1. Introduction

The Megalopolis basin, located in central Peloponnese, Southern Greece, is home to one of the largest lignite mines in Greece (Fig. 1). It is also one of the most promising areas for early Middle Pleistocene palaeoanthropological research, as it preserves one of the thickest and most complete sedimentary sequences of that period in Greece (Tourloukis and Karkanas, 2012; Tourloukis and Harvati, 2018). The discovery of the Lower Palaeolithic site Marathousa 1 in 2013 (Thompson et al., 2018 this issue) attests to the importance of the area (Panagopoulou et al., 2015; Harvati et al., 2016, 2017). Here we present the analysis of the deposits of this site, using both macro-stratigraphic and microstratigraphic-microcontextual approach. We supplemented sedimentary field methods with soil and sediment micromorphology, as well as targeted chemical analysis.

Previous analysis of archaeological sites in lacustrine and wetland settings using micromorphology have revealed important details of their depositional history and their relationship to associated human presence (Macphail, 1999; Wallace, 1999, 2003; Tsatskin and Nadel, 2003; Mallol, 2006; Boschian and Saccà, 2010; Macphail et al., 2010, 2013; Karkanas et al., 2011; Ismail-Meyer et al., 2013; Stahlschmidt et al., 2015). Interestingly, in cases of Lower Palaeolithic sites, such as that of Boxgrove (Macphail, 1999), Ubeidiya (Mallol, 2006), Ebbsfleet (Macphail et al., 2013), Castel di Guido (Boschian and Saccà, 2010), and Schönening (Stahlschmidt et al., 2015) the picture revealed through such analyses was much more complicated than previously hypothesized on the basis of a macro-stratigraphic and a microstratigraphic-microcontextual approach.
field observations alone. Marathousa 1 therefore offers a unique opportunity to investigate site formation processes in a Middle Pleistocene butchering site. Our geoarchaeological research is addressing the depositional environment and the integrity of the site. The site is located in a lacustrine setting and therefore the study of the depositional environment will allow us to assess the timing of human presence in a fluctuating environment both in terms of the physiography of the lake and of changing climatic conditions.

2. Setting

The Megalopolis basin is a post-orogenic graben formed by NNE-SSW trending extension during the Pliocene (Fig. 1) [Vinken, 1965]. The main NNW-SSE trending primary normal faults were followed by Pleistocene secondary faults with a NE-SW direction that shaped the present drainage pattern. The basin is surrounded by low hills which are drained by the Alfeios River and its tributaries flowing to the north. The pre-Pliocene basement consists of Jurassic to Eocene marine sedimentary rocks (flysch, limestone, dolomite and chert), ultramafic Mesozoic rocks, and Paleozoic to Triassic crystalline rocks (schist, marble and phyllite) exposed in the northeastern part.

The Plio-Pleistocene sedimentary formation consists of a combination of fluvial, lacustrine and alluvial fan deposits (Lüttig and Marinos, 1962; Becker-Platen, 1964; Vinken, 1965). The Pliocene sequence contains lacustrine marls of the Makrisaion formation (Fm) followed by the fluviatile Trilofon formation and the Pleistocene Apiditsa alluvial fan formation (Table 1). After the Apiditsa Fm, conditions changed during the Middle Pleistocene and a limnic to limnotelmatic environment prevailed. The Middle Pleistocene, lignite-bearing Marathousa member forms the lower part of the Choremi Fm and is characterized by a cyclic sedimentation of dark lignite and bluish gray mud, fine sand, and occasionally marl sediments. Three main lignite seams are recognized, the lowermost containing the Matuyama/Bruneles paleomagnetic boundary at 0.78 Ma ago (Okuda et al., 2002; Tourloukis et al., 2018a this issue). Peat was forming probably during warm periods of the Pleistocene whereas clastic sedimentation prevailed during cold periods (Vinken, 1965; Okuda et al., 2002). Coal petrography, mineralogical and geochemical analysis of lignite seams suggest that they were deposited in lake fringing marsh and swamp zones. Peat was derived probably by reed mire and generally herbaceous vegetation and deposited under the water table (Sakorafa and Michailidis, 1997; Siavalas et al., 2009). The upper part of the Choremi Fm marks a transition to fluviatile environment (Megalopolis member) followed by the localized Potamia and Thoknia fluvial terrace formations deposited by the proto-Alfeios river system during the upper Pleistocene (Table 1) [Vinken, 1965].

The Marathousa 1 site is located in the north-western part of the Marathousa mine between Lignite Seam II and the lower part of Lignite Seam III. Seam II is a very distinct thick lignite layer that can be followed all along the present artificial tiers of the Marathousa mine (Fig. 2). The overlying Seam III consists of several lignite layers, the lower one probably capping the Marathousa 1 sequence. The site is found ca. 30 m below the present, pre-mine operation surface, at an altitude of ca. 350 m above sea level (masl).

Excavation is still ongoing and is conducted in two areas, A and B, which are 60 m apart (Fig. 2). Area A has yielded cranial and post-cranial remains of a single elephant individual accompanied by relatively few lithics. Konidaris et al., 2018 (this issue) observed cut marks on the elephant remains suggesting that the area represents an elephant butchering site. Compared to Area A, Area B has yielded a higher concentration of lithics as well as several bones, some of which bear cut-marks (Panagopoulou et al., 2015; Konidaris et al., 2018 this issue; Tourloukis et al., 2018b this issue; Panagopoulou et al., 2018 this issue).

3. Methodology

In addition to the two main areas of systematic excavation, eight section profiles located along the sedimentary sequence between the lignite seams were cleaned, logged and sampled (Fig. 3). Undisturbed and oriented blocks of sediment were collected from the excavated trenches and from profiles exposed in the mine for micromorphological study. Selective sampling was employed in all

![Fig. 1. Simplified geological map of the Megalopolis basin with the locations of Marathousa 1 site and Megalopolis town. Inset shows location of Megalopolis in Greece.](image-url)

<table>
<thead>
<tr>
<th>Formation</th>
<th>Member</th>
<th>Sedimentary Environment</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Holocene)</td>
<td></td>
<td>Fluvial terrace</td>
<td>Holocene</td>
</tr>
<tr>
<td>Thoknia</td>
<td></td>
<td>Fluvial terrace</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>Potamia</td>
<td></td>
<td>Fluvial terrace</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>Choremi</td>
<td>Megalopolis</td>
<td>Fluvial</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>Marathousa</td>
<td></td>
<td>Lacustrine</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>Apiditsa</td>
<td></td>
<td>Alluvial Fan</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>Trilofon</td>
<td></td>
<td>Fluvial</td>
<td>Pleistocene</td>
</tr>
<tr>
<td>Markrision</td>
<td></td>
<td>Lacustrine</td>
<td>Pleistocene</td>
</tr>
</tbody>
</table>

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profiles and includes boundaries of major stratigraphic units as well as all sedimentary facies recognized in the field. In total, twenty six monoliths (up to 30 cm long) of undisturbed sediment were collected. The samples were oven-dried at 40 °C for several days and then impregnated with polyesteric resin under vacuum. The cured blocks were cut into thin slabs and fifty-three thin sections of large (70 x 50 mm) format were prepared. The thin sections were studied using a stereomicroscope at magnifications of 5 to 40x and a polarizing microscope at magnifications ranging from 50 to 400x. The terminology used for the description of micromorphological features follows that of Stoops (2003) and Courty et al. (1989).

Bulk samples from all stratigraphic units defined in the field were analyzed for measuring their organic and carbonate content. Organic content was measured with loss on ignition (LOI) at 450 °C after humidity was extracted at 110 °C. Carbonate content was measured with a FOGII Digital Soil Calcimeter with a precision of 1% CaCO₃.

4. Stratigraphy

Grain-size analysis was not employed in this study because Sifogeorgaki and Karampatsou (2014) already conducted a preliminary granulometry for most of the sedimentary units of the site and has been sub-quantitatively confirmed by micromorphological observations. All samples are rich in fine sand (57–85%) and their clay content is generally less than 11%. Hence, almost all are grouped as silty sand to marginally muddy sands following Folk’s classification (Folk, 1965). However, the high amount of fine organic matter for several of the sedimentary units at Marathousa combined with the clay content gives the feeling of a clay-rich mud deposit in the field.

Excavated areas A and B share several common features although Area A is characterized by a relatively thinner sedimentary sequence (Figs. 2 and 4, and Table 2). We identified sedimentary units in Area A (UA) and Area B (UB) based on their macroscopic fabric and sedimentary structures. Direction of numbering is top down. Both areas rest upon archaeologically sterile clastic sediments which overly Lignite Seam II. Sedimentation appears to have been relatively continuous although some depositional units are separated by scour surfaces. A major erosional contact has been identified, dividing the sequence in two parts (Figs. 2 and 3). In the lower part (UB10 to 6, UA7 to 4; Figs. 3 and 4), the environment of deposition was quite variable with the area to the south of Area B characterized by mostly gray to bluish organic-poor silts and sands (Fig. 5), and the area between A and B mostly by silty sands with fluctuating amount of organics. Massive organic-rich clayey sands, graded bedded silty sands, lenticular to wavy bedded and more rarely thinly bedded sand/organic-rich silty sands comprise the lower clastic sedimentary sequence in the area of the site (Figs. 3–7). Often, Lignite Seam II is directly overlain by

Fig. 2. View of the two excavation areas and the clastic sequence between the two lignite seams. Note that the thickness of the clastic sequence increases to the left (south). The contact between the upper and lower sequence is marked with an arrow. See people for scale.

Fig. 3. Part of the section of Area B showing stratigraphic units. Note the erosional contact between the upper and lower part (dashed line). Tape meter is 4 m.
organic-rich silts whereas in other areas bluish sands and silts are observed. Overall, in the whole extension of this lower part of the stratigraphy organic input is fluctuating but relatively low (<4–5%: Table 2 and Fig. 4).

The above discussed lower part of the sequence is capped by eroded remnants of a bluish to gray muddy sand layer (Figs. 4 and 8a). This layer is thicker and better preserved in Area B (UB6) and to the south of the Area B, whereas in Area A (UA4) it is mainly found as discontinuous remnants. In the latter area, a mixed horizon is often observed, where remains of UA4 sediment are mixed with pockets of thinly bedded organic-rich silty sands and mudflows (see below). The mudflows are rich in intraclasts which are partly lithified sediment, derived from the erosion of nearby sediment and deposited within the same area. These bluish muds are characterized by impressive load deformation features in the form of bulges and irregular protuberances often resembling boudinage-like features that develop in competent, stiff layers (Fig. 8a).

In most places of Area A, UA4 is also severely reworked and mixed with mud intraclasts that probably derived from exposed indurated areas of the same sediment. The underlying sediments have acted more hydroplastically, developing upwards water-escape features in the form of flame structures that penetrate the gray bluish muds of UA4. Locally, the underlying silts and sands show evidence of liquefaction and slumping in the form of convolute bedding, small scale thrusting faults, and flame structures (Fig. 8b). Such features are typical of water-saturated silts and sands with high porosity that have lost their strength and stiffness, causing them to behave as a liquid. They are usually developed in sediment buried by less than 5 m of overburden (Owen and Moretti, 2011).

The sedimentary sequence overlying the bluish muddy sands is distinctly different from the already described lower part of the sequence. A series of depositional units bounded by erosional contacts is observed in both areas. They consist of coarser sediments at the base, grading upward into progressively finer ones (Figs. 3, 4 and 9 and Table 2). Each unit has a thickness of about half a meter and shows generally similar sedimentary characteristics. In Area B, small channels with sands showing cross-bedding and ripple lamination (UB5b/c) cut through the boudinaged mud layer, sometimes eroding down to the underlying sand/silt sequence (Figs. 3, 9 and 10). Laterally, the laminated sands are overlain by massive organic-rich silty sands (UB5a) and underlain by organic, intraclast-rich sands. In Area A the channelized sands are not observed, but here the boudinaged layer (UA4) is severely eroded and only small remnants of it have been preserved.

Overlying the sandy unit UB5, in Area B, three more fining-up depositional units were identified (UB4, UB3 and UB2), although the middle one shows rather scouring than clear evidence of erosion at its base (Fig. 4). In Area A, two depositional units are observed (UA3 and UA2) overlying the boudinaged layer (UA4) (Fig. 4). They all start with dark brown, organic-rich, intraclast-rich silty sands at the bottom, often making lags inside small erosional cuts; these are followed by organic-rich massive muds occasionally interrupted by laminae of grey fine sands (Fig. 11). In the field, the intraclast-rich units appear to have a chaotic structure containing also angular rip-up clasts from the underlying sediment and small and large wood fragments (Fig. 11c). They, thus, resemble dilute mudflows. Laterally, sand laminae make distinct units above the so defined mudflows and are followed by massive silty sands. The uppermost unit in both areas (UA2 and UB2) is characterized by the occurrence of a shell-rich layer interbedded within intraclast-rich silty sands. In most places this is followed by locally channelized sand-rich bodies that give way to the overlying clayey lignite beds (UA1 and UB1), which form the base of Lignite Seam III series (Figs. 2 and 4).

In Area A, the elephant remains are found lying on top of the eroded boudinaged layer (UA4) and are buried by the first depositional mudflow unit (UA3), essentially following the contact between UA4 and UA3 (Fig. 12). Similarly, the lithic artifacts occur in
### Table 2

Sedimentary units, their sedimentological description, organic and carbonate content, and interpretation.

<table>
<thead>
<tr>
<th>Description</th>
<th>Facies</th>
<th>Organic content %</th>
<th>Carbonate content %</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AREA A</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UA1 Black lignite</td>
<td>–</td>
<td>32.05</td>
<td>0.40</td>
<td>Reed marsh</td>
</tr>
<tr>
<td>UA2a Dark grey, laminated organic-rich silty sands</td>
<td>C</td>
<td>16.28</td>
<td>2.80</td>
<td>Relatively high energy fluvialite flows entering the margins of the lake within the zone of lake-surface fluctuation</td>
</tr>
<tr>
<td>UA2b Dark grey, organic- and intraclast-rich silty sands with shell fragments and occasionally sand laminae</td>
<td>E, C</td>
<td>14.80</td>
<td>13.10</td>
<td>Subaerial-originated dilute mudflows and hyperconcentrated flows plunged into the lake margin; some intervening discrete surges</td>
</tr>
<tr>
<td>UA3a Dark grey, massive organic rich muddy sand</td>
<td>F</td>
<td>14.03</td>
<td>4.80</td>
<td>Subaquously emplaced hyperconcentrated flows</td>
</tr>
<tr>
<td>UA3b Dark grey, organic-rich silty sand, occasionally interbedded with sand laminae</td>
<td>F, C</td>
<td>11.33</td>
<td>11.40</td>
<td>Subaquously emplaced hyperconcentrated flows with intervening discrete surges</td>
</tr>
<tr>
<td>UA3c Dark grey, massive organic- and intraclast-rich silty sand</td>
<td>E, C</td>
<td>13.41</td>
<td>2.30</td>
<td>Relatively high energy fluvialite flows entering the margins of the lake within the zone of lake-surface fluctuation</td>
</tr>
<tr>
<td>UA4 Blushy grey, massive muddy sand with load deformation structures</td>
<td>D, H</td>
<td>6.97 (upper)</td>
<td>1.10 (upper)</td>
<td>Relatively high energy fluvialite flows entering the margins of the lake within the zone of lake-surface fluctuation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.53 (lower)</td>
<td>0.30 (lower)</td>
<td>Subaquously emplaced hyperconcentrated flows</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.48 (upper)</td>
<td>0.60 (lower)</td>
<td>Subaquously emplaced hyperconcentrated flows with intervening discrete surges</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.61 (middle)</td>
<td>0.40 (middle)</td>
<td>Relatively high energy fluvialite flows entering the margins of the lake within the zone of lake-surface fluctuation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.11 (lower)</td>
<td>0.10 (lower)</td>
<td>Subaquously emplaced hyperconcentrated flows</td>
</tr>
<tr>
<td>UA5a Dark grey, massive muddy sand with some organics and deformation structures; occasionally sand laminae and pockets</td>
<td>F, C</td>
<td>6.77 (upper)</td>
<td>0.10 (upper)</td>
<td>Relatively high energy fluvialite flows entering the margins of the lake within the zone of lake-surface fluctuation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.88 (lower)</td>
<td>0.60 (lower)</td>
<td>Subaquously emplaced hyperconcentrated flows</td>
</tr>
<tr>
<td>UA5b Light grey, laminated silty sand and sand with deformation structures</td>
<td>C</td>
<td>3.51</td>
<td>1.70</td>
<td>Relatively high energy fluvialite flows entering the margins of the lake within the zone of lake-surface fluctuation</td>
</tr>
<tr>
<td>UA6a Blushy grey, massive silty sand</td>
<td>D</td>
<td>6.06</td>
<td>0.10</td>
<td>Subaquously emplaced hyperconcentrated flows</td>
</tr>
<tr>
<td>UA6b Blushy grey, massive silty sand</td>
<td>D</td>
<td>9.71</td>
<td>0.40</td>
<td>Subaquously emplaced hyperconcentrated flows</td>
</tr>
<tr>
<td>UA6c Blushy grey, massive silty sand with some organic-rich seams</td>
<td>D</td>
<td>3.78 (upper)</td>
<td>0.30 (upper)</td>
<td>Relatively high energy fluvialite flows entering the margins of the lake within the zone of lake-surface fluctuation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.61 (middle)</td>
<td>0.40 (middle)</td>
<td>Subaquously emplaced hyperconcentrated flows with intervening discrete surges</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.11 (lower)</td>
<td>0.10 (lower)</td>
<td>Relatively high energy fluvialite flows entering the margins of the lake within the zone of lake-surface fluctuation</td>
</tr>
<tr>
<td>UA7 Black lignitic clay</td>
<td>–</td>
<td>23.95</td>
<td>0.70</td>
<td>Reed marsh</td>
</tr>
<tr>
<td><strong>AREA B</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UB1a Black lignite</td>
<td>–</td>
<td>36.33</td>
<td>0.40</td>
<td>Reed marsh</td>
</tr>
<tr>
<td>UB1b Black bedded lignitic clay</td>
<td>–</td>
<td>24.44</td>
<td>1.10</td>
<td>Reed marsh</td>
</tr>
<tr>
<td>UB2a Dark grey, massive organic-rich silty sand</td>
<td>F</td>
<td>10.01</td>
<td>4.20</td>
<td>Relatively high energy fluvialite flows entering the margins of the lake within the zone of lake-surface fluctuation</td>
</tr>
<tr>
<td>UB2b Dark grey, laminated organic-rich silty sand and sand with a lot of shell fragments</td>
<td>C, F</td>
<td>17.69 (upper)</td>
<td>7.80 (upper)</td>
<td>Relatively high energy fluvialite flows entering the margins of the lake within the zone of lake-surface fluctuation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21.05 (lower)</td>
<td>18.40 (lower)</td>
<td>Subaquously emplaced hyperconcentrated flows</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14.30 (upper)</td>
<td>5.80 (upper)</td>
<td>Subaquously emplaced hyperconcentrated flows</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.11 (lower)</td>
<td>0.10 (lower)</td>
<td>Subaquously emplaced hyperconcentrated flows</td>
</tr>
<tr>
<td></td>
<td></td>
<td>11.91 (upper)</td>
<td>3.50 (upper)</td>
<td>Subaquously emplaced hyperconcentrated flows</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.00 (lower)</td>
<td>0.40 (lower)</td>
<td>Subaquously emplaced hyperconcentrated flows</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.85 (upper)</td>
<td>1.10 (upper)</td>
<td>Subaquously emplaced hyperconcentrated flows</td>
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<td></td>
<td>5.11 (lower)</td>
<td>0.10 (lower)</td>
<td>Subaquously emplaced hyperconcentrated flows</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.43 (upper)</td>
<td>0.30 (upper)</td>
<td>Relatively high energy fluvialite flows entering the margins of the lake within the zone of lake-surface fluctuation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>22.62</td>
<td>0.50</td>
<td>Subaquously emplaced hyperconcentrated flows</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Reed marsh</td>
</tr>
</tbody>
</table>

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UA3 and close to the erosional surface of the contact between UA4 and UA3; at least one artifact (an encoche flake) has been found below an elephant bone (metacarpal). In Area B, the archaeological remains occur at or close to the erosional surface represented by the contact UB5 and UB4 (Figs. 4 and 9). The highest concentration is observed inside the intraclast-rich, mudflow layer (UB4c), close to and at the contact with UB5a, and the find density decreases upward (Giusti et al., 2018 this issue). The overwhelming majority of the lithics is found in the depositional unit UB4.

5. Facies

Six sedimentary facies have been distinguished in the Marathousa 1 succession. The facies, labeled A through H, range from fine sands to clayey silts including fine pebble-sized mud intraclasts. In this study, facies of the lignite seams are not discussed as there is already a rich literature on this subject (Stavlas et al., 2009; Nickel et al., 1996; Sakorafa and Michailidis, 1997).

5.1. Facies A: Bedded and graded muds

In the field they appear as bedded sequences with couplets of bluish gray and orange silts about 10 cm thick (Fig. 7a). They are making bedsets up to 1 m thick. Individual beds are planar of considerable lateral extension. Under the microscope silt-sized sediment grade to clay silts rich in oxidized, mostly amorphous organic matter (Fig. 13a). Rarely, ill-developed, thinly interlayered silt/mud bedding is also observed.

Interpretation: These deposits are thought to have accumulated in the relatively deeper parts of the lake. Sedimentary features indicate suspension fallout in relatively calm water probably combined with transport by weak currents and waves (Benvenuti, 2003). Episodic subaerial ash floods supplied the sediment in the quieter deeper water areas and the relatively thin, rhythmic bedding reflects periodic floods and possibly seasonal storm events.

5.2. Facies B: Wavy to lenticular bedded fine sand and silty sands

Fine sands and silts to clayey silts make continuous or discontinuous, intensively deformed lenticular to wavy bodies up to several cm thick that they build up bodies up to 60 cm thick (Figs. 6 and 7b). Convolute bedding, with small scale folding and faulting characterize this sediment in the field (Fig. 8b). Fine sand beds are moderate to well-sorted. Clasts are composed mainly of quartz, feldspar, chert, mudstone, and mica. Calcite or dolomite, schist and probably a few metamorphic rock clasts are found in subordinate amounts. Post-depositional gypsum crystals are also encountered. Their formation could be associated to subaerial exposure but they are found also in sediments without such indications. Therefore, we interpret their occurrence as the result of post-depositional, burial diagenesis. Often microscopic inclined sand/mud laminae (foreset) are observed. Mud lenses and beds are oxidized or contain moderate amounts of fine grained organic matter with most having visible plant structure. Silt to fine sand limestone clasts is a major component in a variety of this facies.

Interpretation: Based on their sedimentary features, these facies point to deposition in a very shallow water lake environment under the influence of wave and perhaps current activity (Martel and Gibling, 1991).

5.3. Facies C: Thinly interlayered to wavy and ripple bedded fine sand and organic-rich silts

The beds of this facies are characterized by sharp bases as well as erosional channel forms (Fig. 10). They are characterized by finely laminated sands to sand and mud couplets up to 50 cm thick (Figs. 6 and 11b). Areas with cross-bedded sands are also encountered. Sand beds are moderate sorted and consist mainly of fine sand with occasionally thin laminae of coarser, medium sand. Well-developed microscopic cross-bedded features and ripples have been identified (Fig. 14). Laminae of relatively pure sand are alternating with silty laminae very rich in elongated plant material. Lithological content is similar to Facies B but sandstone particles are more abundant in

Fig. 5. Detail of the lower section showing bluish massive and bedded muds and silts overlying black lignite at the base. Scale is 140 cm.

Fig. 6. Field photo of wavy to lenticular bedded fine sand and silty sands (facies B) overlain by thinly interlayered to ripple bedded fine sand and organic-rich silts (facies C).
the coarser sand increments. Radiolarite chert and mollusk fragments are ubiquitous. A variety of limestone-rich facies is also observed for facies C as well.

Interpretation: Similarly to the above facies B, a very shallow lake environment is envisaged for Facies C as well. However, the predominance of fine laminae, rippled and cross-bedding and their occasional channelized forms suggest relatively high energy stream flows (fluvialite) entering the margins of the lake probably within the zone of lake-surface fluctuation (Martel and Gibling, 1991).

5.4. Facies D: Bluish gray, massive to wavy bedded silts and sandy muds

In the field, these are generally mud beds up to 1 m thick with rather massive appearance (Figs. 5 and 8a). Under the microscope they appear as massive silty sand bedded units where silt makes the matrix of fine sand grains. Occasionally, diffuse thin layers of silt and sand are interlayered. Silt appears as wavy lenses inside sand or occasionally makes thicker beds. They are generally very poor in organic matter although some darker bands are also found with moderate amounts of organic matter. In several areas, they have a brecciated appearance, or display lenticular to polygonal cracks. A variety of this facies includes pebble mud intraclasts (see Facies H).

Interpretation: These are thought to represent subaerial generated muddy hyperconcentrated flows that were deposited into ephemeral lake-fringing marsh areas, where peat does not accumulate (Martel and Gibling, 1991). Hyperconcentrated flows are different from regular water flows in that they contain high amount of suspended sediment, with concentration typically between 20 and 50% (Costa, 1988). Their massive appearance imply dumping of thick sand and mud slurries when entering a standing body of water. Occasional sand and silt intercalations reflect activity of waves and currents. The presence of mudcracks, mud intraclasts and mud breccia suggests repeated desiccation events.

5.5. Facies E: Coarse, mud intraclast-rich organic muds

The beds of this facies are tabular, characterized by sharp moderate-relief erosional or more rarely nearly planar surfaces (Fig. 11a). The sediment is a mixture of chaotic to crudely bedded rip-up clast- and intraclast-rich coarse lenses, sometimes with deformation structures at the lower erosional bedding plane, massive organic-rich muds and interbedded finer organic-rich silt lenses or sandy streaks (Fig. 13b). Mud intraclasts are mostly well-rounded with sizes ranging from cm to micro sizes (Fig. 15a). They are mostly derived from organic rich muds and soils. Intraclasts of organic-poor, oxidized and indurated muds are also observed (Fig. 13b and c and 15a, d). Rip-up clasts from the underlying
sediment (Figs. 9 and 13b), large elongated pieces of wood, plant material, and some charcoal as well as varying amounts of mollusk shells are ubiquitous. The minerogenic matrix is mainly sand and silt. It is of importance that rock fragments coarser than medium sand are very rare apart from the mud intraclasts.

Interpretation: The origin of Facies E is attributed to subaerial-originated dilute mudflows and hyperconcentrated flows plunged into the lake. Rapid dumping of the coarser part of suspended sediment load sometimes followed by bed load deposition of sandy increments (Benvenuti, 2003).

5.6. Facies F: Organic-rich massive muds with microscopic stratification

These are dark brown massive bodies of organic silty muds up to 50 cm thick. They also form the finer upper part of Facies E and C (Figs. 9 and 11a). Their minerogenic content is silt to very fine sand. More than 50% of the mud is horizontally bedded, fine elongated plant fragments (Fig. 15b). They are occasionally interrupted by lenses of coarser, fine sand lenses in a wavy appearance that are also rich in plant material. A variety of this facies contains few dispersed fine pebbles of mud intraclasts.

Interpretation: These are interpreted to represent subaqueous emplaced hyperconcentrated flows where both coarse minerogenic and fine organic matter was dumped together into a shallow standing body of water. Sand and silt lenses probably reflect some discrete surges during the final subaqueous depositional stages (Benvenuti, 2003).

5.7. Facies H: Palustrine – exposed muds

This is actually a microfacies recognized under the microscope and only inferred in the field. It includes very thin surface features in the range of a few mm to cm thick found on the top of Facies D (bluish gray, massive to wavy bedded silts and sandy muds) and F (organic-rich massive muds with microscopic stratification) and always followed by Facies E (coarse, mud intraclast-rich organic muds). They demarcate erosional surfaces and long or short hiatuses. They are characterized by hydromorphic features such as organic mottles, iron staining and iron-depletion features as well as incipient indurated calcareous-rich areas (impregnative pedofeatures) and nodules (Figs. 13c and 15c and d). Some channel features tapering down through the exposed surfaces are observed (Fig. 15c). In one case filled mudcracks were observed in the field at the upper surface of UB6 (Fig. 16). A considerable amount of intraclast of Facies E are considered eroded and transported clasts originated from facies H. These intraclasts include indurated pebbles of Facies D with visible root passages (Fig. 15e), but the majority are oxidized massive organic-rich muds occasionally completely stained with decayed organic matter (Fig. 15a). Bioturbation is evident is several of them and their massive appearance is probably the result of it.

Interpretation: This facies represents exposed mudflats with evidence of subaerial exposure, desiccation, hydromorphism, oxidation, and bioturbation. This collectively refers to palustrine environments showing evidence of both lacustrine and pedogenic processes (Platt and Wright, 1992).

6. Organic and carbonate content

In both areas organic and carbonate content show a patterned distribution with rather similar trends (Table 2 and Fig. 4). However, in the thickest sequence of Area B the differences between the lower and upper part are more pronounced, whereas in the more ‘compressed’ sequence of Area A, there is a comparatively stronger fluctuation. In particular, a continuous decrease in organic matter is observed from around 30% in Lignite Seam II (UB10) to a few percent in the boudinaged mud layer UB6 in Area B. This is followed by a rather abrupt increase in the upper sequence, to more than

Fig. 9. Detail of the erosional contact between lower sequence (UB6) and upper sequence (UB5 and UB4) in Area B. UB5 shows here the characteristic tripartite division of the erosional bounded, fining-up, depositional units of the upper sequence with intraclast-rich (UB5c), laminated sand (UB5b), and massive muddy sand (UB5a) sediment. Note the large rip-up clasts (RC) at the base of UB5.

Fig. 10. Field photos of a) channelized sands of UB5 overlying bluish muds of UB6; b) UB5 eroding down to UB7. UB6 has been eroded away in this part of the sequence.
10%, and then continuously rising up to more than 30% in the upper lignite layer, UB1. In Area A the same general pattern is observed, but the trend is not linear and overall the organic matter in all units is increased compared to Area B (Table 2 and Fig. 4).

Carbonate content fluctuation in both areas follows the same pattern (Table 2 and Fig. 4). Low amounts are observed in the lower parts of both sequences, while in the upper part of the sequence there is an abrupt increase in UB4 and UA3 and above until the upper lignite layer. Based on the microscopic observations, carbonate content is directly related to calcite clast input in most units (Fig. 15f), except for the several fold increase in units UA2 and UB2 where large amounts of shell is encountered. Carbonate content is negligible in lignite layers and overall chemically or organic-induced precipitated calcite is very low in all layers.

This characteristic increase in carbonate content in the upper sequence is interpreted as a change in the source of clastic material entering the lake shore (see discussion below). Enhanced weathering of the Cretaceous limestone hills (of the Pindus tectonosedimentary Zone), lying to the west of the site (Alpine basement: Fig. 1), is the most likely explanation. Interestingly, the change in carbonate content in Area B does not occur immediately above the boudinaged muds, as in area A, but after the deposition of the relatively high energy sands of UB5, which is not found in Area A (see Discussion below).

7. Discussion of the depositional sequence

The studied sequence between the two lignite seams represents clastic deposition at the Middle Pleistocene lake margin of the Megalopolis basin. The lignite layers are thickest in the western part of the basin, whereas clastic deposition is more prominent towards the East following the subsidence pattern of the basin in this direction. The Marathousa 1 site is located in an intermediate area but close to the western margin of the plain and this explains the relatively thin clastic sequence between the two lignite seams that sandwich the site (Fig. 2). The approximately 4 m of clastic...

Fig. 11. Field photos of sedimentary facies of the upper sequence: a) facies E of coarse, mud intraclast-rich organic muds, facies F of organic-rich massive muds with microscopic stratification, and facies C of thinly interlayered to wavy and ripple bedded fine sand and organic-rich silts; b) detail of facies C; c) detail of facies E showing large amounts of wood fragments and intraclasts.

Fig. 12. Contact between the lower (UA4) and upper (UA3) sequence in Area A. At the contact a large wood piece (left) and an elephant bone (right) are shown.

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The sediments at the site is in the low range of the observed thickness of the detrital package between Lignite Seam II and III in inner other parts of the mine, i.e. close to the depocenter (4–15 m: Löhner and Nowak, 1965).

The lignite seams have been the focus of several studies, which have shown that they were accumulating as peats in a limnotelmatic environment, under reducing conditions and a high pH. The peat was derived from reed vegetation (marsh/fen types of field) with the surface of the swamp being constantly under water and with a high surface water influx, probably on a lower delta plain depositional setting. Water depth fluctuated from very shallow (reed vegetation zone) in the area of Marathousa to shallow (floating leaf aquatics zone) in the northern part of the basin, at the Thoknia mine field (Siavalas et al., 2005; Nickel et al., 1996; Sakorafa and Michailidis, 1997). Palynological and coal studies indicate that peat was forming during warm and humid periods (interglacial or interstadial stages), whereas clastic sediments prevailed during cold and dry intervals (glacial stages) (Nickel et al., 1996; van Vugt et al., 2000; Okuda et al., 2002).

The present study shows that the clastic sequence has been deposited underwater, at a fluctuating depth, but episodes of subaerial exposure have also been identified. The sandy and silty nature of the sediments implies proximity to fluvial inputs in accordance with the overall attribution of the studied lignite deposits to a lower delta/lake fringe depositional setting (Sakorafa and Michailidis, 1997). In particular, above Lignite Seam II, a gradual deepening of the lake environment is observed in Area B with deposition of massive organic-rich sediment (UB9: ca 10% OM: Table 2 and Fig. 4) in a shallow marshy standing body of water, which was occasionally fed with hyperconcentrated flows coming from the surrounding lake shore area. The overlying deposits of UB8 to 6 suggest further deepening of the lake in this area with deposition of bedded and graded muds and wavy to lenticular and thinly interlayered ripple fine sands and silty sands. Organic matter is relatively low (< ca. 5%: Table 2 and Fig. 4), which probably indicates increased runoff, reduced plant cover, and aridity. Sedimentary structures suggest alternating suspension fallout and transport by currents and waves. Episodic subaerial flash floods supplied the clastic sediment and the relatively thin, rhythmic bedding reflects periodic flooding episodes and possibly seasonal small storm events. In Area A, deepening was probably more abrupt, but there is much more fluctuation of organic matter (4–10%: Table 2 and Fig. 4) suggesting probably a location closer to the shore, as indicated also by the fact that the clastic sequence here is overall shallower compared to Area B. Indeed, a further deepening towards the south is evident, as the thickness of the lower clastic sequence increases and the organic content decreases to the south of Area A (Figs. 2 and 4).

The deposition of the characteristic bluish muds of UB6 and UA4 in Areas B and A, respectively, indicate the existence of an ephemeral lake-fringing marsh area, where peat did not accumulate. The sediments were deposited by subaerially-generated muddy hyperconcentrated flows in a relatively shallow standing body of water occasionally affected by small waves and currents. As described above, there is ample evidence that these deposits later witnessed subaerial exposure, weathering and erosion. However, this depositional hiatus is not associated with a statistical significant time gap as suggested by the luminescence dates between the upper and lower sequence in both areas (Jacobs et al., 2018 this issue). The low content of organic matter in an area close to the shore might imply reduced vegetation cover and perhaps aridity. We should make an important note here that some environmental proxies may not be able to catch this exposure, as these bluish muds have been severely eroded to the point that only patchy remnants of them are preserved in Area A. In addition, they are
characterized by load deformation structured leading to intensive reworking of their content (Fig. 8a).

Evidence of liquefaction and slumping are observed in the lower clastic sequence in both areas (Fig. 8b). In lacustrine environments, such deformation features can be the result of several processes such as storm waves, turbulent flow, tides, rapid sedimentation, overloading, gravity sliding and earthquakes (see Onorato et al., 2016 for a review). The levels affected by this liquefaction in Marathousa 1 show a lateral continuity for hundreds of meters. Large storm waves are not expected to occur in this relatively shallow water environment of the Megalopolis basin and, given the topographically flat setting of the Marathousa area with very low gradients, triggering by gravity collapse can be precluded. Most deformation structures in the lower part of the studied sequence are not associated with beds that were rapidly deposited (but see below for the upper sequence). The Megalopolis basin is located within a seismically active area. Events with a magnitude of 6R have occurred (Papazachos and Papazachou, 2003), while syndepositional faulting is observed in many places in the mine.

Subsidence along the eastern faulted margin of the basin is considered the primary cause of the formation of the lake (Sourlas et al., 2005). Therefore, we interpret these deformation structures as typical lacustrine seismites (Toro and Pratt, 2016; Moretti et al., 2016).

To what extent this seismic event was responsible for the subsequent exposure and erosion of the deformed lower sequence is not easy to answer. Nevertheless, the environmental conditions during the deposition of the overlying, upper part of the sequence were totally different in comparison to the sediments of the above-discussed lower part. As regards the upper part, the first layer to be deposited in Area B was UB5 (Fig. 4). These mostly channelized cross-bedded and finely laminated sands erode in several places the underlying bluish mud (Fig. 9). These mostly channelized cross-bedded and finely laminated sands erode in several places the underlying bluish mud (Fig. 9). They are most likely the result of high energy fluviatile flows that were deposited at the zone of the lake-surface fluctuation and demarcate a new cycle of underwater deposition, albeit different from the lower one. This depositional unit is not observed in area A. However, a thin patchy, reworked zone in Area A, at the contact of the bluish mud and the overlying...
between Area A and B, but also the sudden increase of carbonate content attributed to a substantial increase of carbonate clast input. This increase is observed in units UA3 and UB4 and above, and therefore it is a persistent attribute of the sediment of the upper part of the sequence. It may be interpreted as an increase of mechanical erosion of the surrounding limestone hills at the western margin of the basin. Enhanced mechanical erosion in karstic systems has been attributed to flood activity and increased suspension is often observed after each dry period (Newson, 1971; Bouchaou et al., 2002). The intraclast-rich, mudflow dominating deposits of the upper sequence support the scenario of increased flooding events and erosion of exposed mudflats during the beginning of the rainy seasons. On the other hand, the increase of organic matter would suggest warmer conditions leading gradually to the deposition of the overlying lignite during an interglacial period (Nickel et al., 1996; van Vugt et al., 2000; Okuda et al., 2002). Studies of various environmental proxies in Greece have shown that landscape instability and erosion prevail during climatic transitions and particularly those from cold to warm climates (Tourloukis and Karkanas, 2012, and references therein). In this interpretive scheme, the lower part of the clastic sequence represents a true cold period deposited during a glacial stage, with reduced vegetation cover, aridity, and enhanced runoff. These are typical climatic characteristics of glacial periods in Greece (e.g. Tzedakis, 2005). The upper part, on the other hand, would represent the transition to a warm interglacial climate. Further palaeoenvironmental studies are needed to verify the above scenario. However, care should be taken as some mixing of proxies might have occurred as recurring mudflows were eroding underlying strata, some of which were deposited during different climatic periods (e.g. UA3 eroding UA4).

7.1. The occupation levels

The occurrence of lithics and faunal material at the base of the first mudflow cycle of the upper sedimentary sequence at Marathousa 1 is of great interest in terms of formation processes and the integrity of the archaeological site. As already discussed, UA3 and UB4 can be safely correlated based on stratigraphic, sedimentological, and geochemical evidence, as well as their archaeological components (Tourloukis et al., 2018b this issue). Area A, in particular, includes the remains of a well preserved elephant individual of Palaeoloxodon antiquus (Konidaris et al., 2018 this issue). Most of the elephant bones lie at the top of the bluish muds (UA4) and are covered by the mudflow UA3 (Fig. 12). In a more detailed approach, the bluish muds of UA4 are for the most part of the unit reworked and included as deformed pockets in an intraclast-rich sediment of
UA3c. In addition, pockets of thinly bedded organic-rich silty sands are also mixed at the same level. These parts resemble in many ways locally the bottom parts of UB5b/c sandy deposits that overlie in Area B the bluish muds (Fig. 9). Indeed, several of the elephant bones are sunk in this reworked/transitional type of sediment. A micromorphological sample taken adjacent to a proboscidean humerus, includes the above contact. It appears as a cm-thin exposed, reworked and possibly trampled surface containing hydromorphic features and mud intrasheets (Figs. 13c and 15c). It includes microscopically bedded organic-rich silty sands with some fine intrasheets (a variety of facies F) and underlies coarse, intrasheet-rich organic muds (facies E). The latter are certainly attributed to UA3c whereas the former could be assigned to remnants of the deposit of UB5b/c in Area B, which macroscopically could not be recognized in the field in Area A. To sum up our study shows that the elephant carcass sunk on an exposed surface and very soon afterwards was covered by UA3 mudflow deposit. As suggested by Konidaris et al. (2018) (this issue), because the elephant skeleton is not largely dissociated and several originally articulated bones occur in approximate anatomical association indicates quick burial by the overlying sediment. This interpretation is further supported by fabric, vertical distribution and point pattern analyses, which suggest an autochthonous deposition of the elephant skeletal elements and lithics, subject to localized minor reworking (Giusti et al., 2018 this issue).

While in Area A the elephant bones and the lithics occur at or near the contact of UA3-UA4 (Figs. 4 and 9), the lithic and faunal material in Area B are similarly found close to the base of the UB4 mudflow (equivalent to UA3), with the highest density occurring close to the contact with the sandy sediment of UB5 (Giusti et al., 2018 this issue). They most likely derived from the erosion of exposed mudflat areas and were redistributed locally by mudflow processes at the lake shore. The large amount of rip-up clasts derived from the underlying surface may suggest that some of the lithics could have been detached directly from the deposits of the surrounding excavated area, as the analysis of the spatial patterning of lithics and fauna also suggest (Giusti et al., 2018 this issue).

8. Conclusions

The Middle Pleistocene archaeological remains of Marathonas 1 are found stratified inside a clastic nearshore lake sequence of the present Megalopolis lignite mine. The sequence comprises a full interglacial-glacial-interglacial cycle (probably MIS11-13), starting with a lignite bed, presumably formed in a reed marsh during a warm climatic event, and continuing with organic pure silts and sands deposited at the distal part of a small subaqueous delta, probably under arid and perhaps cold climatic conditions. In addition, this sequence shows indications of liquefaction and slumping attributed to a seismic event. After an erosional hiatus, a sequence of depositional units is observed, comprising cycles of organic-rich sediment, which start with dilute mudflows and are followed by laminated sands and microscopically bedded silts. All of the anthropogenic material, including an almost complete, butchered elephant, is found on remnants of an eroded and exposed surface, which was part of an extensive mudflat surrounding the lake shore at that time. The overlying mudflows have locally redistributed and buried the archaeological remains. This part of the sequence demarcates the return to warm climatic conditions culminating in the overlying lignite seam.

This study demonstrates that the combination of macrostratigraphic and microstratigraphic investigations have the potential to assess the integrity of very old archaeological sites and correctly place them in the local and regional environmental context. It also provides the framework for better interpreting all other environmental proxies and studies.

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