LYDIAN ARCHITECTURE

ASHLAR MASONRY STRUCTURES AT SARDIS

By Christopher Ratté
with a contribution by Michael H. Ramage and Robert H. Tykot

Archaeological Exploration of Sardis

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APPENDIX 4:
GEOLOGICAL ANALYSIS OF LYDIAN BUILDING STONES AND THEIR QUARRY SOURCES

Michael H. Ramage and Robert H. Tykot

The geology of Lydian building stones can help illuminate ancient masonry practice. Comparison of the geological characteristics of bedrock and worked blocks can be used to identify the sources of building stones, providing useful information about quarrying and transport methods. The following analysis of Lydian building stones from Sardis has two parts: petrographic analysis by microscope of the limestone used in the majority of excavated Lydian buildings; and carbon and oxygen isotope analysis by mass spectrometer of marble, used less frequently by Lydian masons. It has been possible to show that Bin Tepe was the source of the limestone used both at Bin Tepe itself and at Sardis but that none of the sampled regional marble quarries provided the marble used by Lydian builders.

This study is based on 24 days of fieldwork in 1994 and an additional two weeks in 1995. Michael Ramage conducted the sampling and limestone analysis, while the marble analysis was done in Robert Tykot's laboratory with interpretation by Ramage and Tykot. The following discussion presents the results of the limestone analysis for the first time and builds on earlier characterizations of marble from selected objects and quarries near Sardis.[1]

SAMPLING

Many limestone and marble samples were collected, both from bedrock outcroppings exhibiting clear evidence of preindustrial quarrying and from ancient buildings. Because the limestone samples are large (ca. 2 cm diameter cores) and therefore destructive, only a limited number of samples were taken from excavated monuments. Marble analysis requires only a small sample (e.g., powder from a small drill hole or insignificant chips) and is therefore less destructive, but because of the paucity both of known marble monuments and of identified sources, the number of marble samples studied was also limited.

Seventy-one limestone samples were taken from outcroppings of the fine-grained white limestone favored by Lydian builders. The limestone quarries of Bin Tepe can be divided into five main areas: one quarry region associated with each of the largest mounds (Tomb of Alyattes, **no. 1**; Karnıyarık Tepe, **no. 2**; and Kır Mutaf Tepe);[2] one quarry near the Gygaean Lake; and an area in the middle of the Gediz (Hermus) plain, which had a number of worked but unused blocks nearby. For comparison with the quarry samples, 35 limestone samples were taken from Lydian monuments, including eight tombs, three ashlar walls, and six "phallic" markers. Not every example of limestone masonry at Sardis was sampled, but the monuments that were examined span the whole range of relevant building types and include monuments of both the Lydian and the Persian periods.

The two largest known ancient marble quarries in the region were also sampled, one south of Sardis in the steep gorge of Mağara Deresi and a lesser-known quarry near the ancient town of Mermere, now known as Gölmarmara.[3] The Gölmarmara quarry is situated at the top of a large hill south of the modern town and has many indications of working from at least Roman times, including pick and wedge marks typical of that period.[4] Other marble quarries in the region near Akhisar, Turgutlu, and Alaşehir were investigated but not sampled because the stone was visually dissimilar to Lydian building stone. Ongoing survey research may well identify quarries in the region that could have been sources of marble in Lydian times.[5] It is of course possible that other quarries remain to be discovered or that small ancient sources of good stone no longer exist. For comparison with the Mağara Deresi and Gölmarmara quarries, 11 samples were taken from the few known examples of marble in Lydian architecture. In Bin Tepe, the tomb chamber in the tumulus of Alyattes (**no. 1**), a worked marble piece from the rubble

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[1] Hanfmann and Ramage, *Sculpture* (Sardis R2), 6; Monna and Pensebene, *Marmi*, 177–79; Tykot and Ramage, "Importation."

[2] On Kır Mutaf Tepe, see above, Ch. 1.

[3] Robert, "Documents."

[4] Rockwell, *Stoneworking*, 162–63.

[5] Roosevelt, *Lydia*, 54.

fill of Karnıyarık Tepe (**no. 2**), and a funerary kline of the sixth century B.C. from a tomb near Kendirlik were sampled;[6] from Sardis itself, samples were taken from an unfinished architectural block, perhaps a crown molding, and a stylobate, both from the "Byzantine Fortress" (**no. 17**).

LIMESTONE QUARRIES AND MONUMENTS

The limestone quarries are generally small and concentrated in Bin Tepe. Although there are limestone deposits outside the Bin Tepe area, none of them are known to have the fine-grained white limestone Lydian builders used. The quarries evaluated were selected based on evidence of use in ancient times. The indications include straight, deliberately cut edges in bedrock, cut blocks, and toolmarks, as seen around the area of Karnıyarık Tepe. Large amounts of broken stone, presumably waste from a stoneworking operation, are a third indication of ancient quarrying. Such piles of stone could be related to diagenesis or weathering, but the abundance of these stones in proximity to areas where there is ample evidence of quarrying suggests working in antiquity. (The stones since have been made into piles by modern farmers.) Not surprisingly, the three largest burial mounds of Bin Tepe, as well as some of the smaller mounds, are associated with individual quarries. This association is twofold: the mounds are situated on top of a limestone ridge and are therefore all the more imposing because of the topography, and the construction of tomb chambers within each tumulus required significant quantities of stone.

The archaeological samples come from buildings that have been dated from ca. 560 B.C., about the time of the death of Alyattes, to the fifth or fourth century. The earliest monuments studied are the Tomb of Alyattes (**no. 1**), Karnıyarık Tepe (**no. 2**), and the terraces and walls of excavation sectors Acropolis North (**no. 16**), Byzantine Fortress (**no. 17**), and MMS/N (**no. 18**). The other monuments follow in time, with the Lydian Altar (LA 1, see Appendix 3) in front of the Hellenistic Temple of Artemis most likely the latest. Some of the monuments sampled are not dated, such as Kır Mutaf Tepe and the "phallic" markers found in the Pactolus valley near Sardis and elsewhere.

LIMESTONE THIN-SECTION ANALYSIS

The limestone was analyzed in thin section using a petrographic microscope and plane and cross-polarized light. Unstained thin sections were compared using visual characteristics, including the texture, the degree of dissolution and recrystallization by groundwater, the presence or absence of fossils or phosphate (the material fish scales are made of), and the presence or absence of volcanic quartz grains. The comparison based on the microscopic criteria is founded on the premise that certain areas of the limestone formation at Bin Tepe have distinct characteristics, from both original depositional differences and subsequent alteration by groundwater.

The limestone of Bin Tepe is all one formation, as shown by widespread similarities in fossil content and thin-section character. The limestone was formed during the Neogene (23.7–1.8 million years ago)[7] and, on the evidence of the ostracod fossils[8] and pelletization, was deposited in shallow water. The beds are about 1 m thick but are ill defined. The texture ranges from micritic, or very fine grained, to pelletal, or coarsely granular. The limestone shows evidence for recrystallization from groundwater alteration throughout the deposit, although the degree of recrystallization varies. Much of the limestone also contains volcanic quartz grains, identifiable by their angularity and because they are strain free, showing no undulose extinction under the crossed polars of a microscope.

The most useful characteristic for distinguishing between different limestones was texture. Because texture varies both in time and space, different layers in the same region may not have the same texture, making it a useful marker for local identification within a larger formation. Pellets were the easiest characteristics to identify and the first divider, after which other criteria were used to distinguish between samples. The second diagnostic characteristic was the amount of detrital quartz, which must have fallen into the basin as airborne detritus from volcanic eruptions. There are numerous Neogene volcanic provinces in the vicinity,[9] and the presence of biotite in some samples is consistent with the idea that these pieces of quartz are volcanic in origin. Variation in the amount of detrital quartz is likely a result of differences in volcanic activity or wind during the time of deposition or in the distance the particular quartz grains were transported (smaller grains tending to travel farther). A third useful criterion for correlation was the amount and type of dissolution and recrystallization within the limestone, both a result of groundwater moving through the limestone after lithification. The results of dissolution and recrystallization appear to be fairly localized and therefore worked well to distinguish similar samples.

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[6] NoEx94.4. On the tomb, see Bilgin et al., "Temizlik Kazısı."

[7] Konak, *Jeoloji Haritası* (scale 1:500,000).

[8] Adams et al., *Sedimentary Rocks.*

[9] Bingöl, *Jeoloji Haritası* (scale 1:2,000,000).

Independently, each of these characteristics might not be decisive, but when used together, they provide a good indication of the quarry source for a particular archaeological sample. Detailed comparisons of the stones were made using visual clues from the petrographic microscope. Certain stones were matched both on the basis of similarities between two or more thin sections and on the basis of differences from the entire body of samples. The analysis was primarily visual, and thus photomicrographs of some matching samples illustrate the comparisons below (Figs. 281–84).

LIMESTONE PROVENANCE

Examination of 106 thin sections yielded 13 matches between artifacts and quarries (Table 1). The correlation between burial mounds and nearby quarries was expected, and this is the case with each of the three largest burial tumuli. Because this is a natural association supported by the geological analysis, it helps to validate the technique. Two stones from the possible crepis wall of Kır Mutaf Tepe match the bedrock in local quarries; similarly, the Karnıyarık Tepe crepis wall (**no. 2**) matches the limestone nearby. Additionally, the limestone used in the ceiling of the chamber of the Tomb of Alyattes (**no. 1**) matches the outlying bedrock, and packing from the flank of the mound, perhaps belonging to a crepis, matches sandstone outcroppings in the vicinity. In other cases, however, it is clear that limestone blocks were transported significant distances from quarries at Bin Tepe to building sites at Sardis.

Full correlations borne out by the analysis are given in Table 1, which shows the definitive matches possible among the samples taken. Some logical matches were not possible; for instance, the limestone marker on top of the Tomb of Alyattes (**no. 1**) has no quarry match, although it is reasonable to assume it was quarried locally. The lack of a match could indicate that it comes from an unidentified quarry or that the variability of the limestone within a quarry prevented a match. In some instances there are multiple samples from the same monument, but only one match to a quarry source. This could suggest multiple quarry sources for a single monument, but without a definitive match to different quarries, it is difficult to draw this conclusion with any certainty.

Table 1. Correlations of limestone and sandstone monuments and quarry samples

Archaeological Samples Location Sample ID	Quarry Samples Location Sample ID	Match Criteria
Alyattes tomb chamber	Alyattes mound	
ATC-5	D	pellets, reprecipitated calcite, abundant quartz
Alyattes "crepis"		
BT/A 93.1	AC	quartz-biotite sandstone
Acropolis North	Karnıyarık Tepe	
AcN 1	Y	micrite, small amount of quartz
MMS/N walls		
MMS/N A3	KT-B	fossils, pelletal pellets
MMS/N C6	G	fossils, pelletal pellets
MMS/N D1	U, KT-DB	fossils, pelletal pellets
Karnıyarık Tepe crepis		
KT-CB	G, U, KT-DB	fossils, pelletal pellets
KT-NEB	G, U, KT-DB	fossils, pelletal pellets
Kır Mutaf Tepe "crepis"	Kır Mutaf Tepe	
BC	BB	phosphate, quartz, slow reaction to HCl
KMT-A	BA	recrystallized calcite, quartz
Pyramid Tomb		
PyT B	BB	phosphate, quartz, slow reaction to HCl
"Phallic" markers		
NoEx62.19	BI	quartz, dissolution, pellets
NoEx84.5	BD	micrite groundmass, recrystallized pellets, small amount of quartz

A limestone block from the Acropolis North retaining walls (**no. 16**, sample AcN 1) and a number of blocks from MMS/N (**no. 18**, samples MMS/N A3, C6, and D1) match bedrock from the area near Karnıyarık Tepe (**no. 2**, samples G, U, KT-B, and KT-DB). The Acropolis North wall sample (Fig. 281) matches bedrock sample Y from Karnıyarık Tepe (Fig. 282) for two reasons. Both samples are a micrite with little dissolution and little quartz. The relatively unusual texture of the rocks and the small amount of volcanic quartz are both striking features. In this case, the similarity of these thin sections, combined with their differences from the rest of the samples, establishes the match. The samples shown in Figures 283 and 284 are more characteristic of the general texture of Bin Tepe limestone.

The match between the stone used in the walls at MMS/N (sample MMS/N A3, Fig. 283) and Karnıyarık Tepe bedrock (sample KT-B, Fig. 284) is based on another feature visible in these samples. Both are pelletal limestones with moderate amounts of quartz and similar calcite recrystallization, of which the most striking feature is the fact that the pellets themselves are pelletal. This represents reworking of already pelletal limestone in the depositional environment, perhaps by waves. This feature was rare in the samples from Sardis.

In another area of Bin Tepe, there are a number of matches between Lydian building stone and the quarries around Kır Mutaf Tepe. In addition to the possible crepis wall of the mound itself, the Pyramid Tomb near Sardis (**no. 15**) and two "phallic" markers (NoEx62.19 and NoEx84.5) match the bedrock quarries near Kır Mutaf Tepe. A stone from the possible Kır Mutaf Tepe crepis and one from the Pyramid Tomb both match sample BB from the Kır Mutaf Tepe quarries. The basis for this correlation is the abundance of phosphatized particles containing pieces of quartz. The phosphatized particles are identified by their amber color and their isotropic nature (they appear black under cross-polarized light). The clear particles within the phosphate pellets are quartz. In addition, all three of these samples were slower to react to hydrochloric acid than many other samples from Bin Tepe.

In the region of the third and largest of the huge burial mounds, the Tomb of Alyattes, there are similarities between the Lydian structures associated with the mound and the surrounding bedrock. Inside the mound, a sample from the ceiling of the tomb chamber matches the stone in a local quarry. The worked block from the packing for the possible crepis is composed of a type of sandstone found in the vicinity of the mound of Alyattes. This correlation was made visually, without the microscope, as the sandstone is extremely rich in quartz and biotite, making it easy to distinguish the worked block and its source from the limestone in the area.

A final stone of interest is the material used to build the Lydian Altar (LA 1)[10] in the sanctuary of Artemis. This stone is not a limestone from the formation at Bin Tepe but is instead a tufa,[11] a soft, porous calcium carbonate deposited by springs, lakes, or groundwater. In hand specimen, the stone is much darker and softer and riddled with small, interconnected holes. The stone also appears different in thin section. There are hot springs near Sardis called Sart Çamur Hamamı, but sources of tufa such as the one used in the construction of the Lydian Altar remain to be identified. Many small sources of good stone could have been quickly worked out or easily concealed by undergrowth.

MARBLE QUARRIES AND ISOTOPE ANALYSIS

The marble quarries of both Mağara Deresi, near Sardis, and Gölmarmara, across the Gediz (Hermus) plain, show extensive evidence of preindustrial working. In both places, the white, coarsely crystalline marble is criss-crossed with pick marks, and many abandoned blocks are lying about. These quarries were sampled to determine whether either one may have been a source of the marble used in Lydian monuments.

Answering this question involves the comparison of stable isotope ratios of carbon (C) and oxygen (O). Individual quarries have been found to have distinct isotopic compositions that can be compared with isotopic compositions of archaeological material.[12] The technique is based on the variations of isotopic values of carbon and oxygen in the depositional environment of a limestone, which are related to the temperature and climate conditions in the water.[13] After metamorphism to marble, the stone retains some of the original isotopic conditions, allowing them to be distinguished. Further isotopic differences may be introduced by hydrothermal waters during metamorphosis, which also serve to homogenize isotope values within one metamorphic complex.[14]

The carbon and oxygen isotope content of the Sardis samples was measured by Tykot using a VG II Isogas mass spectrometer at Harvard's Archaeometry Laboratory. The samples were powdered using an agate mortar, and then a few milligrams were placed in the spectrometer's

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[10] See Appendix 3.

[11] Hanfmann, *SPRT*, 51.

[12] Craig and Craig, "Greek Marbles."

[13] Faure, *Isotope Geology*.

[14] Craig and Craig, "Greek Marbles."

autosampler. The samples were dissolved one at a time in a 100-percent phosphoric acid bath; the ensuing reaction produced CO_2, which was directed to the mass spectrometer, where carbon and oxygen isotopic values were measured simultaneously. The result is reported as a delta value (δ) between the isotopic ratio of the sample and an internationally accepted limestone standard (Pee Dee *Belemnitella*) and is calculated by:

$$\delta(x) = ((R_x - R_{std})/R_{std}) \text{ x } 10^3$$

where R_x is $^{13}C/^{12}C$ or $^{18}O/^{16}O$ of the unknown, and R_{std} is the same ratio for the standard.[15]

MARBLE PROVENANCE

Interpreting the isotopic compositions is a straightforward procedure. Following the example of Craig and Craig and others as summarized by Herz, the data are plotted and compared visually.[16] Typical isotopic compositions are sufficiently constrained so that it is possible to draw boundaries around the data points, giving a region within the graph that corresponds to a particular quarry. It should be noted, however, that the ellipses in Figures 285 and 286 are not statistically determined. The ranges of isotopic compositions of marbles from certain quarries sometimes overlap, so that other rock properties such as grain size, streaking, and historical connections must be used to further narrow possible source areas. At Sardis, the isotopic compositions of the two quarries studied are distinct, particularly in carbon values (Fig. 285, Table 2). The authors' samples from the Mağara Deresi quarries may have two isotopic fields, but the two areas on the graph are consistent with the sampling from the gorge: the samples with $\delta^{18}O$ values between -7 and -8‰ come from a quarry laterally distinct and topographically higher than the samples with values between -10 and -11‰. The authors' samples from Mağara Deresi have $\delta^{18}O$ values ranging from -7 to -11‰ and $\delta^{13}C$ values ranging from 2.5 to 4.5‰. In contrast, the samples from the Gölmarmara quarry have a greater scatter of $\delta^{18}O$ values between -4.6 and -7.6‰ but fairly constrained $\delta^{13}C$ values from 0.8 to 2.5‰.

The isotope values from the archaeological samples plot in yet another isotopic field. The five samples from the tomb chamber of Alyattes have well-constrained isotopic ratios ($\delta^{18}O$: -5.6 to 6.4‰; $\delta^{13}C$: 0.5 to 0.7‰), which indicates that they are from the same source. The other archaeological samples have similar isotopic compositions and are visually similar. The correlation strongly suggests that all the Lydian white marble samples come from a single quarry.

Importantly, the isotope compositions show that the archaeological samples are not derived from the Mağara Deresi quarries of the Sardis hills, nor are they sufficiently close to the isotopic range of the Gölmarmara

Table 2. Marble samples:
Stable carbon and oxygen isotope results

Site	Sample no.	$\delta^{13}C$	$\delta^{18}O$
Gölmarmara quarry	GMQ-1	1.9	-7.6
Gölmarmara quarry	GMQ-2	1.9	-5.1
Gölmarmara quarry	GMQ-3	2.5	-7.5
Gölmarmara quarry	GMQ-4	2.1	-5.6
Gölmarmara quarry	GMQ-5	1.8	-4.6
Gölmarmara quarry	GMQ 95.1*	0.8	-10.3
Gölmarmara quarry	GMQ 95.2*	2.0	-5.8
Gölmarmara quarry	GMQ 95.3*	1.9	-6.6
Gölmarmara quarry	GMQ 95.4*	1.9	-6.7
Gölmarmara quarry	GMQ 95.5*	2.0	-6.9
Gölmarmara quarry	GMQ 95.6*	2.1	-4.8
Gölmarmara quarry	GMQ 95.7*	1.0	-7.4
Mağara Deresi gorge	Q-1	3.4	-11.3
Mağara Deresi gorge	Q-2	2.8	-10.5
Mağara Deresi gorge	Q-3	4.0	-10.1
Mağara Deresi gorge	Q-4	4.4	-7.8
Mağara Deresi gorge	Q-5	4.3	-7.1
Mağara Deresi gorge	Q-6	4.4	-7.4
Mağara Deresi gorge	Q-7	4.3	-9.4
Mağara Deresi gorge	Q-8	3.9	-11.2
Alyattes tomb chamber	ATC-1	0.7	-5.6
Alyattes tomb chamber	ATC-2	0.6	-6.3
Alyattes tomb chamber	ATC 95.1*	0.5	-5.9
Alyattes tomb chamber	ATC 95.2	0.5	-6.4
Alyattes tomb chamber	ATC 95.3*	0.7	-6.4
Karnıyarık Tepe	KT-M1	1.3	-5.8
Sardis, Byzantine Fortress	BF9195.1 stylobate*	0.2	-7.0
Sardis, Byzantine Fortress	BF9195.2 stylobate*	0.9	-5.9
Sardis, Byzantine Fortress	BF9195.3 "crown molding"	1.8	-4.0
Bin Tepe chamber tomb	kline leg*	0.6	-6.6
Bin Tepe chamber tomb	kline top	1.0	-6.5

* indicates results as an average of two analyses

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[15] Anderson and Arthur, "Stable Isotopes."

[16] Craig and Craig, "Greek Marbles"; Herz, "Isotopic Analysis."

quarry (Fig. 285). The data indicate that the marbles are not from the known local quarries. The Sardis samples display isotopic similarities, however, with quarries at Ephesus, Denizli, and Dokimeion (Fig. 286).[17] It is possible that the Lydian marbles come from one of these quarries or that they come from an undiscovered quarry nearer Sardis.

In order to distinguish among these three possible sources, grain-size comparisons between the possible sources and the artifacts are used. In a study of ancient marble quarries,[18] maximum grain size is determined to be a distinguishing characteristic among marble quarries. The maximum grain size for Dokimeion marble is 1.8 mm, whereas the largest grain size for Sardis marbles, measured from thin sections, is 2.6 mm for ATC-2, a sample from the chamber of the Tomb of Alyattes, and 2.0 mm for KT-M1, a piece of worked marble from the tunnels of Karnıyarık Tepe. This suggests that Dokimeion is not a source. Furthermore, neither Denizli nor Dokimeion are sources of marble known to have been used as early as the sixth century B.C. This points to a source other than Dokimeion or Denizli, indicating on isotopic grounds that the quarries of Ephesus are a possible source. Recent archaeological surveys of the northern side of the Gediz plain, however, have located small quarries of white marble.[19] These have not yet been sampled for isotope analysis but may prove to have been a more local source of white marble in Lydian times.

CONCLUSIONS

Geological analysis of Lydian building stones confirms Bin Tepe as the source of at least some of the limestone used at Sardis and environs in the Lydian and Persian periods. Specifically, the limestone of the terrace walls on the Acropolis (**no. 16**) and the defensive walls at MMS/N (**no. 18**) comes from the quarries around Karnıyarık Tepe (**no. 2**); the stone for the Pyramid Tomb (**no. 15**) comes from the area around Kır Mutaf Tepe; and, not surprisingly, the masonry structures associated with each of the three large tumuli exploited quarries nearby.

The source of Lydian architectural marble remains uncertain. Based on the distinct carbon and oxygen isotope ratios in the marbles, the analysis shows that neither of the two known local marble quarries was the source of the architectural marble used in Lydian times. Distant quarries are possible sources: those at Ephesus provide an isotopic and visual match and were exploited during this period; those at Denizli and Dokimeion are isotopically similar but are more fine grained, and there is no evidence that they were active at this time. The geology of the Sardis region would suggest that there may be undiscovered ancient sources of coarse-grained white marble closer to Sardis.

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[17] Herz, "Isotope Ratios."

[18] Moens et al., "Provenance Determination."

[19] Roosevelt and Luke, "CLAS 2006," 312.