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Upper Carboniferous foreland basin evolution in SW Britain

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Upper Carboniferous foreland basins of the Rhenohercynian and Sub-Variscan parts of the Variscan orogenic belt of SW Britain (Culm and South Wales Basins) developed during the structural inversion of previously thinned crust. The transition from an extensional (Middle Devonian-Lower Carboniferous) to compressional tectonic regime (Upper Carboniferous) occurred in early Namurian times and resulted in regional D1 basin inversion. In SW England a basic correlation existed between the thickness of Middle Devonian to Lower Carboniferous syn-rift sequences and the location of subsequent Upper Carboniferous sedimentation. Areas with thick syn-rift sequences such as the Trevone Basin and the North Devon Basin/Bristol Channel region emerged as topographic highs and acted as potential thrust loads as a result of inversion. In contrast, areas of thinner syn-rift sequences (beneath the Culm Basin) became relative lows and sites of subsidence following early Namurian compression. Uplift along the Bristol Channel Fault Zone (BCFZ) - a major Variscan thrust - took place from late Namurian into Westphalian times and resulted in emergence of a landmass which separated and sourced the Culm and South Wales Basins. E-W structures, active during sedimentation in the South Wales Basin are thought to represent Devonian-Lower Carboniferous extensional faults, reactivated during Dl shortening.

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Introduction

The Upper Carboniferous tectonic setting of SW Britain is generally considered to be compressional with sedimentation taking place to the north of the developing Variscan Orogen and to the south of the cratonic Wales-Brabant Massif. The Upper Carboniferous basins of SW Britain (the Culm and South Wales Basins; Fig. 1) therefore represent foreland basins (following the definition of Allen *et al*. 1986). Previous authors have suggested that the Bristol Channel Fault Zone (BCFZ) located between the two basins (Fig. 1), was active as a major strike-slip fault during Devonian to Upper Carboniferous times (Johnson 1984: Holder and Leveridge 1986), therefore rendering any comparison of Devonian and Carboniferous sediments between South Wales and SW England untenable. However, recent seismic reflection interpretations by Brooks *et al.* (1988) illustrate that the BCFZ has the form of a major south-dipping Variscan thrust with little or no strike-slip movement. Consequently, although complexly deformed, the South Wales and Culm Basins maintained their relative palaeogeographic positions throughout Variscan deformation.

The origin of the Culm and South Wales Basins has been attributed to a lithospheric loading mechanism *(c.f* Beaumont 1981) related to thrust nappe emplacement (Kelling 1988; Thomas 1988; Gayer and Jones 1989). Recent interpretations of the structural style of Variscan deformation in SW Britain have been in terms of basin inversion (Pamplin 1988; Powell 1989; Hanna and Graham 1989; Warr 1991) with out-of-sequence thrusting, lateral ramps and footwall short-cuts locally developed. The suggestion that Upper Carboniferous sedimentation occurred synchronously with regional D1 inversion in SW England (Warr 1991) has important implications for assessing the control basin inversion exerted on the nature and position of foreland basin sedimentation in SW Britain.

A detailed review of the Upper Carboniferous sedimentology, stratigraphy and structure of SW Britain is outside the scope of this paper and the reader is referred to Kelling (1974) and Thomas (1988) for greater detail (see Fig. 2 for lithostratigraphy). The pertinent features of the Upper Carboniferous sediments of SW Britain are, however, discussed in terms of placing stratigraphical, sedimentological and structural constraints on basin evolution. Additionally, in order to demonstrate the role of structural inversion on foreland basin development, the Middle Devonian-Lower Carboniferous tectonic history of SW Britain is briefly reviewed.

Middle Devonian-Lower Carboniferous tectonic setting of SW Britain

The stratigraphic record in SW Britain indicates that a main phase of extension occurred during Middle Devonian to Lower Carboniferous times (syn-rift sedimentation). In SW England this has been supported by the results of extensive remapping (undertaken by the University of Exeter) of the largely Middle Devonian to Lower Carboniferous sequences that lie to the south of the Culm Basin. Recent work between the Boscastle and Padstow areas has described the marine successions of the Trevone Basin and those lying on its northern shelf (Warr 1991). The pre-deformational positions of these shelf sequences (the Boscastle and Tintagel Successions) is a subject of debate, as is the proposed area of uplift required to source the Fammenian to earliest Namurian paralic sediments found within the Boscastle Succession (see discussion in Warr 1989, p. 139). Two vital interpretations have been made in order to substantiate the predeformational basin configuration presented in Fig. 3. Firstly, although complexly thrusted and folded, the recognised successions have maintained their relative palaeogeographical positions (Fig. 3). Secondly, the area of uplift required to source the clastics of the Boscastle Succession resulted from footwall uplift to the north initiated during crustal extension. Such an area is now considered to underlie the Upper Carboniferous Culm Basin.

Fig. 3c illustrates the stratigraphical and sedimentological relationship proposed for the basin-fill sequence, which demonstrates thinning of syn-rift sequences from south to north towards the present day Culm rocks. This is accompanied by a transition from basinal slates (3-4km thick) to shallow marine clastics and carbonates (Warr 1991). East of the Boscastle Succession, along the southern margin of the Culm Basin, Upper Carboniferous clastics of the Crackington Formation are seen to conformably overlie Lower Carboniferous basinal facies of black slates and cherts (Selwood and Thomas 1987). These sediment-starved sequences are generally thin and considered to result from a general rise in sea-level during early Carboniferous times (Selwood and Thomas 1986). We therefore envisage the thin syn-rift sequences of the northern shelf of the Trevone Basin to continue beneath the Culm Basin, consequently the Boscastle and Tintagel Successions are not thought to represent intra-basinal highs.

The presence of rapid facies changes reflecting shelf, basin and rise topographies (Isaac *et al.* 1982; Selwood and Thomas 1986), suggests an extensional tectonic regime for Middle Devonian to Lower Carboniferous sedimentation in SW England (excluding south Cornwall). This scenario is supported by the presence of extensive volcanism of alkali basalt affinity (Floyd 1972, 1982) and associated stratiform mineralisation (Scrivener *et al.* 1989). A thick (6.5km), conformable sequence of dominantly shallow marine and terrestrial carbonates and clastics was also deposited in north Devon during Middle Devonian-Lower Carboniferous times (Fig. 2). Sedimentation in north Devon was influenced by end-Caledonian uplift in South Wales and short lived uplift associated with the BCFZ during

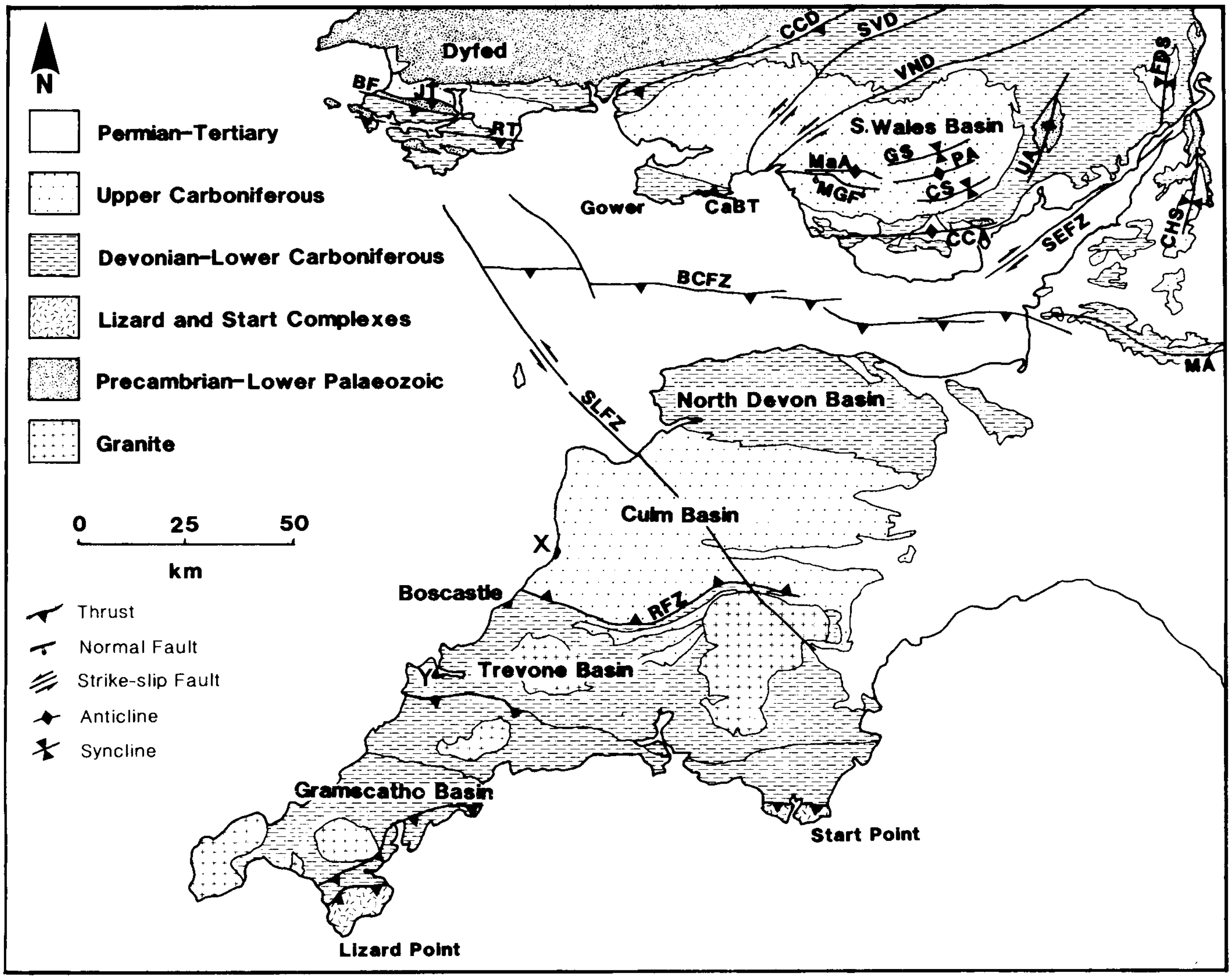

Figure 1. Simplified general geological map of SW Britain, showing Silesian sediments of South Wales, the Culm Basin of SW England and important structural features. CCD = Carreg Cennan Disturbance, SVD = Swansea Valley Disturbance, VND = Neath Disturbance, PA = Pontypridd Anticline, SLFZ = Sticklepath Lustleigh Fault Zone. MGF = Moel Gilau Fault. JT = Johnston Thrust, BF = Benton Fault, RT = Ritec Thrust, CaBT = Caswell Bay Thrust, RFZ = Rusey Fault Zone. CHS = Coalpit Heath Syncline, MA = Mendip Axis, MaA = Maesteg Anticline, GS = Gelligaer Syncline, CS = Caerphilly Syncline, CCF = CardiffCowbridge Anticline, UA = Usk Axis, FDS = Forest of Dean Syncline, SEFZ =Severn Estuary Fault Zone. BCFZ = Bristol Channel Fault Zone. Both the Bristol Channel Fault Zone and the Sticklepath-Lustleigh Fault Zone are shown with inferred Variscan sense of movement. X-Y corresponds to the section shown in Fig. 3.

lower to early mid-Devonian times (Tunbridge 1986), when the BCFZ may have been an extensional fault zone (Gayer and Jones 1989).

In SW Dyfed (Fig. 1) sedimentation during Upper Devonian to Lower Carboniferous times was profoundly influenced by extensional faulting. Marked facies and thickness variations across the Ritec and Benton Faults illustrate that these southerly dipping faults were periodically active in Upper Devonian and Lower Carboniferous times (Sullivan 1965; Powell 1989). Lower Carboniferous carbonate sedimentation in central South Wales also contains evidence for extensional E-W growth faulting in controlling facies and sediment thickness distributions, notably on the Gower Peninsula (Ramsay 1987, 1989). Other regional E-W trending structures which also controlled facies and thickness variations, include the Pontypridd Anticline (Ramsay 1990, *pers. comm.),* the Vale of Glamorgan Axis (Wilson *et al.* 1988) and in north Somerset, the Mendip Axis (Green and Welch 1965). In addition, long-lived NE-SW faults were also active during Devonian-Lower Carboniferous sedimentation including the Vale of Neath Disturbance (George 1954; Owen 1974; Owen and Weaver 1983) and the Swansea Valley Disturbance (Tunbridge 1980; Cope 198 1).

Namurian regional shortening (D1)

In SW England regional D1 shortening can be stratigraphically constrained to post-earliest Namurian times (Warr 1989) and the KAr cooling ages of the associated M1 metamorphism are of Namurian age (Dodson and Rex 1971). In north Cornwall this phase of deformation resulted in the inversion of the Trevone Basin and the successions on its northern shelf (Warr 1991; Fig. 3b). Many of the structural features which resulted from this D1 event such as southerly directed backthrusting and the development of an intra-basinal confrontation zone at Padstow are attributed to a fundamental control exerted by pre-existing structures of Middle Devonian-Lower Carboniferous age (War 1991).

Early Namurian deformation in South Wales resulted in the break- up of the Dinantian carbonate platform, relocation of the basin depocentre, influx of elastic detritus and the development of a progressive onlap unconformity from the centre of the basin (Swansea area) to both the eastern and western margins of the basin (Ware 1939; George 1956). Deformation resulted in reactivation of pre-existing extensional faults (Ramsay 1990, *pers. comm.),* uplift along the N-S trending Usk Axis (George 1956) and movement on the Neath Disturbance (Owen 1953).

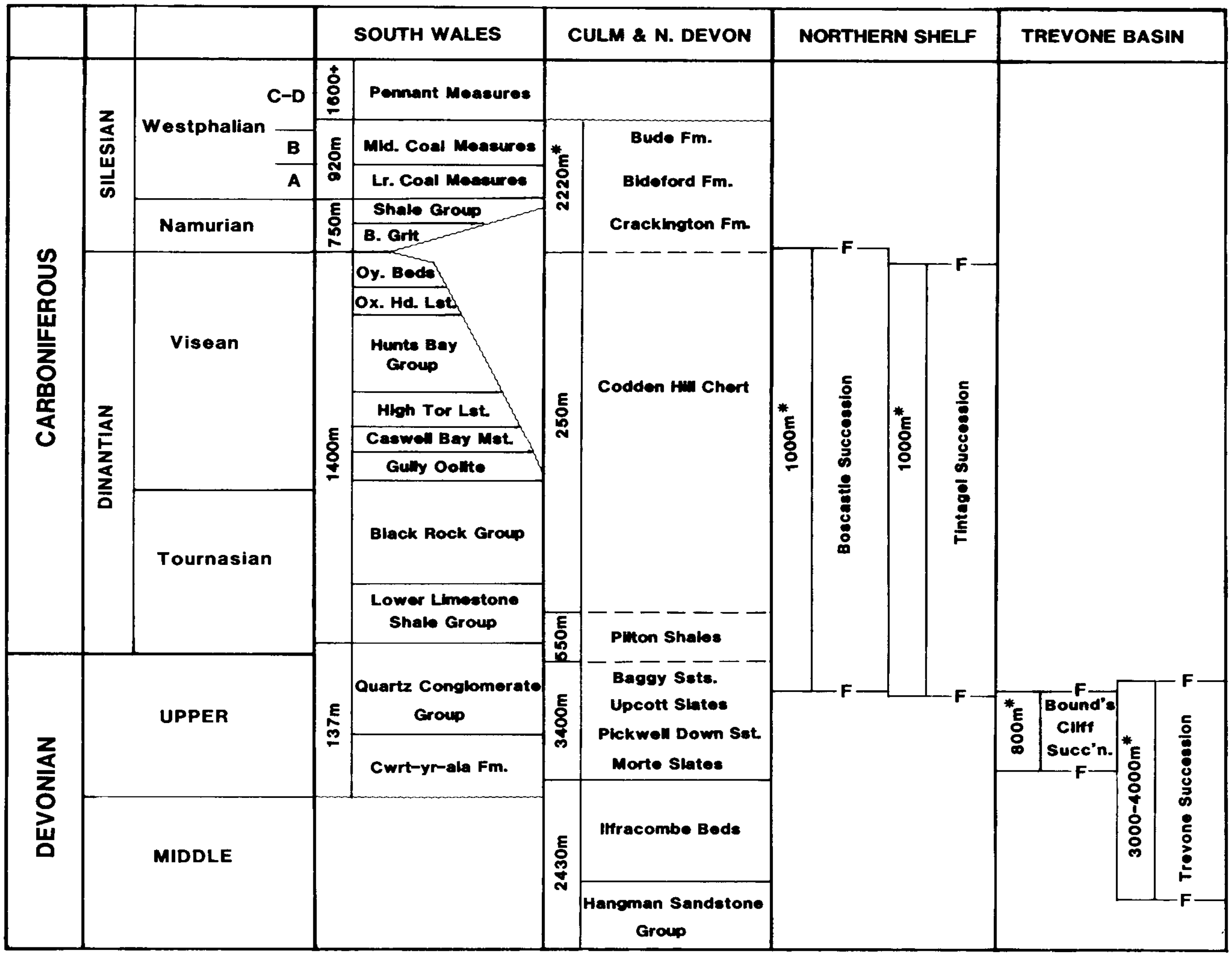

Figure 2. Summary lithostratigraphy of Middle Devonian to Upper Carboniferous successions in SW Britain. Northern Shelf =Northern Margin of the Trevone Basin; Ox. Hd. Lst. = Oxwich Head Limestone. Oy. = Oystermouth, F = fault, B. Grit = Basal Grit, Fm. = Formation, * = approximate structural thickness. Thicknesses for the Dinantian of South Wales are maximums. Compiled from Wilson et al. (1988) and references therein and Tunbridge (19R6). For details of the Formations comprising the successions of the Trevone Basin and its northern shelf see Warr (1989, 1991).

Upper Carboniferous sedimentation

Namurian

In SW England Namurian sediments are represented by the distal turbidites of the Crackington Formation (Mackintosh 1964). The formation displays bimodal E-W palaeocurrent indicators reflecting an axial drainage system (Melvin 1986). Recently acquired palaeontological data suggests that the northerly derived deltaic Bideford Formation (Elliott 1976; Freshney *et al.* 1979) may extend downwards into the late Namurian (Li 1990, *pers. comm.)* indicating that the northerly source to the Bideford Formation was emergent by at least late Namurian times.

Namurian sediments in South Wales record a fining upwards sequence with a change from the high energy, shallow marine quartzites of the Basal Grit to the mudstone dominated, shallow marine lagoonal sediments of the Shale Group (Oguike 1969; Kelling 1974; Hartley 1991). Sediment was supplied mainly from a northerly source area and to a lesser extent from the east and south (Oguike 1969).

Westphalian A to early Westphalian C

The Culm Basin continued to be filled by distal turbidites (Crackington Formation) and deltaics (Bideford Formation) during Westphalian A times supplemented by the influx of a sequence of proximal turbidites and shallow marine and/or lacustrine sandstones represented by the Bude Formation (see Higgs 1984, 1986; Melvin 1986, and Hartley 1991 for further discussion). The Bude Formation extends up to early Westphalian C in age and, like the Bideford Formation, was predominantly derived from the north (Freshney *et al.* 1979).

Sedimentation in South Wales during Westphalian A to early Westphalian C times was dominated by the deposition of mudstones and extensive coals with subordinate sandstones and siltstones of the Lower and Middle Coal Measures. The environment of deposition was considered to have been a low-lying, swampy, coastal plain subject to periodic marine transgressions and traversed by fluvial distributary channels of variable size and sinuosity (Kelling 1974; Jones 1989; Hartley 1991). The rivers were sourced from the north, east and south (Kelling 1974; Hartley 1991). E-W trending structural features were also active in controlling sediment thicknesses and facies patterns, notably the long-lived Pontypridd Anticline a structure which may represent inversion along an extensional fault of Devonian-Lower Carboniferous age (Jones 1989).

Early Westphalian C to late Westphalian D

No post-early Westphalian C sediments are preserved in the Culm Basin precluding correlation with South Wales. Sedimentation in South Wales during this time period showed a marked change in style and nature from the mudstone dominated Coal Measures to the overlying sandstone dominated Pennant Measures. The Pennant Measures are thought to represent proximal braidplain sedimentation with the development of large scale alluvial channel systems, limited mudstone (floodplain) sedimentation and an absence of marine incursions. Palaeocurrent and compositional data indicate derivation from a southerly source composed of immature lithic detritus and coal-bearing sediments (Kelling 1974; Jones 1989; Hartley 1991). EW trending structures continued to be active during deposition of the Pennant Measures, deflecting drainage systems and influencing thickness and facies distributions (Jones 1989).

Last Westphalian to post-early Stephanian regional shortening (D2)

The regional D2 shortening phase in the Rhenohercynian of SW England resulted in the dismembering of F1 folds, with out-of-sequence thrusting, lateral ramp geometries and oblique thrust traces (Turner 1982; Andrews *et al.* 1988; Warr 1988), features common to inverted orogenic terranes (Hayward and Graham 1989). In some areas localised non-coaxial overprinting of deformation within the footwall of D2 thrusts led to complex zones of refolding and multiple cleavage development (e.g. the Padstow Confrontation Zone; see Warr 1991). While in other areas coaxial ductile strains occurred, such as in the underthrusting wedge beneath the southern margin of the Culm Basin (Warr 1989). The main phase of deformation of the Upper Carboniferous Culm occurred during this event with the development of the characteristic transition of north-facing, upward--facing and south-facing folds across the basin from north to south.

Deformation in SW Dyfed has been documented by Powell (1989) who showed that much of the shortening which is post-early Cantabrian in age, was taken up by inversion along pre-existing Devonian extensional faults notably the Ritec and Benton Thrusts (see Fig. 7 of Powell 1989). In the main South Wales Basin, shortening resulted in the development of a major linked thrust system in the incompetent Lower and Middle Coal Measures. Northward verging structures extend to the northern margin of the Coalfield and were buttressed against ENE-WSW Caledonoid basement structures producing prominent zones of disturbance (Trotter 1947; Gayer and Jones 1989). Prominent E-W extensional structures such as the Moel Gilau Fault were also reactivated during shortening (Jones 1989).

Discussion and conclusions

The development of Upper Carboniferous foreland basins in the external Variscan of SW Britain was strongly influenced by the structural inversion of a pre-existing extensional framework. The period of extension spanned some 60Ma in S W England with peak phases of volcanicity and subsidence during Middle Devonian and Lower Carboniferous times. Regional D1 basin inversion occurred in the early Namurian and strongly influenced the position and nature of Upper Carboniferous sedimentation. Areas of thick syn-rift sedimentation such as the Trevone and North Devon Basins (including the Bristol Channel region) emerged as topographic highs during inversion (restacking of their basinal contents) and acted as sites of lithospheric loading. In contrast, the adjacent areas of syn-rift sequences become relative lows and sites of subsidence by downflexing. Although, the probable primary control on regional subsidence was loading of the continental margin to the south of the Culm Basin during the development of the Variscan Orogeny.

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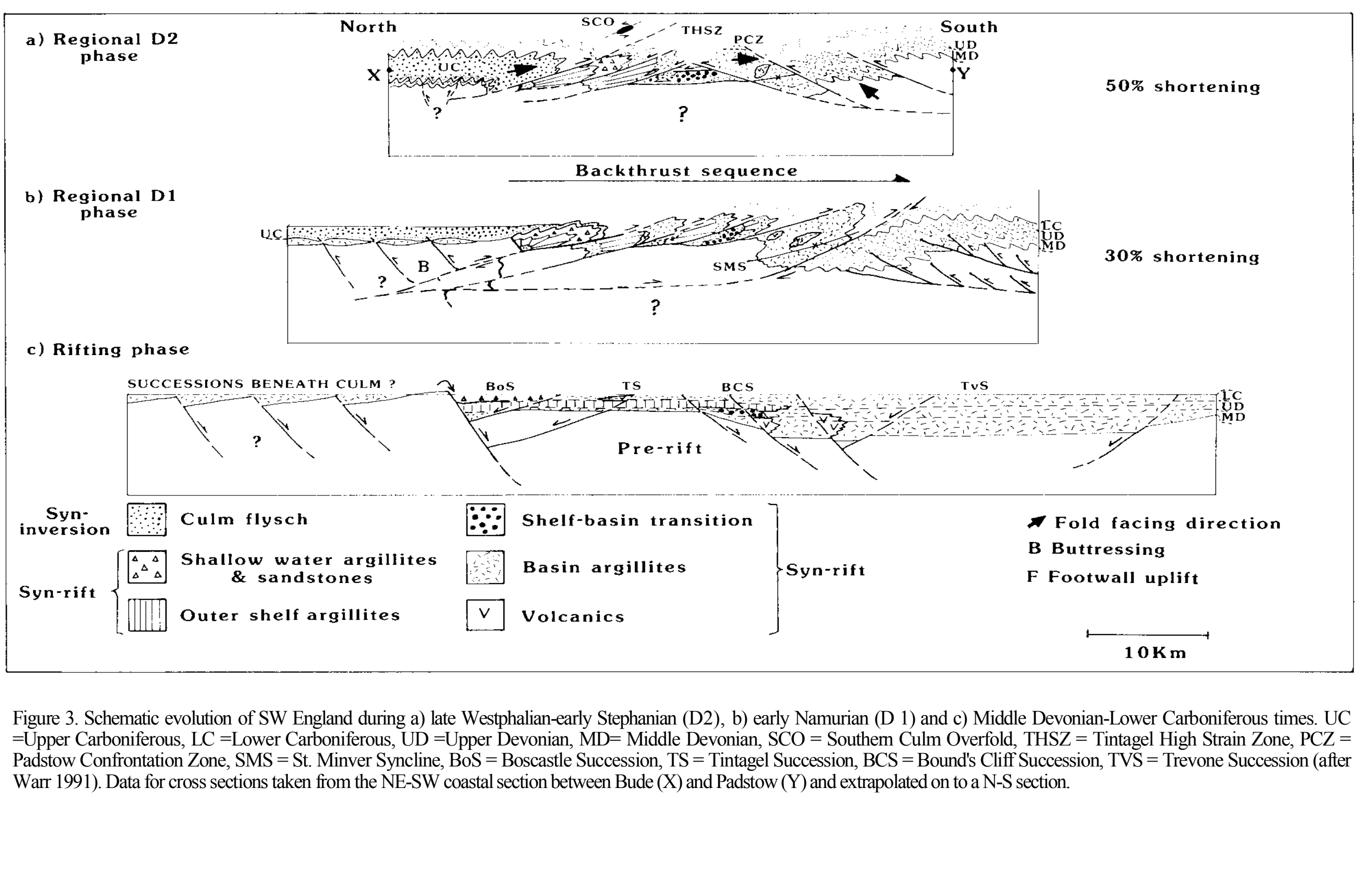

Figure 3. Schematic evolution of SW England during a) late Westphalian-early Stephanian (D2), b) early Namurian (D 1) and c) Middle Devonian-Lower Carboniferous times. UC =Upper Carboniferous, LC =Lower Carboniferous, UD =Upper Devonian, MD= Middle Devonian, SCO = Southern Culm Overfold, THSZ = Tintagel High Strain Zone, PCZ = Padstow Confrontation Zone, SMS = St. Minver Syncline, BoS = Boscastle Succession, TS = Tintagel Succession, BCS = Bound's Cliff Succession, TVS = Trevone Succession (after Warr 1991). Data for cross sections taken from the NE-SW coastal section between Bude (X) and Padstow (Y) and extrapolated on to a N-S section.

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