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Microstructure and palygorskite neoformation in pedogenic calcretes of central Morocco

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ABSTRACT

The aim of this research was the micromorphological and mineralogical characterization of calcrete outcrops located in central Morocco, with particular focus on microstructure development and palygorskite formation processes. Two study sites in the Al Haouz Plain (ca 30 km west to Marrakech city) were identified, in an area dominated by Quaternary sedimentary formations including layers cemented by carbonate and widespread calcareous crusts at the surface. The calcrete samples were examined by means of polarizing microscopy from thin sections, scanning electron microscopy / energy-dispersive X-ray spectroscopy (SEM/EDX) from undisturbed samples, and X-ray diffraction (XRD) methods. The matrix of the calcrete material cementing the schist fragments composed of abundant calcite was associated mainly with palygorskite, quartz, and to a lesser extent illite/mica, feldspar, and chlorite. SEM observations indicated that palygorskite mainly occurred as fibres, fibre bundles and networks mainly grown on and/or enclosing calcite rhombohedrons. The EDX spectra of the palygorskite fibres exhibited strong silicon (Si) peaks followed by Al, Mg and Fe peaks. The EDX analysis of calcite rhombohedric crystals exhibited a strong Ca peak, followed by weak peaks of Si, Mg, Al and Fe possibly due to nearby or overlapped palygorskite crystals. One main palygorskite neoformation process was described. Palygorskite was authigenically formed (neoformed) during and after precipitation of calcite from percolating soil solutions in a near-surface setting. Peculiar sub-rounded microstructural units, here designated as *pedogenic ooids/pisoids* (according to the size), were determined in the matrix of the studied calcretes, associated to pendants and clay-rich rims surrounding them.

1. Introduction

The term calcrete or caliche refers to near-surface, terrestrial accumulations dominated by calcium carbonate, which are mainly of pedogenic origin (Wright and Tucker, 1991; Eren, 2011; Kadir et al., 2014). However, there are calcretes formed in palustrine environments, where calcareous mud precipitated in a lacustrine water body (Alonso-Zarza, 2003), and calcretes whose formation is connected to shallow groundwater and to evaporation in the capillary/vadose zone (Goudie, 1983; Mann and Horwitz, 1979; Semeniuk and Meagher, 1981; Wright and Tucker, 1991). The study of the micromorphological, mineralogical, and geochemical features of calcretes, and of their formation processes, can provide useful indicators of palaeoenvironmental and palaeoclimatic conditions (Kapur et al., 1993; Alonso-Zarza and Wright, 2010; Kaplan et al., 2013; Zucca et al., 2014a, 2014b). Due to their desiccated massive consistence they are often well preserved in the landscape (e.g., as paleo-surfaces), or can be observed as fragmentary relict features. Thus, calcretes can provide particularly useful palaeoenvironmental information when they are framed within well-established stratigraphic contexts.

In central semi-arid Morocco, the Tensift-Al Haouz area, including the Tensift River plain to the South and the Jebilet mountain range to the North, is characterized by widespread calcrete outcrops showing a variety of forms. These range from continuous thick hardpans in parts

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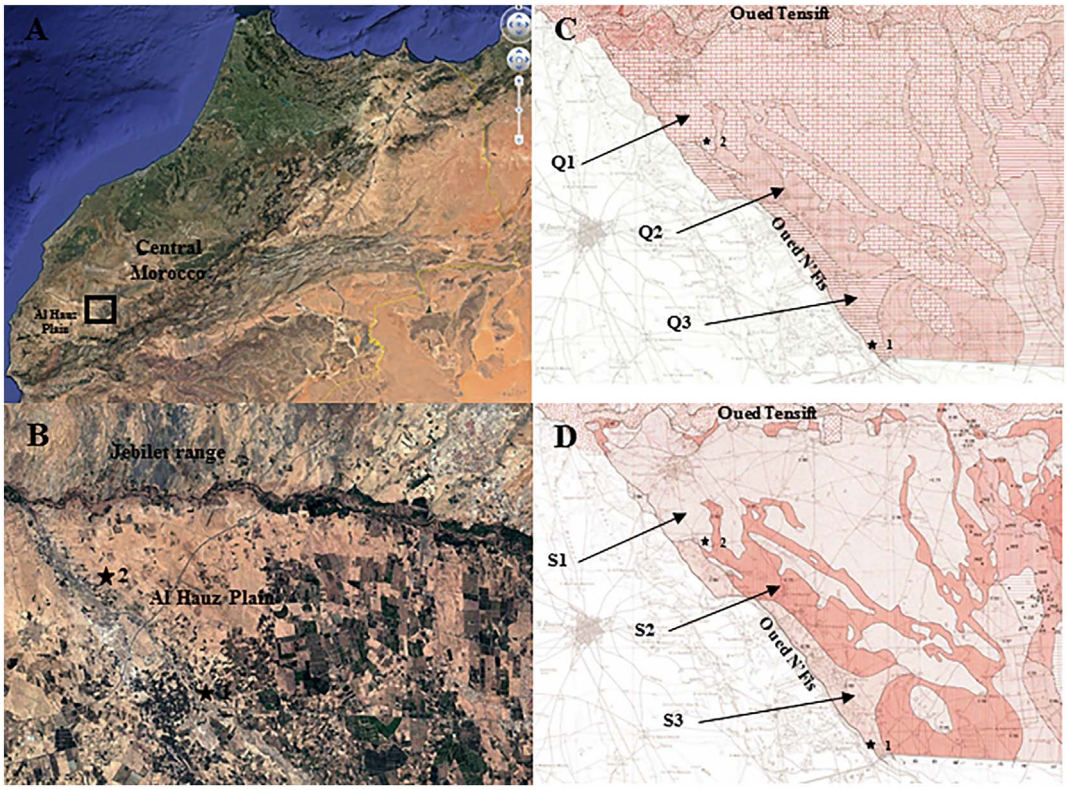

Fig. 1. A) and B) Google Earth images showing the study area, in the plain between the Oued Tensift River and the Oued N'Fis River. C) 1:50,000 map of surface deposits by Moreau (1973a). D) 1:50,000 pedologic map by Moreau (1973b). Soil units were designated by the authors according to CPCS (1967). An indicative correspondence with the international system (IUSS Working Group WRB, 2015) is given in brackets in the note below. North orientation is upwards in all maps.
Q1, Q2, and Q3 = Quaternary sedimentary units respectively defined as "encrusted deposits, with limestone armor (carapace)"; "silty to silty-clayey deposits overlaying nodular limestone crust"; "silty to silty-clayey deposits with sandy and gravelly lenses". S1 = Lithosols (Leptosols) over limestone crust. S2 = Sols isohumiques bruns (Kastanozems, Cambisols, Leptosols) irregularly saline and alkaline. S3 = Siérozems (Calcisols, Leptosols), weakly saline and alkaline.

of the plain to fragmentary relict calcretes on the Jebilet piedmont and slopes. The origin of the main calcrete types of this region were recently investigated by Elidrissi et al. (2017), who studied more than one hundred outcrops highlighting the considerable palaeo-environmental significance of these formations. Our in-depth research was focused on two sites located in a sector of the same Tensift-Al Haouz area, where peculiar micromorphology and mineralogy features were observed that can shed light on the formation processes of these calcretes that have not been considered earlier. Particular attention was devoted to the environmental factors that were decisive for soil formation.

The study of the different forms and formation processes of palygorskite was a major aspect of the research. Palygorskite is a clay mineral typical of the calcretes, which formation in soils requires arid to semi-arid conditions and a calcium and magnesium-rich environment (Verrecchia and Le Coustumer, 1996; Garcia-Romero and Suárez, 2010; Galán and Pozo, 2011). In pedogenic calcretes around the Mediterranean basin palygorskite is frequently observed in association with clay minerals such as smectite and illite (Galán and Pozo, 2011). Much remains to be investigated about these associations of clay minerals, where their varying size, orientation, weathering or dissolution features could indicate specific mineral formation sequences, and formation environments.

The specific objective of this research was to analyze the microstructural development of the selected calcretes by means of micromorphological and mineralogical evidence, with particular attention to the characterization of calcrete grains and ooid-like microstructural units, and to determine the palygorskite formation processes.

2. Geological setting and field description of the calcrete sections

The study area is located in central Morocco (Marrakech-Tensift-Al Haouz region, Marrakech province), around 30 km west to the city of Marrakech, in the El Haouz plain (Fig. 1A, B). The area is ideally defined by the triangle formed by the El Tensift river and the Oued N'fis river, in the eastern part of the El Haouz plain. Two study sites were identified (Fig. 1B): site 1, located along the Oued N'fis river bank (at around 370 m a.s.l.), and site 2, a few kilometres to the north-west, in the plain (ca 350 m a.s.l.). The present-day climate of the area is semi-arid to arid, and the land use is mainly rainfed and irrigated agriculture, and grazing.

The eastern part of the Al Haouz plain is composed of alluvium deposits, including conglomerates, sandstones, silts and clays facies, fed by the dismantling of the Atlas range (igneous and metamorphic Precambrian and Paleozoic formations) during the Neogene and the Quaternary (Elidrissi et al., 2017). Fluvial terraces constitute the main geomorphological environment in the study area. Here the plain is flat to very gently sloping, and deeply incised by the river beds, and is dominated by Plio-Villafranchian and Lower Pleistocene alluvial formations, according to Huvelin (1970). These formations were studied at the 1:50,000 scale by Moreau (1973a, 1973b), who drew a map of the surface deposits and a pedologic map (Fig. 1C, D). According to Moreau (1973a) sites 1 and 2 respectively lay on encrusted deposits, characterized by a limestone "cap-rock" ("carapace calcaire" in local maps), and on silty to silty-clayey deposits with sandy and gravelly lenses.

At site 1 the study was focused on a vertical section exposed along