



DEVON'S ROCKS – A GEOLOGICAL GUIDE



The Geoneedle on Orcombe Point near Exmouth

Developed in partnership with the Devon RIGS Group, this guide contains a simple introduction to the rocks of Devon and a geological map, with subsequent chapters detailing thirteen rock types found in Devon.

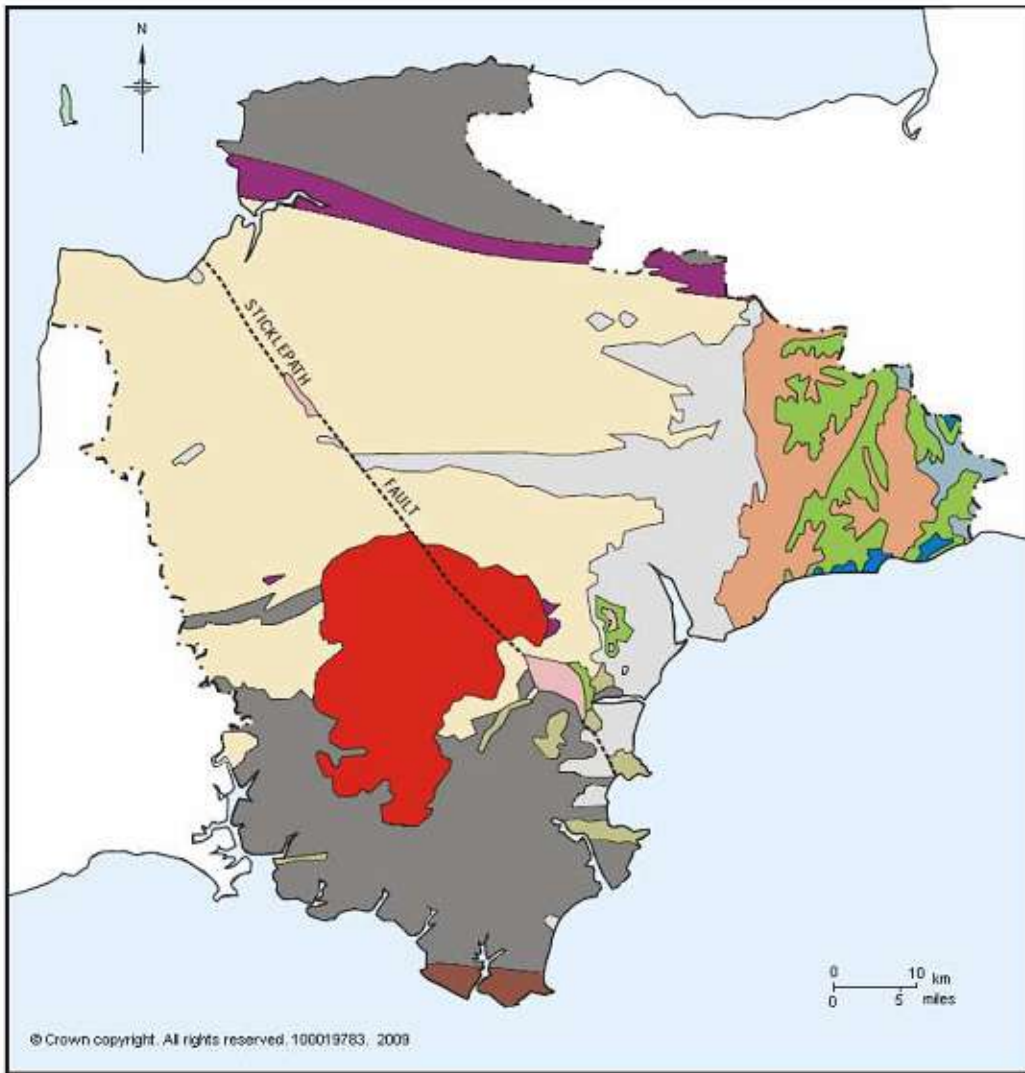
The information in this document was developed in celebration of the International Year of the Planet. The thirteen chapters describing the rock types were written by a team of consultants within David Roche GeoConsulting, with amendments made to the Basic Description sections by Devon County Council.

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Summary Map of the Geology of Devon



KEY

Quaternary Deposits and Landforms		These recent deposits are not on the map	Permian Breccias, Sandstones and Volcanics	
Tertiary Deposits			Dartmoor Granite	
Lundy Granite			Carboniferous Sandstones and Shales	
Chalk			Transition Group (Devonian to Carboniferous boundary)	
Upper Greensand and Gault			Devonian Slates, Sandstones and Volcanics	
Lower Jurassic Mudstones and Limestones			Devonian Limestones	
Triassic Pebble Beds, Sandstones and Mudstones			Lower Devonian Schists	

Introduction to the Geology of Devon

Devon's geology 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 415 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.

Devonian rocks, dating from between 415 and 360 million years ago are the oldest rocks found in the county and represent a time when Devon was under the sea near the equator. Sandstones and shales were deposited at this time and can now be found in both north and south Devon. Also, limestone formed in areas of shallow waters, which can be seen now around Plymouth and Torquay.

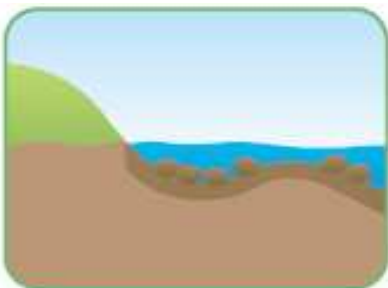


Towards the end of the Devonian period and into the Carboniferous time period, Devon's rocks were part of a (now vanished) chain of mountains. Intense squeezing and folding created the spectacular structures we can see along the north Devon coast today. The uplands of Devon are dominated by the granite of Dartmoor which moved up into the folded rocks during the formation of the mountains.

After the folding, faulting and mountain building, Devon entered a long hot arid period between 300 and 200 million years ago. This covers two geological periods known as the Permian and Triassic. The climate was like that of the Sahara Desert today. Seasonal flash floods swept large quantities of sediment into the valleys and the plains fringing the deserts and both the red mudstone and the Pebble Beds found in east Devon are classic examples of such deposition. Devon also featured volcanoes at this time. The lava erupted from the deposits found around Exeter, known as the Exeter Volcanic Series.



At the end of the Triassic time period, the sea level rose and tropical seas flooded the deserts. This marks the start of the Jurassic geological period (between 200 and 145 million years ago). The rocks which date from this time form the dramatic Jurassic Coast in east Devon, internationally recognised as a World Heritage Site. The cliffs within the Jurassic Coast record 185 million years of the Earth's history in just 95 miles because the rocks tilt or 'dip' down under the sea to the east. Therefore the oldest rocks, at 250 million years in age, are found in the west and younger rocks form the cliffs to the east. These rocks contain important fossils which document the dinosaurs which swam in the seas covering Devon. From the sea, white chalk was deposited across the county of Devon.



In geological history of the Jurassic Coast there is also a "Great Unconformity" or time gap between the rocks of different ages. About 100 million years ago, in the middle of the Cretaceous geological time period, the rocks were in the process of tilting eastwards and were heavily eroded by seas and rivers, especially in the west of the area. As a result,

chalk only occurs in parts of east Devon, due to the extensive erosion, but flint gravels derived from the chalk are scattered across the county.

With a jump in geological time, Devon also contains some younger geological features, namely ball clay deposits and Lundy granite. These date from the Tertiary geological time period and are aged between 65 and 2.5 million years old. Lundy granite was originally thought to be the same age as Devon's Dartmoor granite, however, radiometric dating showed that it was much younger. The ball clay found in the county was deposited in basins formed by subsidence along the Sticklepath Fault, which crossed the whole of Devon.

The youngest rocks of Devon date from the Quaternary geological time period, which represents rocks dated from 2.5 million years ago to today. The major geological event of this time was a succession of ice ages. There is no record of Devon being covered in glaciers, but permafrost conditions which created a wide range of periglacial features and deposits. Fluvial and coastal processes in these conditions created important landforms and other distinct features.

1. LOWER DEVONIAN SCHISTS

by Phil Stephenson & David Roche



Mica schist cliffs at Bolberry Down looking east in direction of Salcombe along the SW Coast Path.

© C Nicholas

1.1. BRIEF DESCRIPTION

In south Devon you can find a rock type called Lower Devonian schist. This rock name can be broken down to 'Lower Devonian', which refers to the geological time period in which the rock was formed, and 'schist' which is a type of rock. This type of rock is believed to be the oldest in Devon and they are quite distinct from other rocks elsewhere in the county.

A schist is characterised by thin parallel bands of minerals and was formed in a process known as metamorphism. The word metamorphism comes from the Greek 'Meta' meaning change and 'Morph' meaning form, so it means to change form. In geology this refers to the changes in mineral assemblage and texture when a rock experiences pressures and temperatures different to the conditions under which the rock was originally formed.

The schist rocks are found only in the southernmost tip of Devon, around Salcombe and the surrounding area in the South Hams district, with outcrops along the spectacular coast between Start Point (in the east) and Bolt Tail (in the west).

The colour and mineral content of the schists are controlled by the original rock type before the process of metamorphism. The age of the schists is not certain because no fossils have survived but they are most likely to be altered Lower Devonian rocks over 400 million years old.

Two types of schist rock are found; green hornblende schists dominated by a mineral called hornblende, and grey mica schists largely formed of a shiny flaky mineral called mica.

The schists were formed and brought to their present position by mountain building processes involving the collision of two continents, this process is known as 'plate

tectonics'. The schists have a faulted contact with younger Devonian rocks to the north. A fault is a fracture in rock in which the rock on one side of the fracture has moved with respect to the rock on the other side. The rocks also feature folds which form a broad arch structure (called an antiform) several kilometres wide, with smaller folds which can be seen in individual outcrops. These characteristics are common in rocks which have been affected by plate tectonic movements.

The distinct green colour and shiny mica rock surfaces, together with the folding, make the schists an attractive and unique rock in the geology of Devon.

1.2. GEOLOGICAL DETAIL

The schist rocks in south Devon form what is known as the Start Point Complex comprising two main rock groups: green hornblende schist and grey mica schist. Schists are generally named according to their most prominent mineral.

Green hornblende schists consist of the minerals hornblende-chlorite-epidote-albite and minor sphene and other amphiboles. The amount of chlorite and hornblende present within the schist depends on the degree of dynamic metamorphism (intense local stress), the greater the metamorphism the increased percentage of hornblende.

Grey mica schists consist of the minerals muscovite mica-quartz-chlorite-albite with a raft of accessory minor minerals including sphene, tourmaline and rutile. Quartz commonly forms bands or veinlets between the mica and chlorite. The mica schists have a well developed schistose fabric (mineral banded foliation) compared to the hornblende schists which are sometimes more massive.

The hornblende schists are formed from original basic lavas, sills and tuffs, and the mica schists are the result of metamorphism of slates or shales, siltstones and sandstones. The mica and hornblende schists are interbanded indicating a close time relationship between the original igneous material and sediments.

The schists are folded on a large scale to an antiformal structure with an east-west trending axis which dips west. Local minor folding is also seen.

The age of the original igneous and sedimentary rocks altered to form the schists has been difficult to identify, because no fossils have survived the metamorphism, but the original rocks are likely to be of Lower Devonian age – over 400 million years ago. The geological structure within the rocks indicates a single major phase of deformation and the east-west trending structure is parallel to the adjoining Devonian slates to the north. Alternatively, much older original rocks have been suggested from Lower Palaeozoic or Pre-Cambrian ages which may date back as far as 500 or 600 million years ago.

1.3. USES

Schist is relatively hard and it cuts easily into elongate shapes, so it has been used as a local building stone in walls, Devon hedge banks and some buildings in the southern area of the South Hams.

1.4. PLACES TO VISIT

Please refer to the safety guidance about visiting geological sites on our website before visiting the places listed below.

The Educational Register of Geological Sites in Devon provides three excellent examples where the schist rocks from the Start Point Complex can be viewed.
(www.devon.gov.uk/educational_register.htm)

North Sands Bay

On the south side of Salcombe (National Grid Reference SX 731 381) provides exposure of the schists and local scale folding. The site is a County Geological Site (www.devonrigs.org.uk) and is readily accessible with safe viewing from North Sands beach on a falling tide.

The Shippen at Outer Hope

Provides the only good exposure of the Start Boundary Fault contact between the schists and Middle Devonian slate with a mylonite fault zone (National Grid Reference SX 675 401). The site is a County Geological Site (www.devonrigs.org.uk).

Prawle Point and Start Point

The South West Coastal Footpath connects Prawle Point and Start Point (National Grid Reference SX 741 373 – SX 819 381) providing exposure of green and grey schist along the route.
(www.southwestcoastpath.com/main/discover/Geology_P2.cfm)

Bolberry Down

The Coastal Footpath can also be readily accessed at Bolberry Down between Salcombe and Hope Cove where there is parking at SX 689 385 with easy access to the cliff tops and extensive exposures of the mica schist and some magnificent coastal views.

1.5. PHOTOGRAPHS



Start Point, at the southern tip of Devon, a rugged coast formed in mica schist rocks with steep schistose fabric dip to the south. © DP Roche



Grey mica schist forming a sharp ridge with saw-tooth profile down to Start Point lighthouse. © DP Roche



Folded green hornblende schist on the south side of North Sands, Salcombe. © DP Roche



Grey mica schist with well developed schistose fabric and much knotted quartz. © DP Roche



Green hornblende schist in a cut rock face (above) and used as building stone in Salcombe (below). © DP Roche



© DP Roche



2. DEVONIAN LIMESTONES

by David Allen



Thatcher Rock, Torquay – a sea stack in Devonian Torquay Limestone, with distant high sea cliffs across Tor Bay at Brixham
© DW Allen

2.1. BRIEF DESCRIPTION

In south Devon you can find limestone rock which dates from the Devonian geological time period, about 416 to 345 million years ago. These limestone rocks are sedimentary rocks and predominately consist of the mineral calcium carbonate. Sedimentary rocks form when material or sediment is deposited and compacted to form a rock.

Devon was the county where the Devonian rock series was first recognised in the mid nineteenth century and rocks of the same age world-wide are referred to as Devonian. The limestones in Devon were formed mainly in the Middle Devonian.

The calcium carbonate which forms this limestone originates from various sea creatures. These range in size from very small planktonic animals, through corals (small creatures but often living in large colonies), to sometimes quite large organisms with individual shells. The abundant life in warm, clear waters produced carbonate sediments which were deposited at the bottom of relatively shallow seas, often around volcanic islands.

One of the most striking features of the Devonian limestone is the abundance of fossils it contains. Where the rocks have been weathered, or have been polished and used in buildings, the clarity of these fossils can be particularly good.

Around Plymouth at the Hoe, Cattewater and Mount Batten you can see distinctive landforms formed of strong limestone rock. Also, around Torbay and Brixham the spectacular cliffs are formed of limestone. In urban Torquay, inland cliffs both natural and manmade (the result of quarrying) are locally characteristic. Devonian limestones can also be found around Ashburton, Buckfastleigh and near Chudleigh.

2.2. GEOLOGICAL DETAIL

During the earliest part of the Devonian, conditions around southwest England changed from continental sedimentation in rivers and lakes to deposition in shallow seas with scattered volcanoes. First of all, the Lower Devonian sediments were mainly sands with some volcanic material and only occasional accumulations of fossil debris resulting in only patchy and generally thin limestone beds.

In the Middle Devonian, continental landmasses were present to both the north and south with variable conditions in the sea ranging from coastal to deep water, representing both shallow marine platform and deep basinal deposits. In shallower water areas, possibly around volcanic islands, conditions were probably similar to those in Pacific Ocean margins today, like Indonesia. Life was abundant in the clear warm water producing a regular and abundant supply of animal remains. This allowed accumulation of thick carbonate shell deposits which produced thick limestones. The volcanoes assisted in the formation of the limestones by building shallow sea floors which encouraged colonial organisms. Although periodic emissions of poisonous gases may have killed the organisms, regular re-colonisation developed deposits of substantial thickness.

The term limestone includes three major groups; organic, chemical and detrital or clastic. Organic limestones include accumulations of carbonate animal remains, either complete or broken, which form reef, shelly, coral or algal limestones etc. depending upon composition. Chemical limestones are deposits derived from carbonate minerals originally dissolved in the water. Detrital or clastic limestones are mechanically deposited carbonate rocks made up essentially of fragments of organic carbonate shells or a pre-existing limestone rock. All three types occur in the Devonian Limestones of Devon although chemical limestones form a relatively small proportion.

The organisms which created the limestones include sponge-like stromatoporids which are small colonial organisms that form mounds in shallow water and can build large reefs. The most abundant and most important fossil group in creating the limestones were the corals, in particular the chain like and compound colonial species which formed substantial reefs. There were also solitary corals which provided shelter for other creatures around the reefs and coastlines. These other organisms included trilobites (early segmented animals), brachiopods (marine invertebrates) and crinoids (sea lilies).

The changing depositional conditions and volcanic activity in South West England during the early Devonian period were a reflection of the start of a significant period of mountain building. These processes continued through the Devonian and Carboniferous periods (about 400 to 300 million years ago) and into the early Permian period. These processes were caused by the collision of moving plates of the Earth's crust – known as 'plate tectonics' or 'continental drift'. Deep troughs (or basins) formed below the narrowing sea and received vast volumes of sediments from the erosion of the nearby continental land masses – Wales and North America to the north and offshoots from the ancient continent of Gondwana to the south. The accumulated carbonate mud sediments were deeply buried and turned into limestones, then folded and contorted and thrust up into mountains by the slow but relentless collision of the continental plates. This long period of earth movements and mountain building is known as the 'Variscan Orogeny'.

As a result the Devonian age rocks in Devon, including the limestones, have a complex structure. In the area which became the southern part of Devon, the sedimentary conditions were particularly complex with sedimentary basins largely controlled by geological faults. The relative movement of fault bounded blocks resulted in both shallow and deep water conditions with further complications arising from the formation of

volcanic islands. Formation of limestones, in particular of reefs, was closely related to the shallower water areas or 'highs'. Later ground movements resulted in further disturbance and complex folding, sometimes with blocks of strata overturned and thrust over others and separated into blocks by faulting.

The most recent geological maps and descriptions by the British Geological Survey identify the individual successions related to depositional basins and local highs that have been recognised across southwest England. As far as the Devonian Limestones in Devon are concerned these include the Plymouth High and the Brixham and Torquay Highs of Torbay.

Essentially these successions relate to the Plymouth Limestone, the Brixham Limestone and the Torquay Limestone formations in their respective districts. Due to the complex tectonics it is not possible to give thicknesses of the limestone deposits.

The carbonate and other minerals which make up the limestone are commonly recrystallised during diagenesis (the processes, low temperature and pressure, which affect sediments at or near to the earth's surface) which tends to destroy some of the original characteristics of the rock. However, these processes can result in spectacular coloured patterns with veins of white calcite and streaks of red haematite in the various background shades of grey. This is particularly so in some limestones around Newton Abbot, Buckfastleigh and Ashburton, the so-called Ashburton Marble, which are able to take a hard polish. The stone is not a true marble since it has not been subject to the extremes of metamorphic (deep burial) heating and in this case the fossil corals are uniquely preserved.

2.3. USES

Probably the earliest usage of Devonian Limestone was for building stone. The extensive old quarries around Plymouth and Torquay bear testimony to its past importance. Many of the quarry sites are located close to the shore for ease of shipment such as around the Cattewater in Plymouth, at Hopes Nose and Berry Head around Torbay.

Rough cut stone has been extensively used in vernacular buildings but historically it's most important use has been as dressed and cut stone in public and other important buildings. It has also seen extensive use in municipal and civil engineering. Slabs of limestone are still to be seen as paving in the streets of Plymouth, Torquay and also to a lesser extent Exeter. It has also been used in retaining walls and harbour works. Much of the mainline railway along the seawall between Teignmouth and Dawlish is faced with blocks of Devonian Limestone brought by sea from Torbay.

The iron oxide minerals, in particular haematite, often gives the stone its distinct pink colouration which can, particularly when polished, appear in many shades through to dark red and maroon. The colouring together with the various greys and almost black, the spectacular fossils and the ability of the stone to take a polish have led to its extensive use for decorative work as 'Ashburton Marble'. This includes stonework in cladding and flooring as well as in monuments and memorials. The most common destination in the UK has been London where it has been used in the foyer of the Post Office Tower and in the bathrooms of the London Hilton. It is the only 'marble' recently produced in Britain and it was an important export, to South Africa, Hong Kong and particularly to the United States where it is seen in public buildings including the President Roosevelt Memorial. Local varieties from Petit Tor near Torquay and Ipplepen near Newton Abbot were also exploited as 'Torquay Marble'. The stone was cut by abrasives drawn by wires to prevent damage and rough handling by extraction with explosives. Polishing of the stone was

mainly carried out in Torquay. Sadly, no quarries working the 'marble' are active today and the local cutting and polishing industry can supply only imported stone.

In more recent years the bulk of the limestone extracted has been used in the manufacture of cement and for construction aggregates. Unfortunately the tendency for limestone to polish precludes its use for road surfacing but large tonnages are used in the foundations of roads and for drainage and for many other construction uses. Large limestone quarries support the built infrastructure in Devon from Moorcroft Quarry near Plymouth, Linhay Quarry at Ashburton and Stoneycombe Quarry near Newton Abbot.

On a much smaller scale the presence of iron minerals in the limestones, and the weathering products from them, have been of past importance for producing pigments. Umber, a brown form of haematite was formerly worked around Ashburton. It was used in paints, for making brown paper and in earlier times for colouring in woollen cloths. Iron ochre was also important for paint manufacture at Brixham where it was worked in open pits on Rea Hill. Red and brown haematite veins were also worked in the limestone at Sharkham Point, on the eastern side of Brixham; the softer material was used in the paint works whilst the harder mineral was sent to South Wales for smelting.

Although limestones generally form important aquifers the Devonian limestones are generally of low primary permeability due to the recrystallisation which occurred during diagenesis. Groundwater occurs only in joints and fissures and although common rocks around Torbay the limestones are only responsible for around 4 percent of the licensed water abstraction in this area. In Plymouth groundwater from the limestone was utilised in the nineteenth and early twentieth centuries for industrial and brewery use. However, due to pollution and saline intrusion from the sea there are currently no licensed abstractions.

2.4. PLACES TO VISIT

Please refer to the safety guidance about visiting geological sites on our website before visiting the places listed below.

Triangle Point, Daddyhole, Torquay

Location: A spectacular and accessible location to see the Devonian Limestone southeast of Torquay town centre off Meadfoot Sea Road.

Ordnance Survey 1:50,000 Sheet 202. National Grid Ref: SX 928 628

Description: The limestones around Triangle Point are exposed in cliffs, foreshore and quarry exposures. The limestones are downfaulted to the south by east-west faults. The steep southwest dipping beds form the inverted limb of a major fold which is overturned to the east-northeast. A number of highly fossiliferous horizons are present. The exposures at the northeast end of in the quarry include large bedding surfaces where a rich fauna appears to be in situ. 'Bun-shaped' stromatoporids, frequently intergrown with solitary corals are seen surrounded by branched tabulate corals. The latter appear to have acted as sediment traps for shell debris.

The coast at Daddyhole is dealt with in the 'Geology in Devon' booklet reference 18, page 26. and www.devon.gov.uk/geo-DAD.pdf. See also the Educational Register of Geological Sites; Torbay Site 5 (www.devon.gov.uk/educational_register.htm).

There is car parking on Meadfoot Sea Road, access is via the Promenade at SX 930 630. There is a beach café (seasonal) and toilet facilities.

Hope's Nose Torquay

Location: Devonian Limestone exposed in an abandoned quarry, accessed from Ilsham Marine Drive to the east of Torquay town centre.

Ordnance Survey 1:50,000 Sheet 202. National Grid Ref: SX 947 635 (access point)

Description: The end of Hope's Nose comprises Devonian Limestones and slates. In the former quarry, near sea level, fossils have been etched out by weathering from the abandoned quarry floor. The fossils are generally deformed – a result of their turbulent geological history, and include corals, crinoids, trilobites, bryozoa and brachiopods.

The beds are cut by thrust planes and the structure is picked out by tuff (volcanic ash) bands. Folded limestones can also be seen in the quarry walls.

The locality is famous for the occurrence of native gold although this is no longer visible due to over collecting of specimens.

The coast at Hope's Nose is dealt with in the 'Geology in Devon' booklet reference 20, page 28. www.devon.gov.uk/geo-HWH.pdf. See also the Educational Register of Geological Sites; Torbay Site 6 (www.devon.gov.uk/educational_register.htm).

There is car parking on Ilsham Marine Drive close to the access point with other facilities at Meadfoot Beach.

Both of the above sites are managed by Torbay Coast and Countryside Trust www.countryside-trust.org.uk and are sites with the English Riviera Geopark www.englishrivierageopark.org.uk.

Kents Cavern

Location: Devonian Limestone exposed in a cave system. In Ilsham Road, Wellswood, to the northeast of Torquay town centre.

Ordnance Survey 1:50,000 Sheet 202. National Grid Ref: SX 934 641

Natural caves formed in Devonian Limestone by water solution. Spectacular geology and cave formations in a location particularly famous for its significant prehistoric human finds as well as associated fossil remains of sabre toothed cat, mammoth and woolly rhinoceros.

The site at Kents cavern is dealt with in the 'Geology in Devon' booklet reference 19, page 27 and www.devon.gov.uk/geo-DAD.pdf. See also the Educational Register of Geological Sites; Torbay Site 7 (www.devon.gov.uk/educational_register.htm).

Kents Cavern is a scheduled Ancient Monument. The site is managed by Kents Cavern Ltd. See www.kents-cavern.co.uk for opening times and admission charges and guided tours. The site includes car parking and visitor facilities including a restaurant, shop and licensed bar.

2.5. PHOTOGRAPHS



Stromatoporid mound with sections through solitary corals in foreground - old quarry floor at Hopes Nose, Torquay. ©DW Allen



Broken corals weathering out from old quarry floor in Torquay Limestone Formation - at Hopes Nose, Torquay. ©DW Allen



Cliffs in Torquay Limestone (Daddyhole Member) with steeply dipping limestone beds, at Daddyhole Cove, Torquay. ©DW Allen



Moorcroft Quarry in Plymouth Limestone, east of Plymouth at Elburton. City Centre and Plymouth Sound far left. © Aggregate Industries



Sections through solitary corals and occasional brachiopods., at Triangle Point, Torquay. ©DW Allen



Ashburton Marble, used as a building stone at County Hall, Topsham Road, Exeter

3. DEVONIAN SLATES, SANDSTONES AND VOLCANICS

by Deryck Laming & David Roche



Hangman Grits – 'Old Red' sandstones of Devonian age exposed in sea cliffs along the north Devon coast near Martinhoe
© DJC Laming

3.1. BRIEF DESCRIPTION

Slates, sandstones and volcanics are types of rocks which form large parts of Devon. They date from a geological period which is called the Devonian period and are the oldest rocks found in Devon, formed about 400 million years ago when Devon was under the sea. Slates, sandstones and volcanics are found in south Devon from Torbay to Plymouth, and on Exmoor in north Devon.

Devon is unique as the only British county to give its name to be used and recognised worldwide as a geological time period and system of rocks – and Devonian age rocks are found in many other countries across the world.

Great thicknesses of rock were formed in Devonian times, during a period of continental collision and mountain building. This activity triggered lots of erosion, creating the sand and mud sediments which became deeply buried and turned into rock. Devon was at the centre of great dynamic activity which created the interesting variety of rocks we can find today, including slates, sandstones, limestones, volcanics and schists.

Life was fairly primitive in Devonian times. Fossil records in Devon include fish, corals and other sea life.

(Devonian Limestones and Devonian Schists are described in separate sections)

3.2. GEOLOGICAL DETAIL

Large parts of Devon are founded upon old rocks, mainly slates, sandstones and limestones of the Devonian system, that have been hardened by pressure from deep burial and tectonic earth movements. They are the oldest rocks in the county, formed between 416–359 million years ago (the time interval known as the Devonian Period),

and underlie two large parts of the county, the Exmoor area in north Devon and south Devon between Torbay and Plymouth.

The Devonian rocks take their name from the county, and this is the only county name to be used and recognised worldwide for a geological system. The name was chosen in 1840 by two distinguished geologists: Revd Adam Sedgwick of Cambridge University and Sir Roderick Murchison, later to become the Director of the Geological Survey, who realised that the rock strata seen in the Exmoor area and across south Devon were older than the coal-bearing Carboniferous rocks of South Wales and the Midlands, but about the same age as the underlying Old Red Sandstone that was widespread in those areas.

For more than 100 million years there was a vast process of mountain building over South West England – during the *Devonian* and *Carboniferous* periods (about 400 to 300 million years ago) and into the early *Permian* period. Caused by the collision of moving plates of the Earth's crust – known as '*plate tectonics*' or '*continental drift*' – deep troughs (or basins) formed below the narrowing sea and received vast volumes of sediments from the erosion of the nearby continents – from land to the north (Wales and North America) and to the south. The sand and mud sediments became deeply buried and turned into rocks, which were then folded and contorted and thrust up into mountains by the dynamic collision of the continental plates. This continued for over 100 million years, during which many kilometres thickness of rocks were formed (slates, mudstones, sandstones, etc). Great reefs of limestones formed along shallow sea ridges and there were also large volcanoes producing volcanic rocks (basalts, tuffs) and sills of dolerite. Later, molten granitic magmas were created deep beneath the mountains to form the granites of Dartmoor and Cornwall. This long period of earth movements and mountain building is known as the 'Variscan Orogeny'. It created a range of mountains across modern South West England (similar to the modern Alps, Atlas and Rockies), extending from eastern Europe to North America.

Exmoor has high ground and steep coastal cliffs largely because of the very hard sandstone layers in the sequence, formed as delta deposits at the mouths of rivers flowing down from the Welsh mountains. Between these layers lie slates and other deposits, including limestone. Slates are common in south Devon, together with reefal limestone masses and some volcanic rocks.

An interesting feature of the Devonian sandstones of deltaic and lagoonal origin is the fish fossils they contain; most had armoured heads as protection against predators. Some of these were primitive and jawless but others had well-functioning jaws. The evolution of the jaw was a most significant and valuable development to vertebrates, and it took place in Devonian times.

A gap in the Devonian outcrop between north and south Devon, of at least 35km, exists because of the overlying Carboniferous (Culm) outcrop, where a deep trough of these younger rocks hides the Devonian. So there is some uncertainty about the nature of the submerged rock strata, and correlation of northern with southern strata is also incomplete.

In north Devon, the sandstones in the Exmoor area are similar to the Old Red Sandstone in Wales, having been deposited in deltas of rivers draining from the Welsh mountain ranges. These flowed across the area where the Bristol Channel now lies, and emptied into a sea that covered most of Devon, part of the much-larger Rheic ocean (now lost due to plate movements). The rivers dropped their sediment load at the coast so that deltas built out southward – creating the thick sandstone deposits of Exmoor, now hardened by time and uplifted by earth movements to form the upland areas. They commonly have a reddish-brown colour caused by tropical weathering in the climate where they were

formed. These are the Hangman Grits, the Pickwell Down Sandstone and the Baggy Sandstone, rock units that were named after the prominent coastal features they create. Being of deltaic origin, these rock formations contain no marine fossils, but fresh-water fish have been found at several levels. The Ilfracombe Slate Group, containing several formations including sandstone and limestone beds, overlies the Hangman Grits, and is in turn overlain by the greenish-grey Morte Slates. With a few interbedded sandstones, these are resistant enough to form the headland of Morte Point. The Pickwell Down Sandstone is another deltaic deposit, and underlies the moorland of its name south of Morte Bay, creating the prominent Baggy Point, which also includes the Upcott Slate and the Baggy Sandstone. The outcrops of these formations extend eastward along the Exmoor upland, disappearing beneath Permian rock strata in Somerset, but reappear in the Quantock Hills where a large fault lifts them up to surface again.

In south Devon, slates are widespread, formed by earth pressures on marine mud deposits, and great thicknesses are present in some areas. The oldest rocks in this area are the distinctive red, green and purple Dartmouth Slate, which forms a wide band of Lower Devonian rocks across the South Hams from Dartmouth to Plymouth. Within the slate are a few beds of sandstone and conglomerate that are similar to the Old Red Sandstone, so at that stage deltas from the north may have extended this far south. Above the slates, the Meadfoot Slate and Staddon Grit are prominent, the latter forming hills because of its hard sandstone beds. Higher still are the Norden Slate and Gurrington Slate, the former having important limestone deposits with abundant reef-type fossils, mainly corals and algae, in the Torquay and Plymouth areas. Britain had a tropical climate during the Devonian, as it then lay south of the equator.

Devonian rocks also form the hard schistose rocks of the Start–Bolt coastal ridge on the south coast, which are dealt with separately. Devonian limestones are also dealt with separately.

3.3. USES

The predominant use of Devonian rocks is quarrying for limestone and other rocks for aggregate use, and limestone was formerly used for cement production. Limestone has been extensively used as building stone in areas near outcrops, and likewise the sandstones of the Staddon Grit and those of the Exmoor area. In earlier times the distance of transport was a significant cost factor, so local deposits were usually preferred. Igneous volcanic rocks occur among the Devonian slates, especially basalt, and these are also utilised as roadstone.

Devonian sandstones and slates in the past have been extensively used for local building stones with characteristic red or grey sandstones present in many villages.

Gritstone quarries were important local sources of aggregate and roadstone. Quarries in important dolerite outcrops were worked in south Devon.

In south Devon around Kingsbridge, there were important quarries for roofing-slates which were exported to other parts of Devon.

Silver and lead mining was a flourishing local industry in the Combe Martin district in the latter half of the nineteenth century.

3.4. PLACES TO VISIT

Please refer to the safety guidance about visiting geological sites on our website before visiting the places listed below.

Lynmouth [NGR SS 728 496 – 735 495]

The shoreline section east of Lynmouth shows strongly cleaved slates of Lynton Slates which, at the eastern end, are faulted against the Hangman Grits.

Combe Martin [NGR SS 578 473]

The shoreline east of Combe Martin shows Ilfracombe Slates including prominent sandstones and shelly limestones. Along the shoreline west of the beach, the Combe Martin Beach Limestone is seen within the Combe Martin Slates.

Croyde [NGR SS 430 397]

The rocky foreshore westward from Croyde Bay exposes Lower Pilton Shales with fossil brachiopods, and a thin band of volcanic ash is visible (at SS 433 396).

Hope Cove, Outer Hope [NGR SX 675 402]

Meadfoot Slates outcrop on the northern side of the cove with numerous quartz veins. On the south side of the beach bands of grey mica schist are present marking the northern boundary fault of the Start Point Complex.

Meadfoot Bay, Torquay [NGR SX 936 633]

Meadfoot Slates are exposed east of the beach with numerous sedimentary structures, and fossils (brachiopods, bivalves and corals) occur in thin calcareous sandstones.

3.5. PHOTOGRAPHS



North dipping interbedded sandstones and shaly mudstones of the Pilton Shale Formation at Bray Valley, north Devon © DJC Laming



Ripple marks on slabby sandstone bedding indicating intertidal sedimentation conditions, at Bray Valley, north Devon. © C Nicholas



Dartmouth Slates in sea cliffs at Blackpool Sands, near Dartmouth, south Devon. © DP Roche



Folded strata and caves in the Hangman Grits at Trentishoe on north Devon coast. © DJC Laming



Purple and green - characteristic colours of the Dartmouth Slates. © DP Roche



Devonian slates steeply dipping into the estuary at Newton Ferrers, south Devon. © PC Stephenson

4. CARBONIFEROUS SANDSTONES AND SHALES

by Deryck Laming & David Roche



Zig-zag folding in Carboniferous sandstones and shales – at Hartland Quay, north Devon

© DP Roche

4.1. BRIEF DESCRIPTION

Sandstones and shales, which date from a geological period called the Carboniferous, underlie much of Devon. These rocks are not easy to see except along the Atlantic coast and in small old roadside quarries. An extensive strip of Carboniferous rock forms a broad band across central and north Devon, and also around the flanks of Dartmoor.

The Carboniferous rocks across Britain are so named because they contain coal, which is a rock rich in a mineral called carbon. In Devon, no economic coal was found because the sediments were laid down in a sea, instead of in tree-choked swamps where more commercial coal forms. The rocks in Devon are dominantly marine shales and sandstones.

Great thicknesses of rock were formed in Carboniferous times, during a period of continental collision and mountain building (known as the Variscan Orogeny). Devon was at the centre of great dynamic activity which created its interesting variety of rocks.

Spectacular zig-zag patterns in the Carboniferous rocks can be seen along the Atlantic coast - at Hartland Quay, and at places inland. This illustrates how the rocks were crumpled and contorted by the collision of crustal plates, and thrust up into mountains.

Between the layers of sandstone and shale, other types of rock can be seen. Limestone is present in northeast Devon, and sparingly in other places. Lavas from volcanoes and layers of volcanic ash are common within the shales, and other igneous rocks also occur.

4.2. GEOLOGICAL DETAIL

The extensive outcrop of Carboniferous strata across central Devon used to be known as the Culm, a term that is still used today in 'the Culm grasslands'. The name derives from the sooty coal that was mined in a few adits near Bideford in the nineteenth century.

Consequently the name 'Culm Measures' was formerly applied to the sandstone and shale sequence in which it was found, being roughly equivalent to the Coal Measures found in South Wales.

Carboniferous strata were deposited between about 360 to 300 million years ago, following on over the older underlying Devonian rocks. In South Wales, the Midlands and Northern England and Scotland, and across Europe, the Carboniferous strata was characterised by the occurrence of large coal deposits of economic importance. Coal Measures were found in the upper parts, with the Millstone Grit and Carboniferous Limestone beneath. However, the coal seams that were the foundation of Britain's wealth in the nineteenth century were absent from Devon, so the county therefore failed to benefit from the mineral wealth.

In Devon, despite careful searching in the early days, no economic coal was found, because the sediments had been laid down in a sea instead of in tree-choked coal swamps. Here the succession is dominated by marine shales and sandstones, in several formations that are quite similar to each other. Moreover, spectacular folding of the strata can be seen on the west coast and at places inland. Limestone is present in northeast Devon, and sparingly in other parts. Basaltic lavas and layers of volcanic ash are common within the shales, and other igneous rocks, mainly dolerite, are also found.

A large part of central Devon is underlain by Carboniferous strata, predominantly hard grey sandstone layers with grey shale in between, which are intensely folded along east-west trends. The outcrop, up to about 45km wide, extends eastward from the Atlantic coast in a broad band as far as Exeter and Tiverton, where it disappears beneath Permian red beds. On the west coast, the cliffs show a spectacular series of folds trending east-west, mainly upright and including some V-shaped and zig-zag folds, the result of the Variscan earth movements that began in the Devonian and lasted until the Permian.

In Carboniferous times, coals were formed in swamps in South Wales, with massive deltaic sandstones and shales interbedded with the coal seams. But the sandstone and shales of the Devon area look very different – in the early days of geology, this caused much uncertainty and dispute as to their relative age. Ultimately it was realised that rivers flowing from the Welsh mountains formed deltas and delta swamps on its southern continental margin. The sea into which they flowed lay where Devon now is, with fine sediment carried down by the rivers settling on the sea floor as shales. Sand from the deltas periodically swept down to deposit layers up to 1m thick over a wide area – these sandstones are often termed greywackes. These rapid flows of intermixed sediment and water are called turbidity currents because they were carried in turbid water. Evidence of the violence of the flow can be seen on the undersides of the sandstone layers as ripples, vortices and grooves caused by the ripping-up of the muddy sea bed as the overlying sand was deposited; and as the sand hardened to rock, these features were preserved as casts.

For more than 100 million years there was a vast process of mountain building over South West England – during the Devonian and Carboniferous periods (about 400 to 300 million years ago) and into the early Permian period. Caused by the collision of moving plates of the Earth's crust – known as 'plate tectonics' or 'continental drift' – deep troughs (or basins) formed below the narrowing sea and received vast volumes of sediments from the erosion of the nearby continents – from land to the north (Wales and North America) and to the south. The sand and mud sediments became deeply buried and turned into rocks, which were then folded and contorted and thrust up into mountains by the dynamic collision of the continental plates. This continued for over 100 million years, during which

many kilometres thickness of rocks were formed (slates, mudstones, sandstones, etc). Great reefs of limestones formed along shallow sea ridges and there were also large volcanoes producing volcanic rocks (basalts, tuffs) and sills of dolerite. Later, molten granitic magmas were created deep beneath the mountains to form the granites of Dartmoor and Cornwall. This long period of earth movements and mountain building is known as the 'Variscan Orogeny'. It created a range of high mountains across modern South West England (similar to the modern Alps, Atlas and Rockies), extending from eastern Europe to North America.

The older Carboniferous strata, transitional from the underlying Devonian, include chert beds, which are flinty deep-sea deposits, interbedded with dark shale. Thin beds of limestone are also present, and the sequence is known as the Meldon Chert Formation at Meldon Quarry, near Okehampton, with shale, quartzite and volcanics. These extend in a curving outcrop around the north margin of the Dartmoor Granite, apparently shouldered aside by the granite as it intruded the surrounding rocks. In north Devon the equivalent sequence is the Codden Hill Chert, which overlies the Pilton Shale which also is transitional from the Devonian. Limestones at Westleigh and Bampton, in the northeast of the county, also belong to the early Carboniferous and are about the same age as the famous shallow-water Carboniferous Limestone of Wales, the Mendips and central England, though in Devon the limestones were deposited in deeper water.

Above these basal sequences, alternating beds of sandstone and shale characterise most of the Carboniferous sediment thickness in Devon. It is possible to divide these into three major formations, named after localities on the west coast but widespread across the county. These are, in ascending order, the Crackington, Bideford and Bude formations, although there is some overlap between the last two. The Crackington shows abundant evidence of deep-water deposition, with extensive turbidity marks on the undersides of sandstone beds, but the other two formations show evidence of being deposited in shallower seas or lakes, the Bude Formation in particular showing massive sandstone beds with some slumped sediment that might have been caused by earthquake shocks affecting loose sediment. The presence of ripple marks suggests an intertidal or lacustrine environment, and there are also many arthropod trails, made by primitive lobster-like or crab-like creatures.

Away from the main outcrop in north and central Devon, Carboniferous rocks are also found to the east and west of Dartmoor in what are often referred to as the Southern Successions. Pebbles of igneous rocks and volcanic ash occur in the lower parts of these successions, indicating a source to the south, and coarser to conglomeratic beds higher up are called the Ugbrooke Sandstone which contains pebbles with Lower Carboniferous fossils – indicating that some tectonic activity was occurring to the south at the time, eroding recently-deposited sediments.

There was a complex history of igneous activity in south Devon, with lava flows and thick accumulations of volcanic ash, together with dykes and sills, notably in the Teign Valley. Thick ash deposits together with dolerite dykes are found at Meldon Quarry, where they are utilised for railway ballast and various grades of aggregate and roadstone. This area was also affected by the Dartmoor Granite, that heated the adjacent rocks as it cooled in the late Carboniferous/early Permian.

4.3. USES

With an abundance of hard sandstones and tough igneous rocks, the Carboniferous is one of the most important geological units in Devon for useful rocks. Sandstone quarries include Venn in north Devon, while Meldon Quarry supplies very hard hornfels rock and

chert, that have been baked by the thermal metamorphism of the nearby granite. Dolerite is quarried in the Teign Valley and limestone comes from near Bampton and Westleigh in the northeast of the county.

In very many smaller quarries worked in the past, building stone and roadstone were won by older methods, and many of these can still be seen beside the roads or settlements they helped to construct. For geologists these remnants are valuable, allowing observation and measurement of the strata or igneous rock types that would otherwise be covered over by soil.

The present utilisation of Carboniferous rocks is mainly confined to exploitation of the harder sandstone bands, which are crushed for aggregate and roadstone, and dolerite and limestone where they occur. In former times they were extensively used for building houses, walls, bridges and churches, most of them still in use today because of the durability of the stone

4.4. PLACES TO VISIT

Please refer to the safety guidance about visiting geological sites on our website before visiting the places listed below.

Hartland Quay [SS 224246]

The spectacular cliffs north and south of the quay show massive sandstone beds with interbedded shale of the Crackington Formation, all of it being spectacularly folded by Variscan earth movements. Close examination of the sandstones shows many features formed by rapid turbid flows of intermixed sediment and water, where the underlying sea-bed muds were ripped and gouged by the currents, now preserved as casts in the underside of the sandstone beds.

Hartland Quay is on the SW coast path and there is ample car parking.

Meldon Quarries, Okehampton [SX 566923]

Hard ballast and aggregate have been worked here for railway use for many years, and slate, quartzite, chert and dolerite are present. Being less than 1km from the margin of the Dartmoor Granite, they have been affected by the thermal metamorphism effects of the cooling granite, with some interesting minerals being found.

There is no public access to the working quarry (unless by prior private arrangement only), however there is access by public footpath to the adjacent Meldon Rock Park which exhibits boulders of the variety of rocks in the quarry, and also nearby exposures of the geology of the Meldon area. Foot access may be gained from the Granite Way cycleway and footpath, and there is car parking nearby in the Okehampton Hamlets car park.

Bonhay Road, Exeter [SX 914927]

Interbedded sandstone and shale beds of the Crackington Formation can be seen in this ancient river cliff, but are best seen from the opposite roadside. Sandstone beds up to 1m thick alternate with shale, and all have been deformed into a near-vertical position by the Variscan earth movements. The site is a Site of Special Scientific Interest (SSSI).

Bickleigh Wood Quarry [SS 945179]

Thick beds of sandstone of the Crackington Formation can be seen in the old quarry, on the east side of the A396, near a lay-by. These were formed in deep water by turbidity currents, and many features of this type of deposition can be seen in this quarry, which is well-known for the scour marks and flute marks seen on the underside of the sandstone beds. Some soft-sediment slumping can also be found. The site is a Site of Special Scientific Interest (SSSI) and is protected by law – do not use a hammer or remove any specimens.

4.5. PHOTOGRAPHS



Interbedded sandstones and shales with zig-zag folds - in cliffs south of Hartland Quay. © DP Roche



Bonhay Road, Exeter (a SSSI) – an old river cliff exposure. © DJC Laming



Black chert bands formed of silica from marine sponges, in the Westleigh Limestone and used in buildings. © SJ Parkhouse



Shales with fissile cleavage and bedding, north Devon. © C Nicholas



Folded Carboniferous Limestone strata at Westleigh Quarry, near Burlcombe, east Devon. Shallow sea limestone debris washed down to deep sea by turbidity currents. © SJ Parkhouse



Thick beds of sandstone with thin interbeds of shale - typical of the Carboniferous in Devon. © C Nicholas

5. DARTMOOR GRANITE

by Clive Nicholas



Haytor Rocks – a classic Dartmoor Granite Tor

© Clive Nicholas

5.1. BRIEF DESCRIPTION

Granite is a type of rock which forms the surface and underlying ground of most of the high moorland of Dartmoor. It is a hard, strong, tough, durable and long-lasting material.

Dartmoor Granite formed from a molten rock (known as magma) which was once at very high temperatures several kilometres deep in the earth in the core. As the magma rose through the earth's crust it gradually cooled and slowly solidified into the attractive coarsely-crystalline rock we see today.

This process of rock formation happened about 300 million years ago below the earth's surface. In the following few million years the rocks above the granite were eroded away exposing the granite at the earth's surface where we now see it in the characteristic 'Dartmoor tor'. A 'tor' has a range of definitions, but generally refers to a rock outcrop formed by weathering, usually found on or near the summit of a hill.

Use of the Dartmoor Granite as a building stone dates back to the Bronze Age 4000 or more years ago. Remains of old mine workings for veins of tin, copper, etc within the granite are scattered throughout the moor. The valuable china clay deposits of southern Dartmoor result from alteration of the granite in later stages of cooling when it was initially formed.

A classic symbol of Devon, Haytor is one of the most visited locations on Dartmoor and it is probably the most easily accessible of the large Dartmoor tors. A short walk up the grassy slopes from car parks and bus stops alongside the road leads to the rocks. The panoramic views from around the rocks are well worth the walk and at the same time you can look at the 300 million years old granite. Boulders of the granite can also be seen in walls and loose blocks near to the road.

5.2. GEOLOGICAL DETAIL

Have a closer look at the granite (see Photo DG 1). It is a rock made up of several different minerals. Most obvious are the large milky-white crystals (known as phenocrysts) of the mineral feldspar, up to about 8cm in length and rectangular in cross section. Surrounding these is a matrix of smaller crystals including some more white feldspar, quartz with a clear to grey, glassy appearance and some dark brown, nearly black, shiny mica. Some varieties of the granite do not have the phenocrysts.

The 250 sq miles area of the Dartmoor Granite is shown in bright red on the accompanying geological map and key. ([link to map](#)) The Dartmoor Granite is connected at depth with the other granite masses of Cornwall, altogether forming an enormous granite intrusion known as a batholith. Heat from this mass of molten rock, at a temperature approaching 1000° C, altered surrounding rocks for several hundred metres beyond the margin, forming a metamorphic rock known as hornfels.

Shrinkage in the cooling granite led to the formation of cracks - 'joints', as geologists call them. More joints developed and were opened by stress release as the weight of the overlying rocks was removed. These joints, further widened by weathering, are seen in the cracked and broken shapes of the tors visible today.

In the final stages of cooling, residual fluids and gases condensed and crystallised in a process known as hydrothermal (water and heat) to form the economically valuable mineralisation of tin, copper and many other spectacular minerals of the southwest England ore field. The Dartmoor mines are no longer worked but remains of old workings are seen in many places. The valuable deposits of china clay (kaolin), worked on a large scale on the southern edge of Dartmoor north of Ivybridge, were formed in the granite by similar processes, later modified by weathering and water circulation in the ground.

About 50 million years ago, in the geological period known as the Eocene, the climate of Devon was especially hot and humid. In this environment the granite of the surface of Dartmoor was intensely weathered, forming the unusual shapes of the tors seen today.

The valuable ceramic clay seams known as ball clays, found in the low-lying ground of the Bovey Basin, were formed at that time. Fossils of tropical plants are found in the clay workings around Kingsteignton.

For about the last 2 million years Britain has mostly been in the grip of 'ice-age' conditions, interspersed with shorter but generally warmer 'interglacial' periods ([link to Quaternary section](#)). Seasonal freezing and thawing of Dartmoor created the boulder fields, or clitter, surrounding the tors and the cover of gravelly, broken-up granite, known as 'head' or 'growan'. Much of the soft soil and weathered rock was stripped away leaving the granite tors of the Dartmoor landscape standing proud above surrounding areas.

The human influence on the landscape has occurred during the more benign climate conditions - an interglacial - in the comparatively short time since the latest ice sheets retreated just over 10,000 years ago.

5.3. USES

Dartmoor has been inhabited by humans for several thousand years. Solid evidence for early habitation in the form of granite structures such as stone burial chambers are believed to date back to the early Neolithic ranging from about 4000-2000 BC when Dartmoor's climate appears to have been milder than it is today.

Dartmoor is particularly notable for its upstanding prehistoric remains, domestic, agricultural and ritual, dating from throughout the prehistoric period. There are many examples of late Bronze Age settlements on the moor in the form of 'round houses', mostly dating back as far as 1000 BC, possibly earlier. Most of the granite was probably obtained as loose blocks from the ground surface but it would appear to have been in great demand for shelter, no doubt supplemented by wood and other vegetation for the round-house roofs, for which little evidence remains.

The ancient stone crosses and clapper bridges made of large blocks of granite appear to date from mediaeval times when travelling routes across the moor were developed for communication between the abbeys.

Granite is so tough that it was difficult to work before iron tools were available, but throughout the high moorland can be seen loose, partly shaped, stone blocks known as 'moorstone', some with clear evidence of attempts at splitting and shaping the stone by means of 'feather and tare'. This involved drilling small shallow holes in a line along a granite block and splitting it with wedges, hammer and chisel. This was the start of using the granite as a shaped building stone for widespread use, especially houses, but also everyday rural items such as gateposts, drinking troughs, headstones, etc. Granite from the Haytor quarries was used, in part, to construct the former London Bridge and much of the rest of the stone appears to have come from Dartmoor quarries near Princetown. Quarrying of Dartmoor Granite was then an important source of employment in the local economy. The Dartmoor Prison at Princetown was, of course, built with Dartmoor Granite.

Quarrying of Dartmoor Granite progressively reduced in the last century, now it is insignificant and sources of Dartmoor granite for building restoration are now scarce.

Also now closed are the metal mines of tin, copper, lead etc which were another mainstay of the Dartmoor economy in years past. Interestingly, there is now renewed interest in reopening a large scale tungsten-tin mine in the granite at Hemerdon on the south western edge of Dartmoor just outside the National Park boundary and this, if it proceeds, could bring a significant boost to the local economy and secure European supplies of this essential metal.

The china clay works in the same area continue to be important in the local economy and in markets both national and international. China clays and the related ball clays of Bovey (together the kaolin minerals) supply the paper, ceramics, plastics and numerous other industries that are now essential parts of our modern society.

5.4. PLACES TO VISIT

Please refer to the safety guidance about visiting geological sites on our website before visiting the places listed below.

Two Bridges Quarry

Location: On Dartmoor, a small disused roadside quarry and car park north of the B3212/B3357 road at Two Bridges near Princetown.

Ordnance Survey 1:50 000 Sheet 191, National Grid Ref: SX 609 751

Description: The small disused quarry is often visited by student parties studying the granite and its alteration to china clay by hydrothermal and weathering processes

(see Photo DG 3). The car park is convenient for moorland walking alongside the West Dart River with examples of prehistoric round-house settlements built of local granite.

Burrator Quarry

Location: 3km east of Yelverton on the south-western edge of Dartmoor
Ordnance Survey 1:50 000 Sheets 201/202, National Grid Ref: SX 549 677

Description: This small disused quarry, with car parking, features one of the few known exposures of the contact between the Dartmoor Granite and the surrounding country rock – in this case Devonian slates altered by heat of the granite to hornfels (see Photo DG 2).

Around Burrator Reservoir, this beautiful area offers many opportunities for country walking and cycling, and of course to look at the geology and landscape and the dam constructed of concrete and granite blocks faced with dressed granite.

An informative book 'The evolution of a Dartmoor landscape – exploring Burrator' by Peter Keene, is available in full at <http://www.dartmoor-npa.gov.uk/au-burrator.pdf>

Haytor Quarries and Granite Railway

Location: On Dartmoor alongside the B3387 Bovey to Widecombe road.
Ordnance Survey 1:50 000 Sheet 191, National Grid Reference: SX 766 771

Haytor is described in the Introduction. Have a look at some of the old Haytor quarries to the north of the tor where the granite was worked for building stone. The unique Granite Tramway was used in the mid-1800's to transport the stone from the moor to Teignmouth and sent for use in London's buildings and elsewhere. See Photo DG 4 and www.devon.gov.uk/templerwayleaflet.pdf.

Widecombe-in-the-Moor

Location. A well known village in the heart of Dartmoor about 6 miles east of Bovey.
Ordnance Survey 1:50 000 Sheet 191, National Grid Ref: SX 718 768.

Description: Widecombe has much to offer the visitor but in this context the interest is in the old buildings made of Dartmoor granite. The large and splendid granite church is known as 'The Cathedral of the Moor' (see Photo DG 5). The high ground to the west is Hameldown with a fine circular walk, following in part the Two Moors Way and passing several old stone barrows (burial mounds) and a fine old stone wall. See Photo DG 6 and www.widecombe-in-the-moor.com/about.php.

5.5. PHOTOGRAPHS



Close-up view of Dartmoor granite crystal texture. 20p coin for scale. Photo DG1. © Clive Nicholas



Burrator Quarry - contact of Dartmoor Granite at right side with slaty hornfels at centre/left. Photo DG2. © Willem Montagne



Explaining china clay origin and weathering in the Dartmoor Granite – at Two Bridges Quarry. Photo DG 3. © Clive Nicholas



Haytor Granite Railway, with its rails made of Dartmoor Granite. Photo DG4. © Clive Nicholas



Widcombe Church. Built with Dartmoor Granite. Photo DG5. © Clive Nicholas



A high moorland Dartmoor Granite dry-stone wall, at Hameldown, near Widcombe. Photo DG5. © Clive Nicholas

6. PERMIAN BRECCIAS, SANDSTONES AND VOLCANICS

by Deryck Laming & David Roche



Dawlish Sandstones well exposed in cliffs alongside the mainline railway and seawall at Dawlish

©DW Allen

6.1. BRIEF DESCRIPTION

Breccias and sandstones are types of rocks which are found in Devon dating from a geological time named the Permian period. Both these types of rocks are generally known as sedimentary rocks. Sedimentary rocks form when material or sediment is deposited and compacted to form a rock. Breccias get their name from the definition of the word 'breccia', which means rubble. The rock of this type found in Devon is formed of angular gravels. Sandstone is a rock which is formed of sand grains which are compacted and cemented together. Both the breccias and sandstones seen in Devon were formed in tropical desert conditions between about 250 and 300 million years ago.

The Permian red rocks were deposited as gravels and sands, formed by erosion of high mountains to the west, which had been created by earth movements following the continental collision in the preceding Carboniferous geological time period.

Deep canyons led eastward from the mountain flanks down to a large desert plain over east Devon and beyond. Occasional storms in the uplands sent flash floods down the canyons, carrying large amounts of loose rock, sand and mud, and large fans of gravelly sediment were laid down. Sand grains were picked up by the wind from these deposits and were blown into sand dunes.

The Permian red rocks in Devon are overlain by the red mudstones, pebble beds and sandstones of the following Triassic geological time period; together these red rocks are known as the New Red Sandstone.

Permian rocks are found in south and east Devon, from Torbay to Exeter and north into Somerset. The sequence of red breccias and sandstones is magnificently displayed along the railway line and sea wall at Dawlish and Teignmouth.

Volcanoes were active in Permian times in the upland areas and at other localities in the vicinity of Exeter, where the remains of the volcanoes can still be seen. Lava flows are found in layers within the Permian sedimentary strata.

Permian red rocks, in particular the stronger and more durable breccias, are used as local building stones and there are many fine examples in the city of Exeter with its famous Heavitree Breccia.

6.2. GEOLOGICAL DETAIL

Permian strata form the lower part of the New Red Sandstone – ‘new’ because it is younger than the Old Red Sandstone rocks of Wales, Northern England and Scotland (see Devonian). While nearly all of it is red, not all is sandstone, as there are coarser conglomerates (with rounded pebbles) and breccias (with angular fragments), mudstones and locally hard lime-cemented stone suitable for building.

The famous red soils of Devon are mainly caused by weathering of the underlying red rocks, and can be seen over wide areas, even where a cover of red rocks used to lie before being removed by erosion.

There are many places, mostly on the south and east coast of Devon, where the sequence of red rocks is magnificently displayed, especially along the railway and sea wall at Dawlish and Teignmouth.

Permian red rocks were deposited as gravels and sands in a desert situation, at a time when Britain lay close to the equator between 299 and 251 million years ago. They were formed by intense erosion of mountains created by the vast earth movements that happened in the preceding Carboniferous times, when large mountains formed over the area of Dartmoor.

Deep canyons led eastward from the flanks of this upland down to a large desert plain that stretched from there through east Devon into Dorset and across where the English Channel now is – it was then all flat desert over to France. Being hot desert, there was little rainfall, but occasional storms in the uplands sent flash floods down the canyons, carrying large amounts of loose rock, sand and mud.

The floods fanned out as soon as the plain was reached, the water seeped down into the porous gravel and large fans of alluvial material, mainly gravel, were laid down. Known as breccias the layers so formed are seen now as cemented gravel beds up to a metre in thickness. The red breccias seen in the sea cliffs of Torbay, Teignmouth and Dawlish are good examples. In some cases, the breccias alternate with red sandstone layers that were formed by lesser stream flows and by water draining out of the fan edges.

Sand grains picked up by the wind from these gravels were blown into sand dunes, which also were washed into alluvial sand deposits. The prevailing wind direction can be deduced from careful measurements of bedding in the old sand dunes, now seen in the cliffs, and it was generally from the southeast confirming other evidence that Britain was then in the climatic zone of the trade winds, the present latitude of most of today's world deserts.

Volcanic rocks were erupted in Permian times, and basalt lava flows are interbedded with the sedimentary strata. These volcanic rocks were formerly known as the Exeter Traps. The age of these rocks is close to that of the Dartmoor Granite so they probably were related. One of the most important eruptions formed a volcanic cone at Rougemont in Exeter, where King William the Conqueror built Exeter Castle of this tough but difficult stone. Other buildings have used this and other volcanic stones, taken from the several Permian volcanoes and lava-fields still present within the red sedimentary strata, including Killerton to the north of Exeter.

A succession of different deposits can be recognised in the Devon coast section, and the thick Oddicombe Breccia is first seen north of Torquay in the cliffs of Oddicombe Beach. This is composed of white limestone pebbles in a red sandy matrix, and the lime cement makes it a hard material which forms high cliffs, such as at Watcombe Heights. Traced north along the shore to Shaldon, however, other strata become visible, overlying the limestone-rich breccias. These are part of the Teignmouth Breccia, which have fragments predominantly of quartzite and a distinctive quartz porphyry, a volcanic rock that probably formed over the Dartmoor Granite, though now completely eroded away, and boulders of it are now found only in the red breccias.

The cliffs towards Dawlish show more of these breccia strata, and just south of Boat Cove large beds of sandstone, sand-dune deposits, are found in the cliffs, one being more than 20m thick. Sand dunes are seen in the cliffs north of Dawlish, forming the Dawlish Sandstone, dipping gently northward and with an increasing proportion of breccia beds, towards the prominent headland of Langstone Rock. Sand deposition had ceased when this formation was laid down, a large alluvial fan that swept south-eastwards from the mountainous region west of Exeter, to form the Exe Breccia – the highest stratum before the start of the Triassic.

Further north, inland, Permian breccias and sands can be traced to beyond the border with Somerset, one important formation being the Heavitree Breccia, similar to the Teignmouth Breccia, quarried extensively for building stone for the city of Exeter up until the 19th Century. Many city churches owe their character and their colour to this stone, though weather and frost have caused some degradation since. The great church at Crediton, and others in mid Devon, are built of similar rocks.

A long tongue of red rocks, including some volcanics, extends westward in the Crediton area, showing as an orange strip on the geological map. This is the result of deposition in a valley created by faulting – the Crediton Trough - which gradually filled in with red breccias and sandstones. A flurry of excitement seized the area a few years ago when small amounts of gold were discovered in the volcanics and associated sediments, but no gold mining has yet been attempted.

6.3. USES

The Dawlish Sandstone (desert sand dunes) is quarried near Exeter on a small scale for use as building sand. Its origin as wind-blown dunes is attested by the sweeping curved bedding planes reflecting the surface form of the dunes. The sand is only weakly cemented so can be dug cheaply with an excavator, but its use is diminishing with more stringent specification requirements. Nearby, the sands give their name to '*Sandy Park*', home ground of the Exeter Chiefs Rugby Club.

Below the Dawlish Sandstone, the Heavitree Breccia once provided large amounts of building stone for Exeter's churches and public buildings, as well as some old walls and farm buildings. Carefully chosen, it could be very durable, but much of it was vulnerable to frost disintegration and when more durable stone became available, it was not generally used except for repair work, and is only now obtainable from demolished buildings.

Pottery clay was derived from the Watcombe Breccia north of Torquay, where the weathered slaty material within it produced the traditional red-brown Watcombe Pottery up until the 1960s, famous for its Devon dialect "motto" inscriptions.

6.4. PLACES TO VISIT

Please refer to the safety guidance about visiting geological sites on our website before visiting the places listed below.

Waterside (Oyster) Cove, Goodrington [SX 895587]

Here the red breccias can be seen overlying the older rocks of Devonian age, the junction being called an 'unconformity'. The breccias, of probable early Permian age, were the first to be deposited in this area, and the limestone pebbles within them were eroded from a nearby limestone mountain to the south, and were laid down over a bare rocky landscape by a storm-driven flash flood.

Roundham Head, Paignton [SX 896598]

The easily-accessible south side of the headland shows *Tor Bay Breccia* of early Permian age, consisting of fragments of limestone, quartzite and some igneous rocks in a sandy matrix, with a layer of wind-blown sand seen best at the eastern end (difficult access) which indicates a northeasterly wind.

The Ness and Ness Beach, Shaldon [SX 939718]

Here the Oddicombe limestone-fragment breccias thin out and become interbedded with other breccias derived from a different source area. Together these are known as the Ness Formation. The other sources are was evidently the Dartmoor upland, where erosion had begun to cut down into the deep-seated granite, and where large amounts of volcanic rocks had been formed. Boulders of these rocks, mainly porphyry, can be found on the foreshore under the Ness headland, and further south along the beach the cliff-face shows intriguing vertical sand dykes, possibly caused by contemporaneous earthquakes.

Coryton Cove, south of Dawlish [SX 961761]

Shows the upper strata of the *Teignmouth Breccia* in the cliff and foreshore, and the lowest part of the *Dawlish Sandstone* in the cliff behind the railway line (inaccessible but can be viewed easily). The *Teignmouth Breccia* is characterised by fragments of quartzite, porphyry, hornfels and a distinctive flesh-pink feldspar, thought to come from a short-lived explosive volcanic phase in the north-eastern part of Dartmoor. A prominent cliff on the north side of the cove shows numerous vertical sand dykes, thought to be due to earthquakes, and in the cliff behind the railway a very large sand-dune unit 20m high is present.

Dawlish – Dawlish Warren [SX 967770 – 978779]

The length of cliffs along the mainline railway and sea wall and **Langstone Rock** undoubtedly form the finest Permian exposure in South West England, with excellent viewing but accessible only at a few places where bridges cross the railway line. The *Dawlish Sandstone* with plenty of cross-bedded sand-dune deposits can be seen. Alternating with these are other sand strata which represent water-redistributed dune material, and fine-grained breccia layers which represent occasional incursions of flash-flood deposits into the sand sea. Closer to Langstone Rock, more breccia layers are found which represent the incoming of an alluvial fan, and the Rock formed of *Exe Breccia* is mainly of quartzite fragments which were deposited as another alluvial fan which came from the northwest.

Exeter City Centre and Castle [SX 921 925]

Here there is a wealth of impressive buildings in the city centre built from the local Heavitree Breccia and also the local volcanic basaltic lavas (Rougemont).

6.5. PHOTOGRAPHS



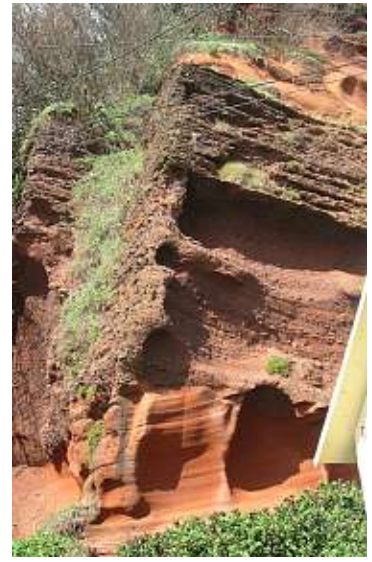
Permian Breccias at Langstone Rock, near the mouth of the River Exe at Dawlish Warren - created by successive flash floods in the hot desert climate that prevailed in Britain 250 million years ago. © DJC Laming



Exe Breccia - a resistant rock with hard angular quartzite fragments. © DJC Laming



Dawlish Sandstone – sand dunes preserved in the cliffs north of Dawlish Station - clear evidence of our desert landscape and hot dry climate in the past, and that the winds blew from the southeast. © DJC Laming



Alternation of sand dunes and alluvial fan deposits north of Dawlish station. © DJC Laming



Exeter city building stones in local Permian red rocks – Heavitree Breccia, Pocombe Lava and Rougemont Basalt – at St Nicholas' Priory. © DJC Laming



Exminster Church tower built in local Heavitree Breccia. © DJC Laming

7.4 TRIASSIC PEBBLE BEDS, SANDSTONES & MUDSTONES

by Deryck Laming & David Roche



Budleigh Salterton Pebble Beds overlain by Otter Sandstone, exposed in high cliffs to the west of Budleigh Salterton, and a Site of Special Scientific Interest (SSSI) for its geology. © DJC Laming

7.1. BRIEF DESCRIPTION

The pebble beds, sandstones and mudstones which date from the Triassic geological time period are mainly red rocks which formed in tropical desert conditions dominated by wide river floodplains and temporary lakes, between about 250 and 200 million years ago.

The first small dinosaurs appeared in late Triassic times, though there had been more primitive reptiles and amphibians before then.

The Triassic geological time period was named after the three-fold series of similar rocks found in Germany, of which only two are represented in Britain.

The Triassic red rocks in Devon are above the red breccias and sandstones of the Permian time period; together they are known as the New Red Sandstone. At the top of the rock series there are greenish-grey mudstones and limestones, followed by younger Jurassic aged strata marking the incoming of marine conditions due to submergence of the land.

Triassic rocks of east Devon, and from Exmouth eastwards along the sea cliffs to Axmouth form an important part of the Jurassic Coast World Heritage Site known as the Red Coast. Triassic rocks probably once spread across much of the lower-lying parts of Devon, covering the older harder rocks, and formed part of a desert plain extending over much of central England and beyond into the North Sea area.

Otter Sandstone is porous and fractured and holds groundwater which provides local supplies of drinking water from boreholes in the Otter Valley.

Unstable sea cliffs occur in the mudstones and sandstones, especially along the coast east and west of Sidmouth, and east of Exmouth.

7.2. GEOLOGICAL DETAIL

The Triassic period (251-200 million years ago) was remarkable for the tranquillity of the geological environment across Britain and most of Europe and also because the Age of

the Dinosaurs began in the latter part of the period. Large four-legged reptiles had developed in the Permian, and amphibians even earlier, but the earliest dinosaurs were smaller and nowhere near as large as they would become in Jurassic times.

Desert conditions were widespread in Britain in Triassic times but, in contrast to the mountainous terrain and alluvial fans of the Permian, much of it consisted of wide plains over which river floods spread on rare occasions. These laid down floodplain deposits, mainly red-brown mudstone but with red channel sands forming horizontal beds at intervals, prominently seen in the cliffs of Exmouth. Near the base of the succession are pebble beds and sandstone deposited by a large delta fan.

The position of the boundary between the Permian and Triassic in Devon is uncertain. Formerly it was taken at the base of the Pebble Beds, but study of rare microfossils has indicated the boundary is lower, at the base of the Exmouth Mudstones. This is not only a boundary between two periods of geological time, but also between the Palaeozoic Era and the Mesozoic Era, characterised by ancient and intermediate life-forms respectively. The boundary also marks the time of a great mass extinction of marine life worldwide.

The upward succession of Triassic rocks in Devon is as follows:

- Exmouth Mudstone and Sandstone Formation is the lowest part of the Triassic (within the Aylesbeare Mudstone Group) and is seen at Exmouth. Both mudstone and sandstone layers make up the cliffs and are visible on the foreshore. Sandstone beds in the cliffs create prominent headlands such as Orcombe Point, but the bays in between are backed by mudstone which is much more vulnerable to erosion. There are some good examples of small scale faults in the cliffs and foreshore, displacing sandstone beds. Rare copper minerals have also been found.
- Budleigh Salterton Pebble Beds (in the Sherwood Sandstone Group) is a very prominent and distinctive gravel (or conglomerate as it should properly be called), with hard and rounded pebbles and cobbles and a substantial proportion of sand deposited by a large river flowing from a distant source. Fossils in the pebbles show that they came from mountains of much older Ordovician age in northern France. The large river continued north into the English Midlands. It ceased flowing into Devon when subsidence created an early version of the English Channel.
- Otter Sandstone lies above the Pebble Beds. It is also of river origin except for a layer of wind-blown sand at the base. Petrified fossil plants are cemented by calcareous encrustations.
- Mercia Mudstone is a group of mainly mudstone strata but thin siltstone and sandstone layers are found, together with gypsum and rock-salt deposits below ground. Previously known as Keuper Marl, the soft mudstone often weathers to clay.
- At the top of the Triassic succession, some marine and brackish-water sediments of Rhaetian age form the Penarth Group, including green-grey mudstone and limestone beds, and the White Lias, which passes up into Jurassic strata of the Blue Lias.

Fossils have been found in the Triassic, notably several bones of rhynchosaur, reptile antecedents of the dinosaurs, found in the Otter Sandstone. Plant fossils, poorly preserved, have been found at Orcombe Point, Exmouth, as have a number of worm tubes similar to those seen in the Permian.

Unstable sea cliffs occur in the mudstones and sandstones, especially along the coast east and west of Sidmouth, and east of Exmouth.

Spectacular large sea stacks can be seen at Ladram Bay. These were previously sea caves in a former cliff headland, which enlarged into cliff arches, which then collapsed due to further sea erosion that separated them from the shore.

7.3. USES

The Budleigh Salterton Pebble Beds is a valuable source of high quality aggregate used for variety of essential end products such as houses, schools, hospitals, etc. It is worked in several large quarries where the pebble beds outcrop on the plateau ridge extending northwards from Budleigh Salterton to the Somerset border. The gravel is extracted by heavy excavator and the stone and sand is crushed and processed to produce a variety of products for different uses.

The mudstones of Exmouth were formerly used for brick-making, but quality and price could not compete with better bricks from elsewhere.

The sandstone was used as building stone in many buildings, including churches, though better stone was obtained where possible for church towers. Much of the extraction was done on the seashore, and incised cart-wheel tracks can still be found from such activity. In areas where harder rocks were not available, mudstone was dug from numerous marl pits and used for traditional Devon cob construction in houses and farm buildings using horsehair as a binder.

7.4. PLACES TO VISIT

Please refer to the safety guidance about visiting geological sites on our website before visiting the places listed below.

The coastal exposures of Triassic rocks are excellent but are accessible at only a few localities from Exmouth eastward; they lie within the Jurassic Coast World Heritage Site and are well described in resources available online.

Orcombe and Rodney Points, Exmouth [SY 019796]

Resistant sandstone layers form these headlands, with the interbedded mudstones backing the coves in between. The sandstones show extensive cross-bedding, a clear indication of river delta deposition, while the mudstones were laid down as floodplain deposits. Rare plant fossils and copper minerals (malachite and native copper) have been found here in the past

The start of the World Heritage Site is marked by the *Geoneedle* on the headland, in the central column displaying stone types from the main rock formations seen along the coast

West Cliff, Budleigh Salterton [SY 060816]

The Budleigh Salterton Pebble Beds form the prominent cliff, and pebbles eroded by wave action form the beach. The beds, about 25m thick, dip beneath the beach to the east, but rise up the cliff westward to form West Down Beacon. Small faults have displaced the bedding in places, as shown by the Otter Sandstone (wind-fretted) appearing lower down adjacent to pebble beds on the left.

Ladram Bay [SY 097852]

The bay has good exposures of Otter Sandstone in the cliffs and (at low tide only) to the south. Occurrences of calcrete beds, many of them shaped like plant roots, can be found there. The massive sea stacks were once joined to the cliffs by natural arches.

Chit Rocks and Jacobs Ladder, Sidmouth [SY 120869]

The Otter Sandstone dips below the beach 1 km west of this locality, but reappears here because of a north-south fault, upthrowing to the east. Cross-bedding and other features of the Otter Sandstone can be seen along the foot of the cliffs, and Mercia Mudstones behind the beach to the west.

Pennington Point, Sidmouth [SY 129873]

The Otter Sandstone reappears here due to a fault along the valley of the River Sid, and striking bedding features are easily visible from the small jetty by the river. This cliff has suffered considerable erosion in recent years and should not be approached. Further along the beach (only at low tide) the Mercia Mudstone can be examined in the cliffs.

7.5. PHOTOGRAPHS



Otter Sandstones dipping gently east and overlain by Mercia Mudstones in the very unstable sea cliffs at Pennington Point, Sidmouth. © DP Roche



Local small faults cut across the boundary of the Otter Sandstones over the Pebble Beds, at Budleigh Salterton West. © DJC Laming



Sandstone and mudstone cliffs at Orcombe Point, east of Exmouth, with fault visible in foreshore. © DJC Laming



Dreikanter pebbles shaped by wind erosion at top of Pebble Beds overlain by yellow wind deposited sands of the Otter Sandstones. © DJC Laming



Pebble Beds – poorly sorted and coarse rounded quartzite pebbles in sand matrix. © SJ Parkhouse

8. LOWER JURASSIC MUDSTONES AND LIMESTONES

by David Roche



Devon's Jurassic coast with Blue Lias limestones and mudstones well exposed at Devonshire Head, just west of Lyme Regis. © DP Roche

8.1. BRIEF DESCRIPTION

Limestones and mudstones from the Jurassic geological time period are found only in the extreme east of Devon along the coast near Lyme Regis and inland to the north and east of Axminster. A 250m thickness of these rocks are reported in east Devon.

Laid down early in the Jurassic period, about 200 million years ago, the deposits which formed the rocks mainly consisted of clays, shells and shell debris, formed in warm tropical seas brimming with sea life. This followed a long period of more than 100 million years (during the Triassic and Permian geological time periods) when Devon was an inland desert.

Sea creatures called ammonites first developed and became prolific during Jurassic times and the fossil *Psiloceras planorbis* marks the start of rocks identified as dating from the Jurassic. Famous for their characteristic spiral shells, ammonites have become iconic symbols in the Lyme Regis district. Fossils are abundant in the Jurassic rocks and include a variety of ammonites, bivalves, brachiopods, echinoids and belemnites.

Dinosaurs also developed and became predominant during the Jurassic period, both on land and in the sea, with a great diversity of species. Large marine reptiles included ichthyosaurs and plesiosaurs.

The Jurassic dated rocks are missing from the rock sequence found in the west of Devon, although both the underlying Triassic and the overlying Cretaceous rocks are present. The missing Jurassic and lower Cretaceous strata represent nearly 100 million years of time, when Devon became land again with erosion, which results in the major unconformity in the series of rocks which can be seen along the sea cliffs between Axmouth and Sidmouth.

Landslides famously occur on the oldest Jurassic rocks, both inland and on the coast, especially along the coast west of Lyme Regis, where the Undercliffs Landslide is one of the largest and best known examples in UK.

8.2. GEOLOGICAL DETAIL

Lower Jurassic limestones and mudstones are found only in the extreme east of Devon near Lyme Regis and Axminster. Approximately 250m thickness of strata are recorded in east Devon consisting mainly of thinly interbedded sequences of mudstones and limestones. Eastwards, in neighbouring Dorset and in the Cotswolds and beyond, there is a much greater thickness and extent of Jurassic strata. The most recent geology map and description by the British Geological Survey subdivides the Lower Jurassic strata of east Devon into the Blue Lias, the Charmouth Mudstone and the Dyrham formations (in ascending order).

Blue Lias Formation consists of 26-38m thickness of thinly interbedded limestones and mudstones. The strong fine grained blue-grey limestone beds typically break into hard tabular 'blue-hearted' blocks which have been used as local building stones. The dark grey mudstones are much weaker, and clayey or shaley.

The Triassic-Jurassic boundary is marked by the appearance of the ammonite *Psiloceras planorbis*. Abundant fossils include bivalves, brachiopods and echinoids.

Charmouth Mudstone Formation is up to 200m thick and was previously known as Lower Lias Clay. It comprises pale and dark mudstones and clays with occasional limestone beds. The sequence is subdivided into several members including the:

- Shales-with-Beef – thin beds of shaley clays with seams of fibrous calcite ('beef')
- Black Ven Marls – dark grey shaley mudstones and calcareous mudstones
- Belemnite Marls – pale and dark grey mudstones with abundant belemnite fossils
- Green Ammonite – black shaley (fissile) mudstones with occasional limestone beds and characterised by ammonite fossils in greenish calcite

Dyrham Formation comprising the Eype Clay Member is up to 50m thickness of blue-grey mudstones with micaceous layers and also some sandy mudstones, siltstones and sandstones.

Landslides are famous and major features of the Lower Jurassic strata, especially along the coast where the Axmouth to Lyme Regis Undercliffs landslide complex (including the Pinhay landslide) is one of the largest and best known in the UK. In neighbouring Dorset, the town of Lyme Regis and the cliffs to the west and east are much affected by old landslips, and the Black Ven Landslide to the east of the town is also one of the largest and best known active landslides in the UK. Caused by sea erosion, groundwater pressures and sliding on weak and clayey layers in the Lower Jurassic strata, large sections of the upper cliffs in the Chalk and Greensand have foundered on a massive scale. Inland there also many landslides affecting valleyside slopes underlain by the Lower Jurassic clays and mudstones.

The best exposures are found along the sea cliffs and foreshore west of Lyme Regis. Inland the strata are generally poorly exposed and typically concealed beneath slope and landslip deposits.

8.3. USES

Limestones, particularly from the Blue Lias, have been used as local building stones in walls and dwellings, as both irregular and dressed blocks, in particular in Lyme Regis where it can be seen around the harbour and in the recent environmental improvement works.

Historically, the limestones have also been used in local cement manufacture at Lyme Regis and also Membury, and the Blue Lias clays in particular were used for brick and tile manufacture at Lyme Regis.

Tolcis Quarry was a relatively large old quarry between Axminster and Membury which quarried the Blue Lias and also the top of underlying Penarth Group (Triassic) mainly for building stones and lime. The quarry is now mostly infilled (with waste landfill) apart from one large quarry face exposure to enable viewing of the principal rock strata.

8.4. PLACES TO VISIT

Please refer to the safety guidance about visiting geological sites on our website before visiting the places listed below.

Lyme Regis

The sea cliffs and foreshore west of Lyme Regis provide excellent exposures of the Blue Lias strata and can be accessed by walking along the beach westward from the Cobb and the Monmouth Beach car park.

Tolcis Quarry

Tolcis Quarry is a County Geological Site and has a large quarry face exposure of the Blue Lias and the underlying Penarth Group (Triassic) strata, however the quarry site is mostly infilled and is within private landownership without a public footpath.

8.5. PHOTOGRAPHS



Blue Lias strata exposed in cliff face and wave cut platform at Devonshire Head, west of Lyme Regis.
© DP Roche



Thinly interbedded pale and dark grey limestones and mudstones exposed in cliff face. © DP Roche



Numerous small ammonite fossils on a mudstone boulder on the beach.
© DP Roche



Large ammonite fossil on a limestone boulder on the beach at Devonshire Head.
© DP Roche



Jurassic limestone building stone full of shelly fossil debris in Lyme Regis.
© DP Roche



Tolcis Quarry SSSI rock face with exposures (overgrown) of Blue Lias limestones/mudstones over Penarth Group (Triassic) strata.
© DP Roche

9. UPPER GREENSAND AND GAULT

by David Roche



Greensand well exposed as golden yellow and greenish grey sands in a recent major coastal landslip to the east of Sidmouth
© DP Roche

9.1. BRIEF DESCRIPTION

'Greensand' and 'Gault' are the names attached to two collections of rock type dating from the mid Cretaceous geological time period. These rocks formed about 100 million years ago. Collections of rocks which geologists recognise and see in various locations have the group name 'formation'. A formation name is sometimes preceded by either 'upper', 'middle' or 'lower', this indicates whether you are looking at the youngest or oldest rocks within that collection. 'Upper' relates to the youngest rocks and 'lower' relates to the oldest rocks, 'middle' are the rocks found in-between. The Upper Greensand Formation is well exposed in east Devon, especially along the sea cliffs, and is up to 50m thick. The Gault Formation is much thinner and is not easy to find.

The name Greensand originated from the slightly greenish colour of the rocks. This colour is due to the presence of an iron-rich mineral called glauconite. However, when the rocks are exposed to air or water the rock is oxidised and turns to a rusty yellow or brown colour (see photos).

The Upper Greensand collection is usually divided into two main rocks.

1. Chert Beds - which are yellow/brown sands and sandstones with visible layers and lumps of a hard mineral, called nodules.
2. Foxmould - which is yellow/grey and 'foxy' brown sandstone with disc shaped lumps made of mainly calcium, called cowstones.

The Upper Greensand Formation is found along the east Devon coast from Sidmouth to Lyme Regis and inland to the Blackdown Hills, and there is another outcrop on the Haldon Hills west of Exeter. The Gault Formation is underneath the Upper Greensand Formation. Typically it appears as a dark grey sandy clay, but it is rarely seen.

The Greensand Formation and the Gault Formation were formed early in the geological time frame named the Cretaceous period, between 95 and 107 million years ago. At this time the sea covered the land and muds and sands were deposited at the bottom of warm shallow tropical seas which contained lots of sea life. The muds and sands were put

under pressure as they were increasingly buried and this process formed the rocks we see today.

Fossils are common in these rocks because there was lots of things living in the warm shallow seas when the rocks were formed. The types of fossils which have been found include molluscs, brachiopods, echinoids, ammonites and fish teeth.

The Greensand rocks are porous, which means they have holes or voids in them. This gives them the capability to hold groundwater, which provides a local supply of drinking water to nearby farms and the towns of Lyme Regis and Axmouth.

9.2. GEOLOGICAL DETAIL

The most recent geology map and description by the British Geological Survey (ref) subdivides the Upper Greensand Formation into:

- Bindon Sandstone Member – up to 8m thick
- Whitecliff Chert Member – up to 32 m thick (Chert Beds)
- Foxmould Member – up to 25m thick (Foxmould)

The strata are described as fine, medium and coarse grained calcareous sandstones with variable amounts of silica, glauconite and comminuted shell debris. They vary from strongly cemented sandstones to poorly cemented sands. There are some beds of mainly shell debris. The Chert Beds include layers of nodular and tabular chert, but these are less frequent westwards from Beer. North into the Blackdown Hills there are some strongly cemented siliceous layers. The Foxmould is generally finer grained and more siliceous, with some clayey beds at lower levels, and calcareous nodular concretions known as 'cowstones'.

Following a period of uplift and erosion during the late Jurassic / early Cretaceous, a transgressive sea submerged the land and deposited sandy clays and silty sands to form the Gault and Greensand strata in warm shallow tropical seas, followed later by the deposition of the overlying Chalk. The beds dip very gently (sub-horizontally) to the east at about 1°. From east to west, the Greensand and Gault progressively overstep the underlying Lower Jurassic and Triassic strata which dip a little more steeply at about 5° to the east – this is termed an 'unconformity'.

Greensand is very well exposed along the east Devon coast from Sidmouth to Lyme Regis where it typically appears as a pale yellow brown layer capping the steep upper sea cliffs, sometimes below a layer of white Chalk. Inland it creates a characteristic landscape of high ground level plateaux with open farmland, woodland or heathland, and steeply incised valleys with Greensand forming steep valley-side escarpments often with a springline along the base, and in some places landslips with a strangely irregular 'hummocky surface' and 'tumbling fields'.

Landslides are famous and major features of the Greensand and Gault strata, especially along the coast between Sidmouth and Lyme Regis where there are some of the best examples in the UK – such as the Axmouth to Lyme Regis Undercliffs landslide complex (including the Haven, Bindon and Pinhay landslides) and the Hooken Landslide between Branscombe and Beer Head. Caused by sea erosion, groundwater pressures and sliding on weak and clayey layers in the Foxmould and Gault beds (and sometimes in the underlying Jurassic), large sections of the upper cliffs in the Chert Beds and Chalk have foundered on a massive scale.

Greensand is a major aquifer which holds water within its porous sand texture and in its open fractures, and this is a valuable local groundwater resource used for local supplies of drinking water from wells at farms and villages and also for the towns of Lyme Regis and Axminster. Natural springs and seepages of groundwater from the base of the Greensand supply the network of surface streams and rivers, and also water into landslide areas.

The Greensand outliers of the Haldon and Newton Abbot areas to the west of Exeter are poorly exposed except where it is worked in small quarries for building sand where the unweathered green colour of the glauconite can sometimes be seen. With different local stratigraphy, the strata dip west under the Tertiary Bovey Basin.

The Gault Formation (below the Greensand) is very thin and very poorly exposed or missing. About 5m thickness of dark grey sandy clay is reported near Charmouth (in Dorset) and similar is noted in the Axmouth to Lyme Regis Undercliffs landslides. Greater thicknesses of Greensand and Gault Clay are found in South East England.

9.3. USES

Chert fragments have been used as local building stones in walls and dwellings, as both irregular and dressed blocks. Local sources were small pits and from ploughing of fields. Loose sand has been used for building sand, again from numerous small pits. Cherty materials (gravelly sand) have been used extensively for construction of local roads and tracks, and as local aggregates for concrete and roadstone.

Salcombe Stone (Bindon Sandstone) was quarried near Salcombe Regis and used as an exterior stone in Exeter Cathedral.

Siliceous sandstones have been used as sharpening stones, know also as 'whetstones', 'scythestones' and 'Devonshire Batts'. These have been obtained from workings (including adits) into the Greensand escarpment – e.g. at Hembury Fort and Blackborough Common.

Drinking water supply is an important local resource derived from the Greensand groundwater aquifer.

9.4. PLACES TO VISIT

Please refer to the safety guidance about visiting geological sites on our website before visiting the places listed below.

Although the Greensand strata are well exposed, especially along the coast from Sidmouth to Lyme Regis, much of the exposures are on high sea cliffs or landslides, and there are relatively few locations which are accessible and safe for close inspection.

Some of the best safe viewpoints include the sea cliffs east of Sidmouth where Greensand is exposed in Salcombe Hill and Dunscombe cliffs, and extending eastwards to Branscombe, and from Axmouth Harbour there is a good view of Haven Cliff at the western end of the Undercliffs landslide complex. All these locations are along the South West coastal footpath, which continues eastwards to Lyme Regis along the Undercliffs landslide complex.

A closer view is found at Seaton Hole where the vertical Greensand cliff may be seen from an adjacent café and picnic area alongside Cliff Road. However, the Seaton Hole Landslip and its impenetrable debris along the toe of the cliff prevent close-up inspection.

One of the best locations where relatively safe and close-up access may be gained is at Chimney Rock which is just inside the Devon border and near the eastern end of the Axmouth-Lyme Regis Undercliffs landslide complex. Chimney Rock is a remnant stack of Chert Beds alongside a public footpath down the steep landslide backscarp from the cliff top at Ware.

Another good location to see the Greensand and to appreciate its involvement in landslides is at Hooken Landslide, along the coastal footpath between Branscombe and Beer Head, where it is possible to descend on a steep footpath from the cliff top to the beach across the landslide.

Inland exposures include Blackborough Common, Blackborough, near Kentisbeare (NGR ST 095 092, OS 1:50,000 sheet 192), a County Geological Site included on the Devon Educational Register of Geological Sites. With public footpath access over private land the site includes a Greensand scarp hillside with old chert workings, historically for scythestones; also sponge and shell fossil debris, and irregular landslipped ground.

Greensand cherts have been used as local building stones with many examples in walls and buildings, including at Offwell Church (see photographs).

9.5. PHOTOGRAPHS



Greensand exposed in cliff face at Seaton Hole. Yellow brown Chert Beds at upper levels with development of open fissures, underlain by grey Foxmould strata, with recent landslip debris at base. © DW Allen



Chimney Rock pinnacle stack in Chert Beds standing out of steep backscarp slope of the Undercliffs landslide complex near eastern end at Ware, Lyme Regis. © PC Stephenson



Greensand in cliff faces at Branscombe. © PC Stephenson



Chert Beds - nodular chert. © PC Stephenson



Cherts as local building stones at Offwell. © C Nicholas



Fossil shell debris in chert - Zig-zag Quarry, near Newton Abbot. © C Nicholas



Greensand in Heathfield Sand Pit, near Kingsteignton. © SJ Parkhouse



Fossil echinoderm found at Heathfield Sand Pit, near Kingsteignton. © SJ Parkhouse

10. CHALK

by David Allen



Excellent cliff exposure of Chalk at Beer, east Devon. Gently dipping beds rising to the east as shown by the thin bands of flint. © DW Allen

10.1. BRIEF DESCRIPTION

Chalk is a very pure soft white limestone rock which is composed predominantly of calcium carbonate minerals. In Devon it is around 100 metres thick and it forms a rounded upland plateau landscape inland and spectacular high and steep sea cliffs.

Chalk is found in east Devon where it forms the upper sea cliffs and high ground inland east of Sidmouth, particularly towards Branscombe, also between the mouth of the River Axe and Lyme Regis, and small areas inland particularly near Membury. The best exposures are in the cliffs at Beer. These are the most westerly chalk outcrops in England, and are a westward extension of the chalk of South East England (e.g. White Cliffs of Dover, Beachy Head, South Downs, etc).

The chalk was formed in a warm tropical sea between about 65 and 100 million years ago. It is composed almost entirely of the remains of small sea creatures and carbonate shells of microscopic algae.

Within the chalk are flints, as small lumps forming layers and best seen in the cliffs. These flints are very hard and are formed of fine grained silica, also derived from sea creatures, which solidified in the soft sediment shortly after it was deposited.

Fossils are abundant and include bivalves (molluscs) and echinoids (sea urchins).

Landslides occur in the chalk and some of the best examples are along the coast near Beer and Lyme Regis.

10.2. GEOLOGICAL DETAIL

The most recent geological map and description by the British Geological Survey subdivides the Chalk in Devon into:

White Chalk:

- Seaford Chalk Formation - up to 20m thick
- Lewes Nodular Chalk Formation - 35 to 40m thick
- New Pit Chalk Formation - up to 25m thick
- Holywell Nodular Chalk Formation - up to 15m thick

Grey Chalk:

- Beer Head Limestone Formation - 5m thick

The Grey Chalk is represented in Devon by the Beer Head Limestone which is a locally much condensed succession. The formations of the White Chalk can be matched both lithologically (rock types) and palaeontologically (fossil content) with parts of the Chalk sequence elsewhere in southern England.

In Devon the Chalk strata outcrop as outliers (limited areas of outcrop of younger rocks completely surrounded by older rocks) that are the remnants of a once continuous cover which extended over much of the county.

Overall the Chalk strata dip very gently to the east but are locally gently folded and the outcrops disturbed by faults. The main outcrop around Beer is in a gentle basin shaped fold or 'syncline'.

The Chalk was formed in the period of earth's history known as the Cretaceous - between about 65 and 100 million years ago - at a time when southern England was covered by a widespread warm sea. Sea levels varied with generally shallow to moderately deep water conditions and life was abundant in the clear water, producing an abundant supply of carbonate sediment.

The Chalk is composed almost entirely of the remains of small animals and microscopic algae. There are two distinct size ranges. The coarser grain size fraction (10-100 micrometres) is dominated by the skeletal remains of small creatures, foraminifera and ostracods together with plate and spine fragments of echinoids (sea urchins) or small colonial organisms called bryozoa. The finer size fraction (0.5-4 micrometres) is composed of the carbonate shells of algae. These near-surface floating organisms had shells of tiny calcium carbonate shapes which were constantly shed during life and death of the algae thereby producing a carbonate rich 'snow' continually falling to the sea bed. Similar 'algal blooms', as they are known, occur in warm weather in the seas off southwest England today.

Study of fossils and comparison with modern forms of similar organisms indicates that in the area at the time of deposition the maximum water depth was of the order of 150 to 300m, that is within the range of penetration of light.

The planktonic life forms provided food for larger organisms such as the echinoids (sea urchins) bivalves (clams and oysters) and crustaceans (crabs and similar). Bivalve fossils are relatively common and are utilised as zone fossils to correlate various horizons within the Chalk.

Although the large exposures in the sea cliffs appear relatively uniform the rocks which make up the Chalk are quite variable. These variations include layers formed predominantly of shell fragments, mainly bivalves; gritty chalk which contains frequent sand grade calcareous fragments and nodular chalk where pockets of harder material are surrounded by a matrix of softer marly (clayey) chalk. In places the chalk has become cemented to form hardgrounds. There is a continuous variation from soft marly chalk through to fully cemented hardgrounds. The different rock types within the Chalk reflect variations in deposition conditions. At times there were breaks when there was no deposition, mainly represented by the hardgrounds.

The flints which are common at many levels within the Chalk are composed of hard, brittle, siliceous mineral which occurs mainly in layers parallel to the bedding. It can vary in form from continuous sheets to very small discrete nodules. Flint was formed during diagenesis (alteration of the rock by pressure and temperature after burial under later sediments) probably from the silica content of small organisms.

The Chalk has a significant role in causing the dramatic landslides which have occurred along the east Devon coast between Branscombe and Beer (the Hooken landslide) and between Axmouth and Lyme Regis (the Undercliff landslide complex). The underlying strata (Greensand, Gault and Lias) are relatively weak and are prone to sliding due to groundwater and to erosion by the sea. This results in the overlying relatively massive Chalk strata, tending to fail as foundered masses on large scale. In the famous Bindon Landslide of 1839 it is said that the harvest was gathered from the fields after the whole area had subsided towards the sea.

Chalk is a major aquifer which holds water within its porous silt texture and in its open fractures and, together with the underlying Greensand, this is a valuable local groundwater resource used for local supplies of drinking water from wells at farms and villages. Natural springs and seepages of groundwater from the base of the Chalk and Greensand escarpments supply the network of surface streams and rivers, and also water into landslide areas.

10.3. USES

The Chalk in Devon has been of economic importance since the earliest times.

Limestone burning for making lime has been carried on for centuries to make lime for mortar and also for agriculture to improve the land. Due to the lack of fuel apart from timber cut from local woodlands the limekilns were typically near the coast for ease of import of coal. There are examples of small chalk pits close to the coast with associated limekilns such as those near Axmouth. Small pits close to the inland exposures of Chalk may also be for this purpose. In the recent past the quarries at Beer have been worked for lime burning.

Perhaps more dramatic an impact has been the use of Chalk as building stone. A specific variation in the Chalk lithology known as Beer Stone is a locally developed layer of hard chalk within the Holywell Chalk Formation. This is particularly suitable as a 'freestone'; a fine grained stone that can be easily sawn. When freshly quarried the stone is soft and easily shaped but hardens on exposure to air to produce a golden coloured stone. The peculiar gritty texture is due to a large concentration of finely broken echinoderm fragments. The thickness of the horizon, around 5m, has allowed the working of the stone underground away from the effects of surface weathering.

The properties of the Beer stone have been known since at least Roman Times. The main workings are at the Beer Quarry Caves between Beer and Branscombe. The earliest sections include Roman diggings while other sections include Norman and more recent excavations up to the early 20th Century. A small amount of Beer Stone is still worked but is now excavated from a surface quarry after removal of overlying Chalk by modern excavators. The location of the workings near the coast allowed the stone to be shipped for the building of many cathedrals and parish churches including St Stephens, Westminster in 1362 and Rochester in 1367. Locally it has been used in Exeter Cathedral and Guildhall and in many of Devon's parish churches. In the local parish it has also been used in houses and cottages.

An ancillary building material from the Chalk has been the flint which has been a common building material particularly where flints have been used as a decorative infill in wall panels etc. The dark, almost black, broken faces of the pebbles form a dramatic contrast when white Beer Stone or other pale limestone or sandstone is used around doors and windows.

Indirectly the Chalk has also been a source of industrial mineral as flint pebbles. Rounded beach pebbles derived from the local cliffs and processed by rolling along in the sea have been used as grinding pebbles in the pottery, paint and chemical industries.

The Chalk strata form a good aquifer but their location on generally high ground, above the water table, has meant that they have only been important locally for water supply.

10.4. PLACES TO VISIT

Please refer to the safety guidance about visiting geological sites on our website before visiting the places listed below.

Location: The places to visit to see the Chalk in Devon are all around the Beer and Branscombe area in the south east of the county accessed from the A3052 coast road and B3174 to Beer.

Ordnance Survey 1:50,000 Sheet 192.

Beer

There are several signposted car parks in and around the village which can also provide most facilities for visitors and is a good base for exploring the locality - www.beer-devon.co.uk

High cliffs backing the east and west beach include the majority of the Devon Chalk sequence. These are accessed from the slipway where the main street meets the sea. National Grid Ref: SY 231 891.

The Chalk in the cliffs to the west of the slipway starts with the lower, Grey Chalk resting on Greensand strata at sea level. To the east of the slipway the particularly flinty Chalk from high in the White Chalk sequence is seen in the upper cliff at Annis's Knob.

The valley which is followed by the main street is approximately coincident with the axis of the Beer syncline. The strata to the west are parallel with the centre of the fold and so appear horizontal while the strata in the east beach cliffs are seen to rise to the east.

The cliffs are best viewed from the beaches which are publicly accessible but subject to tides and can be dangerous in poor weather. The east beach cliffs, in particular are

unstable and warning signs should be obeyed. Annis's Knob is not accessible for close inspection and should be viewed from the beach.

Beer Quarry Caves located on the Beer – Branscombe road, National Grid Ref: SY 214 895, are a local tourist attraction and are open to the public (entry fee applicable). The site is managed by Beer Quarry Caves Limited www.beerquarrycaves.fsnet.co.uk. This is a Site of Special Scientific Interest (SSSI) - www.english-nature.org.uk

The village of Beer contains a wide range of buildings which demonstrate the use of Beer Stone. These range from the public shelter in the Jubilee Pleasure Grounds immediately east of the slipway through random stone in numerous cottages, carved stone details in church windows and larger houses to ashlar stone walls in large old houses particularly at the inland end of the village. Flint infill and decoration is also much in evidence and is seen to particularly good effect in the Dolphin Hotel and the Congregational Church in Fore Street.

To the east of Beer the Chalk strata continue to rise to the east towards Seaton Hole. They form the high, and steep, White Cliff before the Chalk outcrop ends abruptly at a fault; with red Triassic sandstones and mudstones to the east. This cliff is not publicly accessible due to major instability in the underlying Greensand strata but may be viewed from the public beach access path at Seaton Hole, National Grid Ref: SY 235 895, and also from the West Walk Promenade and adjacent beach in Seaton.

Branscombe

This pretty village also provides visitor facilities and is a good base to explore the coastal path both to the west towards Sidmouth where chalk is present in the upper cliffs and to the east through to Beer.

Beach and coastal footpath access from near the car park at Branscombe Mouth, National Grid Ref: SY 207 881).

The Southwest Coast Footpath to the east leads through Hooken where inland Chalk cliffs form the old backscar to the major landslide which occurred in 1788. A circular route including Hooken Cliffs and Under Hooken is possible from Branscombe - www.southwestcoastpath.com.

This area is also accessible from the east by the path from Beer Head car park There are spectacular coastal views from the Beer end of the path above Beer Head looking down into the landslide area.

All of these locations are in the East Devon Area of Outstanding Natural Beauty www.eastdevonaonb.org.uk and are within the Jurassic Coast World Heritage Site - www.jurassiccoast.com.

The coast between Sidmouth and Beer and the Beer quarry caves are dealt with in the 'Geology in Devon' booklet references 25 and 26, pages 32 and 33 respectively. See also www.devon.gov.uk/geo-SID.pdf for information on the Sidmouth to Beer coast. These locations are also in the Educational Register of Geological Sites; East Devon Sites 12 and 2 respectively, www.devon.gov.uk/educational_register.htm.

10.5. PHOTOGRAPHS



Chalk cliffs at Beer extending west to Beer Head.
©DW Allen



Interlayered flint-free hardstand and nodular Chalk with flint bands above and below, Beer ©DW Allen



Flint-rich Chalk, numerous thin bands of small flints with prominent band of larger flints towards the base - Annis's Knob, Beer. ©D W Allen



Ecclesiastical architecture using Beer stone for door and window details with flint for main walls. Congregational Church, Fore St, Beer. ©DW Allen



Underground quarry workings in Beer Stone, at Beer Quarry Caves - between Branscombe and Beer. © Beer Caves



An important local house constructed of Beer Stone. Walls in ashlar stone with carved window lintels and door frames. Beer. ©DW Allen

11. LUNDY GRANITE

by Phil Stephenson



Lundy Granite exposed at Gannet Rock on the eastern side of the northern area of Lundy Island

© Kevin Page

11.1. BRIEF DESCRIPTION

Lundy Granite is unique in southern Britain and is about 240 million years younger than Dartmoor Granite. This rock represents the southernmost example of igneous rocks associated with the initial formation of the North Atlantic Ocean around 60 million years ago. Igneous rock is formed by magma (molten rock from inside the earth) being cooled and becoming solid. Lundy Granite is a coarse grained rock typically with large feldspar crystals (called megacrysts).

Lundy Island is situated off the north Devon coast, about 20km north-northwest of Hartland Point. The island is about 5km long (north-south) and about 1km wide. The island is largely formed of granite but some slate can be seen, which pre-dates the granite. Also, many strips of igneous rock, called dykes, cut across the rocks.

Lundy Granite is similar to a common igneous rock of about the same age found in Scotland and Northern Ireland. The granite was formed about 60 million years ago, pushed from inside the earth into a pre-existing rock. It was initially thought that the granite was the same age as the Dartmoor Granite and others in South West England, but dating confirmed that the rocks were formed during the Tertiary geological time period.

Lundy Island has a long and rich history from prehistoric settlers to King Henry III. Marisco Castle was built in the thirteenth century from quarried Lundy Granite. The island was once owned by the Knight's Templar and has had notorious pirates responsible for wrecking many ships on the island's steep granite cliffs which are littered by sea caves once used by smugglers but now home to seal pups.

Quarrying of the granite has occurred on the island. The granite was then used to construct the island's buildings and it was also exported to the mainland.

11.2. GEOLOGICAL DETAIL

The Lundy Granite is the southernmost occurrence of the British Tertiary Volcanic Province which is closely associated with the formation of the North Atlantic Ocean about 60 million years ago. The majority of the igneous rocks associated with this period of crustal rifting (splitting of the earth's crust) remain in Scotland and Northern Ireland.

The Lundy intrusion is largely composed of coarse grained megacrystic granite although fine grained megacrystic granite is also found. The granite is composed of feldspar megacrysts with a groundmass of feldspar, quartz and varieties of mica. The megacrysts lengths are typically between 18mm and 30mm but have been found up to 70mm. Pegmatites - very coarse grained igneous rocks - also occur.

The granite was intruded through Devonian sediments which now form slates. The contact between the granite and slates is seen along Lundy's southern coast. Some of the contact is considered to be insitu although faulting (movement) has occurred along some of the exposed contact.

The granite and Devonian slates have been intruded by a dyke swarm (vertical or near vertical sheets of igneous material). Over 230 dykes have been recognised. The composition of the dykes is largely basic (basalt-like) and the types include: olivine dolerite, olivine-analcime dolerite, olivine-free dolerite and quartz dolerite. About 30 intermediate composition dykes have been identified and include trachytes and trachyandesites.

The derivation of the granite is complex. A basic igneous body is considered to have been intruded about 10km to the northwest of Lundy, but this remains at shallow depth in the crust. The igneous body is considered to have been intruded at about the same time as the Lundy Granite. The Lundy Granite was derived through development (fractionation) of the magma from the basic igneous body.

Weathering of the granite has produced tor-like features which are normally associated with the granite masses such as the older Dartmoor Granite. Also weathering of the granite has produced karst-like features which is a weathering structure more commonly associated with limestone.

11.3. USES

Quarrying of granite on Lundy occurred for centuries. Lundy Granite has been extensively used as a building stone on the island, and notable buildings include Lundy Castle built in the thirteenth century and the more recent St Helena's Church constructed in Victorian times by the former owner of the island, Reverend Hudson Heaven. The village at the southern end of the island is built from quarried granite.

A commercial quarry (The Lundy Granite Company) was established on the island in 1863 encouraged by the island's then owner William Heaven (father of Rev Heaven). The quarry company employed up to 200 workers at the height of the operation which continued for 5 years, but due to mismanagement and difficulties of transporting the granite stone to the mainland the operation ceased. The quarry and associated buildings can still be seen on the east side of the island.

11.4. PLACES TO VISIT

Please refer to the safety guidance about visiting geological sites on our website before visiting the places listed below.

The only exposure of Lundy Granite is on Lundy Island and hence a boat trip or helicopter ride is required. The Educational Register of Geological Sites in Devon (www.devon.gov.uk/educational_register.htm) provides further description of the geology and how to travel to the island.

Granite is exposed along the island's cliffs with numerous exposures. The former granite quarry is located above Quarry Beach on the east side of the island (SS 138 451). Pegmatite locations include: Battery Point (SS 128 449), crags above Jenny's Cove (SS 134 457) and in Gannet's Combe (SS 135473).

Dykes can be seen at the Landing Beach (SS 143 438) and Lamentry Beach (SS 142 437). The contact with the Devonian slate is seen at the Landing Beach but is faulted at this locality.

11.5. PHOTOGRAPHS



Granite Quarry above Quarry Beach on the eastern side of Lundy Island.

© Kevin Page



Cliffs of Lundy Island showing large sections of Lundy Granite

© Tom Hynes



Lundy Granite used as a building stone on the island

© Tom Hynes



Rocks of Lundy Granite used to construct stone walls on the island

© Tom Hynes



The ruins of the former Lundy Granite Company's buildings on the eastern side of Lundy Island.

© Kevin Page



Sections of Lundy Granite clearly seen from boat in the cliffs of Lundy

© Tom Hynes

12. TERTIARY DEPOSITS

by Clive Nicholas



Ball clay workings at Petrockstowe - pale grey clay with beds of dark lignitic clay

© Clive Nicholas

12.1. BRIEF DESCRIPTION

Rocks which date from the Tertiary geological time period in Devon include ball clays, gravels and clay-with-flints.

Ball clays are used to make a wide range of quality ceramic products in everyday use for domestic and industrial purposes, such as tableware and sanitary-ware. It is a scarce and valuable raw material of national and international importance.

The ball clay deposits in Devon occur locally in thick accumulations of sedimentary sands, silts and clays in ancient lake and swamp basins along an important geological structure, the Sticklepath Fault zone, which cuts across the county southeast-northwest from Torquay to near Lundy Island. The two areas actively worked are the Bovey Basin near Newton Abbot and the smaller Petrockstowe Basin about 10 miles north of Okehampton. The sediments contain beds of nearly black clay formed from accumulations of vegetation within the clay. Fossil plant remains of tropical to sub-tropical species show that the deposits were formed in the early Tertiary period, about 50 million years ago when the climate was much hotter and wetter than now.

The Haldon Gravel is considered to be a residual deposit remaining from the chalk which was completely dissolved away in the aggressive tropical climatic conditions of the early Tertiary. It is an unusual and distinctive accumulation of about 18m of flint gravel that caps the Haldon ridge west of Exeter. The flints can be seen abundantly in soils along the footpaths in the Forest Park on the crest of the ridge. The Aller Gravel is similar flint gravel believed to be of the same age found as a layer beneath the ball clay deposits on the eastern edge of the Bovey Basin near Newton Abbot.

In east Devon (and elsewhere in southern England) a widespread surface layer of rock of a similar age and origin is known by the descriptive term 'Clay-with-Flints'. This is the scourge of farmers and gardeners alike because of the abundant flint cobbles in the soil.

12.2. GEOLOGICAL DETAIL

The ball clay sediments, both in scale and commercial value, are the most important feature described in this section. However, some other rocks of closely similar geological age are grouped with them because they are important for understanding the hot, humid climate of the early Tertiary period.

The two main ball clay basins have been much explored both geologically and commercially by drilling, sampling, geophysics and quality testing. The total thickness of sediment in the Bovey Basin is more than 1000m, but only the upper 300m is known in any detail. The Petrockstowe Basin is about 700 metres deep, again only the upper part is well known. The clay properties are different in detail in both areas and find uses in different applications.

The commercially valuable clays occur only in parts of the sequence and even within those parts the clay varies in quality requiring careful selective working and blending to suit customer needs. Further information can be found at the following link:
www.clayheritage.org/pages/whatisballclay.htm

The sediments formed in hot and humid swamps and temporary lakes in a river flood plain draining a tropically weathered landscape on the southern borders of Dartmoor. The Sticklepath Fault was active at the time. A fault is a geological structure along which movement of the earth's crust takes place - as in an earthquake. In this case most of the displacement appears to have been horizontal, about a mile sideways where the Dartmoor granite is displaced on its northern edge. Gradual subsidence occurred in basins along this weakness allowing accumulation of hundreds of metres of sediment all of shallow water origin.

The Haldon Gravels are made up almost entirely of flint. Flint is nearly pure silica occurring exclusively in the Chalk and in younger gravels derived from the Chalk. A small outcrop of Chalk occurs at Beer in East Devon, but most Chalk occurs to the east of this. There is no Chalk at or near Haldon. So how is there this large deposit of flint gravel up to 18m thick on top of Haldon?

A clue is that flints in the lower part of the Haldon Gravels are mostly unworn and have clearly not been transported any distance. The most likely explanation is that Chalk is believed to have covered the whole of Devon when it was formed and some time in the past, probably about 55-65 million years ago, the entire thickness of several hundreds of metres was dissolved away completely leaving a residue of the insoluble flint.

The upper part of the gravel contains flints that are moderately abraded, indicating some erosion and disturbance. Minor clay content is largely kaolinite (like ball clay and suggesting a connection) indicating a freshwater rather than marine environment. Transport by streams is therefore most likely.

How could there have been a stream on top of Haldon, you may ask? The Haldon ridge was not there at that time, it is a product of more recent erosion. The Haldon Gravels appear to have formed part of a large flood plain east and south of Dartmoor connecting with the Aller Gravel of about the same age near Newton Abbot.

The Aller Gravel is about 25m of grey to brown, moderately abraded flint gravel and silty sand at the base of (and therefore older than) the Lower Tertiary clay and sand sediments in the Bovey Basin. The deposit has the characteristics of sediment transported by a river and, as well as flint, the gravel contains cobbles and pebbles of other minerals and rocks derived from the west, an important clue to the direction from which the river was flowing.

Research on these ancient climates is ongoing but evidence is accumulating that the climate was unusually warm, largely tropical, between about 65 and 45 million years ago when the lower Tertiary sediments were formed.

The 'Clay-with-Flints' forms a cap on the flat topped plateau of East Devon. It can be seen from a distance as a brownish-yellow layer up to about 5m thick on the highest points of the sea cliffs between Sidmouth and Lyme Regis. This deposit is a clay containing abundant unworn flints and, like the Haldon Gravel, it is believed to result largely from Chalk having been dissolved away leaving behind the unworn flints.

12.3. USES

The ball clays of Devon have been in general use in Britain for making pottery since the 17th century and since the mid 19th century they have been exported to countries throughout Europe and to the United States.

High quality ball clays are scarce globally and Devon is fortunate to have this 'world class' mineral resource which supports several hundred jobs locally and many jobs elsewhere in the manufacture of products that we all use everyday without much thought to it. The clays are marketed from Devon throughout the world and they owe their continuing demand to their high quality, unique and consistent combination of physical properties.

The main mineral in ball clay is kaolinite, the same mineral as in china clay but in this case with a different crystal structure. This gives it its value as a ceramic raw material because it is highly plastic and can be formed into intricate shapes like tea services and toilet pans that can be handled before firing in a kiln without undue risk of damage. Moreover, after firing it has a light colour, unusual in most other clays.

Exact standards of quality requirements for different ceramic uses means that clays from different quarries or seams have to be selectively worked and blended.

Ball clay is also used in refractories and electrical insulators, in pharmaceuticals and fertilisers and on a relatively small scale it has uses as a filler for rubber and plastic products such as windscreen wipers and garden hoses.

The Haldon Gravel has been worked intermittently on a small scale, mainly for local use on forestry and farm roads. Wider use for construction purposes was not favoured by the content of mainly coarse flint cobbles of limited use and difficult to crush. Better sand and gravel deposits were available elsewhere. Similarly, the Aller Gravel also suffered from the predominance of coarse flint cobbles of little direct use without expensive processing, but gained from the underlying Greensand being suitable for building sand permitting a wider commercial range of products.

The Haldon flints used to be worked on a small scale as a source of silica in the mix for making ceramic tiles at Bovey. The flints were calcined by burning them slowly for several days in small heaps with sawdust or other fuels readily available locally. The silica product was then in a state to be crushed fine for thorough mixing in the ceramic feed. The Haldon flints would not seem to have any special properties for this purpose, just the location being the source closest to the manufacturing site.

Flint was favoured by Stone Age man for making stone tools. This was because it is nearly pure silica, hard and highly durable. It is very fine grained and capable of being 'knapped' to a fine and very sharp edge. It is also widely distributed.

There is no known evidence for the Haldon Gravel having been a source of flints for tool-making. Flint can be almost any colour from black to white or shades of brown but the Haldon flints are generally pale grey in colour and may be recognisable if found elsewhere (see Photo TD4). Quality of the Haldon flint may have been adversely affected

by the harsh tropical weathering in the Tertiary and later the cold periglacial conditions of the Quaternary.

12.4. PLACES TO VISIT

Please refer to the safety guidance about visiting geological sites on our website before visiting the places listed below.

There are relatively few places to visit to see the Tertiary deposits of Devon. In particular, the ball clay pits are mostly well concealed, and as working clay pits they are not accessible to the public.

Haldon Forest Park, Bullers Hill Quarry – is accessible and provides exposures of the Haldon Gravel.

East Devon Coast (part of World Heritage Coast), in particular the sea cliffs east of Sidmouth – provides long distance views of the surface layer of Clay-with-Flints along the tops of cliffs, but generally there is no safe access to allow close inspection of these deposits.

12.5. PHOTOGRAPHS



Ball Clay working, Southacre Pit, Bovey Basin
Photo TD1 © Sibelco UK



Merton Ball Clay Pit, Petrockstowe Basin
Photo TD2 © Sibelco UK



Aller Gravel, with moderately abraded flints.
Photo TD3 © Clive Nicholas



Haldon Gravel unconformably overlying the Upper Greensand (in badger sett) – at Bullers Hill, Haldon Forest Park. Photo TD4. © Clive Nicholas



Distant view of 'Clay-with-Fints' forming surface layer above the vertical cliff of Greensand Chert, at Dunscombe Cliff, east Devon. Photo TD5 © C Nicholas

13. QUATERNARY DEPOSITS AND LANDFORMS

by Clive Nicholas



Raised beach sandrock unconformable on Upper Devonian slates - at Saunton Sands © C Nicholas

13.1. BRIEF DESCRIPTION

Ice Ages, which feature the advance and retreat of ice caps and glaciers, have dominated worldwide history over the last 2.6 million years. This period of the Earth's history is known to geologists as the Quaternary. Studies of this time are crucial in understanding modern climate change. In this case the past is quite clearly the key to the present - and the future.

The photo above is of a sandy beach raised a few metres above present sea level resting on a wave-cut platform of much older slates. Other examples of raised beaches of late Quaternary age can be seen all around the Devon coastline. How can this be?

Also around the Devon coastline are estuaries known to geographers as 'rias', or 'drowned river valleys', such as Plymouth Sound and at Salcombe and Dartmouth. Sea level must have been much lower in the relatively recent past, perhaps more than 100m lower. How did that happen?

At present we are in an 'interglacial' with a relatively temperate climate and sea level is close to its highest. Conversely, when glacial advance was at its greatest and the weather at its coldest, much of the world's water was locked away in the ice sheets, so sea level was at its lowest – very much lower than today.

The fluctuating ice sheets in the coldest periods only just reached the north coast of Devon. South of this, the Devon's climate was very cold with fluctuating freezing and thawing, known as periglacial conditions. This formed a number of landscape features which can be recognised today, see the photograph gallery for examples.

13.2. GEOLOGICAL DETAIL

There is good evidence for ice having reached North Devon. Erratic boulders ('erratic' in this case means 'from somewhere else') of a variety of different rock types foreign to Devon are known at a number of locations around the coastline. Photo QU 1 (later in this document) is of a rounded pink granite boulder over a metre in diameter, originating probably from western Scotland or Ireland, resting on the wave cut platform with the raised beach on top. Also on the wave cut platform beneath the raised beach, and therefore older, are fossil barnacles, see photo QU2.

On top of the Saunton raised beach is a deposit of 'head', seen at the top right of the photo. Head is the name for an ill-sorted mass of cobbles and pebbles in a finer matrix, generally found on top of everything else and usually regarded as a product of periglacial activity. This indicates that the raised beach was formed before the latest glaciation. The erratic blocks must therefore be from an older glaciation. Take great care if looking at these cliffs, the rocks are uneven underfoot and unstable in the cliffs and, as always, make sure to be aware of the state of the tide.

A pit has been worked for many years at Fremington (SS 529 327) feeding clay to the Brannam's Pottery at nearby Barnstaple. Sadly, the pottery closed in 2008. The pit is said to have worked 4 or 5 distinct units of clay, totalling about 10 metres in thickness. There has been disagreement about where this clay came from but scientists now think that it is from the bottom of a lake dammed by the ice along the north coast. Erratics and microfossils indicate that some of the material was derived, at least in part, from the Irish Sea Basin. It is believed to be about 450,000 years old, the time of the penultimate major glacial advance and this links in with the evidence from Saunton.

Elsewhere in Devon, evidence for periglacial conditions usually relates to the most recent glaciation, often known as the Devensian. This lasted from about 100,000 years ago to about 12,000 years ago, but its closest approach was South Wales.

Photo QU 3 of Great Staple Tor looking east from Cox Tor shows boulder runs formed by downhill solifluction (soil flow) from the tor as the frozen ground melted to a slurry. This photograph also shows 'patterned ground' nearer to the camera, another common, though less well understood effect of freezing and thawing on the flank of Cox Tor. Walk north to the tor at SX 531 762 from the large car park at Pork Hill beside the B3357 Tavistock-Princetown road on the western edge of the moor. The walk is steep and rocky needing good footwear but views make it well worthwhile.

River terraces on valley sides represent former floodplains abandoned and left at higher levels as the river valley became deepened. Terraces occur along most of Devon's river valleys as a result of past climatic and related sea-level changes (see photo QU 6). The pattern is complex and research is ongoing. Palaeolithic implements made largely of local chert from the Upper Greensand and dated at around 200,000 years old, or earlier, have been found in the River Axe terrace gravels in East Devon.

Other human tools and bones of animals, now long extinct in Britain, are known from a range of ages in several limestone caves in South Devon. Kents Cavern at Torquay (SX 934 641), a tourist cave sensitively conserved, has yielded tools that may be as old as 500,000 years or more.

Hippopotamus and elephant remains found in peat and clay at Honiton and Barnstaple date from the last interglacial phase before the present, about 120,000 years ago and indicate that the climate then may have been significantly warmer than today.

13.3. USES

Uses for minerals from the Quaternary in Devon are few, although nationally the industrial value of sand and gravel for construction purposes won from Quaternary river gravels and fluvioglacial gravels (gravels from rivers associated with glaciers) is immense.

Only the Axe Valley gravels close to the Devon-Dorset border have been worked for local construction to any significant extent at Kilmington and Chard Junction.

Valley and terrace gravels of Quaternary age are present elsewhere in the river valleys of the county but they have not been worked because construction aggregates are available more readily from other deposits. There are no fluvioglacial deposits in the county.

Small scale use of the glacial clay of Fremington in the manufacture of distinctive and much valued terracotta pottery at Barnstaple has been mentioned above but the pottery is now closed.

Not strictly a use, but especially important culturally and economically, is the value of the Quaternary landforms to the scenery and the tourism industry of Devon.

13.4. PLACES TO VISIT

Please refer to the safety guidance about visiting geological sites on our website before visiting the places listed below.

Saunton Sands and cliffs

Location: Sea cliffs west of Saunton Sands Hotel, North Devon. Parking and bus service available.

Photo Viewpoint: Saunton Sands beach, looking north.

Ordnance Survey 1:50 000 Sheet 180, National Grid Reference: SS 442 378.

The coastline from Baggy Point south to Saunton Sands is a magnificent sight. The rocks are about 370 million years old (Devonian) and include a wide range of sedimentary rock types such as sandstones, shales, slates and limestones. The bulk of these were probably laid down in shallow marine or brackish waters. Today, the effect is impressive and the coastline boasts rugged cliffs rising in places to 60m. There is evidence of the past stresses and pressures that have been at work here, with dramatic folding and fractures in the rocks being quite common.

Of particular interest are the signs of Ice Age activity in the area. Raised platforms cut by wave action at times of high sea levels are now home to a number of large boulders transported here by ice. Some of these may have been carried considerable distances. The most famous, the Saunton Pink Granite, weighs in at 12 tonnes and is likely to have come all the way from the northwest highlands of Scotland. This can be viewed from the foreshore but if visiting the erratic please check the incoming tide as there is the risk of being cut off from the beach.

Braunton Burrows

Location: Close to Saunton Sands, the same car park and bus service can be used. The SW Coastal Path and Tarka Trail cycle route run close by.

Ordnance Survey 1:50,000 Sheet 202, National Grid Ref: SX 460 370

Braunton Burrows is one of the largest sand dune systems in Britain, about 5km long (north south) and 1½km wide, with lime-rich dunes up to 30m high. The central area of the Burrows consists of three ridges, separated by slacks. The ridges lie parallel to the shore with an overall width of 1.3km. The highest dunes and ridge occur in this region. There is much ecological interest here and most of the dune area is vegetated and considered stable. A mobile part of the dune system occurs at the rear (east side) in a fairly restricted area, Photo QU 6.

This area is part of the much larger world-class North Devon Biosphere, designated by UNESCO for its exceptional biodiversity. www.northdevonbiosphere.org.uk/

William Pengelly Cave Studies Centre and Joint Mitnor Cave, Buckfastleigh

Location: Near the station in Buckfastleigh head uphill on the narrow and steep Russetts Lane towards the ruined church on the hilltop. Parking is available.
Ordnance Survey 1:50,000 Sheet 202. National Grid Ref: SX 744 665

Higher Kiln Quarry and the associated field centre incorporates Joint Mitnor Cave which is famous as a prime location for cave vertebrate remains, it includes a remarkable talus cone in the cave with the richest assemblage in Britain of mammal remains from the last interglacial about 120,000 years ago, see photo QU 5. This includes straight tusked elephant, narrow-nosed rhinoceros, bison, hippopotamus and hyena. There is a display at the centre and guided tours of the cave operate during August, but best to phone beforehand.

Kents Cavern

Location: In a built up area of Torquay, there are displays and a shop and restaurant at the site. A bus service operates from the town and parking is available. Directions are signposted off the main road. Guided tours of the cave operate several times a day throughout the year - www.kents-cavern.co.uk/. There is an admission charge.
Ordnance Survey 1:50,000 Sheet 202, National Grid Ref: SX 934 642

Kents Cavern is fascinating for both its geology and human history. It boasts beautiful and spectacular geological formations and significant prehistoric finds, including flint hand-axes dating from over 450,000 years ago. It is one of the oldest recognisable human occupation sites in Britain.

13.5. PHOTOGRAPHS



Pink granite boulder – an ‘erratic’ - beneath the raised beach at Saunton, north Devon. Photo QU1 © North Devon AONB



Fossil barnacles on the slate platform beneath the raised beach at Saunton, North Devon. Photo QU2 © C Nicholas



Dartmoor periglacial features. Boulder runs at Great Staple Tor in distance; patterned ground in foreground at Cox Tor. Photo QU3 © C Nicholas



Kents Cavern, Torquay show cave, famous for human and animal remains dating back hundreds of thousands of years. Photo QU4. © Kents Cavern



Joint Mitnor Cave, Buckfastleigh. Concentration of vertebrate remains on talus slope in the cave. Photo QU5. © Kevin Page



Three river terraces between the house and the River Exe north of Tiverton. Photo QU6. © Jenny Bennett