THE EVOLUTION OF THE RIVERS OF EAST DEVON AND SOUTH SOMERSET, UK

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With the exception of the River Tone, which appears to have been separated at an early stage from its neighbours to the south by a major fault, the rivers of south Somerset and east Devon were initiated on a southward dipping Tertiary planation surface. The evolutionary histories of the present-day catchments of the rivers Exe and Otter are complex and inter-related. Those of the adjacent Axe and Teign appear to be less complex and may have evolved relatively independently from the Exe-Otter system. The differences in the histories of the catchments are most clearly demonstrated by their terrace systems. The Exe-Otter catchment has 10 or more terrace levels at heights of up to 140 m above the modern floodplain. In contrast, the Axe, Teign and Tone catchments contain only one or two terrace levels all of which are less than 20 m above the present-day valley floor. The explanation suggested here for the difference involves a sequence of river captures that changed the forerunner of the present-day Otter from a major river capable of producing a 3-km wide gravelly braidplain into a minor stream.

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INTRODUCTION

The middle and lower reaches of the River Exe and the adjacent catchments of the Axe, Otter, Teign and Tone drain an area with a complex topographical relief that ranges from over 300 m above Ordnance Datum (O.D.) in the Blackdown Hills to a few metres above O.D. on the Devon coast (Figure 1). Geological resurveys of the Exeter, Newton Abbot, Sidmouth and Taunton districts during the past 20 years have confirmed the 19th century observations of Ussher and others (Ussher, 1902; 1906; 1908; 1913; Woodward and Ussher, 1911) that the terrace sequences of the Exe and Otter catchments are markedly different from those of the Axe, Sid, Teign and Tone. Eight terrace levels, ranging in height from just above, to 60 m above, the modern floodplain, have been recognised along the Exe and its tributaries with patches of 'undifferentiated' terrace at higher levels (Edwards and Scrivener, 1999). An even greater range is preserved in the lower reaches of the Otter Valley where a staircase of ten terrace levels range up to 100 m above the modern floodplain and 'undifferentiated' terrace deposits range up to 150 m above (Edwards and Gallois, 2004). In contrast, Edmonds and Williams (1985) recorded only two terrace levels in the Tone catchment, one mostly *c*. 5 m above the modern floodplain and the other "just above the alluvial flats". Selwood *et al*. (1984) recorded only one terrace level in the Teign catchment, up to a few metres above the alluvium, and no terrace deposit was recorded in the Sid catchment (Edwards and Gallois, 2004).

Extensive terrace deposits crop out on the lower slopes of the Axe Valley at heights up to 20 m above the valley floor between Kilmington (SY 270 980) and Chard Junction (ST 342 047). In contrast to the terrace deposits of the Exe and Otter, those of the Axe are unusually thick (locally up to 15 m). They were worked in Victorian times for road and railway ballast, and continue to be worked at Chard Junction for aggregate. The former workings at Broom (ST 326 024) have yielded a greater number of Palaeolithic implements than any other site in southern England (Wymer, 1999) and the succession there is, in consequence, the most studied terrace deposit in south-west England.

There are too few age data to determine the period of time during which the terrace sequences in south-west England evolved, but comparison with the denudation chronology of southern England as a whole suggests that all the terraces referred to in this account formed during the middle and late Pleistocene. Throughout this period the region experienced alternations of cold and temperate climates, but there is no evidence to indicate that the area was ever glaciated. The climate experienced by the Exe and Otter catchments was not, therefore, sufficiently different from that of the adjacent catchments to explain the differences in the terrace successions. These must relate to the underlying geology.

GEOLOGICAL SETTING

The present-day outcrop geology of the region can be divided into four principal types (Figure 2). In the west and north west the complexly folded and faulted Carboniferous deposits (mostly Crackington and Bude formations) are strongly lithified rocks. They give rise to a high-relief topography in which their predominantly E-W Variscan structural fabric is reflected in the drainage patterns. The Carboniferous rocks are overlain with marked unconformity by a gently dipping, fining-upward succession of Permian breccias, sandstones and mudstones (Exeter Group to Littleham Mudstone Formation) that was deposited in E-W trending extensional basins during the denudation phase of the Variscan mountains, most conspicuously in the Crediton and Tiverton troughs. The Permian deposits are disconformably overlain by early to middle Triassic pebble beds and sandstones (Budleigh Salterton Pebble Beds and Otter Sandstone formations). These and the Permian rocks give rise to generally low-relief, low-lying land, in which the Budleigh Salterton Pebble Beds form a prominent ridge that separates the present-day catchments of the rivers Exe and Otter (Figure 1).

The eastern part of the region is underlain by mid Triassic to early Jurassic rocks (Mercia Mudstone to Lias groups) that are almost wholly weakly lithified mudstones that give rise to a low-relief topography. These are unconformably overlain in the south east of the region by a highly dissected sheet of Cretaceous sandstones, calcarenites and chalks (Upper Greensand Formation and Chalk Group). The Upper Greensand comprises sandstones with well-cemented calcareous and siliceous beds and gives rise to prominent, steep escarpments, notably along the northern and western edges of the Blackdown Hills. The Cretaceous rocks are overstepped in a westerly direction by an early Tertiary (probably Palaeocene) planation surface. This is overlain by the Clay-with-flints, a complex mixture of insoluble residues largely derived form the Upper Greensand and Chalk, that forms a gently undulating plateau. In early Pleistocene times, Cretaceous sediments probably covered all except the northern part of the region, and the Palaeocene planation surface extended across all except the north eastern part. In the north west, the surface would, at that time, have rested on Permian deposits. In the north east, on the upthrow side of the Quantocks (Cothelstone) Fault, the Cretaceous rocks and the Palaeocene surface may have been removed by erosion in the Pliocene.

The region is traversed by numerous major and minor fault belts and associated fracturing, many of which have had a significant influence on the development of the drainage. In the western and central parts of the region the dominant fracture trend in the Carboniferous rocks and their inherited continuations into the Permo-Triassic rocks is E-W. The geological structure of the eastern part of the region is dominated by N-S trending fracture belts. These have been shown by seismic-reflection surveys and field evidence to have been intermittently active from pre-Permian times until at least the Miocene.

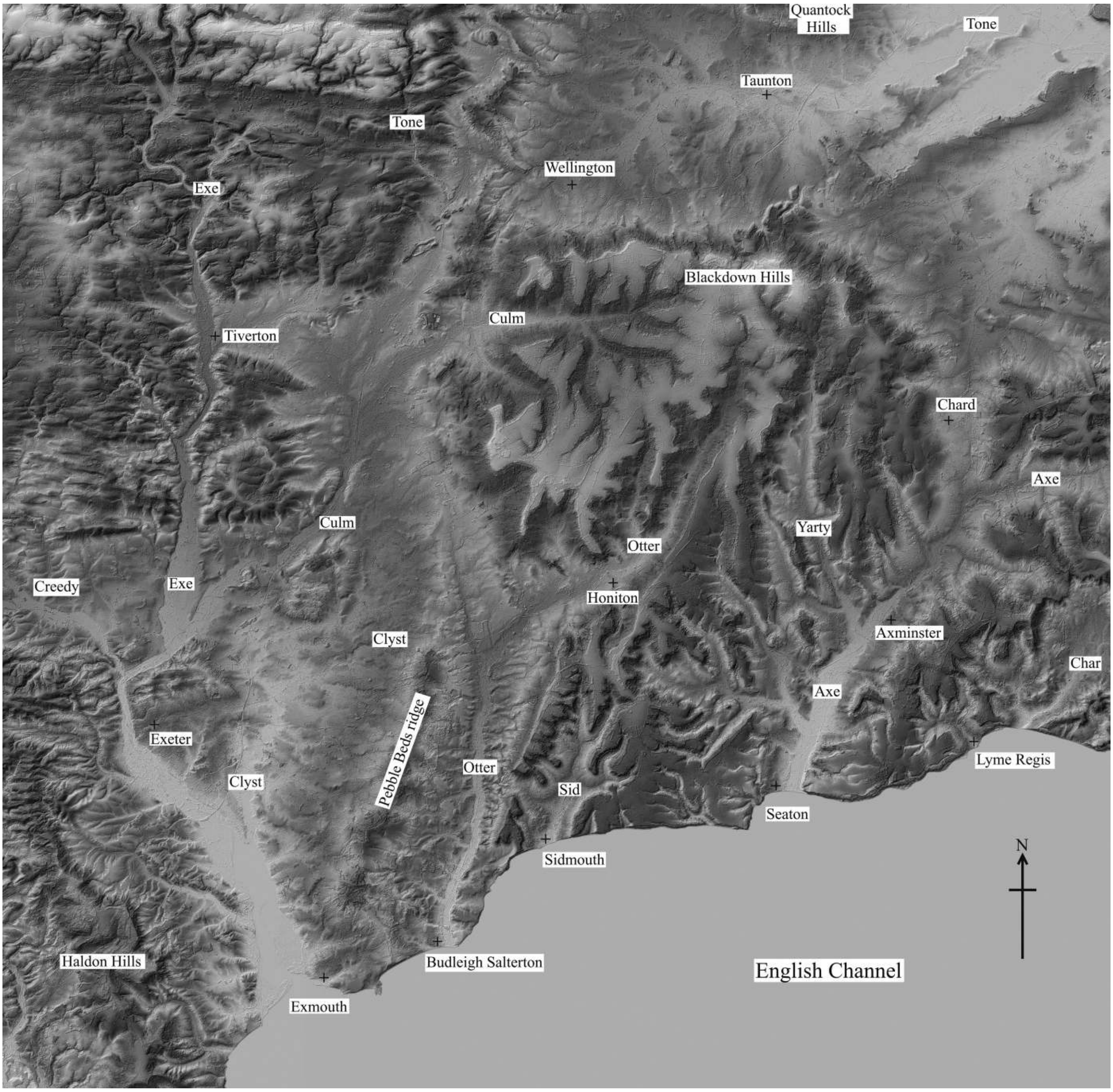

Figure 1. *Digital Terrain Model (DTM) of the Exe-Otter catchment and parts of the adjacent catchments. In the east, the deeply dissected outcrop of the Cretaceous rocks has been preferentially eroded along faults that were intermittently active from pre-Devonian to Miocene times. In the west, the high-relief topography of the outcrops of the Devonian and Carboniferous rocks and Permian breccias contrasts with that underlain by softer Permo-Triassic rocks in the Clyst and Culm catchments. DTM prepared by Michael Hall, British Geological Survey, using NEXTMap Britain elevation data from Intermap Technologies. Copyright BGS.*

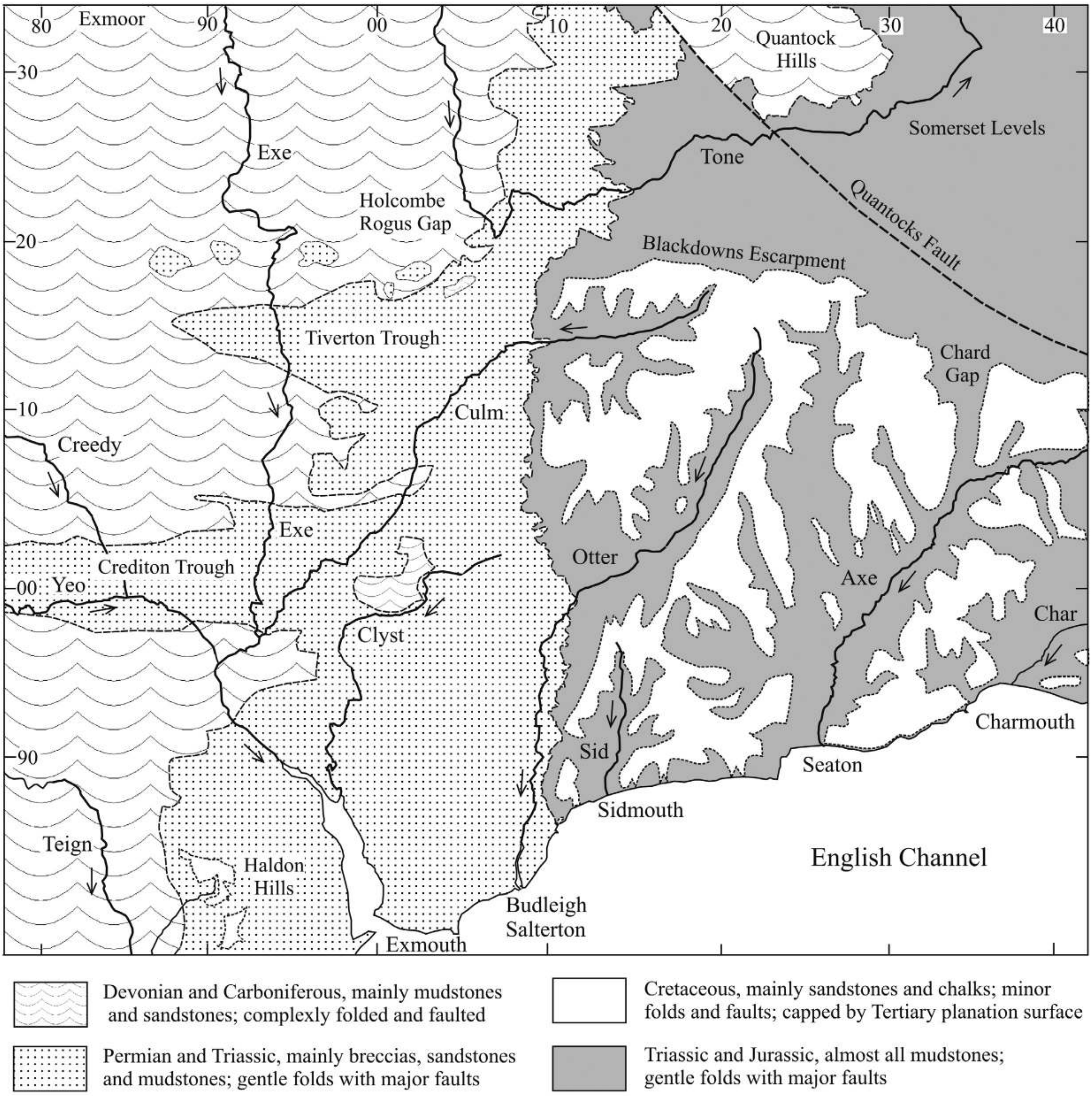

Figure 2. *Simplified geological sketch map of the region showing the principal rock types that influenced the evolution of the drainage system.*

AGE CONSTRAINTS AND INTER-CATCHMENT CORRELATIONS

In the absence of radiometric dates, other than a few radiocarbon dates for material from the younger deposits, estimates of the ages of the terrace deposits of the region have until recently been based on equivocal palaeontological evidence from a few sites. Recent advances in optically stimulated luminescence (OSL) dating have the potential to determine ages in excess of 300,000 years with an accuracy of *c.* ±5% (Bøtter-Jensen *et al.*, 2003). The OSL dating of samples recently collected from the Axe, Exe and Otter terraces (Hosfield *et al.*, in press) should enable reliable correlations to be made where there are none at present.

Edmonds and Williams (1985) correlated the lower of the two Tone terraces with the fossiliferous Burtle Beds of the Somerset Levels. The fossils include plant material, freshwater and brackish-marine shells, bear, deer, elephant, horse, hyena, rhinoceros and wolf, all indicative of a temperate climate (Kidson, 1971). The deposits have been attributed to Oxygen Isotope Stage (OIS) 5e, the most recent temperate phase in the UK Pleistocene. A temperate-climate fossil assemblage that includes plants, elephant, giant ox and hippopotamus was also recorded from a site a few metres above the floodplain of the River Otter at Honiton (ST 162 006) (Turner, 1975). This too has been tentatively attributed to OIS 5e (Edwards and Scrivener, 1999).

The higher terrace of the Tone was assumed by Edmonds and Williams (1985) on circumstantial evidence to have been deposited during the draining phase of a conjectural Lake Maw (Mitchell, 1960), a glacial lake that occupied much of the Somerset Levels during the poorly defined 'Wolstonian Glaciation', 130,000 to 350,000 years ago.

The most accurate age obtained to date from the region is an OSL date of 250,000 to 300,000 years from a terrace deposit at Broom about 10 m above the floodplain of the River Axe (Hosfield and Chambers, 2002; Toms *et al*., 2004). Taken together, these dates suggest that there has been very little downcutting by the River Otter during the last 125,000 years (since OIS 5e) and by the Axe and Tone during the past 300,000 years (since OIS 8 or earlier), despite major climatic changes during that time. Similar low rates of downcutting have been recorded in the more fluvially mature environments of the Thames Estuary area where OIS 5e deposits (in the Kempton Park Gravels) are close to floodplain level and OIS 8 deposits (Lynch Hill Gravel) are only 10 m above the floodplain (Ellison, 2004).

EVOLUTION OF THE DRAINAGE SYSTEM

Gibbard and Lewin (2003) postulated that a large eastward flowing 'Solent River' crossed the region from late Palaeocene times onward and maintained this course throughout most of the Cenozoic Era. There is no depositional or landform evidence within the region to support this hypothesis. The presence of Cornubian-derived heavy minerals in the Palaeogene Wittering Formation of the Hampshire Basin (Morton, 1982) indicates the presence of west to east transport pathways in the early Tertiary, but not necessarily via a single large river nor one that survived beyond the Miocene deformation of the region. Similarly, there is little or no geological evidence in southern England to support the geomorphological concept, popular until the 1960s, of high-level Tertiary marine-planation surfaces. Kidson (1962) recognised up to 10 erosional stages on the basis of a morphometric study of the longitudinal profile of the present-day Exe. He correlated the more prominent of these, the Westermill ('690-foot') and Nethercote ('330-foot') stages with marine-planation surfaces that had been recognised in the Hampshire Basin (Wooldridge and Linton, 1955), south-east Devon (Green, 1941) and Wales (Brown, 1952). Correlations such as these, which are based almost entirely on topographic heights, do not take account of the extensive tectonic deformation of the region in the Miocene, or of neotectonic movements since that time.

In contrast, there is evidence to suggest that the precursors of the courses of the Axe, Exe, Otter and Teign, all of which ran southwards at approximately right angles to the 'Solent River', were initiated on a southward-dipping Palaeocene surface that had been deformed during the Miocene. Where preserved in the eastern part of the region the surface falls from over 300 m above Ordnance Datum (O.D.) on the northern edge of the Blackdown Hills to below 100 m O.D. in the Seaton area. It does so unevenly, being locally displaced by faults with vertical throws of up to 60 m.

In the western part of the region the drainage patterns are strongly influenced by E-W trending fractures in the Carboniferous and Permo-Triassic rocks and by the juxtaposition of harder and softer rocks in E-W trending folds in the Culm deposits. These gave rise to secondary drainage features that developed when the Palaeocene surface and Cretaceous rocks had been removed by erosion. In the eastern part of the region, the course of the Axe, Otter and Sid and their tributaries have all developed along fracture zones associated with the N-S trending fault belts.

All the present-day rivers in the region are misfits, as noted by the early geologists including De la Beche (1829) who wrote "Could these streams have cut such valleys as they now flow through? If there be any true relation between cause and effect they could not." Buckland (1822) initially invoked the Biblical Flood, but was subsequently persuaded by the work of Agassiz (1840) that they had been sculpted by large volumes of gravel-bearing meltwater during the 'Glacial Age'. In addition, in the case of the River Otter the present-day catchment would be too small to produce the extensive terrace-gravel spreads preserved in its lower reaches even if allowance is made for very high flow rates. For example, at Budleigh Salterton large patches of Terrace 6 gravels, preserved at *c*. 55 m above the modern floodplain, were deposited on a gravelly braidplain that was at least 3 km wide.

It is therefore suggested here that the evolutionary histories of the Exe and Otter catchments are complexly interrelated and included several river captures that changed the Otter from a major to a minor river. In contrast, the catchments of the Axe, Teign and Tone have relatively simple development histories. Selected stages in the evolution of the present-day catchments of the region are shown in Figure 3.

Axe, Teign and Tone catchments

The proto-Axe developed on the southward-dipping Palaeocene surface, its detailed development being strongly influenced by faulting. The proto-Teign probably has a similar origin.

The modern catchment of the River Tone is largely confined to the Permo-Triassic outcrop. It is bounded to the south by the Cretaceous escarpment of the Blackdown Hills, a sharply defined topographical feature that may be fault controlled and whose position may have changed little during the Pleistocene. The Tone catchment seems likely, therefore, to have evolved independently from those of its southern neighbours from an early stage, except possibly in two areas. The Cretaceous escarpment is breached at the Chard Gap (90 m O.D.) and terminates at its western end at the Holcombe Rogus Gap (100 m O.D.), which might have acted as capture points that provided links to the Axe and Otter catchments respectively. It has been suggested (Mitchell, 1960) that the Chard Gap acted as the overflow for Lake Maw. However, Green (1974) has shown that terrace gravels of the Axe do not contain any glacially derived erratic material and that the gap did not therefore act as an overflow channel that influenced the evolution of the Axe catchment. The Holcombe Rogus Gap is discussed below.

Exe and Otter catchments

The proto-Otter is also assumed here to have developed on the Palaeocene surface and to have been modified by the structures in the Culm in those areas where the Permo-Triassic rocks were removed by erosion. The middle and lower reaches of the river were bounded on their eastern side by a relatively unbroken Cretaceous escarpment. It was bounded to the west by a ridge of high ground formed by the Budleigh Salterton Pebble Beds. The proposed catchment at this stage (Figure 3a) would have been large enough to produce the broad spreads of gravel preserved in the lower reaches of the modern valley. Successive captures of the higher tributaries of the proto-Otter by the Tone at Holcombe Rogus (1 on Figure 4a), by the proto-Creedy-Yeo at Tiverton (2 on Figure 4b) and by the proto-Exe at Talaton (3 on Figure 4c) reduced the catchment area to its present-day form.

The evolution of the Exe catchment can be interpreted in two principal ways, neither of which can be discounted on the currently available evidence. The simplest interpretation is that the proto-Exe and proto-Otter formed on the Palaeocene surface and ran from Exmoor to the sea on sub-parallel courses. The present-day narrow valleys where the Exe crosses the high ground of the Culm outcrops between the Tiverton and Crediton troughs and at Exeter would then be interpreted as superimposed drainage. However, it is doubtful that the much reduced catchment area of the proto-Otter that this interpretation implies would be sufficient to explain the extensive spreads of the Otter terraces.

The alternative, more complex evolution favoured here suggests that a proto-Creedy/Yeo catchment was initially developed on the Palaeocene surface and soon became strongly influenced by the E-W trending structures in the Permo-Triassic rocks. The successive captures outlined above and in figures 3 and 4 then gave rise to the present-day catchment boundaries.

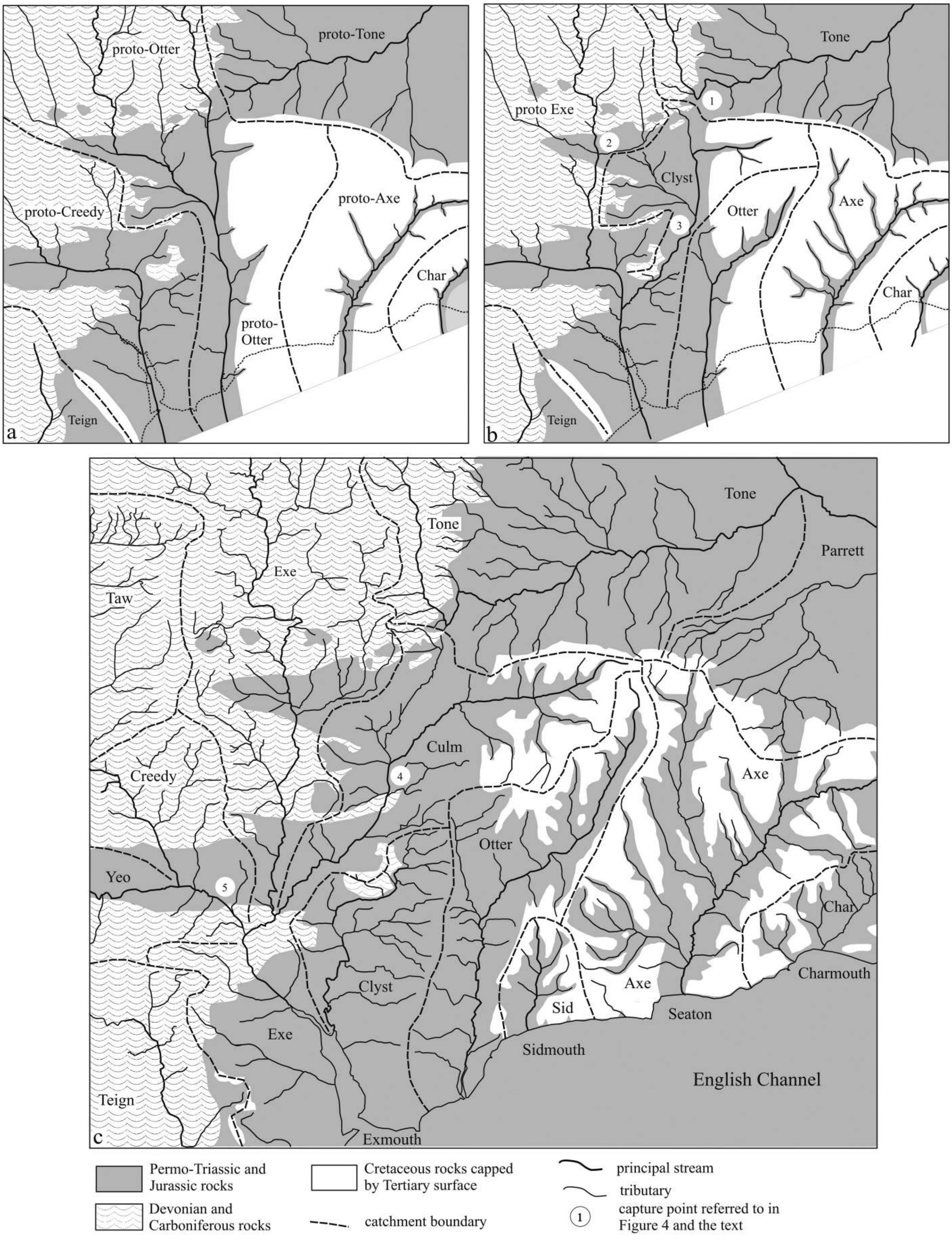

Figure 3. *Selected stages in the evolution of the catchments of the region from the time of deposition of the River Otter 60-m terrace onwards: (**A**) early stage, (**B**) intermediate stage, (**C**) present-day drainage and principal catchment boundaries. See text for explanation.*

There is tantalising evidence to suggest that the proto-Exe and proto-Otter may originally have been a single river southwards from Exeter. At Black Hill (SY 030 852), terrace gravels cap the highest point (160 m O.D.) on the present-day Exe-Otter watershed (Nicholas, 2004). The terrace deposits there are almost wholly composed of clasts derived from the immediately underlying Budleigh Salterton Pebble Beds. Chert and flint are absent, from which one can conclude that the outcrop of the Cretaceous rocks did not extend that far west at that time (Figure 5, Interpretation 1). It is tempting to assume that because the remnants of the Palaeocene surface preserved on the Cretaceous outliers of the Haldon Hills are at a similar height (200 to 230 m O.D.) to that on the nearest Cretaceous outcrop to the east at Sidmouth, that the surface extended between the two as a horizontal sheet until at least the Pleistocene. This was clearly not the case. As in more easterly areas, the surface would have been deformed during the Miocene, but all evidence of this has been removed by erosion.

Cretaceous material is also absent from the 105-m terrace exposed in the cliffs below West Down Beacon. This suggests that the western edge of the Cretaceous escarpment lay to the east of the River Otter at that time and that the 105-m terrace gravels were separated from it by a ridge of Otter Sandstone Formation (Figure 5, Interpretation 2). It seems likely therefore that the position of the western margin of the Cretaceous outcrop, as with the northern margin, was largely fault controlled. Neither appears from the present study to have retreated a significant distance since OIS 8 or earlier.

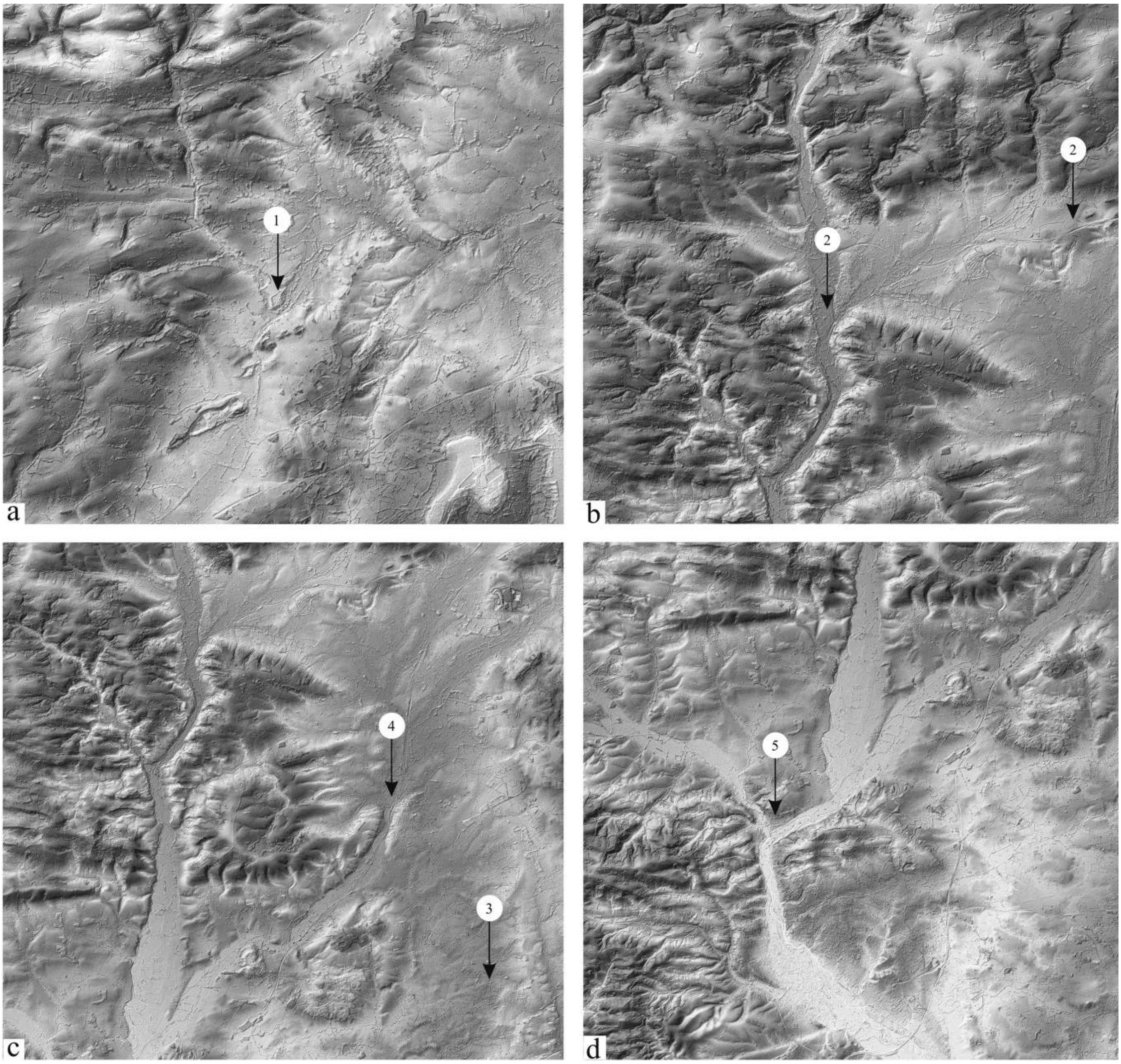

Figure 4. *Summary, in suggested chronological order, of the principal river captures in the evolution of the present-day Exe and Otter catchments: (**A**) 1. Proto-Tone tributary captures a higher tributary of the proto-Otter at Holcombe Rogus. (**B**) 2. Proto-Creedy tributary captures higher tributaries of the proto-Otter at Tiverton and at the eastern end of the Tiverton Trough to form an early stage of what will become the River Exe. (**C**) 3. Proto-Creedy tributary captures the middle tributary of the proto-Otter near Talaton to form the proto-Clyst. 4. Proto-Creedy tributary captures the upper reaches of the proto-Clyst at Cullompton to form the precursor of the modern River Culm. (**D**) 5. A tributary of the River Clyst captures the upper reaches of the River Exe north of Exeter.*

Conclusions

The present-day catchments of the rivers Axe, Exe, Otter and Teign were initiated on a southward dipping Palaeocene planation surface, probably in the early to mid Pleistocene. Their subsequent evolution was strongly influenced by the underlying geological structure, in particular by E-W trending Variscan folds and faults in the western part of the region and by Miocene-reactivated N-S trending faults in the eastern part. The early Tone catchment was separated form its southerly neighbours by the Quantocks Fault belt and evolved more or less independently from them.

The rivers Exe and Otter have extensive terrace 'staircases' that contrast with the small number of low-level terraces of the Axe and Teign Tone. It is suggested here that these river systems underwent little evolution during the late Pleistocene, in contrast to complex and relatively rapid interactions between the Exe and Otter catchments. The River Sid, which has no recorded terraces, appears to be a relatively recently developed tributary of the River Otter.

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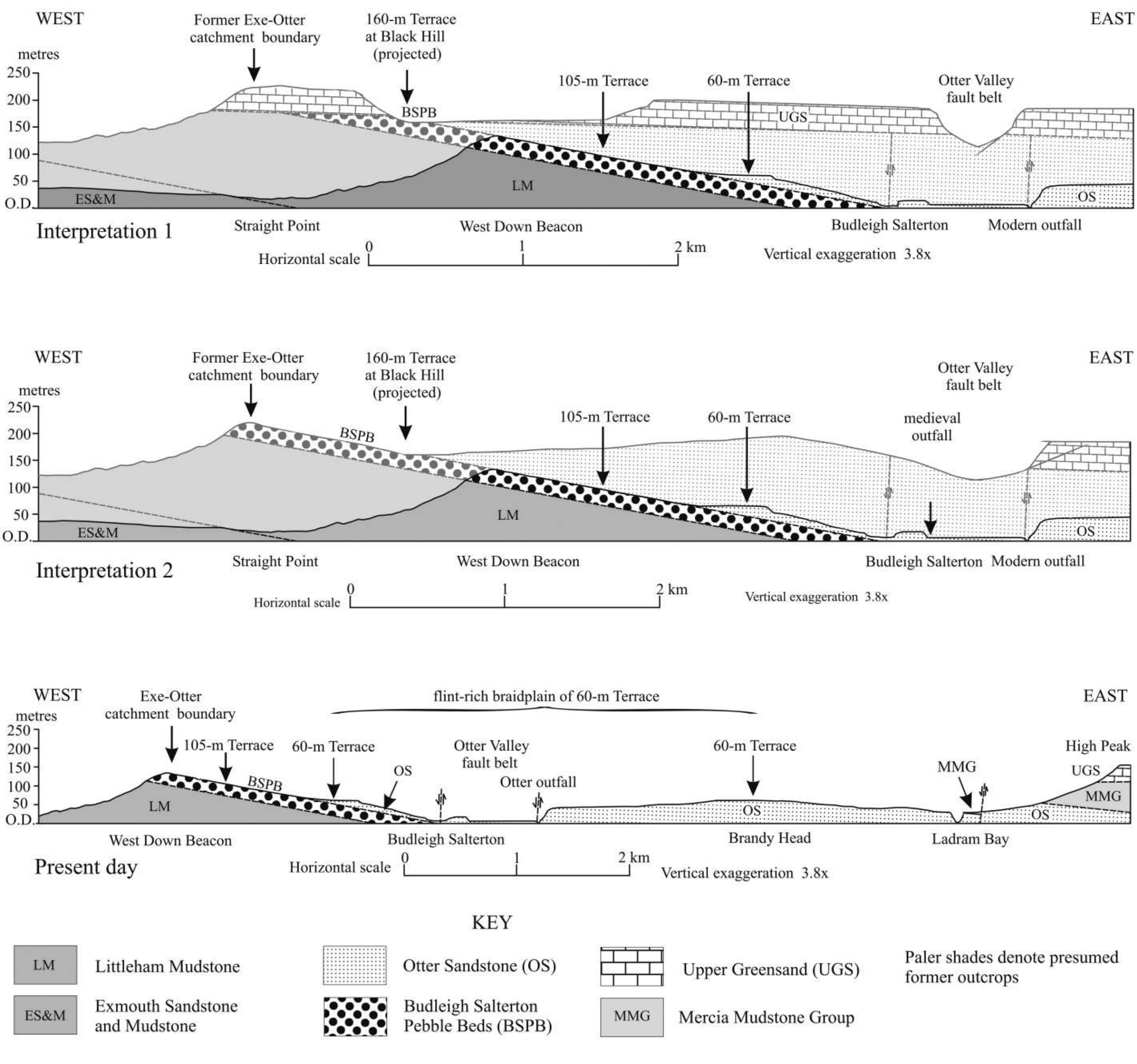

Figure 5. *Alternative interpretations for the suggested evolution of the River Otter terraces at and adjacent to the modern river outfall at Budleigh Salterton. See text for details. Interpretation **1**. The former Upper Greensand outcrop extended westwards as far as Straight Point as an almost unbroken sheet unaffected by folding or faulting. The absence of chert and flint clasts in the high-level terraces at Black Hill (160 m above O.D.) and West Down (105 m above O.D.) shows this interpretation to be incorrect. Interpretation **2**. The former Upper Greensand outcrop extended westwards only as far as the Otter Valley fault belt. Cretaceous-derived clasts are abundant in the 60-m and lower terraces of the River Otter, but are absent from the higher level terraces at Black Hill and West Down. Interpretation **3**. Geological sketch section of the present-day coastline between West Down Beacon and Peak Hill. At the time of the formation of the 60-m terrace the proto-Otter occupied a braidplain up to 3-km wide.*

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