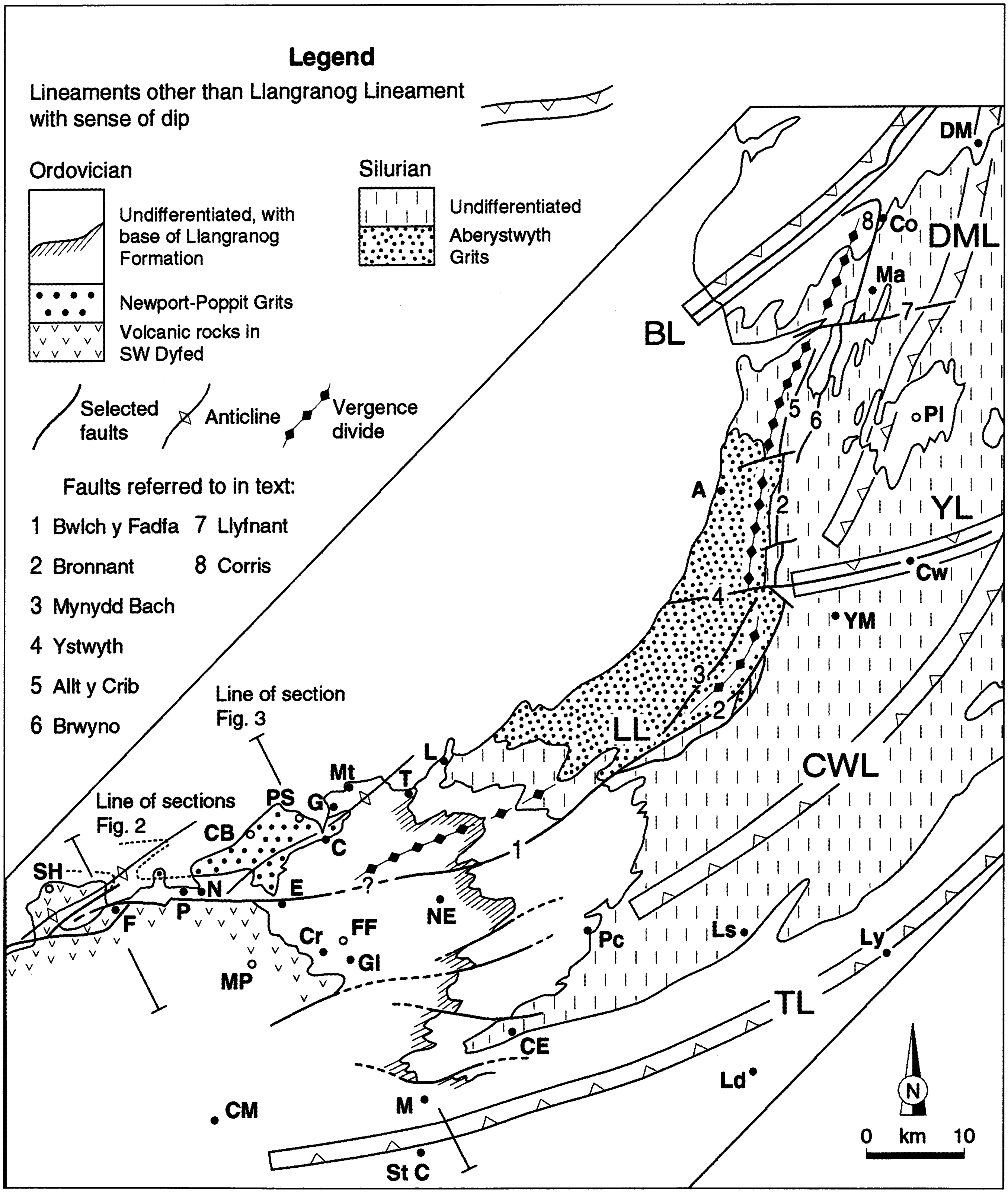

Fig. 1. The Llangranog Lineament as defined by vergence divides and bounding faults on its eastern margin: also shown are other established lineaments.
Legend to localities: A, Aberystwyth; C, Cardigan; CB, Ceibwr Bay; CE, Conwil Elfed; CM, Cotland Mill; Cm, Carmarthen; Co, Corris; Cr, Crymych; Cw, Cwmystwyth; DM, Dinas Mawddwy; E, Eglwyswrw; F, Fishguard; FF, Freni Fawr; G, Gwbert; Gl, Glogue; L, Llangranog; Ld, Llandeilo; Ls, Llansawel; Ly, Llandovery; M, Mydrim (Meidrim); Ma, Machynlleth; MP, Mynydd Preseli; Mt, Mwnt; N, Newport; NE, Newcastle Emlyn; P, Parrog; Pc, Pencader; Pl, Plynlimon; PS, Poppit Sands; SH, Strumble Head; St. C, St. Clears; T, Tresaith; YM, Ystrad Meurig. Key to Lineaments: BL, Bala; CWL, Central Wales; DML, Dinas Mawddwy; LL, Llangranog; TL, Tywi; YL, Ystwyth. Data from Anketell (1987), Cave and Hains (1986), Craig (1987), James (1991 and unpublished), Lowman and Bloxam (1981), McCann (1992) and Wilson *et al.* (1992).

McDonald *et al.* (1992, fig. 6), although the interpretation of basement fault positions shown by these authors does not correspond wholly with that of this paper. Inland of Llangranog, the newly-argued eastern margin of the Lineament lies some 5-7km southeast of the position of the Corris-Llangranog Lineament as depicted by James and James (1969, fig. 1).

Stratigraphical changes across the Lineament

Arenig. Recent study by Traynor (1988) indicates that the sub-Arenig foundation across the trace of the Llangranog Lineament as drawn here is, wherever exposed, formed by the Ogof Velvet Formation (Cambrian). In view of the variable nature of the sub-Arenig foundation elsewhere in South Wales, this suggests quiescence of the Lineament in the early Moridunian. Traynor (1988, p. 289) suggested rapidly increasing localised subsidence in the late Moridunian to early Whitlandian but his palaeogeographical maps (1988, fig. 8) are inconclusive with respect to the influence of fault-control, both with his own positions of basement lineaments (1988, fig. 1) and with those of this paper. It is thus likely that the structural grain of the Llangranog, the Central Wales and, less certainly, the Twyi Lineaments was not strongly developed in the early Arenig and that either inherited regional pre-Arenig structure or local contemporaneous volcano-tectonic structure was still predominant.

Llanvirn. The Fishguard Volcanic Group immediately south of the Lineament is about 90-220m thick around Mynydd Preseli (Evans, 1945) and 65-220m in the equivalent Llanrian Volcanic Formation at Abereiddi Bay (Hughes *et al.*, 1982), which lies to the west of the area shown on Figure 1. It thickens dramatically north of the Lineament to ca. 1800m of subaqueous lavas on the Strumble Peninsula (Bevins and Roach, 1979). This is very suggestive of differential tectonic subsidence across the Lineament and would indicate the same down-to-northwest direction of throw that will be shown below to characterise the later history of the Lineament. However, it could equally indicate differential accumulation of positive relief in a deepwater lava pile and it is plausible that both factors operated (Fig. 2). The thinning of the volcanic rocks across the trace of the Lineament is very rapid and differential isostatic subsidence across it would have been aided by a down-to-northwest fault. The Carn Gelli Fault, which may form a link fault within the Lineament, appears to have been active at this time, bounding accumulation of basaltic pillow lavas (Lowman and Bloxam, 1981, p. 64). On the other hand, any such northwest-facing relief appears to have been locally overcome and indeed reversed by up-building lavas. The evidence for this lies in the sediments of the Strumble Head Series which form thin, local intercalations within the pillow lavas of the Fishguard Volcanic Series near Strumble Head. Thomas and Thomas (1956, p. 301-303) noted that the sediments include cross-bedded feldspathic sands with well-rounded spilitic pebbles, that weathering profiles underlie some of the unconformable contacts of the sediments and that lava stacks had been 'smoothed' before onlap by the sands. These observations suggest shallowing to at least storm wave-base and possibly emergence (George, 1970, p. 27). Southeast of the Lineament, mudstone intercalations replace the intra-lava sands (Evans, 1945), indicating relatively deeper water hereabouts.

Kokelaar (1988, p.771) used evidence from the petrochemistry of the basaltic pillow lavas and of their probable ponding in a graben to propose that the Llangranog Lineament was active at this time in southwest Wales, although he found no evidence that its component faults cut the present day outcrop of the volcanics. He also considered that the volcanics did not form significant positive topography on the sea floor — a view not accepted here. The model illustrated in Figure 2 and the bounding fault location shown on Figure 1 otherwise concur with the majority of Kokelaar's arguments for intra-Llanvirn activity.

Llandeilo. Northwest of the Lineament, Llandeilo rocks comprise the Castle Point Beds (Lowman and Bloxam, 1981) overlain by the mudstones of the Parrog Formation (McCann, 1992). To the southeast the Llandeilo is represented by the Hendre Shales (Evans, 1945). The latter overstep the black shales of the underlying *D. murchisoni* Beds about 2.3km WSW of Eglwyswrw (SN 110 385) (Evans, 1945, p. 99). Judging from the progressive northwest thinning of the *D. murchisoni* Beds over a distance of at least 5km shown by Evans (1945), it is likely that the overstep is genuine and not an artefact of faulting. The overstep suggests that the Lineament then either lay within the southeast flank, or defined the northwest margin of a submarine high north and west of Crymych. The former scenario cannot be proved if the absence of the *D. murchisoni* Beds across the trace of the Lineament in the Goodwick Syncline 1km WNW of Fishguard results from faulting rather than non-deposition, but such faulting is not apparent in the map of Thomas and Thomas (1956, pl. XIV). Absence due to pre-Castle Point Beds faulting is plausible but impossible to prove with current outcrop. The latter scenario, of deepening to the northwest across the Lineament, would be consistent with the presence of thin turbidite siltstones and sandstones in the Parrog Formation (McCann, 1992) and the absence of such deposits in the more calcareous Hendre Shales. The simplest synthesis of this data is that, after the volcanic episode, a northwest facing palaeoslope was not re-established across the Lineament until the Llandeilo (Fig. 2). Subaqueous debris flows within the Castle Point Beds at Fishguard (Lowman and Bloxam, 1981, p. 60) probably indicate proximity to the active Lineament. These debris

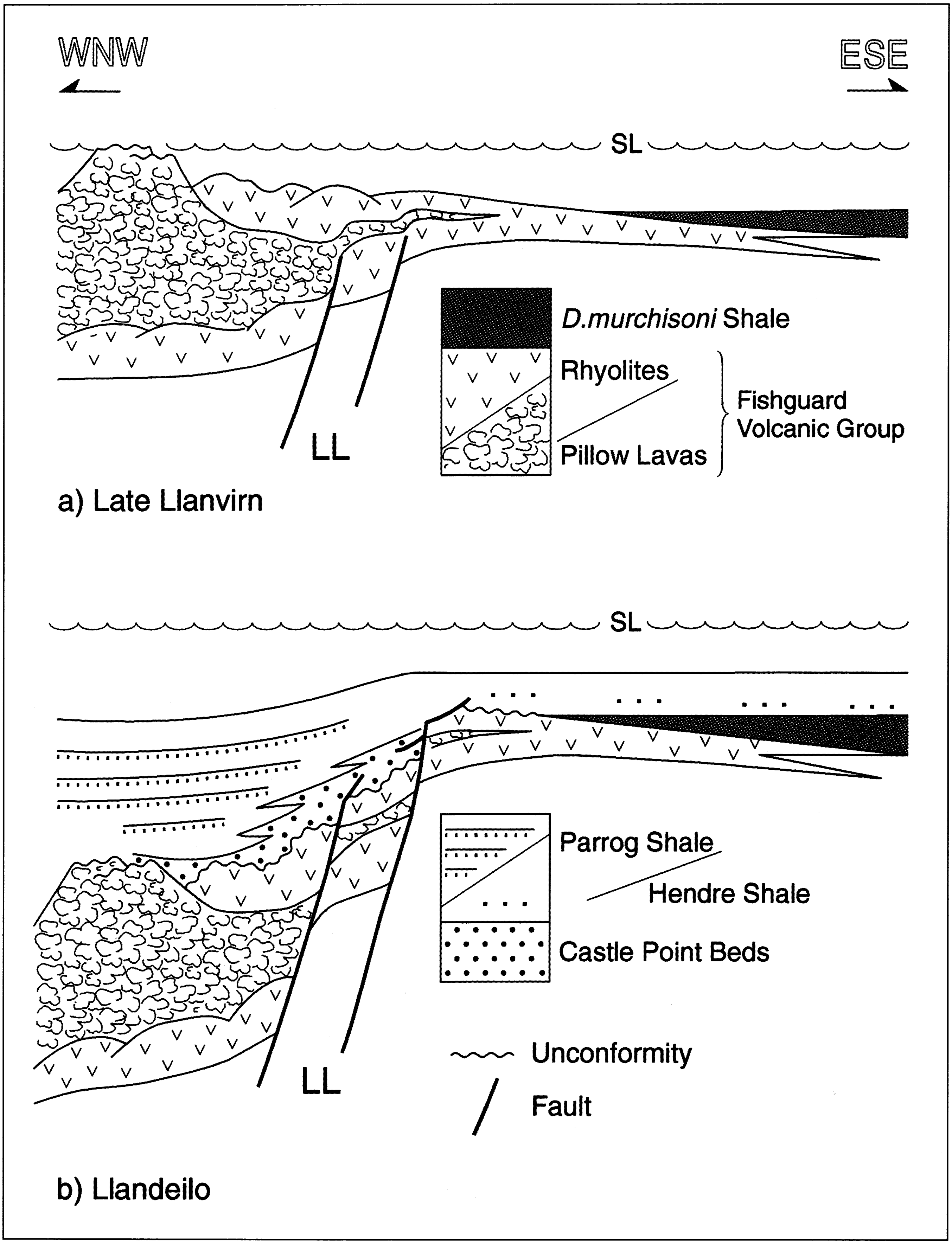

Fig. 2. Cartoon geological sections (not to scale) across the Llangranog Lineament (LL) near Strumble Head (see Fig. 1) illustrating the hypothesis that the Lineament was active in the Llanvirn-Llandeilo. Note the non-deposition of the *D. murchisoni* Shales northwest of the Lineament, a key argument for contemporaneous elevated topography there.

flows, e.g. under the northwest wall of the fort at Castle Point (SM 962 378), contain 2-20cm clasts of black shale and 3-8cm clasts of flinty volcanic rock in a sandy mudstone matrix. However, the majority of the Castle Point Beds consists of parallel laminated 0.1-0.3cm Bouma *ae* sandstone event deposits spaced at 1-2cm intervals within silty mudstone, with rare rusty weathering 3-9cm *ab* beds of high-matrix sandstone. These 'background' beds are not typical turbidites; they show no current or wave ripples, no flute casts, no interbedded mudstone and no fauna, but do contain 1-3cm vertical to inclined burrows with a sandy fill. Although the thin event deposits are commonly individually slurried, large scale mass flow phenomena are absent. Water depth during deposition of the Castle Point Beds at Castle Point is thus equivocable but is not demonstrably deep. It is likely that water depth increased appreciably during sedimentation of the Parrog Formation which is typically 'basinal' in aspect (McCann, 1990b).

Caradoc. Turbidite sandstones and interbedded mudstones of predominantly (possibly entirely) Caradoc age occur in the *N. gracilis* to *D. clingani* Biozones between Dinas Head and Cardigan (James, 1975; McCann, 1992), within a region of spectacular, albeit poorly accessible, coastal exposure and extremely poor inland exposure. In ascending sequence, the succession comprises the Newport, Ceibwr and Poppit formations as defined by McCann (1992), who estimated their thicknesses as 200m, 50m and 300m respectively. There is considerable uncertainty in the precision of these estimates, which imply average northeasterly fold plunges of between 1 and 3 degrees across the extents shown by McCann. Such plunges are at variance with McCann's statement (1992, p. 57) of 35-45 degree plunges and with my own observation of 5-20 degree northeasterly plunges in the Poppit Formation. It is very probable that the total thickness of these turbidite formations is much greater than 550m, although by how much is currently unclear. The thickness of 50m given by McCann for the Ceibwr Formation is less than the 60m height of the cliffs at the type section (McCann, 1992, fig. 7a). In his original (thesis) work McCann (1990b) gave thicknesses of 'up to 700m' for the Newport Sands Formation (now the Newport Formation) and 'c. 750m' for the Poppit Sands Formation (now the Poppit Formation).

The distribution of the Caradoc turbidites inland in sketched in Figure 1 and owes much to the reconnaissance by Challinor (1927). It is fairly clear that the turbidites thin rapidly and/or become faulted out towards Eglwyswrw and the probable WSW prolongation of the Bwlch-y-Fadfa Fault (Anketell, 1987). Across the trace of this fault the partly coeval Mydrim Shales around Crymych appear to be only c. 92m thick (Evans, 1945). No turbidites are reported here although the Caradoc may be, at least locally, incomplete as many of its contacts were mapped as faulted by Evans (1945). The Mydrim Shales are shown as c. 210m thick at Mydrim (Meidrim in current O.S. spelling) by Williams *et al.* (1972) and again, no turbidites appear to be present (D. C. Evans, 1906). There is thus no evidence of clastic supply from the southeast, consistent with (limited) palaeocurrent evidence for northeasterly transport both at Poppit Sands (James, 1975) and within the Newport Formation (McCann, 1990b). The Caradoc turbidites therefore appear to be ponded laterally by the Llangranog Lineament.

Ashgill. In the coastal sections between Cardigan and Aberporth, the Caradoc turbidites of the Poppit Formation are geographically succeeded, in a northeasterly direction, by a muddy succession comprising the Gwbert Formation (at least 380m), the Mwnt Formation (c. 350m), and the Tresaith Formation (c. 350m). These are succeeded by the more sandy Llangranog Formation (c. 140-800m) as shown by Anketell (1987) and McCann (1990a). The Caradoc-Ashgill boundary was placed, without explanation, within the Mwnt Formation by McCann (1990a, fig. 3) who considered the four formations to be stratigraphically sequential without either supporting evidence or reference to the conclusions of Craig (1985), who had earlier presented a well-argued case that the Gwbert Formation correlates with the Tresaith Formation and the Mwnt Formation with the Llangranog Formation. Craig's correlations are plausible sedimentologically but cannot yet be demonstrated directly as a distinctive 5.5m orange weathering horizon with *D. anceps*, which lies 27m below the base of the Llangranog Formation on the coast (Anketell, 1987 p.157), has not yet been found in a comparable position below the base of the Mwnt Formation. No detailed mapping is available to assess the inland extent of the Gwbert and Mwnt formations. However, unless the latter is restricted to the northwest limb of the anticline running through Aberporth (Craig, 1987, fig. 1) it should, if older than the Llangranog Formation, cross the coast between SN 250 520 and SN 270 516 around Aberporth (where exposure is good) and persist inland. My fieldwork shows that this is not the case: the Mwnt Formation is not present along the coast here and neither the Mwnt Formation nor the Gwbert Formation is obvious inland, where the presence of extensive exposures of monotonous Tresaith Formation along the lower portions of the Teifi valley argue against McCann's (1990a) stratigraphical interpretation. The Gwbert Formation is thus best thought of as a local unit within the Tresaith Formation. Both are intensively burrow-mottled, but the Gwbert Formation contains a relatively high proportion of silty/sandy Bouma *cde* intercalations.

The basal Ashgill of the Crymych area is formed by the Glogue Slates (Evans, 1945), which are well exposed in the Glogue quarry (SN 220 328). These are strongly burrow-mottled without silty/sandy intercalations and are thus more reminiscent of the type Tresaith Formation (see below) than the type Gwbert Formation. Evidence that the contact between the Glogue Slates and the Mydrim Shales near Crymych could be unconformable (Evans, 1945, p. 100-101) may be significant. Such an unconformity would lie on the footwall of the Llangranog Lineament and may equate to part of the time represented by the Gwbert Formation. Alternatively, this Formation may have been ponded laterally by the active Lineament. Table 1 illustrates the published stratigraphies.

The Tresaith Formation is a distinctive sequence of both homogeneous and cm-scale layered mudstones with a characteristic, commonly strong, burrow-mottled texture. It was defined in the coastal area by Anketell (1987, p. 157) but is clearly very similar in facies to mudstones cropping out along the Teifi valley from around Newcastle Emlyn to the Carnarvon quarries (SN 190 450) near Cardigan. Similar burrow mottling occurs in the Nant-y-Moch Formation of the Plynlimon area (James, 1971) and in the Nantmel Formation along the Teifi Lineament (Wilson *et al.*, 1993): a Cautleyan/ Rawtheyan age appears likely. In the coastal exposures near Aberporth, the Tresaith Formation contains local disrupted horizons, probably due to slumping on the downthrown side of the Llangranog Lineament. Turbidite sandbodies up to about 70m thick occur within the upper portions of the Tresaith Formation along the Teifi valley (Tata, 1985). Their principal concentration, containing the thickest individual turbidite beds and coarsest grain sizes, is consistent with ponding in the hangingwall of the Central Wales Lineament, implying uplift on the footwall of the Llangranog Lineament. Tata (1985) found that sole marks always indicate northeasterly-directed palaeocurrents, whereas current ripple lamination commonly indicates north to northwest directed flow. This would be consistent with soliton development (Kneller *et al.*, 1991) on a nearby northwest-facing slope caused by movement on the Central Wales Lineament (Fig. 3). The north-westerly disappearance of the unconformably-based shallow water Sholebrook Limestone near St Clears suggests that the Tywi Lineament may have been active in the Rawtheyan and defined the early Ashgill shelf margin. In the basin, possible time equivalents of the Sholebrook Limestone are thin, locally developed, carbonate turbidite beds (unit 3 in Figure 3), typical examples of which may be seen in the Cothi valley (SN 5330 2463), 12km ENE of Carmarthen.

The stratigraphical position of the c. 290 metre-thick Freni Fawr Beds (Evans, 1945, p. 101) is currently unclear. The sandstones and a 2 metre-thick local conglomerate reported in the Freni Fawr Beds by Evans may be a coarse member within a non-mottled variant of the Tresaith-Glogue facies (similar mudstones occur in the commonly burrow-mottled Broad Vein Formation at Corris). Alternatively, they could overlie this facies as the lateral equivalent of a coarse member within the Llangranog Formation, the mudstones of which are not typically burrow-mottled. The latter alternative requires either reversal of the dominant ENE-directed fold plunge, or down-to-southwest faulting in this area and considerable thinning of the Tresaith Formation in the hangingwall of the Central Wales Lineament. The former alternative requires such

				Llangranog Lineament
	Coast (hanging wall)			Inland (footwall)
Series	*a*	*b*	*c*	*d*
Ashgill	Llangranog Fm.	Mwnt Fm.	Llangranog Fm.	not preserved
	Tresaith Fm.	Gwbert Fm.	Tresaith Fm.	----?----?----?----?---- Freni Fawr Beds
	Mwnt Fm.			Glogue Slates
Caradoc		not studied		possible disconformity
	Gwbert Fm.			Mydrim Shales
	Poppit Fm.			
	Ceibwr Fm.			
	Newport Fm.			

Table. 1. Caradoc-Ashgill stratigraphy across the Llangranog Lineament in SW Ceredigion, including alternative correlations in the coastal area. **a**, Cardigan to Llangranog, after McCann (1990b); **b**, **c**, respectively SW and NE of Tresaith, after Craig (1985); **d**, the Crymych area, after W. D. Evans (1945).

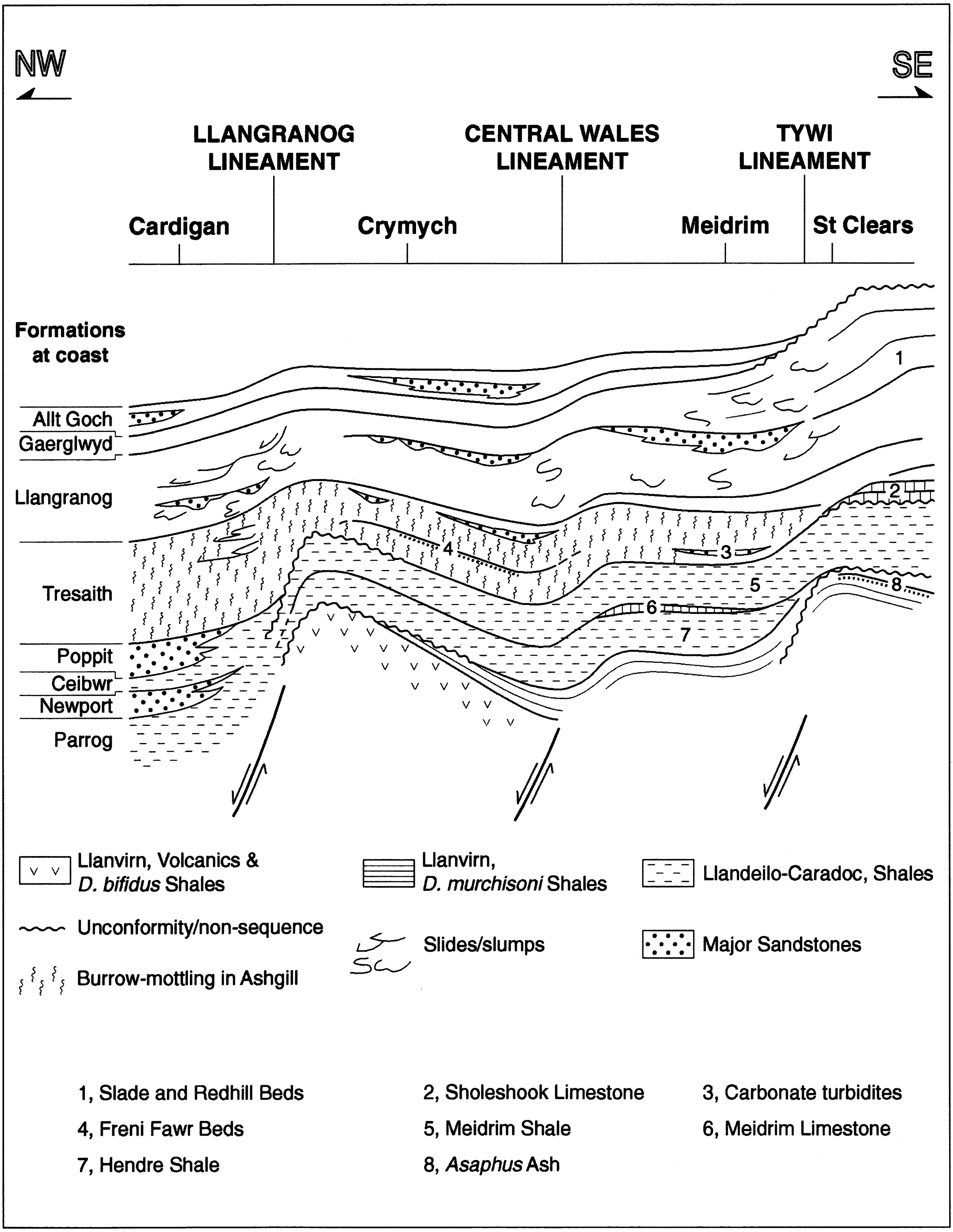

Fig. 3. Cartoon geological section (not to scale) from Cardigan to St. Clears (see Fig. 1) illustrating sedimentary relationships across the lineaments at end-Aeronian time. In the absence of detailed modern study for much of this section it is difficult and subjective to draw the diagram with a true vertical scale. Note the unconformities on footwall highs and the concentrations of major sandstones above hangingwall lows.

structural arrangement only if the Freni Fawr sandstones equate with those studied in the upper portion of the Tresaith formation by Tata (1985). However, if they are stratigraphically lower, no plunge reversal or faulting may be needed. Distinction between these possibilities awaits mapping of the area between Freni Fawr and Newcastle Emlyn. My reconnaissance sampling suggests that non-mottled mudstones with thin (<3cm) siltstones, possibly equivalent to the Freni Fawr Beds, occupy a wide area between the type locality and the Cych valley between Cwmorgan (SN 293 349), and northwest of Llancych around SN 253 832. Exposure is poor but they appear less well developed to the northwest and to lie at a lower stratigraphical level than the sandstones studied by Tata (1985). This conclusion is adopted in Figure 3. The sandstones on Freni Fawr (SN 202 350) are nowadays more sporadically exposed than in Evans' (1945) days, but where seen appear to be generally thin (2-7cm) and intercalated with somewhat thicker (5-12cm) mudstones. Sandstone samples from Freni Fawr resemble the coarser facies of the Nant-y-Moch Formation at Plynlimon (James, 1971), notably in containing re-sedimented shelly material at the base of graded units. This fauna led George (1970) to suggest a shallow water origin for the sandstones of the Freni Fawr Beds. However, the thicker sandstones show typical turbidite structures and no *in-situ* shelf fauna has yet been found in the mudstones. The Freni Fawr Beds are thus considered here to be basinal.

The stratigraphically highest portion of the Ashgill comprises the turbidite sandstones, mudstones and gritty/muddy slumps of the Llangranog Formation (Anketell, 1963; 1987, Hasso, 1974). The junction with the underlying bioturbated mudstones of the Tresaith Formation may represent a major sequence boundary related to late Rawtheyan relative sea-level fall and corresponds to the boundary between the Nant-y-moch Formation and the overlying Drosgol Formation in the Central Wales inliers (James, 1983). The boundary can be traced easily inland to Mydrim (Anketell, 1987, p. 160). Although no major thickness variation appears to occur in the Llangranog Formation across the Bwlch-y-Fadfa Fault, the greater abundance of slumping to the northwest compared to that to the southeast hints that the fault was not quiescent during deposition. Anketell (1987, p. 160) suggests a 'degree of fault control' and time equivalent sequences in the Llyfnant Inlier and at Corris certainly display the influence of the Llangranog Lineament (James, 1972; 1987). The distribution of thick sandstones in the Llangranog Formation in the Pencader-Conwil Elfed area, as shown by Hasso (1974), is further suggestive of contemporary activity on the Central Wales Lineament and on the Tywi Lineament (Fig. 3). The conglomerates at Cotland Mill west of Mydrim in the basinal facies of the Slade and Redhill Beds contain pebbles of graptolitic Caradoc shale (Pringle and George, 1948, p. 31), further indicating relative uplift/erosion immediately southeast of the active Tywi Lineament at this time.

Llandovery. There is no obvious sign of activity on the Lineament in the Rhuddanian Stage of the Silurian in the form of either sedimentary facies changes or thickness variations. The Rhuddanian sediments comprise the Gaerglwyd Formation (Anketell, 1987) and are almost exclusively mudstone within which graptolitic horizons record periodic anoxic conditions. Slow pelagic/hemipelagic deposition at this time may have allowed draping of the Gaerglwyd Formation to preserve some topographic relief across the Lineament.

In the Aeronian Stage, thickness variations and turbidite sandstone distribution in the Allt Goch Formation (Anketell, 1987; Kishimoto, 1989) strongly suggest activity on, or inherited relief across, the Llangranog Lineament in the position postulated in this paper. Kishimoto (1989) demonstrated that the principal concentration of these sandstones, with northeast-directed transport indicated by sole marks, is ponded downslope on the footwall of the Llangranog Lineament, where this may be equally regarded as the hangingwall of the Central Wales Lineament (Fig. 3). Kishimoto (1989) also recorded NNW-directed current ripples suggestive of soliton development along the slope parallel to the Central Wales Lineament. A secondary concentration of sandstones, also with NNW-directed transport, occurs at Llangranog. Kishimoto (1989) suggested that this latter concentration lay immediately adjacent to a Llangranog Lineament (*sensu* James and James, 1969) and defined a Teifi Lineament corresponding to the location of the Llangranog Lineament postulated in this paper. However, palaeocurrents in both the hangingwall and the footwall of Kishimoto's Llangranog Lineament were shown by Kishimoto (1989) to flow to the NNW and to cross this feature obliquely without deviation. The evidence for Kishimoto's interpreted position of the Llangranog Lineament is thus not strong and poor exposure of the Allt Goch Formation inland weakens its justification, at least as a major lineament.

In the Telychian Stage, palaeocurrent evidence suggestive of soliton development occurs in the Grogal Sandstones near Newquay and suggests the existence of a contemporary northwest facing slope along the Llangranog Lineament (Smith and Anketell, 1992). The Grogal Sandstones are succeeded by the Aberystwyth Grits, for which the controlling influence of the Bronnant Fault segment of the Lineament has been conclusively demonstrated by the work of Wilson *et al.* (1992). At this time there was considerable relief across the Lineament, to an extent that makes it likely that accommodation space was being created continuously during sedimentation of the Grits rather than the Grits passively infilling a static bathymetry. The Trefechan and Mynydd Bach sandstone facies of the Aberystwyth Grits are totally confined to the east by the Lineament (Wilson *et al.*, 1992, figs. 7 and 8). Later Telychian deposits are not preserved in the vicinity of the Llangranog Lineament but it has been demonstrated (Clayton, 1993; British Geological Survey, 1994) that contemporary activity on the Central Wales Lineament controlled the southeastern extent of sedimentation of the lower part of the Rhuddnant Grits. This activity may represent an intra-Telychian rejuvenation, as sea-bed relief across the Lineament was subdued in the Aeronian to the extent that it was crossed from the east by flows depositing the Ystrad Meurig Grits (James and James, 1969; Smith, 1987a). The final Telychian turbidite system, the Pysgotwr Grits, also appears to cross the Central Wales Lineament and thus records its quiescence at that time (Smith, 1987a; b).

Synthesis

The seafloor topography induced by synsedimentary activity on the lineaments of Central Wales during much of the late Ordovician/early Silurian is now generally accepted to be one of gentle southeast dipping palaeoslopes above the hanging walls of the basement fault zones and relatively steep, localised northwest-facing slopes above the footwalls (e.g. Smith, 1987a; James, 1991). Such tilt-block geometry was not identified in the early work of James and James (1969) and was first clearly set out by Davies (1981). This study provides further support for the concept.

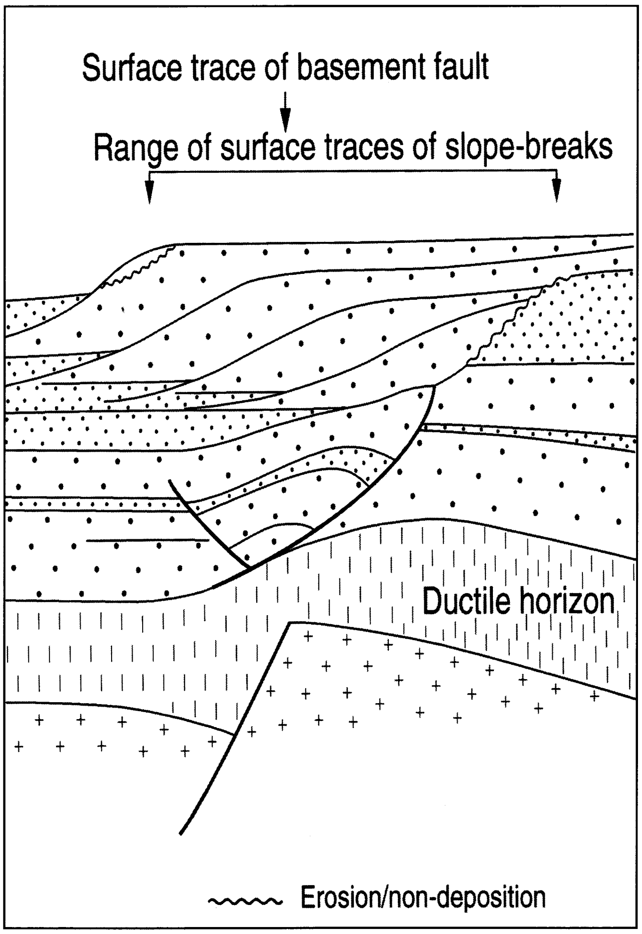

Fig. 4. Cartoon illustrating variable relationship between a basement fault and the position of localised slopes in sedimentary cover.

The exact position of the basement fault — or fault zone — is not easily or simply related to either sedimentary or structural relationships in its cover. This can be due firstly to sedimentary processes of differential lateral and longitudinal supply and accumulation leading to variation in the position of the slope break, and secondly by displacement of the slope break by ductile deformation (e.g. of overpressured shale) adjacent to the fault (Fig. 4). Moreover, at times of high sediment supply rates from the shelf to the southeast, it appears that the gentle southeast-dipping topography over the basement blocks may have been reversed. In this case the fault zone underlies a local increase of dip on a northwest prograding slope apron. This situation probably occurred during deposition of the Llangranog Formation. It is apparent from Figure 4 that the existence of a localised slope does not necessarily indicate contemporaneous activity on the lineament as sedimentary processes may sustain the existence of a slope once this has been tectonically initiated. The best evidence for contemporaneous activity is probably the rapid lateral ponding of longitudinally supplied material following an interval of minor thickness variation across the Lineament.

A further complication in the estimation of the position of the basement fault arises from tectonic deformation of the cover during inversion of the depositional half-graben, notably the possibility of thrust ramping (Schedl and Wiltschko, 1987, fig. 4) which can laterally translate the depositional margin beyond the vertically projected trace of the basement fault. The Bronnant and Bwlch-y-Fadfa Faults are not reversed as would be expected in the case of ramping, although the Brwyno Fault is reversed and might pass down into a local ramp. Experimental data (e.g. Buchanan and McClay, 1992) for non-ramping models afford little or no suggestion of the development of a vergence divide when inversion is accomplished by simple back-stacking of uni-directionally hading basement faults. The vergence divide so prominent in coastal Ceredigion is thus not easy to relate, spatially or genetically, to the sedimentologically requisite northwest-hading basement fault of the Llangranog Lineament. By analogy with seismically defined examples of inverted basins (e.g. Letouzey *et al.*, 1990, figs. 6 and 10), the divide appears to suggest the existence of a subsidiary southeast-hading fault controlling the zone of northwest fold vergence. The very existence of the vergence divide between Cardigan and Corris, and the absence of such a divide in the Central Wales Lineament and the Tywi Lineament, suggests that the Llangranog Lineament may define the central graben and associated bathymetric axis of the Welsh basin in Llanvirn to Llandovery times.

Conclusions

This paper argues for a fairly continuous record of synsedimentary activity on the Llangranog Lineament between the Llanvirn and the late Llandovery — a period of approximately 40Ma. This would extend significantly the previous (discontinuous) recognition of its activity in the Llanvirn and the late Ashgill to early Llandovery. Additionally, the strong suggestion of domino-style linkage between the basement faults of the Llangranog Lineament and the Central Wales Lineament implies that the latter was active over a similar time. This would extend very significantly the previous recognition of its activity in the early Ashgill to late Llandovery. A similar domino-style linkage may exist between the Central Wales Lineament and the Tywi Lineament. The Tywi Lineament is known to have been active from the late Llanvirn to the Wenlock, the Ordovician contrasts in facies and fauna across it having been first set out in the pioneering work of D. C. Evans (1906, p. 599).

There is still unsatisfactory knowledge of the stratigraphy and structure of the early Ashgill strata southeast of Cardigan towards Mydrim, where large areas have not been mapped this century. In particular the provisional lateral correlations of the Freni Fawr Beds deduced herein may bear revision in the event of future detailed mapping.

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