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Cap structures as diagnostic indicators of silcrete origin

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ABSTRACT

Cap structures within silcretes have long been used as a diagnostic indicator of pedogenic silicification. However, a growing number of studies of the micromorphology of non-pedogenic silcretes indicate that this may no longer be appropriate. This paper presents the first systematic investigation of the micro-fabric, geochemistry and mineralogy of cap structures in groundwater silcretes, through an analysis of conglomeratic varieties (puddingstones) from the southern UK. Our results suggest that cap structures in groundwater silcretes fall within a spectrum of types, related to the degree of sorting in the inter-gravel host sediment. At one end of this spectrum are well-defined caps within otherwise well-sorted, overgrowth-dominated silcretes. These caps exhibit a grain-supported fabric, are cemented by micro- and/or cryptocrystalline silica, and contain floating silt-sized quartz and Ti-oxide grains. We propose that these structures developed mainly as a result of in-washing of fine sediments that were subsequently silicified. At the other end of the spectrum are silcretes with caps defined by concentrations of Ti-oxide grains, as opposed to cement type and grain size. These formed mainly as a result of the remobilisation and precipitation of Ti during the silicification of gravels containing interstitial clay-rich sandy sediment. Between these end-members are silcretes with cap structures formed by a combination of in-washing and redistribution of fines plus some local remobilisation of Ti. Overall, the cap structures in this study exhibit a simple micromorphology, lacking the alternating Ti- and silica-rich lamellae typical of pedogenic silcrete. We conclude that the presence of cap structures alone should not be considered diagnostic of pedogenic silicification unless accompanied by other indicators such as a differentiated profile and abundant, complex, way-up structures within the micro-fabric.

1. Introduction

Silcrete is an indurated geochemical sediment produced by the near-surface accumulation of secondary silica within a soil, sediment, rock or weathered material (Summerfield, 1983; Milnes and Thiry, 1992). It has been described on every continent except Antarctica (Summerfield, 1983), and is recognised as a major terrestrial silicon sink (Basile-Doelsch et al., 2005). To date, four models have been put forward to explain silcrete formation (Nash and Ullyott, 2007). *Pedogenic silcretes* are those which form as a result of cycles of downward percolation and precipitation of silica within soil profiles (e.g. Thiry, 1978). Non-pedogenic *groundwater silcretes* form under phreatic conditions through silicification at or close to present or former water tables, or at zones of groundwater outflow (Callen, 1983; Thiry et al., 1988; Thiry and Milnes, 1991). Models to explain the origins of non-pedogenic *drainage-line silcretes* and *pan/lacustrine silcretes* are constrained in terms of geomorphological context, with silicification occurring in alluvial fills in contemporary or former fluvial systems or ephemeral lake basins respectively (Young, 1978; Summerfield, 1982; Nash and Shaw, 1998; Shaw and Nash, 1998).

Distinguishing between the various categories of silcrete is of fundamental importance when, for example, attempting palaeoenvironmental reconstruction, establishing sequence stratigraphy or developing engineering ground models, since pedogenic and non-pedogenic silcrete formation takes place over different temporal and spatial scales and in different environmental contexts (Nash and Ullyott, 2007). A number of diagnostic properties have been proposed to aid recognition. At the macroscale, pedogenic silcretes often exhibit a distinctive profile structure, with columnar and nodular features and a systematic vertical distribution of silica cements (Thiry, 1978; Watts, 1978; Milnes and Twidale, 1983; Thiry and Millot, 1987). In contrast, non-pedogenic silcretes are more massive and lack vertical profile organisation (Summerfield, 1982; Thiry et al., 1988; Nash et al., 1994). Unfortunately, these characteristics are not always clearly developed and are even less likely to be evident in loose boulders or core samples. In these cases, silcrete types may only be distinguished at the microscale.

When viewed in thin-section, non-pedogenic silcretes normally exhibit a simple micromorphology that preserves host sediment structures (Thiry et al., 1988; Milnes and Thiry, 1992; Shaw and Nash,

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1998). Pedogenic silcretes, in contrast, have a more complex micromorphology and incorporate a suite of way-up orientated features. These include: (i) tubule-like structures comprising alternating lamellae of silica and anatase; (ii) colloform structures consisting of layered silica and anatase or iron/manganese oxides; and (iii) pendulous drip-like, stalactitic or beard-like structures developed underneath clasts or on the upper surface of fractures or voids (Frankel and Kent, 1938; Thiry, 1978; Summerfield, 1983; Meyer and Pena dos Reis, 1985; Thiry, 1988; Milnes and Thiry, 1992; Terry and Evans, 1994; Curlík and Forgác, 1996; Ballesteros et al., 1997).

A fourth set of features—silica-cemented conical or cap structures developed on the top of host sediment clasts—is usually added to this list of micromorphological indicators of pedogenesis. Such structures range in size from the millimetre to the sub-metre scale, and typically comprise alternating lamellae of coarser size graded quartz with titaniferous microquartz, sometimes showing cross bedding, graded bedding or reverse graded bedding (Thiry, 1988; Thiry and Simon-Coinçon, 1996; Thiry, 1999; Thiry et al., 2006). These features are often referred to as geopetal caps, cappings or cap-like structures in the silcrete literature (Taylor and Ruxton, 1987; Ullyott and Nash, 2006; Dupuis et al., 2014). The origin of these structures is not entirely clear, but has been suggested to relate to intermittent but repetitive infiltration events (Thiry and Milnes, 1991), which may reflect an alternation of wet and dry conditions. Many reviews of silcrete formation (e.g. Milnes and Thiry, 1992; Thiry, 1999) treat these cap structures as an exclusive product of pedogenesis. However, caps have also been identified in groundwater silcretes from eastern Australia (Taylor and Ruxton, 1987), and have been observed by one of the authors (DJN) on pebble-sized clasts within groundwater silcretes to the north of Adelaide. Caps have further been documented on the upper surface of coarse sand- to cobble-size clasts in groundwater silcretes from the southern UK (Ullyott et al., 2004; Ullyott and Nash, 2006).

Cap structures in groundwater silcretes appear to be less well developed and less pervasive than those found in pedogenic silcretes. However, to date, they have not been described systematically, making it impossible to determine whether they are distinct from their pedogenic counterparts and hence can be used as indicators of silcrete origin. This paper aims to fill this knowledge-gap and, for the first time, document the micromorphology and geochemistry of cap structures within groundwater silcretes. It does so through the analysis of groundwater silcretes from various sites across the southern UK (Fig. 1; Table 1). We focus upon groundwater silcretes developed within gravel-rich, as opposed to predominantly arenaceous, host sediments, since caps are larger and better developed in these materials. On the basis of a range of analyses we discuss the possible origin of cap structures within groundwater silcretes and propose guidelines for the wider use of such way-up orientated features in distinguishing different silcrete types.

2. Background and study areas

2.1. Silcretes in the southern UK

Silcretes are widespread across the southern UK and occur typically as dislocated boulders on the late Cretaceous Chalk, in close association with a number of Palaeogene arenaceous formations, or with the Clay-with-Flints Formation or Pleistocene sediments (Summerfield and Goudie, 1980). Three types of silcrete are recognised on the basis of host sediment type and variations in induration. Those that formed in sandy host materials (termed *sarsens* in the UK literature) can be divided into a *saccharoid* or quartz arenite type, and an *extremely hard* type which varies from quartz arenite to quartz wacke (Prestwich, 1854; White, 1925; Summerfield and Goudie, 1980). The saccharoid type most commonly exhibits a grain-supported (GS-) fabric (*sensu* Summerfield, 1983) with optically-continuous quartz overgrowths and subsidiary microquartz and/or cryptocrystalline silica cements (hereafter referred to as a saccharoid fabric). In the extremely hard variety, cryptocrystalline silica or microquartz cements are dominant,

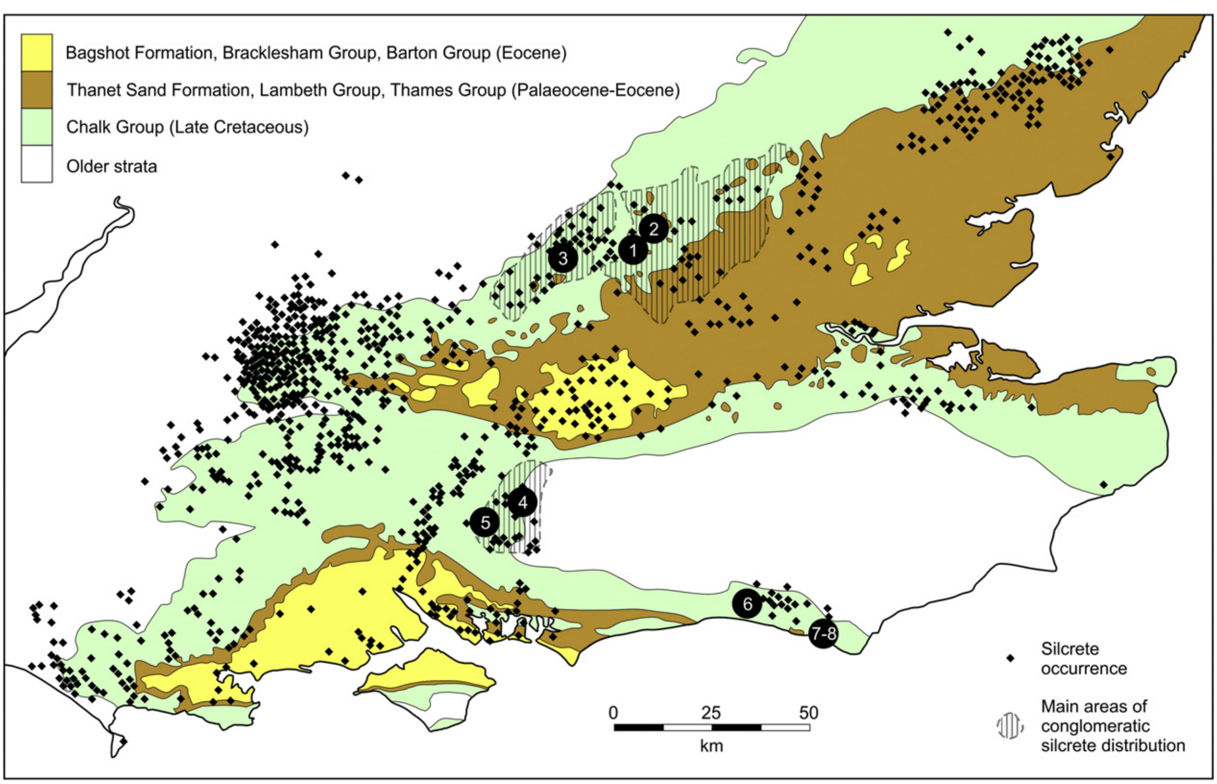

Fig. 1. Simplified geological map of southeast England with sampling locations and the approximate distribution of silcrete occurrences indicated. Silcrete distribution after White (1910), Brentnall (1946), Davies and Baines (1953), Bowen and Smith (1977) and Summerfield and Goudie (1980). Numbers refer to localities detailed in Table 1.