Calcrete-silcrete duricrusts from distal-alluvial fan deposits (Madrid Basin, Torrijos area, Toledo, Spain)

Encostramientos calcreta-silcreta en depósitos distales de abanicos aluviales (Cuenca de Madrid, zona de Torrijos, Toledo, España)

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ABSTRACT

Three duricrust profiles, developed on fine clastic Miocene deposits of the Southwestern area of the Madrid Basin, are studied. Different horizons (3 or 4, depending on the studied sections) are described defining their structure, mineralogy and petrology. They are interpreted as calcrete and silcrete (silicified calcrete and silicified mudstone) profiles formed in distal facies of arkosic fans. These profiles are quite different from those of typical calcretes because they lack the nodular horizon and most of the carbonate appears as cm-thick laminae, mostly horizontal, but also vertical. The carbonate in the profiles formed in relation to root systems and associated microorganisms. All the profiles have been subject to silicification at various intensities and many characteristic textures and structures of both calcretes and mudstones are preserved, suggesting a groundwater origin for the silicification. The levels of silcretes have an extensive lateral continuity and therefore seem to be related to important palaeosurfaces.

Key-words: *Calcrete, pedogenic, silicification, roots, groundwater.*

RESUMEN

En este trabajo se estudian tres perfiles de encostramiento desarrollados sobre depósitos detríticos finos del Mioceno. Se sitúan en el Suroeste de la Cuenca de Madrid. Los perfiles están formados por 3-4 horizontes morfológicamente distintos. En este trabajo se describe la estructura, mineralogía y petrología de estas calcretas y silcretas (calcretas silicificadas y lutitas silicificadas), que se forman sobre las facies distales de abanicos arcósicos. Los niveles de calcretas son atípicos porque debajo del horizonte laminar aparecen estructuras en enrejado, que se interpretan, al igual que el horizonte laminar, como producidas por la precipitación de carbonato en relación con sistemas radiculares y los microrganismos asociados. Todos los perfiles están afectados por una silicificación, de intensidad variable, observándose muy bien las características texturales y estructurales de las rocas caja por lo que deduce que se formaron en ambiente freático. Al presentar gran continuidad lateral se interpreta que están relacionadas con importantes paleosuperficies.

Palabras clave: *Calcreta, pedogénesis, silicificación, raíces, freático.*

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Introduction

The association of calcrete and silcrete duricrusts seems to be a characteristic feature of many continental semi-arid closed basins (Armenteros *et al*., 1995, Ringrose *et al*., 2009; among others). These duricrusts reveal a suite of complex sedimentary, pedogenic and diagenetic processes whose correct interpretation is important for understanding the evolution of ancient continental sedimentary basins. These calcrete/silcrete associations may be indicators of the prevailing sedimentary regimes, vegetation and climate, but also may reveal important changes in the position and chemistry of the water table (Bustillo and Alonso-Zarza, 2007).

The Miocene deposits of the SW area of the Madrid Basin are mostly composed by different types of detrital deposits; however, in some areas, silicified carbonate beds are prominent in the landscape (Bustillo, 1978, López Olmedo *et al*., 2004). The aim of our study is to analyze and interpret the processes which operated in the formation of three different calcrete/silcrete duricrusts situated in the south-western area of the Madrid Basin. The study area is located in the Toledo Province, in the nearby of Torrijos. In this area, the Madrid Basin is relatively narrow and detrital deposits sourced from the Central Systems (at the north) and the Toledo Mountains (at the south) filled the Basin during the Miocene (Fig. 1).

The sedimentary infill of the Madrid Basin has been divided in three main sedimentary units: Lower, Intermediate and Upper (Junco and Calvo, 1983; Alonso-Zarza *et al*., 2004, amongst many others). The deposits studied in this paper are situated at the top of the Lower Miocene Unit, giving an age of Middle Aragonian (López Olmedo *et al*., 2004), which is provided by the paleontological site of Torrijos (Aguirre *et al*., 1982). More specifically, these deposits correspond to the Embalse de Castrejón Arkoses and conglomerates Unit

Fig.1.-Geographical location and palaeogeographic context of the studied profiles (modified from Calvo *et al.*, 1995).

Fig. 1.- Situación geográfica y contexto paleogeográfico de los perfiles estudiados (modificado de Calvo et al.*, 1995).*

(López Olmedo *et al.*, 2004). This Unit was deposited in alluvial fan sytems whose distal parts include carbonate paleosols and possible palustrine deposits (López Olmedo *et al.*, 2004).

Methods

Mineralogy has been determined using X-rays diffraction (powder method) on a Philips XRD system (PW 1710) with CuK radiations. Other mineralogical analyses have been made using a thermo Fisher XRD Raman microscope. Standard optical microscopy was used for petrological study.

Calcretes/silcretes profiles

Three carbonate/silica profiles have been studied.

The Goya profile consists of three main horizons (Fig. 2A and Fig. 3).

1) The lower horizon, (80 cm visible) is constituted of soft reddish-brown silty/sandy mudstones. The amount of sand grains increases from bottom to top. White, soft and powdery carbonate nodules (about 2 cm in diameter) and laminae (1cm thick) are scarce. The white carbonate laminae are inclined with respect to bedding and are internally laminated. These laminae have a lateral continuity of about 2 m.

2) The middle horizon (about 50 cm thick) shows a grille-like structure formed by a vertical and horizontal network of white carbonate laminae included within reddish-brown detrital substrate.

3) The upper horizon (up to 60 cm thick) is laminar and two parts can be distinguished. The base is about 20 cm thick and shows carbonate laminae which laterally are silicified and preserve the primary structure of the calcrete. Relics of the silty/sandy mudstones are present and some are silicified (Fig. 4). The upper part (25 to 40 cm thick) is intensely silicified, but many of the features of the detrital substrate and carbonates are still preserved. This part is extremely hard and show vitreous luster. It is beige/brown where detrital substrate is silicified, and white, where the carbonates are the silicified components. The fabric of nodules and laminae of the previous calcretes are still recognized in the silicified parts and shows glaebules, ovoids and intraclasts.

The Fuensalida-Golf Field profile consists of four horizons (Fig. 2B).

1) The lower one is the substratum with minor modifications. It is composed of brown muddy sandstones. It contains some soft carbonate nodules of a few centimeters in diameter. The upper part of this horizon displays thin carbonate laminae.

2) The second horizon, about 40 cm thick, is composed by carbonate lamina and may contain some soft carbonate nodules (about 20 cm). It displays, in its lower part, small circular or tubular (up to 10 cm) structures which can be associated to the former presence of roots.

3) A laminar horizon is represented by a 15 cm-thick level displaying an alternation between white and dark horizontal laminations (about 5 mm thick). It is intensely silicified.

4) A massive to laminar horizon forms a 50 cm-thick very silicified level. It contains relics of carbonates, muddy sandstones and detrital grains. It is strongly indurated and displays glaebules, intraclasts, cemented horizontal cracks, and also some laminar and nodular silicified structures differentiated inside the silicified horizon.

The *Castillo profile* is composed of three horizons (Fig. 2C)

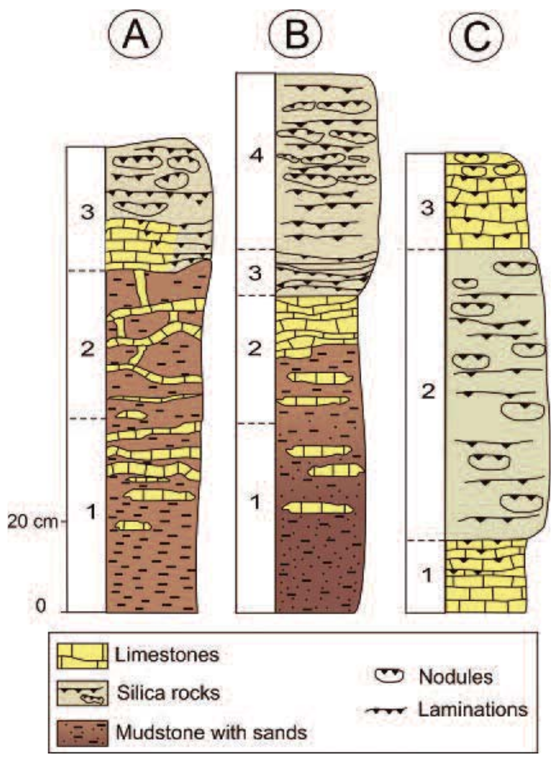

Fig. 2. - Logs of the 3 calcrete/silcrete profiles studied. A) Goya profile. B) Fuensalida – Golf Field profile. C) Castillo Barcience profile.

Fig. 2.- Columnas de los 3 perfiles calcreta/silcreta estudiados. A) Perfil de Goya. B) Perfil del Campo de Golf de Fuensalida. C) Perfil del Castillo Barcience.

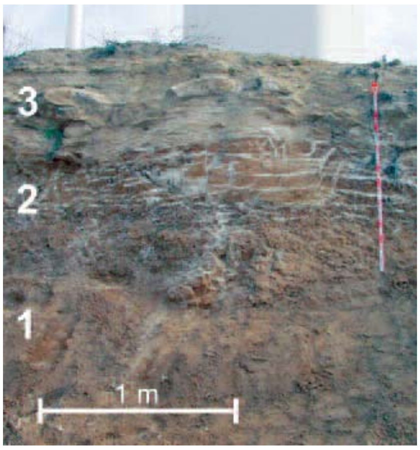

Fig. 3. – The Goya profile. 1) Host rock. 2) Grille-like structure. 3) Laminar structure partially silicified.

Fig. 3. - Perfil de Goya. 1) Roca caja. 2) Estructura enrejada. 3) Estructura laminar parcialmente silicificada.

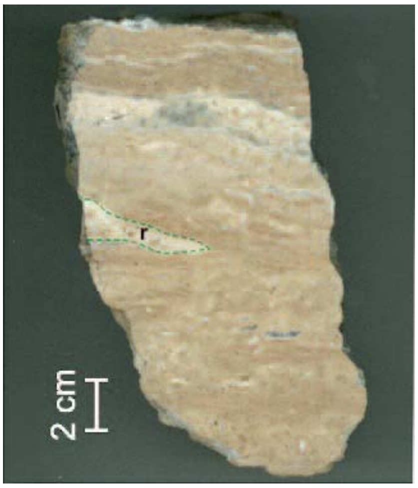

Fig. 4. – Silicified mudstones from Goya the 3rd horizon of Goya profile, with r: silicified root structure.

Fig. 4 - Arcillas silicificadas horizonte 3 del perfil de Goya, con r: estructura de raíz silicificada.

1) The visible part of the lower horizon is 20 cm. It has an important porosity and whitish colour. Relics of clays, detrital grains and calcified root hairs are differentiated. The upper part of this horizon (10 cm) is partially silicified.

2) A thick (1 m), entirely silicified, level is present forming a strongly indurated and massive horizon. The colors also vary (white, cream, brown or even bluish). Ovoids, glaebules, intraclasts, and cemented horizontal cracks are differenciated. The upper part of the level displays nodular structures (at various scales). This level presents some rounded structures which could be assimilated to former carbonate nodules.

3) A softer and whitish carbonate laminar horizon (30 cm thick) is present at the top. It consists of a succession of small layers (about 2 cm) with diffuse laminations and silicified nodules of about 1cm wide.

Mineralogy

According to the XRD analysis, these calcretes are mainly constituted of calcite. However, their silicified parts are composed by combinations, in various proportions, of calcite, opal-CT and quartz, associated in some case to little remains of substratum, such as feldspar or clays. The opal-CT reflexion angle corresponding to cristobalite varies between 4.09 Å and 4.12 Å, and some samples could contain small amounts of opal-A. Micro-Raman analysis of crypto-microcrystalline quartz zones reveals in some case very important quantities of moganite.

Petrology

Under the microscope most of the studied calcretes have laminar structure in which the richest carbonate laminae alternate with laminae containing more clays and sand grains. The carbonate is mostly micritic and it is easy to observe that it replaces and displaces the initial detrital sediment; even though, there is an important amount of detrital grains in most of the laminae. Alveolar septal structures are common. In some case, laminar structure are absent and the carbonate seems to be formed by a heteregenous micrite mass containing clay glaebules, porosity, intraclasts and fenestral-like structures. Coarse sparry cement fills the porosity; however locally some silicified micritic vadose cements are present, forming laminar/columnar structures (Fig. 5).

The silica groundmass is mainly composed of opal. It displays various textures and two main types are observable.

The first one is a common, brownish opal showing important relief when observed in plane light, in optical microscopy. It shows the characteristic isotropy of opal under polarized light and contains many detrital grains.

The second opal type ("opal-glass") does not display the classic brownish color of opal, it is whitish and shows very low relief. When observed with polarized light, it displays white zones of birefringence and is

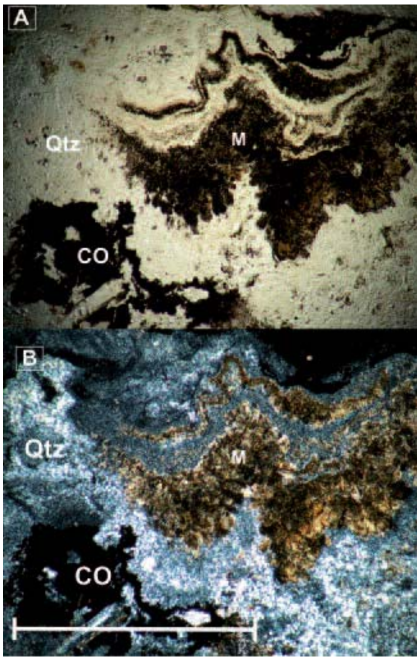

Fig. 5. – Microcrystalline calcite vadose cement partially silicified. CO=Common Opal; Qtz=Quartz; M=Micrite. Scale = 1 mm. A) Plane Polarized light. B) Cross polarized light.

Fig. 5. – Cemento vadoso de calcita microcristalina, parcialmente silicificado. CO=Ópalo Común; Qtz=Cuarzo; M=Micrita. Escala=1mm. A) Luz polarizada con nicoles paralelos. B) Nicoles cruzados.

differentiated around square areas of isotropic opal. "Opal-glass" contains only a little amount of detrital grains (Fig. 6).

Both types show ovoids and glaebules and the silica microfacies, could correspond with F-fabric or M-fabric (massive or glaebular) described by Summerfield (1983). Locally, vadose silica cements appear in some vugs.

These two types of opal are often found in association and in some areas common opal seems to be the first phase of silicification, the latter one being "opal glass".

Crypto/microcrystalline quartz forms also part of the groundmass. It may contain diffuse layers and be surrounded by common opal. Under polarized light, the crypto/microcrystalline quartz displays laminations and nodular morphology. Transition between opal and crypto/microcrystalline quartz takes place gradually. Sometimes, the opal at the boundary displays needle-like structures, which are typical of ageing processes of opal (Bustillo and Alonso-Zarza, 2003).

Most of the silica cement is length fast chalcedony. The most common arrangements of silica cements include from the

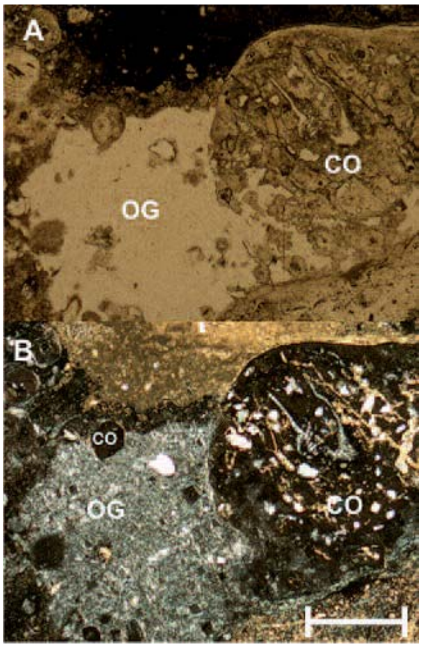

Fig. 6. – Two types of opal in the calcrete. CO=Common Opal; OG=Opal Glass. Scale = 1 mm. A) Plane polarized light. B) Cross polarized light.

Fig. 6. –Dos tipos de ópalo dentro de la calcreta. CO=Ópalo común; OG=Ópalo "cristalino". Escala=1mm. A) Luz polarizada con nicoles paralelos. B) Nicoles cruzados.

wall to the centre of the pore: fibrous opal, and length fast chalcedony.

Discussion and conclusions

The arrangement and the characteristics of the horizons of the three profiles strongly suggest that they are calcrete profiles developed on the distal facies of arkosic fans. However, these profiles show differences with the classic calcrete profiles (Esteban and Klappa, 1983). The main difference is the lack of well developed nodular horizons, below the laminar ones. In the studied profiles, the horizon below the laminar one is formed by a framework of horizontal and/or vertical carbonate laminae intercalated within the host rock. This organization, together with the microstructure of the laminae indicates that these carbonates are formed in relation to root mats, and represent the incipient development of the calcrete (Alonso-Zarza, 1999). Later on the decrease of sedimentation rates favored the amalgamation of the different laminae to form the topmost laminar horizons, which are interpreted as calcified root mats (Wright *et al*., 1988).

In the silicified facies, many characteristics of the calcrete (some detrital grains, relics of mudstones, laminar structure, root structures, glaebules, vadose cements) and of the substratum, remain without important textural modifications.

In Goya profile, zones of the detrital substratum appear intensely silicified and the roots were directly silicified. The initial phase of silicification was opal, but the crypto-microcrystalline quartz is commonly associated with it, due to ageing. The ageing process is frequent in surficial silcretes (Thiry, 1999; Dixon and McLaren, 2009).

The levels of silcretes studied have an important lateral continuity and therefore are commonly interpreted as related to important paleosurfaces. In fact, these levels of calcretes/silcretes are situated at boundary between two stratigraphic units (Lower and Intermediate Units of the Miocene of the Madrid Basin (López Olmedo *et al*., 2004). When calcrete and silcrete are associated in a profile, the calcretization of siliciclastic substratum release much silica, consequently becoming a source for silcrete formation. During the progressive calcretization it would be expected that porewaters would become increasingly saturated in silica unless they were able to be washed away (Nash and Shaw, 1998). However, in groundwater silcretes the silica can be transported mainly through the groundwater (Ringrose *et al*., 2009).

According to Thiry (1999), the good preservation of calcrete and mudstone features, as happens in the studied profiles, is indicative of groundwater silicification processes. However, vadose silica cements found in local points indicate that after the general silicification, a vadose environment also affected the silcrete.

The silicification of calcretes is likely caused by changes of the pH around 9, or by the increase in salinity, because of the plant activity or evaporation (Bustillo and Alonso-Zarza, 2007).

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