Stable Isotope Geochemistry: A Tribute to Samuel Epstein
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Stable isotopes and the Roman marble trade—evidence from Scythopolis and Caesarea, Israel*

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Abstract—Analysis of carbon and oxygen stable isotopes of antique white marbles at two Roman sites in Israel is used to study trade practices in the Roman Empire. The range and variance in $\delta^{18}O$ values for 30 out of 42 marble artifacts from the Scythopolis Theatre (1.33 per mil and 0.237 per mil, respectively) is significantly smaller than the respective range and variance for 17 out of 33 artifacts from the Scythopolis Monument (2.62 and 0.443, respectively). An *F*-test to compare these variances with the variance in $\delta^{18}O$ of the quarry indicates that the variance of the theatre artifacts is significantly different from that of the quarry ($P = 0.02$), whereas the variance for the monument artifacts is not ($P = 0.50$). A probable explanation is that marble for the theatre was purchased directly from the Marmara quarry, and possibly was quarried from a single outcrop. On the other hand, marble for the monument was purchased from a local stock yard which held a variety of marbles, including marble from different sections in Marmara. Similar patterns of variation are found for Corinthian Capitals from Caesarea. Sixteen capitals are similar in their decoration and isotopic composition. A range of 0.35 per mil in $\delta^{13}C$ and 1.1 per mil in $\delta^{18}O$ found for these capitals is smaller than the respective ranges that were found for the theatre and monument artifacts above. This indicates that these capitals are relatively more homogenous. An *F*-test to compare the variances in $\delta^{13}C$ and $\delta^{18}O$ between the capitals and the Marmara quarry indicates that the capitals differ significantly in their variances from the quarry ($P < 0.0001$ for both $\delta^{13}C$ and $\delta^{18}O$). This suggests that these capitals originated from a single outcrop in Marmara. A probable explanation to the similarity of the capitals in both decoration and isotopic composition is that they belong to a single monument. These capitals were found out of their archeological context, suggesting that stable isotope analysis can be used in reconstruction of artifacts to their original archeological context.

INTRODUCTION

ANTIQUE WHITE MARBLE artifacts have been studied by a large number of analytical methods (see HERZ, 1985, for review). In particular, stable isotope analysis has been applied extensively to studies in this field. CRAIG and CRAIG (1972) demonstrated that the distinct isotopic signature of quarries is useful in determining the source quarry of marble artifacts. HERZ and WENNER (1978) suggested isotopic analysis as an objective tool to evaluate whether reconstruction of fragments on the basis of aesthetic criteria is correct. MARGOLIS (1989) used the stable isotope composition of the weathered crust of marbles to evaluate the authenticity of marble statues.

In the present study we discuss the application of stable isotope analysis to study trade practices in the Roman Empire. The degree of homogeneity in the stable isotope signature of groups of artifacts from the same archeological context (*e.g.* a known structure) are discussed. Isotopic exchange in most metamorphic terranes is channelized and thus is limited to the boundaries between marbles and other lithological units (see VALLEY, 1986, for review). Therefore, the isotopic composition of marble samples from a single source is expected to be more homogenous than the isotopic composition of marble samples from several origins which were exposed to different metamorphic conditions. These variations can be related to purchase modes prevailing in the Roman Empire. WARD-PERKINS (1971, 1980) suggested that the Roman marble trade system changed completely during the first century AD. Before that time, marble was purchased directly from the quarry, and that was also the common practice in Classical Greece. The new trade system involved stock-piling in the importing cities, more efficient quarrying methods, standardization of sizes and partial prefabrication. Under this trade system most demands were met by the marble yards, and only exceptionally were direct quarry-customer relations involved. These two modes of marble purchase can be evaluated by the $\delta^{13}C$ and $\delta^{18}O$ values of a group of artifacts. It is expected that the range of isotopic values from artifacts purchased from a single quarry will be smaller than that found for artifacts purchased from a marble yard, as the latter will be more heterogeneous in their isotopic signature. Ranges mentioned in this study are used to describe the absolute difference between the maximum and minimum isotopic value determined for a group of artifacts.

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Roman sites in Israel are most suitable for this type of study. Because there is no local source for marble, extensive marble should have been imported to Roman Palestine in one of these modes, from the Roman quarries around the Mediterranean (Fig. 1). Independent evidence (*e.g.* stone inscriptions) indicates that these quarries were indeed the Roman marble source quarries (see DWORAKOWSKA, 1975, 1983, for review). In this study we apply a multi-method approach to determine the source of the marble artifacts. This approach includes the analysis of $\delta^{13}C$ and $\delta^{18}O$, Mn content and the determination of the calcite/dolomite ratio.

SITES DESCRIPTION

Marble artifacts for this study were collected in the excavations of two Roman cities in Israel, Scythopolis and Caesarea (Fig. 1). These sites were selected because marble was extensively used as an ornamental stone for construction at both sites.

In Scythopois, we selected marble artifacts which are clearly related to one of two structures, the theatre and the so-called monument, where most of the marble artifacts used for construction in Roman Scythopolis were found. Marble artifacts in Scythopolis are found at or close to their original sites, as the city was destroyed by an earthquake during the eighth century AD, and subsequently a swamp developed in the area and preserved the archeological record. The theatre and the monument were constructed during the second century AD, a prosperous period for the city which was established in the third century BC incorporating the biblical Beth Shean. The theatre is a medium-sized Roman theatre of the "western" type. This type is common in Africa. Other theatres in the region, in Caesarea and Palmyra, are of the same type. The monument, of which only the lower part was preserved, was erected in the heart of Roman Scythopolis.

In Caesarea, we studied Corinthian Capitals of unknown archaeological context; *i.e.,* the structure they were part of is not known. Most artifacts from Caesarea are not found in their original archeological context since Caesarea remained an important city during the Byzantine and later periods. Consequently, Roman marble was reused for construc-

FIG. 1. Location map of the major marble source quarries in Turkey and Greece (center), and in Italy (lower left insert), which operated during the Roman period. Notice the convenient location off shore of the Marmara quarry. A location map of the studied sites in Israel is also given (lower right insert).

tion in later periods, and thus the archeological record is not well preserved. These capitals belong to six well-defined groups according to their artistic features, and are related to the second–third centuries AD (FISCHER, 1991). Caesarea was erected by King Herod the Great and became the seat of the prefecture in the year 6 AD. Throughout the Roman period it served as a major port in Roman Palestine.

METHODS

In Scythopolis, marble samples were collected at the site. The theatre and monument artifacts were gathered nearby their place of excavation. In Caesarea, samples were collected in the site and from a local museum. Small portions of marble (a few cm^3) were removed from each artifact. All samples were taken from uncarved surfaces. The weathered surface was mechanically scraped to avoid analysis of the weathered marble crust.

The source of the marbles was determined by the multimethod approach described below. This approach used several geochemical, petrographical and architectural calibrations in order to specify the source quarry, and was adopted because some overlap exists in the ranges of $\delta^{13}C$ and $\delta^{18}O$ values between quarries (HERZ, 1987). Nevertheless, stable isotope analysis is of prime importance as it is the only technique for which an extensive data base is available (HERZ, 1987). The data base includes the stable isotope composition of marble samples from the 22 major white marble source quarries of the Classical World. For some samples the calcite/dolomite ratio was determined by X-ray diffraction (XRD). Data on the calcite/dolomite ratio of marble quarry samples were adopted from LLOYD *et al.* (1988). Mn contents were measured also by electron paramagnetic resonance (EPR). Data on the Mn contents of samples from 14 marble quarries were compiled from the data reported by HERZ and DEAN (1986), MOENS *et al.* (1988), GERMAN *et al.* (1988), and LLOYD *et al.* (1988). This compilation is presented in Fig. 2. A particular advantage of these techniques for analysis of valuable artifacts is the small sample size required. Furthermore, EPR is nondestructive.

Samples were crushed with a mortar and pestle to fine powder, and aliquots were taken for stable isotope, XRD, and EPR analyses. The carbon and oxygen isotopes in marble were measured using the conventional phosphoric acid method (MCCREA, 1950). The CO_2 gas was analyzed in a Varian M250 mass spectrometer, and results are reported using the conventional δ notation relative to the PDB standard. Isotope values were calibrated using the NBS 19 Calcite standard ($\delta^{18}O = -2.20$; $\delta^{13}C = +1.96$). Reproducibility of duplicate samples is better than 0.1 per mil for $\delta^{13}C$ and 0.15 per mil for $\delta^{18}O$. An aliquot of the powder was analyzed by a standard X-ray diffraction (XRD) procedure with a fully computerized automatic Rigaku 505 diffractometer over the range $2\Theta = 26°–32°$ at a rate of one °/min. Weight percent dolomite/(dolomite + calcite) ratio was calculated using the areas under the peaks $2\Theta = 30.94$ and 29.44 based on the formula of WEBER and SMITH (1961). Mn contents were determined by EPR spectroscopy using a Varian E-12 spectrometer. The EPR spectrum of carbonates consists of six peaks. Quantification was done on the low magnetic field peak against the NBS 88 standard (LLOYD *et al.* 1988). A computerized system was used for spectrum collection, baseline correction and double integration. Analytical error is about 10%.

The following rationale was followed in order to determine the marble source of each artifact and the homogeneity in the isotopic signature of groups of artifacts:

(1) The quarry isotopic fingerprint (Qi) was determined by a convex hull drawn through the extreme $\delta^{13}C$ and $\delta^{18}O$ values found for each quarry. These data were taken from the stable isotope data base of quarry samples (HERZ, 1987).

(2) The artifact's isotopic composition (Ai) was compared to the quarry's fingerprint to determine if $Ai \subset Qi$ the marble of Ai originated from Qi.

(3) The Mn content of the artifact was compared with the Mn source quarries' data compilation (Fig. 2), and the calcite/dolomite ratios were compared with the data of LLOYD *et al.* (1988). These steps were performed for some artifacts to confirm the origin which was determined from their isotopic composition.

(4) A group of artifacts was defined to include all the artifacts which were imported from a common origin and belong to the same structure (theatre or monument) in Scythopolis, or to the same artistic type (Caesarea Capitals). To compare the relative homogeneity between groups, the ranges and variances in their $\delta^{13}C$ and $\delta^{18}O$ values were calculated.

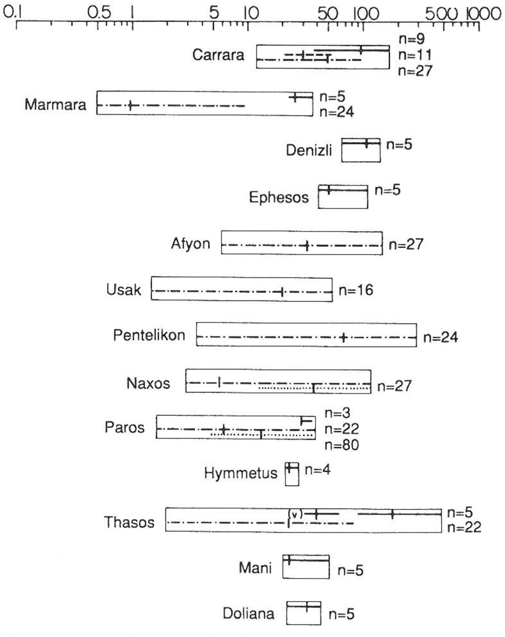

FIG. 2. Compilation of data on Mn contents in source quarry samples. Ranges are given by rectangles. Specific data sources are indicated as follows: – – – HERZ and DEAN (1986); · · · GERMANN *et al.* (1988); —— LLOYD *et al.* (1988); ·–·– MOENS *et al.* (1988). Data for Thasos are for Thasos Aliki (unmarked), and for Thasos Cape vathy (marked with a (v)). N denotes the number of samples. Medians are indicated by vertical bars.

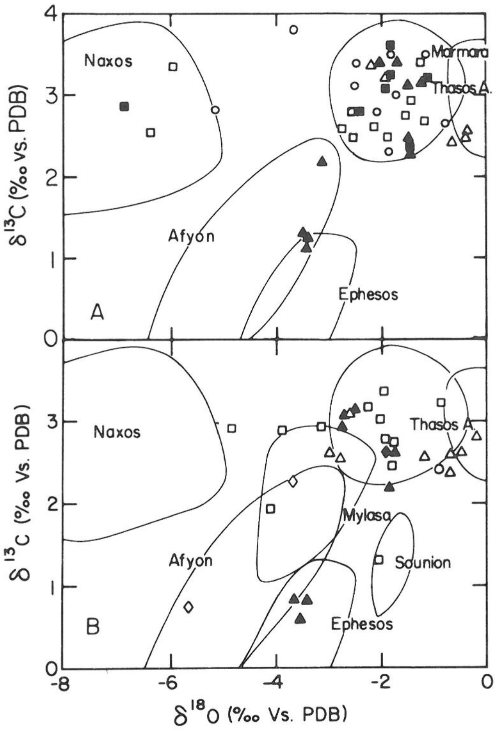

FIG. 3. Isotopic composition of Scythopolis (A) Theatre and (B) Monument artifacts and their possible source quarries. Quarry fields are within the drawn lines. They represent the fingerprint of each quarry as defined in the text. Symbols indicate the architectural function of the artifacts as follows: ◆ = pedestal; ◇ = shaft; ▲ = base; △ = capital; □ = cornice; ■ = architrave; ○ = entablature and unassigned fragments.

(5) An *F*-test (two tailed) was made to evaluate whether the variances in the isotopic signature of groups of artifacts are significantly different from that of the variance in the isotopic signature of their source quarry. A significant smaller variance for the artifacts indicates that their origin is from a restricted section in the quarry, whereas insignificant differences indicate that the artifacts could have originated from the entire quarry. This approach implicitly assumes that the (quarries) sample data base represents the stable isotope signature of the entire quarry.

RESULTS AND DISCUSSION

Scythopolis

Forty-two artifacts from the theatre, including bases, capitals, cornices and architraves, were examined. Their chemical and isotopic composition is listed in Table 1. On the $\delta^{13}C$-$\delta^{18}O$ plane (Fig. 3A) the theatre artifacts cluster into four groups as follows. (a) A group of 30 artifacts originated, according to their isotopic composition, from Marmara. This conclusion is supported by the low Mn content of five samples from this group (2–16 ppm, Table 1). The range in the $\delta^{13}C$ and $\delta^{18}O$ values of these artifacts is 1.33 per mil and 1.95 per mil, respectively. This group includes artifacts of all architectural types. (b) A group of three capitals originated from Thasos Aliki (Fig. 3A). (c) Four bases originated from Afyon (Fig. 3A). Three bases (33–35, Table 1) are distinct also in their size; they have a larger diameter (*ca.* 1m) than all the other bases from the theatre (*ca.* 0.5 m). (d) The remaining five artifacts are depleted in ^{18}O relative to the main cluster. For two of them (9 and 20, Table 1) the

Table 1. Isotopic and chemical composition of marble artifacts from Scytopholis Theatre. Isotopic values are in per mil vs. PDB. Weight percent of dolomite is denoted by dd.

Sample	Description	$\delta^{13}C$	$\delta^{18}O$	dd	Mn (ppm)
1	Cornice	2.48	−2.53	0	
2	Cornice	2.48	−1.87	0	
3	Cornice	2.60	−2.13	0	
4	Cornice	2.53	−6.37	0	2
5	Cornice	2.79	−2.55	0	
6	Cornice	3.43	−1.24	<5	
7	Cornice	2.93	−1.44	12	
8	Cornice	2.76	−1.52	0	
9	Cornice	3.35	−5.96	83	
10	Cornic	2.59	−2.74		
11	Cornic	2.68	−1.17	0	
12	Architrave	3.22	−1.12	15	
13	Architrave	3.24	−1.82	0	
14	Architrave	3.08	−1.91		
15	Architrave	2.35	−1.45	0	
16	Architrave	2.78	−2.40	0	
17	Architrave	2.85	−6.86	tr.	
18	Architrave	3.60	−1.82	tr.	
19	Entablature	3.50	−1.13		
20	Entablature	3.80	−3.65	31	
21	Entablature	2.80	−2.06	0	4
22	Entablature	3.01	−1.72	0	
23	Entablature	2.81	−5.16	<5	
24	Entablature	2.66	−0.79		
25	Entablature	2.30	−1.86		
26	Entablature	3.50	−1.81	36	3
27	Entablature	3.12	−2.50	<5	
28	Capital	2.55	−0.38	0	
29	Capital	2.48	−0.40		
30	Capital	3.21	−1.91	tr.	
31	Capital	3.36	−2.18	0	
32	Capital	2.42	−0.64	0	
33	L. Base	1.26	−3.39	0	102
34	L. Base	1.34	−3.45		
35	L. Base	1.14	−3.40	0	
36	Base	3.42	−1.97	<5	11
37	Base	3.12	−1.47	0	16
38	Base	2.27	−1.39		
39	Base	3.16	−1.23	0	
40	Base	2.18	−3.12	0	
41	Base	2.48	−1.48	0	
42	Base	3.40	−1.68	0	

Table 2. Isotopic and chemical composition of marble artifacts from Scythopolis Monument. Isotopic values are in per mil vs. PDB. Weight percent of dolomite is denoted by dd.

Sample	Description	$\delta^{13}C$	$\delta^{18}O$	dd	Mn (ppm)
1	Cornice	2.88	−3.89	0	3
2	Cornice	3.17	−2.27	0	
3	Cornice	3.36	−1.94	0	
4	Cornice	3.02	−2.02		
5	Cornice	2.93	−3.13	17	
6	Cornice	2.74	−1.77	0	3
7	Cornice	2.91	−4.85	0	
8	Cornice	2.46	−1.79		
9	Cornice	2.79	−1.92		
10	Cornice	1.32	−2.06	9	
11	Cornice	2.74	−1.94		
12	Cornice	3.21	−0.84		
13	Capital	3.09	−2.60	0	
14	Capital	2.59	−0.68	0	
15	Capital	2.36	−0.71	0	
16	Capital	2.61	−2.98		
17	Capital	2.56	−1.17		
18	Capital	2.82	−0.16		
19	Capital	2.54	−2.78	0	
20	Capital	2.62	−0.50	0	
21	Shaft	2.27	−3.67	0	
22	Shaft	0.75	−5.66	0	
23	Base	0.61	−3.50	0	22
24	Base	0.81	−3.37		
25	Base	2.93	−2.74		
26	Base	3.15	−2.48		
27	Base	3.07	−2.67		
28	Base	0.85	−3.65		
29	Base	2.20	−1.83	0	
30	Base	2.61	−1.72	0	
31	Other	1.93	−4.12		
32	Other	2.40	−0.88		
33	Pedestal	2.64	−1.87	0	

marble is partially dolomitic. Their depleted ^{18}O values relative to the main cluster can be explained by isotopic disequilibrium between the coexisting calcite and dolomite (SHEPPARD and SCHWARCZ, 1970). Therefore, these two cornices may not be different from the main group with regard to their origin. For the remaining three artifacts the depletion in ^{18}O probably indicates a different origin, possibly from the island of Naxos (Fig. 3A).

Thirty-three artifacts from the monument were studied. These include bases, shafts, capitals, cornices, and a pedestal. Table 2 lists their isotopic and chemical composition. In general, the monument artifacts are more scattered in their $\delta^{13}C$ and $\delta^{18}O$ values than the theatre artifacts. These artifacts can be divided into four groups according to their isotopic composition. (a) Seventeen artifacts' $\delta^{13}C$ and $\delta^{18}O$ values match with that of Marmara. The range in the $\delta^{13}C$ and $\delta^{18}O$ values of these artifacts is 1.16 per mil and 2.62 per mil, respectively. All architectural functions except the shafts are present in this group. (b) A group of four capitals has an origin in Thasos Aliki. (c) Three bases are from Afyon. (d) Nine artifacts originated in other quarries (Fig. 3B).

The origins of the marbles used in the theatre and monument are mostly from Asia Minor. The quarry of Marmara is the largest source in both cases. From all the studied artifacts, a clear correlation between the isotopic composition and architectural role is found for several capitals from Thasos and for six bases from Afyon (Table 3). These similarities are found in the theatre and in the monument, suggesting that these artifacts might have been purchased at the same time for both structures.

There is a difference between the isotopic signature of the theatre and monument artifacts. (a) Since 30 out of 42 artifacts from the theatre originated in Marmara, but only 17 out of 33 artifacts from the monument originated from this quarry, the theatre artifacts are more homogenous in their isotopic composition. (b) For the theatre and monument artifacts that originated from Marmara a similar range in $\delta^{13}C$ values is found, but a larger range in $\delta^{18}O$ values is found for the monument artifacts (Table 4). (c) It is seen from Table 4 that the theatre artifacts have a significantly lower variance than the monument artifacts in their $\delta^{18}O$ and a similar variance for $\delta^{13}C$. The above three comparisons indicate that the theatre artifacts are iso-

Table 3. Isotopic means (per mil vs. PDB) and ranges for capitals that originated in Thasos Aliki and bases that originated from Afyon found in Scythopolis.

			Mean		Range	
Location	Description	*n*	$\delta^{13}C$	$\delta^{18}O$	$\delta^{13}C$	$\delta^{18}O$
theatre	capitals	3	2.48	−0.47	0.13	0.26
monument	capitals	4	2.60	−0.51	0.46	0.55
theatre	bases	3	1.25	−3.41	0.20	0.06
monument	bases	3	0.76	−3.51	0.24	0.28

Table 4. Ranges, variances and F-values for groups of artifacts originated in Marmara and the quarry fingerprint. See text for discussion. F-values denote the ratio between the quarry and the respective group variances. F-values are used to calculate the probabilities for difference of in variances (P).

		Range		Variance		F-values	
Samples	n	δ^{13}C	δ^{18}O	^{13}C	^{18}C	^{13}C	^{18}O
quarry	41	2.40	3.42	0.2888	0.5874		
theatre	30	1.33	1.92	0.1595	0.2368	1.81	2.48
monument	17	1.16	2.62	0.0998	0.4427	2.89	1.33
capitals	16	0.35	1.40	0.0110	0.0898	26.25	6.54

topically more homogenous than the monument artifacts.

The degree of homogeneity in the isotopic composition relative to the quarry samples is evaluated by the F-test (two tailed). The probability that the variance in δ^{18}O of the theatre artifacts is significantly different from the variance of the Marmara quarry is high ($P = 0.02$), whereas the variance in δ^{18}O for the monument artifacts is not significantly different from that of the quarry ($P = 0.50$). This suggests that the theatre artifacts were quarried from a limited part of the quarry, possibly from a single outcrop. On the other hand the range and variance in δ^{18}O of the monument artifacts suggest that they were quarried from several sections in Marmara.

From these comparisons we infer that marble for the theatre was shipped to Scythopolis directly from one quarry and was not purchased through a marble yard which held stocks of several marble sources. Direct customer-quarry relations are an exception under the Roman trade system (WARD-PERKINS, 1980). The remaining artifacts from the theatre could have been added later to the structure, or possibly replaced damaged blocks from the initial shipment. The isotopically heterogeneous artifacts from the monument reflect a marble purchase from a stock-yard which probably held a variety of marble of different quality, including blocks from different regions in Marmara.

A possible explanation for the difference in the purchase mode between the theatre and the monument materials may lie in the larger amount of marble used for the theatre construction. Marble for the theatre was ordered directly from the quarries because local marble yards could not meet the quantity required for its construction, whereas the smaller quantity required for the monument was available from a local yard supplier. An alternative explanation might lie in the actual construction time of these two structures. If the theatre was erected during a period when large construction projects were under way in Scythopolis and elsewhere, local marble yards' stocks may have become depleted, so constructors would have been forced to "rush" material from the large quarries of Marmara. The existence of these two modes of distribution side by side, as interpreted from the data obtained by isotopic analysis, exemplifies the full development of the advanced Roman marble trade system.

Caesarea

Fifty-eight Corinthian capitals from Caesarea were studied. They form six groups based on their decoration (I–IV, VI–VII). These groups are subdivided according to specific decorative motifs (A–E, λ). Table 5 presents the isotopic and chemical composition and their inferred origin. A large scatter is found in the isotopic signature of 40 capitals of five types (I, II, IV, VI, and VII, Fig. 4). This reflects the multiple origin of these capitals. Eighteen capitals belonging to type IIID and IIIDE were studied. Sixteen capitals cluster into one group. A range of 0.35 per mil and 1.1 per mil is found in their δ^{13}C and δ^{18}O values, respectively. These capitals originated from Marmara, as indicated by their isotopic composition (Fig. 4). The Mn content of these capitals (7–16 ppm) support this conclusion (Fig. 2). Two capitals are enriched in ^{13}C and differ in their ^{18}O relative to the main group. Note also that other capitals of group III also differ from the main IIID–IIIDE group with respect to their isotopic signature and thus indicate a different origin.

As the Corinthian capitals originated from an unknown number of structures, tracing the mode by which their marble reached Caesarea is more complicated. The multiple origin of the 40 capitals of scattered isotopic signature might reflect either the large number of constructions that they were originally part of, or a purchase mode similar to that found for the monument (*i.e.,* from a local marble stock yard), or more likely both. For the 16 capitals of type III we follow the same rationale that was used to evaluate the homogeneity of the theatre and monuments artifacts from Marmara. The ranges and variances of the 16 capitals are smaller

Table 5. Isotopic and chemical composition of Corinthian capitals from Caesarea. The artistic type and the probable origin is also given. Weight per cent of dolomite content is denoted by dd. Isotope values are in per mil.

Sample	Type	δ^{13}C	δ^{18}O	dd	Mn (ppm)	Origin
1	I	2.66	−2.32	0	3	Marmara
2	I	2.96	−5.63	0	3	Naxos
3	I	3.28	−1.84			Marmara
4	I	2.94	−1.02		3	Marmara
5	IB	2.82	−2.41	0	9	Marmara
6	IBD	3.83	−3.66	tr.		Paros
7	IE	2.26	−2.96	tr.		Afyon/Aph.
8	II	3.39	−1.68			Marmara
9	IIA	2.48	−1.78			Marmara
10	IIB	1.68	−2.92	0		Afyon/Aph.
11	IIC	2.24	−2.72		34	Afyon/Aph.
12	IID	1.53	−3.72		26	Afyon/Aph.
13	IID	3.47	−2.14	0	35	Denizli?
14	IIE	2.34	−1.58			Marmara
15	IIIAc	3.32	−2.59	0		Marmara
16	IIIA	2.02	−4.02			Afyon/Aph.
17	IIIA	1.43	−3.65		36	Afyon/Aph.
18	IIIB	3.78	−5.99	0	195	Sardis
19	IIIDc	3.19	−1.88			Marmara
20	IIIDc	3.75	−3.88	tr.		Paros
21	IIIDc	3.87	−0.77	<5		Marmara
22	IIIDc	3.49	−1.75	tr.		Marmara
23	IIIDc	3.26	−1.92	0		Marmara
24	IIIDc	3.50	−1.82	0	13	Marmara
25	IIIDc	3.15	−2.64			Marmara
26	IIIDc	3.24	−1.86	0	7	Marmara
27	IIIDc	3.33	−2.18			Marmara
28	IIIDc	3.23	−2.01	0		Marmara
29	IIIDc	3.23	−2.15			Marmara
30	IIIED	3.41	−2.00			Marmara
31	IIIED	3.36	−1.92			Marmara
32	IIIED	3.37	−2.31	0	13	Marmara
33	IIIED	3.32	−1.75			Marmara
34	IIIED	3.45	−1.83	tr.	14	Marmara
35	IIIED	3.36	−1.24			Marmara
36	IIIED	3.37	−1.84	0	16	Marmara
37	IVA	3.86	−1.63	0	<1	Marmara
38	IVB	2.26	−2.69		25	Marmara/Mylasa
39	IVB	1.87	−2.84		22	Afyon/Aph.
40	IVB	2.41	−4.00	0		Afyon/Mylasa
41	IVB	2.26	−4.50	0		Afyon
42	IVB	1.08	−2.78			Aph./Ephesos
43	IVC	1.42	−3.83	0	26	Afyon
44	IVC	2.53	−2.86		6	Marmara/Mylasa
45	IVC	2.81	−3.86	0	2	Mylasa
46	IVC	0.51	−3.62	0		Aph./Ephesos
47	IVC	2.12	−4.12	0		Afyon/Aph.
48	IVC	2.00	−1.98	0		Marmara
49	VIE	2.06	−7.46	0	18	Naxos
50	VIE	2.56	−0.51		15	Marmara
51	VIE	2.79	−1.21	0		Marmara
52	VII	2.63	−1.40	0	5	Marmara
53	VII	2.01	−0.93	0	5	Marmara/Iasos
54	VII	2.73	−2.75		6	Marmara
55	VII	2.58	−1.24		3	Marmara
56	VII	3.15	−2.84	0		Marmara
57	VII	2.66	−2.37			Marmara
58	VII	1.91	−1.71			Marmara/Iasos

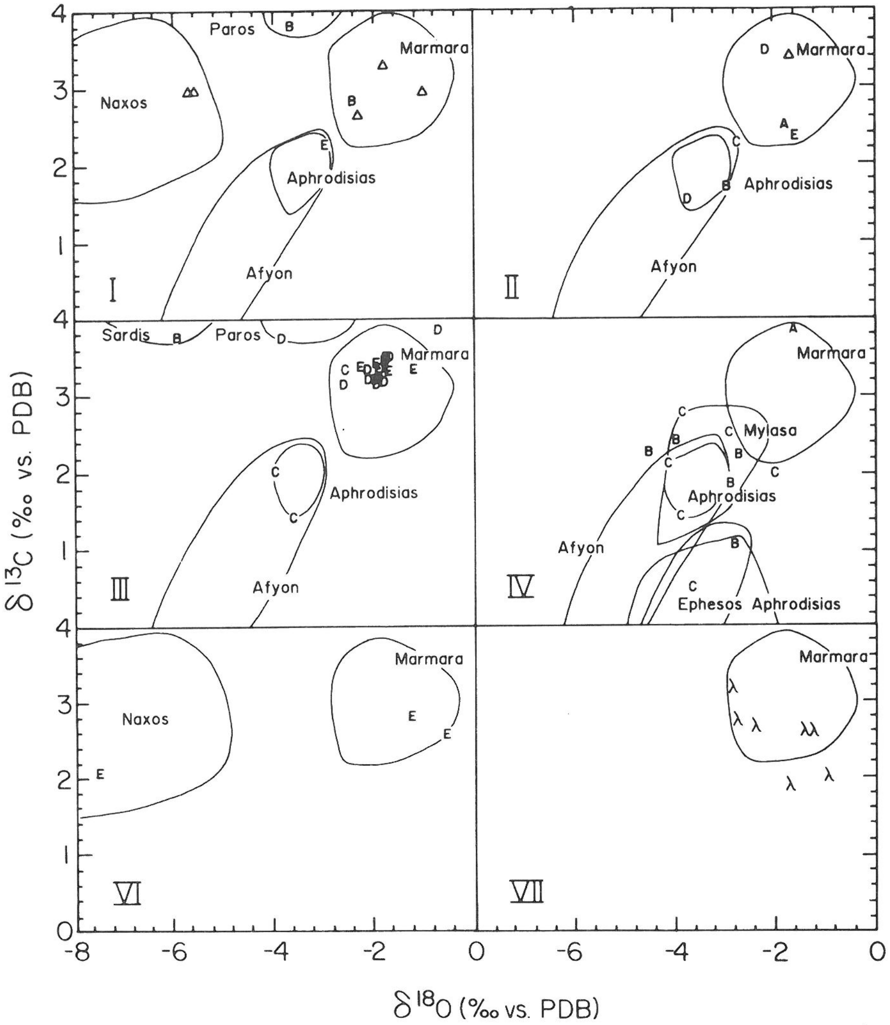

FIG. 4. Isotopic composition and possible source quarries for the Caesarea Corinthian capitals. Quarry fields are as in Fig. 3. Capitals are plotted according to their artistic type (I–VII) and artistic features (A–E; λ). See text for discussion on artistic classification. Triangles represent capitals of which an exact artistic character could not be determined. The determined isotopic composition is given by the center of each letter.

than the respective ranges and variances found for Scythopolis Theatre and Monument in both $\delta^{13}C$ and $\delta^{18}O$ values (Table 4). Further, applying an F-test to compare the variances in the isotopic signature of these capitals to that of their source quarry, Marmara, indicates that the probability that these capitals are different in their variances from the quarry fingerprint is very high ($P < 0.0001$ for both $\delta^{13}C$ and $\delta^{18}O$). This indicates that these capitals were quarried from a single outcrop in Marmara. The similarities in style and isotopic composition suggest that these capitals were part of a single monument in Caesarea. These similarities might imply also a marble purchase mode similar to that proposed for the Scythopolis Theatre.

CONCLUSIONS

Methods which were developed for understanding geological systematics can be applied to other fields of sciences and arts. Professor S. Epstein, who pioneered the field of stable isotopes in geochemistry, was the first to notice their potential use in other fields such as meteorology, oceanography, biology, and medicine. The natural variability of stable isotope composition assists in answering important questions in the relevant field. In this study we have shown that the stable isotope signature of assemblages of artifacts can provide important archeological information. The mode of marble purchase can be estimated provided that all artifacts are related to a single structure. If this approach is applied to other Roman monuments, a more complete understanding of the Roman marble trade system may be reached. A second outcome of this study is the possible use of stable isotopes to relate marble artifacts from an unknown monument together and perhaps to their original monument. In Roman sites like Caesarea, where most of the artifacts are found out of their original context, this is of great importance to historical reconstruction. These and the previously suggested applications of stable isotope analysis to this field (provenance, fragment reconstruction, authenticity) can lead to a better understanding of antique white marble finds.

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