

## TUFA AND SPELEOTHEM OCCURRENCE IN NORTH AND WEST CORNWALL

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Quaternary tufa deposits and speleothems in the inland limestone areas of northern and central England, Wales and Ireland are well documented. Tufaceous deposits and speleothems in Cornwall have been largely unrecorded. They are however, a far from rare occurrence in coastal localities in North and West Cornwall. These coastal tufa accretions, with various fabrics, range in size from small mounds a few metres across to cascades and swathes, extending up to 400 m along cliff-faces. Particularly good examples of speleothems in sea caves have been identified at Holywell Bay north of Newquay. Although small in scale these Cornish speleothems and tufas, several of which are active, offer the opportunity to study the biological, geochemical and geological aspects of their development in a coastal environment.

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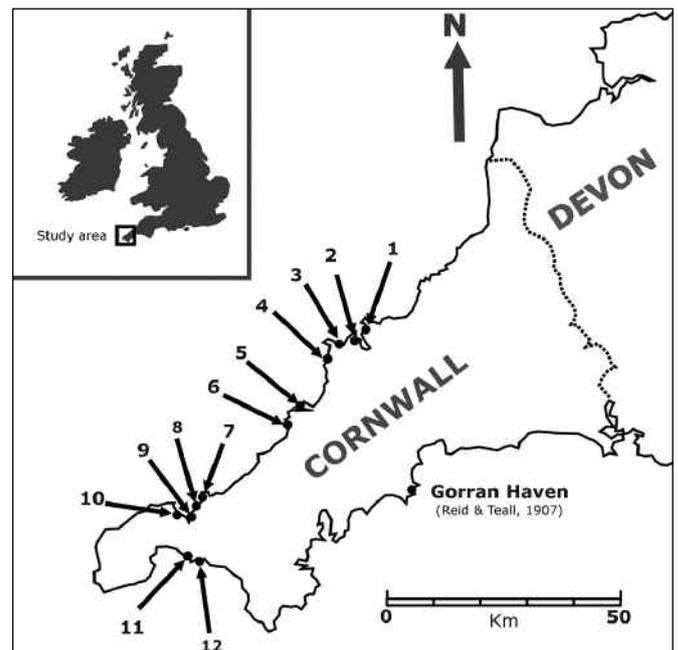
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### INTRODUCTION

Possibly the only extant specific references to tufa occurrence in Cornwall in a geological context are Reid and Scrivenor (1906, p.89) who mentioned tufa in Holywell Cave, near Newquay, North Cornwall, Reid (1907) who noted tufa west and east of Gorran Haven, South Cornwall, and Clarke (1968) who referred to the strong spring-line tufa deposit at Boat Cove, near Porthcothan, North Cornwall (Figure 1). This paucity of references is not surprising since thick limestone sequences, normally associated with better known tufa formation in the other parts of the UK and Ireland are virtually absent in Cornwall. To the authors' knowledge there have been no reports of speleothems in Cornwall. This review draws attention to the widespread distribution and variety of the tufa occurrences seen in North and West Cornwall and outlines their geological setting. It is virtually certain that there are many other tufa and speleothem occurrences in both North and South Cornwall. This preliminary paper is intended to spur their recognition.

### BACKGROUND

The terminology used in the literature on carbonates originating in terrestrial environments is unclear (Flügel, 2004; Pentecost, 2005); the terminology adopted in this paper follows that of Pedley (2003) and Pedley (2009). The term tufa in this paper refers to the normally porous, often soft, calcareous deposits that precipitate from ambient temperature  $\text{CaCO}_3$ -rich freshwater as accretions in open air situations. Calcareous speleothem is used to denote the non-porous, usually hard, precipitates from ambient temperature  $\text{CaCO}_3$ -rich freshwater forming the dripstones, flowstones, stalactites, roof bosses, stalagmites and dams found in caves.



**Figure 1.** Map showing the location of tufa and speleothem occurrences in north and west Cornwall. The numbers refer to the localities listed in Table 1.

Calcareous speleothems and tufas have a similar origin but differ in their mode of formation. At ambient temperatures unpolluted rain water in equilibrium with dissolved atmospheric CO<sub>2</sub> has a mean pH value of 5.6 (Winkler, 1997; p.126). Where this acidic solution percolates through horizons consisting of calcareous deposits such as shelly dunes or through cracks and joints in limestone, it dissolves CaCO<sub>3</sub> to produce HCO<sub>3</sub><sup>-</sup> ions which raise the pH of the leachate to around 8 and the partial pressure of CO<sub>2</sub> (pCO<sub>2</sub>) increases to the point of over-saturation. Where the leachate emerges into the atmosphere through seepage or at a spring, the pCO<sub>2</sub> drops and CaCO<sub>3</sub> will tend to precipitate out of solution. Where carbonate-saturated water free-falls at ledges or flows down slopes colonisation by photosynthesising plants such as bryophytes and algae normally occurs and degassing of CO<sub>2</sub> promotes precipitation of CaCO<sub>3</sub>, usually as calcite. The plant material, as it decays, provides a framework for carbonate precipitation eventually creating a naturally porous fabric which can build up rapidly to form, depending upon surface topography, cascades, mounds, dams and swathes of normally soft, and sometimes layered, porous tufa.

Carbonate-saturated water dripping, flowing or seeping into deep caves undergoes CO<sub>2</sub> degassing and successive precipitation of thin films of CaCO<sub>3</sub> build out from rock surfaces. However photosynthesising plant activity is minimal and purely physico-chemical processes lead to the formation of the familiar spelean dripstones, flowstones, stalactites, roof bosses, stalagmites, drapes and dams of hard, crystalline banded or laminated calcite or, occasionally, aragonite.

Tufa and speleothem calcite from many localities, including a number in the UK, show variability in δ<sup>18</sup>O and δ<sup>13</sup>C values as well as uranium series dating possibilities that, with reservations regarding proximity to contaminants, biogenic influences and the effects of later diagenesis, can provide important Quaternary palaeoclimatic and palaeoenvironmental proxies as well as data for the determination of Quaternary geochronology independent of the marine record (McDermott, 2005; Andrews, 2006; Candy and Schreve, 2007; Wynn *et al.*, 2008). Quartz and feldspar sand grains assimilated in tufa are also a potential source for optically stimulated luminescence (OSL) dating (Rich *et al.*, 2003; Weisrock *et al.*, 2006). Laminated speleothems are increasingly important in chronology building and as potential palaeoclimate proxies (Baker *et al.*, 2008).

## TUFA AND SPELEOTHEMS IN NORTH AND WEST CORNWALL

The tufa and speleothem occurrences described in this review are all located in coastal localities, mainly in North and West Cornwall (Figure 1). Table 1 summarizes the location, type of deposit and geological setting. The variety of depositional conditions is outlined below.

### Trebetherwick Point, Camel Estuary

This locality (Figure 1, Table 1: locality 1) on the east side of the Camel Estuary is dominated by a 15 m Quaternary section deposited on a raised shore platform with raised beach deposits, overlain by 6 m of partially carbonate cemented dune sands (sandrock), head and a thin cover of dune sand, backed by cliffs of Upper Devonian slates (Polzeath Slate Formation). A friable tufa accretion, with hard outer layer, occurs as a mound up to 50 mm thick and 3 m wide on the shore platform and is deposited along a spring originating in and percolating through the overlying Quaternary deposits.

### Harbour Cove, Camel Estuary

Harbour Cove (Figure 1, Table 1: locality 2) lies on the west side of the Camel Estuary, farther upstream than Trebetherwick. This sandy cove is backed by dunes and low (<10 m) cliffs

formed of the Upper Devonian Harbour Cove Slate Formation. An active seep, immediately to the south of the cove has produced small-scale tufa cascades.

### Onjohn Cove, Harlyn Bay

Onjohn Cove (Figure 1, Table 1: locality 3) lies on the western margin of Harlyn Bay and is backed by low cliffs (10 m), eroded into rocks of the Middle Devonian Trevoze Slate Formation. Active tufa mounds and cascades are forming at the back of the cove where water flows down to the beach from a pond at a low point in the stabilised Trevoze - Constantine dune field. Field measurements of the pH of water run-off were carried out using a Tecpel pH703 portable pH meter; on site analyses indicates slight alkalinity at pH 7.6.

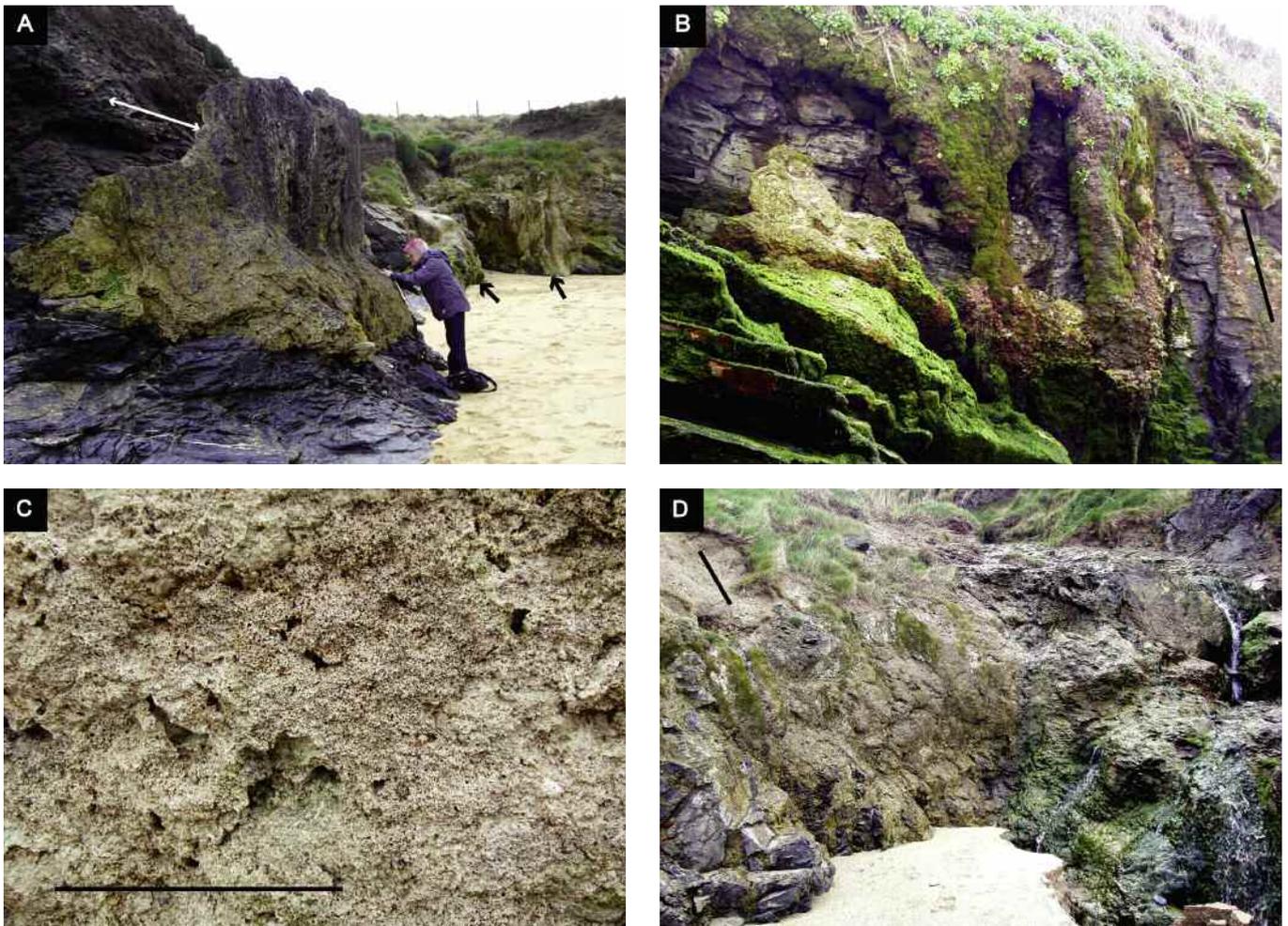
Farther seaward on both sides of the cove occur former inactive cascades, characterised by layered, indurated tufa. That on the south side is completely isolated from the main cliff and is preserved as a narrow linear stack, 2.5 m in height, on the shore platform (Figure 2a). This exceptional outcrop is interpreted as having been isolated by marine erosion of some 2 m of slate behind. Preliminary petrographic examination and XRD analyses (STOE Powder Diffraction System) of samples of this tufa reveal micritic low-Mg calcite intercalated with layers of partially recrystallised aragonitic shell fragments and quartz grains suggesting that beach and dune detrital material may have been incorporated at an early stage of coastal tufa formation.

### Porthcothan Bay and Boat Cove

Porthcothan Bay (Figure 1, Table 1: locality 4) is a long (700 m), narrow (160 m wide) sandy valley mouth cove, developed in slates of the Middle Devonian Trevoze Slate Formation. Dunes occupy the back-beach flats between the beach and the village. Extensive tufa is associated with seeps

Figure 1 Map No.	Location and grid reference	Type of deposit	Geological setting
1	Trebetherick SW 92615 78032	Small spring-line tufa mound	U. Devonian Polzeath Slate Formation, sandrock and raised beach deposits
2	Harbour Cove SW 92044 76402 SW 92058 76404	Small active tufa cascades	U. Devonian Harbour Cove Slate Formation and Holocene dunes
3	Onjohn Cove SW 75802 87235	Active tufa cascades and isolated relict layered tufa cascades	M. Devonian Trevoze Slate Formation and Holocene dunes
4	Porthcothan Bay SW 85719 72053	Active tufa swathes and cascades along 400 m of cliff; associated with beachrock	M. Devonian Trevoze Slate Formation
4	Boat Cove SW72050 85300	Large spring-line tufa mound and cascades	M. Devonian Trevoze Slate Formation
5	Fistral Bay SW 79844 61671	Iron stained tufa associated with cement bags	L. Devonian Bovisand Formation and raised beach deposits
6	Holywell Bay SW 76711 59865	Extensive cliff-side active and inactive tufa cascades	L. Devonian Trendrean Mudstone Formation, limestones and marble bed
6	Holywell Caves SW 76602 60092	Laminated speleothems in two caves (A and B); associated with beachrock near Cave B	L. Devonian Trendrean Mudstone Formation, limestones and marble bed
7	Godrevy Cove SW 58096 42996	Small tufa cascades	Pleistocene sandrock and raised beach deposits
8	Mexico Towans SW 55812 39051	Inactive tufa cascades part-buried in dunes	M. Devonian Mylor Slate and Porthtowan Formations and Holocene dunes
9	Black Cliff SW 55446 38797	Spring-line tufa cascades	M. Devonian Mylor Slate and Porthtowan Formations and Holocene dunes
10	Porth Kidney Sands SW 54836 38097	Active tufa cascades along 300m of Lelant Cliff; associated with beachrock. Speleothems in adit	M. Devonian Mylor Slate and Porthtowan Formations and Holocene dunes
11	Stackhouse Cove SW 54942 28360	Active and inactive tufa cascades; relict tufa/speleothem cemented to raised beach in cave roof	L. Devonian Mylor Slate Formation and Quaternary Head/Loess
12	Bessy's Cove SW 55605 27940	Spring-fed tufa cascades in cliffs	L. Devonian Mylor Slate Formation and Quaternary Head/Loess

**Table 1.** The location and geological setting of tufa and speleothem deposits in north and west Cornwall (numbering as shown on map, Figure 1).



**Figure 2.** (a) Relict tufa stack on south side of Onjobn Cove cemented to spur of Middle Devonian Trevoze Slate Formation. This stack is interpreted as an old cliff side cascade which has been isolated by the erosion of up to 2 m of slate behind the cascade where indicated by double arrowed bar. Two active pond-fed cascades are seen at the back of the cove (arrowed). (b) Tufa cascades covering part of cliff face cut into the Middle Devonian Trevoze Slate Formation at Porthcothan Bay showing (centre and left) cauliflower-like surface structure of tufa enhanced by moss and lichen growth. Scale bar 1 m. (c) Fractured tufa, Porthcothan Bay, revealing millimetre to centimetre scale vugs and spongy fabric. Scale bar 10 cm. (d) Tufa cascade at mouth of stream flowing into Boat Cove. Scale bar 1 m.

and flushes along 400 m of the cliff-face on the south side of Porthcothan Bay. The tufa forms intermittent cascades and swathes, exhibiting a cauliflower-like outer surface structure (Figure 2b) and internal spongy fabric consisting of millimetre to centimetre scale vugs (Figure 2c) and is very light in weight. Incipient beach rock has also formed in some areas at the base of this cliff. Boat Cove (Figure 1, Table 1: locality 4), formed at the mouth of a small hanging valley extending approximately 400 m inland, lies on the southern seaward margin of the cove. In Boat Cove a large tufa mound, noted by Clarke (1968), and cascades have formed where the stream flows down the low-angle cliff at the back of the cove (Figure 2d).

### Fistral Bay

Although this bay is dominated by Holocene dunes, Pleistocene sequences comprising beach deposits overlain by cross-bedded, partially carbonate cemented dune sands (sandrock) of interglacial age, and Lower Devonian calcareous bedrock (Bovisand Formation), the tufa occurrence in the bay (Figure 1, Table 1: locality 5) is almost certainly attributable to human interference. In the Pleistocene section in the southwest of the bay, iron-stained tufa is clearly associated with cliff-side springs flowing through cement bags used for coast protection works. This work is adjacent to and partly covers the unstable iron and manganese cemented raised beach deposits of the section exposed here.

### Holywell Bay

Holywell Bay (Figure 1, Table 1: locality 6), 1 km wide, is developed between two bedrock headlands, formed of slates of the Lower Devonian Trendrean Mudstone Formation which in this region is interbedded with thin intervals of limestone and an extensive marble bed, detected by deep borings north of Perranporth (Selwood *et al.*, 1998). The centre of the bay is occupied by a well developed dune field. Tufa is developed on several active and inactive cascades up to 15 m high on the south west facing cliffs of Kelsey Head at the north end of the bay where water emanates from faults and joints at various elevations in the cliff face (Figure 3a). On site analyses of feed water indicates slight alkalinity (pH in the range 7.5 to 8.0). The tufa is fairly hard, with some sand grain content, but porous.

The notable feature in this northern sector of Holywell Bay is the development of extensive calcareous speleothems in two sea-level caves. The major cave (Cave A), Holywell Cave (St Cuthberts Cave of religious significance, Haslem (1849), p.240) is at least 20 m long and accessible only at extreme low tide. The speleothems consist of hard, buff, pink or green tinged calcium carbonate deposited as a series of cascades and dams, up to 75 cm high (Figure 3b), canopies and drapes. A narrow cave nearby (Cave B), approximately 30 m long contains extensive speleothem cascades, canopies and fluted drapes (Figure 3c). At the base of the cave wall mamillated speleothem has been fractured by waves entering the

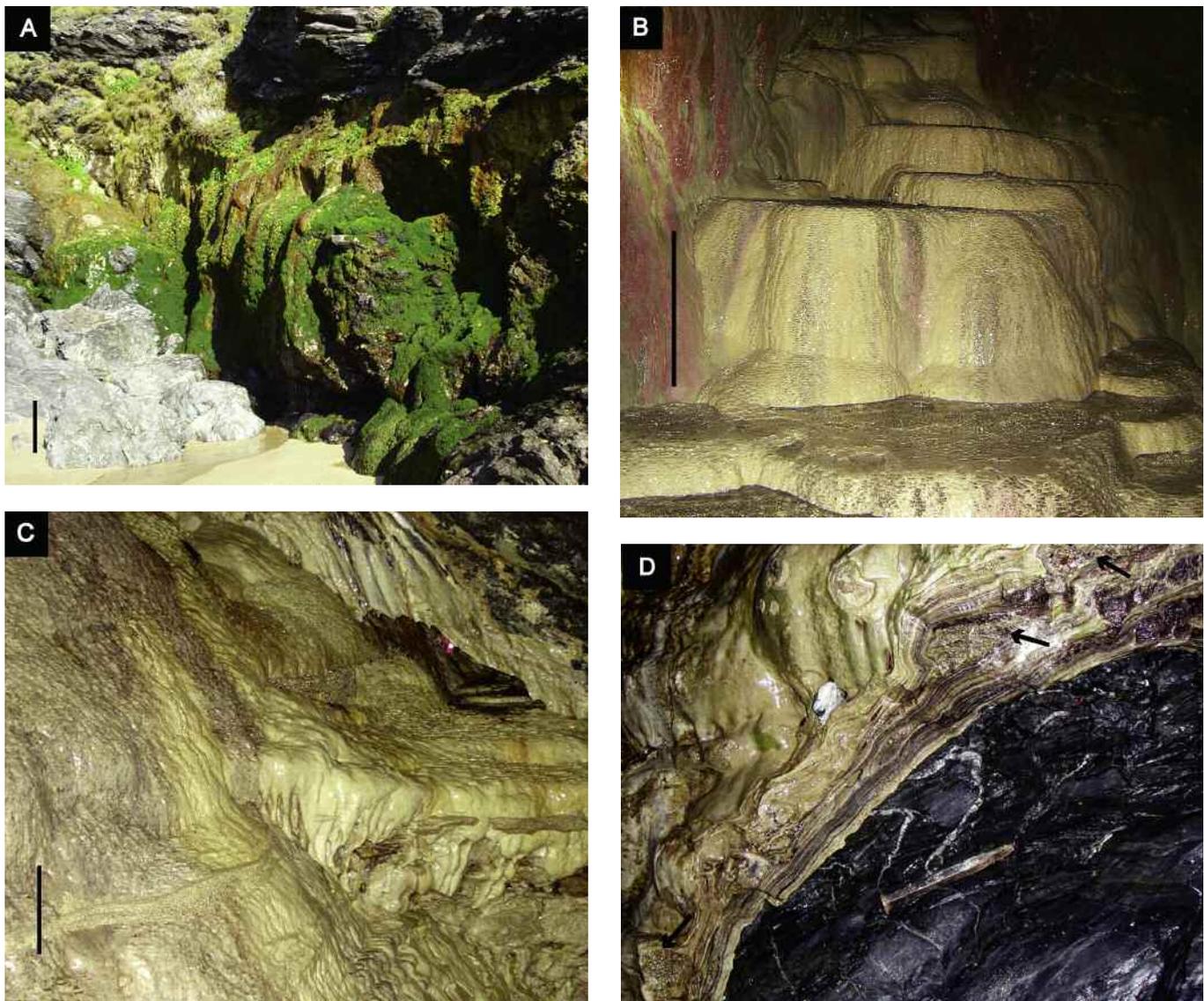
cave, revealing a laminated structure up to 20 cm thick. The speleothem growth appears as a sequence of dark grey or brown bands or layers 0.5 mm to 2 or 3 mm thick and cream or buff layers of calcium carbonate 1 mm and 10 mm thick (Figure 3d). Each of these layers in turn consists of numerous microscopic laminae. Encased irregularly in the speleothem are nodules and lenses of cemented beach deposits (Figure 3d, arrowed); some fracturing and re-cementing of the laminated speleothem has occurred. It is not clear whether speleothem growth in caves A and B is still active. Adjacent to the mouth of Cave B, incipient beachrock has developed below a small tufa cascade.

### St Ives Bay

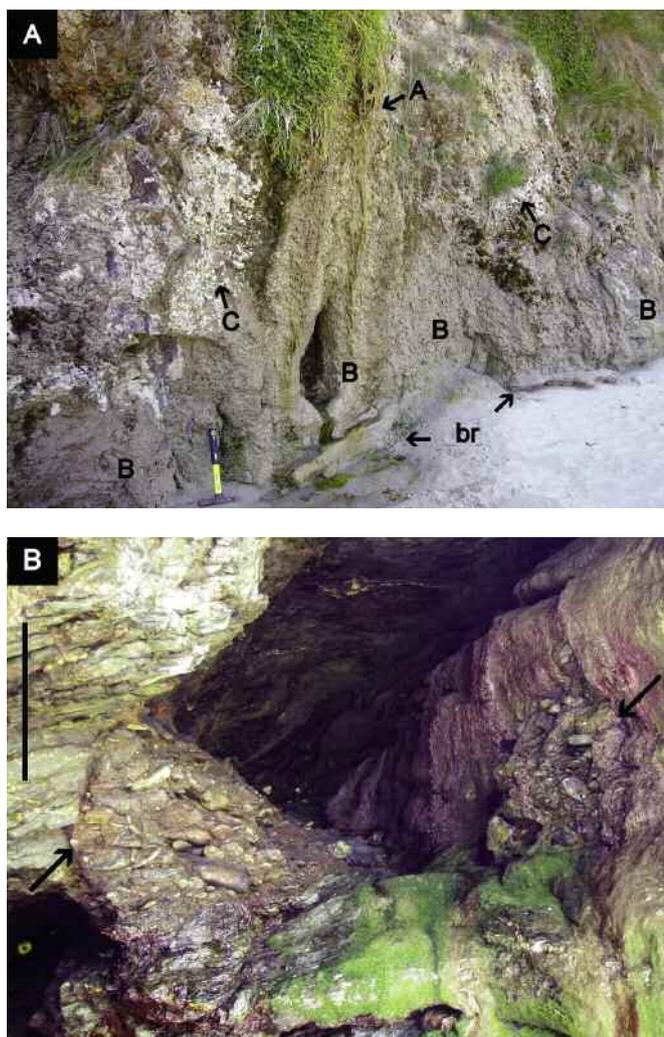
St Ives Bay is backed by the second largest dune field in Cornwall. The bedrock on its lateral margins comprises beds of the Middle Devonian Mylor Slate and Porthtowan formations. Cascades of tufa occur on the low bedrock cliffs on either side of the Hayle Estuary at Mexico Towans, (Figure 1, Table 1: locality 8), Black Cliff (Figure 1, Table 1: locality 9) and Lelant

Cliffs (Porth Kidney Sands) (Figure 1, Table 1: locality 10). At these localities tufa is developed as: (a) soft, spongy sand-coloured rounded masses, up to 100 mm thick where sand grains, most likely blown off the dunes and beach, are caught up in the wet moss/algae and become partially, to completely, CaCO<sub>3</sub> cemented; (b) soft, porous, white and cream coloured calcareous masses, forming on wet rock surfaces, with cauliflower-like outer surface and little or no sand grain content; (c) tufa deposits up to 50 mm thick, containing detrital sand, often with a hard white or cream patina, on cliff faces away from areas of active water percolation. These fabrics are particularly well displayed in tufa deposits associated with springs and run-off from the Lelant dunes along a 300 m section of Lelant Cliff bounding Porth Kidney Sands (Figure 4a). Incipient beachrock development is also seen at the base of these deposits at Lelant Cliff.

Calcareous speleothems have also developed in an adit in Lelant Cliff. Here the walls and roofs are encrusted with an algae covered layer of densely packed crystals 1-2 mm in diameter and up to 10 mm long growing orthogonally off exposed rock surfaces. X-Ray powder diffraction analysis



**Figure 3.** (a) Vertically striped green (algae or moss coated) and buff (dry) tufa cascades covering up to 15 m of cliff section of Lower Devonian Trendrean Mudstone Formation at Holywell Bay. Scale bar 2 m. (b) Calcareous speleothem cascades and dams developed in Cave A, (Holywell Cave), Holywell Bay. Scale bar 50 cm. (c) Speleothem cascades, drapes and canopies in Cave B, Holywell Bay. Scale bar 20 cm. (d) Eroded speleothem covering sloping wave-worn slate wall in Cave B, showing outer mamillated structure, alternating dark and light banding and fine lamination (centre, left to right diagonally) and development around cemented sand nodules (arrowed). For scale chisel is 12 cm long.



**Figure 4.** (a) Tufa cascade on section of Middle Devonian Gramscatho Beds at Lelant Cliff, Porth Kidney Beach, showing spongy calcareous deposit forming on strands of moss and grass at A, soft cream coloured calcareous masses, forming on wet rock surfaces with cauliflower-like outer surface and little or no sand grain content at B and dry, white patinated tufa containing detrital sand at C. A step of associated beachrock (br) is developed at base of cliff. (b) Tufa partially coating raised beach deposits (arrowed) cemented to walls and roof of a higher sea level cave cut into Lower Devonian Mylor Slate Formation in Stackhouse Cove. Scale bar 50 cm.

(STOE Powder Diffraction System) of this material indicates that it is almost pure low-Mg calcite. The relatively common occurrence of the Red Book (Bennallick *et al.*, 2009) listed calcicole plant Maidenhair fern (*Adiantum capillus-veneris* L) along this cliff section and in the adit confirms the high concentration of  $\text{CaCO}_3$  in sediments in the area.

Godrevy Cove (Figure 1, Table 1: locality 7) on the northern margin of St Ives Bay hosts a well known Quaternary 10 m thick section with cemented interglacial sands (sandrock) in the northern part of the section (Scourse, 1996). Active vegetated tufa occurs on the sides of a gully cut into the elevated shore platform which is overlain by a Pleistocene sequence of raised beach, littoral, and 'head' deposits, covered by a thin layer of dune sand.

### Stackhouse and Bessy's coves

These coves have been eroded into Lower Devonian Mylor Slate Formation on either side of the Cudnen Point gabbro/dolerite intrusion. In this area no limestone has been reported as occurring within the bedrock and superficial

deposits are represented by thin (3–4 m) deposits of head/loess.

Stackhouse Cove (Figure 1, Table 1: locality 11) is 200 m wide, with an extensive rocky inter-tidal shore platform extending 100 m seaward, backed by cliffs 15–20 m high. In the basal part of the cliffs onion shaped caves are developed, just above the current High Water Mark (HWM), almost certainly by erosion at a higher sea-level stand. Localised beach deposits, composed of shingle, form a narrow zone confined to the area between HWM and the cliffs. Discontinuous tufa cascades occur in the lower half of the cliffs throughout the cove and several springs have their origin in the slope behind the cove. On site analyses of the water from these springs indicates moderate alkalinity (pH range 8.0 to 8.6). The tufa deposits in the eastern sector of the cove, with their moss and algal cover, appear active and in one locality can be seen developing on the exposed sides of a higher sea-level cave. The deposits in the western sector appear older, lacking vegetation and in one locality were observed covering the side wall and eroded raised beach deposits in a higher sea-level cave (Figure 4b). The cascade covering the eroded raised beach extends more than 5 m into the cave and cannot be explained by cliff based sub-aerial cascades. Carbonate-rich solutions seeping through fractures in the bedrock may be involved. The setting of this particular cascade suggests that it may in fact have a speleothem origin which needs to be investigated further.

Bessy's Cove (Figure 1, Table 1: locality 12) is a smaller, even more deeply incised cove. The tufa deposits are confined to its western margin, are largely associated with algal growth and appear active. On site analysis of the water seeping down the cliff indicates moderate alkalinity (pH range 8.0 to 8.5).

## DISCUSSION

The proximity of the tufa and calcareous speleothem occurrences to Holocene coastal dunes at Porth Kidney Beach, Mexico Towans, Black Cliff and Onjohn Cove, coupled with the absence of limestone bedrock in these areas, would suggest that the source of  $\text{CaCO}_3$  may be the calcareous dune sand occupying the local coastal regions. The tufa occurrences at Trebetherick and Godrevy Cove are immediately adjacent to or close to coastal carbonate cemented littoral/palaeodune (sandrock) deposits of the last and/or penultimate interglacials (Scourse, 1996) and point to another possible older Quaternary source of  $\text{CaCO}_3$ .

Reid and Scrivenor (1906) attributed the tufa (speleothem) in Holywell Cave to wind-drifted shell sand on the cliffs above Holywell Bay. As cliff-side tufa and, possibly, speleothem deposition appears to be currently active and dunes are absent above the cave and cliffs it is suggested that the speleothems and the tufa in the bay are derived from the limestones in the Lower Devonian Meadfoot Group. The situation regarding the occurrence of the tufas at Porthcothan Bay, Boat Cove, Stackhouse Cove and Bessy's Cove is currently problematic in that there appears to be no association with a geological source of calcium.

Many of the tufa deposits described here are active. These are characterised by alkaline water seepage associated with predominantly green algal and bryophyte cushions and, occasionally, red/brown tinged algal and/or bacterial growths. Our observations suggest that as tufa cascades develop on cliff sides, water seeps or flushes move along cliff-faces seasonally or at longer durations; this results in the green and buff vertically striped cliff-faces seen in the region (Figure 3a) or distinct lateral changes between green active tufa forming areas and pale coloured dry hard tufa as at Stackhouse Cove. The relict layered tufa deposits at Onjohn Cove provide evidence that in some localities at least tufa was being deposited prior to the Holocene rise in sea level, indicating a millennia age range. The cascade at Stackhouse Cove cascade could have formed anytime after the formation of this interglacial sea cave.

The deposition of speleothems in the county may also extend over considerable periods. The evidence of a re-cemented

fractured speleothem enclosing older beach deposits from Cave B, Holywell Bay (Figure 3d) indicates that these deposits may have been influenced by both climatic factors and marine transgression and regression phases. Work in other caves in south west England confirms the potential use of speleothems and associated deposits in geochronology and climatology interpretation. At Kent's Cavern, Devon, for example, Lundberg and McFarlane (2007) propose that repeated frost shattering of flowstones followed by calcite re-cementation occurred during Marine Isotope Stages 8, 6c, 4 and 2. The dating of Quaternary speleothems from the halocline caves at Berry Head, Devon (Baker and Proctor, 1996) constrain sea level transgression events there to Marine Isotope Stages 9, 7, 5e and possibly 1. Geochemical investigations, in particular isotopic analysis of the layered tufas and laminated calcareous speleothems described in this review, may assist in shedding further light on the late Quaternary history of south west UK.

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