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Keeping an eye on your pots: the provenance of Neolithic ceramics from the Cave of the Cyclops, Youra, Greece

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ABSTRACT

Combined petrographic and chemical analysis of MN and LN ceramics from the Cave of the Cyclops on the island of Youra, Greece, has revealed a compositionally diverse assemblage with a range of different local and off-island sources. Ceramics deposited in Neolithic times on this barren, rocky outpost of the Sporades chain may have originated from a surprising number of possible origins, including from the Plain of Thessaly, Euboea and the volcanic northeast Aegean islands. This picture challenges traditional assumptions about Neolithic pottery production and indicates that significant movement of ceramics was already taking place within the northern Aegean as early as the beginning of the sixth millennium BC. The discovery of a persistent local pottery tradition, that is also found on the neighbouring island of Kyra-Panagia, indicates significant continuity in ceramic technology over some 1500 years.

1. Introduction

Recent compositional analysis of some of the earliest ceramic vessels from the Aegean has begun to challenge our perception of the production and distribution of pottery in Neolithic Greece. With a few notable exceptions (e.g. Schneider et al., 1991, 1994; Hitsiou, 2003), the traditional view of this period often sees most ceramics as being made locally to their find-spot and not transported over significant distances (Vitelli, 1993a,b; Wijnen 1994; Yiouni, 1996). This contrasts with the circulation of other material goods such as obsidian, which was already being distributed as far as 200–300 km from its source at least as early as the Neolithic in the Aegean (Carter, 2009). However, the detailed compositional examination of EN-LNII ceramics from Knossos, Crete (Tomkins and Day, 2001; Tomkins et al., 2004; Tomkins, 2008) has revealed an unexpected degree of variability in raw materials and technology, reflecting a range of different production locations. This discovery has encouraged us to rethink previous models of Neolithic craft production (Vitelli, 1993b; Perlès, 1992; Perlès and Vitelli, 1999), as well as the role of pottery as an exchange item in this period.

Inspired by this shift in perception, we have sought to investigate in more detail the movement of pottery in Neolithic Greece, and in particular, the scale and direction of maritime exchange of ceramic vessels. Turning our attention to the northern Aegean, we have focused on a diverse assemblage of Neolithic ceramics from the Cave of the Cyclops on the island of Youra in the Sporades (Fig. 1). The Cave appears to have been frequented mainly on an occasional basis during the Neolithic, yet it contains a rich ceramic assemblage that bears close stylistic links with other islands, notably with the settlement of Aghios Petros on the nearby island of Kyra-Panagia, as well as mainland Greece (Sampson, 1996a, 1998, 2008a). No direct evidence of ceramic production has been found on Youra and suitable clay sources are scarce on this barren, rocky, uninhabited island today. Clearly much of the Neolithic pottery found in the Cave of the Cyclops cannot have been local in origin.

Using a combination of thin section petrography and instrumental neutron activation analysis (INAA) we have examined the composition and technology of pottery from the two phases of earliest Middle Neolithic (MN) and Late Neolithic I (LNI) from the Cave of the Cyclops. Our analysis reveals that significant

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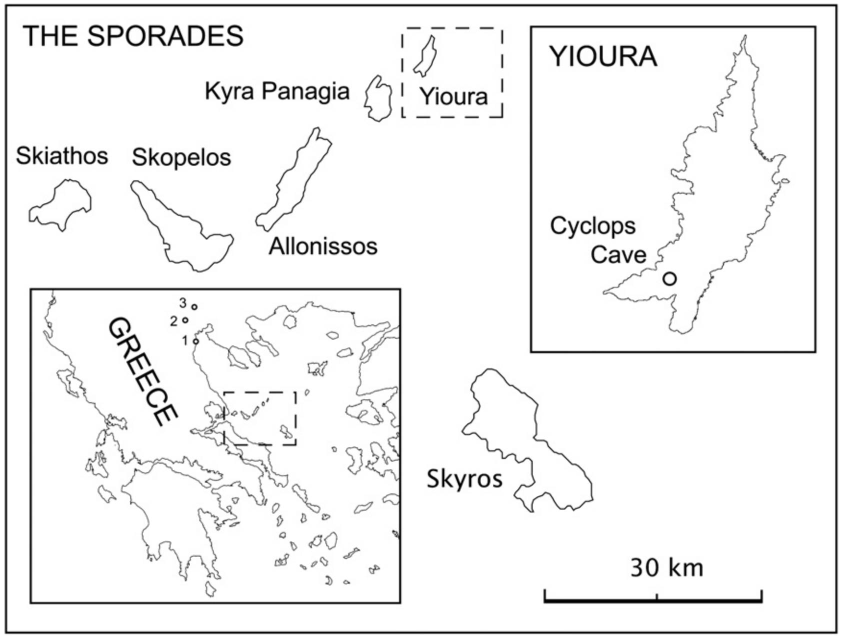

Fig. 1. Location of Youra, the Sporades and the Cave of the Cyclops. 1, Makrygialos; 2, Agrosykia; 3, Giannitsa.

compositional variability exists within the assemblage, which mirrors that seen in the typology of the ceramics. Close correspondence between the petrography and chemistry of the analysed sherds has allowed us to identify numerous well-defined compositional groups that reflect differences in both raw materials and production techniques. With the exception of a common group that occurs throughout the Neolithic sequence and may represent a 'local' ceramic tradition of the northern Sporades, many coarse and painted sherds are incompatible with a provenance on Youra or Kyra-Panagia. By comparing our analysis with local and regional geology, as well as the results of other analytical studies of Neolithic ceramics from the Sporades and Thessaly, we have identified several candidate areas for the provenance of the non-local Neolithic ceramics deposited in the cave.

1.1. The Cave of the Cyclops and its Neolithic ceramics

The Cave of the Cyclops is situated on the island of Youra in the northern Aegean (Fig. 1). Youra is one of the Erimonisa or 'Deserted Islands', lying at the northeastern end of the Sporades chain. A large (c. 50×60 m) natural cave was discovered some 40 years ago on the southwest coast of Youra at around 150 m above present sea level. Surface finds of Neolithic and Roman ceramic sherds within the cave prompted its systematic archaeological investigation, which took place between 1992 and 1996 under the direction of Adamantios Sampson (Sampson, 1996a,b,c, 1998, 2008a).

Excavation in six trenches dug in the mouth and interior of the cave revealed a rich sequence of Mesolithic and Neolithic age. The earliest levels of the site contain no pottery but an abundance of fish bones, hooks and chipped stone attesting to its seasonal exploitation by Mesolithic fishermen (Moundrea-Agrafioti, 2003; Mylona, 2003; Kaczanowska and Kozlowski, 2008). The overlying Neolithic strata, which are recorded in several trenches, are characterised by two phases; an early MN phase dated to the beginning of the sixth millennium BC, separated by a gap of around 800–1000 years from a later phase equivalent to LNI, which should be placed around the end of the sixth and the beginning of the fifth millennium BC.

The excavation of these two phases unearthed a diverse assemblage of coarse- and fineware ceramics with stylistic similarities to other sites in the Sporades and mainland Greece. Of particular interest are sherds of a high quality red-on-white painted fineware bearing weaving-inspired geometric motifs referred to as 'canvas' (Katsarou-Tzeveleki, 2008, 2009), which is represented by about 100 excavated sherds and is common in the MN phase of the site (Fig. 2). The similarity between these ceramics and material excavated by Efstratiou (1985) from the contemporary site of Aghios Petros on Kyra-Panagia may provide evidence for the existence of a single 'Youra-Aghios Petros culture' in the Northern Sporades (Sampson, 1998; Katsarou, 2001; Katsarou-Tzeveleki 2008, 2009; Sampson, 2008a) and should be dated to the earliest phase of the MN on the basis of stylistic criteria. The rich Late Neolithic ceramic assemblage of the Cave of the Cyclops, which suggests more intense human activity in the later phase, contains examples of several well-known types of Neolithic decoration, such as rope, incised and impressed patterns, burnished and the white-on-dark technique.

No evidence of ceramic production has been reported from excavations at the Cave of the Cyclops or surface surveys elsewhere on Youra. The island is composed almost entirely of hard Jurassic and Cretaceous limestone and is devoid of extensive clay deposits. Youra contains few natural springs and is covered today by poor soil, which supports only sparse vegetation. In the light of these shortcomings, the diverse Neolithic ceramic assemblage of the Cave stands out.

Youra is separated by distances of a few kilometers from other islands in the northern Sporades and forms part of a natural bridge between Thessaly and Asia Minor which also includes Lemnos and Euboea (Fig. 1). Sea currents are strong in the northern Aegean at certain times of the year and would have favoured communication with other islands as well as with the mainland of Greece. With this in mind, the ceramic assemblage of the Cave of the Cyclops represents an excellent case through which to investigate the mobility of ceramics in Neolithic Greece.

1.2. Previous analytical studies on Neolithic ceramics of the Sporades and Thessaly

The investigation of Liritzis et al. (1991), a comparison of the characteristic red-on-white painted ware from Aghios Petros on Kyra-Panagia to contemporary ceramics from Dimini and Sesklo on

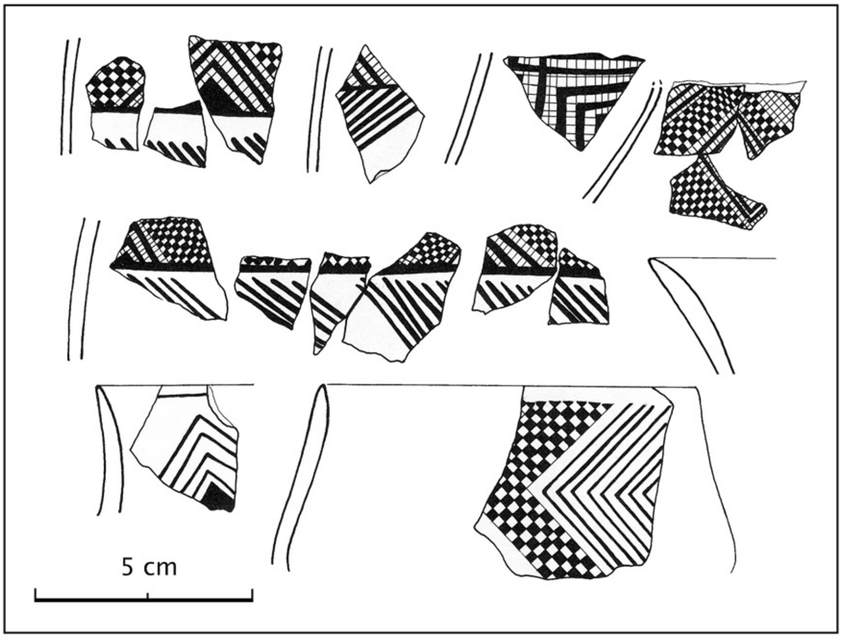

Fig. 2. Red-on-light painted pottery bearing geometric motifs reminiscent of canvas or weaving that is characteristic of the MN phase of the Cave of the Cyclops (from Sampson, 1998, p. 6, Fig 6).

the Thessalian Plain using instrumental neutron activation analysis (INAA), represents the only previously published analysis of Neolithic ceramics from the Sporades (Fig. 3). Based on six elements (Cs, Sc, Eu, Th, Fe and Co), the Aghios Petros sherds were found to be compositionally distinct from the Thessalian material. Liritzis et al. (1991) identified three chemical subgroups within the 24 Neolithic sherds analysed from Aghios Petros, perhaps representing the use of slightly different clays.

Several published studies have brought analytical techniques to bear on the provenance and technology of ceramics from important Neolithic sites in Thessaly on the Greek mainland (Fig. 3). The most extensive of these is the work of Schneider et al. (1991, 1994), which applied X-ray fluorescence (XRF) to some 200 Neolithic surface finds from numerous sites including Sesklo, Dimini, Makrychori and Platia Magoula Zarkou, comparing the results to a large databank of clay samples. At Sesklo and Dimini, Schneider et al. (1991)

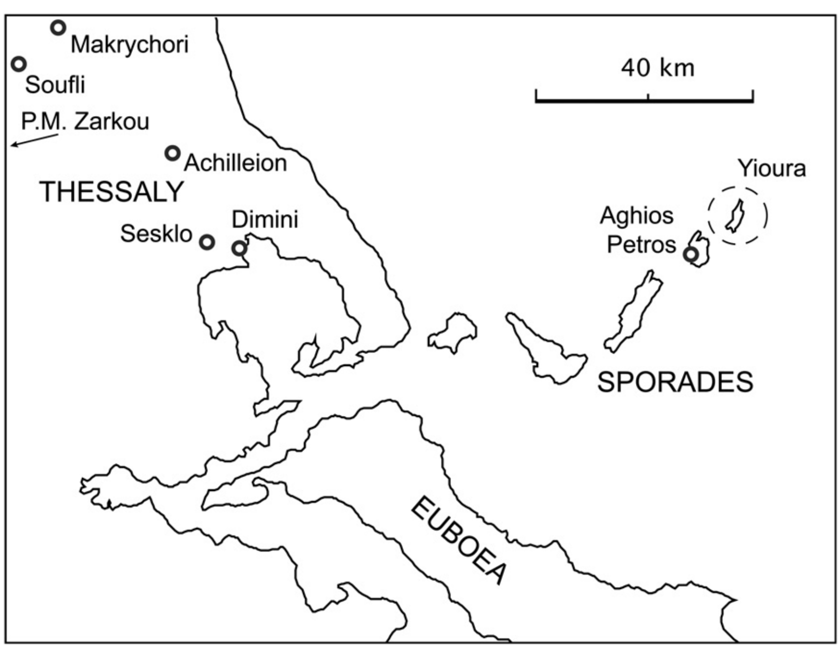

Fig. 3. Location of sites covered by previous analytical studies of northern Aegean ceramics. Aghios Petros (Liritzis et al., 1991), Dimini (Liritzis et al., 1991; Schneider et al., 1991, 1994; Hitsiou, 2003), Sesklo (Maniatis et al., 1988; Liritzis et al., 1991; Schneider et al., 1991, 1994), Makrychori (Schneider et al., 1991, 1994), Achilleion (Ellis, 1989), Platia Magoula Zarkou (Schneider et al., 1991, 1994).

suggested that different local clays could have been selected for the production of specific types of ceramics. Chemical analysis also permitted the distinction between the ceramics from different Thessalian sites, related to differences in the geochemistry of the local clays or temper.

Other analyses relevant to the present investigation include the petrographic analysis of Neolithic ceramics from Achilleion by Ellis (1989) and Bjork (1995), as well as the extensive study of Late Neolithic pottery production technology and circulation from Makrygialos in Pieria by Hitsiou (2003) (Fig. 3). The latter demonstrated that Thessalian brown-on-cream ware may have been transported a distance of around 200 km in Neolithic times.

At some Neolithic sites, previous compositional studies have therefore supported an assumed link between ceramics and locally available raw materials, whereas at others it remains to be rigorously tested. More crucially, some studies have provided compositional evidence for limited but unexpected movement of ceramics between Neolithic sites on mainland Greece.

2. Materials and methods

Sixty-three ceramic samples were selected from the Neolithic assemblage of the Cave of the Cyclops; 41 from the MN phase and 22 from the LNI phase of the site. These samples, listed in Table 1, include both fine- and coarsewares and were selected to cover the range of decorative styles present.

Standard petrographic thin sections were prepared from each ceramic sample at the Fitch Laboratory, Athens and studied with the polarizing light microscope at the Department of Archaeology, University of Sheffield. The individual thin sections were grouped and separated into fabric classes based upon the nature of their dominant non-plastic inclusions, their clay matrix and textural characteristics (Table 1). These compositional groups were described in detail using a modified version of the methodology proposed by Whitbread (1989, 1995, p. 379–388) (Supplementary Appendix A). The main characteristic features of each fabric class were then summarized and, wherever possible, an interpretation of ceramic technology was based upon the evidence seen in thin section.

Chemical analysis of the ceramic samples was performed by INAA following the routine measurement procedure applied to ceramics (Kilikoglou et al., 2007). The external surface of each sample, weighing approximately 1 g, was cleaned with a tungsten carbide drill and then ground to a fine powder. This powder was dried at 110 °C and 150 mg was then carefully weighed into a polyethylene vial, which was heat-sealed. The 63 separate vials were irradiated in batches of 10 with two SOIL-7 standard reference samples in the Demokritos swimming pool reactor at the National Centre for Scientific Research, Athens. The γ-spectra of the samples were measured after 1 week with an HPGe detector to determine the concentration of Sm, Lu, U, Yb, As, Sb, Ca, Na, and La, then after 3 weeks for the elements Ce, Th, Cr, Hf, Cs, Tb, Sc, Rb, Fe, Ta, Co and Eu. The full analytical data for the 21 elements analysed in each of the 63 ceramic samples is presented in Supplementary Appendix B.

Direct comparison was made between the different compositional groupings of the 63 ceramic samples produced by petrography and chemistry. Consideration of the detailed thin section descriptions (Supplementary Appendix A) and the concentrations of individual elements (Supplementary Appendix B) provided a means of reconciling differences between the petrographic and chemical groups, as well as providing a cross-check for the two methods of classification. Finally, the provenance of the main robust compositional groups of ceramics in the Cave of the Cyclops material was interpreted by comparison with geological maps,

Table 1
Details of the 63 Neolithic ceramic samples from the Cave of the Cyclops analysed in this study, with their petrographic and chemical classification.

Sample	Level	Decoration/ware	Petrographic class	Chemical group
1	MN	Red monochrome	Limestone Fabric Group	1a
2	MN	Red monochrome	Limestone Fabric Group	1a
3	MN	Red monochrome	Limestone Fabric Group	1a
6	MN	Coarseware	Limestone Fabric Group	2
7	MN	Coarseware	Limestone Fabric Group	1a
9	MN	Burnished	Limestone Fabric Group	1a
11	MN	Coarseware	Limestone Fabric Group	1a
12	MN	Coarseware	Limestone Fabric Group	1a
13	MN	Coarseware	Limestone Fabric Group	1a
14	MN	Coarseware	Limestone Fabric Group	1a
16	MN	Coarseware	Limestone Fabric Group	–
20	MN	Burnished	Limestone Fabric Group	1a
23	LNI	Burnished	Limestone Fabric Group	1a
24	LNI	Burnished	Limestone Fabric Group	1a
25	LNI	Burnished	Limestone Fabric Group	1a
28	LNI	Coarseware	Limestone Fabric Group	1a
33	MN	Fineware	Limestone Fabric Group	1a
34	MN	Fineware	Limestone Fabric Group	1a
35	MN	Fineware	Limestone Fabric Group	1a
36	MN	Fineware	Limestone Fabric Group	1a
37	MN	Fineware	Limestone Fabric Group	1a
38	MN	Fineware	Limestone Fabric Group	1a
39	MN	Fineware	Limestone Fabric Group	1a
40	MN	Fineware	Limestone Fabric Group	1a
41	MN	Coarseware	Limestone Fabric Group	-
42	MN	Coarseware	Limestone Fabric Group	1a
43	MN	Coarseware	Limestone Fabric Group	1a
44	MN	Coarseware	Limestone Fabric Group	1a
45	MN	Coarseware	Limestone Fabric Group	1a
46	MN	Coarseware	Limestone Fabric Group	1a
47	MN	Coarseware	Limestone Fabric Group	1a
48	MN	Red-on-white	Limestone Fabric Group	1a
49	MN	Red-on-white	Limestone Fabric Group	1a
50	MN	Red-on-white	Limestone Fabric Group	1a
51	MN	Light-on-red	Limestone Fabric Group	1a
52	MN	Light-on-red	Limestone Fabric Group	1a

(*continued on next page*)

Table 1 (*continued*)

Sample	Level	Decoration/ ware	Petrographic class	Chemical group
10	MN	Burnished	Phyllite Fabric Group	–
17	MN	Coarseware	Phyllite Fabric Group	–
22	LNI	Coarseware	Phyllite Fabric Group	–
26	LNI	Coarseware	Phyllite Fabric Group	–
27	LNI	Coarseware	Phyllite Fabric Group	–
29	LNI	Coarseware	Phyllite Fabric Group	–
32	LNI	Coarseware	Phyllite Fabric Group	–
56	LNI	Matt-painted	Fine Mica and Quartz Fabric Group	2
59	LNI	Matt-painted	Fine Mica and Quartz Fabric Group	2
61	LNI	Matt-painted	Fine Mica and Quartz Fabric Group	2
62	LNI	Matt-painted	Fine Mica and Quartz Fabric Group	2
63	LNI	Matt-painted	Fine Mica and Quartz Fabric Group	2
15	MN	Red monochrome	Tuff Fabric Group	5
19	MN	Burnished	Tuff Fabric Group	5
57	LNI	Matt-painted	Serpentinite Fabric Group	4
60	LNI	Matt-painted	Serpentinite Fabric Group	4
21	LNI	Burnished	Grog and Phyllite Fabric Group	–
54	MN	Pattern burnished	Grog and Phyllite Fabric Group	3
55	MN	Pattern burnished	Grog and Phyllite Fabric Group	3
4	MN	Red matt-painted	Calcareous Grog Fabric Group	1a
5	MN	Red matt-painted	Calcareous Grog Fabric Group	1a
8	MN	Coarseware	Grog Fabric Group	–
31	LNI	Coarseware	Grog Fabric Group	–
64	LNI	Matt-painted	Schist Fabric	–
53	LNI	White-on-dark	Polycrystalline Quartz Fabric 1	–
30	LNI	Coarseware	Polycrystalline Quartz Fabric 2	–
18	LNI	Burnished	Clay and Phyllite Fabric	–

reports and the results of the comparative analytical studies of Greek Neolithic ceramics discussed above.

3. Results

3.1. Petrography

In thin section, the 63 Neolithic ceramic samples analysed from the Cave of the Cyclops could be subdivided into a total of 13 different petrographic classes (Table 1). Over half of the samples taken are characterised in thin section by the presence of elongate inclusions of partially metamorphosed limestone in a generally calcareous clay matrix (Fig. 4a). The samples in this large homogeneous petrographic class (Limestone Fabric Group) appear to have been produced by the addition of a quantity of poorly sorted foliated limestone temper to non-calcareous red clay containing natural quartz inclusions. Both coarse and fine variants of this paste recipe occur in the cave material, as well as sherds with a range of decorative styles (Table 1). The Limestone Fabric Group occurs in both the MN and LNI assemblages at the site.

Some seven samples contained a range of low-grade metamorphic rock fragments and associated argillaceous and arenaceous sedimentary rocks (Phyllite Fabric Group) (Fig. 4b). It is not clear whether this material represents temper or occurred naturally in the clay used for the manufacture of these ceramics. Samples with this petrographic composition occur in both phases and all but one of the samples analysed came from undecorated coarseware vessels. A group of five matt-painted LN samples were found to possess a homogeneous, fine non-calcareous paste with small residual quartz and mica inclusions of metamorphic origin. These sherds form the Fine Mica and Quartz Fabric Group (Fig. 4c). Several other individual LN samples also contain inclusions derived from metamorphic rocks, such as biotite- and muscovite-schist (Schist Fabric) and polycrystalline quartz (Polycrystalline Quartz Fabric 1 and Polycrystalline Quartz Fabric 2).

Two highly distinctive petrographic compositions in the assemblage are characterised by the presence of fresh, and highly altered igneous rock fragments respectively. The Tuff Fabric Group (Fig. 4d) contains a range of inclusions of volcanic origin, including tuff, andesite and well-formed crystals of plagioclase and hornblende, in a dark, non-calcareous clay matrix. The fresh nature of these volcanic inclusions suggests that they represent temper rather than the residual inclusions of clay formed from the *in situ* weathering of igneous rock. Both samples of the Tuff Fabric Group come from the MN phase, but have different surface treatments. Within the Serpentinite Fabric Group (Fig. 4e) are two matt-painted LN samples containing numerous yellow and orange, rounded serpentinite fragments. These distinctive fibrous inclusions, which can exhibit relic mineral structures, represent highly altered fragments of a basic igneous rock, such as dolerite or basalt. Their orange colour results from the firing of the ceramics.

Several fabric groups contained evidence of crushed ceramic temper or 'grog'. The identification of grog in thin sections of archaeological ceramics can be problematic (Whitbread 1986; Cuomo di Caprio and Vaughan 1993). However, possible relic vessel surfaces and slip layers can be observed in some samples. Grog inclusions occur alongside phyllite (Grog and Phyllite Fabric Group), limestone (Calcareous Grog Fabric Group) or as the dominant type of aplastic inclusion (Grog Fabric Group). In the latter, it appears that several different types of crushed pottery were used as temper. Some samples were found to contain 'second generation grog' (Fig. 4f) indicating that sherds were crushed and recycled several times. The two Calcareous Grog Fabric Group samples are both red-on-white pattern painted and come from the MN phase of the cave.

In addition to the three grog groups, several of the other fabric classes within the Neolithic ceramics of the Cave of the Cyclops can be linked to one another by the presence of distinctive shared inclusions or petrographic features. For example, rare inclusions of foliated limestone, characteristic of the Limestone Fabric Group, occur in the Polycrystalline Quartz Fabric 2 sample (Fig. 4g). Distinctive inclusions of what appears to have been a fine, dried, orange clay that characterise the Clay and Phyllite Fabric (Fig. 4h) also occur in several other petrographic classes.

3.2. Chemistry

The statistical analysis of the data was performed by excluding the concentrations of particular elements due to either relatively poor counting statistics (As, Sb) or extreme natural variability

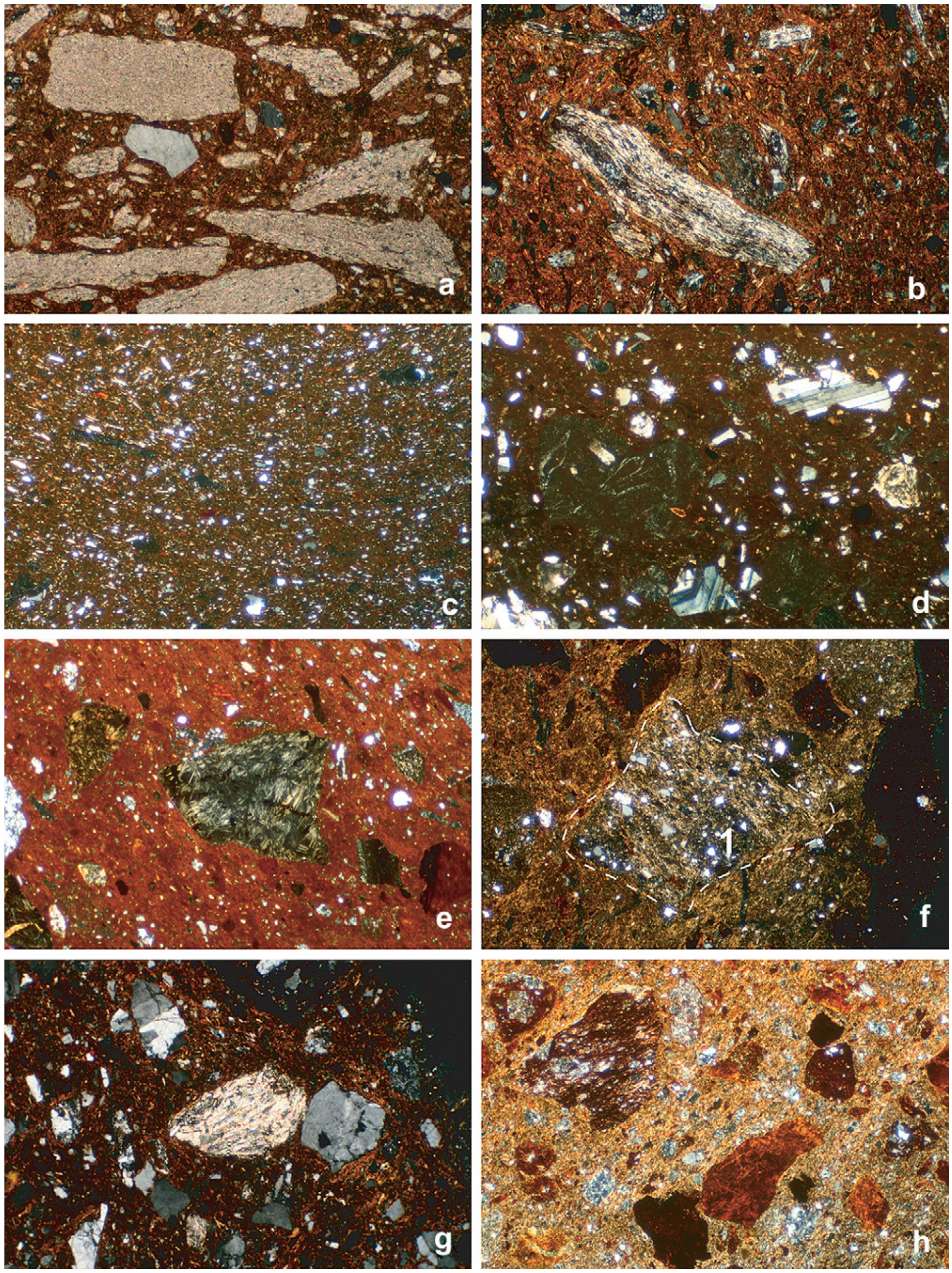

Fig. 4. Thin section photomicrographs of selected Neolithic ceramics from Cave of the Cyclops analysed in this study. Limestone Fabric Group (a), Phyllite Fabric Group (b), Fine Mica and Quartz Fabric Group (c), Tuff Fabric Group (d), Serpentinite Fabric Group (e), Grog Fabric Group, with grog (dashed line) containing probable second generation grog (1) (f), Polycrystalline Quartz Fabric 2, with foliated limestone inclusion (g), Clay and Phyllite Fabric (h). All micrographs taken with crossed polars. Field of view 2.0 mm, except (g) 1.5 mm.

(Ta, Tb) that would obscure any existing natural variability within different provenance groups (Weigand et al., 1977). The final dataset submitted to statistical analysis comprised of 63 samples and 17 elements.

The chemical variability within the compositional dataset was estimated by determining its total variation, following the approach of Buxeda i Garrigós and Kilikoglou (2003). Using this method an $n \times n$ variation matrix (T) is generated, with n being the number of element concentrations, and $\tau_{ij} = \mathrm{var}\{\log(x_i/x_j)\}$ (Aitchinson, 1986), the matrix elements, which present the variances of the element concentrations, expressed as logarithmic ratios. In this way all elements are used successively as a devisor in these ratios. The total variation of the data is then given by:

$$\nu_t = \sum_{ij} \frac{\tau_{ij}}{2n}$$

The sum τ_s of the variances in a particular column of the variation matrix gives the contribution to the total variation, of the element s, which in this case has been used as divisor. Therefore a high ratio v_t/τ_s indicates small variability of the respective element (Buxeda i Garrigós, 1999).

Following the above approach, a v_t of 4.47 was calculated for the complete dataset of ceramics from the Cave of the Cyclops. This value indicates the existence of groups with very large chemical differences among them (Buxeda i Garrigós and Kilikoglou 2003). However, Ca values introduce by far most of this variability since its

v_t/τ_s ratio is 0.09, ten times higher than the next smallest. Indeed all ceramic samples containing limestone exhibit Ca values well above 10%, with the others being either non-calcareous or low calcareous. When Ca was removed from the calculation, the v_t value of the complete dataset dropped to 1.67, demonstrating its effect on the total variability. A v_t of 1.67 indicates either the existence of several rather indistinct chemical groups, or of one group with several outliers. This is compatible with the picture derived from the thin section petrography, which points to a single large limestone fabric group with several other small but distinct groups.

In all v_t calculations, the elements with the least contribution to the variability were found to be the rare earths. According to Buxeda i Garrigós (1999) the elements with low variability are the least likely candidates to have been affected by alterations or contaminations during burial. In order to compensate for the effect of post-depositional phenomena as well as differential tempering, all concentrations were expressed as logarithmic ratios over the element Lu, which exhibited the highest v_t/τ_j (Aitchinson, 1986). Cluster analysis was then performed on the whole dataset, producing the resulting dendrogram shown in Fig. 5.

The main feature of the dendrogram is that most samples on the left side are from the LN phase of the Cave of the Cyclops, whereas the majority of the samples on the right side are from MN contexts. This subdivision is likely to reflect the dominance in MN levels of samples from the large Limestone Fabric Group. With the exception of a few outliers, the samples belonging to this fabric class cluster well in the dendrogram. However, the chemical analysis seems to indicate that significant compositional variation exists in the form of several smaller clusters (Chemical Groups 1a, 1b, 1c) (Fig. 5). Given that the concentration of Ca is more or less uniform in all Limestone Fabric Group samples, these individual chemical groups may reflect differences in the composition of their base clay, rather than variations in the origin or abundance of the limestone temper. Chemical Group 1c on the far right side of the dendrogram is distinguished from the other two closely related clusters of Limestone Fabric Group samples due to its low rare-earth concentrations.

In comparison to the Limestone Fabric Group, the samples belonging to the Phyllite Fabric Group did not group well in terms of their chemistry. Whilst two samples of this petrographic class were associated chemically with one another, the majority were spread across the left side of the dendrogram (Fig. 5). This indicates that the samples included in the Phyllite Fabric Group may be less closely related compositionally than is suggested by their shared petrographic characteristics.

Chemical Group 2 in the middle of the dendrogram consists of a tight cluster of five LN samples belonging to the Fine Mica and Quartz Fabric Group, plus a single Limestone Fabric Group sample (Fig. 5). This group is characterised by a high Th concentration,

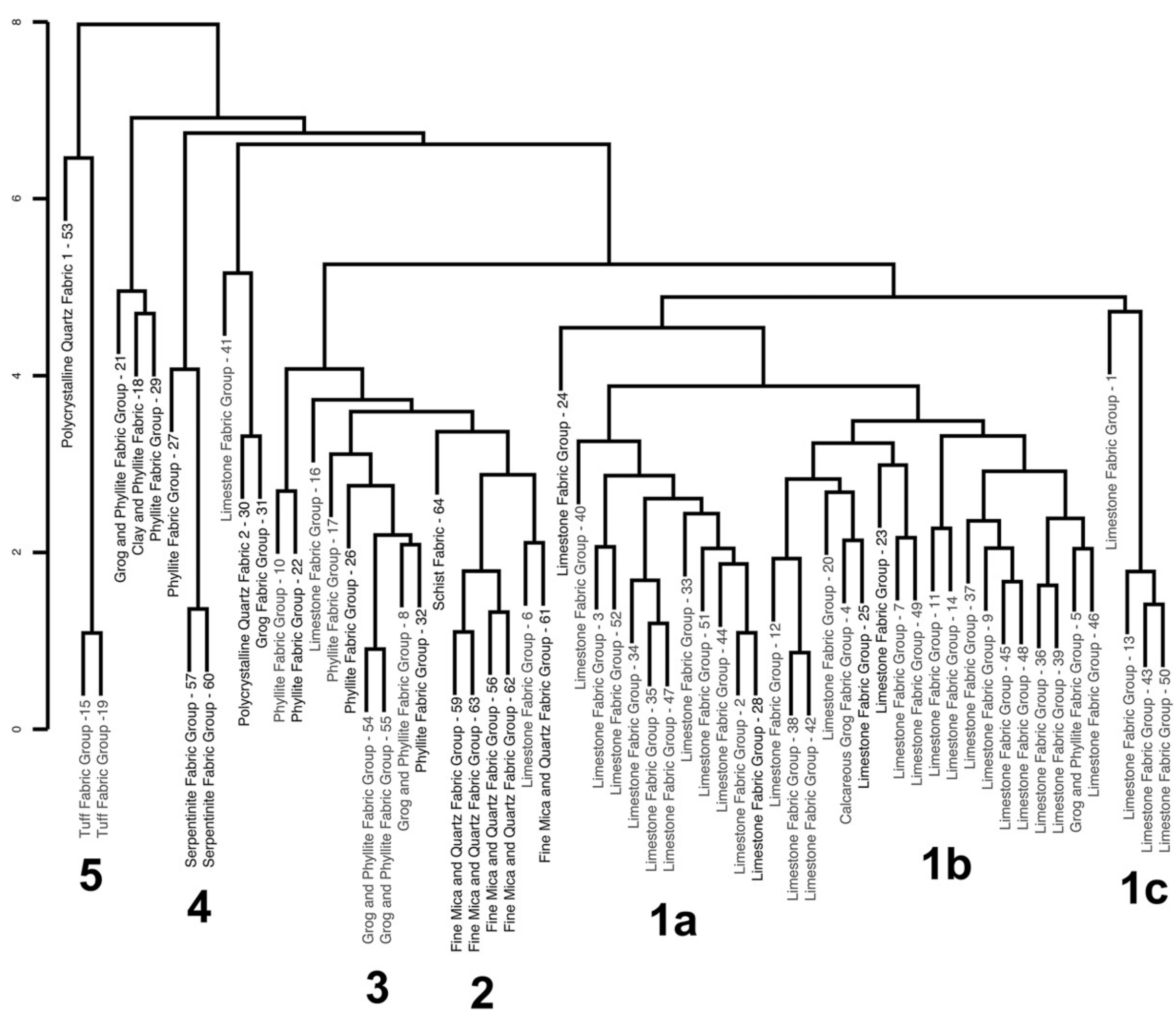

Fig. 5. INAA dendrogram of the Neolithic ceramics from Cave of the Cyclops analysed in this study. MN samples in grey, LNI samples in black. Dashed line indicates broad split in dendrogram between MN and LNI samples. Well-defined chemical groups are indicated by ellipses.

which is indicative of a distinctive base clay. The close chemical composition of the Fine Mica and Quartz Fabric Group samples in Chemical Group 2, correlates well with their petrographic homogeneity observed in thin section. Limestone-tempered sample 6, which also appears in this cluster has a base clay that is compatible to the members of Chemical Group 2 and different to the other 36 Limestone Fabric Group samples.

Three additional small chemical groups, each consisting of two samples, were formed by the cluster analysis of the ceramic samples analysed from the Cave of the Cyclops. Chemical Group 3 contains two of the three samples from the Grog and Phyllite Fabric Group (Fig. 5). The main characteristic of this cluster is its high rare-earth element concentrations. The other Grog and Phyllite Fabric Group sample has a very different chemical signature and therefore appears as an outlier elsewhere in the dendrogram. Chemical Group 4, characterised by high Cr, Fe and Sc, relates well to the distinctive LN Serpentinite Fabric Group (Fig. 5) and Chemical Group 5, characterised by the highest and lowest Th and Cr concentrations respectively contains both samples of the MN Tuff Fabric Group.

Of the four petrographic fabric classes composed of single samples or 'loners', both the Schist Fabric and the Clay and Phyllite Fabric were found to be chemically unique in the cluster analysis of the 63 ceramic samples. Finally the two samples belonging to the Grog Fabric Group appear as outliers and have no chemical affinities between them or with the rest of the chemical groups identified.

3.3. Provenance of Neolithic ceramics from the Cave of the Cyclops

The 63 Neolithic ceramic samples analysed from the Cave of the Cyclops are compositionally diverse. Several distinctive ceramic paste recipes have been identified by our complementary petrographic and chemical analyses. The high degree of correlation between the results of the two methods suggests that the compositional groups are real and archaeologically meaningful. This compositional variability correlates also with differences in typology. The occurrence at the Cave of the Cyclops of a range of ceramic styles, produced from several different types of raw materials, suggests that pottery from a variety of sources was deposited here during Neolithic times.

The dominant limestone-tempered Neolithic ceramics (Limestone Fabric Group) are compatible with an origin on Youra or Kyra-Panagia, which are geologically more or less identical. The bulk of both islands consist of limestone of Jurassic and Cretaceous age (Psarianos and Charalambakis, 1951). The Jurassic limestone on the inaccessible east coast of Youra is described as being intensely tectonised and microfolded (IGME 1984) (Fig. 6), which corresponds well with the foliated limestone inclusions found in the ceramics. However, extensive deformation also occurs in the heavily faulted Cretaceous limestone that covers the majority of Youra and Kyra-Panagia. The rocky, barren nature of both islands suggests that extensive clay sources are likely to be rare. Nevertheless, the dominance of the Limestone Fabric Group in both MN and LNI levels at the Cave of the Cyclops and its occurrence in a range of coarse- and fineware styles indicates that it could have been produced locally. Indeed the Limestone Fabric Group contains several examples of the canvas-painted red-on-white decoration that is thought to be a local phenomenon to the northeastern Sporades (Katsarou-Tzeveleki, 2008). In their analysis of red-on-white ceramics from Aghios Petros, Liritzis et al. (1991) identified a number of chemical subgroups. Their finding seems to be mirrored by the chemical diversity of the Limestone Fabric Group in this study, within which three separate clusters (Chemical Groups 1a, 1b, 1c) have been identified.

Several of the identified compositional groups are geologically incompatible with a source in the local area. For example, rocks of

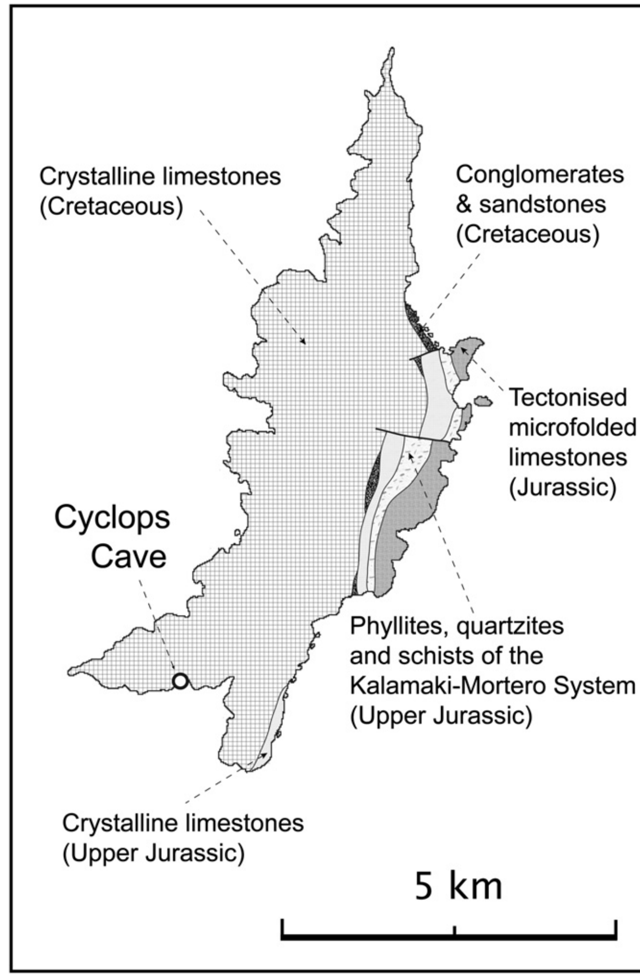

Fig. 6. Geological map of Youra (after Psarianos and Charalambakis, 1951; IGME, 1984).

volcanic origin, such as those, which characterise the distinctive MN Tuff Fabric Group/Chemical Group 5, do not occur on Youra, or on the geologically identical, neighbouring island of Kyra-Panagia (IGME, 1984; Psarianos and Charalambakis, 1951) (Fig. 6). The ceramics of this composition are therefore non-local in origin. The nearest source of volcanic tuff to Youra is an isolated occurrence on northern Skyros (IGME, 1989) (Fig. 7). However, extensive acid and intermediate volcanic tuffs that are closer in composition to the ceramics of the Tuff Fabric Group occur extensively on the northern Aegean island of Agios Efstratios, as well as on Lemnos, Lesbos and Gökçeada (Imbros) further to the east (IGME, 1983) (Fig. 7). Contemporaneous pottery, related stylistically to the LNI red monochrome and burnished Tuff Fabric Group samples from Youra has been recovered from a low mound near the village of Uğurlu on the western part of Gökçeada (Erdoğu, 2003). Typological links also exist between Youra and Poliochni on Lemnos in the form of white-on-dark LNI sherds that occur on both islands (Sampson, 1996a, 1998; Mavridis, 2008).

Another distinctive petrographic composition that could not have originated on Youra is the Serpentinite Fabric Group/Chemical Group 4. The two LN matt-painted samples belonging to this fabric class are unrelated petrographically to any other of the ceramics analysed. Their composition suggests an origin in an area containing serpentinite and metamorphic rocks. The nearest occurrences of serpentinite appear to be on the islands of Skopelos and Skyros in the Sporades (Fig. 7). Only small bodies of this rock type have been found on Skopelos (IGME, 1995). On Skyros, however,

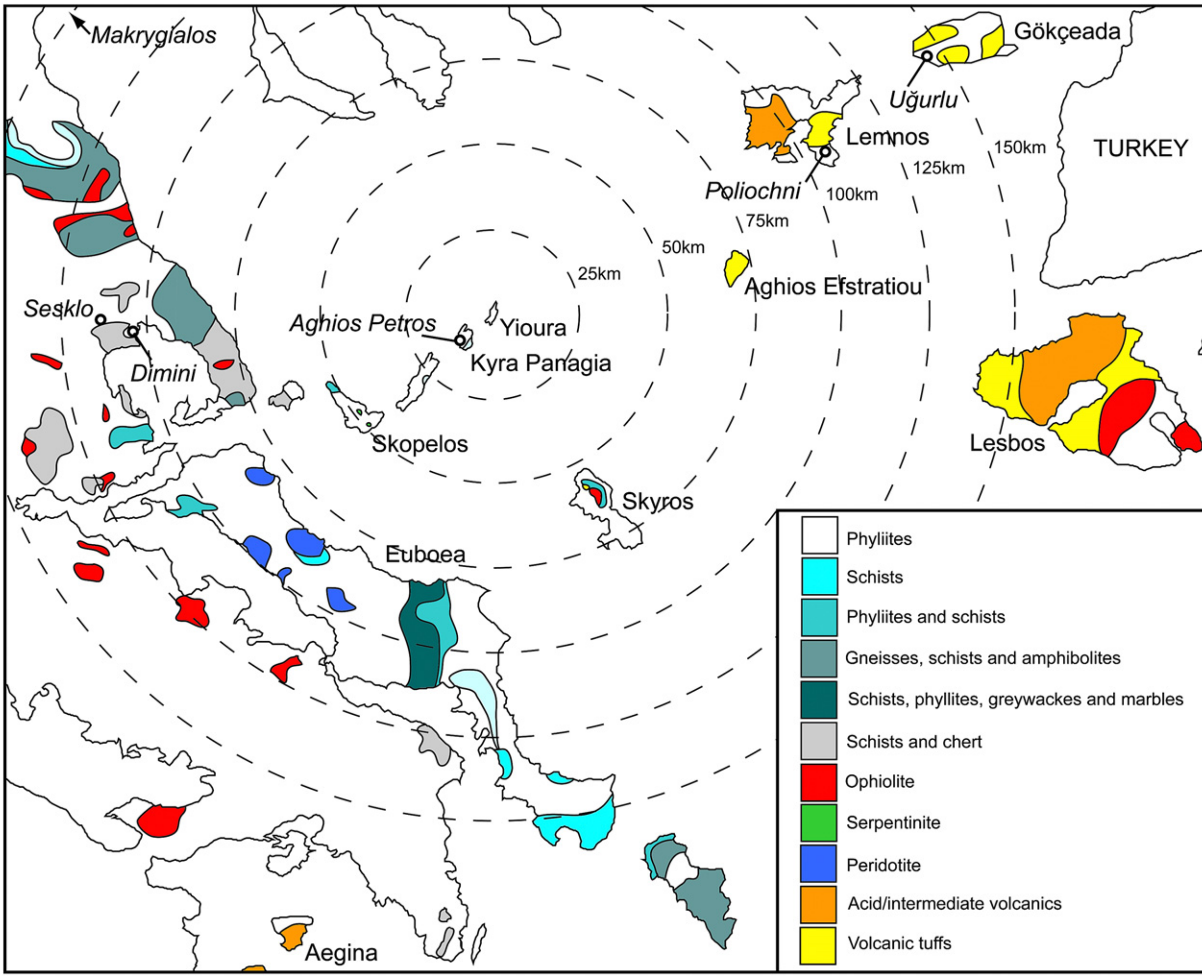

Fig. 7. Probable origins of Neolithic ceramics analysed from the Cave of the Cyclops in this study. Geology (after IGME, 1975, 1983, 1984, 1986, 1989, 1995).

serpentinite forms part of an ophiolitic complex in the centre of the island that also contains mica schists (IGME, 1989). Ophiolite bodies also occur in many places on the mainland, such as Thessaly (IGME, 1983) (Fig. 7). Indeed, Schneider et al. (1991) found that coarse Neolithic ceramics from Soufli contained rounded inclusions of serpentinite, alongside metamorphic rocks such as gneisses and mica schists, and Hitsiou (2003) recorded rare serpentiniferous ceramics at Dimini. Serpentinite commonly derives from the alteration of ultrabasic igneous rocks, such as peridotite. Rocks of this composition occur in many areas of northern Euboea (IGME, 1983). Therefore this group of ceramics has a number of possible sources in neighbouring islands and on the mainland.

Several petrographic groups and individual samples within the Cave of the Cyclops ceramics are characterised by material of metamorphic origin. Most common among these are several MN and LN coarseware ceramics of the Phyllite Fabric Group. The fine-grained biotite, chlorite and muscovite-rich metamorphic rock fragments that characterise these ceramics are geologically compatible with in the 'Kalamaki-Mortero System', which has outcrops on both Youra and Kyra-Panagia (Fig. 6). This group of low-grade metamorphic rocks contains phyllites of various compositions (IGME, 1984). However, on both islands, this metamorphic unit outcrops in steep rocky sea cliffs on the east coast, where Jurassic strata are exposed. As such it may not have been easily accessible from the known Neolithic sites on the western side of both islands.

Chemical analysis indicates that the seven samples of the Phyllite Fabric Group may not be as closely related as is suggested by their petrography. It is therefore possible that they came from more than one source. Furthermore, the rare occurrence in thin section of altered basic igneous inclusions suggests that at least some of these samples could not have originated on Youra or Kyra-Panagia. Phyllites and other low-grade metamorphic rocks occur on several other islands in the Sporades, including Skopelos, Skyros, Skiathos and Alonnissos, as well as on Euboea and in Thessaly (IGME, 1975, 1983, 1989, 1995). The co-occurrence in some Phyllite Fabric Group samples of phyllite, altered basic igneous inclusions and rocks of argillaceous and arenaceous sedimentary origin is compatible with the geology of north-western Skopelos, which contains metabasalts, metaclastics and low-grade metamorphic rocks (IGME, 1995).

Late Neolithic samples 30 (Polycrystalline Quartz Fabric 2), 53 (Polycrystalline Quartz Fabric 1) and 64 (Schist Fabric) are characterised in thin section by inclusions deriving from schistose metamorphic rocks. Schists do not appear to be present on Youra or Kyra-Panagia, but occur on several other islands in the Sporades including Skyros and Skopelos (IGME, 1989, 1995) (Fig. 7). Neolithic ceramics containing schist and quartzite inclusions have been reported from several Thessalian sites including Sesklo (Maniatis et al., 1988), Achilleion (Ellis, 1989; Bjork, 1995), Soufli (Schneider et al., 1991) and Dimini (Hitsiou, 2003). Unfortunately, the quartz-mica schist inclusions in samples 30 and 64 contain little additional evidence that could be suggestive of a more precise origin. However, the occurrence of schistose inclusions with feldspar porphyroblasts in the Polycrystalline Quartz Fabric 1 (sample 53) may link this sample to the schists of the 'Glossa Unit' on Skopelos, which also contains feldspar (IGME, 1995). The heavily deformed, quartz-rich cataclastic inclusions in Polycrystalline Quartz Fabrics 1 and 2 (samples 53 and 30) could originate from one of several metamorphic units in the Sporades, although breccias have been reported specifically from an extensive schistose formation on Skyros (IGME, 1989).

The five matt-painted LN ceramic samples belonging to Fine Mica and Quartz Fabric Group/Chemical Group 2 may also have been made of raw materials with a metamorphic origin. Late Neolithic brown-on-cream pottery with an almost identical petrographic composition have been analysed by Hitsiou (2003) from Dimini, Makrygialos, Agrosykia and Giannitsa (Fig. 1). These ceramics are thought to have been produced close to Dimini and exchanged over long distances.

Ceramics characterised by the presence of grog in thin section are difficult to provenance because of the non-diagnostic nature of their dominant inclusions. An exception is the Calcareous Grog Fabric Group, which bears strong petrographic similarities to Late Neolithic ceramics analysed by Hitsiou (2003) from Dimini. The presence of rare inclusions such as phyllite (Grog and Phyllite Fabric Group) and limestone (Calcareous Grog Fabric Group) in some grog-tempered ceramics might link them to other samples with more certain origin. Similarly, LN burnished sample 18 (Clay and Phyllite Fabric) may be related to the ceramics of the Phyllite Fabric Group, and sample 30 (Polycrystalline Quartz Fabric 2), which contains a single distinctive foliated limestone inclusion was probably produced in the same general area as the dominant Limestone Fabric ceramics.

Based upon the possible source areas for the Cyclops Cave samples, there appears to be a higher proportion of exotic ceramics in LNI than MN, with a corresponding reduction in the 'local' Limestone Fabric Group within the samples analysed. Short- and long-range imports occur in both phases of the site, although some distinct differences in the exact sources of the ceramics may be present.

4. Discussion and conclusions

The combined petrographic and chemical analysis of the MN and LNI ceramic samples from the Cave of the Cyclops has revealed a compositionally diverse assemblage with a range of different broadly local and off-island sources. This evidence adds to the emerging picture of widespread pottery exchange and consumption during the Neolithic of Greece.

In terms of local production, the strongest candidate for a source on Youra or Kyra-Panagia is the dominant Limestone Fabric Group, which includes the characteristic red-on-white vessels that are also found at Aghios Petros. It is this distinctive pottery, which is taken to join the settlement of Aghios Petros with the Cave site on Youra. They are likely to represent a local pottery tradition of this part of the northern Sporades, whose clay recipes and choices of raw materials remain more or less unchanged between the MN and LNI phases at the Cave, reflecting significant continuity in ceramic technology over some 1500 years.

In addition, the project has found evidence of pottery imported from a variety of geological sources, some of which can be correlated with probable production areas. Petrographic analysis has indicated close compositional matches between the well-defined LNI Fine Mica and Quartz Fabric Group/Chemical Group 2, the MN Calcareous Grog Fabric Group and contemporary material from Thessaly identified by Hitsiou (2003). Whilst neither of these groups are diagnostic petrographically in terms of provenance, their strong correlation with previously analysed ceramics from Dimini suggests that they originate in Thessaly, some 100 km from Youra. It is important to note that all these fragments belong to pattern-painted vessels.

Other exotic ceramic compositions recorded in the assemblage at the Cave of the Cyclops include a distinctive group dominated by serpentine and another characterised by volcanic tuff, neither of which could have been produced on Youra or Kyra-Panagia. The location of the nearest sizeable sources of serpentinite to Youra suggest that matt-painted ceramics of this tight LNI petrographic/chemical group could have been transported at least 50-75 km, from either Skyros, Euboea or Thessaly. Similarly, the distinctive tuffaceous MN red monochrome ceramics that occur at the Cave of the Cyclops must also have been imported from a distant source, with the volcanic islands of the northeastern Aegean (100-150 km) as likely candidates.

It seems that there are several sources of fabrics characterised by metamorphic inclusions. While the LNI Phyllite Fabric Group is geologically compatible with a production centre within the northern Sporades, significant variation in their chemistry could indicate that these typologically similar coarse and burnished ceramics arrived at Youra from more than one source. Previous compositional studies of material from Neolithic sites on the Thessalian plain suggest that this could be the origin of some of the metamorphic ceramic compositions recorded in the Cave of the Cyclops assemblage.

This picture of diverse sources for the Youra ceramics would seem to indicate an active exchange of both coarse and painted pottery along the Northern Sporades, from Thessaly and possibly Euboea at the western end, through the islands to volcanic sources, which are likely to be either Gökçeada or Lemnos in the east (Fig. 7). It appears that such movement of pottery is well underway as early as the beginning of the sixth millennium BC and is not a product only of the later phase of the Neolithic. Instead it should be conceived as a basic component of the island identity, ultimately depending on assimilation, connectivity and culture blending for its existence.

Our analysis of the Neolithic ceramics from the Cave of the Cyclops, along with recent typological discussion (Sampson, 2008b; Katsarou-Tzeveleki, 2008, 2009) would seem to suggest the existence of a diverse pottery assemblage. This has important implications for current theories on the function of the cave (Sampson, 2008c) and its role in possible ritual activities (Katsarou-Tzeveleki, 2008; Tomkins, 2009). Perhaps the diversity of the assemblage shows not only the regular movement of ceramic material culture at that time, but specifically the nature of deposition by ships passing Youra, before leaving the Sporades and heading to the eastern Aegean and Asia Minor. Whatever mechanism is responsible for the appearance of exotic non-local ceramics in the rich assemblage of the Cave of the Cyclops, the detailed compositional investigation presented here has demonstrated unequivocally that significant movement of pottery is already taking place in the Aegean during the Neolithic.

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Appendix. Supplementary data

Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.jas.2009.12.005

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