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Chapter 7.

Non-destructive pXRF analysis of Middle Bronze and Iron Age pottery from Malta

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1. Introduction

Trace elemental analysis has played an important role in exploring human movement, trade and interaction in prehistoric societies. Specifically, it has proven useful in determining the provenance of ceramic artefacts by comparing the trace elemental composition between the bulk chemistry of the clay used in pottery productions with the geochemical composition of clay sources (Tykot 2004; 2016). Various instruments used in determining trace elemental compositions of clays such as neutron activation analysis (Mommsen *et al.* 2006), X-ray fluorescence (Barone *et al.* 2015), and hand-held X-ray fluorescence (Pirone 2017) have been employed in studying prehistoric Maltese ceramics.

The use of a portable or hand-held X-ray fluorescence spectrometer (pXRF) is of particular interest because it has become increasingly more popular in ceramic sourcing studies in recent years due to a number of advantages that include the ability to non-destructively analyze ceramic materials on location at museums and the overall affordability in analyzing a large number of artefacts within a relatively short period of time. These advantages are certainly attractive to research archaeologists; however, the heterogeneous nature of ceramic surfaces potentially creates a technical disadvantage in non-destructively analyzing ceramic materials compared to homogenized powder samples. A number of studies have successfully addressed the heterogeneous nature of clay artefacts and have demonstrated methods in non-destructively analyzing only ceramic surfaces (Hunt and Speakman 2015; Speakman *et al.* 2011; Tykot 2016; Tykot *et al.* 2013). Taking into consideration these studies for non-destructively studying ceramic surfaces using a pXRF in the present project, careful attention was given to analyze ceramic surfaces with relatively flat areas and that showed no signs of slip or application of paint or decoration. Additionally, multiple spots on both the inside and outside surfaces of each sherd were analyzed and attention was given in order to avoid analyzing locations where there were visible inclusions.

2. Materials and Methods

The excavations carried out at Qlejgha tal-Baħrija in 1909 (Peet 1910) and 1959 (Trump 1961) produced a large quantity of pottery related to the Late Borġ in-Nadur and Baħrija phases, among which there are certain examples clearly recalling Sicilian and Aegean prototypes (see chapter 3). Alongside the destructive chemical analyses conducted on a limited number of specimens (Tanasi *et al.* in this volume), it was decided to test a larger sample group using a non-destructive technique, which is recently offering more and more reliable results with respect to study of pottery.

For this reason, a total of 274 ceramic samples from the prehistoric site of Qlejgha tal-Baħrija, 270 from Peet's excavation and four from D. H. Trump's 1959 excavation were analyzed using a Bruker Tracer 5*i* pXRF instrument and compared with results obtained for the trace elemental compositions determined for 14 geological clay samples from Għajn Tuffieħa slopes. The group included also a small group of samples from Punic pottery found by Peet, inv. no. 100070-100075 (See Chapter 6). Among the prehistoric samples, there were also two Mycenaean type pottery fragments, BN/P7, found in the Double Chapel of the Borġ in-Nadur temple during Murray's excavations in 1926-1927 (Tanasi 2011,

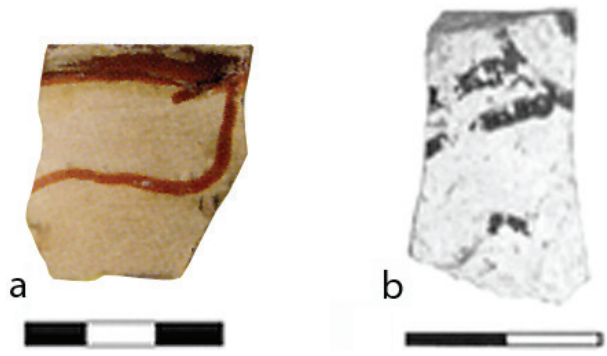

Figure 1. a) LH IIIB kylix fragment BN/P from the Double Chapel of the Borġ in-Nadur temple (Tanasi 2011); b) LHIIIB/IIIC body fragment of a closed shape from Tas-Silġ South (Sagona 2015).

pp. 139-142) (Figure 1a), and 2169/30 found in layer 2169 in Area C (CG3) of the 1995-2005 excavations by the University of Malta excavations at Tas-Silġ South (Vella *et al.* 2015, pp. 80-81; Sagona 2015, pp. 81, 82, fig. 1:121:7; see chapter 3) (Figure 1b). The example from Borġ in-Nadur was already identified as a local production (Pirone and Tykot 2017); there remained the possibility that the other one from Tas-Silġ was actually imported from the Aegean and would, therefore, have functioned as reference to discriminate possible Aegean imports in the group of Baħrija pottery.

The analyses was conducted in summer 2017 at the National Museum of Archaeology, Valletta, on all the Maltese ceramic and geological samples using the setting 50 kV (kilovolts) and 35 μA (microamps) for the primary X-ray beam, and using a filter (12 mil Al + 1 mil Ti + 6 mil Cu) which for the secondary X-rays coming back from the sample removes much of the background thereby providing greater precision and sensitivity for trace elements rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), and niobium (Nb). The Bruker Tracer 5i was positioned upright and the samples carefully balanced on top of the collimator. Both the inner and outer surfaces and the edges, whenever possible for each of the ceramic samples, were analyzed for 45 seconds (Tykot *et al.* 2013). Quantitative values in ppm for each trace element were obtained by calibrating the raw data using the Bruker 5*i* calibration software package. The calibrated values obtained for each of the trace elements were then averaged for each sample (Table 1) and statistically analyzed using

Site	Sample	Context	USF#	Fe	Rb	Sr	Y	Zr	Nb
Borġ in-Nadur temple	BN/P7	1926-1927 excavation	31999	1.53	56	182	12	65	-2
Tas-Silġ South	2169/30	1995-2003 excavation	32000	1.28	40	184	12	69	0
Qlejgha tal-Baħrija	100034a	1909 excavation	32001	1.47	29	194	13	99	6
Qlejgha tal-Baħrija	100034b	1909 excavation	32002	1.50	33	176	12	92	5
Qlejgha tal-Baħrija	100034c	1909 excavation	32003	1.52	34	202	12	81	3
Qlejgha tal-Baħrija	100034d	1909 excavation	32004	1.47	25	179	11	96	4
Qlejgha tal-Baħrija	100034e	1909 excavation	32005	1.49	42	253	13	92	4
Qlejgha tal-Baħrija	100034f	1909 excavation	32006	1.76	31	272	13	112	8
Qlejgha tal-Baħrija	100034g	1909 excavation	32007	1.61	39	242	13	101	5
Qlejgha tal-Baħrija	100034h	1909 excavation	32008	1.75	45	167	13	90	5
Qlejgha tal-Baħrija	100034i	1909 excavation	32009	1.55	36	264	13	86	6
Qlejgha tal-Baħrija	100034j	1909 excavation	32010	1.59	41	199	13	88	4
Qlejgha tal-Baħrija	100034k	1909 excavation	32011	1.93	38	197	12	82	4
Qlejgha tal-Baħrija	100034l	1909 excavation	32012	1.56	36	223	13	103	7
Qlejgha tal-Baħrija	100034m	1909 excavation	32013	1.92	44	225	13	96	8
Qlejgha tal-Baħrija	100061a	1909 excavation	32014	1.39	21	187	12	91	4
Qlejgha tal-Baħrija	100061b	1909 excavation	32015	1.55	31	317	13	95	6
Qlejgha tal-Baħrija	100061c	1909 excavation	32016	1.78	23	213	12	89	5
Qlejgha tal-Baħrija	100061d	1909 excavation	32017	1.68	52	187	14	88	6
Qlejgha tal-Baħrija	100061e	1909 excavation	32018	1.74	33	182	12	94	5
Qlejgha tal-Baħrija	100061f	1909 excavation	32019	1.46	38	184	13	100	5
Qlejgha tal-Baħrija	100061g	1909 excavation	32020	1.57	41	261	13	90	4
Qlejgha tal-Baħrija	100061h	1909 excavation	32021	1.44	36	241	12	90	4
Qlejgha tal-Baħrija	100061i	1909 excavation	32022	1.41	34	377	12	87	3
Qlejgha tal-Baħrija	100061j	1909 excavation	32023	1.54	16	217	12	100	6

Table 1. Trace Elemental Compositions (ppm) for each sample

Site	Sample	Context	USF#	Fe	Rb	Sr	Y	Zr	Nb
Qlejgha tal-Baħrija	100061k	1909 excavation	32024	1.21	37	182	12	86	3
Qlejgha tal-Baħrija	100061l	1909 excavation	32025	1.39	34	184	12	76	3
Qlejgha tal-Baħrija	100061m	1909 excavation	32026	1.29	27	244	12	90	3
Qlejgha tal-Baħrija	100061n	1909 excavation	32027	1.29	41	246	13	89	4
Qlejgha tal-Baħrija	100035a	1909 excavation	32028	1.72	26	233	12	93	6
Qlejgha tal-Baħrija	100035b	1909 excavation	32029	1.36	26	186	11	78	3
Qlejgha tal-Baħrija	100035c	1909 excavation	32030	1.47	30	179	12	98	8
Qlejgha tal-Baħrija	100035d	1909 excavation	32031	1.40	35	216	12	85	4
Qlejgha tal-Baħrija	100035e	1909 excavation	32032	1.31	27	220	11	80	2
Qlejgha tal-Baħrija	100035f	1909 excavation	32033	1.60	31	164	12	87	5
Qlejgha tal-Baħrija	100042a	1909 excavation	32034	1.58	40	237	12	86	5
Qlejgha tal-Baħrija	100042b	1909 excavation	32035	1.33	27	227	12	83	4
Qlejgha tal-Baħrija	100042c	1909 excavation	32036	1.32	30	262	12	86	4
Qlejgha tal-Baħrija	100042d	1909 excavation	32037	1.79	32	172	12	89	6
Qlejgha tal-Baħrija	100042e	1909 excavation	32038	1.61	35	157	13	101	6
Qlejgha tal-Baħrija	100042f	1909 excavation	32039	1.49	32	186	12	92	5
Qlejgha tal-Baħrija	100042g	1909 excavation	32040	1.74	38	254	12	98	5
Qlejgha tal-Baħrija	100042h	1909 excavation	32041	1.33	33	180	12	80	2
Qlejgha tal-Baħrija	100042i	1909 excavation	32042	1.53	39	182	12	86	6
Qlejgha tal-Baħrija	100042j	1909 excavation	32043	1.32	37	259	12	95	4
Qlejgha tal-Baħrija	100042k	1909 excavation	32044	1.56	38	261	12	96	5
Qlejgha tal-Baħrija	100042l	1909 excavation	32045	1.59	30	199	12	88	4
Qlejgha tal-Baħrija	100031a	1909 excavation	32046	1.30	31	178	12	95	3
Qlejgha tal-Baħrija	100031b	1909 excavation	32047	1.67	41	251	13	92	4
Qlejgha tal-Baħrija	100031c	1909 excavation	32048	1.55	41	271	13	99	5
Qlejgha tal-Baħrija	100031d	1909 excavation	32049	1.51	43	257	13	93	5
Qlejgha tal-Baħrija	100031e	1909 excavation	32050	1.13	27	196	12	82	3
Qlejgha tal-Baħrija	100031f	1909 excavation	32051	1.55	45	213	13	85	5
Qlejgha tal-Baħrija	100031g	1909 excavation	32052	1.65	44	275	13	95	5
Qlejgha tal-Baħrija	100040a	1909 excavation	32053	1.68	22	253	12	94	6
Qlejgha tal-Baħrija	100040b	1909 excavation	32054	1.56	39	194	12	89	4
Qlejgha tal-Baħrija	100040c	1909 excavation	32055	1.66	32	249	13	90	4
Qlejgha tal-Baħrija	100040d	1909 excavation	32056	1.71	44	238	13	93	5
Qlejgha tal-Baħrija	100040e	1909 excavation	32057	1.63	42	284	13	93	5
Qlejgha tal-Baħrija	100040f	1909 excavation	32058	1.50	35	238	13	97	5
Qlejgha tal-Baħrija	100040g	1909 excavation	32059	1.19	25	215	11	81	4
Qlejgha tal-Baħrija	100040h	1909 excavation	32060	1.19	32	206	12	78	3

Table 1. Continued.

Site	Sample	Context	USF#	Fe	Rb	Sr	Y	Zr	Nb
Qlejgha tal-Baħrija	100040i	1909 excavation	32061	1.68	24	286	12	96	6
Qlejgha tal-Baħrija	100040j	1909 excavation	32062	1.55	38	213	12	87	5
Qlejgha tal-Baħrija	100040k	1909 excavation	32063	1.20	32	254	11	80	3
Qlejgha tal-Baħrija	100040l	1909 excavation	32064	1.41	19	192	12	91	3
Qlejgha tal-Baħrija	100040m	1909 excavation	32065	1.43	38	181	11	76	2
Qlejgha tal-Baħrija	100040n	1909 excavation	32066	1.77	42	260	13	95	6
Qlejgha tal-Baħrija	100040o	1909 excavation	32067	1.71	36	318	13	96	6
Qlejgha tal-Baħrija	100040p	1909 excavation	32068	1.27	26	209	12	79	3
Qlejgha tal-Baħrija	100040q	1909 excavation	32069	1.19	20	274	11	86	3
Qlejgha tal-Baħrija	100039a	1909 excavation	32070	1.72	42	208	13	84	5
Qlejgha tal-Baħrija	100039b	1909 excavation	32071	1.50	44	263	13	93	5
Qlejgha tal-Baħrija	100039c	1909 excavation	32072	1.60	46	260	14	96	6
Qlejgha tal-Baħrija	100039d	1909 excavation	32073	1.38	27	180	12	88	5
Qlejgha tal-Baħrija	100037a	1909 excavation	32074	1.44	32	176	12	88	4
Qlejgha tal-Baħrija	100037b	1909 excavation	32075	1.33	34	222	13	93	5
Qlejgha tal-Baħrija	100041a	1909 excavation	32076	1.49	37	260	13	97	5
Qlejgha tal-Baħrija	100041b	1909 excavation	32077	1.47	41	275	13	82	3
Qlejgha tal-Baħrija	100041c	1909 excavation	32078	1.58	34	234	13	90	6
Qlejgha tal-Baħrija	100041d	1909 excavation	32079	1.28	30	184	11	73	2
Qlejgha tal-Baħrija	100041e	1909 excavation	32080	1.49	33	176	12	87	5
Qlejgha tal-Baħrija	100041f	1909 excavation	32081	1.54	36	168	12	93	5
Qlejgha tal-Baħrija	100041g	1909 excavation	32082	1.48	38	166	12	85	5
Qlejgha tal-Baħrija	100041h	1909 excavation	32083	1.49	22	221	12	95	4
Qlejgha tal-Baħrija	100041i	1909 excavation	32084	2.01	52	210	14	104	7
Qlejgha tal-Baħrija	100041j	1909 excavation	32085	1.34	32	174	13	93	5
Qlejgha tal-Baħrija	100041k	1909 excavation	32086	1.79	23	197	12	95	5
Qlejgha tal-Baħrija	100041l	1909 excavation	32087	1.55	45	225	13	94	5
Qlejgha tal-Baħrija	100041m	1909 excavation	32088	1.36	34	188	12	82	3
Qlejgha tal-Baħrija	100041n	1909 excavation	32089	1.29	35	175	13	89	4
Qlejgha tal-Baħrija	100043a	1909 excavation	32090	1.32	27	179	12	94	4
Qlejgha tal-Baħrija	100043b	1909 excavation	32091	1.32	33	214	12	81	2
Qlejgha tal-Baħrija	100043c	1909 excavation	32092	1.50	37	133	13	106	6
Qlejgha tal-Baħrija	100043d	1909 excavation	32093	1.46	35	212	12	90	4
Qlejgha tal-Baħrija	100043e	1909 excavation	32094	1.46	39	231	12	86	3
Qlejgha tal-Baħrija	100038a	1909 excavation	32095	1.16	33	198	11	83	3
Qlejgha tal-Baħrija	100038b	1909 excavation	32096	1.58	41	170	12	88	4
Qlejgha tal-Baħrija	100038c	1909 excavation	32097	1.34	32	149	12	77	4

Table 1. Continued.

Site	Sample	Context	USF#	Fe	Rb	Sr	Y	Zr	Nb
Qlejgha tal-Baħrija	100038d	1909 excavation	32098	1.29	28	222	12	96	6
Qlejgha tal-Baħrija	100038e	1909 excavation	32099	1.30	40	241	13	90	5
Qlejgha tal-Baħrija	100038f	1909 excavation	32100	1.41	39	250	13	99	5
Qlejgha tal-Baħrija	100038g	1909 excavation	32101	1.59	37	155	12	87	4
Qlejgha tal-Baħrija	100038h	1909 excavation	32102	1.46	42	280	13	106	5
Qlejgha tal-Baħrija	100038i	1909 excavation	32103	1.64	38	265	12	93	5
Qlejgha tal-Baħrija	100038j	1909 excavation	32104	1.36	39	293	13	101	5
Qlejgha tal-Baħrija	100064a	1909 excavation	32105	1.68	45	159	13	86	6
Qlejgha tal-Baħrija	100064b	1909 excavation	32106	1.48	36	197	13	86	4
Qlejgha tal-Baħrija	100064c	1909 excavation	32107	1.62	40	171	12	83	4
Qlejgha tal-Baħrija	100064d	1909 excavation	32108	1.66	33	225	13	89	6
Qlejgha tal-Baħrija	100064e	1909 excavation	32109	0.99	24	153	11	75	2
Qlejgha tal-Baħrija	100064f	1909 excavation	32110	1.48	37	167	12	91	6
Qlejgha tal-Baħrija	100064g	1909 excavation	32111	1.34	33	188	12	88	4
Qlejgha tal-Baħrija	100064h	1909 excavation	32112	1.37	34	192	12	83	4
Qlejgha tal-Baħrija	100064i	1909 excavation	32113	1.64	46	172	13	89	6
Qlejgha tal-Baħrija	100064j	1909 excavation	32114	1.26	34	141	12	80	3
Qlejgha tal-Baħrija	100064k	1909 excavation	32115	1.18	27	235	11	78	1
Qlejgha tal-Baħrija	100064l	1909 excavation	32116	1.64	42	219	13	84	4
Qlejgha tal-Baħrija	100064m	1909 excavation	32117	1.31	38	237	13	95	6
Qlejgha tal-Baħrija	100064n	1909 excavation	32118	1.72	34	247	13	94	6
Qlejgha tal-Baħrija	100064o	1909 excavation	32119	1.26	30	175	12	81	4
Qlejgha tal-Baħrija	100109a	1909 excavation	32120	1.40	19	218	11	88	4
Qlejgha tal-Baħrija	100109b	1909 excavation	32121	1.44	38	243	13	91	5
Qlejgha tal-Baħrija	100052a	1909 excavation	32122	1.50	39	277	13	91	5
Qlejgha tal-Baħrija	100033a	1909 excavation	32123	1.57	28	267	12	89	5
Qlejgha tal-Baħrija	100033b	1909 excavation	32124	1.60	28	160	11	79	4
Qlejgha tal-Baħrija	100033c	1909 excavation	32125	1.26	30	200	12	85	2
Qlejgha tal-Baħrija	100033d	1909 excavation	32126	1.50	43	278	13	98	6
Qlejgha tal-Baħrija	100033e	1909 excavation	32127	1.46	33	207	12	85	5
Qlejgha tal-Baħrija	100033f	1909 excavation	32128	1.54	31	212	12	86	4
Qlejgha tal-Baħrija	100033g	1909 excavation	32129	1.48	30	220	13	92	6
Qlejgha tal-Baħrija	100033h	1909 excavation	32130	1.47	48	242	13	91	6
Qlejgha tal-Baħrija	100033i	1909 excavation	32131	1.62	35	181	12	97	5
Qlejgha tal-Baħrija	100033j	1909 excavation	32132	1.51	40	182	12	85	5
Qlejgha tal-Baħrija	100033k	1909 excavation	32133	1.67	30	191	12	91	6
Qlejgha tal-Baħrija	100033l	1909 excavation	32134	1.57	40	241	13	85	5

Table 1. Continued.

Site	Sample	Context	USF#	Fe	Rb	Sr	Y	Zr	Nb
Qlejgha tal-Baħrija	100033m	1909 excavation	32135	1.29	24	225	11	83	4
Qlejgha tal-Baħrija	100033n	1909 excavation	32136	1.20	24	140	10	69	1
Qlejgha tal-Baħrija	100033o	1909 excavation	32137	1.64	33	203	13	94	5
Qlejgha tal-Baħrija	100036a	1909 excavation	32138	1.29	37	244	12	96	4
Qlejgha tal-Baħrija	100036b	1909 excavation	32139	1.41	40	240	12	85	3
Qlejgha tal-Baħrija	100036c	1909 excavation	32140	1.67	44	216	12	87	6
Qlejgha tal-Baħrija	100036d	1909 excavation	32141	1.23	31	163	11	79	2
Qlejgha tal-Baħrija	100036e	1909 excavation	32142	1.63	39	174	12	95	6
Qlejgha tal-Baħrija	100036f	1909 excavation	32143	1.49	28	188	11	82	4
Qlejgha tal-Baħrija	100032a	1909 excavation	32144	1.42	33	191	13	80	4
Qlejgha tal-Baħrija	100032b	1909 excavation	32145	1.91	33	201	12	85	5
Qlejgha tal-Baħrija	100032c	1909 excavation	32146	1.86	43	250	13	89	5
Qlejgha tal-Baħrija	100032d	1909 excavation	32147	1.72	44	231	13	99	6
Qlejgha tal-Baħrija	100032e	1909 excavation	32148	1.73	40	253	13	92	6
Qlejgha tal-Baħrija	100032f	1909 excavation	32149	1.73	31	211	12	88	5
Qlejgha tal-Baħrija	100032g	1909 excavation	32150	1.51	25	184	11	83	4
Qlejgha tal-Baħrija	100032h	1909 excavation	32151	1.81	22	355	14	114	9
Qlejgha tal-Baħrija	100032i	1909 excavation	32152	1.80	30	189	12	85	4
Qlejgha tal-Baħrija	100032j	1909 excavation	32153	1.62	31	159	12	87	5
Qlejgha tal-Baħrija	100032k	1909 excavation	32154	1.70	36	237	12	92	6
Qlejgha tal-Baħrija	100032l	1909 excavation	32155	1.53	39	201	12	92	5
Qlejgha tal-Baħrija	100032m	1909 excavation	32156	1.62	40	199	13	87	4
Qlejgha tal-Baħrija	100032n	1909 excavation	32157	1.42	35	255	13	98	6
Qlejgha tal-Baħrija	100032o	1909 excavation	32158	1.91	39	129	12	87	6
Qlejgha tal-Baħrija	100060a	1909 excavation	32159	1.38	41	215	12	87	4
Qlejgha tal-Baħrija	100060b	1909 excavation	32160	1.28	40	243	12	92	4
Qlejgha tal-Baħrija	100048a	1909 excavation	32161	0.64	19	163	11	83	1
Qlejgha tal-Baħrija	100048b	1909 excavation	32162	1.58	39	149	13	80	5
Qlejgha tal-Baħrija	100051a	1909 excavation	32163	1.25	31	150	12	90	4
Qlejgha tal-Baħrija	100051b	1909 excavation	32164	1.24	33	166	12	84	3
Qlejgha tal-Baħrija	100051c	1909 excavation	32165	1.41	35	181	12	83	3
Qlejgha tal-Baħrija	100051d	1909 excavation	32166	1.27	26	262	12	90	3
Qlejgha tal-Baħrija	100049a	1909 excavation	32167	1.43	41	228	13	91	5
Qlejgha tal-Baħrija	100053a	1909 excavation	32168	1.58	39	137	13	89	6
Qlejgha tal-Baħrija	100055a	1909 excavation	32169	0.96	29	204	11	75	2
Qlejgha tal-Baħrija	100057a	1909 excavation	32170	1.36	33	221	11	81	3
Qlejgha tal-Baħrija	100058a	1909 excavation	32171	1.49	38	282	12	95	4

Table 1. Continued.

Site	Sample	Context	USF#	Fe	Rb	Sr	Y	Zr	Nb
Qlejgha tal-Baħrija	100086a	1909 excavation	32172	1.84	29	322	13	101	7
Qlejgha tal-Baħrija	100063a	1909 excavation	32173	1.89	41	182	13	98	6
Qlejgha tal-Baħrija	100059a	1909 excavation	32174	1.45	40	262	12	92	5
Qlejgha tal-Baħrija	100025a	1909 excavation	32175	1.01	31	181	11	82	3
Qlejgha tal-Baħrija	100025b	1909 excavation	32176	1.35	27	153	11	79	4
Qlejgha tal-Baħrija	100025c	1909 excavation	32177	1.18	31	223	12	90	3
Qlejgha tal-Baħrija	100022 a	1909 excavation	32178	1.50	33	193	12	102	5
Qlejgha tal-Baħrija	100022 b	1909 excavation	32179	0.96	31	205	12	94	2
Qlejgha tal-Baħrija	100023a	1909 excavation	32180	1.56	33	242	13	108	5
Qlejgha tal-Baħrija	100023b	1909 excavation	32181	1.42	32	169	12	90	4
Qlejgha tal-Baħrija	100026a	1909 excavation	32182	1.71	40	149	13	108	8
Qlejgha tal-Baħrija	100026b	1909 excavation	32183	1.39	39	242	13	101	6
Qlejgha tal-Baħrija	100027a	1909 excavation	32184	1.21	30	203	12	84	4
Qlejgha tal-Baħrija	100027a	1909 excavation	32185	1.29	36	175	12	83	6
Qlejgha tal-Baħrija	100028a	1909 excavation	32186	1.28	25	179	12	88	5
Qlejgha tal-Baħrija	100029a	1909 excavation	32187	1.10	31	274	11	79	2
Qlejgha tal-Baħrija	100096a	1909 excavation	32188	1.61	43	232	13	90	6
Qlejgha tal-Baħrija	100096b	1909 excavation	32189	1.28	26	159	11	85	3
Qlejgha tal-Baħrija	100096c	1909 excavation	32190	1.66	53	235	14	105	7
Qlejgha tal-Baħrija	100096d	1909 excavation	32191	1.72	39	107	13	88	6
Qlejgha tal-Baħrija	100075a	1909 excavation	32192	0.93	27	260	11	84	1
Qlejgha tal-Baħrija	100075b	1909 excavation	32193	1.28	42	194	12	72	3
Qlejgha tal-Baħrija	100075c	1909 excavation	32194	1.33	34	219	12	69	1
Qlejgha tal-Baħrija	100072a	1909 excavation	32195	1.06	31	250	12	78	2
Qlejgha tal-Baħrija	100072b	1909 excavation	32196	1.80	29	281	14	102	6
Qlejgha tal-Baħrija	100072c	1909 excavation	32197	1.87	18	226	13	100	6
Qlejgha tal-Baħrija	100072d	1909 excavation	32198	0.85	15	188	11	73	1
Qlejgha tal-Baħrija	100071a	1909 excavation	32199	1.49	37	214	13	84	4
Qlejgha tal-Baħrija	100071b	1909 excavation	32200	1.58	47	92	14	132	7
Qlejgha tal-Baħrija	100071c	1909 excavation	32201	2.15	22	266	14	109	8
Qlejgha tal-Baħrija	100071d	1909 excavation	32202	1.80	42	268	13	81	3
Qlejgha tal-Baħrija	100070a	1909 excavation	32203	1.12	27	225	11	74	2
Qlejgha tal-Baħrija	100074a	1909 excavation	32204						
Qlejgha tal-Baħrija	100074b	1909 excavation	32205						
Qlejgha tal-Baħrija	100074c	1909 excavation	32206	1.92	64	131	17	72	3
Qlejgha tal-Baħrija	100074d	1909 excavation	32207	1.75	59	117	16	69	3
Qlejgha tal-Baħrija	100056a	1909 excavation	32208	1.55	24	260	13	113	6

Table 1. Continued.

Site	Sample	Context	USF#	Fe	Rb	Sr	Y	Zr	Nb
Qlejgha tal-Baħrija	100073a	1909 excavation	32209	0.71	24	173	10	77	0
Qlejgha tal-Baħrija	100073b	1909 excavation	32210	1.23	35	145	12	99	3
Qlejgha tal-Baħrija	100073c	1909 excavation	32211	1.00	28	160	12	126	3
Qlejgha tal-Baħrija	100073d	1909 excavation	32212	1.20	26	206	12	107	3
Qlejgha tal-Baħrija	100073e	1909 excavation	32213	1.11	31	190	11	81	2
Qlejgha tal-Baħrija	100073f	1909 excavation	32214	1.22	20	377	11	96	3
Qlejgha tal-Baħrija	100073g	1909 excavation	32215	0.96	25	82	10	112	2
Qlejgha tal-Baħrija	100073h	1909 excavation	32216	1.19	28	233	12	84	2
Qlejgha tal-Baħrija	100073i	1909 excavation	32217	1.40	34	434	12	101	4
Qlejgha tal-Baħrija	100073j	1909 excavation	32218	1.84	44	231	14	96	7
Qlejgha tal-Baħrija	100073k	1909 excavation	32219						
Qlejgha tal-Baħrija	100073l	1909 excavation	32220	1.40	44	346	13	89	4
Qlejgha tal-Baħrija	100073m	1909 excavation	32221	1.47	41	235	12	83	4
Qlejgha tal-Baħrija	100073m	1909 excavation	32222	1.19	34	220	13	92	1
Qlejgha tal-Baħrija	100073o	1909 excavation	32223						
Qlejgha tal-Baħrija	100073p	1909 excavation	32224	1.48	42	309	13	114	5
Qlejgha tal-Baħrija	100073q	1909 excavation	32225	1.08	16	156	10	71	0
Qlejgha tal-Baħrija	100073r	1909 excavation	32226	1.32	29	236	12	118	4
Qlejgha tal-Baħrija	100073s	1909 excavation	32227	1.32	34	355	12	85	3
Qlejgha tal-Baħrija	100073t	1909 excavation	32228	1.09	30	399	12	91	2
Qlejgha tal-Baħrija	2761	1909 excavation	32229	1.46	37	208	12	90	3
Qlejgha tal-Baħrija	2763	1909 excavation	32230	1.56	30	164	12	100	4
Qlejgha tal-Baħrija	2756	1909 excavation	32231	1.49	35	238	12	92	3
Qlejgha tal-Baħrija	B/P50	1959 excavation	32232	1.64	38	205	12	98	6
Qlejgha tal-Baħrija	2760	1909 excavation	32233	1.68	35	236	13	98	5
Qlejgha tal-Baħrija	2755	1909 excavation	32234	1.58	30	241	12	104	7
Qlejgha tal-Baħrija	2664	1909 excavation	32235	1.60	19	211	12	104	5
Qlejgha tal-Baħrija	2723	1909 excavation	32236	1.00	25	165	10	69	1
Qlejgha tal-Baħrija	2651	1909 excavation	32237	1.57	38	211	13	90	5
Qlejgha tal-Baħrija	2649	1909 excavation	32238	1.41	37	250	12	90	3
Qlejgha tal-Baħrija	2702	1909 excavation	32239	1.37	36	116	11	70	3
Qlejgha tal-Baħrija	2746	1909 excavation	32240	1.44	40	222	13	100	5
Qlejgha tal-Baħrija	2752	1909 excavation	32241	1.62	41	226	13	89	4
Qlejgha tal-Baħrija	100083b	1909 excavation	32242	1.20	34	213	12	82	4
Qlejgha tal-Baħrija	100085a	1909 excavation	32243	1.28	30	141	11	84	3
Qlejgha tal-Baħrija	100088d	1909 excavation	32244	0.76	35	161	12	93	5
Qlejgha tal-Baħrija	100088b	1909 excavation	32245	1.35	34	286	12	88	3

Table 1. Continued.

Site	Sample	Context	USF#	Fe	Rb	Sr	Y	Zr	Nb
Qlejgha tal-Baħrija	100088a	1909 excavation	32246	1.48	43	165	13	95	6
Qlejgha tal-Baħrija	100084a	1909 excavation	32247	1.40	32	111	12	95	4
Qlejgha tal-Baħrija	100088c	1909 excavation	32248	1.45	32	164	12	91	4
Qlejgha tal-Baħrija	100087c	1909 excavation	32249	1.34	33	193	13	102	7
Qlejgha tal-Baħrija	100087d	1909 excavation	32250	1.75	32	341	13	102	6
Qlejgha tal-Baħrija	2722	1909 excavation	32251	1.43	40	250	12	91	4
Qlejgha tal-Baħrija	2744	1909 excavation	32252	1.52	34	224	12	83	5
Qlejgha tal-Baħrija	2757	1909 excavation	32253	1.68	44	158	12	87	6
Qlejgha tal-Baħrija	4924	1909 excavation	32254	0.85	21	114	10	71	1
Qlejgha tal-Baħrija	2733	1909 excavation	32255	1.51	40	282	13	96	4
Qlejgha tal-Baħrija	2735	1909 excavation	32256	1.77	50	267	14	102	6
Qlejgha tal-Baħrija	2736	1909 excavation	32257	1.70	42	210	14	106	6
Qlejgha tal-Baħrija	2737	1909 excavation	32258	1.82	46	246	13	85	4
Qlejgha tal-Baħrija	2703	1909 excavation	32259	1.49	44	241	12	88	4
Qlejgha tal-Baħrija	2717	1909 excavation	32260	1.64	39	177	12	82	4
Qlejgha tal-Baħrija	B/P64	1959 excavation	32261	1.59	36	205	13	97	6
Qlejgha tal-Baħrija	B/P206	1959 excavation	32262	1.61	33	211	12	85	4
Qlejgha tal-Baħrija	2652	1959 excavation	32263	1.39	33	237	12	93	5
Qlejgha tal-Baħrija	2666	1909 excavation	32264	1.50	29	260	12	106	7
Qlejgha tal-Baħrija	2748	1909 excavation	32265	1.44	34	230	12	89	5
Qlejgha tal-Baħrija	2667	1909 excavation	32266	1.26	32	163	12	82	4
Qlejgha tal-Baħrija	2770	1909 excavation	32267	1.56	45	233	13	87	3
Qlejgha tal-Baħrija	2707	1909 excavation	32268	1.70	45	246	13	87	5
Qlejgha tal-Baħrija	2709	1909 excavation	32269	1.44	41	234	13	82	4
Qlejgha tal-Baħrija	2720	1909 excavation	32270	1.48	39	294	13	92	6
Qlejgha tal-Baħrija	2670	1909 excavation	32271	1.56	36	157	13	84	5
Qlejgha tal-Baħrija	2656	1909 excavation	32272	1.51	41	245	13	92	6
Qlejgha tal-Baħrija	2730	1909 excavation	32273	1.74	24	236	12	90	5
Qlejgha tal-Baħrija	2706	1909 excavation	32274	1.58	35	185	12	84	3
Għajn Tuffieħa slopes	Clay	–	–	1.16	53	290	13	95	5
Għajn Tuffieħa slopes	Clay	–	–	1.01	47	294	12	91	4
Għajn Tuffieħa slopes	Clay	–	–	1.15	52	313	13	88	5
Għajn Tuffieħa slopes	Clay	–	–	0.99	43	243	12	82	3
Għajn Tuffieħa slopes	Clay	–	–	1.30	56	303	13	97	6
Għajn Tuffieħa slopes	Clay	–	–	1.32	55	299	13	97	5
Għajn Tuffieħa slopes	Clay	–	–	0.95	43	282	12	88	3

Table 1. Continued.

principal component analysis (PCA) applying a Direct Oblimin rotation. The IBM SPSS Statistics 25 software package was used to conduct the statistical analysis.

3. Results

The results of the PCA shows that the vast majority of ceramic samples included in this study can be separated into three clusters, A-C. (Figure 2).

The majority of ceramic samples and all the geological clay samples cluster together in group A with the exception of six prehistoric samples (100064e, 100033n, 100048a, 100055a, 2723, 4924) and three Punic samples (100072d, 100073a, 100073q) clustering in group B and two Punic samples (100074c and 100074d) clustering in group C. There is nothing to suggest the potential cluster B and C represent ceramics made from non-local clays. The trace elemental composition of geological Maltese clays varies depending from where within the blue clay horizon the ancient potters extracted their raw clay materials (Pirone 2017). Therefore, they may also represent ceramics made from local Maltese clays from stratigraphic layers that were not sampled and analyzed for the present study. It is known that the calcium carbonate content of the clays varies throughout the Maltese clay formation but generally increases as the clay comes in greater contact with the underlying Globigerina Limestone (Pedley *et al.* 2002). Changes in the amount of carbonate materials such as calcite affect the amount of Sr that is present (Chen *et al.* 2006). In a previous study (Pirone 2017; Pirone and Tykot 2017) it has been demonstrated that depending from where the clay was extracted from a clay outcrop and its proximity to the Greensand and Globigerina Limestone horizons, there can be considerable variation in the Rb, Sr and Zr trace elements. Based on this understanding of the geological reality of Maltese clays, it is reasonable to conclude that all three clusters represent clays of a Maltese origin and that Groups B and C contain samples demonstrating the potential variation in the trace elemental composition that is observed for the clay formation throughout the islands of Malta and Gozo. Furthermore, the results show that the majority of the ceramics was made with clays from a Maltese source similar in chemical composition to the clays found at Għajn Tuffieħa. The other important finding is represented by the Mycenaean type fragment from Tas-Silġ South plotting within the main cluster A, together with the vast majority of the Baħrija local pottery and the other Mycenaean-type piece from the Borġ in-Nadur temple plotting in proximity of the main cluster, the local origin of which was already proven (Pirone 2017). Such a discovery seems to suggest the existence of a class of Maltese-Mycenaean pottery, comparable to the Italo-Mycenaean production of Aegean pottery classes in southern Italy (Tanasi in press). The last

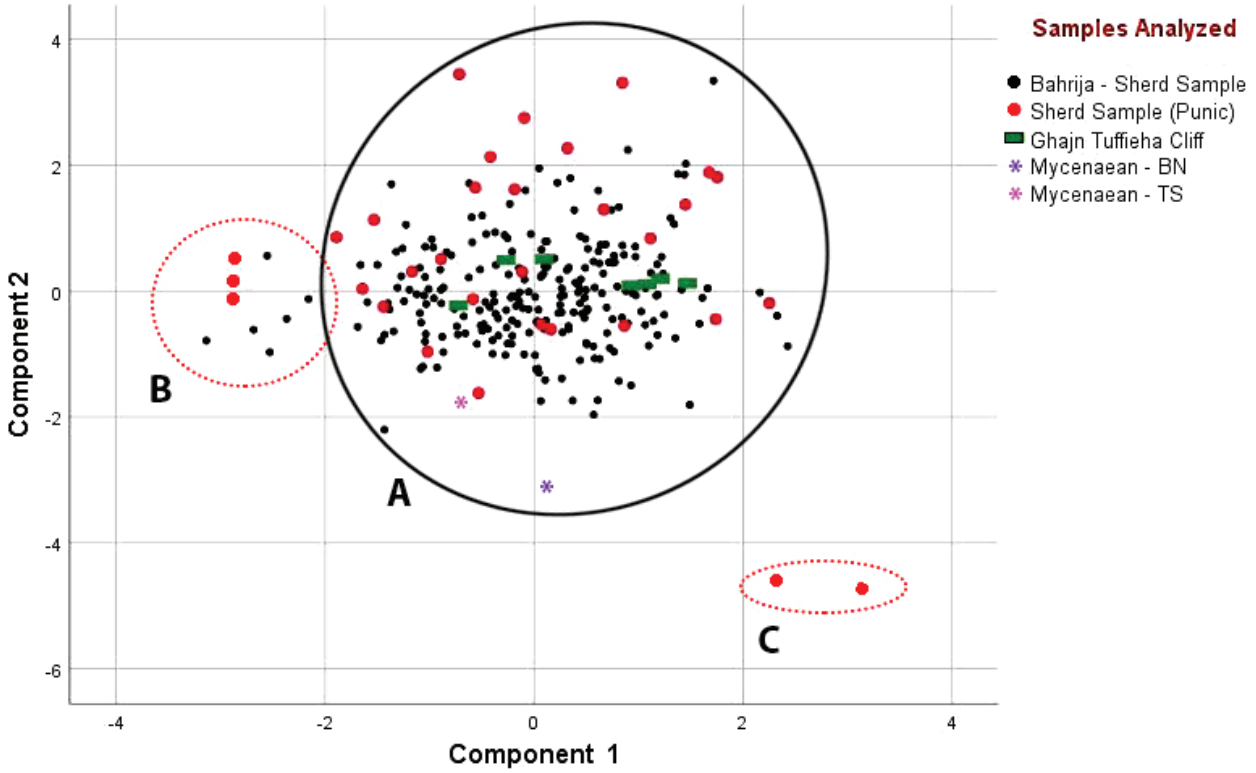

Figure 2. Principal component analysis of the trace elemental composition of all Baħrija ceramics and Maltese clay samples. The majority of the samples clusters together in group A, six prehistoric samples (100064e, 100033n, 100048a, 100055a, 2723, 4924) and three Punic samples (100072d, 100073a, 100073q) cluster in group B and two Punic samples (100074c and 100074d) cluster in group C. Ellipses are an approximation.

result emerging from this study is represented by the fact that those specimens discussed as having possible Sicilian and Aegean features (Tanasi in this volume) turned out to be all locally made.

Ultimately, the two samples 100074c and 100074d, clustered apart as group C, could be determined to potentially represent clay sources that may be statistically different from what can be described as having a Maltese clay origin. These samples were confirmed to be outliers using the Mahalanobis distance, and clearly plot separately from the vast majority of ceramic samples. One possible conclusion is that these samples potentially represent ceramics made with clays originating from outside the Maltese archipelago. Therefore, either the ceramic vessels or the clays from which they were made are foreign imports. However, analysis of additional clay sources are required in order to conclusively determine any of these outliers representing clays from source outside the Maltese islands. Alternatively, these two samples being outliers can simply be an anomaly brought about through contamination or some other error in analyzing these samples.

4. Conclusions

The results of the present study indicate that the vast majority of the samples analyzed for the Baħrija wares were made with local Maltese clays. In fact, with the exception of a few outliers, there is nothing to suggest differently and that the Baħrija ceramics are a product of local Maltese pottery production. Furthermore, the identification of a second example of locally made Mycenaean pottery testifies to the presence in Malta of the cultural phenomenon of Mycenaen-inspired pottery production, unknown so far in the history of the relationship between the Aegean and the Maltese archipelago.

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