EDITORIAL CSIC

Boletín Geológico y Minero
137 (1), January-April 2026,2
ISSN-L: 0366-0176, eISSN: 2253-6167
https://doi.org/10.21701/bolgeomin/137.1/002

ARTICLE

Analysis of the limestone and calcareous rocks exploited in the Vega de Granada from Sierra Gorda and surrounding areas (Granada, Spain) and its archaeological use in the Roman villa of Salar (Granada)

Análisis de las calizas y rocas calcáreas explotadas en la Vega de Granada procedentes de Sierra Gorda y su entorno (Granada) y su empleo arqueológico en la villa romana de Salar (Granada)

Esther Ontiveros Ortega
Instituto Andaluz del Patrimonio Histórico. 41092, Sevilla, España.
esther.ontiveros@juntadeandalucia.es, https://orcid.org/0000-0002-9229-5875

José Manuel Martín Martín
Departamento de Estratigrafía y Paleontología de la Universidad de Granada. 18071, Granada. España.
https://orcid.org/0000-0003-4742-5252

María Luisa Loza Azuaga
Instituto Andaluz del Patrimonio Histórico. 41092, Sevilla, España.
https://orcid.org/0000-0003-2554-8219

José Beltrán Fortes
Departamento de Prehistoria y Arqueología, Universidad de Sevilla, 41004, Sevilla, España.
https://orcid.org/0000-0001-5841-4140

Julio M. Román Punzón
Departamento de Historia Medieval y Ciencias y Técnicas Historiográficas de la Universidad de Granada. 18071, Granada, España.
https://orcid.org/0000-0001-6351-2511

Abstract: The province of Granada (Spain) is of great interest for the advance of the research on the use and exploitation of quarries in Roman times. This work shows the first results on the use of local stone varieties from this eastern area of Roman *Baetica* province. In this respect, a geological and petrographic study of the quarries exploited in the Sierra Gorda sector and surrounding areas is given, taking as reference the archaeological materials documented in the Roman *villa* of Salar, located at the western edge of the Granada Basin (Spain). Sierra Gorda and the areas around the Vega de Granada were a supply site for stone materials in Roman times in the Roman *villa* of Salar. Several lithotypes have been identified, most likely coming from this mountain massif. The use of the Dogger calcareous breccia and, probably, the nodular limestones of the Dogger-Malm stands out. However, the use of the micritic Lias limestones remains to be confirmed. In the case of the oolitic limestones (from the Jurassic) there is a high probability that this typology came from other provinces (Málaga or Córdoba), not from Sierra Gorda. The crinoid limestones used (also Jurassic) are most likely from Sierra Elvira. Finally, the exact location from which the Miocene calcarenites (Alhama or Escúzar) were extracted is yet to be determined.

Keywords: Limestone; Quarries; Ornamental Stone; Archaeological Site; Granada.

Key points: In the Roman *villa* of Salar a calcareous breccia from the Dogger and, probably, the nodular limestones from the Dogger-Malm have been used as *marmora*, which are related to the quarries studied in Sierra Gorda (Granada, Spain).

Some limestones with crinoids have been identified, most likely from Sierra Elvira (Granada), along with some bioclastic calcarenites also of local origin.

A more distant origin is attributed to the oolitic limestones identified in this *villa*, probably coming from the quarries of the Cabra Sector (Córdoba) or Antequera (Málaga).

Resumen: La provincia de Granada es de gran interés arqueológico para el avance de la investigación en el uso y explotación de canteras en época romana. Este trabajo muestra los primeros resultados sobre el uso de las variedades pétreas locales en esta área oriental de la *Baetica* romana. Al respecto, se presenta el estudio geológico y petrográfico de los materiales pétreos de las canteras explotadas en el sector de Sierra Gorda y alrededores, tomando como referencia los materiales arqueológicos documentados en la *villa* romana de Salar (Granada), emplazada en el borde occidental de la Cuenca de Granada (España). Sierra Gorda y las zonas de alrededor de la Vega de Granada fueron los lugares de aprovisionamiento de materiales lapídeos para la construcción de esta *villa*. Se han localizado varios litotipos muy probablemente procedentes de este macizo montañoso. Destaca el uso de la brecha calcárea del Dogger y, probablemente, de las calizas nodulosas del Dogger-Malm. Sin embargo, falta por confirmar el uso de las calizas micríticas del Lias. En el caso de las calizas oolíticas (del Jurásico) existe una alta probabilidad de que esta tipología llegase de otras provincias limítrofes actuales (Málaga o Córdoba), pero no de Sierra Gorda. Las calizas de crinoides utilizadas (también Jurásicas) muy probablemente son de Sierra Elvira. Por último, la localización exacta de donde se extrajeron las calcarenitas Miocenas (Alhama de Granada o Escúzar) está aún por determinar.

Palabras clave: Calizas; Canteras; Piedra ornamental; Yacimiento arqueológico; Granada.

Puntos clave: En la villa romana de Salar se ha usado una brecha calcárea del Dogger y, probablemente, las calizas nodulosas del Dogger-Malm como piedra ornamental, que se relacionan con las canteras estudiadas en Sierra Gorda.

Se han identificado unas calizas con crinoides procedentes muy probablemente de Sierra Elvira (Granada) junto con unas calcarenitas bioclásticas de procedencia también local.

Una procedencia más alejada se atribuye a las calizas oolíticas identificadas en la villa de Salar, probablemente de las canteras del Sector de Cabra (Córdoba) o Antequera (Málaga).

Received: 22-04-2024 / **Accepted**: 06-05-2026 / **Published**: 24-06-2026

Citation: Ontiveros Ortega, E., Martín Martín, J.M., Loza Azuaga, M.L., Beltrán Fortes, J., Román Punzón, J.M. (2026). Analysis of the limestone and calcareous rocks exploited in the Vega de Granada from Sierra Gorda and surrounding areas (Granada, Spain) and its archaeological use in the Roman villa of Salar (Granada). Boletín Geológico y Minero, 137(1), 002. http://dx.doi.org/10.21701/bolgeomin/137.4/002

Supplementary information ↓

1. INTRODUCTION

The research carried out on the use and exploitation of quarries in Roman times in the Roman *Baetica* province (*Hispania*), highlighting its use in archaeological materials, has been important in recent years. It is worth to note the works carried out on marble quarries such as Almadén de la Plata (Seville), Mijas (Málaga) and Aroche –Fuenteheridos (Huelva), that extend towards the Estremoz Anticline and the Evora-Beja Massif (Portugal), along with those of the limestone quarries, both white and colored, in the current provinces of Málaga and Córdoba.

This work shows the first results on the investigation of Roman quarries in the eastern area of the Baetica province, specifically the Sierra Gorda sector (Granada, Spain) and surrounding areas, based on their use in the Roman *villa* of Salar (Granada). This work has been developed in the Departments of Prehistory and Archeology of the University of Seville and Medieval History of Granada, in collaboration with the Andalusian Institute of Historical Heritage and the Department of Stratigraphy and Paleontology of the University of Granada.

The province of Granada is a geological area where a wide variety of stone materials are located, mostly limestone, some of which have been used for ornamental purposes, as well as for stone for construction in Roman times (Beltrán *et al.*, 2011).

The *villa* of Salar constitutes a good example of the use of marble and other stone materials, as an element of prestige in those rooms intended for public use, such as the *triclinium* and the peristyle, where the *dominus* showed his economic power and social recognition both before his friends and clients. This *villa*, located on the west side of the Granada Basin, has a strategic location, close to one of the main communication routes of *Baetica*. (Figure 1), a route for the commercialization of agricultural products such as wheat, oil and wine to other nearby provinces and areas of the Empire. Furthermore, the Granada Basin, bathed by the Genil River and its tributaries, Beiro, Dílar, Monachil, Cubillas, Salar, Cacín and Alhama, must have had an important agricultural activity that led to the creation of new establishments in Late imperial times, among which we highlight the *villae* of Las Gabias (Ruiz *et al.*, 2010), Los Mondragones (Rodríguez Aguilera *et al.*, 2014), Los Vergeles (Calvín Velasco 2016), Armilla (Fornell Muñoz 2011) or El Fiche in Lecrín (Burgos *et al.*, 2009), among other.

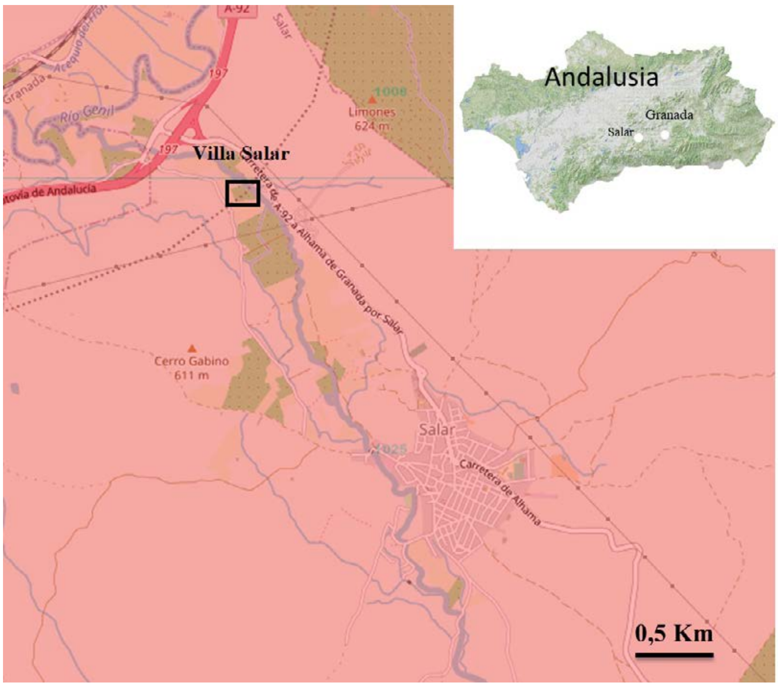


Figure 1. Geographic location of the study area.

Figura 1. Ubicación geográfica del área de estudio.

In the Granada province, the use of local materials has been confirmed in a large number of archaeological, historical and contemporary buildings from ancient times to the present day, with a good number of historical quarries preserved (Navarro *et al.*, 2021). The grey limestone from Sierra Elvira (Atarfe) (Sotomayor & Orfila, 2004; Sebastián *et al.*, 2008, Orfila *et al.*, 1996), the serpentinite from "El Barranco de San Juan" (Navarro *et al.*, 2014), the calcarenites of Santa Pudia (Escúzar) (Navarro et al., 2013) and the travertines of Alfacar (Granada) (Sebastián *et al.*, 1992; Rodríguez Navarro, 1994; Sotomayor & Orfila, 2004; Urosevic *et al.*, 2011) stand out, together with some white and red limestones presumably from some quarries located in the surroundings of Íllora and used in buildings in the ancient city of *Iliberris*, as well as in a good number of buildings in the city of Granada (Sotomayor & Orfila, 2004; Sebastián *et al.*, 2008). Most of these lithotypes have been utilized in Renaissance Granada buildings such as the Cathedral, the Monastery of San Jerónimo, the Royal Chancery or the Palace of Carlos V. However, less known are the calcarenites of Alhama de Granada, the cream-colored limestones of Loja, or the red nodular limestones of Sierra Gorda; some of these typologies have been observed in buildings in the province, such as the Salar church and the Guadix Cathedral, although these have not been studied from an archaeometric point of view. We also highlight a lithotype called "Loja marble", pale pink or salmon-colored with branched purple shapes, used in the sacristy of the Cathedral of Granada (López Burgos, 2002; Acale Sánchez, 2016).

The objective of this work is to expand knowledge about the stone resources offered by the eastern area of *Baetica*. To date, no systematic research work has been carried out on this subject, so this work will contribute to the advancement in the field of Granada archaeological research.

1.1. Stones from Salar Roman villa

In the Roman villa of Salar (Fernandez García *et al.*, 2019, Moreno Alcaide *et al.*, 2019, Neira Jiménez *et al.*, 2024, Román Punzón *et al.*, 2022-2021) the use of various stone varieties of possibly local origin has been confirmed. Firstly, at the top of the *nymphaeum*, which presides over the *triclinium*, there is an inclined front; covered by whitish calcareous tuffs, which turn greenish-grayish when freshly cut. The use of these tuff blocks, of irregular size, would be designed to simulate the appearance of a grotto for the birth of the *nymphaeum*.

Figure 2. Calcareous tuffs at the top of the nymphaeum.

Figura 2. Tobas calcáreas en la parte superior del nymphaeum.

At the bottom of the *nymphaeum*, the fountain *lacus* is formed by two blocks of white micritic limestone and a third curved one, which serves as support for the tuff fragments, of possible local origin.

Figure 3. Upper head of the lacus of the nymphaeum. Micritic white limestone variety.

Figura 3. Cabeza superior del lago del nymphaeum. Variedad de caliza blanca micrítica.

Secondly, the lower part of three of the side walls of the *triclinium* are covered by calcareous slabs, of different thickness, but with a height of around 0.90 m; These slabs are of a calcareous breccia of variable shades ranging from white/cream to pinkish/reddish.

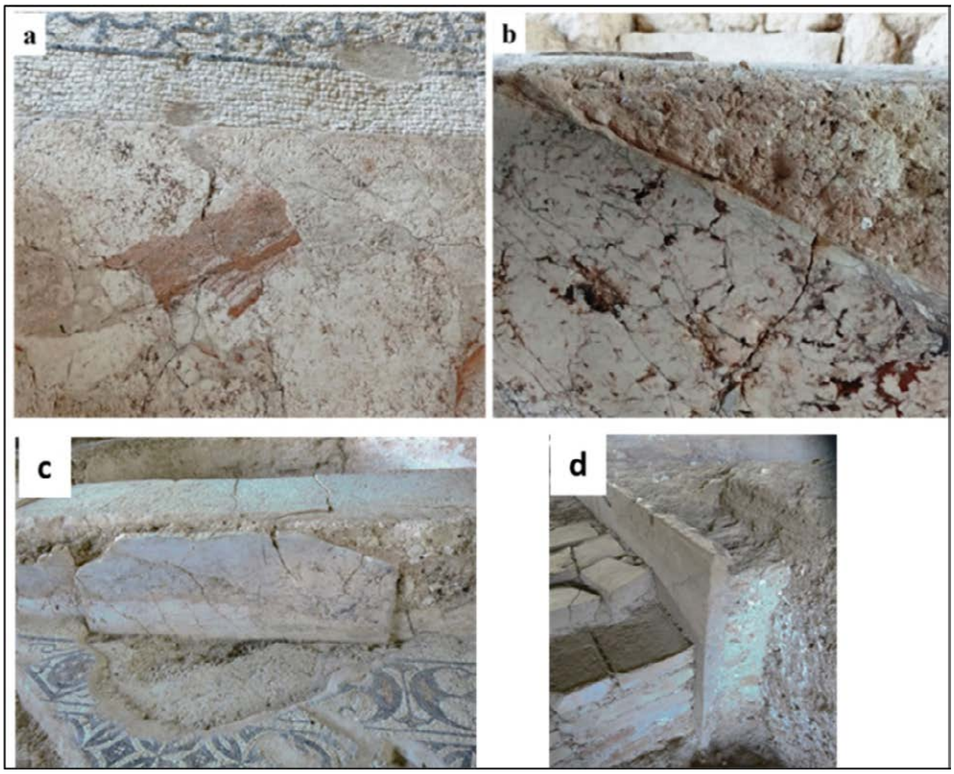


Figure 4. Calcareous breccia with beige-white and reddish color. a) Floor slab between the triclinium and the peristyle. b-c-d) Slab located in the triclinium.

Figura 4. Brecha calcárea de color blanco beige y rojizo. a) Losa del piso entre el triclinium y el peristilo. b-c-d) Losa ubicada en el triclinium.

On top of this solid base, an opus sectile decoration was placed, covering the upper part of the elevation of the walls, which would extend on the upper plane, but which must have collapsed in ancient times, possibly at the time of the definitive abandonment of the *villa* as a result of a fire, which caused the falling of its side walls, as well as the roof, around the first half of the 6th century AD (González, 2014). The part of the *crustae* that made up this opus sectile parietal are currently preserved in the warehouses of the Archaeological Museum of Granada and, to a lesser extent, in the Municipal Archaeological Collection of Salar. This parietal decoration was studied by Marín Díaz in 2016. On the other hand, in the cleaning work carried out in the *triclinium* area by the current excavation team, some pieces of this decorative panel have been recovered. In the reviews we have carried out of these stone plaques, made in different lithotypes, we have been able to differentiate some varieties, which could be of local origin:

– Slate, a metamorphic rock with a foliated structure and very fine grain, dark blue and black in color, commonly used in the production of *crustae* of the parietal decorations both in *Hispania* and in other territories of the Roman Empire, due to its color which, combined with other colored stones, contrasts significantly, and its ductility, which made the work easier. The presence of this type of rock in the nearness of the *villa* suggests a possible local origin from Sierra Tejeda, southeast of Sierra Gorda.
– Red oolitic breccia limestone with irregular white nodules, which may come from the quarries in the closeness of Antequera (Málaga), also known under the name "Torcal red", whose use was widespread in Roman times (Beltrán *et al.*, 2018; Loza & Beltrán, 2012), and has also been used in modern and contemporary times (García Guinea *et al.*, 2021, 61 y 76).
– Slabs made of green porphyr extracted from the quarries of Krokeai in Laconia (Greece) (Marín, 2016) together with a probable local serpentine, which were used to repair the large parietal coating of the *triclinium*.

Finally, another local variety has been identified, a calcarenite, of very good quality, used in great profusion in the *villa* for column shafts, bases, as well as in a good number of ashlars for the construction of walls.

Figure 5. Calcarenite column base located in the peristyle.

Figura 5. Base de la columna de calcarenita ubicada en el peristilo.

Calcarenite is a very porous carbonate rock with a rough finish, not commonly used as an ornamental stone. It is an easily workable rock with good behavior against moisture, which is why it was used to build walls or create decorative elements that were later coated with a stucco to provide them with protection and a better finish. Its use was widespread in imperial times, linked to the urban development that the Roman *Baetica* province experienced, which favored its transportation from other geographical areas, although generally the use of local material was chosen (Roldán *et al.*, 2022).

Along with these local varieties, other materials have been used in the villa that seem to have been imported, specifically a limestone with rudists most likely from Sintra (Portugal), used to make large columns located in the peristyle, and some plates of white marble material with gray veins in the *triclinium*.

2. GEOLOGICAL SETTING

The geological units that provide stone materials of local origin belong to the Subbetico of the External Zones of the Betic Cordillera and to the Granada Basin. Of the first are the Jurassic limestones of Sierra Gorda and Sierra Elvira; and the second corresponds to the Miocene calcarenites. Part of the stone materials found in the villa of Salar were probably extracted in quarries that exploited both Jurassic micritic and breccias limestones and Miocene calcarenites. This analytical study will focus on the geological outcrops of Sierra Gorda.

The materials that make up the External Zones of the Betic Cordillera were deposited in the Iberian palaeomargin in two differentiated domains: Prebetic and Subbetic (Fallot, 1948). Sierra Gorda and Sierra Elvira are located in the latter.

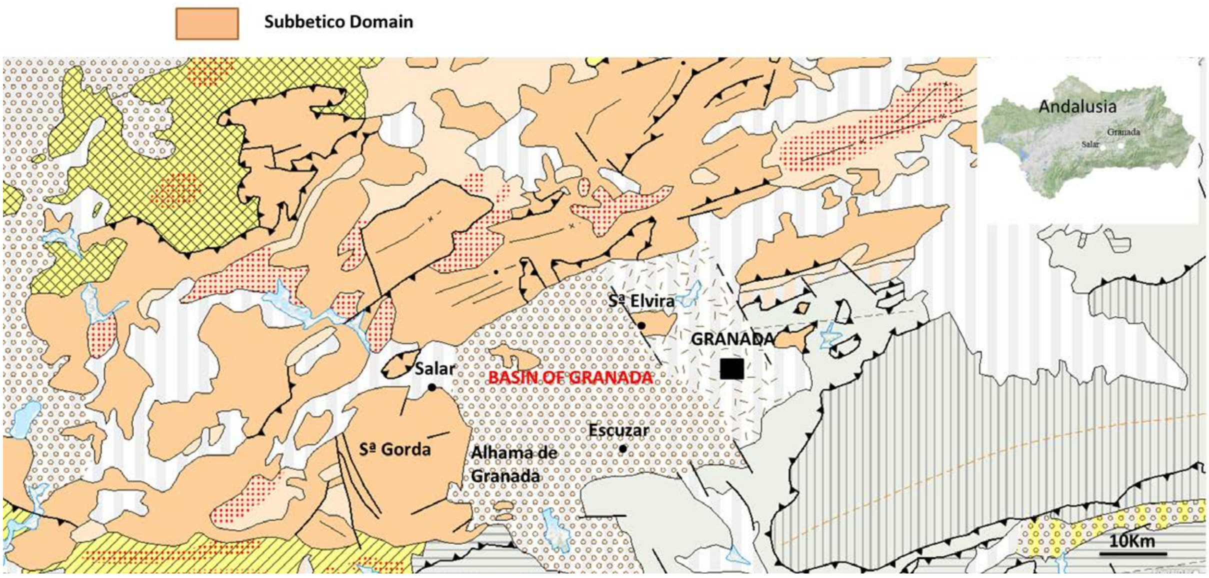


Figure 6. Geological location of the study area.

Figura 6. Ubicación geológica del área de estudio.

Within the Subbético there are three zones: External Subbético, Middle Subbético and Internal Subbético. Sierra Gorda is a calcareous mountain system belonging to the Internal Subbético, located on the western side of the Granada Basin (Linares & Vera 1965). The sedimentary sequence consists of, from bottom to top: white limestones from the Lias and grey limestones from the Dogger (Lower and Middle Jurassic), crowned by nodular limestones of grayish and reddish tones, from the Middle-Upper Jurassic. In the Cretaceous, white calcareous marly limestones were deposited in the Lower Cretaceous, and salmon-colored in the Upper Cretaceous (Vera, 1988).

The white micritic limestones of the Lower Lias reach thicknesses of several hundred meters. They were formed in a very shallow marine environment and contain frequent bioclastic remains of benthic foraminifera, thick-shelled bivalves and gastropods. Just above them are located some thin levels (a few meters thick) of brachiopod lumaquelas and crinoid limestones of Middle Lias age. On top of these levels white and grayish micritic limestones from the Upper Lias-Lower Dogger were deposited, with thicknesses close to ten meters. Under the microscope they show abundant peloids and small bioclasts (of planktonic foraminifera and radiolarians) from the deep open platform environment.

During Dogger, the calcareous massif that makes up the Sierra Gorda today fractured and temporarily emerged, at which time the development of subaerial kartic phenomena and the formation of caves and caverns took place. Inside these cavities, blocks and breccias accumulated as a result of the collapse of top and walls. When the sea invades the area again, the filling of these cavities, together with that of the existing open fractures (neptune dikes; Molina *et al.*, 1985), was completed with more modern marine micritic sediments (from the Upper Dogger), infiltrated from above and acting as a matrix for the breccia. In the latter, gray micritic peloid limestones predominate, which towards the top are enriched in filaments (very thin shell bivalves) indicating a pelagic depositional environment.

The carbonate sequence is crowned by nodular limestones, about 40 m thick, of "Ammonítico Rosso" facies (pelagic condensed biomicrites of a pelagic threshold), of Bathonian to Tithonico-Berriasiense (Dogger-Malm and base of the Cretaceous) age, which contain abundant remains of ammonites in their mid-upper part.

In Sierra Gorda the "Ammonítico Rosso" is characterized by the predominance of limestone levels (Vera, 1984). At the botton it is made up of beige limestones rich in filaments and peloids, which correspond to Packstone-type Biomicrites. Towards the top they acquire more reddish tones and incorporate remains of pelagic crinoids and small benthic and planktonic foraminifera (protoglobigerines). At the top, numerous Hard Grounds with Fe and Mn nodules are observed.

Sierra Elvira is a limestone outcrop associated with the Middle Subbetic located in the northern sector of the Granada Basin. The sedimentary sequence of the Lower/Middle Lías corresponds there to limestones with chert, about 100 m in thickness, with remains of sponges and radiolarians crowned by a package (about 20 m thick) of limestones with crinoids (in this case a biosparite strongly cemented) (García-Hernández *et al.*, 1976), made up of fragments of sand-sized crinoid ossicols and plates, together with highly micritized foraminiferal bioclasts and small oolites (Martín & Dabrio, 1981).

In the Betic Cordillera two domains are differentiated: the External Zones, to the north, and the Internal Zones, to the south (Martín Algarra, 1987), which, from the Early Miocene onwards, begin their collision, and are now strongly deformed (Durand-Delga, 1980; García-Hernández *et al.*, 1980; Martín-Algarra, 1987; Sanz de Galdeano, 1990; Sanz de Galdeano & Vera, 1992). In the course of the Miocene, a series of reliefs begin to take shape, emerging as islands, between strongly depressed areas (basins) (Braga *et al.*, 2003; Martín *et al.*, 2014; Galindo-Zaldívar *et al.*, 2019).

The Granada Basin, located under the Sierra Nevada at the western side of the massif, is one of the main intramountain basins of the Betic Cordillera. This basin was delimited as such, with a morphology and dimensions similar to the current one, in the Tortonian (Upper Miocene) (Braga *et al.*, 2003; Galindo-Zaldívar *et al.*, 2019). From the Tortonian to the present, tectonic compression, combined with extension and subsequent uplift and dismantling by erosion of the surrounding reliefs, has led to the accumulation of notable thicknesses of terrigenous, carbonate and evaporitic sediments (Martín *et al.*, 1984; Rodríguez-Fernández *et al.*, 1984; Sanz de Galdeano, 1988; Montenat *et al.*, 1990; Fernández & Rodríguez Fernández, 1991; Rodríguez Fernández *et al.*, 1993; Buforn *et al.*, 1995; Braga *et al.*, 1996, 1999, 2003, 2006; García-Alix *et al.*, 2008; Puga-Bernabéu *et al.*, 2008; Galindo-Zaldívar *et al.*, 1993, 1999, 2019; García-Veigas *et al.*, 2013). The sedimentation is initially marine and then lacustrine, with an evaporitic episode of desiccation between the two (Braga *et al.*, 2003; Galindo-Zaldívar *et al.*, 2019).

Calcarenites from the Lower Tortonian of the Granada Basin appear in isolated, locally highly tectonized outcrops.

Figure 7. Outcrop of the Cacín River (Granada). Note the very penetrative jointing that the calcarenites present.

Figura 7. Afloramiento del río Cacín (Granada). Obsérvese el marcado diaclasado de las calcarenitas.

In the area studied, the calcarenites are up to about 40 m thick (Fernández & Rodríguez-Fernández, 1991; Puga-Bernabéu *et al.*, 2008; López-Quirós *et al.*, 2016).

The calcarenites are bioclastic in nature and contain abundant fragments of bryozoans, red algae, echinids, bivalves (pectinids and oysters) and, to a lesser extent, gastropods, benthic foraminifera, solitary corals (ahermatypic) and fish teeth, along with siliciclastic grains (quartz and rock fragments) in variable proportion (Braga *et al.*, 2006).

In the Alhama area, two types of carbonate facies are observed; a first type, made up of medium-grained Grainstone to fine-grained Rudstone made up of fragmented and abraded bioclasts (mainly bivalves and bryozoans) with up to 10% terrigenous grains, and a second type, made up of Rudstone with abundant bivalve shells and bryozoans, and minor echinoderm remains (Puga-Benabéu *et al.*, 2008).

3. SAMPLING AND METHODS

3.1. Sampling

For this study, various pieces have been selected from the archaeological site of the *villa* of Salar, made with materials of local origin (see Table 1), that have been used as a reference.

Table 1. Reference samples from the archaeological site of the villa of Salar
Tabla 1. Muestras de referencia del yacimiento arqueológico de la villa de Salar

Samples	Description	Visual observation
GR_Salar-2	Beige and reddish calcareous breccias. Covering slabs of the *triclinium*. On site.	
GR_Salar-3	Beige and reddish calcareous breccias. Covering slabs of the *triclinium*. On site.	
GR_Salar-4	White limestone. Slabs located in the *nymphaeum*. On site.	
GR_Salar-5	Calcarenite. Ashlar located in the *nymphaeum*. On site.	

GR_Salar-6	Greenish gray limestone. Wall of the *nymphaeum* pool. On site.	
GR_Salar-7	Beige and reddish calcareous breccias. Covering slabs of the *triclinium*. On site.	
GR_Salar-9	Beige and reddish calcareous breccias. Covering slabs of the *triclinium*. On site.	
GR_Salar-10	White micritic limestone. Column base located in the *peristyle.* On site.	

GR_Salar-11	White micritic limestone. column shaft located in the *peristyle*. On site.	
GR_Salar-13	Calcarenite. Ashlar and column shafts located in the *peristyle*. On site.	
MG_1	Salmon red limestone. *Crustae* of the *opus sectile*. Archaeological Museum of Granada.	
MG_3	Oolitic limestone. *Crustae* of the *opus sectile*. Archaeological Museum of Granada.	

Subsequently, a field survey was carried out in the Sierra Gorda sector to locate the quarries (see Figure 8) and the subsequent sampling of geological outcrops (see Table 2).

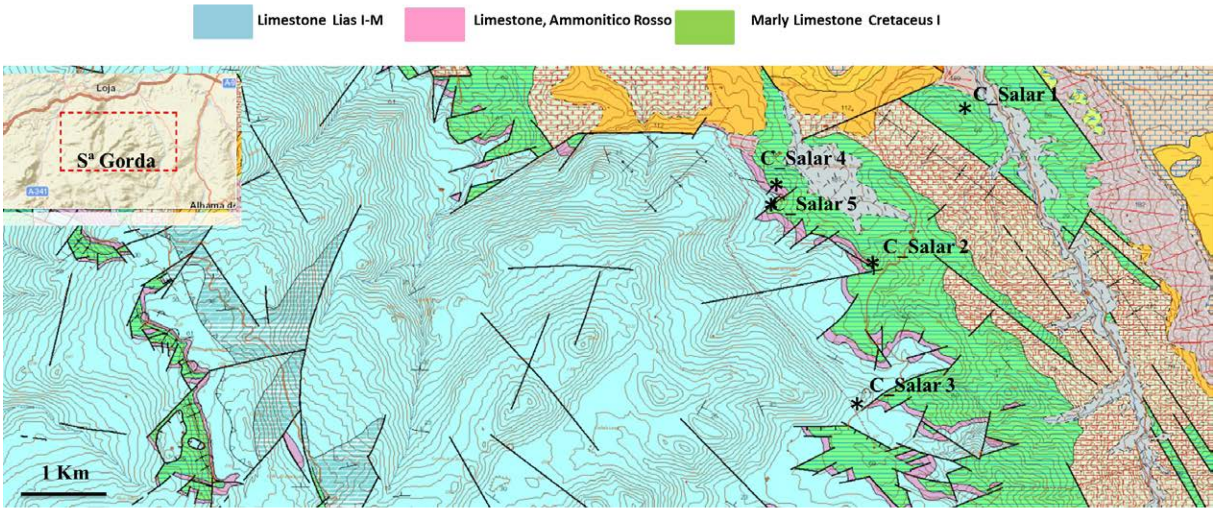


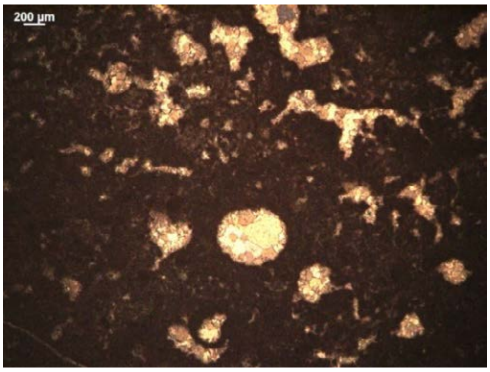
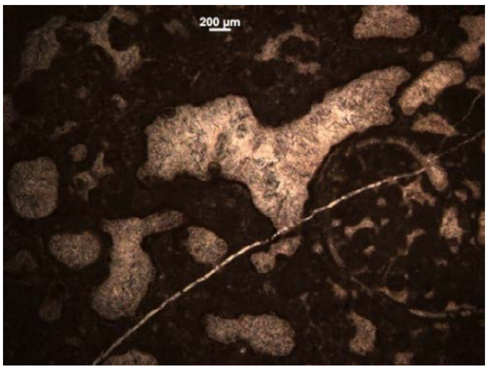
Figure 8. Location of the quarries studied in Sierra Gorda.

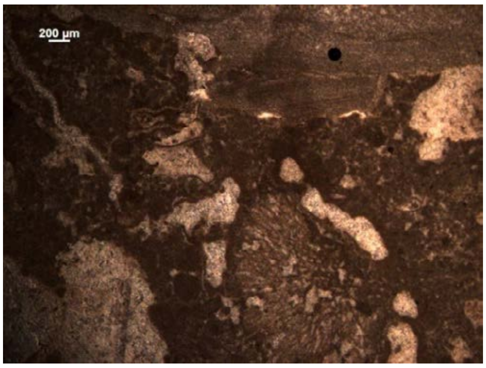
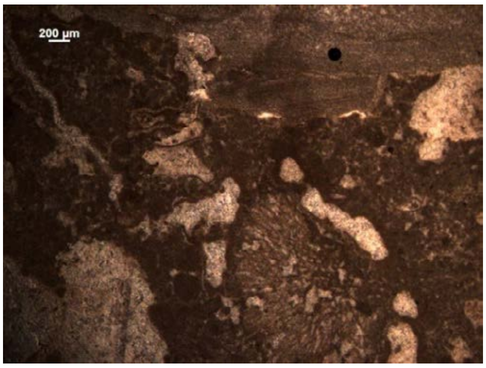
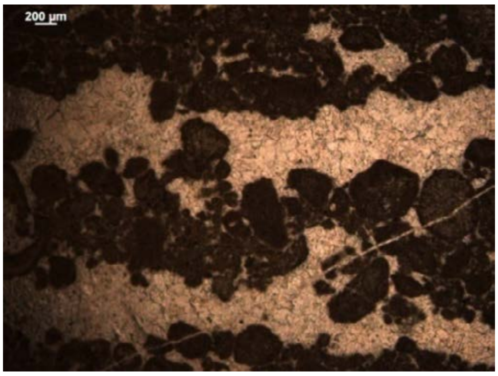
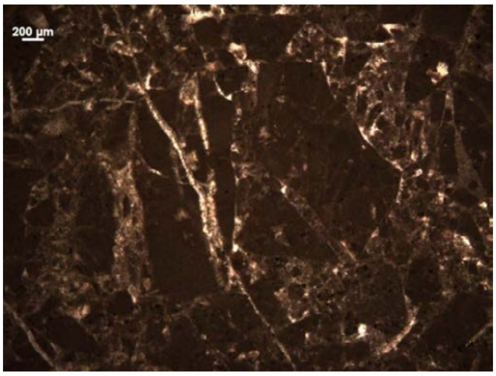
Figura 8. Ubicación de las canteras estudiadas en Sierra Gorda.

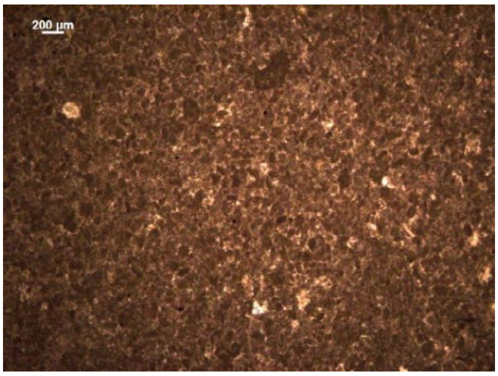
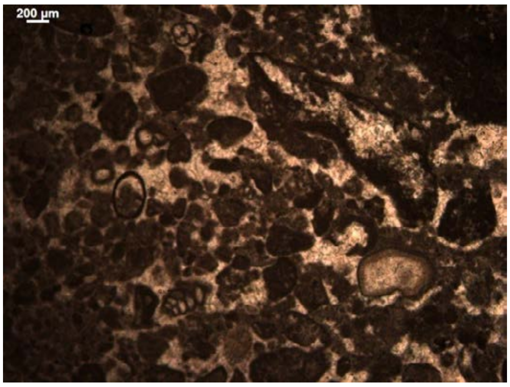
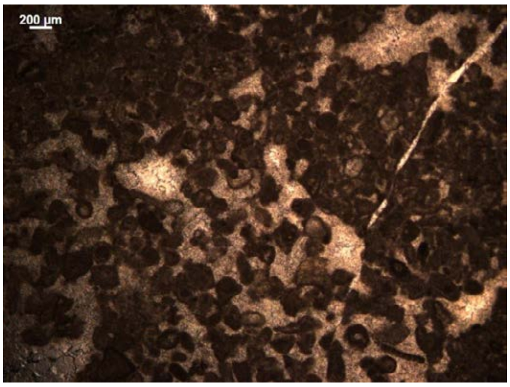
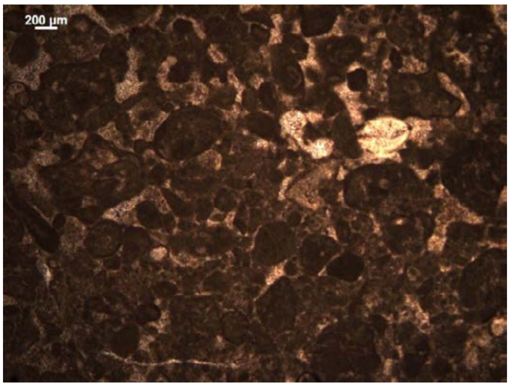
Finally, an exhaustive study of samples from the Sierra Gorda (Granada) outcrops, of Lower Lias age, has also been carried out (see Table 3). They correspond to 10 samples whose initials are from SG-6 to SG-19.

Table 3. Petrographic observation of limestone samples from the Lower Lias of Sierra Gorda (Granada). Parallel Nicols

Tabla 3. Observación petrográfica de muestras de caliza del Lías Inferior de Sierra Gorda (Granada). Nícoles paralelos

Samples	Petrographic Observation	Description
SG-5		Lower Lias. Peloid facies (Packestone) with birdseyes.
SG-6		Lower Lias. Facies of "algal mat (Bindstone) agglutinating intraclasts, peloids and bioclasts (large gastropod) with abundant fenestrae (*birdseyes*).

SG-7		Lower Lias. Facies similar to the previous one with "birdseyes" filled by sparry cement. In one of them, located in the upper part of the photograph, the filling is made of fine particulate internal sediment ("silt" size), from infiltration. The most visible large bioclastic (lower central part) corresponds to a fragment of *Cayeuxia* (calcareous algae).
SG-8		Lower Lias. Oncolithic-peletoidal facies (Rudstone). Some of the grains show very thin pisolithic coatings.
SG-11		Lower Lias. "Algal mat" ("flat stromatolite") (Bindstone) agglutinating intraclasts, oncoliths and peloids. The fenestrae (birdseyes) are quite flat and mark the lamination.
SG-12		Dogger. Calcareous breccias filling fracture (neptune dyke), which crosses the Lias limestones. Angular and irregular fragments.

SG-15		Lower Lias. Facies with abundant peloids (*Packstone*).
SG-16		Lower Lias. Intraclastic-bioclastic-peletoidal facies with some "fenestral" ("rudstone"). A fragment of *Thaumatoporella parvoversiculifera* (algae) can be seen (bottom right), together with small benthic foraminifera and an echinoid spine (center, bottom).
SG-17		Lower Lias. Intraclastic-oolitic facies with fenestrae (birdseyes) (*Rudstone*). The oolites are micritized.
SG-19		Lower Lias. Intraclastic-oncolithic facies (*Rudstone*).

3.2. Methods

The analytical methods are based on the characterization of the rocks by using different analytical techniques including polarized optical microscopy, X-ray diffraction and X-ray fluorescence. Thin sections were polished to a standard thickness of 30µm and examined with a Leica DMLP petrographic polarizing microscope and camera Leica DFC digital image capture system. Calcite and dolomite were distinguished by applying a staining technique with alizarin red.

The mineralogical composition was evaluated by X-ray diffraction (hereinafter XRD), using a D8I 90, BRUKER diffractometer (CITIUS, Seville University) with copper anode tube and following a standard semiquantitative method, tube conditions: 40 kV and 30 mA. The samples were analyzed in disoriented powder, after reducing the rock to powder, for their total mineralogical analysis. Diffrac Suite EVA with an integrated database for the determination of the mineral phases was used as software for the raw data analysis. Quantification of the different mineral phases has been carried out using RIR method (Pinillas Arismendy, 2005).

4. RESULTS

4.1. Analysis of archaeological pieces

From the petrographic point of view, 5 lithotypes have been identified that are described below:

Lithotype 1. It is a calcareous breccia of beige and reddish tones with a predominance of limestone clasts with peloids and small bioclasts of plantonic foraminifera and radiolarian (Pelmicrite by Folk, 1959, 1963; Scholle & Ulmer-Scholle, 2003 or Wackstone by Dunhan, 1963; Kendall, 2005), embedded in a micritic matrix (Figure 9a-b). In other cases, the breccia is cemented by mosaic sparite (Figure 9c-d). Samples: Gr. Salar-2, Gr. Salar-3, Gr. Salar-7 y Gr. Salar-9.

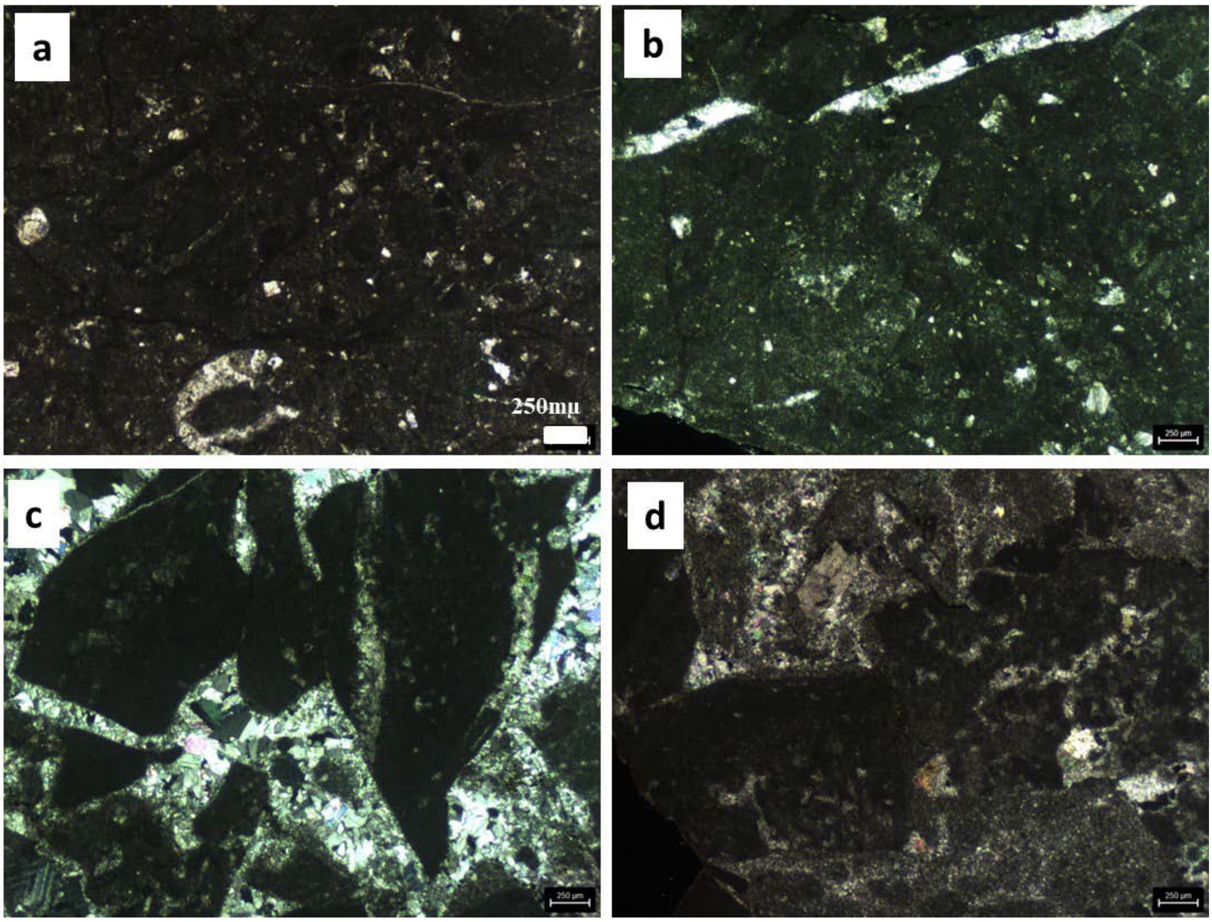


Figura 9. Observación petrográfica de las tipologías de piedra ubicadas en la villa romana de Salar. Brecha calcárea. a-b) Clastos de caliza de la brecha con peloides y moldes de foraminíferos planctónicos y radiolarios. c-d) Clastos de caliza de la brecha con peloides cementados por esparita. Nícoles cruzados.

Lithotype 2. It is a limestone with micritized oolites and with moldic and interparticle porosity partially occluded by sparitic cement (Figure 10a-b) (Ooesparite by Folk, 1959, 1963; Grainstone by Dunhan, 1963). Samples: GR_Salar-4, GR_Salar-10, GR_Salar-11 and MG-3, the latter in the Archaeological Museum of Granada.

Lithotype 3. This is a grayish limestone rich in crinoid fragments and ooliths (Figure 10c-d) (Packstone by Dunham, 1962). Sample Gr. Salar-6.

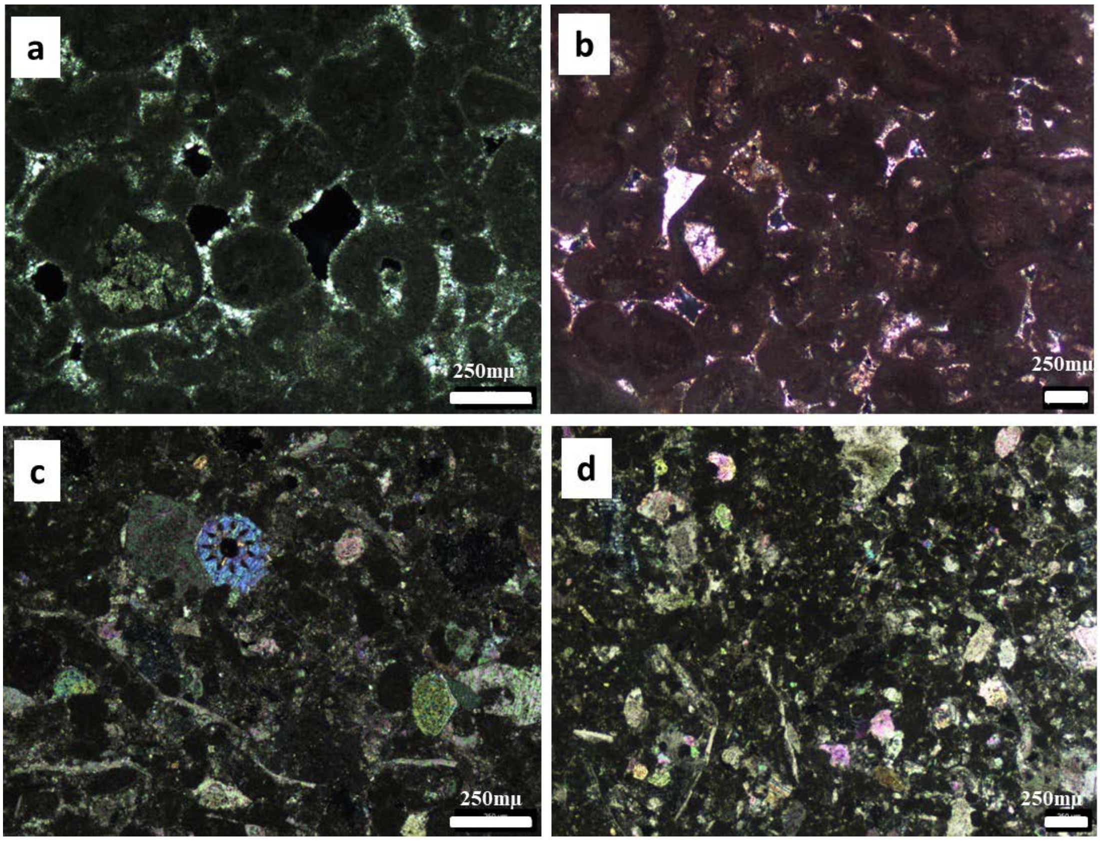


Figure 10. Petrographic observation of the stone typologies located in the villa of Salar. a-b) Lithotype 2. c-d) Lithotype 3. Crossed Nicols.

Figura 10. Observación petrográfica de las tipologías de piedra ubicadas en la villa de Salar. a-b) Litotipo 2. c-d) Litotipo 3. Nícoles cruzados.

Litothype 4. Reddish limestone with of plantonic foraminifera, and radiolarians bioclasts and abundant matrix (Figure 11a-b). It corresponds to a Biomicrite by Folk (1959, 1962) or Wackestone by Dunham (1962). Sample: *MG-1* (currently located in the Archaeological Museum of Granada).

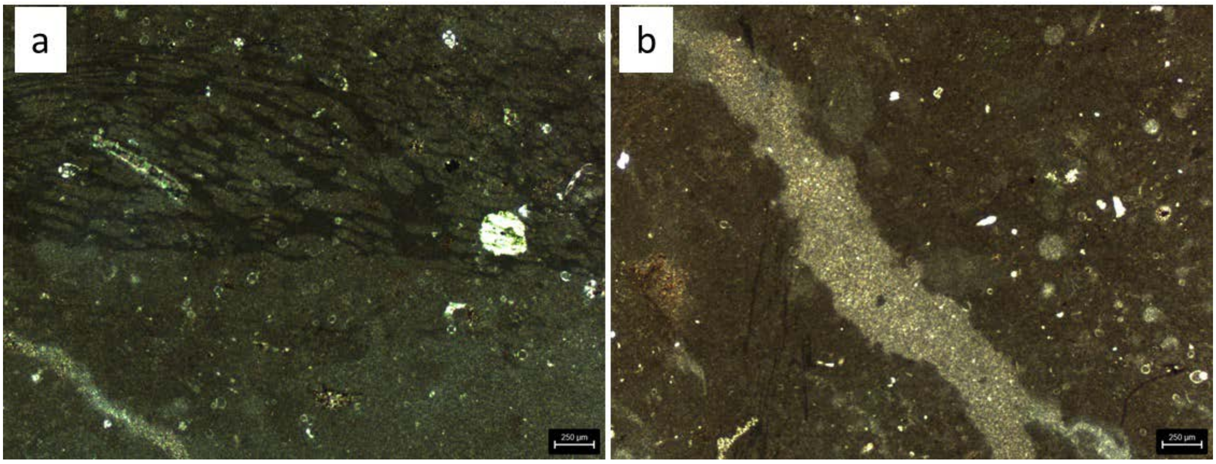


Figure 11. Petrographic observation of the stone typologies located in the villa of Salar. Lithotype 4. In b, the rock is crossed by a late fracture filled with sparite. Crossed Nicols.

Figura 11. Observación petrográfica de las tipologías de piedra ubicadas en la villa de Salar. Litotipo 4. En b, la roca está atravesada por una fractura tardía rellena de esparita. Nícoles cruzados.

Lithotype 5. It is a calcarenite with abundant remains of bivalves, echinoids (spines and plates) and bryozoans, as well as grains of detrital quartz. Carbonate cementation is low and many of the bioclasts are recrystallized (Biomicrite/Biosparite by Folk, 1959, 1963; Rudstone by Embry, Klovan, 1971) (Figure 12 a-d). Samples Gr. Salar-5 and Gr. Salar-13.

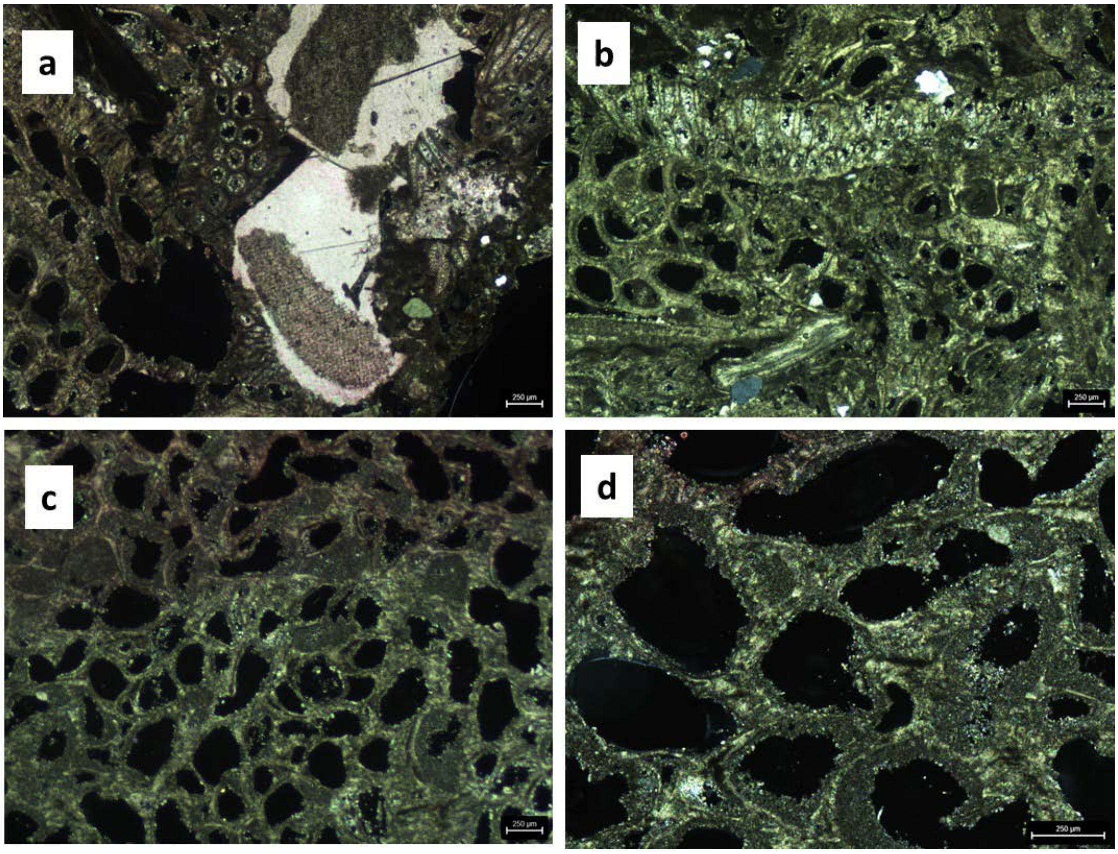


Figure 12. Petrographic observation of the stone typologies located in the Villa of Salar. Lithotype 5. a) Echinoid plates. b) Bioclasts of bryozoans and bivalves. c-d) Details of the bryozoans. Crossed nicols.

Figura 12. Observación petrográfica de las tipologías de piedra ubicadas en la villa de Salar. Litotipo 5. a) Placas de equinodermos. b) Bioclastos de briozoos y bivalvos. c-d) Detalles de los briozoos. Nícoles cruzados.

4.2. Analysis of Sierra Gorda quarry samples

The mineralogical composition of all the samples analyzed in the quarry is calcite with traces of quartz, and no aragonite has been detected. From the petrographic point of view, three different varieties have been differentiated:

Variety 1. It is a white micritic limestone with algae, foraminifera, intraclasts, oncoliths and peloids and little intergranular sparitic cement that also fills pores and microfissures (Figure 13 a-b).

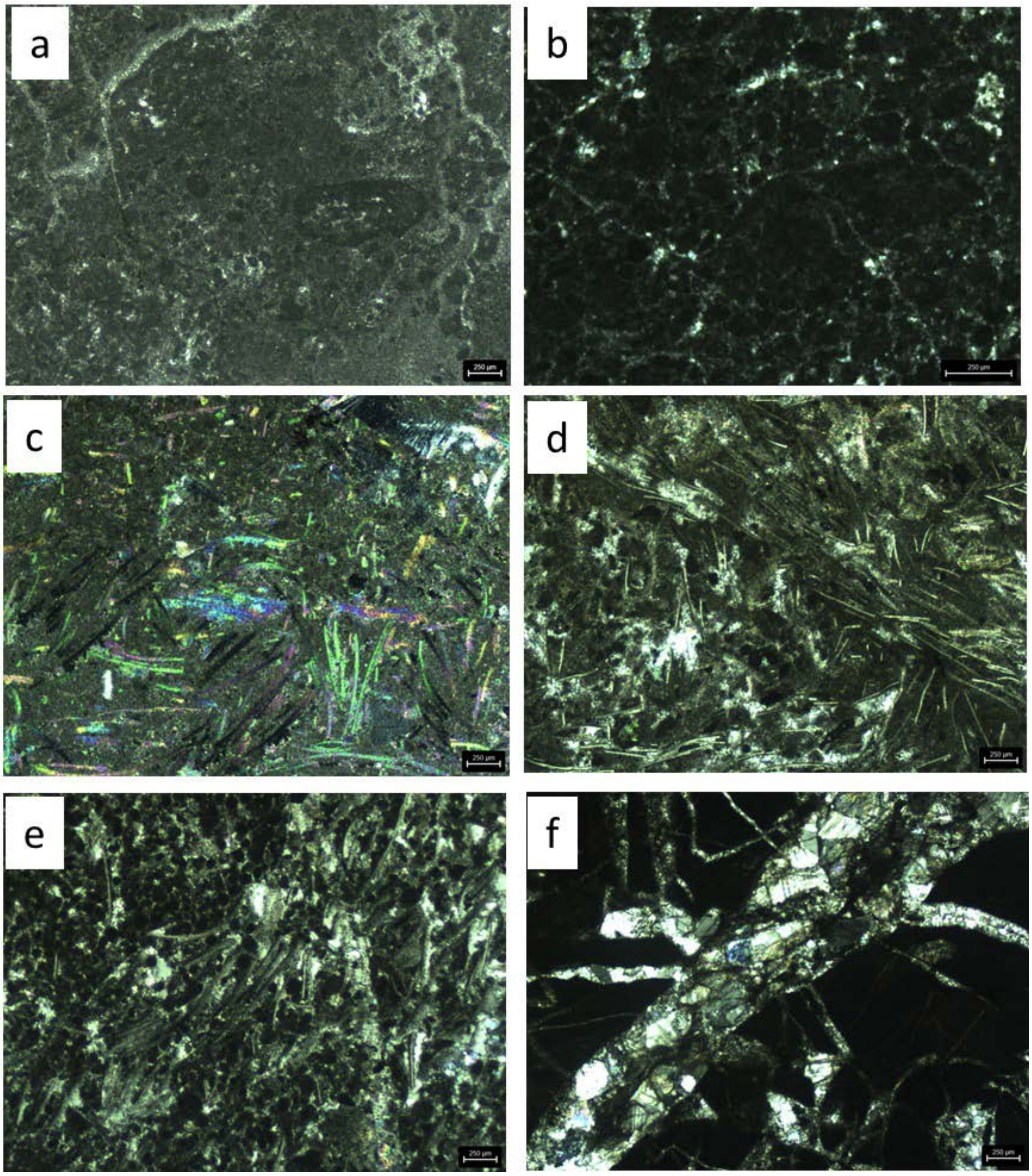


Figure 13. a-b). Variety 1 (C-Salar 1). c-e). Variety 2 (C-Salar 2, 4, 5). f) C- Variety 3 (C-Salar 3). Crossed Nicols.

Figura 13. a-b). Variedad 1 (C-Salar 1). c-e). Variedad 2 (C-Salar 2, 4, 5). f) C- Variedad 3 (C-Salar 3). Nícoles cruzados.

This variety corresponds to the white limestone levels of the Lower Lias and has been located in the C_salar-1 quarry.

Table 2. Sampling in quarries, Sierra Gorda
Tabla 2. Muestreo en canteras, Sierra Gorda

Samples	Description	Outcrop quarries	
C_salar-1	Compact white limestone		
C_salar-2	Pinkish nodular limestone		
C_salar-3 Finca Escardador	White limestone		
C_salar-4 Sierrajuela	Calcareous breccia and Nodular reddish limestone		

https://doi.org/10.21701/bolgeomin/137.1/002

C_salar-5	Nodular reddish limestone		

Variety 2. Micritic reddish limestone with filaments. The texture is Packstone (Dunham, 1962), with 40% micrite, 50% bioclasts and 10% peloids (Figure 12 c-e). These microfacies correlate with the "Ammonitico Rosso" pelagic facies of the Dogger-Malm. The rocks that surface in the C_salar-2 and C_salar-4.5 quarries (Table 2) correlate with this stone variety.

Variety 3. This is a calcareous breccia made up of fragments of limestone rocks with peloids, cemented by a mosaic, sparitic cement (Figure 12f). It is a collapse breccia linked to the emersion and karstification stage that occurred in the Dogger. This variety is correlated with those of the C_salar-3 outcrop.

5. DISCUSSION

From the petrographic point of view, in the studied quarries of Sierra Gorda three varieties have been identified that correspond to the white limestones of the Lower Lias, the grayish breccias of the Dogger and the reddish-gray ones of the Dogger-Malm ("Ammonítico rosso").

The microfacies of the white limestones of the Lower Lias are Biomicrites with abundant remains of benthic foraminifera, thick-shelled bivalves, gastropods and dasycladaceae. They frequently also show pisoliths, oncoliths and fenestral textures linked to emersion phases (see Table 3). These microfacies are not, however, directly related to any of the lithotypes identified in the archaeological pieces analyzed.

Dogger calcareous breccias have also been identified in the quarries studied. These breccias, which correspond to *Lithotype 1* of the archaeological pieces analyzed, are linked to the stage of emersion and karstification that occurred in the Dogger in Sierra Gorda and were generated by the collapse of walls (open fractures) and cavity roofs (caves), their voids being subsequently cemented and/or occluded by a more modern infiltration sediment. They therefore come from Sierra Gorda.

The microfacies of Biomicrites with filaments, plantonic foraminifera and radiolarians are associated with the nodular limestones of the "Ammonítico rosso" also exploited in some of the quarries and correspond to *Lithotype 4* of the archaeological pieces analyzed. We cannot attribute the reddish-colored sample MG-1 (currently located in the Archaeological Museum of Granada) with complete certainty to local stone ("Ammonítico Rosso") outcropping in Sierra Gorda, although it is most likely from there.

However, no oolitic limestones have been located in the outcrops of the analyzed quarries. It is very likely that the oolitic limestones (*Lithotype 2* of the archaeological pieces analyzed) come from quarries in the Córdoba-Cabra Sector or the Málaga-Antequera Sector (Ontiveros *et al.*, 2019).

Although crinoid limestones (*Lithotype 3*) are somewhat present in Sierra Gorda, this typology is more related to the gray stone of Sierra Elvira (Granada), where they are very well represented and where they most likely come from. Sierra Elvira stone is composed of grains and calcium carbonate cement, the microstructure has high density, lacking appreciable porosity. It presents a wide variety of chromatic tones that vary from dark gray to greenish bronze (Sebastián *et al.*, 2008).

The microfacies of *Lithotype 5* correlate with the bioclastic calcarenites of the Tortonian (Upper

Miocene) present in localities near the *villa* of Salar, as in Alhama de Granada, Cacín and Santa Pudia, in Escúzar. Its exact origin (Alhama or Escúzar) is yet to be determined, although those from the Cacín River are ruled out (Figure 7), as heavy jointing prevented there the extraction of large ashlars.

6. CONCLUSIONS

Based on the study carried out, the following conclusions can be established:

- Sierra Gorda and the areas around the Granada Basin were a source of stone materials in Roman times, as demonstrated by their use in the Roman *villa* of Salar.
- Several lithotypes have been located here, most likely coming from this mountain massif. Above all, the use of the Dogger calcareous breccia (*Lithotype 1*) and, probably, the nodular limestones of the Dogger-Malm (*Lithotype 4*) stands out. However, we cannot confirm (based exclusively on the samples of the archaeological pieces analyzed so far) the use of micritic limestones from the Lias of Sierra Gorda.
- Although the use of oolitic limestones has also been evident (*Lithotype 2*), these probably do not come from Sierra Gorda. There is a high possibility that this typology came from other geographical areas not too far away (Málaga or Córdoba).
- The crinoid limestones used (*Lithotype 3*) most likely come from Sierra Elvira where they crop out extensively.
- The exact origin of the bioclastic calcarenites (*Lithotype 5*): Alhama de Granada or Escúzar, is yet to be determined.
- The archaeological materials analyzed from the town of Salar are concentrated in the peristyle area, as well as the *triclinium* and the *nymphaeum*. All these stone materials, for constructive use (bases and shafts of columns; ashlars in the area of the *nymphaeum*), as well as, partially, for decorative use (covering plate and *crustae*), local stones were used, coming from the outcrop quarries of the Sierra Gorda, or regional, such as Alhama de Granada or Escúzar, Sierra Elvira, or the areas of Cabra (Córdoba) or Antequera (Málaga). Only in the case of the *crustae* is noted that local/regional materials served as a complement or replacement for foreign stone materials.
- It is very likely that other local or regional stone materials were used in the *villa*, such as slate or serpentine, but which we have not analyzed, as well as others from much more distant geographical areas, such as limestone from the Portuguese region of Sintra (Portugal).

Supplementary information ↑

Funding sources

Not applicable.

Supplementary material

Not applicable.

Data availability

Not applicable.

Acknowledgements

This research has been carried out through the project: “Italica Adrianea: la Nova Urbs. Análisis arqueológico del paradigma urbano y su evolución, y contrastación del modelo” (PID2020-114528GB-I00; Ministerio de Ciencia, Innovación y Universidades – Agencia Estatal de Investigación, FEDER Founds). We appreciate the support from the Salar City Council and, especially, Mayor Mr. Armando Moya Castilla. The study of these quarries has been favored by the help and information provided by residents of the municipality of Salar, to whom we thank for their selfless collaboration.

Authorship contribution statement

Esther Ontiveros Ortega: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft, Photographs, Image editing, Writing – review & editing.

José Manuel Martín Martín: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft, Image editing, Writing – review & editing.

María Luisa Loza Azuaga: Investigation, Methodology, Writing – original draft, Writing – review & editing.

José Beltrán Fortes: Investigation, Methodology, Writing – original draft, Writing – review & editing.

Julio M. Román Punzón: Investigation, Methodology, Writing – original draft, Writing – review & editing.

Competing interests

The authors of this article declare that they have no financial, professional, or personal conflicts of interest that could have inappropriately influenced this work.

Statement on the use of Artificial Intelligence

Not applicable.

REFERENCES

Acale Sánchez, F. (2016). Metodología para el análisis histórico-constructivo en edificios granadinos. Granada. Universidad de Granada. http://hdl.handle.net/10481/41251

Beltrán Fortes, J., Loza Azuaga, M. L., Ontiveros Ortega, E., Rodríguez Gutiérrez, O. & Taylor, R. (2011). La explotación y el empleo de marmora en la Baetica. Un proyecto de investigación de base arqueométrica. Itálica, 1, 51-76.

Beltrán Fortes, J., Ontiveros Ortega, E., Loza Azuaga, M. L. & Romero M. (2012). Roman use, petrography and elemental geochemistry of the Surco Intrabético limestones (western region of Málaga province, Spain). In: Asmosia IX International Conference. Tarragona, 2009, 500-510. Tarragona. ICAC.

Beltrán Fortes, J., Loza Azuaga, M. L. & Ontiveros Ortega, E. (Ed.) (2018). Marmora Baeticae. Uso de materiales pétreos en la Baetica romana. Estudios arqueológicos y análisis arqueométricos. Sevilla. Universidad de Sevilla.

Burgos Juárez, A., Puerta Torralbo, D., Cabrera Jiménez, E. Pérez Bareas, C. & Torres, F. (2009). Intervención arqueológica en las Termas romanas de Lecrín (Granada). Anuario Arqueológico de Andalucía 2004, I, 1571-1578.

Braga, J.C., Martín, J.M. & Alcalá, B. (1999) Coral reef in coarse-terrigenous sedimentary environments (Upper Tortonian, Granada Basin, Southern Spain). Sedimentary Geology, 66, 135-150.

Braga, J.C., Jiménez, A. P., Martín, J. M. & Rivas, P. (1996). Middle Miocene, coral-oyster reefs (Murchas, Granada, Southern Spain). In: E. Franseen, M. Esteban, B. Ward, J.M. Rouchy (Ed.). Models for Carbonate Stratigraphy from Miocene Reef Complexes of the Mediterranean Regions. SEPM, Concepts in Sedimentology and Paleontology Series, 5, 131-139. Tulsa, Oklahoma.

Braga, J. C. & Martín J. M., Quesada, C. (2003). Patterns and average rates of late Neogene-Recent uplift of the Betic Cordillera, SE Spain. Geomorphology, 50, 1-3, 3-26.

Braga, J. C., Martín, J. M., Betzler & C., Aguirre, J. (2006). Models of temperate carbonate deposition in Neogene basins in SE Spain: a synthesis. In: Pedley, H.M., Carannante, G. (Ed.), Cool-Water Carbonates: Depositional Systems and Palaeonvironmental Controls, 121-135. London. Geological Society.

Buforn, E., Sanz de Galdeano, C. & Udías A. (1995). Seismo - Tectonics of the Ibero -Maghrebian Region. Tectonophysics, 248, 247-261.

Calvín Velasco, Mª.E. (2016). Los núcleos de población del cinturón de Iliberris. La villa romana de Los Vergeles. Arqueoweb. Revista de Arqueología en Internet, 17, 99-114.

Canto de Gregorio, A. (1978). Avances sobre la explotación del mármol en la España romana. Archivo Español de Arqueología, 50-51, 165-188.

Cisneros Cuchillos, M. (1989-1990). Sobre la explotación de calizas en el Sur de España en época romana: Canteras de Gádor (Almería), Atarfe (Granada), Antequera (Málaga) y Cabra (Córdoba). Caesaraugusta, 66-67, 123-142.

Durand-Delga, M. (1980) La Méditerranée occidentale: étapes de sa genesè et problèmes structuraux liés à celle-ci. Société Géologique de France, 10, 203-224.

Dunham, R. J. (1962). Classification of carbonate rocks according to depositional texture. In: Ham, W. E. (ed.), Classification of Carbonate Rocks. A Simpoisum, 108-121. Tulsa, American Association of Petroleum Geologists.

Embry, A. F. & Klovan J. E. (1971). A Late Devonian reef tract on Northern Banks Island, N.W.T. Bulletin of Canadian Petroleum Geology, 19, 730-781.

Fallot, P. (1948). Les Cordilleres Bétiques. Estudios Geológicos, 8, 83-172.

Fernández, J. & Rodríguez Fenández, J. (1991). Facies evolution of nearshore marine clastic deposits during the Tortonian transgression Granada Basin, Betic Cordilleras, Spain. Sedimentology Geology, 71, 5-21.

Fernández García, M. I., Román Punzón, J. M., Moreno Alcaide, M., Ruiz Montes, P. & Ramos Noguera, J. (2019). Los mosaicos de la villa romana de salar (Granada): campañas de excavación de 2017 y 2018. L. Neila (ed.), Mosaicos romanos en el espacio rural: investigación y puesta en valor, 179-192. Roma. http://digital.casalini.it/4618357

Folk, R. L. (1959). Practical petrographic classification of limestones. American Association of Petroleum Geologists Bulletin, 43, 1-38.

Folk, R. L. (1962). Spectral subdivision of limestone types. In: Ham, W.E., ed., Classification of carbonate Rocks. A. Symposium, 62-84. Tulsa, American Association of Petroleum Geologists.

Fornell Muñoz, A. (2011). La villa del Pago de la Cerraca (Armilla) y su papel en el poblamiento romano de la Vega de Granada. Revista Digital de Arqueología, 22-32.

Flügel, E. (1982). Microfacies Analysis of Limestones. Berlin, Springer.

Galindo-Zaldívar, J., González-Lodeiro, F. & Jabaloy, A. (1993). Stress and palaeostress in the Betic-Rif Cordilleras (Miocene to the Present). Tectonophysics, 227, 105-126.

Galindo-Zaldívar, J., Braga, J. C., Marín-Lechado, C., Ercilla, G., Martín, J.M., Pedrera, A., Casas, D., Aguirre, J., Ruiz-Constán, A., Estrada, F., Puga-Bernabéu, A., Sanz de Galdeano, C. García-Alix, A., Vázquez, J. T. & Alonso, B. (2019), Extension in the Western Mediterranean. In: C. Quesada & J.T. Oliveira (Ed). The Geology of Iberia. A Geodynamic Approach. Springer, Regional Geology Reviews, 4, 61-94.

García-Alix, A., Minwer-Barakat, R., Martín, J. M., Martín-Suárez, E. & Freudenthal, M. (2008). Biostratigraphy and sedimentary evolution of Late Miocene and Pliocene continental deposits of the Granada Basin (Southern Spain). Lethaia, 41, 431-446.

García Hernández, M., González Donoso, T. M., Linares, A., Rivas, P. & Vera J. A. (1976). Características ambientales del Lías inferior y medio en la Zona Subbética y su significado en la interpretación general de la Cordillera. In: Reunión sobre la Geodinámica de la Cordillera Bética y Mar de Alborán, 125-157. Granada. Universidad de Granada.

García Hernádez, M., Rivas, P. & Vera, J. A. (1979). Distribución de las calizas de llanuras de mareas en el Jurásico del Subbético y Prebético. Cuadernos de Geología, Universidad de Granada, 10, 557-569.

García-Hernández, M., López-Garrido, A. C., Rivas, P. & Vera, J. A. (1980). Dominios paleogeográficos de las Zonas Externas de las Cordilleras Béticas. Cuadernos de Geología, Universidad de Granada, 10, 359-365.

García-Veigas, J., Cendón, D. L., Rosell, L., Ortí, F., Torres-Ruiz, J., Martín, J. M. & Sanz, E. (2013). Salt deposition and brine evolution in the Granada Basin (Late Tortonian, SE Spain). Palaeogeography, Palaeoclimatology, Palaeoecology, 369, 452-465.

Linares, A. & Vera, J. A. (1965). Precisiones estratigraficas sobre la serie mesozoica de Sierra Gorda (Cordilleras Béticas). Estudios Geológicos, 22, 65-69.

López Burgos del Barrio, M. A. (2002). Los mármoles, la minería en España y la Geología de Granada, en la obra de E. Cook, un viajero inglés de 1830. Cuadernos Geográficos, 229-248. Granada. Universidad de Granada.

López-Quirós, A., Barbier, M., Martín, J. M., Puga-Bernabéu, A. & Guichet, X. (2016). Diagenetic evolution of Tortonian temperate carbonates close to evaporites in the Granada Basin (SE Spain). Sedimentary Geology, 335, 180-196. http://dx.doi.org/10.1016/j.sedgeo.2016.02.011

Marín Díaz, P. (2016). Otium, salubritas, amoenitas. Decoraciones musivas y pictóricas romanas en la Vega de Granada. Diss. Granada: Universidad de Granada.

Martín-Algarra, A. (1987). Evolución geológica alpine del contacto entre las zonas Internas y zonas Externas de las Cordilleras Béticas (Sector central y occidental). Doctoral Thesis. Universidad de Granada.

Martín J. M. & Dabrio, C. J. (1981). Calizas de crinoides del Carixiense Subbético: historia diagenética. Boletín de la Real Sociedad Española de Historia Natural (Geología), 79, 287-291.

Martín, J.M., Ortega Huertas, M. & Torres Ruiz, J. (1984). Genesis and evolution of the strontium deposits of the Granada Basin (SE Spain): evidence of diagenetic replacement of a stromatolite belt. Sedimentary Geology, 39, 281-298.

Martín J. M., Puga-Bernabéu A., Aguirre J. & Braga J. C. (2014). Miocene Atlantic-Mediterranean seaways in the Betic Cordillera (Southern Spain). Revista de la Sociedad Geológica de España, 27, 1, 175-186.

Molina, J. M., Ruiz Ortiz, P. A. & Vera, J. A. (1995). Neptunian dykes and associated features in southern Spain: mechanics of formations and tectonic implications. Sedimentology, 42, 957-969.

Montenat, C., Rodríguez-Fernández, J., Ott d'Estevou, P. & Sanz de Galdeano, C. (1990). Geodynamic evolution of the Betic Neogene intramontane basins (S and SE Spain). In: Iberian Neogene Basins, 6-59. Sabadell, Institut de Paleontología Miguel Crusafonf.

Moreno Alcaide, M., Román Punzón, J. M. & Ruiz Montes, P. (2019). El uso de tubi fittili para cubiertas abovedadas en la Hispania romana. Revisión bibliográfica y estado de la cuestión. Spal, 28.1, 131-156.

Navarro, R., Molina, E. & Baltuille, J. M.(2013). The relevance of Santa Pudia calcarenite: a natural stone to preserve heritage buildings in Andalusia (Spain). Geophysical Research Abstracts, 15.

Navarro, R., Fernández-Suárez, J., Martínez-Martínez, J., Álvarez Areces, E. & Baltuille, J. M. (2021). La protección de las canteras históricas de Granada y su puesta en valor como garantía de conservación del patrimonio arquitectónico. Geotemas, 18, 939-942.

Neira Jiménez, L., Román Punzón, J. M., Moreno Alcaide, M., Ruiz Montes, P., Ramos Noguera & Fernández García, M. I. (2024). Acerca del pavimento con la representación de una nereida en la villa romana de Salar (Granada) en el conventus Astigitanus. Mosaïque en contexte, 203-214.

Orfila Pons, M., Castillo Rueda, M. A. & Casado Millán, P. J. (1996). La cantera romana del cortijo del Canal (Albolote, Granada): composición, explotación y uso en construcción. In: Actas del Primer Congreso Nacional de Historia de la Construcción, 389-394. Madrid, CEHOPU.

Ontiveros Ortega, E., Beltrán Fortes, J. & Loza Azuaga, M. L. (2019). Mineralogical petrographic and geochemical characterization of marmora from the Roman quarries of Cabra (Córdoba) and Antequera (Málaga), External Sector Areas of the Betic Chain, Spain. En: Journal of Archaeological Science: Reports, 1, 27, 1-16.

https://doi.org/10.1016/j.jasrep.2019.101956

Pinillas Arimendis, J. A (2005). Implementacion de los metodos RIR y rietveld para análisis cuantitativo de fases cristalinas con y sin presencia de material amorfo por difraccion de rayos-x de muestras policristalinas. Doctoral Thesis, Universidad Industrial de Santander.

Puga-Bernabéu, A., Martín, J. M. & Braga, J. C. (2008). Sedimentary processes in a submarine canyon excavated into a temperate-carbonate ramp (Granada Basin, southern Spain). Sedimentology, 55, 1449-1466.

Puga-Bernabéu, A., Martín, J. M., Braga, J. C. & Aguirre, J. (2014). Offshore remobilization processes and deposits in low-energy temperate-water carbonate-ramp systems: examples from the Neogene Basins of the Betic Cordillera (SE Spain). Sedimentary Geology, 304, 11-27.

Rodríguez Aguilera, A., García Consuegra, Rodríguez Aguilera, J., Pérez Tovar, M. J. & Marín Díaz, P. (2014). La villa bajoimperial y tardoantigua de Los Mondragones (Granada). Cuadernos de Prehistoria y Arqueología de la Universidad de Granada, 24, 459-496.

Rodríguez-Fernández, J., Fernández, J., López-Garrido, A. C. & Sanz de Galdeano, C. (1984). The Central Sector of the Betic Cordilleras, a realm situated between the Atlantic and Mediterranean domains during the Upper Miocene. Annales Géologiques des Pays Helléniques, 32, 97-103.

Rodríguez-Fernández, J. & Martín-Penela, A. (1993) Neogene evolution of the Campo de Dalias and the surrounding shore areas (Northeastern Alborán Sea). Geodinamica Acta, 6, 255-270.

Rodríguez Navarro, C. (1994). Causas y mecanismos de alteración de los materiales de calcáreos de las Catedrales de Granada y Jaén. Doctoral Thesis. Universidad de Granada.

Roldán, L., Bustamante, M. & Amroui, T. (2022). Técnicas y materiales constructivos en las ciudades del Mediterráneo extremo-occidental. Sobre la transmisión de saberes entre ambas orillas en la antigüedad. In: T. Amraoui, A. Quevedo (Ed.), D'une rive à l'autre: circulations et échanges entre la Maurétanie césarienne et le sud-est de l'Hispanie (Antiquité-Moyen Âge), 133-168. Oxford. Archaeopress.

Román Punzón, J. M., Moreno Alcaide, M., Ruiz Montes, P., & Ramos Noguera & Fernández García, M. I. (2021). La decoración musiva y escultórica en la villa romana de Salar (Granada). Recientes hallazgos. R. Martínez, T. Nogales & I. Rodá (coords.) Las villas romanas bajoimperiales de Hispania, Palencia, 437-445.

Román Punzón, J., Moreno-Alcaide, M., Ruiz Montes, P., Ramos Noguera, J. & Peralta Gómez, A. (2022). Life and afterlife of a Roman villa in western Granada, Spain: Salar from the 4th to the 7th centuries. European Journal of Post-Classical Archaeologies (PCA), 12, 107-134.

Ruiz Montes, P., Fernández García, I. & Rodríguez Ariza, M. O. (2010). Aportaciones a las facies cerámicas de época romana en la Vega de Granada: la villa romana de Las Gabias, Antiquitas, 22, 121-140.

Sanz de Galdeano, C. (1988). The fault system and the Neotectonic features of the Betic Cordilleras. In: E. Banda, L.A. Mendes (Ed.), 5th European Geotransverse Workshop on the Iberian Peninsula, 1, 99-109. Estoril, European Sciences Foundation.

Sanz de Galdeano, C. (1990). Geologic evolution of the Betic Cordilleras in the western Mediterranean, Miocene to the Present. Tectonophysics, 172, 107-119.

Sanz de Galdeano, C. & Vera, J. A. (1992). Stratigraphic record and palaeogeographical context of the Neogene basins in the Betic Cordillera, Spain. Basin Research, 4, 21-36.

Sebastián, E., Zezza, U., Rodríguez-Navarro, C., De la Torre, M. J. & Cardell, C. (1992). La Piedra Franca, biocalcarenita, en la construcción de edificios históricos de Granada. In: I Congreso Internacional Rehabilitación del Patrimonio Histórico y Edificación, 1, 329-336. La Laguna, Gobierno de Canarias.

Sebastián, E., Cultrone, G., Garibaldi, V., Rodríguez, C., De La Torre, M. J. & Valverde, J. (2008). The Sierra Elvira limestone: petrophysical features of a widespread Andalusian decorative material. Materiales de Construcción, 58 (289-290), 51-63.

Sotomayor, M. & Orfila, M. (2004). Un paso decisivo en el conocimiento de la Granada romana (Municipium Florentinun Iliberritanum). Archivo Español de Arqueología, 77, 73-89.

Toro-Moyano, I., Raya de Cárdenas, M. & Ramos Lizana, M. (1987). La villa romana del Cortijo del Canal (Albolote/Granada). In: XIX Congreso Nacional de Arqueología, 803-815. Zaragoza. Seminario de Arqueología.

Urosevic, M., Sebastián, E., Ruiz-Agudo, E. & Cardell, C. (2011). Physical properties of carbonate rocks used as a modern and historic construction material in Eastern Andalusia, Spain. Materiales de Construcción, 61 (301), 93-114.

Vera, J. A. (1984) Aspectos sedimentológicos en la evolución de los dominios alpinos mediterráneos durante el Mesozoico. In: A. Obrador (Ed.), Libro Homenaje a L. Sánchez de la Torre, 25-54. Bellaterra, Universidad Autónoma de Barcelona.

Vera, J. A. (1988). Evolución de los sistemas de depósito en el margen Ibérico de las Cordilleras Béticas. Revista de la Sociedad Geológica de España, 1, 373-391.