A physicochemical study of Medieval and Post-Medieval ceramics from the Aegean

Panagopoulou, A.

CHAPTER 8 OPTICAL MICROSCOPY – CERAMIC PETROGRAPHY

8. INTRODUCTION

An introductory overview on the prevailing geological formations that make up the three areas where the studied ceramic material comes from, namely Attica, central Euboea (Lilas river plain) and eastern Lesvos is given in the following paragraphs. The chapter aims at providing a minimum adequate petrologic and geomorphologic background of the three geographic provinces, considered potentially useful for associations between indigenous clays (or relevant facies) deriving after natural processes from the background formations, and ceramic production in the above areas by exploiting the locally available clay-forming siliceous and argillaceous raw materials. Before it, we attempt a brief explanatory outline of the geological characteristics concerning the wider continental and insular area. Finally, at all of the 245 samples were studied under the microscope and also at thin sections of 30 ceramic samples were applied petrographic analysis.

According to well-established views (e.g. Stille 1924: Schöneberg and Newgebauer 1987) the Greek mainland along with the surrounding Aegean and Ionian islands, geologically belongs to the so called "Neo-Europe", a major geotectonic Alpine-type orogenic entity that predominates in the southern territories of the continent (Iberian Peninsula mountains, Apennines, Balkan/Dinarides, Hellenides) further expanded to Taurides/Anatolia and southern Asia. Main characteristics of the Hellenides as branch of the Alpine belt (Kilias 2018) are their deformation, a number of well-defined geotectonic units (or "zones" such as Attic-Cycladic, Pelagonian etc) and the nape tectonism with successive overthrusts directed from East to West (Katsikatsos 1991), whilst three major Alpine-belts related metamorphic events have taken place (Altherr *et al*. 1982) during the Cenozoic Era (initiated ca. 65 million years ago). Belonging to the three rock classes (igneous, metamorphic and sedimentary) the manifold geological formations of Greece, date as early as 300 million years (Papanikolaou 2021) however the prevailing petrogenetic background has Mesozoic to Palaeocene ages (230-70 million years (Katsikatsos 1991). Nonetheless the geologically "newer" Neogene basins, younger than *ca*. 22 million years, host the -mostly-Pliocene deposited clay layers, the latter quite interesting in the present thesis, as potential raw materials once used for the manufacturing of the studied ceramic collections.[3]

Data related with geomorphological and tectonic features of the examined provinces are marginally mentioned below. This is owed to indirect relationship often inferred between deposited clays and local geomorphological features or tectonics dominating in a certain area. More specifically, the clay formations regarded as clastic deposits (Grim 1968) tend to follow some principal sedimentological principles. So, this brief account of the sedimentology of clays is mainly concerned with the processes that affect their genetic relationship with the pre-existent paternal geological formations, mechanisms of erosion, transport, deposition (Lewis and Mc

[3] Personal contact with Dr. Yannis Bassiakos, Researcher Emeritus at the Institute of Nanoscience and Nanotechnology, NCSR "Demokritos".

Conchie 1994) and tectonic regime, the latter often playing essential role on the vertical dismemberment and on narrow Neogene valleys setting.[4]

8.1 ELEMENTS ON THE GEOLOGICAL SETTING OF ATTICA, IN GREECE

Geotectonic Units, Alpine Rocks and Post-Alpine Sediments of Attica

The geologic substratum of Northeastern Attica consists of Alpine basement rocks, both metamorphic and non-metamorphic, and post-Alpine sediments (Figures 110,111,112,113,114) The Alpine rocks belong to the metamorphic units of the Northern Cyclades and Almyropotamos that extend from Mt Penteli to the southern Euboean gulf and to the non-metamorphic unit of Eastern Greece that outcrops in Mt Parnitha (Papanikolaou 1986; Ghilardi 2014). The Almyropotamos unit is known from southern Euboea, but it crops up also in the area of Marathon. It comprises a thick Mesozoic marble sequence overlain by phyllites representing a metamorphosed Tertiary flysch (Katsikatsos 1969; Dubois and Bignot 1979).

The Northern Cyclades unit (as geological entity) does not appear only at the Northern Cyclades Island complex, but also in a major part of the southern Euboea, where it is known as the ‘Styra unit’ (Katsikatsos 1979). It consists of thick sequences of mica schists and cipolines grading to siliceous marbles with alternations of greenschists and amphibolites, representing a pelagic volcano sedimentary sequence. More to the south the Northern Cyclades unit is tectonically overlying the relative autochthon unit of Attica (Lozios 1993). The non-metamorphic tectonic unit of Eastern Greece comprises: (i) the SubPelagonian Triassic-Jurassic carbonate platform overlying a volcano sedimentary PermoTriassic complex and underlying an upper Jurassic schist-hornsteinmelange formation, (ii) the ophiolite nappe of the Vardar/Axios oceanic basin, and (iii) the upper Cretaceous transgressive sequence made of a shallow-water carbonate platform and a Tertiary flysch. Most part of the Mt Parnitha consists of the lower group (i). The deformation of the Alpine formations of the above units is post-Late Eocene, as dated from the age of the flysch involved in the tectonic structures and extends up to the Early Miocene as the synmetamorphic deformation shows in the metamorphic rocks of the Cyclades (e.g. Schliestedt et al. 1987).

A detachment fault separates the metamorphic units from the non-metamorphic units. This detachment passes from the Ochtonia cape in the Aegean coast of Southern Euboea (northwards in respect to our study area), through Aliveri to Kalamos in northeast Attica and continues to the southwest into the plain of Athens approximately along the Kifissos River (Papanikolaou et al. 1999; Xypolias et al. 2003). Finally, between the metamorphic and the non-metamorphic units and along strike the tectonic contact there is a narrow zone, where some small outcrops of low grade metamorphic rocks occur under the post-Alpine sediments. These rocks could be related to the Alepovouni unit or even to a similar type of unit noticed further south (Papanikolaou et al. 2004a),

[4] Personal contact with Dr. Yannis Bassiakos, Researcher Emeritus at the Institute of Nanoscience and Nanotechnology, NCSR “Demokritos”.

whose lower part comprises a few hundred meters of semi-metamorphic sandstones, schists, and phyllites.

The post-Alpine sediments of the area comprise Late Miocene – Pliocene continental deposits and minor outcrops of Pleistocene and Holocene alluvial (e.g.Mettos 1992). The older sediments comprise a clastic tectono sedimentary formation that appears in the broad region including Kapandriti, Aghios Stefanos and Afidnai. They form a zone of debris-flow deposits situated at a NE-SW direction, that are several hundred meters thick, indicating that a major fault zone in a steep relief was created during Late Miocene. This formation consists of large boulders and blocks within a clay matrix with mixed lithologies both from the metamorphic units cropping out in the east and the non-metamorphic units cropping out in the west. In Kapandriti, it is characterized by a complex/chaotic internal structure and significant lateral variations of permeable (sands, conglomerates, sandstones) and impermeable (marls) lithologies. Semi-cohesive breccio-conglomerates prevail towards its base, with large clasts (reaching up to a diameter of 2 meters) sourced from the alpine bedrock involving schists, limestones and cherts. Towards the upper part of this sequence, clasts become thinner and finer and at places sandstone beds and less frequently conglomerates are also noticed. The same formation outcrops also in the area between Aghios Stefanos and Afidnai and has been evolved laterally to breccio-conglomerates with clasts that are smaller in size, rarely exceeding 30-40 cm in diameter). In the immediate footwall of the Afindai fault its thickness exceeds 150 m and the bedding dips 20o-40o towards NNE. On top of this breccio-conglomerate formation appear lacustrine limestones thick by a few hundred meters. The top lacustrine limestones are also found unconformably overlying the metamorphic basement in the east around Varnava. Pleistocene alluvial fans are noticed within the Athens plain along the southern slopes of Mt Parnitha and the western slopes of Penteli southwards from the Afidnai and the Aghios Stefanos, uncomfortably covering the Neogene sediments (e.g. Papanikolaou et al. 2004b).

Northeastern Attica evidences no outcrops of marine sediments. The southern Euboean gulf, the shallow maritime zone separating Attica from Euboea, was formed in Late Pliocene. The thickness of the Plio-Quaternary sediments within the gulf does not exceed 150 m, except for the southeastern area, where it reaches 250 m in thickness (Papanikolaou et al. 1988a). Marine sediments occur only along the coast of eastern Attica at Rafina area where they have been dated as uppermost Pliocene – lower Pleistocene (Mitzopoulos 1948; Guernet and Sauvage 1970). Finally, recent alluvial sediments are not so thick and surface only in some small narrow bands along the coastline (Oropos, Kalamos, Marathon) and in the Afidnai basin. Roubanis (1961) reported that in the Afindai plain close to the railway station, the metamorphic basement was drilled at a depth of 47 m and that the Neogene sediments were only 15 m thick, revealing that the Late Pleistocene-Holocene sediments are about 30 m thick. Recent drillings for water in the Plain also showed that the alluvial- Quaternary thickness does not exceed 80 m.

Geomorphological and Neotectonic Structure of Attica

Mt. Parnitha and Mt. Penteli dominate the geomorphology of Northern and Eastern Attica respectively. Further north from the southern Euboean gulf and the coastal zone of Oropos-Kalamos down to the Athens Plain, we notice three major drainage basins: 1) The Kifissos basin in the south with a NNE-SSW flow direction, draining the southern slopes of Parnitha and the southwestern slopes of Penteli through the Athenian plain to the Saronic gulf in the southwest. This flow direction is parallel to and near the detachment trace; 2) The Charadros basin with a major W-E flow direction, springs from the eastern Parnitha highs of about 1200 m up and flows towards the Afidnai plain and the Marathon Lake situated at an altitude of about 350 m; 3) The Asopos basin towards the northwest which flows northwards, but has a more complex structure due to the existence of the Avlona-Malakasa and the Milesi faults. Finally, some small approximately N-S trending catchments are noticed in the area of Kalamos and the Microchori plateau from 500 m elevation up to the coast of southern Euboea.

8.2 ELEMENTS ON THE GEOLOGICAL SETTING OF CENTRAL EUBOEA (LILAS RIVER PLAIN), IN GREECE

The Lilas River Drainage Basin in Euboea

The Lilas River spring from the peaks Mt Dirfys and follows a SW course. Its drainage basin has an area of about 300 km2 flowing into the south Euboean Gulf (Figures 115,116,117,118). The drainage basin–fan delta system can be divided morphologically into four sections: (1) the upper mountainous area at Mt Dirfys, the oldest of all (pre-Neogene in age); (2) the intermediate, intermontane section which consists of Pliocene lacustrine formations; (3) the downstream hilly area; and (4) the Holocene fan delta, known also as the Lelantine plain, an alluvial plateau which, in antiquity, was so fertile that it became the reason of a lengthy war between Chalcis and Eretria. The catchment consists of 32.8% easily erodible lacustrine formations (mainly conglomerates, marls, sandstones, and clays of Pliocene age), 28.2% calcareous sedimentary rocks (mainly Mesozoic limestone), 27.2% metamorphic rocks (mainly schist), 6.0% igneous rocks (ultrabasic rock masses, labelled as ophiolites, and 5.7% of unconsolidated sediments (mainly alluvial deposits along the channels of the main streams) (Institute of Geology and Mineral Exploration 1967; Karymbalis 2018). The general climatic conditions of the catchment are typical of the Mediterranean. The average annual rain precipitation ranges from 450 mm near the coastline to 550 mm in the north–northeastern most highlands while the average annual temperature fluctuates between 15_C and 16_C (Katsafados 2012).

Climate conditions within the drainage basin along with its bedrock geology (extensive presence of highly erodible formations) and relief (relatively steep slopes in the upper reaches) are characteristics favorable for weathering and erosion in the area of the catchment. Hence large amounts of sediments supplied by erosion are transported down the valley of the river to the coast. The areas of Nea Lampsakos and “Ambelia” have been providing good quality clays for local ceramic production ever since antiquity (Dr. E. Sapouna-Sakellaraki, former director of the Ephorate of antiquities of Chalcis in Euboea, personal communication).

Geomorphology of the Fan Delta in Euboea

The geomorphological map shows that the dominant process for the recent development of the fan delta is fluvial sedimentation. The present-day active distributary channel flows in a N.NE–S.SW direction and maintains a braided pattern, which is indicative of the large sediment load of the river. Nearly 2 km upstream from the river mouth, at the location where the trace of Lefkandi fault crosses the channel, the river changes its course from N.NE–S.SW to E.NE–W.SW for a short distance. Hence the distributary channel must have been affected by the W.NW–E.SE trending normal fault of Lefkandi the trace of which has been mapped in detail by Rondoyanni et al. (Rondoyanni 2007) using geophysical techniques.

Thus, the activation of the Lefkandi fault could be blamed for the post-1848 earthquakes that affected the broader area. Three earthquakes occurred in 1894, 1914 and 1938 respectively affecting the city of Chalcis in Euboea and its immediate surroundings (Papazachos 1997; Papanastassiou 2011; Roumelioti 2011). There are no indications that the smaller Vassilika fault had any interference in the evolution and morphology of the fan delta. The fan delta is riddled by abandoned tributaries, which form the dominant landforms.

Most of these palaeo-channels, which are clearly visible even from aerial photographs, are no longer identifiable in the fan delta landscape. The survey of the 1848 historical map of the fan delta and aerial photos allowed the identification of five groups of palaeo-distributaries and associated abandoned river mouths which outline changes in the river course and migration of the active mouth of the river. One major former river mouth, associated with channel avulsion, has been identified to the east of the present active mouth, and four more to its west. The most recently abandoned river course is a channel west of the present active one. This channel, which is depicted in a bathymetric chart of the western part of the Evripos channel surveyed in 1846–1847 by Thomas Graves (published in 1848), leads to Bourtzi, about 1 km northwest of the present active mouth of the river).

Further to the west, two major former river mouths (at Agios Nikolaos and Nea Lampsakos) associated with channel avulsion, have been identified 1.6 km and 3 km northwest of Bourtzi, respectively. The avulsion points are located 4.5 and 5.8 km upstream from the active river mouth. Hence, a change from active channel deposition in the western delta to active deposition in the central delta occurred. The westernmost palaeo-channels system begins from the apex of the fan delta, passes through the northwestern secondary extension of the fan delta plain and ends at Liani Ammos of the North Euboean Gulf. The northwesternmost channel of this group has a meandering pattern and is clearly visible in Google Earth images which leads to the hypothesis that it is relatively recent. The fan delta lobe of Kampos, east of the active river mouth, advanced by the sediment supply through a group of now abandoned channels (both straight and meandering) which begin 2.5 km upstream from the active river mouth. The abandoned distributaries of Bourtzi and Agios Nikolaos have been recently activated during a severe rainfall event which happened on 11–12 September 2009. Approximately 350 mm of rainfall in 28 h was recorded at the meteorological station closest to the study area when average rainfall for September is about 10 mm. The extreme discharge caused levee failures and resulted in flooding of the low-lying part of the fan delta plain. This severe flash flood event was accompanied by a storm surge which caused extensive damage at the settlements of Bourtzi and Agios Nikolaos as well as the retreat of the marshy area northwest of the active mouth of the river.

The comparable analysis of the digitized fan delta shorelines of 1945 and 2009 shows that most of the coastline (particularly along the North Euboean Gulf as well as part of the coastline northwest of the present active mouth of the river) is generally stable due to relatively long-term quiet marine conditions. The section of the fan delta coastline from Bourtzi to Nea Lampsakos is sheltered from big waves since the fetch is short and the waters are shallow (the maximum depth is 12 m). On the other hand, the section of the coastline extending from the mouth of the river to the eastern edge of the delta is more exposed to wave activity (particularly to E and SE wave approach directions). Approximately 2.1 km of the eastern fan delta coastline, is currently undergoing erosion. This change in coastline position is the result of redistribution of sediment from the abandoned lobe of Kampos. It is estimated that the maximum shoreline retreat at this part of the fan delta was about 60 m over the 64-year period between 1945 and 2009 (corresponding to a maximum mean erosion rate of -0.94 m/year). The above-mentioned characteristics (i.e. the extended drainage basin, the multi-mineralogical facies -corresponding to different rocks- that feed the plain and the relative faults restiveness are among the main factors that provide a rather wide-spectrum of trace elements, some of them diagnostic in the analyzed ceramic samples.

8.3 ELEMENTS ON THE GEOLOGICAL SETTING OF EASTERN LESVOS ISLAND, IN GREECE

Geotectonic Units, Alpine Rocks and Post-Alpine Sediments of Lesvos

Lesvos island belongs to the Pelagonian geotectonic zone (Mountrakis 1983). The island of Lesvos is made up of the units shown in Figures 119,120,121. The geology of Lesvos has been described by Hecht (1971-1974), Pe-Piper (1978), Katsikatsos et al. (1982), Kelepertsis (1977), and Kelepertsis and Esson (1987). Katsikatsos et al. (1982) studied the geological structure of the oldest Paleozoic rocks (schists, marbles and ophiolites) while Pe-Piper (1978) and Kelepertsis (1978) published details on the petrology, mineralogy and geochemistry of the volcanic rocks. Thick Miocene volcanic rocks overlie the metamorphosed Paleozoic basement. The volcanic rocks consist of andesites and rhyolites of shoshonite type. The meta-Alpine Formation is subdivided into Tertiary and Quaternary. The Tertiary includes pyroclastics, various lava types and sedimentary deposits of marine and lacustrine origin. The sedimentary deposits overlie the pre-Alpine formations (schists, marbles) in the north- western part of Lesvos, and include marls, marly limestones, tuffites, sandstones, and pyroclastic materials. In a number of areas, the sedimentary deposits are overlain by thick layers of pyroclastics in the Sigri-Antissa area. Trunks of petrified trees are found within the pyroclastics. The rocks of the Lapsarna section include a variety of lithologies (pure carbonates and pure siliceous rocks, shales and a few thin coaly layers). The carbonate layers are more thickly bedded whereas the siliceous and shaly rocks are thinly laminated. The island exhibits a rugged topography and complex physiography, characterized by a particular hilly-mountainous relief. The great variety of landscape is the result of the geological dissimilarity caused by the outcrop of different petrographic types and by the tectonic activity (Stephanidis 1909; Archontidou-Argyri and Bassiakos 1986).

Geological Settings of Lesvos

The Miocene-Pliocene formations, that consist mainly of volcanic rocks, minor clastic sediments and mads cover most of the island. The volcanic rocks have been studied by (Pe-Piper 1980a, 1980b, 1984; Pe-piper and Piper 1980; 1992; 1993). Several volcanic rock units can be distinguished. The oldest one is the andesites of the Lower Lava unit (Borsi 1972). The felsic volcanic units overly the former, comprising the Sigripyroclastiks, Polychnitos and Skopelos ignimbrites Kapi rhyolites. The Skoutaros Lava Unit, consisting of basalts and andesites, overlies the acid volcanics. The more recent volcanic activity took place in the eastern part of the island with basaltic-shoshonitic lavas (Mytilint unit) (Pe-Piper 1978). The volcanic activity was continuous into the Sikaminea unit of andesites, dacites and rhyolitic pyroclastics. The younger volcanics, Eressos andesitic dykes (Pe-Piper 1978) are widespread in western Lesvos. Other Neogene marine and lacustrine deposits such as whitish marls, silts and sandstones. In conclusion, the geological map of Lesvos has variable geological features due to the complexity of the geology of the eastern part compared to the western part of Lesvos. At the east part of the island were presented mainly aphiolites in general, greenschists, limestones and metamorphic basement in constant to the west part where volcanic stones existed generally.

8.4 OPTICAL MICROSCOPY – CERAMIC PETROGRAPHY

Optical microscopy is one of the most recurrent, widespread, and oldest examination techniques used in scientific investigation, and of frequent use in the research of archaeological materials. It is based on a microscope that uses light and a system of lenses for the examination of samples. It is capable of magnifying small areas, resulting in the examination of the (micro) constituents and structure of the materials. Most optical microscopes can provide images with magnifications from 50× to 1,000×. An optical microscope can take various configurations, each one with specific advantages for different types of materials. Reflected light optical microscopy is frequently used for observation of ceramics.

Furthermore, thin-section petrography is a valuable tool for the study and classification of clay paste fabrics. Ceramic analysis deals with the compositional characterization of ancient ceramic artifacts through the observation of thin sections made from pots under a polarizing microscope. The petrographic analysis of thin sections is routinely used for the study and characterization of a variety of materials, including rocks, minerals, slags, concrete, mudbrick, plaster and fired clays.

Thin sections are studied using a polarizing light microscope or petrographic microscope. These microscopes employ two modes of observation: under plane polarized light (PPL) and under crossed polars or crossed nicols (XP). The first type acts like regular transmitted light, whereas the second one dissociates the light in two directions, which interacts with the variably orientated mineral crystals providing a spectrum of colours, namely the interference colours. By combining the information obtained through both modes of observation we can proceed to the characterization the mineral optical properties and their subsequent identification. The mineral identification as well as the classification of the rock fragments is carried out by means of optical mineralogy and thin section petrography. Ceramic petrography can also be used for the characterization of ceramic materials, which comprise the heterogeneous mixture of argillaceous raw materials and various kinds of non-plastic materials or aggregates. The latter borrows techniques and methodologies often used in sedimentology, sedimentary petrography and "soil micromorphology", for investigating the textural characteristics of the particles and the matrix characterization respectively. Therefore, the ceramic fabrics can be classified through the examination and identification of their plastic and aplastic components, microstructure and texture, which are further discussed below (Quinn 2013).

The petrographic analysis treats the ceramic fabric in its entirety. The ceramic fabric is defined as the "arrangement, size, shape, frequency and composition of components of the ceramic material" (Whitbread 1986), and so the 'plastic' component of the ceramic fabric as well as the aplastic mineral content are emphasized. Through analyzing ceramic fabrics, we can study the geological state of a region as well as the role of humans in the selection and preparation of raw materials and the firing techniques (Day et al 1999, Day 2010). The examination of the appearance of a ceramic fabric can reveal its origin and significance regarding the technological processes involved in the ceramic production; furthermore, it provides some answers regarding questions of provenance (White 2009).

Petrographic analysis is achieved through thin section examination. Most petrographic studies focus mainly on the characterization of non-plastic inclusions. These inclusions are often called the coarse fraction of the fabric and are either present in naturally occurring clay deposits or can also be intentionally added to clays by the potters, in order to reduce the plasticity of the ceramic paste and enhance its workability. The most common and likely non-plastic types of inclusions that can be identified in ceramic thin sections are (Xanthopoulou 2019):

- Mineral grains
- Rock fragments
- Organic material, such as plant materials, shells and bones
- Grog (crushed pottery of previously fired ceramics)

Important data can also be extracted through the characterization of plastic material forming the micromass of ceramic artifacts. The plastic part of a ceramic is rather associated with the clayey raw materials employed than the inclusions of minerals and rocks fragments. These are often recognizable in the final ceramic object as clay pellets and clay mixing (striation) lines. Such features can be related to the homogenization of the clay mass, the incomplete mixing of two different types of clay, the slaking crusts (Whitbread 1995), and can provide useful information on the manufacturing technology of ceramics. Their presence is particularly revealing in fine wares, for the latter don't usually contain inclusions visible as these usually do not contain inclusions visible under the petrographic microscope. The post-depositional conditions in which the artifacts lie, affect the heterogeneous character of the matrix. When soluble minerals, such as calcite, are precipitated within the matrix by groundwater filtering, patches of micrite are formed and most are visible through crossed polars. The vacuums or the porous substance of the micromass often indicate the technique of the ceramic construction. When their orientation is parallel to the walls of the ceramic, this is usually an indication of the presence of organic material (probably straw or other plant material) added by the potter to improve the physical properties of the clay. During firing, the organic material is burnt out and the result is the creation of long and narrow voids in the micromass of the sherd. In cases of low temperature firing, sometimes part-burnt out remains of the organic matter are detected (Xanthopoulou 2019).

Petrography provides information regarding the compositional and textural character of a ceramic fabric and the raw materials used to create it, as well as the technical choices that craftsmen made during refining the clay, shaping the vessel and finally firing it. All the ceramic typologies, storage and transport containers as well as fine vessels for serving, provide significant information concerning past cultures. Important information, such as the nature and the origin of ceramic raw materials, as well as the manufacturing technology can be also derived from the observation of its colour and heterogeneity. The colour of the clay matrix reflects the composition of the raw materials used, as well as the firing conditions and its post-depositional history (Quinn 2013). Heterogeneity of the matrix may provide information on the manufacturing process, where two or more different clayey raw materials have been intentionally mixed or blended. Furthermore, it is useful in distinguishing between the anthropogenic and natural mixing processes, so giving additional information on the provenance and reconstruction of the manufacturing technology. Finally, data derived from such a compositional analysis of ceramics can be used for the interpretation of their provenance, providing evidence for the social-economic relationships between the ancient settlements, through the trade and exchange, distribution and migration (Quinn 2013).

All the 245 samples were studied with the microscope and also thin sections of 30 ceramic samples were obtained by sawing off a small slab of the material, lapping one of its surfaces through dedicated lapping machines. The resultant flat surface of the sample was resin bonded onto a smeared glass microscope slide and through grinding the exposed surface down to a standard thickness (25-30μm) a transparency was obtained. This standard thickness allowed the mineral observation and their identification, based on specific optical properties. After the preparation, the thin sections were examined using a Leica DM2700P with the Leica MC190HD camera. The thin sections were prepared in the Fitch Laboratory at the British School in Athens, while the study was done at the Department of Geology at the School of Natural Sciences, University of Patras, at the Faculty of History and Archaeology at the University of Athens and at the National National Centre for Scientific Research 'NCSR Demokritos'. Finally, the grain-size distribution (modality) was determined by visual assessment and not by point count analysis.

The fabrics were characterized using Whitbread's thin section descriptive system (1989; 1995, pp.379-388), developed out of techniques of sedimentary petrology and soil micromorphology. The principal criteria for fabric grouping following Whitbread' s system is:

1. The colour and optical activity of the micromass.
2. Void type and orientation.
3. The mineral and rock types comprising the non-plastic inclusions.
4. The quantity, shape, size and grain-size distribution of the non-plastic inclusions.
5. The textural, amorphous and crystalline concentration (depletion) features.

Through the Optical Microscopy a lot of information was provided for the stratigraphic structure, the technical construction and the colours of the glazes. Furthermore, the microscopic study of ceramics had been successfully examined using thin-section petrography. With thin-section examination of kind and structure of clay components provided information about the manufacturing process used to produce the ceramics. Objects that might have a common source were related. Finally, by comparing the mineral components of a ceramic to potential geological sources, the source of manufacture was located.

A 'Fabric Class' brings together Fabric Groups that are related by general geological characteristics (Table 28). A 'Fabric Group' contains related samples that are made from the same raw materials and use the same paste preparation techniques. Individual samples within the group may show variations in the frequency and/or size of the main inclusions, colour differentiation due to firing atmosphere and extent of optical activity resulting from firing temperature. A 'Fabric Sub-group' is a well-defined variant of a Fabric Group. It may represent the use of the same raw materials, but it reflects a slightly different and definable paste recipe such as finer or coarser version. A 'Fabric' is a lone sample representing a discrete fabric type. Yet, because of its microscopic particle size, clay cannot be examined efficiently and so it usually is slightly disregarded during the petrographic analysis. There are, however, other techniques, such as X-ray powder diffraction (XRD) are employed to examine the clay composition and its mineralogical assemblage. Summary descriptions of the fabric groups are presented in this chapter while full thin section descriptions which may be used for comparative purposes are included in the Appendix VI.

8.5 RESULTS AND DISCUSSION OF THE PETROGRAPHIC ANALYSIS

CHALCIS IN EUBOEA

Fabric Groups:

A significant number of examined sherds (8 out of 10 analyzed samples) was assigned to main fabric Group A and its Subgroup A1. The main ceramics typology that classified in this fabric group are fragments of Champlevé Ware (CH84, CH92, CH124), Incised Sgraffito Ware (CH113, CH114) and Amphora [A8A (CH155), Günsenin 2 (CH162) and Günsenin 3 (CH160)]. Furthermore, I observed two other loners: Loner A with Incised Sgraffito Ware sample CH133 and Loner B with Zeuxippus Ware sample CH101 (Figures 122,123,124; Appendix VII).

Main fabric Group A and its Subgroup A1 with samples Amphora [Günsenin 2 (CH162) and Günsenin 3 (CH160)] are mainly characterized by the presence of subhedral to anhedral fragments of Monocrystalline Quartz, Muscovite, Biotite, Polycrystalline Quartz, Clay pellets, Plagioclase and Schists. The minerals of samples are very well to well shorted. The differences of Subgroup A1 from main Group is that these the minerals of two samples are moderately sorted and the inclusions are coarser than samples in group A. Generally, samples of Group A have different firing temperatures and kiln atmosphere.

Microstructure

The porosity is about 20% and is represented mainly by planar. More rarely vughs are observed. The deposition of secondary calcite on the interior surface of the voids in the all the samples was observed.

Groundmass

The groundmass is homogeneous and the micromass is optically active. Its colour is the 2.5YR 4/6 in the Munsell Colour Systemin both polarized light (PPL) and under crossed polars (XP).

Inclusions

C10%: F40%: V20%

Coarse fraction 0.2 mm to 1.8 mm

- Frequent: Monocrystalline Quartz 0.4 mm to 1 mm
- Very few: Polycrystalline Quartz 0.2 mm to 1.8 mm
- Very few to rare: Clay pellets 0.2 mm to 1.2 mm
- Very rare: Schists 0.2 mm to 0.7 mm

Fine fraction 0.2 mm or less

- Frequent: Monocrystalline Quartz
- Common to few: Muscovite and Biotite (very fine)
- Rare: Plagioclase

Textural concentration features (Tcf)

Very few to rare clay pellets: Reddish-brown (PPL and XP), clear to diffuse boundaries, neutral optical state.

Loner A

Incised Sgraffito Ware sample CH133 is mainly characterized by the presence of subhedral to anhedral fragments of Monocrystalline Quartz, Polycrystalline Quartz, Muscovite and Biotite, Plagioclase and Clay pellets. The minerals of sample is well to moderate shorted.

Microstructure

The porosity is about 5% and is represented mainly by vughs. The deposition of secondary calcite on the interior surface of the voids was observed.

Groundmass

The groundmass is homogeneous and the micromass is optically active. The groundmass is at a low percentage. Its colour is the 2.5YR 4/3 in the Munsell Colour System in both polarized light (PPL) and under crossed polars (XP).

Inclusions

C10%: F60%: V5%

Coarse fraction 0.2 mm to 1.8 mm

- Frequent: Monocrystalline Quartz 0.2 mm to 0.6 mm
- Very few: Polycrystalline Quartz 0.2 mm to 0.5 mm
- Rare: Clay pellets 0.2 mm to 0.6 mm

Fine fraction 0.2 mm or less

- Frequent: Monocrystalline Quartz
- Common to few: Muscovite and Biotite (very fine)
- Rare: Plagioclase

Textural concentration features (Tcf)

Rare clay pellets: Reddish-brown (PPL and XP), clear to diffuse boundaries, neutral optical state.

Loner B

Zeuxippus Ware sample CH101 is mainly characterized by the presence of subhedral to anhedral fragments of Monocrystalline Quartz, Plagioclase, Muscovite and Biotite. The minerals of sample is well shorted.

Microstructure

The porosity is about 10% and is represented mainly by vughs. The deposition of secondary calcite on the interior surface of the voids was observed.

Groundmass

The groundmass is homogeneous and the micromass is optically active. The groundmass is less than that of main group. Its colour is the 2.5YR 4/6 in the Munsell Colour System in both polarized light (PPL) and under crossed polars (XP).

Inclusions

C5%: F40%: V10%

Coarse fraction 0.2 mm to 1.8 mm

- Very few: Monocrystalline Quartz 0.2 mm to 0.4 mm
- Very rare: Plagioclase 0.2 mm to 0.3 mm

Fine fraction 0.2 mm or less

- Frequent: Monocrystalline Quartz
- Very rare: Muscovite and Biotite (very fine)
- Rare: Plagioclase

Textural concentration features (Tcf)

Clay Pellets do not exist in this sample.

THE ATHENIAN AGORA IN ATTICA

Fabric Groups:

A significant number of examined sherds (6 out of 9 analyzed samples) was assigned to main fabric Group A. The main ceramics typology classified in this fabric are fragments of Polychrome Painted Ware/Maiolica (AAG29, AAG30, AAG66) and Polychrome Sgraffito Ware (AAG37, AAG60, AAG62). Samples of Group A have different firing temperatures and kiln atmosphere between them. Furthermore, I observed three other Loners: Loner A with Maiolica sample AAG70, Loner B with Zeuxippus sub-Ware sample AAG43 and Loner C with Zeuxippus sub-Ware sample AAG50 (Figures 125,126; Appendix VII).

Main fabric group A is mainly characterized by the presence of subhedral to anhedral fragments of Monocrystalline Quartz, Muscovite and Biotite, Polycrystalline Quartz, Plagioclase, Clay pellets and some Schists. The minerals of samples are very well to well shorted.

Microstructure

The porosity is about 10% and is represented mainly by mainly planar voids. Very rare vughs are observed. The deposition of secondary calcite on the interior surface of the voids in all samples was noticed.

Groundmass

The groundmass is homogeneous and the micromass is optically active. The colours of this group is the 2.5YR 4/6 (AAG62, AAG66), 5YR 4/4 (AAG29, AAG30, AAG37) and 5YR 4/2 (AAG60) in Munsell Colour System in both polarized light (PPL) and under crossed polars (XP).

Inclusions

C5%: F30%: V10%

Coarse fraction 0.2 mm to 1.8 mm

- Rare: Monocrystalline Quartz 0.2 mm to 0.5 mm
- Rare: Clay pellets 0.2 mm to 1.2 mm
- Very rare: Polycrystalline Quartz 0.2 mm to 1.0 mm
- Very rare: Schists 0.2 mm to 1.3 mm

Fine fraction 0.2 mm or less

- Dominant: Monocrystalline Quartz,
- Common: Muscovite and Biotite (very fine)
- Common to few: Polycrystalline Quartz
- Rare: Clay pellets, Plagioclase

Textural concentration features (Tcf)

Rare clay pellets: Reddish-brown (PPL and XP), clear to diffuse boundaries, neutral optical state, concordant with the external matrix.

LONER A

Maiolica sample AAG70 has a high amount of groundmass and two different clays were existed inside it. Its inclusions are few, well sorted, fine and mainly rounded and specifically the presence of Monocrystalline Quartz, Muscovite and Biotite, Polycrystalline Quartz and Plagioclase were observed.

Microstructure

The porosity is about 10% and is represented mainly by vughs. Also, rare plannars are observed. The deposition of secondary calcite was at a high proportion and it is existed in the interior surface of the voids.

Groundmass

The groundmass is inhomogeneous and the micromass is optically active. Two different clays were noticed. Its colour is the 5YR 6/6 in the Munsell Colour System in both polarized light (PPL) and under crossed polars (XP).

Inclusions

C5%: F40%: V10%

Coarse fraction 0.2 mm to 1.8 mm

- Very rare: Monocrystalline Quartz 0.2 mm to 0.5 mm

Fine fraction 0.2 mm or less

- Dominant: Monocrystalline Quartz,
- Common: Muscovite and Biotite (very fine)
- Common to few: Polycrystalline Quartz
- Rare: Plagioclase

Textural concentration features (Tcf)

Clay pellets were observed.

LONER B

Zeuxippus sub-Ware sample AAG43 is poorly to moderately shorted. The inclusions are euhedral to subhedral and specifically the presence of Monocrystalline Quartz, Polycrystalline Quartz, Muscovite and Biotite, Plagioclase, Chert and Shist were observed.

Microstructure

The porosity is about 20% and is represented mainly by plannars. Also, some vughs are observed. The deposition of secondary calcite was observed.

Groundmass

The groundmass is inhomogeneous and the micromass is optically active. Two different clays were noticed. Its colour is the 5YR 6/8 in the Munsell Colour System in both polarized light (PPL) and under crossed polars (XP).

Inclusions

C5%: F40%: V20%

Coarse fraction 0.2 mm to 1.8 mm

- Few: Monocrystalline Quartz 0.2 mm to 0.4 mm
- Very few: Polycrystalline Quartz 0.2 mm to 2.0 mm
- Rare: Chert 0.1 mm to 2.0 mm
- Very rare: Shist 0.1 mm to 2.0 mm

Fine fraction 0.2 mm or less

- Dominant: Monocrystalline Quartz,
- Common to few: Polycrystalline Quartz
- Very few: Muscovite and Biotite (very fine)
- Rare: Plagioclase

Textural concentration features (Tcf)

Clay pellets were observed.

LONER C

Zeuxippus sub-Ware sample AAG50 is moderately shorted. The inclusions are subhedral to anhedral and specifically the presence of Monocrystalline Quartz, Polycrystalline Quartz, Clay Pellets, Schist and Plagioclase were observed.

Microstructure

The porosity is about 20% and is represented mainly by vughs. Also, rare plannars are observed. The deposition of secondary calcite was noticed.

Groundmass

The groundmass is homogeneous and the micromass is optically active. Its colour is the 5YR 6/6 in the Munsell Colour System in both polarized light (PPL) and under crossed polars (XP).

Inclusions

C10%: F30%: V20%

Coarse fraction 0.2 mm to 1.8 mm

- Dominant: Monocrystalline Quartz 0.2 mm to 0.5 mm
- Common to few: Polycrystalline Quartz 0.2 mm to 1.0 mm
- Common to few: Clay Pellets 0.2 mm to 1.8 mm
- Very rare: Schist 0.2 mm to 0.8 mm

Fine fraction 0.2 mm or less

- Dominant: Monocrystalline Quartz,
- Common: Muscovite and Biotite (fine)
- Common to few: Polycrystalline Quartz
- Rare: Schist, Plagioclase

Textural concentration features (Tcf)

Common to few Clay Pellets: Reddish-brown (PPL and XP), clear to diffuse boundaries, neutral optical state, concordant with the external matrix.

THE CASTLE OF MYTILENE IN LESVOS

Fabric Groups:

A significant number of examined sherds (6 out of 11 analyzed samples) was assigned to main fabric Group A. The main ceramics typology classified in this fabric are fragments of Polychrome Sgraffito Ware (MYT209, MYT194), Painted Ware (MYT191) and Monochrome Ware (MYT206, MYT199, MYT172). Furthermore, I observed one more group, Group B with samples of Polychrome Marbled Ware (MYT208, MYT211) and Subgroup B1 (MYT197). Moreover, Loner C with Polychrome Sgraffito Ware sample (MYT217). Finally, Loner D with Polychrome Painted Ware sample (MYT228) (Figures 127,128,129; Appendix VII). The main difference between these samples is that they have different inclusions classification and they are coarser or finer.

Fabric Group A has more volcanic fragments and in general its minerals are coarser than fabric group B.

Fabric group A is mainly characterized by the presence of subhedral to anhedral of Monocrystalline Quartz, Polycrystalline Quartz, Plagioclase, Alkali Feldspars, Volcanic fragments, Biotite, Muscovite, Schists and Clay Pellets. Finally, some fossils were observed. The minerals of samples were moderate to well sorted.

Microstructure

The porosity is about 20% and is represented mainly by plannar which are oriented parallel to the external surface of the ceramic. More rarely vughs are observed. The deposition of secondary calcite is noticed in samples MYT191, MYT209.

Groundmass

The groundmass is homogeneous and the micromass is optically active. The colours are the 5YR 6/8 (MYT194), the 5YR 5/8 (MYT172, MYT191, MYT209), the 5YR 7/6 (MYT206) and the 5YR 6/6 (MYT199) in the Munsell Colour System in both polarized light (PPL) and under crossed polars (XP).

Inclusions

C10%: F40%: V5%

Coarse fraction 0.2 mm to1.8 mm

- Dominant: Monocrystalline Quartz 0.2 mm to 0.8 mm
- Few: Polycrystalline Quartz 0.2 mm to 1.0 mm
- Few: Plagioclase, Alkali Feldspars 0.2 mm to 0.7 mm
- Few: Schists 0.2 mm to 0.4 mm
- Few to Very few: Volcanic fragments0.2 mm to 0.3 mm
- Rare: Biotite 0.2 mm to 0.3 mm

- Very Rare: Clay Pellets 0.5 mm to 1.0 mm

<u>Fine fraction 0.2 mm or less</u>

- Dominant: Monocrystalline Quartz, Polycrystalline Quartz
- Common to few: Plagioclase, Volcanic fragments
- Few: Biotite
- Very Few: Muscovite, Schist

<u>*Textural concentration features (Tcf)*</u>

Few clay pellets: Reddish-brown (PPL and XP), clear to diffuse boundaries, neutral optical state, concordant with the external matrix.

GROUP B

Group B has samples of Polychrome Marbled Ware (MYT208, MYT211) and Subgroup B1 (MYT197). Fabric group B has less volcanic fragments and finer minerals than fabric Group A and it is mainly characterized by the presence of subhedral to anhedral of Monocrystalline Quartz, Polycrystalline Quartz, Biotite, Plagioclase, Volcanic fragments, Muscovite and Clay Pellets. Finally, some fossils were observed. These inclusions were well sorted.

<u>*Microstructure*</u>

The porosity is about 5% and is represented mainly by vughs which are oriented parallel to the external surface of the ceramic. More rarely plannar are observed.

<u>*Groundmass*</u>

The groundmass is homogeneous and the micromass is optically active. Its colours is the 5YR 6/6 (MYT208, MYT211) in the Munsell Colour System in both polarized light (PPL) and under crossed polars (XP).

<u>*Inclusions*</u>

C5%: F40%: V5%

<u>Coarse fraction 0.2 mm to 1.8 mm</u>

- Common to few: Monocrystalline Quartz 0.2 mm to 0.5 mm
- Few to Very few: Plagioclase 0.2 mm to 0.6 mm
- Very few: Polycrystalline Quartz 0.2 mm to 0.6 mm
- Rare: Clay Pellets 0.2 mm to 1.0 mm

Fine fraction 0.2 mm or less

- Dominant: Monocrystalline Quartz, Polycrystalline Quartz
- Common to few: Biotite
- Few: Volcanic fragments
- Rare: Plagioclase, Muscovite

Textural concentration features (Tcf)

Rare Clay Pellets: Reddish-brown (PPL and XP), clear to diffuse boundaries, neutral optical state, concordant with the external matrix.

SUBGROUP B1

Subgroup B1 with sample MYT197 is well shorted. The inclusions are subhedral to anhedral and specifically the presence of subhedral to anhedral of Monocrystalline Quartz, Polycrystalline Quartz, Muscovite and Biotite, Volcanic fragments, Plagioclase and Clay Pellets was observed.

Microstructure

The porosity is about 10% and is represented mainly by plannar which are oriented parallel to the external surface of the ceramic. More rarely vughs are observed. The deposition of secondary calcite was observed.

The Subgroup B1 has less volcanic fragments and more voids than Group B.

Groundmass

The groundmass is homogeneous and the micromass is optically active. Its colour is the 2.5YR 6/6 in the Munsell Colour Systemin both polarized light (PPL) and under crossed polars (XP).

Inclusions

C10%: F30%: V10%

Coarse fraction 0.2 mm to 1.8 mm

- Dominant: Monocrystalline Quartz 0.2 mm to 0.4 mm
- Common to few: Polycrystalline Quartz 0.2 mm to 0.5 mm
- Very rare: Clay Pellets 0.2 mm to 0.5 mm

Fine fraction 0.2 mm or less

- Dominant: Monocrystalline Quartz, Polycrystalline Quartz
- Common to few: Muscovite and Biotite (very fine)
- Few: Volcanic fragments
- Rare: Plagioclase

Textural concentration features (Tcf)

Very rare Clay Pellets: Reddish-brown (PPL and XP), clear to diffuse boundaries, neutral optical state, concordant with the external matrix.

LONER A

The inclusions of Polychrome Sgraffito Ware sample (MYT217) are well sorted with very fine minerals. This sample has the lest volcanic fragments than the other main groups A, B. The inclusions are subhedral to anhedral and specifically the presence of Monocrystalline Quartz, Biotite, Volcanic fragments, Polycrystalline Quartz, Plagioclase and Clay Pellets were observed. Some fossils were observed.

Microstructure

The porosity is about 5% and is represented mainly by vughs which are oriented parallel to the external surface of the ceramic. Very rarely plannar are noticed.

Groundmass

The groundmass is homogeneous and the micromass is the 5YR 7/6 in the Munsell Colour System. Its colour is reddish-orange in both polarized light (PPL) and under crossed polars (XP).

Inclusions

C5%: F40%: V5%

Coarse fraction 0.2 mm to 1.8 mm

- Few: Monocrystalline Quartz O.2 mm to 0.5 mm
- Very few: Polycrystalline Quartz 0.2 mm to 0.4 mm
- Rare: Plagioclase 0.2 mm to 0.3 mm
- Very rare: Clay Pellets 0.2 mm to 1.0 mm

Fine fraction 0.2 mm or less

- Dominant: Monocrystalline Quartz
- Common to few: Biotite
- Few: Volcanic fragments

Textural concentration features (Tcf)

Very rare Clay Pellets: Reddish-brown (PPL and XP), clear to diffuse boundaries, neutral optical state, concordant with the external matrix.

LONER B

The minerals of Polychrome Painted Ware sample (MYT228) is perfectly to well sorted. The inclusions are subhedral to anhedral and specifically the presence of Monocrystalline Quartz and Volcanic fragments were observed.

Microstructure

The porosity is about 5% and is represented by very few voids as plannars and vughs.

Groundmass

The groundmass is homogeneous and the micromass is optically active. Its colour is the 5YR 8/2 in the Munsell Colour System.in both polarized light (PPL) and under crossed polars (XP).

Inclusions

C10%: F50%: V5%

Coarse fraction 0.2 mm to 1.8 mm

- Dominant: Volcanic fragments 0.2 mm to 0.8 mm
- Frequent: Monocrystalline Quartz 0.2 mm to 0.7 mm

Fine fraction 0.2 mm or less

- Dominant: Monocrystalline Quartz
- Frequent: Volcanic fragments

Textural concentration features (Tcf)

Clay pellets do not exist in this sample.

Regarding the thin sections from Chalcis in Euboea, main fabric group A and its subgroup A1 with samples of Amphora are mainly characterized by the presence of Monocrystalline Quartz, Muscovite, Biotite, Polycrystalline Quartz, Clay pellets, Plagioclase and Schists. The differences of Subgroup A1 from main Group A is that the minerals of two samples are moderately sorted and the inclusions are coarser than samples in group A. Generally, samples of Group A have different firing temperatures and kiln atmosphere between them. Incised Sgraffito Ware sample CH133 (Loner A) is mainly characterized by the presence of Monocrystalline Quartz, Polycrystalline Quartz, Muscovite and Biotite, Plagioclase and Clay pellets. But Zeuxippus Ware sample CH101 (Loner B) is mainly characterized by the presence of subhedral to anhedral fragments of Monocrystalline Quartz, Plagioclase, Muscovite and Biotite without clay pellets. The deposition of secondary calcite on the interior surface of the voids was observed in all the samples.

According to the geological map, the raw materials of main fabric group came from the Lelantine plain and specifically form allunial deposits in river valleys and plain areas open to the sea, or in small internal basins. They consist of unconsolidated clayey-sandy materials with dispersed cobbles and pebbles, as well as materials of torrential terraces, of small height. Red loams frequently occur (IGME 1976, Karymbalis 2018, p.3,4). The raw materials of Loner A probably have been derived from a closer proximity to the riverbeds of Lilanta river than main group. Samples from Group A present a finer fabric due to the longer distance from the river that the raw materials had transferred than Incised Sgraffito Ware sample CH133 (Loner A). Zeuxippus Ware sample CH101 (Loner B) was an imported ceramic which had less groundmass than all the previous mentioned ceramics. Finally, the potters from Chalcis in Euboea used the same raw materials source but they followed a different clay processing (Figure 130).

Regarding the thin sections from the Athenian Agora in Attica, main fabric group A is mainly characterized by the presence of subhedral to anhedral fragments of Monocrystalline Quartz, Muscovite and Biotite, Polycrystalline Quartz, Plagioclase, Clay pellets and some Schists. The minerals of these samples are very well to well shorted. Maiolica sample AAG70 (Loner A) has a high amount of groundmass and two different clays existed inside it. Its inclusions are few, well sorted, fine and mainly rounded and specifically the presence of Monocrystalline Quartz, Muscovite and Biotite, Polycrystalline Quartz and Plagioclase were observed. At Zeuxippus Ware Subtype sample AAG43 (Loner B), its groundmass is inhomogeneous and the presence of Monocrystalline Quartz, Polycrystalline Quartz, Muscovite and Biotite, Plagioclase, Chert and Shist were observed. Two different clays were noticed at this fragment. But, at Zeuxippus Ware Subtype sample AAG50 (Loner C), its groundmass is homogeneous and the presence of Monocrystalline Quartz, Polycrystalline Quartz, Clay Pellets, Schist and Plagioclase were observed. The deposition of secondary calcite on the interior surface of the voids was noticed at all samples. In addition, Maiolica sample AAG70 (Loner A) and Zeuxippus Ware Subtype sample AAG50 (Loner C) were imported and both of them have two different clays mixed. Finally, Zeuxippus Ware Subtype sample AAG43 (Loner B) was an imitation of original Zeuxippus Ware.

Main fabric group A was locally manufactured in the Athenian Agora in Attica as it was proven by WD-XRF analyses. This group consisted of a completely different clay which is a pinkish shade clay and it is not the same as the common red Attica clay that that was used in earlier centuries. The potential provenance of this clay is the Municipality of Vari-Voula-Vouliagmeni at the Saronic Gulf in Attica, GR which is close to the Athenian Agora in Attica about 15 km far away (Latsoudas, IGME, 1976,1977,1979,1991,1992). This area is characterized by brown-coloured, terrestrial and fluvial-terrestrial deposits and specifically cohesive clayey-loams, of various lithological composition, with dispersed cobbles. Another area with this light-coloured clay is Mesogaia in Attica, GR which is a complex of municipalities of Eastern Attica that extend east of Ymittos that separates them from the basin of Attica but this region is quite far away about 20-30 km.

The Maiolica produced in Italy were widely used that period and as a result the Athenian potters found a way to face this competition. For that propose, firstly they found another clay from another region ‘a light-coloured clay- a pinkish shade clay’ and secondly, they made a unique pottery type ‘Polychrome Painted Ware/Maiolica’. The Athenian potters were very experienced and flexible potters as they had a long pottery construction tradition many centuries ago. Concerning the pottery laboratories from the other under studied areas, the potters in the Ancient Agora seemed to have strong artistic influences from Italy and Spain in that period (Figure 131).

Regarding the thin sections from the Castle of Mytilene in Lesvos, fabric Group A is mainly characterized by the presence of Monocrystalline Quartz, Polycrystalline Quartz, Plagioclase, Alkali Feldspars, Volcanic fragments, Biotite, Muscovite, Schists and Clay Pellets. Finally, some fossils were observed, which are compatible to the local geology. Fabric Group B has less volcanic fragments and finer minerals than fabric group A and it is mainly characterized by the presence of Monocrystalline Quartz, Polycrystalline Quartz, Biotite, Plagioclase, Volcanic fragments, Muscovite and Clay Pellets. Finally, some fossils were observed. Subgroup B1 is well shorted. The presence of subhedral to anhedral of Monocrystalline Quartz, Polycrystalline Quartz, Muscovite and Biotite, Volcanic fragments, Plagioclase and Clay Pellets was observed. Subgroup B1 has less volcanic fragments and more voids than Group B. Fabric Group A has more volcanic fragments and general its minerals are coarser than fabric Group B. Groups A, B present secondary calcite also. Polychrome Sgraffito Ware sample MYT217 (Loner A) is well sorted with very fine minerals. This sample has the lest volcanic fragments than the other main groups A, B. Its inclusions are Monocrystalline Quartz, Biotite, Volcanic fragments, Polycrystalline Quartz, Plagioclase and Clay Pellets. Some fossils were noticed. The minerals of Polychrome Painted Ware sample MYT228 (Loner B) is perfectly to well sorted. The inclusions are the Monocrystalline Quartz and Volcanic fragments. Clay pellets do not exist in this sample. The difference between these samples is that their inclusions are different sorted and the inclusions are either coarser or finer. Fabric Group A has more volcanic fragments and its minerals are coarser than fabric group B. Fabric Group A have some fossils also. This means that the raw materials of fabric Group A came from an area near the coast.

The raw materials seemed to have come from the eastern part of the island and specifically from an area near the castle. Clay is extant at the south east coastal area and specifically from Mytilene, the capital of Lesvos, to the airport and farther down where a military base exists where access to the public is forbidden. Another clay yielding area is at the south east coastal area ‘Moria’ about

6,5 km away. Unfortunately, we do not have a clear picture for the residential area in Mytilene or Moria in Lesvos where their geological information has been lost. Apart from the above, another area relatively close to the city with good quality of clay is Thermi about 10 km away. According to the personal opinion of the Emeritus Researcher Mr. Bassiakos Ioannis and the PhD candidate Katerina Pollatou who are geologist, this area has excellent raw material for ceramics and is 10-15 km away from the castle. These areas have quaternary undivided with grey and red clays, sands, gravels, coastal conglomerates continental deposits.[5] Katerina Pollatou interviewed the 3rd generation potter Mr Zachariadis Anastasios in Mytilene, who told her that his grandfather was getting clay from a coastal area north of Mytilene. Today, Mr Zachariadis Anastasios buys clay from abroad. He did not remember exactly the name of the area. From his description, we believe that this area was in Moria or in Thermi (Figure 132).

[5] Personal contact with Dr. Yannis Bassiakos, Researcher Emeritus at the Institute of Nanoscience and Nanotechnology, NCSR "Demokritos and Katerina Pollatou, PhD candidate of Geology.

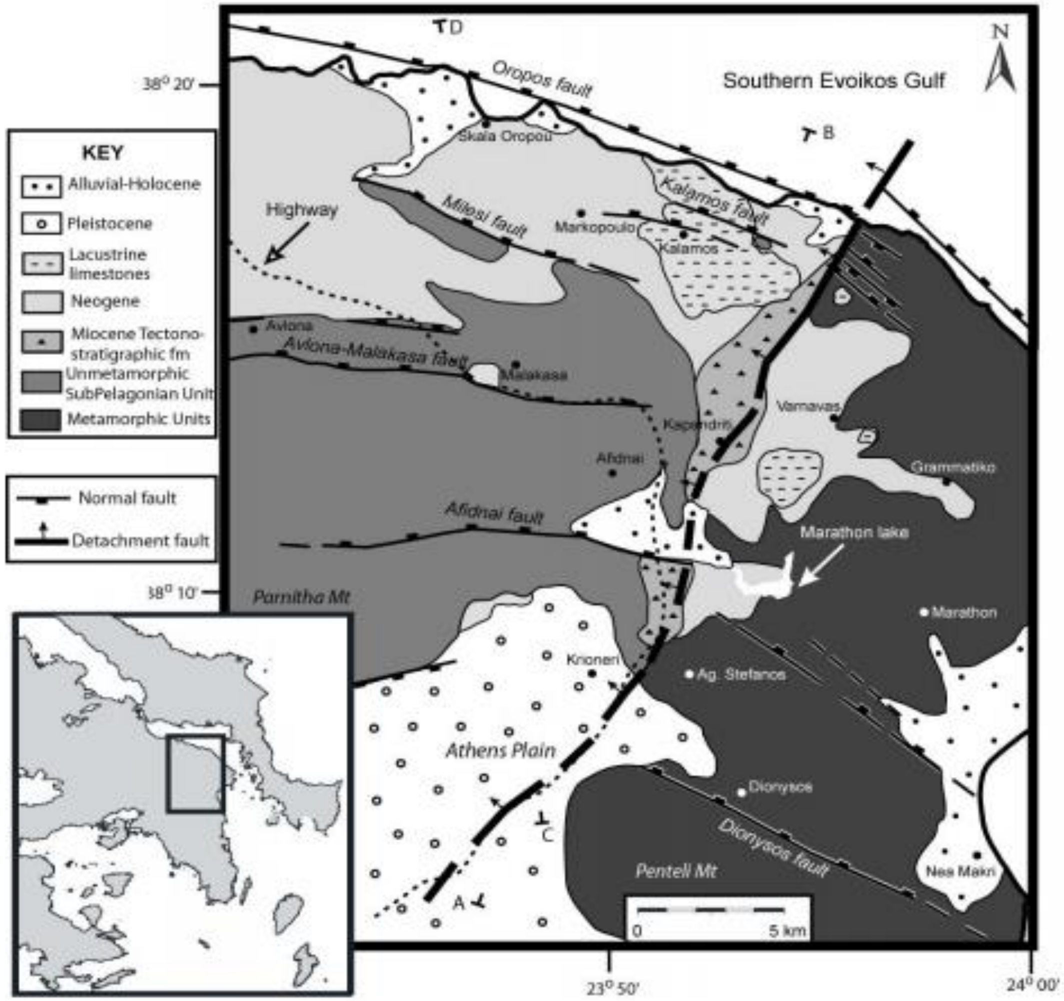


Figure 110 Geological map of NE Attica, Greece (after Papanikolaou and Papanikolaou 2007, p. 427).

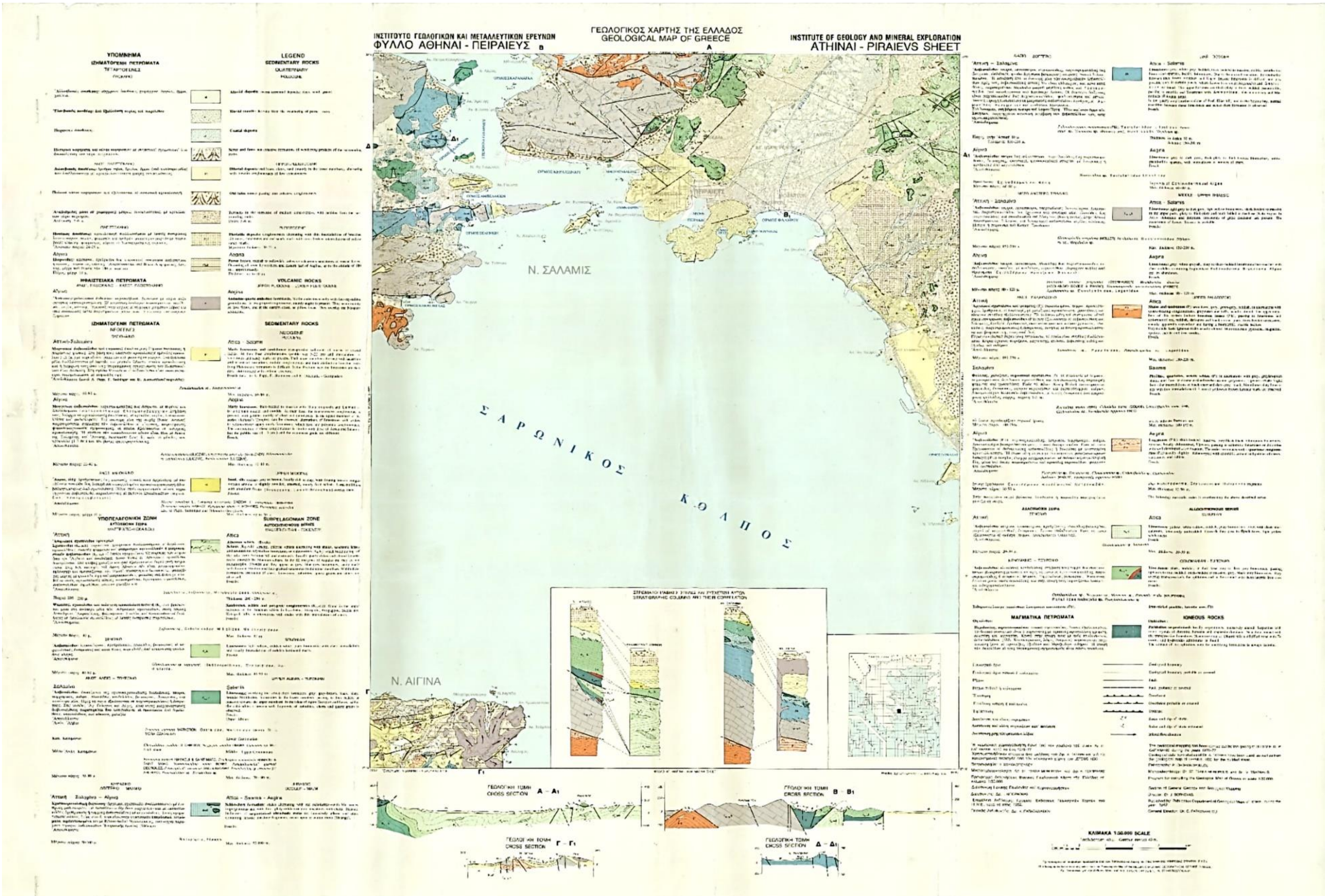


Figure 111 Geological map of Piraeus in Attica, Greece (Gaitanakis (IGME) 1976-77).

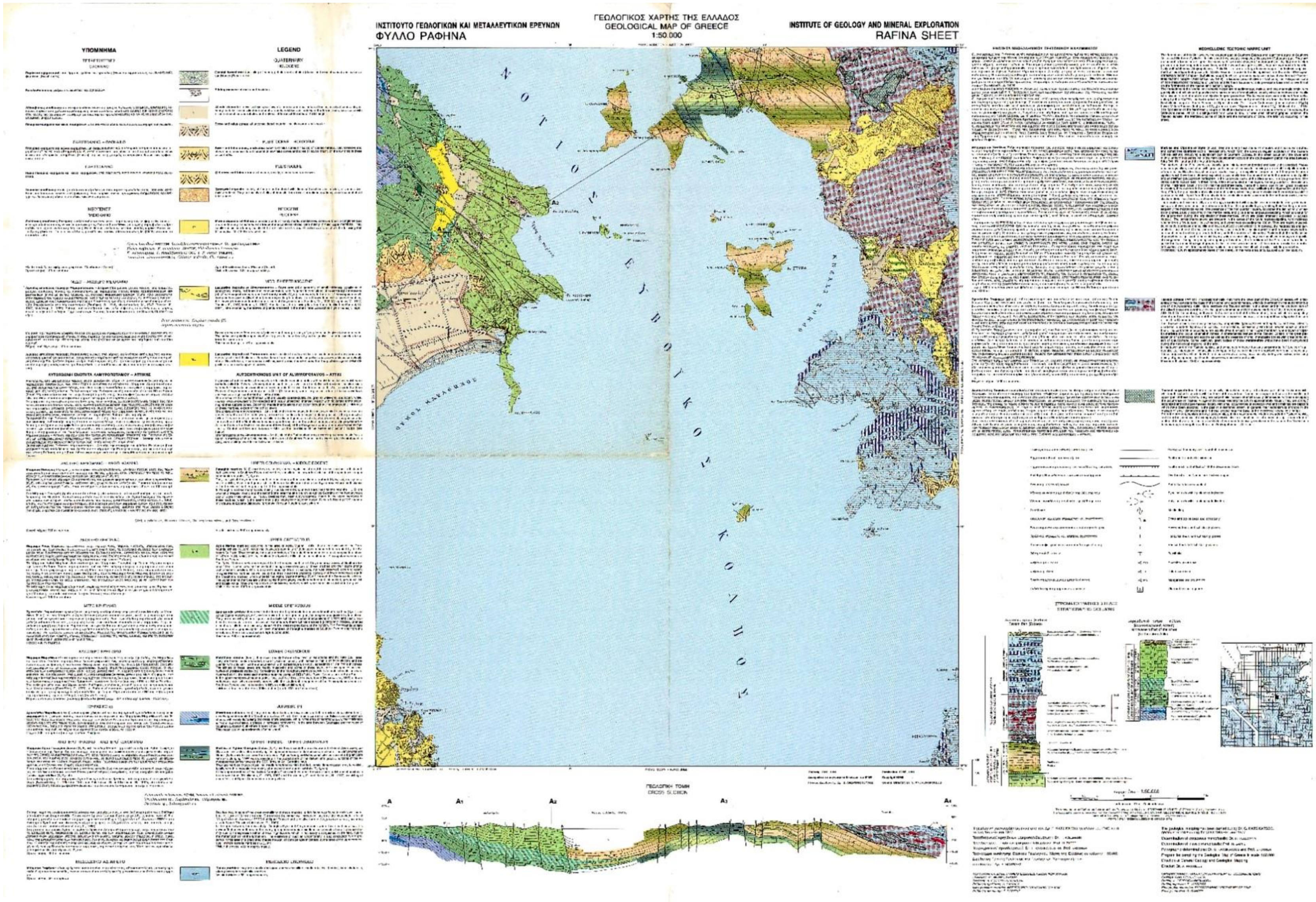


Figure 112 Geological map of Rafina in Attica, Greece (Katsikatsos (IGME) 1966-67; 1977).

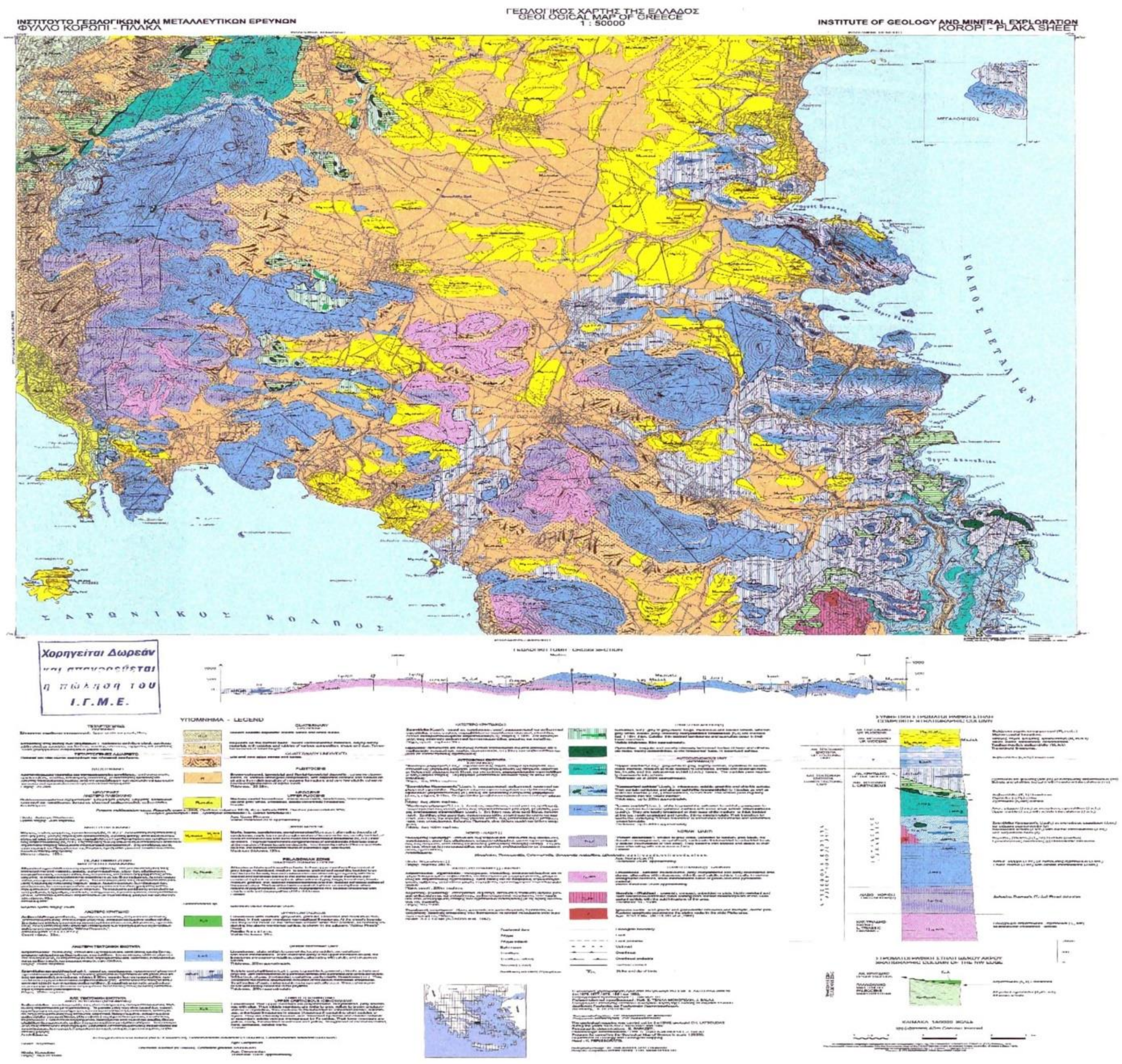


Figure 113 Geological map of Koropi-Plaka in Attica, Greece (Latsoudas (IGME) 1976;1977;1979;1991;1992).

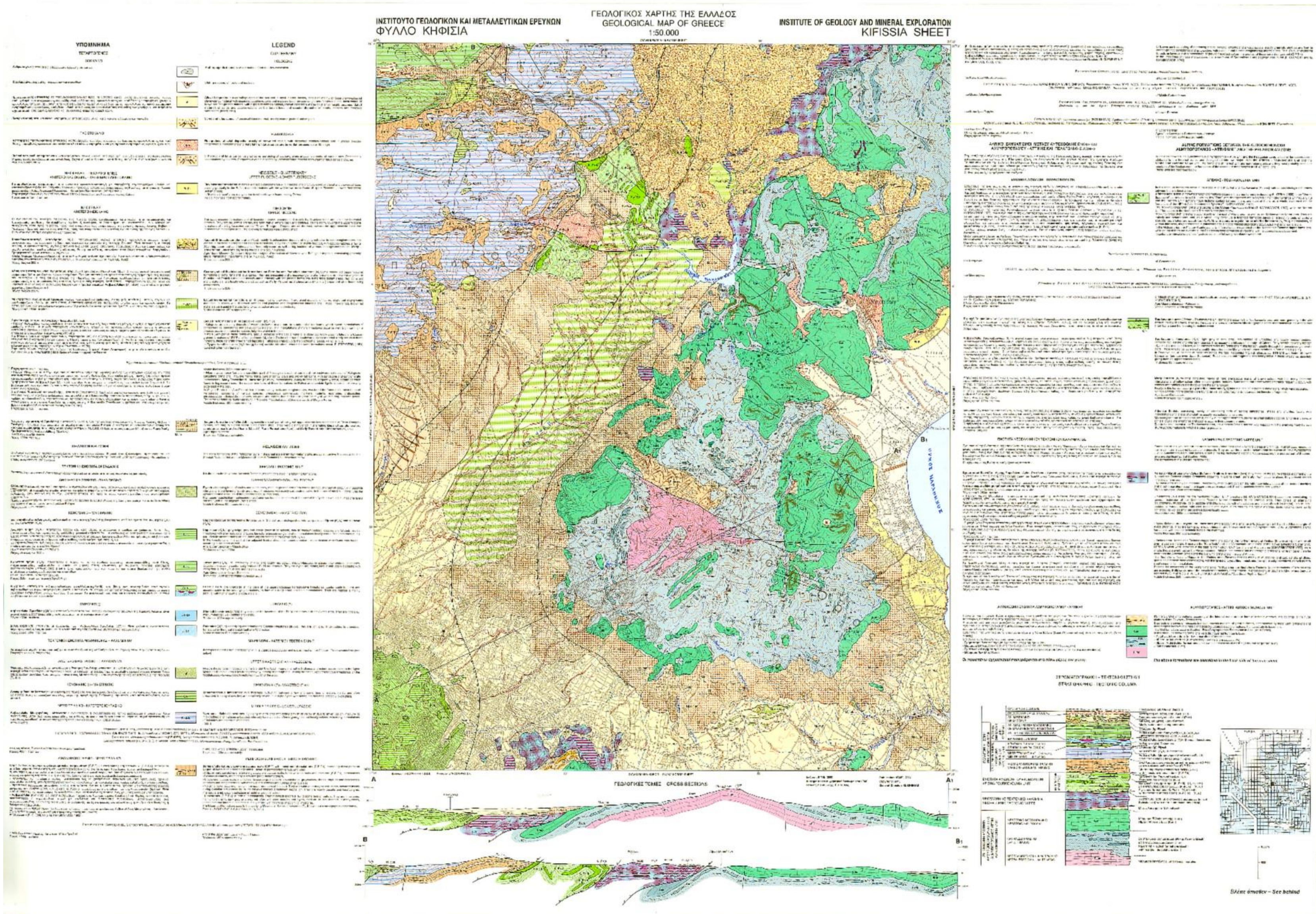
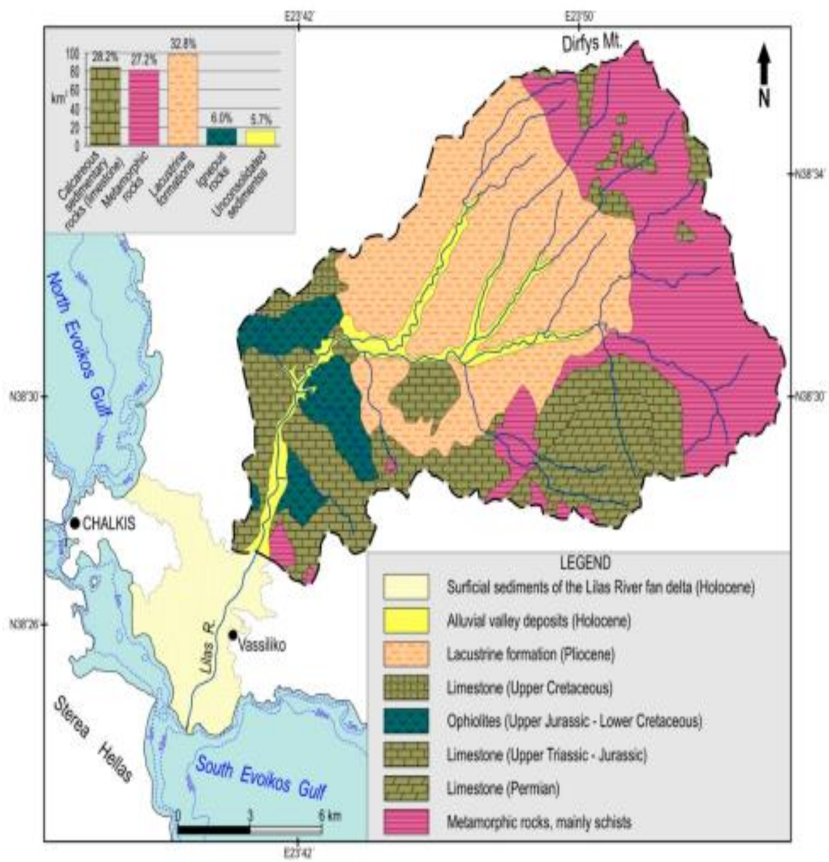


Figure 114 Geological map of north Attica, Greece (Clement and Katsikatsos 1982).



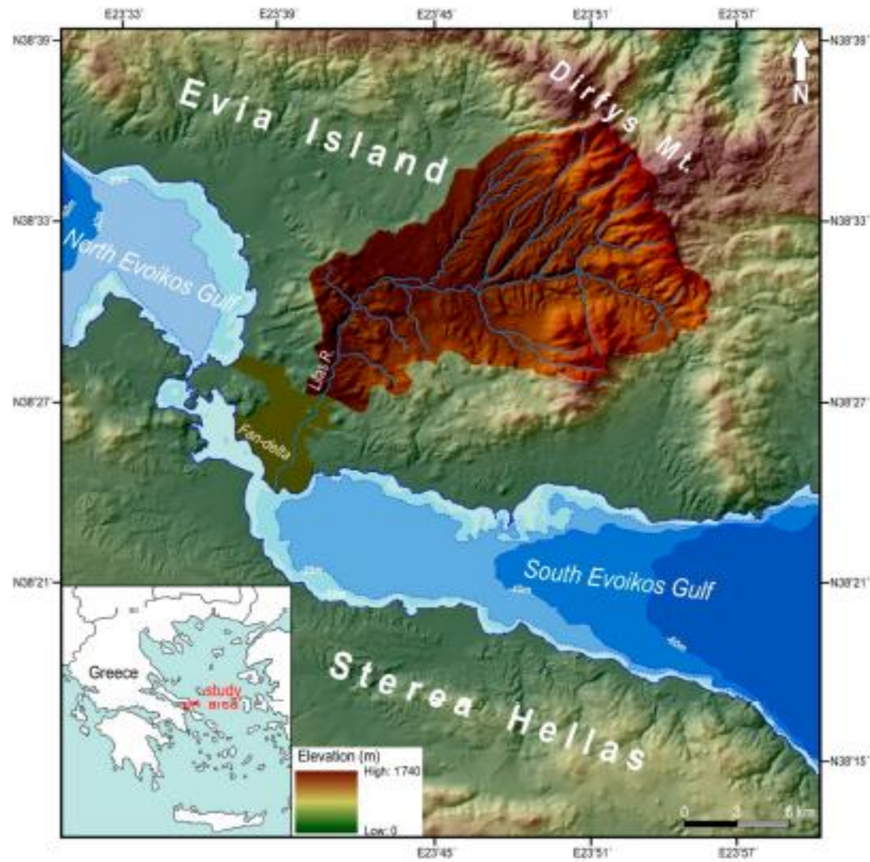


Figure 115 Digital elevation model (DEM) of the broader area of the Lilas River catchment and fan delta. One notices clearly the bathymetry of the northern part of the South Euboean Gulf as well as the southern part of the North Euboean (left) (after Karymbalis 2018, p. 3).

Figure 116 Simplified lithological map of the Lilas River drainage basin depicting also a diagram of the percentage area of each one of the lithological types in the catchment. After the Greek Institute of Geology and Mineral Exploitation (IGME) 1:200,000 scale geological map of Greece (right) (after Karymbalis 2018, p. 4).

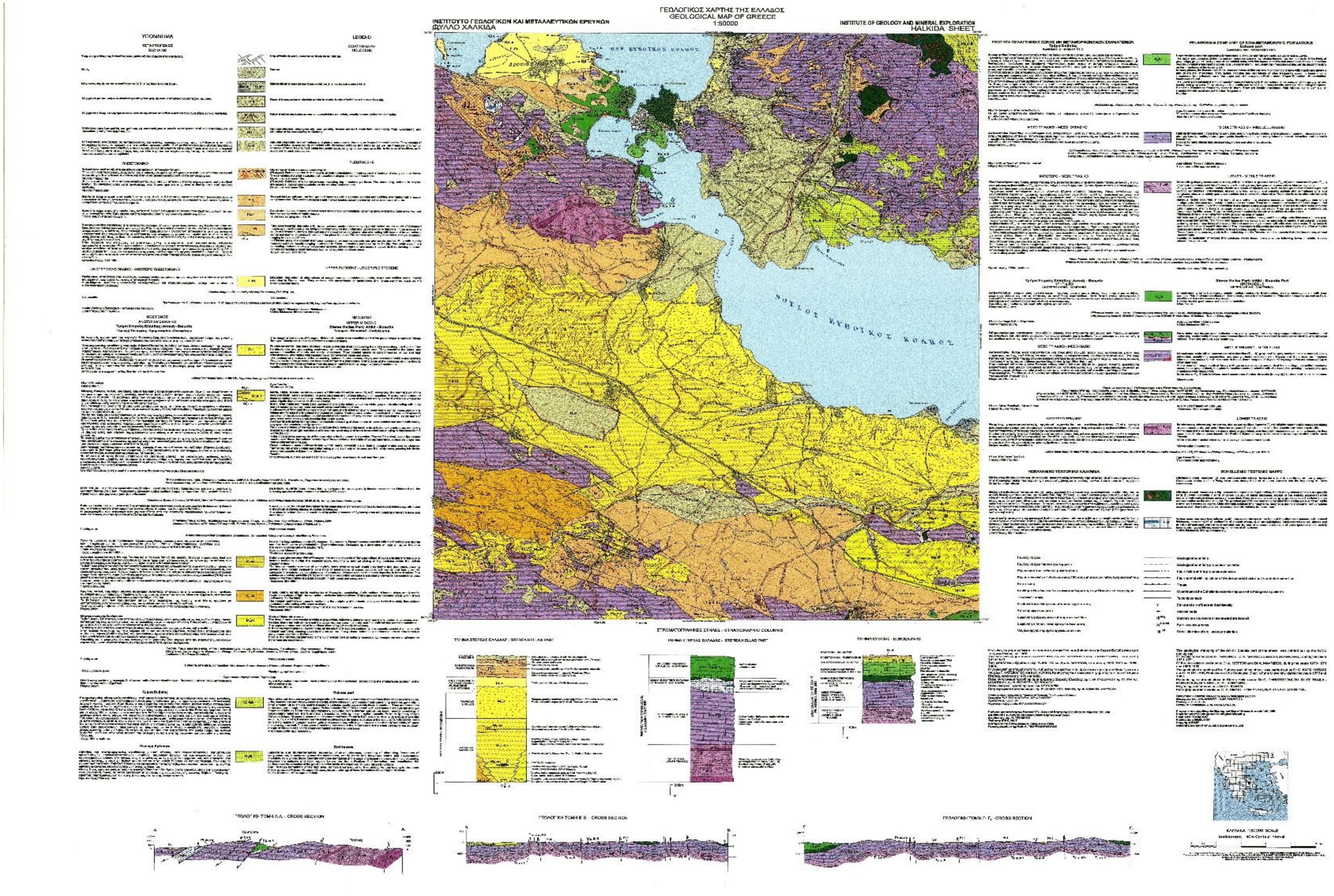


Figure 117 Geological map of Chalcis in Euboea, Greece (IGME 1976).

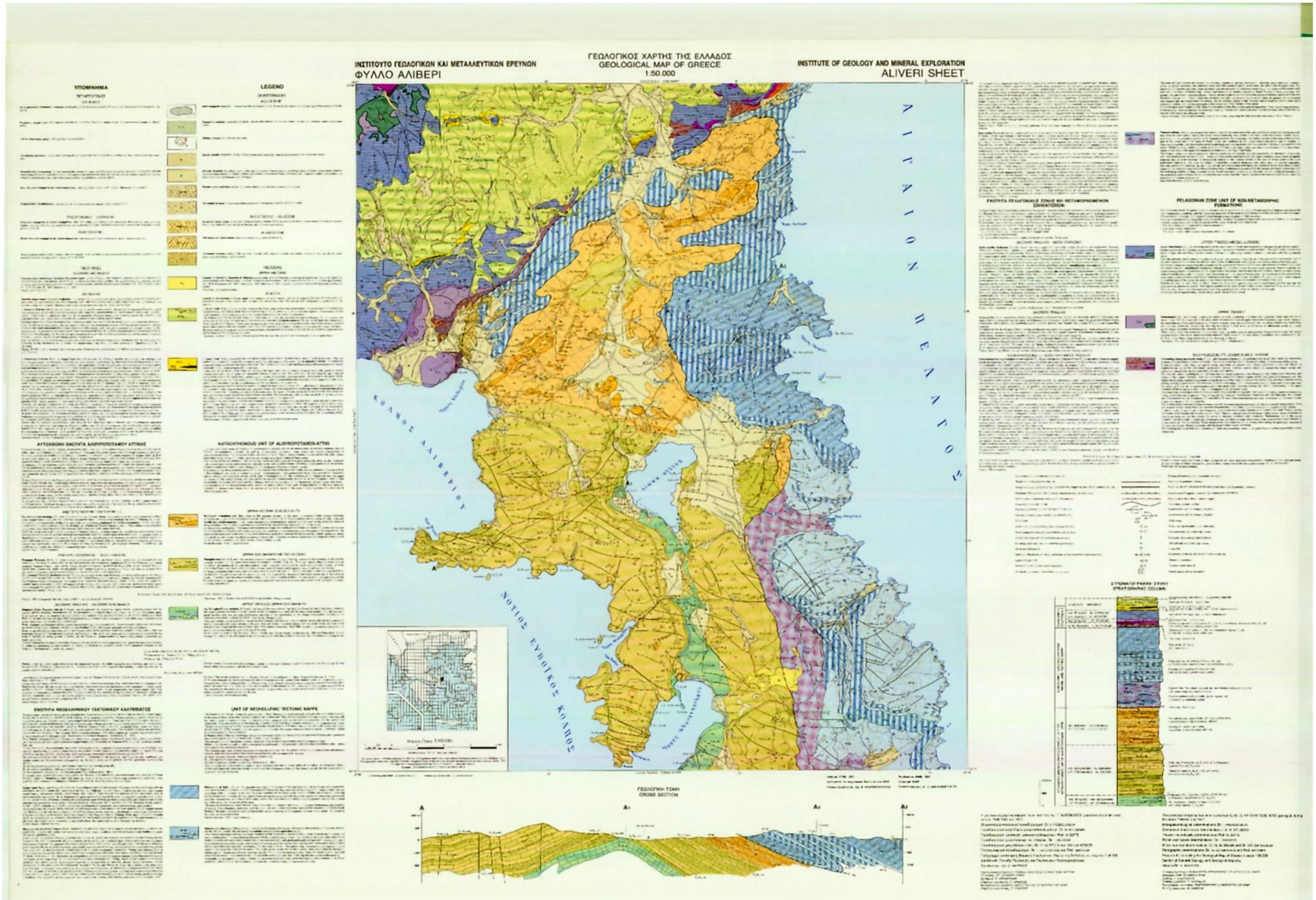
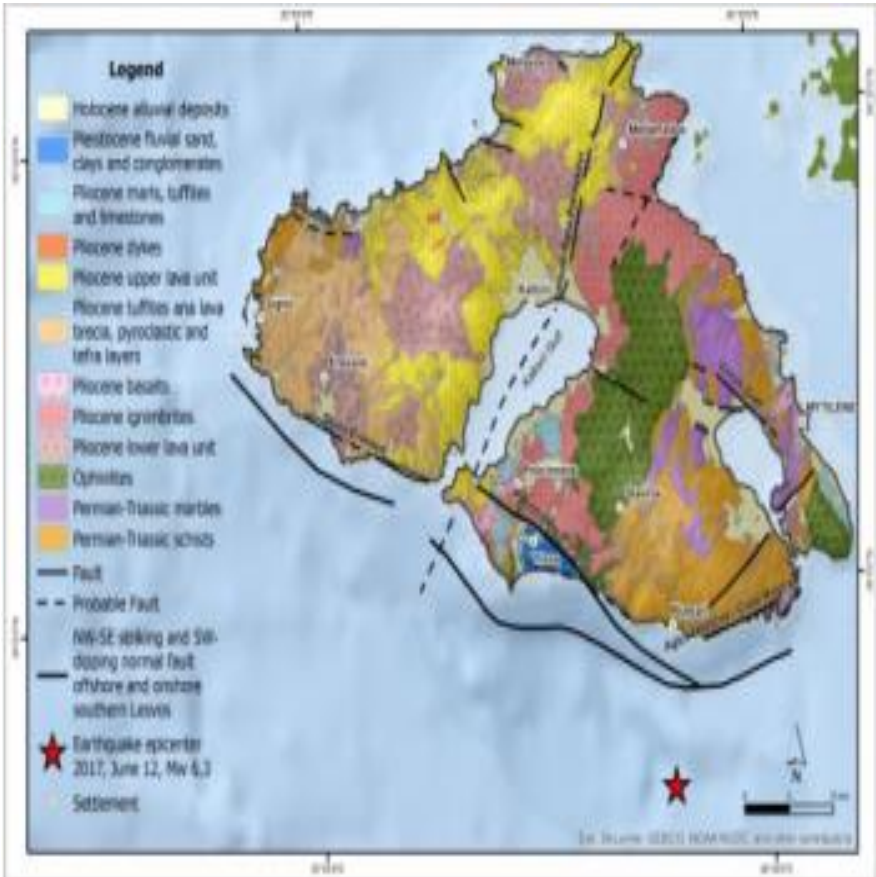


Figure 118 Geological map of Aliveri in Euboea, Greece (Katsikatsos (IGME) 1966-67; 1977).



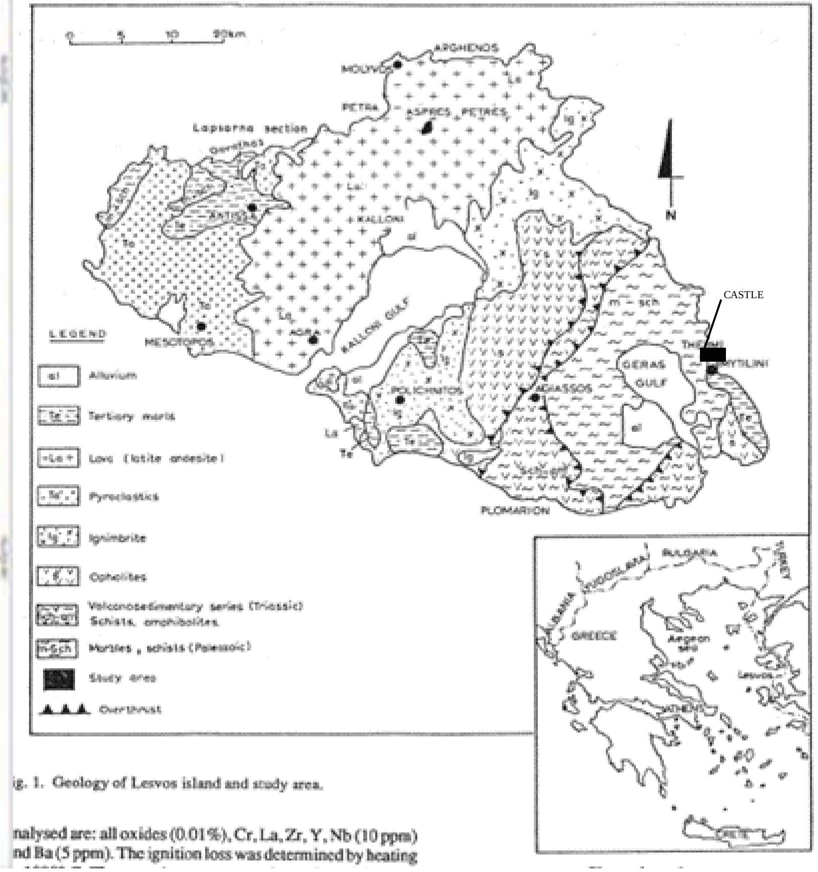


Figure 119 Geological map of Lesvos island, Greece (left) (after Andreadakis 2017).

Figure 120 Geology of Lesvos and the studied area (right) (after Kelepertsis 1992, p.114).

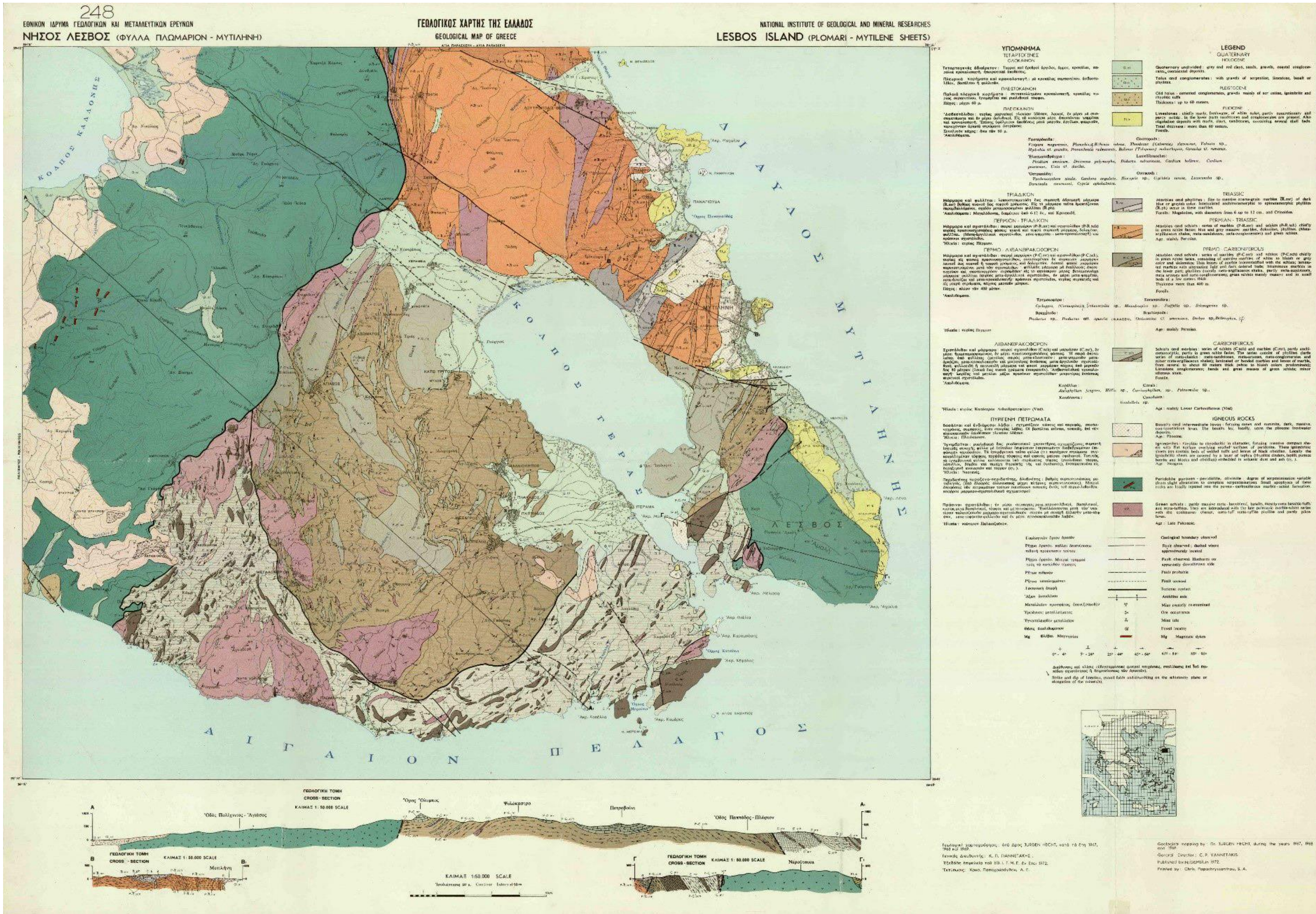
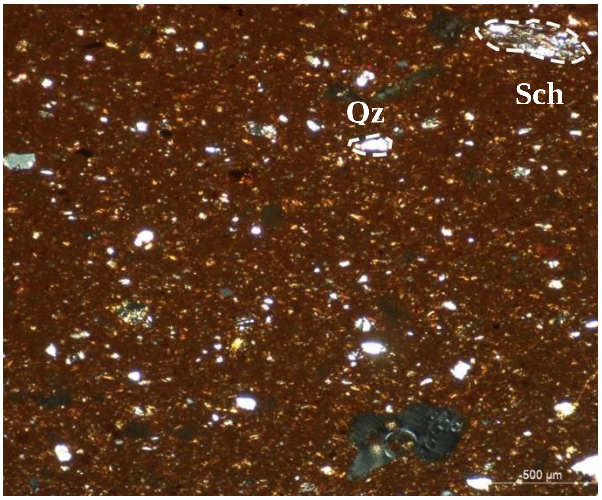


Figure 121 Geological map of Plomari area in Lesvos island, Greece (Hecht (IGME) 1967-1969).

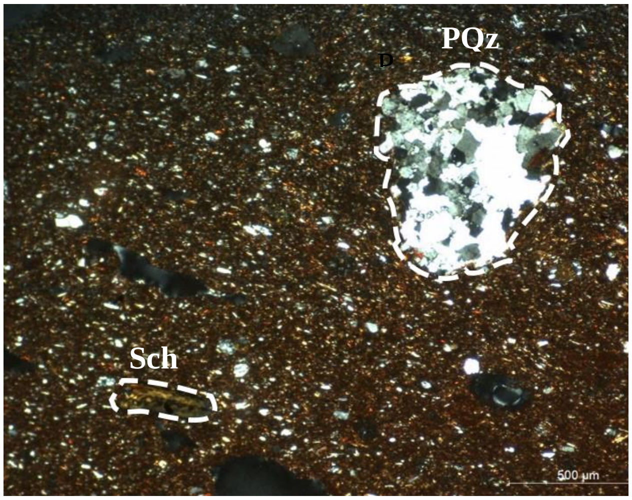
MINERAL	ABBREVATIONS	CHEMICAL FORMULA*	d001 (A˚)
Original minerals			
Quartz	Qz	SiO_2	3.34
Calcite	Cal	$CaCO_3$	3.04
Muscovite	Ms	$KAl_2(Si_3AlO_{10})(OH)_2$	10.0
Illite	Ilt	$(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$	10.0
Dollomite	Dol	$CaMg(CO_3)_2$	2.89
Original and neoformed minerals			
Hematite	Hem	Fe_2O_3	2.69
Alkali Feldspar	Kfs		3.25
Orthoclase	Or	$KAlSi_3O_8$	3.31
Sanidine	Sa	$(K,Na)(Si,Al)_4O_8$	3.31
Microcline	Mc	$KAlSi_3O_8$	3.29
Anorthoclase	Ano	$(Na,K)AlSi_3O_8$	6.39
Plagioclase	Pl		3.19
Albite	Alb	$NaAlSi_3O_8$	3.19
Anorthite	An	$CaAl_2Si_2O_8$	3.18
Neoformed minerals			
Diopside	Di	$CaMgSi_2O_6$	2.99
Cristoballite	Crs	SiO_2	4.05
Gehlenite	Gh	$Ca_2Al_2SiO_7$	2.85
Halite	Hl	NaCl	
Mullite	Mul	$Al_6Si_2O_{13}$	3.40
Analcime	Anl	$NaAlSi_2O_6 \cdot H_2O$	5.61

*Mineral abbreviations from (Whitney and Evans, 2010)

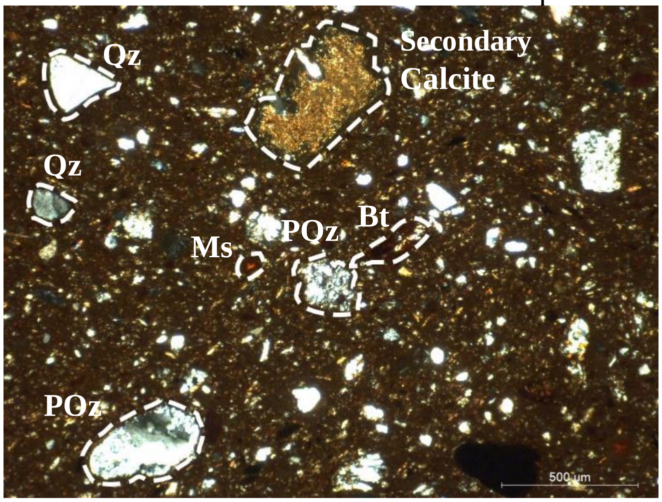
Table 28 Minerals, chemical formulae, and the diagnostic XRD peaks (d001) used for identification in the present study.



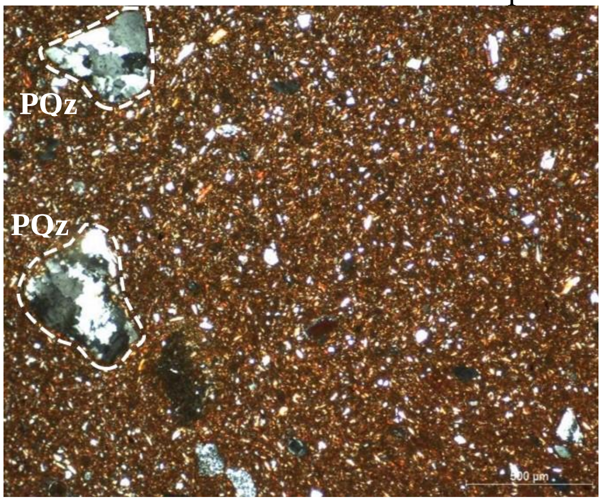
Champlevé Ware CH84 5x



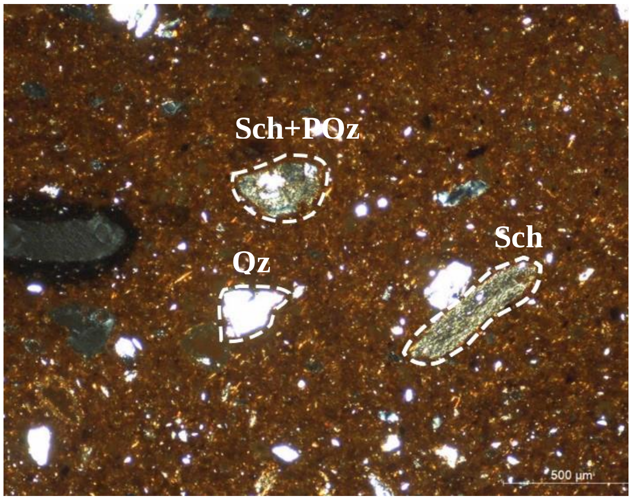
Champlevé Ware CH92 5x



Champlevé Ware CH124 5x

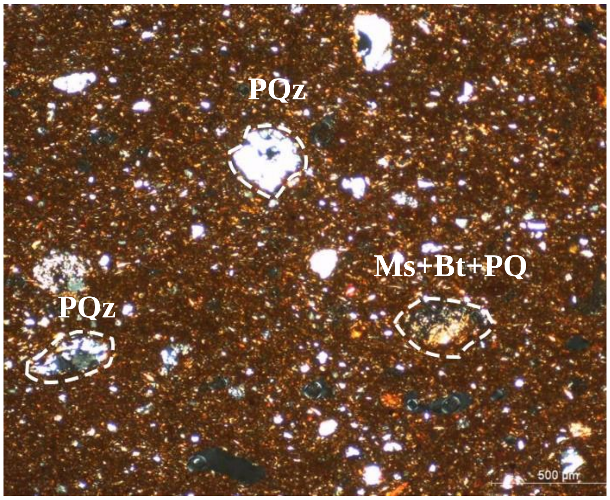


Incised Sgraffito Ware CH113 5x

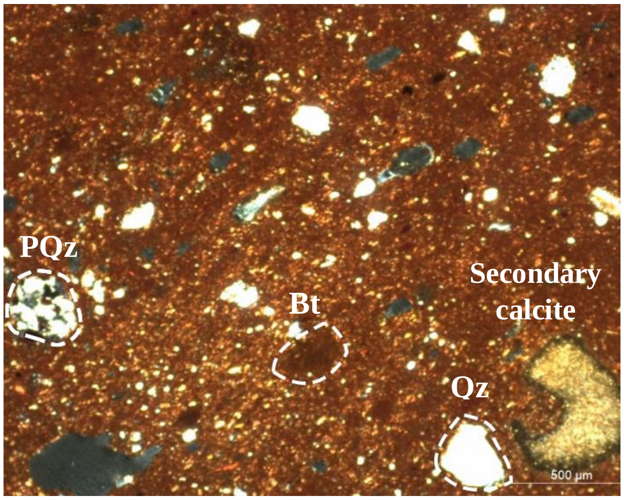


Incised Sgraffito Ware CH114 5x

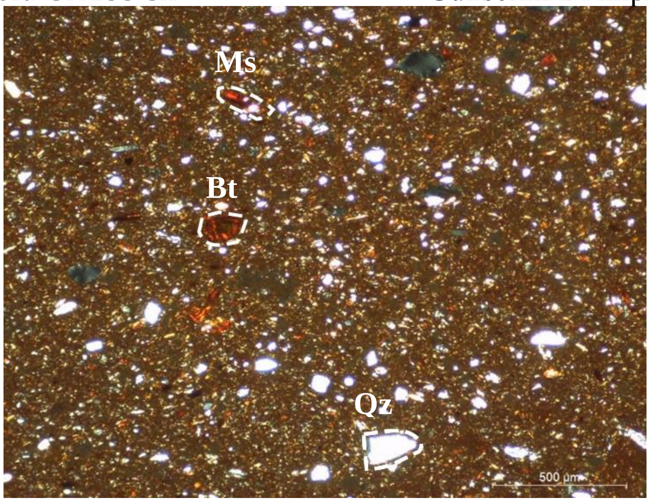
Figure 122 Petrographic analysis of Main Fabric Group A from Chalcis in Euboea.



A8A Amphora CH155 5x

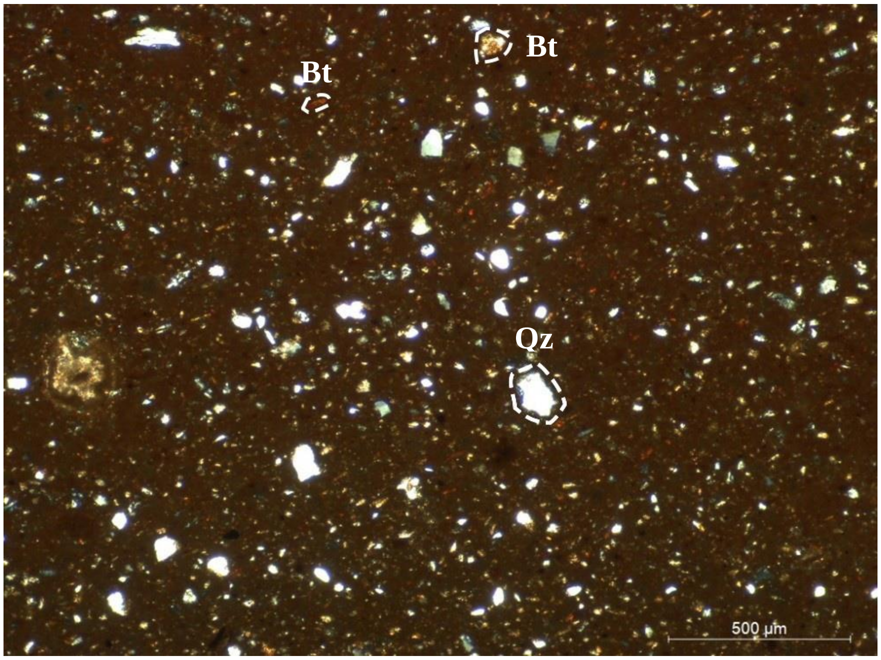


Günsenin 2 Amphora CH162 5x

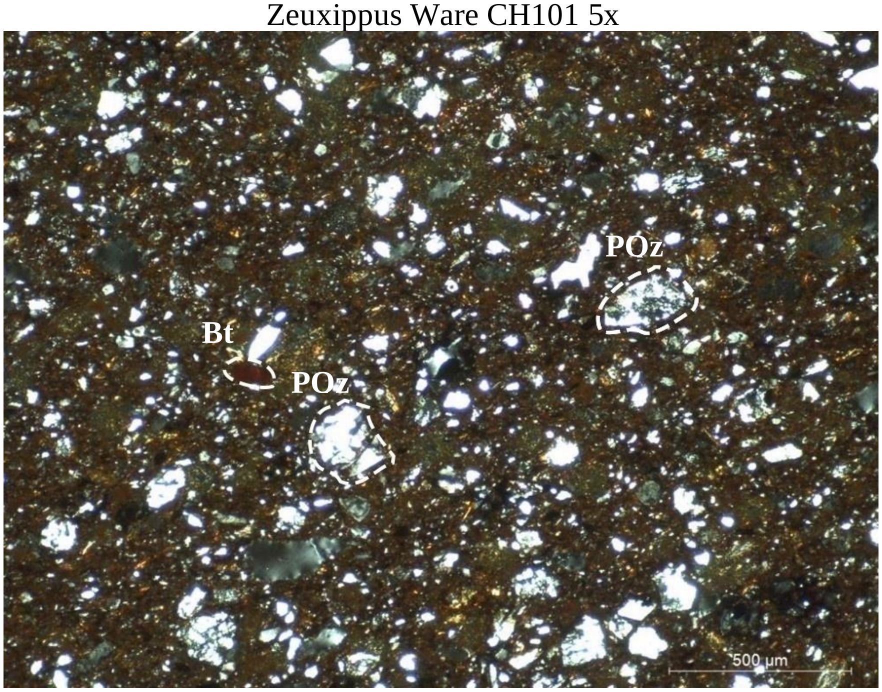


Günsenin 3 Amphora CH160 5x

Figure 123 Petrographic analysis of Main Fabric Group A from Chalcis in Euboea.

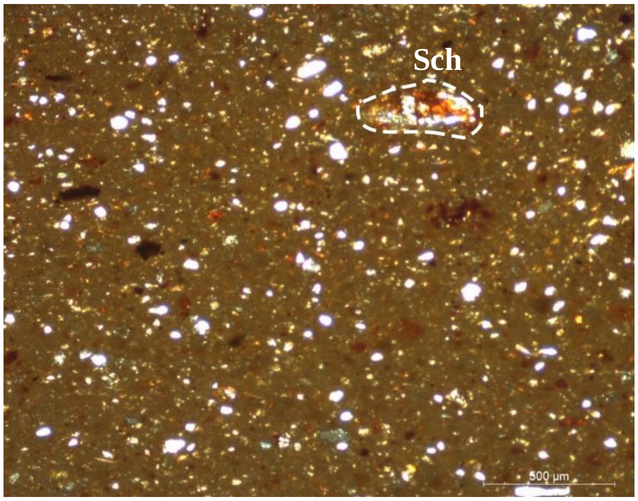


Zeuxippus Ware CH101 5x

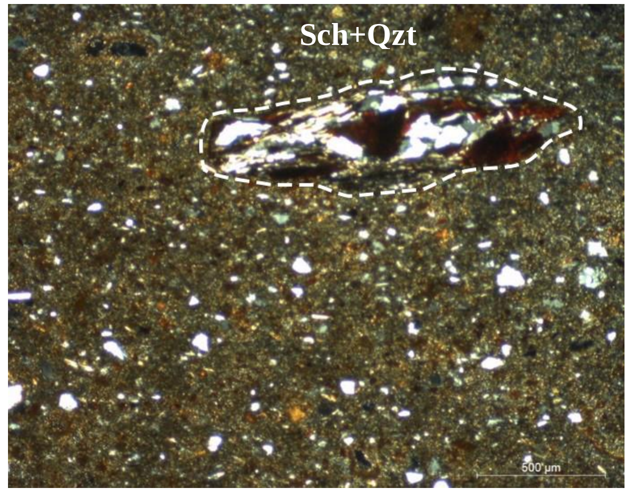


Incised Sgraffito Ware CH133 5x

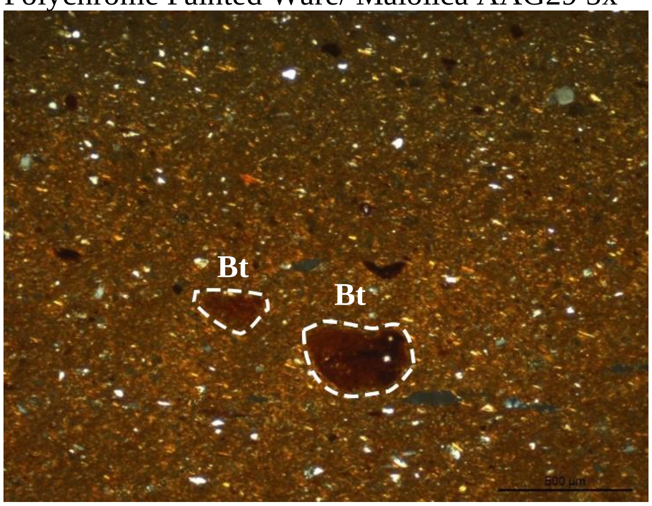
Figure 124 Petrographic analysis of Loner A (CH133) and Loner B (CH101) from Chalcis in Euboea.



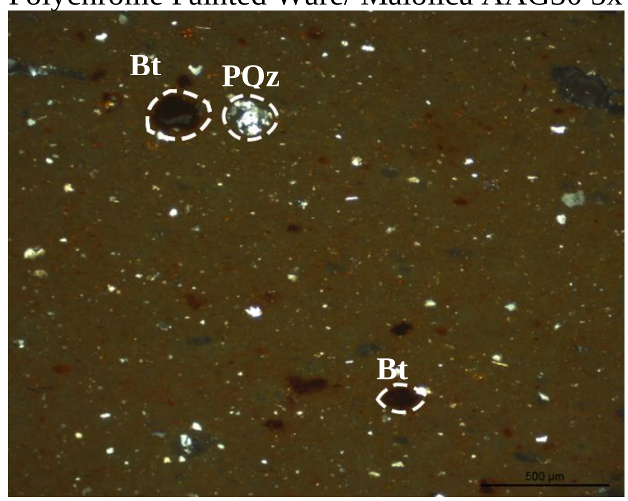
Polychrome Painted Ware/ Maiolica AAG29 5x



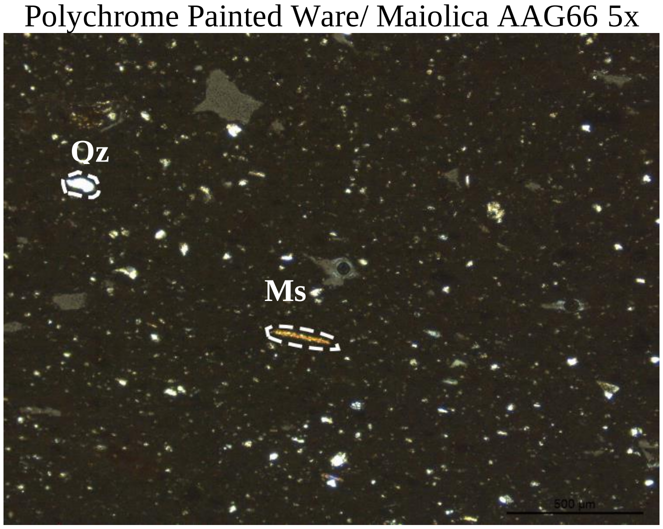
Polychrome Painted Ware/ Maiolica AAG30 5x



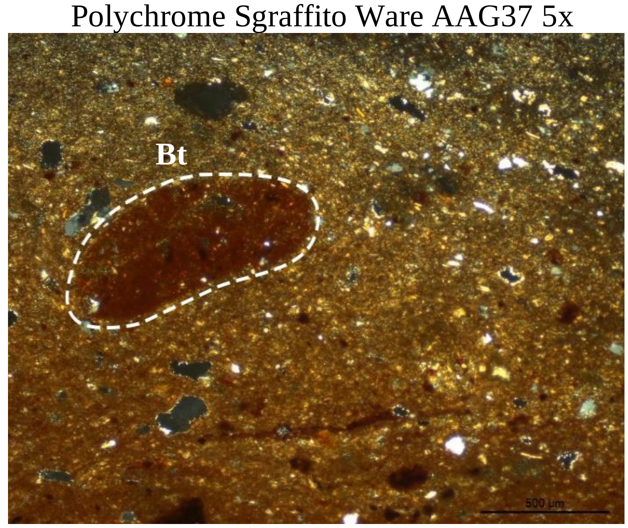
Polychrome Painted Ware/ Maiolica AAG66 5x



Polychrome Sgraffito Ware AAG37 5x

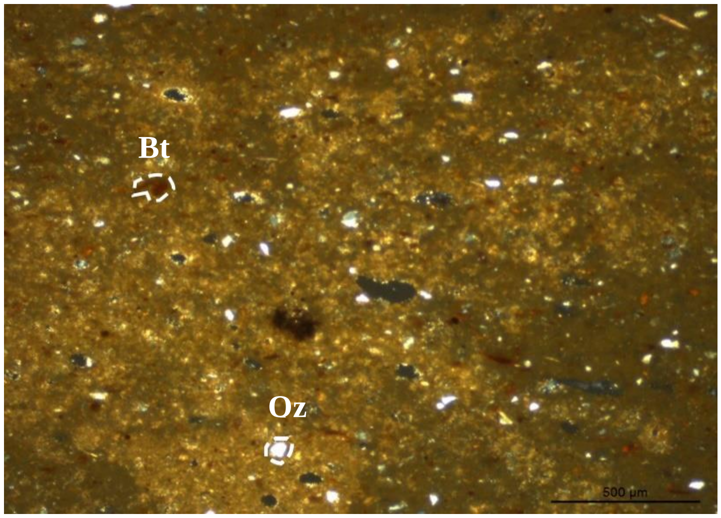


Polychrome Sgraffito Ware AAG60 5x

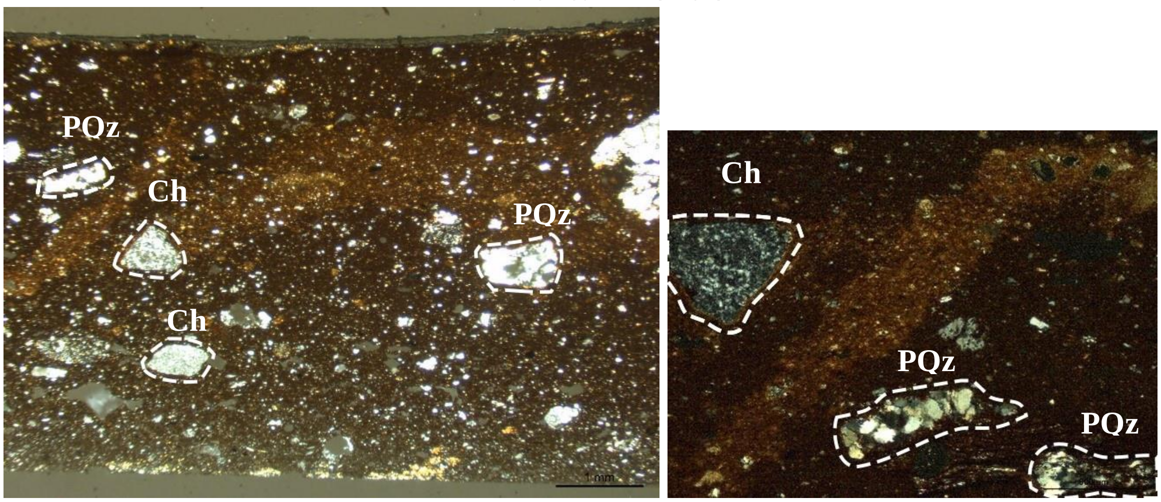


Polychrome Sgraffito Ware AAG62 5x

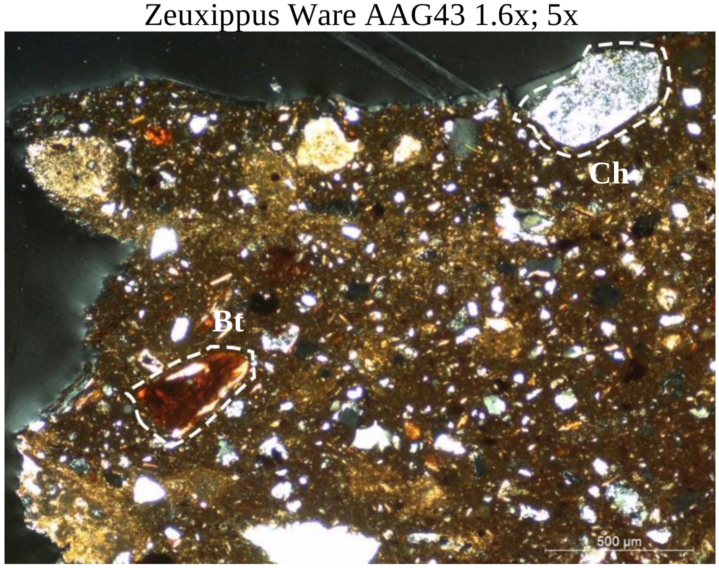
Figure 125 Petrographic analysis of Main Fabric Group A from the Athenian Agora in Attica.



Maiolica AAG70 5x

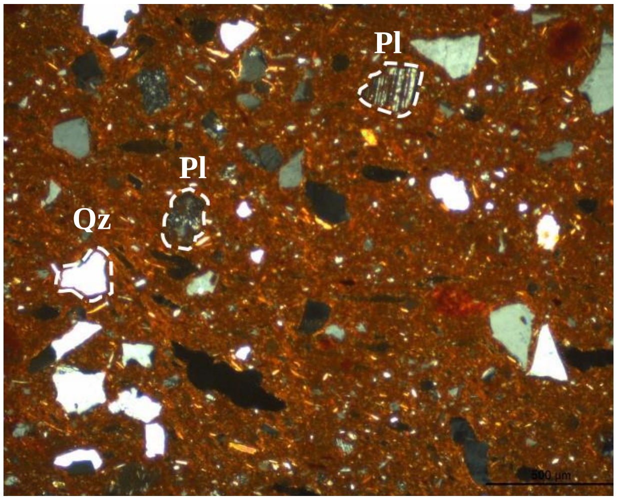


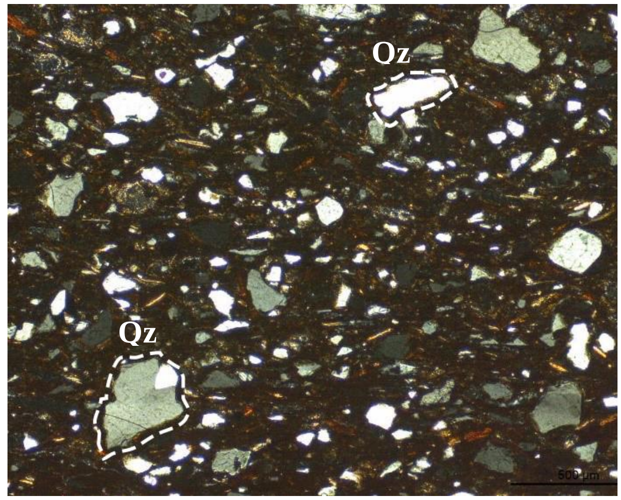
Zeuxippus Ware AAG43 1.6x; 5x



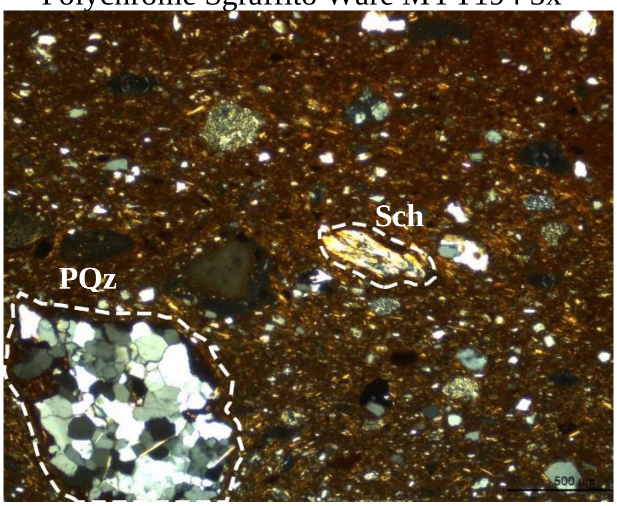
Zeuxippus sub-Ware AAG50 5x

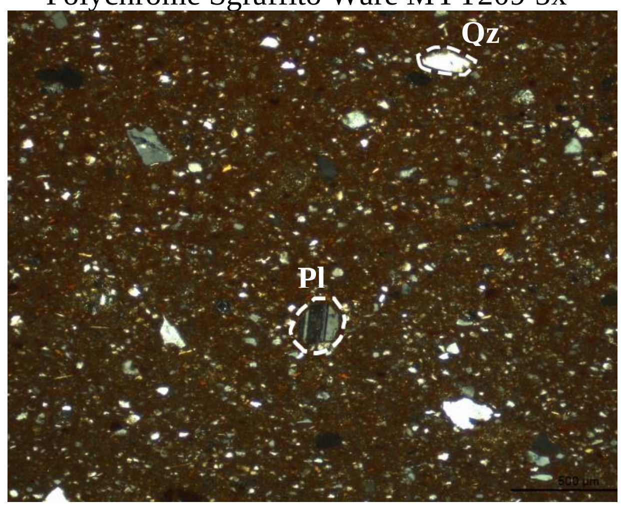
Figure 126 Petrographic analysis of Loner A (AAG70), Loner B (AAG43) and Loner C (AAG50) from the Athenian Agora in Attica.



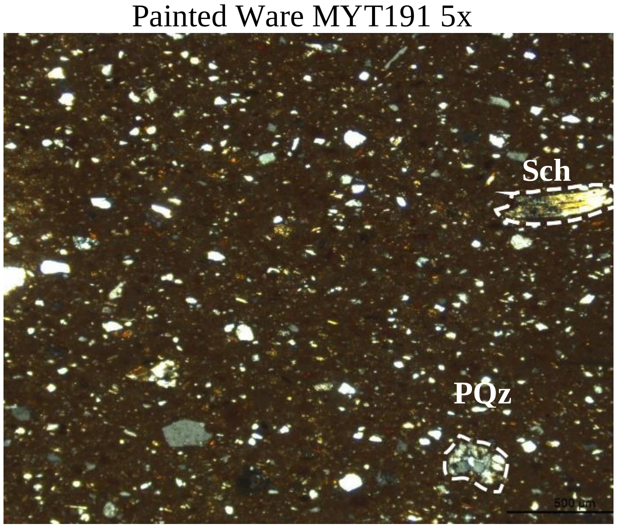


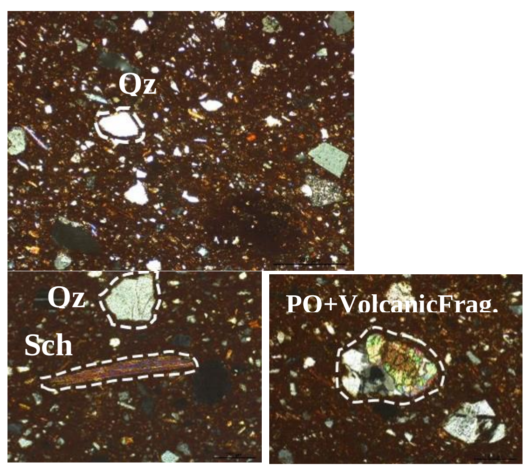
Polychrome Sgraffito Ware MYT194 5x Polychrome Sgraffito Ware MYT209 5x





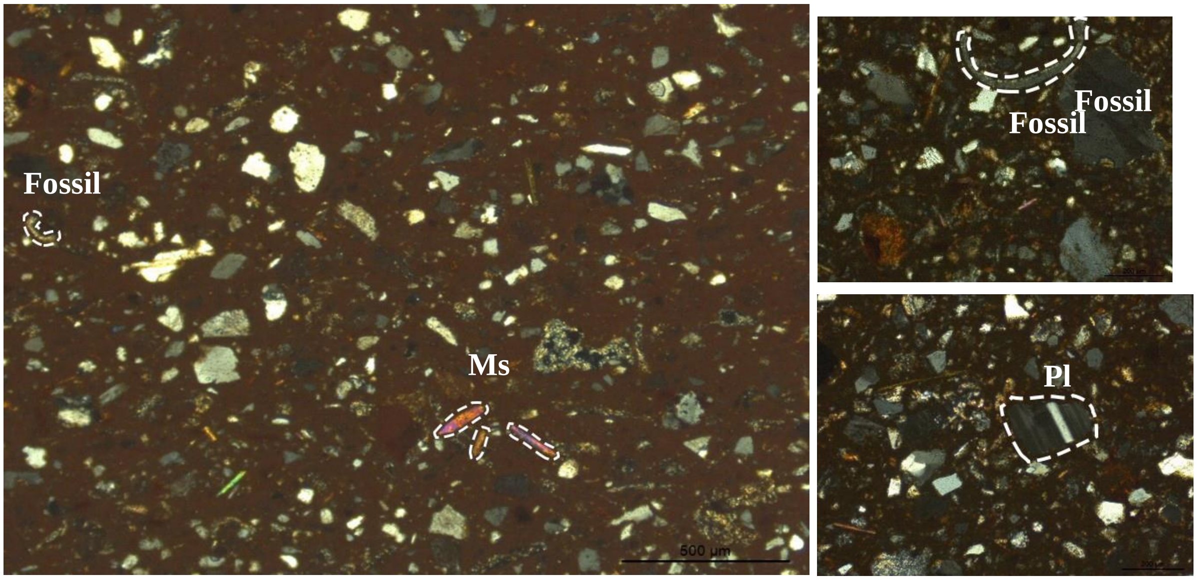
Painted Ware MYT191 5x Monochrome Ware MYT199 5x



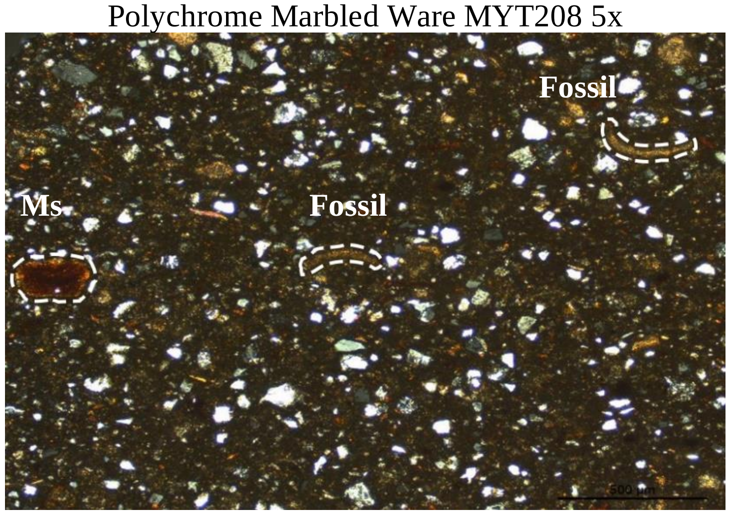


Monochrome Ware MYT206 5x Monochrome Ware MYT172 5x

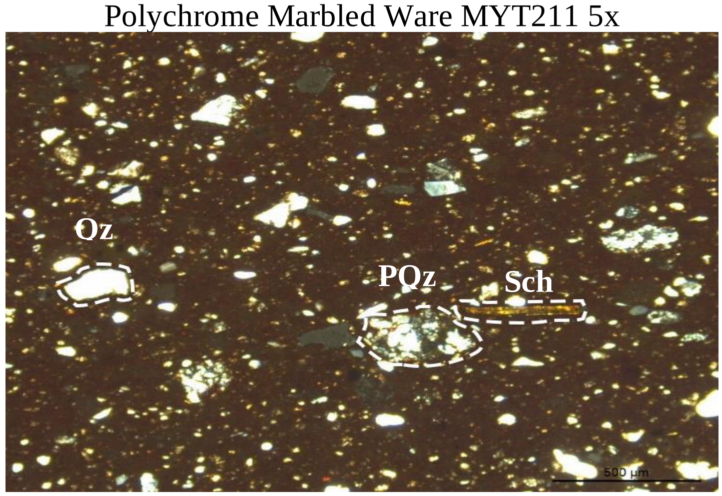
Figure 127 Petrographic analysis of Fabric Group A from the Castle of Mytilene in Lesvos.



Polychrome Marbled Ware MYT208 5x

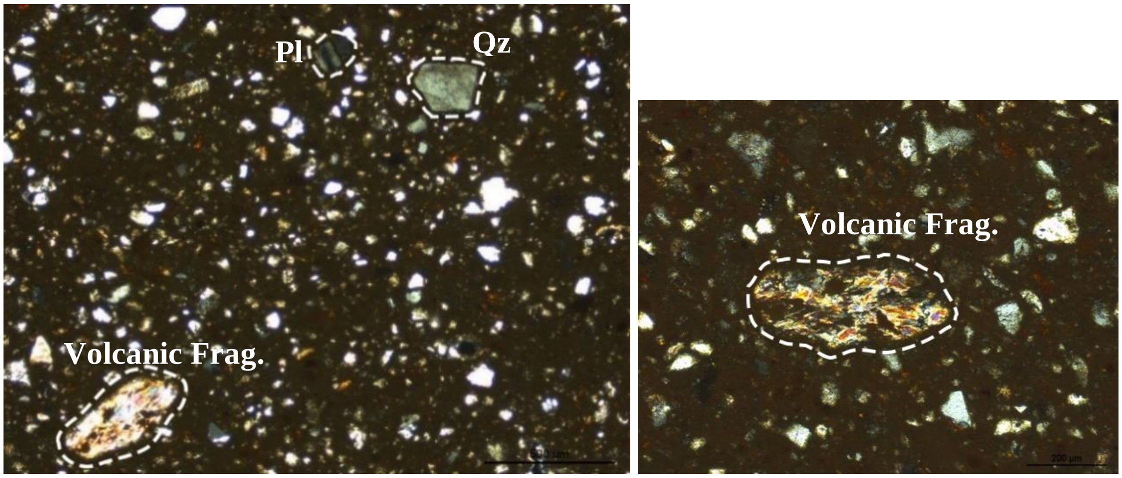


Polychrome Marbled Ware MYT211 5x

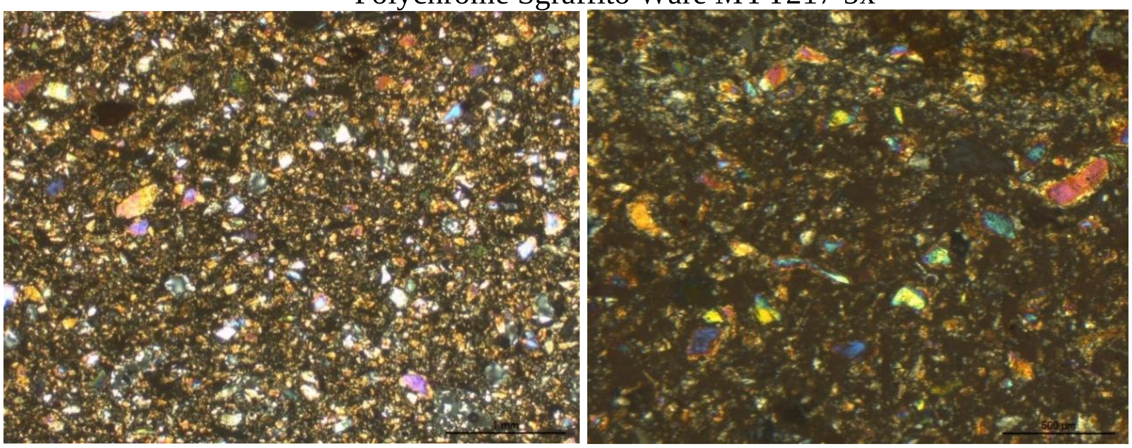


Polychrome Marbled Ware MYT197 5x

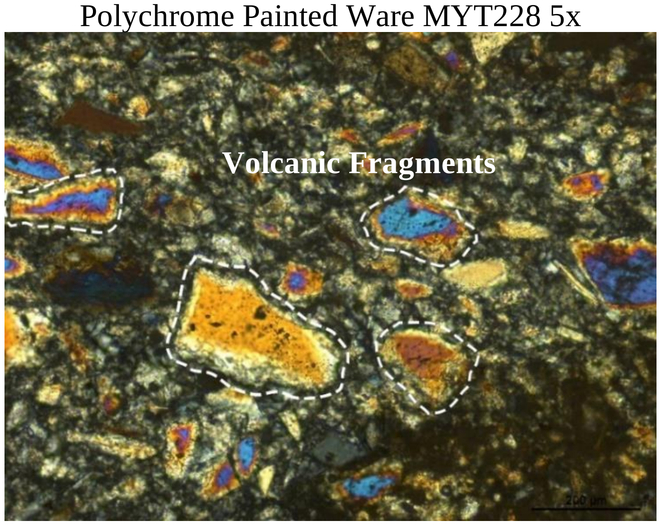
Figure 128 Petrographic analysis of Fabric Group B from the Castle of Mytilene in Lesvos.



Polychrome Sgraffito Ware MYT217 5x



Polychrome Painted Ware MYT228 5x



Polychrome Painted Ware MYT228 10x

Figure 129 Petrographic analysis of Loner A (MYT217) and Loner B (MYT228) from the Castle of Mytilene in Lesvos.

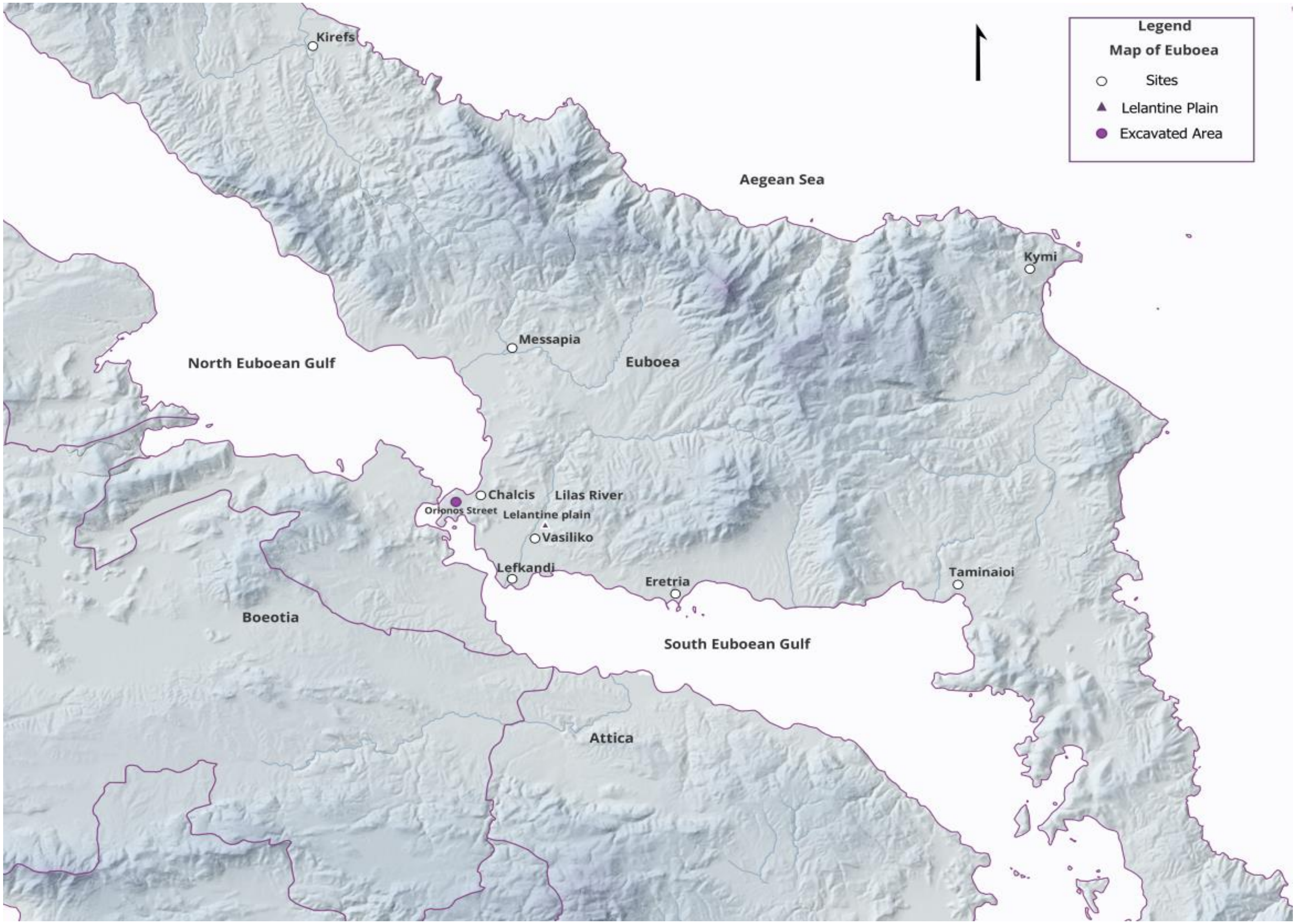


Figure 130 Chalcis in Euboea and clay deposits areas (Lelantine plain). Drawing M. Staikou.

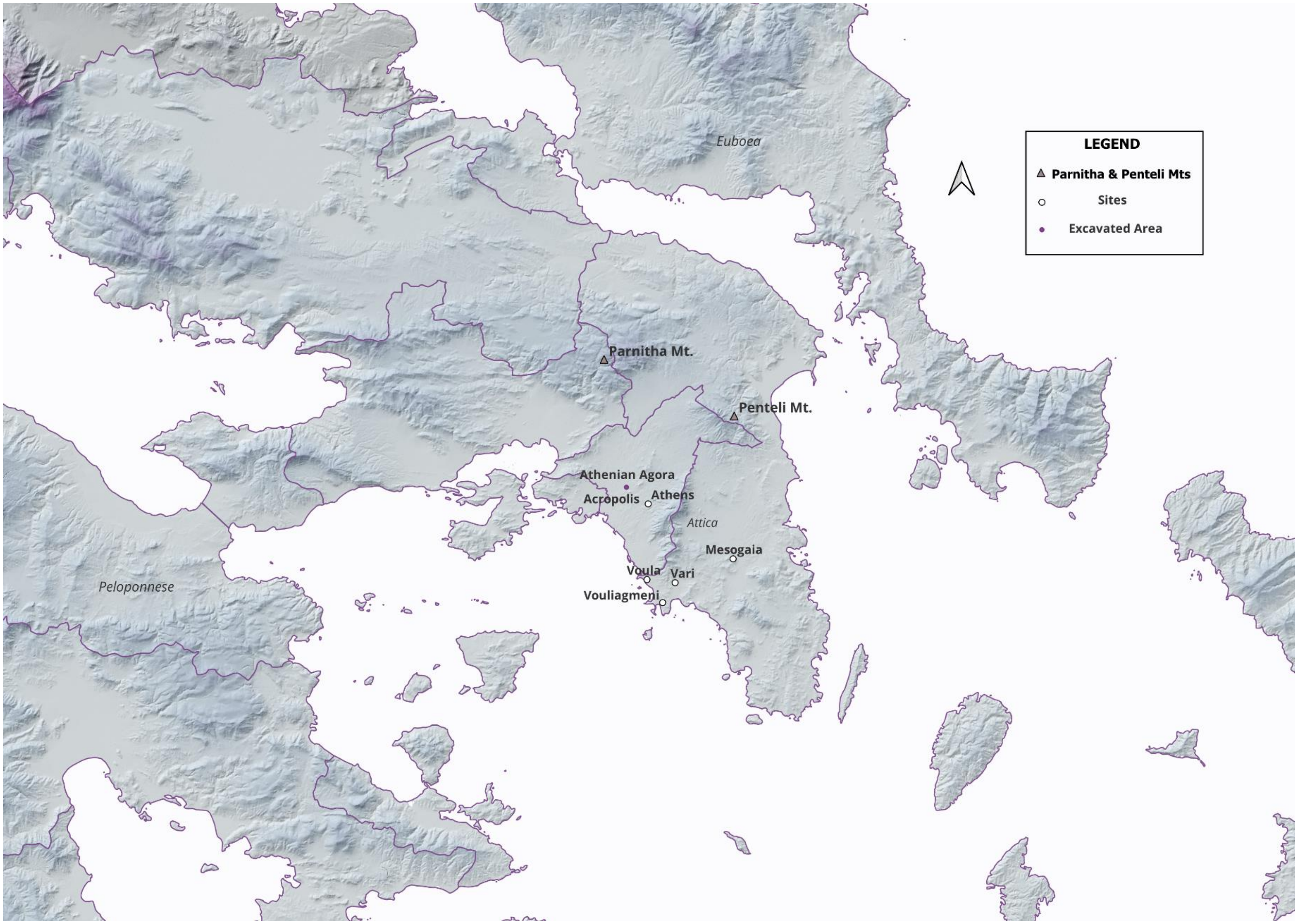


Figure 131 The Athenian Agora in Attica and clay deposits areas (Parnitha mountain, Penteli mountain, Mesogaia; Voula-Vari-Vouliagmeni). Drawing M. Staikou.

Figure 132 The Castle of Mytilene in Lesvos and clay deposits areas (south-east coastal area of Mytilene; Moria; Thermi). Drawing M. Staikou.