A rare example of thermal-contraction polygons in South-West England.

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There is abundant evidence in South West England in the form of depositional and erosional features to show that the region was subject at times in the late Pleistocene to a periglacial climate in which permafrost was present. Thermal-contraction polygons are a common feature in present-day permafrost areas and are present, but relatively rare, in former permafrost areas such as midland and eastern England. In contrast to single ice-wedge casts which are common throughout South West England, thermal-contraction polygons have not previously been recorded farther south than Gloucestershire. The examples described here, at Langport in Somerset, are similar in size and form to those described elsewhere in the UK where they have formed in relatively uniform, fine-grained sedimentary rocks. Comparison with fossil and present-day examples suggests that they indicate the presence of long periods of permafrost during the Devensian Stage at times when the Mean Annual Air Temperature (MAAT) was lower than -6°C. The Langport examples are the most southerly example of thermal-contraction polygons in the UK recorded to date.

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Introduction

There is no evidence to suggest that the South West region was ever covered by a continental ice sheet, but sea ice may have reached as far south as the Scilly Isles in the Devensian Stage (McCarroll *et al.*, 2010) and Dartmoor may have had an ice cap as recently as 12ka Before Present (Evans *et al.*, 2012). In addition, the cold phases of the Pleistocene gave rise to many erosional and depositional features that are characteristic of a periglacial climate (Te Punga, 1957). Freeze-thaw action in the form of frost-shattering and cryoturbation produced large amounts of weathered material that was widely redistributed by solifluction processes, meltwater torrents and strong winds. Ground-ice features include brecciation, the formation of stone circles, polygons and stripes; ice-wedge casts (e.g., Palmer and Neilson, 1962; Keene, 1990; James, 2004; Ealey, 2012); periglacial creep folds (Hutchinson and Hight, 1987; Gallois, 2010) and pingos (Gallois and Sole, 2014). Structures described as 'patterned ground' and/or 'polygons' have been recorded in South West England, but these mostly refer to raised accumulations of frost-shattered rock in which the larger clasts have been preferentially uplifted with respect to the smaller clasts and the surrounding finer grained sediments by cryoturbation processes. They are fundamentally different from thermal-contraction polygons which form as a result of the dilation of fine-grained materials with high moisture contents such as mudstones and chalks when cooled below -6°C. They also differ from the solitary ice-wedge casts exposed on the Devon and Cornwall coasts, some of which extend down for more than 15 m. Thermal-contraction polygons are widely distributed in the English Midlands and in northeast and eastern England in the area lying south of the maximum extent of the Devensian ice (Williams, 1964). The closest examples to South West England are those recorded from Worcestershire (Shotton, 1960) and Gloucestershire (Allen, 1984).

Somerset examples

A systematic search of the Google Earth air photographs of Cornwall, Devon, Dorset and Somerset failed to yield unequivocal evidence of thermal-contraction polygons except for four examples at Langport, Somerset [ST 423 267] at heights of 15 to 25 m above Ordnance Datum. According to the published BGS 1:50k map of the area (Sheet 296, Glastonbury, 1968) two of these are sited on River Terrace Deposits that rest on Penarth Group mudstones and limestones, one directly on the Penarth Group and one on the Mercia Mudstone Group (Figure 1). However, the Penarth Group in the Langport area is attenuated and much affected by faulting. The field evidence suggests that all four sites are underlain by mudstone in the upper (Norian Stage) part of the Mercia Mudstone Group.

Site 1 [TL 4289 2776], the best preserved of the examples, shows complete and incomplete polygons and rectangles that are mostly 7 to 12 m across in a relatively flat field (Figure 2). They are absent from the northern part of the area where the ground slopes upwards. The surface layer of the soil comprises bleached white limestone clasts derived from nearby outcrops of the White Lias and Blue Lias in a sand matrix that is cut by streaks of organic-rich dark sandy soil. Similar, but less well-defined patterned ground is visible on the December 31st 2010 air photograph at Site 2 [TL 4266 2748], but this is not currently visible on the ground due to the presence of a large amount of imported material. Partially preserved polygons are well preserved at Site 3 [TL 4260 2713] where they are similar in size to those at Site 1 (Figure 3). The surface soil is a heavy clay with a few scattered limestone clasts. Fragmentary patterns are visible on the December 31st 2010 air photograph at Site 4 [TL 4087 2701] where they appear to be on a heavy clay soil with a patchy veneer of sandy soil.

Thermal-contraction patterns similar to those at Langport, which are also in mudstones in the Mercia Mudstone Group, were described by Allen (1984) in the intertidal zone in the Severn Estuary at Oldbury on Severn [TL 600 938]. These are in

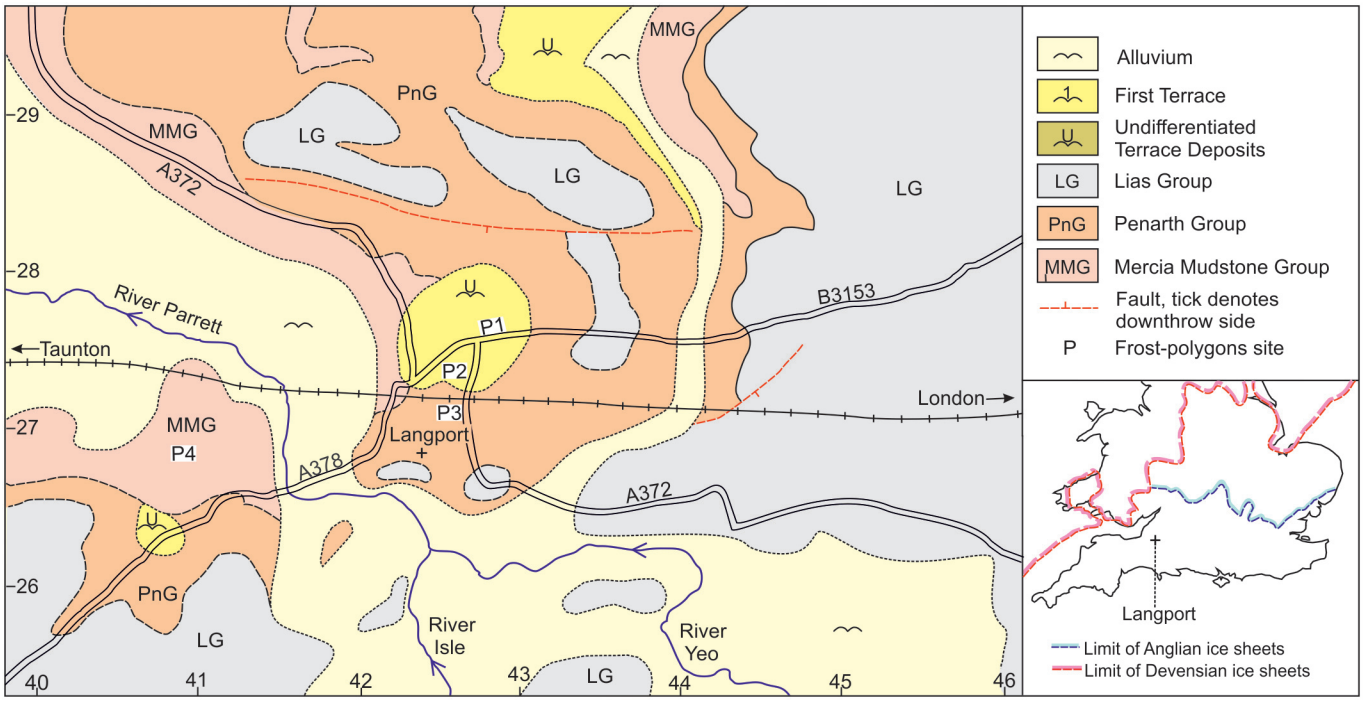

Figure 1. *Geological sketch map of the area around Langport, Somerset showing the location of the frost-polygon sites. Based on British Geological Survey 1:50k Sheet 296 (Glastonbury), 1968. Ice-sheet limits after McMillan, 2005.*

part visible on the Google Earth air photograph dated 9th August 2014 although largely covered by modern estuarine muds. The large tidal range and the partly exhumed nature of the polygons enabled Allen (1984) to examine the structures in three dimensions and show that they were 7 to 30 m across, that the cracks are wedges infilled with ill-sorted, locally pebbly sand that tapered downwards, and that the wedges were bounded by disrupted mudstones with upturned bedding. He concluded that they were ice-wedge casts of possible Devensian age that formed by dilation, dessication or thermal contraction of the mudstones, and that they record the establishment of continuous permafrost in the area.

Frost polygons of the type described here in which cracks infilled with collapsed debris form the boundaries of adjacent polygons were described by Washburn (1956) as non-sorted fissure or contractional polygons. Many of the published descriptions of polygons of this type form in lithologically relatively uniform sediments with high moisture contents, such as peats, sands, mudstones and chalks, which shrink when they and their contained water are cooled below *c.* -6ºC for periods of several months or more. In an isotropic medium the thermal-contraction cracks form an hexagonal pattern in accordance with the second law of thermodynamics, i.e., the maximum shrinkage will be achieved for the minimum energy (crack length) involved. The boundary cracks become visible at the surface when they are overlain by a permeable granular material such as sand or gravel and repeated freeze-thaw cycles cause the cracks to become wide enough for material to collapse into them. Modern examples include those in peats in Arctic Canada (Ellis and Rochefort, 2004) and sands in Antarctica (Black and Berg, 1966). Fossil examples in England include those in till in Cheshire (Worsley, 1966), in Mercia Mudstone in Gloucestershire (Allen, 1984) and, most abundantly, those in Chalk in East Anglia, Lincolnshire and Kent (Williams, 1964; 1969). Bateman *et al.* (2014) have shown that some of the chalkland examples in East Anglia experienced multiple phases of activity during the Devensian Stage, but do not date back to earlier glacial cycles.

Figure 2. *Frost polygons at Site 1, December 31st 2010. Darker, organic-rich infillings contrast with the pale limestone-rich gravelly soil. Air photograph reproduced courtesy Google Earth.*

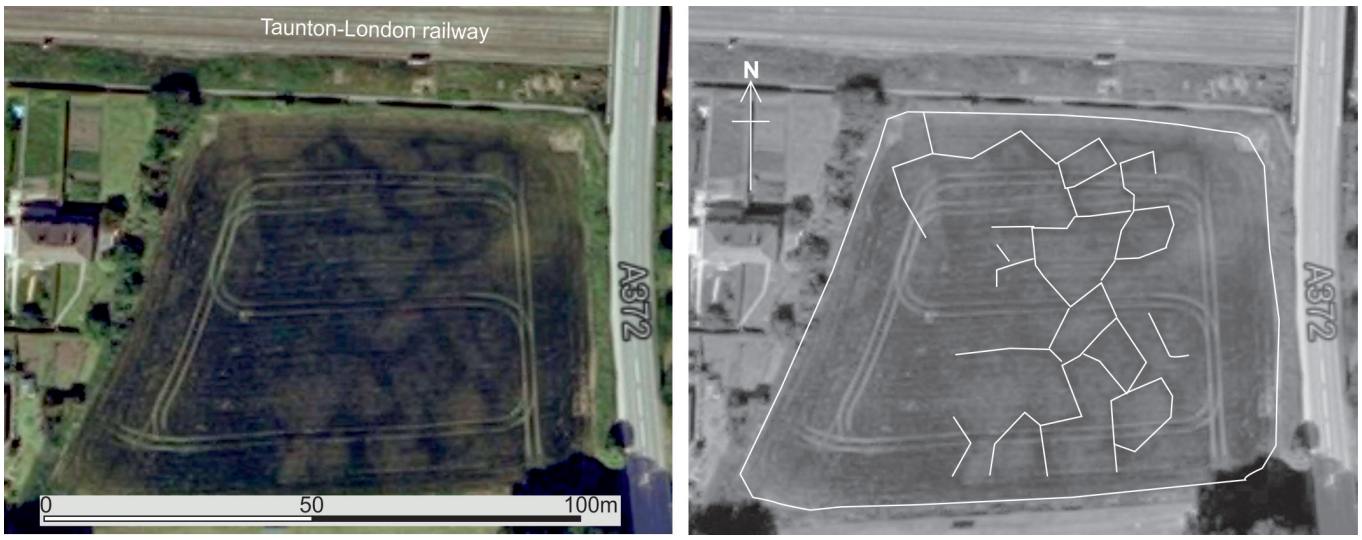

Figure 3. *Frost polygons at Site 3, December 31st 2010. The dark organic-rich infillings appear to be more smeared out than at Site 1. Air photograph reproduced courtesy Google Earth.*

Summary and conclusions

Several authors have suggested that permafrost may not have been present throughout

South West England during the last (Devensian) cold stage of the Pleistocene. West (1969, fig. 1) concluded that permafrost was largely absent in South West England except for parts of Dartmoor and Exmoor, Ballantyne and Harris (1993) thought that it might not have been present, and James (2004) that it might have been only sporadically present. However, McCarroll *et al*. (2010) concluded that the Devensian ice sheet reached the Scilly Isles in 22–21ka BP, and Evans *et al*. (2012) suggested that Dartmoor was covered by an ice sheet during this glaciation and that it might have been present as late as the Younger Dryas cold phase, *c*. 12.9ka to *c*. 11.7ka BP. In addition, descriptions of a wide range of cryoturbation features throughout the region at lowland and upland sites suggest that permafrost was present throughout the region for parts of the Devensian Stage. If this was the case then one might expect to find more examples of thermal-contraction polygons given that there are extensive outcrops of fine-grained sediments in the region, including Triassic and Jurassic mudstones and Chalk that could act as a suitable medium for their formation.

The Langport examples (Latitude 51°.041′ N) are the first to be described from South West England and are the most the southerly thermal-contraction polygons recorded to date in the UK.

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