meter berechnet (Lage, Flächengröße, Hangrichtung, Hangneigung, Rauhigkeit), die dann später analysiert werden können. In den Gebieten rund um den Erdrutsch zeigen die Streichrichtungen der geologisch relevanten Ebenen eine gute Korrelation mit der Orientierung der Lineamente die auf ALS-DGMs kartiert wurden. Die Hauptstreichrichtung liegt ONO - WSW. Innerhalb des von der Massenbewegung beeinflussten Gebietes sind jedoch markante Unterschiede zwischen den geologischen Messungen und den Lineamenten erkennbar. Die OSO - WNW orientierten Lineamente auf den TLS-DGMs konnten nicht im Gelände kartiert werden. Die Ursachen für diese Abweichungen werden noch untersucht. Im Falle der automatischen Segmentierung zeigen Elemente im Bereich um die Massenbewegung herum ebenfalls gute Korrelation sowohl in den Streich-, als auch in den Fallrichtungen. Die Erkennung von steilen Störungsflächen innerhalb des Erdrutsches liefert vielversprechende Ergebnisse, die durch die Anpassung der Eingangsparameter noch verbessert werden könnten.
Die im Allgemeinen gute Korrelation der durch drei verschiedene Methoden kartierten Elemente (strukturgeologische Kartierung, Lineamentanalyse und Segmentierung) zeigen die Genauigkeit der LiDAR-Daten und die Verlässlichkeit der von diesen DGMs abgeleiteten Beobachtungen.

Dorninger, P. & Pfeifer, N. (2008): A Comprehensive Automated 3D Approach for Building Extraction, Reconstruction, and Regularization from Airborne Laser Scanning Point Clouds. - Sensors, **8** (11): 7323-7343.

Maximum Grain Size (MGS) in marble provenance studies: various methods and their influence on the results - a review

Zöldföldi, J.[1], & Szekely, B.[2,3]

[1] Institut für Geowissenschaften, Universität Tübingen, Wilhelmstr. 56, 72074 Tübingen, Germany;
[2] Institut für Photogrammetry und Fernerkundung, Technische Universität Wien, Gußhausstr. 27-29, 1040 Wien, Austria;
[3] Department of Geophysics and Space Science, Eötvös University, 1117 Budapest, Pazmany P. setany 1/C., Hungary

The Maximum Grain Size (MGS) analysis, a technique that is based on the finding and measurement of the largest grain in a polished surface or in this section of a stone sample, has been found as a straightforward, and often decisive provenance method in marble provenance (e.g., Schmid et al 1995). Owing to the successful provenance determinations in Mediterranean marbles (e.g., Moens et al. 1988), numerous authors have started to publish their results measured primarily on material from classic antique marble quarries and important historic artefacts (e.g., Perugini et al. 2003, Zöldföldi & Satir 2003, Cramer 2004; Unterwurzacher et al. 2005, Attanasio et al. 2006, Morbidelli et al. 2007, Zöldföldi & Szekely 2004, 2005, 2008, Szekely & Zöldföldi 2009). Despite the numerous contributions and the high number of published MGS values, for the most studied marbles like e.g., Proconnesian (Marmara), Penteli, Naxos and Carrara types, there is some discrepancy in the data and this is often beyond the expected scatter (Perugini et al. 2003, Szekely & Zöldföldi 2009). The purpose of this paper is to tackle the problem of various measurement techniques and their possible effect on the MGS values.
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 having rinsed and dried the sample, the crystalline grains, or at least the largest of them, have been observed with the aid of a normal reflecting microscope, equipped with a polarising filter. In this way the value of the MGS, the maximum dimension of the largest microcrystal present in the sample, have been 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 they show that the classical thin section method and that just described provide MGS results in agreement 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 investigating of the Telephosfries marbles. He measured parameters of the grains along a traverse in the thin section. Of these grains the longest diameters and perpendicularly to those the width of each grain was measured. In his approach, for some cases the „mean grain size“ („*mittlere Kornanschnitt*“) was also derived, that means, 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 crossed grains 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 bias accidentally the values. Thus, the values often turn out to be larger in the second that offers a more realistic picture. However, using the second largest, and not a certain

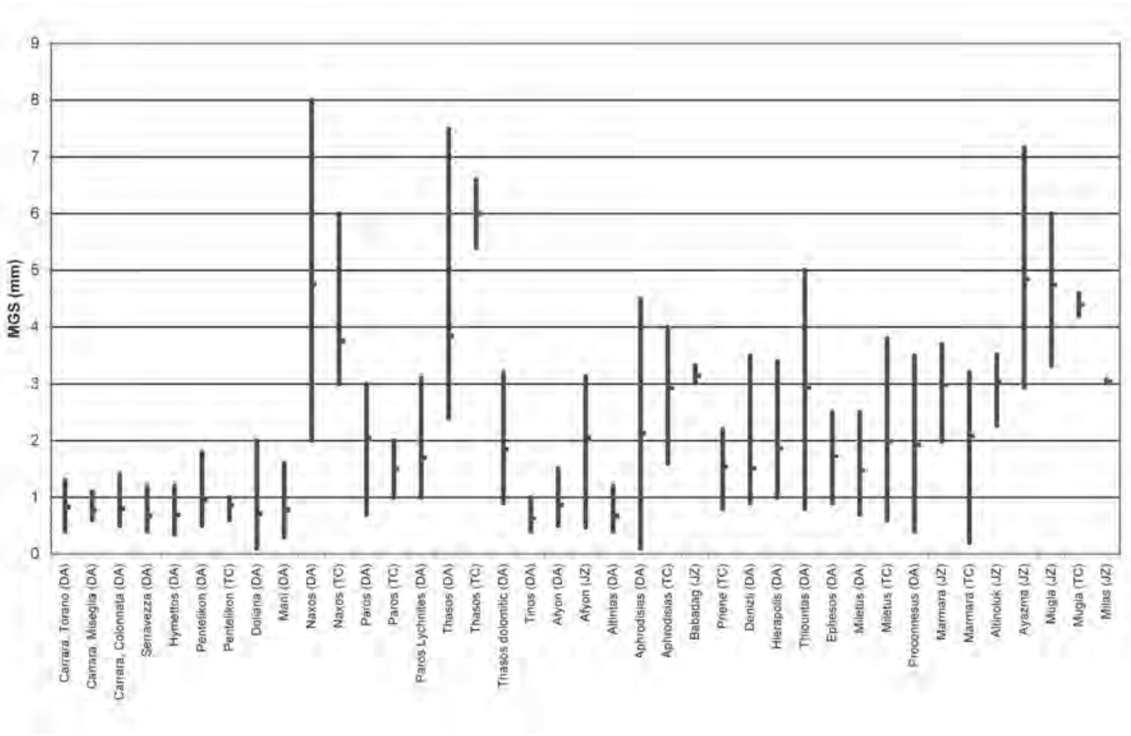

Fig. 1: Range of the maximum grain size (MGS) for the investigated quarry districts based on the databases of Attanasio et al. 2003 and 2006 (labelled as DA on the X-axis), Cramer 2004 (labelled as TC on the X-axis) and own measurements (labelled as JZ on the X-axis and partly published in Szekely & Zöldföldi 2009, Zöldföldi & Szekely 2004, 2005, 2008).

quantile of the distribution, introduces a further type of ambiguity depending on the crystal texture.

The databases published by Attanasio (2003) and Attanasio et al. (2006) and by Cramer (2004) were compared with the results of our work (Zöldföldi & Szekely 2003, 2004, 2005, 2008) using the MissMarble data base (Zöldföldi et al. 2008). By carrying out this comparison, however, we must keep in mind that different methods have been used to determine MGS values, therefore the results of the investigation are very inconsistent. Figure 1 shows some of the occurrences that were investigated in the framework of the aforementioned studies. For example, in the case of marble of Aphrodisias (today Babadag), Attanasio measured MGS 0.2 to 4.5 mm, Cramer 1.6 to 4 mm and in our previous work MGS ranged between 3 and 3.3 mm were measured. Similarly, in the case of Proconessos (today Marmara), Attanasio measured MGS between 0.5 and 3.5 mm, Cramer 0.3 to 3.2 mm; while the results in this work have closer interval, namely between 1.9 to 3.7 mm.

Tests were carried out for a random selection from real data sets, where the complete distribution of grain sizes were available. The conclusion of these studies is that in the cases in which a tendency for heteroblastic texture exist, MGS values scatter considerably, and this effect can be so significant that for some marble types it is not a good provenance indicator anymore.

Recognizing this inconsistency we proposed to use a statistically more robust parameter $MGS_{99\%}$ which is the 99 % quartile of the grain size distribution (Szekely & Zöldföldi 2009). Considering that the number of grains present in a normal sample can reach the order of magnitude of 1000-2000, $MGS_{99\%}$ would pick the 10th largest crystal that gives a quite robust estimate.

Despite the advantages of this property, it is not expected that the most important marble occurrences and even if the artefacts were analysed with respect to this parameter in the near future, the archive data are not comparable anyhow. We also tried to evaluate the $MGS/MGS_{99\%}$ ratio and it correlates with the fractal dimension of the outlines of the crystal texture that is again a measure of heteroblasticity.

The results show that the standardisation of the MGS determination is imperative if we aim at integration of these data into large data bases. Furthermore, the archive data has to be considered a little more cautiously, especially if the presented data/samples for a single rock type or artefact is not enough numerous.

Attanasio, D., Brilli, M. & Ogle, N. (2006): The Isotopic Signature of Classical Marbles. - (L'Erma di Bretschneider) Roma.

Cramer, T. (1998): Die Marmore des Telephosfrieses am Pergamonaltar. - Berliner Beiträge zur Archäometrie, **15**: 95-198, Berlin.

Cramer, T. (2004): Multivariate Herkunftsanalyse von Marmor auf petrographischer und geochemischer Basis. - Doctoral Thesis Technical University Berlin, Berlin.

Moens, L., Roos, P., De Rudder, J., De Peape, P., van Hende, J., & Waelkens, M. (1988): A multimethod approach to the identification of white marbles used in Antique artifacts. - (In: Herz, N. & Waelkens, M. **(**Eds): Classical Marble:

Geochemistry, Technology, Trade), NATO ASI Series E, Applied Sciences, **153**: 243-250, (Kluwer Academic Publishers) Boston.

Morbidelli, P., Tucci, P., Imperatori, C., Polvorinos, A., Martinez, M.P., Azzaro, E. & Hernandez, M.J. (2007): Roman quarries of the Iberian peninsula: „Anasol“ and „Anasol“-type. - European Journal of Mineralogy, **19**: 125-135, Stuttgart.

Perugini, D., Moroni, B., & Poli, G. (2003): Characterization of marble textures by image and fractal analysis - (In: Lazzarini L. (Ed.): ASMOSIA VI, Interdisciplinary Studies on Ancient Stone), Proceedings of the 6th International Conference of the Association for the Study of Marble and Other Stones in Antiquity), 241-246 (Bottega d'Erasmo Aldo Ausilio Editore) Padova.

Schmid, J., Ramseyer, K. & Decrouez, D. (1995): A new element for the provenance determination of the white marble: Quantitative Fabric Analysis - (In: Schvoerer, M. (Ed.): ASMOSIA IV, Archeomateriaux), Marbres et Autres Roches, Actes de la IVème Conference Internationale, de l'Association pour l'Etude des Marbres et Autres Roches Utilises dans le Passe), 171-175 (Presses Universitaire de Bordeaux) Bordeaux.

Szekely, B. & Zöldföldi, J. (2009): Fractal analysis and quantitative fabric analysis database of West Anatolian white marbles - (In: Maniatis, Y (Ed.): ASMOSIA VII), Proceedings of the 7th International Conference of Association for the Study of Marble and Other Stones in Antiquity), Bull. Corresp. Hellenique Supplement, **51**: 719-734, Athens.

Unterwurzacher, M., Polleres, J & Mirwald, P. (2005): Provenance study of marble artefacts from the roman burial areas of Faschenforf (Carinthia, Austria). - Archaeometry, **47** (2): 265-273, Oxford.

Zöldföldi, J., Hegedüs, P. & Szekely, B. (2008): Interdisciplinary data base of marble for archaeometric, art historian and restoration use - (In: Yalcin, Ü., Özbal, H & Pasamehmetoglu, G. (Eds.): Ancient Mining in Turkey and the Eastern Mediterranean), (Atilim University) Ankara.

Zöldföldi, J & Satir, M. (2003): Provenance of white marble building stones in the monuments of the ancient Troia - (In: Wagner, G.A., Pernicka, E., Uerpmann, H.P. (Eds.): Troia and the Troad), (Springer) Berlin.

Zöldföldi, J. & Szekely, B. (2004): Kiserlet a nyugat-anatoliai tektonikai egyegek kvantitativ texturaelemzesen alapulo szetvalasztasara regeszeti szarmazasvizsgalati szempontbol. (An attempt to separate Western Anatolian tectonic units based on Quantitative Textural Analysis for archaeological marble provenance; in Hungarian). - Archeometriai Mühely, **1**(1): 22-26, Budapest. (available on-line at www.ace.hu/am)

Zöldföldi, J. & Szekely, B. (2005): Quantitative Fabric Analysis (QFA) and Fractal Analysis (FA) on marble from West-Anatolia and Troy. - Proceedings of the 33rd International Symposium on Archaeometry, 22-26 April 2002, Amsterdam. Geoarchaeological and Bioarchaeological Studies, **3**: 113-119, Amsterdam.

Zöldföldi, J. & Szekely, B. (2008). Quantitative Fabric Analysis (QFA) on marble from West Anatolia: Application of raster- (fractal) and vector-based (geometric) approaches. - (In: Facorellis, Y., Zacharias, N. & Polikreti, K. (Eds.), Proceedings of the 4th Symposium of the Hellenic Society for Archaeometry, National Hellenic Research Foundation, Athens, 28-31 May 2003), Archaeological Reports Int., **1746**: 413-420, (Archaeopress), Oxford.