

Petrology of a barrage tufa system (Pleistocene to recent) in the Ruidera Lakes Natural Park (Central Spain)

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ABSTRACT

The Ruidera Lakes Natural Park, Central Spain, contains a well-exposed Pleistocene to Recent freshwater carbonate succession in a fluvio-lacustrine setting. Carbonate precipitation continues today and is manifested in active phytoherm barrage constructions, marginal lacustrine stromatolitic terraces, lacustrine lime muds, and sand-grade detrital tufa. Phytoherm barrage deposits consist of coarse sparite fringe in vigorous flow areas associated with phytoherm framestones, and alternating sparite and micrite fringes, which are most common in areas with lower velocity flow. Holocene lake margin deposits consist of laterally growing mammillate stromatolites. These are developed as pinnacle stromatolites at the foot of overhangs associated with the lake margins. Pre-Holocene marginal lacustrine terraces have no associated stromatolite rims but contain abundant oncoidal deposits close to their base. In some ephemeral channels and pools located on the active phytoherm barrages stromatolitic pavements are developed which are comprised of elongate domes composed of fibrous calcite crystals encrusting cyanobacterial filaments. The erosion of phytoherms and continuous rain of fragments from pinnacles, pavement and marginal stromatolites in the active system provides abundant detrital tufa. These allochthonous detrital tufas are volumetrically the most important carbonate deposits in Ruidera Lakes and dominate the lower reaches of the Upper Guadiana River valley. The lake depocentres accumulate carbonate muds, which are locally rich in Chara.

Key words: tufa, freshwater cements, carbonates, fluvial barrages, Spain.

INTRODUCTION

The Ruidera Lakes Natural Park, is located along the Upper Guadiana River valley, in the Castilla-La Mancha, region of Central Spain (Fig. 1). Upstream of the village of Ruidera the river is incised into a gorge cut into Triassic and Jurassic strata.

Fifteen lakes are developed along the 35 km river section upstream of Ruidera village (Fig. 1).

These water bodies are connected by discharge via streams, waterfalls, and important circulation and seepage along the boundary between the Jurassic 'Carniolas' and the upper Triassic gypsiferous marls. The average longitudinal dimension of each lake is about 1 km, and the average width is 0.25 km. This fluvial system contains a well-exposed Pleistocene to Recent freshwater carbonate succession in a fluvio-lacustrine setting.

Extensive tufa precipitates of low magnesium calcium carbonate (confirmed by X-ray diffraction), with minor amounts (0-5%) of terrigenous minerals, occur along the

upper Guadiana throughout the Ruidera Natural Park. Much of the carbonate occupies the present day valley floor where it continues to be deposited within lakes and the associated transverse barrages, which impound them. Higher on the valley sides are erosional remnants of former barrage deposits, some of which present accessible profile sections for measurement.

Four main types of deposit occur: a) phytoherm barrage (dam) deposits, sometimes with cascade deposits; b) marginal stromatolitic terraces; c) degraded barrage deposits; d) lacustrine carbonates. The field relationships of these are described in Ordóñez *et al.*, 1986 and Pedley *et al.*, (1996); in this paper we will describe in detail the petrographic characteristics.

Phytoherm barrage (dam) deposits

Within the Ruidera phytoherm barrage (dam) deposits, and sometimes also in association with cascade deposits, we recognise polycyclic isopachous fringe cements which

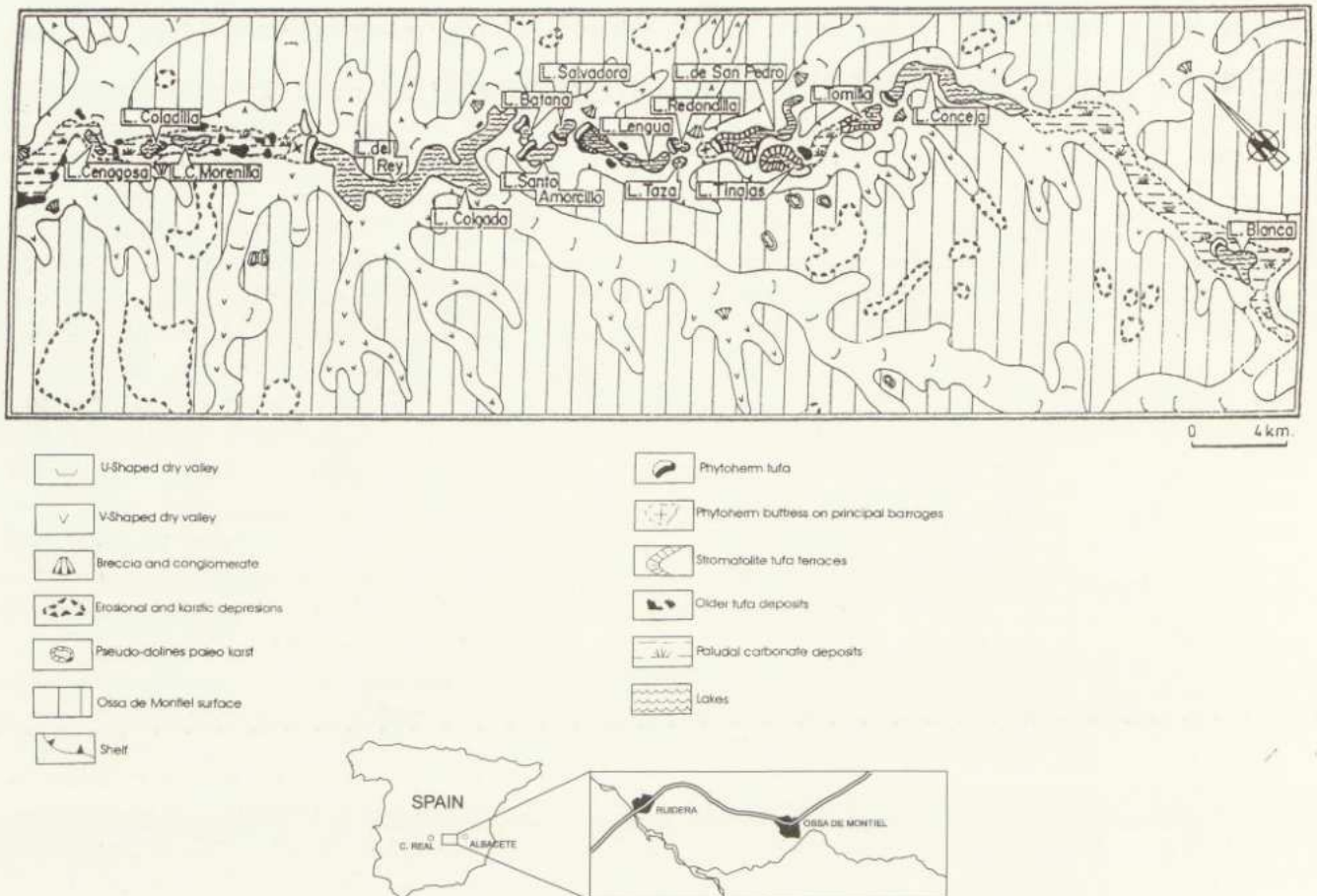


FIGURE 1: Geomorphological map and location of the Ruidera Lakes. (After Ordóñez et al., 1986)

coat all available surfaces, and dominate most tufa frameworks. The common associations are: a) coarse sparite fringes, and b) alternating sparite and micrite fringes.

a) Coarse sparite fringes:

Centimetre-thick laminated crusts are well developed in the barrages of Laguna Tomilla and Laguna del Rey (Ordóñez et al., 1986), particularly in the cascade splash zones. These are comparable to crusts within the older cascade and barrage tufas in the Plitvice National Park (Chafetz et al., 1990).

Often the Ruidera crusts contain multiple laminae; for example, Ordóñez et al. (1986) described a recent crust of Laguna del Rey composed of eleven laminae. The crusts are formed of clear, low-Mg calcite ray-crystals $0.7 \mu\text{m}$ to $2 \mu\text{m}$ long and $30 \mu\text{m}$ to $50 \mu\text{m}$ wide. Some crystals contain cyanobacterial filaments and/or filament moulds similar to those described in diagenetic laminated travertine crusts by Love and Chafetz (1988). Borings are also preserved in this lithology, being most common on the laminae interfaces. Micrite often covers the external idiomorphic edge of the crystals. We attribute this phenomenon to a syndepositional origin for these crystals. Folk et al. (1985) observed similar types of laminae, which

grew daily, having crystallised directly from agitated stream water to form a hard crust in a modern carbonate-precipitating stream in central Texas. These crusts provide the principal cement framework in areas of vigorous flow in many barrage phytoherms.

b) Alternating sparite and micrite fringes:

Thin (up to $30 \mu\text{m}$ wide) cyclic fringe cements (spar/micrite couplets) frequently are developed on the once living plant surfaces, and often develop on fallen leaves during the autumn (Fig. 2.2). Spar-micrite fringe cements are also well developed on mosses (*Didymodon* and *Barbula* (E. Ron, pers. com.) at barrages and waterfall sites in the Ruidera Park (Fig. 2.4, 2.5 y 2.6). Exclusively micritic microfacies with clotted and peloidal textures also are common. Some micrite precipitates show stromatolitic features such as 'porostomata' fabrics, but with occasional *Rivularia*. Spar crystal sizes range from 10 to $30 \mu\text{m}$ and their habit varies from anhedral to subhedral. Irion and Müller (1968) describe similar facies in the Schwäbische Alb (Germany). These cements are closely comparable to those described by Pedley (1990) as freshwater isopachous fringe cements. Such mixed sparite and micrite laminae are most common in phytoherm areas with sluggish through flow.

MARGINAL STROMATOLITIC TERRACES

Vertically orientated cylindrical encrustations are common on these surfaces. They originate as tufa coatings on the stalks of aquatic macrophytes such as rushes and reeds ("vertical tube facies" of Ordóñez and García del Cura, 1983). After decay of the plant tissues the tufa cylinders collapse to the terrace surface and become cylindrical oncoids. The majority of cylindrical oncoids are built of stromatolitic laminae dominated by both spongostroma and porostroma fabrics, which commonly entomb fans of filamentous cyanobacteria. Trailing macrophytes may also be encrusted on the downstream-facing margins of primary frameworks, and similar fabrics have been observed on *Chara* stems in central Spain and in Afghanistan (Lang and Lucas, 1970).

The older terraces contain fringe cements, which originally coated the stalks of aquatic macrophytes which are intercalated with oncoid beds. The oncoids are usually freeform in shape and vary in size from 4-10 mm. They are often closely associated with stromatolites in the older tufa deposits of the system. Oncoids are uncommon in the present-day active system.

The Ruidera oncoids were generated primarily by prokaryote-microphyte biofilms (cyanobacteria, heterotrophic bacteria and diatoms). The oncoid nuclei consist of phytoherm fragments, branches of macro-vegetation, shell fragments (esp. gastropods), limestone clasts and rare quartz grains (<0.06 mm). The oncoids have a predominantly porostromata fabric but with zones of dense spongostromata. The Ruidera Park oncoids are closely comparable to oncoids described by Stoffers (1975) from Plitvice, Croatia.

In the basal part of some vertical lake margin rims (e.g. Laguna Lengua) metre-scale stromatolitic pinnacles are found. These stromatolites have been constructed by microbial laminite frameworks (Skeletal stromatolite). The shallower water parts of the rims are constructed by laterally growing mammillate stromatolite colonies (for details see Pedley, *et al.*, 1996). Other stromatolite constructions are developed on degraded barrages in the bottom of ephemeral channels, where they can be 30 cm thick and are similar to those described by Freytet, (1990). These stromatolitic pavements may show lateral gradation from thin encrustations on plants, to dome-headed stromatolites (skeletal stromatolite).

Living *Oscillatoria*, *Phormidium*, pennate diatoms, unicellular colonies of *Chroococals*, *Rivularia* and gametophytes of *Barbula* are found in stromatolite layers generated in the summer months. The microstructure of the stromatolitic crusts is complex, displaying clear fibrous calcite cement fringes interlayered with thrombolitic layers (Ordóñez *et al.*, 1986). The microstructure of the stromatolites on the vertical pool margins is typically dominated by layered thrombolitic growths.

Degraded barrage deposits: Detrital tufa

Detrital tufa ("intraclast tufa" of Pedley, 1990) is generated by episodic erosion of the phytoherm barrages and by the constant rain of microdebris from the lake margin stromatolites. The resulting detrital clasts accumulate in the headward areas of the downstream lakes. Much of the lake-floor margin sediment is generated from debris liberated from the adjacent stromatolite walls (Pedley *et al.* 1996). Individual tufa fragments range in size from silt to pebble, and deposits may display fining-upward sequences.

A degraded, Pleistocene Laguna Lengua barrage with its upper surface 15 m above present day water level is intercalated with lime muds on its downstream-facing buttress. These lacustrine lime muds contain four discontinuous sedge-cushion phytoherm levels around their margins, and *Unio* valves are common away from the shoreline. The highest beds in the exposure show a further 4 m of lacustrine lime muds topping the barrage.

Lacustrine carbonates

From a volumetric viewpoint the most important deposits of the Holocene barrage tufa systems are the lacustrine precipitates, and detrital tufa which enter during erosive phases. In terms of preservation, it is the phytoherm constructions (both barrages and marginal terraces) which dominate the geological record.

The finest carbonate lake muds in depocentre areas consist of fine (1-4 μm) micrite without clear crystal form. *Chara* lime mud is very abundant in Laguna Blanca and occurs as friable layers in cores taken from Laguna Redondilla.

Discussion and conclusions

In order to understand the precipitation of large volumes of freshwater calcium carbonate in the Ruidera Park it is necessary to consider the carbonate precipitation processes. These are controlled by the rate of through-flow within the lakes system and its chemistry. The ground water supply to the Upper Guadiana River, and Ruidera Lakes, originates principally from the Lower Jurassic (Carniolas) aquifer. The pCO_2 and temperature of ground water, and the pCO_2 and temperature of lake water balance together water flow are the hydrochemical parameters to understand the bulk carbonate precipitation.

A major question here is whether the carbonate deposition is purely physico-chemical or whether there is significant biomediation of calcite, associated with the abundant macro- and microphytes colonising the system.

In a purely inorganic driven system the only opportunities of triggering calcite precipitation is at sites of rapid CO_2 loss such as downstream phytoherms and waterfalls. As most of the water entering the Ruidera park

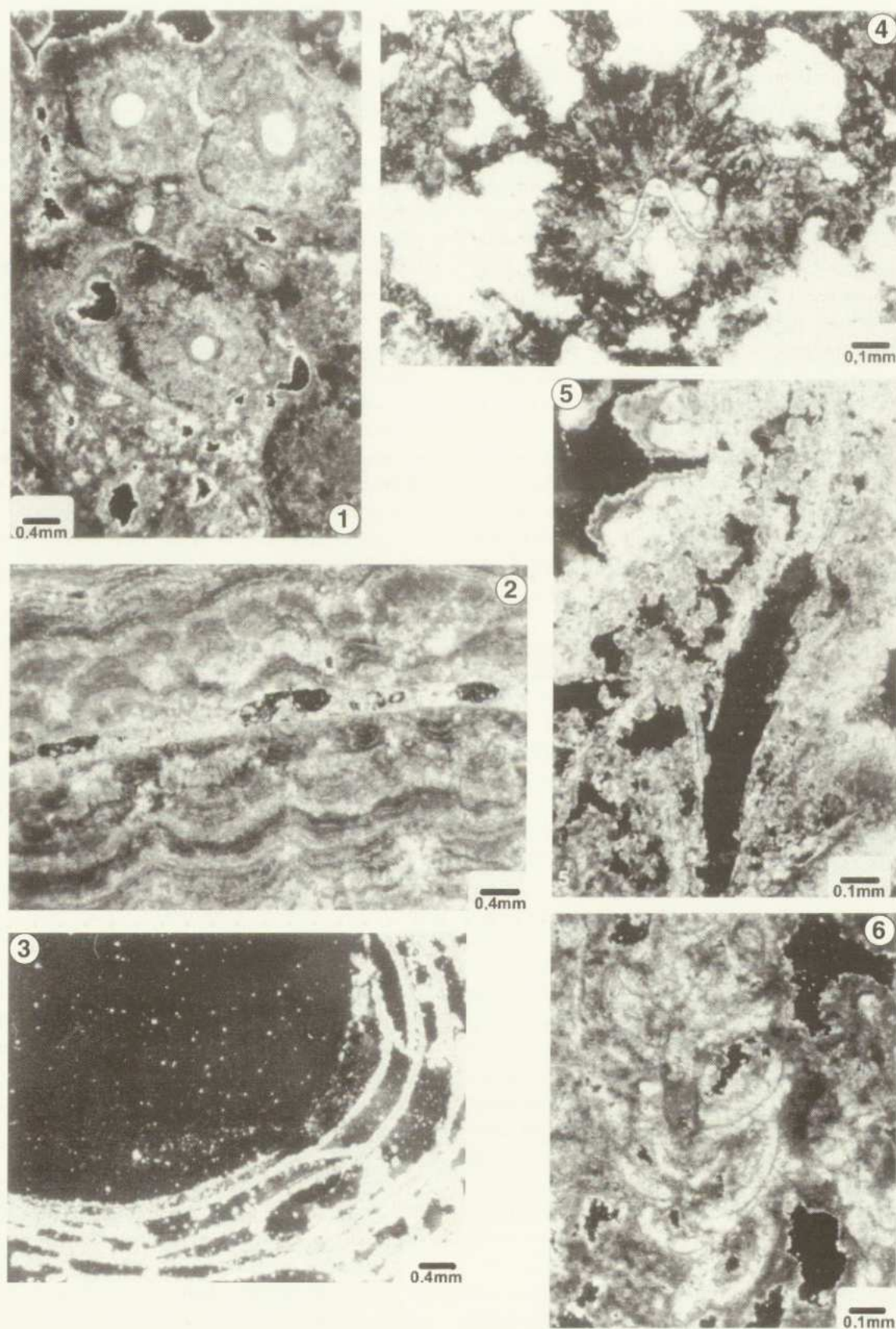


FIGURE 2: 1. Photomicrograph of vertical tube facies in transverse section (in situ sedge), flat top the marginal stromatolite terrace. Laguna Lengua. 2. Photomicrograph of a sedge stem in longitudinal section showing spongiostromata texture associated with the tufa encrustation. Crossed nicols. 3. Photomicrograph of microcrystalline fringe cements originally coating grass stem and leaves (carbonaceous material now lost) in the Holocene Laguna del Rey barrage. Crossed nicols. 4. Photomicrograph of stromatolitic microfacies (porostromata type) associated with moss. Laguna Redondilla barrage tufa. 5. Photomicrograph of moss tufa with sparite microfacies and micritic cement to illustrate the preservation of older fabrics. (Stage 3 system). Laguna Lengua. Crossed nicols. 6. Photomicrograph of typical shallow water barrage curtain moss facies with sparite and micrite fringe cements. Holocene barrage, Laguna Lengua. Crossed nicols.

lakes is by seepage and little spill over occurs at the barrages. The barrages are unlikely to grow rapidly by this mechanism.

The high precipitation rates of upstream phytoherms and laterally growing stromatolites are associated with extensive microphyte-prokaryote biofilms, Pedley *et al.*, (1996) which cover the barrage walls. These microcommunities remove CO₂ and, consequently, must tip the system in favour of carbonate precipitation in their immediate vicinity. The resulting fine micrite precipitates coat and/or partly bury the biofilm surfaces. Particles trapped and precipitated on to the biofilm-bound substrates also act as nuclei for the further heterogeneous nucleation of low-Mg calcite.

Collectively, this results in the ubiquitous encrustation, by low magnesium carbonate, of leaves and stems of living plants and plant fragments at the barrage sites. In fact, biofilms colonise any available surface including detrital grains and larger clasts. Many of these may ultimately develop into oncoids where water velocities are just sufficient to periodically turn them.

Metabolic activity of marginal semiaquatic higher plants during photosynthesis must also lead to a local reduction of the pCO₂ in shallow water areas and is probably an important additional process in triggering calcite precipitation around the lake margins.

Seasonal changes in photosynthetic activity are controlled by light intensities, water depth, variations in flow velocities, and warming of waters and may be instrumental in encouraging lamination in the barrage deposits. The stromatolitic laminations (spar/micrite couplets) well developed in the upstream dam face and marginal terraces may also reflect these fluctuations.

Planktic microbial blooms are especially well developed during the summer months. The water column takes on a characteristic turquoise colour at this time as a result of these phytoplankton blooms. This is invariably associated with a milky calcite suspension, which we also consider to be a byproduct of planktonic metabolic activity. There must, nevertheless, be a small contribution from physico-chemical processes during the summer season as surface waters warm up and CO₂ is expelled at the air/water interface. This must render the surface water layers even more prone to precipitation during planktonic metabolic activity. The finely particulate lime mud settles slowly to the lake floor. In the Laguna Redondilla depocentre this accumulates at an average rate of c. 0.2 m per hundred years.

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REFERENCES

- Chafetz, H.S., Srdoc, S. and Horvatincic, N. (1990): Pervasive sparmicritization of waterfall and barrier travertines, Plitvice National Park, Croatia, Yugoslavia. Abstracts 13th Int. Sedimentological Con., IAS. Nottingham: 82-83.
- Folk, R., Chafetz, H.S. and Tiezzi, P.A. (1985): Bizarre forms of depositional and diagenetic calcite in hot-spring travertines, Central Italia. In: N. Schneidermann & P.M. Harris (eds.). Carbonate Cements, Tulsa: Spec. Pub. Soc. Econ. Pal. and Min., 36: 349-369.
- Freytet, P. (1990): Contribution à l'étude des Tufs du Bassin de Paris: Typologie des édifices tuffacés (stromatolitiques) des chenaux fluviaux (aspect macroscopique). In: (Colloquium coordinator F. Lecolle), Les tufs et travertins quaternaires des bassins de La Seine et de La Somme, et des régions limitrophes: 9-28. Caen.
- Irion, G. and Muller, G., (1968): Mineralogy, petrology and chemical composition of some calcareous tufa from the Schwäbische Alb, Germany. In: G. Müller and G.M. Friedman (eds.), Recent Developments in Carbonate Sedimentology in Central Europe: 157-171. Springer-Verlag, Berlin.
- Lang, J. and Lucas, G. (1970): Contribution à l'étude de biohermes continentaux: barrages des lacs de Band-e-Amir (Afghanistan central). Bull. Soc. Géol. France, (Ser. 7), 12: 834-842.
- Love, K.M. and Chafetz, H.S. (1988): Diagenesis of laminated travertine crusts, Arbuckle Mountains, Oklahoma. J. Sedim. Petrol., 58: 441-445.
- Ordóñez, S. and García del Cura, M.A. (1983): Recent and Tertiary fluvial carbonates in Central Spain. In: J.D. Collinson and J. Lewin (eds.), Ancient and Modern Fluvial Systems. Special Pub. IAS, 6: 485-497.
- Ordóñez, S., González Martín, J.A. and García del Cura, M.A. (1986): Sedimentación carbonática actual y paraactual en las Lagunas de Ruidera. Rev. Mat. Proc. Geol., 4: 229-255.
- Pedley, H.M., (1990): Classification and environmental models of cool freshwater tufas. Sedim. Geol., 68: 143-154.
- Pedley, H.M., Andrews, J.E., Ordóñez, S., González Martín, J.A., García del Cura, M.A. and Taylor, D.M. (1996): Climatically controlled fabrics in freshwater carbonates: a comparative study of barrage tufas from Spain and Britain. Palaeogeography, Palaeoclimatology Palaeoecology, 121: 239-257.
- Stoffers, P. (1975): Recent carbonate sedimentation in the lakes of Plitvice (Yug.). Neues Jahr. Min., 9: 412-418.

