

This is the peer reviewed version of the following article:

Butrint (Albania) between eastern and western Mediterranean glass production: EMPA and LA-ICP-MS of late antique and early medieval finds / S., C., T., C., Arletti, R., M., V.. - In: JOURNAL OF ARCHAEOLOGICAL SCIENCE. - ISSN 0305-4403. - 49:1(2014), pp. 6-20. [10.1016/j.jas.2014.04.014]

*Terms of use:*

The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website.

26/06/2026 13:06

(Article begins on next page)

Manuscript Number: JASC13-507R2

Title: Butrint (Albania) between Eastern and Western Mediterranean glass production: EMPA and LA-ICP-MS of Late Antique and Early Medieval finds.

Article Type: Full Length Article

Keywords: Keywords: late antique glass, trace elements, LA-ICP-MS, HIMT, Levantine.

Corresponding Author: Dr. Sonia Conte,

Corresponding Author's Institution: University of Modena and Reggio Emilia

First Author: Sonia Conte

Order of Authors: Sonia Conte; Tania Chinni; Rossella Arletti; Mariangela Vandini

Abstract: ABSTRACT

In the Late Roman period, the city of Butrint (SW Albania) was one of the most important seaports of the eastern Mediterranean due to its very favorable position and an extended presence of human settlements (from the 5th century BC to the modern age). The city seems to have particularly flourished after being declared a Roman colony under Augustus in 31 BC, but even after the Roman period, Butrint remained a central node in eastern trade routes.

During the archaeological campaign of 2011 directed by David Hernandez (University of Notre Dame - US), aimed at identifying the eastern border of the Butrint Roman Forum, several glass artifacts were recovered and dated to the late antique and early medieval period.

In this study 33 fragments of glass (32 transparent, 1 opaque) were analyzed from different objects (drinking glasses, bowls, etc) mostly dated from the 5th to the 6th centuries AD.

The aims of this work are: i) understanding the raw materials, the manufacturing techniques employed for glass production, and their evolution through the time; ii) correctly classifying items of uncertain date; iii) interpreting the economic development and trade models of the area.

Chemical analyses were performed by electron microprobe (EMPA) for major and minor elements and by ICP mass spectroscopy (LA-ICP-MS) for trace elements.

The chemical results indicate that the samples were produced with natron as fluxing agent. They can be divided, on the basis of the concentrations of Fe, Ti, and Mn, between the two main compositional groups widespread in the Mediterranean from the 4th century onward: HIMT (23 samples), and Levantine I (10 samples). Among the HIMT samples, both "weak" HIMT (13 samples), and "strong" HIMT (10 samples) were identified. This variety of compositions indicates that in Butrint, between the end of the 4th and the end of the 6th century, the glass materials were probably imported from different suppliers.

Chrono-typological and chemical classification of glass from Butrint are reported.

Comparison of glass varieties with the coeval production in the Mediterranean.

Correspondence of chemical and typological/chronological groups is shown.

Levantine I and HIMT are distinguished on chronological basis and product quality.

Compositional grouping aids chronological definition of finds and site stratigraphy.



UNIMORE

UNIVERSITÀ DEGLI STUDI DI  
MODENA E REGGIO EMILIA

Ateneo fondato nel 1175



**DIPARTIMENTO DI SCIENZE CHIMICHE E GEOLOGICHE**

Modena, April 9<sup>th</sup> 2014

Dear Editor,

please find enclosed the revised version of manuscript **BUTRINT (ALBANIA) BETWEEN EASTERN AND WESTERN MEDITERRANEAN GLASS PRODUCTION: EMPA AND LAICP-MS OF LATE ANTIQUE AND EARLY MEDIEVAL FINDS**. by Sonia Conte, Tania Chinni, Rossella Arletti, Mariangela Vandini.

All the minor changes suggested by the editor have been done (correction in the text, in the tables and figure 7).

Best regards

Sonia Conte

---

**Direzione:** L.go S. Eufemia, 19 – 41121 Modena  
Tel.: 059 205 5805 – Fax: 059 205 5887 - e-mail: direttore.chimgeo@unimore.it

**Amministrazione** - Via Campi, 183 – 41125 Modena  
Tel.: 059 205 5075 – Fax: 059 205 5602 - e-mail: segreteria.chimgeo@unimore.it

Partita IVA.: 00427620364

per Creditori Privati: Conto Unicredit: IT40H0200812930000102063651 – SWIFT CODE: UNCRITMM  
Codice ISTAT: 3138 - Codice anagrafico: 46957 - Codice Bilancio UNIMORE: A .005

per Creditori Pubblici: Conto Banca d'Italia: IT23E0100003245243300037150 (indicare nella causale il Codice Struttura: A.005)

**Butrint (Albania) between Eastern and Western Mediterranean glass production: EMPA and  
LA-ICP-MS of Late Antique and Early Medieval finds.**

S.Conte<sup>1</sup>, T. Chinni<sup>2</sup>, R. Arletti<sup>3</sup>, M. Vandini<sup>4</sup>

<sup>1</sup>*Department of Chemistry and Earth Sciences, University of Modena and Reggio Emilia(I)*

[sonia.conte@unimore.it](mailto:sonia.conte@unimore.it)

<sup>2</sup>*Department of History and Culture, University of Bologna(I)*

<sup>3</sup>*Department of Earth Sciences, University of Torino(I)*

<sup>4</sup>*Department of Cultural Heritage, University of Bologna(I)*

**ABSTRACT**

In the Late Roman period, the city of Butrint (SW Albania) was one of the most important seaports of the eastern Mediterranean due to its very favorable position and an extended presence of human settlements (from the 5th century BC to the modern age). The city seems to have particularly flourished after being declared a Roman colony under Augustus in 31 BC, but even after the Roman period, Butrint remained a central node in eastern trade routes.

During the archaeological campaign of 2011 directed by David Hernandez (University of Notre Dame - US), aimed at identifying the eastern border of the Butrint Roman Forum, several glass artifacts were recovered and dated to the late antique and early medieval period.

In this study 33 fragments of glass (32 transparent, 1 opaque) were analyzed from different objects (drinking glasses, bowls, etc) mostly dated from the 5<sup>th</sup> to the 6<sup>th</sup> centuries AD.

1 The aims of this work are: i) understanding the raw materials, the manufacturing techniques  
2 employed for glass production, and their evolution through the time; ii) correctly classifying items  
3 of uncertain date; iii) interpreting the economic development and trade models of the area.  
4  
5

6  
7  
8 Chemical analyses were performed by electron microprobe (EMPA) for major and minor elements  
9 and by ICP mass spectroscopy (LA-ICP-MS) for trace elements.  
10  
11

12  
13 The chemical results indicate that the samples were produced with natron as fluxing agent. They  
14 can be divided, on the basis of the concentrations of Fe, Ti, and Mn, between the two main  
15 compositional groups widespread in the Mediterranean from the 4<sup>th</sup> century onward: HIMT (23  
16 samples), and Levantine I (10 samples). Among the HIMT samples, both “weak” HIMT (13  
17 samples), and “strong” HIMT (10 samples) were identified. This variety of compositions indicates  
18 that in Butrint, between the end of the 4<sup>th</sup> and the end of the 6<sup>th</sup> century, the glass materials were  
19 probably imported from different suppliers.  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30

31  
32  
33  
34  
35 **Keywords:** late antique glass, trace elements, LA-ICP-MS, HIMT, Levantine.  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

## 1. Introduction

Set on a small hill, facing the Vivari Channel, between the Butrint swampland and the Mediterranean Sea, the ancient *Buthrotum* was one of the strongholds of the main Hellenistic and Roman trade routes.

The origins of the site are not easily traceable, but the finding of some lithic tools has led to the hypothesis of a Neanderthal settlement (Hodges and Hansen, 2007). The few data traceable to the Hellenistic period seem to indicate a first nucleus dated to the 8<sup>th</sup>-7<sup>th</sup> century BC, linked to the presence of some Trojan exiles (as testified by Virgil). The construction of an important temple dedicated to Asclepius is possibly dated to the 3<sup>rd</sup> century BC, a period in which Butrint assumed a significant administrative role in the *koinon* of the Praesebes tribe (Hodges and Hansen, 2007).

In 44 BC, Julius Caesar proposed transforming Butrint into a colony (Hodges and Hansen, 2007; Hernandez and Çondi, 2008), but only in 31 BC Augustus decreed this status. From that time onwards, Butrint flourished progressively and several infrastructures were realized, including an imposing aqueduct (Ugolini, 1937; Hodges and Hansen, 2007; Hernandez and Çondi, 2008). The town entered a crisis starting from the end of the 4<sup>th</sup> to the beginning of the 5<sup>th</sup> century AD, when the ancient Roman buildings started to be ransacked and the area of the forum was occupied by common houses (Hodges and Hansen, 2007). After that, the history of Butrint is again uncertain with the archaeological stratifications providing little information for the 6<sup>th</sup> century AD, and even less for the period between the 7<sup>th</sup> and the 9<sup>th</sup> century AD (Hodges et al., 2000).

The following centuries were characterized by Byzantine dominion over the area, with Butrint being recognized as a strategic geographical position of primary importance for the control of the Aegean sea. Subsequent rapid changes of dominion confirm the great instability of the area in medieval times. (Hodges et al., 2000) and in the 16<sup>th</sup> century AD, the city of Butrint was definitively abandoned.

1 Butrint was rediscovered by an Italian archaeologist, Luigi Maria Ugolini, who excavated the  
2 ancient town in the years 1928-1936. Italian teams (until 1940), the Albanian Archaeological  
3 Insitute and the Butrint Foundation (from 1993) gave continuity to the archaeological  
4 investigations in the area (Ugolini, 1937; Hodges et al., 1997; Hodges and Hansen, 2007;  
5 Hernandez and Çondi, 2008).  
6  
7  
8  
9  
10

11  
12 In 2004 a new research project was started with the aim of redefining Butrint's historical phases,  
13 directed by Richard Hodges (The American University of Rome), David Hernandez (University of  
14 Notre Dame du Lac, Indian- USA), and Dhimitër Çondi (Albanian Archaeological Institute), and  
15 co-sponsored by the American Philosophical Society. The archaeologists managed to locate the  
16 north-eastern boundary of the Roman forum (dated at the 2<sup>nd</sup> half of the 1<sup>st</sup> century AD), built with  
17 remarkably large limestone slabs, with estimated dimensions of 20 x 70 m, much wider than  
18 expected (Hernandez, 2011). During the 4<sup>th</sup> century AD, possibly after a violent earthquake, the  
19 forum floor was covered with a raised layer (Hernandez, 2007). Around the 5<sup>th</sup> - 6<sup>th</sup> century AD,  
20 new buildings were erected in the area providing evidence of the endurance of the site until at least  
21 the end of the 6<sup>th</sup> century AD. During the 7<sup>th</sup> century, erosion layers from the adjacent acropolis  
22 accumulated on the forum area and some necropolises were constructed. The area was again  
23 occupied between the 10<sup>th</sup> and the 16<sup>th</sup> century, with new buildings and a cemeterial area, possibly  
24 connected to a Byzantine settlement (Hernandez, 2007).  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44

45 The excavation campaign in 2011 in the area of the Roman Forum (Hernandez, 2011), substantiated  
46 the chronological stratification of the area and the persistence of commercial activity. Among the  
47 various materials (coins, ceramics, etc.), several glass finds were recovered and analysed.  
48  
49  
50  
51  
52

53 Typological studies of the glass material dated around 800 AD ca. from Butrint (tower 1 and 2 of  
54 the Western defence) were conducted by Jennings (Jennings, 2010 and Jennings and Stark, 2013).  
55  
56

57 In these studies, the large group of objects is represented by wine glasses classidicable as: a) short  
58 stem, b) long stem and c) hollow stem. A previous study by Schibille (2011) represents the first  
59  
60  
61  
62  
63  
64  
65

1 attempt to investigate the chemical complexity of the glass types found in Butrint. Schibille presents  
2 data for different types of glass artifacts (tesserae, windows, vessels, debris), variably dated and of  
3  
4 different provenance within the Butrint area, leading to the confirmation of regional and temporal  
5  
6 variations in glass composition, as is well attested in the Mediterranean area, indicating the  
7  
8 existence of primary glass production groups. The marked complexity that emerged and subsequent  
9  
10 difficulty in systematizing the range of glass production data is possibly due to the great variety of  
11  
12 the finds (types, colours, chronology, provenance) considered.  
13  
14  
15

16  
17 In the present study the materials - mostly well dated (on the basis of precise archaeological data),  
18  
19 and including different types of glass - were selected from a single provenance (the Roman Forum).  
20  
21 Most of the material analysed in the present work is dated between the 5<sup>th</sup> and the 6<sup>th</sup> century, on the  
22  
23 basis of archaeological and typological criteria. Obtaining chemical features of a number of selected  
24  
25 diagnostic fragments (i.e. attributable to recognised forms) will allow to define compositional  
26  
27 groups, to establish relation of each group to the form and/or chronology of the glass, and to  
28  
29 compare the glass varieties from Butrint with the coeval scenario of glass production in the  
30  
31 Mediterranean. In some cases, the chemical composition could also confirm or support an  
32  
33 archaeological hypothesis. This is achieved by establishing the major and minor chemical  
34  
35 component fingerprints for a certain type or chronology, but fundamental support is also provided  
36  
37 by the analysis of trace elements, extremely helpful for identifying glass production types of the  
38  
39 Mediterranean area in the first millennium CE (Arletti et al., 2010a,b; Freestone et al., 2002, Šmit et  
40  
41 al., 2013).  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52

## 53 **2. Glass chemical composition of Late Roman period: the state of the art.**

54  
55 The Late Roman period is perceived to be a period of transition in many field, from the new  
56  
57 political organisation of the Empire –which was formally divided into Eastern and Western in the  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

4<sup>th</sup> century AD- to the general social, cultural and economic changes, that are reflected in the material records. As observed by Foster and Jackson (2009), also the glass of the Late Roman period differs from that produced in the previous centuries: while the 1<sup>st</sup>-3<sup>rd</sup> the glass was commonly blue-green, in the 4<sup>th</sup> century it was characterised by a yellowish-green colour. This change in colour was coupled with a general decline in the quality of the glass, the later glass showing more bubbles and unaesthetic inclusions. A number of recent publications (Freestone et al., 2000, 2002; Foy et al., 2003) have suggested that at least two new glass compositions were introduced in the 4<sup>th</sup> century AD and continued to be produced until the 8<sup>th</sup> century AD: Levantine I glass and HIMT (High Iron Mangese Titanium). Freestone (1994) named HIMT a glass (previously identified by Sanderson et al., 1984) characterised by high level of iron, manganese and titanium, with a positive strong correlation between iron and titanium and a less strong positive correlation between iron and manganese. Subsequently (2005) he stressed also the positive correlation between iron and alumina. Moreover, Foster and Jackson (2009) observed for this glass the presence of higher soda (Na<sub>2</sub>O ~18-19%), magnesia (usually MgO ≥0.8%), and lower lime (CaO ~6%) with respect to that normally found in the earlier Roman glass. Glass of the same composition was recognised also by Foy et al. (2003) in Late Roman glass from France (Group 1 and 2). The other glass type introduced in the 4<sup>th</sup> century - called Levantine I by Freestone et al. (2000) and matching the 'Group 3' identified by Foy et al.'s (2003) - contains lower soda (Na<sub>2</sub>O ~15%), higher lime (CaO ~9%), and often lower levels of iron (FeO ~0.4%) than HIMT glass (Foster and Jackson, 2009).

These chemical features have been recognised in many other studies, relative to the Levantine I (e.g. Freestone et al., 2002; Foster and Jackson, 2009; Schibille et al, 2008) and to the HIMT glass (e.g. Arletti et al., 2010a,b; Freestone et al., 2002; Foster and Jackson, 2009; Mirti et al., 1993, Šmit et al., 2013). Table 1 reports the minimum, maximum and the average of Al<sub>2</sub>O<sub>3</sub>, FeO, MgO, CaO, Na<sub>2</sub>O, K<sub>2</sub>O, TiO<sub>2</sub> and MnO, relative to the samples analysed in the aforementioned papers (and also

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

this work). Foy et al. (2003) observed a sub-division of HIMT glass into “strong” (Group 1) and “weak” (Group 2) on the basis of their Fe, Ti, and Mn concentrations. A similar subdivision was found by Foster and Jackson (2009), whose sub-group HIMT1 corresponds to Group 2 Foy et al., while the sub-group HIMT2 is characterized by the lowest concentration of the key oxides. The splitting of HIMT glass into two groups, on the basis of iron, titanium, and manganese (that is HIMT1 and 2 Foster and Jackson, 2009 Table 2) can be recognised also in other HIMT sample sets analysed by Arletti et al. (2010a, b), Freestone et al. (2002, 2005), Mirti et al. (1993) and Šmit et al. (2013) all around Europe.

### 3. Materials

During the 2011 excavation campaign numerous glass objects were recovered from the area of the Roman Forum, although not referable to the Roman phase but to later productions. Most of them are characterized by a high degree of fragmentation. After recovery, rapid water washing and mechanical cleaning were adopted to remove residues and deposits, avoiding an abrupt transition to dry conditions. A total of 157 glass fragments was divided morphologically and by functional subcategories: diagnostic elements of vessels (rims, bottoms and handles, which allow recognition of the original forms by comparison with known typologies); vessel walls (each fragment is attributable to a glass vessel, but without significant elements useful for identifying the original form); architectural glass (window glass and mosaic tesserae); cullets. When possible, the typological classification proposed by C. Isings (Isings, 1957) was applied, with further additions by comparisons with more recent catalogues (see Table 3). A number of samples (33 in total) was selected from the complete set representative of the various typologies and chromatic varieties. The description of the samples, selected on the basis of type and colour, their chronological indications (based both on stratigraphic and typological data) and relevant bibliographical references are reported in Table 3.

## *Fragments of vessels*

1  
2  
3 The chrono-typological study of the glass material shows a more concentrated chronological  
4 distribution between the 5<sup>th</sup> and 6<sup>th</sup> centuries AD. Among the diagnostic elements of vessels, the  
5 most common class is represented by beakers (25% of the total of the recognised forms), most of  
6 them with rounded rims and flat bottom. Due to the high degree of fragmentation, it was not always  
7 possible to identify the original form and therefore the possibility that some of the rims could be  
8 related to the more defined form of the stemmed beakers cannot be excluded. The stemmed beakers  
9 (representing the 13% of the total) are generally identified as form Isings 111 (Isings, 1957). This is  
10 one of the most common objects in the Mediterranean basin between 5<sup>th</sup> and 8<sup>th</sup> century AD  
11 (Sternini, 1995; Uboldi, 1999; Saguì, 2001; Stiaffini, 2004; Gallo et al., 2014) and represents "the  
12 watershed between Late Antiquity and the Middle Ages" (Saguì, 1993), although after the 8<sup>th</sup>  
13 century it disappeared, replaced by beakers with high hollow stems, or fully twisted stems (Silvestri  
14 and Marcante, 2011). The success of this form is also evident in the numerous variants recognized  
15 throughout the Mediterranean, which show different profiles of rim and stem (see for exemple  
16 Dussart, 1998 and Falcetti, 2001). This large variability in shapes and sizes has led some authors to  
17 assume that they are not a result of a chronological evolution of the form, but of different degrees of  
18 specialization of the workshops (Falcetti, 2001; Corti, 2012). The identification of the variants of  
19 the stemmed beakers is connected to the techniques of production of the stem. Three main types of  
20 stem - folded base, short stem and short solid stem – were firstly described by Isings (Isings, 1957,  
21 pp.139-140) and extensively recalled and redefined by many other authors (for example Jennings,  
22 1997-1998, 2006 and 2010; Jennings and Stark, 2002; Falcetti, 2001; Stevenson, 2001; Foy, 2000  
23 and 2003).

24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55 In this study, the dominant form of I.111 is the folded base type from which five samples were  
56 taken (BT 4, 7, 12, 17, 38). That of the stemmed beakers is the only form that could compare with  
57 the findings of Jennings (2010), since the production technique is probably the same even if, due to  
58  
59  
60  
61  
62  
63  
64  
65

1 differences in dimensions, foot inclination and type of stem, only one of the forms identified by  
2 Jennings can be considered to have similarities with the beakers of the present study. The  
3  
4 conformation of the foot of our fragment from sample BT38 (Figure 1) shows close comparison  
5  
6 with the stemmed beaker reported in Figure 5, 6 by Jennings (2010), but this latter have a hollow  
7  
8 stem.  
9

10  
11  
12 Among the class of drinking glasses, sample BT29 is likely to be attributed to a long stemmed  
13  
14 beaker (Fünfschilling, 2010): it is a fragment of light green twisted glass, slightly longer than 10  
15  
16 cm, but the absence of the two ends does not allow a definite attribution.  
17  
18

19  
20  
21 Glass fragments connected to cups are also well represented in our set (12% of the total of the  
22  
23 recognised forms) from which three samples were collected: one from a cup with thick filament  
24  
25 applied under the rim (BT5 – Glençler, 2003; Jennings, 2004-2005) and two from cups raised on  
26  
27 foot (BT16 and 32 - Sternini, 1995; Foy, 1995; Glençler, 2003).  
28  
29

30  
31  
32 From the category of bottles (11% of the total), sample BT39 from the body and 39a from the  
33  
34 decoration are representative of a bottle with mid-dark blue glass thread under the rim. This kind of  
35  
36 bottle is very common in the late Roman and Early Byzantine period (see for example Jennings,  
37  
38 1997-1998; Dussart, 1998; Foy, 2000; Jennings and Abdallah, 2002).  
39  
40

41  
42 Sample BT15 comes from a fragment in green glass with circular stamps on the surface.  
43  
44 Considering its slightly concave profile, it appears plausible to attribute the glass to the bottom of a  
45  
46 bottle with circular stamps (similar, for example to the Isings 50/51 type, Isings, 1957).  
47  
48 Unfortunately, this kind of marks are very common in the Mediterranean area since the Roman  
49  
50 period and the profile of fragment doesn't allow a more precise definition.  
51  
52

53  
54  
55 Sample BT6 was taken from a hanging lamp (lamps represent the 9% of the total) with hollow  
56  
57 stemmed bottom (Uboldi, 1995; Foy, 1995 and 2004). This kind of lamp was produced from the  
58  
59  
60  
61

1  
2 late 5<sup>th</sup> century AD to the early 7<sup>th</sup> century AD, with a widespread distribution throughout the  
3 Mediterranean sea, from East to West (Uboldi, 1995).  
4

5 One sample (BT45) is from the unguentaria or toilet bottles category (5% of the total) of dark blue  
6 glass. These small containers for perfumes or oils were made in the Roman period with good  
7 quality glass but, from the 6<sup>th</sup> century AD , their presence in urban sites seems substantially  
8 increased (Uboldi, 1995).  
9

10 The remaining samples from vessels subject to analyses, identified as “walls”, can not be attributed  
11 to a specific typology and were selected for the color of the glass.  
12  
13

#### 14 *Not identified glass and cullets*

15

16 The two areas of excavation of the Roman Forum brought to light only five small objects identified  
17 as cullet and deformed “blocks”, all of which were analysed: BT 2, 3, 10, 19, 35. These should not  
18 be indicative of the presence of a secondary production area in the Forum of Butrint and probably  
19 represent random moments of negligence.  
20  
21

## 22 **4. Experimental methods**

23  
24

25 The good state of preservation of the samples permitted removal of small chips of only few  
26 hundreds  $\mu\text{m}^3$ . Scrupulous attention was paid in sampling outside the recognizable profile of the  
27 diagnostic parts of vessel's fragments. Micro-sampling was performed on the body and different  
28 coloured decorations of each find in order to characterise the composition of the bulk and all the  
29 different coloured decorations.  
30  
31

### 32 *4.1 Electron microprobe analysis*

33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1 The chemical analyses of major and minor elements (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P, S, Cl,  
2 Cr, Co, Cu, Sn, Sb, and Pb) were carried out using a Cameca SX 50 microprobe equipped with four  
3 scanning wavelength-dispersive spectrometers (WDS). The samples were embedded in epoxy resin  
4 and polished with diamond paste. The reference Smithsonian glass A standard (Jarosewich, 2002)  
5 was employed as primary reference sample. Details of analytical conditions, standards used and  
6 accuracy and precision of the measurement are reported in supplementary material S1 and S2. Ten  
7 points were analysed on each sample to test homogeneity and the mean value was calculated. The  
8 standard deviations among the analysed points resulted to be between 2-3 and 3-4% for major and  
9 minor constituents, respectively. The correction program is based on the PAP method (Pouchou and  
10 Pichoir, 1988) and was used to process the results for matrix effects. The results are reported in  
11 Table 4. The elements Ti, Cr, Co, Cu, Sn, Sb, and Pb were also analysed by LA-ICP-MS.  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26

### 27 *3.2 Laser-ablation inductively coupled plasma mass spectrometry*

28  
29  
30 LA-ICP-MS was used to determine the concentration of 37 trace elements. The analyses were  
31 carried out with a Thermo Fisher X-Series<sup>II</sup> quadrupole based ICP-MS coupled with a New Wave  
32 ablation system with a frequency quintupled ( $\lambda = 213$  nm) Nd:YAG laser, at the Centro Grandi  
33 Strumenti of the University of Modena and Reggio Emilia. The laser repetition rate and laser energy  
34 density on the sample surface were fixed at 20 Hz and  $\sim 18$  J/cm<sup>2</sup>, respectively. The analyses were  
35 carried out using a laser spot diameter of 100  $\mu$ m on the same polished fragments used for EMPA.  
36 External calibration was performed using NIST SRM 610 and 614 glass as external standard, and  
37 <sup>29</sup>Si, previously determined by EPMA, as internal standard, following the method proposed by  
38 Longerich et al. (1996). Standard Reference Material NIST612 (Pearce et al., 1997) was used as a  
39 secondary reference sample to check precision and accuracy, which are reported in supplementary  
40 material S3, while the results are reported in Table 5.  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57

## 58 **4. Results**

1 The chemical analyses of the major and minor elements carried out by Electron Microprobe are  
2 reported in Table 4, and the trace elements composition obtained by LA-ICP-MS in Table 5.  
3  
4

#### 5 *4.1 Major components* 6 7

8 All the analysed samples are silica glass, with SiO<sub>2</sub> values ranging from 63.33% to 71.91%. The  
9 data indicate that the samples were produced with natron as the source of flux, since the contents of  
10 K<sub>2</sub>O vs. MgO, (Figure 2) never exceed 1.5 wt. % and since the Na<sub>2</sub>O contents are quite high,  
11 ranging from 14.18 to 22.34 wt%.  
12  
13  
14  
15  
16  
17

18 The contents of Al<sub>2</sub>O<sub>3</sub> and CaO - reflecting the feldspatic and carbonatic fractions present in the  
19 sand, respectively - give indications about the sand employed as vitrifying components. The  
20 samples show a relative homogeneity: they have Al<sub>2</sub>O<sub>3</sub> ranging from 1.54% to 2.91% and more  
21 variable CaO from 4.55% to 8.90%. In Figure 3 (Na<sub>2</sub>O vs. CaO) the samples are plotted along with  
22 other coeval samples from literature (HIMT: Freestone et al., 2002; Arletti et al., 2010a; 2010b;  
23 Mirti et al., 1993; Foster and Jackson, 2009; Šmit et al., 2013; and Levantine I: Freestone et al.,  
24 2002; Foster and Jackson, 2009; Schibille et al., 2008). From the plot it is possible to identify two  
25 groups, mainly distinguishable on the basis of Na<sub>2</sub>O and CaO levels: i) Group 1 composed by 23  
26 Butrint samples, with high Na<sub>2</sub>O (between 16.89% and 22.34%) and rather low CaO (between  
27 4.55% and 8.57%); ii) Group 2 (10 Butrint samples) with lower Na<sub>2</sub>O (ranging from 14.18% to  
28 17.13%) and higher CaO (ranging from 6.68% to 8.90%). The two groups also differ for their  
29 contents of MgO, FeO, TiO<sub>2</sub>, MnO, and trace elements such as Zr, V, and Cr which are always  
30 higher in the Group 1 with the exception only of sample BT39 (Tables 4 and 5).  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50

51 In agreement with literature data, these chemical differences allow the identification of two distinct  
52 glass compositions: Group 1 belonging to the so-called HIMT glass (with the exclusion of BT39),  
53 and Group 2 falling within the compositional field of Levantine I glass.  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

On the basis of the Fe, Ti, Mn, Zr, Ni and Cr levels, the Butrint HIMT glass can be further divided into: HIMT1, HIT (named after Rehren and Cholakova, 2010, see below) and HIMT2 (see Table 4, 5). The HIMT1 group (7 samples) contains, on average, higher contents of FeO, TiO<sub>2</sub>, MnO, Zr, Ni and Cr with respect to the HIMT2 group (13 samples). Anyway the highest levels of Fe, Ti, Zr, Ni and Cr are found, on average, in the HIT (3 samples) group which, on the contrary, exhibits very low Mn. Two of the groups (HIMT1 and 2) have already been recognised in literature by Foy et al.(2003) and by Foster and Jackson,(2009) at several coeval sites in France and Britain, respectively. The mean values of iron, titanium, and manganese in HIMT1 and 2 observed in this work fit perfectly with those reported in Table 2 and show the typical correlation between FeO and TiO<sub>2</sub> (Figure 4). Conversely, HIT appears to exhibit different features, not well documented, anyway their very high concentration of the key oxides suggest that HIT could be a sub-group of the HIMT1. The HIT samples display the highest levels of iron and the lowest contents of MnO. It is important to take into account that the three samples (BT39a, BT41, BT45) are all blue. Glass with similar features have been recognised by Rehren and Cholakova (2010) in green samples from Dichin (Bulgaria), and called HIT for the absence on manganese; however the Dichin HIT show lower FeO (1.42%) than the Butrint's one (2.57%). HIMT glass with very high levels of iron (3.23±0.57%) are reported by Gallo et al. (2014) for Aquileia samples, nevertheless they display also very high contents of MnO (1.78±0.27%). Considering our Butrint blue HIT we can observe that some elements result associated to iron, in particular cobalt and copper, indicating the use of the same colorant to obtain the desired nuance. Therefore, the higher contents of iron can be related to its unintentional introduction, as a component of the cobalt colorant raw materials, as suggested also by Foy et al. (2003).

The very high level of Ni in the HIT samples (84 ppm cf. 15ppm of HIMT1 and 12 ppm of HIMT2) can also be related to the source of Co (Gratuze et al., 1992). An explanation for the low level of MnO can be found in the final color of these HITglass. As known, the addition of manganese in

1 HIMT glass was aimed at preventing the glass turning black, and contributed to lend it a  
2 characteristic green-yellow coloration (Freestone, 2006). In this case, the blue glass varieties were  
3  
4 intentionally coloured by adding some cobalt colorant, thus decoloration was unnecessary. These  
5  
6 data seem to suggest that the chemical differences between HIMT1 and HIT are mainly related to  
7  
8 the introduction of a cobalt colorant, while only in one case (sample BT41) to the use of different  
9  
10 sands. Considering the remarkable chemical similarity of the BT39a and BT45 samples we can  
11  
12 suppose that they came from the same batch, while BT41 sample exhibiting lower silica and higher  
13  
14 lime, was probably produced with different raw materials.  
15  
16  
17  
18  
19

20 The Levantine I glass of the Butrint assemblage exhibits a very homogeneous composition, the  
21  
22 main differences involve the deep blue coloured sample BT36a which has high iron content (as  
23  
24 shown in Figure 4). The Levantine I group of samples can be divided into two sub-groups  
25  
26 distinguished on the basis of the MnO content: high MnO (BT10, 27, 39, 43) and low MnO (BT3,  
27  
28 5, 14, 16, 36, 36a), if considering 0.5% the threshold value discriminating the intentional addition of  
29  
30 the element (Jackson, 2005). In the high MnO group the introduction of manganese had a  
31  
32 decoloration purpose in the colourless samples BT39, BT43 and possibly in the yellowish BT27  
33  
34 glass, while it could be the effect of recycling or contamination in sample BT10, a glass scrap. The  
35  
36 separation in two groups, with respect of MnO content, of Levantine I glasses has already been  
37  
38 reported in studies by Foster and Jackson (2009) and Brill (1988), the latter showing high levels of  
39  
40 the oxide both in cullet and vessels glass.  
41  
42  
43  
44  
45  
46

#### 47 *4.2 Colorants*

48  
49  
50

51 Butrint glass comes in a wide selection of colours. Colourless samples (BT36, BT39, BT43)  
52  
53 uniquely belong to the Levantine I group and were decoloured by the addition of manganese to the  
54  
55 batch (BT39: 0.77% MnO, BT43: 1.71% MnO), with the exclusion of BT36 which has excessively  
56  
57 low MnO 0.01% and was probably decoloured by acting on the furnace atmosphere. The single  
58  
59 brown glass (the HIMT2 BT19) and the yellow samples (BT11, BT22-HIMT2, BT42-HIMT1;  
60  
61  
62  
63  
64  
65

1 BT27-Levantine I) owe their colours to the presence of FeO and MnO. Overall, the amounts of FeO  
2 in the Levantine I green glass samples (BT3, BT5, BT10, BT14, BT16) are quite low ( $\leq 0.50\%$ ), but  
3  
4 enough to provide the coloration. The coloration of the HIMT green samples (BT2, BT4, BT6, BT7,  
5  
6 BT12, BT15, BT17, BT21, BT28, BT29, BT32, BT34, BT35, BT38, BT40) is a consequence of the  
7  
8 FeO and MnO levels. On average, in the blue glass of both the Levantine I (BT36a) and HIMT  
9  
10 groups (BT30, BT39a, BT41, BT45), coloration is provided by cobalt (0.07-0.25%), often  
11  
12 associated with high FeO and  $\text{Cu}_2\text{O}$ .  
13  
14  
15  
16

17 It is generally assumed that the presence of repeated recycling can be reflected in the amounts of  
18  
19 certain additives (e.g. Co, Cu, Zn, Sb, Pb). When these are present at levels above those associated  
20  
21 with the occurrence of natural impurities (100 ppm), but below levels that suggest their intentional  
22  
23 addition ( $\sim 1000$  ppm), it is assumed they derive from the recycling of earlier glass (Foster and  
24  
25 Jackson, 2009). It is important to take into account that the non-detectable presence of Co, Cu, Zn,  
26  
27 Sb, Pb could only demonstrate that no earlier glass with high contents of those elements was  
28  
29 recycled. In addition, for the HIMT glass, copper, lead and antimony occurring at mean  
30  
31 concentrations  $< 89$  ppm,  $\leq 200$  ppm,  $\leq 100$  ppm respectively, have been taken as an indication of  
32  
33 natural impurities in unrecycled HIMT glass by Foy et al. (2003). Therefore after the exclusion of  
34  
35 the more deeply colored samples (BT6, BT36a, BT39a, BT41, BT45), we can observed that the  
36  
37 HIMT samples show levels of these elements in the range of the natural impurities (except the  
38  
39 BT21 sample), hence they probably derived from newly manufactured “fresh” glass, in contrast  
40  
41 with the literature data regarding HIMT glass (Foster and Jackson, 2009). Some of the Levantine I  
42  
43 samples conversely exhibit slightly high levels of antimony (BT3, BT10, BT14 which shows a  
44  
45 slight degree of opacity), indicating the possibility of some recycle or contamination, especially in  
46  
47 the case of BT3 and 10 that were taken from glass cullets, the latter also showing a high content of  
48  
49 manganese.  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59

#### 60 *4.3 Trace elements*

1 A trace element study was conducted on all the samples, with the exclusion of BT28 and BT29 due  
2 to their limited dimensions. The averaged values were normalised to the concentration of the upper  
3 continental crust (Wedepohl, 1995). As can be seen in Figure 5, the average composition of the  
4 Butrint samples is depleted for most of the trace elements, with the exception of strontium. This is  
5 probably due to the presence of aragonite in the coastal sand used as the vitrifying raw material  
6 (Freestone et al., 2003, Freestone, 2006). Aragonite is the polymorph of calcite that forms seashells,  
7 in which Sr can substitute Ca. The three chemical groups (HIMT1(+HIT), HIMT2 and Levantine I)  
8 differ in trace element composition: firstly, HIMT glass exhibits a higher absolute concentration of  
9 Zr and REE compared to Levantine I. The high level of zirconium in HIMT glass is probably  
10 related to the presence of zircon in the sand. Differences on elements concentration are present also  
11 in the HIMT groups, being the strongest values in most of the cases related to HIMT1 and HIT  
12 glass - see for example the amount of zirconium (on average 146 ppm HIMT1, 188 ppm HIT cf. to  
13 61 ppm HIMT2), vanadium (on average 31 ppm HIMT1, 32 ppm HIT cf. to 25 ppm HIMT2),  
14 yttrium (on average 8 ppm HIMT1, 9 ppm HIT cf. to 6 ppm HIMT2), hafnium (on average 4 ppm  
15 HIMT1, 5 ppm HIT, 2 ppm HIMT2). An important exception is Ba. HIT exhibits a negative  
16 anomaly for Ba, which might be related to the very low levels of MnO observed in these glass  
17 varieties. It has been suggested firstly by Silvestri (2008) and then by Arletti et al. (2010a) that, as  
18 an alternative to the well-known use of the mineral pyrolusite to introduce MnO into the batch, the  
19 mineral psilomelane [(Ba, H<sub>2</sub>O)MnO<sub>5</sub>O<sub>10</sub>] could also have been used for this purpose. This phase is  
20 documented in manganese oxides/hydroxides deposits (Peacor, 1978). Therefore the use of  
21 psilomelane involves the presence of quite a high level of barium in the final glass and a positive  
22 correlation between MnO and Ba. In this case HIMT1 and 2 exhibit this behaviour (high MnO-high  
23 Ba, with positive correlation), while in contrast, the low contents of barium in HIT can be explained  
24 by the lack manganese introduction into the batch.  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1 The REE patterns (Figure 6) are very similar for all the analysed samples, which are depleted in  
2 REE, with a stronger depletion for light REE. The main difference within the groups lies in the  
3 relative abundance of REE, which is higher, as already observed for the other trace elements, in  
4 HIMT glass. This probably indicates the use of an impure sand rich in heavy minerals as monazite,  
5 zircon, rutile, and iron oxides, as also suggested by the large amount of Zr, Y, V, FeO, and TiO<sub>2</sub>. It  
6 is again noted that the highest values are related to HIMT1 and HIT.  
7  
8  
9  
10  
11  
12  
13  
14

## 15 **5. Discussion**

16 The Butrint assemblage (33 samples) is composed by natron glass. The samples can be subdivided  
17 into HIMT glass and Levantine I glass on the basis of their contents of soda and lime, and for their  
18 levels of MgO, FeO, TiO<sub>2</sub>, MnO, and trace elements such as Zr, V and Cr, always higher in HIMT.  
19  
20  
21  
22  
23  
24  
25

26 The HIMT typology, first recognized by Sanderson et al. (1984) and named by Freestone in a study  
27 about a raw chunks from Carthage (Freestone, 1994), represents a type widespread in the western  
28 Mediterranean, particularly during the 4<sup>th</sup> century. It is characterized by relatively low lime, high  
29 soda, and high contents of iron, manganese and titanium, compared to Levantine I glass, which is  
30 the typical Syro-Palestinian production between the 4<sup>th</sup> and the 9<sup>th</sup> century AD. In the graph of  
31 Figure 7 the data for the natron Butrint glass and available literature data for HIMT and Levantine I  
32 glass varieties are plotted. Relevant data to HIMT are reported from Maroni Petrera, Cyprus  
33 (Freestone et al., 2002), Ganzirri, Italy (Arletti et al., 2010a), Galeata, Italy (Arletti et al., 2010b),  
34 Augusta Praetoria, Italy (Mirti et al., 1993), Tonovcov, Slovenia (Šmit et al., 2013), and several  
35 sites in Britain (Foster and Jackson, 2009). As regards Levantine I data from Maroni Petrera  
36 (Freestone et al., 2002) and several sites in Britain (Foster and Jackson, 2009) are also plotted with  
37 the addition of samples from Petra (Schibille et al., 2008).  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55

56 The comparison of the chemical data of this study with glass from Butrint previously studied by  
57 Schibille (2011) shows that the chemical groups identified in this study are substantially different.  
58 In her study on vessel and window glass, Schibille isolated two main groups divided in subgroups:  
59  
60  
61  
62  
63  
64  
65

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

“WD” (with the subgroups WD1 and WD2) constituted by samples from the Western defences (6<sup>th</sup> – 8<sup>th</sup> century AD) and ”Misc” group of miscellaneous vessels and window glass with the subgroups Misc1, Misc2 and Misc-HIMT (1<sup>st</sup> – 5<sup>th</sup> century AD). The first group, chronologically closer to our samples, includes a first subgroup (WD1) recognized as “Egypt II type”, which shows important differences when compared with the sample here analysed. In fact, respect to the HIMT glass of our study, they show lower alkalis, higher lime and scarce manganese; moreover they don’t exhibit the HIMT typical iron-alumina and iron-titanium correlation. With respect to our Levantine I glass they differ for the content of lime and soda. The second subgroup WD2 is quite controversial since it lies in a mid-way between HIMT and Levantine I types. In fact, even if the contents of lime and alumina would be compatible with Levantine I they show too high iron, titanium and manganese. In the group of miscellaneous glass Schibille isolated the Misc2 type, a Roman antimony decolorised type, not present in our set. The subgroup Misc1, tentatively post-dated (4th century or later) with respect to the Misc2 type on the basis of the use of manganese as a decolorizer, shows quite close resemblances with the Levantine I type glass found in our study, even if our set shows samples with slightly lower lime. Finally – and surprisingly – only two samples were recognized by Schibille as HIMT type: the Misc-HIMT group presents similarities with our HIMT1 type, although our samples are characterized by lower alumina.

As previously noted in the results, the natron glass of the present study fits perfectly with the HIMT category (23 samples) and Levantine I category (9 samples) with the exception of BT39, which exhibits some peculiarities: the typical chemical traits of Levantine I (i.e. high Ca, low Mg, low Ti, low trace elements, etc.) are contrasted by high levels of soda that prevents a precise grouping. In addition, sample BT39 has a very low alumina content, (1.54% Al<sub>2</sub>O<sub>3</sub>). This sample, even if dated to the 5<sup>th</sup> - 6<sup>th</sup> century AD, has the peculiarity of being composed of an archaeologically non classifiable colorless base glass, decorated with a rim in blue glass which, in contrast, belongs to the HIT type, making this object a peculiarity in the glass production panorama.

1 A more detailed subdivision can be made among the Butrint HIMT samples, distinct in three sub-  
2 groups on the basis of the contents of titanium, iron, manganese, zirconium, nickel and chromium.  
3  
4 As can be seen in Figure 8, seven Butrint HIMT samples (cross) belong to the so-called HIMT1-  
5 strong (diamond), and thirteen (circle) to the HIMT2-weak (square) groups (Foy et al., 2003; Foster  
6 and Jackson, 2009). The remaining three glass samples (HIT-triangle) show higher levels of iron  
7 and cobalt and lower manganese (see Table 4 and 5 ) as a consequence of their blue color.  
8  
9

10 The generally low levels of trace elements is a typical trend observed in many ancient glass (Arletti  
11 et al., 2010a, Arletti et al., 2011, Freestone et al., 2000) and suggests the use of a mineralogically  
12 mature sand, rich in quartz and poor in clay and heavy minerals. This is confirmed by the fact that  
13 the higher depletion is, on average, related to the samples richer in SiO<sub>2</sub>. In addition, the levels of  
14 strontium suggest the use of a coastal sand as vitrifying raw material in all the Butrint samples. It  
15 has also been noted that, even if trace elements are depleted in all the samples, the HIMT glass  
16 samples (in particular HIMT1 and HIT) exhibit the highest concentrations. Since iron, titanium,  
17 zirconium, and REE are related to the heavy mineral and/or mafic fraction of the sand (e.g., zircon,  
18 rutile, ilmenite, monazite, and iron oxides), the chemical composition of the HIMT indicates the use  
19 of an less pure sand source (Foster and Jackson, 2009). As shown in Figures 9 and 10, these data are  
20 consistent with literature data for coeval samples.  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42

43 An important observation can be made by considering the type, chronology, and form of the glass  
44 objects, and their subdivision in compositional groups. The first relevant point is that all the closed  
45 forms (stemmed beakers – I.111 and lamps) belong to the HIMT2 type, a medium grade glass  
46 (better quality than HIMT1 since it contains less impurities, but worse than Levantine glass). This is  
47 the evidence of a different selection of raw glass for the production of these objects (particularly of  
48 I.111), starting from the same supply of primary glass. This production is chronologically placed in  
49 a period between the 5<sup>th</sup> and 6<sup>th</sup> century, as can be deduced from archaeological data (matrix data  
50 and typologies – see Table 3). Conversely, a precisely recognizable form cannot be identified for  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1 the HIMT1 type, except the bowl BT32, dated to the 5<sup>th</sup> – 6<sup>th</sup> century for its shape, and we can  
2 consider this chemical group as belonging to a later production on the basis of archaeological data,  
3  
4 assigning this set to the second half of the 6<sup>th</sup> century. The earlier spread of HIMT2 has already  
5  
6 been observed by Foster and Jackson (2009), on the basis of the relatively high presence of  
7  
8 recycling indicators (such as Cu, Pb, Sb). In contrast with these examples, the Butrint HIMT2  
9  
10 samples have no recycling indicators that suggest their dilution with other glass, and are instead  
11  
12 freshly made glass. An obvious difference is the lower quality (colour heterogeneity, presence of  
13  
14 bubbles) of the glass belonging to the HIMT1 group compared to the other natron type groups.  
15  
16 Higher quality is recognizable in the Levantine set: only two glass samples (BT5 and BT16) are  
17  
18 attributable to known forms of bowls, but the value of these vessels is certainly higher than the  
19  
20 “common” form of beakers of type HIMT2. Therefore, the Levantine type, whose chronology  
21  
22 overlaps the HIMT 1 and 2 types, can be distinguished for superior product quality, also  
23  
24 corroborated by high glass quality.  
25  
26  
27  
28  
29  
30

31  
32 Five cullets (BT2, BT3, BT10, BT19 and BT35) fit perfectly into the three main chemical  
33  
34 categories: BT35-HIMT1, BT2 and BT19-HIMT2, BT3 and BT10-Levantine I. For some samples  
35  
36 (in particular BT17, 32, and 36 but also 19, 21, and 34), the lack or doubt of chronological location  
37  
38 from archaeological data can be overcome by the definition of the object chrono-type and/or using  
39  
40 chemical data to locate the sample in a recognized compositional group: the earliest find is sample  
41  
42 17, a stemmed beaker of the HIMT2 type (5<sup>th</sup> – 6<sup>th</sup> cen AD); samples 21 and 32 are of the HIMT1  
43  
44 type of lower quality and later chronology (second half of the 6<sup>th</sup> century) and samples 19, 34, 36,  
45  
46 belong to Levantine I type, whose production is attested in the 4<sup>th</sup> to 7<sup>th</sup> century AD production.  
47  
48  
49  
50  
51  
52  
53  
54  
55

## 56 **6. Conclusions**

57  
58  
59  
60  
61  
62  
63  
64  
65

1 The very interesting result of this work, which gives particular importance to considering type,  
2 chronology, and form of glass objects, is the correspondence of chemical and  
3 typological/chronological groups, all the more impressive considering the brief time span involved.  
4  
5 In some interesting cases compositional grouping helped the chronological definition of the site  
6 stratigraphy. The production of the three natron types identified in this work can be distinguished on  
7 a chronological basis (HIMT1 later than HIMT2) and product quality criteria (Levantine I better  
8 than HIMT2, which in turn is better than HIMT1). This indicates that in Butrint, between the end of  
9 the 4<sup>th</sup> and the end of the 6<sup>th</sup> centuries glass materials were imported (at present, no signs of primary  
10 or secondary production are attested) either from (a) different suppliers evaluating the cost and the  
11 quality of glass, or from (b) the same supplier who consciously selected the type of primary glass  
12 for more costly or cheaper items (compare Levantine with HIMT2 and later with HIMT1).  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30

### 31 **Acknowledgements**

32  
33  
34 The authors would like to thank David Hernandez (University of Notre Dame du Lac, Indian-  
35 USA), and Dhimitër Çondi (Albanian Archaeological Institute), directors of the 2011 excavation  
36 campaign in Butrint. Three anonymous referees and the Editor Thilo Rehren are kindly  
37 acknowledged since their suggestions greatly improved the manuscript.  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

## References

- 1  
2  
3 Arletti, R., Giacobbe, C., Quartieri, S., Sabatino, G., Tigano, G., Triscari, M., Vezzalini, G., 2010a.  
4 Archaeometrical investigation of Sicilian Early Byzantine glass: chemical and spectroscopic data.  
5 Archaeometry, 52, 1, 99-114. <http://dx.doi.org/10.1111/j.1475-4754.2009.00458.x>  
6  
7  
8  
9  
10 Arletti, R., Vezzalini, G., Benati, S., Mazzeo Saracino, L., Gamberini, A., 2010b. Roman window  
11 glass: a comparison of findings from three different Italian sites. Archaeometry, 52, 2, 252-271.  
12 <http://dx.doi.org/10.1111/j.1475-4754.2009.00479.x>  
13  
14  
15  
16  
17 Arletti, R., Bertoni, E., Vezzalini, G., Mengoli, D., 2011. Glass beads from Villanovian excavation  
18 in Bologna (Italy): an archaeometrical investigation. Eur J Mineral, 23, 959-968.  
19 <http://dx.doi.org/10.1127/0935-1221/2011/0023-2166>  
20  
21  
22  
23  
24  
25 Brill, R.H., 1988. Scientific investigations of the Jalame glass and related finds. In: Weinberg, G.D.  
26 (Ed.), Excavations at Jalame, Site of a Glass Factory in Late Roman Palestine. University of  
27 Missouri Press, Columbia, pp. 257–293.  
28  
29  
30  
31  
32 Corti, L., 2012. I vetri di Salto del Lupo e Santa Maria in Padovetere (Comacchio, Ferrara). Note  
33 sulla circolazione tra tardo Antico e alto Medioevo nell'antico delta padano. In: Larese A., Seguso  
34 F. (eds), Il vetro nel Medioevo tra Bisanzio l'Islam e l'Europa (VI – XIII secolo). Aggiornamenti  
35 scavi e ricerche sul vetro (Comitato Nazionale Italiano, atti delle XII Giornate di Studio, Venezia  
36 19-21 ottobre 2007). Association Internationale pour l'Histoire du Verre, Venezia, pp. 41-49.  
37  
38  
39  
40  
41  
42  
43 Dussart, O., 1998. Le verre en Jordanie et en Syrie du sud. Institut Française d'Archeologie du  
44 Proche-Orient, Beyrouth.  
45  
46  
47  
48 Fadić, I., Štefanac, B., 2012. Workshop stamps on square bottles from the Zadar region. In:  
49 Antonaras, A., Ignatiadou, D. (eds), Annales du 18e Congrès de l'Association Internationale pour  
50 l'Histoire du Verre (Thessaloniki 2009). Association Internationale pour l'Histoire du Verre,  
51 Thessaloniki, pp. 206-211.  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

1 Falcetti, C., 2001. La suppellettile in vetro. In: Mannoni T., Murialdo G. (eds), S. Antonino. Un  
2 insediamento fortificato nella Liguria bizantina. Istituto Nazionale di Studi Liguri, Bordighera, pp.  
3 403-454.  
4

5  
6  
7 Foster, H. E., Jackson, C. M., 2009. The composition of “naturally coloured” Late Roman vessel  
8 glass from Britain and the implication for models of glass production and supply. *J Archaeol Sci*,  
9 36, 2, 189-204. <http://dx.doi.org/10.1016/j.jas.2008.08.008>  
10  
11

12  
13  
14 Foy, D., 1995. Le verre de la fin du IVe au VIIIe siècle en France méditerranéenne: premier essai de  
15 typo-chronologie. In: Foy, D. (ed), *Le verre de l'Antiquité tardive et du haut Moyen Âge: typologie,*  
16 *chronologie, diffusion, actes de la huitième rencontre de l'Association Française pour l'Archéologie*  
17 *du verre* (Guiry-en-Vexin, 18-19 novembre, 1993). Musée Archéologique Départemental du Val  
18 d'Oise, Guiry-en-Vexin, France, pp. 187-242.  
19  
20  
21  
22

23  
24  
25 Foy, D., 1998. Les niveaux de l'antiquité tardive : Les verres des sondages 6-7. In: Bonifay, M.,  
26 Rigoir, Y., Carre, M.B., 1998. *Fouilles à Marseille: le mobilier (1er – 7e siècles ap. J.-C.)*. Errance  
27 - Adam, Paris, pp. 127-132.  
28  
29  
30

31  
32 Foy, D., 2000. Un atelier de verrier à Beyrouth au début de la conquête islamique. *Syria*, 77, 239-  
33 290.  
34  
35  
36

37  
38 Foy, D., 2003. Le verre en Tunisie: l'apport des fouilles récentes tuniso-françaises. *J Glass Stud*, 45,  
39 59-89.  
40  
41

42  
43 Foy, D., 2004. Le verres. In: Ben-Abed-Ben Khader, A., Fixot, M., Bonifay, M., Roucole, S. (eds),  
44 Sidi Jdidi I. *La basilique sud*. École Française de Rome, Rome, pp. 317-329.  
45  
46  
47

48  
49 Foy, D., 2010. *Les verres antiques d'Arles: la collection du Musée départemental Arles antique*.  
50 Musée départemental Arles antique, Errance, Paris.  
51  
52

53  
54 Foy, D., Picon, M., Vichy, M., Thirion-Merle, V., 2003. Caractérisation des verres de la fin de  
55 l'Antiquité en Méditerranée occidentale: l'émergence de nouveaux courants commerciaux. In: Foy,  
56 D., Nenna, M.-D. (eds), *Échanges et commerce du verre dans le monde antique, actes du colloque*  
57  
58  
59  
60  
61

1 de l'Association Française pour l'Archéologie du Verre (Aix-en-Provence et Marseille, 7-9 juin  
2 2001). Monographies Instrumentum, 24. Monique Mergoil, Montagnac, pp. 41-85.

3  
4  
5 Freestone, I. C., 1994. Chemical analysis of "raw" glass fragments. In: Hurts, H. R. (ed.),  
6 Excavations at Carthage, Vol II, 1, The Circular Harbour, North Side. Oxford University Press,  
7 Oxford, p. 290.

8  
9  
10  
11  
12 Freestone, I. C., 2006. Glass production in late antiquity and Early Islamic period: a geochemical  
13 perspective. In: Maggetti, M., Messiga, B. (eds.), Geomaterials in cultural heritage. Geological  
14 Society of London Special Publication 257, London, pp. 201-216.

15  
16  
17  
18  
19  
20 Freestone, I. C., Gorin-Rosen, Y., Hughes, M. J., 2000. Primary glass from Israel and the  
21 production of glass in late antiquity and the early Islamic period. In: Nenna, M.-D. (ed.), La route  
22 du Verre. Ateliers primaires et secondaires du second millénaire av. J.-C. au Moyen Âge. Travaux  
23 de la Maison de l'Orient Méditerranéen, No. 33. Maison de l'Orient Méditerranéen, Lyon, pp. 66-  
24 83.

25  
26  
27  
28  
29  
30  
31 Freestone, I. C., Greenwood, R., Gorin-Rosen, Y., 2002. Byzantine and early Islamic glassmaking  
32 in the eastern Mediterranean: production and distribution of primary glass. In: Kordas, G., (ed.),  
33 Hyalos Vitrum Glass: history, technology and conservation of glass. Proceedings of the First  
34 Balkan Conference, Rhodes, 2001. Glasnet Publications, Athens, pp. 167-174.

35  
36  
37  
38  
39  
40 Freestone, I. C., Leslie, K. A., Thirlwall, M., Gorin-Rosen, Y., 2003. Strontium isotopes in the  
41 investigation of early glass production: byzantine and early islamic glass from Near East.  
42 Archaeometry, 45, 1, 19-32. <http://dx.doi.org/10.1111/1475-4754.00094>

43  
44  
45  
46  
47 Freestone, I. C., Wolf, S., Thirlwall, M., 2005. The production of HIMT glass: elemental and  
48 isotopic evidence, Annales du 16e Congrès de l'Association Internationale pour l'Histoire du Verre  
49 (London, 2003). Association Internationale pour l'Histoire du Verre, Nottingham, pp. 153-157.

50  
51  
52  
53  
54 Fünfschilling, S., 2010. Byzantine glass finds from Carthage: from the German excavations, the  
55 English excavations at Bir Messaouda and from the Canadian excavations. In: Keller, D.,  
56 Drauschke, J. (eds), Glass in Byzantium: production, usage, analyses. International workshop  
57  
58  
59  
60  
61

1  
2 organised by the Byzantine Archaeology (Mainz, 17-18 January 2008), Römisch-Germanisches  
3 Zentralmuseum, Mainz, pp. 215-223.  
4

5 Gallo, F., Marcante, A., Silvestri, A., Molin, G., 2014. The glass of the "Casa delle Bestie Ferite": a  
6 first systematic archaeometric study on Late Roman vessels from Aquileia. *J Archaeol Sci*, 41, 7–  
7 20. <http://dx.doi.org/10.1016/j.jas.2013.07.028>  
8  
9

10  
11  
12 Glençler, Ç., 2003. IX.2. I vetri. In: Equini Schneider E. (ed), *Elaiussa Sebaste, II: un porto tra*  
13 *Oriente e Occidente*. L'Erma di Bretschneider, Roma, pp. 708-736.  
14  
15

16  
17  
18 Gratuze, B., Soulier, I., Barrandon, J.-N., Foy, D., 1992. De l'origine du cobalt dans le verres. *Rev*  
19 *Archéom*, 16, 97-108.  
20  
21

22  
23 Gürler B., Lafli E., 2010. Middle and Late Roman glass from the Agora of Smyrna from the  
24 excavation seasons 1997 and 2002-2003. In Keller D., Drauschke J. (eds), *Glass in Byzantium.*  
25 *Production, usage, analyses*. International workshop organised by the Byzantine Archaeology  
26 (Mainz, 17-18 January 2008), Römisch-Germanisches Zentralmuseum, Mainz, pp. 121-144.  
27  
28  
29  
30

31  
32 Hernandez, D. R., 2007. *Novità archeologiche da Butrinto: gli scavi al foro*. *Groma: archeologia tra*  
33 *Piceno, Dalmazia ed Epiro*, Quaderni del Centro Studi per l'archeologia dell'Adriatico, 1, 93-97.  
34  
35  
36

37  
38 Hernandez, D.R., 2011. The refuse of urban history excavating the Roman Forum at Butrint.  
39 *Expedition Magazine*, 53, 3, 37-42.  
40  
41

42  
43 Hernandez, D.R., Çondi, D., 2008. The Roman forum at Butrint (Epirus) and its development from  
44 Hellenistic to medieval times. *J Roman Arch*, 21, 275-292.  
45  
46  
47

48  
49 Hodges, R., Hansen, I. L., 2007. *Roman Butrint: an assessment*. *Oxbow books for the Butrint*  
50 *Foundation*, Oxford.  
51  
52

53  
54 Hodges, R., Saraçi G., Bowden W., Chiles P., Gilkes O., Lako K., Lane A., Martin S., Mitchell J.,  
55 Moreland J., O'Hara S., Pluciennik M., Watson L., 1997. Late-antique and Byzantine Butrint:  
56 interim report on the port and its hinterland (1994-95). *J Roman Arch*, 10, 207-234.  
57  
58  
59  
60  
61

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

Hodges, R., Bowden W., Gilkes O., Lako K., 2000. Late Roman Butrint, Albania: survey and excavations, 1994-98. *Archeologia Medievale*, 27, 241-257.

Isings, C., 1957. Roman glass from dated finds, J.B. Wolters, Groningen-Djakarta.

Jackson, C.M., 2005. Making colourless glass in the Roman period. *Archaeometry* 47, 763–780.

<http://dx.doi.org/10.1016/j.jas.2008.08.008>

Jennings, S., 1997-1998. Roman and Early Byzantine glass from the Souks Excavations: an interim statement. *Berytus*, 43, 111-146.

Jennings, S., 2004-2005. Vessels glass from Beirut Bey 006, 007 and 045. *Berytus*, 48/49.

Jennings, S., 2010. A group of glass ca. 800 A.D. from Tower 2 on the Western Defence, Butrint, Albania. In Keller D., Drauschke J. (eds), *Glass in Byzantium. Production, usage, analyses. International workshop organised by the Byzantine Archaeology (Mainz, 17-18 January 2008)*, Römisches-Germanisches Zentralmuseum, Mainz, pp. 225-235.

Jennings, S., Abdallah, J., 2002. Roman and later blown glass from the sub excavations in Beirut (sites bey 006, 007 and 045). *Aram*, 13-14 (2001-2002), 237-264.

Jennings, S., Stark, K., 2013. Appendix: The glass from Tower 1 in the Western Defence. In: Hodges, R., Leppard S., Hansen, I. L., (eds), *Butrint 4: the archaeology and histories of an Ionian town*. Oxbow books for the Butrint Foundation, Oxford, pp. 257-259.

Jarosewich, E. 2002. Smithsonian Microbeam Standards. *Journal of Research of NIST*, 107, 6 (November-December 2002), 681-685. <http://www.nist.gov/jres>

Longerich, H. P., Jackson, S. E., Gunther, D., 1996. Inter-laboratory note. Laser ablation inductively coupled plasma mass spectrometric transient signal data acquisition and analyte concentration calculation. *J Anal At Spectrom*, 11, 899-904. <http://dx.doi.org/10.1039/JA9961100899>

1 Mirti, P., Casoli, A., Appolonia, L., 1993. Scientific analysis of Roman glass from Augusta  
2 Praetoria. *Archeometry*, 35, 2, 225-240. <http://dx.doi.org/10.1111/j.1475-4754.1993.tb01037.x>  
3  
4

5 Peacor, D. R., 1978. Manganese. In: Wedepohl, K. H. (ed), *Handbook of geochemistry*. 2.3  
6 Elements Cr(24) to Br(35), Springer, Berlin.  
7  
8

9  
10 Pearce, J.G., Perkins, W. T., Westgate, J. A., Gorton, M. P., Jackson, S. E., Neal, C. R., Chenery, S.  
11 P., 1997. A Compilation of New and Published Major and Trace Element Data for NIST SRM 610  
12 and NIST SRM 612 Glass Reference Materials. *Geostandards Newsletter*, 21, 1, 115-144.  
13  
14 <http://dx.doi.org/10.1111/j.1751-908X.1997.tb00538.x>  
15  
16  
17

18  
19 Price J., 1997. The glass. In: Potter, T. W., King, A. C. (eds), *Excavations at the Mola di Monte*  
20 *Gelato: a Roman and medieval settlement in South Etruria*. The British School at Rome, British  
21 Museum, London, pp. 265-286.  
22  
23  
24

25  
26 Pouchou, J.L., Pichoir, F.M.A, 1988. Determination of Mass Absorption Coefficients for Soft X-  
27 Rays by use of the Electron Microprobe. In: Newbury, D.E. (ed.), *Microbeam analysis 1988:*  
28 *proceedings of the 23<sup>rd</sup> Annual Conference of the Microbeam Analysis Society (Milwaukee, 8-12*  
29 *August 1988)*. San Francisco Press, San Francisco, pp. 319-324.  
30  
31  
32  
33  
34

35  
36 Rehren, Th., Cholakova, A., 2010. The Early Byzantine HIMT Glass from Dichin, Northern  
37 Bulgaria, ИНТЕРДИСЦИПЛИНАРНИ ИЗСЛЕДВАНИЯ XXII–XXIII СОФИЯ,  
38 АРХЕОЛОГИЧЕСКИ ИНСТИТУТ С МУЗЕЙ – БАН.  
39  
40  
41

42  
43 Saguì, L. 1993. Produzioni vetrarie a Roma tra tardo-antico e alto medioevo. In: Delogu, P., Paroli,  
44 L. (eds.), *La storia economica di Roma nell'Alto Medioevo alla luce dei recenti scavi archeologici,*  
45 *atti del Seminario (Roma, 2-3 aprile 1992)*. All'insegna del giglio, Firenze, pp. 113-136.  
46  
47  
48  
49

50  
51 Saguì, L. 2001. Vetro. In: Arena, M.S. (ed), *Roma dall'antichità al medioevo: archeologia e storia*  
52 *nel Museo nazionale romano Crypta Balbi*. Electa, Milano, pp. 307-322.  
53  
54  
55

56 Sanderson, D.C.W., Hunter, J.R., Warren, S.E., 1984. Energy Dispersive X-ray Fluorescence  
57 Analysis of 1st Millennium AD Glass from Britain. *J Archaeol Sci*, 11, 1, 53-69.  
58  
59 [http://dx.doi.org/10.1016/0305-4403\(84\)90041-4](http://dx.doi.org/10.1016/0305-4403(84)90041-4)  
60  
61  
62

1 Schibille, N., 2011. Supply routes and the consumption of glass in first millennium CE Butrint  
2 (Albania). *J Archaeol Sci*, 38, 11, 2939-2948. <http://dx.doi.org/10.1016/j.jas.2011.06.002>  
3  
4

5  
6  
7 Schibille, N., Marii, F., Rehren, Th., 2008. Characterization and provenance of late antique window  
8 glass from the Petra Church in Jordan. *Archaeometry*, 50, 4, 627-642.  
9 <http://dx.doi.org/10.1111/j.1475-4754.2007.00346.x>  
10  
11

12  
13  
14 Silvestri, A., 2008. The coloured glass of Julia Felix. *J Archaeol Sci*, 35, 6, 1489-1501.  
15 <http://dx.doi.org/10.1016/j.jas.2007.10.014>  
16  
17

18  
19  
20 Silvestri A., Marcante A., 2011. The glass of Nogara (Verona): a “window” on production  
21 technology of mid-Medieval times in Northern Italy, *J Archaeol Sci*, 38, 2011, 2509-2522.  
22 <http://dx.doi.org/10.1016/j.jas.2012.03.016>  
23  
24

25  
26  
27 Šmit, Ž., Milavec, T., Fajfar, H., Rehren, Th., Lankton, J.W., Gratuze, B., 2013. Analysis of glass  
28 from the post-Roman settlement Tonovcov grad (Slovenia) by PIXE-PIGE and LA-ICP-MS. *Nucl*  
29 *Instrum Meth B*, 311, 53–59. <http://dx.doi.org/10.1016/j.nimb.2013.06.012>  
30  
31  
32

33  
34 Sternini, M., 1995, *Il vetro in Italia tra V e IX secolo*. In: Foy, D. (ed.), *Le verre de l'Antiquité*  
35 *tardive et du haut Moyen Age: typologie, chronologie, diffusion, actes de le huitième rencontre de*  
36 *l'Association Française pour l'Archéologie du verre (Guiry-en-Vexin, 18-19 novembre, 1993).*  
37 *Musée Archéologique Départemental du Val d'Oise, Guiry-en-Vexin, France, pp. 243-289.*  
38  
39  
40

41  
42  
43 Sternini, M., 2013. I reperti in vetro dallo scavo della Basilica Portuense. In: Maiorano, M., Paroli,  
44 L. (eds), *La basilica portuense. Scavi 1991-2007, II. All'insegna del giglio*, Firenze, pp. 619-641.  
45  
46  
47

48  
49 Stevenson J., 2001. The vessel glass. In: Mitchell, J., Hansen, I.L., (eds), *San Vincenzo al Volturno:*  
50 *the finds from the 1980-1986 excavations, vol. 3. Centro Italiano di Studi sull'Alto Medioevo,*  
51 *Spoletto, pp. 203-251.*  
52  
53  
54

55  
56 Stiaffini, D., 2004. Repertorio del vetro post-classico. *Association Internationale pour l'Histoire du*  
57 *Verre - Comitato Nazionale Italiano, Contributi Storico-Tecnici*, 5, La Mandragola, Venezia.  
58  
59  
60

1 Tabaczynska, E., 1977. L'officina vetraria. In: Leciejewicz, L., Tabaczynska, E., Tabaczynsky, S.  
2 (eds), Torcello. Scavi 1961-62. Istituto nazionale di archeologia e storia dell'arte, Monografie III,  
3 Roma, pp. 89-153.  
4

5  
6  
7 Uboldi, M., 1995. Diffusione delle lampade vitree in età tardoantica e altomedievale e spunti per  
8 una tipologia. *Archeologia Medievale*, 22, 93-145.  
9

10  
11  
12 Uboldi, M., 1999. I vetri. In: Brogiolo, G.P., (ed), S. Giulia di Brescia: gli scavi dal 1980 al 1992 -  
13 reperti preromani, romani e alto medievali. *All'Insegna del giglio*, Firenze, pp. 271-307.  
14  
15

16  
17  
18 Ugolini, L. M., 1937. *Butrinto: il mito d'Enea, gli scavi*. Istituto Grafico Tiberino, Roma.  
19

20  
21  
22 Wedepohl, K. H., 1995. The composition of the continental crust. *Geochim Cosmochim Acta*, 59, 7,  
23 1217-1232. [http://dx.doi.org/10.1016/0016-7037\(95\)00038-2](http://dx.doi.org/10.1016/0016-7037(95)00038-2)  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

## Table captions

**Table 1:** Minimum, maximum and average values of Al<sub>2</sub>O<sub>3</sub>, FeO, MgO, CaO, Na<sub>2</sub>O, K<sub>2</sub>O, TiO<sub>2</sub> and MnO, relative to the HIMT and Levantine I samples analysed here and reported in literature.

Literature data are taken from: Maroni Petrera, Cyprus (Freestone et al., 2002), Ganzirri, Italy (Arletti et al., 2010a), sites in Britain (Foster and Jackson, 2009), Galeata, Italy (Arletti et al., 2010b), Augusta Praetoria, Italy (Mirti et al., 1993), Tonovcov, Slovenia (Šmit et al., 2013) and Petra, Jordan (Schibille et al., 2008).

**Table 2:** Minimum, maximum and average values of FeO, TiO<sub>2</sub> and MnO, relative to the HIMT 1 and 2 reported by Foster and Jackson, 2009.

**Table 3:** Summary table of the analyzed samples: description, chrono-typological definition (when applicable), chronology (on the basis of the form and/or archaeological matrix data).

**Table 4:** Chemical data for major and minor elements obtained by EMPA (oxide weight %). n.d.= not detected.

**Table 5:** Chemical data for trace elements obtained by LA-ICP-MS (ppm). n.d.= not detected.

## Figure captions

**Figure 1.** Drawings of I.111 stemmed beakers: BT38.

**Figure 2.** K<sub>2</sub>O vs. MgO (weight %) for the analysed samples.

**Figure 3.** Na<sub>2</sub>O vs. CaO (weight %) for the analyzed samples and for literature data relative to HIMT glass-group 1 (Maroni Petrera-Cyprus, Freestone et al., 2002; Ganzirri-Italy, Arletti et al., 2010a; Galeata-Italy, Arletti et al., 2010b; Augusta Praetoria, Italy-Mirti et al., 1993; Britain, Foster and Jackson, 2009; Tonovcov-Slovenia, Šmit et al., 2013), and Levantine I glass-group 2 (Maroni Petrera-Cyprus, Freestone et al., 2002; Britain, Foster and Jackson, 2009; Petra- Jordan, Schibille et al., 2008). The sample BT39 shows high level of soda, unusual for the Levantine I glass, but all the other chemical features (i.e. high Ca, low Mg, low Ti, low trace elements, etc.), are typical of that type.

**Figure 4.** TiO<sub>2</sub> vs. FeO (weight %) for the analysed samples.

**Figure 5.** Average trace element composition for Butrint compositional glass group (with the exclusion of BT28, BT29) normalised to the composition of the upper continental crust (Wedepohl, 1995).

**Figure 6.** REE average composition for Butrint compositional glass group (with the exclusion of BT28, BT29), normalised to the composition of the upper continental crust (Wedepohl, 1995).

**Figure 7.** Al<sub>2</sub>O<sub>3</sub> vs. FeO (weight %) for the analysed samples compared with literature data. HIMT data are taken from: Maroni Petrera, Cyprus (Freestone et al., 2002); Ganzirri, Italy (Arletti et al., 2010a); Galeata, Italy (Arletti et al., 2010b); Augusta Praetoria, Italy (Mirti et al., 1993); Tonovcov, Slovenia (Šmit et al., 2013); Britain (Foster and Jackson, 2009). Levantine I are taken from Maroni

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65

Petrera, Cyprus (Freestone et al., 2002), Britain (Foster and Jackson, 2009), and Petra, Jordan (Schibille et al., 2008).

**Figure 8.** TiO<sub>2</sub> vs. FeO (weight %) for the analysed samples compared with literature data.

Literature data are the same as for Table 1.

**Figure 9.** Average trace element composition for Butrint compositional glass group (with the exclusion of BT28, BT29) normalised to the composition of the upper continental crust (Wedepohl, 1995) compared with literature data from Maroni Petrera, Cyprus (Freestone et al., 2002) Ganzirri, Italy (Arletti et al., 2010a), Apollonia, Israel (Freestone et al., 2000).

**Figure 10.** REE average composition for Butrint HIMT (with the exclusion of BT28, BT29) normalised to the composition of the upper continental crust (Wedepohl, 1995) compared with literature data from Ganzirri, Italy (Arletti et al., 2010a), and Tonovcov, Slovenia (Šmit et al., 2013).

### Supplementary captions.

Table S1: EMPA analytical conditions.

Table S2: Comparison of “known” values and data from EMPA for Smithsonian Glass A (Jarosewich, 2002). The standard deviation, the accuracy and the detection limits are also shown.

Table S3: Comparison of “known” values and data from LA-ICP-MS for NIST612. The standard deviation and the accuracy are also shown. “Known” values are given according to recommended composition (Pearce et al., 1997).

Table1

			Al <sub>2</sub> O <sub>3</sub>	FeO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	TiO <sub>2</sub>	MnO	
<b>HIMT</b>	<b>BUTRINT, this study</b>	min	1.73	0.51	0.55	4.55	16.89	0.30	0.07	0.07	
		MAX	2.72	2.76	1.43	8.57	22.34	0.88	0.59	3.24	
		average	2.32	1.10	1.00	6.82	19.07	0.52	0.23	1.15	
	<b>MARONI- PETRERA (Freestone et al., 2002)</b>	min	2.12	0.83	0.94	5.20	19.50	0.34	0.10	0.20	
		MAX	2.80	1.58	1.45	8.70	20.50	0.67	0.54	2.22	
		average	2.39	1.20	1.13	6.86	20.00	0.50	0.24	1.11	
	<b>GANZIRRI (Arletti et al., 2010a)</b>	min	3.10	1.69	1.07	5.67	15.90	0.41	0.49	1.77	
		MAX	3.87	3.69	1.41	6.70	18.60	0.78	0.59	2.36	
		average	3.47	2.25	1.26	6.12	17.40	0.63	0.54	2.03	
	<b>BRITAIN (Foster and Jackson, 2009)</b>	min	1.53	0.47	0.42	3.89	15.56	0.28	0.09	0.55	
		MAX	3.42	2.28	1.53	7.96	22.87	0.91	0.72	3.04	
		average	2.34	0.95	0.84	6.03	19.46	0.55	0.19	1.24	
	<b>GALEATA (Arletti et al., 2010b)</b>	min	1.99	0.35	0.96	6.61	16.68	0.39	0.06	0.14	
		MAX	2.63	1.08	1.58	7.54	22.65	0.75	0.15	2.15	
		average	2.37	0.77	1.30	7.03	19.96	0.50	0.12	1.29	
	<b>AUGUSTA PRAETORIA (Mirti et al., 1993)</b>	min	2.18	0.40	0.81	5.21	16.27	0.67	0.39	1.81	
		MAX	3.28	2.29	1.27	6.38	20.47	1.92	0.79	2.52	
		average	2.55	1.51	1.02	5.67	17.44	0.94	0.56	2.09	
	<b>SLOVENIA (Šmit et al., 2013)</b>	min	2.42	1.38	0.92	5.75	17.00	0.48	0.46	1.76	
		MAX	2.91	1.58	1.23	6.27	18.70	0.67	0.52	2.12	
		average	2.68	1.48	1.08	6.09	17.80	0.58	0.49	1.98	
				Al <sub>2</sub> O <sub>3</sub>	FeO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	TiO <sub>2</sub>	MnO
	<b>LEVANTINE I</b>	<b>BUTRINT, this study</b>	min	1.54	0.30	0.43	6.68	14.18	0.31	0.05	0.02
			MAX	2.91	1.28	0.66	8.90	20.74	1.03	0.08	1.71
average			2.52	0.46	0.55	7.85	16.46	0.67	0.07	0.56	
<b>PETRA (Schibille et al., 2008)</b>		min	2.25	0.39	0.38	7.52	13.40	0.58	0.07	0.11	
		MAX	3.06	0.64	4.45	10.98	19.98	1.78	0.11	0.80	
		average	2.85	0.49	0.70	9.13	15.24	0.96	0.09	0.28	
<b>MARONI- PETRERA (Freestone et al., 2002)</b>		min	2.65	0.32	0.63	6.30	15.10	0.36	0.10	0.10	
		MAX	3.23	0.61	1.08	11.00	19.90	0.79	0.21	1.13	
		average	2.97	0.46	0.81	8.54	16.69	0.60	0.12	0.17	
<b>BRITAIN (Foster and Jackson, 2009)</b>		min	2.30	0.29	0.36	7.12	12.94	0.43	0.05	0.02	
		MAX	3.42	0.64	0.95	9.59	16.79	0.92	0.10	2.10	
		average	2.85	0.39	0.55	8.48	15.22	0.64	0.06	0.85	

Table2

	HIMT1			HIMT2		
	Foster and Jackson, 2009			Foster and Jackson, 2009		
	min	max	average	min	max	average
<b>FeO%</b>	0.90	2.28	1.36	0.47	1.02	0.72
<b>TiO<sub>2</sub>%</b>	0.11	0.72	0.33	0.09	0.22	0.12
<b>MnO%</b>	0.81	3.04	1.71	0.55	1.47	0.98

Table3

Sample	Area	Description	Typology	Form dating	Matrix dating	References
BT2	16	Cullet			5 <sup>th</sup> – 6 <sup>th</sup> century AD	
BT3	16	Cullet			4 <sup>th</sup> century AD	
BT4	16	Bottom of stemmed beaker	Goblet Isings 111	From the 5 <sup>th</sup> century AD onwards	5 <sup>th</sup> century AD	Isings, 1957, form 111; Stevenson, 2001, p. 236, fig. 7:66
BT5	16	Rim of bowl with a thick thread of the same colour	Bowl Jennings, 2004-2005, fig. 5.20, n.7	5 <sup>th</sup> century AD	5 <sup>th</sup> century AD	Glençler, 2003, pag. 719, fig. 35.18 (3 <sup>rd</sup> century); Jennings, 2004-2005, fig. 5.20, n.7 (5 <sup>th</sup> century)
BT6	16	Bottom of hanging lamp with hollow stem	Hanging lamp Uboldi, 1995, IV.2	end of 5 <sup>th</sup> – 6 <sup>th</sup> century AD	5 <sup>th</sup> – 6 <sup>th</sup> century AD	Tabaczynska, 1977, fig. 113, n.23 (context dated at 4 <sup>th</sup> century); Saguì, 1993, fig. 9, n.84 (6 <sup>th</sup> century); Uboldi, 1995, type IV.2; Price, 1997, fig. 93, nn. 146-149 (5 <sup>th</sup> century onwards); Glençler, 2003, p. 735, tav. 51 (5 <sup>th</sup> – 6 <sup>th</sup> century AD); Corti, 2012, fig. 6, n. 11 (end 5 <sup>th</sup> – early 6 <sup>th</sup> century)
BT7	16	Bottom of stemmed beaker	Goblet Isings 111	6 <sup>th</sup> century AD	10 <sup>th</sup> – 11 <sup>th</sup> century AD with pottery from 4 <sup>th</sup> – 5 <sup>th</sup> century AD and glass from 6 <sup>th</sup> – 7 <sup>th</sup> century AD	Isings 1957, form 111; Foy, 1998, p.131, fig.97, n.190; Falcetti 2001, p. 419, tav. 49, n. 99 (6 <sup>th</sup> century – 7 <sup>th</sup> century)
BT10	17	Cullet			mid-6 <sup>th</sup> century AD	
BT11	17	Rim of beaker or goblet	Beaker or goblet	6 <sup>th</sup> century AD	mid-6 <sup>th</sup> century AD	Falcetti, 2001, p. 429, fig. 53, n. 264 (identified as rim of goblet); Foy, 2004, p. 322, fig. 188, n. 24 (end 6 <sup>th</sup> – 7 <sup>th</sup> century AD); Sternini, 2013, p. 638, fig. 15.4, n. 75 (7 <sup>th</sup> century AD – identified as rim of beaker Is. 106/109)
BT12	17	Bottom of stemmed beaker	Goblet Isings 111	5 <sup>th</sup> - 6 <sup>th</sup> century AD	end of the 6 <sup>th</sup> century AD	Isings, 1957, form 111; Foy, 1995, forme 14, pl. 10, n. 95 (5 <sup>th</sup> century); Dussart, 1998, BIX.1 suite n. 75 (end of 6 <sup>th</sup> century)
BT14	17	Wall in light green glass			mid-6 <sup>th</sup> century AD	
BT15	17	Bottom of bottle with stamp (possible)	Probably bottle		mid-6 <sup>th</sup> century AD	Fadić-Štefanac 2012, fig. 2, n. 17 (similar stamp but more ancient).
BT16	17	Bottom of bowl raised on long foot	Bowl Sternini 1995, fig. 15, n. 203	4 <sup>th</sup> – 5 <sup>th</sup> century AD	4 <sup>th</sup> century AD	Sternini, 1995, p. 283, fig.15, n. 203 (5 <sup>th</sup> century AD); Glençler, 2003, p. 722, tav. 38, n. 65 (Late Antique period)
BT17	17	Bottom of stemmed beaker	Goblet Isings 111	from the 6 <sup>th</sup> century AD		Isings, 1957, form 111; Foy, 1998, p. 130, fig. 86, n.183 (6 <sup>th</sup> century AD); Dussart. 1998, BIX.1 suite n. 3 (with byzantine pottery)

<b>BT19</b>	16	Cullet				
<b>BT21</b>	16	Wall in green glass				
<b>BT22</b>	16	Wall in amber glass			5 <sup>th</sup> – 6 <sup>th</sup> century AD	
<b>BT27</b>	16	Wall in yellowish glass			4 <sup>th</sup> century AD	
<b>BT28</b>	17	Wall in water green glass			mid-4 <sup>th</sup> century AD	
<b>BT29</b>	17	Probably long twisted stem of goblet	Probably goblet	From the 7 <sup>th</sup> century AD onwards?	mid-6 <sup>th</sup> century AD	Fünfschilling, 2010, fig. 8, pag. 222 (7 <sup>th</sup> century).
<b>BT30</b>	17	Wall in dark blue glass			mid-6 <sup>th</sup> century AD	
<b>BT32</b>	19	Bottom of bowl raised on a long foot	Bowl Foy, 1995, form 10	5 <sup>th</sup> – 6 <sup>th</sup> century AD		Sternini, 1995, p. 283, fig.15, n.205; Foy, 1995, p. 225, pl.7, n. 46 (second half of the 5 <sup>th</sup> century AD)
<b>BT34</b>	16	Wall in light green glass				
<b>BT35</b>	16	Cullet			5 <sup>th</sup> century AD	
<b>BT36 (a)</b>	16	Wall in colourless glass with light blue thread				
<b>BT38</b>	16	Bottom of knobbed goblet	Goblet Isings 111	5 <sup>th</sup> – 7 <sup>th</sup> century AD	end of 6 <sup>th</sup> century AD	Isings 1957, form 111; Falcetti 2001, p. 421, fig. 50, n. 123; Glencler 2003, p. 733, tav. 49 (without knob; 5 <sup>th</sup> – 7 <sup>th</sup> century AD); Gürler-Lafli, p. 134, fig. 10, n. 67 (7 <sup>th</sup> century)
<b>BT39 (a)</b>	17	Rim of bottle with blue thread	Bottle with blue thread	from the 5 <sup>th</sup> century AD onwards	mid-6 <sup>th</sup> century AD	Jennings, 1997-1998, pp. 142-143; Jennings-Abdallah, 2002 p. 7, n. 13
<b>BT40</b>	17	Wall in light green glass			mid-6 <sup>th</sup> century AD	
<b>BT41</b>	17	Wall in blue glass			end of 6 <sup>th</sup> century AD	
<b>BT42</b>	17	Wall in amber glass			mid-6 <sup>th</sup> century AD	
<b>BT43</b>	17	Wall in colourless glass			mid-6 <sup>th</sup> century AD	
<b>BT45</b>	17	Refolded rim of unguentarium	Unguentarium	4 <sup>th</sup> – 6 <sup>th</sup> century AD	mid-6 <sup>th</sup> century AD	Foy, 2010, pag. 480, n. 780 (3rd – 4th century AD)



Table5

Sample	Classification	Sc	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	Rb	Sr	Y	Zr	Nb	Sn	Sb	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	Au	Pb	Th	U
BT15	HIMT1	4.9	2382	30	45	8.5	15	31	23	4.1	5.0	432	8.0	190	3.7	5.5	0.8	292	8.8	16	2.0	8.7	1.8	0.5	1.6	0.3	1.5	0.3	0.9	0.1	1.0	0.1	4.2	0.2	n.d.	53	1.5	1.0
BT21		3.7	895	35	19	16	25	81	39	3.6	9.1	731	8.3	73	2.2	62	120	320	10.0	14	2.1	9.3	1.9	0.5	1.8	0.3	1.7	0.4	1.0	0.1	1.0	0.1	2.2	0.2	0.08	773	1.3	1.1
BT32		3.3	1250	28	23	7.8	14	16	23	3.5	4.8	539	6.7	91	2.4	1.0	0.7	456	7.8	13	1.7	7.7	1.6	0.4	1.5	0.2	1.4	0.3	0.8	0.1	0.8	0.1	2.8	0.2	n.d.	9.0	1.2	1.2
BT35		6.4	1493	28	30	6.9	12	20	25	6.3	4.3	446	7.0	129	2.8	2.7	0.3	312	7.9	13	1.7	7.2	1.5	0.4	1.4	0.2	1.4	0.3	0.8	0.1	0.8	0.1	3.3	0.2	n.d.	8.0	1.3	1.1
BT40		8.4	1312	25	29	5.5	10	38	17	6.2	7.4	472	7.9	118	2.6	2.4	19	235	8.6	13	1.8	7.4	1.5	0.5	1.4	0.2	1.5	0.3	0.9	0.1	0.9	0.1	3.0	0.2	n.d.	52	1.2	0.9
BT42		9.7	3044	39	66	14	11	42	23	7.7	5.7	491	12	275	5.5	9.1	2.7	297	13.0	33	2.9	12	2.5	0.6	2.3	0.4	2.3	0.5	1.3	0.2	1.4	0.2	6.7	0.4	0.01	50	2.3	1.4
BT39a	HIT	9.9	2498	32	56	1 617	81	1 985	67	9.8	5.2	375	8.5	204	4.3	51	2.3	126	8.8	15	1.9	8.1	1.7	0.5	1.5	0.3	1.6	0.3	1.0	0.1	1.0	0.2	5.2	0.3	0.01	2 886	1.7	1.4
BT41		8.3	1779	32	37	875	91	1 351	43	11	7.0	650	8.4	154	3.8	30	34	199	9.1	16	2.0	8.0	1.7	0.5	1.5	0.3	1.6	0.3	0.9	0.1	1.0	0.1	3.9	0.2	0.01	929	1.7	1.5
BT45		9.0	2563	33	57	1 631	81	1 911	69	9.9	5.6	391	8.7	206	4.4	53	2.4	129	8.8	16	2.0	8.1	1.7	0.5	1.5	0.3	1.6	0.3	1.0	0.1	1.0	0.2	5.2	0.3	n.d.	2 772	1.7	1.4
BT2	HIMT2	3.9	712	30	13	7.2	8.8	37	16	2.8	5.1	716	6.4	56	1.7	12	53	367	6.9	11	1.5	6.6	1.4	0.4	1.3	0.2	1.2	0.3	0.7	0.1	0.7	0.1	1.6	0.1	0.01	66	0.9	0.9
BT4		3.7	583	20	12	4.2	8.1	22	11	2.7	5.4	503	5.5	53	1.5	0.9	5.6	284	5.9	9.7	1.3	5.7	1.2	0.3	1.1	0.2	1.0	0.2	0.6	0.1	0.6	0.1	1.5	0.1	n.d.	18	0.8	1.0
BT6		3.7	797	21	17	491	25	622	32	4.2	5.8	563	6.1	68	1.8	12	2.3	235	6.4	11	1.4	6.2	1.3	0.3	1.2	0.2	1.1	0.2	0.6	0.1	0.7	0.1	1.9	0.1	n.d.	647	1.0	0.9
BT7		3.6	660	23	12	5.5	8.3	46	16	2.9	6.2	648	6.3	57	1.8	9.0	54	302	6.9	11	1.5	6.7	1.4	0.3	1.2	0.2	1.2	0.2	0.7	0.08	0.7	0.08	1.6	0.1	n.d.	43	0.9	1.0
BT11		3.3	582	24	12	6.4	9.2	28	16	2.9	6.1	547	6.1	52	1.5	4.8	2.8	294	6.6	11	1.4	6.3	1.3	0.4	1.2	0.2	1.1	0.2	0.6	0.1	0.7	0.1	1.4	0.1	n.d.	39	0.8	1.0
BT12		3.7	677	25	13	7.1	13	34	18	3.3	8.0	598	6.8	58	1.8	3.7	73	305	7.7	12	1.7	7.3	1.5	0.4	1.4	0.2	1.3	0.3	0.7	0.1	0.7	0.1	1.6	0.1	n.d.	98	1.0	0.7
BT17		3.2	738	23	15	6.1	9.3	53	26	3.0	6.7	691	6.3	61	1.8	13	34	273	7.0	11	1.5	6.6	1.4	0.4	1.2	0.2	1.1	0.3	0.6	0.09	0.6	0.1	1.6	0.1	0.01	139	0.9	0.8
BT19		3.8	767	23	15	6.0	10	40	19	3.2	6.9	660	6.2	63	1.9	4.0	105	341	6.9	11	1.5	6.5	1.4	0.4	1.2	0.2	1.2	0.3	0.7	0.09	0.7	0.1	1.8	0.1	0.01	48	1.0	0.9
BT22		2.8	510	18	9.8	4.4	6.8	25	14	2.4	4.8	590	5.9	46	1.3	0.8	9.1	294	6.3	10	1.4	6.0	1.2	0.3	1.2	0.2	1.2	0.2	0.6	0.09	0.6	0.1	1.4	0.1	n.d.	7.0	0.8	1.1
BT30		3.4	1262	28	24	8.0	14	16	23	3.5	4.8	548	6.6	91	2.5	1.0	0.8	471	8.0	14	1.8	7.7	1.6	0.4	1.5	0.2	1.4	0.3	0.8	0.1	0.8	0.1	2.8	0.2	n.d.	9.0	1.3	1.2
BT34		6.5	782	27	16	9.7	14	64	31	6.0	9.4	583	6.3	64	2.4	10	68	266	7.8	13	1.6	6.8	1.4	0.4	1.2	0.2	1.2	0.2	0.7	0.1	0.7	0.1	1.7	0.1	0.01	118	1.4	0.9
BT38		5.8	706	32	14	9.5	16	45	22	6.9	8.4	604	7.3	61	2.0	4.3	117	366	8.4	13	1.8	7.5	1.6	0.4	1.4	0.2	1.4	0.3	0.8	0.1	0.8	0.1	1.6	0.1	0.01	68	1.1	0.8
BT3		Levantine I	3.4	353	5.9	11	1.9	3.2	14	6.2	2.8	13	419	5.5	31	0.9	74	1.5	220	5.5	10	1.2	5.5	1.1	0.4	1.1	0.2	1.0	0.2	0.5	0.08	0.5	0.08	0.9	0.06	n.d.	207	0.6
BT5	3.3		296	5.7	13	1.1	3.4	5.0	38	3.3	14	393	4.3	22	0.9	1.1	0.3	190	4.7	10	1.1	4.7	0.9	0.3	0.9	0.1	0.8	0.2	0.4	0.06	0.4	0.06	0.6	0.06	n.d.	11	0.5	0.5
BT10	3.2		385	49	11	8.1	13	10	15	3.2	5.7	464	5.9	33	1.1	2.2	216	440	5.8	9.8	1.3	5.7	1.2	0.3	1.1	0.2	1.0	0.2	0.6	0.08	0.6	0.08	0.9	0.07	n.d.	15	0.7	0.6
BT14	2.8		352	11	11	4.2	7.1	7.1	12	3.1	7.4	498	6.2	32	1.1	2.4	239	256	6.3	11	1.4	6.2	1.3	0.4	1.2	0.2	1.1	0.2	0.6	0.09	0.6	0.09	0.9	0.06	n.d.	45	0.7	0.7
BT16	3.1		566	13	12	5.5	9.0	21	14	2.8	4.9	517	5.3	44	1.4	1.7	2.3	256	6.0	10	1.3	5.8	1.2	0.3	1.1	0.2	1.0	0.2	0.5	0.08	0.6	0.08	1.2	0.09	0.01	16	0.7	0.7
BT27	2.4		357	19	11	8.8	14	11	20	2.8	7.0	490	5.8	33	1.0	1.0	12	277	6.1	9.9	1.3	5.9	1.3	0.4	1.2	0.2	1.1	0.2	0.6	0.09	0.6	0.1	1.1	0.08	n.d.	7.0	0.8	0.7
BT36	5.1		289	7	11	1.0	3.3	3.4	7.9	5.1	9.5	342	4.0	22	0.9	0.5	0.1	209	4.6	9.8	1.1	4.3	0.9	0.3	0.7	0.1	0.7	0.1	0.4	0.06	0.4	0.05	0.6	0.05	n.d.	5.0	0.5	0.5
BT36a	5.3		355	8.8	11	293	103	1 431	28	7.8	9.9	392	5.5	30	1.1	199	18	231	5.7	10	1.3	5.4	1.1	0.3	1.0	0.2	1.0	0.2	0.5	0.08	0.5	0.08	0.8	0.07	0.01	7 689	0.7	0.6
BT39	6.8		358	17	8.5	3.6	5.4	12	11	4.1	4.8	482	5.8	39	1.1	5.2	0.3	170	6.0	9.3	1.3	5.3	1.1	0.3	1.0	0.2	1.1	0.2	0.6	0.09	0.6	0.09	1.0	0.07	n.d.	27	0.7	0.8
BT43	6.4		386	38	11	7.9	6.3	5.9	11	7.4	7.5	502	7.0	35	1.2	0.4	0.3	326	7.1	12	1.5	6.4	1.3	0.4	1.2	0.2	1.3	0.3	0.7	0.1	0.7	0.1	0.9	0.09	n.d.	4.0	0.8	0.9

Figure1  
[Click here to download high resolution image](#)

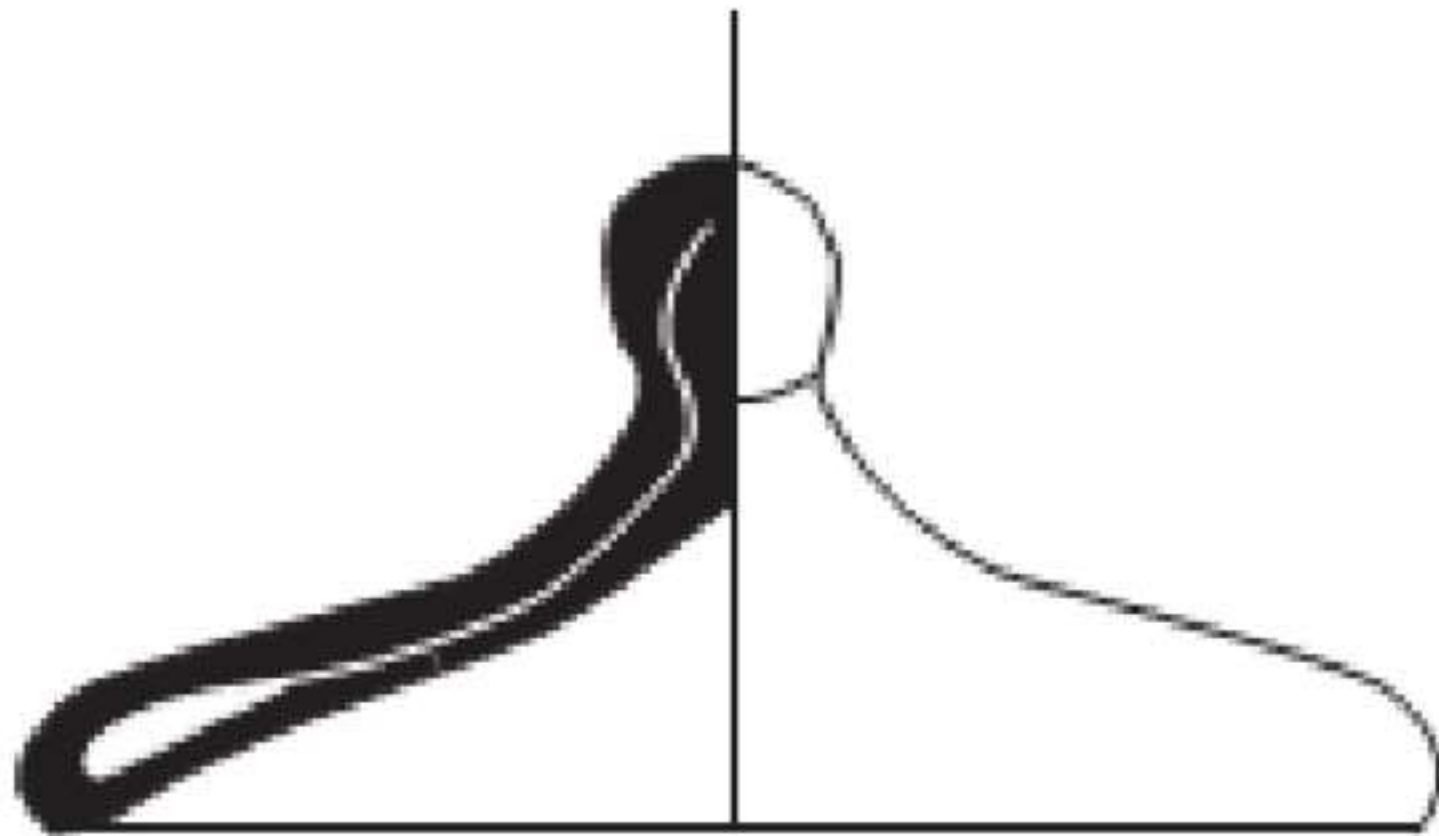


Figure2

[Click here to download high resolution image](#)

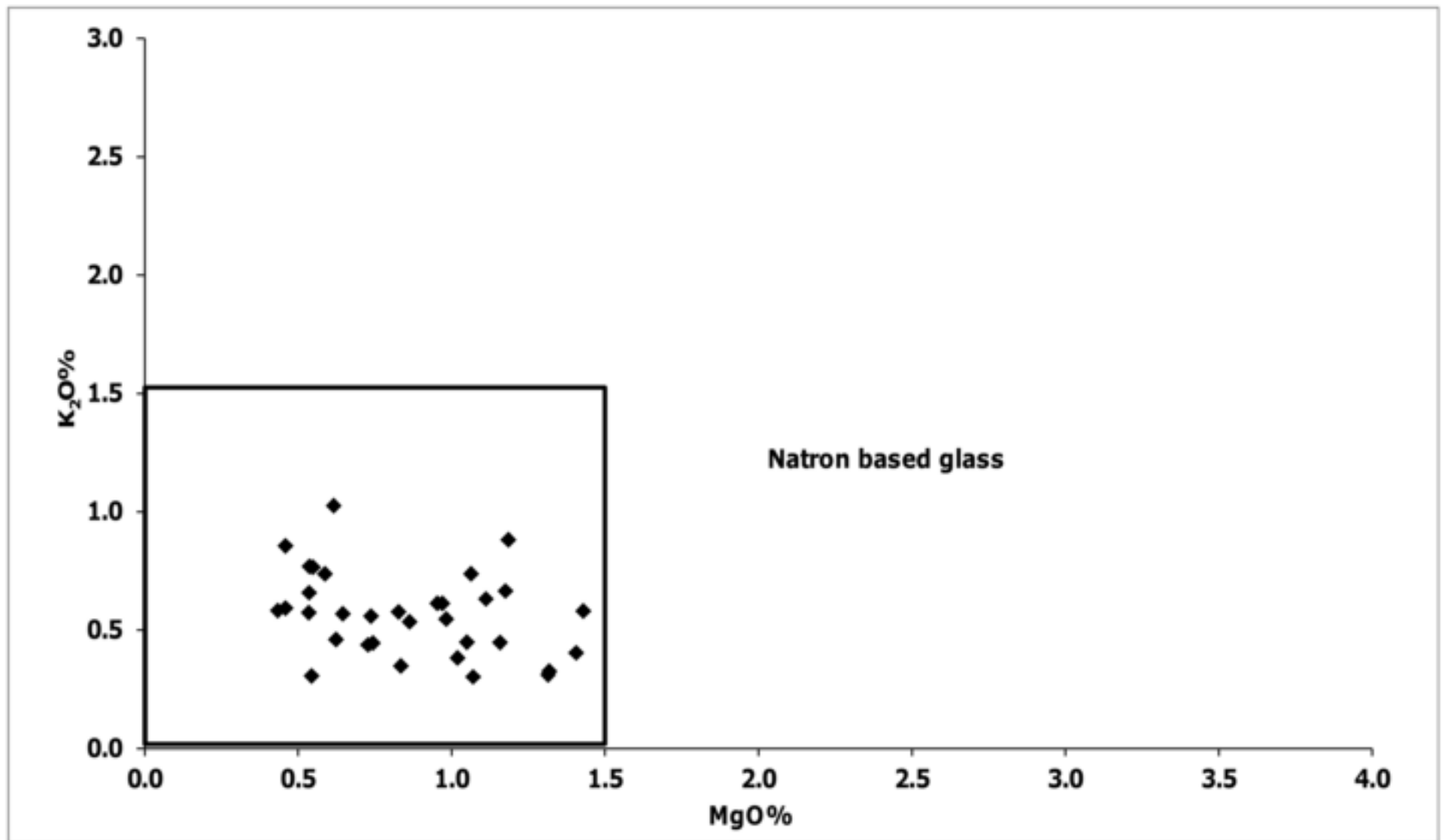


Figure3

[Click here to download high resolution image](#)

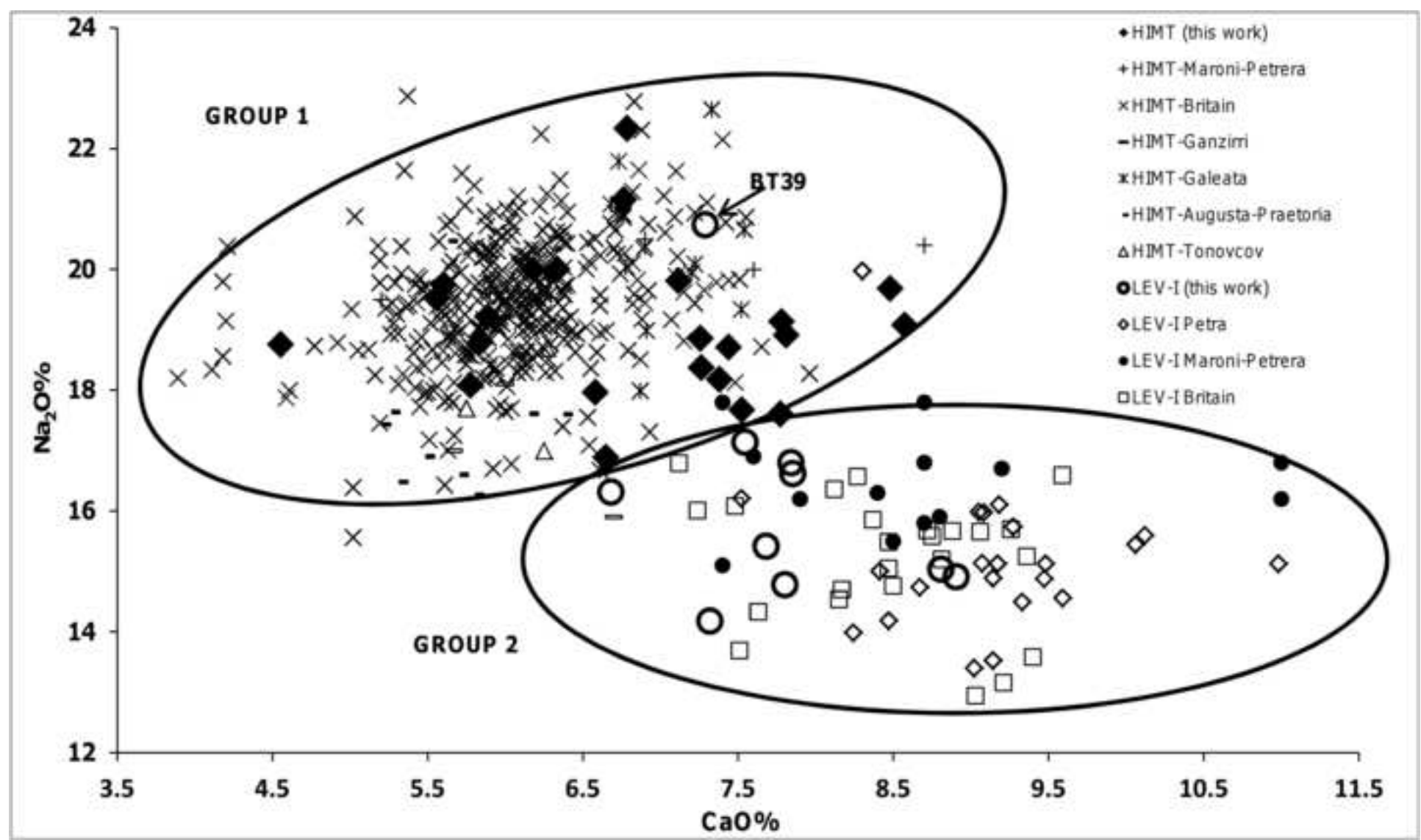


Figure4

[Click here to download high resolution image](#)

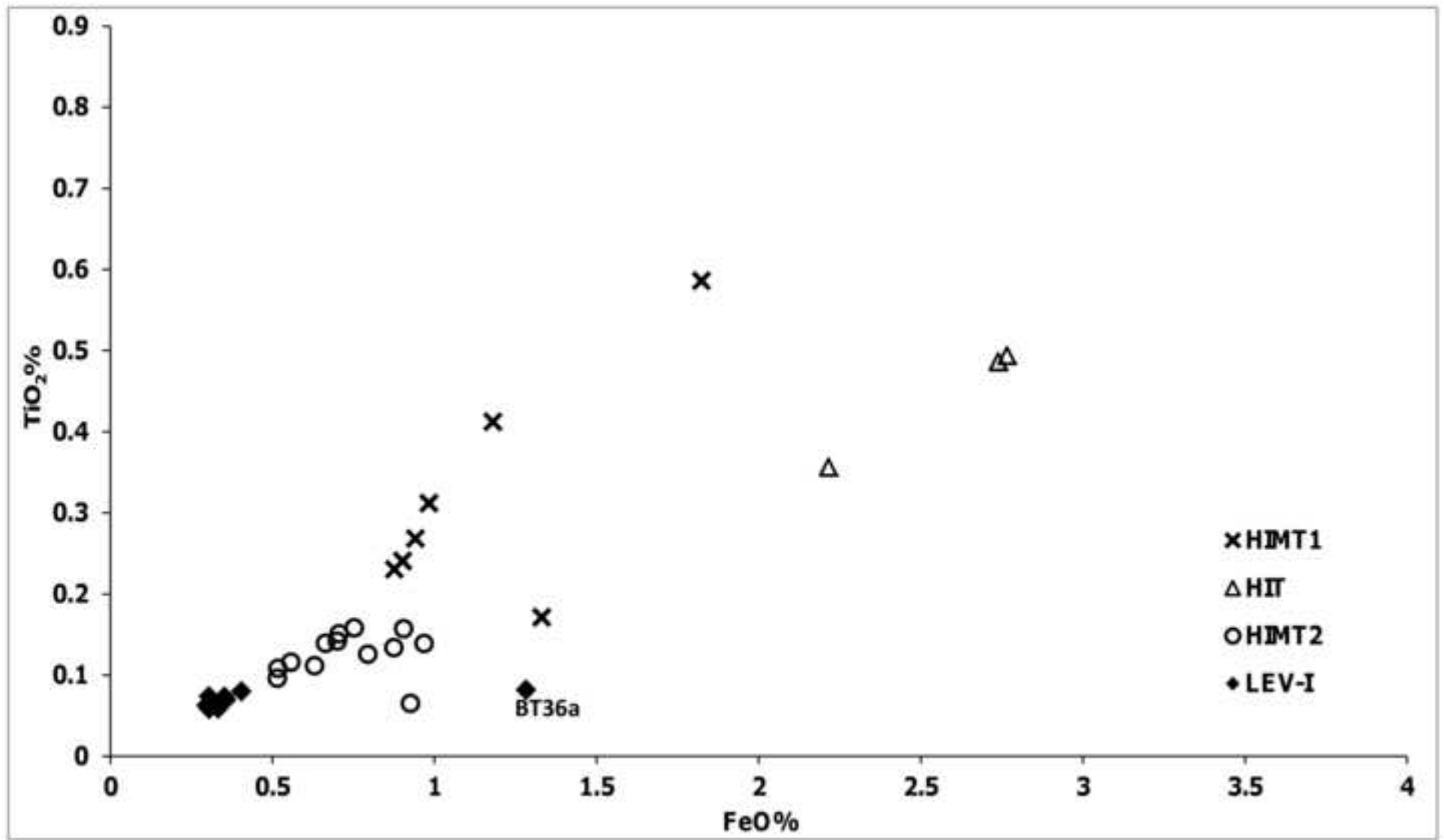


Figure5  
[Click here to download high resolution image](#)

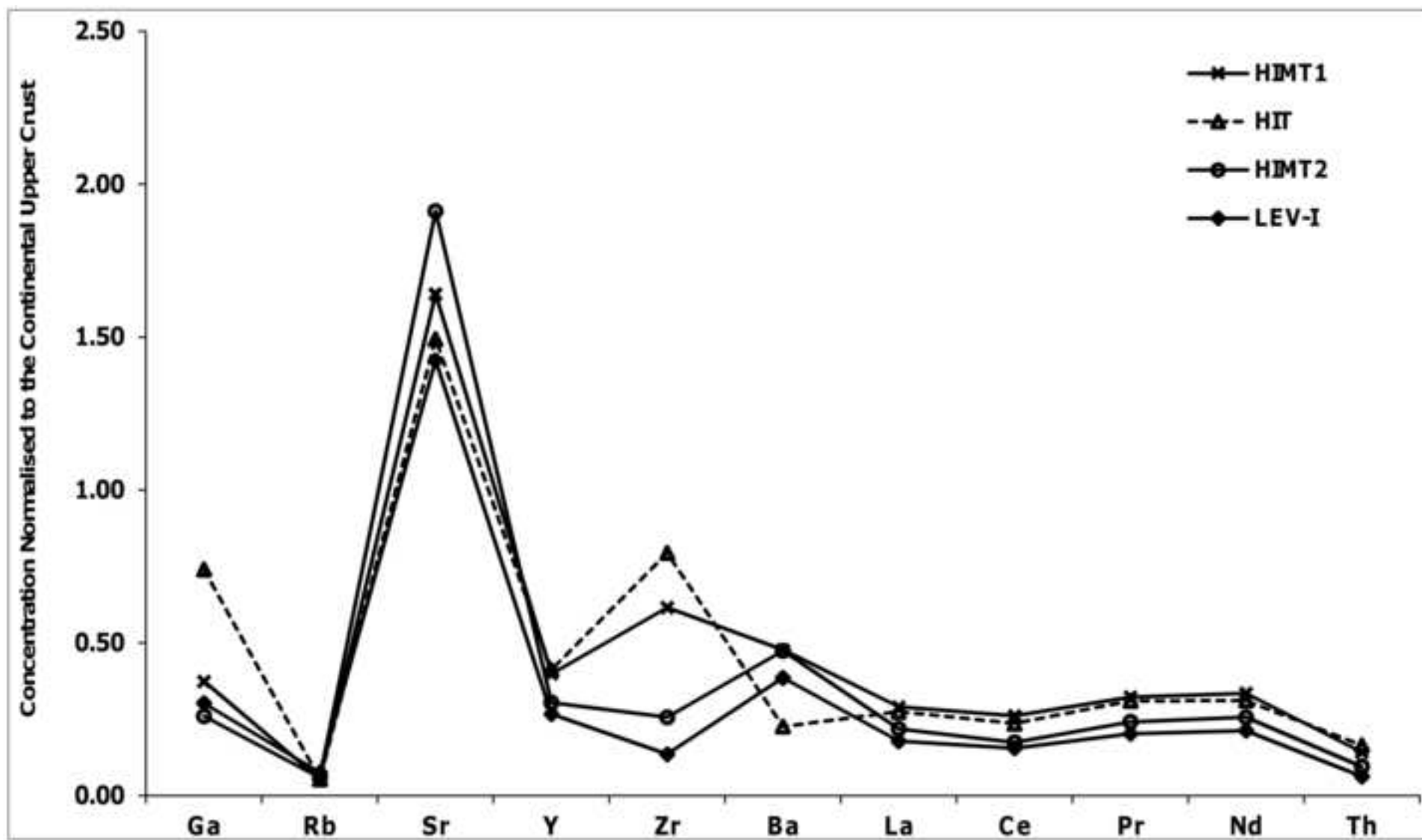


Figure6  
[Click here to download high resolution image](#)

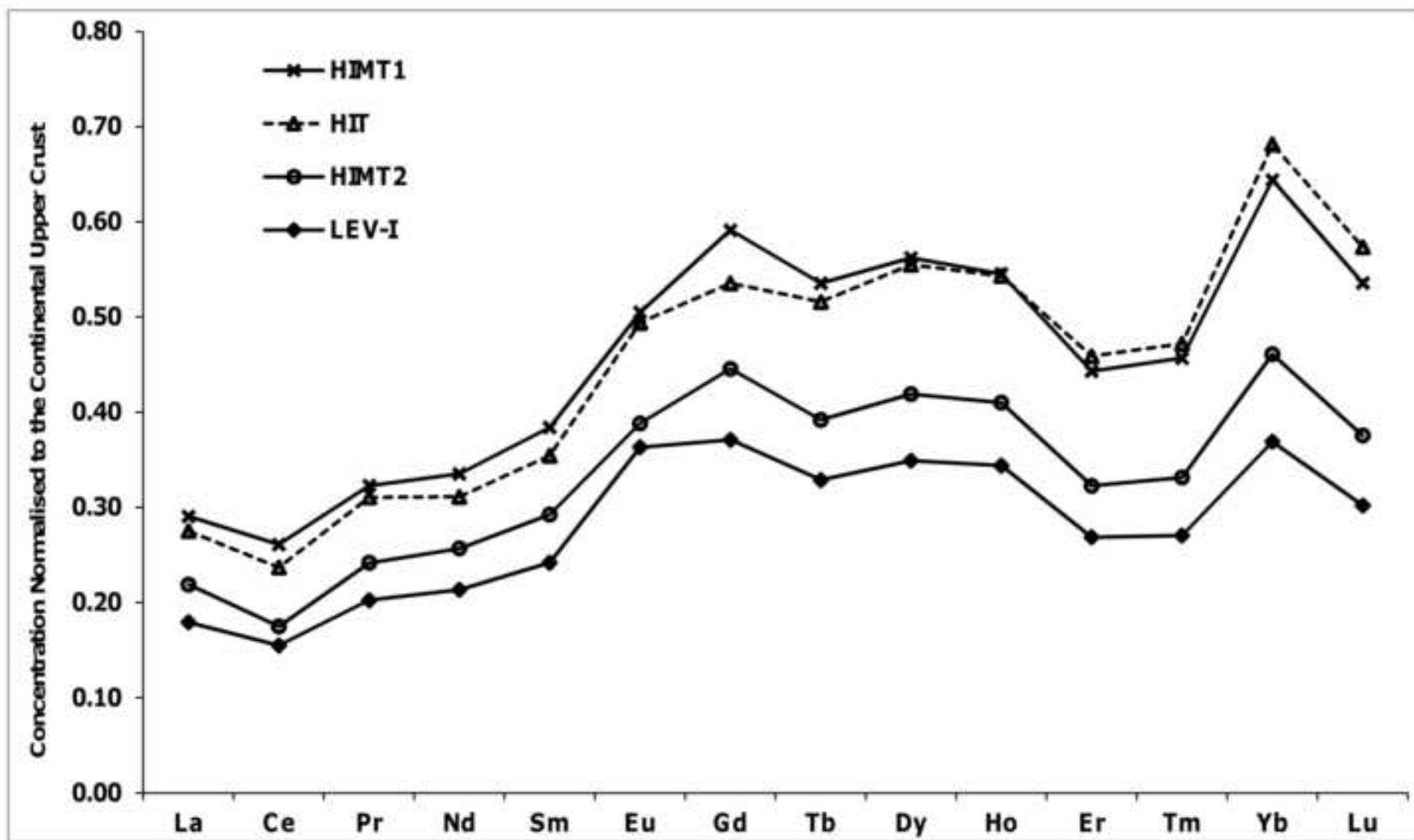


Figure7

[Click here to download high resolution image](#)

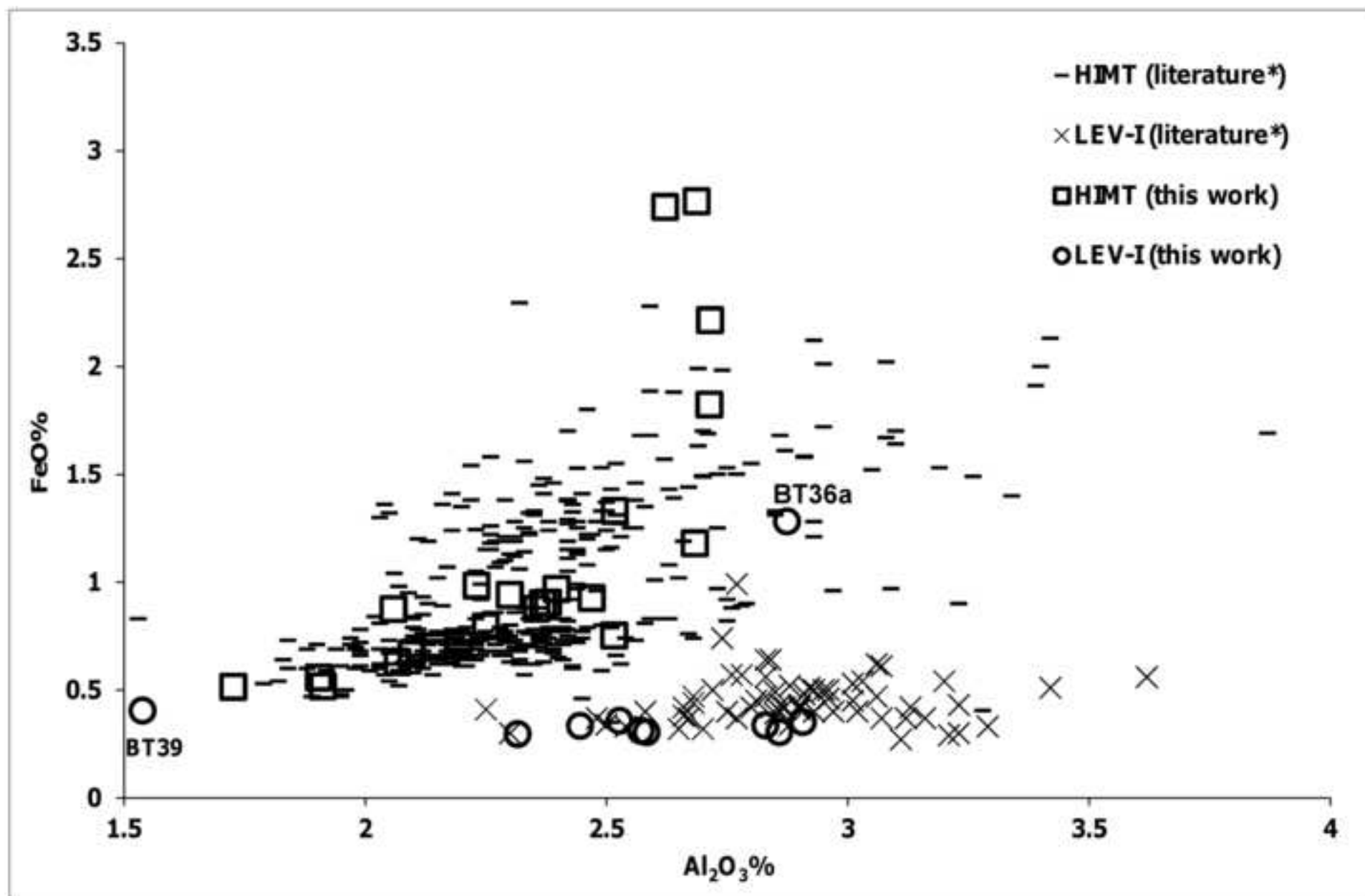


Figure8

[Click here to download high resolution image](#)

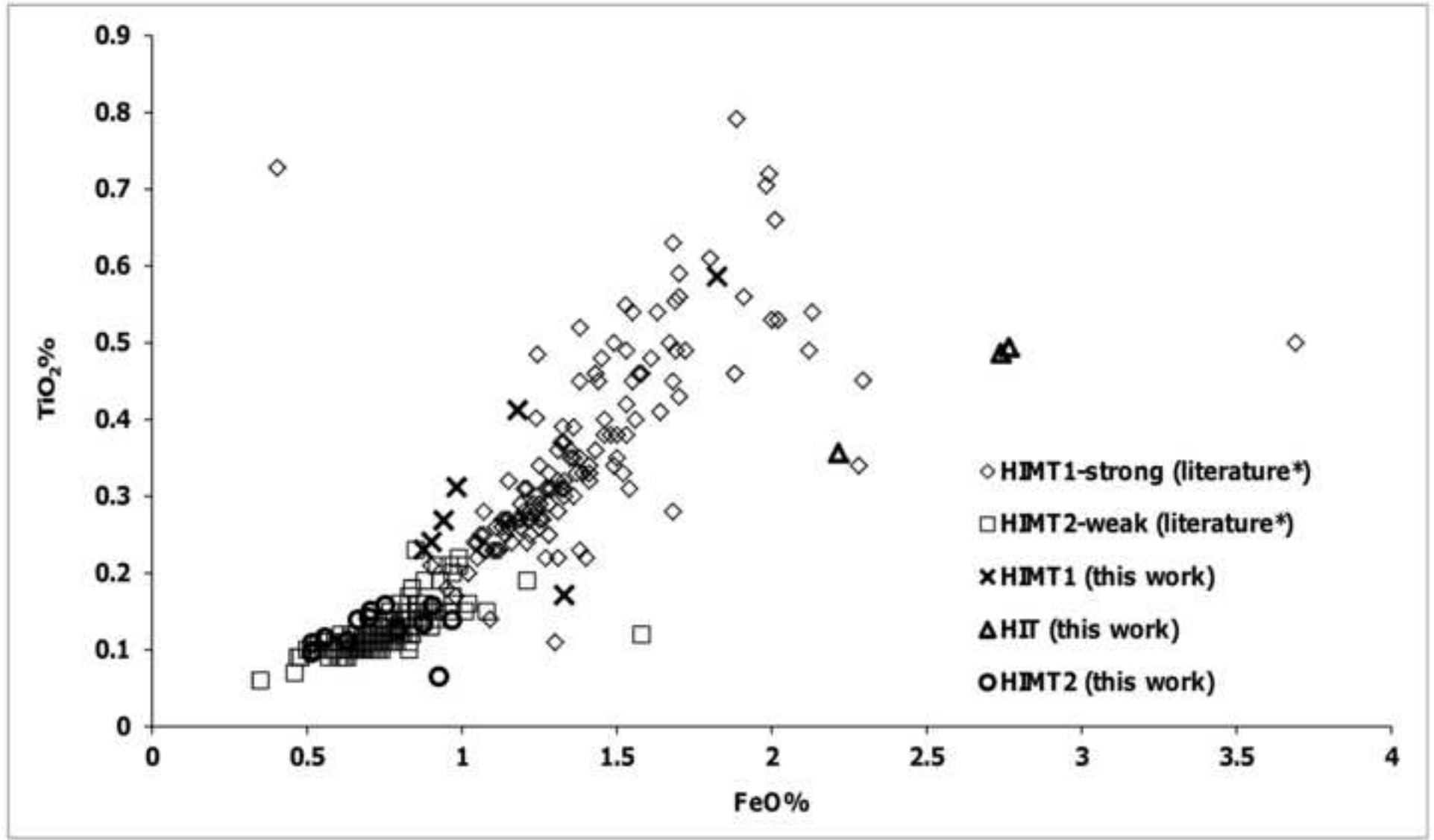


Figure9

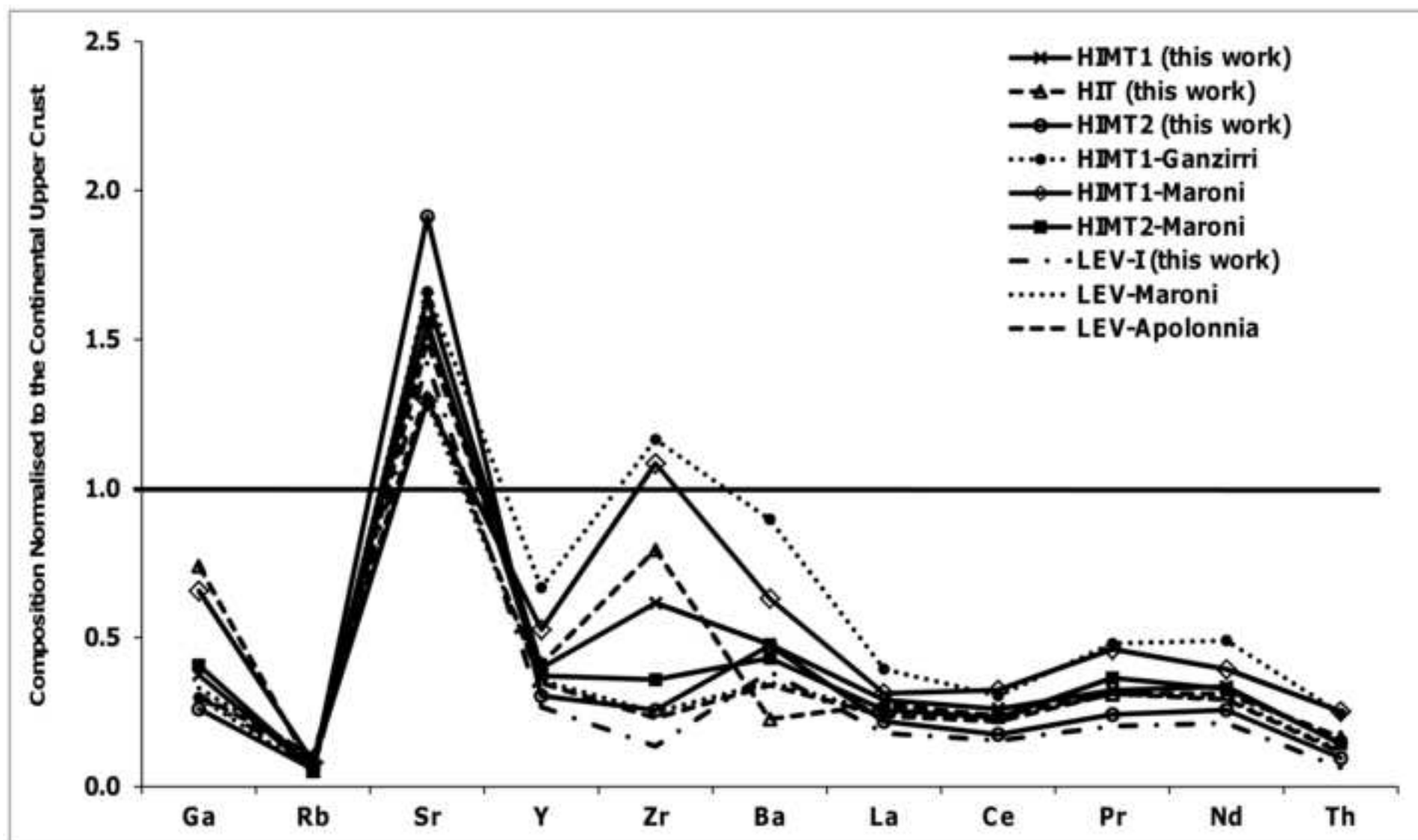
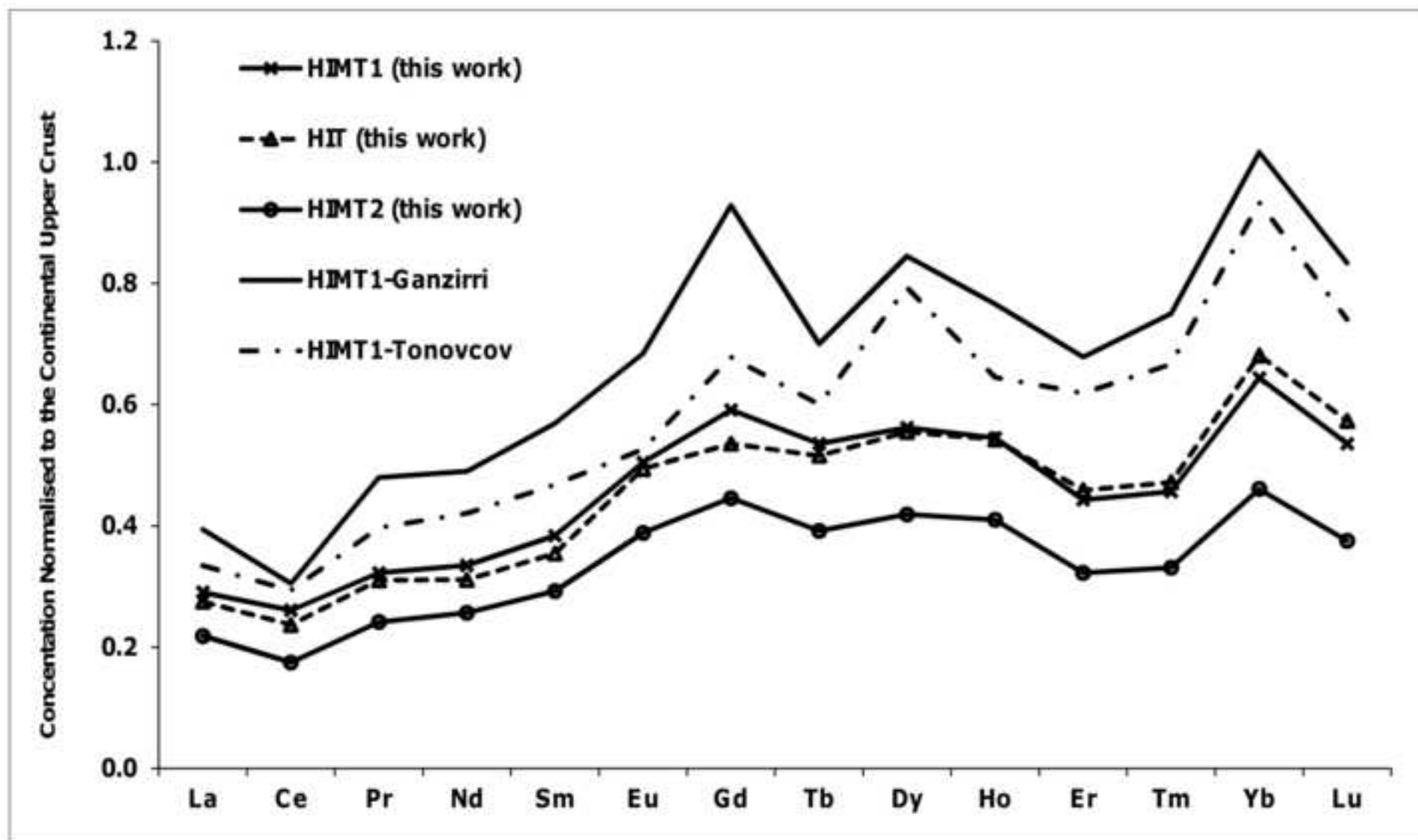
[Click here to download high resolution image](#)

Figure10  
[Click here to download high resolution image](#)



**Supplementary MaterialS1**

[Click here to download Supplementary Material: SupplemataryMaterialS1.docx](#)

**Supplementary MaterialS2**

[Click here to download Supplementary Material: SupplemataryMaterialS2.docx](#)

**Supplementary MaterialS3**

[Click here to download Supplementary Material: SupplemataryMaterialS3.docx](#)