Archaeometry
Published by Blackwell Publishing for University of Oxford

Provenancing of Lightweight Volcanic Stones Used in Ancient Roman Concrete Vaulting: Evidence from Turkey and Tunisia

Journal:	*Archaeometry*
Manuscript ID:	draft
Manuscript Type:	Original Article
Date Submitted by the Author:	

Complete List of Authors:	Lancaster, Lynne; Ohio University, Department of Classics and World Religions Sottili, Gianluca; Università di Roma-"La Sapienza", Dipartimento di Scienze della Terra Marra, Fabrizio; Istituto Nazionale di Geofisica e Vulcanologia Ventura, Guido; Istituto Nazionale di Geofisica e Vulcanologia

Keywords:	scoria, pumice, Pantelleria, Sardinia, Turkey, Tunisia, Ceyhan, Osmaniye, XRF, Cilicia, trade routes, concrete vault

For Peer Review

scholarONE™
Manuscript Central

Provenancing of Lightweight Volcanic Stones Used in Ancient Roman Concrete Vaulting: Evidence from Turkey and Tunisia

The mastery of the use of lightweight rocks in concrete as a means of controlling the thrusts of large scale vaults was among the most important contributions of the Roman builders to the development of vaulted architecture. The string of volcanoes along the Tyrrhenian coast of Italy produced a variety of lightweight rocks, which allowed the builders in Rome to develop highly sophisticated ways of manipulating form and mass to create stable structures. The use of lighter rocks in vaults and heavier in foundations occurs from the mid first century B.C. in Rome, but the systematic use of imported lightweight rocks only began in the early second century A.D. under Trajan (Lancaster 2005, 59-64). Soon thereafter the technique of using lightweight stones to build large vaults spread throughout the empire, usually to areas that had a local source of lightweight volcanic material. However, there was also a seaborne trade in lightweight rocks to areas that did not have local sources of such material. The intention of our analysis is to determine as precisely as possible the provenance of the lightweight stones used in vaulting of two areas of the Mediterranean, modern Turkey (ancient Cilicia) and Tunisia (ancient Africa Proconsularis), and thus to provide a better understanding of the nature of this trade.

THE STRUCTURES AND THEIR CONTEXT

For Peer Review

The first sample (01 Anaz) comes from a bath building at Anazarbos in Smooth Cilicia (Cilicia Pedias) (Fig. 1), where a number of scoria cones lie along the fault running between Ceyhan and Osmaniye parallel to the axis of the Gulf of Issus (Fig. 2). M. Spanu (2003, 25) has recently noted the presence of scoria in the vaults of a number of bath buildings in Smooth Cilicia. In addition to our sample at Anazarbos, similar looking dark gray vesicular scoria occurs in bath buildings at Tarsus and Hieropolis Castabala. There are no clear dates for any of the buildings, but second/third century A.D. is generally assumed.

The second sample (025 ElSeb) comes from the Reticulate Baths at Elaeussa Sebaste in Rough Cilicia (Cilicia Tracheia), which lies about 150 km southwest of the Ceyhan-Osmaniye volcanic district. This building was once considered Augustan, but Spanu (1999, 112-13) has recently argued convincingly for a date in the first half of the second century A.D. The scoria is visually similar to the scoria found in the structures from Smooth Cilicia closer to the scoria cones (Fig. 3).

Our goal in analyzing these samples is to verify that the scoria used in vaults at Anazarbos, which lies near the Ceyhan-Osmaniye volcanic district, is in fact compatible with material produced by this system and to provide a control for the sample from

For Peer Review

Elaeussa Sebaste, which is much further from the volcanic district and must have arrived at the site by sea.

The other two samples come from structures in Tunisia, part of the ancient province of Africa Proconsularis, which does not have a local source for volcanic rocks; therefore, any lightweight volcanic stones found in the vaulting of structures there necessarily must have been imported, thus making it an excellent subject for the study of trade in this area.

The first Tunisian sample (03 AntBaths) comes from the Antonine Baths at Carthage (146-162 A.D.), the largest of the baths in North Africa. The structure is a well known example of the use of lightweight stones in vaulting; its use here in the domes was documented as early as the 11th-century by the geographer Al Bakri (Lézine 1969, 30). Presently most of the visible standing vaulting belongs to the substructures of the baths, which do not employ lightweight stones, but at the north end of the complex there is one piece of fallen vaulting from the superstructure, which contains a dark olive to reddish brown vesicular scoria (Fig. 4). Similar looking material occurs nearby in the fallen vaulting of the so called Baths of Gargilius (today signed as “l’édifice à colonnes”). In 1861, C. Beule suggested a provenance for the scoria of Sardinia or Sicily, but more recently Lézine (1969, 30 n. 4) suggested Sicily; however, neither suggestion was based on scientific evidence. Presumably Lézine's attribution of Sicily in part was based on

For Peer Review

Vitruvius's (*De Arch* 2.6.2-3) mention of Etna as a source of sponge stone (*spongia*), which he likens to the *pumex pompeianus* of Vesuvius.

The second sample (04 Lepti) from Tunisia is light gray/brown pumice from the fallen frigidarium vault of the East Baths (late second-early third century A.D.) at Leptiminus (Fig. 5). Initial speculation was that it came from the Aeolian Islands because Pliny the Elder (*HN* 36.154) mentions them as the source of very lightweight, white colored pumice (Dodge 1992, 157).

The two samples from Tunisia are clearly very different rocks occurring in very different contexts. The Antonine Baths represent the premier bath complex of one of the most important trading centers in the Mediterranean whereas the East Baths at Leptiminus occur on the east coast of Tunisia away from the major ports (Fig. 6). In both cases, the origin of the stones has significant implications for the nature of the trade in this central zone of the Mediterranean, particularly because the stone is not likely to be a primary product of the shipping route (as marble would be) but rather a secondary if not tertiary product.

For Peer Review

Given the different geographical contexts in which these four samples are found, they should provide some insight into the different types of trade patterns that existed for building materials in central and eastern Mediterranean.

PETROGRAPHIC AND GEOCHEMICAL FEATURES

For Peer Review

The collected samples have been analyzed using thin section for the detection of the mineral phases and textural features. Selected samples have been also analyzed by X-Ray Fluorescence Spectroscopy (XRF) and laser ablation inductively coupled plasma mass spectrometry (LS-ICO-MS) to determine the concentration of major and selected trace elements. Wet chemical techniques were used to measure the loss on ignition (LOI). International rock standards have been used for curve calibration. Precision is better than 5% for Rb and Sr, better than 10% for Ni, Zr, Nb, Ba, Ce and La and better than 15% for the other elements. As will be specified in the following sections, we will not use some major elements (e.g. Na, K, Fe) to classify the samples with microscopic (e.g. zeolites) or geochemical (e.g. high LOI) evidence of alteration because the concentration of these elements may significantly change during weathering (Duzgoren-Aydin et al. 2002). We will use trace elements (e.g., Nb, Zr, Y, Ti, V) whose concentration does not vary during water-dominated and/or low metamorphism processes (Floyd and Winchester 1978). Therefore, on the basis of the above considerations, classical classification and/or discrimination diagrams (e.g. SiO_2 vs. Na_2O+K_2O; Le Bas et al. 1986) cannot be used for altered and/or contaminated volcanic rocks.

01-Anazarbos (Anaz) and 025-Reticulate Baths Elaiussa Sebaste, Turkey (ElSeb)

The samples 01 (Anaz) and 025 (ElSeb) are oxidized scorias. The sample 01 (Anaz) is dark gray (10YR 4/1) and characterized by 50 vol. % of phenocrysts and 30 vol.% of vesicles with a density of 1235 kg/m^3. The size and shape of vesicles is heterogeneous: large, 4 to 6 mm vesicles are elongated whereas the smaller (0.1-0.5 mm) vesicles are subrounded. The mineral phases of the sample 01 (Anaz) are: Fe-Ti oxides, olivine, and clinopyroxene. Plagioclase occurs in the groundmass along with some crystals of apatite. Olivine is altered in iddingsite, which consists of a mixture of clay minerals, iron oxides and ferrihydrides, thus suggesting that the sample was affected by weathering. About 1 vol.% of calcite has been recognized. This mineral probably represents the remnants of some plaster or mortar material. The sample 025 (ElSeb) is black (5Y 2.5/2) and has 35 vol.% of crystals and about 60 vol.% of vesicles with a density of 1250 kg/m^3. The mineral phases are Fe-Ti oxides, olivine, and minor clinopyroxene. Plagioclase is confined in the groundmass and apatite is an accessory phase. Olivine is altered to iddingsite and the groundmass is heavily oxidized. Therefore, alteration processes affected this sample.

For Peer Review

Despite the evidence of alteration, the mineral association of the samples 01 (Anaz) and 025 (ElSeb), as well as their low SiO_2 (44.84-45.59 wt.%) and high MgO (7.07-8.02 wt.%) contents, indicate that the scorias are of basaltic composition. In addition, a distinctive feature of these samples is the high TiO_2 contents (2.55-2.56 wt.%) (Table 1). These values are well above those of the basaltic rocks from the Plio-Quaternary Italian volcanoes (e.g. Etna and Ustica, etc.), which have TiO_2<2 wt.% (Peccerillo 2005), and from the 'Levant' (Israel) and Libyan areas, characterized by TiO_2<2.2 wt.% (e.g., Antonelli et al. 2005). In the Mediterranean area, basalts with TiO_2 values consistent with those of the samples 01 (Anaz) and 025 (ElSeb) outcrop in Sardinia, eastern Sicily (Hyblea) and western Turkey. We exclude the Sardinia basalts because these rocks have V $\geq$ 200 ppm for $SiO_2 \leq 48$ wt.% (Peccerillo 2005) and the samples 01 (Anaz) and 025 (ElSeb) show values of V$\leq$186 ppm at SiO_2<46 wt.%. Therefore, two possible source areas can be proposed for the samples 01 (Anaz) and 025 (ElSeb): Turkey and Hyblea. However, both samples have been collected in an area of southern Turkey where the Ceyhan-Osmaniye Quaternary basalts diffusely outcrop (Polat et al. 1997). In particular, the sample 01 (Anaz) has been collected in a zone where at least three volcanic centers (Gertepe, Topprakale and Delihalil Tepe) occur within a radius of 20-40 km from the sampling site. The scorias from these centers have the same mineralogical association and TiO_2 content of the samples 01 (Anaz) and 025 (ElSeb) (Yurtmen et al. 2000). Therefore, we suggest that these samples come from a center of the Ceyhan-Osmaniye basaltic province.

For Peer Review

03-Antonine Baths, Carthage, Tunisia (AntBaths)

Sample 03 (AntBaths) is a dark olive (5Y 2.5/2) to reddish brown (5YR 4/3) scoria with a density of 1220 kg/m^3. It is characterized by 18 vol.% of crystals and 65 vol.% of coalescing vesicles that are 0.5 to 0.8 mm in size; a few 4 to 5 mm large vesicles are also present. The mineral phases are plagioclase, Fe-Ti oxides, clinopyroxene. Olivine is an accessory phase. The groundmass is highly oxidized. The SiO_2 content (44.61 wt.%) and the mineral association indicate that the rock is of basaltic composition (Table 1). The occurrence of plagioclase as main crystal phase and the lack of apatite as an accessory phase exclude that the source area of this sample is Turkey (see the features of the Turkish basaltic rocks in the previous section). TiO_2 content is high (TiO_2=3.02) thus excluding a provenance from the Plio-Quaternary Italian volcanoes (e.g. Etna and Ustica, etc.), ‘Levant’ (Israel), and Libyan areas which have TiO_2<2.0-2.2 wt.% (Antonelli et al. 2005; Peccerillo 2005). Therefore, two main source areas can be proposed, both characterized by TiO_2>2.5: Hyblea and Sardinia. However, the Nb content of sample 03 (AntBaths) is significantly lower (Nb=32 ppm) than that of the Hyblea basalts, which range between 52 and 170 ppm (Peccerillo 2005), whereas it falls within the range of the Sardinia basalts, which is between 28 and 107 ppm. The vanadium content (V=212 ppm) of sample 03 (AntBaths), is also consistent with that of the Sardinia basalts (V≥200 ppm for SiO2<48 wt.%; see above) Therefore, we conclude that the source sample 03

(AntBaths) is from Sardinia, even if we cannot further isolate the precise location on the island.

04-Leptiminus, Tunisia (Lepti)

Sample 04 (Lepti) is a very pale brown (10YR 8/2) subaphyric pumice with a density of 600 kg/m^3 and a crystal content not exceeding 5 vol.%. The glass is fresh, colourless and the vesicle content is 65-70 vol.% . Vesicles are coalescing and stretched; their size varies from 0.1-0.2 mm to 1 mm. Crystals show a maximum size of 1 mm. The mineral phases are: anorthoclase, alkali-amphibole, aenigmatite, quartz with embayment, Fe-Ti oxides, and apatite (Fig. 7). Anorthoclase and quartz are, in some cases, in intergrowth association suggesting the cotectic crystallization of the two phases. The petrographic features of the sample are consistent with pumiceous lapilli related to an explosive event. The mineral association, and, in particular, the occurrence of alkali-amphibole and aenigmatite indicate that the rock may be classified as peralkaline rhyolite. In the Mediterranean area such rocks outcrop on Pantelleria Island (Sicily Channel;Civetta et al. 1998; Ferla and Meli 2006) and southwestern Sardinia (San Pietro Island). However, the peralkaline rhyolites from Sardinia are characterized by the occurrence of sanidine, whereas those from Pantelleria Island have anorthoclase as a ubiquitous phase. Therefore, on the basis of the mineralogy of the sample 04 (Lepti), the source area of this pumice is Pantelleria, whose volcanism developed between 324 ka BP to 4 ka BP.

For Peer Review

CONCLUSIONS

The geochemical results have shown that the scorias from Anazarbos and Elaeussa Sebaste originated from one of the Ceyhan-Osmaniye volcanoes: Delihalil Tepe, Uçtepeler, or Gertepe. The use of the scoria in Smooth Cilicia is clearly a regional phenomenon surrounding the scoria cones. Tarsus is further away from cones than Anazarbos and Hierapolis Castabala, but it was reachable by boat via the inland port of Rhegnum and the river Cydnus (Ramsey 1903, 364-65; Strabo 14.5.10, 14.5.12), thus reducing overland transport required.

More unusual is the presence of this basaltic scoria in the walls and vaults of the so-called Reticulate Baths at Elaeussa Sebaste in Rough Cilicia. Unlike the previous examples from Smooth Cilicia in which the scoria is used as caementa for the entire vault, the scoria at the Reticulate Baths is used very sparingly for some blocks of the reticulate in the opus mixtum walls and along the line of the crown of some of the vaults (Fig. 3). In this case it is not used in a systematic manner nor is it used in large enough quantities to have had any structural effect on the building. Its use here is likely explained by the practice of cabotage, which was certainly occurring along the southern coast of Turkey ((Hohlfelder and Vann 2000; Arnaud 2005, 207-36). Such activity would accord with X.

For Peer Review

Nieto's (1997, 154-58) proposal of a maritime distribution model utilizing primary and secondary ports. The large long-haul ships transported goods to primary ports that had the infrastructure available for large draft ships and for unloading heavy cargoes. These goods were then redistributed to secondary ports by small coastal vessels carrying a mixed cargo to small ports that could not receive the larger ships.

Given the sporadic application of the scoria in the Reticulate Baths, it does not seem to have been specially acquired as was the case for the examples at Tarsus, Anazarbos, and Hieropolis Castabala nor would it have made effective ballast. However, recent analysis of finds on board Ship B (Augustan) excavated at Pisa shows that stones could also be used as stowage material to stabilize cargo, and this is perhaps a more likely explanation. The pointed ends of the amphorae on board Ship B were packed in volcanic lapilli and scoria from the Naples area. The amphorae themselves were being reused and some (Laboglia 2) contained sand that was identified as probably from Campania based on the sanidine and augite content. The ballast on the ship was identified as coming from various places along the Tyrrhenian coast. The small size of the ship (capacity of 70-80 tons) and its heterogeneous cargo show that it was involved in cabotage stopping at a major port in the Bay of Naples and then making its way north along the Tyrrhenian coast to Pisa (Pecchioni et al. 2007, 18; Bruni 2000, 42-43). Similarly one can imagine the scoria in the Reticulate Baths having been loaded at a major port closer to the scoria cones possibly as stowage material and then unloaded at Elaeussa Sebaste, where it was used in a rather haphazard manner in this one structure.

For Peer Review

The samples from Tunisia provide a somewhat different scenario for the trade in the central area of the Mediterranean. The geochemical results isolated the provenance of the dark scoria from the Antonine Baths at Carthage to Sardinia, thus eliminating Sicily as a source. The lava of Sardinian volcanoes was also quarried for grain mills, and Sardinia was apparently one of the major suppliers of grain mills for Carthage (Williams-Thorpe 1988, 284-88; Williams-Thorpe and Thorpe 1989).The scoria, therefore, was likely arriving at Carthage as a secondary product along with the mills. Given the quantity that would be needed for the vaults of such a large structure, the material was probably specially ordered, but the fact that there was an established shipping route for the grain mills and presumably land transport from the various quarries on the island would have made such orders economically feasible.

The source of Sardinia as opposed to Sicily is also enlightening from a navigational perspective. Eastern Sicily had its own source of volcanic scoria from the Etna and Hyblea volcanoes, which were presumably the sources of the scoria in the vaults at the theater at Taormina (Belvedere 1988, 365 n. 129, tav. 6-7), the odeum at Catania (Belvedere 1988, 367 n. 144, tav. 11, 13), and the "Gymnasium" at Syracuse (Cavallari and Holm 1883, 399). However, the use of a port along the eastern coast of Sicily would require ships on a north-south course to pass through the Strait of Messina, which could at times be treacherous due to winds and difficult currents (Arnaud 2005, 24-25, 175). On

For Peer Review

the other hand, the Sardinian ports of ancient Tharros or Carralis, both of which are near volcanic districts on the island, provided a direct and easy voyage to Carthage, thus making the Sardinian scoria a more attractive product.

The provenance of the pumice in the vaults of the East Baths at Leptiminus was established as Pantelleria from a thin section analysis of the minerals phases. Its origin is clear due to a rare mineral assemblage that characterizes some of the products of that volcano, particularly the presence of the mineral aenigmatite, or cossyrite, which takes its name from the ancient name of the island, Cossyra. The result was somewhat surprising but ultimately logical from the standpoint of trade routes. The anticipated source of the Aeolian Islands, which were mentioned by Pliny (*NH* 36.154) as a source of pumice, would again have required passage through the sometimes treacherous Strait of Messina, whereas Pantelleria was a major navigational hub in the Sicily Channel and had a particularly important role in the transshipment of goods to and from North Africa (Arnaud 2005, 163). Though we know of no other recorded examples of Pantellerian pumice in other vaults, there are examples of exported basaltic mill stones from Pantelleria found at Carthage, Utica, Thuburbo Maius, Celibia, and El Maklouba in Tunisia (Williams-Thorpe 1988, 296-305) and more recently at Cyrenaica in Libya (Antonelli et al. 2005, 140-42). The island had little to offer in terms of agricultural surplus and therefore took advantage of its role as port of call to develop an export trade in the local volcanic stones and a locally fabricated cookware, Pantellerian Ware (Mosca 1998, 1147-48). The distribution of the millstones from Pantelleria indicates that they

For Peer Review

were shipped only southwards (Williams-Thorpe 1988, 286), as opposed to Pantellerian Ware which is found throughout the western Mediterranean (Montana et al. 2007). Thus, as with the Sardinian scoria from Carthage, the pumice in the vaults of the East Baths at Leptiminus can be explained as part of a regional trading network, in this case emanating from the navigational hub of Pantelleria.

Ultimately, the samples from both the islands of Sardinia (03 AntBaths) and Pantelleria (04 Lepti) come from important shipping points in the western Mediterranean and are associated with the export of mill stones, which were no doubt in much greater demand than the scoria and pumice. In both cases the lightweight rocks seem to have been a secondary product both in terms of quarrying and of shipping. The samples from Cilicia, on the other hand, have a much smaller distribution, largely local to the source area. However, the example from Elaeussa Sebaste provides a glimpse into the smaller scale transport system based on cabotage to secondary ports along the southern coast of Asia Minor.

For Peer Review

ACKNOWLEDGEMENTS

We would like to thank colleagues at Mersin University, archaeologists Emel Erten and Serra Durugönül as well as geologists Kivanç Zorlu and Hidayet Tağa for their help with research on the Cilician volcanoes. Special gratitude goes to Emel Erten for her hospitality and energetic guidance of one of the authors (LCL) through the sites of Cilicia. We also thank Lea Stirling and David Stone of the Leptiminus Archaeological Project in Tunisia. This work was funded by a grant from the National Science Foundation and by the Istituto Nazionale di Geofisica e Vulcanologia. The geochemical analysis was performed at the XRF laboratory at Michigan State University.

For Peer Review

CITATIONS

Antonelli, F., L. Lazzarini, and M. Luni, 2005, Preliminary study on the import of lavic millstones in Tripolitania and Cyrenaica (Libya), *Journal of Cultural Heritage*, **6**(**2**), 137-45.

Arnaud, P., 2005, Les routes de la navigation antique: itinéraires en Méditerranée: Paris, Errance.

Belvedere, O., 1988, Opere pubbliche ed edifici per lo spetacolo nello Sicilia di età imperiale, *ANRW*, **2.11.1**, 346-413.

Bruni, S., 2000, Il porto urbano di Pisa e i relitti del complesso ferroviario di `Pisa-San Rosore', in *Le navi antiche di Pisa: ad un anno dall'inizio delle ricerche*, (S. Bruni, ed.), 21-79, Polistampa, Florence.

Cavallari, F. S., and A. Holm, 1883, Topographia archeologica di Siracusa: Palermo.

Civetta, L., M. D'Antonio, G. Orsi, and G. R. Tilton, 1998, The geochemistry of volcanic rocks from Pantelleria Island, Sicily Channel; petrogenesis and characteristics of the mantle source region, *Journal of Petrology*, **39**(**8**), 1453-91.

Dodge, H., 1992, Construction techniques and building materials, in *Leptiminus (Lamta): a Roman port city in Tunisia. Report no. 1*, (N. Ben Lazreg, and D. J. Mattingly, eds.), 157-62, Ann Arbor.

Duzgoren-Aydin, N. S., A. Aydin, and J. Malpas, 2002, Re-assessment of chemical weathering indices: Case study from pyroclastic rocks of Hong Kong, *Engineering Geology*, **63**, 99-119.

For Peer Review

Ferla, P., and C. Meli, 2006, Evidence of magma mixing in the "Daly Gap" of alkaline suites; a case study from the enclaves of Pantelleria (Italy), *Journal of Petrology*, **47**(**8**), 1467-507.

Floyd, P. A., and J. A. Winchester, 1978, Identification and discrimination of altered and metamorphosed volcanic-rocks using immobile elements source, *Chemical Geology*, **21**(**3-4**), 291-306.

Hohlfelder, R. L., and R. L. Vann, 2000, Cabotage at Aperlae in ancient Lycia, *International Journal of Nautical Archaeology*, **29**, 126-35.

Lancaster, L. C., 2005, Concrete vaulted construction in imperial Rome: Innovations in context: New York, Cambridge University Press.

Le Bas, M. J., R. W. Le Maitre, A. Streckeisen, and B. Zanettin, 1986, A chemical classification of volcanic rocks based on the Total-Alkali-Silica Diagram, *Journal of Petrology*, **27**, 745-50.

For Peer Review

Lézine, A., 1969, Les thermes d'Antonin a Carthage: Tunis, Societe tunisienne de diffusion.

Montana, G., B. Fabbri, S. Santoro, S. Gualtieri, I. Iliopoulos, G. Guiducci, and S. Mini, 2007, Pantellerian Ware: A comprehensive archaeometric review, *Archaeometry*, **49**(**3**), 455-81.

Mosca, A. P., 1998, Cossyra fra Africa e Sicilia. Aspetti della sua economia, *L'Africa romana* **12**, 1469-78.

Nieto, X., 1997, Le commerce de cabotage et de redistribution, in *La navigation dans l'antiquité*, (P. Pomey, ed.), 146-59, Edisud, Aix-en-Provence.

Peccerillo, A., 2005, Plio-Quaternary volcanism in Italy: Petrology, geochemistry, geodynamics: Berlin, Springer-Verlag.

For Peer Review

Pecchioni, E., E. Cantisani, P. Pallecchi, F. Fratini, A. Buccianti, E. Pandeli, S. Rescic, and S. Conticelli, 2007, Characterization of the amphorae, stone ballast and stowage materials of the ships from the archeological site of Pisa-San Rossore, Italy: Inferences on their provenance and possible trading routes, *Archaeometry* **49**(**1**), 1-22.

Polat, A., R. Kerrich, and J. F. Casey, 1997, Geochemistry of Quaternary basalts erupted along the East Anatolian and Dead Sea Fault zones of southern Turkey: Implications for mantle sources, *Lithos*, **40**, 55-68.

Ramsey, W. M., 1903, Cilicia, Tarsus, and the Great Taurus Pass, *The Geographical Journal*, **22**(**4**), 357-410.

Spanu, M., 1999, Analisi di alcuni complessi architettonici, in *Elaiussa Sebaste 1*, (E. Equini Schneider, ed.), 83-114, L'Erma di Bretschneider, Rome.

Spanu, M., 2003, Roman influence in Cilicia through architecture, *Olba*, **8**, 1-38.

For Peer Review

Williams-Thorpe, O., 1988, Provenancing and archaeology of Roman millstones from the Mediterranean area, *Journal of Archaeological Science*, **15**, 253-305.

Williams-Thorpe, O., and R. S. Thorpe, 1989, Provenancing and archaeology of Roman Millstones from Sardinia (Italy), *Oxford Journal of Archaeology*, **8**(**1**), 89–113.

Yurtmen, S., P. A. Floyd, F. Isler, J. D. Piper, G. Rowbotham, and J. A. Winchester, 2000, Petrogenesis of basalts from southern Turkey. The Plio-Quaternary volcanism to the north of Iskenderun Gulf, in *Tectonics and Magmatism in Turkey and the surrounding area (Geological Society Special Publications 173)*, (E. Bozkurt, ed.), 489-512, London.

For Peer Review

FIGURE CAPTIONS

Table 1. Chemical analysis of selected samples.

Fig. 1: Baths at Anazarbos with scoria in vaults. (Photo: L.C. Lancaster)

Fig. 2: Map of Cilicia showing Ceyhan-Osmaniye volcanic district. (Drawing: L.C. Lancaster)

Fig. 3: Reticulate Baths at Elaeussa Sebaste (second century A.D.) with scoria as caementa of vaults and blocks of reticulate. (Photo: L.C. Lancaster)

Fig. 4: Antonine Baths at Carthage (146-162 A.D.). Fallen vault of superstructure with caementa of scoria. (Photo: L.C. Lancaster)

Fig. 5. East Baths at Leptiminus (late second/early third century A.D.). Fallen vault with caementa of pumice and limestone. (Photo: L.C. Lancaster)

For Peer Review

Fig. 6. Map of western Mediterranean. Navigational routes based on Arnaud 2005, Fig. 154-155 (Drawing: L.C. Lancaster)

Fig. 7. Thin sections of Leptiminus pumice sample (04 Lepti) showing main mineral phases. (Photos: G. Ventura)

For Peer Review

Sample	01 (Anaz)	025 ElSeb)	03 (AntBaths)
		(wt.%)	
SiO2	44.84	45.59	44.61
TiO2	2.55	2.56	3.02
Al2O3	15.18	15.91	13.81
Fe2O3	11.01	11.18	13.2
MnO	0.17	0.17	0.19
MgO	7.07	8.02	5.82
CaO	8.54	7.46	10.61
Na2O	4.49	4.72	3.12
K2O	1.3	2.39	1.05
P2O5	0.92	0.69	0.55
LOI (%)	3.71	1.1	3.88
Totals	96.07	98.69	95.98
(ppm)			
Ni	-	143	-
Cu	-	36	-
Zn	-	71	-
Rb	62	25	20
Sr	881	829	415
Zr	306	335	185
Ba	362.5	276.24	279.33
La	51.12	43.73	38.1
Ce	82.7	74.42	52.27
Pr	9.66	9.22	8.47
Nd	38.17	36.3	36.67
Sm	7.48	7.62	8.13
Eu	2.3	2.17	2.46
Gd	7.05	6.26	7.89
Tb	0.94	0.9	1.08
Y	30.41	29.01	40.89
Dy	5.21	5.2	6.44
Ho	0.93	1.03	1.15
Er	2.56	2.63	3.11
Yb	2.22	2.44	2.69
Lu	0.32	0.36	0.39
V	142.19	186.08	212.43
Cr	133.58	144.45	81.39
Nb	50.19	56.18	32.06
Hf	6.61	6.9	4.53
Ta	3.71	4.1	2.35
Pb	6.48	2.72	10.19
Th	6.85	5.44	3.59
U	1.48	1.41	0.77

For Peer Review

Fig. 1. Baths at Anazarbos with scoria in vaults.
150x95mm (300 x 300 DPI)

For Review

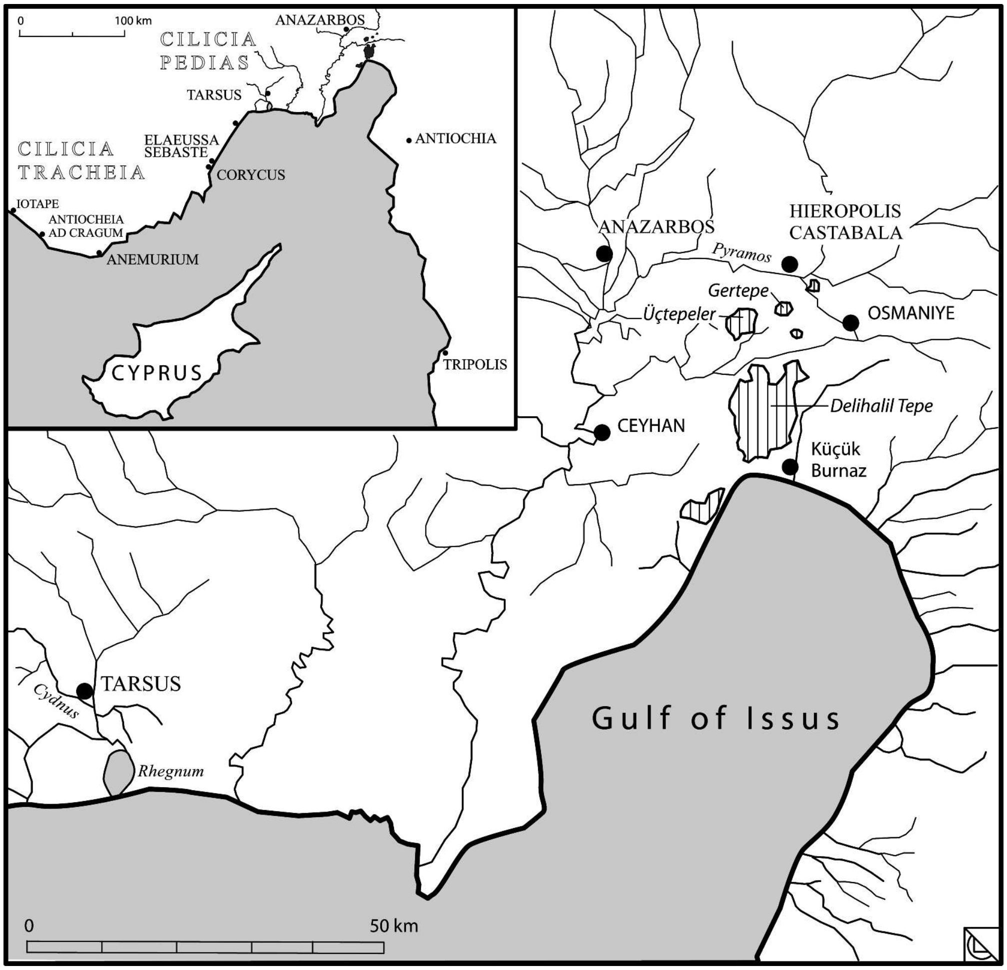

Fig. 2. Map of Cilicia showing Ceyhan-Osmaniye volcanic district.
141x135mm (600 x 600 DPI)

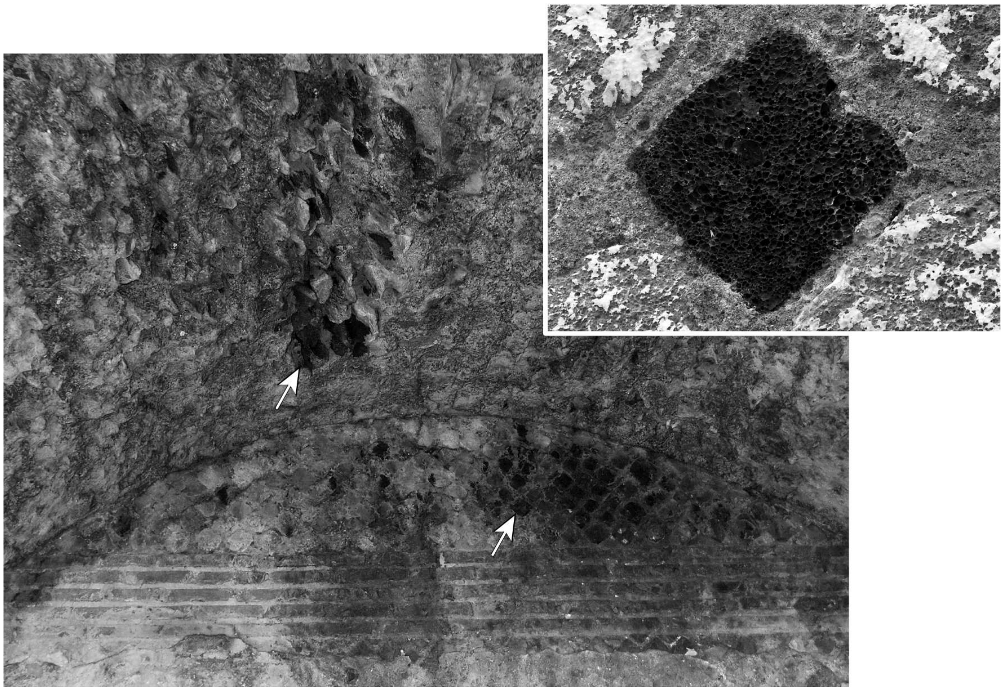

Fig. 3. Reticulate Baths at Elaeussa Sebaste (second century A.D.) with scoria as caementa of vaults and blocks of reticulate.
150x103mm (300 x 300 DPI)

Review

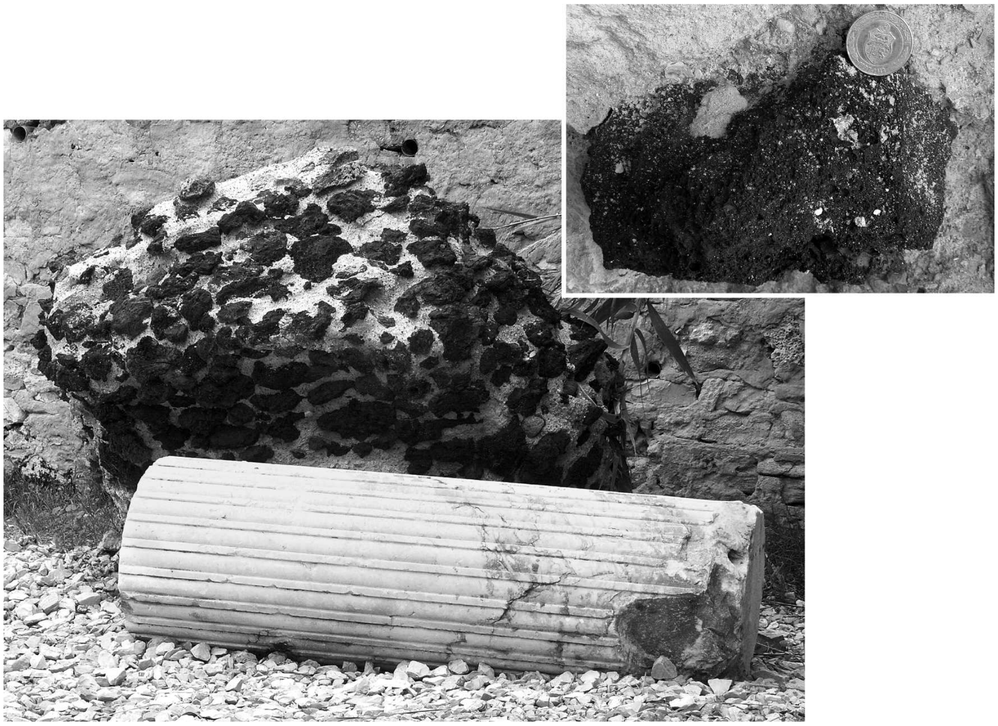

Fig. 4. Antonine Baths at Carthage (146-162 A.D.). Fallen vault of superstructure with caementa of scoria.
150x108mm (300 x 300 DPI)

Fig. 5. East Baths at Leptiminus (late second/early third century A.D.). Fallen vault with caementa of pumice and limestone.
150x104mm (300 x 300 DPI)

eview

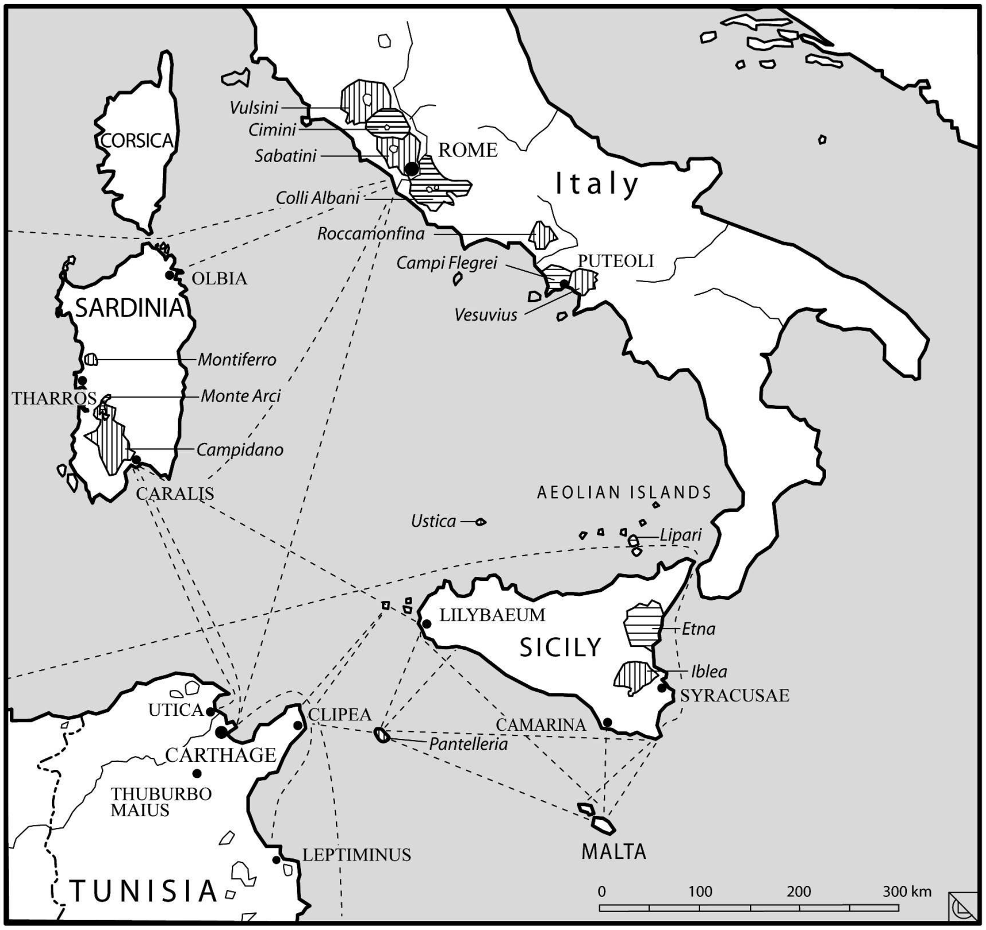

Fig. 6. Map of western Mediterranean. Navigational routes based on Arnaud 2005, Fig. 154-155.
147x141mm (600 x 600 DPI)

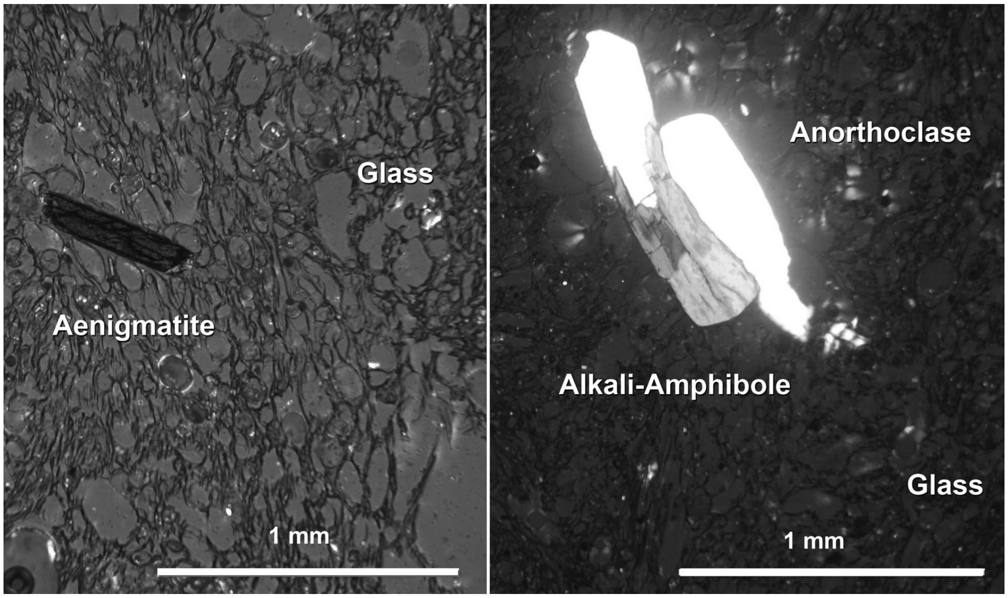

Fig. 7. Thin sections of Leptiminus pumice sample (04 Lepti) showing main mineral phases.
152x90mm (300 x 300 DPI)

For Peer Review