

# Unraveling the Carrara - Göktepe Entanglement

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# CONTENT

<b>PRESENTATION</b> .....	15
<b>NECROLOGY: NORMAN HERZ (1923-2013) by Susan Kane</b> .....	17
<b>1. APPLICATIONS TO SPECIFIC ARCHEOLOGICAL QUESTIONS – USE OF MARBLE</b>	
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 <sup>th</sup> C.) and the Basilica of San Lorenzo (5 <sup>th</sup> 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 <sup>nd</sup> C. Bc – Late 1 <sup>st</sup> C. Ad) <i>Stefan Ardeleanu</i> .....	155
<i>Amethystus</i> : Ancient Properties and Iconographic Selection <i>Luigi Pedroni</i> .....	167
<b>2. PROVENANCE IDENTIFICATION I: (MARBLE)</b>	
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 Bahadir 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 <sup>th</sup> And 17 <sup>th</sup> 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
<b>3. PROVENANCE IDENTIFICATION II: (OTHER STONES)</b>	
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
<b>4. ADVANCES IN PROVENANCE TECHNIQUES, METHODOLOGIES AND DATABASES</b>	
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
<b>5. QUARRIES AND GEOLOGY</b>	
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
<b>6. STONE PROPERTIES, WEATHERING EFFECTS AND RESTORATION, AS RELATED TO DIAGNOSIS PROBLEMS, MATCHING OF STONE FRAGMENTS AND AUTHENTICITY</b>	
Methods of Consolidation and Protection of Pentelic Marble <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): 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
<b>8. SPECIAL THEME SESSION: „THE USE OF MARBLE AND LIMESTONE IN THE ADRIATIC BASIN IN ANTIQUITY”</b>	
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
<b>INDEX OF AUTHORS</b> .....	1009

# UNRAVELING THE CARRARA – GÖKTEPE ENTANGLEMENT

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## Abstract

Systematic investigations of imperial portraits from the first century AD up to late antiquity revealed a dramatic change in the portrait marbles starting approximately in Trajanic times. By the beginning of the 2<sup>nd</sup> century a so far unknown marble of exceptional quality suddenly arrived in Rome and became the portrait marble par excellence, which has hitherto been taken for Carrara marble. The isotope composition alone does not discriminate sufficiently, but there are several other characteristics to enable unambiguous archaeometric identification. Trace element contents, namely low Fe, Mn and the exceptional high Sr numbers, discriminate the Göktepe perfectly against Carrara marbles. Characteristic differences in the trace mineral contents of these marbles also exist.

The analytical data of the Göktepe and Carrara marbles presented in this paper allow an unambiguous discrimination of these marbles, those from Göktepe being in fact the most important portrait marbles of Roman Antiquity.

## Keywords

Göktepe marbles, Sr-content, trace element analysis

## 1. Introduction

As a consequence of the discovery of the Göktepe quarries in the Aphrodisias region some years ago a re-evaluation of the use and provenance of portrait marbles, especially all through imperial times, became inevitable. Soon after this discovery, it became evident that this marble is very similar to the famous and widely used Carrara marbles. Existence of a new unknown marble type had not been recognized and the marbles from the yet unknown Göktepe site were commonly mistaken for Carrara. Systematic search and investigation of a big number of artefacts displayed in many museums soon uncovered the prominent use of the Göktepe marbles. This quarrying area supplied the most important portrait

marble in Roman imperial times. By the beginning of the 2<sup>nd</sup> century a so far unknown marble of exceptional quality suddenly arrived in Rome and became the portrait marble par excellence. The provenance analyses of the marbles of 163 imperial portraits revealed that the preponderance of Parian Lychnites and Carrara marbles in early imperial times abruptly gave way to the dominant use of Göktepe marbles for imperial portraits starting in Trajanic/Hadrianic times. A detailed investigation of the diachronic use of the marbles of the imperial portraits and a comprehensive reference of the use of the Göktepe marbles in general is given elsewhere (Attanasio *et al.*, this volume). For the description of the Göktepe quarries and their location and characteristics we refer to previous publications on this topic.<sup>1</sup>

Because of the overwhelming importance of these two types of marbles and the fact that they can easily be confused with one another, the fundamental characteristics of the Göktepe marbles in comparison to those of Carrara will be explained below. We assume that the specific material characteristics of the Carrara marbles are well known and therefore this paper focuses on the petrographic and chemical characteristics of the Göktepe marbles, their similarities to and differences from Carrara marble and the discussion of the cause of the Carrara - Göktepe entanglement.

An essential prerequisite for marble provenance analysis is the access to and the availability of a databank for the variables analyzed. Numerous stable isotope data for different regions and quarries were published in the past<sup>2</sup>. However, systematic data on other variables for further discrimination such as trace element chemistry are only sporadically available. Our databank comprises approximately 3000 quarry samples and includes the numeric data for stable isotopes, trace elements, EPR data, the results of inclusion fluid chemistry and MGS (maximum

1 ATTANASIO *et al.* 2008; 2009.

2 The most comprehensive published collection of isotope data is given by ATTANASIO *et al.* 2006.

	DS	MgCO <sub>3</sub>	Fe ppm	Mn ppm	Sr ppm	Li/Na	Cl/Na	K/Na	F/Na	Br/Na	I/Na	SO <sub>4</sub> /Na	δ <sup>18</sup> O <sub>(PDB)</sub>	δ <sup>13</sup> C <sub>(PDB)</sub>	MGS
<b>Carrara</b>															
median	2550	1,60	100	27	158	1,64	1711	306	8,6	4,7	17,0	561,8	-1,87	2,12	0,80
mean	3086	1,63	152	28	165	1,71	1649	395	11,5	6,5	20,4	1011,3	-1,87	2,14	0,81
SD (σ)	1881	0,27	166	9	23	0,90	289	264	12,3	8,2	14,6	2113,0	0,53	0,15	0,19
<b>Göktepe</b>															
median	3877	0,74	39	6	626	0,39	1511	132	16,4	2,2	2,4	235,4	-3,06	2,46	0,68
mean	6176	0,79	41	5	647	0,45	1564	205	19,0	2,4	2,8	818,9	-3,37	1,80	0,66
SD (σ)	5698	0,20	10	4	178	0,26	353	234	13,1	1,2	2,1	3130,8	0,97	1,50	0,17
<b>Göktepe low Sr</b>															
median	1939	0,95	93	11	130	0,75	2086	625	13,0	2,8	4,2	439,7	-3,14	2,08	0,40
mean	3305	1,76	102	9	137	1,00	2016	573	19,1	3,9	11,0	657,7	-3,13	1,73	0,45
SD (σ)	3386	1,78	48	8	37	0,65	470	281	17,8	4,0	14,2	463,7	1,06	1,00	0,30

Table 1. The average numbers and standard deviation of the analytical data

grain-size) numbers. Furthermore, a collection of microscopic thin-sections of the classical marbles is available.

In the following we refer to three groups of samples from our databank; all three groups deal exclusively with white marbles. The marbles from Carrara are all grouped in one set and no intra-site discrimination (although possible to some extent) will be discussed here. Here we deal only with white Carrara marbles and we do not include “Carrara Bardiglio” in these considerations. Secondly the Göktepe samples from the ancient quarry sites are being grouped as “Göktepe” and these are usually high Sr-marbles. Finally a set of samples collected outside the site at distances ranging from 15 to 0.9 km from the ancient quarries are grouped as “low Sr-Göktepe. It is important to note that no evidence of ancient exploitation or use of these regional marbles could be found. The only remarkable exceptions are the low Sr marbles extracted from the small ancient quarry identified as “2C” (Attanasio *et al.* 2015). Here black as well as white marbles were mined; however, we refer only to the white marbles in this paper. Recent studies of the marbles of the Esquiline Group sculptures proved the at least limited use of this type of Göktepe marble.<sup>3</sup>

## 2. The methods applied

During the last few years the problems arising when the provenance of white marbles is investigated by one single method, like stable isotope analysis, have been discussed in detail.<sup>4</sup> A detailed description of the analytical procedures

is given in these papers and therefore only a summary of the procedures is listed below. The obvious consequence from the complexity of the characteristics of marbles and their overlap is to apply a combination of analytical methods followed by a statistical evaluation of the results.

In this work, ample space is given to the characterization of the petrographic descriptions of the marbles. The mean values of the analytical data are presented in table 1.

*Petrographic methods:* In general a sound investigation of the microfabric of the investigated marbles is desirable. While these investigations easily can be done on quarry samples, the tininess of many samples available from artefacts prevents a sound petrographic investigation. The rarely occurring plagioclase is characteristic, for example, of Carrara marbles, but the chance of finding one crystal in a small thin section of a few mm<sup>2</sup> is rather small. Also, according to petrographic standards, for grain size measurement a few hundred mineral grains should be counted. A widely used parameter is maximum grain size (MGS), which is either determined by petrographic microscopy or by a hand magnifier on polished surfaces. The characteristics of the grain boundaries and intergrowth of crystals are also evaluated.

*Isotopic methods:* This method is the state of the art and the most widely used approach in marble provenance analysis. A considerable advantage of this method is the very small amount of sample required. It has to be kept in mind, however, that the extremely small size of samples in the order of some mg taken from weathered or partly weathered surfaces of ancient artefacts entails the risk of wrong results because of appreciable modification of the isotope composition due to weathering of the

3 ATTANASIO *et al.* 2015.

4 PROCHASKA, GRILLO 2010; PROCHASKA, ATTANASIO 2012.



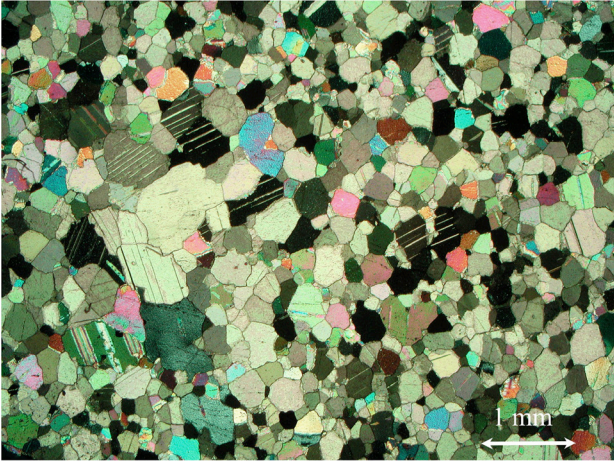


Fig. 1. Thin section of a fine-grained Göktepe marble with calcite groundmass of approx. 0.3 mm and patchy recrystallization (left hand side) with calcite grains of up to 0.8 mm

corresponding surfaces. Furthermore, only in rare cases will the exclusive use of stable isotope analysis without combination with other methodological approaches provide satisfactory results.

*Trace element chemistry:* Additional variables can be obtained by chemical analysis of the marbles.

In this context it is important to mention that those elements that are incorporated into the carbonate lattice (Mg, Fe, Mn, Sr, and Zn) exhibit a fairly homogeneous and consistent distribution and can advantageously be used to discriminate different types of white marbles. As we will demonstrate below, the discrimination of the marbles from Carrara and from Göktepe can be achieved solely on the basis of their Sr content.

*Analysis of fluid inclusions:* This technique for characterizing marbles was developed to establish further analytical variables for a better discrimination of different marbles. This method can be used in concert with the established methods and enhance discrimination success when using multivariate statistical discrimination. The results from fluid inclusion investigations of carbonate rocks show that the fluid phase is usually relatively uniform with respect to its chemical composition. A series of chemical parameters (cations as well as anions) can be detected simultaneously by means of ion chromatography. During recent years, this method has been repeatedly applied for the discrimination of different marbles when other methods failed.<sup>5</sup>

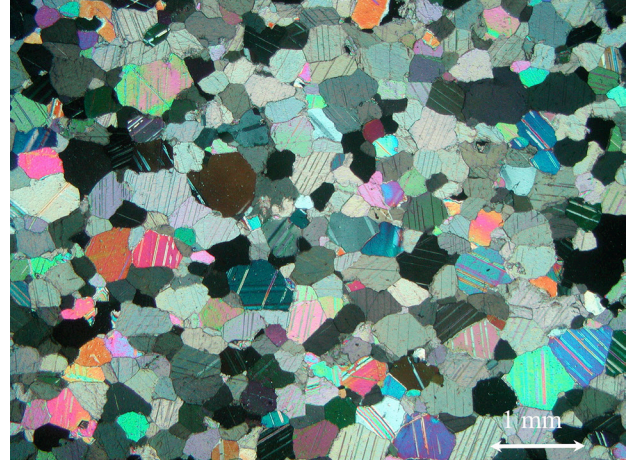


Fig. 2. Thin section of a fine-grained Carrara marble with a homoeoblastic calcite texture of approx. 0.7 mm MGS

*Evaluation of the data:* The acquisition of a big number of variables requires statistical data processing. When combining the results from isotope analysis, trace element analysis and the analysis of the chemistry of inclusion fluids, we use multivariate discrimination analysis for data evaluation. The compositional fields of the marbles from a quarry or a given marble-producing site are usually presented as statistical ellipses (90 % ellipses, which means that 90 % of the samples of this population is within the ellipse).

### 3. The analytical results

#### 3.1. The petrographic features

The macroscopic features of Göktepe marble are very similar to other high quality marbles used in antiquity and they very much resemble the characteristic Carrara marbles. The trained eye, however, becomes aware of the finer grain of the Göktepe marbles and the “ivory” feel of these marbles. Yet the average numerical MGS data are not too different, 0.8 mm for the Carrara and 0.68 mm for the Göktepe marbles. The reason is the homogenous grain-size of the Carrara marbles, slightly below 1 mm, whereas in the Göktepe marbles occasionally patchy recrystallized clusters of a few grains up to 1 mm can be observed in a polygonal groundmass of calcite crystals of approximately 0.3 mm (Figs. 1, 2). This paper generally deals with the white varieties of the Göktepe marbles, and yet it should be mentioned that there also occurs a black variety of very fine-grained Göktepe marble (grain-size below 0.1 mm) directly bordering on the white varieties (Fig. 3). As in the case of the Carrara Bardiglio marbles, the organic pigmentation and further

5 PROCHASKA, GRILLO 2010; PROCHASKA 2013.

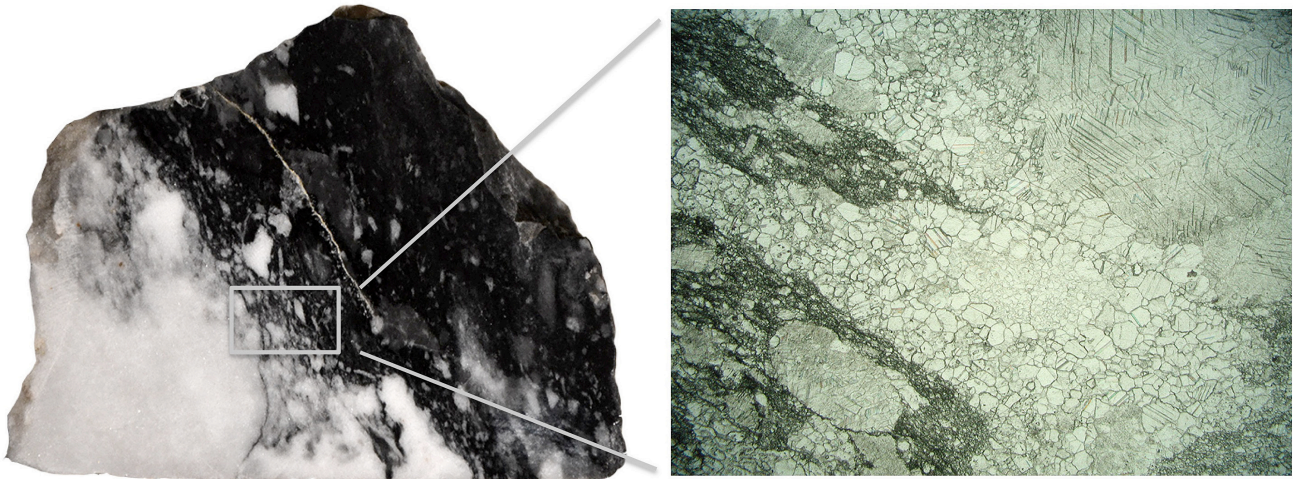


Fig. 3. Transition between the black and the white varieties of the Göktepe marbles. In the thin section (image length is 7 mm) on the right hand side the polygonal texture of the white marble sections can be recognized. The very fine-grained parts are the black varieties. In the right upper corner of the image a big relic of a shell fragment can be seen

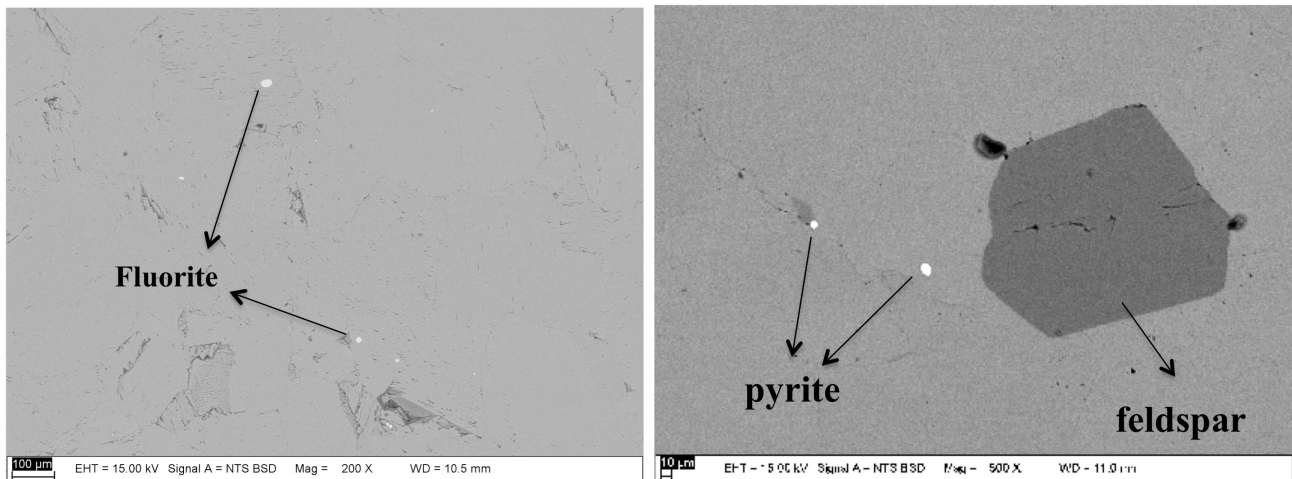


Fig. 4. SEM images of a Göktepe marble (left hand side) with only tiny fluorite crystals and a Carrara marble on the right hand side with small pyrite crystals and a larger feldspar crystal

impurities of clay minerals prevent the calcite crystals in this rock type from recrystallization in contrast to the white, very pure varieties. This black Göktepe marble also was used for very high-quality sculptures and artefacts which can be found in different museums.

Under the microscope, both Carrara and Göktepe marbles show typical polygonal textures with straight grain-boundaries; however, the Göktepe marbles develop the above described patchy recrystallizations. To distinguish between these two marbles solely on a petrographic basis can be extremely difficult. The polygonal textures with straight grain-boundaries in both marbles indicate a good recrystallization under equilibrium condition and practically no post-crystalline deformation.

Despite the very similar petrographic/textural features of the two marbles with respect to the calcite fabric, there are clear and crucial differences in the nature of the

trace minerals. However, both marbles are generally very pure and the few trace minerals can only be safely determined by scanning electron microscopy. The only trace mineral in the Göktepe marbles is fluorite occurring in tiny crystals of a few  $\mu\text{m}$ . Accessory minerals in the Carrara marbles are ubiquitous, small apatite grains, pyrite and sporadically occurring larger feldspar crystals (Fig. 4).

*The grade of metamorphism:* The purity of the white Göktepe marble and especially the lack of critical trace minerals prevent a sound estimate of the metamorphic grade. However, the organic pigmentation of the black variety allows the estimation of the maximum temperatures the rock underwent during metamorphic crystallization. Investigations by Raman spectroscopy indicate that the organic colouring substance is semi-graphite (Fig. 5). This marble suffered a maximum



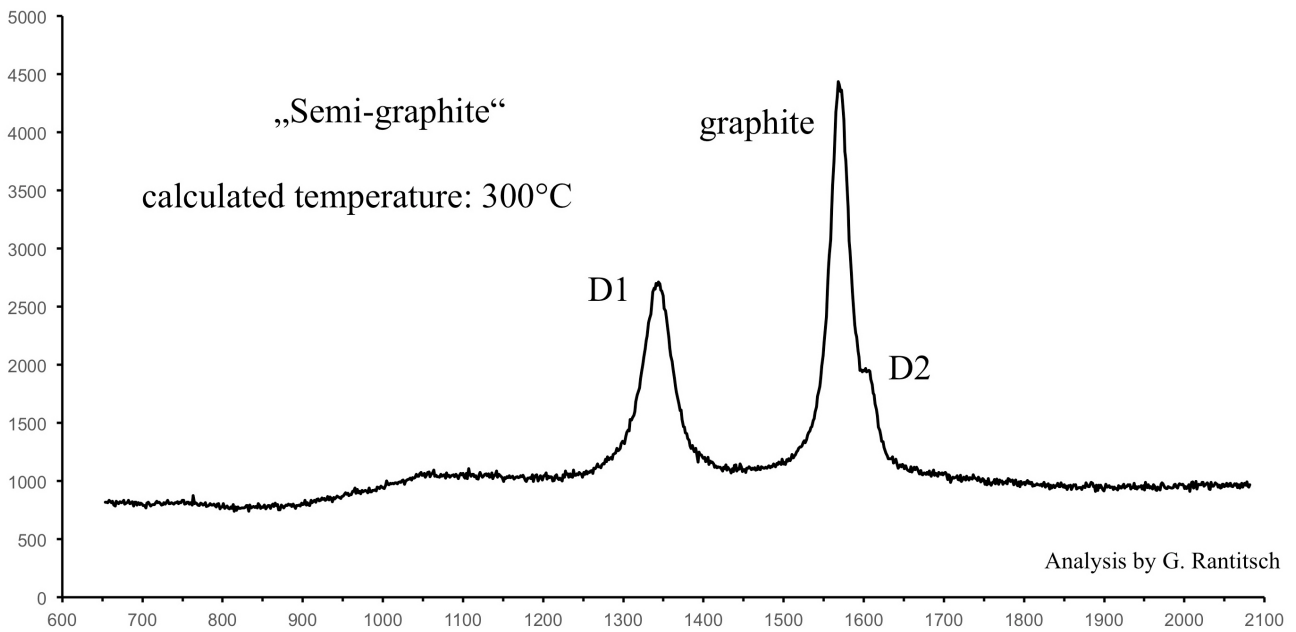


Fig. 5. Raman spectrum of the organic residue of a black Göktepe marble. The degree of recrystallization is very low as indicated by the pronounced D1 and D2 peaks and the not very sharp graphite peak

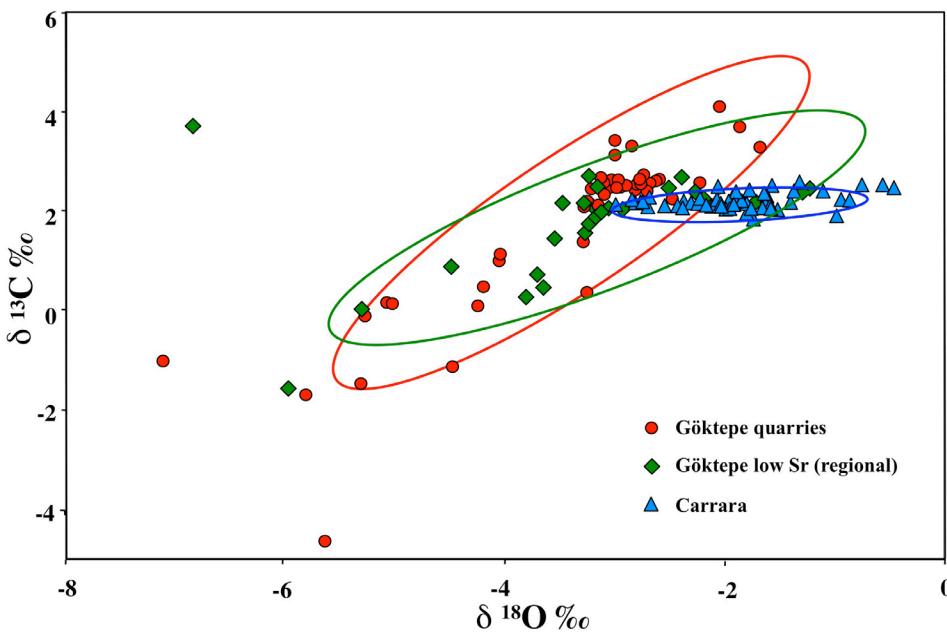


Fig. 6. Stable isotope diagram of the 3 investigated types of marbles. Clearly the data fields overlap to a high degree thus inhibiting a precise provenance determination on that basis

metamorphic temperature of approximately 300° C and is, in petrographic terminology, at the transition of limestone to marble. Consequently, relics of fossils can still be observed in the black Göktepe marbles. For the Carrara marbles a slightly higher temperature of metamorphism ( $325 \pm 30^\circ\text{C}$ ) was reported<sup>6</sup>.

### 3.2. The isotopic composition

The results of the isotope analyses of the three groups of marbles are displayed in fig 6. As can be seen in table 1 and fig. 2 the isotope composition alone does not discriminate sufficiently enough between the two data fields of the Göktepe and Carrara marbles. The C-isotopes of the Carrara marbles are in a very small range and also the scatter in the O-isotopes is limited, resulting in a very consistent data field with a compact core field without any considerable outliers.

6 OESTERLING *et al.* 2007.

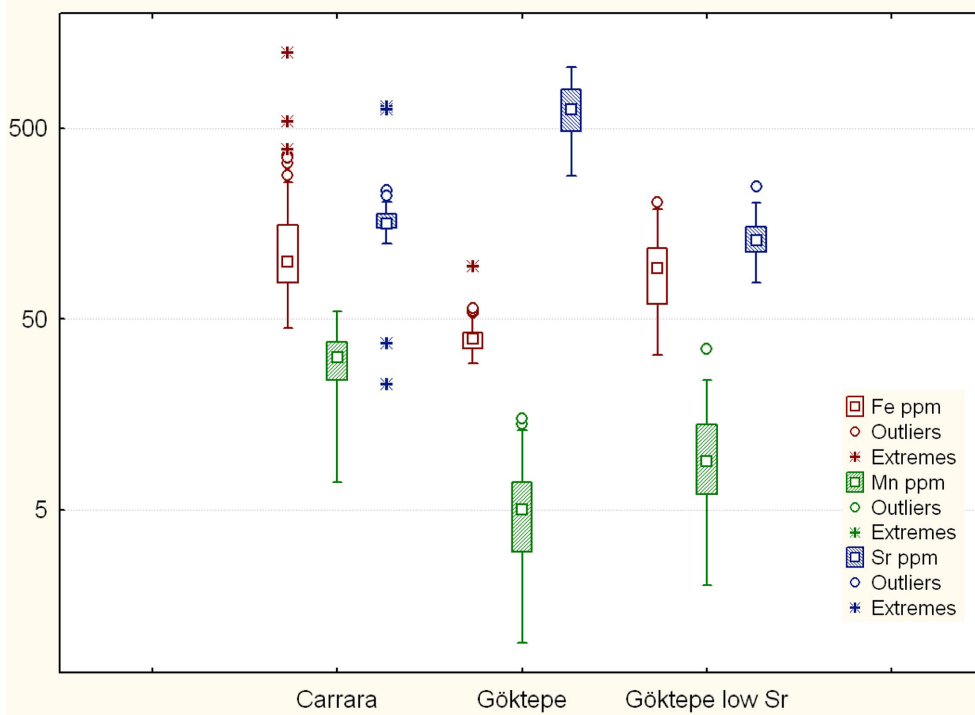


Fig. 7. Boxplot for the Fe, Mn, and Sr contents of the three marble types under investigation. While the low Sr-Göktepe marbles are not too different in their composition, the Göktepe quarry samples clearly can be differentiated

The Göktepe projection points show a concise core field in both O- and C-composition, but there are also a series of outliers towards lighter isotopes that result in a relatively big 90 % ellipse. The core field of the Göktepe marbles is shifted more than 1‰ towards lighter O-isotopes compared to the Carrara core-field whereas the C-isotope composition is relatively similar.

The regional, low Sr-Göktepe marbles show a wide scatter in the isotope diagram and largely overlap with both the Göktepe quarry samples and the Carrara marbles.

### 3.3. Trace element and fluid inclusion composition

As mentioned above, trace element analysis focused on those elements that are bound to the calcite lattice and substitute basically for Ca. These elements (Fe, Mn, and Sr) are not related to sporadically and inhomogeneously occurring trace minerals like e.g. the rare earth elements which usually are bound to apatite and consequently these trace elements show a relatively homogeneous distribution within the marbles. The most striking and obvious difference in the chemical composition is the exceptional high Sr content of the Göktepe marbles (283/1039 ppm) compared to Carrara (124/237 ppm). In our databank of approximately 3000 marble samples only the marbles from Cap de Garde in Algeria and some Alpine marbles exhibit similar high Sr contents; however, these marbles are very coarse-grained and cannot be confused with the marbles discussed here. Elevated Sr contents can be found in some Carrara Bardiglio marbles, but also here the petrographic features are clearly

different from the marbles considered in this paper and are not susceptible to being confused which each other.

There is also a significant difference in the Fe and Mn contents between the Carrara and the Göktepe marbles to the effect that the latter shows distinctly lower numbers of these elements due to its very high purity. As can be seen in the boxplot in fig. 7, a perfect discrimination between the Carrara and the Göktepe marbles can already be achieved by the use of these three trace elements alone.

The regional low Sr-Göktepe marbles resist discrimination from Carrara marbles much more because of their similar Fe and Sr contents. Mn is considerably lower than in the Carrara marbles and is therefore of some use for discrimination.

However the composition of the inclusion fluids offers the chance to improve the discernibility of this group from the Carrara marbles as well as from the Göktepe quarry samples. In particular, the elemental ratios (normalized to Na) of Li, K, Br, and I can be used in this case when applying a statistical approach, as will be shown below.

### 4. Evaluation of the analytical data

Trace element contents, namely the low Fe, Mn and the exceptional high Sr numbers, discriminate the Göktepe marbles perfectly from Carrara marbles. The high Sr contents alone discriminate them very well from other fine-grained marbles and are therefore the most important analytical parameter for the discrimination of these two marbles. As stated above, more effort and

		Carrara	Göktepe	Göktepe low Sr	total
no of cases	Carrara	64	0	1	65
	Göktepe	0	56	0	56
	Göktepe low Sr	1	0	24	25
%	Carrara	98,5	0,0	1,5	100
	Göktepe	0,0	100,0	0,0	100
	Göktepe low Sr	4,0	0,0	96,0	100

Table 2.  
The degree of the reassignment of the corresponding samples to their group using the variables MGS, Mg, Fe, Mn, Sr, DS, Li/Na, Cl/Na, K/Na, Br/Na, I/Na,  $\delta^{18}\text{O}$  ‰ and  $\delta^{13}\text{C}$  ‰

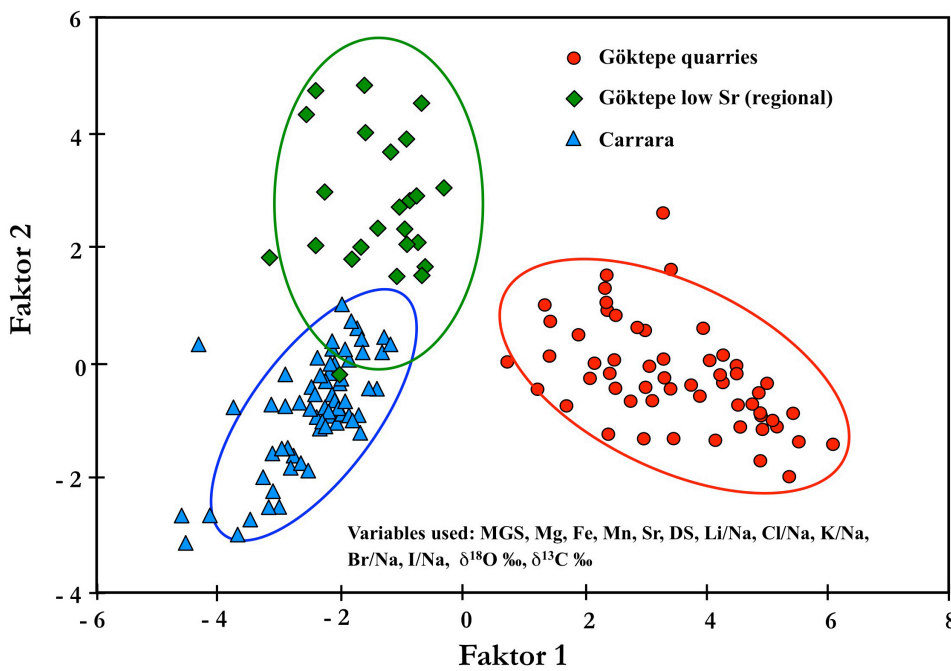


Fig. 8.  
Multivariate diagram of the two most powerful canonical functions of the results of the discriminant analysis. The data fields are displayed as 90 ° ellipses and the three marble types considered are largely separated

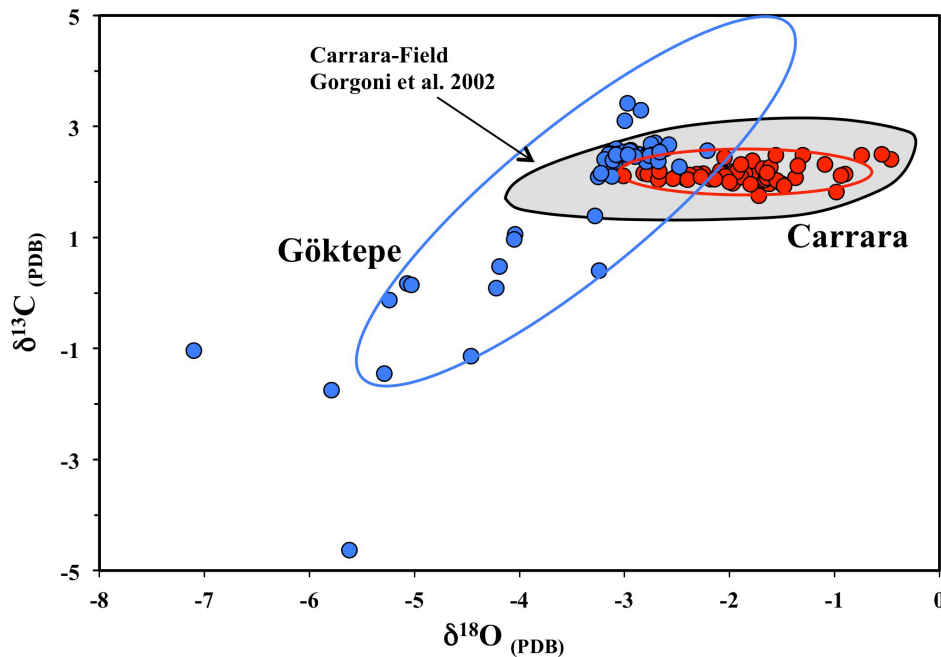


Fig. 9.  
The widely used data field of Gorgoni *et al.* 2002 covers both core fields of the Göktepe and the Carrara marbles in the stable isotope diagram and thus the 2 different types of marbles cannot be discriminated on that basis

the use of more variables and a statistical, multivariate discrimination has to be used to safely set apart the low Sr-regional Göktepe marbles from the two other groups.

In table 2, the overall result of the statistical evaluation is presented. The best result for the correct reassignment of the analyzed samples to their corresponding group is obtained when a large number of variables for the multivariate calculation is used. These variables are MGS, Mg, Fe, Mn, Sr, DS, Li/Na, Cl/Na, K/Na, Br/Na, I/Na,  $d^{18}\text{O}$  ‰,  $d^{13}\text{C}$  ‰. The success rate for the reassignment is 100 % for the Göktepe quarry samples and in both other cases only one sample each is misclassified. In the bivariate diagram in fig. 8 the two most powerful canonical functions of the results of the discriminant analysis are graphically displayed. The data-fields (90 % ellipses) of the three considered marble types are largely separated.

## 5. Discussion and conclusions

The discovery of the Göktepe marbles some years ago unveiled the existence of a so far unknown marble of utmost importance which had not been previously recognized as an important type of portrait marble of its own. The production of this fine-grained white marble of highest quality used almost exclusively for portraits is attested from the beginning of the 2<sup>nd</sup> century until advanced late antiquity.

During recent years the general acceptance of this crucial role of the Göktepe marbles and even the existence of this marble as a prime portrait marble made slow progress. This inevitably raises the question of why a marble of that importance was not recognized for decades. While most of the provenance analyses involving these marbles were so far conducted by one research group the possibility of a provenance from the Göktepe marbles for Roman artefacts is more and more considered in recent publications by different scientists<sup>7</sup>.

Innumerable investigations have been conducted on ancient marble quarries throughout the ancient world and a wide series of analytical methods have been applied. By contrast precise scientific investigations of artefacts like portraits and sculptures are much more rare. This is due to the fact that non-destructive analytical methods suitable for an established provenance analysis are, so far, not available. For serious geochemical investigations a certain amount of rock samples has to be available for analysis. Acquiring permission for the sampling of high quality artefacts, e.g. in museums, often meets considerable problems and the provenance estimation of a marble is often based solely on visual examination. Therefore the macroscopic resemblance of the Carrara

marbles with those from Göktepe is the basic reason for the Carrara – Göktepe entanglement.

These circumstances also prevent in most cases a thorough petrographic investigation of the marbles of artefacts for in this case the sample size should be in the range of 1 cm. Because of the above-described textural similarities of the Carrara and Göktepe marbles, discrimination with a petrographic microscope is often difficult. However, in the case of the availability of a scanning electron microscope a trustworthy discrimination is possible.

A certain mitigation of the problem of taking large samples seemed to be at hand with the introduction of stable isotope analysis in marble provenance analysis. This was the only approach that was intensely applied during the last decades and where databanks were available. The extremely small amount of sample necessary, a few mg, scratched from a hidden surface seemed to be tolerable but problems with sample homogeneity and contamination cannot be controlled easily in this case. In this context it should be mentioned that the isotopic core fields of the Carrara marbles are indeed different from those of Göktepe, and yet their data fields overlap considerably as shown in figs. 6 and 9. The widely used isotope field for Carrara marbles published by Gorgoni *et al.* 2002<sup>8</sup> comprises a large area and includes both core fields and even a cursory discrimination is not possible on that basis (Fig. 9).

The petrographic and chemical features of the Göktepe and Carrara marbles presented in this paper allow an unambiguous discrimination of these two types of marbles. If a provenance investigation can be reduced to the differentiation between Carrara and Göktepe marbles and other fine-grained marbles can be eliminated by a different argumentation, a trace element analysis alone will result in an unambiguous result and will help in unravelling the Carrara-Göktepe entanglement.

7 LAPUENTE *et al.* 2012; PENSABENE *et al.* 2015.

8 GORGONI *et al.* 2002



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