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RESEARCH

Agios Petros and the Neolithic pottery-making traditions of the deserted islands, Northern Sporades, Greece

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Abstract
The Neolithic sites of the Cyclops Cave and Agios Petros provide insights into a once flourishing culture that inhabited the 'Deserted Islands' of the northern Sporades in the Greek north Aegean. Building on scientific analysis of ceramics from the seasonally inhabited Cyclops Cave, the present study examines in detail 39 sherds from the permanently settled site of Agios Petros on the adjacent island of Kyra Panagia, using a combination of thin section petrography, geochemistry, scanning electron microscopy and X-ray diffraction. The two ceramic assemblages have been directly compared, revealing close similarities and differences that provide insights into the relationship between the neighbouring sites and their functions. The chaîne opératoire of the dominant local pottery-making tradition of the Deserted Islands is reconstructed and its implications for the identity of the Agios Petros-Yioura/Northern Sporades Culture are considered.

Keywords Neolithic · Ceramics · Greece · Sporades islands · Thin section petrography · Geochemistry · Scanning electron microscopy · X-ray diffraction · Technology · Production · Tradition · Provenance · Chaîne opératoire

Introduction

The 'Deserted Islands' of Kyra Panagia and Yioura constitute the northernmost extent of the Sporades chain in the Greek northern Aegean (Fig. 1). This isolated barren archipelago is uninhabited at the present day and was once thought to have been deserted in prehistoric times. However, the excavation of the sites of Agios Petros on Kyra Panagia (Theochares 1970; Efstratiou 1985) and the Cyclops Cave on neighbouring Yioura (Sampson 2008) (Fig. 1a) have demonstrated that the Deserted Islands were settled, or at least visited, from as early as the Mesolithic. These two key sites provide a glimpse of life on these far-flung outposts of the northern Aegean. Their material culture, particularly ceramics, exhibits links with the Greek mainland, the Northeast Aegean, Western Anatolia and perhaps the Balkans. Yet the region appears to have developed its own unique character from as early as the beginning of the Neolithic, represented by distinctive red-on-white painted pottery and 'rod-head' figurines (Fig. 2a and b).

The Deserted Islands and their prehistoric culture represent an important aspect of the peopling of the Aegean in Mesolithic and Neolithic times. The presence of Melian obsidian at the two excavated sites indicates that they may have participated in wide-ranging interregional networks. In an attempt to better understand these connections, the provenance of Neolithic ceramics unearthed from the Cyclops Cave on the rocky island of Yioura (Fig. 1a) was scientifically investigated by Quinn et al. (2010). This site appears to have been utilised by fishermen on a seasonal basis only, yet it contains a rich, stylistically diverse assemblage of pottery. Thin section petrography and geochemistry revealed that this is matched by high compositional diversity, reflecting the presence of ceramics from multiple origins. In addition to a 'local' signal from somewhere in the Deserted Islands, it contained a range of rare non-local artefacts that might have been transported from the northeast Aegean, the Greek mainland and other Sporades islands. Thus, scientific data appeared to confirm the suspected stylistic connections suggested by the shape and decoration of the sherds.

Authors' declarations This manuscript contains original research, and we confirm that it has not been published elsewhere and is not under consideration by another journal.

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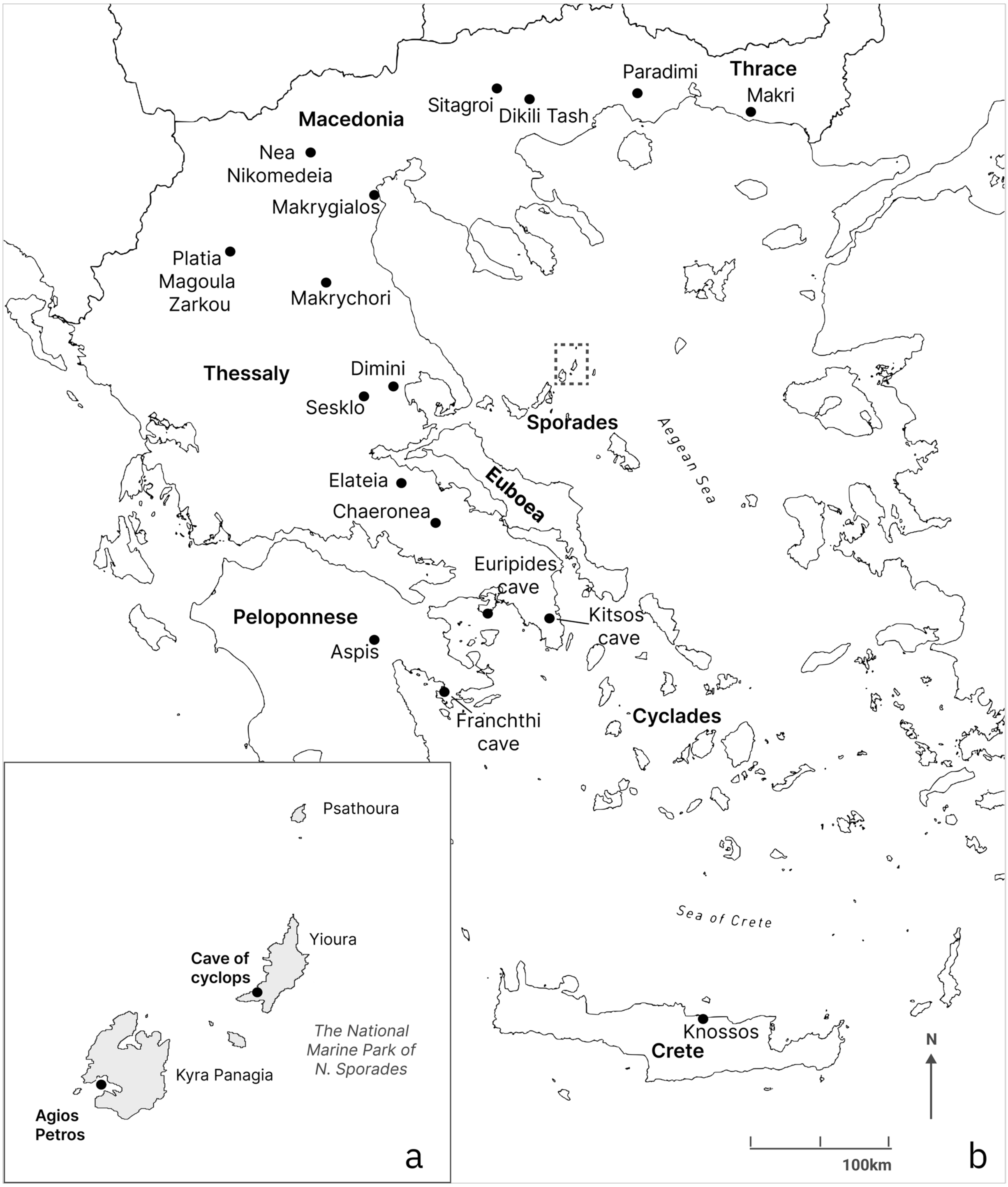


A possible archaeological interpretation of these findings is that the Cyclops Cave was used as a base by the inhabitants of a nearby island and that the non-local ceramics were deposited by passing boats (Quinn et al. 2010). The Sporades, which are separated by short distances and are located in an area of favourable sea currents (Sampson 2008), may have represented ‘stepping stones’ that were used to pass across the northern Aegean between mainland Greece and Western Anatolia.

Inspired by these findings, the present study focuses on the ceramic assemblage of the contemporary site of Agios

◂**Fig. 1** Map the Deserted Islands of Kyra Panagia and Yioura with the sites of Agios Petros and the Cyclops Cave (**a**). Map of Greece and the Aegean with the location of previously published studies on archaeological ceramics mentioned in the text (**b**): Dimini (Liritzis et al. 1991; Schneider et al. 1991; 1994; Hitsiou 2003), Sesklo (Maniatis et al. 1988; Liritzis et al. 1991; Schneider et al. 1991; 1994; Wijnen 1994), Elateia (Weinberg 1962); Makrychori and Platia Magoula Zarkou (Schneider et al. 1991; 1994; Pentedeka 2017), Makrygialos (Saridaki et al. 2019; Hitsiou 2003), Nea Nikomedeia (Yiouni 1996), Dikili Tash (Commenge-Pellerin and Tsirtsoni 2004; Yiouni 2001); Sitagroi (Keighley 1986; Gardner 1978), Paradimi (Bakalakis and Sakellariou 1981), Makri (Yiouni 1995), Cyclops cave (Quinn et al. 2010), Agios Petros (Liritzis et al. 1991), Chaeronea (Parker and Tzavella- Evjen 1995), Euripides cave (Whitbread and Mari 2014), Kitsos cave (Courtois 1981), Aspis (Touchais 1980), Franchthi cave (Vitelli 1993), Knossos (Tomkins et al. 2004). The coordinates of the sites can be found in Supplement 1

Petros on neighbouring Kyra Panagia. This permanently inhabited Early-Middle Neolithic settlement, located in a shallow protected bay (Flemming 1983) (Fig. 1a), is a strong candidate for the source of the dominant local ceramics found in the Cyclops Cave (Quinn et al. 2010). In addition to confirming this connection and providing insights on the ceramic craft traditions of the proposed 'Agios Petros-Yioura Culture' (Sampson 1998: 20, 2008: 221–222; Katsarou-Tzeveleki 2001; 2009: 54), it was hoped that the ceramic assemblage of Agios Petros may shed further light on the nature of seafaring and maritime connections suggested by the Cyclops Cave study.

To this end, a total of 39 pottery sherds with a diverse range of decorative styles have been analysed via thin section petrography and 37 of them via neutron activation analysis (NAA). These were compared to both the Cyclops Cave dataset and raw material field samples collected from Kyra Panagia, in order to investigate their production locations and the possible movement of ceramics. Scanning electron microscopy (SEM) and X-ray diffraction (XRD) have also been applied to selected archaeological samples for the reconstruction of aspects of ancient ceramic technology.

The results reveal strong compositional connections between the ceramic assemblages of Kyra Panagia and neighbouring Yioura. In comparison to the diverse range of origins interpreted for the ceramics of the Cyclops Cave, the material recovered from Agios Petros seems to be local in origin. It is likely that ceramics were manufactured at or close to the settlement, following a well-developed manufacturing tradition that arrived in the Deserted Islands at some point during the late 7th millennium BC. This remains largely unchanged over 1000 years, indicating a strong continuity in craft practise and the existence of a distinct local identity in this part of the Northern Aegean, despite interaction with other cultures via interregional communication networks and visitation by boats passing along the island chain.

Agios Petros and its ceramics

Agios Petros represents one of the earliest settlements discovered in the Sporades with an occupation from the Late Early Neolithic (LEN) to Late Neolithic I (LNI), based on the Thessalian pottery sequence and revised C-14 (cal) dates (5740–5520 cal BC-Phase II and 4860–4500 cal BC-topsoil) (Efstratiou 1985: 213; Bowman et al. 1990: 72; Reingruber and Thissen 2005: 298). The main cultural phase of the site corresponds to the first half of the 6th millennium BC, equating to the Early Middle Neolithic. Detailed investigation of Agios Petros was performed by Theochares (1970) between 1969 and 1971, who detected the existence of three main strata (Fig. 3). Subsequent excavation undertaken in 1981 by Efstratiou (1985), recorded a shallow, but undisturbed deposit, up to 1.3 m in depth, rich in archaeological material. The deposit was considered fully representative of the cultural sequence of the site and confirmed the tripartite stratigraphy of Theochares (1970). The three layers follow a chronological and cultural sequence, without sudden changes between the strata in terms of the pottery typology and other material finds.

Rich archaeological remains have been excavated from the site, including pottery, 'rod-head' figurines (Fig. 2b), stone tools, and obsidian that exhibit a combination of stylistic and cultural traits from nearby and distant sites in Greece, Anatolia and the Balkans (Efstratiou 1985: 67–70). The pottery is characterised by a variety of open and closed shapes and decorative styles, including painted, black-topped, incised pointillé and red monochrome wares (Fig. 2a and c). The most characteristic pottery type is the canvas-like red-on-white painted sherds, characterised as a local phenomenon of the north-eastern Sporades (Katsarou-Tzeveleki 2008) (Fig. 2a). This pottery shows shared stylistic attributes, including the typical carinated shapes from Çatal Hüyük West and Hacilar I in Anatolia (Mellaart 1970), and Elateia in central Greece (Fig. 1b) (Weinberg 1962), as well as several linear painted motifs from Early Neolithic sites such as Chaeronea (Parker and Tzavella-Evjen 1995). Red-on-white painted decoration was common during the 6th millennium BC throughout central Greece, as well as on Euboea (Mastrogiannopoulou and Sampson 2017: 37). Stratigraphic evidence suggests that this decorative technique seems to have been used in Northern Sporades as early as the late 7th millennium BC (Theochares 1970: 57; Sampson 1998: 7).

Several non-pottery ceramics occur in Strata II and III, including clay ladles, a clay 'ear plug' and several rod-head figurines (Fig. 2b and d). The clay figurines are close to the naturalistic Thessalian style, but some exhibit links to material from Anatolia and the Balkans (Efstratiou 1985: 68–70). A considerable amount of obsidian was recovered from Agios Petros, particularly in the upper levels. This seems to exceed the likely requirements of the site and may

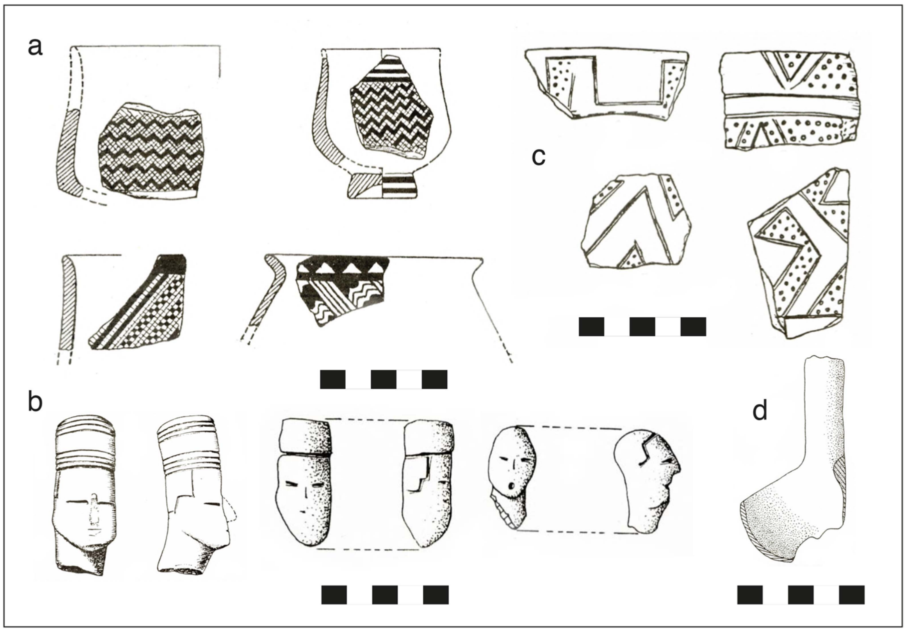


Fig. 2 Selected ceramic finds from the Neolithic site of Agios Petros. Typical red-on-white painted pottery with patterning reminiscent of weaving (**a**), Rod-head figurines (**b**), Incised pointillé decorated sherds (**c**), Clay 'ladle' (**d**). Reproduced from Efstratiou (1985, figs. 5, 25, 58, 64, 75b; p. 218, 239, 272, 286, 297). Scale bars a = 5 cm, b = 4.5 cm, c = 5 cm, d = 8 cm

Fig. 3 Stratigraphy sequence of Agios Petros with arbitrary excavation levels of Cutting Z, interpreted archaeological phases and calendrical dates of Northern Greece (Andreou et al. 2001). Modified from Efstratiou (1985, fig. XXII, p. 213)

Stratigraphy	Cutting Z	Archaeological Phases	Years B.C.
Topsoil	Levels 1,2,3,4	Late Neolithic I	5400/5300-4700/4500
Stratum III	Level 5		
	Level 6	Middle Neolithic	5800/5600-5400/5300
Stratum II	Level 7		
	Level 7a		
Stratum I	Level 8	Early Neolithic	6700/6500-5800/5600

therefore suggest that it acted as a redistribution centre in prehistory (Efstratiou 1985: 74). The Neolithic material culture of Agios Petros exhibits close stylistic links with that of the Cyclops Cave on the nearby Yioura, particularly in terms of red-on-white carinated vessels found in a great abundance in the cave during its first occupation phase in the 6th millennium BC (Katsarou-Tzeveleki 2008).

In addition to the research of Quinn et al. (2010) described above, the only published analytical study on prehistoric ceramics from the Sporades Islands is that of Liritzis et al. (1991), which subjected 24 red-on-white painted sherds from Agios Petros to instrumental neutron activation analysis (INAA) and compared them to contemporary ceramics from Dimini and Sesklo in Thessaly (Fig. 1b) in terms of six elements (Co, Cs, Eu, Fe, Sc and Th). The Agios Petros sherds were found to be compositionally distinct from the analysed Thessalian material. The presence of three geochemical groups within the red-on-white painted sherds was considered to be the result of several separate local ceramic traditions or production units (Liritzis et al. 1991: 310–312).

Materials and methods

Cutting 'Z' from the 1981 excavation of the site (Efstratiou 1985) (Fig. 3) was chosen for detailed study as it exhibited all three strata identified by Theocares (1970) and yielded abundant ceramics. A total of 39 pieces were selected for analysis (Table 1). The sampling selection was subject to the availability of the materials and the aims of the study. The goal was to collect a representative sample, covering a range of decorative styles from the nine arbitrary excavation levels of cutting 'Z' that provides a full record of the successive Neolithic layers. This choice would permit (1) the examination of a wide range of decorative styles in detail; (2) the correlation between the material processing and decorative techniques and (3) the identification of differences between the stratigraphic phases. Unfortunately, it was not possible to sample the diagnostic pieces illustrated by Efstratiou (1985) and the majority of the available sherds were small in size. This meant that the shape of their parent vessels could not be reconstructed with any certainty.

Of the non-pottery ceramic items, one of the ladles and a clay 'chisel' were chosen for analysis. The rod-head figurines could not be sampled due to their rarity and cultural value. The ceramics were assigned analytical codes from APC001–APC039 (Agios Petros Ceramics) (Table 1).

All sherds were thin-sectioned at the Fitch Laboratory at the British School of Athens using a modification of the standard geological technique and studied under the polarising light microscope. The 39 ceramic thin sections were visually classified into petrographic fabrics based upon the nature of their inclusions, clay matrix and voids (Quinn 2022: 91–97). These were directly compared to the 63 Neolithic ceramic thin sections of Quinn et al. (2010) from the Cyclops Cave in order to detect compositional matches and similarities between the two assemblages. The detected fabrics were characterised in detail using qualitative descriptive procedures (Quinn 2022: 97–124) (Supplement 2) and selected samples were subjected to point counting with a 'PETROG' digital stepping stage and software in order to obtain textural and modal data (Quinn 2022: 136–146). The latter was used to investigate compositional variation within the main petrographic and chemical groups, as well as to investigate aspects of their paste preparation technology.

The samples were geochemically characterised via INAA at the Archaeometry Laboratory of the University of Missouri Research Reactor (MURR). According to in-house protocols (Glascock 1992) the surfaces of a 1–2 cm^2 subsample of each sherd were removed with a silicon carbide drill bit before it was ground into a fine powder and dried at 100 °C for 24 h. Unfortunately, two sherds were too small after thin sectioning to be analysed by INAA. Approximately 150 mg of powder was placed in a high-density polyethylene vial and used for short irradiations, and c. 200 mg was transferred to a high-purity quartz vial for long irradiations. The ceramic powders were analysed along with NIST-certified standard reference materials SRM-1633 b (Coal Fly Ash), SRM-688 (Basalt Rock), SRM-278 (Obsidian Rock) and an in-house standard (New Ohio Red Clay) for calibration and quality control purposes. The samples were exposed to two irradiations and three gamma rays counts, resulting in the quantification of a total of 33 elements (Al, As, Ba, Ca, Ce, Co, Cr, Cs, Dy, Eu, Fe, Hf, K, La, Lu, Mn, Na, Nd, Ni, Rb, Sb, Sc, Sm, Sr, Ta, Tb, Ti, Th, U, V, Yb, Zn and Zr) (Supplement 3).

In order to directly compare the geochemical composition of the Agios Petros sherds with the data on contemporaneous sherds from the cave of Cyclops (Quinn et al. 2010), which was collected at the National Centre for Scientific Research (NSCR) 'Demokritos' in Athens, a correction factor was applied to the data from MURR. The NSCR data were adjusted for comparability with MURR by analysing samples of SOIL-7 as unknowns, using SRM-1633b for calibration.

The geochemical data on the 37 Agios Petros sherds was explored via descriptive statistics before transforming it via the unweighted centred log ratio (CLR) method and submitting it to multivariate statistical analysis via principal components analysis (PCA). The latter was used to explore the compositional patterning within the dataset, to define compositional groups and compare these to the petrographic classification and decorative attributes of the sherds. Both the Agios Petros dataset and the combined Agios Petros-Cyclops Cave dataset of 100 samples including the data of Quinn et al. (2010) was subjected to PCA.

Selected samples of particular decorative types and from specific petrographic and geochemical groups were analysed in the scanning electron microscope (SEM) and via X-ray diffraction (XRD). A Carl Zeiss EVO 25 scanning electron microscope, fitted with an Oxford Instruments energy dispersive spectrometer and operated at 20 kV with a working distance of 8.5 mm was used to characterise the chemical composition of the clay matrix, slip and paint layers on polished carbon-coated resin mounted blocks. Certified reference materials (BHVO-2G, BCR-2G) were used to assess the accuracy and precision of EDS measurements.

X-ray diffraction was used to assess the equivalent firing temperature of a representative sample from the main petrographic fabric, based on the presence/absence of specific

Table 1 Details of 37 Neolithic ceramic samples from Agios Petros analysed in this study, including their petrographic fabric assignment and geochemical composition. Major and minor elements given as percentage weight (%wt) oxides and traces as parts per million (ppm) elemental values. The proportion of inclusions is given for samples belonging to the Foliated Limestone Fabric

Samples	Sample type	Level-Stratum	Decorative type	Fabric	Incl. (%)	Lu	U	Yb	Ca	Na	La	Ce	Th	Cr	Hf	Cs	Sc	Rb	Fe	Co	Eu	Sm
APC001	Ceramic	Level 1 (Topsoil)	Incised Pointillé	Metamorphic and Volcanic Fabric	No data	0.64	1.78	4.51	0.83	0.66	18.26	40.09	6.81	127.95	3.82	5.99	27.47	75.88	5.86	20.03	1.38	5.57
APC002	Ceramic	Level 1 (Topsoil)	Incised Pointillé	Metapsammite Fabric	No data	0.55	1.97	3.67	0.83	0.53	13.13	28.44	4.9	75.37	3.35	4.33	24.68	50.72	5.44	11.11	1.12	4.35
APC003	Ceramic	Level 1 (Topsoil)	Incised Pointillé	Metapsammite Fabric	No data	0.49	1.47	3.62	1	0.55	10.67	20.42	4.04	84.13	3.1	4.68	20.98	50.72	5.38	8.72	0.95	3.59
APC004	Ceramic	Level 3 (Topsoil)	Monochrome	Foliated Limestone Fabric	25–35	0.85	1.91	6.08	14.7	0.18	48.51	54.95	9.26	133.21	2.38	12.23	22.58	135.42	5.46	23.77	3.18	12.36
APC005	Ceramic	Level 3 (Topsoil)	Monochrome	Foliated Limestone Fabric	36–40	0.66	1.71	4.61	13.37	0.26	23.38	50.57	8.31	124.45	2.73	10.81	21.38	128.78	5	17.44	2.12	8.24
APC006	Ceramic	Level 4 (Topsoil)	Monochrome	Metapsammite Fabric	No data	0.55	1.4	3.59	0.91	0.7	12.31	27.58	4.3	76.25	3.31	3.94	23.38	45.27	4.73	9.96	1.13	4.31
APC007	Ceramic	Level 5 (Stratum III)	Monochrome	Metapsammite Fabric	No data	0.56	1.96	3.79	0.89	0.51	15.59	36.35	6.1	78	3.62	4.02	22.38	58.15	5.56	14.74	1.21	4.76
APC008	Ceramic	Level 6 (Stratum III)	Late Painted (red on white)	Foliated Limestone Fabric	41–50	0.68	2.41	4.76	16.53	0.15	42.26	46.18	5.8	113.05	2.65	9.81	14.29	116.69	4.05	15.57	2.48	9.39
APC009	Ceramic	Level 6 (Stratum III)	Late Painted (red on white)	Foliated Limestone Fabric	25–35	0.36	2.05	2.19	15.21	0.16	19.9	34.96	6.18	121.82	2.58	13.87	14.09	123.83	4.26	18.27	1.11	4.67

Table 1 (continued)

Samples	Sample type	Level-Stratum	Decorative type	Fabric	Incl. (%)	Lu	U	Yb	Ca	Na	La	Ce	Th	Cr	Hf	Cs	Sc	Rb	Fe	Co	Eu	Sm
APC010	Ceramic	Level 6 (Stratum III)	Incised Pointillé	Grog and Phyllite Fabric	No data	0.51	1.78	3.29	1.1	0.55	30.15	65.75	13.33	249.77	4.8	12.34	25.17	134.23	6.66	24.29	1.62	7.08
Samples	Sample type	Level-Stratum	Decorative type	Fabric	Incl. (%)	Lu	U	Yb	Ca	Na	La	Ce	Th	Cr	Hf	Cs	Sc	Rb	Fe	Co	Eu	Sm
APC011	Ceramic	Level 7 (Stratum II)	Black-Topped	Foliated Limestone Fabric	40–50	0.34	1.21	2.36	15.59	0.19	24.92	41.05	10.7	141.1	3.19	11.82	16.78	101.54	4.49	15.98	1.18	5.41
APC012	Ceramic	Level 7 (Stratum II)	Late Painted (red on white)	Foliated Limestone Fabric	25–35	0.31	1.68	2	15.59	0.11	16.21	31.75	7.59	127.95	2.86	13.45	16.28	115.7	4.43	16.61	0.84	3.71
APC013	Ceramic	Level 7 (Stratum II)	Black-Topped	Foliated Limestone Fabric	36–40	0.68	1.35	4.74	15.78	0.38	17.85	58.58	6.16	89.39	2.63	5.74	17.88	79.05	3.77	16.61	1.97	7.45
APC014	Ceramic	Level 7 (Stratum II)	Black on red	Foliated Limestone Fabric	25–35	0.37	2.43	2.49	15.51	0.18	23.69	41.48	6.34	127.08	2.68	9.88	14.49	74.89	3.87	19.72	1.29	5.35
APC015	Ceramic	Level 7 (Stratum II)	Monochrome	Foliated Limestone Fabric	25–35	0.36	2.24	2.13	13.26	0.38	8.82	22.13	5.12	100.79	2.54	8.53	20.88	100.05	4.47	8.93	0.71	2.85
APC016	Ceramic	Level 7 (Stratum II)	Black-Topped?	Foliated Limestone Fabric	40–50	0.31	1.88	2.17	19.01	0.18	13.13	27.69	5.48	96.4	1.98	7.85	14.09	84.5	3.97	12.56	0.89	3.63
APC017	Ceramic	Level 7 (Stratum II)	Monochrome	Foliated Limestone Fabric	25–35	0.64	1.68	4.04	11.77	0.32	19.79	41.69	6.72	106.92	2.91	6.31	20.98	99.56	4.72	16.19	1.91	7.03
APC018	Ceramic	Level 7 (Stratum II)	Late Painted (black on white)	Foliated Limestone Fabric	25–35	0.41	1.48	2.6	14.91	0.19	27.59	39.02	8.33	141.98	3.01	9.1	18.68	83.61	4.63	16.09	1.31	5.61

Table 1 (continued)

Samples	Sample type	Level-Stratum	Decorative type	Fabric	Incl. (%)	Lu	U	Yb	Ca	Na	La	Ce	Th	Cr	Hf	Cs	Sc	Rb	Fe	Co	Eu	Sm
APC019	Ceramic	Level 7 (Stratum II)	Late Painted (red on white)	Foliated Limestone Fabric	36–40	0.31	1.14	2.3	18.4	0.18	25.95	35.81	9.13	126.2	2.73	8.87	14.79	87.87	3.95	11.83	1.16	5.25
APC020	Ceramic	Level 7 (Stratum II)	Black-Topped	Foliated Limestone Fabric	25–35	0.51	1.46	3.55	12.87	0.22	24.1	41.05	7.56	132.34	2.97	7.22	19.48	76.18	4.98	16.4	1.77	6.63
Samples	Sample type	Level-Stratum	Decorative type	Fabric	Incl. (%)	Lu	U	Yb	Ca	Na	La	Ce	Th	Cr	Hf	Cs	Sc	Rb	Fe	Co	Eu	Sm
APC021	Ceramic	Level 7 (Stratum II)	Late Painted (red on white)	Foliated Limestone Fabric	25–35	0.31	2.5	1.95	14.32	0.11	17.85	36.77	6.02	112.18	2.51	12.35	14.59	124.42	4.12	16.4	0.85	3.99
APC022	Ceramic	Level 7 (Stratum II)	Black-Topped	Foliated Limestone Fabric	25–35	0.33	1.85	2.33	17.71	0.26	18.56	41.16	7.27	100.79	3.03	7.68	14.59	86.58	3.69	22.21	1.03	4.44
APC023	Ceramic	Level 7 (Stratum II)	Black-Topped?	Foliated Limestone Fabric	36–40	0.58	1.94	3.78	11.15	0.22	29.44	50.99	8.5	127.08	3.32	6.08	18.78	79.45	4.93	18.27	1.85	7.51
APC024	Ceramic	Level 8 (Stratum I)	Late Painted (black on white)	Foliated Limestone Fabric	40–50	0.34	2.48	2.26	18.52	0.23	18.05	31.22	6.64	100.79	2.24	8.71	14.79	75.78	3.66	16.5	0.98	4.41
APC025	Ceramic	Level 8 (Stratum I)	Late Painted (black on white)	Foliated Limestone Fabric	25–35	0.75	1.59	5.32	16.01	0.22	37.85	85.74	7.53	110.43	2.68	7.01	17.48	80.93	4.13	22.42	2.87	11.39
APC026	Ceramic	Level 8 (Stratum I)	Late Painted (red on white)	Foliated Limestone Fabric	40–50	0.3	1.51	1.93	17.35	0.41	16.92	37.84	7.1	132.34	2.66	10.31	15.28	66.17	3.87	16.5	0.87	3.84
APC027	Ceramic	Level 8 (Stratum I)	Late Painted (black on white)	Foliated Limestone Fabric	41–50	0.32	1.93	2.14	17.99	0.1	18.26	32.07	6.06	117.44	2.57	11.36	14.49	126.1	4.15	14.74	1.03	4.54

Table 1 (continued)

Samples	Sample type	Level-Stratum	Decorative type	Fabric	Incl. (%)	Lu	U	Yb	Ca	Na	La	Ce	Th	Cr	Hf	Cs	Sc	Rb	Fe	Co	Eu	Sm
APC028	Ceramic	Level 8 (Stratum I)	Indet. Painted	Foliated Limestone Fabric	41–50	0.3	1.87	2.16	16.49	0.14	16.31	30.47	5.88	106.92	2.61	11.22	14.49	109.17	3.96	15.47	1.06	4.46
APC029	Ceramic	Level 8 (Stratum I)	Late Painted (black on white)	Foliated Limestone Fabric	36–40	0.38	1.64	2.46	17.61	0.18	18.36	32.71	6.75	107.8	2.66	6.91	16.78	75.39	3.6	11.94	1.13	4.6
APC030	Clay ladle	-	Undet	Foliated Limestone Fabric	41–50	0.49	1.59	3.14	12.75	0.28	11.08	28.44	5.39	98.16	2.78	7.23	20.38	115.9	4.44	16.92	1.23	4.65
Samples	Sample type	Level-Stratum	Decorative type	Fabric	Incl. (%)	Lu	U	Yb	Ca	Na	La	Ce	Th	Cr	Hf	Cs	Sc	Rb	Fe	Co	Eu	Sm
APC031	Clay 'chisel'	-	Undet	Foliated Limestone Fabric	41–50	0.51	0.99	3.58	17.06	0.17	39.59	40.09	9.96	112.18	2.54	8.56	19.08	79.35	4.58	20.03	1.83	7.64
APC032	Ceramic	Level 3 (Topsoil)	Black-Topped	Foliated Limestone Fabric	41–50	0.56	1.99	3.93	16.54	0.18	28.31	34.96	7.66	117.44	2.14	10.49	19.38	100.94	4.86	14.22	2.11	8.26
APC033	Ceramic	Level 1 (Topsoil)	Black-Topped Painted	Micrite and Phyllite Fabric	no data	0.31	1.48	2.25	4.73	0.76	20.82	44.15	7.81	166.51	4.19	6.94	13.19	93.91	4.19	12.56	0.95	4.52
APC034	Ceramic	Level 1 (Topsoil)	Early Painted (red on white)	Foliated Limestone Fabric	25–35	0.51	2.16	3.59	16.13	0.12	29.23	39.87	7.54	127.08	2.61	11.07	18.88	119.07	4.62	16.4	1.81	7.18
APC035	Ceramic	Level 2 (Topsoil)	Early Painted (red on white)	Foliated Limestone Fabric	41–50	0.34	1.07	2.47	16.12	0.31	16.82	25.23	7.79	106.92	2.51	8.29	19.88	78.95	4.58	10.69	1.1	4.52
APC036	Ceramic	Level 2 (Topsoil)	Early Painted (red on white)	Foliated Limestone Fabric	25–35	0.55	1.99	3.59	12.49	0.29	28.72	44.79	7.87	128.83	3.08	8.3	18.88	95.1	4.45	16.5	1.93	7.51

Table 1 (continued)

Samples	Sample type	Level-Stratum	Decorative type	Fabric	Incl. (%)	Lu	U	Yb	Ca	Na	La	Ce	Th	Cr	Hf	Cs	Sc	Rb	Fe	Co	Eu	Sm
APC037	Ceramic	-	Red on white	Foliated Limestone Fabric	36–40	0.31	1.13	2.16	17.07	0.17	21.74	33.89	8.22	104.29	2.17	10.07	14.49	110.35	3.55	12.66	1.01	4.52
APG001	Terra rossa clay	-	-	-	no data	0.69	2.91	4.36	1.281	0.35	62.1	114.9	20.64	269	7.57	14.61	24.3	186.8	6.92	28.2	2.19	10.86
APG002	Alluvium	-	-	-	no data	0.51	1.99	3.44	0.159	0.7	24.2	51.9	7.48	120	4.11	5.78	18.5	84	5.19	19.8	1.35	5.59
APG001+007	Replicate	-	-	-	no data	0.6	2.09	4.02	0.905	0.8	34.5	63.5	11.24	162	5.17	8.51	27.5	116	6.88	22.5	1.56	7.05
APG002+004	Replicate	-	-	-	no data	0.53	1.99	3.38	0.132	0.83	18.3	40.8	6.08	98	3.81	5.31	20.7	72.5	4.94	17.9	1.18	4.64

mineral phases that form or disappear at particular temperatures and atmospheric conditions (Maggetti 1982: 128; Maritan 2004: 304; Maritan et al. 2006: 533; Nodari et al. 2007). Approximately 5 g of sherd was dried for 24 h at 110 °C and powdered in a planetary ball mill. Small 0.5 g subsamples of the powder were re-fired at a maximum temperature of 700, 750, 800, 850, 900, 950 and 1000 °C for 1 h under oxidising conditions. Mineralogical characterisation was undertaken using a Rigaku MiniFlex 600 X-ray diffractometer equipped with a Cu-X-ray tube running at 40 kV/15 mA and a graphite primary monochromator. The resulting diffractograms were compared to the International Centre for Diffraction Data-Joint Committee of Power Diffraction Standards, 2006 (ICDD-JCPDS) database. The XRD spectra of the re-fired subsamples were compared with one another and the published bar diagrams to reconstruct the disappearance of mineral phases.

The clay vitrification microstructure of the same samples was also studied in the fresh fracture in the SEM for comparison. Small sub-samples were re-fired at the above temperatures, then platinum-coated and compared to one another, as well as published studies on ceramic vitrification (Tite and Maniatis 1975; Maniatis and Tite 1981).

In order to determine the geological source of the Agios Petros ceramics, comparisons were made with geological maps and reports as well as the composition of published studies on neolithic ceramics from Thessaly and Northern Greece (e.g. Liritzis et al. 1991; Schneider et al. 1994; Yiouni 1995, 1996; Pentedeka and Kotsakis 2008; Pentedeka and Dimoula 2009; Quinn et al. 2010) (Fig. 1b). The possible sources of local raw materials were investigated by direct geochemical and petrographic comparisons with field samples collected on Kyra Panagia (Fig. 4), including both clay and hard rock samples. The island of Kyra Panagia is composed of folded Cretaceous limestone of the Cretaceous age (IGME 1984). Cretaceous conglomerates-sandstones of approximately 20–50 m thickness overlie the Upper Jurassic limestones, consisting of eroded fragments of basement rocks including ophiolitic material rocks. The metamorphosed Kalamaki-Mortero group in the eastern part of the island is characterised by schistose rocks of low-grade metamorphism, i.e. phyllite, and metavolcanic rocks, ranging from basalt to rhyodacite (Pe-Piper et al. 1996). Specific clay and rock samples were combined to replicate certain fabrics and compared with the archaeological ceramics in thin sections. The clay samples and several replicated pastes were subjected to NAA using the methods described above and compared to the geochemical groups of ceramics.

Compositional patterning

Several petrographic fabrics, characterised by specific raw materials and paste preparation technologies, occur within the 39 thin-sectioned sherds from Agios Petros (Fig. 5;

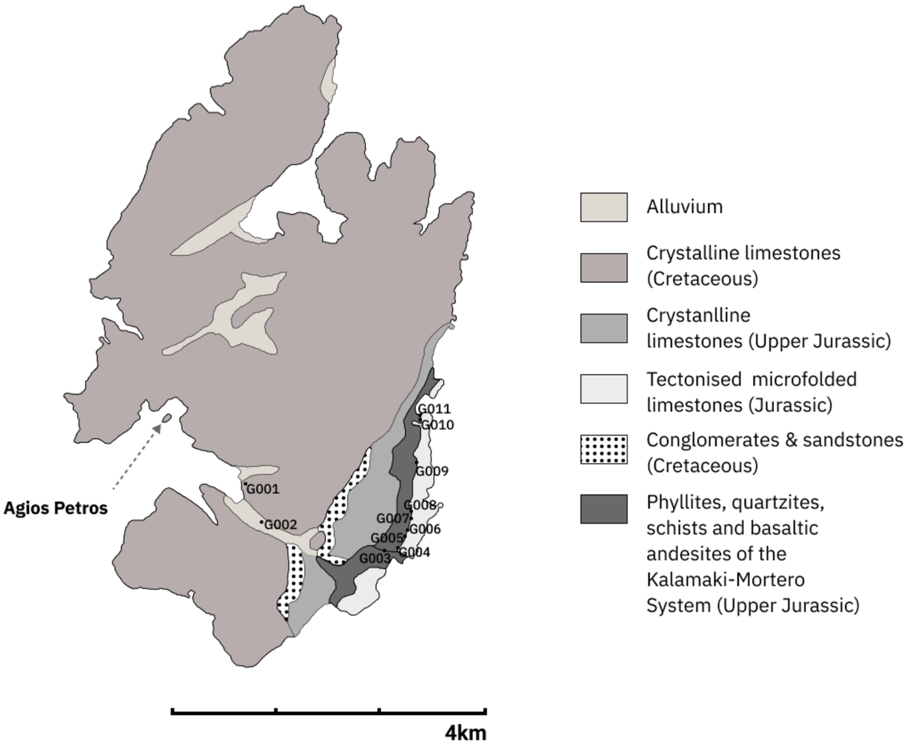


Fig. 4 Geological map of Kyra Panagia with the location of raw material field samples collected in the present study. Based on IGME (1984) and Pe-Piper et al. (1996). Details of the collected field samples can be found in Supplement 4

Table 1). These include a single dominant composition, the Foliated Limestone Fabric, characterised by abundant fissile metamorphosed limestone and rarer quartzose inclusion in a generally non-calcareous red-firing clay matrix (Fig. 5a). This large fabric exhibits variation in terms the size and abundance of the limestone inclusions and the presence/absence of rare rock fragments in the thin sections including phyllite and volcanic material. The Foliated Limestone Fabric occurs in a range of decorative styles, including red monochrome, black-topped, black-topped painted, black-on-red and red-on-white painted wares, derived from the Levels 3–8 (Table 1). However, none of the incised pointillé sherds have this composition. The Foliated Limestone Fabric is closely related to the dominant fabric detected at the Cyclops Cave by Quinn et al. (2010) (Fig. 5b).

Several other distinct but less common petrographic fabrics also occur in the sampled Agios Petros ceramics. The Metapsammite Fabric (Fig. 5c) contains abundant rock and mineral inclusions derived from a low-grade metamorphosed sandstone and less common phyllite in a non-calcareous iron-rich clay matrix. It occurs in sherds with monochrome and incised pointillé decorative styles of the Levels 1, 4 and 5 of Cutting Z (Table 1). Although this fabric has not been reported at the Cyclops Cave, rare metapsammite inclusions occur in a single sherd of another fabric in the study of Quinn et al. (2010). Two incised pointillé sherds from the upper Level 1 are characterised by sand-sized metamorphic inclusions and rare fresh volcanic material in a non-calcareous clay matrix, and are classified as the Metamorphic and Volcanic Fabric (Fig. 5d). They share some common metamorphic inclusions with the Metapsammite Fabric. The small volcanic inclusions are composed of amphibole and plagioclase feldspar phenocrysts in a dark, glassy matrix and may tentatively be classified as andesite. While the Metamorphic and Volcanic Fabric was not reported at the Cyclops Cave, fresh volcanic material was common in sherds of the Tuff Fabric of Quinn et al. (2010: 1047, Fig. 4d) in the form of welded volcanic glass fragments and well-formed plagioclase and amphibole.

A single black-topped painted sherd from Level 1 containing fine low-grade metamorphic rock inclusions and micritic calcite inclusions has been classified as the Micrite and Phyllite Fabric (Fig. 5e). Comparable phyllite inclusions were reported in the Phyllite Fabric from the Cyclops Cave material analysed by Quinn et al. (2010: 1047, Fig. 4b), though these sherds did not contain any micrite. Finally, one incised pointillé decorated sample from Level 6 forms the Grog and Phyllite Fabric due to the presence of abundant grog inclusions and rare phyllite in a non-calcareous clay matrix (Fig. 5f). Petrographically related but not identical material was also detected at the Cyclops Cave (Quinn et al. 2010: 1046, Table 1).

Based on the measurement of certified reference materials, the accuracy of the INAA data is better than 5%

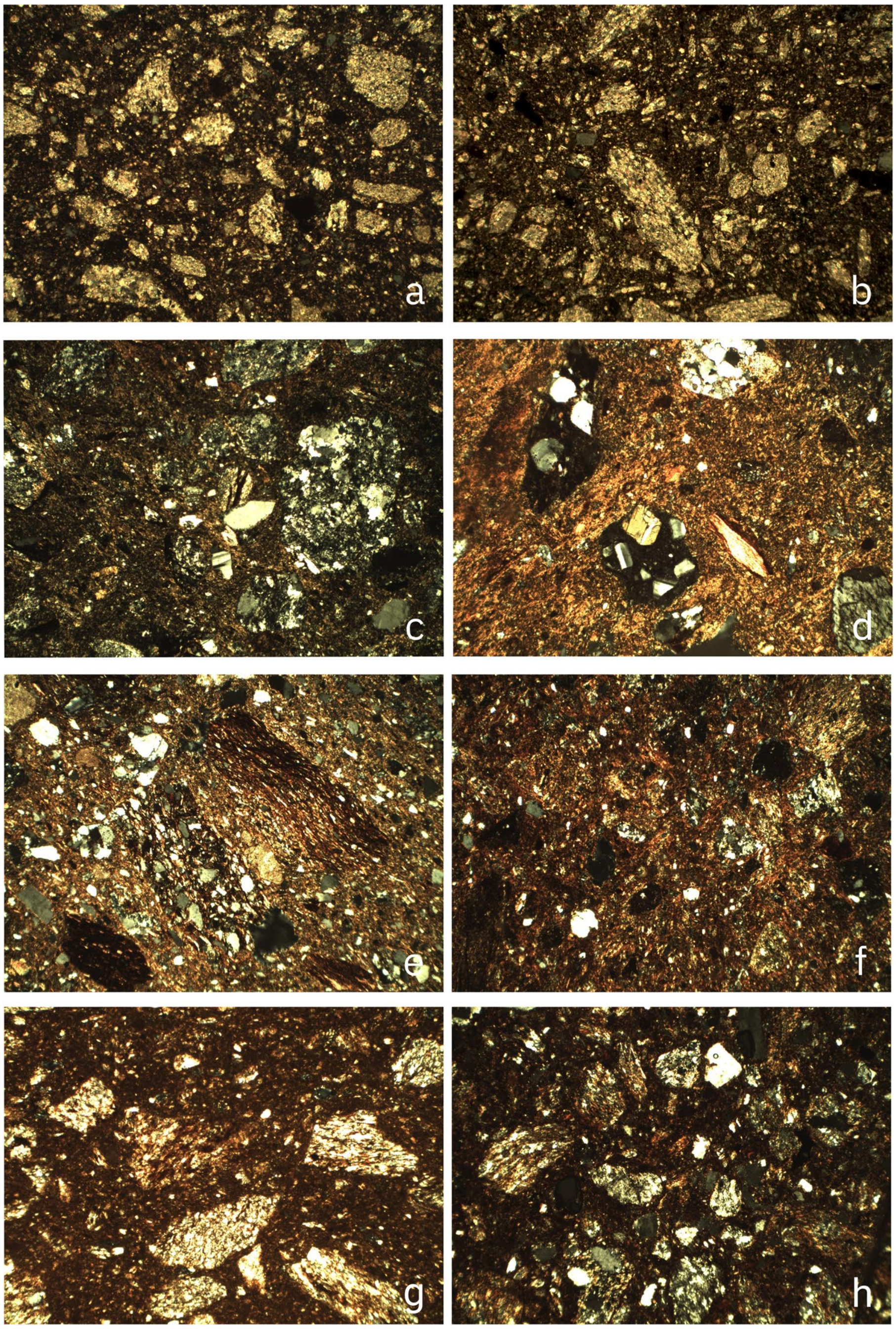


Fig. 5 Thin section photomicrographs of petrographic fabrics detected in 39 Neolithic ceramics from Agios Petros in the present study, with compositional matches from the study of Quinn et al. (2010) on contemporary ceramics from the Cyclops Cave and matches with replicated pastes made from raw materials collected on Kyra Panagia. Foliated Limestone Fabric (**a**). Limestone Fabric from Cyclops Cave (**b**), Metapsammite Fabric (**c**), Metamorphic and Volcanic Fabric (**d**), Micrite and Phyllite Fabric (**e**), Grog and Phyllite Fabric (**f**), Paste created by adding crushed foliated limestone to fine red non-calcareous terra rossa clay (**g**), Paste created by adding crushed metamorphic rock to alluvium (**h**) All images taken in crossed polars (XP). Image width = 2.9 mm

for most elements, except Yb and Lu that have a relative error > 10%. The latter were therefore omitted from the geochemical dataset on the 37 analysed sherds. In order to directly compare the combined Agios Petros and Cyclops Cave datasets, another 14 elements were removed, leaving 17 common chemical variables present in both. The Agios Petros dataset has a total variation (V_t) of 3.33 using the methodology of Buxeda i Garrigos and Killikoglou (2003), indicating the existence of several chemical groups within the dataset. Principal components analysis conducted on the combined Agios Petros, and Cyclops Cave dataset transformed by CLR explains 77% of its variation. A score plot of components 1 and 2 reveals the presence of several distinct chemical groups that correlate well with the petrographic classification of the sherds (Fig. 6a). The Foliated Limestone Fabric samples from both sites plot in a large loose group characterised by a high abundance of calcium (> 10%) (Fig. 6a and b; Table 1). Principal components analysis of these samples only (Fig. 6c and d) compared with the proportion of inclusions in the Agios Petros and Cyclops cave sherds, as indicated by petrographic point count data (Table 1), suggests that this variation is not due to differences into the proportion of limestone temper. Removing the element Ca and normalising the data reveals that the Agios Petros Foliated Limestone Fabric samples may contain two chemical subgroups (Fig. 6e and f), distinguished by their higher values for Eu, Lu, Sm and Yb, one of which overlaps with many of the Cyclops Cave sherds.

The four Metapsammite Fabric samples from Agios Petros form a tight geochemical group separate from the others (Fig. 6a and b). The single Grog and Phyllite Fabric sherd plots close to those from the Cyclops Cave, suggesting that they have a similar chemical composition. No Agios Petros samples correspond chemically with sherds of the Cyclops Cave Phyllite Fabric, Fine Mica and Quartz Fabric, Serpentinite Fabric or Tuff Fabric, which are revealed to be chemically distinct in the PCA (Fig. 6a).

Raw materials and provenance

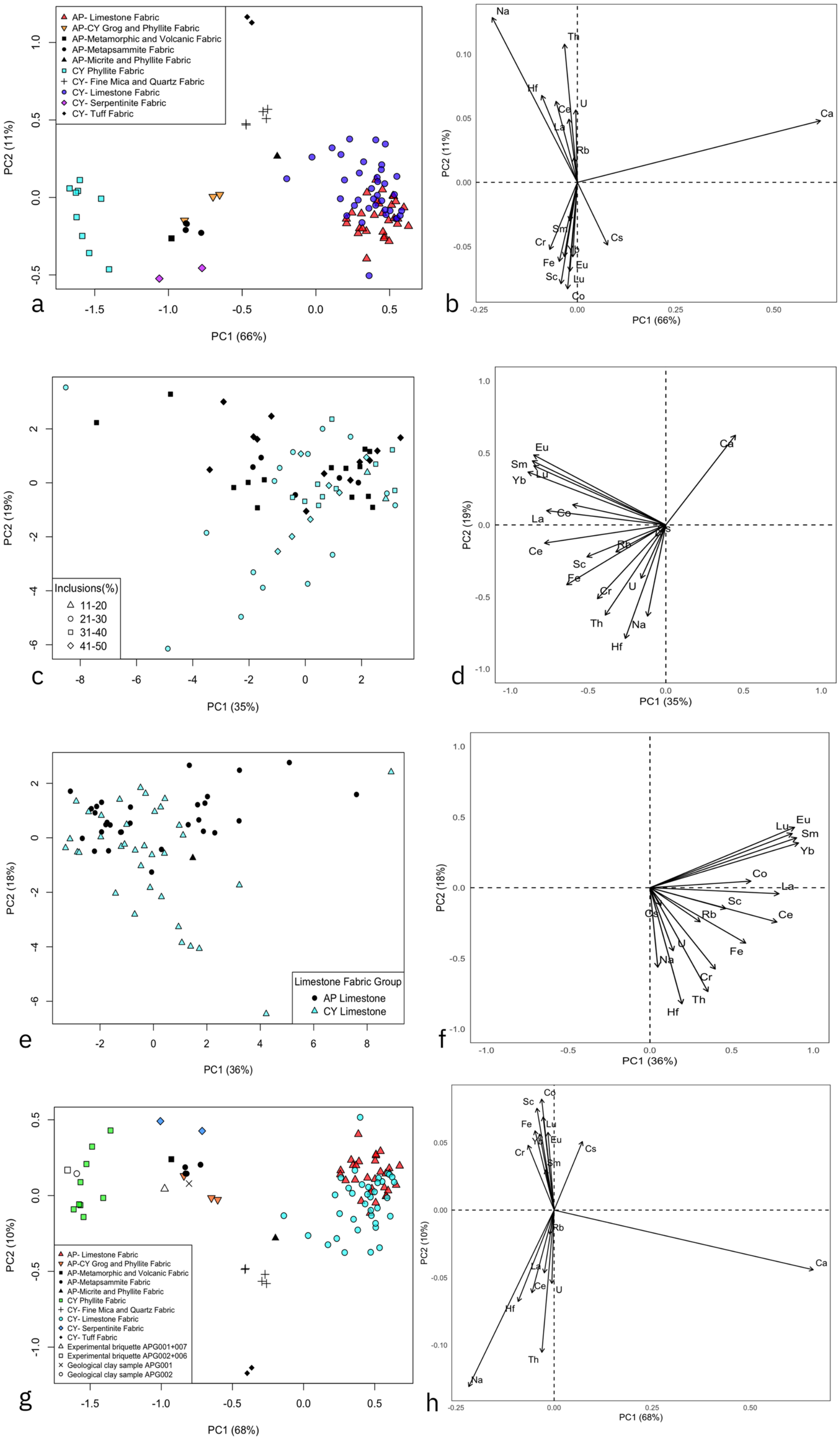
Petrographic matches for the main inclusions in some of the fabrics could be found among the geological samples collected from the southeastern part of Kyra Panagia (Fig. 4). Several hard rock samples were revealed to be limestone with aligned sparry crystals, of the type that is present in Foliated Limestone Fabric (e.g. APG003). Crushed fragments of this material, when added to fine red non-calcareous terra rossa clay (APG001) from the Agios Petros bay, closely resemble the dominant fabric in thin sections (Fig. 5g). Several other metamorphic rock specimens contain equant quartz crystals and fine white mica and are thus a match for the inclusions in the Metapsammite Fabric (e.g. APG006). Similar material also occurs as small intrinsic clasts in a sample of recent alluvial clay from a valley on the south of the island (APG002; Fig. 4). Mixing this clay source with crushed metamorphic rock resulted in a paste composition comparable to the Metapsammite Fabric (Fig. 5h). Phyllite sampled in the field on Kyra Panagia matches the inclusions in the Grog and Phyllite and Micrite and Phyllite Fabrics (APG007; Fig. 4).

A comparison of the geochemical composition of the two clay samples and experimental replicates with the archaeological ceramics via PCA (Fig. 6g) reveals close correspondence between both the terra rossa (APG001; Fig. 4) and terra rossa mixed with phyllite temper (APG007), and the Cyclops Cave Phyllite Fabric in terms of the elements Cr, Fe and Sm. The alluvial clay sample (APG002; Fig. 4) and this material, mixed with crushed metamorphic rock sample APG006 (Fig. 4), plot chemically with sherds belonging to the Metapsammite Fabric from Agios Petros due to their similar concentrations of Cs, Eu and Lu (Fig. 6g).

Based on the above comparisons, as well as published geological information on the Deserted Islands, it seems feasible that most, if not all of the Neolithic sherds analysed from Agios Petros could have been manufactured from raw materials that occur on Kyra Panagia or Yioura. This is certainly true of the Foliated Limestone Fabric given that a good match for its distinctive inclusions was found in the field and that this paste composition occurs in sherds with the distinctive red-on-white painted decoration that is characteristic of the Deserted Islands. The sherds of the Metapsammite Fabric, Grog and Phyllite Fabric and Micrite and Phyllite Fabric may also have been made on Kyra Panagia or Yioura. While metamorphic rock occurs within the 'Kalamaki-Mortero System' on Yioura (Fig. 4), Quinn et al. (2010: 1050) considered this to be difficult to access on the steep west coast of the island. The same unit could be sampled without difficulty on the more accessible terrain of Kyra Panagia. Given that the Cyclops Cave seems to have been occupied on a seasonal basis only (Sampson 2008: 200), that it is located on a steep hillside, and that Yioura may be lacking in significant deposits of clay, it seems likely that the majority of the pottery analysed from both sites was produced somewhere on Kyra Panagia.

The exact location of ceramic production on Kyra Panagia is not currently known, though given the petrographic and geochemical correlation between specific raw materials collected on the south of the island and several compositional groups of ceramics, it seems probable that pottery may have been made at or close to the site of Agios Petros. The existence of several chemical groups within the Limestone Fabric, revealed by this study (Fig. 6e) and in the data of Quinn et al. (2010: 1048, Fig. 5) and Liritzis et al. (1991: 310, Fig. 2), seems to suggest the use of more than one clay source, to which limestone temper was added. It is not clear, without more extensive field sampling, where these different clay sources could have been located and it is therefore possible that ceramics were made at two or more separate sites. Archaeological survey on Kyra Panagia and other islands in the Northern Sporades has not detected any other Neolithic sites so far (Efstratiou 1985: 11; Sampson 2008: 179–185, 222).

The analysis of sherds and raw materials from Kyra Panagia has revealed that certain ceramic compositions occurring at the Cyclops Cave have a more local origin than interpreted by Quinn et al. (2010). These include the Phyllite Fabric, the Grog and Phyllite Fabric and the Clay and Phyllite Fabric. It is also feasible that the Schist Fabric, Polycrystalline Quartz Fabric 1 and Polycrystalline Quartz Fabric 2 could have


AP- Limestone Fabric
AP-CY Grog and Phyllite Fabric
AP-Metamorphic and Volcanic Fabric
AP-Metapsammite Fabric
AP-Micrite and Phyllite Fabric
CY Phyllite Fabric
CY- Fine Mica and Quartz Fabric
CY- Limestone Fabric
CY- Serpentinite Fabric
CY- Tuff Fabric
PC1 (66%)
PC2 (11%)
a
b
PC1 (35%)
PC2 (19%)
Inclusions(%)
11-20
21-30
31-40
41-50
c
d
Limestone Fabric Group
AP Limestone
CY Limestone
PC1 (36%)
PC2 (18%)
e
f
Experimental briquette APG001+007
Experimental briquette APG002+006
Geological clay sample APG001
Geological clay sample APG002
PC1 (68%)
PC2 (10%)
g
h

◂**Fig. 6** Geochemical patterning within dataset of 17 elements in 37 Neolithic sherds from Agios Petros analysed in this study, plus 63 contemporaneous sherds from the site of the Cyclops Cave analysed by Quinn et al. (2010) and geological field samples, as revealed by principal components analysis. Score plot of principal component 1 versus 2 labelled by petrographic fabric (**a**). Plot of loadings for principal components 1 and 2 determining patterning in a (**b**). Score plot of PCA conducted on Foliated Limestone Fabric sherds only, with the proportion of inclusions indicated (Agios Petros = black, Cyclops cave = blue) (**c**). Plot of loadings for principal components 1 and 2 determining patterning in c (**d**). Score plot of principal component 1 versus 2 of PCA on Foliated Limestone Fabric sherds only, excluding Ca, labelled by site (**e**). Plot of loadings for principal components 1 and 2 determining patterning in e (**f**). Score plot of PCA conducted on all Agios Petros and Cyclops Cave sherds as well as clay samples and experimental replicates, labelled by petrographic fabric (**g**). Plot of loadings for principal components 1 and 2 determining patterning in g (**h**)

been manufactured on the Deserted Islands. The discovery of small intermediate volcanic inclusions within the Metamorphic and Volcanic Fabric, as well as less commonly in certain samples of other fabrics, is perhaps surprising given that no volcanic material is reported on either island on the geological map (IGME 1984). However, Pe-Piper et al. (1996) report that basaltic andesite occurs in several places in the northern Sporades including Alonnisos, Psathroura and Kyra Panagia (Fig. 4). A metamorphic inclusion within the Metapsammite Fabric contains some grains that could have come from an igneous source and were incorporated into clastic sedimentary strata that were subsequently metamorphosed, though no such material is present in the thin sectioned field samples. A final possible source of the rare volcanic inclusions within certain locally produced ceramics is the use of volcanic implements in the preparation of the paste. Small numbers of andesite tools have been found at the Cyclops Cave (Sampson 2008: 164), that are suggested to have come from the nearby island of Psathoura, although this has not been tested.

The volcaniclastic material in the Tuff Fabric of Cyclops cave ceramic material (Quinn et al. 2010) does not appear to have a source on Kyra Panagia or Yioura and these ceramics are therefore likely to have been non-local in origin. The analysis of ceramics and raw materials from Kyra Panagia in this study has not shed additional light on the provenance of the ceramics of the Serpentinite Fabric and Fine Mica and Quartz Fabric reported from the Cyclops Cave and the source of these may therefore be outside of the Deserted Islands.

Pottery technology and chaine operatoire

A range of different raw material types was used to manufacture analysed ceramics at Agios Petros. These occur in sherds with various decorative styles (Table 1), for example the Foliated Limestone Fabric exists as monochrome, black-topped, early and late red-on-white painted pottery, as well as characterising the clay ladle and 'chisel'. It is however notable that all of the red-on-white painted pottery is made from the Foliated Limestone Fabric and the incised pointillé samples do not occur in this fabric. The latter occur as the Metapsammite Fabric, Metamorphic and Volcanic Fabric and Grog and Phyllite Fabric and mainly in the upper strata of Cutting Z at Agios Petros.

Most of the ceramics appear to have been made by the addition of temper to a fine base clay. The abundant calcareous material added to the dominant fabric seems to have been added as poorly-sorted crushed limestone, due to the presence of bodies and streaks of red non-calcareous clay that appear to represent the base clay to which was added (Fig. 7a), as well as the resemblance between this fabric and the mixture of field samples APG001 and APG003 (Fig. 5g). The use of the foliated limestone as temper could be explained by both its availability on the island and its functional properties. Inclusions with an elongate platy shape are better at preventing crack propagation than equant inclusions (Müller et al. 2010), thus improving the toughness of ceramics. Calcareous inclusions also have a thermal expansion coefficient that is similar to that of clay (Rye 1976; Hoard et al. 1995; Steponaitis 1984), reducing stresses that build up in pots during heating and cooling. One drawback of using calcareous material as temper is its breakdown at c. 750 °C during firing and its subsequent recarbonation (Rice 2015: 81). Despite this issue, crushed calcite or limestone temper was also used in the production of Neolithic ceramics from several sites elsewhere in Greece and adjacent areas (Vitelli 1993; Tomkins and Day 2001; Pentedeka and Kotsakis 2008; Whitbread and Mari 2014).

Crushed ceramic tempering, recorded in several fabrics, is a common technique in the Neolithic period in Greece (e.g. Tomkins et al. 2004; Whitbread and Mari 2014) and the Balkans (e.g. Spataro 2017; Amicone et al. 2020). While its use as a filler has functional advantages, the addition of grog and a second type of temper in the Grog and Phyllite Fabric (Fig. 7b) could suggest that one or other may have had a social-symbolic meaning (Gosselain and Livingstone-Smith 2005: 41; Quinn and Burton 2009: 288). The Fine Mica and Quartz Fabric from Cyclops Cave are notable for the fineness of its inclusions and was almost certainly not tempered (Quinn et al. 2010: 1047). Though it is difficult to confidently provenance these matt-painted ceramics, it is suspected that they could be non-local, given their petrographic and stylistic similarities to samples from several sites on Thessaly, e.g. Dimini, Platia Magoula Zarkou, Makrychori (Hitsiou 2003; Schneider et al. 1991; Pentedeka 2017).

Coil-building seems to have been the main primary forming technique for the analysed pottery sherds given visible evidence in hand specimen and the concentric orientation of inclusions in a vertical thin section due to the presence

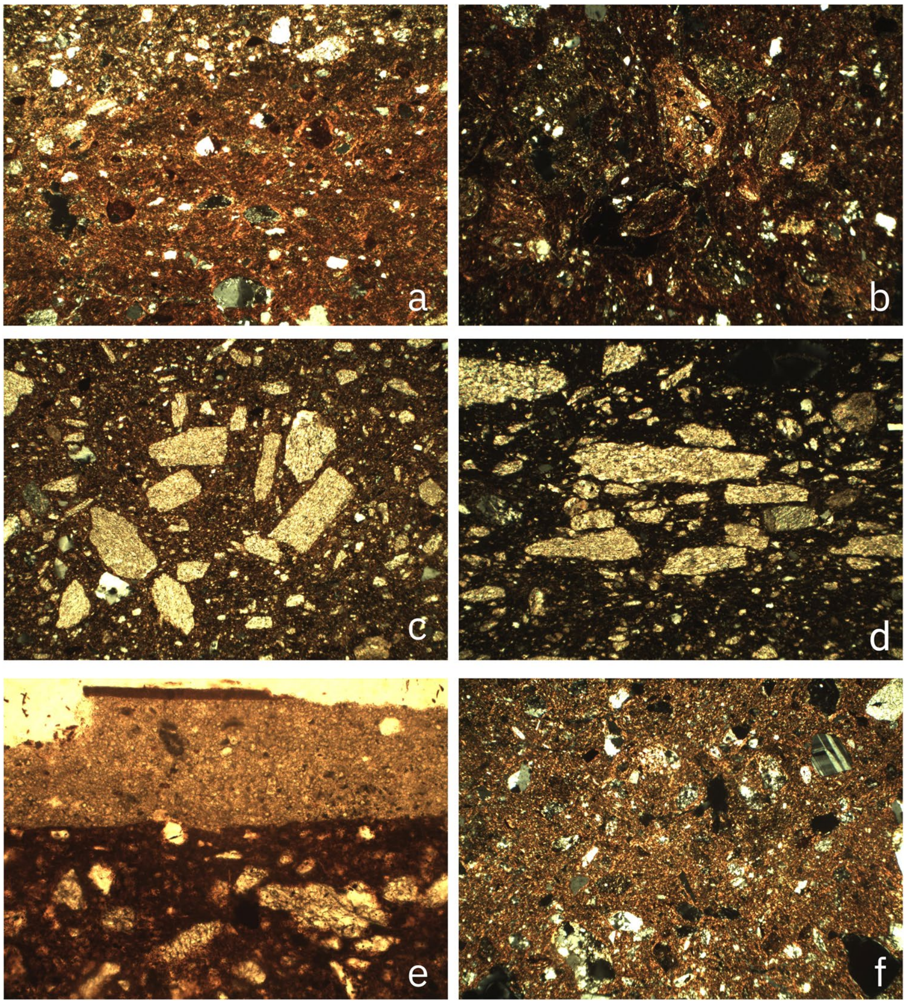


Fig. 7 Aspects of ceramic technology visible in thin sections of Neolithic ceramics from Agios Petros in the present study. Area of red clay without limestone inclusions within Foliated Limestone Fabric sample that could represent remnant base clay which did not receive temper (**a**). Crushed pottery temper and metamorphic rock fragments visible in the Grog and Phyllite Fabric (**b**). Concentric orientation of inclusions in a vertical thin section picking out relic coils from primary forming (**c**). Strong inclusion alignment parallel to the vessel margins, perhaps due to secondary forming with a paddle and anvil (**d**). Calcareous slip and iron-rich paint layers covering body made of Foliated Limestone Fabric (**e**). Optical activity seen in the clay matrix of a Metamorphic and Volcanic Fabric sherd in crossed polars (**f**). All images taken in crossed polars (XP), except e (PPL). Image width = 2.9 mm

of relic coils (Fig. 7c). However, others feature strong inclusion alignment parallel to the vessel margins, perhaps due to secondary forming with a paddle and anvil (Fig. 7d). The sherds reveal a range of different finishing techniques such as incising, burnishing, slipping, painting and partial reduction. The typical red-on-white sherds from Agios Petros and the Cyclops Cave feature a fine-grained light-coloured slip, which is revealed in thin sections and via SEM–EDS to be highly calcareous (Fig. 7e; Fig. 8). This was used to cover the red-firing body beneath and create a 'canvas' on which a paint was applied in a fine pattern that is reminiscent of weaving (Efstratiou 1985: 52; Sampson 1998: 7; Katsarou-Tzeveleki 2008) (Fig. 2a). A comparison of the chemical composition of the slip with that of the clay matrix of the body (Fig. 8; Table 2), assuming a pure CaCO3 composition for the fine calcite fraction, suggests that these two components may also have been used for the production of the calcareous slip, but in different proportions and more finely ground. Chemical characterisation of the paint reveals it contains elevated iron relative to the slip and body. It also has a significant aluminosilicate component meaning that it may have been made by adding iron-rich pigment such as haematite to a small amount of very fine clay. This gave it a red colour when fired in an oxidising atmosphere.

Optical activity observed in the matrix of the thin sectioned sherds in crossed polars (Fig. 7f) suggest that the clay minerals were not destroyed during firing and the ceramics were therefore not subjected to temperatures of > 850 °C for a sustained period (Quinn 2022: 266–269). Scanning electron microscope imaging of the microstructure of re-fired and 'as recieved' fragments of selected samples in fresh fracture (Fig. 9) and X-ray diffraction of the same pieces (Fig. 10) confirm and refine this interpretation to ≦ 800 °C, due to the absence of 'Initial Vitrification' (Tite and Maniatis 1975), the presence of clay minerals and calcite, and an absence of high-temperature minerals such as wollastonite and gehlenite. It has been suggested that the pottery of Agios Petros was 'incompletely' fired based on their characteristics in hand specimen (Efstratiou

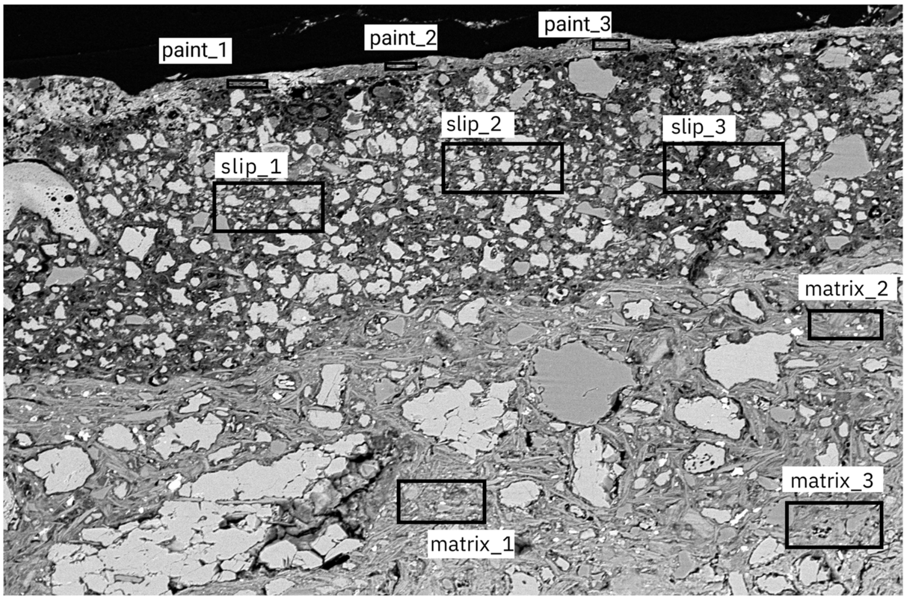


Fig. 8 SEM–EDS analysis of body, slip and paint layers in sample of Neolithic red-on-white painted sherd of Foliated Limestone Fabric from Agios Petros. Image width = 325 µm. Data presented in Table 2

Table 2 Geochemical composition of analysed areas and features in Fig. 8, normalised to 100%, both with and without CaO, revealing close geochemical composition between the clay fraction of the slip layers and the clay matrix of the body, if a pure $CaCO_3$ composition for the fine calcite fraction of the slip is assumed. Analytical total before normalisation given and standard deviation of the averaged values. Accuracy for the reported elements is expressed as relative percentage difference between the average analysed and average given values of two basalt standards

Sample and feature		SiO_2	Al_2O_3	Na_2O	MgO	CaO	Fe_2O_3	SO_2	K_2O	P_2O_3	TiO_2	MnO	Non-normalised Total
APC024 SLIP		29.5	15.7	0.2	2.0	37.7	6.8	ND	1.8	2.6	1.9	0.2	55.0
	without CaO	48.4	25.8	0.3	3.3	-	11.2		2.9	4.2	3.2	0.4	
	st. dev	*3.02*	*0.45*		*0.18*	*1.85*	*0.80*		*0.70*	*0.03*	*1.56*	*0.02*	
APC024 CLAY MATRIX		47.4	23.6	0.4	1.8	9.5	11.4	ND	3.2	0.8	1.0	ND	67.4
	st. dev	*5.13*	*4.17*	*0.13*	*0.47*	*3.17*	*1.62*		*0.47*	*0.22*	*0.37*		
APC037 SLIP		38.8	14.0	0.6	1.4	38.0	4.9	ND	1.4	0.3	0.7	ND	57.3
	without CaO	62.2	22.6	1.0	2.2	-	7.96		2.28	0.5	1.2		
	st. dev	*3.72*	*0.47*	*0.18*	*0.14*	*4.35*	*0.26*		*0.11*	-	*0.01*		
APC037 CLAY MATRIX		47.7	23.4	0.4	1.6	13.2	9.3	ND	3.4	ND	0.6	ND	75.3
	st. dev	*2.58*	*3.43*	*0.02*	*0.40*	*8.60*	*1.75*		*0.46*		*0.03*		
APC039 SLIP		29.5	14.6	0.4	1.0	46.4	5.8	0.3	0.8	0.7	0.7	ND	54.2
	without CaO	54.4	27.0	0.8	2.0	-	10.8		1.6	1.3	1.3		
	st. dev	*4.17*	*1.53*	*0.27*	*0.18*	*7.15*	*0.33*	-	*0.12*	*0.06*	*0.19*		
APC039 CLAY MATRIX		54.8	19.8	0.5	1.6	8.7	9.9	ND	2.7	0.7	1.2	0.2	79.0
	st. dev	*3.60*	*2.42*	*0.13*	*0.32*	*2.88*	*1.56*		*0.24*	*0.08*	*0.84*	-	
AOC039 PAINT		43.8	26.2	0.4	1.9	6.9	15.6	ND	2.5	1.2	0.9	0.6	67.1
	st. dev	*1.12*	*0.19*	-	*0.09*	*1.66*	*1.20*		*0.26*	*0.10*	*0.09*	*0.12*	
Accuracy (%)	BCR-2G	1.07	1.38	−0.39	0.48	1.47	0.21		3.63		8.51	28.3	
	BHVO-2G	−0.83	0.69	0.22	0.06	−0.74	−1.60		5.28		3.48	12.5	

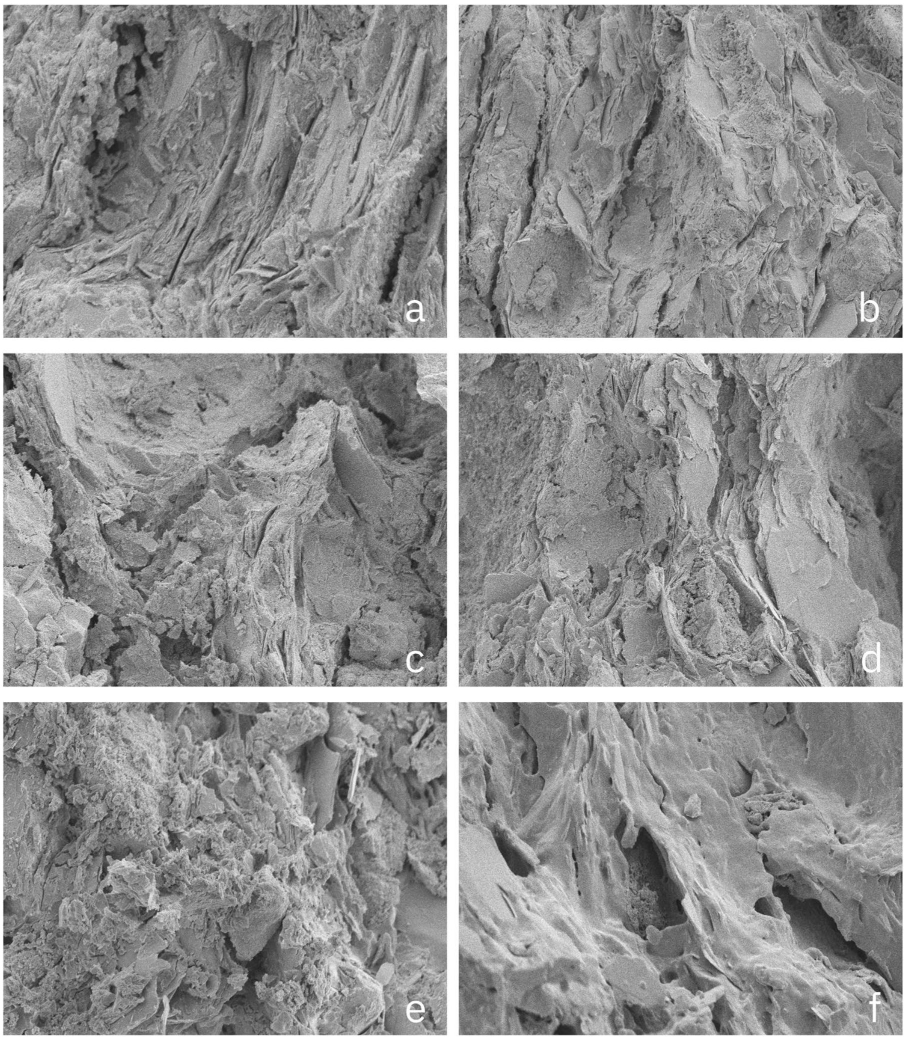


Fig. 9 Vitrification microstructure of selected Neolithic sherd of the Foliated Limestone Fabric from Agios Petros in the scanning electron microscope under secondary electron imaging. Sherd 'as received' (**a**). Refired in oxidising atmosphere at 700 °C (**b**), 750 °C (**c**), 800 °C (**d**), 850 °C (**e**) showing 'Initial Vitrification', and 900 °C (**f**) exhibiting 'Extensive Vitrification' with fine bloating pores. Image width = 50 µm

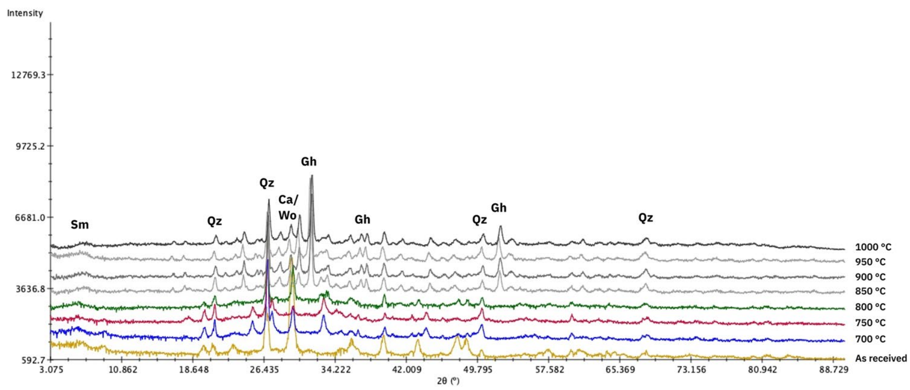


Fig. 10 X-ray diffractograms of selected Neolithic sherd of the Foliated Limestone Fabric from Agios Petros refired in oxidising atmosphere at various temperatures. 700 °C and 750 °C with quartz, calcite and smectite, 800 °C with calcite reacting with the clay fraction to form wollastonite, 850 °C, 900 °C, 950 °C and 1000 °C containing gehlenite neophase. Sherd 'as received' containing calcite and quartz, and lacking wollastonite and gehlenite, suggesting a maximum equivalent temperature of 750 °C. Mineral abbreviations are according to Whitney and Evans (2010)

1985: 26), and perhaps less well fired than contemporaneous sherds from the Greek mainland (Liritzis et al. 1991: 309). Though the latter cannot be tested in this study, the combination of observations in thin section and under the SEM, as well as data from XRD confirm that the analysed samples were not highly fired. Nevertheless, the survival of sherds 7500 years later attests to the adequacy of the ancient firing process in hardening the paste. In the case of the Foliated Limestone Fabric sherds and those with a calcareous slip, it is possible that the potters intentionally kept the firing temperature below the temperature at which calcite breaks down (c. 800 °C) in order to avoid 'lime spalling' (Rice 2015: 81, 109). This would suggest a good knowledge of the behaviour of the locally available raw materials during firing and an ability to control firing.

Control over the atmosphere of firing is also visible in terms of the generally well-oxidised nature of the paste in thin sections, the absence of fire clouding on the exterior of the small sherds. An exception is the black-topped samples, in which the upper part of the vessel was intentionally starved of oxygen. The technology of similar vessels from northern Greece was examined by Gardner (1978), who proposed several methods via which the dark effect could be achieved, including the iron reduction technique, the application of manganese-rich pigment or the use of organic substances. Another technique used to produce a black finish on vessels is the use of graphite paint (e.g. Amicone et al. 2021: 15–16). Visual inspection of the black-topped sherds from Agios Petros seems to rule out the idea that graphite or manganese pigment could be applied to these pots, pointing to preferential reduction by excluding oxygen from the upper part during firing.

No evidence for pottery manufacture was reported from either Agios Petros or the Cyclops Cave. The potters of the Deserted Islands most probably fired their ceramics in a bonfire or pit, which would have been sufficient to reach the equivalent temperatures interpreted above and is likely to have been used to manufacture Neolithic pottery in other parts of Greece, as well as Western Anatolia and the Balkans (e.g. Yiouni 2001: 22; Vuković, 2018; Amicone et al. 2020: 3). Control over firing atmosphere could have been achieved by the covering and uncovering of the load with fuel at different stages of the process. It is not clear what type of fuel was used, though parts of Kyra Panagia were once wooded and the animal bones recovered from Agios Petros (Efstratiou 1985: 9–10) indicate that goats lived on the island in Neolithic times, so dung could also have been an option.

Ceramic traditions and cultural identity of the deserted islands

The local origin of all 39 Agios Petros sherds analysed in this study is perhaps surprising given the findings of Quinn et al. (2010) at the Cyclops Cave. It seems that the inhabitants of Agios Petros were not involved in the maritime exchange of ceramics with other settlements, despite participating in the circulation of obsidian from the island of Melos (Efstratiou 1985: 74). The rare non-local sherds found at the Cyclops Cave in Late Neolithic I phase, that are geologically incompatible with the Deserted Islands, seem to represent a rare case of long distant transport of ceramics. These could have been deposited by boats using the cave while passing along the islands on their way across the Northern Aegean, as suggested by Quinn et al. (2010). No such activity has been detected at Kyra Panagia in the samples analysed in this study. The absence of pottery from the Thessalian mainland has been previously suggested via geochemical data by Liritzis et al. (1991). Ceramics however seem to have been transported a short distance (c. 3–5 km) to neighbouring Yioura by the inhabitants of Agios Petros, while using the cave on a seasonal basis for fishing or other activities (Sampson 1998: 20, 2008: 203–207).

A comparison between Neolithic pottery from Agios Petros and the analysis of contemporaneous material from the nearby Cyclops Cave by Quinn et al. (2010) reveals that close compositional, and technological connections exist between the two assemblages. These include the occurrence of ceramics made from the same raw material types and paste preparation recipes, as well as similar forming and decorative techniques, and comparable firing technology. This correlates well with their previously reported stylistic similarities (Katsarou-Tzeveleki 2008), such as the fine red-on-white decoration, carinated bowls and globular closed shapes. These multiple lines of evidence clearly support the existence of a distinctive pottery-making tradition on the Deserted Islands, that was the product of several generations of craftspeople practising in the area (Sampson 2008: 222).

While exhibiting its own character, the ceramic assemblages of both islands, including pottery and figurines, also share stylistic similarities with material from Anatolia, the Balkans and Greece, reflecting either the origins of this ceramic tradition and/or its influences. From a technological perspective, the Agios Petros ceramic assemblage exhibits similarities and differences with these areas in terms of the type of tempering, surface treatment and firing. The use of calcite temper has been documented in other contemporaneous sites including Franchthi cave in Peloponnese (Vitelli 1993) and Knossos in Crete (Tomkins 2001; Dimitriadis 2013), but this occurs occasionally, alongside other inclusions. In addition, grog tempering is a common practise during Neolithic in Crete and other settlements and caves in Peloponnese, Attica and Salamis (e.g. Aspis, Kitsos cave, cave of Euripides), where it is used both as the sole filler material or alongside other inclusions. The relatively low firing temperatures of the

Agios Petros ceramics are in line within those suggested by relevant studies from Early and Middle Neolithic sites in Thessaly (Maniatis et al. 1988; Maniatis and Tite 1981; Pentedeka and Kotsakis 2008). The black-topped decoration, which requires some control of the firing atmosphere, is common in Northern Greece and rest of the Balkans in the Neolithic, including Makri and Paradimi in Greek Thrace (Bakalakis and Sakellariou 1981; Yiouni 1995) and Sitagroi, Nea Nikomedeia, Dikili Tash and Makrygialos in Greek Macedonia (Keighley 1986; Yiouni 1996, 2001; Saridaki et al. 2019). While this could suggest links with the black-burnished tradition in the Balkan peninsula, the absence of graphite-painted wares and chaff tempering, common in the Neolithic Balkan sites, suggests that the black-topped ceramics of Agios Petros could instead be a local variation of the painted wares (Efstratiou 1985: 64).

It seems likely that the ceramics of both sites were produced on Kyra Panagia, with Agios Petros as the probable location of production, given the absence of other permanently settled Neolithic sites in the Deserted Islands and the presence of matches with field samples collected close by. No evidence of ceramic manufacture has been reported from either island during excavation or field survey. Nevertheless, the probable small scale of production, the use of hand-building techniques and firing in a pit or bonfire means that direct traces of production units are unlikely to have been preserved several thousand years later. The existence of several chemical groups within the dominant Foliated Limestone Fabric sherds at Kyra Panagia in this study, as well as within the equivalent ceramics analysed by Quinn et al. (2010) from Yioura, and in the earlier data of Liritzis et al. (1991), could be interpreted as indicating the existence of several productions, which used the same technology, but slightly different clay sources. However, it may also be explained by geological factors, such as the areal distribution of suitable clay (Arnold 2000: 360–361), since clay deposits in Kyra Panagia seem to be limited, which might have led potters to use different sources over time.

The use of other local raw material resources for the production of the ceramics belonging to the various metamorphic fabrics from Agios Petros and the Cyclops Cave can be explained in several possible ways. These could represent ceramic manufacture by different artisans at Agios Petros or another site on Kyra Panagia via a different tradition (Amicone et al. 2020; Quinn 2022: 209–211), or perhaps the use of specific raw materials for particular ceramic shapes/functions. It is not possible, based on the small size of the analysed sherds, to comment on the likelihood of the latter, though it is worth noting that the dominant Foliated Limestone Fabric was used to make pottery vessels as well as other types of objects. The persistence of the latter fabric at the site suggests that potters did not collect and combine raw materials at random but instead followed strict recipes. The correlation between the incised pointillé sherds and the rarer fabrics in the upper strata of Cutting Z at Agios Petros seems to be significant and might indicate a change in pottery technology in the latter period of the site. The pointillé technique is not common in Thessaly and may be associated with the Eastern Aegean islands (Efstratiou 1985: 68), suggesting the arrival of new inhabitants or cultural influences. This may correlate with the presence of non-local imports in the Late Neolithic I period of the Cyclops Cave (Quinn et al. 2010).

The existence of Mesolithic artefacts at the Cyclops Cave, including abundant fish bones, hooks, and chipped stones (Sampson 1998, 2008: 170–172, 2011: 155) attests to the earlier occupation of the Northern Sporades. Indeed, several potentially Palaeolithic sites have also been recorded in the area (Sampson 1998: 19). In light of this, the sudden appearance of a well-developed pottery-making tradition in the Late Early Neolithic at Agios Petros, and the Early Middle Neolithic at the Cyclops Cave is surprising. Notwithstanding a preservational bias, ceramic technology seems to have arrived fully formed on the Deserted Islands (Efstratiou 1985: 56), without an incipient stage of experimentation. The origins of this mature tradition, which once established on the islands persists for several millennia, is not clear, given the combination of stylistic influences from multiple areas including the Greek Mainland, Anatolia and the Balkans. Despite the 'multicultural' nature of the Neolithic ceramic assemblage of the Agios Petros-Yioura/Northern Sporades Culture, it also exhibits its own individual character, demonstrated by the fine red-on-white decorative technique and carinated bowls. This could imply that the ceramic tradition developed on one or more islands of the Sporades chain, perhaps during the Early Neolithic, before spreading to its extremities, including Kyra Panagia and Yioura. With this in mind, we can perhaps expect that several other Neolithic settlements existed in this part of the northern Aegean but are yet to be discovered.

After c. 2000 years, the Neolithic inhabitants of Kyra Panagia and Yioura seem to have left the islands and did not return. Notwithstanding occasional use in the Early and Middle Bronze Age, the northern part of the Sporades archipelago appears to have remained more or less deserted until the present day, and is now part of Europe's biggest protected marine park (Fig. 1). The cultural remains buried in Agios Petros Bay and the Cyclops Cave attest to the once flourishing early cultures that existed in this isolated region in the Neolithic, including its daily activities and its craft traditions. It is by studying these archaeological finds that we gain more insights into the early communities of the North Aegean and their relationships with the adjacent areas of the central and eastern Mediterranean during the 7th and 6th millennia BC.

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Author contribution AB was responsible for the analysis (ceramic petrography; SEM–EDS, XRD) methodology, investigation, writing the original draft, reviewing and editing the final draft and the visualisation. PQ completed the formal analysis (ceramic petrography), conceptualisation and the methodology, reviewed and edited the original and final draft, and was responsible for the visualisation and supervision of the project. NE supervised the project and reviewed the original and final draft. All authors read and approved the final manuscript.

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Code availability Not applicable.

Declarations

Ethics approval This manuscript contains original research, and we confirm that it has not been published elsewhere and is not under consideration by another journal. All authors have read and approved the manuscript and agree with its submission to the Archaeological and Anthropological Sciences Journal.

Consent to participate Informed consent was obtained from all authors included in the study.

Consent for publication The authors consent to the submission of the research paper to the journal.

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References

Amicone S, Radivojević M, Quinn PS, Berthold C, Rehren T (2020) Pyrotechnological connections? Re-investigating the link between pottery firing technology and the origins of metallurgy in the Vinča Culture, Serbia. J Archaeol Sci 118:105123. https://doi.org/10.1016/jjas2020105123

Amicone S, Forte V, Solard B, Berthold C, Memmesheimer A, Mirković-Marić N (2021) Playing with fire: exploring ceramic pyrotechnology in the Late Neolithic Balkans through an archaeometric and experimental approach. J Archaeol Sci: Reports 37:102878. https://doi.org/10.1016/jjasrep2021102878

Andreou S, Fotiadis M, Kotsakis, K (2001) Review of Aegean Prehistory V: The Neolithic and Bronze Age of Northern Greece. In: T Cullen (ed) Aegean Prehistory: A Review. American Journal of Archaeology, Supplement 1. Archaeological Institute of America, Boston, pp 259–327

Arnold DE (2000) Does the standardization of ceramic pastes really mean specialization? J Archaeol Method Theory 7(4):333–375

Bakalakis G, Sakellariou A (1981) Paradimi. Phillipp von Zabem

Bowman SGE, Ambers JC, Leese MN (1990) Re-evaluation of British museum radiocarbon dates issued between 1980 and 1984. Radiocarbon 32(1):59–79

Buxeda i Garrigos J, Kilikoglou V (2003) Total variation as a measure of variability in chemical datasets. In: van Zelst L (ed) patterns and process: a Festschrift in honor of Edward V Sayre Smithsonian Center for Materials Research and Education. Suitland, MD, pp 185–198

Commenge-Pellerin C, Tsirtsoni Z (2004) Les récipients en céramique: formes et décors du Néolithique Moyen. In: R. Treuil (ed) Dikili Tash, village préhistorique de Macédoine orientale: I. Fouilles de Jean Deshayes (1961-1975), Volume 2. Ecole française d'Athènes, Paris, pp 27–61

Courtois L (1981) Etude Physico-chimique de la Cramique. In: N Lambert (ed) La Grotte Préhistorique de Kitsos (Attique): Missions 1968-1978, Recherche sur les grandes civilizations 7, Tome I. Ecole française d'Athènes, Paris, pp 373–389

Dimitriadis S (2013) Fabric Diversity in the Neolithic Ceramics of Knossos. In: Efstratiou N, Karetsou A, Ntinou M (eds) The Neolithic Settlement of Knossos in Crete: new evidence for the early occupation of Crete and the Aegean Islands. Philadelphia, pp 47–51

Efstratiou N (1985) Agios Petros - a Neolithic site in the Northern Sporades Aegean relationships during the Neolithic of the 5th millennium BC. BAR International Series 241, London

Flemming NC (1983) Preliminary geomorphological survey of an early Neolithic submerged site in the Sporadhes, N Aegean. In: Masters PM, Flemming NC (eds) Quaternary coastlines and marine archaeology. Academic Press, London, pp 233–268

Gardner EJ (1978) The pottery technology of the Neolithic period in southeastern Europe, PhD thesis. University of California

Glascock M D (1992) Characterization of archaeological ceramics at MURR by neutron activation analysis and multivariate statistics. In: H Neff (ed) Chemical Characterization of Ceramic Pastes in Archaeology. Prehistory Press, Madison, Wisconsin, pp 11–26

Gosselain O P, Livingstone-Smith A (2005) The Source: Clay selection and processing practices in Sub-Saharan Africa. In: A Livingstone Smith, D Bosquet, R Martineau (eds) Pottery Manufacturing Processes: Reconstruction and Interpretation. BAR International Series 1349. Archaeopress, Oxford, pp 33–47

Hitsiou E (2003) Production and circulation of the Late Neolithic pottery from Makrygialos (phase II), Macedonia, N Greece Vol I. PhD thesis. Department of Archaeology, University of Sheffield, UK.

Hoard R, O'Brien M, Khorasgany M, Gopalaratnam V (1995) A materials-science approach to understanding

limestone-tempered pottery from the Midwestern United States. J Archaeol Sci 22:823–832
IGME (1984) Geological Map of Greece 1:50 000. Kira Panayia Island Institute of Geology and Mineral Exploration, Athens
Katsarou-Tzeveleki S (2001) I Keramiki me Erythra Kosmimata apo ta Stromata this Mesis Neolithikis tou Spilaiou tou Kyklopa. In: Sampson A (ed) Archaiologiki Erevna stis Voreies Sporades. Alonnessos, pp 11–31
Katsarou-Tzeveleki S (2008) Middle Neolithic weavers paint: red patterns as markers of the local group's identity. In: Sampson A (ed) the Cave of the Cyclops: Mesolithic and Neolithic Networks in the Northern Aegean, Greece: I Intra-site Analysis, Local Industries, and Regional Site Distribution. INSTAP Academic Press, Philadelphia, pp 69–110
Katsarou-Tzeveleki S (2009) Cave of cyclops: contribution of the painted pottery to the discussion on Middle Neolithic Symbolisms. In: Mazarakis-Ainian A (ed) Archaeologiko Ergo Thessalias kai Stereas Elladas 2, Praktika Epistimonikis Synantisis, Volos, vol I. University of Thessaly, Volos Ministry of Culture, pp 53–59
Keighley JM (1986) The Pottery of Phases I and II. In: Renfrew C, Gimbutas M, Elster ES (eds) Excavations at Sitagroi: a prehistoric village in Northeast Greece, vol 1. Los Angeles. Institute of Archaeology, UCLA, pp 345–390
Liritzis Y, Orphanidis-Georgiadis I, Efstratiou N (1991) Neolithic Thessaly and the Sporades Oxford. J Archaeol 10(3):307–313
Maggetti M (1982) Phase analysis and its significance for technology and origin. In: Olin J, Franklin A (eds) Archaeological Ceramics Smithsonian. Institution press, Washington DC, pp 121–133
Maniatis Y, Tite MS (1981) Technological examination of Neolithic-Bronze Age pottery from central and southeast Europe and from the Near East. J Archaeol Sci 8(1):59–76
Maniatis Y, Perdikatsis V, Kotsakis K (1988) Assessment of in-site variability of pottery from Sesklo. Thessaly Archaeometry 30(2):264–274
Maritan L (2004) Archaeometric study of Etruscan-Padan type pottery from the Veneto region: petrographic, mineralogical and geochemical-physical characterisation. Eur J Mineral 16(2):297–307
Maritan L, Nodari L, Mazzoli C, Milano A, Russo U (2006) Influence of firing conditions on ceramic products: experimental study on clay rich in organic matter. Appl Clay Sci 31:1–15
Mastrogiannopoulou V, Sampson A (2017) Euboea during the Neolithic period A review of the evidence. In: Z Tankosic, F Mavrides, M Kosma (eds) An island between two Worlds. The Archaeology of Euboea from Prehistoric to Byzantine Times. Proceedings of International Conference, Eretria, 12-14 July 2013. Papers and Monographs from the Norwegian Institute at Athens Volume 6, Athens, pp 33–49
Mellaart J (1970) Excavations at Hacıilar British Institute of Archaeology at Ankara Occasional publications. British Institute of Archaeology at Ankara Edinburgh University Press, Edinburgh
Müller N, Kilikoglou V, Day P, Vekinis G (2010) The influence of temper shape on the mechanical properties of archaeological ceramics. J Eur Ceram Soc 30:2457–2465. https://doi.org/10.1016/jjeurceramsoc2010040
Nodari L, Marcuz E, Maritan L, Mazzoli C, Russo U (2007) Hematite nucleation and growth in the firing of carbonate-rich clay for pottery production. J Eur Ceram Soc 27:4665–4673
Parker DR, Tzavella-Evjen H (1995) Analysis of Neolithic wares from Chaeroneia, Greece: local and Foreign Industries. Am J Archaeol 99:322
Pentedeka A, Kotsakis K (2008) Thin Sectioning Neolithic Identities: The Red Monochrome Ware (A1) from Middle Neolithic Sesklo, Thessaly. In: Y Facorellis, N Zacharias, K Polikreti (eds) Proceedings of the 4th Symposium on Archaeometry of the Hellenic Society of Archaeometry, National Hellenic Research Foundation, 28-31 May 2003, Athens. BAR International Series 1746. Archaeopress, Oxford, pp 305–311
Pentedeka A, Dimoula A (2009) Early pottery technology and the formation of a technological tradition: the case of Theopetra Cave, Thessaly, Greece. In: Quinn PS (ed) Interpreting Silent Artefacts. Oxford, UK, Archaepress, Petrographic Approaches to Archaeological Ceramics, pp 121–138
Pentedeka A (2017) Pottery exchange networks under the microscope: the case of Neolithic Thessaly. In: A. Sarris, E. Kalogiropoulou, T. Kalayci, L. Karimali (eds) Communities, Landscapes, and Interaction in Neolithic Greece. International Monographs in Prehistory, Archaeological Series 20, pp 339–352 https://doi.org/10.2307/j.ctvw049k3.29
Pe-Piper G, Matarangas D, Jacobshagen V (1996) The Mesozoic metavolcanics rocks of Alonnisos and Kyra Panagia islands, Sporades, Greece. N Jb Miner Mh 6:251–263
Quinn PS (2022) thin section petrography, geochemistry and scanning electron microscopy of archaeological ceramics. Archaeopress Publishing Ltd, Oxford, UK
Quinn PS, Burton MM (2009) Ceramic Petrography and the reconstruction of hunter-gatherer craft technology in late prehistoric Southern California. In: Quinn PS (ed) interpreting silent artefacts: petrographic approaches to archaeological ceramics. Archaeopress, Oxford, UK, pp 267–295
Quinn PS, Day P, Kilikoglou V, Faber E, Katsarou-Tzeveleki S, Sampson A (2010) Keeping an eye on your pots: the provenance of Neolithic ceramics from the Cave of the Cyclops, Youra. Greece J Archaeol Sci 37(5):1042–1052
Reingruber A, Thissen L (2005) 14C database for the Aegean catchment (eastern Greece, southern Balkans and western Turkey) 10,000-5500 cal BC. In: C Lichter, R Meriç (eds) How Did Farming Reach Europe? Anatolian-European relations from the second half of the 7th through the first half of the 6th millennium cal BC. Proceedings of the International Workshop, 20-22 May 2004, Istanbul (Byzas 2). Ege Yayınları, Istanbul, pp. 295–327
Rice PM (2015) Pottery analysis: a sourcebook (Second edition). University of Chicago Press
Rye OS (1976) Keeping your temper under control: materials and the manufacture of papuan pottery. Archaeol Phys Anthropol Ocean 11:106–137. https://doi.org/10.1002/j1834-44531976tb00245x
Sampson A (1998) The Neolithic and Mesolithic occupation of the Cave of Cyclops, Youra, Alonnessos, Greece. Annual Br School Athens 93:1–22
Sampson A (2008) The Cave of the Cyclops: Mesolithic and Neolithic networks in the Northern Aegean, Greece: I Intra-site Analysis, Local Industries, and Regional Site Distribution. INSTAP Academic Press, Philadelphia, PA
Sampson A (2011) The Cave of the Cyclops: Mesolithic and Neolithic Networks in the Northern Aegean, Greece, Volume II: Bone Tool Industries, Dietary Resources and the Paleoenvironment, and Archaeometrical Studies. Prehistory Monographs 31. INSTAP Academic Press, Philadelphia, PA
Saridaki N, Kotsakis K, Urem-Kotsou D, Papadakou T, Papaioannou A (2019) Pottery production at Neolithic Pieria, Macedonia, Greece. In: Amicone S, Quinn PS, Marić M, Mirković-Marić N, Radivojević M (eds) Tracing Pottery-Making Recipes in the Prehistoric Balkans 6th–4th Millennia BC. Archaeopress Publishing Ltd, Oxford, UK. https://doi.org/10.2307/j.ctvndv954.16
Schneider G, Knoll H, Gallis, C J, Demoule J P (1991) Production and distribution of coarse and fine pottery in Neolithic Thessaly, Greece. In: E Pernicka, G A Wagner (eds) Archaeometry '90. Proceedings of the 27th Symposium on Archaeometry, 2-6 April 1990, Heidelberg, Germany. Birkhäuser, Basel, pp 513–522
Schneider G, Knoll H, Gallis, K, Demoule J P (1994) Production and Circulation of Neolithic Thessalian Pottery: Chemical and Mineralogical Analyses. In: J-Cl Decourt, B Helly, K Gallis (eds) La Thessalie: 15 Annees de Recherches (1975-1990). Bilan et

Perspectives. Actes du Colloque International, Lyon 17-22 avril 1990. Greek Ministry of Culture, Athens, pp 61–70
Spataro M (2017) Innovation and regionalism in the middle/late Neolithic of south and south-eastern Europe (ca 5,500–4,500 cal BC): a ceramic perspective. In: L Burnez (ed) Matières à penser. Raw materials acquisition and processing in Early Neolithic pottery productions. Proceedings of the Workshop of Namur, 29–30 May 2015, Belgium. Société préhistorique française, Paris, pp 61–80.
Steponaitis VP (1984) Technological studies of prehistoric pottery from Alabama: physical properties and vessel function. In: van der Leeuw SE, Pritchard AC (eds) The Many Dimensions of Pottery. University of Amsterdam Press, The Netherlands, pp 79–122
Theochares D R (1970) Excavations on the island of Aghios Petros at Kyra Panagia. Archeologikon Deltion 25, Chronica 1970. Greek Ministry of Culture, Athens
Tite M S, Maniatis Y (1975) Examination of ancient pottery using the scanning electron microscope. Nature 257:122–123
Tomkins P (2001) The production, circulation and consumption of ceramic vessels at Early Neolithic Knossos. PhD Thesis, University of Sheffield, Crete
Tomkins P, Day PM (2001) Production and exchange of the earliest ceramic vessels in the Aegean: a view from Early Neo lithic Knossos. Crete Antiquity 75(288):259–260
Tomkins P, Day PM, Kilikoglou V (2004) Knossos and the earlier Neolithic landscape of the Herakleion basin. Br School Athens Stud 12:51–59
Touchais G (1980) La cramique nolithique de l'Aspis. Bull De Corresp Hellénique Supplément 6(1):1–40
Vitelli K D (1993) Franchthi Neolithic Pottery, Volume 1: Classification and Ceramic Phases 1 and 2, Fascicle 8 (Excavations at Franchthi Cave, Greece). Indiana University Press, Bloomington
Vuković J (2018) Late Neolithic Vinča pottery firing procedure: reconstruction of Neolithic technology through experiment. Opuscula Archaeologica 30:25–35
Weinberg SS (1962) Excavations at Prehistoric Elateia, 1959. Hesperia 31(2):158–209
Whitbread I, Mari A (2014) Provenance and proximity: a technological analysis of Late and Final Neolithic ceramics from Euripides Cave, Salamis, Greece. J Archaeol Sci 41:79–88
Whitney DL, Evans BW (2010) Abbreviations for names of rock-forming minerals. Am Mineralogis 95(1):185–187. https://doi.org/10.2138/am.2010.3371
Wijnen M (1994) Neolithic pottery from Sesklo. Technological aspects. In: J-Cl Decourt, B Helly, K Gallis (eds) La Thessalie: 15 Annees de Recherches (1975-1990). Bilan et Perspectives. Actes du Colloque International, Lyon 17-22 avril 1990. Greek Ministry of Culture, Athens, pp 149–155
Yiouni P (1995) Technological analysis of the Neolithic pottery from Makri. Bull De Corresp Hellénique 119:607–620. https://doi.org/10.3406/bch.1995.4641
Yiouni P (2001) Surface treatment of Neolithic vessels from Macedonia and Thrace. Ann Br School Athens 96:1–25. https://doi.org/10.1017/S0068245400005207
Yiouni P (1996) The early Neolithic pottery: technology. In: K A Wardle (ed) Nea Nikomedeia I: the Excavation of an Early Neolithic Village in Northern Greece 1961-1964. Supplementary Volume No. 25, The British School at Athens, London, pp 55–78

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