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Geoarchaeology of “anthropogenic” travertine: a story of water and life etched in stone

Julien Curie* and Christophe Petit

The notion of “anthropogenic” carbonate deposits takes into consideration human impact on continental limestones precipitated from hot (travertine) or cold (calcareous tufas, speleothems) waters. It is documented here by a geoarchaeological study of the Roman site of Jebel Oust, Tunisia, where the exploitation of a hot spring is attested from the first century AD to the end of Late Antiquity. Petrographical and geochemical analyses performed on travertine deposits offer evidence of the anthropisation of the hot spring and its associated deposits, and reveal new elements of water management and bathing practices during Roman times.

La notion de dépôts carbonatés “anthropiques” prend en compte l’influence des activités humaines sur la précipitation des calcaires continentaux issus d’eaux chaudes (travertins) ou froides (tufs calcaires, spéléothèmes). Elle est ici illustrée par une approche géoarchéologique du site antique de Jebel Oust, en Tunisie, où l’exploitation d’une source chaude est attestée depuis le début de notre ère jusqu’à la fin de l’Antiquité tardive. L’analyse pétrographique et géochimique des dépôts de travertin a permis de mettre en évidence une anthropisation majeure des dynamiques sédimentaires associées à la source chaude et de fournir des éléments inédits à la question de la gestion des eaux chaudes pour des pratiques thermales dans l’Antiquité romaine.

La noción de depósitos de carbonato “antropogénicas” toma en cuenta el impacto humano sobre calizas continentales precipitados a partir de aguas calientes (travertino) o frías (tobas calcáreas, espeleotemas). Está documentado aquí por un estudio geoarqueológica del yacimiento romano de Jebel Oust, Túnez, donde la explotación de una fuente termal está atestiguada desde el siglo I dC hasta el final de la Antigüedad tardía. Los análisis petrográficos y geoquímicos realizados en los depósitos de travertino ofrecen evidencia de la antropización de las aguas termales y sus depósitos asociados, y revelan nuevos elementos de gestión del agua y las prácticas de baño durante la época romana.

Terrestrial carbonates are very widespread on Earth’s surface, offering a great diversity in origin, development, morphologies and lithologies. Known as *Lapis Tiburtinus* (“Tibur Stone”) and named after the volcanic precipitating spring of Bagni di Tivoli (about 25 km from Rome, Italy) during Roman Times, travertine is a type of terrestrial carbonate precipitated by hot waters. Travertines usually differ from (calcareous) tufas, which form from cool waters under ambient temperature (for a complete definition of fresh water carbonates, see Capezuolli *et al.*, 2014). These two kinds of rocks, and their associated processes and features, were well known during Antiquity, as writings of several ancient authors reveal (e.g. Pliny the Elder, Strabo, Vitruvius). And both of them have been used extensively for construction by ancient societies, first by the Greek civilization (e.g. the ancient Greek town of Paistos, later to become the Roman town of Paestum, Italy; the Segesta temple, Sicily), then by the Romans for many public monuments (e.g. the Colosseum, Rome).

* Laboratory ArTeHiS 6298 Archéologie, Terre, Histoire et Sociétés, julien.curie@u-bourgogne.fr



Figure 1: Plan of the archaeological Roman site of Jebel Oust, Tunisia, and locations of the three downstream sections (sanctuary-aqueduct-Roman baths) and travertine’s sedimentary facies defined in the Roman Baths (A, B, C, D).



Figure 2: A pool incrustated with travertine, Roman baths of Jebel Oust, Tunisia.

Continental limestones are of great interest due to their natural depositing conditions and climate reconstructions, and have been used for many years as reliable palaeoenvironmental indicators. Thus, they have been the subject of a recent and complete review (Pentecost, 2005). For a few decades now, some studies have integrated the impact of human activities on carbonates development (Goudie *et al.*, 1993). Furthermore, a new research area (sometimes called *Carbonate Geoarchaeology*) involved with the interactions between anthropogenic processes and carbonate environments has developed in the last decade. “Anthropogenic” carbonates are sediments precipitated under both natural conditions (climate and regional tectonics) and due to anthropogenic factors derived from human activities like exploiting waters of a spring, controlling water flow, quarrying former deposits, etc.



Figure 4: Puff-pastry travertine filling the aqueduct at Jebel Oust, Tunisia. The black arrow indicates an archaeological element encrusted in the precipitated sediment; the channel is about 1 m wide.

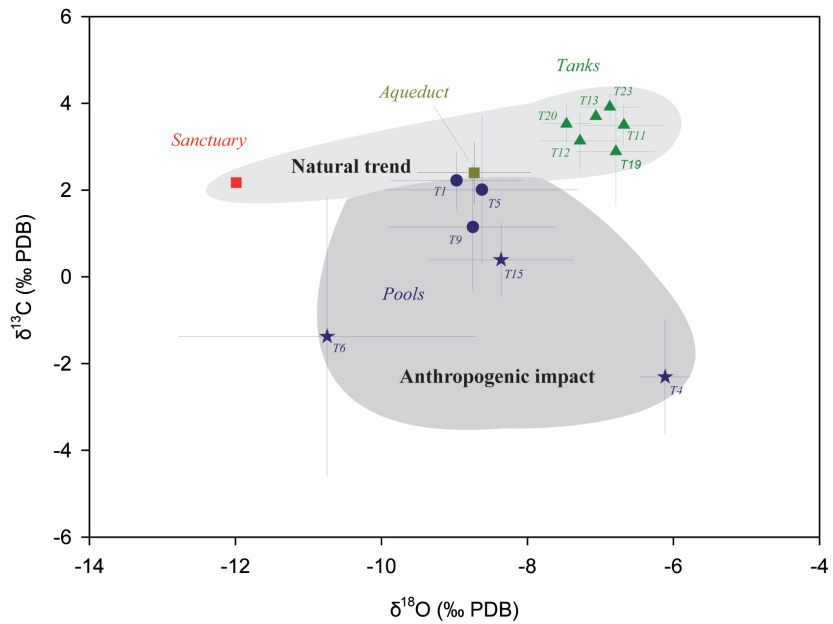


Figure 3: Oxygen and carbon isotopic compositions of travertine samples collected from the downstream sections of the archaeological site of Jebel Oust, Tunisia.

“Anthropogenic” carbonates: a question of water management and human engineering

Since the pioneer work performed on the aqueduct of Nîmes, in South-East Gaul (Guendon and Vaudour, 2000), some studies dealing with anthropogenic carbonates preserved in archaeological structures have been performed, mostly dealing with deposits preserved in Roman aqueducts, like the Gallo-Roman aqueducts of Arles (Guendon and Leveau, 2005) and Fréjus (Bobée *et al.*, 2010), or in other hydraulic structures like the water tower (*castellum aquae*) of the antique city of Ostia (Carlut *et al.*, 2009). Through these studies, archaeological carbonates are truly seen to represent a “memory of water”. Advances in laboratory analytical techniques allowing the collection of high resolution signals offer great perspectives to understand Roman hydraulic engineering and water management, as has been shown in a study of several ancient aqueducts (Sürmelihihi *et al.*, 2013). In this article we present the case of exploitation of a hot carbonate-rich spring (hydrothermal waters) in antique Tunisia, an exemplary site illustrating a geoarchaeological study of “anthropogenic” travertines. Our geoarchaeological approach on the site of Jebel Oust aims to define the morphologies and sedimentary facies (petrography and geochemistry) of travertines precipitated throughout the ancient site, including human structures and anthropogenic features.

The “anthropogenic” travertine of the Roman site of Jebel Oust, Tunisia

The site of Jebel Oust, located 25 km south-east of Tunis, Tunisia and dating from the 1st century AD to the end of Late Antiquity, is the subject of fieldwork by a Tunisian and French cooperation directed by A. Ben Abed¹ and J. Scheid² (for a review of the preliminary results of first investigations,

1 Institut National du Patrimoine, Tunis.
2 Collège de France, Paris.



Figure 5: An alternate black/white laminated travertine (Facies A) from Roman baths, Jebel Oust, Tunisia.

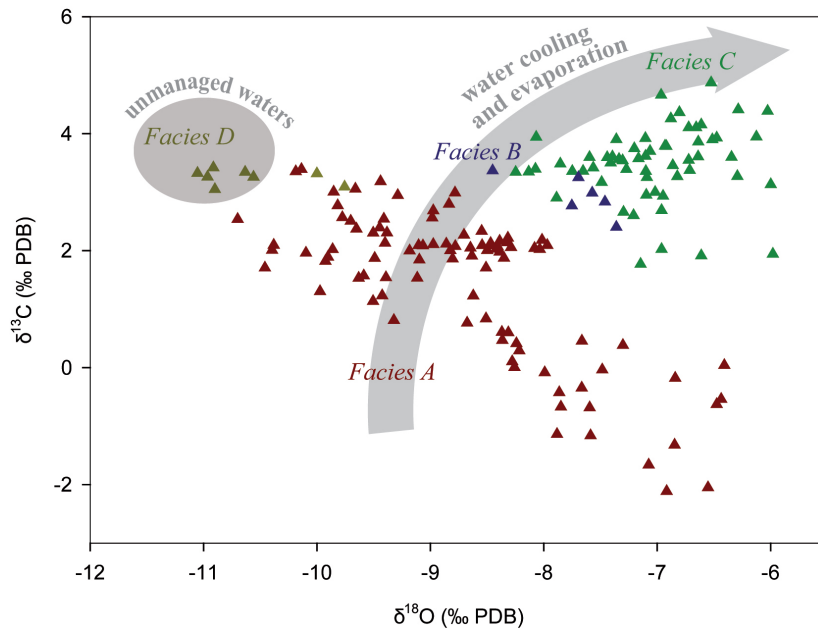


Figure 6: Oxygen and carbon isotopic compositions of travertine samples collected from the Roman baths of Jebel Oust, Tunisia.

see Ben Abed and Scheid, 2005). The site is characterised by a temple settled around the vent of a hot spring, associated with Roman baths located about 100 m downstream and supplied with hot water via an aqueduct (Fig. 1). The carbonate-rich waters of the spring precipitated considerable carbonate travertines where waters used to flow during Antiquity, covering the structures of the site (e.g. the Roman baths, Fig. 2) with travertine deposits.

Samples were collected from the sanctuary (upstream part of the site), from the aqueduct (proximal slope) and from the Roman baths (downstream section). Petrographical analyses by optical microscopy and geochemical analyses were performed on the samples. The analyses of the stable isotope (C and O) composition of travertine show valuable results reported in a $\delta^{13}\text{C}/\delta^{18}\text{O}$ diagram (Fig. 3). The $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values increase from the proximal part of the site (i.e. the sanctuary: $\delta^{13}\text{C}=2.17$ and $\delta^{18}\text{O}=-12.0\text{‰}$ PDB) and the middle part (i.e. the aqueduct: $\delta^{13}\text{C}=2.40$ and $\delta^{18}\text{O}=-8.73\text{‰}$ PDB) to some of the rooms of the Roman baths (i.e. the distal part of the site) used as tanks ($\delta^{13}\text{C}$ values around 3.44‰ and $\delta^{18}\text{O}$ values around -7.02‰). The downstream change of stable isotope shows a “natural trend” reflecting progressive water cooling and evaporation (CO_2 degassing), a phenomenon previously described for the famous Pamukkale travertines, Turkey (Kele *et al.*, 2011). But at Jebel Oust, this phenomenon is not typical of all of the travertine deposits. Indeed, some stable isotope values of travertine from the

distal part of the site, preserved in some of the pools of the Roman baths, differ significantly from this natural trend (see Pools in Fig. 3). This fact highlights the anthropogenic impact on travertine development due to water management by Roman engineers.

Beside this anthropogenic impact on travertine development, our geoarchaeological study also deals with the petrographical and geochemical analysis of travertine sedimentary facies in relation to their depositional environment. This aims to bring new insights of ancient hydraulic engineering at Jebel Oust. The travertine deposit precipitated in the aqueduct is entirely controlled by the morphology of the channel (Fig. 4). It is a puff-pastry travertine with presence of encrusted stones (detrital material) and a few archaeological elements (see the fragment of an arch tube, Fig. 4). This facies is due to the precipitation of microbial mats growing at the water surface (*hot water ice*), which suggests relatively still waters flowing in this aqueduct.

The anthropogenic travertines preserved in the Roman baths show a great variety in their morphology and their petrographical and geochemical features. Four sedimentary facies (see Fig. 1) have been defined relating to different depositional environments directly linked to the nature and function of the room where they precipitated. First, an alternate laminated travertine (Facies A, Fig. 5) shows a regular lamination of black/white laminae and average values of 1.44‰ for $\delta^{13}\text{C}$ and of -8.71‰ for $\delta^{18}\text{O}$ (see the data of each facies reported in a $\delta^{13}\text{C}/\delta^{18}\text{O}$ diagram, Fig. 6). This traver-

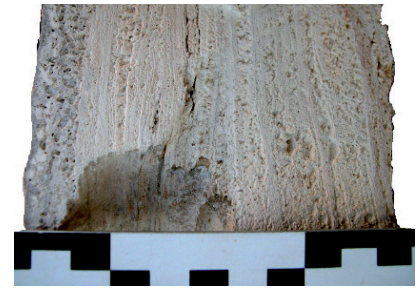


Figure 7: An alternate dense/porous laminated travertine (Facies B) from Roman baths, Jebel Oust, Tunisia.

tine precipitated in warm pools (*natatio*) regularly provided with hot spring water and covered by a roof (preventing water cooling and evaporation). A second facies (Facies B) is characterised by a regularly and alternating dense/porous lamination (Fig. 7) and by higher average values ($\delta^{13}\text{C}=2.93$ and $\delta^{18}\text{O}=-7.71\text{‰}$) than Facies A, reflecting cooler and evaporated waters. It precipitated in an open-air lukewarm pool which used to play a major part in ancient thermal practices, in association with warm pools (Facies A). A third facies (Facies C) is characterised by a spongy fabric (Fig. 8) and by the highest $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values (3.49 and -7.05‰ PDB, respectively), reflecting more evaporated and cooler waters than those precipitating Facies A and B. This travertine precipitated in open-air places used as tanks where standing waters from the hot spring cooled down. These cooling tanks represent a major element of antique water management, according to Seneca, the famous natural philosopher and tutor to Emperor Nero, who recommended this process when using hot waters³. Finally, the

3 *Natural Questions*, III, 24.



Figure 8: A spongy fabric travertine (Facies C) from Roman baths, Jebel Oust, Tunisia.



Figure 9: A crystalline crust travertine (Facies D) forming a small cascade, Roman baths of Jebel Oust, Tunisia.

fourth and last facies is defined by a dense orange layered crystalline crust (Facies D) found in localised and small travertine cascades (Fig. 9) with micro-terraces forming at their surface. Due to low values of $\delta^{18}\text{O}$

(around -10.60‰, reflecting the highest temperatures of water), to their stratigraphic position (covering Facies A) and to the presence of a number of encrusted archaeological elements from the thermal architecture, this facies is interpreted as a phase of decay of the Roman baths, where water still flowed but was not being managed. The study of the “anthropogenic” travertines enable us to identify a management of water in the ancient Roman baths of Jebel Oust, with the association of hot, warm and cold waters simultaneously used for a classical thermal circuit during Roman Antiquity.

A geoarchaeological approach to read the “anthropogenic” travertines

The question of “anthropogenic” travertines deals with the interactions between

anthropogenic processes and carbonate environments. A geoarchaeological study of these deposits offers new issues of importance, such as water management (exploitation of carbonate-rich waters), thermal baths organisation and management (nature and function of the thermal rooms), water temperature, and *geoarchitectural* approaches (including both architectural engineering and carbonate deposits). Earlier studies on anthropogenic carbonates and our work at Jebel Oust (see Curie, 2013) show the great interest of developing interdisciplinary programs to decipher these sedimentary archives of human water management and thus to read, with a geoarchaeological approach, the interactions between nature and humans, as recorded in these carbonate sediments.

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