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PALAEOGENE BASIN DEVELOPMENT: NEW EVIDENCE FROM THE SOUTHERN PETROCKSTOW BASIN, DEVON

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The Petrockstow Basin is bounded by faults belonging to the Sticklepath-Lustleigh fault zone (SLFZ). New exposures in the Woolladon and Stockleigh ball clay pits at the southern end of the basin show the faulted contacts on both the east and west sides of the basin. On both sides the Palaeogene basinal sediments are overlain by the Upper Carboniferous Bude Formation. The faulted contacts dip away from the basin margin at angles between sub-horizontal and 25°. Field evidence suggests active vertical fault movement coeval with sedimentation. Basin development was clearly related to reactivation of major Variscan strike-slip faults, although the sense of fault motion is uncertain.

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INTRODUCTION

In south west England there are a large number of north-west-southeast orientated strike-slip faults, on which the main dextral movement predates the intrusion of the Variscan granites. The Sticklepath-Lustleigh fault zone (SLFZ) appears to belong to this group of faults, although this fault zone has undergone significant Tertiary reactivation. A number of fault-defined basins, infilled by Tertiary non-marine sediments, are known along the SLFZ (Figure 1). These include the Bovey Basin in South Devon, the Petrockstow Basin in north Devon and the offshore Stanley Banks Basin. Until recently, the only exposure of the faulted contact between the Palaeogene basin sediments and the adjoining Upper Palaeozoic rocks was on the south side of the Bovey Basin, where Upper Devonian slates and volcanics are thrust on top of sands and clays of the Bovey Formation (Bristow and Hughes, 1971). Several authors have emphasised the tectonic control on sedimentation within these basins (e.g. Freshney, 1970; Edwards, 1976; Freshney *et al.,* 1979), and Reading (1980) considered the Bovey Basin to be a good example of sedimentation in a strike-slip basin.

Until recently, the geometry of the basin margin faults was poorly known. Within the Petrockstow Basin, extensions of the Woolladon and Stockleigh ball clay pits over recent years have exposed the main boundary faults on the west and east sides of the basin. The basin margin faults are now well displayed in the upper benches of the pits. Field data, combined with exploration borehole data, allow an interpretation of the near-surface geometry of the basin margin faults to he made.

PREVIOUS STUDIES

The significance of the SLFZ was first recognised by Blyth (1957; 1962), working in the north-eastern area of Dartmoor. Subsequently, Dearman (1963), Shearman (1967) and later workers, showed the importance of dextral strike-slip faulting in south-west England. Reactivation of these dextral strike-slip faults, notably the SLFZ, in the Tertiary resulted in the development of a series of sedimentary basins (Edwards, 1976; Freshney *et al.,* 1979; Freshney *et al.,* 1982). These sedimentary basins include the commercially important Bovey and Petrockstow basins on the SLFZ, which yield high quality ball clays (pale firing, kaolinitic clays with exceptional plasticity and green strength).

Eocene-Oligocene sedimentation within the Petrockstow Basin been described by Freshney (1970) and Freshney *et al.* (1979) basin was interpreted by Freshney *et al.* (1979) to be subdivided to a central axial fault-bounded trough, with two shelf areas `developed to the north-east and south-west. Sedimentation within the axial trough was dominated by the deposition of cyclic fluvial sands and gravel, with relatively minor clay sedimentation. Within the axial trough there is a marked fades variation along its length, with coarser-grained sediment to the south-east and finer-grained sediment to the north-west (Freshney *et al.,* 1979). This is consistent with an interpreted palaeoflow direction from south-east to northwest. The shelf areas to the north-east and south-west are clay-dominated, although sands also occur in the Woolladon shelf sequence to the south-west. The shelf fades of the Woolladon area are bounded to the south-west by a north-west-south-east trending fault, and to the east by a 'spine' of Carboniferous strata (Freshney *et al.,* 1979).

Although the control of faulting on sedimentation within the basin has long been recognised, the nature of the boundary faults was poorly known. Previous published studies (e.g. Freshney *et al.,* 1979) and unpublished commercial reports envisaged the basin margin faults to be vertical. However, Freshney *et al.* (1979), based on geophysical investigations of the Petrockstow Basin, suggested that the fault separating the axial trough from the north-eastern shelf was a reverse fault dipping 45° to the north-east. The contact between the

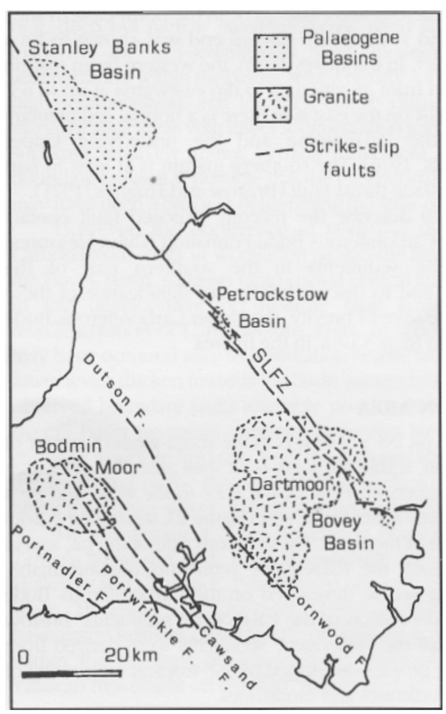

Figure 1: The Palaeogene basins along the SticklepathLustleigh fault zone and other associated strike-slip faults in south Denon and east Cornwall. SLFZ = Sticklepath-Lusleigh fault zone.

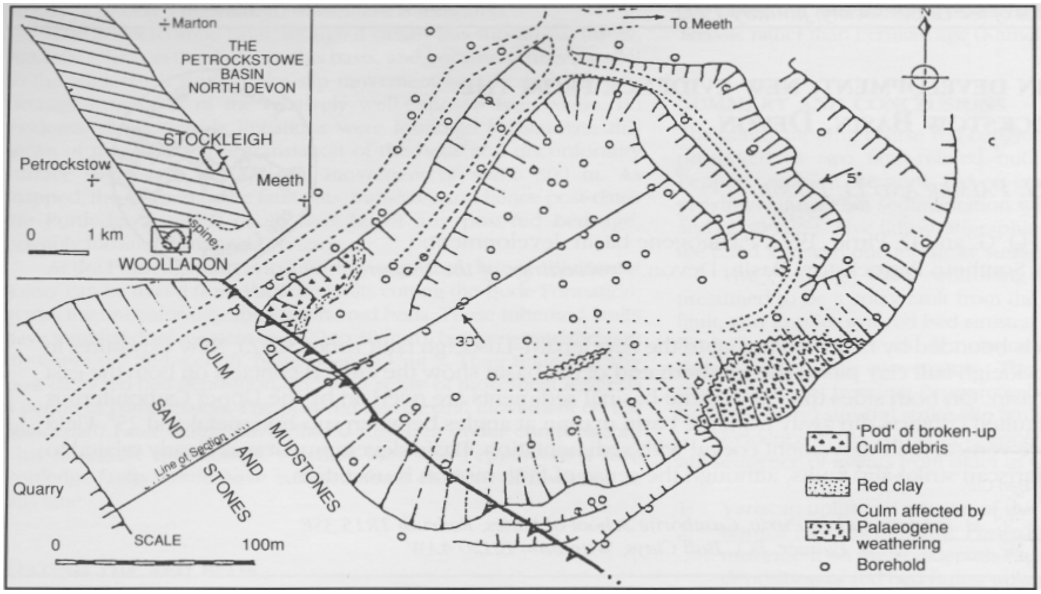

Figure 2: Geological plan of Woolladon pit, north Devon showing the boundary thrust fault. For the sake of brevity the term 'Culm' is used for the Upper Carboniferous Bude Formation

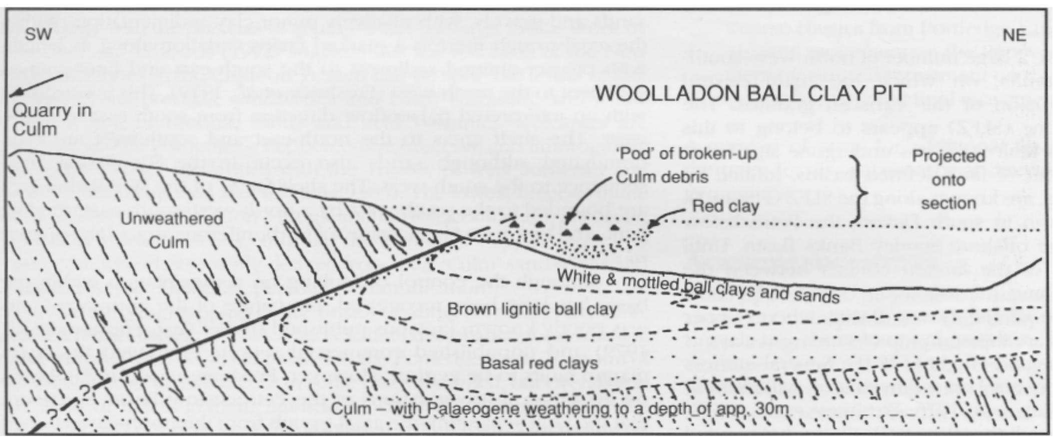

Figure 3: Geological section through Woolladon ball clay pit; for location of section see Figure 2. The hatchet ornament for the Culm is not intended to indicate the actual dip.

Carboniferous and Palaeogene in the north-eastern shelf area of the basin and at the south-eastern end was shown to be a gently dipping contact. In the Bovey Basin, the western basin margin fault was interpreted from gravity data to dip eastwards at up to 63° (Fasham, 1971), whilst on the east side there is a normal sedimentary contact between the Palaeogene and the underlying Upper Greensand (Edwards, 1976). The southern margin is at least in part defined by the Ringslade thrust fault (Bristow and Hughes, 1971).

We aim here to describe the recently exposed fault contact between the Upper Carboniferous Bude Formation (Culm Measures) and the Palaeogene sediments in the southern part of the Petrockstow Basin, and to discuss briefly the significance of these observations. For the sake of brevity, the Upper Carboniferous Bude Formation is referred to as 'Culm' in the figures.

THE WOOLLADON AREA

Woolladon ball clay pit [SS 529 081] is in the south-western corner of the Petrockstow Basin, within the south-west shelf area. This shelf area is bounded by the Greencliff Fault of the SLFZ to the west, and by a 'spine' of Carboniferous strata to the east (Figure 2), separating it from the main axial trough of the basin. On the south side of the pit, and in the present pit bottom, the Palaeogene sediments unconformably overlie a weathering profile developed on the Carboniferous Bude Formation, prior to deposition of the Palaeogene sediments. Bristow (1968) has shown that the Palaeogene sediments were derived from chemical weathering profiles developed by sub-tropical weathering of the Carboniferous mudstones and sandstones.

Within the Woolladon pit, the lower part of the sequence includes seams of brown lignitic ball clay which thicken towards the western boundary fault. The upper part of the sequence includes the allochthonous 'pod' of Carboniferous strata, and also some red staining, which may represent the post-depositional alteration of clasts of Bude Formation debris to ball clay mineralogy.

Recent drilling on the west side of the pit has shown that the western boundary fault zone dips to the south-west at about 20 to 25° (Figure 3). The contact between the Palaeogene sediments and the hanging wall of Carboniferous strata is well-exposed on the west side of the pit [SS 528 080]. The typical hanging wall sequence in the southern corner of the pit [SS 529 079] comprises four units in ascending order (Figure 4):

- Unit 1. Bude Formation mudstones and sandstones.
- Unit 2. Dark grey, intensely sheared Bude Formation; 2 to 5 m thick
- Unit 3. Red clay, commonly containing spherulitic siderite, with a sharp base; 2 to 7 m thick.
- Unit 4. Palaeogene sands and clays, commonly containing spherulitic siderite near the fault zone.

The dip of the Palaeogene sediments increases towards the fault zone implying minor drag folding with brown clay from the Palaeogene sequence dragged up along the fault plane (Figure 5). Unit 3 is repeated in the southern corner of the pit, suggesting the presence of two (parallel fault planes, 2 to 3 m apart. The main fault plane is considered to be at the base of Unit 3. Based on drilling data, the fault is considered to maintain its observed dip to at least 20 to 30 m below the original land surface.

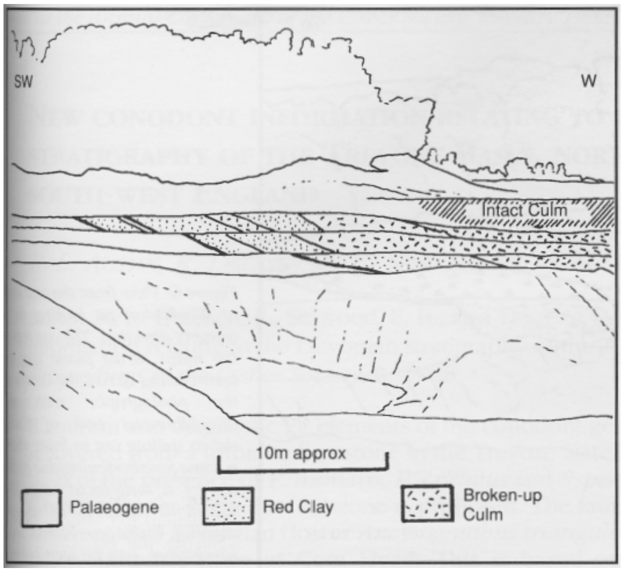

Figure 4: Tracing from a photograph of the upper benches in the southern corner of Woolladon ball clay pit. The main fault plane is marked by a thick black line and is dipping away from the camera at about 25°.

The strike of the fault zone is 125°, which is somewhat different from the strike of 150° for the western boundary fault of the basin, marked on the BGS Chulmleigh Sheet 309, and the overall strike of the SLFZ across Devon (140°).

In the north-west corner of the pit, an allochthonous mass of Carboniferous sediment, 50 m long and at least 7 m thick (top not observed) is enclosed within the Palaeogene strata (Figure 6). This allochthonous mass is bordered by a zone, approximately 1 m thick of reddened, weathered clay; internally most of the material within the 'pod' appears disaggregated, although there are areas where the Carboniferous bedding is preserved. The red clay probably represents reworked Culm debris, which was altered to ball clay mineralogy by fluids expelled from the adjoining Palaeogene sediments.

Within the Bovey Basin, disaggregated masses of weathered Upper Devonian slate and volcanic rocks occur in front of the Ringslade thrust (Bristow and Hughes, 1971). A commercial grade of clay ('Ringslade mottled') was formerly produced from this slate debris, which had been wholly altered to ball clay mineralogy by Palaeogene chemical weathering. Edwards (1976) suggested that the Ringslade mottled unit wedged out away from the basin margin. This sequence is analogous to the development of a small scale olistostrome in a non-marine environment.

Although not so well exposed, the eastern boundary fault is seen on the east side of Stockleigh ball clay pit [SS 535 095] and borehole information indicates a similar situation to that on the western margin of the basin, with a hanging wall of Carboniferous slates, resting on Palaeogene sediments. The faulted contact dips away from the basin, at similar angles to those seen at Woolladon.

DISCUSSION

On both sides of the Southern end of the Petrockstow Basin, the faulted contacts between the Carboniferous Bude Formation and the Palaeogene sediments dip outwards at angles varying between a few degrees and 25° (Figure 7). If these faults steepen with depth, then the field observations would be consistent with the geophysical data from the north-eastern part of the basin, which were interpreted by Freshney *et al.* (1979) as representing a reverse fault dipping at 45° to the north-east. The overall appearance of the faults is reminiscent of positive flower structures (which are a series of convex-upward reverse faults in which the trace of the fault plane is asymptotic to the vertical), developed within strike-slip fault zones. If this analogy is correct, one would expect the fault planes to steepen at depth to near-vertical. This would be consistent with the previous interpretation of the related Bovey Basin as a strike-slip basin (Reading, 1980). In addition, the basins associated with the

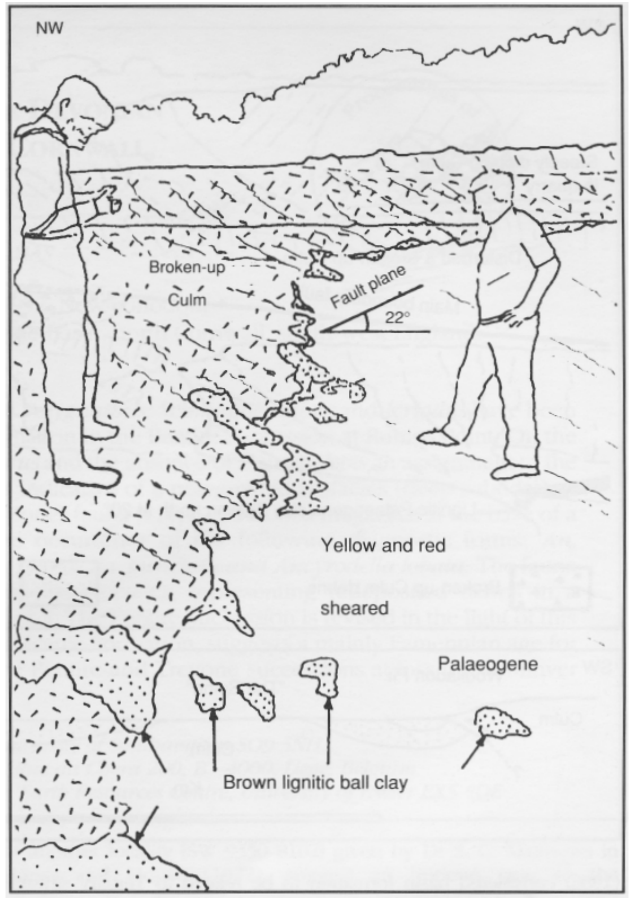

Figure 5: Tracing of a photograph looking southwards along the outcrop of the main thrust fault plane, taken at a point close to the line of section. Note the shreds of brown lignitic clay which have been brought up on the thrust plane from the seam of brown lignitic ball clay which is about 20 to 30 m below the figures. The beginning of the allochthonous 'pod' of Culm debris is seen in the top right corner of the photograph.

SLFZ all have features typical of strike-slip basins (e.g. deep but narrow basin geometry, rapid sedimentation rate and evidence for syn-sedimentary fault movement). The style of sedimentation within the basins, with a rapidly subsiding axial zone with high sedimentation, and localised coarse clastic input, bordered by marginal shelf areas with lower sedimentation and subsidence rates also supports relatively minor vertical movement on the major basin bounding faults. It is possible that the exceptional plasticity of ball clays may have been a factor in determining the style of deformation.

However, the occurrence of both the allochthonous 'pod' of Carboniferous strata in Woolladon pit and the Ringslade mottled unit in the Bovey Basin, suggests rapid coeval vertical fault movement, leading to the development of unstable fault scarps, and Subsequent resedimentation of Carboniferous Strata. In Woolladon pit, fault uplift may have occurred after sedimentation began, as clay seams within the lower levels thicken towards the basin margin faults. Thus, although the observed boundary faults resemble positive flower structures and the overall basin geometry supports strike-slip basin development, the currently available field data from the exposed basin bounding faults at the south end of the Petrockstow Basin only supports minor vertical, rather than strike-slip or oblique slip motion at this locality.

The development of the Bovey and Petrockstow basins within a Tertiary strike-slip fault zone is generally accepted (Reading, 1980; Holloway and Chadwick, 1986). Based primarily on data from the Bovey Basin, Holloway and Chadwick (1986) suggested that these basins have many features characteristic of onshore pull-apart basins formed within the overlaps of side-stepping transcurrent faults. Although Variscan movement on the SLFZ was dextral, Holloway and Chadwick (1986) considered basin formation to be related to Tertiary

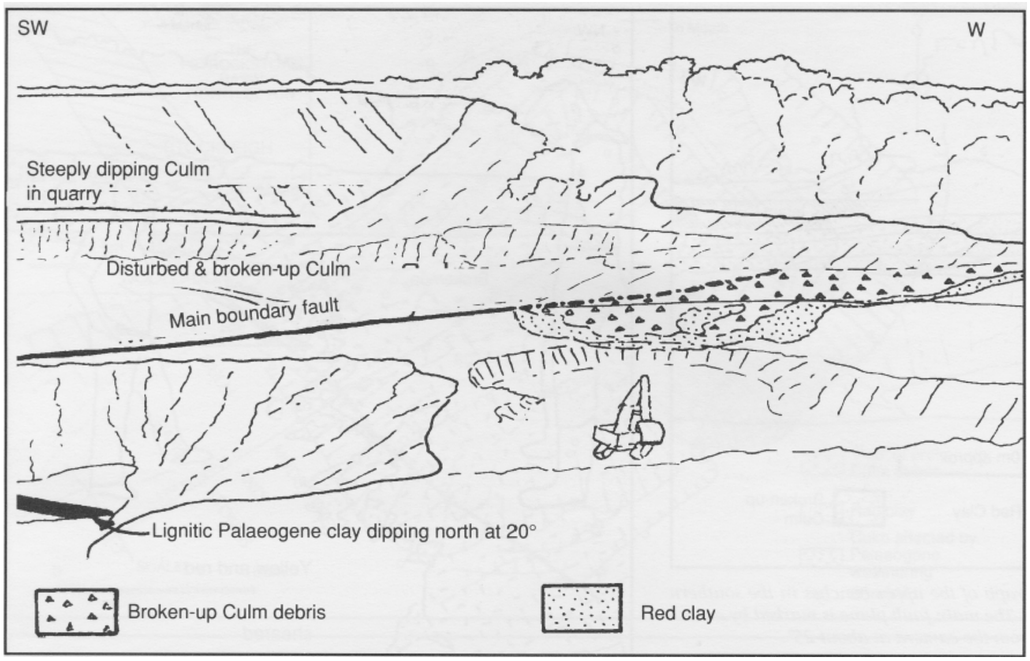

Figure 6: View from the east side of Woolladon pit looking in a westerly direction. The outcrop of the main thrust plane can be seen cutting across the centre of the photograph, with the allochthonous pod of Culm debris spilling out in front, there is some foreshortening due to the use of a long focus lens. The roadstone quarry, in steeply dipping Culm mudstones and sandstones, can be seen behind the thrust fault. In the bottom of the ball clay pit a seam of lignitic hall clay can be seen dipping north at 20°.

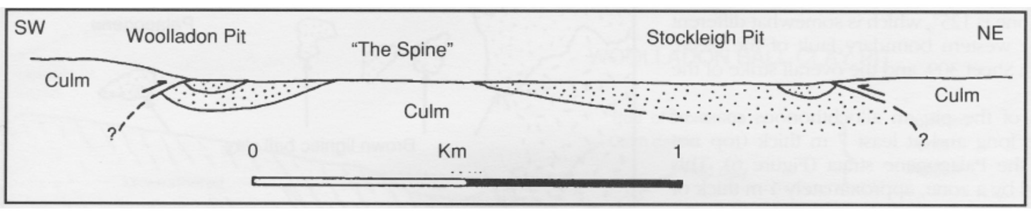

Figure 7: Schematic geological cross-section across the Petrockstow Basin.

sinistral reactivation of the SLFZ. Previous theoretical studies on pull-apart basin development in strike-slip fault zones have shown that basins developed at left-stepping offsets are produced by sinistral strike-slip (or oblique slip) movement (Rodgers, 1980). Left-stepping dextral fault movement is thought to produce a zone of compression rather than basin formation (Rodgers, 1980). Conversely, right-stepping dextral fault zones produce a zone of subsidence and basin formation. Although the Bovey Basin is proposed to have been formed at a left-stepping offset due to sinistral reactivation of the SLFZ (Holloway and Chadwick, 1986), the field evidence presented in this paper suggests that the Petrockstow Basin developed at a right-stepping offset because of dextral fault motion. Other evidence for dextral movement on strike-slip faults in south-west England include field observations of the Portwrinkle, Cawsand and Cornwood faults which only show minor post-granite dextral movement where they intersect the Variscan granites. Equally, the post-granite displacement by the SLFZ of the north-east lobe of the Dartmoor granite appears to involve an overall dextral sense of movement.

In summary, although the Tertiary sedimentary basins associated with the SLFZ clearly developed in association with a major strike-slip fault, the tectonic development of individual basins along the fault zone appears to differ. Additional work is needed to fully determine the tectonic development of these economically important basins

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