

# The Budakalász Travertine Production

---

Djurić, Bojan; Kele, Sándor; Rižnar, Igor

Source / Izvornik: **ASMOSIA XI, Interdisciplinary Studies on Ancient Stone, Proceedings of the XI International Conference of ASMOSIA, 2018, 545 - 556**

Conference paper / Rad u zborniku

Publication status / Verzija rada: **Published version / Objavljena verzija rada (izdavačev PDF)**

<https://doi.org/10.31534/XI.asmosia.2015/03.04>

Permanent link / Trajna poveznica: <https://urn.nsk.hr/urn:nbn:hr:123:032758>

Rights / Prava: [In copyright](#) / [Zaštićeno autorskim pravom.](#)

Download date / Datum preuzimanja: **2025-03-12**



Repository / Repozitorij:

[FCEAG Repository - Repository of the Faculty of Civil Engineering, Architecture and Geodesy, University of Split](#)



UNIVERSITY OF SPLIT

  
DIGITALNI AKADEMSKI ARHIVI I REPOZITORIJI



# ASMOSIA XI

Interdisciplinary Studies on Ancient Stone

## PROCEEDINGS

of the XI ASMOSIA Conference, Split 2015

Edited by Daniela Matetić Poljak and Katja Marasović



Interdisciplinary Studies on Ancient Stone  
Proceedings of the XI ASMOSIA Conference (Split 2015)

Publishers:

ARTS ACADEMY IN SPLIT  
UNIVERSITY OF SPLIT

and

UNIVERSITY OF SPLIT  
FACULTY OF CIVIL ENGINEERING,  
ARCHITECTURE AND GEODESY

Technical editor:  
Kate Bošković

English language editor:  
Graham McMaster

Computer pre-press:  
Nikola Križanac

Cover design:  
Mladen Čulić

Cover page:

*Sigma shaped mensa of pavonazzetto marble from Diocletian's palace in Split*

ISBN 978-953-6617-49-4 (Arts Academy in Split)

ISBN 978-953-6116-75-1 (Faculty of Civil Engineering, Architecture and Geodesy)

e-ISBN 978-953-6617-51-7 (Arts Academy in Split)

e-ISBN 978-953-6116-79-9 (Faculty of Civil Engineering, Architecture and Geodesy)

CIP available at the digital catalogue of the University Library in Split, no 170529005



Association for the Study of Marble & Other Stones in Antiquity

# ASMOSIA XI

## Interdisciplinary Studies of Ancient Stone

Proceedings of the Eleventh International Conference of ASMOSIA,  
Split, 18–22 May 2015

Edited by  
Daniela Matetić Poljak  
Katja Marasović



Split, 2018

**Nota bene**

All papers are subjected to an international review.

The quality of the images relies on the quality of the originals provided by the authors.

# CONTENT

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

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

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

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



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

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

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

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

# THE BUDAKALÁSZ TRAVERTINE PRODUCTION

Bojan Djurić<sup>1</sup>, Sándor Kele<sup>2</sup> and Igor Rižnar<sup>3</sup>

<sup>1</sup> University of Ljubljana, Ljubljana, Slovenia (bojan.djuric@ff.uni-lj.si)

<sup>2</sup> Institute for Geological and Geochemical Research, Research Centre for Astronomy and Earth Sciences, Hungarian Academy of Sciences, Budapest, Hungary (keles@geochem.hu)

<sup>3</sup> G. E. Geološke Ekspertize, Ljubljana, Slovenia (igor.riznar@telemach.net)

## Abstract

The stone monuments from the Roman towns along the Danube include a wide range of sepulchral, votive and architectural pieces made of the travertine quarried in the Buda Hills. The representative quarries of this rock are located at Budakalász, on the slope of the Monalovác Hill north of *Aquincum*, and in the Kápolna Hills (north of Budapest), while another small and abandoned (Roman) travertine quarry lies in Budapest, on Gellért Hill. From at least the Flavian times to the 4<sup>th</sup> century, the products made in the quarry(ies) and in the Aquincum workshops were transported southwards, down the Danube as far as Viminacium. From Mursa onwards, travertine products were transported alongside those of Eastern Alpine marble coming down the Drava River. The two productions were the only ones of interprovincial importance in Noricum, Pannonia and Upper Moesia.

## Keywords

Budakalász travertine, stone production, Danube

## General remarks

The production, products and their distribution considered in our analysis are strongly marked by the geological and geographical conditions of Pannonia where the Romans quarried and used Budakalász travertine. The specific isolation of the Pannonian Basin, enclosed within the Alps, the Carpathians and the Dinarids<sup>1</sup> (Fig. 1), determined the routes and modes of heavy load transport. With the preference for waterways – sea and rivers – for such transport<sup>2</sup>, white and coloured Mediterranean marbles could only reach

Pannonia across the Black Sea and up the Danube, a route that led through the treacherous gorges of the Iron Gates<sup>3</sup>. This meant that Mediterranean marbles were only exceptionally used in Pannonia and north-western Upper Moesia, mostly for imperial (palace in *Sirmium*<sup>4</sup>) or religious (Isaeum in *Savaria*<sup>5</sup>) architecture, occasionally also for cult and imperial images (*Aquincum*<sup>6</sup>, *Mursa*<sup>7</sup>, *Scarbantia*<sup>8</sup>). Consequently, the Roman towns in Pannonia were completely dependent on the local and regional resources, preferably situated near navigable waterways – the main ones including the Danube, the Raab/Raba, the Zala-Balaton-Sió, the Drau/Drava/Dráva, the Sava and the Drina. The distance from the quarry to the town was determined by specific geographic conditions, but only rarely exceeded 20 kilometres.

There are two main rock types suitable for stonemasonry in Pannonia and its periphery: Neogene rocks of Badenian and Sarmatian age, and the much rarer travertine. The former were extensively used in the Roman towns in Pannonia and north-western Upper Moesia, and mostly occur all along the margins of the Pannonian Basin (Fig. 2)<sup>9</sup> as whitish to yellowish, more or less porous detritic limestone and sandstone with carbonate cement. The latter, less extensively used rock is Pliocene and Pleistocene travertine that occurs in several locations within the Transdanubian Range Unit<sup>10</sup>. In the western Pannonian Basin, these rocks are

1 LÓCZY, STANKOVIANSKY, KOTARBA 2012.

2 See CAMPBELL 2012; SCHEIDEL, MEEKS, WEILAND 2012; RUSSEL 2013, 105-110.

3 ŠAŠEL 1973; for literary description see JÓKAI 1872 and MAGRIS 1986.

4 DJURIĆ *et al.* 2006.

5 MEZŐS 2005, 253, fig. 2.

6 KÉRDŐ 1999, 270.

7 DJURIĆ, MÜLLER, FILIPOVIĆ 2009, 10.

8 MÜLLER 2001.

9 The map was generated from the geological maps of Yugoslavia, Austria, Hungary and Romania. Special thanks to Edisa Lozić for her commitment.

10 KELE *et al.* 2003; KELE 2009.





Fig. 1. Map of the Roman Empire with the Pannonian area marked (courtesy of: Digital Atlas of the Roman Empire)

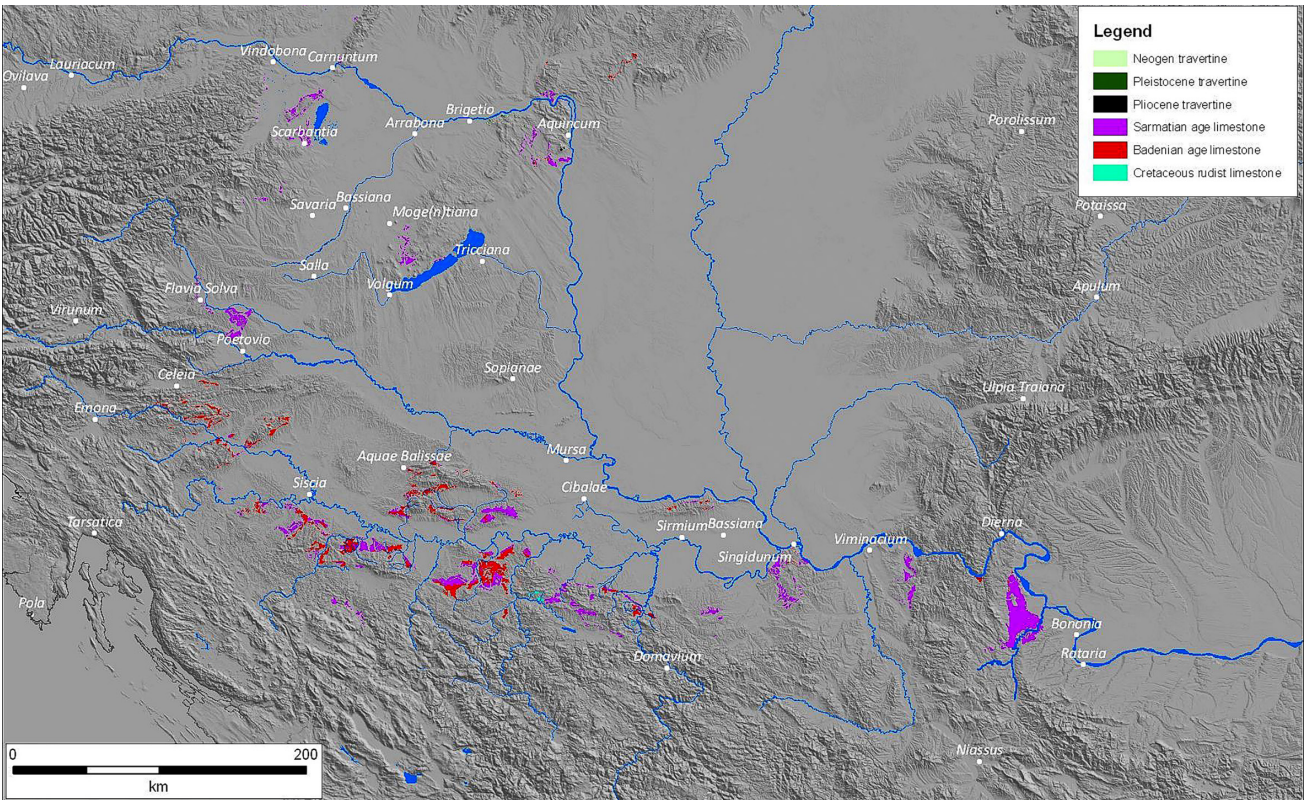


Fig. 2. Map of Pannonia with the occurrence of limestones of Badenian and Sarmatian age (drawing: E. Lozić)



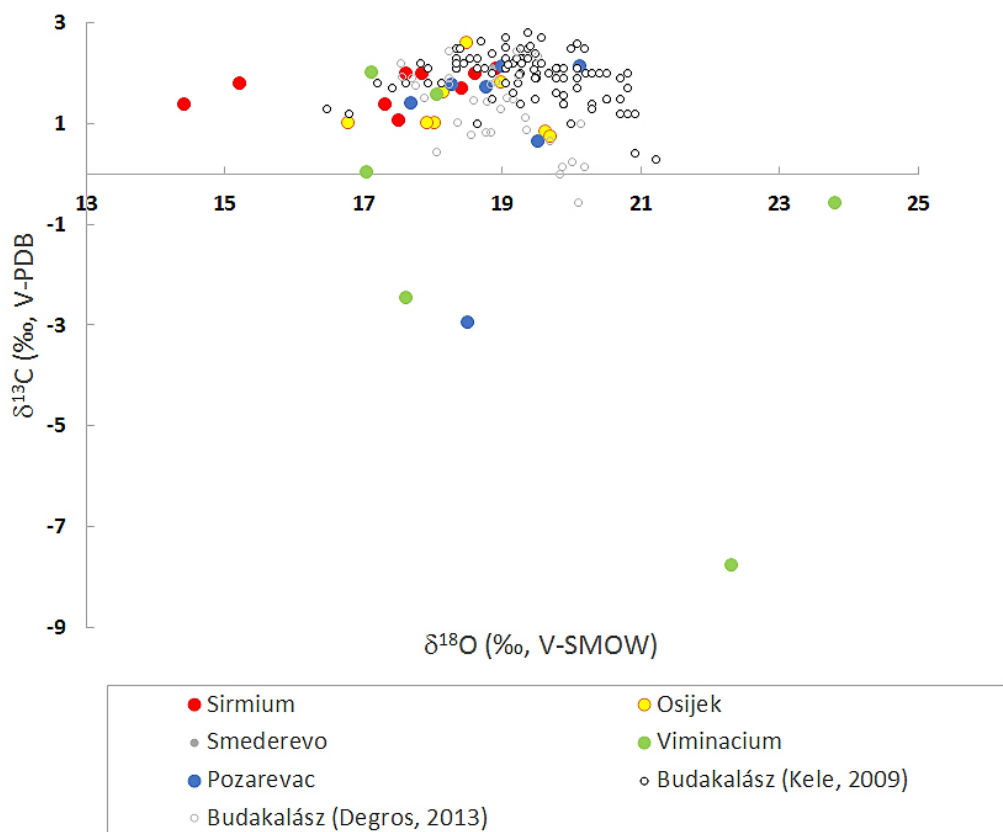


Fig. 3. Results of  $^{13}\text{C}$  and  $^{18}\text{O}$  stable isotope analysis (drawing: S. Kele). Among the mapped samples the VIM 25 (door threshold) sample shows a possible provenance from the Gerecse Hills (Süttő quarry) where the travertines have negative  $\delta^{13}\text{C}$  values in general (KELE 2009, fig. 6.6-1). Mixing with soil carbonate and diagenesis can also cause negative  $\delta^{13}\text{C}$  values

complemented or substituted for by sandstone of *Oligocene* age and with Eastern Alpine marble<sup>11</sup>.

The rocks that exceeded local or regional importance and were used in the Roman towns across Pannonia were quite rare. The most important one was certainly Eastern Alpine marble from Gummern in Austria<sup>12</sup>. It has been confirmed that it first appeared in Pannonian and Moesian towns in the Flavian period<sup>13</sup>. In the post-Trajanic time, it was joined on the Pannonian markets by the marble quarried on Pohorje in Slovenia, both persisting to and including the 4<sup>th</sup> century<sup>14</sup>. The distribution of the finished and semi-finished marble products is tied almost exclusively to river transport, principally along the Drau/Drava and the Danube.

## Travertine

### Methods<sup>15</sup>

All carbonate samples were powdered and homogenised using an agate mortar and pestle. The powders were then analysed using the continuous flow technique with the  $\text{H}_3\text{PO}_4$  digestion method<sup>16</sup>.  $^{13}\text{C}/^{12}\text{C}$  and  $^{18}\text{O}/^{16}\text{O}$  ratios of  $\text{CO}_2$  generated by acid reaction were measured using a Thermo Finnigan Delta Plus XP continuous flow mass spectrometer equipped with an automated GasBench II (Thermo Fisher Scientific Inc., Waltham, Massachusetts, USA). The results are expressed in the  $\delta$ -notation [ $\delta = (R_1/R_2 - 1) \times 1000$ ] where  $R_1$  is the  $^{13}\text{C}/^{12}\text{C}$  or  $^{18}\text{O}/^{16}\text{O}$  ratio in the sample and  $R_2$  is the corresponding ratio of the standard Vienna Pee Dee Belemnite (V-PDB), in parts per thousand (‰). Duplicates of standards and samples reproduced to better

11 Observations based on mesoscopic examination of the objects in the lapidaria of the Arheološki muzej Zagreb, Pokrajinski muzej Ptuj Ormož and the Savaria Múzeum Szombathely.

12 MÜLLER 2007; DJURIĆ, MÜLLER 2009.

13 DJURIĆ *et al.* 2006, 115-116; DJURIĆ, MÜLLER, FILIPOVIĆ 2009, 10.

14 DJURIĆ *et al.* 2006, 115-117.

15 Analysis carried out at the Institute for Geological and Geochemical Research, Hungarian Academy of Sciences, Budapest.

16 ROSENBAUM, SHEPPARD, 1986; SPÖTL, VENNEMANN, 2003.

| Samples /<br>Objects | $\delta^{18}\text{O}$<br>(V-PDB) | $\delta^{18}\text{O}$<br>(V-SMOW) | $\delta^{13}\text{C}$<br>(V-PDB) |
|----------------------|----------------------------------|-----------------------------------|----------------------------------|
| SRM 38               | -16.0                            | 14.4                              | 1.4                              |
| SRM 59               | -13.2                            | 17.3                              | 1.4                              |
| SRM 61               | -12.2                            | 18.4                              | 1.7                              |
| SRM 73               | -15.2                            | 15.2                              | 1.8                              |
| SRM 146              | -11.9                            | 18.6                              | 2.0                              |
| SRM 227              | -11.7                            | 18.9                              | 2.1                              |
| SRM 270              | -13.0                            | 17.5                              | 1.1                              |
| SRM 279              | -12.9                            | 17.6                              | 2.0                              |
| SRM 301              | -12.7                            | 17.8                              | 2.0                              |
| OSJ 01               | -12.4                            | 18.1                              | 1.6                              |
| OSJ 05               | -11.0                            | 19.6                              | 0.8                              |
| OSJ 06               | -13.7                            | 16.8                              | 1.0                              |
| OSJ 08               | -11.6                            | 19.0                              | 1.8                              |
| OSJ 09               | -12.5                            | 18.0                              | 1.0                              |
| OSJ 10               | -10.9                            | 19.7                              | 0.8                              |
| OSJ 14               | -12.6                            | 17.9                              | 1.0                              |
| OSJ 15               | -12.1                            | 18.5                              | 2.6                              |
| SMD 01               | -11.7                            | 18.9                              | 2.1                              |
| VIM 04               | -13.4                            | 17.1                              | 2.0                              |
| VIM 08               | -12.9                            | 17.6                              | -2.5                             |
| VIM 20               | -6.9                             | 23.8                              | -0.6                             |
| VIM 25               | -8.4                             | 22.3                              | -7.8                             |
| VIM 40               | -13.5                            | 17.0                              | 0.0                              |
| VIM 42               | -12.5                            | 18.0                              | 1.6                              |
| POZ 01               | -12.8                            | 17.7                              | 1.4                              |
| POZ 03               | -11.1                            | 19.5                              | 0.7                              |
| POZ 04               | -12.0                            | 18.5                              | -2.9                             |
| POZ 06               | -11.8                            | 18.8                              | 1.7                              |
| POZ 09               | -12.3                            | 18.3                              | 1.8                              |
| POZ 11               | -11.6                            | 19.0                              | 2.2                              |
| POZ 12               | -10.5                            | 20.1                              | 2.2                              |

Fig. 3a. Results of  $^{13}\text{C}$  and  $^{18}\text{O}$  stable isotope analysis

than  $\pm 0.1$  ‰, for both the O and C isotopes. No other methods were employed.

The other rock of presumed interprovincial importance is the limestone determined as Lithotype 2b during our analyses of the rocks used at Sirmium<sup>17</sup>. The analysis of the  $^{13}\text{C}$  and  $^{18}\text{O}$  stable isotopes in 31 samples<sup>18</sup>

17 RIŽNAR, JOVANOVIĆ 2006; DJURIĆ *et al.* 2006; DJURIĆ *et al.* 2007.

18 Nine (9) from Sremska Mitrovica (SRM 38, 59, 61, 73, 146, 227, 270, 279, 301), eight (8) from Osijek (OSJ 1,

revealed it to be Pleistocene travertine quarried today at Budakalász<sup>19</sup> (Fig. 3), on the slope of Monalovác Hill, north of Aquincum, and in the Kápolna Hills, north of Budapest<sup>20</sup>. The quarry on Monalovác Hill lies at an altitude of 240-250 meters, and is approximately 800 meters long and 15-20 meters high. To the south of Aquincum, on Gellért Hill (Budapest)<sup>21</sup>, a smaller Roman quarry was excavated in 1993-94<sup>22</sup>. The Roman products made of Pleistocene travertines from the Buda Hills have not yet been analysed in detail and are temporarily treated here under the common name of Budakalász travertine.

Travertines in the Pannonian Basin have been studied for almost one hundred years, making their genesis and characteristics quite well known<sup>23</sup>. They mainly occur in the Transdanubian range, more precisely the Bakony, Gerecse and Buda Hills (Fig. 4). The gradual uplift of this area from the Miocene onwards caused erosion and subsequent exposure of the Triassic-Eocene carbonate rocks in the area<sup>24</sup>. Meteoric waters penetrated the exposed carbonate sequences and then ascended as thermal waters due to the above-average geothermal gradient in the basin area. During their ascent, the thermal waters mixed with cold karstic waters, causing a strong corrosive effect. Reaching the surface, these highly saturated waters deposited travertines. This occurred at the margins of the mountains, mainly along the NW-SE trending normal faults. As the Danube formed a series of river terraces below the thermal springs, travertine deposits covered the slopes and steps between the terraces<sup>25</sup>.

Mathieu Degros<sup>26</sup> recently described several facies of the travertine in the Budakalász quarry, distinguished on the basis of porosity and other sedimentary structures, and accordingly interpreted their depositional environment. This travertine varies in colour, from almost pure white to brown. The different colours have also been

5, 6, 8, 9, 10, 14, 15), one (1) from Smederevo (SMD 1), six (6) from Viminacium (VIM 4, 8, 20, 25, 40, 42) and seven (7) from Požarevac (POZ 1, 3, 4, 6, 9, 11, 12).

19 KELE *et al.* 2003; for this Roman quarry see TORMA 1984.

20 TÖRÖK *et al.* 2013.

21 KELE *et al.* 2009.

22 PETŐ 1998; another ancient quarry (from the Árpád period?) lies in the area of Pomáz-Holdvilágárok, KÖREK 1984.

23 SCHEUER, SCHWEITZER 1988; KELE 2009.

24 GOLDSCHIEDER *et al.* 2010; NÁDOR 1993.

25 NÁDOR 1993.

26 DEGROS 2013; see also DEGROS *et al.* 2016.

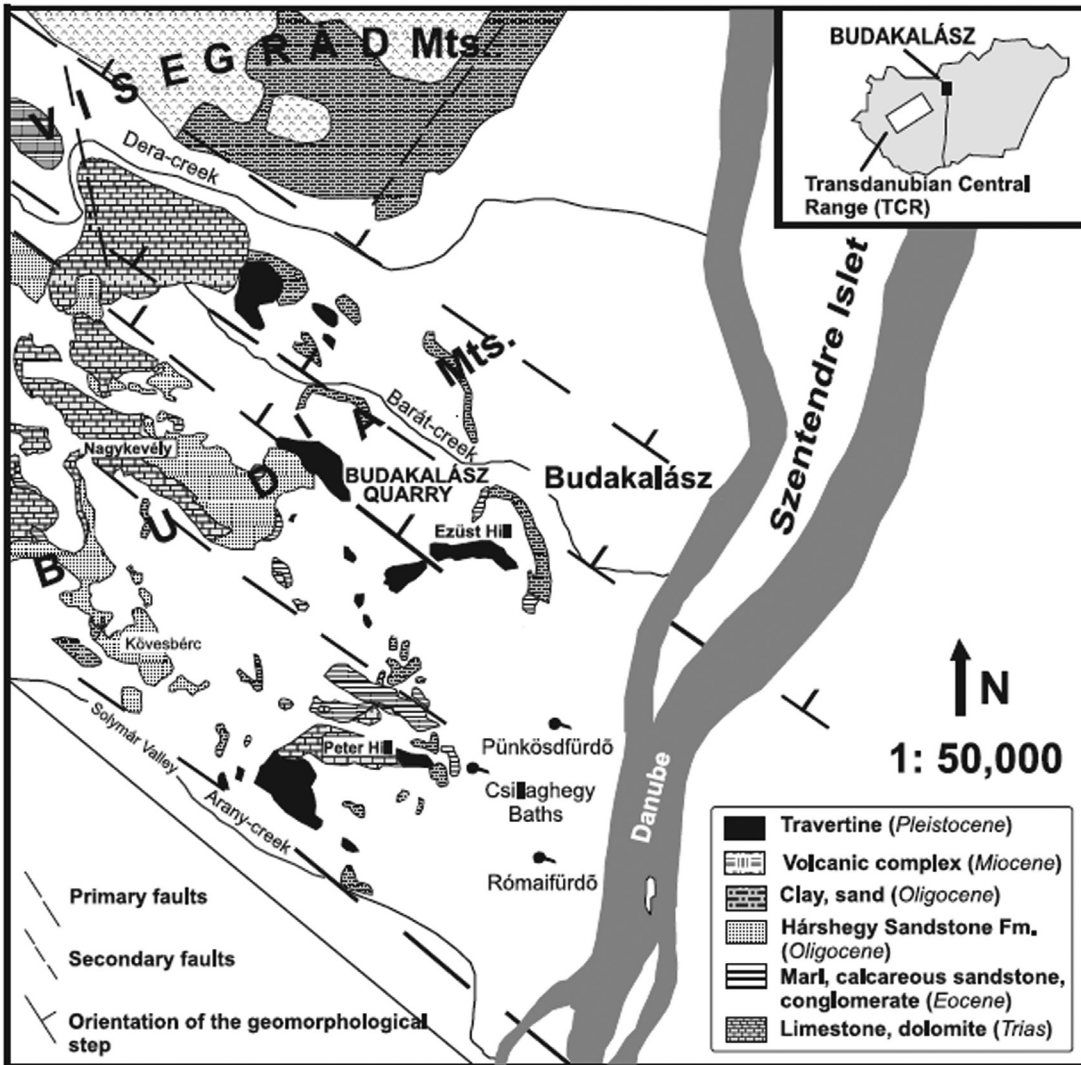


Fig. 4. Map of the occurrence of travertine in the Buda Hills (after: KELE *et al.* 2003)

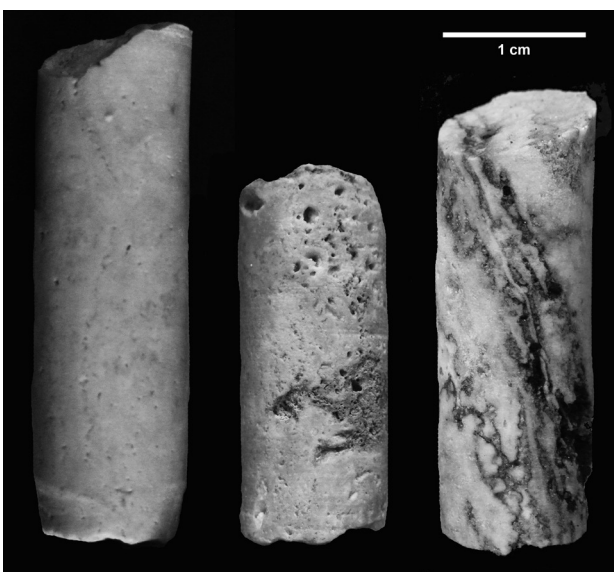


Fig. 5. Core samples of travertine of different characteristics as observed on the monuments from Sremska Mitrovica (photo: I. Rižnar)

identified on the monuments from Sremska Mitrovica<sup>27</sup> (Fig. 5), but these have not yet been classified according to the characteristics of individual facies.

One of the most important limiting factors in working with travertine is certainly the tectonically induced cleavage. Budakalász travertine formed very recently<sup>28</sup> and has not been exposed to long-lasting tectonic activity; it is therefore not deformed and is without fractures. It is well cemented and has a very high flexural and compressive strength; the massive variety is actually almost as good as marble in terms of the requirements of the stonemasons. It was valued according to its colour and porosity, with the most sought-after varieties being almost white in colour, while those of the most massive appearance and almost non-porous were particularly suitable for statuary.

27 RIŽNAR, JOVANOVIĆ 2006.

28 In geological terms, the age of Budakalász travertine is roughly 570 – 270 ky. KELE 2009.

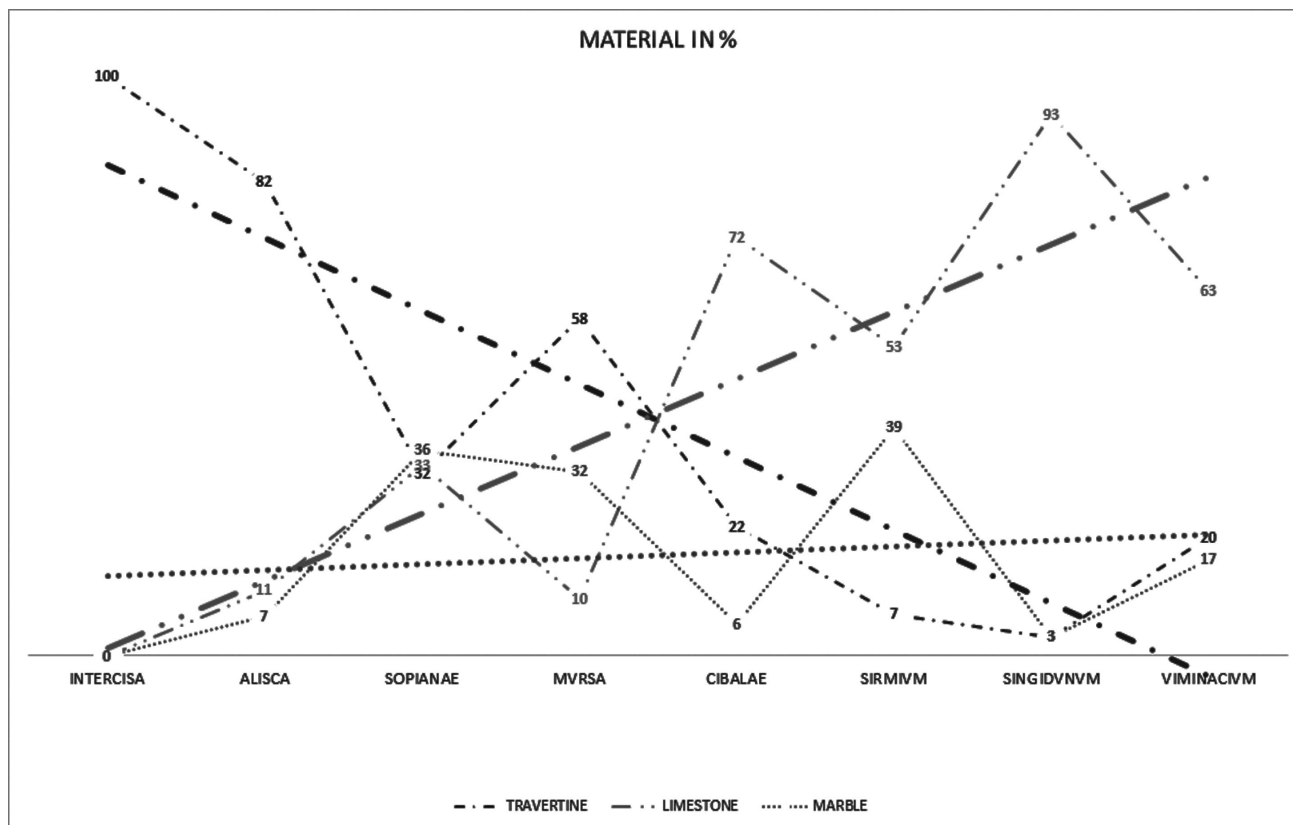


Fig. 6. Numbers of the documented travertine, limestone and marble products in the centres along the Danube and their general trends (drawing: B. Djurić)

In Aquincum, practically all stone monuments are made of travertine<sup>29</sup>. The situation is similar in the centres down the Danube<sup>30</sup>: all of the 78 documented monuments at *Intercisa* (Dunaújváros) are of travertine, 82% of the 44

monuments at *Alisca* (*Szekszárd-Ócsény*), 32% of the 76 monuments at *Sopianae* (*Pécs*), 57% of the 93 monuments at *Mursa* (Osijek), 27% of the 18 monuments at *Cibalae* (Vinkovci), 8% of the 403 monuments at *Sirmium* (Sremska Mitrovica), 3% of the 61 monuments at *Singidunum* (Belgrade) and 20% of the 108 monuments at *Viminacium* (Kostolac). As the distance from Aquincum down the Danube grows, other stones appear alongside travertine, namely local or regional limestones and Alpine marbles. Interestingly, travertine more or less prevails over other stones or is present in significant quantities all the way down to Mursa, where it meets a strong presence of Alpine marbles coming down the Drava<sup>31</sup>. In nearby Sopianae, a variety of regional limestone that is almost absent in Mursa covered one third (33%) of the town's needs, while one third was taken up by marble and just one third by travertine. Down the Danube from Mursa, local and regional limestones prevail (*Cibalae* 72%, *Sirmium*<sup>32</sup> 53%,

29 SZIRMAI 2003; a brief mesoscopic verification of the stones used for the monuments in the lapidarium of the Aquincumi Múzeum in Budapest was carried out in 2013, confirming an absolute predominance of travertine.

30 A mesoscopic verification of the stones used for the monuments in the lapidaria of the Intercisa Múzeum Dunaújváros, Wosinsky Mór Megyei Múzeum Szekszárd, Janus Pannonius Múzeum - Régészeti Múzeum Pécs, Narodni muzej Beograd, Muzej u Smederevu, Narodni muzej Požarevac and the stone collection at the site of Viminacium was carried out in 2014-15. For the permission and help we would like to thank Ernyey Katalin from Budapest, Farkas Lajos, Buza Andrea and Keszi Tamás from the Intercisa Múzeum Dunaújváros, Ódor János from the Múzeum Szekszárd, Veselinka Ninković from the Narodni muzej Beograd, Tatjana Gačpar and Ljiljana Nikolić from Smederevo Museum, Dragan Jacanović from the National Museum in Požarevac, Miodrag Korač and Emilija Nikolić from the SANU Archaeological Institute, Belgrade.

31 DJURIĆ, MÜLLER, FILIPOVIĆ 2009; a large quantity of the Alpine marble monuments in the area between castellum Alisca and Sopianae might point to their transport along the Zala-Balaton-Sió waterway.

32 The limestone from the Dardagani quarry and from another, as yet unknown, quarry.



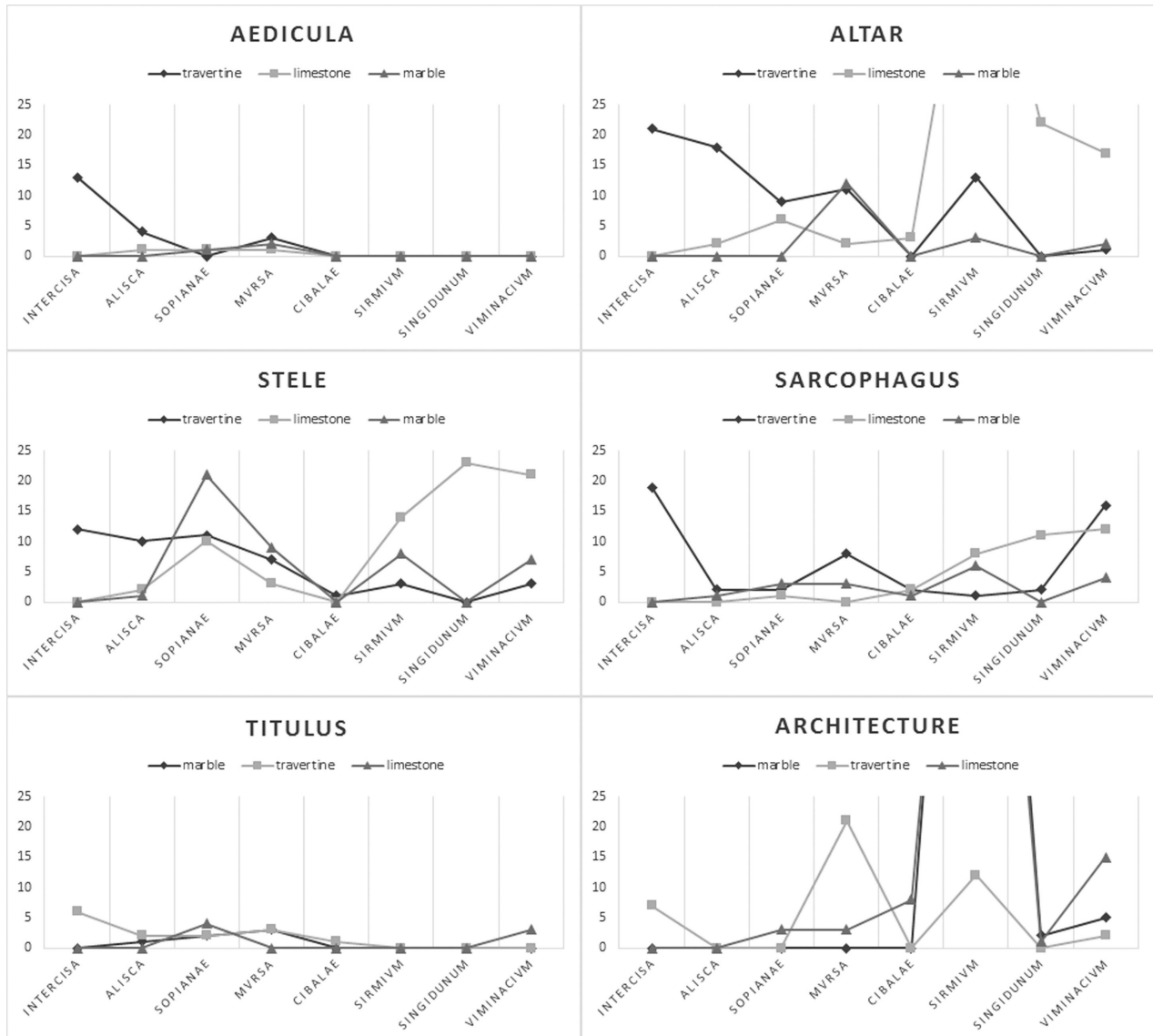


Fig. 7. Occurrence of the travertine, limestone and marble in different products in the centres along the Danube (drawing: B. Djurić)

Singidunum<sup>33</sup> 93%, Viminacium<sup>34</sup> 63%), accompanied by travertine and marble in almost equal shares. The general trend in the use of travertine in the centres along the Danube is clearly descending with the distance from the source, whilst marble is more or less evenly represented (Fig. 6). This is true at a general level, while a closer look at the different types of products shows a slightly but significantly different picture (Fig. 7).

## Products

**Aediculae**, the most representative and expensive sort of composite sepulchral architecture in Pannonia, are known mainly in Aquincum<sup>35</sup> and the nearby areas south of it<sup>36</sup>, with only rare pieces reaching their farthest point at Mursa<sup>37</sup>. The distribution model of these monuments follows the same economic logic already observed in Noricum in the aediculae of Alpine marbles<sup>38</sup>.

33 The limestone from the Tašmajdan quarry.

34 Limestone of as yet unknown provenance.

35 For the stone products in Aquincum see NAGY 1971; for the sepulchral architecture there see ERTEL 1999.

36 DJURIĆ 2012, 43-45, fig. 2.

37 POCHMARSKI, FILIPOVIĆ 1997.

38 KREMER 2001.



Fig. 8. A stela with the portrait under the arch (1-Sirmium) (sample SRM 146) and a stela with the portrait under the arch in the shell niche (2-Viminacium) (sample POZ 12) (photo: B. Djurić)

Simple monolithic sepulchral monuments such as **stelae** show a markedly different distribution. From the late Flavian time onwards, travertine stelae are present in all centres along the Danube quite evenly and together with the marble stelae represent the most prestigious examples of this monument type in local cemeteries. Their general forms demonstrate an affiliation with the quarry workshops at Budakalász and Aquincum, suggesting trading in semi-finished or even fully finished products. We may assume this affiliation in at least two series (Fig. 8): of the portrait stelae with the portrait under an arch (*Aquincum*<sup>39</sup>, *Intercisa*<sup>40</sup> and *Sirmium*<sup>41</sup>) and the portrait stelae with the portrait(s) under the arch in a shell niche (*Aquincum*<sup>42</sup>, *Intercisa*<sup>43</sup> and *Viminacium*<sup>44</sup>).

Votive and sepulchral **altars** made of travertine were very popular in all centres along the Danube, but their occurrence from Mursa to Viminacium diminishes rapidly in favour of those made of local or regional limestones. The situation in Sirmium<sup>45</sup> is typical in this respect.

The most significant and widely spread products of the Budakalász/Aquincum workshops are **sarcophagi**<sup>46</sup>. Their distribution down the Danube to Viminacium<sup>47</sup> demonstrates the popularity and prestige ascribed to these products that were competing on the markets there with the sarcophagi of Alpine marbles<sup>48</sup>. The prevailing general form of the receptacles was the same for both the travertine and the marble sarcophagi, marked by a tripartite front panel incorporating a sunken and moulded central field intended for the inscription; only a small number have a flat front panel. This general quarry form was diversified by applying different decorative motifs to the moulded frame of the central field, in most cases the different forms of the Norico-Pannonian volute. Recently, Erwin Pochmarski described several variants of these motifs in *Intercisa*<sup>49</sup> and *Aquincum*<sup>50</sup> and noted that his Types 3a

39 Three stelae: NAGY 2007, No. 22; LUPA 4677; NÉMETH 1999, No. 172.

40 BARKÓCZI *et al.* 1954, No. 5; NAGY 2007, No. 23.

41 DAUTOVA 1983, No. 6.

42 NÉMETH 1999, 51 No. 133.

43 BARKÓCZI *et al.* 1954, No. 95; LUPA 3972.

44 LUPA 5398.

45 DJURIĆ *et al.* 2007.

46 On the sarcophagi from Aquincum and Intercisa see: POCHMARSKI 2011; 2014; POCHMARSKI, POCHMARSKI-NAGELE 2013.

47 See DAUTOVA-RUŠEVLJAN 1983; ĐORĐEVIĆ 1989-90.

48 DJURIĆ 2001.

49 POCHMARSKI E., POCHMARSKI-NAGELE M. 2013.

50 POCHMARSKI 2014.





Fig. 9. Sarcophagi with Type 3a (1-Mursa /sample OSJ 14/, 2-Singidunum, 3-Viminacium /sample POZ 04/) and Type 7 decoration (4-Mursa, 5 /sample VIM 40/ and 6-Viminacium /sample POZ 09/) (photo: B. Djurić)

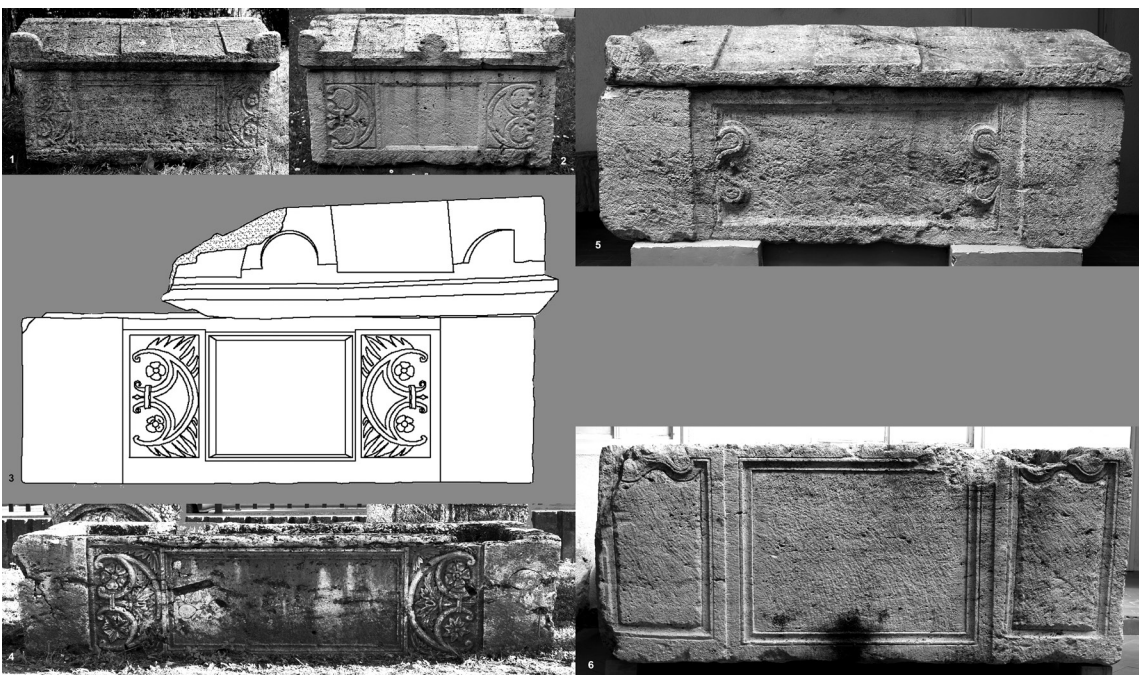


Fig. 10. Sarcophagi with the pelta-type decoration (1-Intercisa, 2-Siscia, 3 and 4-Viminacium /sample POZ 03/), a sarcophagus with the simple Norico-Pannonian decoration (5-Mursa /sample OSJ 09/) and a sarcophagus of the Poetovian type (6-Mursa /sample OSJ 08/) (photo: B. Djurić)



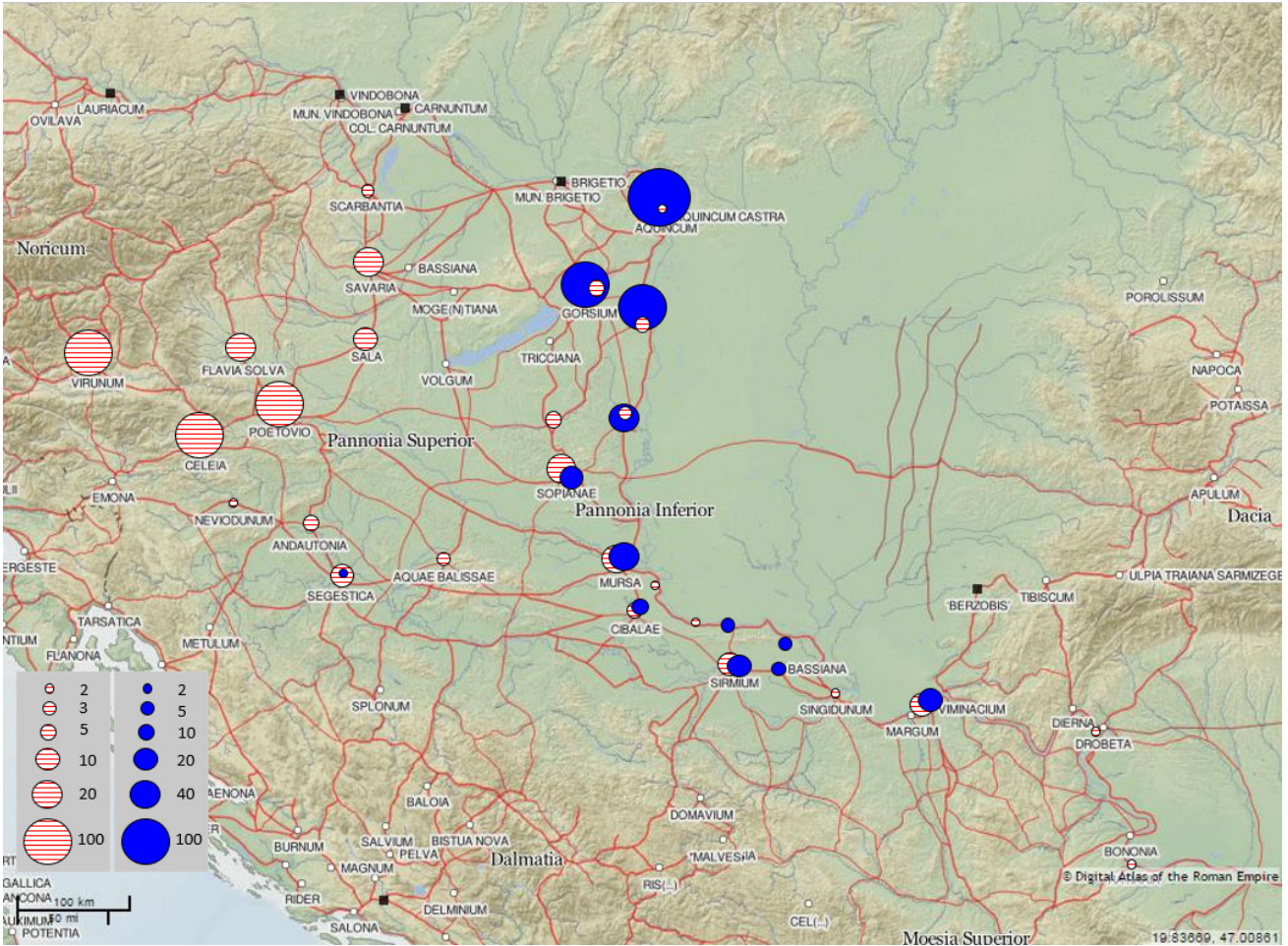


Fig. 11. Distribution map of the products made of Eastern Alpine marble and of Budakalász travertine (drawing: B. Djurić)

and 7 were the most popular<sup>51</sup>. The examples found along the Danube between Aquincum and Viminacium confirm his findings (Fig. 9; Fig. 10). They also show, quite clearly, that sarcophagi were mainly traded in the quarry condition to be finished later<sup>52</sup>. One sarcophagus from Mursa<sup>53</sup> is clearly a travertine imitation of a marble sarcophagus, and was probably made in Mursa from a block of travertine or possibly just finished there, because the moulded lateral fields of the front panel are executed in the manner typical of the Poetovian type of marble sarcophagus.

Blocks of travertine were also used to build the Roman bridge across the Drava at Mursa<sup>54</sup>, which suggests that travertine was traded along the Danube even

as blocks and architectural elements. The poor state of research into the architectural remains prevents us from drawing any conclusions, but evidence from the Roman centres along the Danube does suggest that Budakalász travertine played a significant role in the construction activities in the area.

The general distribution of the stones used in the Pannonian and Upper Moesian centres clearly shows that the prestigious (sepulchral) monuments of Budakalász travertine successfully complemented those of Alpine marbles (Fig. 11). The question that remains open is the degree to which the quarry workshops in the Buda Mountains were related to the Alpine quarry workshops; certain forms and motifs on their products as well as the quality of their execution suggest that some kind of interaction existed<sup>55</sup>.

51 POCHMARSKI 2014, 415, fig. 9.

52 One of the best examples is the Jonah sarcophagus from Belgrade; POP-LAZIĆ 2002, 21-22.

53 GÖRICKE-LUKIĆ 2000, 36-37.

54 FILIPOVIĆ 2004, 160; blocks of this bridge were lifted and brought to the Muzej Slavonije, Osijek, during the cleaning campaign of the Drava riverbed in 1985.

55 See DJURIĆ 2012.

## BIBLIOGRAPHY

- BARKÓCZI L., ERDÉLYI G., FERENCZY E., FÜLEP F., NEMESKÉRI J., ALFÖLDI M. R., SÁGI K. 1954: *Intercisa I.*, (Dunapentele - Sztálinváros), *Geschichte der Stadt in der Römerzeit*, Budapest.
- CAMPBELL B. 2012: *Rivers and the Power of Ancient Rome*. University of North Carolina Press, Chapel Hill.
- DAUTOVA-RUŠEVLJAN V. 1983: *Rimska kamena plastika u jugoslovenskom delu provincije Donje Panonije*. Savez arheoloških društava Jugoslavije, Novi Sad.
- DEGROS M. 2013: *Sedimentological-Petrological Study and Reservoir Characterisation of the Budakalász Travertine Carbonates (Buda Mountains, Hungary)*, Leuven (PhD thesis).
- DEGROS M., HANNES C., SOETE J., CLAES S., KELE S., MINDSZENTY A., TÖRÖK A., SWENNEN R. 2016: "Geobody architecture, genesis and petrophysical characteristics of the Budakalász continental carbonates, Buda Hills (Hungary)", *Quaternary International* (submitted).
- DJURIĆ B. 2001: "Production of marble sarcophagi in Poetovio", *Budapest régiségei* 34, 47-62.
- DJURIĆ B. 2012: "Mitološki prizori na noriških in panonskih sepulkralnih spomenikih", *Keria* 14, 41-54.
- DJURIĆ B., DAVIDOVIĆ J., MAVER A., MÜLLER H. W. 2006: "Stone use in Roman towns: resources, transport, products and clients: case study Sirmium: first report", *Starinar* 56, 103-137.
- DJURIĆ B., DAVIDOVIĆ J., MAVER A., RIŽNAR I. W. 2007: "Stone use in Roman towns: resources, transport, products and clients: case study Sirmium: second report", *Starinar* 57, 83-99.
- DJURIĆ B., MÜLLER H. W. 2009: "White marbles in Noricum and Pannonia: an outline of the roman quarries and their products", in *ASMOSIA VIII*, 111-127.
- DJURIĆ B., MÜLLER H. W., FILIPOVIĆ S. 2009: "Karakteriziranje mramornih spomenika Murse", *Osječki zbornik* 29, 9-18.
- ĐORĐEVIĆ M. 1989-90: "Rimski kameni sarkofazi iz Viminaciuma", *Viminacium* 4-5, 133-147.
- ERTEL Ch. 1999: "Konstruktive Bauteile von römischen Grabbauten im Aquincum-Museum", *Budapest régiségei* 33, 197-241.
- FILIPOVIĆ S. 2004: "Colonia Aelia Mursa", in M. ŠAŠELKOS, P. SCHERER (eds.): *The autonomous towns of Noricum and Pannonia*. Pannonia II. NMS, Ljubljana, 2004, 157-168.
- GOLDSCHIEDER N., MÁDL-SZŐNYI J., ERŐSS A., SCHILL E. 2010: "Review: Thermal water resources in carbonate rock aquifers", *Hydrogeology Journal* 18/6, 1303-1318.
- GÖRÍCKE-LUKIĆ H. 2000: *Sjeveroistočna nekropola rimske Murse*, HAZU, Zagreb-Osijek.
- JÓKAI M. 1872: *Az arany ember (The Golden Man)*, Pest.
- KELE S. 2009: *Investigations on freshwater limestones from the Carpathian-Basin: paleoclimatological and sedimentological studies*. Eötvös Loránd University, PhD Thesis, Budapest (in Hungarian). ([http://real-phd.mtak.hu/28/1/kele\\_sandor\\_2009\\_doktori\\_ertekez.es.pdf](http://real-phd.mtak.hu/28/1/kele_sandor_2009_doktori_ertekez.es.pdf)).
- KELE S., SCHEUER GY., DEMÉNY A., SHEN C.-C., HONG-WEI C. 2009: "U-series dating and isotope geochemical study of the Gellért Hill (Budapest) travertine", *Central European Geology*, 52/3-4, 199-224.
- KELE S., SZABÓ C., VASELLI O., MINISSALE A. 2003: "Stable isotope geochemistry of Pleistocene travertine from Budakalász (Buda Mts, Hungary)", *Acta Geologica Hungarica* 46/2, 161-175.
- KÉRDŐ K. 1999: "Beitrage zur Materialuntersuchung der Aquincumer Marmordenkmäler", *Budapest régiségei* 33, 269-277.
- KOREK J. 1984: "Pomáz Árpád-kori kőbányakőbányászata. The Pomáz quarry from Árpád-Period", in J. GÖMÖRI (ed.): *Iparrégészeti kutatások = Research in industrial archaeology and archaeometry in Hungary*, Veszprém, 1982. *A Magyar Tudományos Akadémia Veszprémi Akadémiai Bizottságának, Veszprém*, 55-60.
- KREMER G. 2001: *Antike Grabbauten in Noricum. Katalog und Auswertung von Werkstücken als Beitrag zur Rekonstruktion und Typologie*. *Sonderschriften des Österreichischen Archäologischen Institutes* 36, Wien.
- LÓCZY D., STANKOVIANSKY M., KOTARBA A. (eds.) 2012: *Recent Landform Evolution. The Carpatho-Balkan-Dinaric Region*, Springer, Dordrecht.
- LUPA: [www.ubi-erat-lupa.org](http://www.ubi-erat-lupa.org).
- MAGRIS C. 1986: *Danubio*, Garzanti, Milano.
- MEZŐS T. 2005: "A szombathelyi Iseum helyreállítás-története és új elvi rekonstrukciója", *Építés - Építészettudomány* 33, 245-287.
- MÜLLER H. W. 2001: "Herkunftsbestimmung von römischen Marmorobjekten aus der Gegend des Balaton", *Balácai Közlemények* 6, 245-254.
- MÜLLER H. W. 2007: "Der Marmor von Gummern und seine Bedeutung für die römischen Provinzen Pannonien, Norikum und Rätien", in V. HÖCK, F. LANG, W. WOHLMAYR (eds.): *Akten zum 2. Österreichischen „Römerstein-Treffen“ 2006 in Salzburg*, Phoibos Verlag, Wien, 33-36.

- NÁDOR A. 1993: "Palaeokarsts and long-term karst evolution of the Buda Mountains, Hungary", *Bulletin de la Société géographique de Liège* 29, 139-143.
- NAGY M. 2007: *Lapidárium*. Magyar Nemzeti Múzeum, Budapest.
- NAGY T. 1971: "Kőfaragás és szobrászat Aquincumban. Taille de pierre et sculpture à Aquincum", *Budapest Régiségei* 22, 103-160.
- NÉMETH M. 1999: *Vezető az Aquincumi Múzeum*. Budapesti Történeti Múzeum, Budapest.
- PETŐ M. 1998: "A gellérthegyi kőbánya. The Gellért hill quarry", *Budapest Régiségei* 32, 123-133.
- POCHMARSKI E. 2011: "Ikonographische und chronologische Probleme der Sarkophage aus Aquincum", *Anodos* 11, 247-268.
- POCHMARSKI E. 2014: "Die Sarkophagwerkstätten von Aquincum und Brigetio", *Acta Archaeologica Academiae Scientiarum Hungaricae* 65, 405-426.
- POCHMARSKI E., FILIPOVIĆ S. 1997: "Eine Gruppe Dionysischer Reliefs aus Mursa (Osijek)", *Osječki zbornik* 22-23, 33-44.
- POCHMARSKI E., POCHMARSKI-NAGELE M. 2013: "Die Sarkophage von Intercisa", in N. CAMBI, G. KOCH (eds.): *Sepulkralna skulptura zapadnog Ilirika i susjednih oblasti u doba Rimskog Carstva: zbornik radova s međunarodnog simpozija održanog od 27. do 30. rujna 2009, Split = Funerary sculpture of the Western Illyricum and neighbouring regions of the Roman Empire : proceedings of the International Scholarly Conference held in Split from September 27<sup>th</sup> to the 30<sup>th</sup> 2009*, Književni krug, Split, 281-301.
- POP-LAZIĆ S. 2002: "Nekropole rimskog Singidunuma", in M. POPOVIĆ (ed.): *Singidunum 3*, Arheološki institut, Beograd.
- RIŽNAR I., JOVANOVIĆ D. 2006: "Stone material of regional provenance from Sirmium", *Starinar* 56, 139-152.
- ROSENBAUM J., SHEPPARD S. M. F. 1986: "An isotopic study of siderites, dolomites and ankerites at high temperatures", *Geochimica et Cosmochimica Acta* 50, 1147-1150.
- RUSSEL B. 2013: *The economics of the Roman stone trade*, OUP, Oxford.
- SCHEIDEL W., MEEKS E., WEILAND J. 2012: "ORBIS: The Stanford Geospatial Network Model of the Roman World" on [http://orbis.stanford.edu/orbis2012/ORBIS\\_v1paper\\_20120501.pdf](http://orbis.stanford.edu/orbis2012/ORBIS_v1paper_20120501.pdf).
- SCHEUER GY., SCHWEITZER F. 1988: *Freshwater limestones of the Gerecse and Buda Hills. Földrajzi Tanulmányok 20*, Akadémiai Kiadó, Budapest 1988 (in Hungarian).
- SPÖTL C., VENNEMANN T. W. 2003: "Continuous-flow isotope ratio mass spectrometric analysis of carbonate minerals. Rapid Communication", *Mass Spectrometry* 17, 1004-1006.
- SZIRMAI K. 2003: "Die Steinbearbeitung in Aquincum", *Forschungen in Aquincum 1969-2002*, *Aquincum nostrum* II.2, 233-244.
- ŠAŠEL J. 1973: "Trajan's Canal at the Iron Gate", *Journal of Roman Studies* 63, 80-85.
- TORMA I. 1984: "Római kori kőbánya Budakalász határában / Roman quarry near the village Budakalász", in J. GÖMÖRI (ed.): *Iparrégészeti kutatások = Research in industrial archaeology and archaeometry in Hungary*, Veszprém, 1982. A Magyar Tudományos Akadémia Veszprémi Akadémiai Bizottságának, Veszprém, 39-49.
- TÖRÖK Á., ÜNNEP V., BALÁZS A., MINDSZENTY A., KELE S. 2013: "A kápolna-hegyi édesvízi mészkőkúp komplex szedimentológiai, geokémiai és geofizikai vizsgálata (Budai-hegység). Complex sedimentological, geochemical and geophysical study of the Kápolna-hegy spring-cone (Buda Hills, Hungary)", *Bulletin of the Hungarian Geological Society* 143/3, 251-264.