The Upper Greensand of the Haldon Hills and East Devon

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Abstract: When the Upper Greensand of the Haldon Hills was surveyed in the 1960s poor exposure made its subdivision impossible, but a seismic survey revealed a remarkable thickness variation from 16m to 84m. This variation was explained in terms of contemporaneous down-folding of the basement during deposition. Later excavations for the re-aligned A38 road across Great Haldon yielded good sections that enabled a succession to be compiled and aided correlation with the sections in East Devon. There remain major questions concerning the erosional history of the Upper Greensand, and there is no explanation either for the survival of the Haldon Hills themselves or for the absence of any Upper Greensand outliers between Haldon and the main outcrop of East Devon.

The Upper Greensand is the youngest formation of the British Cretaceous sequence beneath the Chalk Group, which overlies it unconformably. In south-east England it crops out extensively along the edge of the Chalk outcrop, and in East Devon, as far west as Sidmouth, there are several large outliers only locally overlain by the Chalk Group. There is then a 20-km gap from there to the outliers on the Haldon Hills and even farther west on the eastern side of the Bovey Basin (Fig. 1).

Between Exeter and Teignmouth, the Haldon Hills form an elongated plateau remnant, capped by the Palaeocene Haldon Gravels, which are underlain by the Upper Greensand and then the Permian Teignmouth Breccias. In the 19th century there were extensive quarries in the Greensand on Haldon, working chert for whetstones as well as working the sands (Ussher, 1913), and also building a profitable trade in silicified fossils for sale throughout Europe. By 1966 these excavations were overgrown, and exposures were restricted to streambeds and disused quarries in the Haldon Gravels. The latter have also since become overgrown, so the exposure is even worse now, and for anyone interested in the Upper Greensand (Gallois, 2004: Edwards and Gallois, 2004), the best place to start is on the coast sections of East Devon, between Sidmouth and Charmouth, where sections in the sea cliffs are kept fresh by continual landslips and marine erosion (Fig. 2).

During the Late Albian (topmost Lower Cretaceous), blankets of glauconitic sand were deposited throughout southern England beneath rising sea levels, and the resulting Upper Greensand consists of fine-, medium- and coarse-grained calcareous sandstones along with calcarenites with varying amounts of silica, glauconite, comminuted shell debris and broken shells. There is a rich shallow-water fauna of bivalves, brachiopods, gastropods and echinoids, with a very few ammonites that confirm a Late Albian age. Sedimentary structures including trough and planar cross-bedding, hummocky cross-stratification and ripple-drift bedding indicate current-agitated water throughout. The green mineral glauconite is indicative of tropical marine deposition, and accounts for the name Greensand, although at outcrop the glauconite has usually weathered to red or brown iron hydroxides or washed out completely,

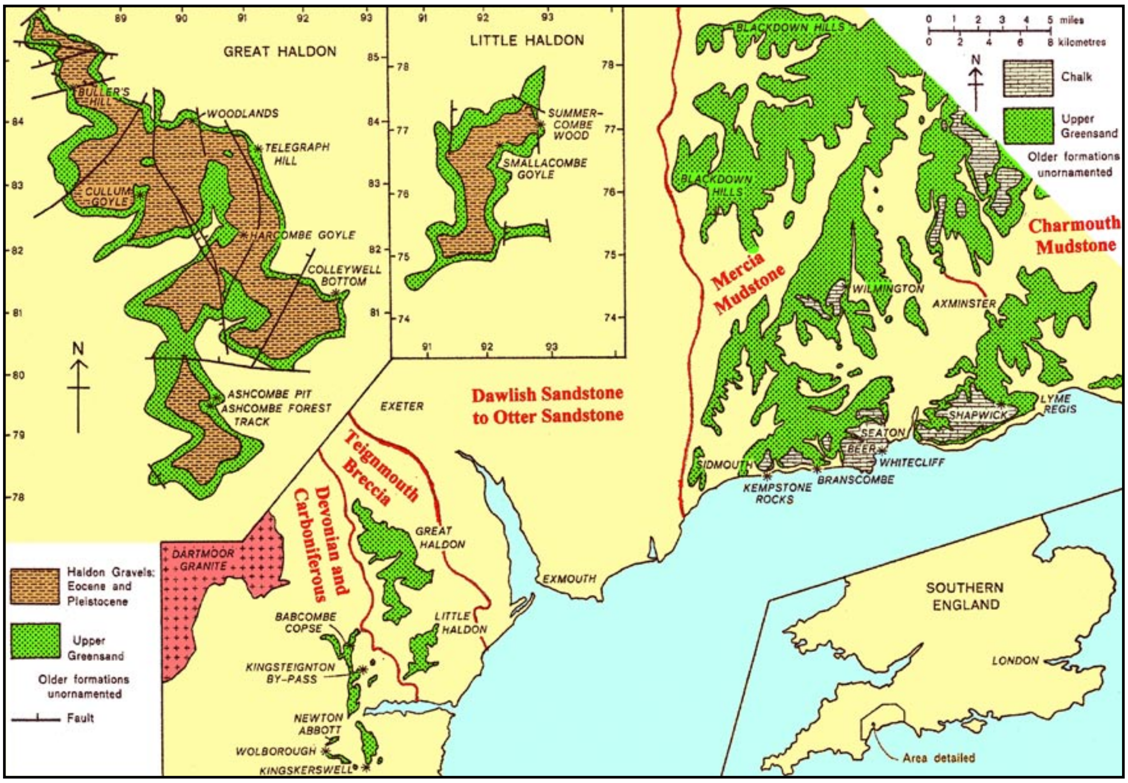

Figure 1. *Cretaceous outcrops in Devon, with inset maps of Great Haldon and Little Haldon (after Hamblin and Wood, 1976). Limits of pre-Cretaceous strata are shown in red.*

***Figure 2**. Cliffs west of Branscombe exposing almost the complete Upper Greensand sequence overlain by white Lower Chalk. Foreground vegetation is on the landslip debris.*

so that the Upper Greensand is either shades of brown or pale yellow. In the Sidmouth-Beer district the formation is 45-55 m thick and is divided into three members, separated by mineralised erosion surfaces or hard-grounds (Table 1).

Bindon Sandstone Member (up to 8m): fine- to coarse-grained sandstone and calcarenite; chert horizons restricted to the lower part of the member east of Beer Head; slumped beds, contortions and festoon-bedding in the higher part.	
Whitecliff Chert Member (up to 32m): fine- to coarse-grained sandstone and calcarenite with many horizons of nodular and tabular chert.	
Foxmould Member (20-25m): finer grained and more siliceous than the overlying members, fine- to medium-grained sand with clay beds, calcareous cement and siliceous doggers. The high quantity of glauconite accounts for the common 'foxy red' colour of this member, which in turn accounts for its name.	

***Table 1**. The Upper Greensand in East Devon.*

Mapping in the 1960s

In the Haldon Hills the Upper Greensand generally exhibits steep slopes with changes of slope, which are easily mapped, against the overlying Haldon Gravels and the underlying Teignmouth Breccia. Small exposures demonstrate that the Upper Greensand on Haldon is coarser and less clayey than that farther east, which is to be expected since during the deposition of the Upper Greensand, the Dartmoor massif would have been land and the coastline was only about 8 km west of Haldon. The presence of this land was confirmed by large quantities of Dartmoor-derived quartz and schorl (quartz-tourmaline rock) in the Greensand (Tresise, 1960). The Upper Greensand of Haldon is more deeply weathered than that in East Devon, possibly because the lack of clay made it more permeable, and the Haldon material is totally decalcified, falling thus in the 'Blackdown Facies' (Tresise, 1960). Little glauconite survives, although its previous widespread presence is commonly confirmed by red colouration of the sands, particularly in the lower parts of the sequence (Fig. 3). Fossils, particularly exogyrine oysters, are common, but wholly silicified to the mineral beekite.

Poor exposure then made it impossible to prove or disprove the presence of the three members known in the Upper Greensand of East Devon (Table 1). However, the Haldon sequence did appear to be divisible into three units, since a loose quartz conglomerate and coarse pebbly sands form a shelf roughly half way up the hillside (Selwood *et al*., 1984). However it was not possible to correlate this with the Whitecliff Chert Member (Table 1) since exposures in quarries for the Haldon Gravels indicated that the chert beds on Haldon occur in the top unit of the Upper Greensand (Fig. 4).

The Upper Greensand is marked by steep slopes that were traced all around Haldon and made it easy to measure the thickness of the unit, which varied between 16m and 37m, but this degree of variation was surprisingly high. Since Haldon was so near to the coast during deposition of the Upper Greensand, it would be expected to be thinner there than farther east, where it is 45-55 m thick on the East Devon coast. Indeed, Dewey (1948) states 'The Greensand of Devon decreases in thickness from east to west. In East Devon it is 200 ft thick, at Beer, 156 ft, at Peak Hill, Sidmouth, 90 ft, whilst in the most westerly outliers of the Haldon Hills, near Exeter, the minimum thickness recorded is 75 ft'. Not only was Dewey wildly wrong with the thickness at Haldon, but Upper Greensand was not recognised farther west, in the Bovey Basin (Fig. 1). This most westerly Upper Greensand in Britain was shown by William Smith on his maps of 1815 and 1820.

Clearly the thickness of the Upper Greensand on Haldon needed further investigation, and the seismic survey system at Exeter University proved adequate for recording the depths of the bases of the Haldon Gravels and of the Upper Greensand (Durrance and Hamblin, 1969). Twenty seismic lines were run, and contour maps were produced for the base of the Upper Greensand (Fig. 5) and the base of the Haldon Gravels (Hamblin, 1972). Normal, dip-slip faults known from mapping around the hill were confirmed and could now also be plotted across the hill (Fig. 5). Throws ranged up to 20 m, and since they all cut the base of the Haldon

***Figure 3**. 'Foxy red' fine- to medium-grained sands low in the Upper Greensand sequence on Haldon (Telegraph Hill Sands); the colour is due to glauconite oxidising to ferric hydroxides.*

Figure 4. Massive chert blocks worked from the top of the Upper Greensand sequence (Cullom Sands with Cherts Member) at Buller's Hill Quarry (see Figure 1).

Gravels as well as that of the Upper Greensand, they were clearly all post-Late Cretaceous. Thicknesses measured for the Upper Greensand not only confirmed the remarkable variation of thickness on Haldon, but also had maxima that were unexpectedly high compared with East Devon. Eight measured thicknesses exceeded the 55 m figure for East Devon, and the maximum was 75m, and since this was measured below the crest of the hill it must represent an original thickness of the Upper Greensand of 84 m, by far the thickest known anywhere in England.

Structural interpretations

To produce a map of the base of the Upper Greensand as it would have been in immediately post-Upper Greensand times (Figure 6), the effects of these faults and also of the gentle folding found in the base of the Haldon Gravels were removed. The base of the Upper Greensand proved to be far more complex than expected, comprising a series of minor warps on a larger, shallow structure (Fig. 6). The minor warps take the form of inverted periclines, orientated east-west and separated by anticlinal areas: it proved impossible to interpret the data as forming upright periclines. The larger structure indicated by the contours at 200, 190 and 180 m, describing a roughly semi-circular arc around Harcombe (Fig. 6), could be interpreted as a trough plunging to the WSW or as the eastern half of a large basin - another inverted pericline (Fig. 7).

The shape of the surface between the Upper Greensand and the Teignmouth Breccia could not readily be interpreted as the results of fluvial erosion of the breccia before the Upper Greensand transgression, or as the result of tidal scouring during the transgression. It had to reflect tectonic folding (Durrance and Hamblin, 1969). Whereas all the faults detected are post-Late Cretaceous, this folding must be pre-Late Cretaceous, since the effects of folding of the Haldon Gravels have been removed from Figures 6 and 7. The question of whether this folding was contemporary with or after the period of formation of the Upper Greensand was

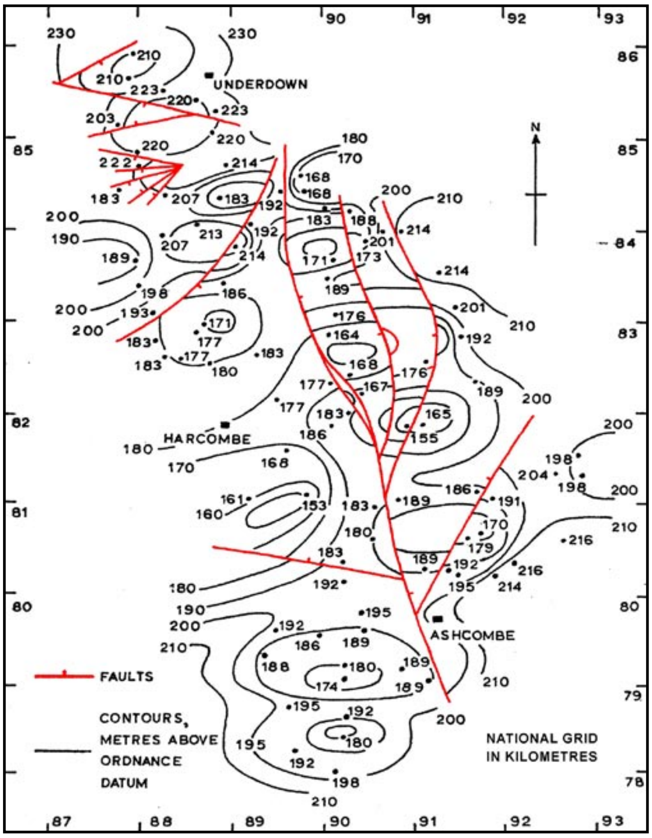

Figure 5. Contour map of the base of the Upper Greensand on Great Haldon, showing all post-Senonian faults known to cross the hill (after Durrance and Hamblin, 1969).

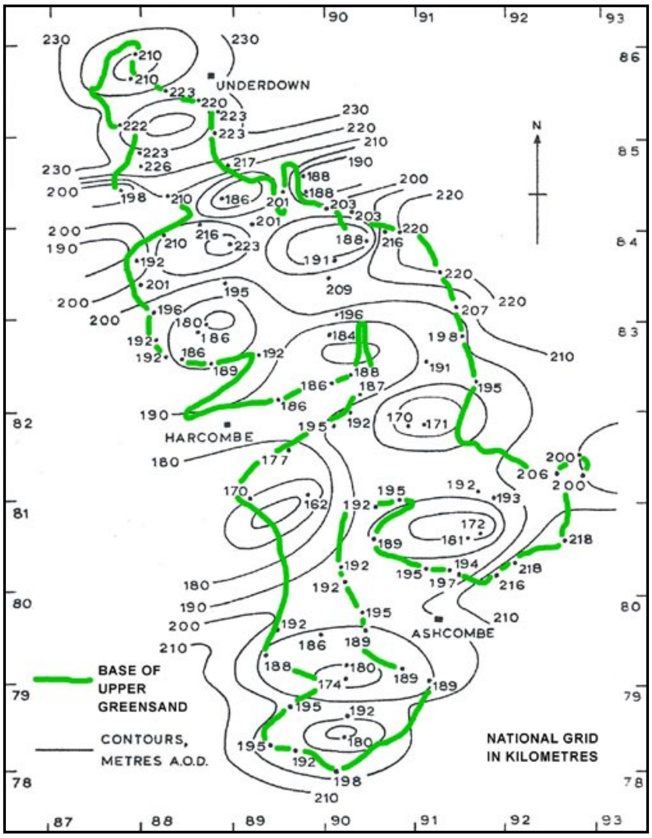

Figure 6. Contour map of the base of the Upper Greensand after removal of the effects of post-Senonian faulting (after Durrance and Hamblin, 1969).

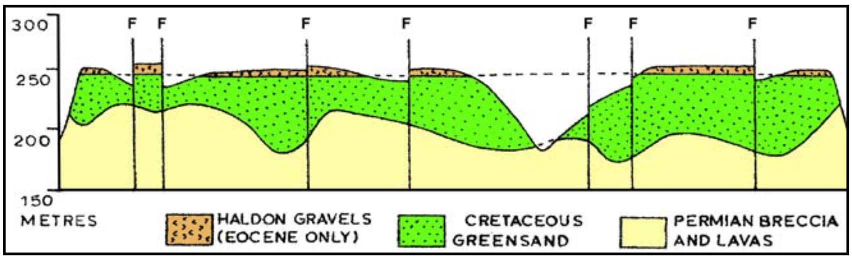

Figure 7. Diagrammatic section along the length of Great Haldon, with the effects of post-Senonian faulting removed in order to restore the base of the Upper Greensand to its pre-Chalk situation, the section extends over 7500 metres (after Durrance and Hamblin, 1969).

debatable (Durrance and Hamblin, 1969). However, it must be contemporaneous, because if there had been no folding or subsidence during deposition, it is inconceivable that 84 m of Upper Greensand could be deposited within the Haldon area while only 45-55 m was deposited in East Devon. Support for this age of the folding was given by the loose quartz conglomerate being apparently restricted to areas of thinner Upper Greensand, where a shallower-water facies would be subjected to current winnowing. Also, boreholes southeast of Underdown (Figs. 5, 6) showed greater development of chert in the more tranquil conditions of the areas where thicker Upper Greensand was deposited. It was concluded that the folding resulted from simple north-south compresion, with deformation of the Permian-Cretaceous cover more or less independently of the Hercynian basement, comparable with more gentle folding in the Beer-Seaton district (Smith, 1965).

The survey also explained the shape of the Haldon Hills, since a comparison of the Upper Greensand outcrop with the position of the basins (Figs. 6, 7) demonstrates that the basins are largely contained within the hill and the outcrop follows the structural highs between the basins. This is due to the style of erosion of the Upper Greensand: rain-water soaks into the very permeable sand, travels freely down through it, and emerges at the base on the impermeable Teignmouth Breccia. Where the base of the Upper Greensand slopes outwards from the hill at the outcrop, water drains out and causes the sand face to retreat by spring-sapping. When this retreat reaches the ridge between the inverse periclines, the base of the Upper Greensand ceases to dip out of the hill, so the spring-sapping and back-wearing stops, and erosion proceeds elsewhere. Thus much of the outcrop of the base of the Upper Greensand follows the ridges between the basins. Erosion now takes place on the west side of the hills, where the westward plunge of the major trough causes the ridges between the periclines to be lower than on the east side of the hills and groundwater therefore emerges at the base of the sand.

Mapping in the 1970s

Excavation of cuttings for the re-aligned A380 (Exeter to Torquay) road in 1968 (Fig. 8) did not contribute to interpretations of the sequence, because the earth-scrapers smeared the exposures, though grass rapidly grew along the base of the Upper Greensand where water emerges. Excellent sections finally appeared in the Upper Greensand of Haldon in 1971, when torrential rain excavated deep gullies in cut faces along the re-aligned A38 (Exeter to Plymouth) road across the north end of Great Haldon (Fig. 9). The sections were logged in detail, and a formal lithostratigraphy could at last be created (Hamblin and Wood, 1976), based on a type section at Woodlands Goyle at NGR SX902840 (Fig. 10). Variations in thickness down to the level of individual beds were observed and these confirmed the concept of folding contemporaneous with deposition. In the Woodlands section, beds measured in the centre of the Bovey Basin totalled 21.4 m, of which Beds 6 to 21 totalled 14.8 m, whereas on the flanks of the basin (at NGR 901838) these beds are thinned to a total of only 7.3 m. The longest, continuous, measured section on Haldon, at the former quarry at Smallacombe Goyle (Jukes-Browne and Hill, 1900), totalled 28 m, and correlation of its description with the type section suggests expansion of individual beds rather than the addition of higher beds. Based on the Woodlands type section, four members were recognised within the Upper Greensand of Haldon (Table 2, Figs. 11, 12, 13).

Detailed palaeontology and sedimentology (Hamblin and Wood, 1976) enabled correlation of the Telegraph Hill Sands with the Foxmould of East Devon, the Woodlands Sands with the bulk of the Whitecliff Chert, and the Ashcombe Gravels with the remainder of the Whitecliff Chert (Beds 15 and 16 of the Ashcombe Gravels) and the Bindon Sandstone (Beds 17 to 19 of the Ashcombe Gravels). The Cullom Sands with Cherts are correlated with the Beer Head Limestone Formation of Cenomanian age. Whereas the latter is represented at Beer by a highly bioturbated, richly fossiliferous, porcellanous limestone (Edwards and Gallois, 2004), inland from Beer it includes the Wilmington Sand Member, a glauconitic calcareous sandstone. However, both chronostratigraphically and lithologically the Beer Head Limestone is a part of the

Figure 8. A cutting along the re-aligned A380 road exposing the boundary between the yellow-bown Upper Greensand and the underlying red Teignmouth Breccia.

Cullom Sands with Cherts (Figure 11; Beds 20 to 23 on Figure 10, 6.71m thick at Woodlands). Green and brown, glauconitic, slightly pebbly sands with banded cherts and clay bands, horizons of quartz granules, tourmaline and kaolinised pebbles. Exogyrine oysters and abundant orbitoline foraminifera in the blocks of chert.
Ashcombe Gravels (Figure 11; Beds 15 to 19, 5.28m thick at Woodlands). Sandy quartz gravels and coarse gravelly quartz sands, with cross-bedding, iron cementation, kaolinised rock fragments. Fauna dominated by beekitised exogyrine oysters.
Woodlands Sands (Figure 12; Beds 7 to 14, 4.14m thick at Woodlands). Complex and variable succession of glauconitic clayey sands, shell drifts and sands with carious siliceous concretions and chertified sandstones. Coarser than the Telegraph Hill Sands, less well sorted and essentially clay-rich, with bands of green clay. Fauna has 27 species of coral, oysters and other bivalves, bryozoans, sponges and brachiopods, but no orbitolines. Corals prove a tropical shallow-water environment (Wells, 1967); pholadid borings in the corals confirm the near-littoral situation.
Telegraph Hill Sands (Figure 13; Beds 1 to 6; 5.26m thick at Woodlands). Sands, green and red with weathered glauconite; clay-free, well sorted, poorly consolidated. Glauconitic quartziferous sandstones and careous siliceous concretions (cherts). Fauna is dominated by molluscs, gastropods and very few ammonites. Small pebbles at the base. A massive basal conglomerate locally in depressions in the pre-Cretaceous floor, with a diverse oyster fauna, and fragmentary corals and orbitolines (the earliest occurrence of orbitoline foraminifera in the British Cretaceous).

***Table 2**. The Upper Greensand on the Haldon Hills.*

Grey Chalk Group, whereas the cherty sands of the Cullom Sands with Cherts are included in the Upper Greensand Formation. The presence of Cenomanian Upper Greensand on Haldon was not entirely unexpected, since fossils within the flints preserved in the Haldon Gravels are all Senonian and it is unlikely that the Cenomanian and Turonian were represented by a major hiatus on Haldon (Hamblin, 1968).

Survival of the Haldon Hills

By the mid-1970s the stratigraphy, structure and mode of erosion of the Upper Greensand of Haldon were reasonably well understood. But the problem remained as to why the Haldon Hills were still there at all. The main outcrop of the Upper Greensand of southern England extends as far west as Sidmouth (Fig. 1), and it is likely that erosion has steadily worked this western limit back eastwards from an original position on the

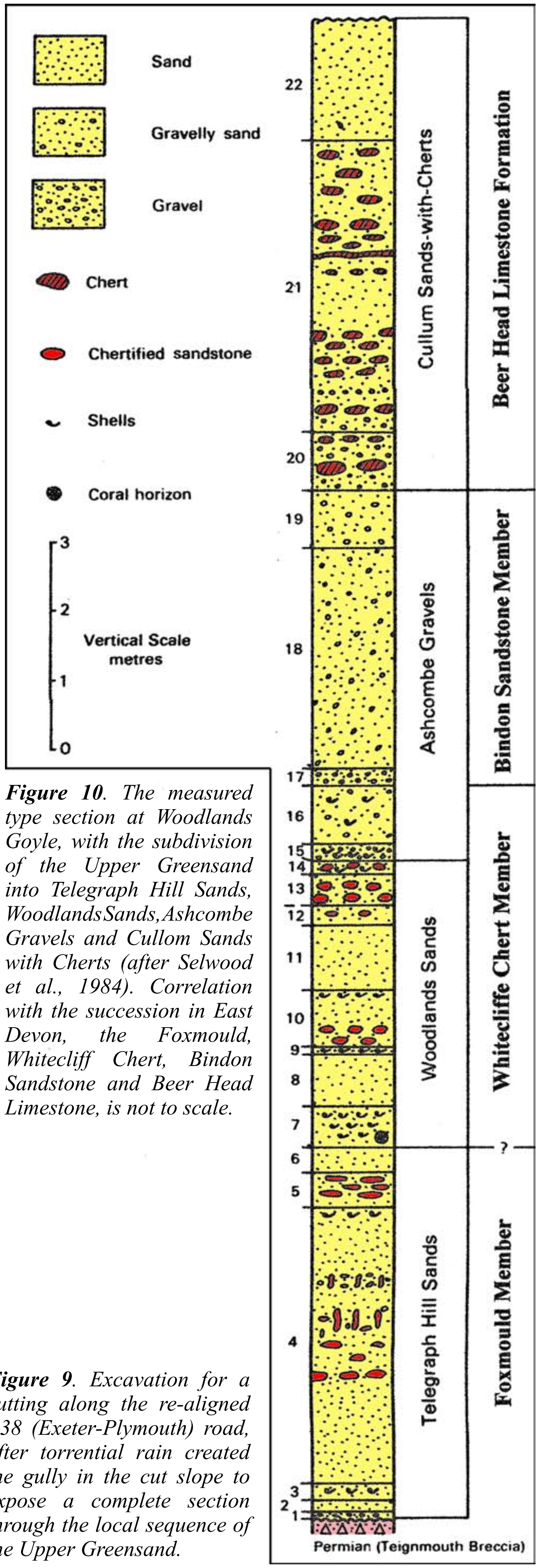

***Figure 10**. The measured type section at Woodlands Goyle, with the subdivision of the Upper Greensand into Telegraph Hill Sands, Woodlands Sands, Ashcombe Gravels and Cullom Sands with Cherts (after Selwood et al., 1984). Correlation with the succession in East Devon, the Foxmould, Whitecliff Chert, Bindon Sandstone and Beer Head Limestone, is not to scale.*

***Figure 9**. Excavation for a cutting along the re-aligned A38 (Exeter-Plymouth) road, after torrential rain created the gully in the cut slope to expose a complete section through the local sequence of the Upper Greensand.*

Figure 11. *Ashcombe Gravels, coarse green and brown sands of Beds 18 and 19, and (level with Chris Wood's head) pale brown Beds 20-21 of the Cullom Sands with Cherts.*

flanks of Dartmoor. Why has Haldon survived as an outlier, 20 km west of the main outcrop? The Bovey Basin, immediately west of Haldon and in which are found the down-faulted Upper Greensand outcrops from Babcombe Copse to Kingskerswell (Fig. 1), is a major structure of enormous depth, a pull-apart basin lying along the Sticklepath Fault. This is a major Tertiary wrench fault, and the Bovey Basin dropped down during the late Eocene (Selwood *et al*., 1984). Since the Tertiary deposits would never have filled the basin, Haldon must have stood as a hill ever since the Eocene. The Upper Greensand of Haldon is eroding on the west side of the hill, since the overall dip of the base is westward, so the hill should be retreating eastward. So why is it still sitting just above the Bovey Basin, where it must have stood from the Eocene to the present day?

This question is still unanswered, and a further complication has appeared. The Upper Greensand is seen to erode at its base where it rests on an impermeable substrate; it would be then expected that where the Upper Greensand rests on a permeable substrate, it should be stable, since percolation of groundwater freely down through the underlying sand would preclude spring

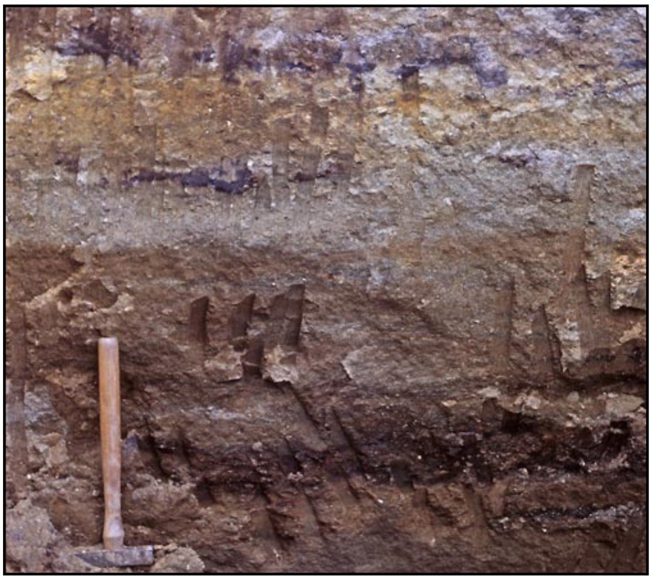

Figure 12. *Woodlands Sands, Beds 8 to 11 at Woodlands: glauconitic clayey sands, shell drifts and sands with careous siliceous concretions, chertified sandstones and green clay.*

Figure 13. *Telegraph Hills Sands, Beds 4 to 6 at Woodlands, green and brown sands and pebbly sands with cherts.*

development and the associated sapping and erosion at the base of the Greensand. Yet the exact opposite appears to be the case in Devon. Across most of its outcrop the Upper Greensand rests conformably upon the impermeable Gault clay, and beyond the western limit of the Gault it lies unconformably on similarly impermeable Jurassic Charmouth Mudstone and then Triassic Mercia Mudstone. However, across the 20 km gap between Sidmouth and Haldon, where the Upper Greensand is absent, the permeable Otter Sandstone, Exe Breccias and Dawlish Sandstone occur at the surface, and then the Upper Greensand of Haldon appears again resting on the impermeable (and ill-named) Teignmouth Breccia. This appears to be the wrong way round in terms of erosional susceptibility. Even if the rivers Exe, Otter and Axe can be blamed for a lot of erosion, why are there no Upper Greensand outliers resting upon the permeable Permian and Triassic formations between Exeter and Sidmouth? The Upper Greensand outlier on the Haldon Hills appears to be a complete anomaly, and by all logical reasoning should have been eroded away a long time ago. An explanation will be welcome.

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