Trojan pithoi: A petrographic approach to provenance of Bronze Age storage vessels from Troy

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1. Introduction

The use of large vessels, called pithoi, as storage containers or for burials is a widespread phenomenon especially in the Mediterranean and the Near East. Even though the study of pithoi provides significant scientific findings regarding nutrition and economy, these vessels have received archeological interest only in the last few years (e.g., Christakis, 2005; Margomenou, 2005; Pilides, 2000; Schuster-Keswani, 2009). At Troy, a large number of pithoi have been unearthed from the beginning of the excavation in the 19th century to the present day (Blegen et al., 1958; Dörpfeld, 1902; Schliemann, 1881) (Fig. 1a and b–f). The volume of the vessels varies from about 200 L to 600 L, with some being up to 1000 L in volume and with height ranges from about 1 m to 1.80 m and diameters from about 70 cm to more than 1 m. They were in use from the Early Bronze Age (EBA) with a peak in the Late Bronze Age (LBA) Troy VIIa (ca. 1300–1190/1180 BC). The Early Bronze Age pithoi vary from those of the Late Bronze Age by displaying a neck and handles (Fig. 1d), while the shape of the Late Bronze Age is ovoid or pear-shaped with the shoulder starting immediately beneath the rim without handles (Fig. 1b, c and e). This latter form was usually sunk into the ground to their shoulder or even the rim and then covered with a stone lid (Fig. 1f). Within the citadel they are in great quantities mainly found in the magazine rooms along the inner side of the citadel wall points to a centralized storage system, as in other houses. They were also found in the lower town, even at the very edge of the settlement. The pithoi that are inside of the settlement and standing in upright position are considered to be used for storage purposes and the remaining for burial purposes (Basedow, 2000). The finding of many pithoi in the magazine rooms along the internal side of the citadel wall points to a centralized storage system, since such extended storage system cannot be domestic in nature and must have been controlled by administrative officials.

Although scientific applications in the archeological research at Troy have a long history (Wagner et al., 2003) and various types of pottery from different periods have been subjected to several archeometric studies (e.g., Felts, 1942; Guzowska et al., 2003; Knacke-Loy, 1994; Mommesen and Pavuk, 2007; Pinter, 2005), pithoi have so far received little attention (exception, Grave et al., 2013) as is the case in archeometric studies in general. This may be rooted in the traditional assumption that large vessels are generally considered to have been locally produced and not transported over significant distances due to the effort involved in their transportation. In this paper we report the results of petrographic thin section analysis of the Early Bronze and the Late Bronze Age pithoi from Troy (Fig. 1). The main aim of this study was to characterize the raw material used for the production of the selected pithos samples, to explore the relationship between archeological groups and their petrographic features, production techniques, choice strategy of the raw clays and their provenance.

2. Samples

The majority of the samples analyzed in this study belong to the Late Bronze Age period (20 samples). Additionally, three samples...
from the Early Bronze Age period and one sherd from an unknown context were also selected. On the basis of macroscopic features such as general color, matrix, density and general size of inclusions and its frequency in the matrix, the samples were first classified into 10 different archeological groups. According to standard archeological criteria the majority of the samples are considered to be local productions. We also selected some samples which are macroscopically not related to the Trojan groups and occurred infrequently and therefore they are considered to be imports. The archeological groups and their macroscopic features relevant to this study can be summarized as follows.

2.1. Late Bronze Age pithoi

2.1.1. Archeological Fabric Group 1 (AFG 1)

This is the most characteristic archeological group for the Late Bronze Age (VI Late and VIIa) at Troy. It can be divided into three main variation types with fine and coarse sub-variations. The first subgroup (AFG 1A) is characterized by a friable loose sandy matrix, with middle-coarse and fine sub-angular and angular inclusions of ca. 0.5–3 mm. The color is reddish brown or light brown (Munsell 5YR 5-7/4-6), sometimes with a grayish core. The samples selected for archeometric analysis belonging to this group are TR-2 (z7.1300.2), TR-3 (B7.18), TR-4 (z7.715 + 556), TR-5 (y8.244), TR-F (VIIγ1), and TR-B (E9.1153). Sample TR-6 (A8.671) seems to be quite similar to this group, but it contains macroscopically observed shells as additional inclusions. The second macroscopic group, AFG 1B, is characterized by a fine sandy matrix, is more compact and harder in its structure and is reddish brown or light brown in color (Munsell 5YR 5-6/4-6), with minor fine sub-angular and angular inclusions of ca. 0.5–1 mm; samples TR-7 (G6.340) and TR-8 (E8.451) belong to subgroup AFG 1C.

2.1.3. Archeological Fabric Group 10 (AFG 10)

Sample TR-E (B7.8.110) shows a very fine and compact reddish brown clay matrix (Munsell 5YR6/6) with fine sub-angular and angular inclusions (~0.5 mm) of different colors and mica inclusions.

2.1.4. Probable import samples

Some of the selected samples show distinct macroscopic features and are considered as imports. They are separated into several archeological groups summarized below.

2.1.5. Archeological Fabric Group 3 (AFG 3)

This group is characterized by a dark red clay paste (Munsell 2.5R 3/6-5-YR 4-6/4) with a high amount of large muscovite inclusions as large flakes. Due to its distinct macroscopic features and its sporadic occurrence, it is considered as an import in Troy. This group is represented in this study by one sample, TR-10 (z6/7.233).
2.1.6. Archeological Fabric Groups 4, 5, and 6 (AFG 4, AFG 5 and AFG 6)

Three samples, TR-11 (z8.634), TR-12 (z7.1293A), and TR-13 (K4.740.22) belonging to different archeological groups, show macroscopic features that are not characteristic for the Trojan pithoi and are considered as imports. They are separated into three archeological groups: 1) sample TR-11 (AFG 4) is distinguished from the common Trojan pithoi by the presence of sub-rounded and sub-angular large opaque white grains of 1–3 mm and a loose and friable clay matrix; 2) sample TR-12, grouped into the archeological group 5, shows an untypical fine and creamy, pale beige paste (Munsell 2.5YR 2/2) with prevailing fine tempering particles and smudge marks on the surface; and 3) sample TR-13 seems to be imported because it is characterized by a beige slip, a fine light brown matrix (7.5YR6/4) and small, predominantly sub-rounded dark inclusions of 0.5 mm.

2.1.7. Archeological Fabric Group 9 (AFG 9)

The sample TR-D (z8.860) shows a rather fine compact matrix and small dark and bigger white inclusions. According to context and shape, it is difficult to assign this sample to the LBA or Post Bronze Age period. Despite this uncertainty, according to the petrographic analysis (see e.g., Reedy, 2008; Riederer, 2004), this sample may be associated with the archaic period due to a general macroscopic similarity of archaic pithoi to the examples from the Early Bronze Age, the archeological group 7.

2.2. Early Bronze Age Pithoi

2.2.1. Archeological Fabric Groups 7 and 8 (AFG 7 and AFG 8)

The three pithos samples of the Early Bronze Age can be divided into two main categories. The archeological group 7 is characterized by a noticeable tempering, with slaty and angular components of 2–3 mm. The clay color ranges from brown to dark red (Munsell 5YR 5/2), with prevailing fine tempering particles and smudge marks on the surface; and 3) sample TR-13 seems to be imported because it is characterized by a beige slip, a fine light brown matrix (7.5YR6/4) and small, predominantly sub-rounded dark inclusions of 0.5 mm.

3. Method

To investigate the research aims mentioned above, we examined twenty-four pithos sherds using petrographic thin section method. This is a powerful technique, especially for coarse ceramics and allows material identification, grouping specimens according to macroscopic features, identifying possible geological source of the raw materials, reconstructing production techniques, technological changes and variation over time and space and choice strategy of the raw materials (see e.g., Peterson and Betancourt, 2009; Reedy, 2008; Riederer, 2004). Thin sections were prepared from each sherd using standard techniques and examined by polarizing microscope. For the preparation of thin sections, a thin slice of a cross section of a ceramic sherd is dissected and polished on one side. In the case of the friable specimens, the potsherds are vacuum impregnated with epoxy as a preliminary step to stabilize the sample enough to permit cutting and grinding processes. For details see e.g., Reedy, 2008; Riederer, 2004). The percentage of the rock and mineral inclusions as well as pores in the sherds was estimated using the comparison chart of Rice (1987, 348).

4. Geological framework

Geologically, Northwest Turkey, also known as Biga Peninsula, lies in the Alpine orogenic system of the northern Aegean region. The region displays a complex geology with outcrops of various metamorphic, magmatic and sedimentary rocks (Fig. 3). They are usually grouped into two main tectonic zones: the Sakarya and the Istanbul and Rhodope–Strandja zones and further subzone or tectonic units (Okay and Tuysuz, 1999; Okay et al., 1991, 1996). The rocks assembled into the Sakarya zone, outcrops in the southern part of the peninsula, are subdivided into the Kazdağ massif, Ezine and Ayvacık-Karabiga zone and Bayramic magmatic complex.

The Kazdağ Massif forms a topographic anomaly in the South Eastern part of the Biga Peninsula, rising to 1767 m above sea-level. It consists of high-grade metamorphic rocks of felsic gneisses, amphibolites, marbles, and metamorphosed ophiolitic rocks (e.g. Duru et al., 2004; Okay et al., 1991, 1996). The Ezine zone, lying in the

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south western of the Peninsula, comprises the SW–NE trending Karadağ Unit, the Denizgören ophiolite and Çamlıca micaschist. The Karadağ Unit consists of slightly metamorphosed Late Paleozoic–Triassic sedimentary sequence of metashale, fine to medium grained metasedanstone, metaquartzite and calci-schist, recrystallized limestone, metamorphosed fine-grained shale, siltstone, calciturbidite, pelagic cherty and limestone (Okay et al., 1991). They overlie Permian to Early Triassic Denizgören ophiolite which consists of ultramafic rocks and serpentinite (Okay et al., 1991). The Çamlıca micaschist is outcropped in a wide area north and northeast of Ezine (Fig. 3), shows monotonous lithology, and mainly consists of medium grained metasedimentary rocks and micaceous quartz-micaschist with common mineral assemblage of quartz + muscovite + carbonate + albite and ± chlorite, clinozoisite and garnet (Okay et al., 1991). The rocks, grouped into the Ayvacık–Karabiga zone, are exposed between Evcilir granitoid in the east, the Karadağ Massif in the south and the Ezine zone. It comprises two main units: the Çetmi ophiolitic mélangé and the Alakeçi mylonitic zone. Çetmi ophiolitic mélangé outcrops in a large area in the west of the Karadağ massif, in the surrounding area of Ayvacık (Fig. 2). It is a tectonic mélangé amalgamating slice and/or block, largely made up of splitized volcanic and pyroclastic rocks, including Upper Jurassic and Lower–Upper Cretaceous limestone blocks, shale and greywacke and some serpentinite, radiolarian chert, spilitic basalt and limestone blocks (Okay et al., 1991). The mylonitic zone (Alakeçi mylonitic zone) comprises mylonitized gneiss and metaspernentine. The drainage network area of the Menderes river (also called Karamenderes river) is outcropped over wide area migmatic rocks of the Bayramić magmatic complex that comprises Late Oligocene granodiorite, quartz monzonite, monzodiorite and quartz diorite (Birkle, 1992; Genç, 1998) and Oligocene–lower Miocene volcanic rocks with lithological affinity of basalt, andesite, trachyandesite, dacite, rhyolite and the association of pyroclastic rocks intercalated with sedimentary rocks such as silstones, sandstones, claystones and shales ( Genç, 1998).

The western and northwestern parts of the Biga Peninsula, including Troy and its surrounding area are predominated by homogenous rocks of Tertiary calcareous sediments and small basaltic rock outcrops, assembled into the Istanbul and Rhodope–Strandza zone (Fig. 3). They are members of various formations, mainly marine and fluvial deposits such as Gazhanedere, Kirazlı, Aşağıtepe and Tevfiktepe–Truva Formation. The first stratigraphic unit starts with Miocene–Pliocene fluviolacustrine sediments of the Gazhanedere Formation above a pre-Early Miocene unconformity, which consists of a coarse clastic fanglomerate (Çağatay et al., 2006). Over Gazhanedere Formation lies the Kirazlı Formation, Late Miocene sediments of fluviatile and beach environments, consisting of cross-bedded sandstones, Untio–bearing green mudstones and sandstones and Mactra-bearing sandstones towards the top. The Kirazlı Formation is conformably overlain by the Aşağıtepe Formation and is characterized by cross-bedded calcareous sandstones and gravels, representing shallow-marine and lacustrine depositional environments. The Latest Miocene–Early Late Pliocene, Truva and Tevfiktepe Formations consist of fluviolacustrine clastic sediments and algal limestone and are over most sedimentary succession in the region. There are Plio–Quaternary basaltic rocks at the eastern part of the Dümrek River, near the Dümrek village, outcropped in a small area (Çağatay et al., 2006; Gürür et al., 2000; Sakaç et al., 1999; Valtıtrak and Alpar, 2002; Valtıtrak et al., 1998).

5. Results

Based on the petrographic features such as the type of major rock and mineral inclusions, its frequency and the general texture, the selected pithos samples from Troy can be divided into four distinct petrographic groups (labeled petrographic groups 1, 2, 3 and 4) and further subgroups. Samples of the petrographic groups, the main inclusion types of each sample and its estimated quantity in percentage have been listed in Table 1. These main petrographic groups suggest the use of at least four different clay sources for their production. The groups comprise examples that are classified into different archeological groups. Common features, observed in most samples are high quantity of rock and mineral fragments (grains larger than 0.01 mm), varying between 24 and 41% in volume (Table 1, Fig. 2).

The grains are largely angular and sub-angular, however, well-rounded single grains are also observed in some sherds. Further common features are high quantity of visible pores and reddish-brown matrix color. The main petrographic characteristics of the groups and subgroups can be described as follows.

5.1. Petrographic group 1 (PG-1)

This group comprises 16 samples and is the largest group (Table 1). It contains examples of archeological groups 1, 2, 5 and 8, but specimens from the archeological group 1 are prevalent (Table 1). The clay fabrics are characterized by large potassium feldspar fragments (K-feldspar), ranging from 6 to 15% in volume. Further inclusions are quartz, represented in polycrystalline and monocrystalline types, which show its metamorphic and magmatic origin (Fig. 2a). Plagioclase is the third predominant inclusion type. Mafic minerals such as olivine, pyroxene and biotite and hornblende are also present in minor quantity. Some samples also include calcite, micritic limestone and volcanic fragments, along with small quantities of fine-grained metamorphic fragments. The clay paste has a generally red-brown color in crossed polarized light. Based on the quantity of the main inclusions and overall clay quality, the content of silt-sized grains, and the clay mineral content, the sherds can be subdivided into three further subgroups.

5.1.1. Subgroup 1a

Nine samples, TR-1, TR-2, TR-3, TR-6, TR-7, TR-8, TR-16, TR-G and BT-1 show more similarity in their fabric features and can be distinguished into a separate subgroup (Table 1). Except sample TR-16, which belongs to the archeological group 8, all examples belong to the archeological group 1. The characteristic inclusions of this subgroup are angular K-feldspar of high quantity, up to 15%, ranging from fine sand-size to 2 mm large fragments and large polycrystalline as well as monocrystalline quartz (Fig. 2a). Plagioclase fragments, which are easily recognizable by their typical twinning, are the third abundant inclusion type in this subgroup. The grains are generally angular and show principally hiatal distribution in the clay matrix (Fig. 2a). The same minerals are also presented in the clay matrix as fine clasts. This suggests that they are most probably natural occurrence, however, the large grains and their hiatal distribution (Maggetti, 1994) in the raw clay have also been tempered, at least to some extent. There are also other inclusions represented in minor quantity. These are generally small fragments of mafic minerals such as olivine or pyroxene. Small biotite and hornblende flakes are also present in minor quantity. Other inclusions observed in minor quantity are mostly small fragments of serpentinite, schist, chert and micritic limestone (not excess 2%). The predominant inclusions of K-feldspar, quartz and plagioclase in the matrix and their presence as a part of the matrix indicate that the raw clay used for subgroup 1a was mainly derived from felsic rocks such as granite/granodiorite or equivalent metamorphic rocks. Besides, the occurrence of mafic minerals and rock fragments such as serpentinite and limestone in small quantities, displays the outcropping of similar parent rock within the catchment area of the clay deposits in limited extension.
sub-angular, sub-rounded and partly well-rounded. Additionally, they contain fragments of volcanic rock (dacite–andesite), chert, serpentinite, schist and limestone in minor quantity (1–2%). A clear contrast between grains and clay matrix was observed (Fig. 2b), displaying a hiatal distribution pattern. All these features suggest that the raw clay was most probably tempered by a potter, who obviously used river sand as tempering material.

5.1.3. Subgroup 1c

TR-9 and TR-12, classified to the archeological groups 2 and 5, include mineral and rock fragments mostly similar to those observed in the subgroups 1a and 1b (Fig. 2c), however, this group also contains small number of limestone fragments. Sample TR-12 additionally contains more micritic limestone, also as single small shells. In general the TR-12 clay paste contains more limestone, which apparently influences the vessel’s light color. This implies that the clay material used for this group is different to some extent from both subgroups (1a and 1b). The grains show a noticeable contrast to the matrix and suggest that the raw clay was probably tempered in the production processes.

5.2. Petrographic group 2 (PG-2)

This group contains three samples: TR-5, TR-11 and TR-13, classified to the archeological groups 1, 4 and 6 (Table 1). The samples contain largely similar inclusion types like fabric group 1, the overall fabric features are also comparable with the fabric group 1, especially samples TR-5 and TR-11. However, they are distinguished from other groups due to the presence of large volcanic fragments, which occurred in high quantity, up to 12% (Fig. 2d). They can be divided into further subgroups. Samples TR-5 and TR-11, which belong to the subgroups 2a, are characterized by large andesite fragments and plagioclase fragments. The matrix includes also small, angular plagioclase fragments in large quantity, as part of the matrix that was apparently derived from andesite. The inclusions, especially andesite, show hiatal grain-distribution (Fig. 2d) and thus suggest that they were deliberately added to the clay by a potter. Sample TR-13,

Fig. 2. Photomicrographs of the pithos samples from main fabric groups and subgroups. a—subgroup 1a (sample TR-6), b—subgroups 1b (sample TR-A), c—subgroup 1c (sample TR-9), d—fabric group 2 (sample TR-9), e—fabric group 3 (sample TR-15), f—fabric groups 4 (sample TR-10). Abbreviation: Kfs—K-feldspar, Q—quartz, Pl—plagioclase, An—andesite, Px—pyroxene, Hb—hornblende, Ms—muscovite, St—schist (all photomicrographs were taken with cross-polarized light).
belonging to subgroup 2b, is slightly different. It is characterized by finer clay paste and presence of pyroxene fragments in high quantity.

5.3. Petrographic group 3 (PG-3)

Samples TR-14, TR-15 and TR-D belong to the archeological groups 7 (TR-14 and TR-15) and 9 (TR-D) and show distinct petrographic features in terms of the main inclusion types and overall appearance of the fabric features. It is characterized by coarse clay and predominantly consists of large, angular serpentinite and mafic minerals of pyroxene, olivine and minor hornblende fragments. The clay matrix is also composed of small flakes of the same material (Fig. 2e). There are some K-feldspar and quartz fragments observed in minor quantity, e.g. TR-15 (Fig. 2e). The fabric textures as a whole, the flake shape, distribution and structure of the predominant inclusions, even in the clay matrix, suggest that this clay is an in situ occurrence from ultramafic parent rocks such as peridotite/serpentinite (ophiolite), unless the weathered materials were not transported far from the parent rocks. Although the clays for petrographic group 3 are of the same origin, they show some differences in their grain size and clay matrix. The samples TR-14 and TR-15 are close to each other in their fabric features, whereas sample TR-D is made from finer clay with small number of magmatic fragments that contrast the clay matrix and can be seen as deliberate addition by a potter. The latter suggests that the pithoi from petrographic group 3 were produced from the clays derived from the same geological source, however, the potters apparently used clays with different quality, coarse and relatively fine clays (for further discussions see below).

5.4. Petrographic group 4 (PG-4)

This group consists of two samples, belonging to the archeological groups 3 and 10. The group has a distinct appearance even visible in hand-specimen. It is characterized by large muscovite-schist fragments, muscovite flakes and some polycrystalline quartz fragments (Fig. 2f). The composition of the clay matrix and the general appearance suggests that the raw material for this group also occurred in situ, derived from muscovite rich metamorphic rocks, most probably muscovite-schist. The sample TR-10 consists of coarse clay with large, very angular schist fragments and muscovite flakes, even in the matrix (Fig. 2f), whereas the sample TR-E is made from relatively fine clay.

6. Discussion and conclusions

The petrographic analysis of the selected 24 pithos samples of the Early Bronze (3 samples), 1 of unknown date and the Late Bronze Age (20 samples) from Troy (Troia Vllla, ca. 1300-1190/80 BC), outlined above provides significant compositional differences existing within the sample assemblage and suggests the use of multi-clay sources for their production. Regarding the question of the provenance, the clay sources can be assigned broadly to four geological areas south of Troy, in the surrounding regions of the Ezine district (Fig. 3). The main characteristic of petrographic group 1, represented by the substantial presence of large K-feldspar, quartz inclusions and silt-sized fine grains as part of the matrix, suggests that the raw material is derived predominantly from magmatic rocks such as granite/granodiorite. Serpentinite and schist fragments found in the sherds in minor quantity also show the occurrence of ultramafic and metamorphic rocks within the catchment area of the clay deposit. Comparing these reconstructed lithotypes of the sherds to the geology of the western Biga Peninsula, it shows similarity with the local geology, especially with the southern and southeastern parts of Ezine, where granodioritic (Kestanbol granodiorite), volcanic and metamorphic rocks of the Kazdağ Massif outcrop within the drainage network of the Menderes and Akem Rivers (Fig. 3). The Early Miocene Kestanbol granitoid consists of quartz monzonite and monzogranite with major mineral composition of K-feldspar, quartz, sub-ordinate hornblende and biotite (Birkle, 1992; Şahin et al., 2010). The unconsolidated Pliocene–Quaternary clay-rich fluvial sediments in the right and left banks of the Menderes and Akem Rivers may be the source of the raw clays for the pithos production for petrographic group 1 (area PG-1 in Fig. 3).

The second petrographic group contains also granitic–granodioritic and to some extent, metamorphic inclusions. However, the inclusion pronounced by the presence of andesitic fragments suggests its predominant occurrence within the catchment area of the clay source for petrographic group 2. In the region, west, south-west and south of the Ezine outcrops comparable volcanic rocks in a relatively large area, associated with the Kestanbol granitoid and Ezine volcanics, largely consist of andesite trachyandesite, dacite, rhyodacite and pyroclastics (Arık and Aydin, 2011). Petrographic analysis of fresh samples from Ezine volcanics reported by Arık and Aydin (2011) shows hypocrystalline porphyritic texture. Plagioclase crystals often show a zoned structure (Arık and Aydin, 2011). Similar zoned structure was also observed at the plagioclase phenocrysts in the large andesite inclusions, as well as single plagioclase grains found in fabric group 2. This suggests that Ezine volcanics is largely the parent rock for the raw clay of the petrographic group 2 and consequently, the unconsolidated young fluvial deposits around the Ezine plain seem to be the possible clay source for petrographic group 2 (area PG-2 in Fig. 3). However, it should also be considered that the hydraulic sorting of rock and mineral clasts by sedimentary processes into granulometric fractions, due to the different grain sizes and its specific gravity, could modify the proportions of the grains and grain types in sedimentary deposits. Accordingly, the differences in some lithotypes and grain-size distribution between petrographic groups 1 and 2, as well as the subgroups, can also be generated by such sedimentation processes. Therefore, the clay sources for these both fabric groups and subgroups suggested, can be seen as local compositional variation of the fluvial deposits of the large depositional area in the Ezine plane. This results (for petrographic groups 1 and 2) are also supported by petrographic analysis of medium to coarse sand and silty sand samples from Menderes riverbeds in the flood plain, close to Troy, reported by Pinter (2005). These reference samples (labeled Tr-1a and Tr-1b in Pinter, 2005) consist of various rock and mineral fragments. The main mineral inclusion types of sample Tr-1a are quartz (mostly with adulatory extinction), plagioclase, K-feldspar (partially microcline), muscovite, amphibole and opaque grains. Rock fragments are dominated by volcanic fragments of basalt, obsidian and recrystallized (silicified) felsic volcanic rocks (probably rhyolite andesite or latite). He also reported the presence of gabbro fragments, serpentinite, multilrabrasis, chert and chalcedony in minor quantity. The second sample (Tr-1b, silty sand) from the same region also shows similar lithotype fragments, but additionally contain carbonate clasts in their cores with quartz, quartzite, chert and magmatite fragments (Pinter, 2005). Though the type of inclusions of river sediments and pithos samples of the petrographic groups 1 and 2 is generally coinciding, a dominant presence of basalt, gabbro and carbonatic clast, quartzite, chert in the Menderes River samples was not observed in the pithos samples. Most likely the basalt fragments are derived from the young basaltic rocks exposed in Akçapınar (Fig. 3). The gabbro fragments and multilrabrasis are most probably derived from Denizgören ophiolite, cropping out in a north–south direction in a large area northwestern of Ezine and in the type-site Denizgören (Fig. 3). Furthermore, the carbonate inclusions and chert may originate from tertiary carbonate deposits outcropping as cover rock in the region west to northwest of Biga Peninsula (Fig. 3). The lack of all these inclusions in the pithos sherds suggests that the clay sources in the flood plain close to Troy may not be used as raw clay sources for the petrographic groups 1 and 2 and as suggested above, it is located in the surrounding area of the Ezine plain (Fig. 3). In the case of subgroup 1c (samples TR-9 and TR-12), however, which contains slightly high carbonate fragments and the matrix contains slightly increased amounts of small micritic limestone as well, a clay
source for this sample somewhere close to Troy is also possible and needs to be verified.

In contrast to the first two petrographic groups (PG-1 and PG-2), due to their distinctive features discussed above, the petrographic groups 3 and 4 can be assigned to distinct regions with more confidence. The type of inclusions of the petrographic group 3 that consist of serpentinite, both as large inclusions and small flakes as main part of the matrix (Fig. 2e) indicates clearly that the raw clay is of ultramafic origin. The angular grains, large quantity and lack of sorting texture suggest that the clay material was occurred in situ. The Early Triassic Denizgören ophiolite in the north of Ezine seems to be the best possible parent rock for raw clay source for the petrographic group 3 (area PG-3 in Fig. 3). This tectonic unit is exposed in a large area, extending in the North-East direction and in the type section area, in Denizgören between Troy and Ezine (Fig. 3). It is composed mainly of serpentinite, metagabbro, peridotite and metabasit (Okay et al., 1996; Şengün, 2005). However, since the lithological similarity of the Denizgören ophiolite, separated in two regions, north and south
The last group distinguished in this study, the petrographic group 1, is mainly in accordance with the most typical Trojan Late Bronze Age pithos group (AFG 1), although there are exceptions (Table 1). In other groups, between the petrographic and archeological groups, there is no clear conformance. Petrographic analysis also shows that the raw clays used for pithoi not only are from different sources, but also have different lithological origins and different qualities. In the case of the petrographic group 1, the raw clay is generally silty and contains large K-feldspar and quartz fragments in different sizes. The fact that the K-feldspar and quartz inclusions show contrast to the clay matrix, suggests that the raw clay was most likely tempered with angular, sub-angular rock and mineral fragments obviously derived from felsic rocks. Tempering can be recognized more clearly in the subgroup 1b. Here, the clay was initially quite pure: low silt clasts and high clay mineral content. The contrast between inclusions and matrix is clear (hedral distribution) and suggests that the raw clay has been tempered in the paste preparation processes.

In contrast, the last two groups, the petrographic groups 3 and 4 are distinctive in their origin and clay quality and general clay properties, showing different procurement strategies in the choice of the raw material. As mentioned above, both clays are in situ occurrence, originated from the weathering of ultramafic and metamorphic rocks (serpentinite, peridotite for group 3 and schist or similar felsic rocks for group 4). Both clay types are predominated by inclusions with platy shape (flakes) and are in contrast to the first two fabric groups, which are characterized by angular grains with high sphericity (Fig. 2). It is a general agreement that temper increases workability of clay body and it prevents shrinkage and cracking during drying and firing processes (see e.g., Rice, 1987). Moreover, the type and shape of tempers, its proportion and firing temperature also influence performance characteristics of vessels such as fracture strength and toughness of the vessel (Müller et al., 2010). Müller et al. (2010) have shown that inclusions with high sphericity (in our case the granitic fragments of the PG-1 and 2) and platy (platy shape of serpentinite and muscovite inclusions of the PG-3 and PG-4) behave differently. In general, the addition of temper increases the toughness of a vessel at low and intermediate firing temperatures (≤1050 °C). Platy temper (e.g., phylite flakes) results to much smaller microcracks during firing than granitic temper, however, fracture strength is higher for phylite tempered vessels (Müller et al., 2010). Raw clays and tempers are not just picked up randomly by artisans, they are consciously procured for particular reasons (Costin, 2000). If we consider the results of present study in this context, the use of the raw clays with specific features and tempering practice of Trojan pithoi discussed above may be not coincidental, rather deliberate decision of the potters. This may also explain the relatively large distance between the location of the clay sources in the southern part of the Biga Peninsula and its final use in Troy, though this needs further analysis.

The occurrence of the carbonate fragments observed in petrographic group 1 indicates that the pithoi were fired at a relatively low temperature. Though from petrographic data alone the exact firing temperature is difficult to determine, since the mineral durability of carbonate depends on various factors, such as grain-size, heating time, and firing atmosphere (Cultrone et al., 2001; Riccardi et al., 1999), however, the presence of carbonate fragments suggests that the firing temperature would have been around 750–850 °C, the durability temperature interval of calcite (Cultrone et al., 2001; Maggetti, 1982). A similar firing temperature may also be suggested for other examples, since there are no clear indications for higher temperatures, such as sintering.


