# Project Thera Ashes – Pumice Sample from Knossos

*Max Bichler,* Heinz Huber,** and Peter Warren****

## Introduction

The project "Thera Ashes" is the volcanological-radiogeochemical part of the Austrian Special Research Program SCIEM 2000 (Synchronization of Civilizations in the Eastern Mediterranean in the $2^{nd}$ millennium B.C.). The aim of this project is to use the eruption products of the so-called Minoan eruption of the Thera volcano (Santorini) in the $2^{nd}$ millennium B.C. to establish a datum line in the stratigraphies of the Eastern Mediterranean region. During this strong explosive event a large volume of magma was erupted in a short time-span of not more than a few days, and the eruption products were distributed over a large area (for an overview see[1]). The majority of this material consists of chemically homogeneous pumice tephra,[2] the volume estimations range from 16 to 35 $km^3$. The major part of the erupted material was deposited directly into the sea.[3] Pumice, which consists mainly of highly vesicular silicate glass, floats on water. Depending on the size of the pumice lumps it takes some time until the fine glassy bubble walls break, the pumice gets soaked and finally sinks. In the meantime marine currents and wind could transport the floating pumice over large distances all over the Eastern Mediterranean region.[4] It can be assumed that within weeks after the eruption large amounts of pumice accumulated along the shorelines.

Pumice is a useful abrasive and has been collected and traded since prehistoric times. This is well documented by finds from archaeological excavations.[5] The applicability for chronological purposes has been checked in earlier studies by demonstrating that the "Minoan" pumice can be distinguished from other pumice sources by its trace element distribution pattern.[6] Its first appearance in an archaeological context can therefore be used for relative dating and can contribute valuable information for the synchronization of the civilizations in the Eastern Mediterranean Region. The aim of this work was to identify a pumice sample found with vase SEX/97/P2423 in the Stratigraphical Museum Site excavations directed by P.M.Warren for the British School at Athens.

## Analytical Techniques

First the sample was analyzed microscopically to check if crystalline minerals ("phenocrysts") such as pyroxene, feldspar, or ore-minerals are present in the glassy matrix. The investigations were performed on whole samples using a ZEISS STEMI SV8 stereomicroscope with variable magnification from 8 to 128.

Instrumental Neutron Activation Analysis (INAA) was used to determine the major and trace element abundances. INAA is a suitable technique to detect simultaneously a large number of geochemically significant trace elements, and was therefore used to enable the identification of such eruption products by their element distribution patterns, the so-called "chemical fingerprint". In particular, the elements 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 were determined. The applicability of this technique for the distinction of Santorini "Minoan" pumice (Bo, Upper pumice) from other, chemically rather similar eruption products of various potential pumice sources, such as the older Santorini eruptions (Middle tuff [Bm], Lower pumice tuff [Bu], Cape Riva, Cape Therma), or Kos, Giali, Nisyros, and Milos from the southern Hellenic volcanic island arc and Lipari from the Aeolian Islands, has been demonstrated by earlier studies.[7] The first application to stratified pumice from excavations at Tell-el-

* Atominstitut of the Austrian Universities, Stadionallee 2, A-1020 Vienna, Austria

** Institute of Geophysics and Planetary Physics, University of California, 405 Hilgard Avenue, Los Angeles, CA 90095-1361, USA.

*** Dept. of Archaeology, University of Bristol, 43 Woodland road, Bristol BS8 1UU, UK

[1] Bichler 2003.

[2] Pichler and Schiering, 1980; Vitaliano *et al.*, 1978; Bichler *et al.*, 1997; Peltz *et al.*, 1999.

[3] Sigurdsson *et al.*, 1990; Friedrich, 1999.

[4] Sutherland, 1965.

[5] Faure, 1971; Warren and Puchelt, 1990.

[6] Peltz *et al.*, 1999.

Dabᶜa showed that even long storage under wet conditions like in the Nile-Delta sediments does not affect the proper classification by chemical fingerprinting.[8]

The pumice sample from Knossos (Warren, this volume) and a control sample of "Minoan" Upper Pumice (Bo) were routinely prepared for INAA including a thorough cleaning procedure in distilled water in an ultrasonic bath, a microscopical investigation, and homogenization of a representative amount using an agate mortar and pestle. Quantities of about 100 mg each were weighed into Suprasil™ quartz glass vials, sealed, and irradiated together with internationally certified standard reference materials in the neutron flux of the TRIGA Mark-II reactor at the Atominstitut in Vienna. After decay times of one and four weeks, the activation products were measured by gamma-spectrometry and the concentrations of the respective elements were calculated by comparative measurements of the standards (BCR 142 light sandy soil, CANMET reference soil SO-1, NIST SRM 1633b Coal fly ash, and rhyolite GBW-07113).

## Results and Discussion

The results of the geochemical investigations are presented in Table 1. The data indicate that the sample is clearly not from the Upper Pumice (Bo) produced by the "Minoan eruption". Figure 1 shows the element distribution pattern of all elements determined, normalized to mean "Minoan Pumice" composition[9] together with the results obtained from a control sample of „Minoan Pumice" analyzed in parallel. The results clearly show the small but significant differences in the concentrations of indicative elements such as K, Sc, Fe, Cs, Sm, Eu, and Ta.

The results were also compared to the compositions of the Lower Pumice (Bu; about 200 ka BP), the Middle Pumice (Bm; about 100 ka BP) and the products of the Cape Riva eruption (about 21 ka BP).[10] Figs. 2–4 show the normalized element distribution patterns. A very sensitive indication is also given by plotting the ratios of element concentrations such as Eu/Th versus Ba/Ta. The ratios allow to decide whether a sample is a product of the Minoan eruption or an earlier event at Santorini. If the latter is the case, Eu/Ta versus Th/Hf clearly separates preminoan pumices (see Figs. 5, 6).

## Conclusion

According to the chemical fingerprinting, the source of the sample in question is the Lower Pumice 2 eruption. The element As shows large inhomogenities („nugget effect") due to its presence in sulphidic ore particles that liberate As during corrosion. The Cr enrichment is supposed to be environmental contamination introduced by dust particles as the primary concentration of Cr in the Santorinian pumices is extremely low. The immobile elements, and especially the most indicative rare earth elements (La – Lu) fit satisfactorily within their natural distribution range in Bu-pumice. The results of the stereomicroscopical investigation agree perfectly with the chemical analysis (presence of clear feldspar and greenish pyroxene phenocrysts in the vesicular glassy matrix, accessorial ore particles).

| | Na [wt.%] | K [wt.%] | Fe [wt.%] | Sc | Cr | Co | Zn | As | Rb | Zr | Sb | Cs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Knossos | 3.56 | 3.00 | 2.92 | 11.8 | 84.8 | 4.08 | 91.2 | 11.2 | 117 | 271 | 0.38 | 3.85 |
| Control Bo | 3.59 | 2.60 | 2.25 | 8.77 | 2.08 | 4.05 | 56.4 | 2.85 | 109 | 278 | 0.25 | 2.91 |

| | Ba | La | Ce | Nd | Sm | Eu | Tb | Yb | Lu | Hf | Ta | Th | U |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Knossos | 483 | 35.4 | 64.4 | 28.6 | 7.94 | 1.33 | 1.15 | 5.20 | 0.72 | 9.05 | 1.02 | 19.9 | 6.64 |
| Control Bo | 566 | 30.1 | 61.8 | 26.2 | 5.85 | 1.02 | 1.05 | 5.03 | 0.83 | 7.61 | 0.84 | 19.6 | 5.49 |

All data in mg/kg; except as noted

Table 1 Concentrations of major and trace elements in a pumice sample from Knossos and a control sample of "Minoan" Upper Pumice (Bo

[7] Peltz *et al.*, 1999; Duma 2002.
[8] Peltz and Bichler 2001.
[9] Peltz *et al.*, 1999.
[10] Druitt *et al.*, 1999.

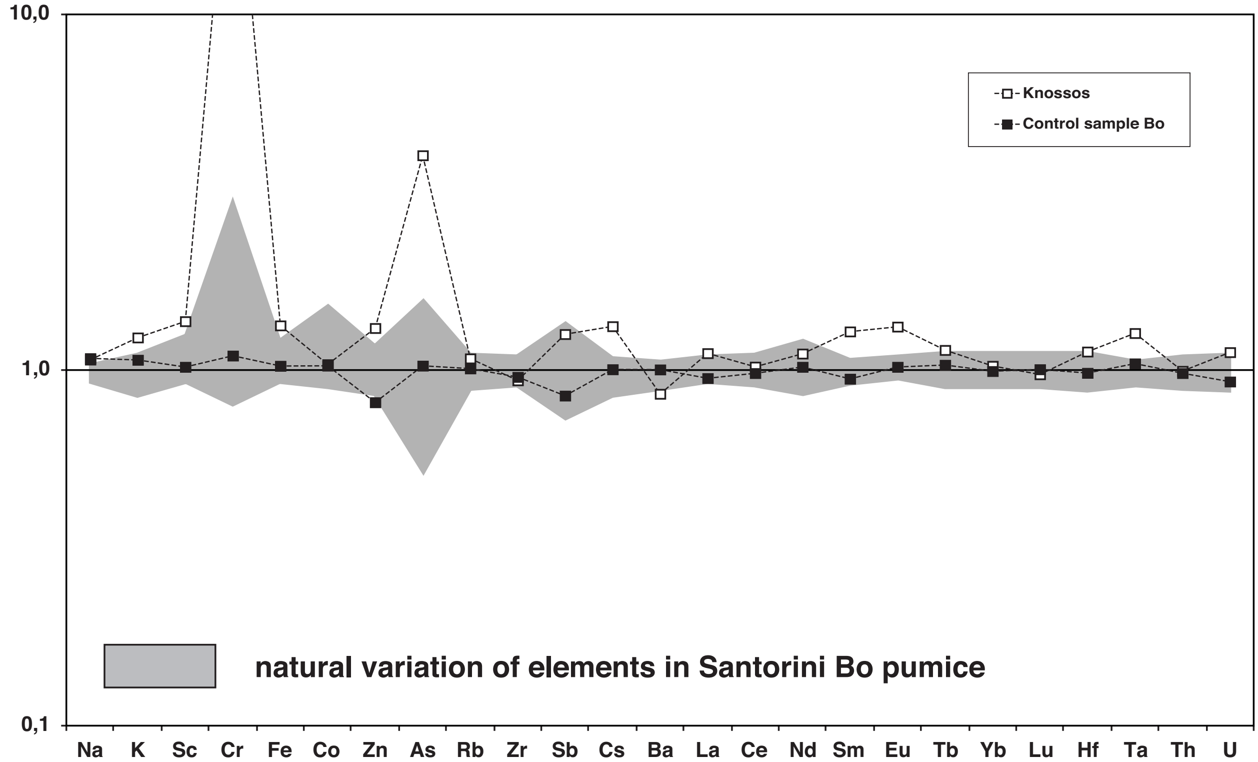


Fig. 1 Distribution of elements in a pumice sample from Knossos and a control sample of „Minoan“ pumice (Upper Pumice, Santorini Bo-pumice). All values are normalized to the average concentrations of elements in Santorini Bo-pumice (data from Peltz *et al.*, 1999)

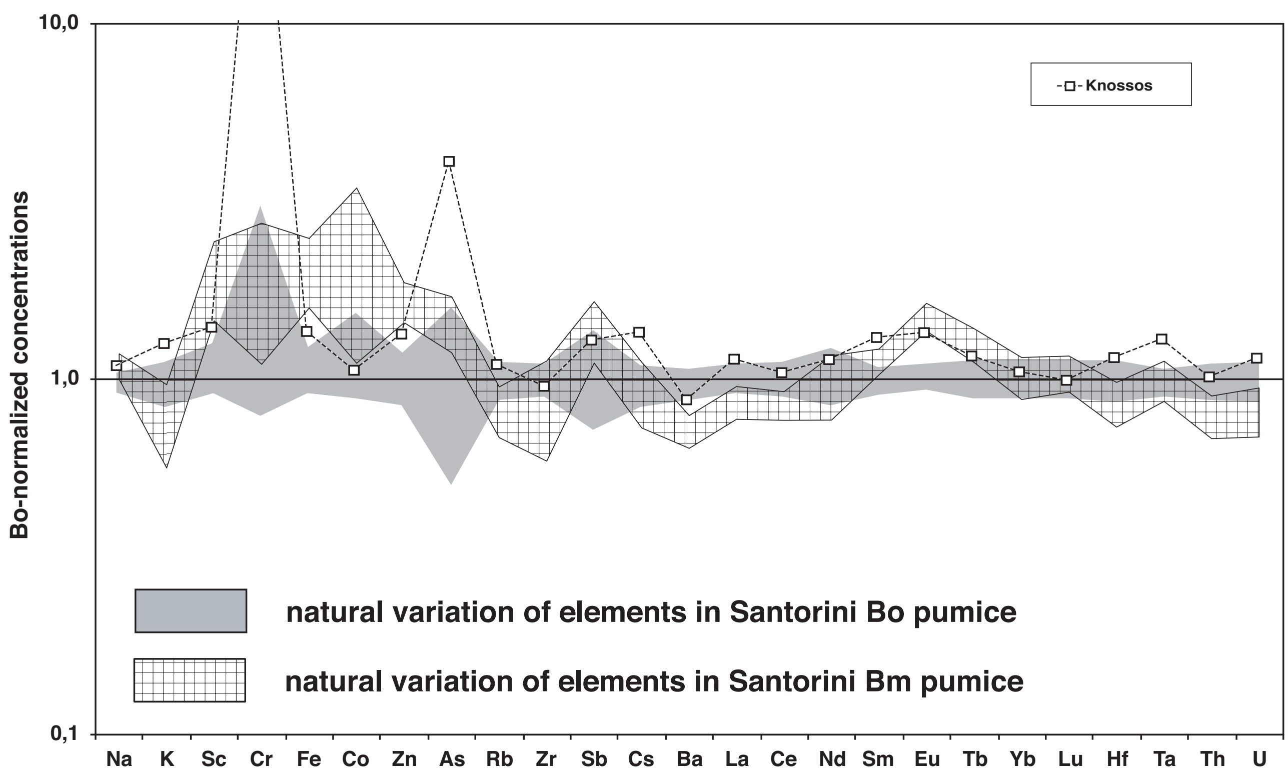


Fig. 2 Distribution of elements in a pumice sample from Knossos compared to Santorini Middle Pumice (Santorini Bm-pumice). All values are normalized to the average concentrations of elements in Santorini Bo-pumice (data from Peltz *et al.*, 1999)

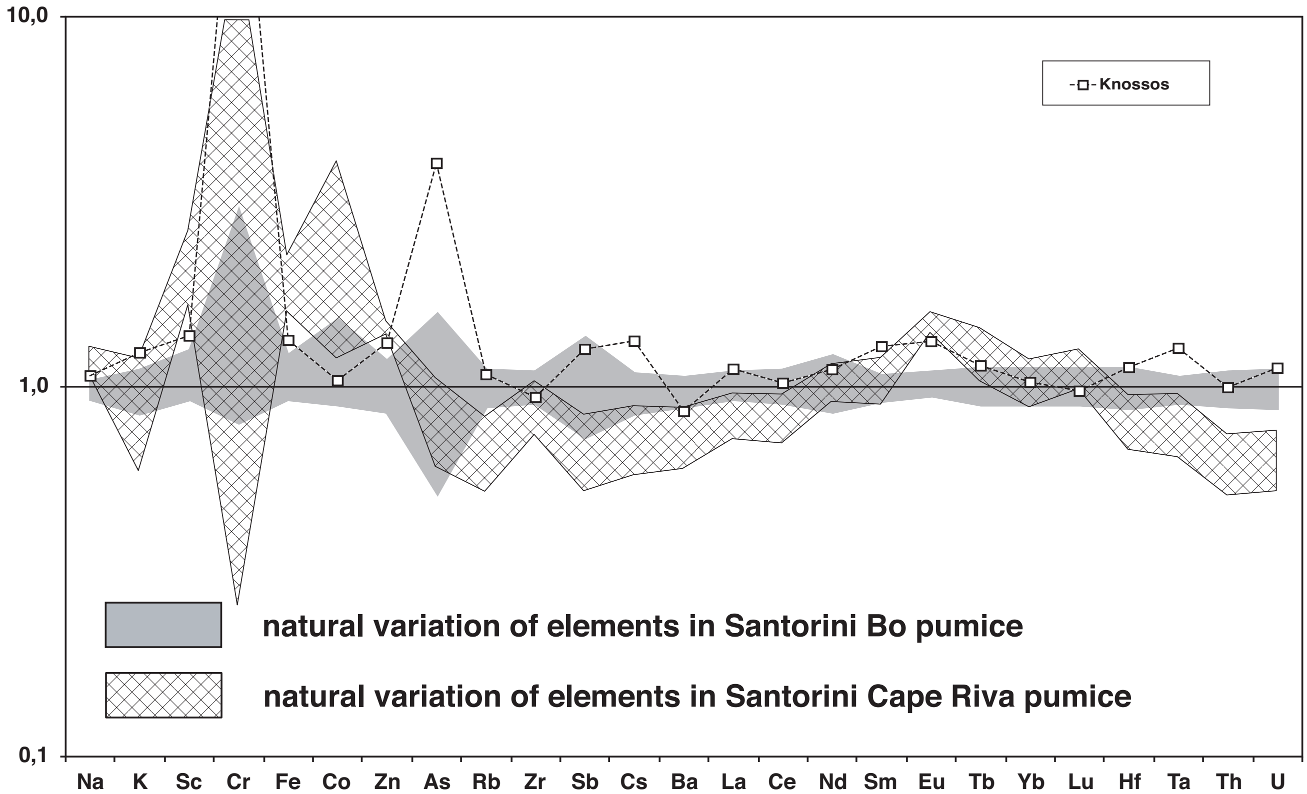


Fig. 3 Distribution of elements in a pumice sample from Knossos compared to Santorini Cape Riva Pumice. All values are normalized to the average concentrations of elements in Santorini Bo-pumice (data from PELTZ *et al.*, 1999)

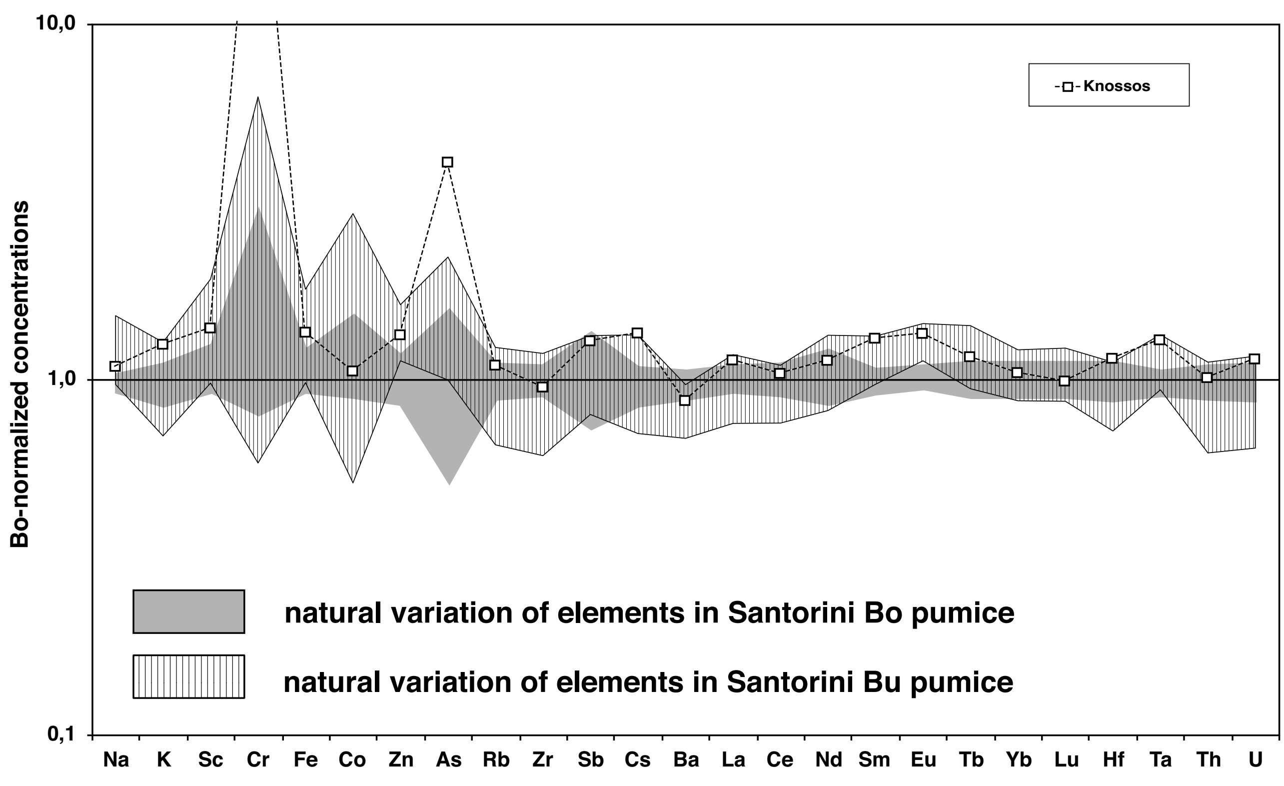


Fig. 4 Distribution of elements in a pumice sample from Knossos compared to Santorini Lower Pumice (Santorini Bu-pumice). All values are normalized to the average concentrations of elements in Santorini Bo-pumice (data from PELTZ *et al.*, 1999)

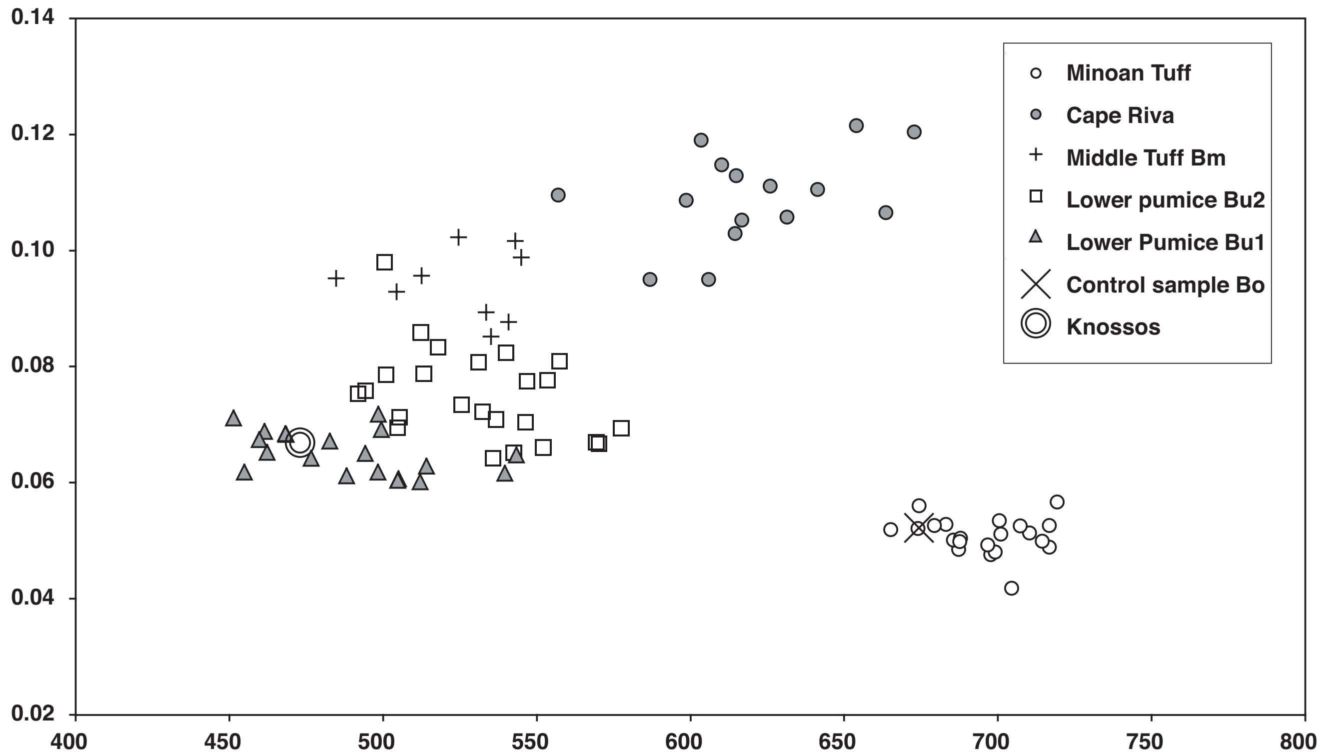


Fig. 5 Binary plot of concentration ratios of the elements Eu/Th versus Ba/Ta

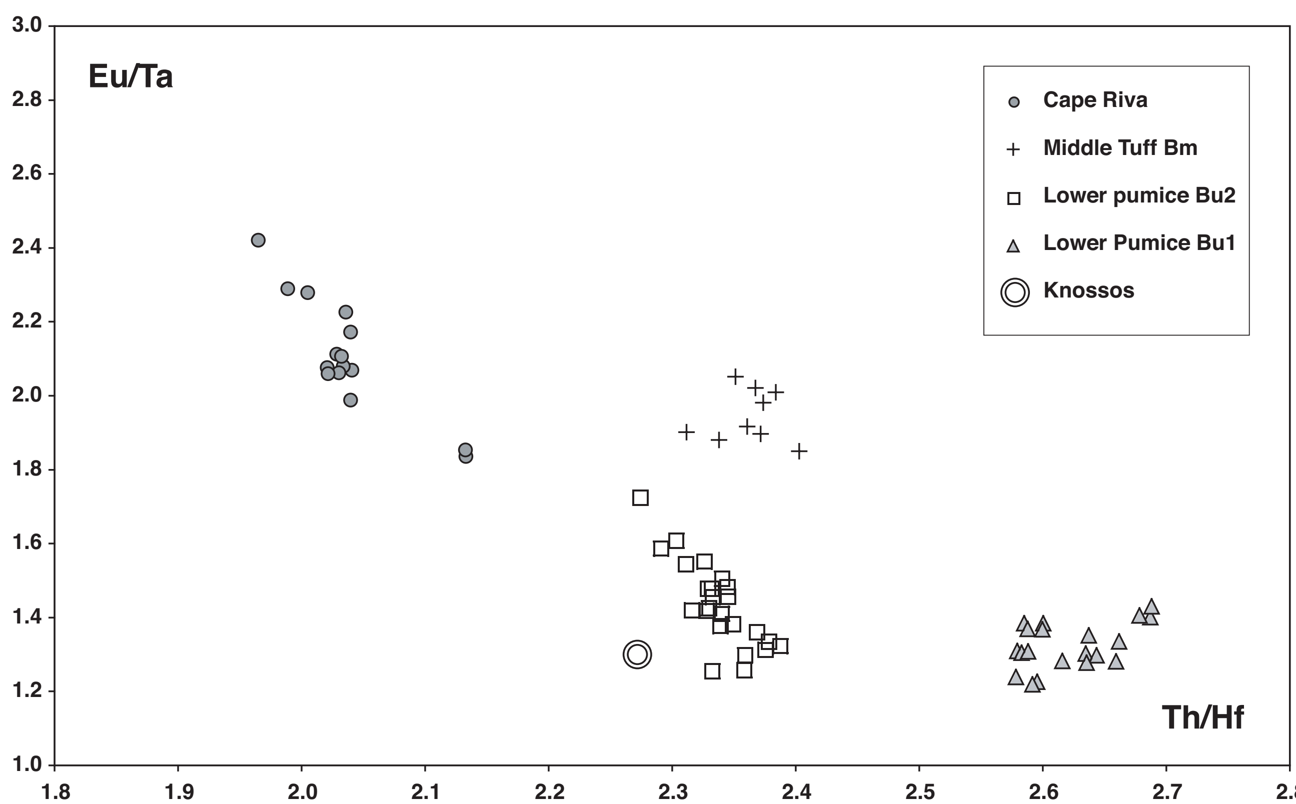


Fig. 6 Binary plot of concentration ratios of the elements Eu/Ta versus Th/Hf

## Bibliography


Bichler, M., Egger, H., Preisinger, A., Ritter, D., Stastny, P.

1997 NAA of the 'Minoan pumice' at Thera and comparison to alluvial pumice deposits in the Eastern Mediterranean region, *Journal of Radioanalytical and Nuclear Chemistry* 224, 7–14.

Bichler, M., Exler, M., Peltz, C., Saminger, S.

2003 Thera Ashes, 11–21, in: M. Bietak (ed.), *The Synchronisation of Civilisations in the Eastern Mediterranean in the Second Millennium BC. II: Proceedings of the SCIEM 2000 – EuroConference, 2nd of May–7th of May 2001, Haindorf,* CChEM 4, Vienna.

Druitt, T.H., Edwards, L., Mellors, R.M., Pyle, D.M., Sparks, R.S.J., Lanphere, M., Davies, M., Barriero, B.

1999 *Santorini Volcano*, Geological Society Special Publications, Geological Society of London Memoir 19.

Duma, B.

2002 *Aktivierungsanalytische Untersuchung präminoischer Eruptivgesteine der Insel Thera (Santorini)*, Dipl. Thesis, Vienna Univ. of Technology.

Faure, P.

1971 Remarques sur la présence et l'emploi de la Pierre Ponce en Crète Néolithique à nos jours, 422–427, in: S. Marinatos and D. Ninkovich (eds.), *Acta of the 1st International Scientific congress on the Volcano of Thera*, Athens.

Friedrich, W.L.

1999 *Fire in the sea, The Santorini volcano: natural history and the legend of Atlantis*. Cambridge University Press.

Peltz, C. and Bichler, M.

2001 Classification of archaeologically stratified pumice by INAA, *Journal of Radioanalytical and Nuclear Chemistry* 248, 81–87.

Peltz, C., Schmid, P., Bichler, M.

1999 INAA of Aegean pumices for the classification of archaeological findings, *Journal of Radioanalytical and Nuclear Chemistry* 242/ 2, 361–377.

Pichler, H. and Schiering, W.

1980 Der spätbronzezeitliche Ausbruch des Thera-Vulkans und seine Auswirkungen auf Kreta, *Archäologischer Anzeiger,* 1–37.

Sigurdsson, H., Carey, S., Devine, J.D.

1990 Assessment of mass, dynamics and environmental effects of the Minoan eruption of Santorini volcano, 100–112, in: D.A. Hardy and A.C. Renfrew (eds.) *Thera and the Aegean World III,* vol. 2, London.

Sutherland, F.L.

1965 Dispersal of pumice supposedly from the 1962 South Sandwich Islands eruption on Southern Australian shores, *Nature* 207, 1332–1335.

Vitaliano, C.J., Fout, J.S., Vitaliano, D.B.

1978 Petrochemical study of the Tephra sequence exposed in the Phira Quarry, Thera, 203–215, in: C. Doumas (ed.), *Thera and the Aegaean World I*, London.

Warren, P.M., Puchelt, H.

1990 *Stratified pumice from Bronze age Knossos*, 71–81, in: D.A. Hardy and A.C. Renfrew (eds.), *Thera and the Aegean World III*, London.