Catena 146 (2016) 48–61

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Human induced calcretisation in anthropogenic soils and sediments: Field observations and micromorphology in a Mediterranean climatic zone, Israel

Danny Itkin [a,*], Haim Goldfus [a], H. Curtis Monger [b]

[a] Department of Bible, Archaeology and Ancient Near East, Ben-Gurion University of the Negev, Beer Sheva, Israel
[b] National Soil Survey Center, USDA, Lincoln, NE, USA

ARTICLE INFO

Article history:
Received 1 October 2015
Received in revised form 13 June 2016
Accepted 16 June 2016
Available online 30 June 2016

Keywords:
Calcrete
Pedogenic carbonate
Calcrete cement
Geoarchaeology
Soil micromorphology

ABSTRACT

For over a century, the study of pedogenic calcrete and its formation focuses on natural processes, disregarding the possible role of humans in its formation. Here we present field and micromorphological evidence from archaeological and modern sites in the eastern Mediterranean region (Israel) that indicate that some specific calcretes are human induced. We demonstrate that anthropogenic affected calcrete differs from 'natural' (non-human induced) calcrete. We show that the occurrence of the human induced calcrete is spatially limited and is associated with both macro- and micro-scale remnants, and occasionally high content of organic material. We propose an operative definition for anthropogenic calcretisation as the interference of humans with a component(s) that influence the formation of calcrete. We assume that if present-day calcretised environments will retain their calcretisation prone conditions for the next 5–10 millennia, a distinct calcretic morphology could become a significant terrestrial formation. This discovery can be particularly useful for evaluating past human impact on the environment, adding a new archaeological set of research tools that should further be developed.

1. Introduction

Can humans affect the formation of calcrete? Calcrete, as used in this paper, consists of heterogeneous terrestrial accumulation of predominantly calcium carbonate ($CaCO_3$) that form under pedogenic conditions in permeable host regolith and its bedrock, with or without a subaerial phase, regardless of its hardness or state of maturity. Other terms to describe this material include pedogenic carbonate, caliche, tosca, croûte calcaire, kankar, secondary carbonate, authigenic carbonate, and, depending on its origin, geogenic, lithogenic, primary, and inherited carbonate (Monger et al., 2015a). When physically associated, the influence of soil materials on calcrete is most pronounced (Watts, 1980; Chafetz et al., 1985; Wright et al., 1993; Kraimer and Monger, 2009) rightfully allowing 'pedogenic calcrete' to be defined as a classifiable calcrete type. Pedogenic calcretisation (namely the formation of pedogenic calcrete) is controlled by the interactions between host regolith, climate, aeolian dust, Ca^{2+} in precipitation, biogenic activity, topography, tectonic stability, and time of formation (Gile et al., 1966; Wright and Tucker, 1991; Alonso-Zarza and Wright, 2010; Monger et al., 2015a; Verrecchia, 2016-in this issue). The aim of this work is to discover whether anthropogenic actions have an influence on the formation of calcrete cements, and if so, to suggest explanations for this mode of calcretisation.

Calcrete is considered as a palaeoclimate proxy of arid (BWk) to temperate (Csa, 'Mediterranean'; Peel et al., 2007) regions (Yaalon, 1971; Wright and Tucker, 1991; Alonso-Zarza and Wright, 2010), as well as an utmost important indicator of palaeopedogenic conditions (Yaalon, 1971; Wright and Tucker, 1991; Zucca et al., 2014). The evolution of the Mediterranean climate and vegetation in the Mediterranean Basin began in the early Pliocene and became amplified during the Pleistocene (Suc, 1984; Suc et al., 1995; Thompson, 2005). As expected, the results of different dating methods that have been applied for late Cenozoic calcretes in this region (Özer et al., 1989; Plaziat et al., 2008; Shtober-Zisu et al., 2008; Candy and Black, 2009; Zilberman et al., 2011; Ryb et al., 2013; Zucca et al., 2014) indicate a multi-phased calcretisation since the early Pleistocene, and possibly the late Pliocene. Common morphologies of hardpan-capped calcrete in the Levant are called 'nāri' (Itkin et al., 2012 and references therein). In the most general sense, nāri profiles can be divided into three distinct zones, from top downwards: 1) a thin 'laminar crust' of a few to 10s of mm, 2) a 'hardpan' of 1–5 m, and 3) a 'transition zone' of 1–5 m (also called 'lower nāri'; Yaalon and Singer, 1974; Verrecchia, 2016-in this issue).

---

* Corresponding author.
E-mail addresses: danitkin@gmail.com (D. Itkin), hgoldfus@bgu.ac.il (H. Goldfus), curtis.monger@lin.usda.gov (H.C. Monger).

http://dx.doi.org/10.1016/j.catena.2016.06.025
0341-8162/© 2016 Elsevier B.V. All rights reserved.

While the formation of hardpan calcrete can continue over ~100,000 years and more (Watts, 1980; Gile, 1999, 2002; Candy and Black, 2009), initial calcrete morphologies can be identified in the field within less than a century to ~10,000 years (Strong et al., 1992; Monger and Gallegos, 2000). Compared to the distinctive field appearance of calcretes (Wright and Tucker, 1991; Alonso-Zarza and Wright, 2010), features of early stage calcretisation are not as prominent. Applying techniques of soil micromorphology is often necessary in order to interpret the unique nature of pedogenic calcium carbonate cements (Wieder and Yaalon, 1982; Verrecchia, 1990; Wright, 1990a; Monger et al., 1991; Kapur et al., 1993; Khormali et al., 2006; Durand et al., 2010).

The formation of soils can be highly influenced by human actions (Yaalon and Yaron, 1966; Holliday, 2004; Yaalon, 2007) as can the whole 'critical zone' (Richter and Billings, 2015). Considering the frequent interface of humans with the terrestrial carbon cycle (Suarez, 2000; Lal, 2004; Chapin et al., 2011), it is suggested that there is an anthropogenic influence on the calcification of host soils and sediments in regions where calcretisation prone environments meet an intense and prolonged human imprint. If that is so, such influence could presumably derive from agents that induce calcium carbonate cementation, such as the rhizosphere of agricultural plants, lime (CaO; 'quicklime') and carbonate building materials. The Levant serves as a suitable study area to explore this interaction; since prehistoric time and up until the early 20th century, the frequent distribution of nāri in this region has made it an integral material in the everyday life of humans. This is well evident in both prehistorical and historical sites in areas where nāri outcrops are prevalent (Shiloh and Horowitz, 1975; Kloner, 1993; Henry et al., 1996; Goren and Goring-Morris, 2008; Abu-Jaber et al., 2009; Tsatskin and Zaidner, 2013; Ackermann et al., 2014). Still, compared to studies on natural calcretisation (Wright and Tucker, 1991; Alonso-Zarza and Wright, 2010), the impact of anthropogenic activities on the formation of calcrete cement has not yet been studied in detail.

Insofar as this paper is presented in the framework of a special tribute to Dan H. Yaalon (1924–2014), his part in motivating this idea should be mentioned. Triggering this study, a hypothesis according to which humans could noticeably enhance or even generate calcretisation in their locality, was suggested in a series of discussions with Yaalon. Much attention was devoted to the value of field observations, the spatial extent of their distribution, and the degree of their validity and merit to archaeology. The pertinence of soil micromorphology to this subject was assessed, considering its sole advantage of analysing the in situ morphological state of regoliths (Stoops et al., 2010).

In light of the above, we describe seven representative case studies whereby humans are the direct or indirect source of chemical species controlling the carbonate system dynamics in host soils and sediments. Apparently, a suitable way to describe this process might be 'anthropo-calcretisation'. This concept could add to the increasing interest in the study of archaeological materials (Macphail and Goldberg, 2010; Benedetti et al., 2011) and thereby could contribute to interpreting the accompanying environmental history of archaeological sites (Netterberg, 1974; Yaalon, 2005). We offer this approach as highly promising for pedoarchaeological research and propose further investigation possibilities in order to broadly quantify both the mechanisms of human induced calcretisation and the ways by which they affect the environment.

2. Materials and methods

2.1. The study area

The study area on which this paper focuses is situated at the eastern Mediterranean Basin and includes the northwestern part of the Judean Hills and the Judean foothills (Shephelah), Israel (Fig. 1). The bedrocks in this area are predominantly composed of Upper Cretaceous and Eocene carbonates with some Quaternary alluvium and conglomerates (Sneh et al., 1998; Bar et al., 2016). These bedrocks are typically calcretised in the top 0.5–5 m. The soils of this area are mostly human-altered; Brown Rendzinas (Calcic and Typic Haploxerolls; Lithic Xerorthents) and Terra Rossas (Lithic and Typic Rhodoxeralfs) with a limited distribution of Pale Rendzinas (Lithic Xerorthents) and Vertisols (Chromic and Typic Haploxererts; Chromic and Typic Calcixererts), (Singer, 2007; Soil Survey Staff, 2014). The Pale Rendzinas in this area are relatively young soils which are formed on chalk that is not capped by nāri (Dan and Koyumdjisky, 1975) or on exposed transition zone nāri. Unclassified Anthroportic soils (Soil Survey Staff, 2014) fill the numerous agricultural stone wall terraces in the area.

The formation of the above mentioned soils has been influenced by 'Mediterranean climate' with xeric moisture regime, abundance of slopes, significant supply of aeolian dust, large proportion of calcareous parent materials, and intense anthropogenic impact (Yaalon, 1997). The same factors have affected the formation of the Quaternary pedogenic calcretes in the region. The climate in the study area is characterised by a temperate-dry-hot summer (Csa, 'Mediterranean'; Goldreich, 2003) with mean annual precipitation of 350–530 mm (Israel Meteorological Service, 2015). The phytogeographical conditions are predominantly Mediterranean. The vegetation is of an open park forest with carob trees (*Ceratonia siliqua* L.), interspersed in a mosaic with patches of planted pine (*Pinus halepensis* Mill.) forests and olive orchards (*Olea europaea* L.), associated with *Sarcopoterium spinosum* batha shrubland and annual plants (Sapir, 1977; Danin, 1988). Lichens, such as *Caloplaca citrina*, *Caloplaca erythrocarpa*, and *Toninia sedifolia* (Galun and Mukhtar, 1996; Temina and Nevo, 2009) cover the upper surfaces of the nāri outcrops, mostly on their north face. Lastly, this area has been under intense human influence during the last few millennia (Reifenberg, 1955; Naveh and Dan, 1973).

2.2. Methods

A field survey and micromorphological analyses were conducted in order to locate and study profiles of human-affected regoliths that bear calcretic morphologies. Seven characteristic 'anthropogenic profiles' in four different sites were chosen and documented in the framework of the field work (Table 1; see Section 3), out of which thirteen undisturbed samples were taken out for micromorphological examination. The samples were extracted by applying the 'selective sampling' method, given that specific questions relating environments to distinct lateral variations were employed (Courty et al., 1989). All samples were collected from their in situ location except for the Nahal Zanoach samples that were found a few metres away from their assumed original location (see Section 3.6). The preparation of the thin sections was made at the Leon Recanati Institute for Maritime Studies at Haifa University, according to Gottlieb (2015), emphasising the careful attention needed for the processing of man-made lime-based friable samples. The samples were observed using an Olympus BX53 polarising microscope and photographed using an Olympus DP23 digital camera mounted on the microscope, in the Sedimentology Lab of the Leon H. Charney School of Marine Sciences at Haifa University. The micromorphological description was made according to Stoops' guidelines (Stoops, 2003).

3. Results and first interpretation

The following case studies (Table 1) are presented according to their geographical distribution:

3.1. Calcification of a lime-based building material embedded beneath a stone wall boulder (BH; Binyanei Ha'Uma site)

Binyanei Ha'Uma site is located on a hill at the western modern outskirts of Jerusalem, 825 m a.s.l (Fig. 1). This site was intermittently inhabited since the Late Iron Age (8th–7th c. BCE; Arubas and Goldfus, 2005). The soil in this site is palaeo-Terra Rossa with high