

Espejón Limestone and Conglomerate (Soria, Spain): Archaeometric Characterization, Quarrying and Use in Roman Times

García-Entero, Virginia; Gutiérrez Garcia-M., Anna; Vidal Álvarez, Sergio; Peréx Agorreta, María J.; Zarco Martínez, Eva

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CONTENT

PRESENTATION	15
NECROLOGY: NORMAN HERZ (1923-2013) by Susan Kane	17
1. APPLICATIONS TO SPECIFIC ARCHEOLOGICAL QUESTIONS – USE OF MARBLE	
Hermaphrodites and Sleeping or Reclining Maenads: Production Centres and Quarry Marks <i>Patrizio Pensabene</i>	25
First Remarks about the Pavement of the Newly Discovered Mithraeum of the Colored Marbles at Ostia and New Investigations on Roman and Late Roman White and Colored Marbles from Insula IV, IX <i>Massimiliano David, Stefano Succi and Marcello Turci</i>	33
Alabaster. Quarrying and Trade in the Roman World: Evidence from Pompeii and Herculaneum <i>Simon J. Barker and Simona Perna</i>	45
Recent Work on the Stone at the Villa Arianna and the Villa San Marco (Castellammare di Stabia) and Their Context within the Vesuvian Area <i>Simon J. Barker and J. Clayton Fant</i>	65
Marble Wall Decorations from the Imperial Mausoleum (4 th C.) and the Basilica of San Lorenzo (5 th C.) in Milan: an Update on Colored Marbles in Late Antique Milan <i>Elisabetta Neri, Roberto Bugini and Silvia Gazzoli</i>	79
Sarcophagus Lids Sawn from their Chests <i>Dorothy H. Abramitis and John J. Herrmann</i>	89
The Re-Use of Monolithic Columns in the Invention and Persistence of Roman Architecture <i>Peter D. De Staebler</i>	95
The Trade in Small-Size Statues in the Roman Mediterranean: a Case Study from Alexandria <i>Patrizio Pensabene and Eleonora Gasparini</i>	101
The Marble Dedication of Komon, Son of Asklepiades, from Egypt: Material, Provenance, and Reinforcement of Meaning <i>Patricia A. Butz</i>	109
Multiple Reuse of Imported Marble Pedestals at Caesarea Maritima in Israel <i>Barbara Burrell</i>	117
Iasos and Iasian Marble between the Late Antique and Early Byzantine Eras <i>Diego Peirano</i>	123

Thassos, Known Inscriptions with New Data <i>Tony Kozelj and Manuela Wurch-Kozelj</i>	131
The Value of Marble in Roman <i>Hispalis</i> : Contextual, Typological and Lithological Analysis of an Assemblage of Large Architectural Elements Recovered at N° 17 Goyeneta Street (Seville, Spain) <i>Ruth Taylor, Oliva Rodríguez, Esther Ontiveros, María Luisa Loza, José Beltrán and Araceli Rodríguez</i>	143
<i>Giallo Antico</i> in Context. Distribution, Use and Commercial Actors According to New Stratigraphic Data from the Western Mediterranean (2 nd C. Bc – Late 1 st C. Ad) <i>Stefan Ardeleanu</i>	155
<i>Amethystus</i> : Ancient Properties and Iconographic Selection <i>Luigi Pedroni</i>	167
2. PROVENANCE IDENTIFICATION I: (MARBLE)	
Unraveling the Carrara – Göktepe Entanglement <i>Walter Prochaska, Donato Attanasio and Matthias Bruno</i>	175
The Marble of Roman Imperial Portraits <i>Donato Attanasio, Matthias Bruno, Walter Prochaska and Ali Bahadır Yavuz</i>	185
Tracing Alabaster (Gypsum or Anhydrite) Artwork Using Trace Element Analysis and a Multi-Isotope Approach (Sr, S, O) <i>Lise Leroux, Wolfram Kloppmann, Philippe Bromblet, Catherine Guerrot, Anthony H. Cooper, Pierre-Yves Le Pogam, Dominique Vingtain and Noel Worley</i>	195
Roman Monolithic Fountains and Thasian Marble <i>Annewies van den Hoek, Donato Attanasio and John J. Herrmann</i>	207
Archaeometric Analysis of the Alabaster Thresholds of Villa A, Oplontis (Torre Annunziata, Italy) and New Sr and Pb Isotopic Data for <i>Alabastro Ghiaccione del Circeo</i> <i>Simon J. Barker, Simona Perna, J. Clayton Fant, Lorenzo Lazzarini and Igor M. Villa</i>	215
Roman Villas of Lake Garda and the Occurrence of Coloured Marbles in the Western Part of “Regio X Venetia et Histria” (Northern Italy) <i>Roberto Bugini, Luisa Folli and Elisabetta Roffia</i>	231
Calcitic Marble from Thasos in the North Adriatic Basin: Ravenna, Aquileia, and Milan <i>John J. Herrmann, Robert H. Tykot and Annewies van den Hoek</i>	239
Characterisation of White Marble Objects from the Temple of Apollo and the House of Augustus (Palatine Hill, Rome) <i>Francesca Giustini, Mauro Brilli, Enrico Gallochio and Patrizio Pensabene</i>	247
Study and Archeometric Analysis of the Marble Elements Found in the Roman Theater at Aeclanum (Mirabella Eclano, Avellino - Italy) <i>Antonio Mesisca, Lorenzo Lazzarini, Stefano Cancelliere and Monica Salvadori</i>	255

Two Imperial Monuments in Puteoli: Use of Proconnesian Marble in the Domitianic and Trajanic Periods in Campania <i>Irene Bald Romano, Hans Rupprecht Goette, Donato Attanasio and Walter Prochaska</i>	267
Coloured Marbles in the Neapolitan Pavements (16 th And 17 th Centuries): the Church of <i>Santi Severino e Sossio</i> <i>Roberto Bugini, Luisa Folli and Martino Solito</i>	275
Roman and Early Byzantine Sarcophagi of Calcitic Marble from Thasos in Italy: Ostia and Siracusa <i>Donato Attanasio, John J. Herrmann, Robert H. Tykot and Annewies van den Hoek</i>	281
Revisiting the Origin and Destination of the Late Antique Marzamemi 'Church Wreck' Cargo <i>Justin Leidwanger, Scott H. Pike and Andrew Donnelly</i>	291
The Marbles of the Sculptures of Felix Romuliana in Serbia <i>Walter Prochaska and Maja Živić</i>	301
Calcitic Marble from Thasos and Proconnesos in Nea Anchialos (Thessaly) and Thessaloniki (Macedonia) <i>Vincent Barbin, John J. Herrmann, Aristotle Mentzos and Annewies van den Hoek</i>	311
Architectural Decoration of the Imperial Agora's Porticoes at Iasos <i>Fulvia Bianchi, Donato Attanasio and Walter Prochaska</i>	321
The Winged Victory of Samothrace - New Data on the Different Marbles Used for the Monument from the Sanctuary of the Great Gods <i>Annie Blanc, Philippe Blanc and Ludovic Laugier</i>	331
Polychrome Marbles from the Theatre of the Sanctuary of Apollo Pythios in Gortyna (Crete) <i>Jacopo Bonetto, Nicolò Mareso and Michele Bueno</i>	337
Paul the Silentiary, Hagia Sophia, Onyx, Lydia, and Breccia Corallina <i>John J. Herrmann and Annewies van den Hoek</i>	345
Incrustations from Colonia Ulpia Traiana (Near Modern Xanten, Germany) <i>Vilma Ruppiniè and Ulrich Schüssler</i>	351
Stone Objects from Vindobona (Austria) – Petrological Characterization and Provenance of Local Stone in a Historico-Economical Setting <i>Andreas Rohatsch, Michaela Kronberger, Sophie Insulander, Martin Mosser and Barbara Hodits</i>	363
Marbles Discovered on the Site of the Forum of Vaison-la-Romaine (Vaucluse, France): Preliminary Results <i>Elsa Roux, Jean-Marc Mignon, Philippe Blanc and Annie Blanc</i>	373
Updated Characterisation of White Saint-Béat Marble. Discrimination Parameters from Classical Marbles <i>Hernando Royo Plumed, Pilar Lapeunte, José Antonio Cuchí, Mauro Brillì and Marie-Claire Savin</i>	379

Grey and Greyish Banded Marbles from the Estremoz Anticline in Lusitania <i>Pilar Lapuente, Trinidad Nogales-Basarrate, Hernando Royo Plumed, Mauro Brilli and Marie-Claire Savin</i>	391
New Data on Spanish Marbles: the Case of <i>Gallaecia</i> (NW Spain) <i>Anna Gutiérrez García-M., Hernando Royo Plumed and Silvia González Soutelo</i>	401
A New Roman Imperial Relief Said to Be from Southern Spain: Problems of Style, Iconography, and Marble Type in Determining Provenance <i>John Pollini, Pilar Lapuente, Trinidad Nogales-Basarrate and Jerry Podany</i>	413
Reuse of the <i>Marmorata</i> from the Late Roman Palatial Building at Carranque (Toledo, Spain) in the Visigothic Necropolis <i>Virginia García-Entero, Anna Gutiérrez García-M. and Sergio Vidal Álvarez</i>	427
Imperial Porphyry in Roman Britain <i>David F. Williams</i>	435
Recycling of Marble: Apollonia/Sozousa/Arsuf (Israel) as a Case Study <i>Moshe Fischer, Dimitris Tambakopoulos and Yannis Maniatis</i>	443
Thasian Connections Overseas: Sculpture in the Cyrene Museum (Libya) Made of Dolomitic Marble from Thasos <i>John J. Herrmann and Donato Attanasio</i>	457
Marble on Rome's Southwestern Frontier: Thamugadi and Lambaesis <i>Robert H. Tykot, Ouahiba Bouzidi, John J. Herrmann and Annewies van den Hoek</i>	467
Marble and Sculpture at Lepcis Magna (Tripolitania, Libya): a Preliminary Study Concerning Origin and Workshops <i>Luisa Musso, Laura Buccino, Matthias Bruno, Donato Attanasio and Walter Prochaska</i>	481
The Pentelic Marble in the Carnegie Museum of Art Hall of Sculpture, Pittsburgh, Pennsylvania <i>Albert D. Kollar</i>	491
Analysis of Classical Marble Sculptures in the Michael C. Carlos Museum, Emory University, Atlanta <i>Robert H. Tykot, John J. Herrmann, Renée Stein, Jasper Gaunt, Susan Blevins and Anne R. Skinner</i>	501
3. PROVENANCE IDENTIFICATION II: (OTHER STONES)	
Aphrodisias and the Regional Marble Trade. The <i>Scaenae Frons</i> of the Theatre at Nysa <i>Natalia Toma</i>	513
The Stones of Felix Romuliana (Gamzigrad, Serbia) <i>Bojan Djurić, Divna Jovanović, Stefan Pop Lazić and Walter Prochaska</i>	523
Aspects of Characterisation of Stone Monuments from Southern Pannonia <i>Branka Migotti</i>	537

The Budakalász Travertine Production <i>Bojan Djurić, Sándor Kele and Igor Rižnar</i>	545
Stone Monuments from Carnuntum and Surrounding Areas (Austria) – Petrological Characterization and Quarry Location in a Historical Context <i>Gabrielle Kremer, Isabella Kitz, Beatrix Moshhammer, Maria Heinrich and Erich Draganits</i>	557
Espejón Limestone and Conglomerate (Soria, Spain): Archaeometric Characterization, Quarrying and Use in Roman Times <i>Virginia García-Entero, Anna Gutiérrez García-M, Sergio Vidal Álvarez, María J. Peréx Agorreta and Eva Zarco Martínez</i>	567
The Use of Alcover Stone in Roman Times (<i>Tarraco, Hispania Citerior</i>). Contributions to the <i>Officina Lapidaria Tarraconensis</i> <i>Diana Gorostidi Pi, Jordi López Vilar and Anna Gutiérrez García-M.</i>	577
4. ADVANCES IN PROVENANCE TECHNIQUES, METHODOLOGIES AND DATABASES	
Grainautline – a Supervised Grain Boundary Extraction Tool Supported by Image Processing and Pattern Recognition <i>Kristóf Csorba, Lilla Barancsuk, Balázs Székely and Judit Zöldföldi</i>	587
A Database and GIS Project about Quarrying, Circulation and Use of Stone During the Roman Age in <i>Regio X - Venetia et Histria</i> . The Case Study of the Euganean Trachyte <i>Caterine Previato and Arturo Zara</i>	597
5. QUARRIES AND GEOLOGY	
The Distribution of Troad Granite Columns as Evidence for Reconstructing the Management of Their Production <i>Patrizio Pensabene, Javier Á. Domingo and Isabel Rodà</i>	613
Ancient Quarries and Stonemasonry in Northern Choria Considiana <i>Hale Güney</i>	621
Polychromy in Larisaeon Quarries and its Relation to Architectural Conception <i>Gizem Mater and Ertunç Denктаş</i>	633
Euromos of Caria: the Origin of an Hitherto Unknown Grey Veined Stepped Marble of Roman Antiquity <i>Matthias Bruno, Donato Attanasio, Walter Prochaska and Ali Bahadır Yavuz</i>	639
Unknown Painted Quarry Inscriptions from Bacakale at <i>Docimium</i> (Turkey) <i>Matthias Bruno</i>	651
The Green Schist Marble Stone of Jebel El Hairech (North West of Tunisia): a Multi-Analytical Approach and its Uses in Antiquity <i>Ameur Younès, Mohamed Gaied and Wissem Gallala</i>	659
Building Materials and the Ancient Quarries at <i>Thamugadi</i> (East of Algeria), Case Study: Sandstone and Limestone <i>Younès Rezkallah and Ramdane Marmi</i>	673

The Local Quarries of the Ancient Roman City of <i>Valeria</i> (Cuenca, Spain) <i>Javier Atienza Fuente</i>	683
The Stone and Ancient Quarries of Montjuïc Mountain (Barcelona, Spain) <i>Aureli Álvarez</i>	693
<i>Notae Lapidinarum</i> : Preliminary Considerations about the Quarry Marks from the Provincial Forum of <i>Tarraco</i> <i>Maria Serena Vinci</i>	699
The Different Steps of the Rough-Hewing on a Monumental Sculpture at the Greek Archaic Period: the Unfinished Kouros of Thasos <i>Danièle Braunstein</i>	711
A Review of Copying Techniques in Greco-Roman Sculpture <i>Séverine Moureaud</i>	717
Labour Forces at Imperial Quarries <i>Ben Russell</i>	733
Social Position of Craftsmen inside the Stone and Marble Processing Trades in the Light of Diocletian's Edict on Prices <i>Krešimir Bosnić and Branko Matulić</i>	741
6. STONE PROPERTIES, WEATHERING EFFECTS AND RESTORATION, AS RELATED TO DIAGNOSIS PROBLEMS, MATCHING OF STONE FRAGMENTS AND AUTHENTICITY	
Methods of Consolidation and Protection of Pentelic Marble <i>Maria Apostolopoulou, Elissavet Drakopoulou, Maria Karoglou and Asterios Bakolas</i>	749
7. PIGMENTS AND PAINTINGS ON MARBLE	
Painting and Sculpture Conservation in Two Gallo-Roman Temples in Picardy (France): Champlieu and Pont-Sainte-Maxence <i>Véronique Brunet-Gaston and Christophe Gaston</i>	763
The Use of Colour on Roman Marble Sarcophagi <i>Eliana Siotto</i>	773
New Evidence for Ancient Gilding and Historic Restorations on a Portrait of Antinous in the San Antonio Museum of Art <i>Jessica Powers, Mark Abbe, Michelle Bushey and Scott H. Pike</i>	783
Schists and Pigments from Ancient Swat (Khyber Pukhtunkhwa, Pakistan) <i>Francesco Mariottini, Gianluca Vignaroli, Maurizio Mariottini and Mauro Roma</i>	793
8. SPECIAL THEME SESSION: „THE USE OF MARBLE AND LIMESTONE IN THE ADRIATIC BASIN IN ANTIQUITY”	
Marble Sarcophagi of Roman Dalmatia Material – Provenance – Workmanship <i>Guntram Koch</i>	809

Funerary Monuments and Quarry Management in Middle Dalmatia <i>Nenad Cambi</i>	827
Marble Revetments of Diocletian's Palace <i>Katja Marasović and Vinka Marinković</i>	839
The Use of Limestones as Construction Materials for the Mosaics of Diocletian's Palace <i>Branko Matulić, Domagoj Mudronja and Krešimir Bosnić</i>	855
Restoration of the Peristyle of Diocletian's Palace in Split <i>Goran Nikšić</i>	863
Marble Slabs Used at the Archaeological Site of Sorna near Poreč Istria – Croatia <i>Đeni Gobić-Bravar</i>	871
Ancient Marbles from the Villa in Verige Bay, Brijuni Island, Croatia <i>Mira Pavletić and Đeni Gobić-Bravar</i>	879
Notes on Early Christian Ambos and Altars in the Light of some Fragments from the Islands of Pag and Rab <i>Mirja Jarak</i>	887
The Marbles in the Chapel of the Blessed John of Trogir in the Cathedral of St. Lawrence at Trogir <i>Đeni Gobić-Bravar and Daniela Matetić Poljak</i>	899
The Use of Limestone in the Roman Province of Dalmatia <i>Edisa Lozić and Igor Rižnar</i>	915
The Extraction and Use of Limestone in Istria in Antiquity <i>Klara Buršić-Matijašić and Robert Matijašić</i>	925
Aurisina Limestone in the Roman Age: from Karst Quarries to the Cities of the Adriatic Basin <i>Caterina Previato</i>	933
The Remains of Infrastructural Facilities of the Ancient Quarries on Zadar Islands (Croatia) <i>Mate Parica</i>	941
The Impact of Local Geomorphological and Geological Features of the Area for the Construction of the Burnum Amphitheatre <i>Miroslav Glavičić and Uroš Stepišnik</i>	951
Roman Quarry Klis Kosa near Salona <i>Ivan Alduk</i>	957
Marmore Lavdata Brattia <i>Miona Miliša and Vinka Marinković</i>	963
Quarries of the Lumbarda Archipelago <i>Ivka Lipanović and Vinka Marinković</i>	979

Island of Korčula – Importer and Exporter of Stone in Antiquity <i>Mate Parica and Igor Borzić</i>	985
Faux Marbling Motifs in Early Christian Frescoes in Central and South Dalmatia: Preliminary Report <i>Tonči Borovac, Antonija Gluhan and Nikola Radošević</i>	995
INDEX OF AUTHORS	1009

ESPEJÓN LIMESTONE AND CONGLOMERATE (SORIA, SPAIN): ARCHAEOLOGICAL CHARACTERIZATION, QUARRYING AND USE IN ROMAN TIMES¹

Virginia García-Entero¹, Anna Gutiérrez Garcia-M.², Sergio Vidal Álvarez³,
María J. Peréx Agorreta⁴ and Eva Zarco Martínez⁵

¹ Universidad Nacional de Educación a Distancia (UNED), Madrid, Spain (vgarciaentero@geo.uned.es)

² Institut de Recherche sur les ArchéoMATériaux (IRAMAT) - Centre de Recherche en Physique Appliquée à l'Archéologie (CRP2A), Université de Bordeaux Montaigne, Bordeaux, France
(anna.gutierrez@u-bordeaux-montaigne.fr)

³ Museo Arqueológico Nacional (MAN), Madrid, Spain (sergio.vidal@cultura.gob.es)

⁴ Universidad Nacional de Educación a Distancia (UNED), Madrid, Spain (mperex@geo.uned.es)

⁵ (eva.zarco.m@gmail.com)

Abstract

We present the first results of an on-going research project on a decorative stone that might have been one of the main ornamental stones in Roman Spain's inland, the limestone and conglomerate from Espejón. Within the framework of exploitation and uses of other Hispano-Roman stone resources, these results will add significant data to the whole picture of non-foreign *marmora* exploitation and use in *Hispania*. So far, the archaeological materials of several sites have been inspected, a survey to locate quarrying evidence has been undertaken and a multimethod analytical protocol has been initiated. Thus, we have established the basis for an archaeometric reference corpus, which will be henceforth enlarged and used as tool for comparison with archaeological items in order to determine the extent of this limestone and multi-coloured conglomerate's distribution and use.

Keywords

Espejón Limestone, *Hispania*, Roman times

1. Brief location and context

The village of Espejón is located in the westernmost area of the province of Soria (central north Spain), bordering on the province of Burgos in the northern plateau. Yet the decorative limestone that takes its name also crops out in the nearby Espeja de San Marcelino and Cantalucia. Espejón limestone has been especially well known since modern times due to its intense exploitation between the 16th and 19th centuries for the decoration of the Escorial Monastery (16th c.) by Philip II, the Royal Palace of Madrid and other buildings built by the Bourbon dynasty². Nevertheless, it was highly valued due to its macroscopic appearance not only in modern times but also in Antiquity³. As such, it was widely employed in Roman times in *Hispania* from the Augustan era onwards, both in the framework of major new urban ornamental programs and in the domestic sphere, for the decoration of *domus* and *villae*.

The archaeometric characterization of all existing lithological varieties is essential, as it can present very different aspects. Hence the importance of having a detailed reference core to be compared with archaeological objects supposedly made of Espejón limestone. This is especially important as this stone's chromatism (from red and yellow to pale ochre and white) makes it perfect for small *tessellae* used in mosaics. Moreover, we undertook a survey of the territory around Espejón in order to obtain a picture as complete as possible not only of where and how the different varieties of Espejón limestone crop out but especially of the quarrying points, as a first step towards understanding how the exploitation of this stone took place and was organized.

1 This research was performed within the Project "*Marmora Hispaniae. The Quarrying, Use and Trade of Espejón Limestone in Roman and Late Antique Hispania*" (HAR2013-44971) funded by the Ministerio de Economía y Competitividad of Spain and directed by V. García-Entero, in collaboration with the project "*Lapides et Marmora Hispaniae: ...*" of the LabEx Sciences Archéologiques de Bordeaux programme supported by the ANR (n° ANR-10-LABX-52), directed by A. Gutiérrez Garcia-M.

2 TÁRRAGA 1992; 1999; 2002; 2009; FRÍAS 2005.

3 For a preliminary study see SALÁN 2012.

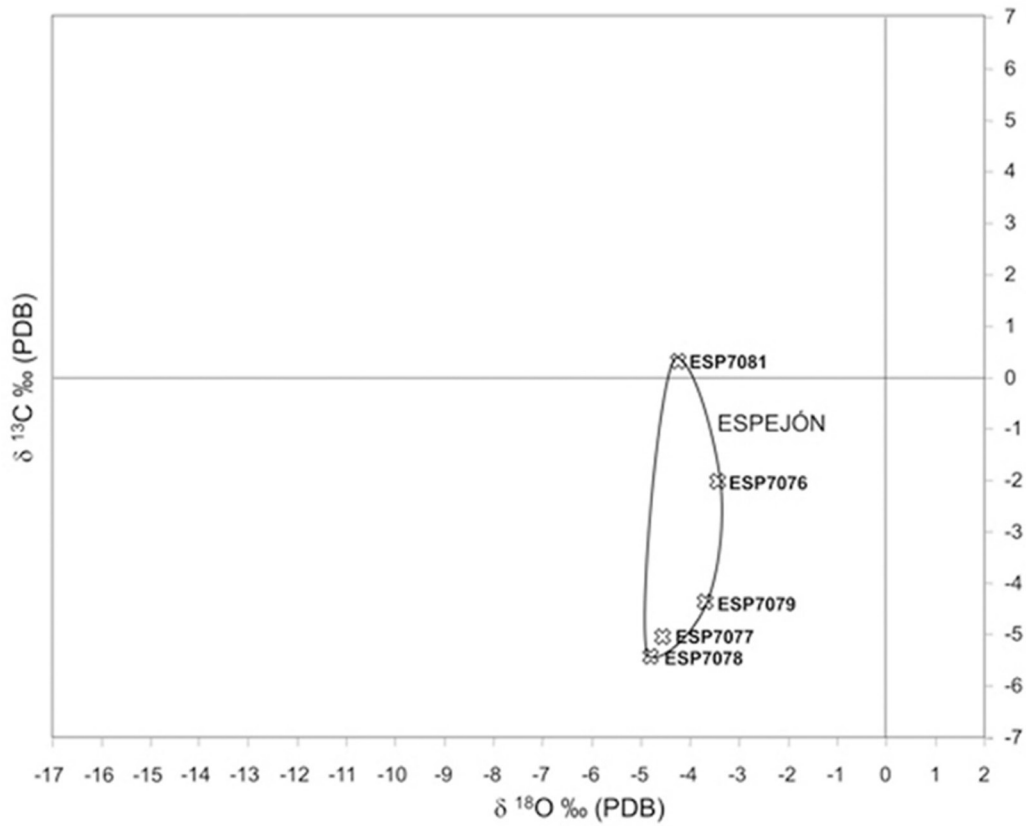
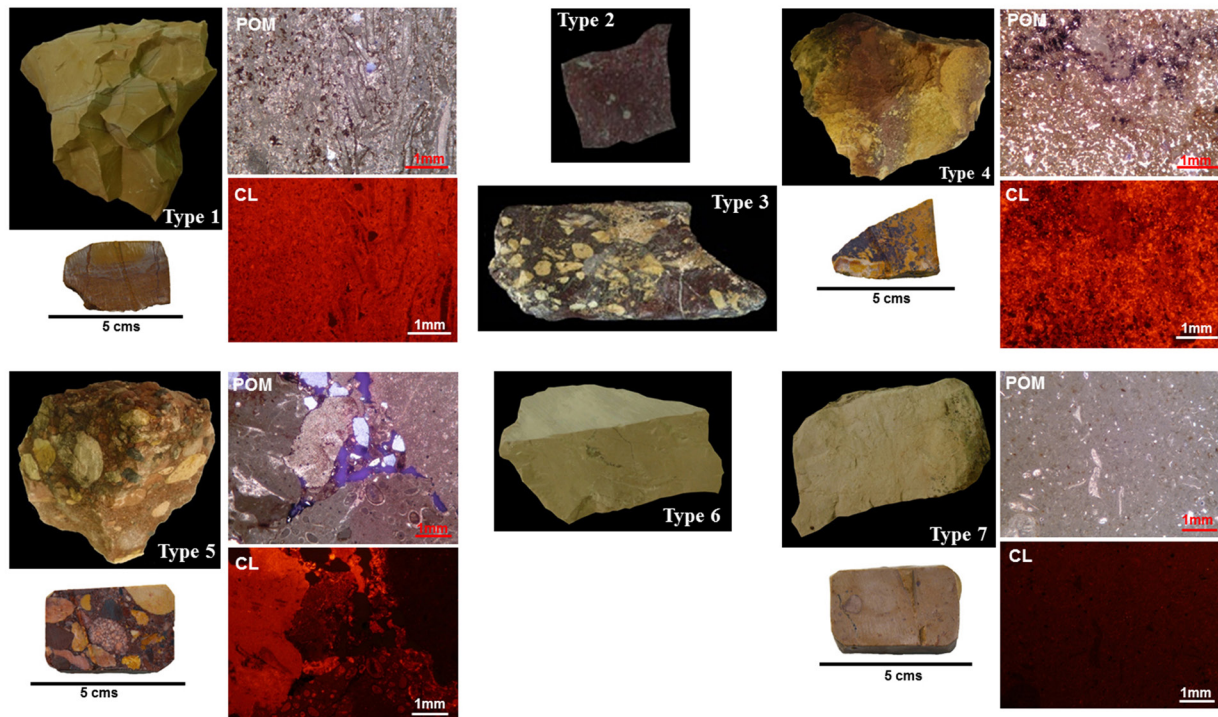


Fig. 1. Above: samples and photomicrograph of cross-polarized light and cathodoluminescence aspect of Espejón varieties 1, 4, 5 and 7. Below: Scatter plot with $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ isotopic values (in ‰, PDB) of samples corresponding to yellowish micritic fractions and equivalent clasts in breccia types. Initial proposal of general distribution field for the types of Espejón Stone

2. The archaeometric characterization (Fig. 1)

Espejón *marmor* is a highly variable Cretaceous stone⁴ that presents seven main types:

- a mainly yellow quite homogeneous limestone (type 1),
- a mainly red-purple quite homogeneous limestone (type 2),
- a brecciated yellow and red-purple limestone (type 3),
- a red/purple-yellow banded limestone (type 4),
- a highly multicoloured brecciated conglomerate locally known as “Jaspe” (type 5), and
- a white (type 6) to pale-coloured variety (type 7).

They can all be found in Espejón municipality, but outcrops of type 4 can be also found in Espeja de San Marcelino while type 5 occurs both in Espeja de San Marcelino and Cantalucia.

The multimethod analytical protocol applied includes the following techniques: thin section/petrographic optical microscopy (POM), cathodoluminescence (CL), stable isotope analysis ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$), X-ray Spectrometry (XRS) and X-ray Diffraction (XRD)⁵. Four varieties of Espejón *marmor* have been so far analysed: types 1, 4, 5 and 7. The results provide information on the mineralogical and textural parameters of these varieties. They form the basis of a reference corpus that will be subsequently enlarged with the other varieties⁶ and used for future comparisons with the archaeological materials.

Type 1. Yellow micrite, usually quite homogeneous but sometimes with yellow ochre and brown bands⁷. The yellow part (left half of the microphotograph in Fig. 1) can be classified as pelmicrite⁸ or micro-packstone⁹ with very fine allochems or micropeloids easily

distinguished from the micrite-microsparite matrix due to its high iron content. Small bivalves and rare microfossils can be distinguished among the microfossils, which show a microsparite filling, as well as some irregular iron oxide concentrations. The brown part (right half of the microphotograph in Fig. 1) is classified as biopelsparite¹⁰ or grainstone¹¹. Bioclasts dominate over other allochems (peloids and intraclasts, some with embedded microfossils). The skeletal components are almost completely micritized and have elongated shapes and a sub-parallel orientation, which results in a strong lamination visible even at macroscopic scale. Among them, algae fragments and orbitolinids can be distinguished. All allochems show iron-rich rims or envelopes. Monocrystalline, angular quartz is present in both parts but particularly in the fossil-rich areas. Tourmaline has also been identified as accessory mineral. Irregular microcracks, subperpendicular to the bedding, are filled with sparite and present iron-rich nodules. Under CL, it shows a medium intensity in orange with a higher intensity in yellowish-orange of the sparry cement in the bioclastic and pelitic fraction of the biopelsparite. The CL intensity of these components decreases with the development of iron oxide envelopes. Siliciclastic quartz and calcite filling the microfractures show a very weak luminescence.

Type 4. Red/purple and yellow banded limestone, often brecciated, classified as pelsparite¹² or grainstone¹³. It is composed of allochems remarkably uniform in size (mainly micrite peloids of *c.* 100 μm with circular or slightly elliptical sections and rare, fragmented bioclasts). The colour difference is due to the various concentrations of iron oxide coats around them and the presence of small opaque minerals. This variety also presents irregular yellowish micritic mud areas. Detritic tourmaline has been identified as accessory mineral in this type¹⁴. Interparticle and secondary porosity is filled by sparry cement, reduced by compaction. It has a heterogeneous-cathodoluminescence determined by the iron oxide concentrations (mainly on the allochems rims) which is predominantly of orange medium intensity, especially in areas of micritic mud. Sparitic crystals that fill the larger pores have typical zoned luminescence of druse growth, with low intensity core.

4 ÁLVAREZ *et al.* 2009, 54-59.

5 Petrographic (POM), cathodoluminescence (CL) and X-ray Spectrometry (EDX) analyses were conducted at the Unitat d'Estudis Arqueomètrics (UEA) of the Institut Català d'Arqueologia Clàssica (ICAC) at Tarragona. Mass Spectrometry Isotopic Relations (IRMS) analysis was conducted at the Istituto di Geologia Ambientale e Geoingegneria (IGAG) of the CNR at Rome. X-ray Diffraction (DRX) is in progress at the Institut de Recherche sur les ArchéoMATériaux (IRAMAT)- Centre de Recherches Physiques Appliquées à l'Archéologie (CRP2A) at Bordeaux. See GARCÍA-ENTERO *et al.*, 2017.

6 The study of types 2, 3 and 6 is currently in progress.

7 Description based on sample ESP7076 from El Piñueco outcrop (Espejón).

8 FOLK 1959; 1962.

9 DUNHAM 1962.

10 FOLK 1959; 1962.

11 DUNHAM 1962.

12 FOLK 1959; 1962.

13 Description based on samples ESP7077 and ESP7078 from Matalea and Hoyancos quarries (Espejón). DUNHAM 1962.

14 ÁLVAREZ *et al.* 2009, 126.

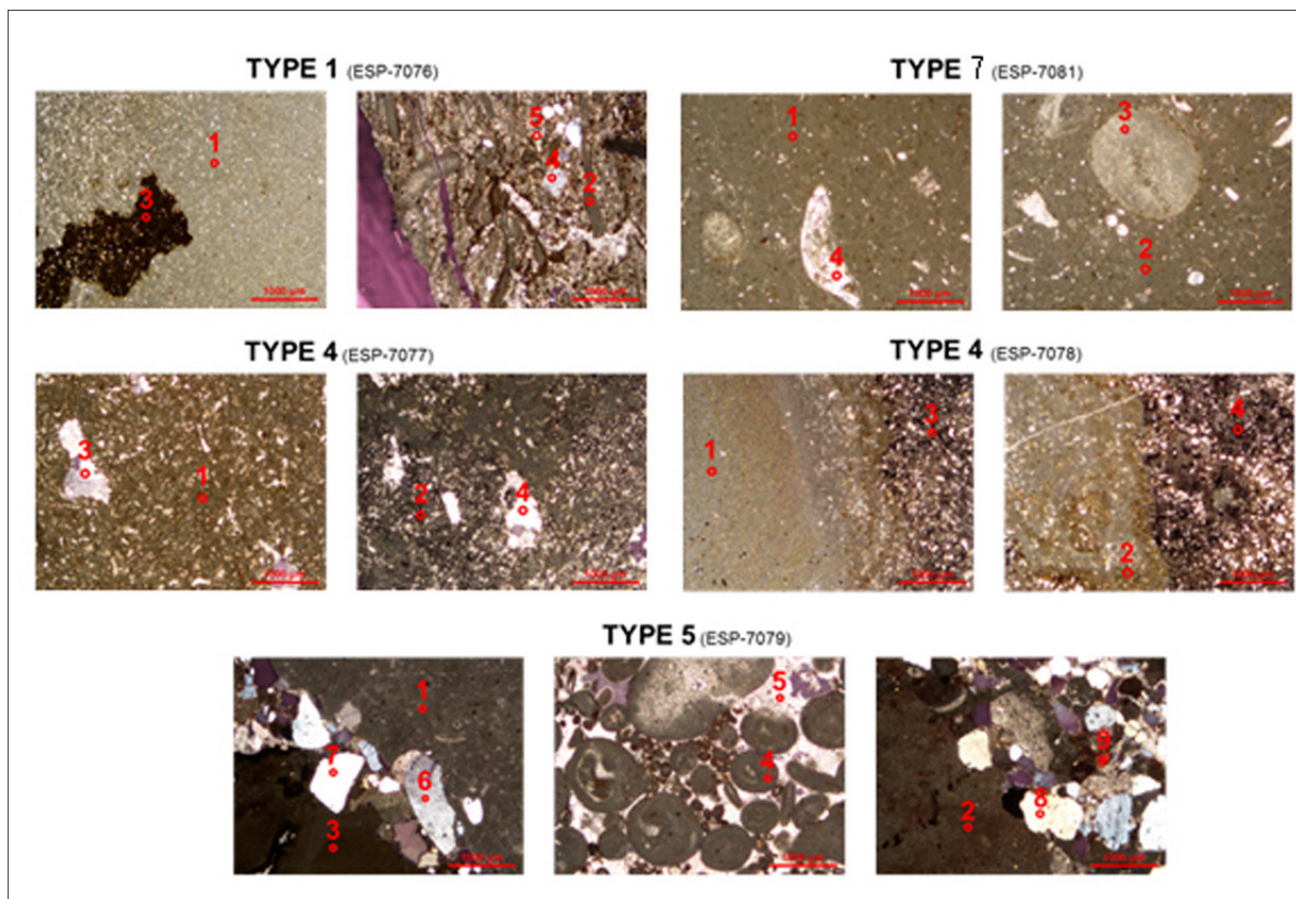


Fig. 2. Chemical composition analyses. Photomicrographs of the components analyzed with the exact point of measurement, in each lithotype. The correspondence of numbering analysis points is shown in Fig. 3

Type 5. Highly multicoloured framework-supported conglomerate or a poorly to moderately-sorted petromict orthoconglomerate¹⁵ with a scarce iron-rich matrix, hence its reddish colour¹⁶. The clasts are subrounded and of carbon nature: micrites or mudstones, biomicrites or mudstones with <10% bioclasts, oosparites or oolitic grainstones, intrasparites or intraclast grainstones, peloid micrites or wackestone according to Folk and Dunham¹⁷. Monocrystalline, subrounded to subangular quartz form most of the terrigenous fraction but there is also tourmaline as accessory mineral. This variety shows a sparite cement and sutured grain contacts that reveal a major compaction process. Under CL this stone presents different intensities of luminescence: the limestone fragments show reddish brown to reddish orange colours depending on the iron content of their components; the sparry cement and irregular sparitic areas show a bright luminescence of

yellowish-orange hue; the micrite matrix with iron oxides has a medium intensity luminescence in orange, particularly visible between darker components. Only the siliciclastic quartz are slightly- to non-luminescent.

Type 7. Pale yellow to white biomicrite¹⁸ or wackestone¹⁹. Allochems are scarce but > 10% and among the larger bioclasts skeletal fragments of algae, gastropods, bivalve shells (some very fine or filamentous) and possible echinoderm plates, along with many microforaminifers and circular microspines of echinoids can be distinguished. There are very few carbonated intraclasts. The dominant micrite matrix presents dispersed iron oxides and patchy microsparite recrystallization. The fraction of terrigenous quartz is not significant while stylolites in which iron oxides accumulated are characteristic. This stone shows a homogeneous cathodoluminescence of low intensity and reddish-brown hue, which decreases in intensity where iron oxides accumulate. Rounded, carbonated, intraclasts stand out due to their slightly lower intensity.

15 BOGSS, 1992.

16 Description based on sample ESP7079 from the "Abandoned quarry" (Espejón).

17 FOLK 1959; 1962 and DUNHAM 1962.

18 FOLK 1959; 1962.

19 Description based on sample ESP7081 from La Corta outcrop (Espejón).

TYPE 1 (ESP-7076)	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O
1 Cal (micritic matrix)	0,0		0,0			0,0	100,0		
2 Cal (orbitolinid)	0,0						100,0		
3 [Ox(Fe)]	10,0		4,3	11,8		3,6	70,3		
4Qtz	100,0						0,0		
5Tur	43,2	0,4	19,9	2,5		7,8	24,2	2,1	
TYPE 4 (ESP-7078)	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O
1 Cal (micritic matrix)	0,0		0,0	0,0		0,0	100,0		
2 Cal (micropeloid)	0,0		0,0	0,0		0,0	100,0	0,0	
3 Cal + Ox(Fe) (micropeloid ox.)	4,2		1,5	5,4			89,0		
4 Cal + Ox(Fe) (micropeloid ox.)	5,5			3,7			90,9		
TYPE 4 (ESP-7077)	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O
1 Cal (micropeloid)	0,0						100,0		
2 Cal(micropeloidox.)	0,0		0,0	0,0		0,0	100,0		
3 Cal (sparry cement)	0,0						100,0		
4 Cal (sparry cement)	0,0					0,0	100,0		
TYPE 5 (ESP-7079)	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O
1 Cal (micritic matrix)	0,0						100,0		
2 Cal (micritic matrix)	0,0		0,0				100,0		
3 Cal (micriticox.matrix)	0,0			0,0			100,0		
4 Cal (ooid)	0,0						100,0		
5 Cal (sparry cement)	0,0						100,0		
6 Qtz	100,0						0,0		
7 Qtz	100,0						0,0		
8Qtz	100,0						0,0		
9Tur	51,9	0,6	21,3	3,2		7,7	13,2	2,1	
TYPE 7 (ESP-7081)	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O
1 Cal (micritic matrix)	0,0		0,0			0,0	100,0		
2 Cal (micritic matrix)	0,0		0,0				100,0		
3 Cal (micritic filling)	0,0						100,0		
4 Cal (bivalve)	0,0						100,0		

Fig. 3. Point-by-point chemical analysis of the carbonate components and accessory minerals distinguished microscopically in each of the samples considered for each rock type defined visually. Cal: calcite, Ox (Fe) iron oxide, Qtz quartz, Tur: tourmaline. []: Masked by other adjacent majority mineral (calcite)

EDX analysis results (Fig. 2 and Fig. 3)

EDX was carried out to check indirectly the type of carbonate in the different carbonate components of the rock as well as the nature of the accessory minerals²⁰. The results confirmed that types 1, 4, 5 and 7 present a low content of non-carbonated components, generally less than 10% and never exceeding 30% even in the detrital case (type 5). The

presence of quartz, a common accessory mineral, is ratified but most interestingly, tourmaline has been detected in types 1 and 5. Although it is found in very low percentages, its presence constitutes a more discriminating element.

IRMS analysis results²¹ (Fig. 1)

The study of the carbon and oxygen stable isotopes ratio ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) is commonly used to characterize

20 DUNHAM 1962; CAPEDETRI *et al.* 2004. It was performed by an electron emission device with an EDX detector (CITL CL8200 Mk5-1 with an Amptek Axis SDD raig X detector) coupled to a polarized light microscope and a Germanium (Ge) standard was used due to the reliability of its spectrum. Measurements were made with an electron beam at 200 μA of and 18 kV at points of 50 μm in diameter.

21 It was carried out by using a FINNIGAN GasBench II belonging to IGAG-CNR and according to the usual procedure (MCCREA 1950; CRAIG 1957). The results are expressed as a relative percentage to international reference standard PDB (Pee Dee Belemnite).

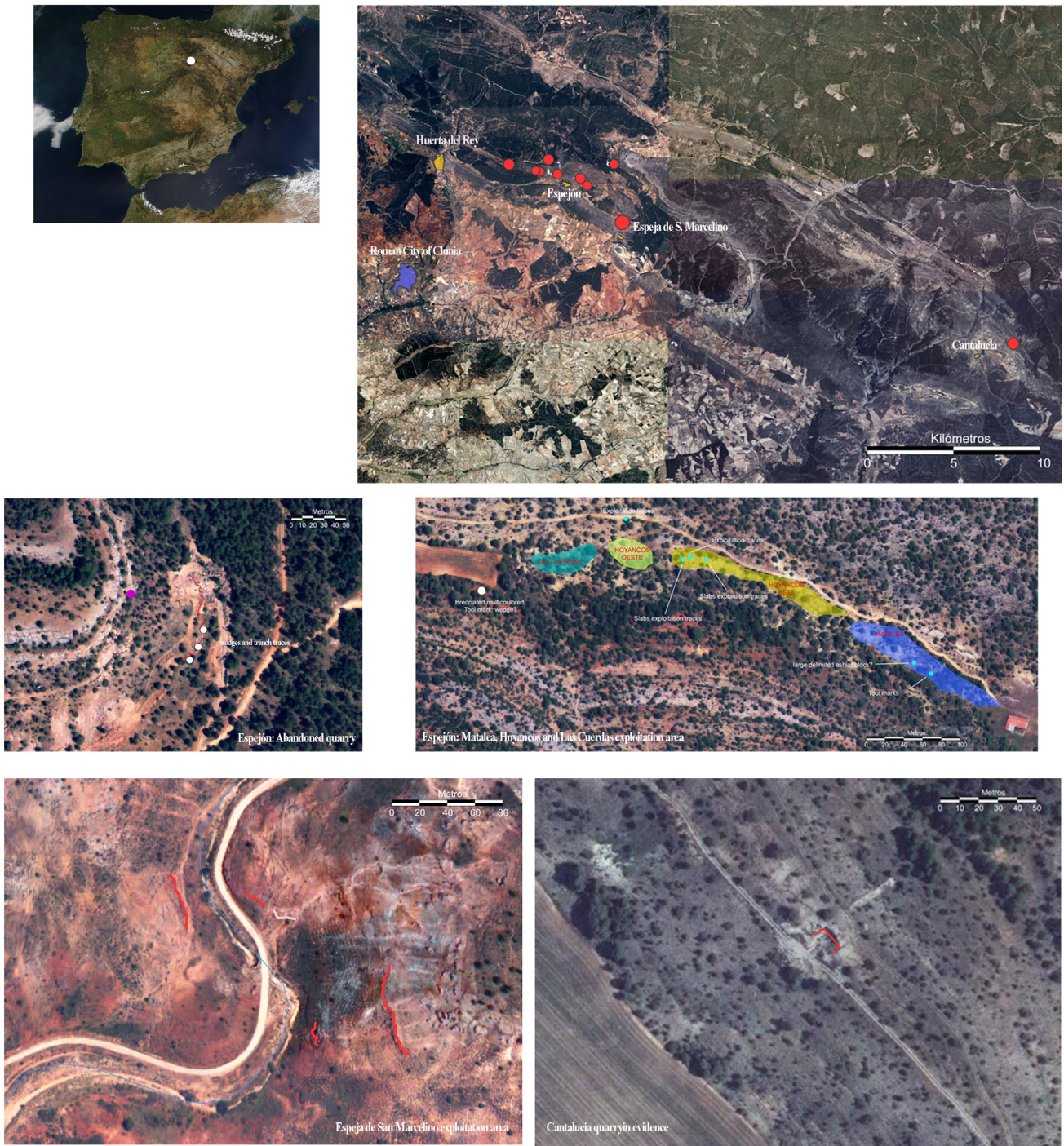


Fig. 4. Exploitation and quarrying evidences in Espejón, Espeja de San Marcelino and Cantalucia municipalities

carbonate rocks. To obtain this initial proposal of Espejón limestone and multi-coloured conglomerate isotopic distribution field, we have included the four lithotypes already described. The samples were taken from the yellow micrite fraction of each of them or the equivalent clasts in the breccia and conglomerate types.

The range of isotopic values is relatively wide, especially for $\delta^{13}\text{C}$, which shows mostly negative values. Indeed, they fluctuate from -5.39 to 0.32 ‰ (PDB) for $\delta^{13}\text{C}$

and from -4.81 to -3.44 ‰ (PDB) for $\delta^{18}\text{O}$. Although the discriminating capacity of this method for this lithology is for the moment limited due to the lack of reference isotopic studies in other, similar, stones used in antiquity, it is an essential step towards the definition of the discriminating traits of Espejón limestone and multi-coloured conglomerate.

3. Exploitation and quarrying traces (Fig. 4)

The field survey has led to the identification of several exploitation fronts and quarrying traces. Unfortunately, the intensive extraction activity from the 16th c. onwards and the fact that the extraction techniques have changed very little over the centuries²², makes it very difficult to distinguish the Roman traces from those of modern age.

Espejón municipality: five areas have been surveyed:

“Abandoned quarry”: Located northwest of the village, this quarry exploited a highly coloured conglomerate (type 5) outcrop until the 1980s. On the hillside, we have detected a 30 m long and 4 m high front where trenches and wedges are visible.

Matalea-Las Cuerdas exploitation area: A wide pit-type exploitation area (c. 1 km long and 15/20 m high) lies west of the village. Three zones can be distinguished: Matalea, Hoyancos and Las Cuerdas. It is a very clogged extraction area where some exploitation traces are preserved: a large delimited rectangular block, slab extraction traces, trenches, wedges and pick and chisel marks on the bedrock. Types 3, 4 and 5 crop out here.

Pico La Cantera quarry: It is a large quarry still exploiting the white and pale-yellow varieties (types 6 and 7) northwest from the village. Yet there is no evidence of ancient exploitation, since it has been intensively exploited until very recently.

La Corta and El Piñueco areas: Two areas east of Espejón were explored due to the large outcrops existing (of type 7 and type 1 varieties) and the common belief of the villagers suggesting a possible ancient extraction. Nevertheless, no evidence of ancient activity were found.

Espeja de San Marcelino municipality: West of the town of Espeja de San Marcelino, there is a wide area with types 4 and 5 outcrops. Three lineal fronts of about 40 m long and 2 m high each prove that extraction was quite intense here.

Cantalucia municipality: North of the little village of Cantalucia we discovered a lineal extraction front which seems to have been used during two different moments: in modern times and then in the 19th c. (until 1960s). This outcrop provides the multicoloured conglomerate variety (type 5).

4. Use and distribution of Espejón *marmor* (Fig. 5)

Although the information available is still partial, this *marmor* seems to have been one of the main ornamental stones in the Peninsular inland. We can thus leave behind the previous idea of it being a secondary material linked almost exclusively to the nearby Roman

city of *Clunia* (Burgos) where Espejón limestone was abundantly used from Julio-Claudian times onwards both in the public and in the private sphere²³. Indeed, Espejón limestone was widely employed in *Hispania* from the Late Augustan era, in the framework of new public ornamental programs of towns immersed in “marbling” processes. The city of *Segobriga* (Saelices, Cuenca)²⁴, provides a good example: together with other Hispanic and imported marbles, Espejón limestone slabs²⁵ were used in the Late Augustan period in the pavement of the *Curia*²⁶. Evidence of the use of Espejón limestone in public buildings from the Claudian and Flavian times is found at the Roman towns of *Uxama Argaela* (Burgo de Osma, Soria)²⁷, *Legio* (León)²⁸ and *Asturica Augusta* (Astorga, León)²⁹.

Its use continued in Late Roman official ornamental programs. At *Complutum* (Alcalá de Henares, Madrid)³⁰ Espejón limestone was used in the *Forum Basilica* –originally built in mid-1st c. AD- and in the great

-
- 23 Only at 10 km from the exploitation area, *Clunia* received all types of Espejón stone. They were extensively used in the ornamental programs of the public buildings (Los Arcos I and II baths, the *Forum* baths, the *Basilica*, the *Forum* and the Theater) and domestic buildings (i.e. Taracena House) not only for architectural elements (pilaster and column shafts, base and capitals), pavement and wall revetment slabs, mouldings cornices and plinths, *opera sectilia crustae*, mosaic *tessellae* but also for epigraphy (GUTIÉRREZ BEHEMERID 2003; PALOL, VILELLA 1987; RODRÍGUEZ, SALIDO 2014).
- 24 In the Southern plateau and 300 km far from Espejón.
- 25 Of about 116 x 58 x 8 cm.
- 26 CEBRIÁN 2004, 2012.
- 27 Located at 36 km from Espejón; despite the lack of specific studies on the use of *marmor* at this town, some *crustae* of the red/purple brecciated type are visible in “Los Plintos” and “Sectile” houses. About this Roman town, see GARCÍA MERINO, 1999.
- 28 Where one of the most outstanding pieces of Espejón limestone was found: it is a quite large (1.8 m diameter and 25 cm high), 2nd c. AD, basin –*labrum*- made in the red/purple and yellow brecciated type probably from the public baths. It was carved from a single block but only three fragments have survived after its destruction in mid-3rd c. AD, when the baths underwent some improvements (MORILLO, SALIDO 2010).
- 29 Capital of the *Conventus Asturicum* and 300 km distant from Espejón, where Espejón limestone was used at least from Claudian to Flavian times at the “Wall House” (CISNEROS *et al.* 2010-2011, 111). However, new findings are expected as a study of this town marble is in process.
- 30 Located in the Southern plateau and distant more than 200 km from Espejón.

22 Until the introduction of explosives and drilling tools.



Tessellae for mosaics:



Epigraphy: *Clunia*. 1st c. AD



Furniture elements: *Legio, Labran* Roman basin from the Public Baths. 2nd c. AD



Architectural elements: pilaster and columns shafts: *Clunia* and Roman *villae* of Quintana del Marco and La Olmeda

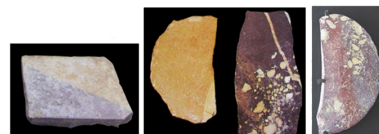


Architectural moulding elements:

Complutum Basilica (3rd c. AD) and *Carranque* Late Roman Palace (4th-5th c. AD)



Pavement and wall revetment slabs: *Segobriga Forum* (Late Augustan era), *Clunia* (1st c. AD), *Carranque* Roman Palace (4th-5th c. AD), etc.



Opera Sectilia crustae: *Clunia, Uxama, Complutum, Carranque, Asturica Augusta, Cueva de Soria*, etc. (1st to 4th c. AD)

Fig. 5. The use of Espejón limestone in *Hispania*

monumental façade added to the *Curia* at the end of 3rd c. AD³¹. These two public buildings provide abundant evidence of types 1, 3 and 4 being used for wall and floor *opus sectile crustae*, wall revetment slabs, mouldings cornices and plinths³². On the other hand, Espejón limestone was rarely used at *Caesaraugusta* (Zaragoza), where it has been attested only in the Late Roman pavement of the *orchestra* theatre³³. This is the easternmost testimony in *Hispania* and the only example of the use of Espejón limestone in the Ebro Valley³⁴. Pending further evidence, the question remains whether or not the Ebro Valley represents a boundary for the distribution of Espejón limestone.

As already mentioned, Espejón limestone was also abundantly used in urban and rural domestic contexts where the massive use of *marmora* had a prominent role in the self-representation strategies of the elite, especially in Late Antiquity. Espejón limestone played a major role on the decoration of the large rural complexes of Carranque (Toledo), where types 1, 2, 3 and 4 were very abundantly used in pavement and revetment panels, moulding cornices and *crustae* for *opera sectilia* in the Late Roman palatial building. Moreover, they were employed next to more than 30 varieties of marble imported from Egypt, Asia Minor and Greece, which demonstrates the importance of and prestige associated to this stone³⁵. Espejón limestone was also used, although rarely,³⁶ at Las Pizarras (Coca, Segovia), a major Late Roman building (4th-6th c. AD) where dozens of Mediterranean and Hispanic marbles were used³⁷. Espejón limestone (type 3) *crustae* for *opus sectile* have also been uncovered at the Roman villa of Cuevas de Soria (Dehesa de Soria, Soria). The small, conglomerate (type 4), column shaft found at the Roman villa of La Olmeda (Saldaña,

Palencia) (4th-5th c. AD) and the fragment of the type 3 Espejón limestone pilaster shaft from the Roman villa of Los Villares (Quintana del Marco, León) (1st-5th c. AD) add significantly to our knowledge of its use in the rural context³⁸.

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- 31 RASCÓN, SÁNCHEZ 2010.
- 32 DURÁN 1998, 102-103.
- 33 CISNEROS 2012, 129. For the ornamental program of the Theatre of *Caesaraugusta* see also LAPUENTE *et al.* 2009.
- 34 As shown by the in-depth studies of the marble assemblages from *Bilbilis* (Calatayud, Zaragoza), *Celsa* (Velilla de Ebro, Zaragoza), *Los Bañales/¿Tarraga?* (Uncastillo, Zaragoza), *Labitolosa* (Puebla de Castro, Huesca) and *Osca* (Huesca) and other sites of "Alto Aragón" where the Espejón limestone and Conglomerate are absent. (see CISNEROS 2012; LAPUENTE *et al.* 2011; ANDREU *et al.* 2015; LAPUENTE *et al.* 2015; GISBERT, CISNEROS 2015).
- 35 GARCÍA-ENTERO, VIDAL 2007; 2012.
- 36 Only five small fragments of revetment panels belonging to type 3 variety have been found. Our warmest thanks to Olivia Reyes and César Pérez for this still unpublished information.
- 37 PÉREZ *et al.* 2012.
- 38 It must be noted that in spite of what was published by RODRÍGUEZ and SALIDO (2014, 639) Espejón limestone has not been found during the detailed inspection of the whole *marmor* assemblage from the Late Roman *villa* of Noheda (Cuenca) that we undertook as part of this project. Our thanks go to Miguel Valero for kindly allowing this study. For a preliminary study of the *marmora* of this *villa*, see VALERO *et al.* 2015.

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