GULLS, DATES AND AXES: RECENT QUATERNARY RESEARCH IN SOUTH-WEST ENGLAND

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This paper reviews the Quaternary research that has been undertaken in South-West England since the late 1990s and focuses on three major themes. Firstly, changes to chronological frameworks, involving the designations of the base of the Pleistocene and the Holocene Epochs, are discussed together with the advances of understanding that have flowed from the application of optically stimulated luminescence, cosmogenic isotope and other dating techniques. Secondly, new work on the terrace gravel sequences, especially that undertaken through the Palaeolithic Rivers of South West Britain (PRoSWEB) project, is highlighted, and the hitherto largely unrecognized role of rapid de-periglaciation in generating important thermokarst features in the region is emphasized. Thirdly, recent research into Holocene to Anthropocene palaeoenvironments is considered especially in relation to the record of sea-level change and coastal evolution, the effect of quarrying and mining on fluvial systems, and the interaction of climate with human impact on river form and process. It is concluded that the peculiarities and unique diversity of South-West England have provided a stimulus for Quaternary research in an increasingly inter-disciplinary context.

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INTRODUCTION

The South West of England has played a major role in the development of Quaternary geosciences over the last two centuries. Mid to late 19th century geological mapping and observations by W. A. E. Ussher and Sir Thomas Henry De la Beche of the 'Head' and other superficial deposits, along with studies in the 20th Century of river gravels and raised beach deposits are part of our national Quaternary history (Mather, 2011). We can see in this history a strong and early linkage between Quaternary Geology and Archaeology through the study of cave sites such as Kents Cavern (Torquay), raised-beaches, peats and river terrace gravels by Pengelly (1867, 1884), Zeuner (1960), Godwin (1948), Lacaille (1958) and Wymer (1999). The state of Quaternary research in South-West England was reviewed in the early 1980s by Cullingford (1982) with an emphasis on Devon, and in more depth and breadth by the Geological Conservation Review published in 1998 (Campbell *et al.*, 1998). The present review concentrates on research that has been conducted since that date and is complimentary to Gallois (in press) although broader in scope. Much of the post-1998 Quaternary research in South-West England has been published in the Quaternary Research Association field guides for Devon and East Cornwall (Charman *et al.*, 1996), Somerset (Hunt and Haslett, 2006), the Isles of Scilly (Scourse, 2006) and most recently the Exe Valley and adjoining areas (Basell *et al.*, 2011a). It is, however, impossible to review the full wealth of Quaternary studies in South West England over even this relatively short period and so this review is necessarily selective and inevitably influenced by the author's research interests.

CHANGING CHRONOLOGICAL FRAMEWORKS

Since 1998 there have been changes to the formal stratigraphic column which have significant implications for this review. Firstly in 2009 the base of the Pleistocene (and thus also the Quaternary) was formally re-designated as the base of the Gelasian Stage with a date of 2.59 Ma (Gibbard *et al.*, 2010). This effectively lengthens the formal Pleistocene by 40% and moves the St Erth Beds dated to 2.1-1.9 Ma (Jenkins, 1982; Messenger *et al.*, 2005) from the Pliocene into the early Pleistocene. Whilst this obviously makes no difference to the interpretation of these fossiliferous shallow marine deposits it does bring into the Quaternary nearly a million years of the 41 Ka cycle-dominated world and a period of higher sea levels (Hart *et al.*, 2011). One of the mysteries, however, of South-West England is the relative, or apparent, lack of associated raised beach deposits until the late Pleistocene. Raised beaches from the last interglacial (the Ipswichian or MIS 5e) are common around the South West coast from the Somerset Levels to Portland Bill (Hunt and Haslett, 2006; Baker and Proctor, 1996). There are also probably earlier interglacial deposits at sites such as Prawle Point although these are poorly dated. Another chronological change was the formal designation of the start of the Holocene at 11,700 yr b2k (before the years AD 2000) in 2009 (Walker *et al.*, 2009). Although again clearly not affecting geological interpretations, this change does package the Holocene as truly post-glacial with the first signs of climatic warming at the end of the Younger Dryas/Greenland Stadial 1 cold phase.

The use in Walker *et al.* (2009) of a Global Stratotype Section and Point (GSSP) identified from isotopic, geochemical and dust data from an ice core (NGRIP) to demarcate the Pleistocene/Holocene boundary does emphasis the increasing importance of analytical techniques combined with chronometric (or non-stratigraphic) dating methods, in this case annual ice layers. Dating methods have greatly increased in variety, precision and application over the last twenty years. However, South-West England presents some particular problems as sediments and ground-waters are mostly decalcified, with exceptions being in the vicinity of small limestone outcrops (Carboniferous and Devonian) in Devon, and in the Mendip Hills. The result is that non-cave sites with the preservation of mollusca and bones are rare in South-West England and this severely limits the application of both uranium series (U-series) and amino acid racemisation (AAR) dating which has recently provided a chronological framework for Quaternary deposits in the rest of England (Penkman *et al.*, 2011). In fact organic-rich Pleistocene deposits are in general rare with the outstanding exception still being the Honiton Hippopotamus site (Turner, 2011). This lack of a mammalian or AAR chronology has forced the application, and indeed development, of other chronometric methods including optically stimulated luminescence (OSL) and cosmogenic isotope dating (Brown, 2011). Over 20 sites have been dated in the last ten years using OSL (Figure 1). OSL dating of gravel terraces has now provided a preliminary chronology for the late Pleistocene and Holocene alluvial deposits of the Exe catchment (Brown, *et al.*, 2010) and a longer chronology for the Axe Valley (Basell *et al.*, 2011b; Brown *et al.*, Submitted) both of which will be discussed further later in this review. Cosmogenic dating has been applied to the tors of Dartmoor (Hägg, 2009; Gunnell *et al.*, 2013) and most recently the glaciation of Lundy (Rolfe *et al.*, 2012). In the case of Dartmoor a variety of ages were initially obtained from 19 to 126 Ka but have been subsequently refined to 36 to 50 Ka. However, it is not yet clear how these dates relate to recent re-interpretation of both deposits and landforms on Dartmoor as resulting from Pleistocene glaciation albeit of limited extent (Evans *et al.*, 2012). In the case of Lundy the dating and geomorphological interpretation suggests a MIS 4/3 glaciation by a lobe of the British-Irish Ice Sheet (BIIS). Along with the evidence for MIS3/2 glaciation of the Scilly Isles (Scourse, 2006) and possibly cirque glaciers on the Exmoor Massif (Harrison *et al.*, 1998, 2001, 2011) this sets potential climostratigraphic boundaries to the South West and emphasises its location at the margin of the Pleistocene glaciations of North-West Europe.

As previously mentioned there are limestone outcrops in South-West England and in these areas both U-series and radiocarbon dating has been possible. This has been almost

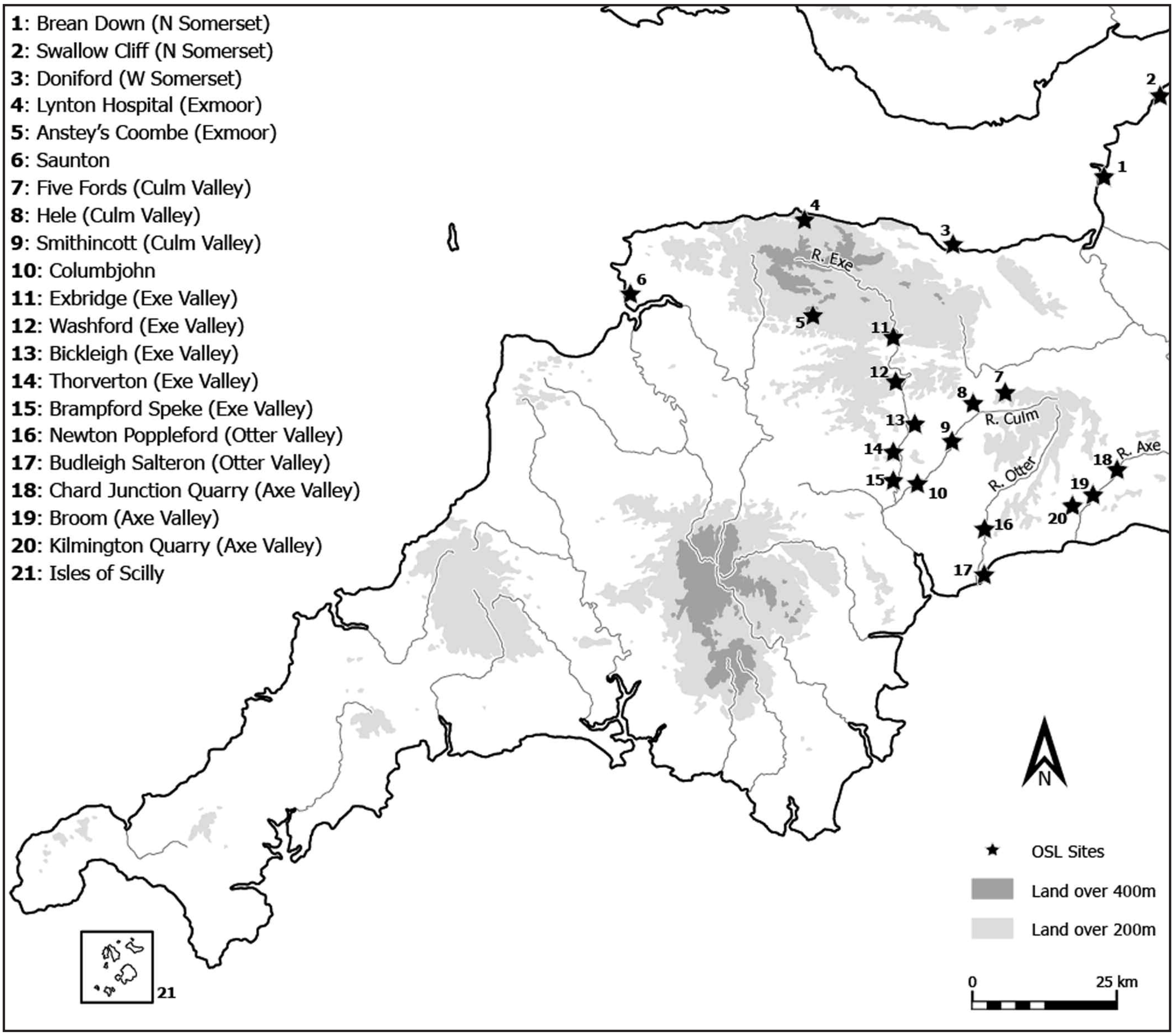

Figure 1. *Map of South-West England showing sites dated using OSL many of which are referred to in the text. All sites have been dated by the author in collaboration with P. Toms, and/or by E. Rhodes except for the Isles of Scilly (Scourse et al., 2004) and Saunton (Rhodes pers. comm.).*

exclusively from archaeological sites. The U-series dating of Kents Cavern shows hominins present in the South West from before MIS 10 and perhaps even as early as Boxgrove (MIS 13), and radiocarbon re-dating using ultra-filtration has provided the earliest evidence for anatomically modern humans (*Homo sapiens*) in northwest Europe at *c.* 42.5 Ka BP (Higham *et al.*, 2011). In the Mendip Hills continued excavations at Banwell Bone cave has revealed a remarkably rich cold-fauna that on faunal grounds probably correlates with Wood Quarry in Nottinghamshire which has an MIS4/3 date of *c.* 60-70 Ka BP based on U-series dating (Pike *et al.*, 2005). Research into a nearby cave in Ebbor Gorge is currently revealing a rich lateglacial faunal assemblage (D. Schreve pers. comm.). Recent AMS dating from the lost site of Cattedown Bone caves, Plymouth by the Ancient Human Occupation of Britain (AHOB) project has suggested post-glacial human habitation in the area as early as *c.* 18,000 BP (S. Underhill pers. comm.). Along with other sites in the Mendips (such as Hyena Den) and sites in South Wales (Paviland and Caldey Island) we now have a record of episodic occupation of South-West England from just over 40 Ka BP to the Holocene with the only two unsurprising gaps at 28-19 Ka BP - the late glacial maximum (LGM) and less markedly during the Younger Dryas.

The improvement in the chronology of fluvial terraces, raised beaches and karstic features has allowed one component of landscape evolution, namely uplift, to be better constrained (Westaway, 2011). Although there are still major uncertainties and some controversy over the appropriate geophysical models, uplift modelling suggests an overall uplift of the South West peninsula of around 110 m over the last 2 M years and about 130 m since the start of the Quaternary. This is in line with sites further east, such as Boxgrove, and provides the potential energy for the climatically-driven cold-stage terrace development discussed below. In contrast relative sea level studies have suggested subsidence over the last 16,000 years with a maximum of 1.2 mm yr^{-1} due to glacial isostatic rebound (Shennan and Horton, 2002) but as discussed later in this review that has been refined in South-West England.

Terraces, thermokarst and deperiglaciation

Although studied in the 1960s (Kidson, 1962) there has been little research on the terrace gravels of the South West until the recent injection of archaeological funding for the Palaeolithic Rivers of South West Britain (PRoSWEB) project (Brown *et al.*, 2010). The aim of this project was to try and assess, and if possible date, the occurrence of Palaeolithic archaeology to the west of the River Axe. Due to a lack of quarrying of river gravels in the 20th century (largely due to the occurrence of other aggregate sources and transport costs) it was not known if the patchy distribution of stone tools, such as bifaces (or hand axes) did, or did not, reflect prolonged or repeated Palaeolithic occupation of the South West by hominins. The project established that the published pattern was correct but probably an under-representation of the density of artifacts, and also started the process of constructing a chronology into which finds could be fitted. The most striking aspect of this first terrace chronology for the Rivers Exe and Otter is that the lowest four river terraces as mapped by the BGS all fall into the last cold period (MIS4-2) and the lowest three post-date the LGM (Figure 2). This confirms that these terraces are cold stage gravel accumulations and most probably the result of stadial-interstadial transitions (Brown *et al.*, 2009a) with an important factor being permafrost-induced brecciation of bedrock straths as proposed by Murton and Belshaw (2011). Work by PRoSWEB at Doniford on the north Somerset coast has shown that the gravel accumulated from late MIS 4 through MIS 3 and then again after the LGM (Basell *et al.*, 2011c). This is consistent with a build-up of the British-Irish Ice Sheet in MIS4 (Rolfe *et al.*, 2012). On a field excursion by the Quaternary Research Association to Doniford in April 2011 a fresh boute coupé hand axe was found at the base of the section. This is significant since boute coupé hand axes are regarded as being diagnostic of *Homo neanderthalensis* which is believed to have gone extinct in the UK around 36,000 years BP (White and Petitt, 2011) although this is not well constrained. The occurrence of late Upper Palaeolithic material made by *Homo*

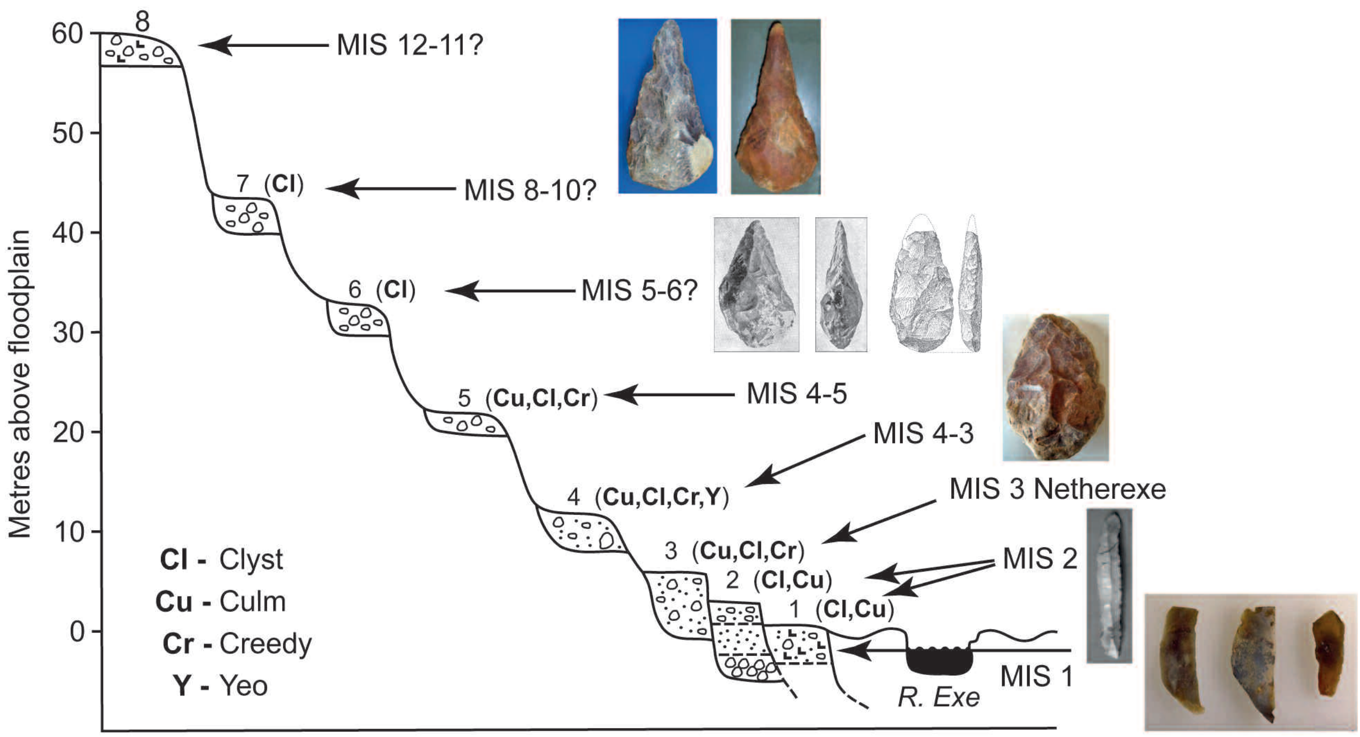

Figure 2. *A preliminary terrace gravel chronology for the Exe Valley.*

sapiens at the site and the possibility of stratified material makes this a site of exceptional importance for Quaternary science (Basell *et al.*, in prep.).

It has long been realised that lying just outside, or even on, the maximum extent of British-Irish ice sheets the South West peninsula must have experienced periglacial conditions for much, if not most of, the Quaternary (Waters, 1965; Cullingford, 1982). Although not well preserved in hard-rock areas periglacial features such as patterned ground, rock-glaciers and even pingos are known from the region (Brown *et al.*, 2011b). The most ubiquitous legacy of the periglacial climate is the poorly sorted superficial deposits mapped as 'Head' by the British Geological Survey (BGS) which cover a large proportion of the area especially on the softer lithologies. Recent work has shown that this head is frequently polyphasic and also can be associated with gullies which can be cut into brecciated (weathered) bedrock (Gerrard, 1988). Work on the Quaternary terrace gravels has also revealed cryoturbation including frost wedges and cracks in both the Exe and Otter Valleys (Brown *et al.*, 2010; Basell *et al.*, 2011b; 2011c; 2011d, Figure 3) and the discovery of residual sarsens in the interfluve area of the Exe and Creedy Valleys too large to be transported by river flow can only be explained by periglacial mass flow processes (Scrivener *et al.*, 2011). The geographical range of sarsens throughout South West England (including Somerset, Prudden, 2010) and suspected associations with terraces and valley topography such as dells (blind valleys), dry valleys and areas of persistent landsliding (such as Lyme Regis, Gallois, 2009) suggests that the importance of periglacial imprint on the landscape is neither fully appreciated nor understood. Ironically the rapid rate of melting of Arctic permafrost due to human-induced global warming is providing new insights into the processes of rapid de-periglaciation (Froese *et al.*, 2008). This is causing the thinning of permafrost which is excess ice (i.e. over 50% by vol.) by (a) conduction – producing an increase in the thickness of active layer, (b) thermal melting by over-ice and under-flow producing meltwater badlands, and (c) surface ablation (Table 1, Murton, 2001). One of the dominant processes in these areas is retrogressive thaw-slumping which results in steep arcuate or bowl-shapes failure scars into hillslopes with a fan or debris-flow tongue and they are generally polycyclic through re-activation (Kokelj *et al.*, 2009). Today they are relatively small typically 50-100m in width and have an area of a few hectares (Lantuit and Pollard, 2008, see Figure 4), but it must be remembered that although the rapid melting may be a reasonable analogue for the Lateglacial, the modern Arctic is generally underlain by hard Palaeozoic rock and not the soft lithologies found in parts of southern England. It can be hypothesised that these processes, now collectively known as thermokarst (Table 1), would be of even greater magnitude on semi-permeable and weakly bonded lithologies such as weakly-cemented sandstones, mudstones and chalk.

Figure 3. *Periglacial polygonal features associated with periglacial gullying at Crediton Golf Club, 2010. Photograph courtesy of R. Scrivener.*

Figure 4. *A small retrogressive thaw slump near Eureka, Ellesmere Island, Canadian High Arctic (July, 2010) © David Leverington 2011.*

Given that these processes will be far more effective on weakly bonded (uncemented or weakly-cemented) permeable fine-grained rocks with moderate relief one might expect to see resultant forms in the Blackdown Hills (Upper Greensand), the chalk of west Dorset and the Lias scarps such as the Polden Hills. Geomorphological mapping has identified what are believed to be hillslopes scars of retrogressive thaw-slumping

Mode	Processes and forms	Possible Quaternary forms and examples
Active layer deepening	Meltout, involutions, creates thaw unconformities	Head & cryoturbation features in superficial deposits
Ice-wedge melting	Ice-wedge vein casting	Ice-wedges in fluvial gravels
Thaw-slumping	Debris flows diamictons, vertical sand veins & sand-filled desiccation cracks	Head, alluvial fans (e.g. Ivybridge), increased sediment supply to rivers
Groundwater flow	Through tunnels & pits (sinks)	Cave breccias (e.g. Banwell Bone Cave)
Shoreline thermokarst	Erosional niche, collapsed blocks	Large unstable coastal sections (e.g. Lyme Bay)
Basin thermokarst	Sandy fore-set beds across basins floor and lake deposits	Some sediments underlying the Somerset Levels?

Table 1. *Six thermokarst modes from Murton (2001) and pers. comm.*

upslope from debris-fans in the Axe valley (Brown, unpublished). The layers of uncemented sand, clays overlying an aquiclude (Charmouth Mudstone) may have provided the optimum conditions for these processes with the result that abnormally high volumes of chert gravel were fed into the Axe Valley at a rate that far exceeded the capacity of the river to remove it resulting in semi-continuous aggradation over the last 400,000 years (Basell *et al.*, 2011b). Additional support for this theory comes from the observation of phreatic tubes in the Whitecliff Chert some 5 km to the east of the valley now exposed in the Shapwick Grange Quarry (Brown *et al.*, 2011a). The occurrence of dry valleys in South-West England, outside of the area of the chalk outcrop, is well known in areas such as the South Hams, the Exeter region and the Otter Valley (Gregory, 1971; Cullingford, 1982). Recent sedimentological studies of terraces 7 and 8 in the Otter valley have revealed not only cryoturbation features but a large raft of intact Mercia Mudstone deposited in a matrix of Otter Sandstone at the base of the terrace gravels. This transport of rafts of relatively soft bedrock presumably in a frozen state, or by ice-flows, supports the idea that the main process of dry valley formation was the detachment of bedrock from hillslopes by processes operating whilst the permafrost was melting i.e. during de-periglaciation. The extreme cold of the periglacial climate may also have been responsible for the formation of fissures in bedrock commonly called gulls which frequently form small caves (Self, 1986). These are seen in many quarry faces in South West England (Figure 5) and are occasionally filled with diamicton (H. Prudden pers. comm.), and Gallois (2010) has shown what are probably cryoturbation structures penetrating well into the Jurassic mudstones exposed at the cliffs at Seatown.

Figure 5. *Gulls revealed at Ham Hill (Prudden 2011).*

The evidence of periglacial processes within the river gravels shows that such periglacial and de-periglacial conditions occurred both during, and at the end of Pleistocene cold phases (i.e. Glacials) and a chronology is beginning to emerge; however, erosional landforms, such as gulls, bedrock structures and dells are more problematic to date. This is also the case with possible glacial features such as the Devil's Punchbowl on Exmoor which has been interpreted as having been formed, or at least occupied, by a small cirque glacier (Harrison, 2011) although this has not been universally accepted (Prudden *et al.*, 2001). But as Harrison (2011, p. 90) remarks "*the existence of glacial ice on uplands in southwest England should not be surprising*" as during the MIS 2 (LGM) and probably MIS 12 the edge of the ice sheet was no more than 47 km from Exmoor and 68 km from Dartmoor, and probably much less. The brief extension of a wet-based ice lobe onto northern areas of the South-West peninsula suggested by modelling also agrees with the evidence of glaciation of Lundy by Rolfe *et al.* (2012), the Somerset Levels (Hunt, 2006) and possibly the Bude area (Campbell *et al.*, 1998).

A palaeoecological perspective on the Devensian has been provided by the analysis of a deep core from Dozmary Pool on Bodmin Moor by Kelly *et al.* (2010). The site was previously well known for its lateglacial sequence (Brown, 1977) but the pollen data have now been extended to *c.*26 Ka BP and so the sequence spans the Late Glacial Maximum. It shows surprisingly high *Picea* (spruce) and other trees (*c.* 40% TLP) which could be interpreted as long-distance transport from the south (France or even Iberia) but is argued by the authors to be evidence of a 'cryptic northern refugia'. The identification of earth-hummocks as indicators of previous periglacial processes (frost-heave) on Dartmoor by Bennett *et al.* (1996) and recently supported by Killingbeck and Ballantine (2012) remains wholly unconvincing and indeed has been shown to be much more likely to be the result of the well-known hummock-forming activity of the yellow meadow ant *Lasius flavus* (Morey, 2010).

The Holocene to the Anthropocene

Research since 1998 on the Holocene palaeoenvironments of South-West England has remained strongly focussed on palaeoecological studies of peatlands particularly the uplands of Bodmin Moor, Dartmoor and Exmoor. This has primarily been driven by broadly archaeological concerns of landscape change and human settlement history, as is illustrated by the South West Archaeological Framework published in 2008 (Webster, 2008). Studies in the early 2000s showed that the Netherexe reach of the Exe Valley had seen human impact probably as early as the late Mesolithic and certainly by the Neolithic (Fyfe *et al.*, 2004a). This has been supported by the discovery and work on a cursus (a long, probably ceremonial, monument) that runs along the valley floor at Netherexe (Griffith, 1985; Bayer, 2008). The palaeoecological studies also suggested that lime (*Tilia*) had extended this far west in the early to middle Holocene. The rather diminutive Neolithic or early Bronze Age stone monuments of Exmoor have also received long-overdue research (Gillings *et al.*, 2010).

Dartmoor is famous for its 'reaves' which are co-axial field systems of Bronze Age date (Flemming, 1979). Recent re-excavation at Shovel Down (Fyfe *et al.*, 2008) and associated palaeoecological work has provided evidence to support the hypothesis that a marked climatic deterioration occurred in the late Bronze Age that can be linked to the abandonment of the reaves (Amesbury *et al.*, 2008). Research at a large number of sites from Exmoor to Mid Devon (Greater Exmoor) has shown that woodland clearances are recorded throughout the later Prehistoric period with increasing magnitude and spatial extent (Fyfe *et al.*, 2004b). However, the use of multiple profiling suggests that woodland clearance is spatially discrete, even within an area of only 4 km^2 (Fyfe *et al.*, 2004c). Pastoral land use is dominant around the uplands until around AD 900–1,000, and there is no discernible Roman or post-Roman period impact in the vegetation, suggesting cultural stability from the late Iron Age to the early Medieval period. By AD 1,100 there is a shift to mixed arable-pastoral farming which appears to continue well into the post-Medieval period. Recent work on Bodmin Moor has also tried to refine our chronology and environmental context for Prehistoric settlement and has shown peaks in human activity in the Bronze Age and again in the Medieval period (Gearey *et al.*, 2000a, b). Whilst the limestone of the Mendip Hills has preserved one of the longest records of human habitation in the UK within its cave systems, it is not an environment that preserves pollen well and this has forced environmental archaeologists and others to look to other deposits and particularly tufas which are common (Davies *et al.*, 2006). Tufas preserve mollusca well and so can contain a record of changes in vegetation, human impact and potentially climate through their oxygen and carbon stable isotopes (Garnett *et al.*, 2004). Sites investigated so far, such as Willow Brook, near Midsomer Norton have revealed Mesolithic stone tools and there is the potential to look at the Neolithic and early farming. The Neolithic is a period which is well represented on the Mendips by the famous Priddy Circles, one of which was unfortunately partially destroyed in 2011 (Lewis, 2011).

Although there has been continuing research into these upland areas some new research has taken place in the lowlands and other hills in South-West England which have always been the most densely settled part of the peninsula. In a first comprehensive study of the Blackdown Hills, Brown *et al.* (2011c) have shown that although the plateau was cleared during the Bronze Age some valley slopes remained wooded and this is most likely linked to the management of woodland resources to fuel the iron working industry from the late Iron Age onwards. Interestingly Exmoor also saw Roman iron working which created a sediment pulse into some valleys (Brown *et al.*, 2009b) but did not lead to the preservation of combe-side woodlands. The reason for this maybe that the Exmoor hillsides are essentially stable and can be converted to grazing land but the Blackdown hillslopes are characterised by springs, spring mires and landsliding. Work in other areas including the Somerset Levels, Severn Estuary and Mendip Hills has been rather more fragmented. Particular highlights have been the publication of the remarkable Mesolithic sites in the inner Bristol Channel by Bell (2007) which has provided an unparalleled insight into the Mesolithic world ranging from the occurrence of a band of children out on the tidal flats in spring or summer, to additional Mesolithic site types. The discovery of Sweet Track in 1970, which remains the oldest wooden trackway in Europe, and the recognition of the outstanding ecological value of the Somerset Levels qualify the area as one of international importance. There have been incremental advances in the Somerset Levels, particularly concerning the Roman and Medieval salt industry and reclamation (Leech *et al.*, 1983; Rippon, 1997; Jones, 2003), as well as an increasing realisation of the earlier coastal linkages of wetlands settlement history including Glastonbury Lake Village (Aalbersberg and Brown, 2011). There is little doubt, however, that much remains to be done to link the archaeological data with environmental data for this region in order to provide an understanding of processes and rates of change in this internationally important environment.

Although the focus of Quaternary geomorphological and geological research in South-West England has been concerned with deposits and landforms of Pleistocene age there have been three particular areas of research into the Holocene Epoch: the record of sea-level change and coastal evolution (including mass movements), the effect of quarrying and mining on fluvial systems, and the interaction of climate with human impact on river form and process.

Sea-level change and coastal evolution

The long, and complex, coastline of the South West peninsula has always provided opportunities for assessing relative sea level (RSL) history as well as coastal geomorphology (Kidson and Heyworth, 1978; Cullingford, 1982) and recent work has continued this research theme (Massey *et al.*, 2008). However, an additional dimension has been added by the use of RSL curves to try and estimate vertical land movements. Gehrels *et al.* (2011) have used coastal back-barrier marsh sediments at Thurleston Bay not only to refine the local RSL curve but also to estimate present land subsidence (at 1.1 m yr^{-1}) due to on-going glacial isostatic adjustment. This work shows how important glacial isostatic adjustment remains for land-motion rates and therefore near future sea-level predictions. Recent research along the north coast of Devon in the Taw Estuary has also provided some evidence that local RSL trends and also tidal characteristics may have been affected by changing river water and sediment discharge, factors which are both climatically and anthropogenicaly influenced (Havelock, 2009). Research into coastal geomorphology in South-West England has been understandably concerned with past and present vulnerability to coastal flooding. This has included palaeoenvironmental studies of barrier breaches such as at Porlock Bay in 1996 (Jennings *et al.*, 1998) and more recently the erosion of the barrier at Slapton Ley on the south coast (Chadwick *et al.*, 2005). Continued research into the classic areas of landsliding along the Dorset coast has concentrated on the hydrogeological controls of present movements and the engineering implications, but they have also revealed how important the Quaternary history has been through deep weathering of the hydrologically critical lithologies (Brunsden and Jones, 1976; Brunsden and Moore, 1999; Gallois, 2011).

The effect of quarrying and mining on fluvial systems

Due to the abundance of economically valuable minerals and hard rocks in and around the South West massif the extractive industries have a long history in the region. All the metals which were an integral part of our technological development occur in the Cornubian orefield including in historical-use order gold (Crediton Trough), tin and copper (Dartmoor), lead (Mendips), iron (Exmoor and Blackdown Hills) and many other minerals still used in our 'post-industrial' industries such as arsenic, barites, tungsten and silver. Quaternary research has been concerned with this mining history in two ways. Firstly, one of the major problems in studying the archaeology of mining is that later mining generally destroys the evidence of earlier mining. This makes it difficult to study the early history of extractive industries and geomorphological studies can help. All mining produces waste which has elevated levels of the target mineral along with other accessory minerals. If this waste is stratified in river valleys or terrace deposits and can be dated, it can provide indirect evidence of phases of mining not recovered by conventional archaeology. As Table 2 shows, this approach has been applied to tin mining on Dartmoor and iron mining on Exmoor and in both cases it provides evidence of Roman mining which in the case of Exmoor is confirmed by archaeological studies (Juleff and Bray, 2007).

Geochemistry	Location	Dated spikes	References
Sn, Cu, Pb, Zn, Th, Ce, Sr	Hayle Estuary	Prior to 1880	Rollinson *et al.* (2007)
Sn, Cu, Zn	St Austell	AD 895-1155	West *et al.* (1997)
Sn, As	Dartmoor	AD 245-386 & AD 1288-1389	Thorndycraft *et al.* (2003, 2004)
Ba, Cu, Zn, Pb	Teign Catchment	Undated	Simmons *et al.* (2011)
Fe	Exmoor	Romano-British Period & 16th-17th Centuries AD	Brown *et al.* (2009b)
Pb	Mendips	18th-19th Centuries AD	Macklin (1985)

Table 2. *Geomorphological and sedimentological studies on mining history in SW England.*

Unlike in other parts of the world (e.g. Tasmania, Knighton, 1991) there has been relatively little study of the geomorphological impact of this mining probably because of its relatively small scale and the small fluvial systems affected. This is ironic since the first English environmental legislation was passed under Elizabeth 1st in response to the silting up of harbours due to tin mining (Greeves, 1981). Recent studies have shown that it was probably a major contribution to the regressive sequence of many South Western estuarine sequences (Rollinson *et al.*, 2007).

Climate and human impact on river form and process

Small segments of river channels and hillslopes in the South West have acted as open air laboratories for process research into both fluvial and slope systems (Nicholas, 2003; Burt and Butcher, 1985), although this has rarely been linked as it has in other areas (e.g. Howgill Fells, Chiverrell *et al.*, 2008). These studies were very much of their time in trying understand internal processes, rates and thresholds and they were not explicitly evolutionary being concerned with current environmental problems such as agricultural runoff. However, an increasing awareness of storage within catchments, and medium-term processes, has led to the consideration of longer time horizons including the identification of accelerated Medieval soil erosion from alluviation in the South Hams area of Devon (Foster *et al.*, 2000). However, the most notable research in this area has been work by Walling and colleagues who pioneered the uses of short-lived isotopes such as ^{137}Cs in the estimation of both soil erosion rates and floodplain deposition (Walling and Bradley, 1989; Walling *et al.*, 1991; He and Walling, 2003). The Exe and in particular its tributary the Culm has been more extensively studied than any other catchment in the UK and probably Europe. This research has provided baseline data for a lowland agricultural system and river restoration. The baseline in these systems is a multiple - channel (anastamosing) river pattern which can be copied in order to maximise habitat diversity by maintaining or creating multiple channels in single reaches. This allows the fluvial system to persist with areas subject to 'intermediate disturbance' and is probably similar to past natural disturbance regimes (Davis *et al.*, 2007) such as when beavers were an integral part of the lowland landscape in Britain (Worsley, 2009).

The research in the Culm valley by Brown (2007) and Davis *et al.* (2007) has sought to provide a long-term and palaeoecological perspective to these studies and to link the medium and short term chronologies. The use of a combination of OSL, ^{14}C, ^{137}Cs and ^{210}Pb dating has shown that the River Culm remained an active braided to wandering gravel-bed river well into the late Holocene and that extensive overbank deposition did not occur until 300-200 years ago (Figure 6). This contrasts markedly with similar sized lowland rivers elsewhere in southern and midland England and northern France. The reasons are believed to lie in an oversupply of pre-formed fluvial gravel from both Tertiary and Mesozoic sources and land-use history. Although the Blackdown plateau was deforested and cultivated in the Bronze Age there was a lack of coupling with the valleys due to the persistence of valley-side woodland as mentioned earlier, and it was not until the 18th and 19th centuries that enclosure led to arable agriculture on the lower slopes of the catchment increasing the supply of fine sediment to the river valley. Interestingly the record also contains a climatic signal showing how sediment supply to the fluvial systems interacted with climate change to produce a composite response (Hoffman *et al.*, 2010). In an addition to this work, Brown *et al.* (2007, 2008) have quantified a component of the organic load (seston) of the Culm namely the pollen and spore load or palynomorph load. There were two reasons for undertaking this research, firstly some evidence suggested that palynomorphs might act as aggregating agents for suspended sediment, and secondly most palaeoecological studies of vegetation change are derived from lakes which have both aquatic and atmospheric inputs. With regard to the first reason it was found that both palynomorphs and suspended sediment are independently driven by discharge, and palynomorphs, although they can form a significant part of the seston, are probably not important in the way hypothesised (Brown *et al.*, 2008). With respect to the second stimulus, changes in lake pollen concentration almost certainly reflect changing aquatic inputs depending upon the lake area-catchment ratio. However, it appears that the aquatic component is just as, if not more, closely related to catchment vegetation as the atmospheric influx (Brown *et al.*, 2007). This suggests that lake records may even enhance land-use signals from their catchments.

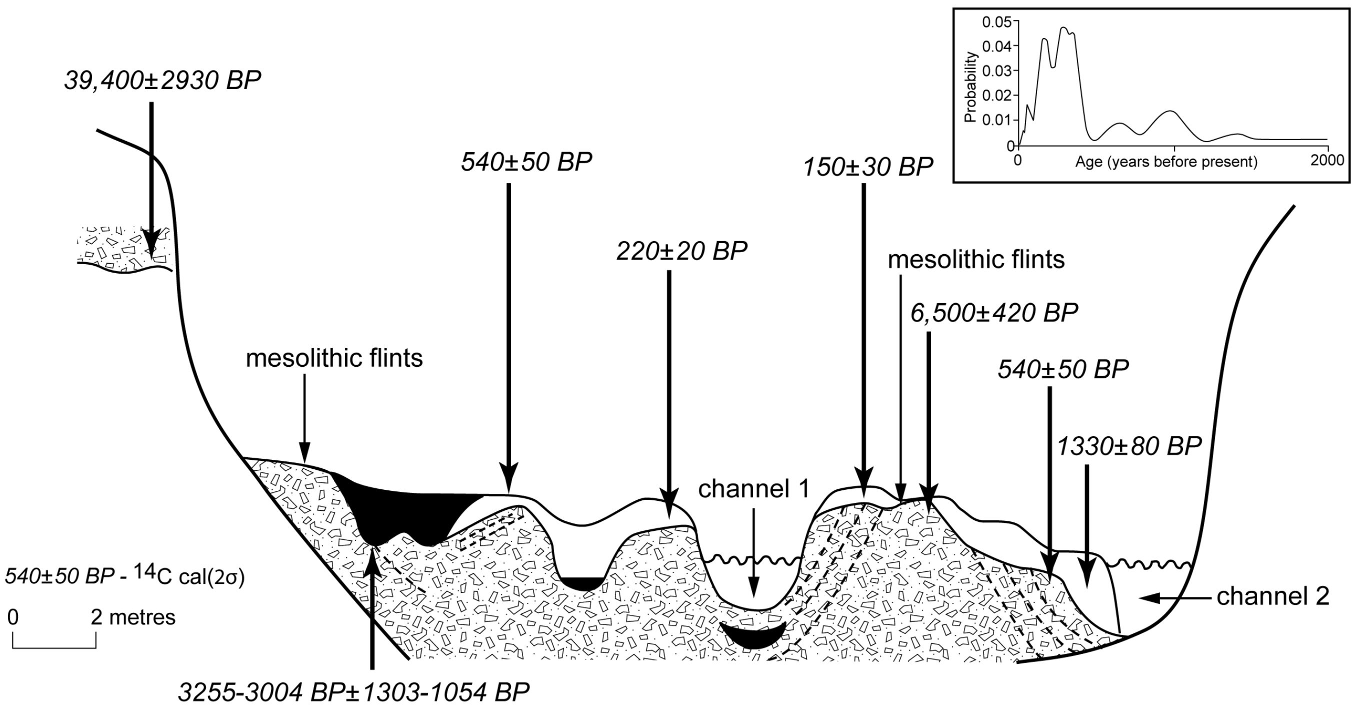

Figure 6. *A generalised cross-section of the Culm floodplain at Five Fords with indicative dates of formation. Insert shows the probability distribution from the OSL dates alone.*

Conclusions

The last two decades of Quaternary research have tended to be rather more question-driven than earlier research, in effect using the South West as a location in which ideas can be tested, be they geomorphological ideas concerning glaciation and periglaciation, or geoarchaeological questions such as the causes of settlement change. In many ways this has just mirrored the nature of academic research and whilst there are benefits there are also drawbacks, most obviously in the unsystematic and disjointed nature of our understanding of landform evolution at the regional scale. On the positive side neglected avenues have been re-discovered such as the role of hydrogeological processes in cold-stage Quaternary landform evolution and the potential of the Palaeolithic record contained in South Western river gravels. The peculiarities of the South West have also continued to play a role in for example promoting, by necessity, the development of OSL dating of fluvial deposits and also through the recognition of fluvial styles rarely seen in other parts of the United Kingdom. Another distinctive characteristic of the South West is its relatively low population density and this has again negative and positive Quaternary aspects. On the negative side a low level of urban development has limited the scope for large-scale Quaternary investigations such as have occurred in the London basin, due to the Olympics or airport development. But on the positive side far less destruction has taken place of our geomorphological and archaeological heritage, allowing continued research into climatic and human impacts on the landscape. It may have struck readers that much of the recent research cited here has been funded by non-geological sources, be they industry, archaeology or both. This is not just a reflection of the author's bias but reflects both a relative lack of geological funding for Quaternary science but also an increased awareness of the interdependence and inter-disciplinary nature of Quaternary research coupled with the unique diversity of the South West of England.

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