Israel Museum Studies in Archaeology 10 · 2020–21

Appendix: Marble Analysis

Yannis Maniatis
Laboratory of Archaeometry, National Centre for Scientific Research, "Demokritos," Athens

Dimitris Tambakopoulos
Laboratory of Archaeometry, National Centre for Scientific Research, "Demokritos," Athens

Introduction

A larger than life-sized marble head of Alexander the Great from the site of Beth Shean (ancient Nysa-Scythopolis), Israel, was subjected to analysis in order to scientifically identify the source of the marble used for its manufacture. A sample was received from the head and submitted to our laboratory in 2016 by Dr. Irene Bald Romano, with the permission of the Israel Museum, Jerusalem. This study was designed to determine the quarry of origin of the marble and provide possible evidence for its date of manufacture – depending on whether the periods of exploitation of the specific quarry are known.

Sample and Techniques

The sample was taken from beneath the neck of a larger than life-sized male head (IAA 1931-7) from ancient Nysa-Scythopolis, Tel Beth Shean, currently on display in the Israel Museum, Jerusalem, identified as a Hellenistic portrait of Alexander the Great from the third to first century BCE. The head belongs to a Roman statue of Alexander the Great, probably dating to the later second or early third century CE (as discussed by Romano et al. above).

The sample was analyzed using the following techniques:[1]

1. Measurement of Maximum Grain Size (MGS) and Most Frequent Grain Size (MFS) under a stereoscopic microscope and qualitative examination of the marble crystalline features.
2. Electron Paramagnetic Resonance Spectroscopy (EPR).
3. Stable Isotope Analysis of carbon and oxygen using Isotope Ratio Mass Spectrometry (IRMS).

MGS Measurements and Sample Preparation

The sample was examined under an optical microscope at the Laboratory of Archaeometry, and the MGS, MFS, and the marble crystallization features were measured and assessed. The superficial weathered layer of the sample was then

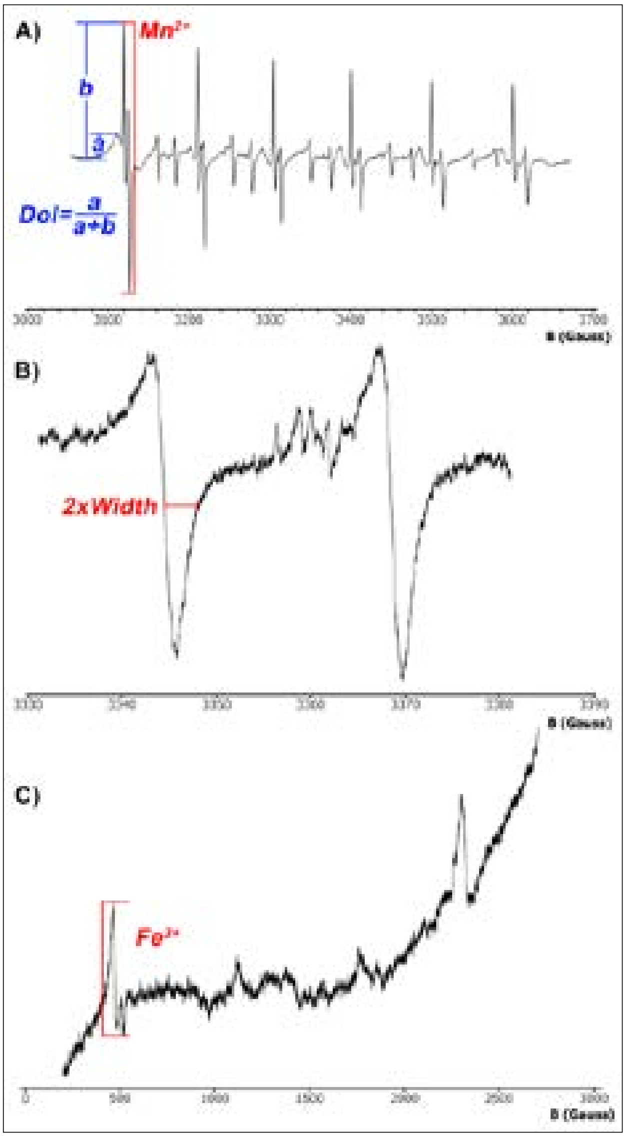

Fig. 1 The three spectra obtained with EPR spectroscopy at different magnetic field regions showing the measured parameters: *Mn^{2+}* is measured from the intensity of the first doublet (spectrum A); *Dol* is the approximate percentage of dolomite present in the calcitic marble and is measured from the relative intensities of the two peaks shown in Spectrum A; *Width* is measured as one-half of the full width at half maximum of the 5th forbidden peak (Spectrum B); and *Fe^{3+}* is measured at the low-field region as shown in Spectrum C. For more details see Polikreti and Maniatis 2002 and Tambakopoulos and Maniatis 2017

mechanically cleaned, and the clean sample was ground gently in an agate mortar and sieved to retrieve fractions between 63 and 180 µm for the EPR analysis. A finer fraction aliquot, less than 63 µm, was also collected during the sieving for the stable isotope analysis.

EPR Analysis

As described in Polikreti and Maniatis[2] and Tambakopoulos and Maniatis,[3] three spectra were obtained for the powder sample at different operating conditions using an X-Band EPR spectrometer (EPR BRUKER ER-200) operating at approximately 9.4 GHz (fig. 1). From these spectra we measured the height of the first peak of the sextet of the Mn^{2+} in relative units (parameter *Mn^{2+}*), the half-width at half maximum of the 5th "forbidden" peak in Gauss (parameter *Width*), the height of the peak with g = 14.25 in relative units (parameter *Fe^{3+}*), and the type of marble (calcitic or dolomitic) was evaluated from the line shape. The percentage of dolomite in the sample, if it was present, was estimated from the low magnetic field peak of the sextet as shown in figure 1.[4]

Stable Isotope Analysis

The isotopic ratios of $^{13}C/^{12}C$ (parameter $\delta^{13}C$‰) and $^{18}O/^{16}O$ (parameter $\delta^{18}O$‰) were measured at the Department for Applied Geosciences and Geophysics, University of Leoben, Austria, by Professor Walter Prochaska, using an IRMS analyzer with a multiple collector,[5] and compared to the international standard PDB (Pee Dee Belemnite).

Databases

The results of the above analyses were compared to the data for known ancient marble quarries from Greece, Turkey, Italy, Portugal, Spain, and Morocco accumulated over the last 30 years by measurements at the Laboratory of Archaeometry, NCSR "Demokritos"[6] and by data published in the literature.[7] Our EPR data was integrated and amalgamated with that from Attanasio 2003 and Attanasio et al. 2006 by using as a theoretical standard the mean value of Mn^{2+} of all the Penteli samples from each laboratory, given the large number of the analyzed samples (161 for Attanasio and 277 for Demokritos).

Table 1 Results of the Optical and Physicochemical Analyses

Object	Marble	MGS (mm)	MFS (mm)	Mn^{2+} (r.u.)	Width (Gauss)	Fe^{3+} (r.u.)	Dol (%)	$\delta^{18}O$ (‰)	$\delta^{13}C$ (‰)
IAA 1931-7 (head)	Whitish, medium-grained, very well-crystallized, homoblastic	2.0	1.0–1.5	600.94	2.40	11.91	n.d.	–3.50	2.25

n.d. = not detected

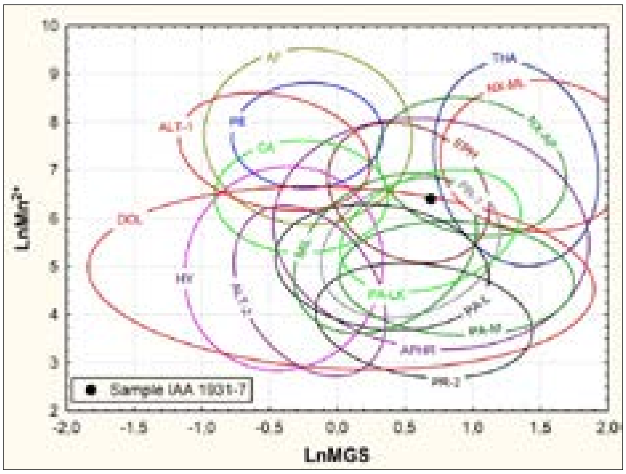

Fig. 2 Diagram of the natural logarithm of Mn^{2+} vs. the natural logarithm of MGS for sample IAA 1931-7 and the ancient marble quarry fields of: Dokimeion/Afyon (AF), Penteli (PE), Altintas (ALT-1/2), Carrara (CA), Hymettos (HY), Doliana (DOL), Aphrodisias (APHR), Ephesos (EPH), Miletos (MIL), Proconnesos (PR-1/2), Paros (PA-LK/L/M), Thasos (THA), Naxos (NX-AP/ML). The ellipses represent 95% probabilities

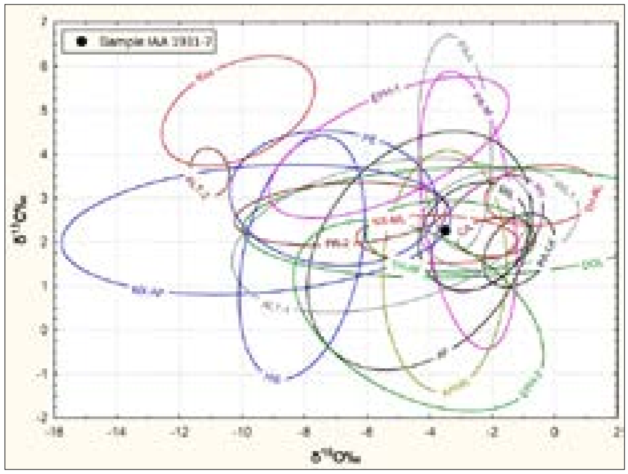

Fig. 3 Diagram of the isotopic signature $\delta^{13}C$‰ vs. $\delta^{18}O$‰ for sample IAA 1931-7 and the isotopic fields of the ancient marble quarries of: Dokimeion/Afyon (AF), Penteli (PE), Altintas (ALT-1/2), Carrara (CA), Hymettos (HY), Doliana (DOL), Aphrodisias (APHR), Ephesos (EPH-1/2), Miletos (MIL), Proconnesos (PR-1/2), Paros (PA-LK/L/M), Thasos (TH-AL/AF), Naxos (NX-AP/ML), Kos and Hierapolis (HIE). The ellipses represent 95% probabilities

Results

The results of all the analyses are listed in Table 1. The optical examination of the sample showed that the marble is medium-grained (MGS = 2.0 mm and MFS = 1.0–1.5 mm), whitish in color, well-crystallized, and of a homoblastic texture. No dolomite peaks were detected in the EPR spectrum of the sample, so it is clear that the marble is purely calcitic. We then compared statistically the Mn^{2+} parameter from EPR and MGS from optical measurements, using the logarithms of these values as best representing the natural distribution in the quarries,[8] against the equivalent parameters of all known ancient quarries (fig. 2). As can be seen from this diagram there are a number of possible quarries of origin, namely Aphrodisias, Miletos, Proconnesos, Ephesos, Paros-Lakkoi, and Naxos-Apollon. Next, we compared the isotopic signature of the sample against the isotopic field values of

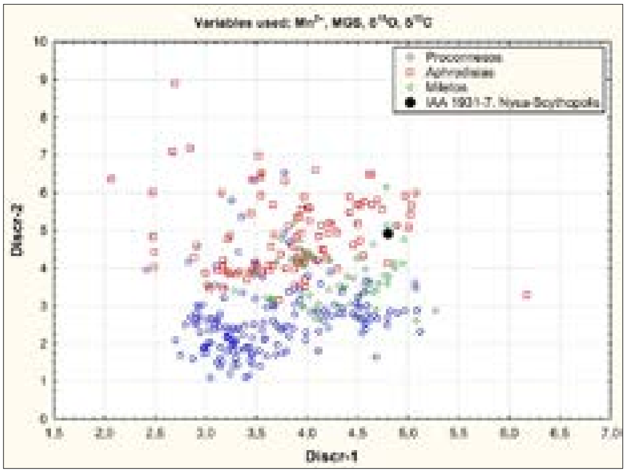

Fig. 4 Diagram of variables derived from discriminant analysis for sample IAA 1931-7 and its three probable quarries: Aphrodisias, Miletos, and Proconnesos

the known ancient quarries (fig. 3). Here again the isotopic values of the sample plot in a region where several quarries of origin are possible. However, using the exclusion principle there are only three quarry regions that are compatible with all the databases: EPR, MGS, isotopes – Aphrodisias, Miletos and Proconnesos – and hence these are the only possibilities for the origin of the marble.

In order to further narrow the possible quarries, we performed discriminant analyses, with StatSoft Statistica v.8.0.360, using several parameters together for the sample and the three possible quarries. The results are presented graphically in the diagram of figure 4. As can be seen, the sample falls practically outside the Proconnesos field point distribution, but inside those of Aphrodisias and Miletos. The program returned the following probabilities: 61% for Aphrodisias, 33% for Miletos, and 6% for Proconnesos.

Discussion

The results of the isotopic, spectroscopic analyses, and statistical treatment of the marble of the larger than life-sized Alexander head (IAA 1931-7) point to an Aphrodisias origin. Furthermore, its marble characteristics, medium-grained whitish marble with very good crystallization, grains well defined and with mostly straight boarders, with no inter-grain material, further strengthen the Aphrodisias option. Regarding the two other options given by the analyses with lower probabilities, we can note the following: For Proconnesos, the fact that the sample falls entirely outside the Proconnesos distribution field points (fig. 4) with the very low (6%) theoretical probability, calculated only because there is certain proximity of the field points, makes that option negligible. In addition, the marble characteristics of Proconnesos are essentially different, so on the whole we can safely exclude this possibility entirely. Miletos, on the other hand, cannot be excluded physicochemically, although it has a lower probability. However, the marble from Miletos as described by Attanasio et al.[9] is gray or of various shades of gray and rarely white and is of inferior quality. This could further largely reduce the Miletos possibility, but not entirely dismiss it. Therefore, the most probable provenance of the marble of the Alexander head is Aphrodisias, with a second option but with a much lower probability for Miletos.

Dating Suggestions

Acknowledging Aphrodisias as the probable provenance of the marble head, a few interesting clues about its dating emerge. Although, Aphrodisian marble was used locally from pre-Hellenistic and early Hellenistic times, it was largely exploited only after the later first century BCE for the construction of the Temple of Aphrodite and other buildings in the city,[10] as well as for the construction of the *scaenae frons* of the theater at Nysa (Sultanhisar, Turkey), some 40 km southwest of Aphrodisias.[11] Furthermore, a female head discovered in Gerasa, northern Jordan (77 km from Nysa-Scythopolis and another city of the Decapolis, of which Nysa-Scythopolis was the administrative capital), probably dating to the second–third century CE, was identified as Aphrodisian marble.[12] Therefore, it is reasonable to suggest that the marble of Aphrodisias was exported during later times to this region. Consequently, a dating later than the first century BCE for the head would be more realistic than the third–first century BCE date suggested in various sources.[13]

Conclusions

With the combined use of three techniques and statistical analyses the marble provenance of the larger than life-sized head of Alexander from ancient Nysa-Scythopolis was narrowed down to three possible origins. Using further qualitative criteria, we identified the most likely quarry of origin as that of Aphrodisias in Asia Minor. Consequently, in view of the history of that quarry and other evidence for Aphrodisian marble found outside Asia Minor, a date for the manufacture of the head can be suggested after the first century BCE.

Notes

1 Maniatis 2004.

2 Polikreti and Maniatis 2002.

3 Tambakopoulos and Maniatis 2017.

4 Tambakopoulos and Maniatis 2017.

5 Craig and Craig 1972; Allison et al. 1995; Attanasio et al. 2006.

6 Polikreti and Maniatis 2002; Maniatis et al. 2012.

7 Herz 1987; Gorgoni et al. 2002; Lazzarini and Antonelli 2003; Attanasio 2003; Attanasio et al. 2006; Lazzarini and Malacrino 2010.

8 Polikreti and Maniatis 2002.

9 Attanasio et al. 2006.

10 Long 2012.

11 Toma 2018.

12 Al-Bashaireh 2018, sample no. 13 (1688; G1188) with no context.

13 See Romano above.

Bibliography

Al-Bashaireh, K.
2018 Archaeometric Characterization and Provenance Determination of Sculptures and Architectural Elements from Gerasa, Jordan. *Applied Physics A*, 124: 135–38.

Allison, C. E., Francey, R. J. and Meijer, H. A. J.
1995 Recommendations for the Reporting of Stable Isotope Measurements of Carbon and Oxygen in CO_2 Gas. *Reference and Intercomparison Materials for Stable Isotopes of Light Elements*, *IAEA-TECDOC 825*, 155–62. Vienna.

Attanasio, D.
2003 *Ancient White Marbles: Analysis and Identification by Paramagnetic Resonance Spectroscopy*. Rome.

Attanasio, D., Brilli, M. and Ogle, N.
2006 *The Isotope Signature of Classical Marbles*. Rome.

Craig, H., and Craig, V.
1972 Greek Marbles: Determination of Provenance by Isotopic Analysis. *Science* 176/4033: 401–3.

Gorgoni, C., Lazzarini, L., Pallante, P., and Turi, B.
2002 An Updated and Detailed Mineropetrographic and C-O Stable Isotopic Reference Database for the Main Mediterranean Marbles Used in Antiquity. In *ASMOSIA 5: Interdisciplinary Studies on Ancient Stone – Proceedings of the Fifth International Conference of the Association for the Study of Marble and Other Stones in Antiquity*, eds. J. Herrmann, N. Herz, and R. Newman, 115–131. London.

Herz, N.
1987 Carbon and Oxygen Isotopic Ratios: A Data Base for Classical Greek and Roman Marble. *Archaeometry* 29/1: 35–43.

Lazzarini, L., and Antonelli, F.
2003 Petrographic and Isotopic Characterization of the Marble of the Island of Tinos (Greece). *Archaeometry* 45/4: 541–52.

Lazzarini, L., and Malacrino, C. G.
2010 The White Marble of Kos, Its Quarries and Archaeometric Characterisation. *Marmora* 6: 57–70.

Long, L. E.
2012 Regional Marble Quarries. In *Aphrodisias V, The Aphrodisias Regional Survey*, eds. C. Ratté and P. D. De Staebler, 164–202. Mainz.

Maniatis, Y.
2004 Scientific Techniques and Methodologies for the Provenance of White Marbles. In *Physics Methods in Archaeometry, Proceedings of the International School of Physics "Enrico Fermi,"* eds. M. Martini, M. Milazzo, and M. Piacenntini, 179–202. Amsterdam.

Maniatis, Y., Tambakopoulos, D., Wescoat, B. D., and Matsas D.
2012 The Sanctuary of the Great Gods on Samothrace: An Extended Marble Provenance Study." In *Interdisciplinary Studies on Ancient Stone, Proceedings of the IX Association for the Study of Marbles and Other Stones in Antiquity Conference*, eds. A. Gutierrez Garcia, P. Lapuente, and I. Roda, 263–78. Tarragona.

Polikreti, K., and Maniatis, Y.
2002 A New Methodology for the Provenance of Marble Based on EPR Spectroscopy. *Archaeometry* 44/1: 1–21.

Tambakopoulos, D., and Maniatis, Y.
2017 Determination of the Marble Source of Sculpture and Other Objects. In *ALASERNA VI, Sculpture, Stone Carving, Inscriptions,* ed. G. Kokkorou-Alevras, 205–38. Athens.

Toma, N.
2018 Aphrodisias and the Regional Marble Trade. The Scaenae Frons of the Theatre at Nysa. In *Interdisciplinary Studies on Ancient Stone*, *Proceedings of the XI ASMOSIA Conference, Split*, eds. D. Matetić Poljak and K. Marasović, 513–21. Split.