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THE PORTLEDGE-PEPPERCOMBE PERMIAN OUTLIER

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The presumed Permian red beds overlying the Variscan unconformity on the north Devon coast between Portledge and Peppercombe are divided into five sedimentary units, ranging from coarse alluvial conglomerates via burrowed calcretes representing playa lakes to cross-bedded fluvial channel deposits. Decimetre- to metre-thick lobes of breccia are always present. A decrease in dip from the base (about 40°) to the top (about 20°) of the 130 m sequence indicates deposition was controlled by some 75 m of syn-sedimentary movement on the Portledge Fault forming a small half-graben with a further 75 m of post-depositional movement indicated. Formation of the half-graben is related to an early sinistral phase of movement on the nearby Sticklepath Fault. Some 300 m of sinistral strike-slip movement on the Peppercombe Fault, running parallel to the Sticklepath Fault, cuts the half-graben and represents a later phase of deformation.

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INTRODUCTION

A small area of coarse red conglomeratic and marly sandstone, unconformably overlying the folded Bude Formation (Culm) sandstones, is preserved in two `half-graben' between Portledge and Peppercombe on the north Devon coast (Figure 1). Excellent coastal exposure with rapid erosion allows a detailed inspection of the 800 m section. Access is available via public footpaths (1.5 km falling 150 m to sea level) from Horns Cross [SS 384 232] on the A39 road west of Bideford. The coastal path runs along the top of the cliff.

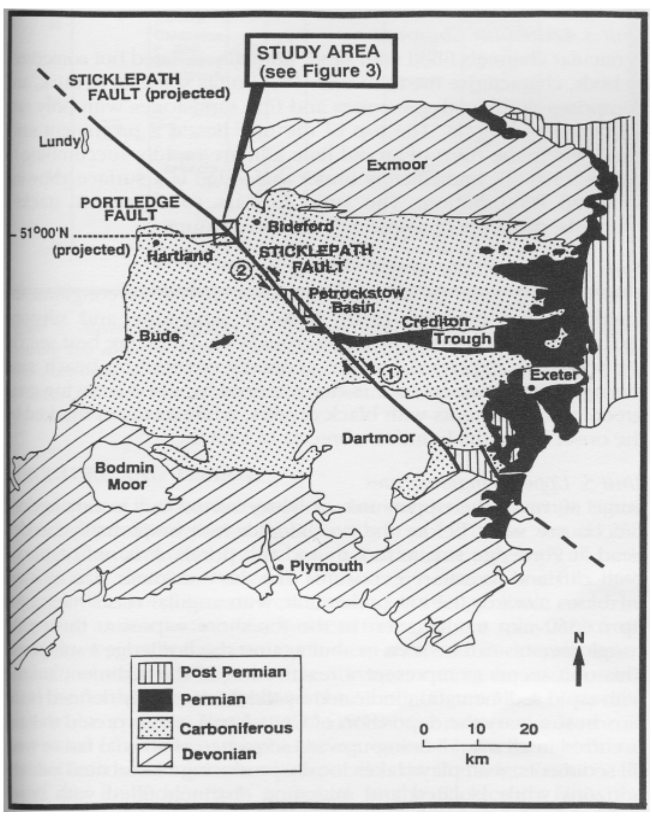

Figure 1: The location and regional context of the Portledge-Peppercombe Permian outlier, North Devon, UK. The numbers 1 and 2 refer to the dextral and sinistral senses of movement on the Sticklepath Fault. The projection of the Portledge Fault into the Hartland area is confirmed by topography and red bed soils (Edmonds et al., 1979).

The outlier has been mapped by the Geological Survey (1:50,000 Solid and Drift Sheet 292, Bideford and Lundy island), and is briefly described in the accompanying Memoir (Edmonds *et al.,* 1979). The tilted Variscan unconformity is clearly visible both in cross - section in the cliff (Figure 2), and in plan view on the foreshore (Figure 3), with shallow - dipping conglomeratic red beds overlying the strongly folded and red-stained Westphalian sandstones and mudstones of the Bude Formation. The age of the red beds is presumed to be Permian on the basis of colour and lithology, by analogy with the south Devon outcrops (Edmonds *et al.,* 1979). No diagnostic fossils have been discovered although trace fossils are common.

The Peppercombe-Portledge exposure provides a rare opportunity to see the Variscan unconformity well exposed in both cliff and foreshore sections. The folding in the indurated sandstones and mudstones of the underlying Bude Formation (Culm) is complex and generally overturned: correcting for rotation during half-graben formation indicates an original modest northerly asymmetry. Locally the Bude Formation sediments at and near the unconformity surface are fractured, with the fractures filled with calcite from the overlying red beds. Variscan quartz-filled fractures are also common.

SEDIMENTOLOGY AND LITHOSTRATIGRAPHY

Sedimentologically, the Peppercombe and Portledge sections comprise bright-red poorly bedded, largely matrix-supported conglomerate with monomictic, apparently locally derived, angular to sub-angular clasts interbedded with sandstones and siltstones. The matrix of fine sand and silt sized grains is strongly calcareous. This, rather than compaction, appears to give the rock its induration. The clasts of sandstone and subordinate mudstone are similar to the Bude Formation lithologies which underlie the unconformity, and a direct local derivation is indicated. The clasts are very similar to those seen in the periglacial `head' deposits of the district. The sorting is poor and bedding generally crude making the subdivision of the unit difficult, though a five-fold subdivision is suggested here.

Stratigraphic columns for both Peppercombe and Portledge outliers are shown in Figure 4, where the BGS recorded section is compared with the section recorded for this study. Five lithostratigraphic units are proposed both on the basis that similar sequences are identified at both outliers, and that the divisions are maintainable on the foreshore and in the cliff. Single beds are rarely of great lateral extent. Units 1 and 2 are discernible in both outliers. From the unconformity surface upwards, the five units are:

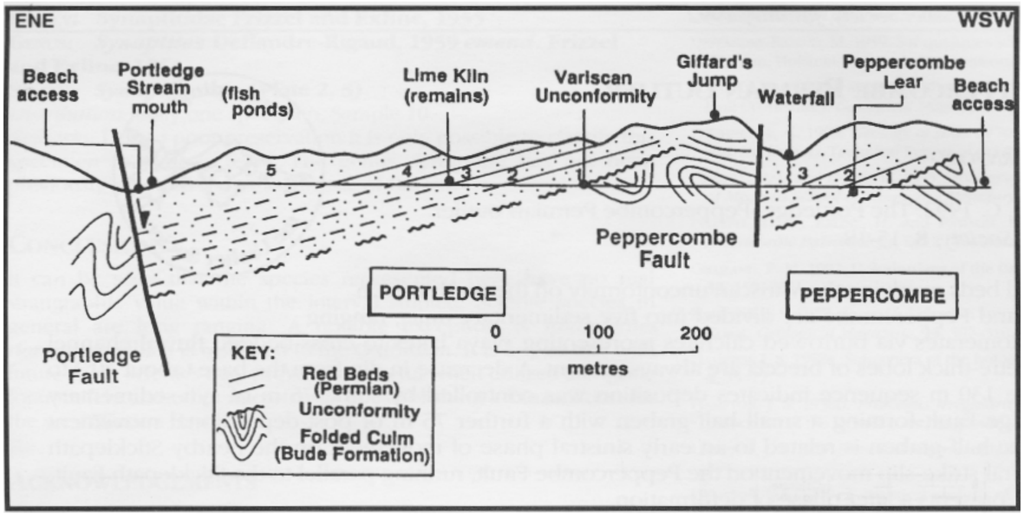

Figure 2: Sketch section of the geology in the cliffs from Portledge Mouth (SS 387 248] to Peppercombe Lear (SS 379 243]. The numbers 1 to 5 refer to the lithostratigraphic units defined and discussed in Figure 4 and the text. The folding in the Culm is largely schematic.

Unit 1. Basal Conglomerate

Overlying the unconformity is a basal conglomeratic unit about 16 m thick, comprising coarse breccia (<650 min) clasts on both foreshore and the Peppercombe Cliff exposure, but finer (<125 mm) breccia overlying the Portledge unconformity. Interbeds of sandstone and occasional siltstone complete this unit. The deposition of the first carbonate horizon forms the top of this unit.

Unit 2. Burrowed Calcretes

This unit is 18 m thick with nodular calcareous (?calcrete) horizons, and trace fossils, the most spectacular of which are up to 75 mm in diameter and in excess of 1.5 m long. Most trace fossils are horizontal, with occasional branching, and weather prominently to show as white tubes in the deep red siltstones and sandstones. Smaller traces down to 4 to 5 mm in diameter are seen. The traces are generally internal moulds of calcite, but some are silicified and a few towards the top of this unit are filled with sand and silt. A large number of fining-upwards cycles can be seen in this unit (Figure 3).

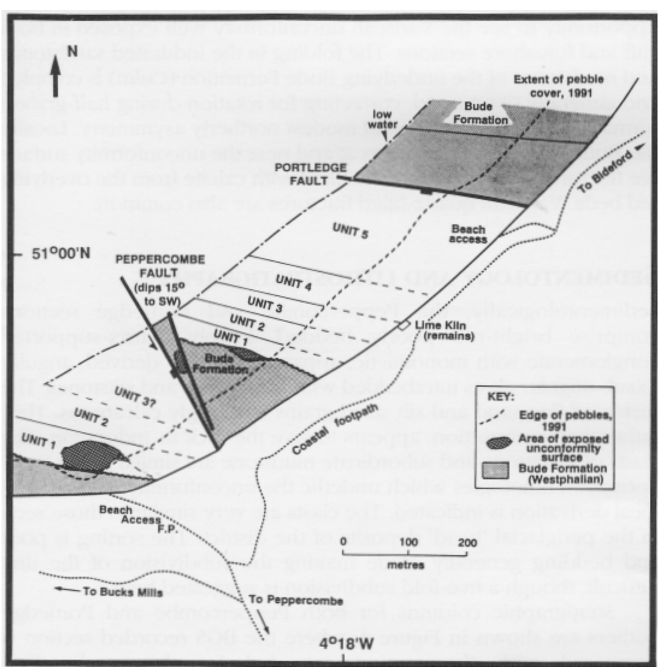

Figure 3: Sketch mapping of the ?Permian beds exposed on the foreshore between Portledge and Peppercombe. All beds dip in a direction between 10° and 35° east of north, dip being controlled by movement of the Portledge Fault. Offset of the 5 lithostratigraphic units show some 300 m of net strike-slip movement on the Peppercombe Fault.

The breccia exhibits a sharp base with waning energy depositing sand then silt and finally a nodular carbonate-rich silty interval with bioturbation. Each cycle may represent the filling of a depression, with the breccia representing flash-flood deposits, the silts and sands falling energy water flow, and the nodular carbonates calcretes deposited within the sediment profile during the drying out of a temporary lake. The source of the trace fossils is not clear. Broadly similar Structures in south Devon (Ridgeway, 1974) were thought to result from the activities of reptiles or amphibians rather than annelids, on the basis of the indigestibility of the matrix (Laming, 1982): roots or crustacean burrows are also possible.

Unit -3. Lenticular Channels

Lenticular channels filled with sand, normally isolated but sometimes as beds, characterise the third unit. This unit is some 20 m thick, and comprises dominantly siltstones and fine sandstones with only rare injections of breccia. The top of the unit lies at a prominent sand band where the ruins of an old lime kiln are rapidly succumbing to coastal erosion. Immediately under this ledge is a surface showing silt-filled bioturbation. The unit appears to represent stacked channels, probably of a relatively transient nature.

Unit 4. Cross-Bedded Sands

This interval, some 33 m thick, is almost devoid of conglomerate interbeds, but contains many beds of sandstone and siltstone characterised by coarse low-angle cross-beds. These are best seen in the foreshore exposure, but are generally covered by beach sand during the summer. Its base is characterised by a bed showing grey-green reduction spots with black centres, while its top is marked by the onset of the thick uniform breccia of Unit 5.

Unit 5. Upper Conglomerates

Some 40 m of the upper unit of better sorted but poorly-bedded breccia are seen, before the unit merges into horizontally bedded head at Portledge stream mouth and fish ponds. It is noticeable on both cliff and foreshore exposures that the maximum size of clasts increases towards the top of this unit, with angular clasts measuring up to 550 mm in diameter. In the foreshore exposure the coarse conglomerates can be seen to abut against the Portledge Fault plane. This unit seems to represent a reactivation of the sediment source, with rapid sedimentation indicated by the thick, poorly defined beds.

In summary the deposition of Units 1 to 4 is interpreted to have occurred in an overall fining-upward sequence of alluvial fan or wadi fill sediments, with playa lakes locally producing bioturbated calcrete horizons while isolated and migrating channels filled with cross-bedded sands attest to fluvial action. Within this gross fining-upwards cycle, multiple fining-upwards elements are seen. Unit 5 represents reactivation of the sediment source, possibly representing the base of a new gross cycle. Further work is required to establish the transport directions of the breccias (from imbrication directions), and channels and cross-bedded sands (from foreset orientations).

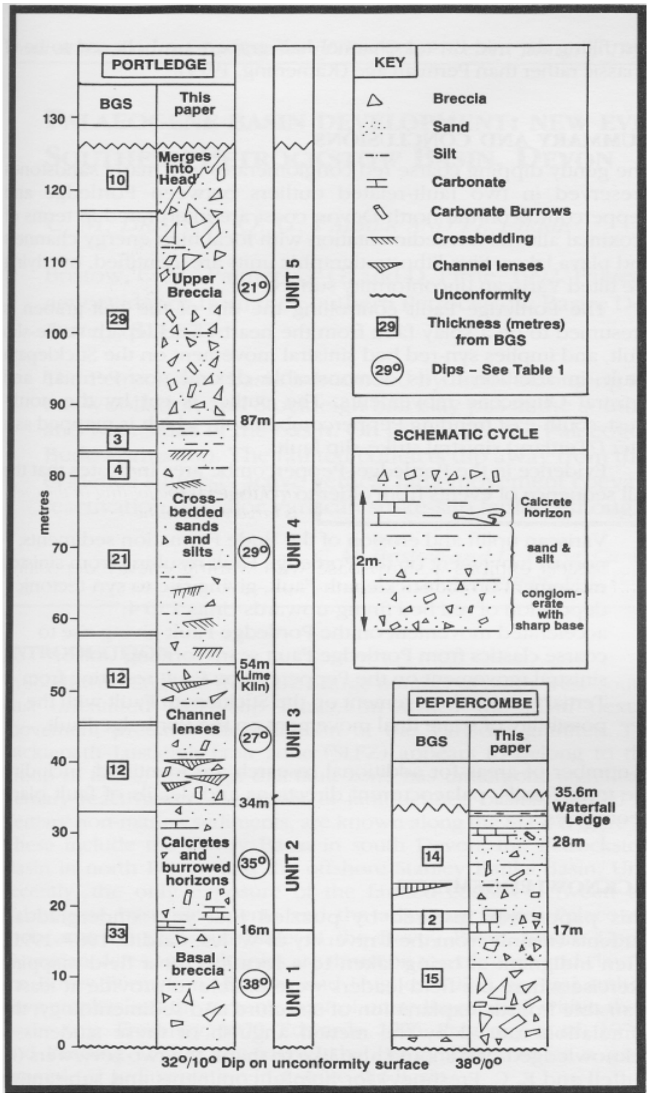

Figure 4: Measured sections at Portledge (left) and Peppercombe (right), showing the division into 5 lithostratigraphic units. The BGS columns are from Edmonds et al. (1979). The average dips reported in Table I are indicated, for each unit. A reasonable correlation is apparent between Units 1 and 2 at the two locations.

STRUCTURE AND TIMING

The structure of the two `half-graben' is not identical, as shown in Figure 3. The general dips reported by Edmonds *et al.* (1979) as `around 25°' appear to be controlled by the major Portledge Fault, with all beds dipping in a direction between 10° and 35° east of north in both outcrops. The roughly east-west trending Portledge Fault could he interpreted as reactivation of a Variscan thrust, or as a splay fault from the nearby regionally extensive north-west-south-east Sticklepath strikeslip fault, which was mapped by the Survey as cutting the coast some 2 km to the north-east near Babbacombe Mouth (Figure 1). A composite origin is also possible. Brooks *et al.* (1988) have proposed a Mesozoic reactivation of a Variscan thrust as being responsible for the mid-Bristol Channel fault zone, a feature which parallels the Portledge Fault.

If the Portledge Fault is linked to the Sticklepath fault, the extensional development of the half-graben demands a sinistral sense of motion on the latter fault. This situation is shown in diagrammatic form in Figure 5. Movement on the Sticklepath Fault is recognised to be complex (Arthur, 1989), the Petrockstow Basin to the south-east and the Stanley Bank Basin to the north-west being filled with Eocene to Oligocene sediment, and forming by sinistral movement during the Tertiary. Translation of the eastern segment of the Dartmoor Granite and the westerly extension of the Crediton Trough demands post-Permian dextral movement (Figure 1), while Arthur (1989) reviews evidence for a late Carboniferous (Stephanian) phase of dextral movement. The interpretation proposed in this paper requires an additional early, syn-red bed phase of sinistral movement.

The recent explanation of the structure of the Lundy area by Arthur (1989) speculates on the possibility of two splay faults (termed the North and South Lundy Fault Zones) propagating from the Sticklepath Fault and bounding a larger sinistral strike-slip basin to the north-west of the study area. These bounding faults parallel the Portledge Fault and are structurally analogous, though the implied movement is of Tertiary age.

Measurement of the detailed dips in the red beds on the foreshore and at the foot of the cliff places limits on the timing of the movement on the Portledge Fault, and are reported in Table 1. These dip measurements must result from palaeo-topographic and sedimentary dips in addition to any subsequent tectonic tilting. In addition it must he acknowledged that measuring dips in poorly-bedded coarse clastics is problematic. The data in Table 1 should be viewed in this light.

Different average values are obtained from the measurements on the cliff and foreshore, with generally lower dips measured on the deeply eroded foreshore beds. For this reason the cliff data are preferred. Overall, the values show a tendency towards a progressive decrease in dip up the section suggesting syn-sedimentary rotation of the half-grabens by movement on the Portledge Fault. If the linkage indicated in Figure 5 is accepted, then sinistral movement of the Sticklepath Fault during the deposition of the ?Permian red beds is implied.

Figure 2 schematically shows the sub-red bed unconformity dipping constantly at approximately 40° into the Portledge Fault. However, if as suggested the structure is a half-graben, it might be expected that the unconformity will increase in dip towards the fault, producing a wedge-shaped red bed sequence thickening towards the controlling fault. Similarly the dip on the unconformity will decrease away from the fault. The geometry of the resultant roll-over anticline will reflect the listric shape of the deeper parts of the Portledge Fault. We have not yet determined the full geometry of the roll-over anticline and thus cannot comment on fault shape at depth.

The data in Table 1 indicate a small angular unconformity between Units 1 to 4 and Unit 5. The rejuvenation of the sediment source indicated by the introduction of Unit 5 on top of the previously fining-upwards succession fits in with active fault movement. Also, the increase in size of the clasts noted towards the top of Unit 5 (as one approaches the Portledge Fault) may represent talus being shed from the active fault scarp. This suggests enhanced fault movement between deposition of Units 4 and 5, a proposition that could be substantiated by measuring imbrication within the coarse breccias of Unit 5 and comparison of channel orientation in Unit 3 and foreset direction in Unit 4 as indicators of palaeo-transport direction: this work has yet to be done.

TABLE 1: Average dip angles (in degrees) for the 5 Units of the Portledge outcrop measured on the foreshore and cliff foot exposures. The Standard Deviation is for `n' measurements of dip. All beds dip in a direction between 10° and 35° east of north.

Lithostratigraphic unit	Foreshore mean (n)	Standard deviation	Cliff Foot mean (n)	Standard deviation
Unit 5	-(-)	-	21(30)	3.85
Unit 4	23(22)	6.41	29(34)	4.27
Unit 3	30(3)	-	27(11)	2.66
Unit 2	22(9)	2.78	35(22)	3.44
Unit 1	27(10)	5.04	38(4)	-

NB: the unconformity surfaces seen at the foot of the cliff dip at approximately 32° and 38° for Portledge and Peppercombe respectively.

Since Unit 5 dips at about 20° and the basal beds and unconformity dip at about 40°, about half of the movement on the Portledge Fault is syn-sedimentary and half post-Unit 5 deposition. If the throw on the Portledge Fault is about 150 m (i.e. in excess of the 135 m of red bed sediment forming the hanging wall), some 75 m of syn-red bed movement and 75 m of post-sedimentation (or more strictly post-Unit 5 deposition) movement is indicated.

The Peppercombe Fault, though it clearly has substantial throw, has little effect on the dips. On this basis, and because it runs parallel to the Sticklepath Fault, strike-slip movement is indicated. Despite detailed inspection of the relatively well-exposed fault plane, no evidence of slickenside lineations were found to substantiate this sense of movement. The translation of the beds and unconformity surface suggests a net sinistral movement of some 300 m. As mapped, the Peppercombe fault cuts, translates and hence post-dates the Portledge Fault. It could thus be of any post-red bed age, possibly forming during the Tertiary.

At the Portledge Cliff unconformity exposure, minor adjustment 'joints' can be traced from Variscan faults cutting the Bude Formation, across the unconformity and into the red beds. These inherited faults have minimal displacement (e.g. 20 to 30 mm), but penetrate through the entire red bed section, being seen in Unit 5. Their timing clearly post-dates red bed deposition, and their sense of movement suggests a period of compression. The post-red bed dextral movement on the Sticklepath Fault would have placed this area under compression. This raises the question of whether both the Peppercombe and Portledge faults would have suffered some element of inversion at this time.

DATING THE RED BEDS

A Permian age is attributed to the Portledge - Peppercombe red beds by analogy with the breccias of south Devon (Laming, 1982). Work by Scrivener and Edwards (1992) suggests that the red beds of the New Red Sandstones in the Crediton Trough can be split into a unit of late Carboniferous breccias, sandstones and basic volcanics, and a late Permian unit of breccia, sands and acid volcanics. Volcanics are absent from the Portledge - Peppercombe breccias, and lithologically they have greater similarities with the Triassic of west Somerset and South Wales (Edmonds and Williams, 1985). The lowest breccias in the western end of the Crediton Trough and at Hollacombe are, however, devoid of volcanic debris, and like the Portledge-Peppercombe red beds, comprise clasts mainly derived from local 'Culm' sandstones and mudstones (E.C. Freshney, personal communication).

The offshore mapping of the Bristol Channel (Brooks *et al.,* 1988, and references therein) shows a mid-channel disturbance zone, running approximately east-west, i.e. parallel to the Portledge Fault. The form of the mid-channel disturbance is in some cases a wrench, but overall is in the form of a half-graben, mimicking, on a much larger scale, the geometry and orientation of the Portledge half-graben.

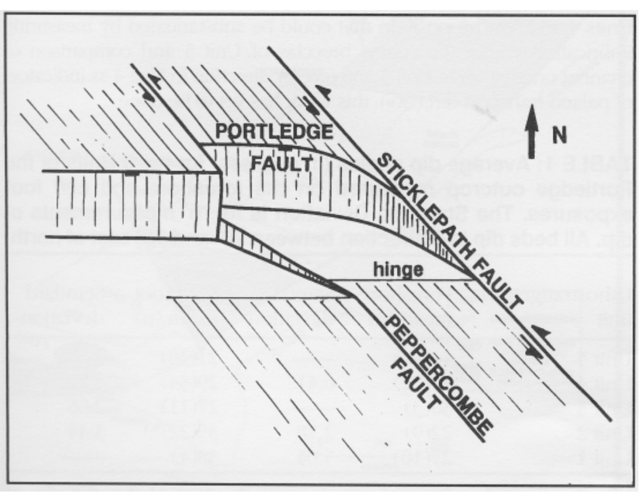

Figure 5: Cartoon to illustrate the proposed movement of the Portledge (normal dip-slip) and Peppercombe (sinistral strike-slip) faults. The relationship with the Sticklepath Fault is conjectural, though supported by the geometry.

The sediments first filling the mid-Bristol Channel half graben are believed to be of Triassic rather than Permian age (Kamerling, 1979).

SUMMARY AND CONCLUSIONS

The gently dipping coarse red conglomerates and marly sandstone preserved in two fault-related outliers between Portledge and Peppercombe on the north Devon coast are interpreted in terms of proximal alluvial fan sedimentation with local high energy channel; and playa lakes. Five lithostratigraphic units are identified, overlying the tilted Variscan unconformity surface.

The Portledge Fault controlling the dip of the half-graben is presumed to be a splay fault from the nearby Sticklepath strike-slip fault, and implies syn-red bed sinistral movement on the Sticklepath Fault. In addition to its demonstrable dextral post-Permian and sinistral Oligocene movements. The outlier is cut by the northwest-south-east trending Peppercombe Fault, which is mapped as a later (?Tertiary) sinistral strike-slip fault.

Evidence in the Portledge-Peppercombe area indicates that the full sequence of events from older to younger is:

1: Variscan uplift and erosion of the Bude Formation sediments;
2: normal movement on the Portledge Fault resulting from sinistral movement on the Sticklepath Fault, giving rise to syn-tectonic deposition of red bed fining-upwards Units 1 to 4;
3: accelerated movement on the Portledge Fault giving rise to coarse clastics from Portledge Fault scarp forming Unit 5;
4: sinistral movement on the Peppercombe Fault resulting from Tertiary sinistral movement on the Sticklepath Fault with the possibility of some final movement on the Portledge Fault.

A number of areas for additional research are identified, including the trace fossils, palaeocurrent directions and details of fault plane geometries.

ACKNOWLEDGEMENTS

This paper was inspired by puzzled first year undergraduate students (mainly from the University of Wales, Cardiff, 1987-1991), often indignant at being taken to a location for a field mapping exercise where the field leaders were unable to provide at least a plausible holistic explanation of structure and sedimentology; the stimulation caused by the mental anguish of these students is acknowledged. We should also like to thank the two reviewers (A. Ruffell and E. C. Freshney) for helpful comments and substantive suggestions.

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