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MARBLE ANALYSIS AND PROVENANCE STUDY OF OBJECTS FROM THE NORTHWEST QUARTER OF THE DECAPOLIS CITY OF GERASA, JORDAN.

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Abstract:
This archaeometric study investigates the provenance of marble sculptures and architectural elements from the Northwest Quarter of Gerasa, Jordan, spanning the Roman and Byzantine periods. Fourteen samples were analyzed using macroscopic examination and various techniques, including optical and cathodoluminescence microscopy, X-ray diffraction, and mass spectrometry. The results revealed that the coarse-grained dolomitic marble from Thassos-3 Island (Greece) was used for the Roman sculpture of Artemis of the Rospigliosi type, the prestigious fine-grained calcitic Docimian marble (Iscehisar, Turkey) was used for an arm fragment of a Roman statue, while Proconnesian-1 or Parian-2 (Lakkoi, Paros Island) marbles were identified as probable sources for the molding of a wall revetment. Notably, the study revealed that Proconnesian-1 marble (Marmara, Turkey) is the most likely source for the medium- to coarse-grained marble used in eight architectural elements. However, the source of marble for the Byzantine sigma table fragment and the Corinthianizing pilaster capital remains uncertain. Despite the secondary use of these elements, the findings align with previous studies indicating that Proconnesian-1 marble was the primary imported marble source in the region, particularly in Gerasa and other Decapolis cities, during the Roman and Byzantine periods. The study also highlights the widespread use of Thassian-3, Docimian, and Parian marbles during the same period.

1. Introduction

Between 2011 and 2016 a Danish-German team conducted archaeological work in the Northwest Quarter of Gerasa, one of the famous Decapolis cities in modern northern Jordan, fig. (1) [1-4]. In total 24 trenches that were excavated during the five campaigns some marble fragments, all in non-primary contexts, were found and have already been published, tab. (1) [5,6]. In the wake of the excavations, a set of scientific analyses on the marble fragments were undertaken. These results are presented here and add significant knowledge about the provenance and import patterns in the region in antiquity. Gerasa, also known as Antioch on the Chrysorrhoas, was a middle-sized city in the Roman period, covered an area of approximately 85 hectares, enclosed by city. The city is best known for its monumental ruins, excavated in large parts by an American-British team in the early 20th century and again intensely from the 1980s onwards, starting with the Jerash Archaeological Project, which was supported, among others, by the UNESCO (For further references to the earlier investigations and historiography of the site see: [7,8]). The site of Gerasa was continuously occupied from antiquity until a devastating earthquake or potentially several ones that hit the city around the middle of the 8th century CE. Some occupation at the site seems to have gone on after the earthquake of 749 CE, however, the overall impression has been that large parts of the site was destroyed around this time and occupation would have contracted significantly (On this debate and for varying interpretations of the severeness of the earthquake and its consequences see: [8-10]). This is relevant since it holds significance for the way in which use and reuse of materials at the site can or cannot be studied in context. In the Northwest Quarter the marble fragments were all found in reused contexts: most used as building materials for later period buildings of the Byzantine to early Islamic periods and in one case middle Islamic period. Marble was not an indigenous stone in the Near East and all marble was therefore imported to the region either by sea- or land-borne transportation or a combination of both [11, 12]. It is widely assumed that Gerasa was tied into the same trade networks as the other cities in the region and that potentially even less marble would have reached an inland site, such as Gerasa, than a coastal site for example [13]. In Gerasa fragments of marble sculpture, architectural elements as well as inscriptions on marble have been published over time starting with some pieces published in Kraeling 1938 [1]. Publications of inscriptions on marble from the site were done even earlier than the Kraeling volume, but solely with a focus on their epigraphic value and not with any attention to the stone itself. The latest substantial publications on marble from Gerasa are the ones by Weber-Karyotakis [14-16]. Among the hitherto known marble objects from Gerasa, Roman sculpture has been analysed, underlining that a variety of quarries in Greece and Asia Minor and even Italy were the sources for the Roman sculptures [17-19]. Archaeometric studies on architectural elements from Gerasa suggest that the main source was Proconnesus [17]. This study carried out an archaeometric characterisation of 14 marble samples from the Northwest Quarter of Gerasa, using various analytical techniques to identify their sources.

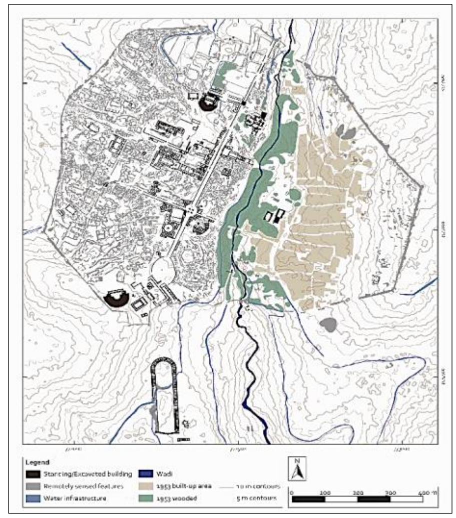


Figure (1) map of Gerasa (After: Lichtenberger, et al., 2019) [20].

Table (1) description of the studied samples [21]

S.N.	Description	Date	Photo	Reference	Provenance of the marble
1 (J16-Uc-60-42)	Fragment of sigma table	Byzantine		[5: 62 no. 1]	Uncertain
2 (2. J16-Wg-107-3x)	Fragment of decorated marble relief in champlevé technique	5th/6th century CE		[5: 63 no. 3]	Proconnesus-1
3 (J16-Vdf-73-14)	Corinthianizing pilaster capital/leaf capital ('Blattkranzkapitell')	5th/6th century CE		[77: 39 no. 39]	Uncertain
4 (J12-B-2-478)	Molding of a wall revetment	unknown		[77: 46 no. 60]	Proconnesus-1/ Paros-2
5 (J13-Fd-40-32)	Molding of a revetment	Roman		[77: 47 no. 62]	Proconnesus-1
6 (J14-Kc-3-134)	Molding	Byzantine		[77: 48 no. 63]	Proconnesus-1
7 (J16-Ud-1-25)	Molding, possibly of a wall revetment	Roman		[77: 49 no. 66]	Proconnesus-1
8 (J16-Vi-55-8)	Molding of a revetment	Roman		[77: 51 no. 70]	Proconnesus-1
9 (J15-Jl-32-11)	Decorated panel	Byzantine		[77: 54 no. 74]	Proconnesus-1
10 (J16-Wf-109-1)	Decorated slab	Byzantine		[77: 55 no. 76]	Proconnesus-1
11 (J15-Nm-76-3)	Molded slab	unknown		[77: 55 no. 77]	Proconnesus-1
12 (J16-Sh-63-1)	*Loculus* block for reliquary	Roman/Byzantine		[77: 57-58 no. 81]	Thassos-3
13 (J13-Da-10-2x)	Sculpture of Artemis, type Rospigliosi	2nd/3rd century CE		[6: 12-14 no. 1]	Thassos-3
14 (J15-Nm-76-4)	Fragment of arm	2nd/3rd century CE		[6: 15 no. 3]	Docimium

2. The Danish-German excavations in the Northwest Quarter

The Northwest Quarter is the highest area within the Roman period city walls and the history of the area is complex due to the reuse of both the hill as settlement as well as of the materials there, fig. (2). It is known that it was intensely exploited for quarrying most likely already at the latest in the early Roman period and it also held Roman period architectural complexes. However, it is the late Roman to early Islamic constructions that the area holds most of. These were entirely devastated by the mid-eighth century earthquake and the area was only resettled again in the middle Islamic period. Previous excavations in the Northwest Quarter have un-earthed many marble artefacts from various trenches. The marbles were used for sculptures and architectural elements and were dated to different periods. They vary in color from white to light grey and in grain size, indicating that they were imported from different sources. Many of the marble sources that were quarried in antiquity were white marble; therefore, it remains hard to distinguish between them based on their macroscopic characteristics, especially the artifacts with highly polished surfaces. Although macroscopic characteristics such as grey streaks and large grains, may assist in characterizing the sources of some marbles, it is the combination of different analytical techniques that allow the identification of the most probable marble sources [22-24]. In this study multiple archaeometric techniques were applied to characterize 14 marble samples and determine their sources. Even with only 14 samples the results widen our knowledge about the sources of the marbles used for sculptures and architectural components at Gerasa and therefore present a new dataset, which can be used in other comparative studies of imported marble in the region.

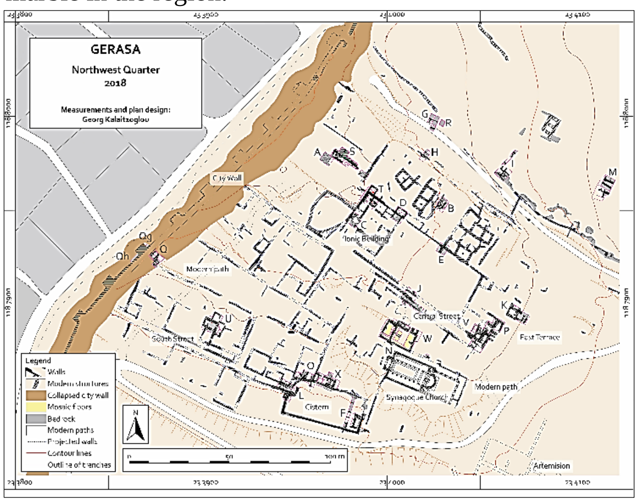


Figure (2) map of the Northwest Quarter of Gerasa with main features and trenches (*After: Danish-German Jerash Northwest Quarter Project*)

3. Materials and Methods

Fourteen marble samples were examined in this study. They were used to carve two sculptures: the torso of Artemis Rospigliosi type (sample 13) and a hand fragment, i.e. part of a statue (sample 14); and to produce 12 architectural elements (samples 1-12), tab. (1). One of the architectural elements, sample 1, is a fragment of a sigma table. The fragments analyzed in this study stem from ten different trenches (B, D, F, J, K, N, S, U, V & W) [25]. Five are dated to the Roman period, and two cannot be closely dated and the rest are late Roman/ Byzantine. Only two fragments in this study stem from sculptures in the round, tab. (1; nos. 13 and 14), one object, almost complete, has been identified as a possible loculus block for reliquaries and the rest stem from either decorative architectural elements or are molding fragments. Characteristic for all pieces, but the block, is that they have been heavily damaged, broken or cut into larger use than their primary functions. Small samples (approx. 2×2 up to 3 cm) were taken from each of the 14 marble artifacts listed in table 1 with chisel and hammer. After macroscopic examinations of the collected samples, they were subjected to a series of analytical methods including optical microscopy OM, X-ray diffraction XRD, and mass spectrometry MS. The results were compared to the main databases and studies on Mediterranean marble sources; for instance [26-38]. The mineralogical composition of the samples was identified on bulk powders using a Shimadzu Lab X, 6000 X-Ray Diffractometer (at Yarmouk University, Irbid, Jordan), under the following conditions: CuKα radiation (λ=1.5418Å) with 30 kV, 30 mA energy and Graphite Monochromatic. In addition, because of similarities of some samples in macroscopic feature and function, the calcite $CaCO_3$/dolomite $CaMg(CO_3)_2$ content of samples 6, 9 and 10 was examined by the diluted hydrochloric acid test on powder, where instant bubbling and fizz indicate calcite, and low bubbling and no fizzing indicate dolomite. Thin-section examinations using a Leica DMLSP polarizing microscope were adapted to identify petrographic parameters of important diagnostic significance for marble; fabric, maximum grain size (MGS) of calcite or dolomite grains and their boundary shapes (GBS) [39-41]. Thin sections were prepared according to the standard procedures [42] in the workshop of the faculty of Archaeology and Anthropology at Yarmouk University, Irbid, Jordan. Cathodoluminescence (CL) was conducted, using the settings of Wielgosz-Rondolino et al. [38], on selected thin sections of samples (1,3,4) to examine their debated sources and sample 14 to support its source suggested by other methods. A CITL Mk5-2 cold cathode stage combined with a Nikon Eclipse 80i polarizing microscope was operated at the following conditions: ~17 kV beam energy, ~0.3 mA beam current at ~0.003 mBar vacuum. The conditions for non-luminescent samples were manipulated in the ranges of 12-18 kV and 0.2-0.5 mA. Photomicrographs were recorded with a Nikon DS-Ri1 digital camera. All CL microphotographs were taken with identical camera settings to obtain internally comparable images of luminescence intensity: 6 seconds exposure time, ISO 200. For non-luminescent samples, additional overexposed CL images were recorded. The isotopic measurements of carbonates were carried out using an automated carbonate preparation device (KIEL-III) coupled to a gas-ratio mass spectrometer (Finnigan MAT 252). The results were expressed in terms of $\delta^{13}C$ or $\delta^{18}O$ and measured in parts per mil (‰) relative to the international reference standard PDB [43]. The precision of the isotopic ratio is ±0.1‰ for $\delta^{18}O$ and ±0.06‰ for $\delta^{13}C$ (1 sigma), and the measurements were calibrated based on repeated measurements of NBS-19 and NBS-18. Isotope analyses were carried out at the Environmental Isotope Lab., the Department of Geosciences at the University of Arizona, Tucson, Arizona, USA.

4. Results

The studied marbles were used to carve two sculptures: the torso of Artemis of the Rospigliosi type (sample 13) and a hand fragment (sample 14), and to produce 12 architectural elements (samples 1-12) listed in tab. (1). One of the architectural elements, sample 1, is a fragment of a sigma table. Table (2) summarizes the results of macroscopic examination and other analytical techniques gathered from the studied samples (microscopic features, mineralogical composition, and isotopic signatures), fig. (3) illustrates the XRD results, and fig. (4) presents the isotopic results where the carbon and oxygen isotopic signatures of the studied samples are compared to the main Mediterranean marbles used in antiquity. Samples 6, 9, and 10, examined by the diluted hydrochloric acid test, showed instant bubbling and fizz, indicating calcite composition. The main textural features of the fine-grained samples (Samples 1, 3 & 14) and medium-coarse studied marble (Samples 2, 5-11, 12 & 13) are presented in fig. (5). The description of the microscopic features is based on those of [26,33,35,44]. Grain size distribution (MGS) of fine and medium-coarse marbles is illustrated in fig. (6). Finally, CL results are illustrated in fig. (7).

Table (2) presents a brief description of the samples, $\delta^{13}C$ and $\delta^{18}O$ values, summary of the petrographic analysis and the probable provenance

S.	Color	Minerals: *Major*	*Accessory*: *D*	*Cal*	*Qz*	*Gr*	Petrographic features: *MGS (mm)*	*GBS*	*Tex*	*Fabric*	$\delta^{13}C$‰	$\delta^{18}O$‰	Prov
1	White, fine grained		-		-	-	1.25	Straight-curved	Ho	Mosaic	0.72	-4.17	Uncertain
2	Light grey, coarse grained		-		±	+	2.50	Curved-embayed, sutured	He	Mosaic, mortar	2.66	-0.95	Pr-1
3	Light grey- grey, grey strikes		-		-	-	1.00	Straight-curved	Ho	Mosaic	2.77	-5.24	Uncertain
4	Light grey, coarse grained		-		-	-	1.80	Straight-curved	He		2.23	-5.02	Pr-1/Pa-2
5	White-light grey, grey strikes, medium grained		-		±	+	1.70	Curved-embayed, sutured	He		1.65	-4.48	Pr-1
6	Light grey- grey, grey strikes, coarse grained		-		±	+	2.75	Curved-embayed, sutured	He		3.21	-2.64	Pr-1
7	Light grey- grey, grey strikes, medium-coarse	Cal	+		+	+	2.00	Curved-embayed, sutured	He		1.85	-2.66	Pr-1
8	Light grey, coarse grained, grey strikes		-		±	+	2.75	Curved-embayed, sutured	He	Mosaic, mortar	2.87	-1.28	Pr-1
9	Light grey, coarse grained, grey strikes		-		±	+	2.75	Curved-embayed, sutured	He		2.29	-0.62	Pr-1
10	Grey, coarse grained, grey strikes		-		±	+	2.75	Embayed-Sutured	He		1.35	-4.45	Pr-1
11	Grey, coarse grained, grey strikes		-		±	+	2.70	Curved-embayed, sutured	He		2.44	-1.17	Pr-1
12	White/Beige, coarse grained	Dol	-	+	-	+	2.00	Embayed-Sutured	Ho	Mosaic, slightly strained	3.45	-3.75	T-3
13	White/Beige, coarse grained		-	+	-	+	2.00	Embayed-Sutured	Ho		3.60	-2.49	T-3
14	White, fine grained	Cal	-		±	±	0.50	Embayed-curved	He	Mosaic	2.65	-3.96	Doc

***D**: Dolomite, **Cal**: Calcite, **Qz**: Quartz, **Gr**: Graphite, **MGS**: max. grain size, **GBS**: Brain Boundary Shape, **Tex**: Texture, **He**: Heterogeneous, **Ho**: Homogeneous, **Prov**: Provenance, **T-3**: Thassos-3, **Pr-1**: Proconnesus-1, **Doc**: Docimian, **Pa-1**: Paros-1, **Pa-2**: Paros-2, + present; ± traces.*

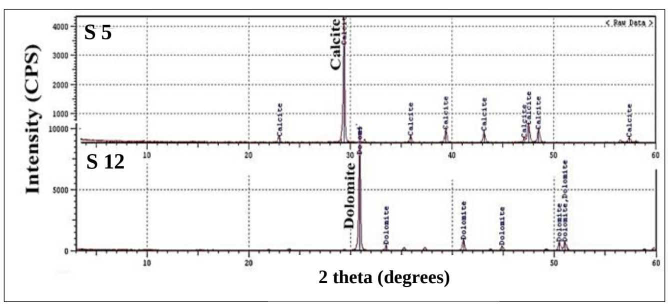


Figure (3) XRD results showing the calcitic composition of sample 5 and the dolomitic composition of sample 12.

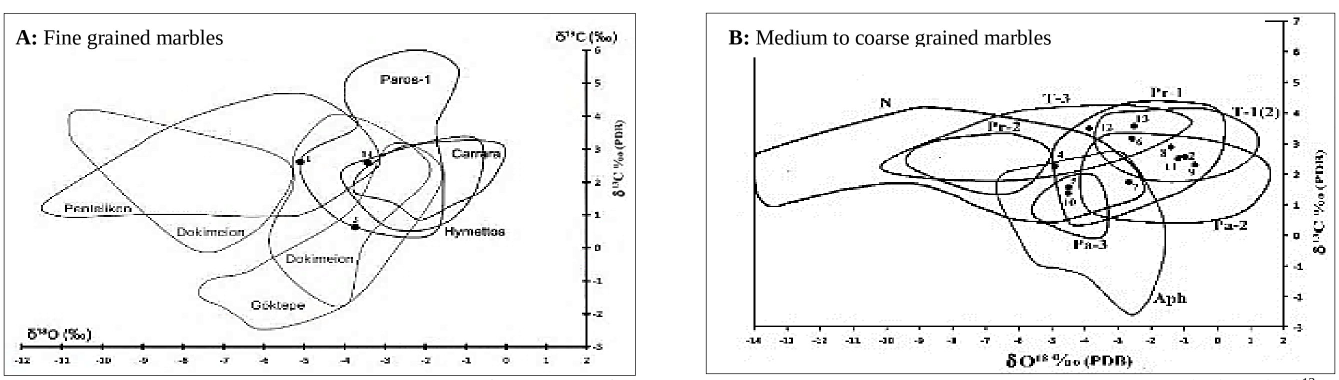
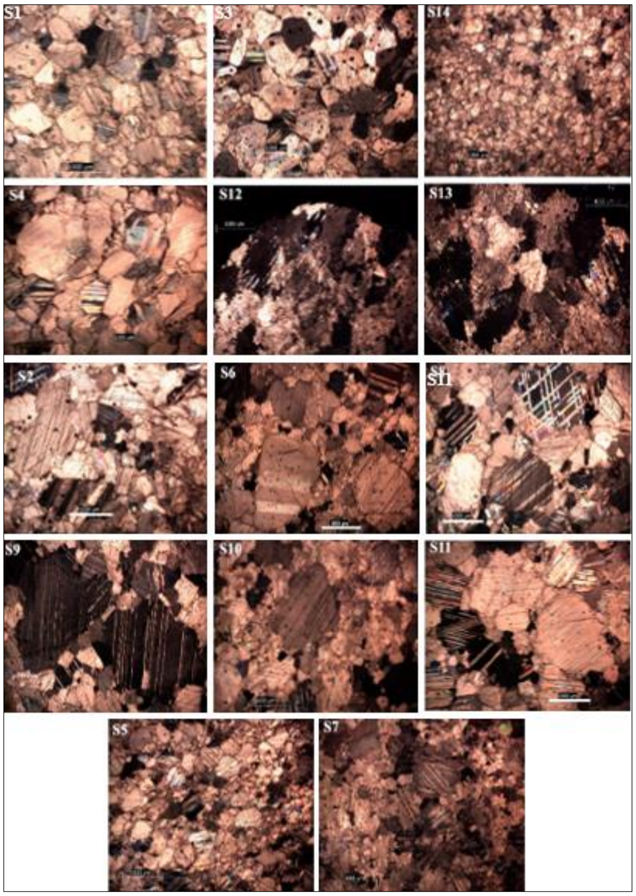


Figure (4) the carbon and oxygen isotopic signatures of the marbles from Gerasa compared to the main Mediterranean marbles used in ant-iquity. The $\delta^{13}C$-$\delta^{18}O$ values are plotted in the diagram (*After: Wielgosz-Rondolino, 2020*) [39] for the fine-grained marble (a modification of and in the diagram (*After: Antonelli & Lazzarini, 2015*) [27] for the coarse-grained samples (**A**= fine grain and **B**= medium-coarse grain). **C**= Carrara, **Pa-1**= paros lychnites, **Pe**= penteli, **Doc**= docimium, **Gkt**= göktepe, **Hy**= hymettus; **N**= naxos; **Pr**= proconnesus (**Pr-1**= proconnesus from saraylar; **Pr-2**= pro-connesus from camlik); **Pa**= Paros (**Pa-2**= chorodaki valley; **Pa-3**= agios minas valley); **T**= Thassos (**T-1**= district of phanari; **T-2**= district of aliki; **T-3**= district of cape vathy), **Aph**= aphrodisias.



(5) Microphotographs of the thin sections showing the main textural features of the fine (samples 1, 3 & 14) (above) and medium-coarse (below) studied marble samples (samples 4, 12 & 13; samples 2 & 5-11); (XPL, Bar length=1mm).

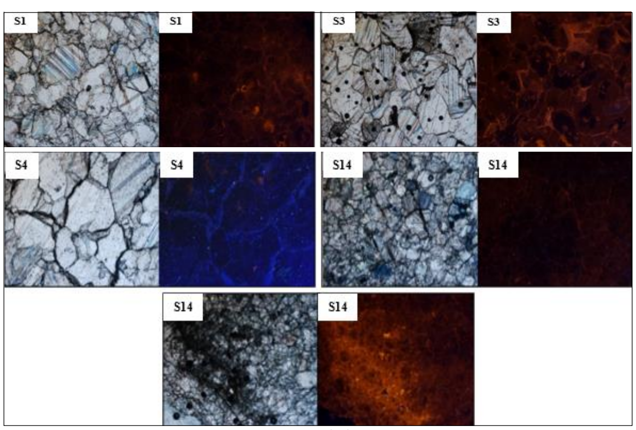


Figure (6) Grain size distribution of fine and medium-coarse marbles (*After: Some authors* [27, 34, 52, 76]).

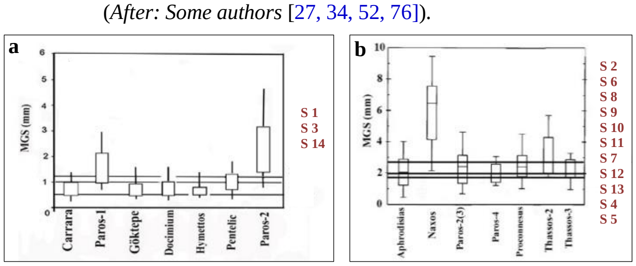


Figure (7) CL microfacies of selected samples (1,3,4,14), (image's width = 3.28 mm).

5. Discussion

5.1. *The sculptures*

Macroscopic examination revealed that the sculptures are carved from two different marble sources: the torso of Artemis (sample 13) is carved from a coarse-grained white-beige marble; while the hand fragment (sample 14) is carved from a fine-grained white marble. Both sculptures are dated to the 2nd-3rd centuries AD and the torso of Artemis is attributed to a local workshop based on its stylistic features [4,15].

5.1.1. XRD analysis

The results of XRD analysis illustrated in fig. (3) revealed that the mineralogical compositions of the coarse-grained sample 13 and the fine-grained sample 14 are dolomite and calcite, respectively. Meanwhile, the XRD results are unable to assign the source of the calcitic marble of sample 14; the dolomitic composition of sample 13 excludes the probable quarry origin from the calcitic marble origins and suggests its provenance from the dolomitic Thassian-3 coarse marble quarries, Thassos Island, Greece.

5.1.2. Isotopic analysis

As shown in fig. (4), the values of the ^{13}C and ^{18}O isotopes of sample 13 are located in the middle of the isotopic region of the dolomitic marble of Thassos-3 (T-3) and within the isotopic fields of the Proconnesian-1 (Pr-1) and the Thassian-1(2) (T1-2) marble. The ^{13}C and ^{18}O isotopic values of sample 14 are located in the middle of the isotopic regions of the fine-grained Docimian and Göktepe marbles and on the bottom border line of the isotopic region of Hymettian marble. The isotopic results alone are unable to distinguish between these different sources due to the overlapping of the isotope fields, but they are useful to rule out all other marble sources in the diagram as probable sources for the two samples. It is worth mentioning that when using the isotopic diagram of Prochaska and Attanasio [36] the isotopic values of S14 are located only within the isotopic field of Docimium. Unfortunately, this database does not include Thassos-3 marble.

5.1.3. Petrographic analysis

Optical microscopic examinations, fig. (5) of the two samples showed two different microscopic features. Sample 13 showed mosaic fabrics, heteroblastic texture, curved to sutured grain boundary shapes, deformed polysynthetic twinning, and MGS= 2.0 mm, figs. (5 & 6). The similarity of the microscopic features to those of dolomitic Thassian-3 marbles from Cape Vathy, Thassos Island [31,33], suggests that this source is the most likely origin of the sample. In addition, the coarse grains, the ^{13}C isotopic value which is more positive than those of Sevic dolomitic marbles and the ^{18}O isotopic value which is more negative than them, negate the possibility that the sample was quarried from the Sevic (Macedonia) dolomitic marbles [45]. Sample 14 is composed of fine grains (MGS= 0.5 mm) having straight boundaries and forming heteroblastic lineated texture with strained finer calcite crystals of embayed boundary shapes, fig. (5), for similar microscopic features see for example [26,36,46]. The compatibility of these features with those of Docimium (Iscehisar, Turkey) indicate that Docimian marble is the most likely source of the sample.

These features are different from those of Göktepe, Pentelic, Paros-1, and Carrara marbles; see their characteristics in [26, 33,36].

5.1.4. Cathodoluminescence analysis (CL)

The CL results of sample 14 in fig. 7 exhibit a CL pattern of low intensity and zonation or lenses with higher intensity CL similar to those of the Docimian marble [47-49]. These results support the above Docimium provenance assigned for sample 14 by other methods. All the above-discussed results support each other and indicate that Thassian-3 marble and Docimian marble are the most likely sources of samples 13 and 14, respectively.

5.2. *Architectural elements*

This group of marble objects comprises 12 elements, tab. (1). Most of the samples were attributed to the Byzantine period (1, 2, 3, 6, 9 & 10), some were Roman (5, 7 & 8) and some could not be securely dated (4, 11, 12). Macroscopic examinations classified the samples into two groups based on their grain size: two fine-grained samples (1 & 3) and ten medium-coarse-grained samples (2, 4-12). The analytical analysis showed the following results.

5.2.1. XRD analysis

The results of the XRD analysis revealed that the loculus block for the reliquary (sample 12) is formed of dolomitic marble, while all other architectural elements are made of calcitic marble, fig. (3).

5.2.2. Isotopic analysis

As shown in Fig. 4 the values of the ^{13}C and ^{18}O isotopes of sample 12 fall within the isotopic regions of the dolomitic Thassian-3 (T-3) and Proconnesian-1 (Pr-1) marble. The ^{13}C and ^{18}O isotopic values of each of the calcitic samples fall within one or more isotopic fields of different marble sources used in antiquity including: Pr-1, Pa-2, Pa-3, T-1, T1-2, Aph, N; see fig. 3. It can be noted that samples (2, 8, 9 & 11) form a cluster located in the isotopic regions of Pr-1, Pa-2 and T-(1-2) marbles. Samples 5 and 10 fall within the regions of Pr-1, Parian-3 (Pa-3), Aphrodisian, and Naxian marbles. The ^{13}C and ^{18}O isotopic signatures of sample 1 are located within the isotopic regions of Göktepe and Docimium marbles and on the border of Pa-1 marble, while those of samples 3 are located within the isotopic regions of Pentelic and Docimian marble and on the border of Pa-1 marble. Although isotopic results alone cannot definitively identify the sources, they help rule out certain possibilities. For instance, Carrara and Hymettos marbles are excluded for both samples 1 and 3, while Pentelic marble is ruled out for sample 1, and Göktepe marble for sample 3. The isotopic values of sample 4 are located outside the isotopic region of Pa-2 marble, inside those of Naxian and Aphrodisian marbles, and close to the left of the border of Pr-1 isotopic region. Given the limitations of isotopic analysis in distinguishing between these sources, petrographic features provide more decisive insights, as discussed below. It is notable that when using the isotopic diagram of Prochaska and Attanasio [33], the isotopic values of S1 are located exclusively within the isotopic field of Göktepe, suggesting a probable source for this sample. In contrast, the isotopic values of S3 do not indicate any source, as they fall outside all the isotopic fields in the diagram. However, the proposed Göktepe source for sample S1 is not supported by petrographic features, which are quite distinct. Specifically, Göktepe marble typically exhibits MGS values less than 0.5 mm and often displays a homeoblastic texture with polygonal grain boundaries and triple points [36]. Similarly, when using the isotopic diagram of Prochaska and Attanasio [35], the isotopic values of S4 are located exclusively within the isotopic field of Pr-I, near its left border, suggesting that the sample likely originates from this source. However, this database lacks petrographic analysis for comparison. As discussed above, the petrographic features support Pa-2 marble more than Pr-1, when compared to other databases. The isotopic values of samples S5 and S10 fall outside all the isotopic fields in the diagram, which do not point to any particular source. The locations of the remaining samples in this isotopic diagram are as follows: S2 (Pr-I, Pr-III, Thassos Aliki), S6 (Pr-I, Pa-Marathi), S7 (Pr-I, Pa-Marathi), S8 (Pr-I, Pr-III, Thassos Aliki), S9 (Pr-I, Pr-III, Pa-Korodaki), and S11 (Pr-I, Pr-III, Thassos Aliki, Pa-Korodaki). Notably, this database does not include petrographic analysis for direct comparison with our results.

5.2.3. Petrographic analysis

The dolomitic sample 12, which is similar to sample 13, has identical microscopic features, fig. (5) to those of Thassos-3 Cape Vathy, Thasos Island, Greece. This result agrees with the above conclusions about sample 13 and confirms that sample 12 comes from quarries of Thassos-3 Cape Vathy, Thasos Island, Greece. The microscopic examinations classify the calcitic samples into three groups based on their microstructural features: the first group comprises 2 fine-grained samples (1 and 3); the second group comprises the medium-grained sample 4, and the third group comprises the coarse-grained samples (2, 5-11). The microscopic characteristics (detailed below) are useful for identifying their sources.

5.2.3.1. *The 1st group*

Both samples 1 and 3 show similar petrographic features to the marble of Paros-1 (Lychnites), they are formed of mosaic fabrics of fine grains of MGS = 1 mm and 1.2 mm, respectively, straight-curved boundaries (granoblastic) with heteroblastic texture of variable grain sizes, see fig. 5 [26,33,36,43]. Although their MGS values concord with those of the Docimian and Pentelic fine-grained marbles, see fig. (5), other petrographic features are different from both marbles; therefore, Docimium and Penteli marbles were ruled out. The Docimian marble commonly exhibits a much more regular homeoblastic-to-heteroblastic mosaic fabric, often with strained and clearly embayed or embayed-to-curved calcite crystals with a significant presence of opaque minerals (e.g., iron oxides). Pentelic marble is characterized by a more regular mosaic microstructure, very often foliated, with calcitic crystals exhibiting clear embayed boundaries and the significant presence of mica or chlorite as accessory minerals. Göktepe marble typically exhibits MGS values less than 0.5 mm and often displays a homeoblastic texture with polygonal grain boundaries and triple points [26,32,33,36,50]. The observed petrographic features point to the island of Paros (Paros-1, lychnites, near Marathi, Stephani, Greece) as the probable origin of the two samples. The ^{13}C and ^{18}O values of samples 1 and 3 in fig. (4) form an anomaly and do not support well the source of Paros-1 (Lychnites) for both samples. The closest anomaly ^{13}C and ^{18}O values of the two samples reported in previous research are those reported for both marbles (1.96‰, -3.40‰) and (3.25 ‰, -4.76 ‰) [46,51], respectively, who assigned Paros-1 (lychnites) for them based on their petrographic features. The sample of [46] is a Corinthian capital carved of fine-grained (0.9mm) white marble and the sample of [51] is a female bust carved of fine-grained (1.3 mm) white marble. While Parian-1 marble has not been reported in Gerasa, it was used in Gadara for the Enthroned Zeus "Nikephoros" sculpture, dated to the early 3rd century AD. [22]. Notably, Parian-2 (Pa-2, Lakkoi) quarries occasionally produced fine to medium-grained marble, as noted in previous studies [31,40,52]. Given this, it is possible that the two samples originate from this source. For instance, in Gadara, another Decapolis city, a medium grained (MGS 1.5 mm) Parian-2 marble was used for the Aphrodite torso, "Type Syracuse/Landolina" [53]. However, similar to the Paros-1 (lychnites) provenance, the Pa-2 (Lakkoi) provenance is not supported by the isotopic signatures of both samples, as they fall outside the Pa-2 isotopic field. The provenance of both samples remains uncertain due to the contradiction between the isotopic and petrographic results.

5.2.3.2. *The 2nd group*

Sample 4 has medium-grain size (MGS value about 1.8mm) and reveals straight to curved-embayed grain boundaries (with some deformed polysynthetic twinning) forming a mosaic texture of a heteroblastic fabric, fig. (5). While these features are similar to those of Parian-2 marble [26,33], they are different from the very coarse-grained Naxian marble and the typical coarse curved/embayed and sometimes stressed crystals of Aphrodisian marble [27,33,50]. Although Pa-2 and Pr-1 has often similar microscopic features, the sample does not show the typical mortar of the Proconnesian-1 marble, therefore it is probable that the sample belongs to a variety of the medium-grained (with MGS < 2 mm) marble from Pa-2 (Lakkoi, Paros Island), Greece [33,54].

5.2.3.3. *The 3rd group*

The samples (2, 6, 7, 8, 9 & 11) in this group exhibit similar microscopic features, including characteristic mortar fabric, heteroblastic textures, sutured to embayed crystal boundaries, and deformed polysynthetic twinning. These features are indicative of Proconnesian-1 marble from Marmara Island, Turkey [27,33]. The maximum grain size (MGS) of samples 2, 6, 8, 9, and 11 is approximately 2.75 mm, while sample 7 has an MGS of about 1.70 mm. Although MGS values alone may not be sufficient to determine the source due to the overlap between different marble sources, fig. (6), the above-detailed microscopic features strongly suggest a Proconnesian (Pr-1) origin. Sample 5 exhibits fine-grained veins parallel to the medium-sized grains, while sample 10 displays medium- to coarse-grained grains forming a mortar texture in a finer matrix, fig. (5). These latter features, although less common, are often present in Proconnesian-1 marble [55]. The similarity between the microscopic features of the samples and those of Pr-1 marble from Marmara suggests that Proconnesian (Pr-1) is the most probable source for them. Moreover, the macroscopic features of these samples, their color, dark grey streak, and sulfur odor emission from some samples provide more support to this source [27,33,44].

5.2.4. The cathodoluminescence (CL) analysis

In fig. (7) reveals the CL microfacies of samples 1 and 3, which exhibit heterogeneous CL patterns characterized by non-luminescent to very faint luminescent calcite grains and low-intensity orange margins with a bluish tone under prolonged exposure to light. These CL patterns differ from the typical homogeneous blue luminescence of Parian-1 marble [30,47]. However, similar CL patterns to those of samples 1 and 3 have been observed in Pa-1 marble samples [333,56,57]. The CL results reflect the low Mn content of samples 1 and 3, which is consistent with the known properties of Paros marbles as having low Mn content [35,36,58,59]. Given these CL patterns, Parian-1 cannot be securely confirmed based on the CL results, and the source of the samples remains uncertain. The CL analysis of sample 4 reveals intrinsic blue CL features, fig. (7) under prolonged exposure to light, which are compatible with those of Pr-1 marble [30,47]. This result supports the Pr-1 provenance for sample 4, consistent with the isotopic analysis using the Prochaska and Attanasio diagram [35], as discussed above.

5.3. *General statement*

The analytical results reveal that the marbles under investigation originated from three primary sources, tab. (2): two Turkish (Marmara Island and Docimium) and one Greek (Thassos Island), with a probable fourth source being the Greek Island of Paros. Eight calcitic samples used for architectural elements originated from the Proconnesus (Pr-1) quarries, Marmara Island. The Proconnesian-1 origin of six samples was confirmed by isotopic and petrographic analysis, while petrographic analysis confirmed the provenance of two samples (5 and 10), as isotopic results were inconclusive for these cases. Combined XRD, isotopic, and petrographic results collectively confirm that samples 12 and 13 originate from Thassian-3 marble quarries (Cape Vathy/Saliara, Thassos Island), while isotopic, petrographic, and cathodoluminescence (CL) results confirm that sample 14 originates from expensive Docimium (Iscehisar) quarries [60,61]. Isotopic, petrographic, and CL results of samples 1 and 3 were inconclusive for both samples due to conflicting data and the origin of the samples remains uncertain. Finally, the conflicting results suggest that sample 4 likely originates from either Proconnesian-1 (Pr-1) or Parian-2 (Pa-2); isotopic and (CL) petrographic results support Pr-1 origin while petrographic results suggest Pa-2 origin. The quarries of the dolomitic variety from Cape Vathy/Saliara (Thassos-3), on Thassos Island, provided the marble used for a Loculus block for a reliquary and a sculpture of Artemis. It is well known that, in antiquity, Thassian-3 marble was the major source of the white-beige coarse-grained dolomitic marble mainly used for sculpture and objects of valued function [62,63] in the Mediterranean region. On the contrary, the western Mediterranean sources of dolomitic marbles were used primarily on a local basis

[45]. The quarries of Parain-2 (Lakkoi), Paros Island are a probable source that provided a medium-grained marble used in molding a wall revetment. The source of the two fine-grained marbles used for a sigma table and a corinthianizing pilaster capital/leaf capital ('Blattkranzkapitell') remains uncertain, paros-1 is a probable source based only on petrographic features. Locally, in Jordan, Docimian, Thassian-3, Proconnesian, and Parian marbles were commonly used in Gerasa and other archaeological sites. The Docimian marble was used to carve different statues uncovered from the Eastern Baths at Gerasa, for example: the rounded pedestal with a pillar-shaped support rising at the right rear edge, a cylindrical object, and the right shoulder of the statue of an enthroned Muse, as well as the pedestal fragment of the joins of the Zeus Type Florence [18]. Other artifacts and statues of Docimian marble were uncovered at the storage of Gerasa: part of a small panel with an inscription of four Latin letters, small capital decorated with acanthus leaves, cylindrical column, part of a broken plaque showing a man and other incomplete decoration [17]. Similarly, Thassian-3 marble was carved out to produce several statues uncovered at Gerasa, see for example the Gerasa's large Aphrodite statue dated to AD 154 [18], the fragmented statue of Enthroned Cybele [19], the Artemis torso, the lower part of a togated male, the lower part with plinth of a torso of a Roman type of the small Herculanean female type, the lower torso and thighs of a youthful nude male (Apollo or Dionysos) [64], and several broken parts of statues at the Gerasa Museum [17]. It was also reported that the statue of the Athlete dated to the 2nd century AD exhibited in the Gadara museum is carved out from Thassian-3 marble [22]. At Philadelphia (Amman), the two draped female statues found in the newly uncovered Roman bath at the center of the ancient city were carved out of Thassian-3 marble probably during the late 2nd and early 3rd centuries AD [65]. Beyond Roman use, Thassian-3 marble appeared in Byzantine church installations, such as the fonts at Udruh, south Jordan [66]. Parian-2 (Lakkoi) marble was commonly used, with similar and lower MGS values found in artifacts from Gerasa and other sites in Jordan. At Gerasa, Pa-2 marble was used for several objects uncovered from the Eastern Baths, including the burned statue, Apollo, dancing Satyr, and a statue chest [18]. Additionally, numerous statues and architectural elements from various locations in Gerasa, now stored in the site's storage facility, were also carved from Pa-2 marble [17]. In Gadara, another Decapolis city, a medium-grained Parian-2 marble (MGS 1.5 mm) was identified in the lower part of a standing female statue (torso) of Aphrodite, dated to after the mid-2nd century AD and reused toward the end of the 2nd or the beginning of the 3rd centuries AD [21]. Finally, Proconnesian-1 marble was the main source and was widely used for architectural and ecclesiastical elements [66]. It was used abundantly at several sites in Jordan including Gerasa, for instance, at Gerasa see [18,19,66], at Hayyan A-Mushrif [67], at Gadara [56] and Abila [68,69], and also in southern Jordan, at Udhruh [70,71].

6. Conclusions

The results of the archaeometric analysis of the two sculptures and twelve architectural elements uncovered from the Northwest Quarter in Gerasa show that the two sculptures are carved out from two different imported prestigious white marbles: Thassian-3 and Docimian marbles, while the architectural elements are made from Proconnesian-1. In addition to Pr-1, Parian-2 marble is a probable source of one sample. The dolomitic Thassian-3 marble is also used to carve out the loculus block for a possible reliquary. The use of Proconnesian-1 marble for most of the architectural elements was an expected finding, given its widespread use in Jordan for such purposes. The source of two samples (1 and 3) remains uncertain due to conflicting results, further analysis might find an origin for the samples. Some of these marble varieties were expensive to import from Greece and Turkey to inland Gerasa which underlines the considerable effort invested in equipping Gerasa buildings with these valuable materials. It is noteworthy to mention that during the Imperial period, the dolomitic marble from Thassos-3 was commonly used for fine sculpture and objects of special function. The moldings and decorative panels from our sample set often were made from the economic Proconnesian marble, underlining that there is a certain hierarchy in the use of marble with using fine marble in more exquisite applications and Proconnesian as common revetment and decoration. Compared to other Decapolis cities, Gerasa used the same sources of fine-quality marble and the imperial Proconnesian marble for architectural and ecclesiastical elements of standard sizes. It is proposed to carry on with the characterization of marble objects uncovered in the following fieldworks to provide more data and context for the use of marble in the Northwest Quarter in particular and Gerasa in general. It also implies a need for additional techniques to gather more data and broaden the scope of the research.

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