

Grainoutline - a Supervised Grain Boundary Extraction Tool Supported by Image Processing and Pattern Recognition

Csorba, Kristóf; Barancsuk, Lilla; Székely, Balázs; Zöldföldi, Judit

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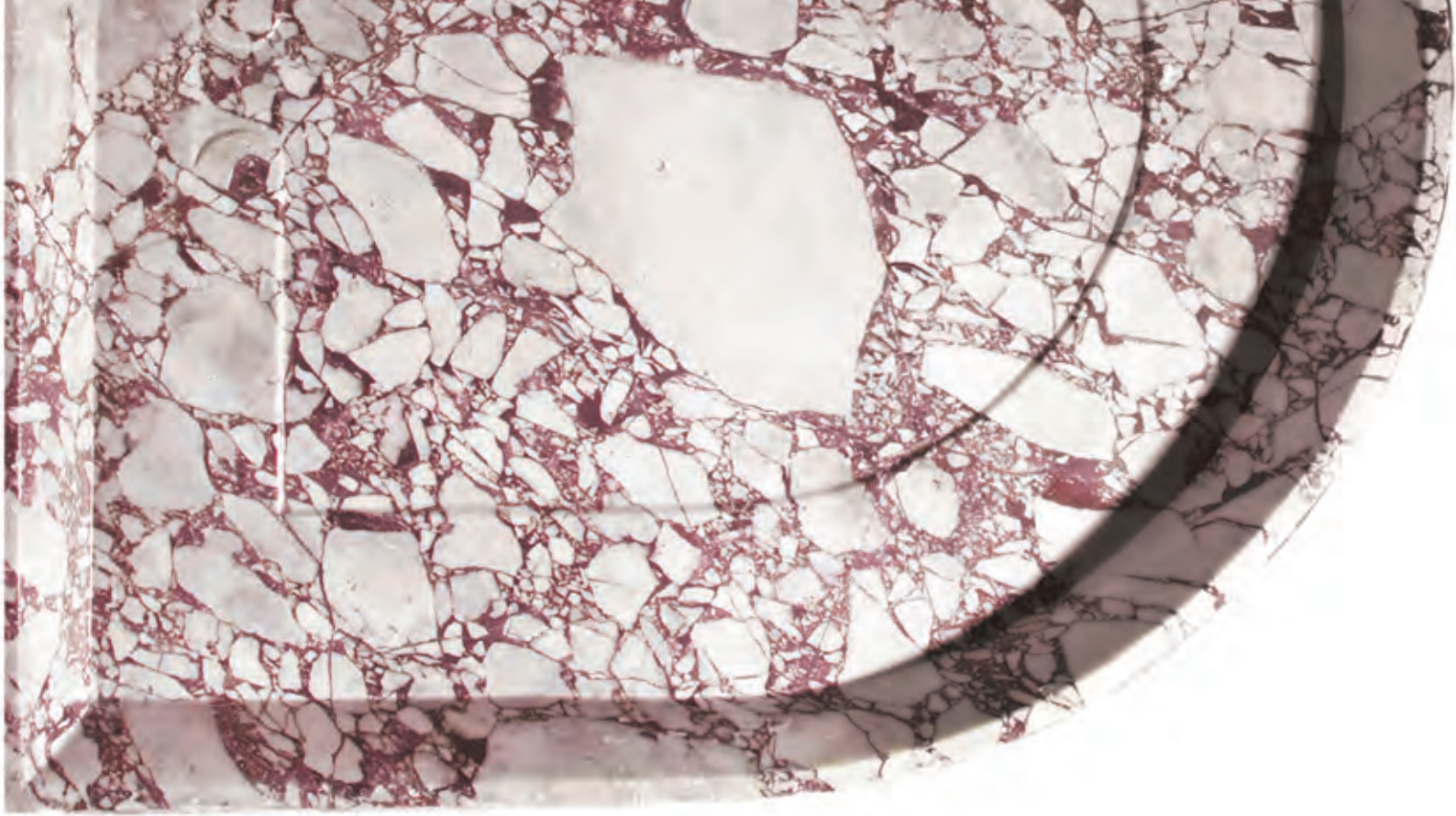
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CONTENT

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

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

Two Imperial Monuments in Puteoli: Use of Proconnesian Marble in the Domitianic and Trajanic Periods in Campania <i>Irene Bald Romano, Hans Rupprecht Goette, Donato Attanasio and Walter Prochaska</i>	267
Coloured Marbles in the Neapolitan Pavements (16 th And 17 th Centuries): the Church of <i>Santi Severino e Sossio</i> <i>Roberto Bugini, Luisa Folli and Martino Solito</i>	275
Roman and Early Byzantine Sarcophagi of Calcitic Marble from Thasos in Italy: Ostia and Siracusa <i>Donato Attanasio, John J. Herrmann, Robert H. Tykot and Annewies van den Hoek</i>	281
Revisiting the Origin and Destination of the Late Antique Marzamemi 'Church Wreck' Cargo <i>Justin Leidwanger, Scott H. Pike and Andrew Donnelly</i>	291
The Marbles of the Sculptures of Felix Romuliana in Serbia <i>Walter Prochaska and Maja Živić</i>	301
Calcitic Marble from Thasos and Proconnesos in Nea Anchialos (Thessaly) and Thessaloniki (Macedonia) <i>Vincent Barbin, John J. Herrmann, Aristotle Mentzos and Annewies van den Hoek</i>	311
Architectural Decoration of the Imperial Agora's Porticoes at Iasos <i>Fulvia Bianchi, Donato Attanasio and Walter Prochaska</i>	321
The Winged Victory of Samothrace - New Data on the Different Marbles Used for the Monument from the Sanctuary of the Great Gods <i>Annie Blanc, Philippe Blanc and Ludovic Laugier</i>	331
Polychrome Marbles from the Theatre of the Sanctuary of Apollo Pythios in Gortyna (Crete) <i>Jacopo Bonetto, Nicolò Mareso and Michele Bueno</i>	337
Paul the Silentary, 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>Marmora</i> from the Late Roman Palatial Building at Carranque (Toledo, Spain) in the Visigothic Necropolis <i>Virginia García-Entero, Anna Gutiérrez García-M. and Sergio Vidal Álvarez</i>	427
Imperial Porphyry in Roman Britain <i>David F. Williams</i>	435
Recycling of Marble: Apollonia/Sozousa/Arsuf (Israel) as a Case Study <i>Moshe Fischer, Dimitris Tambakopoulos and Yannis Maniatis</i>	443
Thasian Connections Overseas: Sculpture in the Cyrene Museum (Libya) Made of Dolomitic Marble from Thasos <i>John J. Herrmann and Donato Attanasio</i>	457
Marble on Rome's Southwestern Frontier: Thamugadi and Lambaesis <i>Robert H. Tykot, Ouahiba Bouzidi, John J. Herrmann and Annewies van den Hoek</i>	467
Marble and Sculpture at Lepcis Magna (Tripolitania, Libya): a Preliminary Study Concerning Origin and Workshops <i>Luisa Musso, Laura Buccino, Matthias Bruno, Donato Attanasio and Walter Prochaska</i>	481
The Pentelic Marble in the Carnegie Museum of Art Hall of Sculpture, Pittsburgh, Pennsylvania <i>Albert D. Kollar</i>	491
Analysis of Classical Marble Sculptures in the Michael C. Carlos Museum, Emory University, Atlanta <i>Robert H. Tykot, John J. Herrmann, Renée Stein, Jasper Gaunt, Susan Blevins and Anne R. Skinner</i>	501
3. PROVENANCE IDENTIFICATION II: (OTHER STONES)	
Aphrodisias and the Regional Marble Trade. The <i>Scaenae Frons</i> of the Theatre at Nysa <i>Natalia Toma</i>	513
The Stones of Felix Romuliana (Gamzigrad, Serbia) <i>Bojan Djurić, Divna Jovanović, Stefan Pop Lazić and Walter Prochaska</i>	523
Aspects of Characterisation of Stone Monuments from Southern Pannonia <i>Branka Migotti</i>	537

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

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

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

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

GRAINAUTLINE – A SUPERVISED GRAIN BOUNDARY EXTRACTION TOOL SUPPORTED BY IMAGE PROCESSING AND PATTERN RECOGNITION

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Abstract

Marble provenancing is often based on stable isotopic ratios and maximum grain size (MGS). Methods for retrieving a reliable MGS value sufficiently accurate for provenancing require the observation of many grains. As this involves significant work, automation of the process is desirable. GrainAutLine, the software tool proposed in this paper is designed to find grain boundaries in a semi-automatic way and ensure high quality results. This allows marble provenancing approaches to use statistics derived from the exact boundaries, like grain-size histograms. GrainAutLine is like a very specialized drawing program featuring several sophisticated tools for boundary detection and correction. It allows the users to segment thin section, or other high resolution images including twin crystal lines and boundary discontinuities much faster than doing it manually. Segmentation results can then be exported into industry-standard shape files and further analyzed for example by GIS applications.

Keywords

marble, thin section, image segmentation, grain boundary, software tool

Introduction

The extraction of grain boundaries from marble thin sections is an important starting point for several material analysis applications. It is used, for example, to calculate maximum grain sizes (MGS) which has a long tradition in marble provenancing. Earlier, MGS was estimated with the naked eye (e.g. LEPSIUS 1890), later, thin sections were used (e.g. CRAMER 2004; UNTERWURZACHER *et al.* 2005). However, until some years ago, in most of the cases hardly any numerical results were published on this topic, and furthermore any description

of the method used to determine this very important parameter is an exception. In recent years some authors listed detailed results in their works, like (ZÖLDFÖLDI, SATIR 2003; CRAMER 2004; UNTERWURZACHER *et al.* 2005; ATTANASIO *et al.* 2006; MORBIDELLI *et al.* 2007; ZÖLDFÖLDI, SZÉKELY 2004; 2005; 2008; SZÉKELY, ZÖLDFÖLDI 2009). The most comprehensive database of maximum grain size with more than 1300 samples was published by ATTANASIO *et al.* (2006). Their measurement of marble grain size is generally based on the microscopic examination of the thin sections. Since a large number of samples needed to be measured, they used a simpler, rapid method. A cut and polished sample surface is treated with HCL 2N for approximately 30 seconds in order to display the edges of the crystalline grains more clearly. After the sample was rinsed and dried, the crystalline grains, or at least the largest of them, were observed with the aid of a normal reflecting microscope, equipped with a polarising filter. In this way the value of the MGS (maximum grain size), the maximum dimension of the largest microcrystal present in the sample, was measured in mm with the aid of a graduated eyepiece. In some cases, the observation value depends on the direction of the surface cut of the polished section, and for this reason it is often useful to compare the results from two different sections, with cuts that are perpendicular to each other. A series of controls was carried out by ATTANASIO *et al.* (2006) and shows that the classical thin section method and that just described provide MGS results in agreement to within 10 %. This is not true when an estimate of the average value of the crystalline grain size is necessary. Extremely small crystals, in fact, are difficult to observe due to reflection from the polished surface and this reduces the accuracy of the results.

CRAMER (1998) used a different approach while investigating the Telephosfries marbles. In his studies, he measured parameters of the grains along a traverse in the thin section. Of these grains, the longest diameters

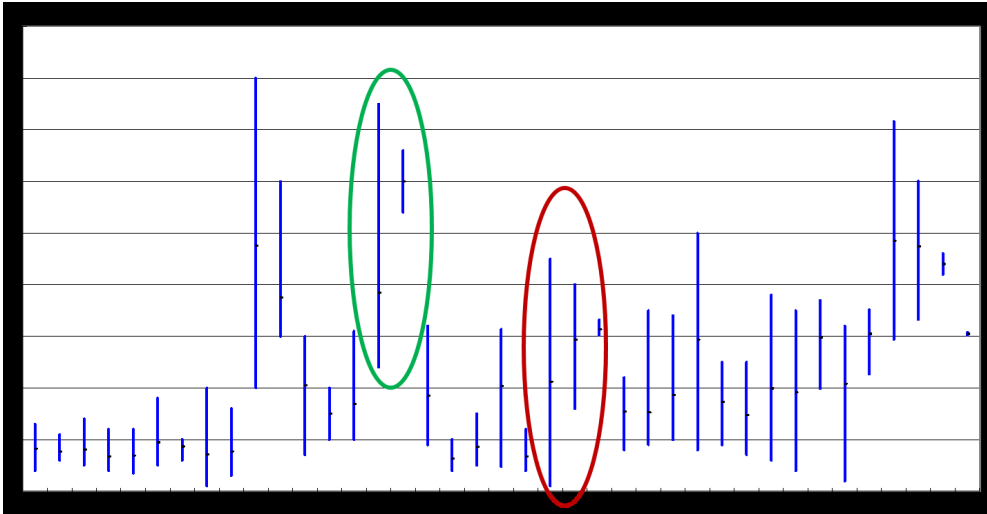


Fig. 1. MGS measurements may lead to significantly different results even from the same site, emphasizing the need for accurate and standardized measurement methodologies (data from CRAMER 2004; ATTANASIO 2006; ZÖLDFÖLDI 2011)

and, perpendicularly to them, the width of each grain was measured. In his approach, for some cases the “mean grain size” (the “mittlere Kornanschnitt”) was also derived, i.e., the measured distance was divided by the number of the grains that was crossed by the track of the traverse. This procedure can result in a smaller grain diameter than with the first procedure. A similar procedure was applied in (CRAMER 2004). However, the measurements were not carried out directly in the microscope. Average grain size (AGS) was calculated by dividing the measured distance by the number of the grains crossed along several measuring traverses on the enlarged image of the thin section. For determining the maximum grain size (MGS) the three biggest punches in each case were measured. The quotient from MGS and AGS can be a measure of the heterogeneity or homogeneity of the crystal lattice structure. Recognizing the ambiguity of the MGS parameter, Cramer used the second largest grain as an important property. These values of the second largest grain are of course lower, however, because of statistical reasons; they describe somewhat better the heterogeneous grain structure, because an isolated big grain cannot accidentally bias the values. Thus, the values often turn out to be larger in the second, which offers a more realistic picture.

Unfortunately, these methods often risk lower accuracy which may significantly influence the classification and the reusability of the results. Figure 1 shows some of the occurrences that were investigated by ATTANASIO (2006), CRAMER (2004) and ZÖLDFÖLDI (2011). For example, in the case of Aphrodisias (today Babadağ), Attanasio measured MGS between 0.2 to 4.5 mm, while Cramer measured MGS between 1.6 to 4 mm and Zöldföldi between 3.0 and 3.4 mm. Similarly, in the case of Proconessos (today Marmara), Attanasio measured MGS between 0.5 and 3.5 mm, but Cramer between 0.3 to 3.2 mm and Zöldföldi between 2.0 and 3.7 mm.

The currently used software methods for automatically drawing the grains are unable to recognize the calcite grains in the marble thin section, because the characteristic appearance of the calcite twinings. This is why a common approach is the manual drawing of the grain borders, which is a very time consuming procedure. In cases involving many samples, it is unsuitable. Mainly because the significant time requirement, many applications still use a simplified MGS calculation method to avoid the need for boundary extraction.

GrainAutLine is software designed for the automation of thin section evaluation using state-of-the-art image processing and pattern recognition technologies. It is a smart drawing application designed for drawing grain boundaries on a thin section image in a semi-automated way. Significant efforts have been invested into automatizing the boundary recognition and outlining of the grains, nevertheless it is designed with a strong emphasis on user-supervised operations. Every step performed by the automatic tools can be checked and proven or modified by the user, before it is finalized. This ensures a high quality output even if the software does not recognize all boundaries precisely.

High quality boundary extraction allows us not only the accurate estimation of MGS, but as the process is significantly faster than traditional approaches with the same accuracy, GrainAutLine opens a wide range of further applications which were too time consuming to start, until now. Having a fast and easy-to-use processing tool allows for example the analysis of 3 dimensional sequences of thin sections opening access to 3 dimensional reconstruction of the internal grain structures.

The remaining part of this paper is organized as follows: first we summarize the most important approaches for calculating the MGS value for a given marble sample. As we will see, highly reliable results require the measurement of many grains. This leads to

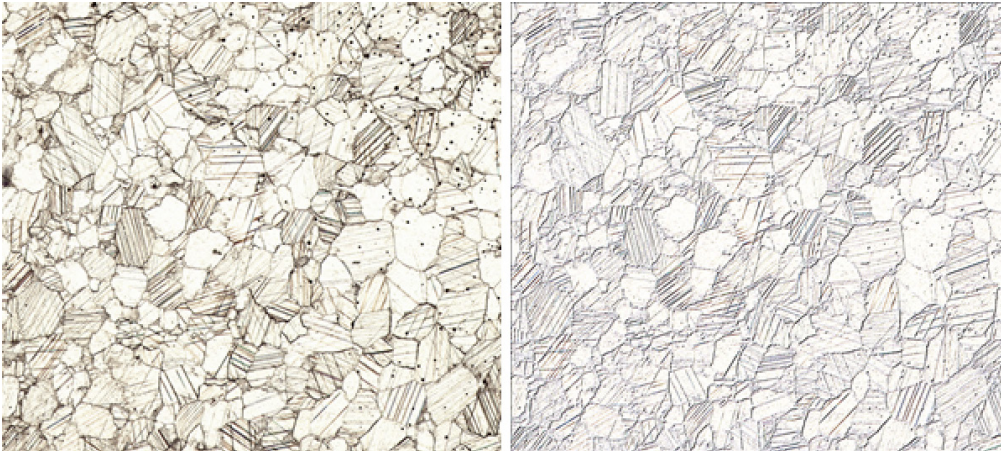


Fig. 2. A thin section image (left) and the result of edge detection (right). The presence of lines caused by crystal twinnings is the main reason why marble thin section images are still often processed by hand

the GrainAutLine tool we propose for accelerating this process. We first discuss the principal operation of our software solution, then we present experimental results. Finally, we summarize how the reader can start using our tool, and draw conclusions.

Related work

Several methods have been proposed for measuring MGS with various levels of available technology and accuracy requirements. The simplest method is pure visual observation; that is applied when the sampling of the artefact is not possible. This can be improved with microscopes providing a visual measurement grid overlaid on the sample. In a statistical sense, MGS is the maximal value of a probability distribution, a statistical parameter that is not robust: it depends highly on the selection of the sample. Another sample taken from the same piece of marble may have a single, very big grain, which leads to a completely different MGS value. Of course, visual inspection can handle such outlier cases, but especially in the case of a heteroblastic texture, this may lead to different results, and, consequently the result gets less and less objective and thus less reliable.

To overcome this instability in MGS, several improvements were proposed: as detailed above, CRAMER (2004) suggested drawing a line along the sample and measuring the grain diameters only along this line. By taking the average of the 3 maximum sizes, we get a more stable value than by taking only the maximum one. Unfortunately, in this case, we do not measure the maximum diameter of the grains, so we will get a somewhat consistent, but smaller value. Several other approaches were proposed in (MOLLI, HEILBRONNER 1999; GREEN *et al.* 2002; PENTIA *et al.* 2002; OESTERLING *et al.* 2007; ZÖLDFÖLDI 2011).

Finally, there are MGS calculation methods that take the sizes of all grains into consideration: (ZÖLDFÖLDI, SZÉKELY 2004; SZÉKELY, ZÖLDFÖLDI 2009)

suggest calculating a more robust statistic using the diameter histogram of the grains. Of course, this requires the measurement of all grains, but if this is available, one can calculate the MGS99 value which is the 99% percentile of the grain diameter distribution. As this measure discards the upper 1% grain sizes as potential outliers (which may be the case in a very heteroblastic texture), with respect to the selection of the sample it is expected to be much more robust than the other methods that do not take all grains into consideration. But in order to calculate the MGS99 value, one needs to know the complete grain size histogram or a significant part of it.

Extracting the grain boundaries is an image segmentation task: the original image has to be divided into several contiguous areas based on the image content. The most common approach to solve this is edge detection (BURGER, BURGE 2009). Usually, edges are recognized as a significant change in brightness relative to the surrounding image area. Using the relative change in brightness instead of absolute brightness is needed to adapt the segmentation method to possible slow brightness changes between different areas of the image.

If the grains can be expected to have different colors, a color-based segmentation approach (ROY CHOUDHURY, MEERE, MULCHRONE 2006, 363-375) may be also viable. In this case, boundaries are detected at significant color changes, avoiding problems arising from boundaries with low contrast parts. Low contrast boundaries may cause the edge-based segmentation to merge multiple grains if the boundary has some gaps.

Color-based segmentation is typically not suitable in the case of marble images, as the grains in our thin section images have similar color. There are some applications using images taken under polarized light that cause the different grains to glow under different polarizations, for example to identify the quartz grains in a sandstone, but it is not possible in the case of marble, because of the very inhomogeneous appearance of the calcite in polarized light, additionally to the problems of twins.

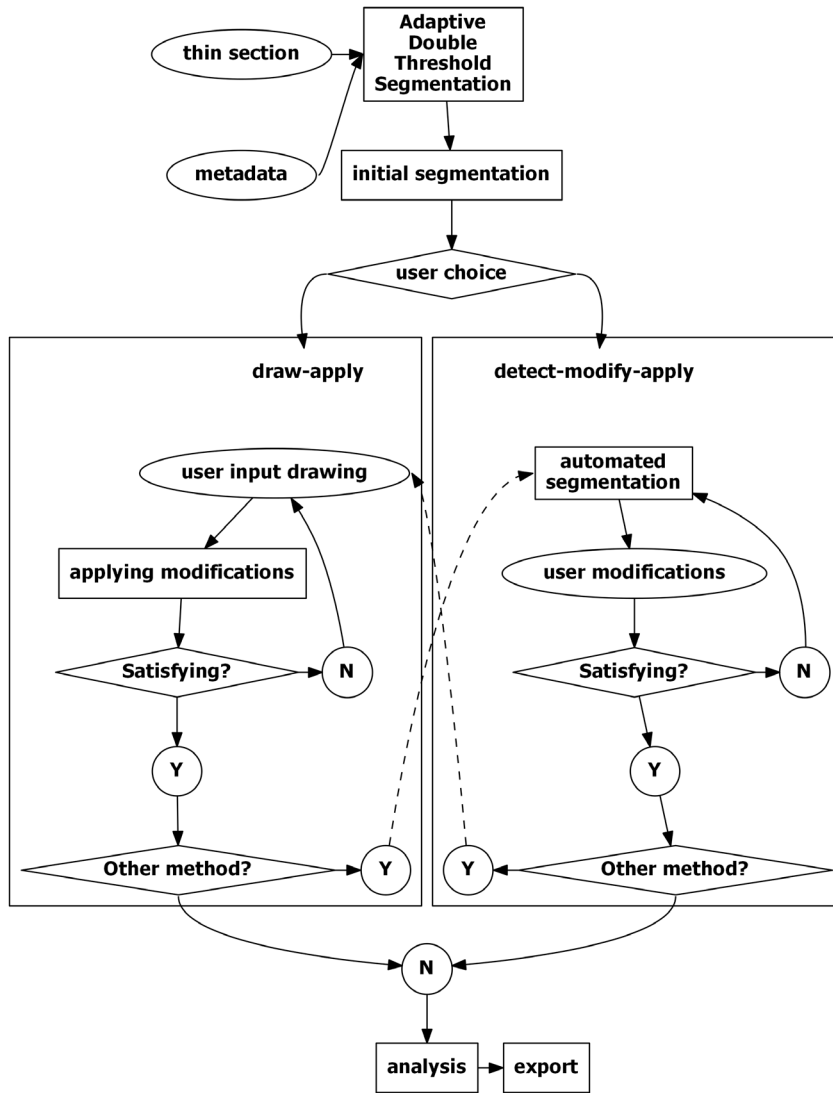


Fig. 3. Operation of GrainAutLine. A sequence of automatic and semi-automatic steps is applied to the image to achieve a final segmentation suitable for analysis

On its own, traditional edge detection based segmentation fails with marble thin sections due to the presence of crystal twinings as shown in Fig. 2: in many samples, high contrast lines cover the internal areas of the grains making edge detection methods divide these grains into many small pieces. This means, that edge detection cannot be used without additional means to overcome the twin crystal problem.

The operation of GrainAutLine

The principal operation of GrainAutLine is summarized in Fig. 3. The system uses the image of thin sections and possible metadata as input. Based on the image, automatic and semi-automatic tools help the user to create an accurate segmentation of the grains. As soon as the segmentation is ready, several options are available for further processing: on one hand, statistics can be calculated inside the software and exported, or on the other hand, the user can export the grain boundaries into files suitable to be imported into already well known GIS systems. This

allows access to the very wide range of analysis techniques provided by common GIS applications, independently of the statistics capabilities of GrainAutLine.

In this section we will introduce the most important tools available in the software tool named GrainAutLine. We describe the tools in the order of their typical application during a thin section segmentation. For the evaluation, we use the Miss Marble database (ZÖLD-FÖLDI *et al.*, 2011) containing many high quality thin section images of marbles collected from several sources.

To reliably ensure a clean segmentation result at the end, all tools provided by GrainAutLine follow one of the following two schema as shown in Fig. 3:

- detect-modify-apply: functions like finding boundaries and segmenting the image along these boundaries follow this concept. They involve some kind of automatic detection and then an operation based on this detection. Between the detection and the application of the results, GrainAutLine gives the user the opportunity to modify the detection results, so that the successive operation is applied using a correct detection.

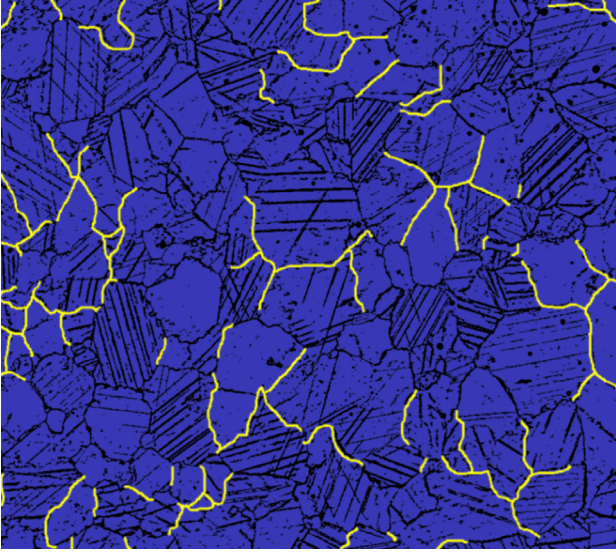


Fig. 4. Original thin section image and result of the Adaptive Double Threshold Segmentation as the initial segmentation step

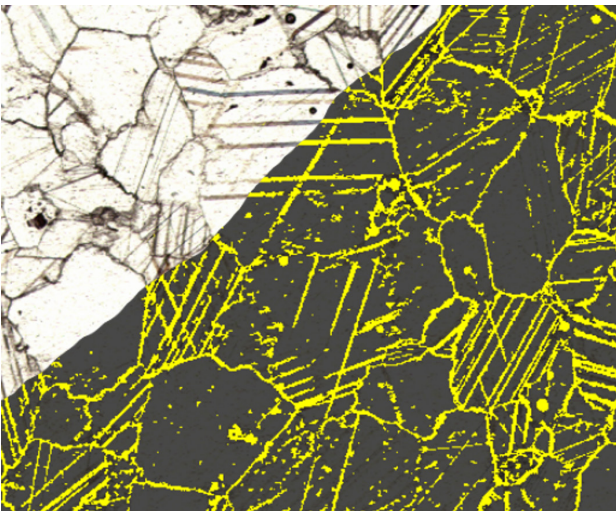


Fig. 5. Drawing additional lines that can be used to cut the blobs covering multiple grains

- draw-apply: there are operations that can be guided by the user via marking areas in the image. In these cases, the user can use drawing functions to prepare the operation before applying it.

Initial segmentation

Creating a clean and correct segmentation of a thin section image usually starts with an automatic, initial segmentation which is followed by manual correction steps to fix issues not handled by the fully automatic segmentation. Currently, GrainAutLine contains an Adaptive Double Threshold Segmentation algorithm (RUSS 2011) which can identify the grain boundaries

characterized by their darker color, compared to their direct surrounding. Adaptive means in this case that the image may have darker or lighter areas, and all of them will be handled correctly. The key idea behind double threshold segmentation is that we apply two segmentations: one with a looser threshold, finding more dark areas, and one with a strict threshold finding only a few, darker areas. The final result is built by selecting those connected areas marked by the loose threshold which also contain at least one dark enough area passing the strict threshold as well.

An example for the result of this initial segmentation is shown in Fig. 4. As expected, most boundaries are already found, but twin crystal lines and boundary discontinuities need further corrections.

Adding further boundaries

After the initial segmentation, GrainAutLine can collect the connected components of the image. We call these initial candidates for the grains blobs. The goal of all further steps is to make every grain completely covered by exactly one blob.

If the blobs and the real grains do not match, a combination of the following two cases is possible: either (1) multiple grains were merged into the same blob as their boundary had some gaps which made the two grains belong to a single connected component, or (2) a grain was cut into multiple blobs, for example by a twin crystal line. The first case can be easily solved by drawing the missing boundary into the image. The second case will be handled by merging multiple blobs as described later.

GrainAutLine allows the user to draw arbitrary lines on a separate image layer, called the Aux (Auxiliary) layer as shown in Fig. 5 with yellow lines. These lines can be later used for several operations. In this case, we can subtract these additional lines from the blobs: if a line crosses a blob, subtracting it from the blob will make that blob fall into multiple pieces. This way, cutting the blobs along missing grain boundaries is an easy task.

If two blobs belong to the same grain, they should be merged into one. Although adding a line connecting these blobs would make these blobs get connected, this operation would either require painting the whole false boundary by hand, or it would leave line segments inside the blob. A better solution is to use the merge tool in this case.

Merging blobs

A frequent case is where grains are divided into several blobs by twin crystals. The blob merge tool only needs the user to draw a single stroke of a line connecting every blob which should be merged into one. (Multiple lines are also allowed if they are easier to draw.) After

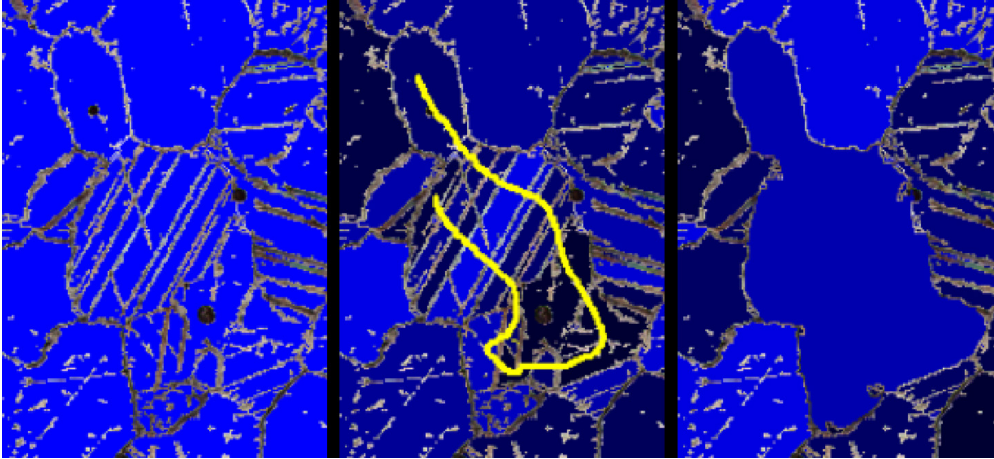


Fig. 6. Merging blobs with a quick stroke connecting the parts of the grain and using the blob-merge tool

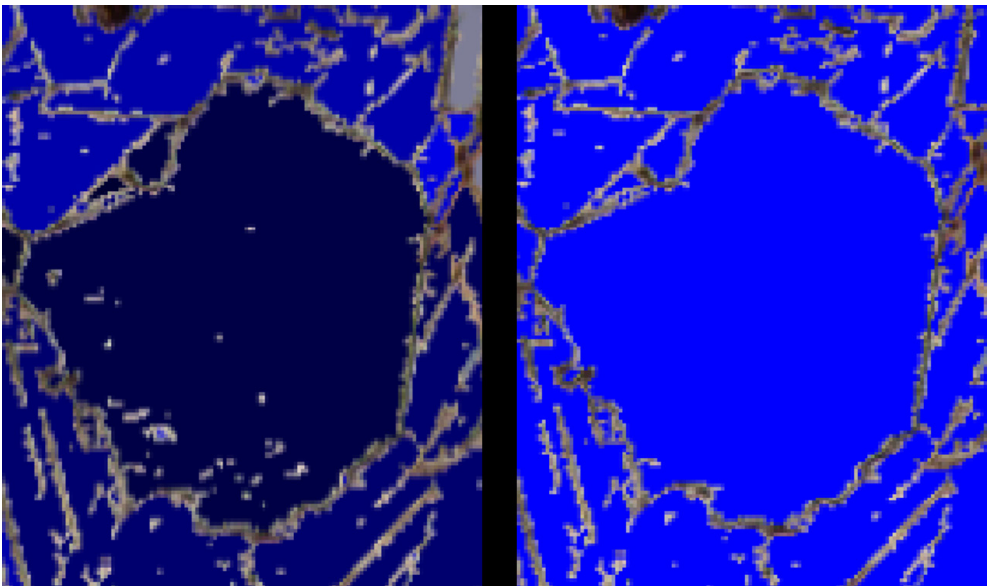


Fig. 7. The hole-filling function removes all boundaries inside the blobs making the segmentation clean and more suitable for the analysis

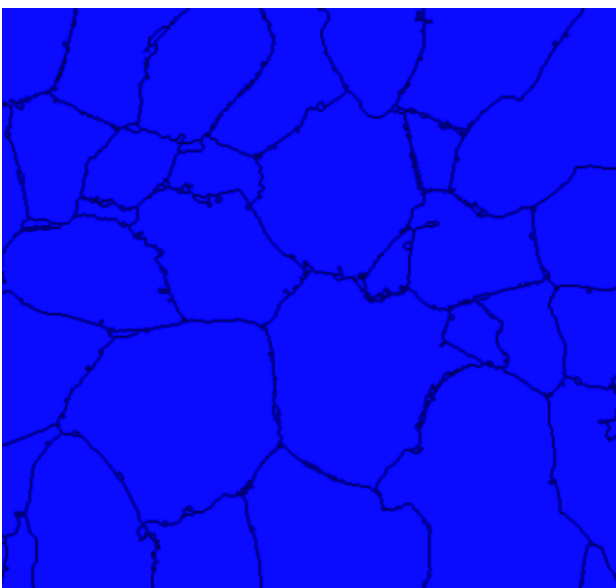


Fig. 8. Part of a clean segmentation of a thin section image processed with GrainAutLine

quickly connecting the to-be-merged blobs with strokes, the blob merge tool is used to merge all blobs connected by these lines. This operation takes care of the remaining unnecessary lines running inside the resulting blobs, ensuring a clean result. This operation is shown in Fig. 6. Using this tool is significantly faster than manually removing all undesired boundary segments.

Filling holes

There may be noises inside the grains that cause blob boundaries inside the blobs. Although these do not conflict with the goal of exactly one blob per grain, they disturb the segmentation and may distort the statistics generated based on it. Filling holes inside all or a set of grains is done by simply using the hole-filling tool as shown in Fig. 7. All boundaries not connected to the outer perimeter of the blobs are removed.

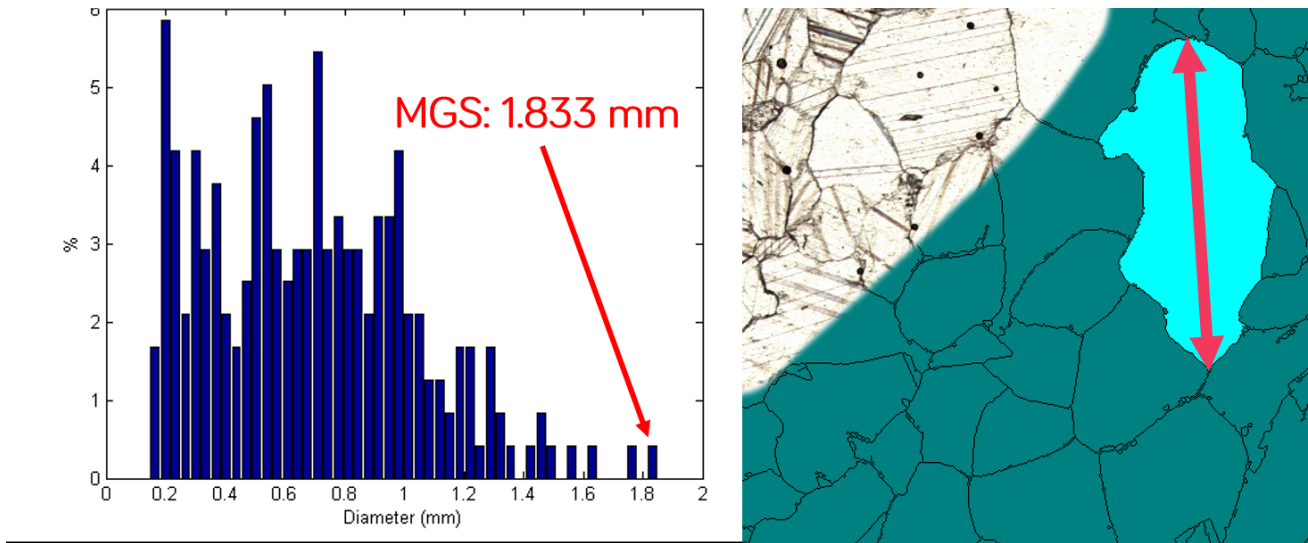


Fig. 9. Histogram of grain sizes retrieved from the resulting thin section segmentation. Although it is suitable to identify the maximal grain size, it opens a much wider spectrum of possibilities.

Further tools

GrainAutLine is still under active development, so the list of available tools is not final. Tools which are considered stable enough for our users are described in the online documentation in details. Such tools include closing narrow gaps between almost separated grains, automatic recognition of lines caused by crystal twinning, estimating boundaries in low-contrast images, and automatic removal of blobs below a given size to delete noise.

Results

In this section we present results achieved after successfully applying the tool set of GrainAutLine to a marble thin section image. As soon as the clean segmentation result shown in Fig. 8 was ready, it could be exported for further analysis. For convenience reasons, we provide an additional tool that can export the segmentation results from the GrainAutLine file format to standard ESRI Shape File format. This allows the user to perform the analysis in a common GIS system. This way, analysis is not limited by the capabilities of GrainAutLine.

First, we have chosen to investigate the histogram of the maximum grain diameters. Fig. 9 shows the results. The maximum value appearing in this histogram corresponds to the classic maximum grain size, but knowing the full histogram opens a much wider range of possible applications like calculating MGS99 mentioned before.

From the geometric point of view, in addition to the grain size determination, three parameter groups for classification can be integrated (e.g. SZÉKELY, ZÖLDFÖLDI 2009):

- measured grain parameters: long axis, short axis, perimeter, area, convex hull parameters (perimeter and area)
- derivative grain parameters: axial difference, orientation of the long axis, perimeter/area ratio, shape factor
- whole-image parameters: fractal dimension (box counting and information dimension), maximum grain size.

Knowing the grain boundaries makes shape and neighborhood analysis a simple task. Fig. 10 presents the histogram of the number of neighbors a grain has. Although it is less important for marble provenancing, several applications related to microstructure and porosity may benefit from such results, emphasizing the usefulness of GrainAutLine also outside the marble thin section analysis applications.

GrainAutLine as an open source project

GrainAutLine is an open-source project. It can be accessed via its website at <http://bmeaut.github.io/grainautline/>. Currently a version for Windows is available for download, the development of a Linux version is under consideration, depending on the demand of the community using provenancing techniques. The source code is also available to make it even more flexible and, to support potential collaboration in the development process. The website features an up-to-date user manual and step-by-step hints on how to start using the application. The development team has a strong ergonomic focus, so that one can learn quickly how to use the application.

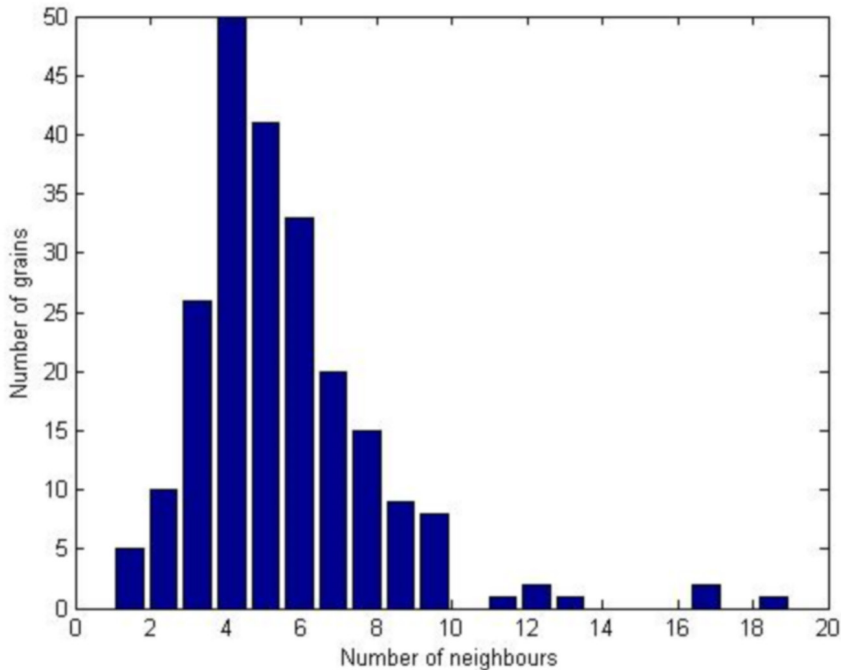


Fig. 10.
Further statistics can be calculated from the clean segmentation of the image including the histogram of the number of neighbors of the grains

Conclusions

Reliable provenancing requires reliable databases containing accurate MGS values for various marble sources. To get an accurate and reliable MGS value, standardized ways of measurement are needed. In a previously published approach, the MGS99 measure was proposed. Using the exact boundaries of 300-400 grains of the sample it is sufficiently reliable to be used in any marble provenancing project.

GrainAutLine is an open source application for the analysis of marble thin sections. Its primary goal is to create statistics from the grain boundaries. Due to twin crystals and possible low contrast grain boundary segments, the image segmentation cannot be absolutely correct, therefore in this tool it is performed in a supervised, semi-automatic way. Most of the work is done by automatic tools as far as is possible, on the other hand the user has full control over the process. The system allows the user to add manual corrections in every stage of the work. This way, the result can be guaranteed to be accurate and suitable for further evaluations.

Although the system can create statistics by its own, it also offers the option to export the grain boundaries into any common GIS application formats. This lets professionals use their well-known working environment for the later analysis steps.

Despite the fact that GrainAutLine was designed for the processing of marble thin sections, it has many generic image segmentation tools that are not limited to these kinds of images: several further geology and material technology related applications can benefit from its capabilities.

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