

THE SUB-FOSSIL ASSEMBLAGE FROM A HOLOCENE CALCAREOUS PALAEO SOL IN DAYMER BAY, NORTH CORNWALL

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The Daymer Bay submerged forest site, on the east side of the Camel Estuary, N. Cornwall, has recently been re-examined. This thin intertidal organic-rich deposit yields a well preserved sub-fossil biota consisting of terrestrial gastropods, insects and small vertebrates as well as rooted tree stumps and other plant macrofossils. The preservation of a fossil assemblage of this type is unusual in the peat-rich deposits normally associated with Holocene submerged coastal forests in Cornwall. Preliminary indications suggest that, rather than an acidic peat or histosol, the Daymer deposit represents a calcareous hydromorphic soil probably developed in an inland, predominantly well-drained scrub/woodland environment, with minor input of flora and fauna from bordering ponds and streams running into the River Camel. There are some indications that this deposit has preserved evidence of a snail death assemblage. There is no evidence of contemporaneous marine biological input or influence in the deposit which was probably buried by dune encroachment before humification and loss of calcareous elements could occur. The calcicole elements of the sub-fossil fauna and flora indicate the influence of blown calcareous sand in this early ecosystem as is seen in present day ecosystems fringing dunes along the N. Cornish coast. A sample of wood from the palaeosol has been radiocarbon dated to Cal BC 2470-2290 (2 Sigma cal. 95% probability). Later marine transgression, coupled with meteorologic run off from the shell-rich dunes, is considered to be responsible for the development of the associated beachrock and calcareous sand reefs.

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INTRODUCTION

The remains of Holocene forests, frequently associated with peat-rich palaeosols, are a feature of the coastlines and estuaries of the South-West peninsula and the Bristol Channel (French, 1999; Bell, 2007). Major studies of coastal wetland deposits in Devon and the Severn Estuary (Balaam *et al.*, 1987; Bell, 2007) reveal organic-rich palaeosols associated with submerged forest remains as important sources of plant macrofossils, pollen and diatoms. Vertebrate remains, associated with human artefacts and activities, are relatively common in many of these deposits (Bell, 2007). In his review of the submerged forest palaeosols of Cornwall, French (1999) summarized palaeobotanical information on submerged forest and palaeosol deposits in the county, including radiocarbon dates, but noted a dearth of evidence of associated human activity.

Radiocarbon dating indicates that these submerged forest and peat deposits formed in southwest UK during the development of coastal wetlands linked to rising sea level throughout the Holocene (French, 1999; Bell, 2007). In broad terms UK relative sea level (RSL) was some 50 m lower than at present at the beginning of the Holocene (~12 ka BP) but rising rapidly after the last deglaciation (Lambeck, 1995; Shennan and Horton, 2002). The rate of RSL decreased, probably between 7 ka and 4 ka BP, when sea levels were ~10 m and ~2 m, respectively lower than today (Edwards, 2006; Gehrels *et al.*, 2011). It is mostly those forests formed and preserved during

that time interval and later that are intertidally exposed today in the far south west of the UK. The few detailed studies on coastal peats and submerged forests in Cornwall and the Isles of Scilly where radiocarbon dates are recorded generally span 8-1 ka BP (Johns *et al.*, 2008; Healy, 1995; Cole, 2001; Ratcliffe and Straker, 1996) and listed by Hazell (2008) and the Cornwall and Scilly Historic Environment Record website (CSHER, 1975-present).

Although usually observed in inter-tidal zones, peat deposits and forest beds have also been recorded by off-shore drilling in, for example, Mounts Bay (Camm, 1999) and Falmouth Bay (Ratcliffe, 1997), by on-shore drilling around Penzance (Healy, 1995), exposed by coastal erosion in North Cornwall (Clarke, 1976) and historically inland by stream tin gravel workings (Ussher, 1879a). Of the Cornish palaeosols and submerged forests the most extensive is the intertidal forest and associated peat exposed in Mount's Bay around Penzance. A number of radiocarbon dates around 4 ka BP for wood and peat from this and other localities have been recorded (Hazell, 2008) and were interpreted as evidence of mid to late Holocene transgressive submergence of Cornish coastal forests. It is now considered (French, 1999) that several factors may have played a part in submergence, including shoreline sediment barriers, and that the formation of submerged forest deposits was not the result of a single transgression event.

The Daymer Bay submerged forest bed, located on the east

side of the Camel Estuary, 2 km north of Padstow (Figure 1), has rarely been well exposed over the past century and a half. Good exposures occurred in 2009 and 2012/13 permitting detailed examination and sampling of the preserved forest bed fauna, particularly the terrestrial gastropods and macroflora, and an assessment of the adjacent beachrock and cemented sand reef. Although sub-fossil snails are well known from a number of sites in Cornwall (Turk, 1984; Turk *et al.*, 2001), records from palaeosols associated with submerged forests, other than noted in passing by Henwood (1858) and Ussher (1879b) at Daymer, are absent. This study summarises the history of the Daymer Bay submerged forest site, records data on the analysis of the deposits and macrofauna and macroflora contained therein. Preliminary evaluation of the snail shell assemblage and plant macrofossil content is presented, a radiocarbon date for the

deposit recorded and an assessment made of the environmental conditions at the time of deposition.

Historical observations

The 'Submarine Forest' in Daymer Bay, exposed in 1857, was first described by Henwood (1858) as layers of earth and "vegetable mould", containing *in situ* tree stumps, with roots extending up to 6 m horizontally, together with trunks including oak, yew and hazel, overlain by sand and earth containing dune-dwelling snail shells and, allegedly, horns of red deer. Henwood noted that this layer extended beneath the Doom Bar, and he connected the Daymer Bay forest to traces of submerged forest found c. 1800 in Harbour Cove (Figure 2) on the west side of the Camel Estuary. Trollope (1860) also describes the 1857 exposure, noting large indurated trunks, remains of softwood trees, layers of hazel nuts intercalated with hazel leaves, and remains of various animals. Ussher (1879b) describes masses of peaty matter in Daymer Bay containing twigs and very fragile land shells (including *Cepea* (*Helix*) *nemorialis* and *Bythnia tentaculata*) adjacent to an old beach reef consisting of laminated consolidated shell sand. He did not appear to locate the submerged forest commenting that "During the 17 years which had elapsed between Mr Henwood's visit and my own, considerable changes must have taken place, both in the destruction of the vegetable remains, and in the exposure of the old consolidated beach reefs". Reid *et al.* (1910) considered that the Daymer Bay forest was rooted upon cemented sand reefs identical to the cemented deposits forming the cliffs at Trebetherick Point.

Little is recorded on exposures of the Daymer submerged forest during the rest of the 19th and first half of the 20th Centuries. Arkell (1943) remarked that the forest was exposed at spring tides; Clarke (1965) however noted at the time that no one in living memory remembered the forest remains being uncovered at any time. Unpublished reports in Cornwall and Scilly Historic Environment Record (CSHER, 1975-present) record exposure of cart rutways in "swampy salt marsh deposits" and a large shell midden "in the muds of the relict salt marsh" in Daymer Bay; images of the midden (Cornwall and Scilly Historic Environment Record Office, 2001) clearly show that this occupies the upper part of the Daymer forest bed.

Henwood (1858) mentions and Ussher (1879b) described in some detail the cemented intertidal beach reefs adjacent to the forest bed in Daymer Bay. Ussher considered that the beach reef marked a late Pleistocene raised beach formed when sea level was formerly at its present level. Howie (2009) described the cemented sand associated with the forest deposit as a Holocene beachrock.

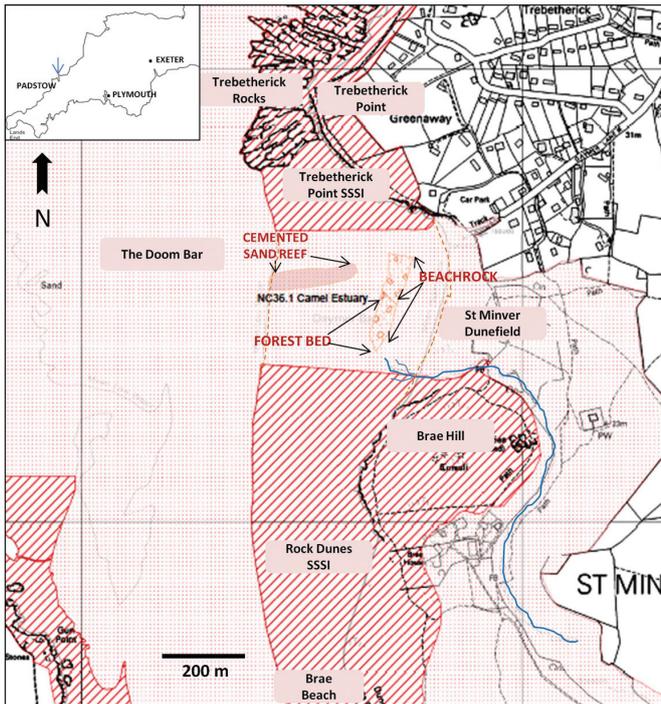


Figure 1. Map of Daymer Bay in the Camel Estuary (arrowed in inset map) showing location of intertidal exposures of the forest bed, beachrock, cemented sand reef and main stream and relationship with The Doom Bar and St Minver dunefield. Ordnance Survey © Crown copyright. All rights reserved. Licence number AL 100002614.

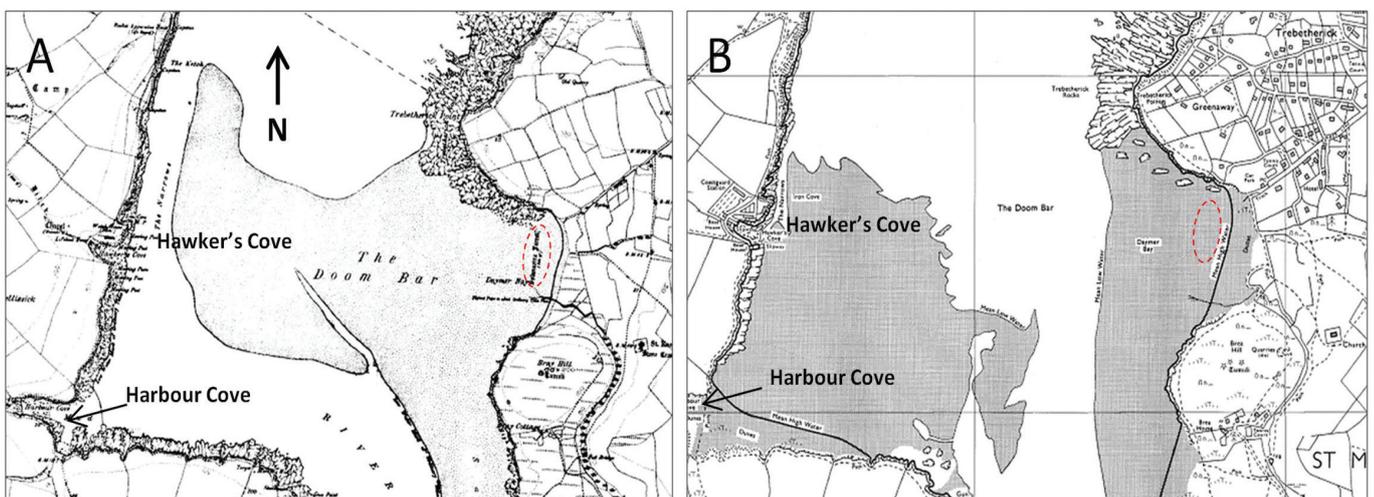


Figure 2. Camel Estuary. A natural shift in The Doom Bar occurred in the early 20th Century when the main river channel opened up on the east side of the Camel Estuary seen when comparing the 1888 (a) and 1979 (b) Ordnance Survey maps. The position of the Daymer Bay intertidal forest is shown dashed red. Henwood (1858) suggested that the forest originally extended west to Harbour Cove.

GEOGRAPHICAL AND GEOLOGICAL SETTING

Daymer Bay, North Cornwall, is situated on the east side of the Camel Estuary which here forms a ria, and consists of a shallow and sheltered sandy partial embayment some 1000 m in length and 450 m wide at low spring tide. Recent sand movements in the estuary (2009 and 2012/13) have exposed an area some 300 m by 100 m of fossiliferous silty/sandy organic-rich deposits (the forest bed) with several rooted tree stumps and small trunks and associated beachrock and, in 2013, an area of cemented sand reef, approximately 250 m by 100 m, close to low spring tide level (Figure 1).

Daymer Bay is cut into fossiliferous Upper Devonian slates, visible as a raised platform and ancient cliff face at Trebetherick Point to the north (Trebetherick Point Geological SSSI and Daymer Bay Geological Conservation Review Site GCR 28) and Devonian slates and Carboniferous intrusions at Brae Hill to the south (Rock Dunes SSSI) and is backed by Holocene dunes to the east. The bay is bounded to the north by sub-cliffs at Trebetherick Rocks, where the older Harbour Cove Slates are thrust over the younger Polzeath Slates; the Trebetherick Thrust of the Padstow Confrontation (British Geological Survey, 1994; Selwood *et al.*, 1998). Towards Trebetherick Point the slates are overlain by a sequence of Quaternary deposits consisting of Pleistocene breccias, raised beach sands and gravels, cemented dune sand with palaeokarst piping, the controversial Trebetherick 'boulder gravels' (variously interpreted as a glacial, solifluction, fluvial or raised beach deposit (Scourse, 1999)), head deposits, Holocene sub-dune colluvium and blown sands containing sub-fossil marine and terrestrial molluscs (Arkell, 1943). This headland forms a well-defined barrier protecting the bay from strong northerly and northwesterly tidal movements in the mouth of the Camel Estuary. Brae Hill to the south, consists of Polzeath Slates with Carboniferous hydrous alkali dolerite intrusions and extends some 150 m across Daymer beach which then continues south onto Brae Beach.

The bay is backed to the east by extensive Holocene dunes (St Minver dunefield). The dunefield extends inland ~1 km eastwards, running south of Trebetherick, and to the east of Brae Hill to the village of Rock, infilling what is considered part of the pre-Holocene valley system flanking the Camel River ria, flooded by Flandrian rising sea levels (Clarke, 1963, 1980). Solifluction clays with slate pebbles and dune sands near Rock Church, probably Holocene in age, yield both marine and terrestrial sub-fossil mollusca (Clarke, 1965). To the south of Brae Hill modern calcareous speleothems and tufas occur in and around a littoral cave (West, 1970). On Rock Beach a thin but persistent bed of cemented sand (Howie, 2009) extends northwards towards Brae Beach but it is not clear whether this is a cemented beach or dune deposit. The local area is rich in geoarchaeological sites with Mesolithic and later finds in St Minver and Trebetherick (Arkell, 1943; CSHER, 1975-present) and on the west side of the Camel near Hawker's Cove (Wessex Archaeology, 2008); some were probably preserved by episodic encroachment of dunes along the Camel Estuary.

Currently intertidal sands and gravels, together with marine (possibly in part dune derived) alluvium, occupy the floor of the Camel valley for ~9-10 km inland (British Geological Survey, 1994). The beach and dune sands in the Camel Estuary are highly calcareous, containing 60 to 85% CaCO₃ (Karkeek, 1846; Merefield, 1982; Howie, 2009). There is net sediment inflow into the estuary, mainly coarse marine shell sand, forming three prominent sandbars, but little fluvial/terrestrial input (CISCAG, 2009). The major sandbar, the Doom Bar, currently west of Daymer Bay but originally adjoining Daymer beach (see Figure 2a) has been a major shipping hazard since at least the time of Henry VIII (Paris, 1863). Significant dredging of the highly calcareous sand from the estuary, in particular from the Doom Bar, for agricultural use in liming has taken place for centuries with an average of ~100,000 tons of sand removed each year. Consideration was given to removing the sandbar during the 19th Century, however this was not

considered practical and the Doom Bar sand was described as 'hard sand' possibly because it was continuously replenished. A significant long term shift in the Doom Bar occurred during the early part of the 20th Century when a new permanent main channel opened up naturally on the east side of the estuary seen when comparing the 1888 and 1979 Ordnance Survey maps (Figure 2a and b). With predominantly northwesterly winds the Doom Bar may have been a major source of sand for the St Minver dunefield for several millenia. Two small streams run across Daymer Bay beach, the larger, at the southeast, rising in the dunefield to the east of Brae Hill (Figure 1).

METHODS

Field observations

The forest bed deposit lies directly on a planed surface or pavement of compacted Devonian head consisting of moderately to well sorted, sub-rounded to rounded predominantly green-grey and purple Devonian slate pebbles and cobbles (Figure 3a). Scattered over this surface were large cobbles and boulders mainly of quartzite, granite and slabs of cemented beach sand; Devonian bedrock was not encountered in the forest bed area. The palaeosol exposed in 2009 and 2012 consisted of isolated sheets a few square metres to areas ~300 m² (Figure 3b) of a sequence comprising a dark organic-rich deposit overlying a pale silty sand (Figure 3c) in a zone ~150 m ENE-WSW by ~100 m E-W centred on grid reference SW 92700 77520 (see Figure 1). The top of the sequence was uniform but undulatory in places with the eroded edges slightly upturned.

The upper organic-rich bed (Daymer Forest Bed 1 - DFB-1) consisted of 15-40 cm of compact, homogeneous grey to dark grey soil rich in organic material. The lower bed (Daymer Forest Bed 2 - DFB-2) consisted of 5-20 cm of pale grey to buff, generally friable silty sand resting on the Devonian slate pebble/cobble pavement. Both DFB-1 and DFB-2 lacked horizonation and appeared to be stone free. DFB-1 was particularly rich in plant fragments including masses of twigs, rootlets, seeds and sporadic thin layers of leaves as well as comminuted and whole snail shells, with *Cepea nemoralis* and *Pomatias elegans* clearly visible *in situ* (Figure 3c). Occasional roots or small branches and shell fragments were seen in DFB-2. There was no visible field evidence of stratification in either DFB-1 or DFB-2. Small fallen trunks, partially washed out of DFB-1, were slightly flattened by compaction. Exposed tree stumps of indeterminate species, with diameters up to 50 cm (Figure 3d and e), were observed rooted through both DFB-1 and DFB-2 into the underlying slate pavement. The bark on the tree stumps was not preserved and the state of the wood varied between soft and friable to hard and carbonized. The wood showed little evidence of damage by marine mollusc boring. A disturbed spread approximately 1 m wide, within the top part of DFB-1 [SW 92706 77473], contained limpets, mussels and a few oysters and possibly charcoal, suggested the location of a kitchen midden.

The forest bed sequence is adjacent to an area ~150 m by ~100 m of laminated beachrock (Figure 1). This occurs as a 20-50 cm thick deposit overlying the slate pavement (Figure 3f) and as detached slabs up to 1.5 m in diameter, which were also scattered throughout the forest bed area, mainly between the palaeosol sheets but sometimes on its surface. The beachrock consisted of crumbly to hard calcite cemented, comminuted marine shell sand, conglomeratic in part, with slate pebbles and cobbles and contained marine molluscs, mainly *Mytilus*, *Acanthocardia* and *Littorina*. Some distance seaward of the forest bed and beachrock [SW 9255 7753] is a zone, approximately 250 m E-W and up to 100 m N-S extending westwards below low spring tide level (Figure 1), consisting of a reef of slabs and blocks up to 2 m in diameter of tough, indurated and crudely laminated calcite cemented beach sand, some slabs apparently cemented to the slate cobble/pebble pavement. This reef is noticeably eroded.

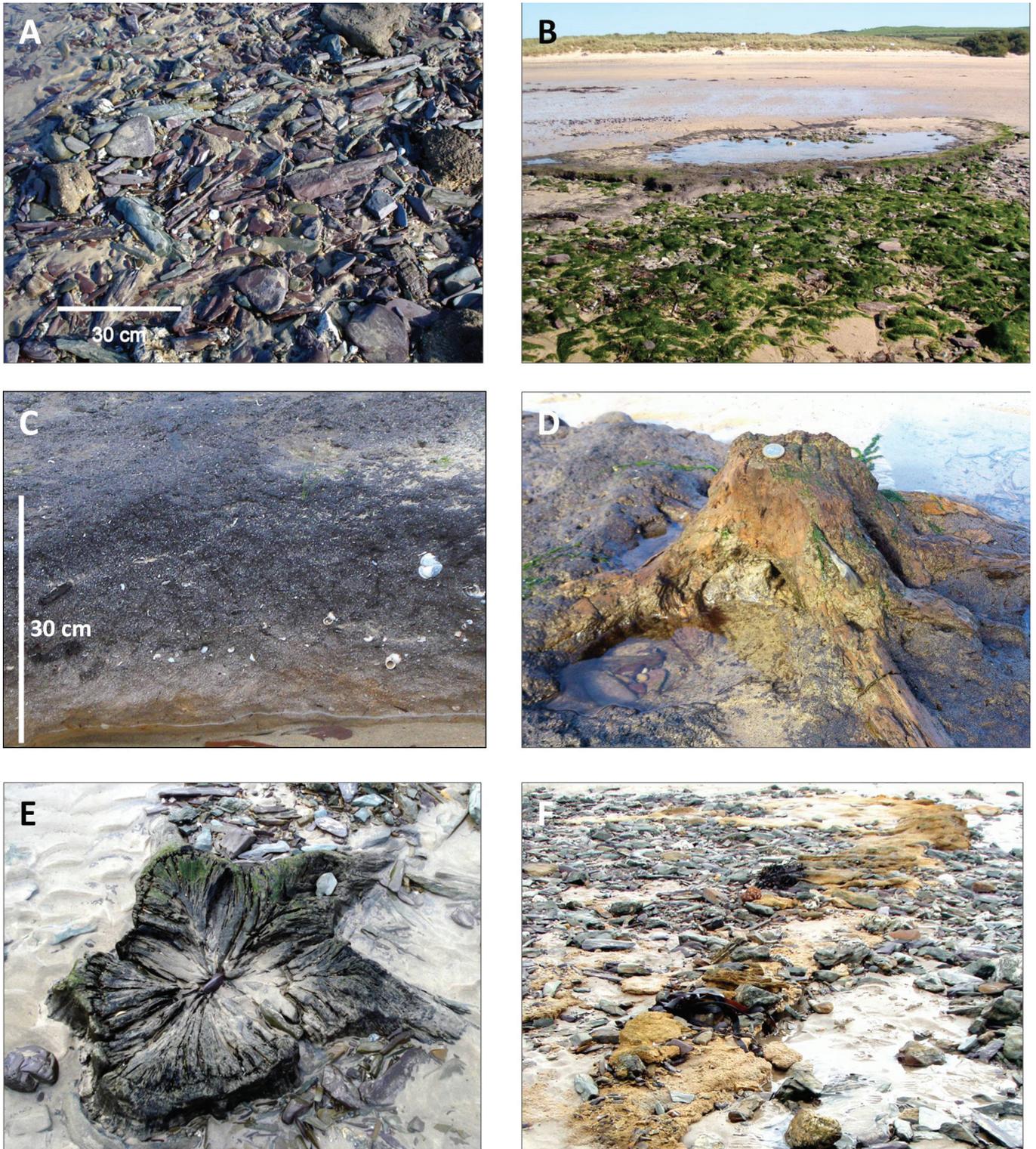


Figure 3. Daymer Bay, intertidal features. (a) Planed surface of Devonian head, mainly green-grey and purple Devonian slate pebbles and cobbles. (b) Eroding palaeosol bed showing smooth undulatory surface; Minver dunefield at back of beach. (c) Palaeosol sequence - dark organic-rich deposit DFB-1 with snails *Cepea nemoralis* (middle right), *Pomatias elegans* (lower right) and woody fragments (left) overlying pale silty sand DFB-2. (d) Exposed tree stumps rooted in DFB-1 and (e) into the underlying slate pavement. (f) Laminated sheets of calcite cemented marine shell sand (beachrock) overlying the slate pavement. (Figure 3e reproduced by kind permission of Mike Langshaw).

Palaeosol sediment analysis

A core sample approximately 5 x 5 cm square and 20 cm deep was cut from the middle of one of the palaeosol sheets (DFB-1 only sampled) and air dried to constant weight. One face of the dried core, scraped flat and lightly brushed, revealed a homogeneous fabric of fine particulate material and snail fragments (Figure 4a). The sample was disaggregated

physically, thoroughly mixed and two 30 g fractions analysed for organic and inorganic content. Analysis was undertaken by flotation in water for one fraction (A) to determine the approximate carbonaceous content. The dried plant fragments and seeds were floated off, dried and weighed. A rough separation of the residual calcareous and minerogenic fraction

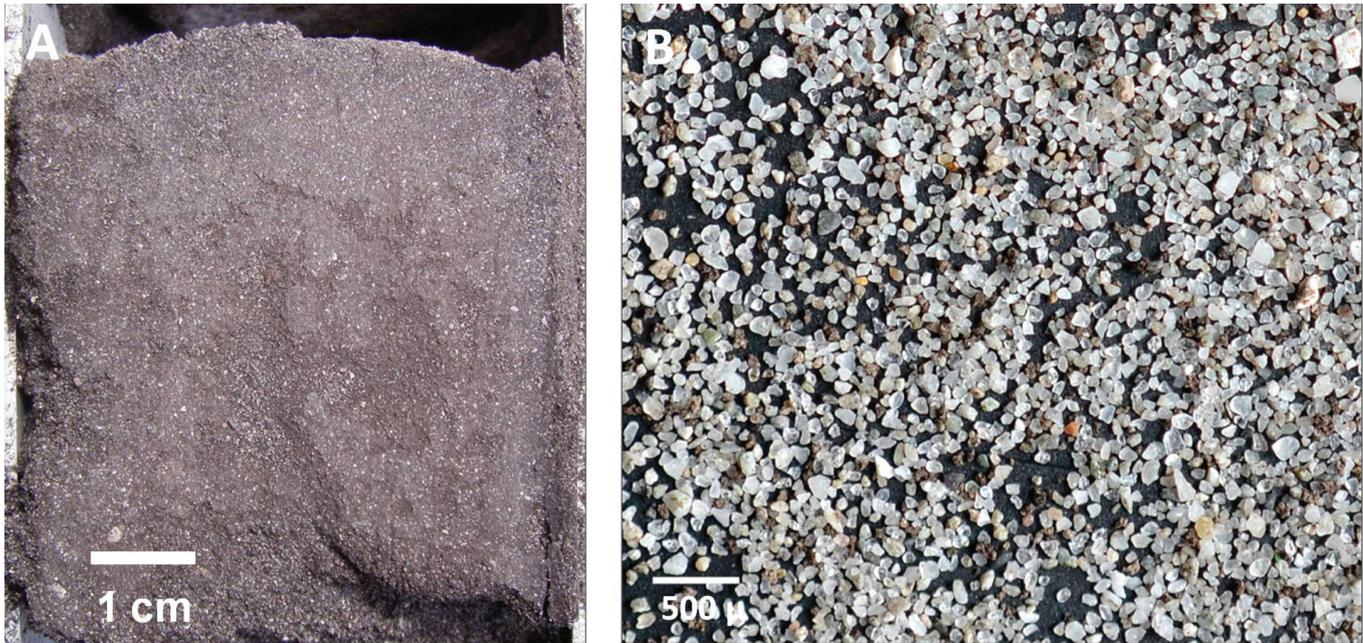


Figure 4. Daymer Bay palaeosol. (a) Cut surface of dried core of DFB-1 showing homogeneous fabric. (b) DFB-1 acid insoluble and organic free residue comprised of predominantly quartz and feldspar grains, particle size 50–350 µm.

from A was carried out by swirling, and the calcareous debris was found to consist mainly of angular snail fragments down to ~0.5 mm diameter. The other fraction (B) was digested in 10% HCl to determine the approximate calcium carbonate content. The carbonaceous content was 21% by weight and the CaCO₃ content was 32% by weight. The carbonaceous fraction consisted mainly of aggregates of plant (leaf, stem and rootlet) particles and seeds. The acid insoluble fraction from B was dried, slurried in water to remove plant debris and passed through a 1.18 mm mesh sieve which allowed approximately 95% of the minerogenic fraction to pass with the residue consisting of coarse sand and granules. The fines consisted predominantly of angular to rounded quartz, feldspar and a small fraction of slate grains (Figure 4b) with particle size in the range 50–350 µm.

Sampling procedure and fossil identification

The upper bed of the forest deposit, DFB-1, contains abundant snails and plant macrofossils and less commonly, insect and small vertebrate remains. Two ~200 g wet samples of DFB-1 from different parts (A and B) of the exposure were soaked in warm water and sieved down to 1.18 mm mesh size. The residues were sorted under a low power microscope and the plant macrofossils, snails and other biota retained for identification and counting. The seeds were identified to genus or species level by reference to the Digital Seed Atlas (www.seedatlas.nl) and Colin French (personal communication). The results are shown in Table 1. The snail shells were identified and habitat details checked by reference to Kerney (1999), Pflieger (2000), Turk *et al.* (2001) and the AnimalBase website (www.animalbase.org/). The results are shown in Table 2.

RESULTS

Taphonomically, the snail shells were affected by degrees of corrosion, colour loss and breakage, particularly around the aperture; all traces of periostracum had disappeared. Although fragile the snail shells were sufficiently well preserved to enable identification to genus and, in many cases, species level (Table 2). A total of 16 genera or species of snail were identified, the most abundant were *Pomatias elegans* and its opercula (Figure 5a), *Discus rotundatus* (Figure 5b), *Vallonia exentrica*, *Clausilia*

bidentata and *Aegopinella nitidula*. With the exception of the pupillids and the clausidiid, a range of shell sizes from juvenile to adult was present (Table 3). *P. elegans* opercula were abundant but not seen attached to or within apertures. The succineid *Oxyloma* sp. (Figure 5d) has not previously been recorded as sub-fossil in the Holocene of Cornwall and *Radix peregra* (Figure 5c) is rarely recorded (Turk *et al.*, 2001).

The seeds from both samples were relatively well preserved and a total of eight genera and species were identified with *Rubus fruticosus* and *Sambucus* sp. most abundant (see Table 1). Most seeds had retained their original coloration, however several were fragmentary, perhaps gnawed, or had split open by desiccation, particularly *Rubus fruticosus* and *Sambucus nigra* seeds (Figure 6). Indeterminate leaf, grass, stem and root fragments were common in both samples. A sample of a small carbonized trunk or branch, probably *Fraxinus*, from DFB-1, ~20 cm below the surface of the exposure, was sent to Beta Analytic for radiocarbon dating and gave a date of Cal BP 4420–4240 (Table 4).

The identifiable insect remains found in one sample (Table 2) consisted of Curculionid weevil elytra and Diptera larval cases (Figure 5e and f); indeterminate chitinous fragments were relatively common in both samples. The vertebrate remains, which consisted of stickleback spines and postcranial anuran (frog or toad) bones including vertebra, tibio-fibulars and possibly femur (Figure 5g), were found in the same sample.

DISCUSSION

Ussher (1879b) considered that both the Daymer submerged forest and the beach reef were contemporaneous with the raised beach at Trebetherick Point and were 'later Pleistocene' in age. Ussher also considered that the beach reef marked a late Pleistocene raised beach formed when sea level was formerly at its present level. This he postulated was subsequently elevated to allow for its consolidation and re-exposed by the latest marine incursion. It now seems certain that the isolated beachrock slabs may be the remnants of a once more extensive late Holocene deposit which formed on, and covered, the beach. It is uncertain however whether this beachrock formed directly on the surface of the palaeosol. There are however indications that beachrock formation is currently underway, with areas of partially calcite-cemented sand forming below and at beach level (Howie, 2009) close to

Fauna Identified	No. in Sample A	No. in Sample B	Habitat Type
INSECTA			
Curculionidae Weevil elytra	-	3	Widespread
Diptera Larvae cases	-	2	Widespread
MOLLUSCA			
Clausidiidae			
<i>Clausilia bidentata</i> (Ström, 1765)	13	16	Damp rocks & woodland
Cochlicopidae			
<i>Cochlicopa lubrica</i> (Müller, 1774)	7	-	Damp woodland & marsh
Discidae			
<i>Discus rotundatus</i> (Müller, 1774)	27	28	Rotting wood & scree
Ellobiidae			
<i>Carychium tridentatum</i> (Risso, 1826)	9	-	Dry leaf litter
Helicidae			
<i>Cepaea nemoralis</i> (L., 1758)	3	1	Dry or damp & dunes
Hydrobiidae			
<i>Peringia ulvae</i> (Pennant, 1777)	1	-	Estuarine, saltmarsh
Lymnaeidae			
<i>Radix peregra</i> (Müller, 1774)	10	2	Springs & brooks
Pomatiasidae			
† <i>Pomatias elegans</i> (Müller, 1774)	35	20	Shrubby areas
<i>P. elegans</i> opercula	+50	+40	
Pupillidae			
<i>Pupilla muscorum</i> (L., 1758)	7	4	Dry grassland & dunes
<i>Lauria cylindracea</i> (da Costa, 1778)	8	4	Maritime grassland
Succineidae			
* <i>Oxyloma</i> sp.	7	-	River banks & reeds
Valloniidae			
? <i>Acanthinula aculeata</i> (Müller, 1774)	3	-	Dry leaf litter
<i>Vallonia exentrica</i> (Sterki, 1892)	35	5	Dry grassland
Zonitidae			
<i>Aegopinella nitidula</i> (Draparnaud, 1805)	20	24	Damp stoney ground
<i>Nesovitrea hammonis</i> (Ström, 1765)	12	10	Damp leaf litter & marsh
VERTEBRATA			
Gasterosteidae			
Stickleback spines	-	2	Freshwater
Anura			
Frog or toad (postcranial fragments)	-	~20	Damp areas

Table 1. Daymer Forest Bed DFB-1: Sub-fossil fauna and habitat.

†Obligatory calcicole (Boycott, 1934); * not previously recorded as sub-fossil in Cornwall.

Flora Identified	No. in Sample A	No. in Sample B	Habitat Type
Adoxaceae			
<i>Sambucus nigra</i> L.	12	10	Moist, shaded
Apiaceae			
indet	2	4	
Betulaceae			
<i>Corylus avellana</i> L.	5	-	Mixed woodland: calcicole
Ranunculaceae			
<i>Ranunculus</i> subg. <i>Batrachium</i> sp.	5	6	Ponds and streams
Potamogetonaceae			
<i>Potamogeton</i> sp.	2	-	Ponds & streams: tends to calcicole
Rosaceae			
<i>Rubus fruticosus</i> agg.	20	40	Scrub & woodland: tends to calcicole
Violaceae			
<i>Viola</i> sp.	6	2	Woodland & banks
Lamiaceae			
<i>Stachys</i> sp.			Scrub & grassland

Table 2. Daymer Forest Bed DFB-1: Sub-fossil flora and habitat.

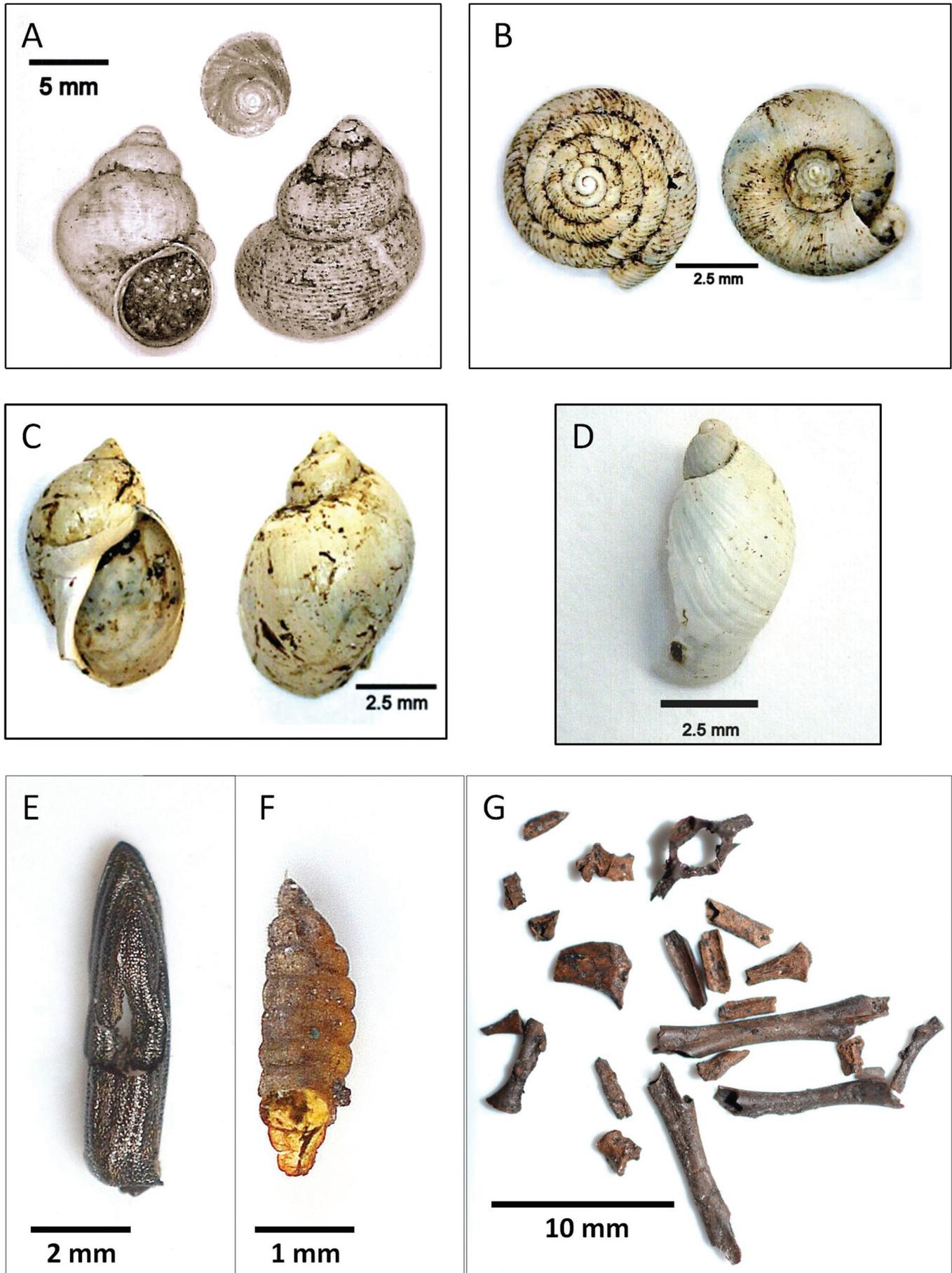


Figure 5. Daymer Bay palaeosol. Sub-fossil snails, insects and a vertebrate. Snails: (a) *Pomatias elegans*; left, apertural view; right, abapertural view; top, operculum. (b) *Discus rotundatus*; left, apical view; right, apertural view. (c) *Radix peregra*; left, apertural view; right, abapertural view. (d) Succinid (*Oxyloma* Sp.) abapertural view. Insects: (e) Curculionid (weevil) elytron and (f) Diptera larval case. Vertebrate: (g) postcranial anuran (frog or toad) bones.

	<i>P. elegans</i>	<i>D. rotundatus</i>	<i>A. nitidula</i>	<i>N. hammonis</i>	<i>C. bidentata</i>
Habitat details^a	Obligatory calcicole ^b (needs >5% Ca soil). Prefers rubbly scrubland & open woodland. Good burrower - estivates in hot weather. Hibernates at ≤10°C at depth of ~10 cm. Resents disturbance, poor disperser ^c .	Tolerates non-Ca substrates. Lives in rotting leaves & timber. Prefers moist shade & open ground. Establishes large colonies.	Below leaf & ground litter in forests, moist grassland & rocks.	Ubiquitous in leaf litter, moist forests, open ground, lake margins. Tolerates acidity.	Near-calcicole, prefers calcareous substrates, moist ground, under litter, fallen timber & rocks. Climbing species.
Diet^a	Leaf litter & rotting wood. Adapted to absorb Ca from substrate (esp. shell fragments).	Key digester of leaf litter & rotten wood.	Predatory on slugs, slow worms, insects & other snails. <i>N. hammonis</i> recorded as preferred prey species ^d .	Rotting wet leaves, fungi & fruit.	Lichen & moss on trees & limestone.
Life cycle^a	In temperate zone eggs hatch in autumn. Juveniles ~7 mm length at 2 months. Adults 13-18 mm length - lifespan 4-5 years.	Juveniles ~3 mm diam. at 3 months. Adults 5-6 mm diam - lifespan ~3 years.	-	Juveniles ~3 mm diam. at 3 months. Adults ~6 mm. Lifespan ~3 years.	-
Life stages seen in Daymer palaeosol	Adults ~20%, juveniles (≤7mm) 30%.	Adults and juveniles.	Adults and juveniles.	Mainly adults.	Adults only.
Occurrence around Daymer	Extinct locally; as sub-fossil in dunes.	Live locally; as sub-fossil ^f in dunes.	Live locally; as sub-fossil ^f in dunes.	Not reported.	Live locally; as sub-fossil ^f in dunes.

^aData from AnimalBase website, ^bBoycott (1934), ^cPfenninger (2002), ^dMordan (1977), ^eDickinson and Pugh (1974), ^fTom Walker (pers. comm.).

Table 3. Daymer Forest Bed DFB-1: Characteristics of predominant sub-fossil snails.



Figure 6. Daymer Bay palaeosol. Sub-fossil macroflora. Seeds of (p) *Potamogeton* Sp.; (r) *Rubus fruticosus*; (s) *Sambucus* Sp.; (v) *Viola* Sp.

Laboratory number	Beta-348787
Conventional radiocarbon age	3900±30 BP
2 Sigma calibrated result: (95% probability)	Cal BC 2470 to 2290 (Cal BP 4420 to 4240)
Intercept data	Cal BC 2460 (Cal BP 4410) and Cal BC 2420 (Cal BP 4370) and Cal BC 2410 (Cal BP 4360)

Table 4. Daymer Forest Bed DFB-1: Sub-fossil wood sample - radiocarbon date.

the eroded edges of the palaeosol sheets. It is likely that this beachrock deposit has been forming and eroding intermittently from the time this part of the Camel Estuary became tidal. The likely source of cementing agent for the beachrock is CaCO₃-rich runoff, as proposed for the formation of the Harlyn Bay beachrock (Howie, 2009), from the highly calcareous St Minver Dunefield, with the added influence of the stream which drains from the dunes and runs across the southern part of the beach near the fresh beachrock deposits. The mechanism for the formation of the calcareous reef towards low tide level is more uncertain. This material is highly eroded and may be considerably older than the beachrock associated with the forest bed.

Arkell (1943) considered the forest to be late Mesolithic or early Neolithic as “it seems certain that the blown sands and implements ... are later than the forest period for there is no sign of the peaty layer in the overlying sands”; here he means the nearby Holocene blown sands where Mesolithic artefacts had been found. In the absence of any human artefact finds in the forest bed itself archaeometric dating has not been possible. The radiocarbon date obtained here, albeit from a single detached wood fragment, suggests late Neolithic or early Bronze Age (Cal BP 4420-4240). However, as no samples for dating were taken from the rooted tree stumps or from pollen, the application of this radiocarbon age to the palaeosol is tentative. In all probability the forest was established much earlier, as is suggested for the Crooklets Beach submerged forest on the coast further east near Bude (Cole, 2001).

The number and diversity of seeds recorded was insufficient for any precise analysis of habitat. There appears to be a prevalence of species preferring scrub or lightly wooded habitats and calcium-rich soils (Table 2). Insect and small vertebrate remains are rare but are recorded from Holocene peat deposits in Cornwall (Clarke, 1976) and elsewhere, often associated with human occupation (Bell, 2007). The fish spines

and anuran post cranial bones from DBF-1 are undoubtedly not autochthonous but coeval with the deposit and may be the remnants of a sub-fossil owl pellet. Well dated small vertebrate remains from the Holocene of Cornwall are rare (Simon Parfitt pers. comm.).

Although the total count of snails identified in this study was fairly small (~300) it is possible to estimate their diversity and abundance; ~64% of the species were suited to dry habitats, ~30% to damp conditions with ~6% aquatic or bank dwelling species. The presence in the palaeosol of the moisture-loving succineid *Oyloma* and *Radix peregra*, commonly known as the Wandering Pond Snail, is indicative of proximity to streams and ponds. With the exception of a single shell of the saltmarsh snail *Peringia ulvae*, no marine or saltmarsh fauna or flora was found in the palaeosol sequence. The present day habitats and life cycles of the predominant snail species in relation to the Daymer palaeosol are summarised in Table 3.

The use of Quaternary, particularly Holocene, land snail assemblages as palaeoenvironmental and palaeoecological proxies (Goodfriend, 1999) and for landscape analysis at archaeological sites (Evans, 1972; Davies, 2009) is dependent on shell taphonomy and death assemblage fidelity, i.e. ability to reflect the original biological signal of the population (Yanes, 2012). Initial burial in calcimorphic soils and maintenance of alkaline conditions (Pearce, 2008) during early diagenesis are considered to be important factors in snail preservation and retention of original ecological information. The Daymer palaeosol would appear to meet these criteria in that the high Ca content of the palaeosol sequence, mainly snail shell fragments, has created a calcimorphic preservation environment. In DBF-1 the particle size of the minerogenic components is in the silt to fine sand range (50-350 µm); this suggests a soil to some extent augmented by local dunes where particle size is predominantly in the 125-500 µm range (Merefield, 1989). The association of different snail species, adults and juveniles, sharing similar habitat and proximity to food sources, as preserved in the palaeosol, strongly suggests that, unlike dune deposits where dead shells are wind transported and concentrated, the Daymer forest bed preserves evidence of snail death assemblage.

It is likely that the Daymer Bay forest bed dates from around 4-6 ka BP when RSL was -3 to -4 m O.D. (Gerhels *et al.*, 2011) and the local shoreline some 2 km to the northeast. The channel of the Camel would have meandered across a low-lying alluvial floodplain some 2.5-3 km wide, perhaps blanketed periodically by calcareous dunes which were developing to the east. The lower soil horizon, here identified as DFB-2 overlying the Devonian pebble pavement, may represent the ancient subsoil (B horizon). The warm late Holocene climate coupled with high soil Ca levels would have encouraged the development of a rich flora (Wilson, 1960; Sevink, 1991), including *Sambucus* and the calcicoles *Rubus* and *Ranunculus* as well as a snail population suited to dry conditions particularly *Vallonia exentrica*, the Pupillids and *Cepaea nemoralis*, in dune slacks and depressions, perhaps in evidence here as the undulatory surface of DFB-1 (Figure 3b). With continued input of wind transported Ca-rich sediment and *in situ* snail shell disintegration inhibiting soil acidification, podzolisation and fen peat formation, a well drained Ca-rich humus would have accumulated. The homogeneous nature of DFB-1 suggests the development of a cumulative soil, with calcareous material and decomposing litter rapidly incorporated into the fabric by soil biota reworking. Initial colonisation by *Corylus* and *Sambucus* probably preceded the larger, long-lived trees, in evidence here as stumps and reported historically as oak and yew.

The combination of a favourable water table, deciduous plants and accumulation of leaf litter would explain the prevalence of moisture-loving snails including *Clausilia bidentatus*, *Discus rotundatus* and the Zonitids, whilst the presence of buried snail shell suited the obligatory calcicole *Pomatias elegans* (see Table 3). The occurrence of aquatic and semiaquatic species of plants (*Ranunculus* and the calcicole

Potamogeton) and snails (*Radix peregra* and the Succineid) reflect proximity to ponds and flowing water. The probability of frequent flooding by the Camel which, as sea level rose would have become tidal, coupled with increased soil salinity, would have led to tree death. Since there is no evidence of salt marsh flora or fauna or reducing conditions (absence of pyrite and iron-stained sediments or shell) in DFB-1 it is proposed that the forest bed was rapidly buried, possibly initially by dune movement and later by beach sediments. Waterlogged conditions and sediment pH buffering between 6 and 8 (here by the high proportion of snail shell; around 20% CaCO₃ in DFB-1) are conducive to the preservation of shell, macroflora and bone together (Retallack, 2001). Post-depositional maintenance of these conditions limited significant humification and therefore subsequent formation of peat in the Daymer forest bed, in contrast to the deposits seen in most other submerged forest deposits in South-West England.

CONCLUSIONS

Given the lack of similar studies, the development in Daymer Bay of a Holocene calcareous palaeosol facies with a sub-fossil terrestrial molluscan fauna in association with a well preserved macroflora is unusual in Cornwall. The relationship with calcareous cemented beachrock has undoubtedly enhanced the preservation of the deposit. This study indicates that the calcareous environment created by the shell-rich marine and dune sands in North Cornwall and its importance to coastal ecology was well established by the mid to late Holocene and that although the dunes did not play a direct role in the development of the Daymer forest bed they were indirectly important for its chemistry and preservation. Further work constraining the age range for the palaeosol should be possible through radiocarbon dating of wood from rooted tree trunks, pollen analysis and amino acid racemization dating, particularly of *Pomatias elegans* shell and opercular material. Further taphonomic and stable isotope analysis of the Daymer palaeosol snail fauna and comparison with local Holocene dune and living snail populations would augment geological and archaeological field studies in North Cornwall.

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