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New light on old pumice: the origins of Mediterranean volcanic material from ancient Egypt

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ABSTRACT

This paper presents and discusses the Neutron Activation Analysis (NAA) results newly obtained from pumice pieces found decades ago at the Egyptian sites of Maiyana, Sedment, Kahun, and Amarna – now in the collections of the Ashmolean Museum, Oxford, and the Petrie Museum of Egyptian Archaeology, London – which could be successfully related to several volcanic eruptions in the Mediterranean. The work contributes to the constant accumulation of knowledge concerning the first appearance of pumice from the so-called Minoan eruption of the Santorini volcano. In addition, it unexpectedly sheds more light on the long-distance trade of Mediterranean volcanic material in the Bronze Age world by disclosing another connection between Lipari and the Eastern Mediterranean.

1. Introduction

Neutron Activation Analysis (NAA) of archaeologically retrieved pumice can contribute to the ongoing debate over the date of the so-called Minoan eruption of Santorini in the mid-second millennium B.C.E. (Peltz and Bichler, 2001; Foster and Bichler, 2003; Huber and Bichler, 2003; Friedrich et al., 2006; Manning et al., 2006; Manning, 1999; Bietak, 2003a, 2004; Doumas, 1983; Friedrich, 2000; Hammer et al., 1987, 2001, 2003; Bronk Ramsey et al., 2004; Pearce et al., 2004a,b; Steinhauser et al., 2006b). The work forms part of the Thera Ashes Project within the framework of the Special Research Programme Synchronisations of Civilizations in the Eastern Mediterranean Region in the Second Millennium B.C. (SCIEM2000: Bietak and Kleinsgütl, 2000; Bietak, 2000, 2003b).

Substantial evidence identifying contextualized volcanic products with specific eruptions provides a definite terminus post quem for the stratigraphic horizon in which the ejecta were found. Highly reliable identification is achieved by means of ‘chemical fingerprinting’, applying NAA to the measurement of 25 elemental concentrations in an expanding database of volcanic eruptiva (Peltz et al., 1999; Steinhauser et al., 2006b, 2007).

Egyptian contexts of the late Second Intermediate/Hyksos Period and early Eighteenth Dynasty are particularly important for chronological issues (Wiener, 2007). If the Santorini volcano erupted in the late 17th century, as indicated by Friedrich et al. (2006) and Manning et al. (2006), and if pumice was used frequently as an abrasive at that time, one would expect, according to the present state of Egyptian chronology (Kitchen, 2007, and references therein.), to find pumice from this event in strata of the Hyksos period. If, however, Santorini erupted about 1525 B.C.E., as others hold, it ought to appear for the first time only in later levels. So far, NAA work carried out on pumice from sites in Egypt and the Levant has not found pumice from the Minoan eruption occurring earlier than the Eighteenth Dynasty (Warren, 2007; Bichler et al., 2007). However, since the number of excavated samples from later periods greatly exceeds the number of samples from the earlier period, the pumice data are still not conclusive.

A related problem is that pumice is usually absent from the archaeological record by the very nature of its use as an abrasive (Lucas and Harris, 1962). Most pumice from ancient Egypt outside of workshop areas, survives because pieces were placed in graves for cosmetic use in the next life.

The present project focuses on pieces of pumice that Petrie and others found decades ago in Egyptian graves of this crucial timeframe after the Hyksos period. The material is now in the collections of the Ashmolean Museum, Oxford and of the Petrie Museum of Egyptian Archaeology, London. As part of the research

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program, pumice from Amarna in the Petrie Museum was also sampled.

2. Archaeological Contexts

2.1. Maiyana and Sedment

In the winter of 1921, Petrie and Brunton excavated several small, modest cemeteries in the desert near Maiyana and Sedment, located at the mouth of the Faiyum Oasis (Petrie and Brunton, 1924). The graves of Maiyana Cemetery K belonged to members of a community of largely assimilated Pan-grave Nubians, who had moved into this area of Egypt at the end of the Hyksos period. The men typically rendered military service, sometimes fighting on the side of the Hyksos, sometimes on the side of the Thebans and the first pharaohs of the Eighteenth Dynasty.

Pumice piece Ashmolean 1921.1320 comes from Maiyana Grave 1262, which thieves had all but emptied, leaving only a small round basket in a corner. In the basket were an alabaster vase, a Bichrome jug, blue glass and faience scarabs, shell ring beads, amulets, seashells, and the lump of pumice, intended for cosmetic use. For dating purposes, the most diagnostic items are the scarabs and the Bichrome jug, which indicate a chronological range of the final years of the Hyksos period and the period of the Theban campaigns against them, including the first years of the reign of Ahmose, that is, spanning about 1560–1525 B.C.E. (Foster and Bichler, 2003).

The nearby site of Sedment included cemeteries of the Old Kingdom, First Intermediate Period, and Eighteenth Dynasty. Pumice piece Petrie UC 31375 is labeled as perhaps from Tomb 421, which is listed in the published register as an Old Kingdom grave, but which is described in Section 4 as a First Intermediate Period grave, in any event, undistinguished. As the Eighteenth Dynasty burials yielded large numbers of cosmetic containers, it seems likely that our pumice came from one of them and lost its findspot.

2.2. The Tomb of Maket, Kahun

In 1890, Petrie excavated the walled town of Kahun, located about 20 km north of Maiyana. The rock-cut cellar beneath one of the houses, built originally for personnel associated with the nearby Twelfth Dynasty pyramid of Sesostris II, was re-used in the Eighteenth Dynasty as a tomb (Petrie, 1894). Twelve coffins containing over 40 bodies, as well as two boxes for infants, were jammed into the cellar chambers, often pushed aside to make room for fresh interments. Coffin 7 contained the only inscribed objects, jewelry belonging to 'the lady of the house, Maket,' who has given her name to the ensemble. The two lumps of pumice Ashmolean 1890.885 and Petrie UC 27929, both intended for cosmetic use, were found in the jumble of items piled in the main chamber.

Though there are a few heirloom scarabs from previous reigns, all the burials in the Tomb of Maket appear to have taken place in the reign of Thutmose III (1479–1425 B.C.E.) The most diagnostic pieces include Cypriote Base-Ring I wares and a Late Helladie IIB squat jar from the Aegean, supporting the dating of this context.

2.3. Amarna

A few years into his reign (1352–1336 B.C.E.), the pharaoh Amenhotep IV changed his name to Akhenaten and moved to a new capital city he built in Middle Egypt, which he called Akhetaten, now known by its modern name of Amarna. After the deaths of Akhenaten and his immediate family/successors, Amarna was abandoned, resulting in a single-horizon site dating essentially to his reign.

Petrie, followed by many subsequent excavators, investigated the site in 1890–1891. Pumice pieces Petrie UC 43538 and 43539 come from unknown findspots there, but it seems very likely that Petrie found them in the manufacturing areas he discovered, including workshops for pottery, metal goods, faience, glass, wood, and stone. Some of the other Petrie pieces of unknown provenance may also come from Amarna, perhaps from the same contexts and likewise intended for industrial use as an abrasive.

3. Methods

3.1. Sampling

For sampling, the respective objects were examined with a microscope and, if sampling was indicated, cleaned with distilled water in an ultrasonic bath. The samples were about 5–10 mg each, extracted under a microscope with a pair of small stainless-steel pincers from already existing cracks in the surface so as not to alter the outer appearance of the objects.

Since pumice consists mainly of a volcanic glass matrix with a minor percentage of crystal inclusions which can be characteristic for different eruption products, the microscopic investigation is necessary. Especially the occurrence of biotite (dark mica) can clearly exclude an origin from the Minoan eruption of Santorini.

Utmost care has been taken to obtain samples free of phenocrysts visible at a magnification of 64×. The authors are aware that these sample quantities are not fully representative from an analytical point of view, but, as shown by Schmid et al. (2000) and Saminger et al. (2000) the differences between bulk pumice and the glass phase mainly affect the major element concentrations, while the characteristic trace element distribution patterns are well preserved.

Sampling was only performed on pieces that were pumice and that had archaeological context. The following samples were

Table 1
Elemental concentration in mg kg^{-1} of the six pieces of pumice investigated in this study. Errors due to counting statistics are ≤10% for the elements K, As, Nd, Sm, Lu, and U and ≤5% for all other elements. Bo-Norm values (Steinhauser et al., 2007) are used for normalization in Figs. 2–6.

	Ashmolean		Petrie				
	1890.885	1921.1320	UC 27929	UC 31375	UC 43538	UC 43539	Bo-Norm
Na	30,900	31,300	29,400	28,200	32,500	22,700	33,300
K	33,000	21,000	22,000	39,000	26,000	37,000	24,300
Sc	3.89	12.71	8.56	1.39	7.94	2.87	8.58
Cr	3.6	4.3	4.2	2.8	3.1	13.9	2.0
Fe	16,800	31,900	21,600	10,300	22,000	10,600	21,800
Co	2.81	4.14	4.42	0.71	4.14	2.38	3.93
Zn	48	87	69	52	57	36	69
As	7.3	2.2	3.4	17.6	3.2	7.7	3
Rb	111	83	110	273	101	135	108
Zr	220	250	270	190	240	120	290
Sb	0.36	0.23	0.34	1.00	0.53	0.58	0.30
Cs	3.7	2.5	3.0	14.1	2.8	4.4	2.9
Ba	850	460	560	120	500	840	564
La	38	28	27	53	30	34	31.7
Ce	66	57	61	86	56	66	63
Nd	21	22	31	33	26	18	26
Sm	3.7	7.0	5.0	9.9	6.4	2.9	6.2
Eu	0.56	1.40	0.93	0.15	0.83	0.39	1.003
Tb	0.46	1.19	0.99	0.97	0.93	0.41	1.01
Yb	2.6	5.7	5.4	3.8	4.9	2.2	5.1
Lu	0.44	0.91	0.83	0.63	0.71	0.39	0.83
Hf	6.1	7.0	8.5	5.5	7.4	3.8	7.75
Ta	1.35	0.79	0.86	2.13	0.84	1.49	0.80
Th	14	14	20	44	18	17	20.0
U	4.1	4.6	5.3	15.2	6.4	3.9	5.9

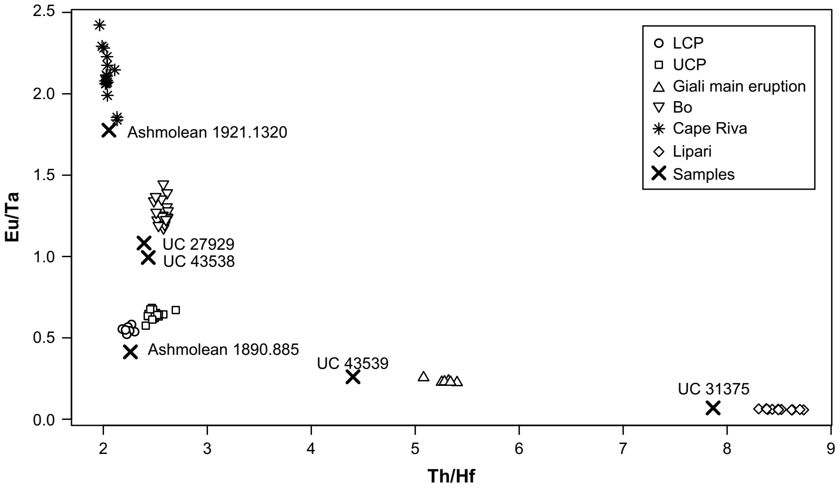

Fig. 1. Comparison of data from our database (Steinhauser et al., 2006b) with the samples taken for this study. The plot of element ratios Th/Hf against Eu/Ta offers a first indication of the origin of the sample. (LCP and UCP: Lower- and Upper Caldera Pumice, Nisyros; Bo: Minoan eruption of Santorini; Cape Riva: pre-Minoan Eruption of Santorini).

examined (text in parentheses copies the information found on the tags included with the objects).

Ashmolean 1890.885 (*pumice from Maket tomb*). In 1973, the pumice lump was cut for sampling. No biotite can be seen, only few phenocrysts visible on the surface.

Ashmolean 1921.1320 (*pumice foam, Maiyana 1262*). The part of the surface that was used for grinding can easily be identified. Heavily contaminated with soil particles, only a few phenocrysts visible.

Petrie UC 7324. A probably scoriaceous piece with a conical form. Outer dark reddish coloring is due to weathering. No sample taken.

Petrie UC 27929 (*Tomb of Maket*). A grey lump of pumice, one side has been cut relatively cleanly for a 1984 sampling. The cut surface is marginally lighter in color than the rest of the pumice lump. Some phenocrysts can be observed, feldspar and most probably pyroxene. The sample was taken from the cut surface.

Petrie UC 31375 (*Sedment,? Tomb 421, unpublished,? DYN. VI*). Heavily contaminated with soil particles. Slightly red in color, the surface of the lumps shows many white curved tubes of marine worms. Microscopic examination shows no phenocrysts.

Petrie UC 31635A,B (*Tomb 1300, (From Casket), pumice — two lumps A and B plus fragments, Cf. Sedment I, p. I9 Second Intermediate*). The smaller piece appears to be a crystal aggregate of slightly weathered galena on hostrock; the second piece consists of well-rounded, aeolian quartz grains in a fine grained white matrix, maybe plaster.

Petrie UC 43538 (*Amarna, pumice*). The surface is heavily contaminated with soil. A middle- to light-grey pumice with large feldspar and pyroxene.

Petrie UC 43539 (*Amarna, Iron-rich pumice*). A light, yellow-white pumice with signs of yellow and reddish weathering, no phenocrysts observed.

Petrie UC 43697. Pumice sample of unknown origin, no sample taken.

Petrie UC 43698. Unknown origin, no sample taken. The pumice shows groove-like depressions and superficial yellow coloring. No phenocrysts can be seen.

Petrie UC 43699. Unknown origin, no sample taken. Two pieces, containing large feldspar.

Petrie UC 43701 (*pumice with quartz and copper*). Unknown origin, no sample taken. A white, fibrous pumice with biotite and large quartz grains. From this superficial examination, the outer appearance and the crystal content suggest an origin from the Kos Plateau Tuff eruption.

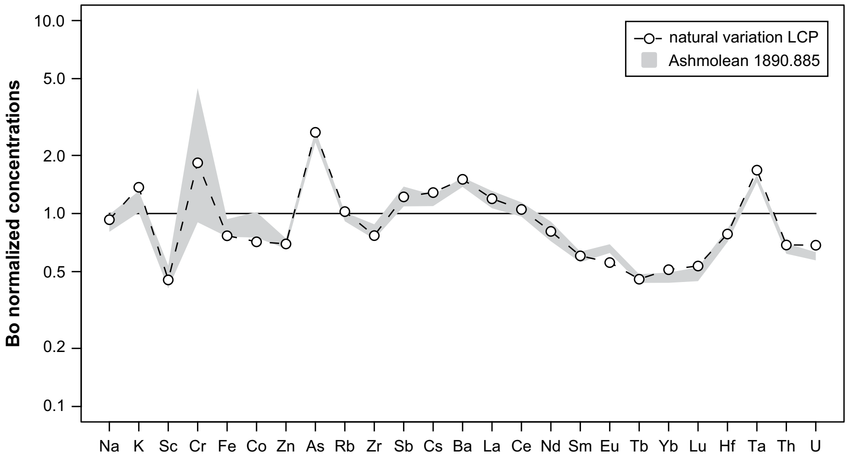

Fig. 2. Comparison of the chemical fingerprint of sample Ashmolean 1890.885 to the natural variation range of the Lower Caldera Pumice of Nisyros (Peltz et al., 1999; Steinhauser et al., 2006b), 8 samples.

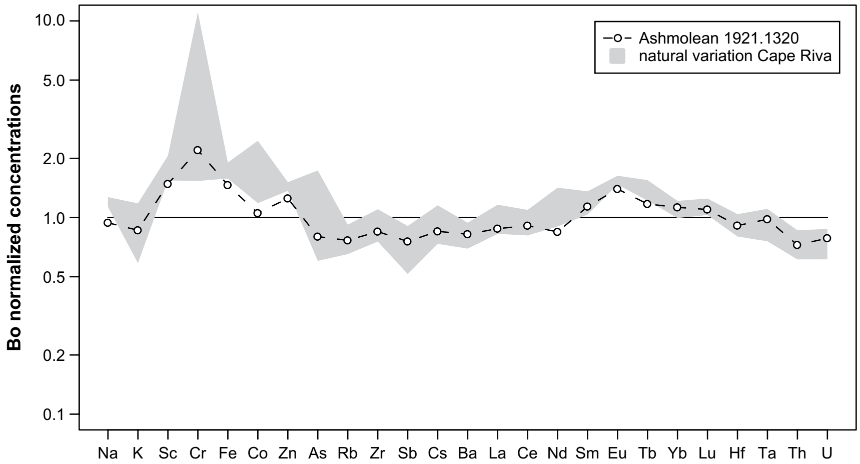

Fig. 3. Comparison of the chemical fingerprint of sample Ashmolean 1921.1320 to the natural variation range of the Cape Riva pumice according to Bichler et al. (2004), 16 samples.

Petrie UC 59773. Unknown origin, no sample taken. A very light, almost floury object, definitely not pumice. Contains small quartz grains.

Even though the samples Petrie UC 31635A and B turned out not to be pumice, a sample of the collected dust in the box was taken, decarbonized and investigated in a polarizing microscope to find any traces of volcanic glass, to clarify if the original sample was removed by mistake. However, no traces could be found.

3.2. Neutron Activation Analysis

All samples taken were dried for 12 h at 110 °C and weighed and sealed into Suprasil™ quartz glass vials for irradiation. Activation was performed in the central irradiation tube of the TRIGA Mk II reactor of the Atominstitut at a neutron flux density of approximately 1×10^{13} cm^{-2} s^{-1} for 35 h together with the internationally certified reference materials CANMET Reference Soil SO-1, MC Rhyolite GBW 07113, NIST SRM 1633b Coal Fly Ash, BCR No. 142 light sandy soil and NIST SRM 2702 Inorganics in Marine Sediment.

After irradiation, the samples were unpacked, the vials decontaminated and repacked into polyethylene-vials fitting the sample changer of the Atominstitut. The reference materials were then used to measure the element concentrations of Na, K, Sc, Cr, Fe, Co, Zn, As, Rb, Zr, Sb, Cs, Ba, La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Hf, Ta, Th and U in two measurement runs. Both measurements were performed using a γ-spectrometry system consisting of a 222 cm^3 HPGe-detector (1.78 keV resolution at the 1332 keV ^{60}Co peak; 49% relative efficiency) connected to a PC-based multi-channel analyzer with a preloaded filter and a Loss-Free Counting system. The first measurement was performed after a decay time of 5 days yielding results on the radioisotopes ^{24}Na, ^{42}K, ^{76}As, ^{140}La, ^{153}Sm and ^{239}Np (decay product of ^{239}U) after a measurement time of 1800 s. In the second measurement, after an additional 3 weeks of decay, the activities of the radioisotopes ^{46}Sc, ^{51}Cr, ^{59}Fe, ^{60}Co, ^{65}Zn, ^{86}Rb, ^{95}Zr, ^{124}Sb, ^{134}Cs, ^{131}Ba, ^{141}Ce, ^{147}Nd, ^{152}Eu, ^{160}Tb, ^{169}Yb, ^{177}Lu, ^{181}Hf, ^{182}Ta, and ^{233}Pa (decay product of ^{233}Th) were recorded during the measurement time of 10,000 s.

4. Results and discussion

The results of the NAA can be found in Table 1. To establish the geological origin of the samples, a comparison with the data from our extensive database of volcanic eruption products in the Mediterranean (Steinhauser et al., 2006b, 2007; Peltz et al., 1999) was performed. As a first overview, a plot of two element ratios like Eu/Ta versus Th/Hf (as shown in Fig. 1) usually yields a good

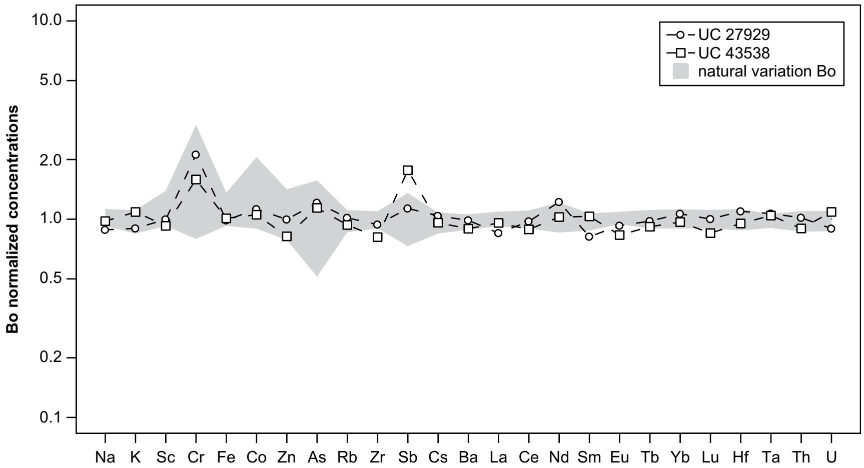

Fig. 4. Comparison of the chemical fingerprint of samples Petrie UC 27929 and UC 43538 to the natural variation range of the Minoan eruption according to Peltz et al. (1999), 18 samples.

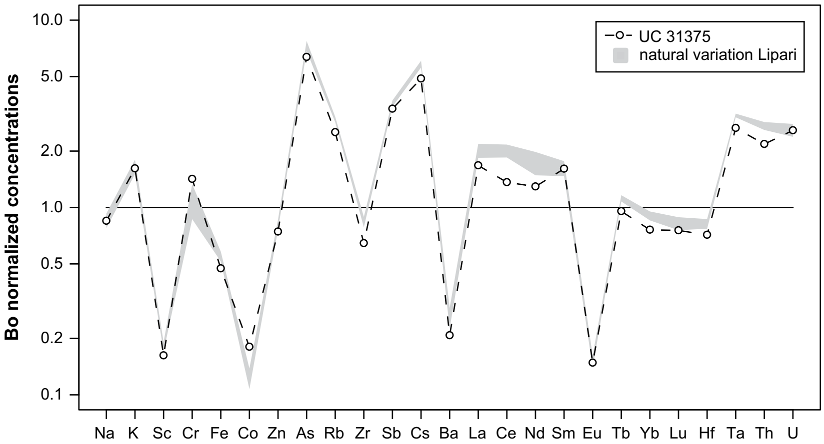

Fig. 5. Comparison of the chemical fingerprint of sample Petrie UC 31375 to the natural variation range of the Mt. Pilato eruption, Lipari according to Steinhauser et al. (2006a), 14 samples.

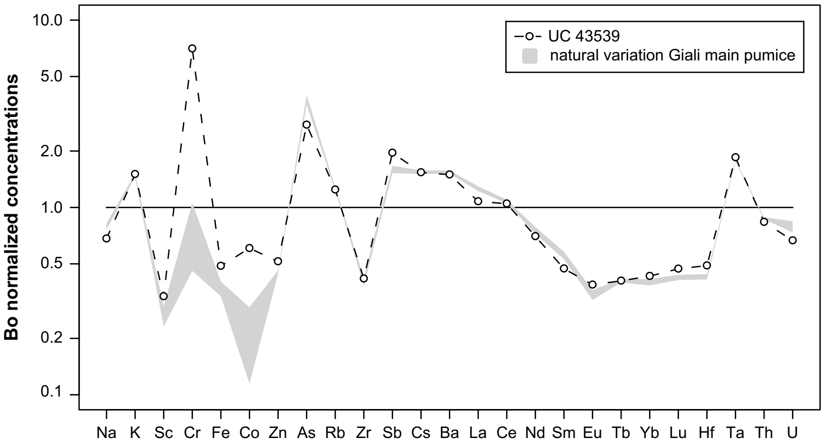

Fig. 6. Comparison of the chemical fingerprint of sample Petrie UC 43539 to the natural variation range of the Giali main pumice according to Peltz et al. (1999) and Steinhauser et al. (2006b), 6 samples.

indication of possible volcanic sources. The crystal content of the samples, as observed by microscopy, adds valuable information to this first estimate.

For the final classification, a spider graph is used where the normalized elemental concentrations are plotted in the order of the atomic numbers. Since the most interesting origin of an archaelogically relevant pumice is, in most cases, the Minoan eruption (Bo), the mean values of its elemental concentrations (Peltz et al., 1999; Steinhauser et al., 2007) are used as a normalization in the figures. Figs. 2–6 show the Bo-normalized values for the samples compared to the natural variation of the respective eruption products (shaded areas).

Sample 1890.885 from the Ashmolean clearly shows the distinct pattern of pumice from the caldera-forming eruptions of Nisyros. A distinction between the two possible sources, the Upper and the Lower Caldera Pumice (UCP and LCP) is possible either by Linear Discriminant Analysis or by the aforementioned plot of elemental ratios (Sterba et al., 2006), in this case Th/Hf vs. Eu/Ta (see Fig. 1). By applying both methods, the sample is clearly shown to originate from the Lower Caldera Pumice, an eruption that took place approximately 24,000 years ago (Rehren, 1988; Limburg and Varekamp, 1991; Hardiman, 1999; Hunziker and Marini, 2005).

Sample 1921.1320 from the Ashmolean is a typical example of Santorini pumice ejected prior to the Minoan eruption. Its chemical composition shows a close relation to the mean composition of the Minoan eruption with several significant deviations. As can be seen in the general plot (Fig. 1), the slightly higher content in Eu and Tb in combination with the lower content in Th and U offer a possibility for the distinction from the Minoan eruption. A comparison of the different patterns from the pre-Minoan eruptions classifies sample 1921.1320 as an eruption product from the Cape Riva eruption of Santorini, approximately 22,000 years old (Wulf et al., 2002).

Samples UC 27929 and UC 43538 from the Petrie Museum can easily be classified as stemming from the Minoan eruption of Santorini as both Figs. 1 and 4 show. The slight elevation of the Sb content in sample UC 43538 is most probably due to anthropogenic contamination.

Table 2
Samples, their archaeological context and their volcanic origin.

Sample	Context	Volcanic origin
Ashmolean Museum 1890.885	Tomb of Maket	Nisyros (Lower Caldera Pumice)
Ashmolean Museum 1921.1320	Maiyana 1262	Santorini, Cape Riva Eruption
Petrie UC 27929	Tomb of Maket	Santorini, Bo
Petrie UC 31375	Sedment	Italy, Lipari
Petire UC 43538	Amarna	Santorini, Bo
Petrie UC 43539	Amarna	Giali main pumice

Fig. 7. Geographic overview of the Mediterranean, including the sites of the excavations as well as the source volcanoes.

Sample UC 31375 can instantly be recognized to be from the Aeolian island Lipari in Italy (Eruption cycle IX, see Crisci et al., 1991) due to its very characteristic chemical fingerprint. Natural marine transport to Egypt seems improbable because of the great distance (more than 1500 km) coupled with the effective barrier of the Straits of Messina. Since this piece joins earlier evidence of pumice from Lipari in Egypt and Palestine (Steinhauser et al., 2006a; Huber and Bichler, 2003), we postulate that Lipari pumice was a Bronze Age trade item, especially since the pumice from Lipari has excellent qualities as a polishing stone due to the absence of phenocrysts. The pumice is approximately 8600 years old (Crisci et al., 1991; De Rosa et al., 2003) which agrees also with the stratigraphic position in recent deep sea cores (Di Roberto et al., 2008).

Sample UC 43539 is similar in its chemical composition to both the Kos Plateau Tuff Eruption (KPT) and the Giali main pumice (Yali D according to Bond, 1976). However, since no traces of biotite, a telltale signature of KPT, could be found it is classified as Giali main pumice (see Fig. 6). Unfortunately, the Giali main pumice eruption is not dated, however, the definitively younger Giali Top eruption (Yali C according to Bond, 1976) is dated to 31,000 years (Federman and Carey, 1980).

Table 2 shows the final classification of the pumice samples from this study and Fig. 7 gives a geographic overview showing both, excavation sites and source volcanoes.

5. Conclusion

In sum and in chronological order, the Maiyana pumice comes from the Cape Riva eruption of Santorini; the Tomb of Maket pumice lumps come from Nisyros and the Minoan eruption of Santorini; the Amarna pumice pieces come from the Minoan eruption of Santorini and from the Giali main eruption.

Our conjecture that the Sedment pumice derives from an Eighteenth Dynasty grave seems to be borne out by the discovery that it comes from Lipari. While this finding can add nothing to the Santorini eruption debate owing to the lack of contextual information, it does shed unexpected light on the international trade of pumice and other materials in the Late Bronze Age. Beginning in the mid-15th century, the Mycenaeans were in regular contact with the Central Mediterranean, including Lipari and the other Aeolian islands (Laffineur and Greco, 2005). Since we know of no direct Egyptian connections with the Central Mediterranean and although there could have been other intermediaries, the Mycenaeans seem likely to have been the prime exporters of Lipari pumice. Our analysis adds to previous evidence for the existence of a very long-distance Mediterranean pumice trade, and it raises intriguing questions bearing on the internationalism of the age, which go beyond the scope of the present paper.

Our results are consistent with the pumice sourcing picture that has emerged so far from this facet of the SCIEM2000 project. Pumice from the Minoan eruption of Santorini has not yet been found in pre-Eighteenth Dynasty contexts. Volcanic material from this eruption of Santorini is seen beginning just after Ahmose, or possibly in the last year or two of his reign.

If the Egyptian chronology is used as reference frame, these findings contrast with the latest ^{14}C-dating of the Minoan eruption of 1627–1600 B.C.E by Friedrich et al. (2006). Thus, various explanations are needed as to why masses of pumice from the Minoan eruption do not show up earlier – it lay uncollected on the shore; it was not favored for use; we have not yet excavated Hyksos-era workshops; and so forth. Or, this means that major upward adjustments are needed in the absolute chronology of Egypt and the Aegean, which thus far seem unwarranted from the egyptological point of view, see Bietak (2003a), Wiener (2007) or Kitchen (2007). We look forward to further investigations and excavations with keen anticipation.

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