THE GEOLOGY OF DEVON

Introduction

Devon's Earth Heritage resource is one of the most varied in the British Isles and this is reflected in the great variety of its landscapes. The County records around 410 million years of Earth history and is particularly distinguished by being the only one in the British Isles to give its name to an interval of geological time of world-wide recognition - the Devonian Period. The relationship between the varied bedrock of the County and its landscape is also more faithfully represented in Devon than in many more northerly areas of Britain, as it remained unglaciated during the Pleistocene 'ice ages' and consequently was not either levelled by ice sheet erosion or blanketed by glacial deposits as the ice melted.. Nevertheless, the development of permafrost conditions created a wide range of periglacial features and deposits and fluvial and coastal processes have created important landforms and other features.

Devon's geological deposits ranges in age from the ancient slates of the lower part of the Devonian Period, around 410million years ago, to the most recent and still accumulating sandy and muddy deposits of its rivers and coastline. A summary of Devon's geological history is given below, with the present day distribution of its bedrock geology illustrated by Figure 2.2.

Devon's Geological History

Devonian:

The oldest rocks in both North Devon and the South Hams date from the lower part of the Devonian Period and are around 410 million years. These sediments were laid down on coastal plains possibly in lakes and river systems and very locally contain the remains of primitive armoured fish (including within the Dartmouth Group of South Devon). Sea levels gradually rose and by around 407 million years ago marine conditions had spread across the region, often including shallow water sandy deposits with marine shells such as brachiopods and even rare woodlouse-like trilobites (includes the Meadfoot Group of South Devon). In North Devon the muddy and sandy Lynton Group appears to represent late Lower Devonian shallow water sediments deposited close to the margin of the arid landmass, known as the 'Old Red Sandstone continent', that occupied more northerly areas of Britain throughout the Devonian Period.

The sea continued to deepen and muddy conditions became widespread in more southerly areas during the early Middle Devonian, by around 395 million years ago. These deposits are now represented by the dark slates in Torbay and south of Plymouth. The subsidence which caused this deepening was related to continental stretching as Plate Tectonic movements created an ocean to the south of Britain. A by-product of this activity was the creation of a series of east-west marine basins with relatively shallow water 'rises' between. Each of these basins and rises had a distinctive geological succession, meaning that the many different names are now used to describe the different rock units that were deposited.

By the later Middle Devonian, around 392 to 385 million years ago, extensive reef belts dominated by coralline sponges had developed along the ridges. These reef and associated shallow tropical sea deposits often contain rich fossil faunas, some of

which were used to first characterise the Devonian time period in the mid to late nineteenth century. They are dominated by the thick limestone deposits which now outcrop between Torbay and Chudleigh and near Totnes and around Plymouth. Locally volcanic activity was also significant. In North Devon, although the early Middle Devonian includes the sandy river-lain deposits of the 'Hangman Grit', some limestone bands with corals and shells are associated with the sandy and muddy shallow water deposits of the Ilfracombe and Coombe Martin slates.

By the early Upper Devonian, around 385-375 million years ago, even the shallower rises had sunk into deeper waters and muds were being widely deposited in more southerly areas, as now represented by slates south-east and west of Dartmoor. A victim of these changes were the reef systems, which were smothered as they subsided into deeper waters. The rich coral and shelly faunas of the reefs disappear and are replaced by deep water assemblages including the spiral shells of early ammonoids – an extinct group of cephalopod molluscs related to squids. In North Devon, although the earliest part of the Upper Devonian includes the Morte Slates, the proximity of the 'Old Red Sandstone' continent is indicated by near-shore sands of the 'Baggy Beds' and the plant bearing non-marine 'Pickwell Down Sandstone' which has yielded some of the earliest known seed plant remains in Britain.

Carboniferous:

Deep marine conditions continued into the lower part of the Carboniferous Period, around 359 million years ago, which is marked by the extensive volcanism in West Devon, producing the distinctive green hardened ash of which most of the centre of Tavistock is constructed, and the lavas which form the distinctive knoll of Brentor. Associated in both north and south Devon are thick deposits of chert, a hard siliceous rock deposited in deep water, and dark slaty shales – the former is particularly prominent south of Barnstable where it forms the Codden Hill ridge. Few fossils are generally found in these rocks, although locally ammonoids and trilobites are recorded. In north-east Devon, in particular, bands of limestone are also present and represent lime mud, and locally other debris, washed into the deep basin from shallow water areas to the north-west where thick deposits of Carboniferous limestone are well developed, as in the Mendips. These deep water limestones have been extensively quarried in the Bampton and Westleigh districts.

By the Upper Carboniferous, around 318 million years ago, earthquakes associated with the rise of a mountain chain to the south dislodged sands and muds on the sides of the marine basin, which then flowed into deeper areas as turbid currents. As the speed of the current dropped as it reached gentler slopes towards the bottom of the basin, the sands settled out of suspension followed by the muds. This process repeated countless times, eventually formed the alternating sandstones and shales of the well known 'Culm Measures' of mid and north-west Devon – and known more correctly as the Crackington and Bude formations.

In north-west Devon a coastal lake developed inhabited by fresh water mussels and plant remains locally accumulated to form sooty coal – these deposits being of equivalent age to the 'Coal Measures' of South Wales and the rest of Britain. These are the deposits of the Bideford Formation, a lateral equivalent of the thick sandstones of the Bude Formation, the youngest deposits of the Carboniferous in Devon. The Crackington, Bideford and Bude Formations give rise to typical marshy 'Culm' grassland – a habitat of European importance.-

The Variscan Orogeny, granites and mineralisation (mainly Carboniferous-Permian):

The Lower Carboniferous rocks of Devon are marked by the beginning of an intense phase of tectonic activity which climaxed with intrusion of the Dartmoor granite magma close to the boundary between the Carboniferous and Permian time periods. This phase, the Variscan Orogeny, was a direct consequence of the tectonic plate collision of Africa with Europe. Sediments which had accumulated in ocean basins between the continents were squeezed up and thrust over each other as great slices known as 'nappes', to form a huge mountain chain, running from eastern North America (which was joined to Europe at the time), through Cornwall and Devon to Belgium, the Czech Republic and beyond.

By around 300-290 million years ago, the Variscan Mountains had been piled so high that their base sank far enough into the Earth that it melted to form a magma. This magma was then intruded into the upper layers of the crust and solidified as the granite masses of south west England of which Dartmoor is the most easterly and largest. The extreme heat of the granite 'cooked' the rocks it came into contact with as it was emplaced, producing a metamorphic aureole, often around a kilometre wide. Fluids leaking from the granite contributed to this process by reacting with the surrounding 'country' rocks, locally producing a remarkable range of metamorphic minerals including garnets within skarn deposits. During the final stages of the crystallisation of the granite, small pockets of fluids rich in rarer elements such as lithium accumulated before being injected as veins into the aureole. The most remarkable of these is the Meldon Aplite, near Okehampton, which has long been known as a source of rare and unusual minerals. In south-west Dartmoor, the granite released fluids that began to react with itself, decomposing its component feldspar crystals to form china clay.

The heat of the granite intrusion also produced vast convection cells in the surrounding country rocks as superheated water circulated, leaching metals from the sediments and associated volcanic rocks. These fluids were subsequently injected into cracks in the cooling granite and surrounding rocks and minerals crystallised out to form copper and tin-rich mineral veins. Over 10s of millions of years as cooling continued, lead, zinc and other ores were also deposited. These mineral deposits have long been of economic importance in the County, perhaps back to pre-Roman times, but were the raw material that fuelled the mining boom of the late eighteenth and nineteenth centuries.

The Variscan Orogeny had a very fundamental effect on the Devonian and Carboniferous rocks of Devon and was responsible for their intense folding and faulting. From Dartmoor southwards, the structure of the County is very complex and dominated by 'nappes' transported from the south, often with slices of Devonian and Carboniferous rocks of different ages shuffled together. The 'Culm Basin' of mid Devon, however, although strongly folded and faulted by the compression associated with the continental collision – as spectacularly seen on the coast around Hartland Point - is more or less where it was originally. Similarly, the sequence of Devonian and Lower Carboniferous deposits in north Devon is much less disturbed than its equivalents in the south of the County.

The southernmost tip of Devon, however, between Start Point and Bolt Tail shows a quite distinct geology dominated by relatively 'high grade' metamorphic schists. These rocks were subjected to pressures and temperatures high enough to recrystallise their original mineralogy. How and exactly where this took place remains

unclear, but the Start Complex was eventually faulted into place against the nappe terrain of south Devon during the Variscan Orogeny.

Permian and Triassic:

The new Variscan mountain chain had risen in a desert climate and began to erode very rapidly. In the early Permian, around 290 million years ago, stony deposits accumulated in basins around the mountains, as seasonal flash floods washed loose scree down desert valleys known as wadis. These deposits are well exposed in Torbay and also at Peppercombe in north-west Devon and typically form the lowest part of the well-known 'New Red Sandstone' of the County. The typical red colour of these and later Permian and Triassic deposits is a consequence of the oxidation of iron minerals in the sediments under intense desert conditions.

Later in Permian vast sand dune systems crossed the County, sections of which are most famous exposed in Dawlish Cliffs, but are also well exposed at Sowton, in Exeter. The early Permian also saw volcanic activity between Exeter and Hatherleigh, the lavas formed becoming an important building stone from the Middle Ages onwards, including the well-known 'Exeter Traps'. Very little could survive in these deserts although reptile footprints have been found near Exeter and burrows presumed to have been created by giant millepedes are present in Torbay.

Desert conditions continued into the Triassic Period, from around 250 million years ago, as 'New Red Sandstone' deposition continued. The Variscan Mountains were already subdued by erosion and where Triassic rocks are preserved in East Devon, most deposition was taking place in broad arid basins. Muds were laid down during seasonal floods and in temporary playa-style lakes but the County's best known Triassic deposits are the Budleigh Salterton Pebble Beds, the product of a large, seasonal river systems. Most of the pebbles in this deposit are unlike any rock known in Devon and include quartzites of Ordovician and Devonian age, potentially carried from as far away as Brittany. Although fossils are generally rare in the Triassic rocks of Devon, near Sidmouth bones of primitive reptiles have been found associated with sandy and muddy river deposits.

Jurassic:

At the end of the Triassic Period, around 200 million years ago, the sea flooded across the desert plains and clays and limestones were deposited in the tropical seas of the early Jurassic Period. These deposits are only exposed in the extreme south east of the County to the east of the Axe Valley, most spectacularly in the cliffs west of Lyme Regis, which are largely within Devon not Dorset. These rocks – known as the 'Lias' - are famous for their fossils including the spiral shells of ammonites and extinct marine reptiles such as icthyosaurs.

Cretaceous

Higher parts of the Jurassic are no longer preserved in Devon and by around the end of the Period, around 146 Million years ago the region was land. The sea returned, however, in the late Lower Cretaceous (around 112 million years ago), cutting across the older rocks of the County and depositing the shallow water sands of the 'Upper Greensand'. Locally these yield rich shelly faunas of bivalve and gastropod molluscs, which were historically famous in the Blackdown Hills. 'Upper Greensand' deposits are preserved as far west as Newton Abbot but have their most dramatic effects on the Devon landscape where they form the flat plateaux of the the Haldon Hills and the Blackdown Hills as far as the coast around Sidmouth.

The sea deepened and limestone deposition took over as countless remains of calcareous plankton accumulated on the sea floor to form white Chalk – each centimetre cubed of which can contain the remains of around 92 million coccolith algae! The Chalk now has only a very limited outcrop in the Beer and Membury areas of East Devon, but its cover was once much more extensive - patches of flint gravel left behind after its dissolution being present on the Haldon Hills and elsewhere in Devon.

The "Tertiary": Palaeogene and Neogene periods:

The Chalk sea receded and during the Eocene and Oligocene epochs of the succeeding Palaeogene Period, between around 56 and 23 million years ago, the Bovey and Petrockstow basins developed, initially with pebbly river deposits but subsequently with large lakes. The latter accumulated economically important china-clay rich clays washed down from highlands in which the Dartmoor granite has now well exposed and deeply weathering under the tropical conditions. The Bovey Basin in particular, often contains evidence of the vegetation of this hinterland, including branches and trunks of giant redwood trees washed down from the uplands. Sometimes this debris is so abundant as to from beds of 'brown coal', or lignite.

During the Eocene and early Oligocene, to at least 30 million years ago, tectonic activity produced a number of major NW-SE faults across Devon, the most famous of which is the Sticklepath Fault which runs from Bideford Bay to Torbay. Movement on on this fault created the 'pull-apart' basins of the Bovey Tracey and Petrockstow areas but the system is still active, the last (small) earthquake being recorded in 1956! In the mid Palaeogene the Lundy granite was intruded, an igneous rock with greater affinities to those of similar age in western Scotland than anything else in southern Britain. Little evidence remains in Devon of the Neogene Period, which lasted from around 23 to 1.8 million years ago, although intense tropical weathering continued producing the stony, lateritic soils which are locally recorded in East Devon.

Quaternary (Pleistocene and Holocene):

During the Pleistocene Epoch of the early Quaternary Period, global temperatures collapsed and as climates fluctuated dramatically, several ice ages developed. During these intervals, periglacial permafrost conditions took hold across the County, which largely lay to the south of the maximum extent of ice sheets. Seasonal melting of the top metre or so of this permafrost during the slightly warmer summers caused loose soil and rock to creep downhill as a stony sludge and accumulate as a deposit known as 'head'. Locally, especially in East Devon, large landslip systems also developed on slopes where the bedrock geology was dominated by relatively weak clays and sands. Periglacial processes could eventually expose bare rock on the crest of hills, thereby creating the tors of Dartmoor with their extensive rocky 'blockfields' below, but also lead to the accumulation of thick blankets of clayey and stony 'head' in valleys and the lower parts of other slopes. Most of these deposits are likely to date form the last or Devensian glaciation, which lasted from around 90,000 to 11,000 years ago, as earlier deposits are likely to have been disturbed during the previous interglacial or 'reworked' during this latest glacial phase.

Remarkably, however, the north-west coast of Devon does including some evidence of ice sheet-processes, as large 'erratic blocks' transported from northern Britain are known around Croyde and clays with a glacial origin are recorded near Barnstable (and formerly worked to supply a local ceramics industry). There is considerable

debate about the interpretation of these deposits, however, and they could indicate either a maximum extent for Pleistocene ice sheets, or material rafted by sea ice.

Between the ice ages, climates improved and warm temperate conditions with relatively high rainfalls developed. River erosion during such phases created much of the present day landscape of Devon, as it dissected a relatively level Neogene landscape. This process is recorded as a series of terraces, representing sections of former floodplains left high and often dry as the river system cut down deeper, in part in response to changing sea level changes. The Exe and the Axe valleys, in particular, have important river terrace records, the highest of which have been dated back to at least 350,000 years ago. In the Axe valley the gravels deposited on these ancient floodplains are an important source of Palaeolithic stone implements and near Honiton other deposits have also yielded *Hippopotamus* remains, dating from the last interglacial – the Ipswichsian – around 120,000 years ago. The limestones of south Devon in particular developed cave systems during the warm, moist interglacials of the Pleistocene which then accumulated deposits recording the climate and faunal changes over this dramatic interval. The latter include both interglacial faunas with hippopotamus, forest rhinoceros, straight tusked elephant, hyena, sabre toothed cat and bison and glacial assemblages with mammoth, reindeer, bear and woolly rhinoceras. Devon's caves also record the presence of the County's earliest known inhabitants, a hominid close to *Homo heidelbergensis* who left stone tools at Kents Cavern in Torquay.

Changing sea levels associated with the build up of ice sheets and their subsequent melting had a dramatic effect on Devon's coastline. The high stands of the Ipswichian interglacial around 120,000 years ago cut a raised beach around 7m above present sea level, but during the subsequent Devensian ice age, sea levels fell again and the coastline receded several kilometres away its present position in many places. As these ice sheets melted, the sea flooded back, drowning over-deepened estuaries to form the County's famous rias. It also rolled a vast bank of shingle landward in south-east Devon as it rose, to form the Slapton Ley barrier. Few places in Britain show these changes as dramatically as the coast near East Prawle, west of Start Point, where an ancient cliff line, with a linked raised beach platform, dating from the last interglacial is draped with periglacial 'head' deposits from the succeeding Devensian glacial interval. Above an earlier marine platform and cliff-line is also visible… Important post-glacial climate records and deposits are also preserved Devon, in peat deposits on its moors but also in estuarine and 'submerged forests' deposits along its coasts – the latter drowned by rising sea levels as the Devensian ice melted.

Devon's coasts are still evolving as geomorphological processes re-established after the end of the last ice age continue. Complex sediment systems driven by tides and currents dominate estuary systems, sand dunes still evolve where human intervention has been limited and the East Devon coast east of Axmouth is famous for some of the largest coastal landslip systems in Europe. Inland rivers erode and deposit, despite attempts at intervention. All these processes have implications for our society's interaction with the geological and geomorphological heritage of Devon - whether it be coastal erosion issues or flood alleviation, an understanding of natural processes is fundamental to both our own use of the landscape of Devon and that of future generations.