Geomorphological development of Zakynthos, Greece

Relating geomorphology and artefact distribution

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MSc. thesis, 2010

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Incorporated within Zakynthos Archaeology Project

Preface

This report represents my MSc. thesis that I carried out as one of my final objectives in completing the Master program Physical Geography at the faculty Geoscience at the University Utrecht. It is the result of a research project which was defined within the Zakynthos Archaeology Project. This project is a multidisciplinary research program organized by the University of Amsterdam (UvA) in collaboration with the Netherlands Institute in Athens (NIA) and the Hellenic ministry of culture and tourism. The project started in 2005 and I participated in the summer campaign of 2009 when I performed my own fieldwork together with my field buddy R.Goudriaan.

First of all, I want to thank dr. G.J. van Wijngaarden, the director of the project, for giving us thrust and having patience. But also for being honest, fair and approachable to everyone, and for financial and logistical support. With mentioning him I want also mention my supervisor at the University Utrecht, dr. ir. G.Sterk, who gave me supervision from the University Utrecht and advised me in writing the final report. Besides these persons, I would also like to thank all participants during that summer for the very good atmosphere during the fieldwork period. I would also like to mention M.Konert who helped us in the laboratory at the Free University (VU) in Amsterdam, and J. van der Laan, who was our roommate and shared his thoughts about his own research which partly overlaps my study.

Finally but not least, I want to thank my field buddy R.Goudriaan who accompanied me during the preparing period, fieldwork and periods afterwards. It was already our third fieldwork together, but I think we are still a good team. After all, it was a very educational and useful experience on a very dynamic island (see my photograph at the front page).

Abstract

This study was conducted to provide some insights to the relation between artefact distribution/ origin and geomorphological development during the late Pleistocene and Holocene. Geological, lithological and geomorphological research showed several distinguishable landscape units. In the western part of the study area a swamp is present that used to be a lake, which can be seen as a favorable location for ancient human settlement. Besides this geomorphology focused research, also archaeological surveys have been done around this swamp and at some main locations of interest north of the swamp (e.g. Kamaroti hill). This study concluded that the artefact distribution along Kamaroti hill can be related with a former marine environment that was implicated by lithological research. However, the headward erosion of the walls of the highly abundant agricultural terraces in the study area caused exposure of artefacts through time. This is one of the reasons for the archaeologically complexity of the scattering of artefact distribution. Thick accumulations of terra rossa between a relative isolated region between the mountains in the western part of the study area were related with ancient soil erosion on the mountain slopes and the subsequent colluvial transport to these sediment catches.

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1. Introduction

Zakynthos is the southernmost of the Ionian islands that is situated in the Mediterranean Sea. In comparison with the neighbouring islands (like Cephalonia) and the Western Peloponnese, relatively little is known about the archaeology of this island (Kalligas, 1993). As Zakynthos is conveniently situated along various maritime routes and within sight of the western Peloponnese, suitable (ancient) harbours played a large role in the Mediterranean maritime traffic (figure 1.1). This strategic position, being the last seaport before entering the Mediterranean Sea, and fertile lands made sure the wealth of the inhabitants and the islands' distinguished position in various empires throughout history (e.g. the Roman Empire) (Van Wijngaarden, 2006). Zakynthos has been inhabited since the Middle Palaeolithic (late Pleistocene - early Holocene) (Van Wijngaarden, 2005). The archaeological remains on Zakynthos consist of shards of pottery, from a wide range of periods. Also lithic artefacts are abundant on the island, due to the presence of natural flint. The oldest remains are from the Middle Paleolithicum (Van Wijngaarden, 2006).

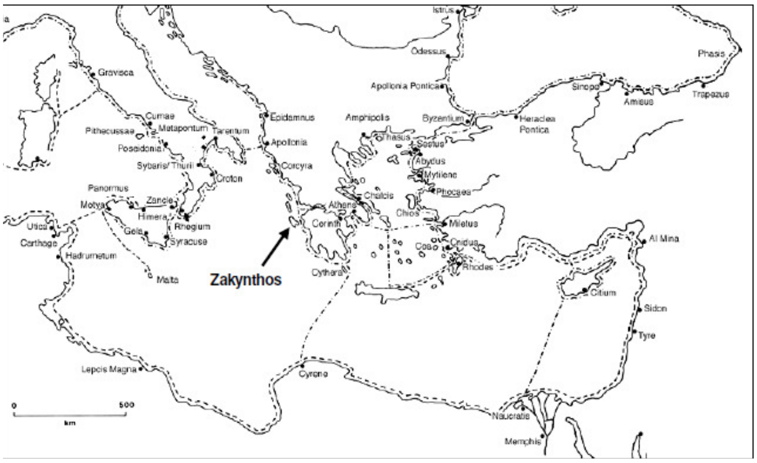


Figure 1.1: Zakynthos Island within the Mediterranean Sea routes during the Classical period; the Greeks (dash-dotted line) and the Phoenicians (dashed line) were the main traders (Talbert, 1985; modified by Tendürüs, 2009).

1.1 Problem definition

A clear archaeological record however is missing, caused by a history of natural hazards, especially soil erosion and tectonic activity (Van Wijngaarden, 2006). As Zakynthos is characterized by dry summers followed by torrential rainfalls, soil erosion is quite severe. During these rain events and earthquakes, the history of Zakynthos is being washed away in time. Results from coring in 2007 indicated the mix-up of the archaeological record of Zakynthos (Van Wijngaarden, 2007). Knowledge about the development of the area from late Pleistocene to Holocene, as well as the current erosion pattern, is important for interpreting artefact distribution and origin. Besides erosion, tectonic activity strongly affects the geomorphology of Zakynthos (Gournelos et al., 1999).

Many studies underlined the importance of geomorphologic processes on the archaeological record in general (e.g. Bintliff, 2002; Tartaron et al., 2006; James et al., 1994). Ripley (1998) showed that landscape evolution and human occupation are often related and can provide useful information on both aspects. For example, Robertson (2002) studied the alluvial stratigraphy in order to relate human occupation to the geomorphological development during the changing Holocene landscape. The study demonstrated the ubiquity of banded deposits that suggest geomorphic histories that are characterized by periodic deposition and periods of landscape stabilisation and soil formation. Furthermore, this study recommended the use of geomorphic criteria to identify settings that can be linked to archaeological sites. As Zakynthos still suffers from severe erosion, linking geomorphology to ancient occupation should give more insight to the scattered pattern of surface finds. This scattered pattern indicates that prehistoric occupation was present at the same landscape at several times in the past. The ability to derive more detailed archaeological information is often limited due to a lack of spatial and temporal control of the archaeological sites (Ripley, 1998).

The artefacts that have been found on Zakynthos are mixed up by erosion and deposition patterns. In order to say something about the scattered distribution of artefacts, more information about prehistoric human settlement would substantially contribute to understanding where artefacts could come from. Together with natural processes that influenced the local geomorphology, a relation between the scattered pattern and possible ancient human occupation can be obtained. By linking the known archaeology and the current geomorphology, this relation can be valuable in explaining current artefact distribution and assists the archaeological interpretation.

Besides the natural factors that influence geomorphology, human factors have played a role during the landscape development. Zakynthos has heavily been terraced which strongly influenced the relief on smaller scales. Besides past natural dynamics, these human factors should also be taken into account (Tendürüs et al., 2009). As these factors can severely influence surface artefacts, this study is also implemented for determining whether these kind of artificial measures have influenced the transport process of artefacts. Together with past landscape evolution, the current artefact distribution could be explained.

1.2 Goals

This research was implemented in the Zakynthos Archaeology project (ZAP). This project is an interdisciplinary research undertaken by a cooperation of the University of Amsterdam (UvA), the 35th Ephorate of Prehistoric and Classical Antiquities and the Netherlands Institute in Athens. The ZAP tries to reconstruct the history of the island Zakynthos, with special interest to the influence of natural processes (hazards) on the preservation of the archaeological record (for more information see Van Wijngaarden, 2006). The main goal of the Zakynthos Archaeology Project is to relate the natural dynamics to the distribution of archaeological material found. The project will be an example for other, upcoming, archaeological research.

As part of the ZAP, this study aimed to provide insight in the relation between artefact distribution, origin and geomorphological development during the late Pleistocene and Holocene. Both past natural development as well as recent artificial development was taken into account. The following research questions were addressed:

Primary question:

- How is the geomorphological development related to the distribution of artefacts?

Secondary questions:

- How did the area form?
- Is there a relation between ancient erosion/ deposition patterns and artefact distribution?
- What is the influence of recent anthropogenic landscape processes (e.g. terracing) on artifact distribution?

2. Study area and methods

2.1 Study area

Zakynthos island consists of three major areas: a limestone mountain belt in the west, a fertile central plain and the Vassilikos peninsula in the east (Gournelos et al., 1999). The island has a Mediterranean climate, with typical long, dry summers, and torrential rains during winter (October-February). This climate enables the cultivation of vineyards, olives, and citrus fruits. In the last two decades the economy on Zakynthos has shifted from agriculturally driven to mostly tourism driven (Gournelos et al., 1999). The central plain remains dominated by agriculture, whereas most of the coastline is dominated by tourism.

The study area coincides with one of ZAP project areas. The overall research of ZAP takes place in three areas (figure 2.1). This study was conducted in 2009 in area A near the village Limni Keriou bordered along the Ionian Sea in the south-eastern part of the island. The study area has a total surface of 7 km² (figure 2.2).

Figure 2.1: Research within the Zakynthos Archaeology Project takes place in area A, B and C (from ZAP project).

Limni Keriou borders a large swamp in the east of the study area that used to be a lake. Now this swamp is dominated by high grasses and is part of the large alluvial basin in the east that consists of Oligocene marly carbonates and Miocene clastics and carbonates. The western part of the area consists mainly of limestone hills, with a maximum altitude of approximately 400m. These hills mainly consist of Eocene carbonates and some Cretaceous carbonates. The study area has been intensively terraced, from the swamp border till the higher elevated mountain slopes (although in less extent).

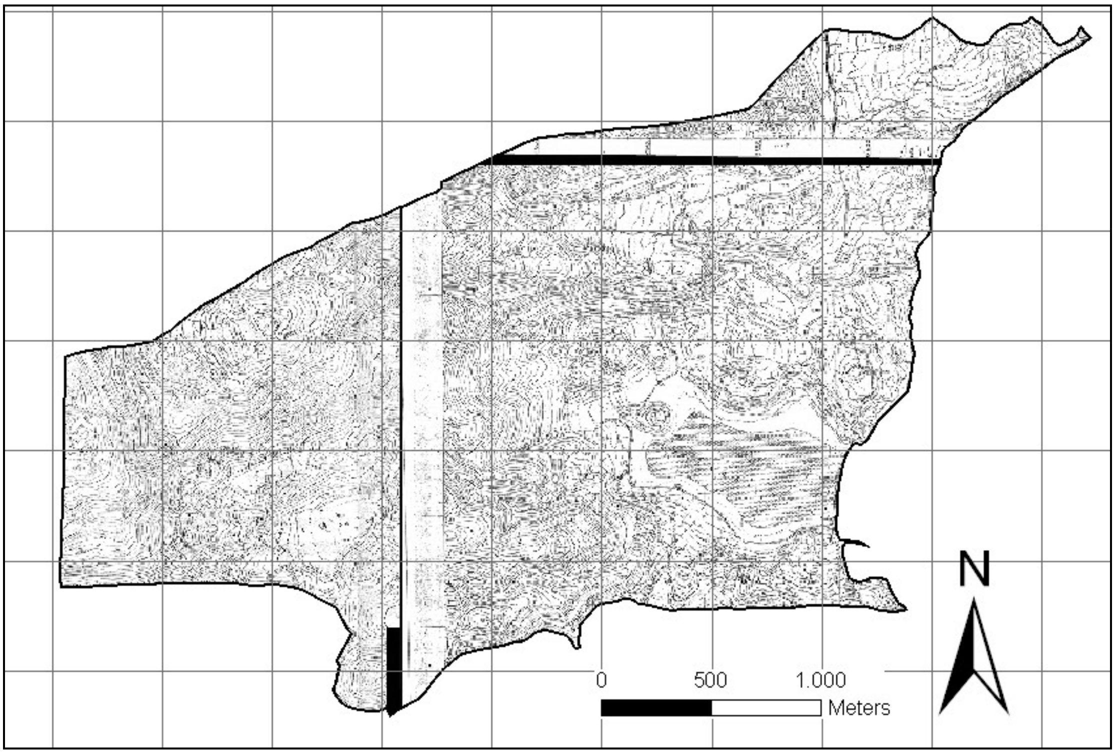


Figure 2.2: Study area A.

The whole study area was investigated in order to correlate archaeological findings to landscape dynamics. Special interest was given to the basins where sediment was suspected to be accumulated over time and where there is an archaeological interest. Land cover in the study area varies from pine forests, scrubland, marsh vegetation, olive trees, bare soil and artificial constructions (infrastructure and village). As the local Mediterranean climate enables vegetation which can sustain long periods of drought, the area is dependent on the cultivation of olive tree vineyards.

2.2 Methods; landscape evolution

The following description of the methods was based on the secondary research questions given in chapter 1. In order to answer the first question how the area was formed, geological, lithological and geomorphological research was performed.

2.2.1 Geological research

As the geology is the basis for further geomorphological description, this is the first terrain which was examined. The study on geology was performed by a literature study and by field observations. The current geological maps (Kati & Scholle, 2008; IGME, 1982) and the strike and dip measurements in the field were the main data on which the description was based on. The strike and dip measurements were done using a geological compass. Further additional data obtained in the field like notes, drawings and photos were also taken into account. In order to collect more detailed information on the geology, the Institute of Geology and Mineral Exploration (IGME) in Athens was visited.

2.2.2 Lithological research

In order to examine the more recent sediments on top of the geological units, 91 corings have been conducted (appendix I). These corings have been done with an Edelman handauger. Every 10 centimetres, a sample was taken and described using texture, organic material, plant remains, colour, oxidation/reduction state, gravel percentage, grain size, calcium content (shells), iron content and the presence of recognizable soil layers (according to Berendsen & Stouthamer, 2001). The focus was on distinguishing the main groups of sediments and providing some information about the relative age. The coring practices have been done at accessible locations that contain soils without limestone fragmented and shallow bedrock.

During the coring work, 36 soil samples have been taken for further laboratory analysis. The samples were mainly taken to confirm the characteristics of a large variety of abundant sediments. First, a grain size analysis was performed at the VU (Free University in Amsterdam). Grain size is an important characteristic as this affects the entrainment, transport ability and deposition of sediments. These aspects can refer to the origin/source, transport path or conditions during deposition. These characteristics may indicate ancient environment conditions and are considered of major importance. Besides the grain size analysis, the organic matter and carbonate content were measured at the UU (University of Utrecht). These tests give some information of respectively, soil formation and the parent rock. More details about the technical procedure of the three analyses can be found in appendix VIII.

2.2.3 Geomorphological research

The geomorphology has been examined by observing the main landforms that were visible in the current landscape. Observations were mapped and divided into geomorphological units which were finally worked out in a geomorphological map. Besides the observations in the field, the description was also based on a detailed digital elevation model (DEM). This DEM has been constructed by digitizing 4m elevation lines from the available topographic map (1:5000). This DEM is included in appendix II. The lithological and geological results were also taken into account in order to reconstruct the landscape evolution.

2.3 Methods; landscape evolution vs. artefact distribution

In order to relate the landscape to the artefact distribution, ancient erosion and deposition areas were identified based on the geomorphology and lithology, archaeological data was analysed and anthropogenic landscape processes have been taken into account.

2.3.1 Identifying ancient erosion and deposition areas

Identifying ancient erosion and deposition patterns was already done implicitly during the geomorphological and lithological research, because these patterns are closely related to the paleo-environment. Important to know is why sediments have been settled or not, or perhaps have been eroded away. Both ancient landscape patterns as well as recent patterns were identified.

2.3.2 Archaeological distribution mapping

The archaeological teams have done surveys in the study area. The basic analytical unit of the survey is the tract, which is determined by topographical features and does not exceed 50m^2. In every tract, the same procedure is followed. Within a tract, field walkers were placed at ca. 5m intervals. The survey methodology is based on the hypothesis, that field walkers record archaeological finds within a strip of two meters. Within this strip, the field walkers just count the number of artefacts on the surface with the help of clickers. On their way back along the same walking strips the archaeological finds are collected. In this way 40% of the totals of finds in tracts are documented (Van Wijngaarden, 2006). The artefacts are cleaned and studied which finally results in estimated ages. During this study, these ages were spatially linked with the tracts and finally some distribution maps have been constructed (appendices V (a-i)).

2.3.3 Spatial correlation

In order to find a relation between artefacts and the current landscape, the spatial distribution of artefacts was correlated to the geomorphological units. As these units represent geomorphological processes, a relation could be useful to put human occupation spatially in context. Both the geomorphological and the archaeological data were reworked in order to apply an analysis of variance (ANOVA). Besides this statistical part, also an analysis has been performed in a descriptive way.

2.3.4 Anthropogenic landscape processes

Besides ancient erosion and deposition patterns (implied in the geomorphology and landscape evolution) also recent anthropogenic processes which can influence the artefact distribution were analyzed. This was mainly done based on the observations and results from research in the same area which was done simultaneously in 2009 (Goudriaan, 2010). Also aerial photos were used to provide insight on the recent anthropogenic changes through time like terracing.

3. Geology and Tectonics

3.1 Tectonic setting

Zakynthos is situated in the Hellenic orogenic belt that characterizes western Greece. The convergence of the African and Eurasian major plates resulted in this complex geological and tectonic region. Both subduction and collision between these two plates contribute to the complexity of this region (Tendürüs et al., 2009). These two geological zones are connected by the Cephalonia transform fault zone (figure 3.1A).

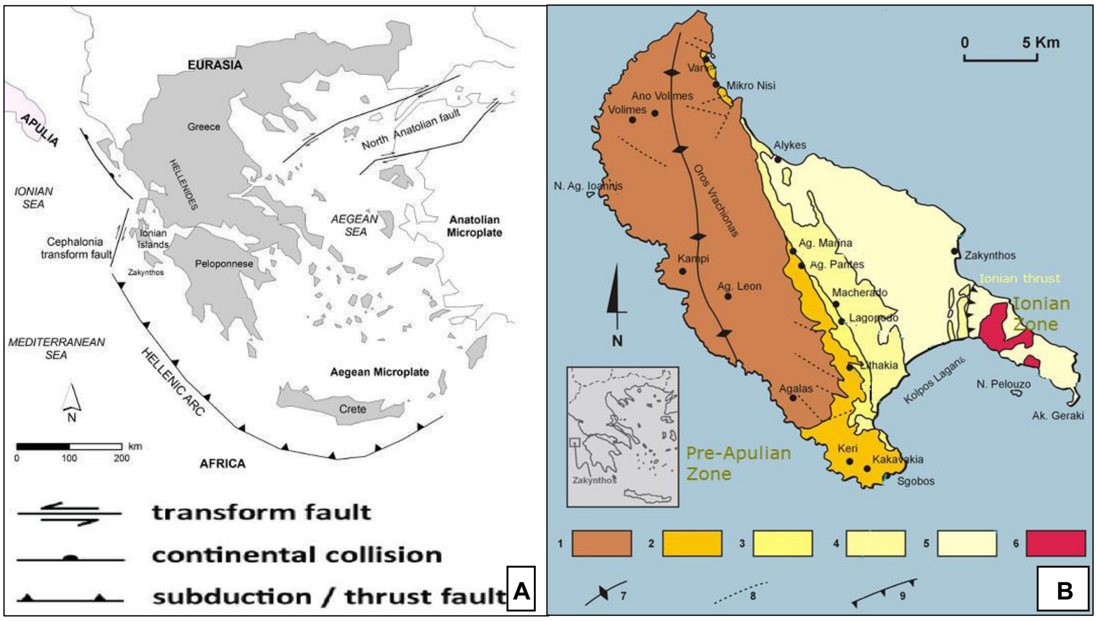


Figure 3.1: A: The Cephalonia transform fault zone (after Tendürüs et al., 2009). B: Geological map with legend; 1. Cretaceous carbonates. 2. Eocene carbonates, 3. Oligocene marly carbonates, 4. Miocene clastics and carbonates, 5. Pliocene-Quaternary alluvial deposits, 6. Ionian evaporites and breccias, 7. Anticline, 8. Fault, 9. Main thrust (Ionian) (Modified after Kati & Scholle, 2008).

The Ionian basin of the African plate subducts beneath the Aegean continental micro plate which is part of the Eurasian plate. Besides this subduction, the Apulian continental crustal part of the African plate collided with the Eurasian plate in the north (figure 3.1A). This collision began late Cretaceous - early Eocene and is propagating westward, forming several fold-thrust systems (Kamberis et al., 1996; Tendürüs et al., 2009). This collision causes the shortening of the lithosphere which is reflected by the NW-SE directed nappes. These nappes form several isopic zones which are separated by west directed thrust faults (figure 3.2B). Zakyntos belongs to two of these isopic tectonic zones; the Pre-Apulian zone (Paxos zone) and the Ionian zone. These two zones are separated by the Ionian thrust which runs across several of the Ionian Islands (figure 3.2A).

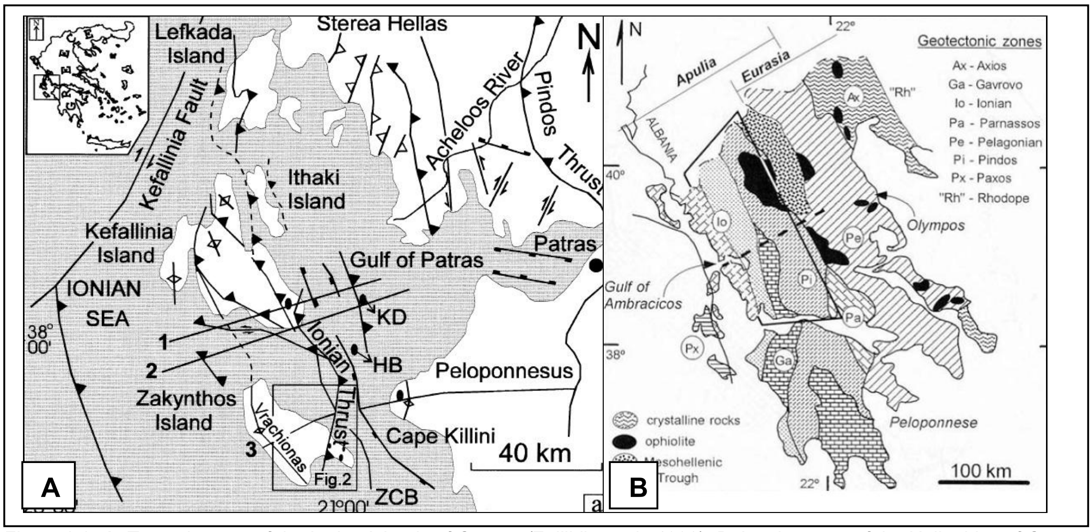


Figure 3.2: A: Tectonic map of the Ionian Islands of Greece (Zelilidis et al., 1998). B: Isopic zones of the Hellenides of Greece (Gonzalez Bonorido, 1996).

The sea basins east of Zakynthos are subsiding and therefore undergo extension. As the Ionian Islands are located between a subduction zone and a region of rapid extension, a complex syn-sedimentary tectonic environment developed which involved a foreland propagating fold and thrust system (Zelilidis et al., 1998). The tectonic environment resulted in the outcrop of several geologic units as shown in figure 3.1B.

3.2 Geological setting of Zakynthos

The following chronological description was based on information obtained from literature and the geological map (Kati & Scholle, 2008). The literature study was complemented by field observations to evaluate the geological situation in the study area. A geological time scale table can be found in appendix VI.

Cretaceous-Paleogene

The Pre-Apulian zone is considered as the eastern slope of the Auplian foreland and is characterized by the presence of a series of anticlines (left part in figure 3.3). The Vrachionas mountains in the western part of Zakynthos are part of one of those anticlines. They display an alteration of pelagic and detrital limestones (Dermitzakis, 1994). Most limestones are from Cretaceous age and the eastern slope of the Vrachionas anticline is also dominated by Eocene and Oligocene marly limestones. These thick Mesozoic and Paleogenic limestone layers overly the Apulian crystalline basement (Zelilidis et al., 1998). According to Kamberis et al. (1996), a thick sediment sequence of neritic limestones was deposited during the period Late Triassic - Eocene. The carbonate sedimentation in the Pre-Apulian zone is assumed to have lasted longer than in the Ionian zone. Later on, the carbonate sedimentation was followed by deposition of terrigenous-clastic sediments during the Miocene (Dermitzakis,1994; Kamberis et al., 1996). The Pre-Neogene rocks of the Ionian zone are represented by predominantly evaporitic sediments, mostly with Triassic age (Dermitzakis, 1994).

Oligocene-Miocene

As result of the collision of the Apulian continental crustal part of the African plate with the Eurasian plate, a foreland basin developed in the Ionian zone. In this basin Lower Oligocene – Lower Miocene flysch accumulated (Zelilidis et al., 1998). Westward, this flysch changes into Miocene marls. During the Late Oligocene, thrusting resulted in segmentation of this flysch basin.

Pliocene

In the Early Pliocene deformation of the Pre-Apulian zone took place (Kamberis et al., 1996). This deformation subdivided the pre existing Miocene basin into two independent basins in the late Pliocene; the Alikas basin (central Zakynthos) and the Geraki basin (south east Zakynthos). The sedimentary succession of the Alikas basin spans the entire Pliocene and extends to the early Pleistocene (Zelilidis et al., 1998). Besides deformation of the Pre-Apulian zone during the Early Pliocene, also the uplift of the Vrachionas anticline is assumed to have started in the same period. The presence of limestone pebbles in the Lower Pliocene sediment is seen as a significant evidence.

Quaternary

It is assumed that from the mid-Quaternary the extended Pliocene-Quaternary basins experienced rapid subsidence which resulted in the separation of the Ionian islands from mainland Greece. These subsiding basins involve the current Zakynthos channel (east of Zakynthos) and the outer Gulf of Patras. Current rates of subsidence locally exceed 5 mm per year. Besides these subsiding basins, thrusting through the Quaternary in Zakynthos resulted in a progressive uplift of Pliocene and lower Pleistocene sediments and Quaternary marine terraces.

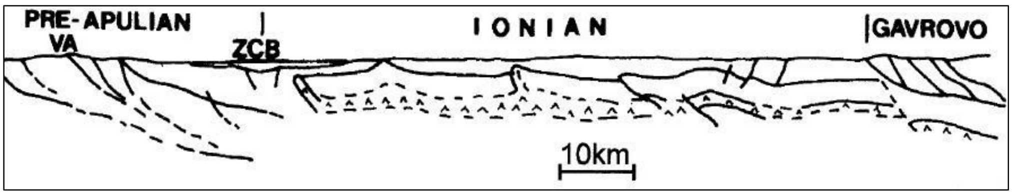


Figure 3.3: Structural cross-section along the line (3) from figure 3.2A (from Zelilidis et al., 1998). It shows the foreland basin in the Ionian zone which is related with the thrusting in the Pre-Apulian zone. VA=Vrachionas anticline, ZCB=Zakynthos channel basin.

Field observations

The main part of the study area consists of lime stones. Figure 3.4 shows part of the geological map of Zakynthos (Institute of Geology and Mineral Exploration of Greece, 1980) with the study area border. The area reveals six geological units ranging from the Cretaceous to Holocene deposits.

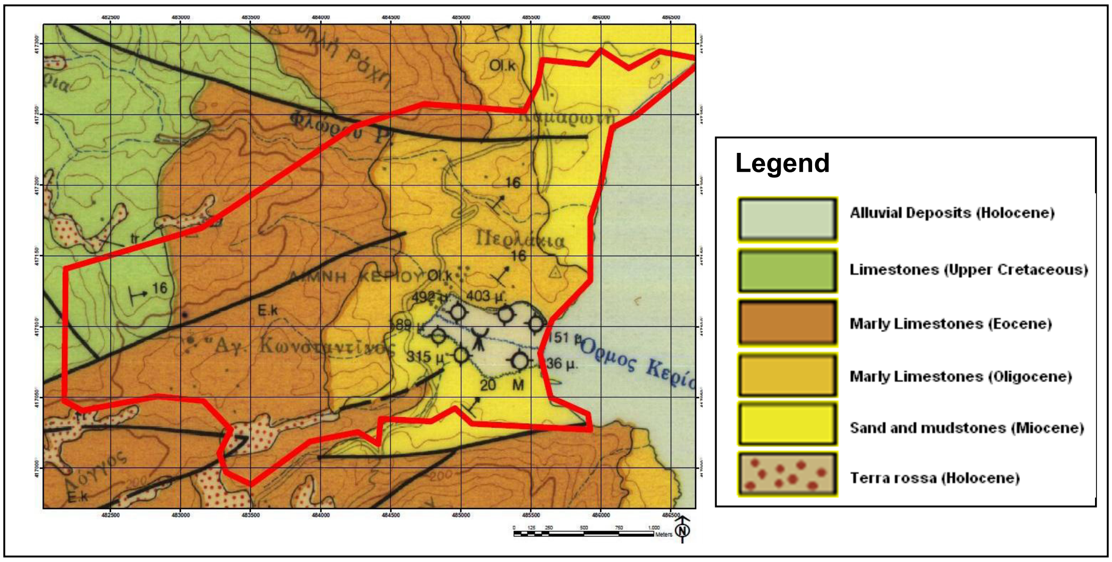


Figure 3.4: Modified geological map of the study area (after IGME, 1980).

The western part of the area mainly consists of white to grey limestones. These limestones are characterized by fragmentation, cracks and signs of physical and chemical weathering (karst). The fragmented character (figure 3.5) can probably be ascribed to tectonic forces. Eastward of these Upper Cretaceous limestones, other limestones can be found in the area. Although these are geologically different limestones from the Eocene and Oligocene, the differences can hardly be distinguished in the field. This is further hampered by the fact that most geologic layers are heavily disturbed by historical and present tectonic influences. Lekkas (1993) created a neotectonic map of Zakynthos and labelled these limestones Vrachionas limestones, after the Vrachionas mountain belt. His description of this part confirms the highly weatherable characteristics of the observed limestones.

Besides the Cretaceous and Palogenic limestone deposits, also some Miocene sandstones, mudstones and bluish marls can be found in the study area. These deposits are mainly situated in the north-eastern and south-eastern part of the study area. These can be best observed at outcrops along the coast. Finally, the map shows two Holocene depositions; the alluvial deposits. These most recent deposits will be discussed in chapters 4 and 5.

Figure 3.4: A: Horizontal layering along the souther border of the study area, B: Dipping white limestonelayers, C: Marly limestone, D: Fractured limestone mass, E: A local fault along the red line, F: Karstic characteristics of the limestones

In order to get an overview of the local geological structure in the study area, strike- and dip measurements have been made in the field. In figure 3.5 on the next page, the orientation of geological layers is plotted with symbols that show the strike of the layer with the dip angle. As the layers in the study area are heavily disturbed and fragmented by tectonics, it is hard to observe whether the measured layer is one of the basic layers that can give valuable information about the geological structure. Although this disadvantage, the results seem to show a global east-west dip direction. It is likely that the hilly part of the study area represents the foothills of the Vrachionas mountains in the west. As these mountains are in fact an anticline, the measured dip direction should represent the eastern side of the geological phenomena. Some deflected measurements, especially in the north east of the area, can be ascribed by the measured tectonically disturbed layers that not represent the main geological structure.

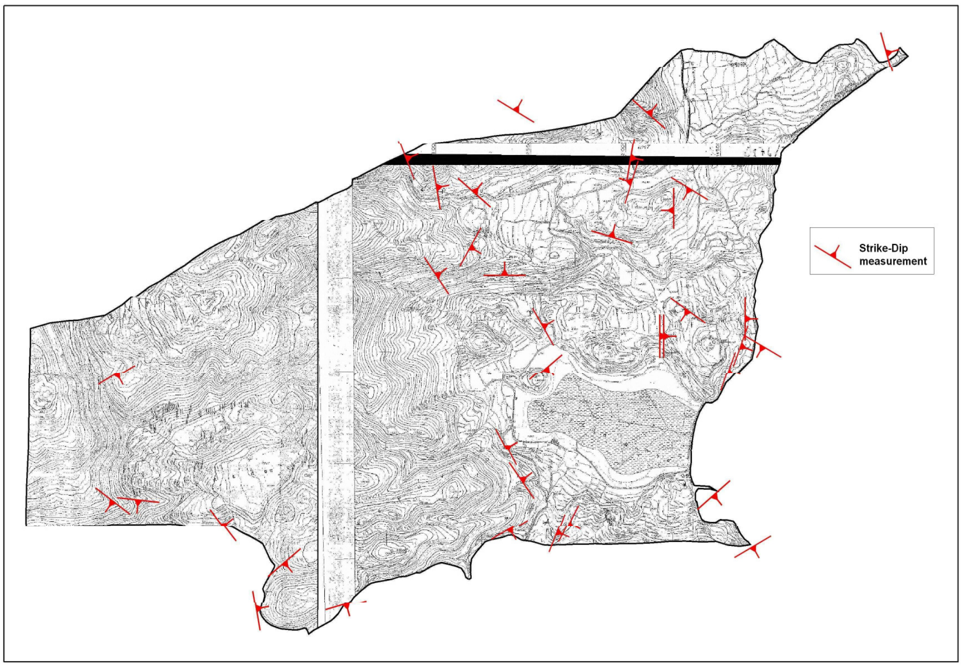


Figure 3.5: Distribution of the dip measurements (in red).

Comparing these results with the geological map, the geological layers seem to become situated against each other starting with the eastern side of the Vrachionas anticline. A similar observation for the Neogene layers was made by Dermitzakis (1994) who suggested that the Neogene forms a monoclinal succession which overlies the Cretaceous-Paleogene limestones of the Vrachionas mountains. In the study area this seems also to be valid for the Paleogene part that is situated against the Cretaceous limestones. Taking a look at the elevations in the area, the overall elevation decreases towards the east, but there are some smaller hills in the east showing large masses of bedrock. These bedrock parts probably became separated from the anticline by uplift through geological times. Some of these massive bedrock parts seem to have protected the underlying rocks against erosion, and acted as a large capstone.

4. Lithology

4.1 Coring areas

In order to evaluate the formation of the study area and its ancient erosion and deposition patterns (secondary research questions), 91 corings have been conducted in the area (figure 4.1). Six areas of coring can be distinguished. The first group comprises the corings in the swamp (1). The second group comprises the corings around the swamp. Furthermore, some corings have been conducted in the lower elevated area in the west, situated between the Vrachionas mountains and the foothills more eastwards (3). Another part was conducted along the foothills adjacent to a small river valley situated in the central north of the study area (4). Finally there is an area in the north-east (5) and the area surrounding the earlier referred Kamaroti hill (6).

Because of the high rock content in a large part of the study area where coring was not possible, coring has been done in the parts that contain soils without limestone fragments and bedrock. Figure 4.1 shows the higher density in the eastern part of the study area. Within this eastern part, a small area in the north-east was covered with a higher core density. Those corings were done as part of a separate study on the actual erosion patterns along the slopes of Kamaroti hill (Goudriaan, 2010).

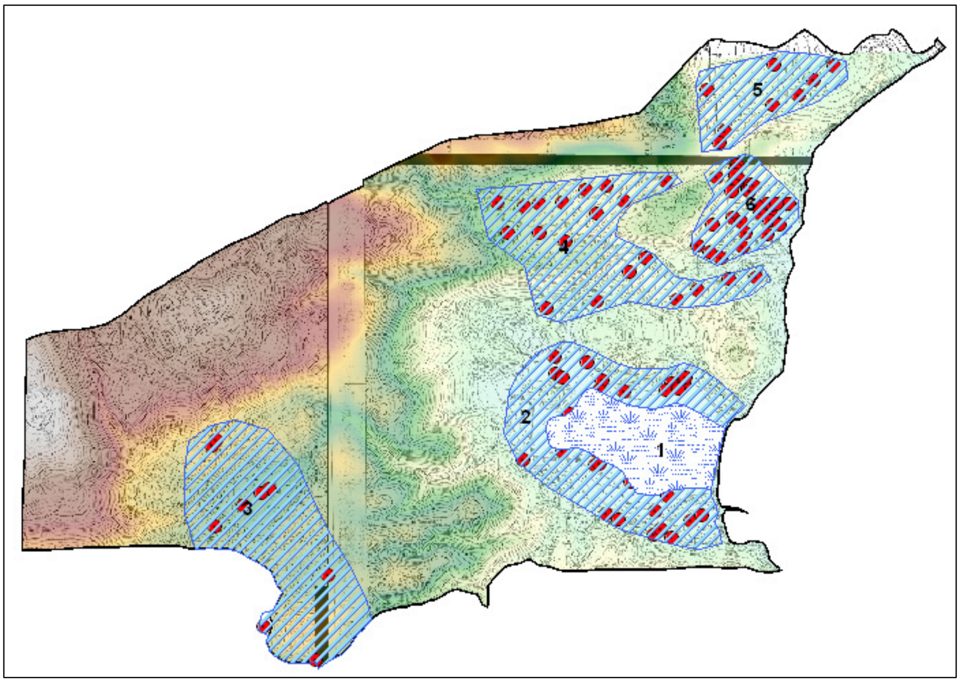


Figure 4.1: Coring distribution in the study area.

Beside this larger core density around the Kamaroti hill, the corings in the swamp have been conducted by another study on the evolution of this swamp (Van der Laan, 2010). As those corings provide shared interests, they are also used in this study. The next paragraphs describe the main coring results while more extensive descriptions and maps can be found in appendices Xa-Xf. The lab analyses have been done in order to confirm the exact texture which was approximately determined in the field. A summary of these results can be found in appendix IX.

4.2 Swamp

The historic topographical map of Zakynthos from 1891 clearly shows a small bay around Limni Keriou, partly at the current location of the swamp. Besides the bay, a lake is shown too. Herodotos, a Greek historican in ancient times (around 450 years B.C.), mentioned this lake as source of tar which was used to make ships waterproof (van Wijngaarden, 2005). Appendix Xa shows a more detailed map with the corings in and some near the swamp. Most corings contain an alternation of peat and clays with a significant organic matter content. Considering the large amounts of peat found in the corings, it seems obvious that this ancient lake has slowly become land by invading vegetation (siltation).

The main trend in the coring results is the decreasing thickness of the peat layer towards the east which assumes that a former lake experienced a siltation process from the western direction. Also the increasing clay amount towards the east is a trend that can be ascribed to a more dominant influence from the sea. As the southern corings show a thinner peat layer and a clay layer that was found less deep compared with the northern corings, the sea influence reached further landwards in this south western part. However, these (often organic) clays could only settle under calm conditions. These conditions were probably met by the presence of an ancient sand ridge which played a role in a former lagoon system. The eastern corings contain clear layers of sand that used to be a part of a sand ridge. This ridge could explain the necessary calm conditions behind it, at which the clays could settle.

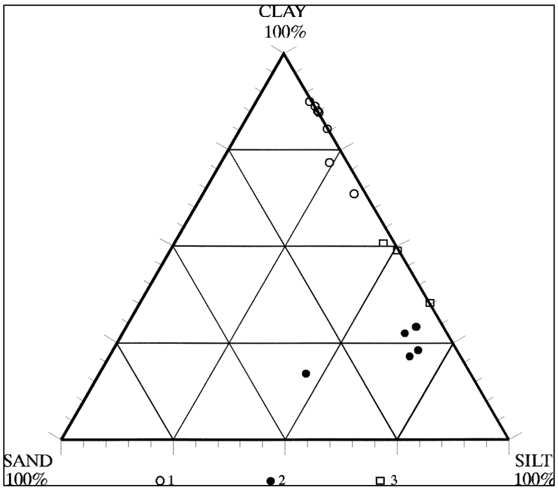
The corings in the centre of the swamp show complex alterations of clay and peat that can be explained by transgression and regression events of the sea. Because of these events, the ancient lagoon was flooded several times which resulted in different sedimentation regimes. The mid of the swamp probably consisted once of a pool and wet swamp system, which may explain the spatial sedimentation of clays and formation of peat at the same time. At a certain moment the lagoon system must have developed into a lake that eventually closed later on from the west. This resulted in a thick peat accumulation that can be found now.

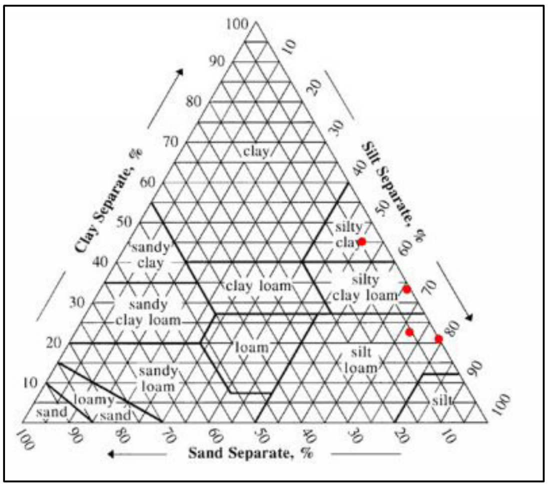
4.3 Around the swamp

Appendix Xb shows the corings that were conducted around the swamp. The small town Limni Keriou is situated directly south of the swamp. In this town terracing already begins towards the hill slopes. Also north of the swamp, terracing against the relative steep hills is the dominant landscape feature. Appendix Xb describes two core zones; one flat zone directly bordered along the swamp, and one outer zone against the nearby mountain slopes. The corings in the first zone show some influence of the former lake and its siltation process. These more heavy clays are mostly organic and comprise even some shells and plant remnants. Especially in the (north) western part, these imply more landward influence than the current artificially bordered swamp suggests. However, going more westward, the soils become shallower and sometimes bedrock could be clearly noticed at the end of a coring. As these corings are situated near the swamp, it is likely that the former bay and lake did not reach much further than the present location of the swamp. Also the sediment layer becomes more homogenous and more red coloured in westward direction. This pattern could also be noticed by the corings closer to the terraced hills (second zone). They contained silty clays and silt loams which were mostly calcium rich. Most sediments were too dry and hard to core through. Also the presence of limestone pebbles made coring difficult. It appeared that these sediments have a colluvial character and have its origin in the adjacent calcareous mountains and hills. Mainly against the foothills, these sediments seemed to be disturbed by terracing. In the corings near the swamp the colluvial sediments were often found on top of the marine sediments.

4.4 Western part

This higher elevated part is very rocky with much exposed bedrock on which shallow soils were expected during the fieldwork. However, this part comprises some deep corings (appendix Xc). Overall, the typical red brown (silty) clay that was found is a fairly homogeneous layer which varied in depth locally. This sediment type can be referred to 'terra rossa' soils that appear in the Mediterranean region. Durn (2003) investigated the terra rossa soils in the Mediterranean. This study formulates terra rossa as "a reddish clayey to silty-clay material, which covers limestone and dolomite in the form of a discontinuous layer ranging in thickness from a few centimetres to several meters". The most common theory is that terra rossa develops from the insoluble residue of carbonate rocks. The red colour is a diagnostic feature and the result of the preferential formation of haematite over goethite. Although this clear notation of terra rossa, there are different opinions among scientists on the origin of these soils. Most authors today believe that terra rossa is a polygenetic relict soil formed during the Tertiary and/ or hot and humid periods of the Quaternary. The question is whether this terra rossa can also be seen as a polygenetic relict soil. Durn et al. (1999) mentioned "pedo-sedimentary colluvial complexes" that indicate thick accumulations of terra rossa-like material situated in karst depressions. If such a karst depression is isolated, terra rossa would have formed exclusively from the insoluble residue of limestone or dolomite. Durn et al. (1999) compared particle size distribution of terra rossa samples with the particle size distribution of insoluble residues of the surrounding limestone and dolomite in order to see whether the terra rossa could only be formed from the erosion of limestone and dolomite. Figure 4.2a shows the particle size analysis of insoluble residues of limestone (1) and marls (2) from that study. Comparing these results with the samples of corings 30, 36 and 28 (figure 4.2b), shows that the clay content in the samples should be slightly higher when assuming terra rossa development from only (marly) limestones. Despite this, it seems a reasonable approximation for the possible origin of the terra rossa in the study area.





a

b.

Figure 4.2: Particle size distribution of the insoluble residues of limestone (1) and marls (2) from Durn et al. (1999).Figure 4.2b: Particle size distribution of the terra rossa samples of corings 28, 30 and 36 indicated by the red dots.

The current landscape settings in the study area can be considered as a quiet isolated karst terrain, as there are many indications found of karstification (chapter 5). Erosion and deposition processes are superimposed on karst terrains and are influenced by climatic changes, tectonic movements and certain human activities like tree logging (deforestation). This might be responsible for both the patchy distribution of terra rossa and the thick colluvial accumulation in karst depressions. This patchy character is visible in the study area and is further discussed in chapter 5. Olson et al. (1980) indicated that terra rossa is mainly debris derived from erosion of higher clastic sedimentary rocks, and is transported and deposited on pediments cut into lower situated limestones. Despite all these indications, it is still plausible that the terra rossa found in the study area comprises a larger range of parent materials. Since the terra rossa accumulations are quite thick (till 3m and maybe deeper), an extensive thickness of (marly) limestones must have been dissolved. Besides this, the preservation of the calcareous sediments during the Neogene must have been very high.

4.5 Area in the central north

The corings in this group are distinguished in three parts as described in appendix Xd. Overall, this coring group in the central northern part of the study area showed a variety of sequences. The first two most northern parts contained colluvial material from the adjacent steep mountain hills. One part of it was settled on a compacted glued limestone mass, and the other part has been accumulated as a thick layer of silty clays in a local depression. The remaining corings in the third part showed an increasing sand content towards the east. In the west, relative homogeneous silty clays (and silt loams) were deposited on top of the more shallow bedrock, while in the more eastern coriings more sandy material dominated like sandy clays. Finally, a coring in the low elevated river valley showed silts and silty clays on top of blue grey clays that suggests an ancient landward invaded sea influence.

4.6 Area in the north-east

Appendix Xe shows the corings carried out in the north eastern part of the study area. These corings are situated on a relative low sloping area and showed a more complex sequence of sediments with alternating clay- and sand layers. The coring results suggest a former beach environment at which sand and clay deposition altered through time. Although most sands were fine, well rounded and sorted, some sands were badly sorted and showed some larger sharp grains that probably washed in once. This indicates a more energetic beach environment. Also some gravel concentrations were found in the sands and clays. Even a flint and presumable potshard were found in coring 47 at a depth of 240 cm. Also coring 89, which is situated on the northern slopes of Kamaroti hill showed a clear potshard within very well rounded and sorted sand. This same coring also showed large shell remnants. Most corings also showed clear iron concretions, organic matter and plant remnants in the clays and sands. These imply ancient exposure of the sediments at the land surface. Overall, this group corings showed an interesting sequence that comprises both colluvial sediments and former marine sediments. Together with the findings of shell remnants and even some archaeological material, this area seems an interesting area in an archaeological sense.

4.7 Area around Kamaroti hill

Finally, the area around Kamaroti hill was studied. As this area was also encountered in the research of Goudriaan (2010), this area comprises many corings. Most corings were conducted along the southern slopes of Kamaroti hill (appendix Xf). Chapter 6 described the archaeological meaning and value of this hill. The corings in this area varied a lot, both in composition as well in depth.

Overall, the different sediment sequences imply several influences. First of all, the presence of the very fine loamy sands (mostly situated between brown, grey and blue clays) indicates former marine influence. Just as the case in the north eastern part of the study area, this could imply former alternations of the sea level. There was also found a zone with some peat accumulation that could be referred to locally invading seawater. On top of the marine clays and sands, clays with a more colluvial character were found. The sandy character of the upper layers seems to increase to the east. Also plant remnants, organic matter and iron content were often found and indicate a relative recent past. A part of this content can be explained by the terracing practices and a part by alternating marine influences. A prominent aspect is that Kamaroti hill seems to be preserved against erosion since the top of the hill still comprised of relatively deep soils. Bedrock varied locally in depth, and along the steeper hill slopes colluvial material was found (sometimes with gravels and young plant remnants). In the area around Kamaroti hill, four corings groups could be distinguished which are evaluated more in detail in appendix Xf. Besides sediments, also some artefacts were found near one coring at the end of a terrace (coring 25). It concerned a concentrated amount of ca. 30 potshards with different ages that were found in ca. 40 cm^2. These shards were probably moved to the end of this terrace during construction of the terrace, and show the large influence terracing on artefact scatter.

5. Geomorphology

This chapter evaluates the geomorphology of the study area. It contains descriptions that are based on field observations and some visible landscape features that could be derived from the DEM and a satellite image. A DEM was constructed by digitizing all elevation contour lines of the available topographic map (1:5000) and is included in appendix II. This chapter describes the geomorphological features and tries to integrate them with the interpretations of the corings (chapter 4). The result of the geomorphological descriptions and interpretations are represented in the geomorphological map (appendix III). This map shows the main geomorphological units that were distinguished within the study area. The units are evaluated separately in the next paragraphs.

5.1 Tectonic influences

The DEM (appendix III) was modified with a ‘hill shaded’ effect which shows more clear landscape contours. The elevation map clearly indicates some diverse relief characteristics. The eastern and northern part comprise mainly mountainous areas, while the eastern part comprises a more flat terrain with the swamp and some single hills. Besides this coarse distinction, some flat parts are recognisable between the mountainous area in the west, and a very clear small valley is visible in the north eastern part. As Zakynthos is highly affected by geological tectonics, the local tectonics are assumed to have an important role in the geomorphology. Figure 5.1B shows a part of the neotectonic map of Lekkas (1993). This map shows, apart from some (post)alpine formations, the present active faults in the area. Most faults are east-west oriented, except the two faults in the western part that cross the area in a north-south direction. These faults can also be seen in a modified version of this map which was used in the study of Avramidis and Kontopoulus (2009) (figure 5.1A).

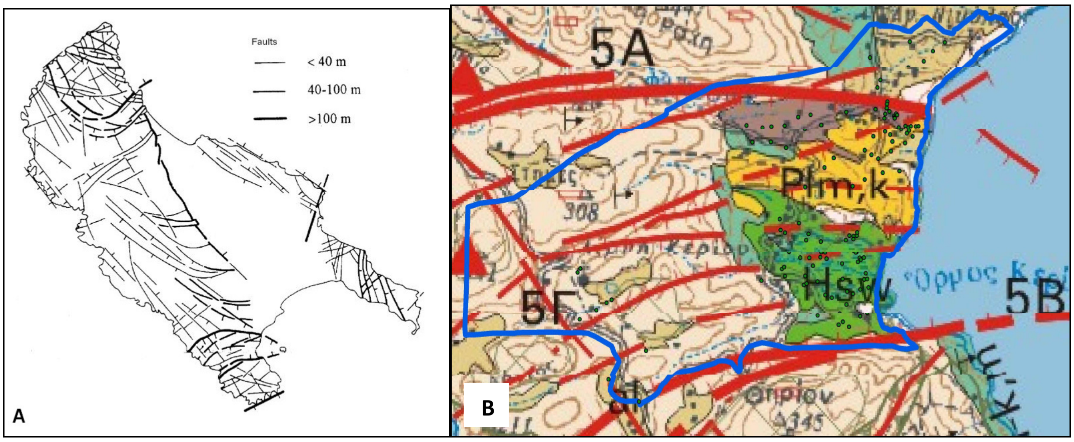


Figure 5.1: A: (Modified) tectonic map of Zakynthos (Avramidis and Kontopoulus, 2009). B: Part of the neotectonic map of Zakynthos (Lekkas, 1993).

This version indicates the vertical displacement for each fault. Figures 5.1B shows that the study area is situated between two east-west oriented faults which had a significant vertical displacement (uplift) of more than 100 m. The original neotectonic map even ascribes 300 meter vertical displacement to these main faults. According to Lekkas (1993) these fault zones are one of the five most active zones in Zakynthos which are also the cause for local seismic shocks. The fault zones on either side of Keri bay created the topographic lowering of the bay. Also some fault with a vertical displacement of 40-100 meter and 0-40 meter cross the study area. Comparing these faults with the DEM, there is a reasonable agreement with the valleys and hills that are assumed to be the east west oriented foothills of the Vrachionas mountains. Also the north-south oriented valley in the western part coincides with the mapped faults. It seems obvious that tectonic influence played a key factor in the evolved landforms in the study area.

5.2 Geomorphological units

The geomorphology is divided into three basic units based on location in the study area; the mountain area in the west (5.2.1), the eastern part of the study area with the low sloping plains single hills (5.2.2) and the coastal zone (5.2.3).

5.2.1 Mountain area

5.2.1.1 Mountain slopes

This unit comprises the higher elevated parts of the study area which border the study area in the west and north. In the west the mountains reach more than 320 m a.s.l. This part can be seen as a clear part of the Vrachionas mountain belt which extends from the north-west to the south-east of Zakynthos. These mountain slopes consist of (marly) limestones of several geological ages (chapter 3). In the north and west the mountain slopes are mostly bare with little vegetation that mainly consists of bushes. Several pits were found (even on the tops) which assumes water availability that is probably the results of the good water storage abilities of the karstified limestones. A study of Diamantopoulo & Voudouris (2007) indicated that Zakynthos is completely dependent on its groundwater resources for fulfilling the demands of water supplies. These developed aquifers in the karstified limestones are probably the most important ones in the study area. The karstic characteristic of the bare rocks was often found which indicates high rates of chemical weathering (karstification). Many cracks and fragmentation resulted in a disturbed character of the limestones which is probably the direct consequence of the local tectonics. Besides gravitational forces on the slopes, these tectonics probably also triggered some mass movements and debris transport on the mountain slopes. Figure 5.2A clearly shows a vegetated contour line along the western mountain slopes. These bushes and small trees seem to be grown on colluvial material that was transported downward. This colluvial character is probably the cause for accumulation of material on less steep slopes that allow the development of very shallow red soils. The best example is the filling of small scale gullies that were eroded along the mountain slopes. Even in rills, which are incised in artificially constructed unpaved roads, this colluvial material accumulated and imply the downslope transport of material (figure 5.2B). These mountain slopes are assumed to be the origin of the red terra rossa, found in the depositional areas in which coring was done (chapter 3).

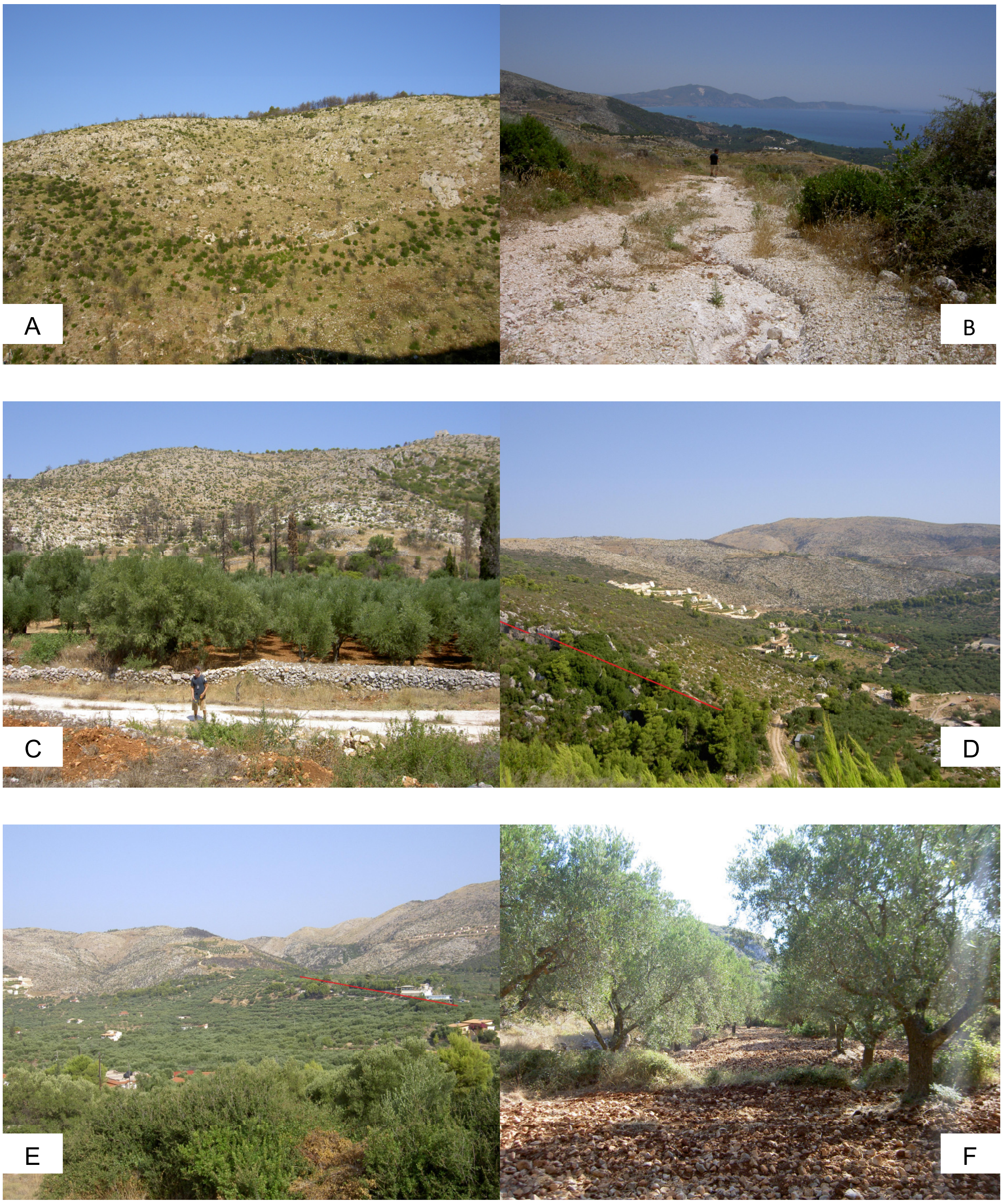


Figure 5.2: A:Vegetated contour line along the bare limestones, B: Small scale sediment transport through rills, C: Terra rossa accumulation just behind the elevated ridge (Ambelos), D: Uplifted ridge with large exposed bedrock masses along a tectonically formed valley, E: Uplifted ridge (red line) standing in the landscape, F: Colluvial transport along a eastern directed patch (photos by N.bekkers, 2009).

5.2.1.2 Colluvial accumulation area

The lower elevated terrain in the west can be clearly seen on the DEM (appendix II). On this map it looks like a local depression which is surrounded by a mountainous landscape. The red sediment is assumed to be an accumulation of terra rossa which is transported from the adjacent mountain slopes into the local depression. In chapter 3 two parts were distinguished based on core locations. Based on geomorphology, three parts can be distinguished. The central located part comprises the largest area which contains just olive trees on red brown soils. The southern part is situated at about the same elevation but is separated from the central part by a hill. The neotectonic map shows a fault along this hill ridge which is probably responsible for the topographic elevated ridge. The third (northern) part is situated in a more elevated part behind the higher elevated ridge which can be clearly seen in the landscape (figure 5.2C). Taking the neotectonic map (figure 5.1) into account, this part is probably situated on the down or up thrown block (hanging wall) of a normal or reverse dip slip fault (figure 5.3) at which terra rossa accumulated later on.

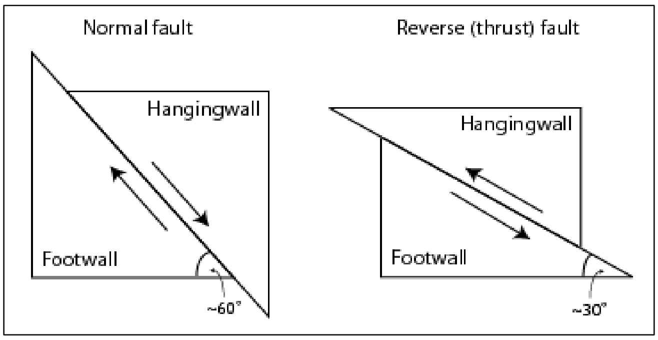


Figure 5.3: Normal and reverse dip slip fault (Wikipedia, 2010).

At some parts, the terra rossa was transported through the eastern situated valleys, which resulted in a patchy pattern. These patches with planted olive trees through the small valleys can be clearly recognised in the satellite image (appendix IV). Besides these western situated parts, this unit also comprises a small part in the north. Corings 45a, 45b and 46 showed the same material till larger depth than expected (chapter 4). This small part is also situated at the foot of the steep mountain hills and apparently acted like a catchment for colluvial material because it is probably a (karst) depression with deep situated bedrock.

5.2.1.3 Mountain foothills

This part is considered as the eastern foothills of the Vrachionas mountains in the west and spreads over the middle part of the study area. The differences with the unit ‘mountain slopes’ are the lower elevation and more vegetation. A large part of this unit is densely vegetated although vegetation differs locally from bare soils with bushes until dense woods. The hills are rounded or present as elongated hill ridges. The relief seems to be affected by the faults zones as the faults seem to coincide with the ridges (compare appendix II and figure 5.1B). Figure 5.2D shows an uplifted ridge that exposes large blocks of limestones. As these parts consist of (marly) limestones also karstification took place which is represented by the highly weathered rocks. A clear recognisable SW-NE oriented ridge is located in the northern part of the area. This uplifted ridge clearly stands in the landscape (figure 5.2E). It forms the southern border of the debris fan which is described in paragraph 5.2.2.4.

The ridges are separated by small valleys that were probably formed by the fault zones. Afterwards, consequent streams could have occupied these valleys and may have incised the valleys. So in this case, the drainage pattern is determined by fault zones. In the geomorphological map these valleys are indicated as fault valleys. Currently, the valley bottoms serve as downslope gullies in which colluvial material is transported, and act as good soils for olive trees (figure 5.2F). This resulted in the patchy character which is a good example of terra rossa transport from the colluvial accumulation area via valleys to lower elevated terrain.

5.2.2 Eastern part

5.2.2.1 Low sloping plain

The mountain foothills change into lower sloping plains that eventually change into the flat area that borders the swamp (chapter 4). These parts are more cultivated and inhabited than the central steeper foothills. The fault valleys diminish in this flatter terrain which still contains colluvial material on top of shallow bedrock. Only close to the present swamp, the bedrock was found deeper (chapter 4). South of the swamp the village Limni Keriou is partly situated in this unit. This unit changes into the foothills towards the southern mountain ridge which is outside the study area. This ridge reaches 340 m a.s.l. and is affected by the southern primary fault. A prominent aspect is the round hill west of the swamp. Although this hill is just 30 meters, it shows only a bedrock mass that seemed a typical uplifted part of almost horizontal oriented layers.

5.2.2.2 Swamp

The swamp forms a flat plain between the mountainous area and the sea. An asphalt road and the artificially constructed beach separate this swamp from the sea. The swamp is mainly covered with reed and is bordered by an unpaved road. Chapter 4 evaluated the evolution of this swamp which used to be a lake. The east-west directed fault zones on either side of Keri bay created the topographical lowering of the bay. Under this landscape condition the lake and later on the swamp developed.

5.2.2.3 River valley

One clear river valley was observed during the fieldwork. It enters the study area through the northern mountains and follows its pathway to the east where it finally discharges into sea. Figure 5.4A shows the typical v-shaped valley that developed by incision of the river through an uplifted landscape. During the fieldwork, a little water stream was flowing through this gully but observations in the gully indicate that this stream can be very active. Mainly in the upstream parts (there was no water flow at that moment) clear signs of erosion were visible. The stream gradient is steep (8-9%) in this part and a lot of vegetation and debris was found. The present sediment comprises large blocks, boulders, pebbles and fine sediment. At some parts of the gully, the gradient is so steep that the gully is characterized by steep steps of the bedrock at which the water experienced suddenly changes in gradient. At the foot of such location, the bedrock is hollowed by the high energetic water (waterfalls) in which recent finer sediment accumulated. Besides limestone boulders, pebbles and fragmented material, also conglomerates and sandstones were found. On both sides limestone masses were clearly visible at which the former river cut in to. Hollowing and cavity were observed too, especially in the outer bounds of the gully curvature. At many locations, sharp and poorly rounded sediment seem to have settled in these polished gully walls. Later on this sediment probably glued together which now looks like the border of a wide spread river deposit. Given that the surrounded landscape consists of large masses of limestone bedrock, those visible river deposits probably only limit along the gully walls themselves. At some locations in the gully, the steep walls reach heights of around 15-20 meter exposing a lot of glued sediment (figure 5.4B). Although these deposits are assumed to be settled very locally, clear alterations were observed of glued layers containing small and large sediment. This indicates that a former river was active during different climatic conditions, when it was more or less active. Paragraph 5.3.2 evaluates the past climatic conditions in more detail.

Figure 5.4: A:V-shaped river valley, B: Glued sediment along gully wall, C: Cuesta, D: Low sloping coastal terrace (to the north) (photos by N.Bekkers, 2009).

The downstream part showed a more wide valley, and groundwater enters the gully and discharges finally at the beach. This part is characterized by more green vegetation (appendix IV) as the water availability in this part of the gully is enhanced by the relative higher groundwater table. Especially during the summer periods, there is no surface runoff in the upper part of the gully which makes groundwater availability more important.

5.2.2.4 Scree / debris fan

This part comprises the shallow corings 37-44 which were described in chapter 4. This relative flat part is situated directly along the steep northern mountain slopes and contains mainly debris-like soils on top of a limestone layer which locally outcrops at the southern wall of the gully. This debris fan was probably transported from the adjacent steep mountains during colder periglacial times. Limestone fragments subsequently glued together and formed this limestone mass.

5.2.2.5 Cuesta area

Figure 5.4C shows a dipped hill that is characterized by an asymmetric shape. This hill is a typical cuesta which is usually characterized by a low sloping part (parallel to the layering) on one side, and a steep face on the other side where a cliff cuts across the layers (Marshak, 2001). The low sloping part of this hill exposes mainly flat bedrock with very shallow to no soils. The steep part is expressed as a high cliff of around 30m which exposes a wide variety of geological layering. The foot of the cliff is situated around 30m a.s.l, from where a large debris cone seems to starts downward until the beach. This cone is characterized by a chaotic mass with rock parts, soils and debris, and is later on terraced. The cuesta itself is part of a larger uplifted area (appendix III) that contains shallow soils or bedrock. This area reaches till the river valley in the north where it expresses as a lower sloping area with a lot of planted olive trees. On the digital elevation model, some local hill tops are visible in the area around the cuesta. These outcrops of bedrock are probably the result of local tectonics or resistance against erosion through geological times. Chapter 3 (geology) gave already an example of this second possibility. The southern slopes of this area are relatively steep and finally reach the north side of the swamp.

5.2.2.6 Uplifted hilly area

This area borders the river valley in the north and consists of Kamaroti hill and the south west situated hill. Both hills have an elongated shape which can be clearly seen in the digital elevation model. Comparing the fault which is responsible for the uplifted mountain ridge (as evaluated in paragraph 5.2.1.3) with the location of the hills, assumes that these two hills are part of the same fault. The river cut into this presumable elongated ridge. As Kamaroti hill is not connected with the hill south west of it and there are no clear indications of another river valley, this gap between the hills probably developed as a result of local tectonics. The northern primary fault is situated along Kamaroti hill. This implies that Kamaroti hill was mainly affected by this major fault. It is also possible that this fault is the cause of the separation of the two hills. The zone south of these two hills seems very complex. The hill south west of Kamarotti hill exposes a lot of bedrock just like the other uplifted smaller hills in the area. The zone south of the two hills seem to be very complex as colluvial parts are deposited on top of marine sediments. This complexity is increased by the fact that Kamaroti hill exposes bedrock more downslope while thick soils are present on and around the top of this hill. The complexity is further evaluated in the next paragraph.

5.2.3 Coastal zone

5.2.3.1 Coastal terrace

This part is a low sloping plain which is oriented to the north (figure 5.4D). It is gradually inclined towards the sea where this unit ends at the cliff tops. As assumed in chapter 4, this area contains sediment alterations of marine clays and loamy sands. However, this unit is found on 20-40 m a.s.l. so only an uplift of this marine terrace seems to be a logical explanation of the relative high elevation of these sediments. The whole area is planted with olive trees and, in contrast with the rest of the study area, more green vegetation is present. A small stream flows into this area. Besides this little stream, a lot of ditches were noticed along the fields which indicate good drainage during wet periods. Although no groundwater was encountered in the corings in this area, a higher groundwater table could be form due to the stagnation of water on top of the clay package which was found here. Besides from the aquifers in karstic limestones, water in Zakynthos is also extracted from (phreatic) aquifers that are developed in alluvial deposits (Diamantopolou & Voudouris, 2007). This makes the previous assumption plausible.

5.2.3.2 Beaches

The eastern border of the study area consists of coastline with beaches and cliffs. All beaches consist of rocks and pebbles although fine sands were found under water. A variety of limestones, mudstones, sandstones and conglomerates dominate the beaches. The limestones are highly porous which is the result of chemical weathering. The beaches are very small and consist at many locations also of the debris from rockfall which seem to be the main form of mass movement along the cliffs. At some locations, relative undisturbed beaches were noticed where the sorting of material by wave influence could be noticed (figure 5.5A). Keri beach, which is situated adjacent to the swamp, is a narrow artificially constructed beach with some planted trees. On this beach the swamp is connected with the seawater by an artificially constructed stream. This little canal allows the interactions of the salt water with the fresh water of the former lake which is now replaced by a shallow groundwater table. South of this beach, a groundwater spring was found. Fresh water pours on the beach through the cliff wall at 1 meter height.

Figure 5.5: A: Sorting along beach, B: Cliff erosion; rockfall, C: Gully development on landslide, D+E: tectonic deformed layers, F: Stream+colluvial material in cliff walls

5.2.3.3 Cliffs

The whole coastline that borders the study area show cliffs with heights from several meters to tens of meters. The cliffs show a high degree of deformation. First of all, deformations occured due to cliff erosion, which very clear in the form of rock fall (figure 5.5B). A large part of the small beach is covered with debris and large boulders that came from the steep cliffs. The fact that this rockfall was also seen in action during the field observations (see photo at the front page) demonstrates the highly active erosion potential of the coastline of this island. Besides the rockfall, also some other types of mass movements were identified. Rock- and land slides, slumps and creep were identified. A major landslide was found north east of Kamaroti hill. This lob shaped landslide is east-west oriented and now exposes blue grey clayish material. This material consists of a loose platy structure and many cracks and is already exposed to a high degree of erosion which explains the gully development (figure 5.5C). The cliffs around the mid of the coastline clearly show the yellow marly limestones that are situated on top of grey mudstones and marls. The geological map confirms the presence of Miocene mudstones and sandstones along the coast. Secondly, deformation occurred during tectonic movements. The most clear examples were found along the cliffs in the northern part of the study area. Figure 5.5D and 5.5E show layers that are highly deformed by tectonic activity. East of these high cliffs, a small stream discharges at the north eastern border of the study area (figure 5.5F). This photo also shows colluvial material in the cliff walls next to the stream which confirms the idea that the sediment transport in the study area is mainly based on colluvial transport.

<u>5.3 Past environmental conditions</u>

<u>*5.3.1 Sea level change vs tectonics*</u>

An important factor in constructing ancient environments is sea level change. Climate change forces the sea level changes which are in fact adaptations to new (equilibrium) conditions. Perissoratis and Conispoliatis (2003) studied the impacts of sea level changes on the morphology of the Ionian and Aegean seas during Holocene and Pleistocene times. They used the sea level curves of Fairbanks (1989) and Brard et al. (2003) which are presented in figure 5.6.

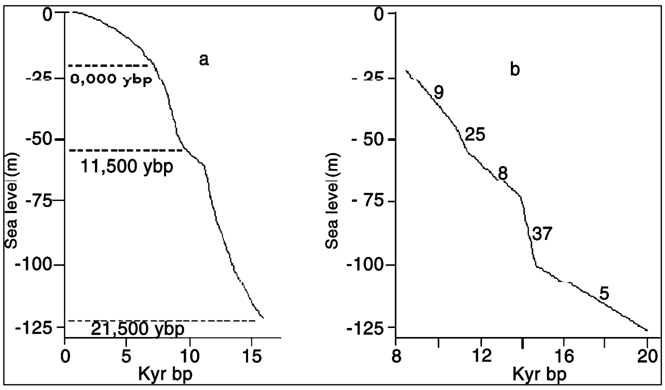


Figure 5.6: Sea level curve (a) after Fairbanks (1989) and (b) after Bard et al. (1990). Numbers in (b) indicate rate of sea level rise (mm/yr).

In the Late Pleistocene (at 21.5 Kyr BP) the sea level was about 120 m lower, and started to rise rapidly from 18 Kyr BP with a rate of 5 mm/year. At 11.5 Kyr BP it was still 60m lower. Thus before this transgression, large segments of now submerged areas were aerially exposed once. Because the steep character of most islands of Greece, the sea level of -15m at 8 Kyr BP was already very close to its present position. However, for a lowland alluvial plain this sea level change must have had significant implications. The swamp in the study area is such a low plain, and coring data showed the past sea influence (chapter 4). Figure 5.7 shows the sea level curve for the eastern Mediterranean for the last 6500 year BP.

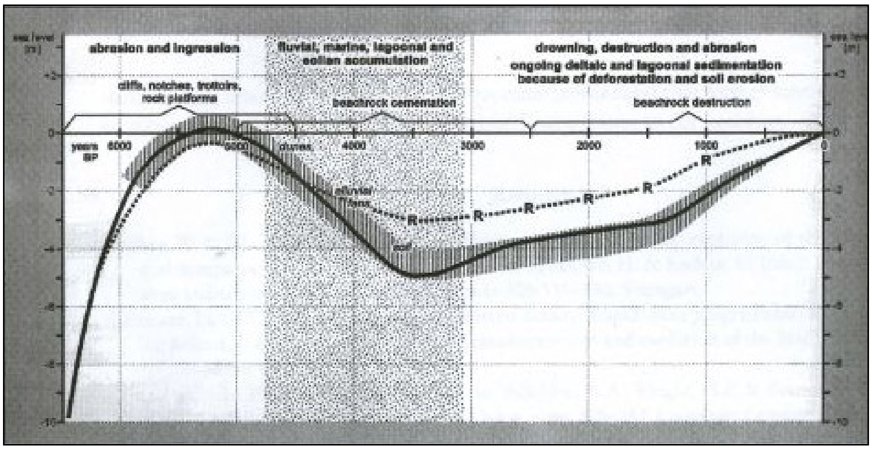


Figure 5.7: Local sea-curves from the Eastern Mediterranean (Kellertat, 2005).

For the Mediterranean area, there is general agreement that the sea level has been rising since at least 2500 years with 2 meter, which is concluded from numerous drowned ruins in antic times (Kelletat, 2005). The cause of a regression from 5000 BP could be the dry period around 4000-4200 BP or the markedly Early Subatlantic glacier re-advance around 2800-2200 BP. Another general agreement is the fact that neotectonics along the Eastern Mediterranean shorelines are the major obstacle for the identification of general trends of sea level change. One can say that the Holocene sea level in the Eastern Mediterranean at places without an uplift never was significantly higher than today. However, a relative recent study of Lagios et al. (2007) demonstrated the high deformation rates during 2005-2006 (figure 5.8).

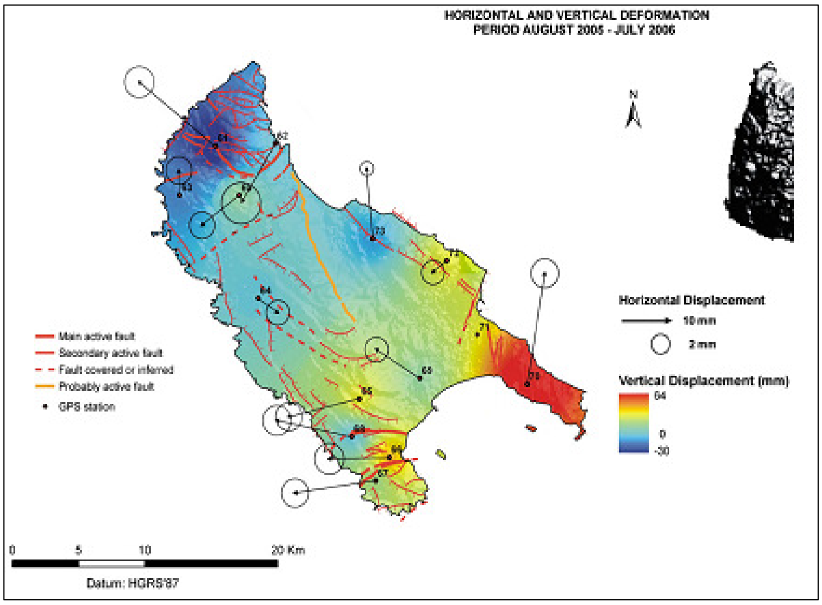


Figure 5.8: DGPS results with vertical displacement rates in the period 2005-206 (Lagios et al., 2007).

Figure 5.8 shows high vertical displacement rates of 43 mm at point 66 which is situated within the study area. Although many authors presume the minor role of tectonics with respect to sea level change, the presented rates by Lagios et al. (2007) imply the contrary. As these rates are just based on the year 2005-2006, there is no reason to extrapolate these rates back in time. However, corings around Kamarotti hill and in the north eastern part of the study area did show clear marine sediments at heights of 20-65m a.s.l. which clearly indicates a significant uplift of these regions. The earlier mentioned study of Perissoratis & Conispoliatis (2003) contains constructed maps with the tentative coastline positions at the mentioned low stand stages 11.5 and 21.5 cal Kyr BP (see figure 5.6). However, they assumed offsets of the active normal faults of approximately 0.05-1.30 mm/yr but usually less than 0.5mm/yr. It is assumable, that the study area underwent much larger uplift rates considering the high elevated marine sediments and the demonstrated rates by Lagios et al, (2007). An additional indication is the find of an eroded but recognizable large fossil shell which was buried within a terrace wall at 60m a.s.l. north of the top of Kamaroti hill (figure 5.9). According to specialists, this is a Spondylus sp. that probably lived in (sub) tropic conditions near a coastal reef or in a sandy/rocky environment in undeep water. The estimated age is Pleistocene-Miocene.

Figure 5.9: A fossil shell, buried in a terrace wall at 60m a.s.l. (photo by Bekkers, 2010).

5.3.2 Paleoclimate and vegetation

The palaeoclimate of the Mediterranean has been investigated by many studies (e.g. Ariztegui et al., 2000; Bar-Matthews et al., 2003; Hughes et al., 2006; Margari et al., 2009). Dormoy et al. (2009) performed a climatic reconstruction through time (15 - 4 kyr BP), based on pollen records from two sea cores. One was located in the Aegean Sea and interpretation is used here to report the main development from the Younger Dryas era onwards.

Younger Dryas (12.5 – 11.7 kyr BP)

The Younger Dryas is a cold and arid period ranging from 12.5 – 11.7 kyr BP. Foraminifera, pollen records and isotopic marine data document this climate event (e.g. Ariztegui et al., 2000; Bar-Matthews et al., 2003; Dormoy et al., 2009; Favaretto et al., 2008; Lawson et al., 2004; Wilson et al., 2007). Mediterranean land conditions represented a cool semi-desert/steppe. Annual and winter rainfall in the Mediterranean was much lower than nowadays (figure 5.10; appendix VI) (Bar-Matthews et al., 2003; Dormoy et al., 2009). Summer precipitation is considered more or less similar to nowadays (Renssen et al., 2001; Dormoy et al., 2009).

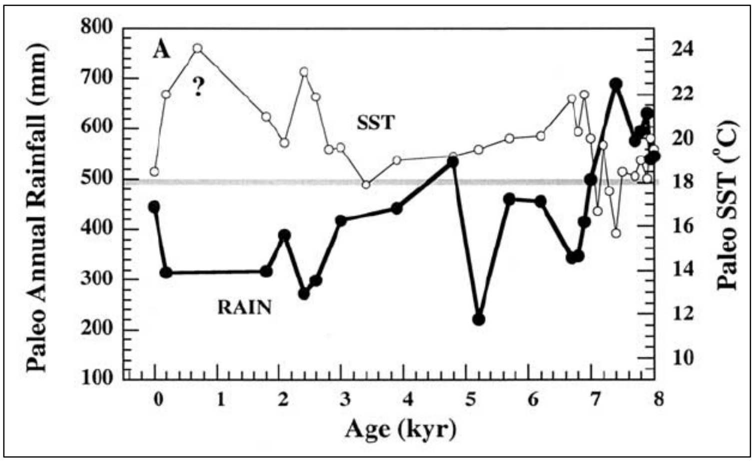


Figure 5.10: Annual rainfall in the past 8000 years (8kyrs), derived from sea surface temperatures for the Eastern Mediterranean. The grey horizontal bar represents the present day annual rainfall (Bar-Matthews et al., 2003).

The plant cover consisted mainly of small herbs. Dominant assemblies of these small herbs occur nowadays in steppe and desert regions in the Eastern Mediterranean. Arboreal pollen are little present in the pollen records as trees probably just survived in sheltered environments (Lawson et al., 2004).

Early to mid-Holocene (11.7 – 4 kyr BP)

There is clear evidence of increasing (winter) temperatures and precipitation which indicates the onset of the Preboreal (Dormoy et al., 2009). Increasing terrestrial lake depths in Greece indicates enhanced precipitation at the beginning of the Holocene (Bar-Matthews et al., 2003; Wilson et al., 2007). A rapid increase in arboreal pollen indicates the transition from steppe to forest vegetation. At 9.5 kyr BP the coldest and warmest months approach modern day values. The increased seasonality, with moist temperate winters and hot dry summers, resembled the modern climate. Between 9.5 – 7.5 kyr BP high temperatures and moist annual and winter conditions characterized the eastern and western Mediterranean (Dormoy et al., 2009). The taxa from the Boreal indicate warm-temperate conditions. There are indications of increased atmospheric humidity requiring mean annual temperatures of 9 ^{o}C and 1200 mm of precipitation (Favaretto et al., 2004). Later in the early Holocene woodlands, which were mainly dominated by Quercus, were replaced by more mixed forests.

Pollen evidence from the Adriatic Sea suggests cooling of the climate in correspondence with decreased precipitation between 8.5 – 7.5 kyr BP (Ariztegui et al., 2000). At 8.2 kyr BP a short-lived cooling trend was observed in the Aegean Sea. A drying phase started at 7.9 kyr BP in Italy, while temperatures start to decline in the Aegean Sea from 7.2 kyr BP (Dormoy et al., 2009). Diatom evidence from Lake Ioannina (250 km north of Zakynthos) showed shallowing of the lake between 7.6 – 7.3 kyr BP, suggesting a decrease in rainfall. Study areas in Northern Israel also showed a drop in rainfall amount after 7.5 kyr BP. Dormoy et al. (2009) suggests two cool phases in the Aegean Sea between 7.5 – 7.0 kyr BP and 6.5 – 6 kyr BP. The latter cooling trend proceeded until 4 kyr BP in the Mediterranean (Marchal et al., 2004; in Dormoy et al., 2009). Finally a humid period was found between 4.5 – 4 kyr BP (Bar-Matthews et al., 2003)

Late Holocene (4 kyr BP – present)

Human influence was detected in pollen records from the onset of the Bronze Age (3 kyr BP) and possibly since the Early Neolithic (Fuchs, 2007). Evidence from Lake Ioannina showed a substantial decrease in tree cover. Various taxa indicate developing agriculture. Two stages of deforestation are discerned; 4 kyr ^{14}C BP and 2 kyr ^{14}C BP. The first stage occurred along with increased soil loss near Lake Ioannina. The occurrence of a short-term climatic event is suggested which influenced the anthropological development. After the first stage of deforestation, woodland recovered almost completely and mixed woodlands increased again. The second stage of deforestation coincided with the cold and arid conditions of the Younger Dryas. The olive tree was the only tree specie in this period, that survived probably by cultivation. Furthermore, cereals and weeds increased and ongoing expansion of agriculture was noticed (Lawson et al., 2004).

Similar results were found during a palynological investigation of Jahns (2005) at Lake Voulkaria, a coastal lake around 150 km north of Zakynthos. It was found that deciduous oaks dominated the natural vegetation throughout the Holocene. Pollen indicate a shift towards a drier climate at 7.3 kyr BP. Since 5.5 kyr BP, an increase of evergreen shrubs clearly indicates anthropogenic land-use. Olive trees increased slightly, which is assigned to an expansion of wild olives rather than human influence. From 2.8 kyr BP on, far reaching changes in vegetation occurred. Because of the combination of human influence and a shift towards a drier climate, there was a spread of hard-leaved vegetation. Increased settlement activities are represented by an increase of olives and tree nuts. Between 2.2 – 1.9 kyr BP olive tree nuts populations decreased again which is assigned to reducing farming activities because of war. The scarcity of trees in the more modern environments was suggested relatively recent and was not observed in the above studies.

5.3.3 Landscape evolution

Literature about landscape evolution in Zakynthos appeared to be rare. Certainly because the study area comprises for a large part of some basic geological units, just a few studies have been applied to more recent (Pleistocene-Holocene) evolution. In fact, the swamp serves as a good indicator for Holocene evolution. Papazisimou et al. (2000) carried out some corings in the swamp and did some C14 dating and pollen analysis. Coring data coincides reasonable well with the data used during this study. Figure 5.11 shows the W-E cross section through the centre of the lake.

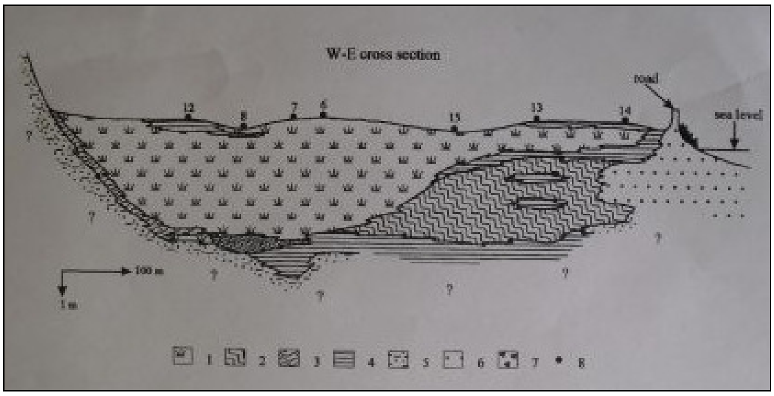


Figure 5.11: Cross section of the Keri fen (1:peat, 2: dedrital mud, 3: clay, 4: limnic clay, 5: terrestrial loam, 6: sea sand, 7: sea wall, 8: coring site).

Together with results of the own coring data (chapter 4) the evolution from lake to swamp can be constructed by a few stages based on C14 dates (appendix XI). In the first stage (A), a lake formed, and limnic (=under water) clay began to accumulate in the central part. Terrestrial loam continued to form in the western part of the fen. In the second stage (B), limno-telmatic (around the water table) conditions prevailed in the western part where the terrestrial loam was deposited. Peat and detrital mud started to accumulate. Around 2740 yr BC (C), the water table declined and the siltation process extended to the east as peat forming conditions were better than before. The limno-telmatic conditions from stage (B) enhanced the detrital mud accumulation in this stage. During stage D, the peat formation continued (around 625 yr BC) in the same fen as the previous stage. Dedrital mud sedimentation was limited in the eastern part, whereas coastal sand built a sand barrier (chapter 4) from the west.

Around 560 yr AD (E), the water table rose and a lake covered the eastern and central parts of the fen. Peat started to accumulate again and deposition of sand was limited around the central part of the sand barrier which was also noticed in the current study. Finally, around 886 yr AD (F), peat forming conditions became favourable at almost the whole fen. Limnic conditions were restricted to small patches which were also mentioned in chapter 4 as a pool and wet swamp system.

Papazisimou et al. (2000) calculated an average accumulation rate of 1 mm/yr from 2740 BC on. Another study on sedimentation rates of the Alikes lagoon (Avramidis & Kontopoulos, 2009) in the north of Zakynthos mentioned a sedimentation rate of 1.03 mm/yr between 5590 yr BP and modern times. This rate is comparable with the mean relative sea level. However, the oldest peat in the swamp is about 4740 year (in contrast with the 5590 yr at Alikes lagoon). This sedimentation rate in the swamp is not completely comparable with the sea level change as is the case for the Alike lagoon. Local tectonics are probably the reason for this difference.

6. Archaeology

After the geological and geomorphological descriptions of the study area, the archaeological distribution was evaluated. First a short overview of the main archaeological situation is given. Archaeological data from the ZAP project was used to make distribution maps, which are mainly based on the available estimated ages that became available after comprehended examination of the finds by the archaeological team. After this mapping, the spatial distribution was analyzed with special interest to the geomorphological units. Table 6.1 shows the different archaeological time eras.

Table 6.1: Archaeological time table as used in the ZAP (according to Van Wijngaarden, 2010).

Time era	Sub division	Age (yr)
Palaeolithicum		befor **10000/8000 BC**
Mesolithicum		**8000-6000 BC**
Neolithicum		**6000-3000 BC**
Bronze Age		**3000-1100 BC**
	Early Bronze Age	*3000-2000 BC*
	Middle Bronze Age	*2000-1600 BC*
	Late Bronze Age (Mycenean)	*1600-1100 BC*
Early Iron Age		**1100-700 BC**
Archaic period		**700-480 BC**
Classic period		**480-330 BC**
Hellenistic period		**330-146 BC**
Roman period		**146 BC - 600 AD**
Medieval		**600-1500 AD**
Venetian		**1458-1900 AD**
Early modern period		**19th - early 20th century**
Modern (recent)		after **World War II**

6.1 Archaeological situation

The archaeological survey was concentrated in three zones. The first zone is situated in the west (around the colluvial accumulation area, see chapter 5) near Ambelos. At the elevated ridge in this area remnants of an ancient village were present which was mentioned on a 17^{th} century map. It was hoped that the origins of this town could be dated back to Medieval times (600-1500 yr AD). The second zone of interest is the zone around the swamp. As mentioned in chapter 4, this swamp used to be a lake which assumes ancient human settlement at the hills around the lake. Especially Kastello hill, which is the cuesta north of the swamp as mentioned in chapter 5, has been used as an important region for the archaeological surveys. The third zone consists of the area around Kamaroti hill. As high concentrations of finds had been found in a pilot survey in 2005, again a detailed survey was done here in 2009. This hill is considered as an old fortress which was situated on the favorable eastward slopes with a clear view towards the sea and the harbor of Keri Lake (Van Wijngaarden, 2009). The concentration of artefacts is mostly marked at the top of the hill. The south eastern slopes contained artefacts form several ages. Goudriaan (2010) evaluated these finds more in detail with respect to erosion and deposition patterns on Kamaroti hill. More common details concerning the finds on this hill can be found in Van Wijngaarden (2009).

6.2 Distribution maps

Appendices Va-Vi contain the distribution maps that were constructed during this study. The maps show the spatial distribution of tracts within the study area and are specified by archaeological age. The tract distribution was based on the three main zones on which the archaeological focus was. As some ages were (spatially) poorly distributed, those were taken together to map their spatial distribution. Appendix Vb shows the tracts of found artefacts from the Bronze Age, mainly found in the area around Kamaroti hill and around Kastello hill (cuesta). On the top of Kastello hill, much pottery from the Early Bronze Age and even from the Neolithicum was found. Besides these main regions, there were also findings at the lower sloping plain, west of the swamp. Appendix Vc shows the younger artefacts of the period Early Iron Age till the Roman period. The distribution of this scarce material is limited to the north western and south eastern slopes of Kamaroti hill. In contrast with this scarce material, the more recent Venetian artefacts are distributed reasonable well in the study area, in this case also in the western part (Ambelos). Unlike the assumptions of the archaeological team, this part did not reveal Medieval artefacts, but apparently did show younger Venetian material. The same holds for the colluvial accumulation area in the central north (unit 1 in appendix III). Another prominent feature is that none of the ages so far were represented in the area between the southern border of the river valley and Kastello hill. This is even the case for the 19-20th century and recent periods (appendix Ve). Concerning the small concentration tracts south of Limni Keriou village, the already mentioned ages were not represented here. This is different for the Palaeolithic lithics which form the oldest material in the study area, showed in appendix Va. Note that the additional 'potential Palaeolithic' in the legend of this appendix differs from 'possibly Palaeolithic'. The archaeological team could not have distinguished Palaeolithic lithics from Prehistoric (Neolithicum-Bronze Age) as this demands more detailed examination in the lab. So at locations where also Prehistoric ceramics were found, the lithics could also be of Prehistoric age and are assumed as 'potential Palaeolithic' for now. The Palaeolithic age seems to be distributed equally in the study area. Except for some large tracts in the centre of the study area (northern mountain foothills), it is represented almost everywhere. Finally, appendix Vf shows the distribution of Ancient material. This vague notion refers to material which is reasonable worn material (not well determinable) and is assumed as 500 yr AD and older (so roughly Roman age and older). The main quantities were also found in the eastern part of the study area around Kamaroti hill. Interestingly, ancient material was also found at Ambelos. Despite there was no Medieval material found here, some older ancient material was found. According to the archaeological team, there are also some implications of Hellenistic-Roman times (330 yr BC – 400 yr AD).

6.3 Statistical analysis of the archaeological data

In order to provide a statistical basis for further evaluation, the archaeological data was statistically examined. The main question was whether the ages of the artefacts that were represented in the study area are related to the geomorphological units. In other words, what is the variance of ages between or maybe within geomorphological units? The archaeological and geomorphological data were organized to conduct an analysis of variance (ANOVA) whereby the number of appearances of a certain age was analyzed per geomorphological unit. Note that it is about frequencies of a certain age within a geomorphological unit, not about quantities of a certain age. Table 6.2 shows the resulting statistical table.

Table 6.2: ANOVA results, groups refer geomorphological units.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10044,96	6	1674,161	2,692924	0,024398	2,290432
Within Groups	30462,75	49	621,6888			
Total	40507,71	55				

Assuming a null hypothesis which supposes that there is no difference between the geomorphological units (so the difference of found ages within an unit are just attributable to change fluctuation), one can reject this. Apparently, the difference of found ages can be attributed to the geomorphological unit. So there is statistically a relationship between the found ages and a geomorphological unit whereby the each unit appears to be different (based on the found ages in each unit). In fact, 7 units were used and 8 groups of ages. By applying a two-way ANOVA test, more statistical noise could be eliminated. During the first test, the 8 groups of ages were analyzed per unit. Now, the statistical focus is on the 7 units per age group. Table 6.3 shows the results of this two-way ANOVA test.

Table 6.3: Two-way ANOVA results, rows and columns refer to respectively age groups and geomorphological units.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	9290,571	7	1327,224	2,632862	0,023807	2,23707
Columns	10044,96	6	1674,161	3,321092	0,00911	2,323994
Error	21172,18	42	504,0995			
Total	40507,71	55				

Now the statistical noise at the first ANOVA test is divided by influences of age groups (Rows) and residual noise (Error). Table 6.3 shows that difference in age groups (rows) was indeed responsible for a lot extraneous noise in the first ANOVA test. In this way, stronger statistical leverage is obtained to reject the null-hypothesis ($F=2.69 > F= 3.32$) and one can say that the geomorphological units are connected with the archaeological ages. The next chapter discusses the question how this connection can be interpreted.

7. Discussion and conclusions

This chapter discusses the relation of the artefact distribution with the geomorphology, the assumptions that were made to support some hypothesizes, and finally summarizes the conclusions that can be made.

7.1 Origin artefacts

Before discussing the relation between artefact distribution and geomorphological development, it is important to question whether the archaeological finds were in situ or came by sediment transport processes. Goudriaan (2010) has studied the modern soil erosion/deposition processes on the south-eastern slopes of Kamaroti hill. His conclusion was that these processes are probably of no importance to the artefact scatter. Artefacts become exposed by detachment by splash erosion and by headward erosion of the agricultural terraces (figure 7.1). However, the transport capacity on a relative flat terrace is not large enough to transport the artefacts further than the base of the terrace wall. The archaeological team confirms that most artefacts were found at the base of the terrace wall.

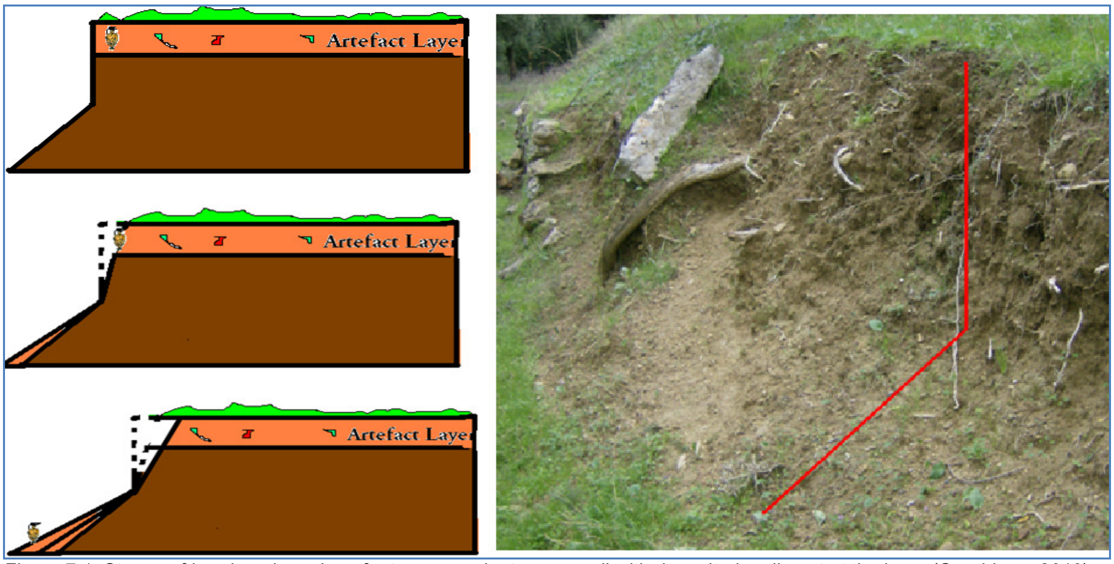


Figure 7.1: Stages of headward erosion of a terrace and a terrace wall with deposited sediment at the base (Goudriaan, 2010).

During a second visit to the study area in May 2010, the focus was on these terrace walls. Scraping of some terrace walls resulted in a lot of exposed artefacts. It seems indeed obvious that headward erosion is a very important process in exposing new artefacts. The largest part of the study area consists of a terraced landscape. Assuming that headward erosion takes place at all terrace walls on down sloping erodible soils, one can say that the artefacts are rather in situ than originated from elsewhere. However, this assumption is based on research to current erosion and sediment processes on a single hill. Past erosion and sedimentation patterns could give more insights in the artefact scattering.

7.2 Artefact distribution vs. geomorphology

The past erosion and deposition processes did play a role in landscape evolution and subsequently in human settlement. Chapter 4 and 5 showed the variety in sediments and geomorphology in the study area. This paragraph discusses human settlement (which is represented by the artefact distribution) in the past versus the landscape evolution (which is represented by the geomorphology). The focus here is on the three main archaeological zones as referred in chapter 6.1.

The area around Ambelos is, as mentioned before, situated in the western colluvial accumulation area. Chapter 4 already presented the large terra rossa accumulations. It is assumed that this depositional area acted as a sediment catch for transported soils from the higher elevated mountains.

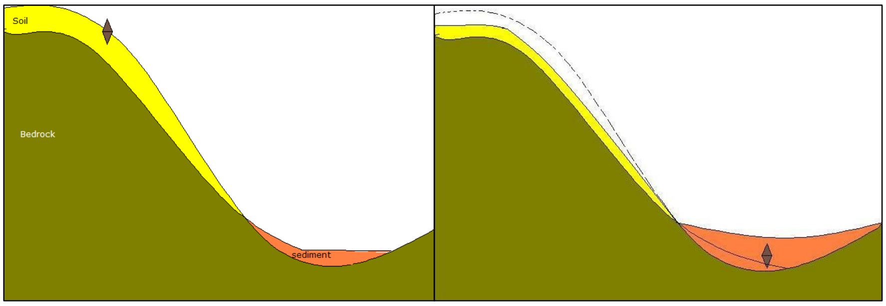


Figure 7.2: Simplified presentation of the downslope transport and burial of an artefact (the diamond); initial stage and final stage (from Goudriaan, 2010).

It seems reasonable to assume that this transport of sediment from the mountains was the result of severe soil erosion on the mountain slopes, which are now almost bare in the surrounded area. This soil erosion could be linked to human activities like tree logging. That would mean that possible artefacts were transported downward and buried in the area around Ambelos (figure 7.2). Corings revealed no archaeological material, but did show clear layers with recognizable plant remnants and organic matter (appendix Xc) which could imply ancient vegetated soils from higher elevations. The archaeological data generally contains just surface finds, and in the case of Ambelos, mainly reveals Palaeolithic-, Venetian material and some Ancient material at the higher elevated ridge. Assuming that the terra rossa came from higher elevations, it is possible that the Palaeolithic material also came from the surrounded mountain area and thus should not be considered as in situ. As this accumulation area is the only area within the study area which contains a large sediment pack of terra rossa (which means developed fertile soils), this area could have increasingly been favorable for human settlement. The absence of Bronze Age material could indicate that the accumulation of terra rossa started later on in the Holocene. In other words, during the Bronze Age, there was no or insufficient sediment available in this lower karst depression for favorable settlement, or ancient humans simply preferred other locations like the area near the swamp and Kamaroti hill. Paragraph 5.3.2 described the climate shift in the Palaeolithic from cold and arid conditions to warmer and wetter conditions, which represents the period till the Middle Bronze Age (4 kyr BP). Erosion probably started in this period which affected the transport of Palaeolithic material. In the period afterwards, the human influence increased which resulted in even more erosion (logging, farming) (paragraph 5.3.2). The Ancient material at Ambelos (elevated ridge) indicates that there was sufficient sediment available that enhanced human settlement. Speculatively, the absence of the Medieval material could be ascribed to tectonic activity and hazards taken place in short periods which could have buried the material with terra rossa. The recognizable layers in the corings that contained plant remnants and organic matter could imply that the terra rossa sedimentation occurred in several stages. Two main cooling trends in the early- and mid Holocene (paragraph 5.3.2) can probably be linked with this sedimentation pattern.

The area around Kamaroti showed a complex landscape evolution (chapter 4). The area revealed several ages (see several distribution maps). Just only the single slopes of Kamaroti revealed this variety of ages. However, the following evaluates the relation between landscape evolution and human settlement at a larger scale than the complex archaeological situation just on the south eastern hill slopes of Kamaroti (described by Goudriaan 2010). As mentioned before, most artefacts are assumed to be in situ, except the Palaeolithic material in the western part. As also Palaeolithic material was found in the areas around Kamarotti and Kastello hill, an important question is whether these also came from higher elevated terrain or have to be considered as in situ. Especially some tracts near Perlakia, which is a slightly elevated prolonged part of the cuesta, showed a large number of lithics (appendix Vg). This area is assumed to be an uplifted part of the cuesta and contains shallow soils. During uplift, ancient soils probably eroded away; these soils could not come from outside this area due to the high elevation of these soils. So this area can be considered as ‘open air fields’. The area around Kamaroti implied an ancient marine environment, which is also confirmed by the coastal terrace in the north east. The fact that sands were found relatively high (even near the top of Kamaroti hill) implies that Kamaroti was (partly) surrounded by sea. Found artefacts in the sand in some corings, and the find of a large fossil shell (buried in a high situated terrace wall) also give strong indications. Depending on the tectonics in the past, Kamaroti hill could even have been an island once. Tendürüs (2009) conducted a study of the landscape evolution on the southern coastal plain of Zakynthos. This study hypothesized that the coastal plain was a marine environment before mid-Holocene, and was later on developed to a lagoonal system (figure 7.3). This assumption was based on corings and C14 dating methods. The range at which this ancient sea extends was based on a DEM. As tectonics were assumed to be inferior to sea level change, the sea extended as in figure 7.3. This region is situated a couple of kilometers north of the current study area. Like mentioned before, the tectonics in the study area did play a major role, which enhanced an uplift of the area of Kamaroti hill, and the coastal terrace. So it is possible that this ancient sea from the study of Tendürüs (2009) extended to Kamaroti hill. Or it may have reached the north of Kamaroti hill just locally (by a single intruded bay) depending on the local variety of uplift rates. In any case, Kamaroti hill can be considered as a major location of human settlement. Ancient beaches could have surrounded this hill, which means that Kamaroti hill was directly situated along the sea.

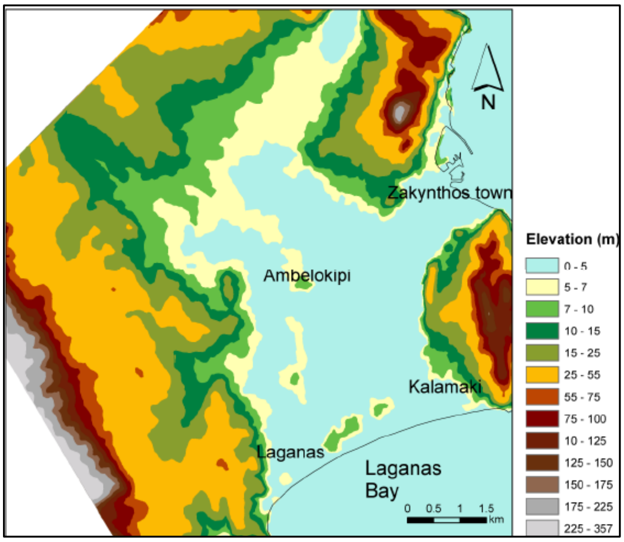


Figure 7.3: Tentative coastline at 6000 yr BP (Tendürüs, 2009).

A prominent aspect is the difference between the area of Kamaroti hill, north of the river valley, and the area around Kastello hill, south of the river valley. In the northern part, thick soils are present, that display both marine and terrestrial (colluvial) sediments. However, the area around the cuesta shows shallow soils, and a lot of bedrock. Both parts revealed Bronze Age and Palaeolithic material, probably because of the favorable places along an ancient bay or lake (Kastello hill), or else along a hillslope with a clear sea view. The presence of a river valley probably allowed the sea intruding the study area. This was already shown by coring 6 and the corings at the slopes of Kamaroti hill. This idea is confirmed by finds (assumed to be in situ) along the slopes of the hill, south east of Kamaroti.

7.3 Assumptions

The relations concerning the relationship between archaeology and landscape evolution, as described above, are mainly based on some important assumptions. First of all, tectonic uplift is the major factor in the interpretation of landscape evolution. The main aspect is the ratio of sea level rise versus tectonic displacement. Most literature assumes that tectonics played an inferior role in respect of the change of the sea level. However, field data seems to point the opposite in this study area. Mainly the area around Kamaroti can be seen as uplifted part, which contains significant layers of marine sediments that are situated nowadays 30-65m a.s.l. Lagios et al. (2007) demonstrated the extreme rates in the period of 2005-2006. Despite the fact that these rates can be linked with earthquakes, the question is whether these rates can be taken constant in time, and if not, how these rates changed in time. Extrapolating the mentioned rates by Lagios et al. (2006) back in time, results in very significant changes that seem impossible. However, apparently a local uplift, superior in respect with sea level change, did probably occur in the area around Kamaroti. This area (together with the coastal terrace north of it) could be a part of a larger coastal area north of the current study area. It even may extend till the central plain at which the presence of an ancient sea was assumed by Tendürüs (2009). The buried fossil shell implies that the location of the shell (60m a.s.l.) was once situated under water.

Another important assumption concerns the origin of the terra rossa in the accumulation area in the western part of the study area. Chapter 4 already mentioned that, despite that there is a clear notation of terra rossa, there are different opinions among scientists on the origin of these soils. The key question is whether this sediment in formed in situ or came from the adjacent mountain hills. Based on the available data, this study concluded that it probably came from the mountains. However, it is possible that just the upper part of the thick accumulation pack can be ascribed to transport from elsewhere. The underneath terra rossa could be an in situ relict soil, which is in literature seen as a soil that formed during the Tertiary and/or hot and humid periods of the Quaternary. In an archaeological point of view, this means that the Palaeolithic material can be seen as in situ.

7.4 Conclusions

After discussing the relation between artefact distribution and geomorphology, some conclusions can be summarized. First of all, for the study area it appeared to be difficult to relate the artefact scatter to geomorphological development because the artefacts are located in a very dynamic landscape which experienced a complex evolution. Relating the archaeological situation with geomorphology on the study area scale, results in a statistical confirmation of the existence of a relation. However, questioning how this relation can be interpreted on a small scale is mainly hampered by the terracing. First of all, terracing resulted in disturbed soil layering which hampers a good interpretation of a paleo environment. Besides this, terracing probably played an important role during the construction (flattening) of the terraces with machinery. In this way archaeological material was scraped together and moved by machinery. The buried concentrated archaeological material found in a coring on the end of a terrace, just underneath the top of Kamaroti hill, clearly showed this influence. However, terracing also played an important role in exposing new artefacts by erosion processes. The study of Goudriaan (2010) demonstrated the headward erosion of a terrace wall and the little transport possibilities of artefacts along terraced slopes. This indicates that most artefacts can be assumed to be in situ. Although the small scale relation between artefact scatter and geomorphology was difficult to detect, this study showed relations between some areas of paleo environmental interest with the artefact scatter. Especially, the terraced surroundings of Kamaroti hill showed a wide range of artefact ages, which implies the favorable location for human settlement through time. The study showed that this area can be seen as a former beach environment which is just one of the interesting parts of the high tectonically deformed landscape of the study area. Also the swamp, which used to be a lake, can be seen as a favorable location for human settlement in the past. This former lake was located in a neotectonic depression between two major east-west directed faults and experienced several stages with alternating peat and clay deposition. The system can be seen as a former lagoon in which a sand barrier was build by invading sea influence. The area north of the former lake may have been served as ridge between the lake in the south and the beach environment north of the river valley. This beach environment comprises the area around Kamaroti hill, the uplifted coastal terrace north of it, and may be, taking the study of Tendürüs (2009) into account, comprises a larger extended area in the north.

Also in the western part of the study area, a potential relevant paleo- environment was detected in this study. This area comprises a thick pack of terra rossa on top of the bedrock and could be related with archaeological finds.

After all, this study showed that there is a relation between artefact scatter and geomorphology. On a small scale (single slopes) the interpretation is hampered by terracing processes, but on the study area scale, some reasonable relations were detected which are confirmed by statistical evidence.

Recommendations

Based on this research some recommendations can be made concerning still existing questions and uncertainties. These recommendations should increase the understanding of landscape evolution and artefact distribution in this study area.

In case of Ambelos, it is important to be sure about the origin of the thick layer of accumulated terra rossa. It is recommended to investigate this soil type and the rock matrix of the surrounding mountains. The particle size distribution of terra rossa samples should be compared with the particle size distribution of the calcareous rocks surrounding this terra rossa accumulation. In this way one can determine whether this terra rossa was formed exclusively from the insoluble residue of the limestones and thus if it originated from these mountain slopes.

Another recommendation concerns the area around Kamaroti. This area should be studied in more detail with special interest to the marine sediments. This could give stronger indications for large uplift rates and give more knowledge of the paleo environment of this important hill. Also the area north of Kamaroti hill implies a potential relevant new area from an archaeological point of view. This coastal terrace comprises a lot of clays and sands which imply a former beach environment. Mainly the sands and clays could be investigated in more detail to determine more properties of the sediment. These sediments should be compared with the sediments found by Tendürüs (2009) and Rink (2005).

Finally, it is strongly recommended to investigate the uplift rates. Although it would be difficult to determine these rates in the past, it will surely include or exclude some scenarios. Also the exact geophysical consequences of (neo) tectonics should be known.

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Appendices

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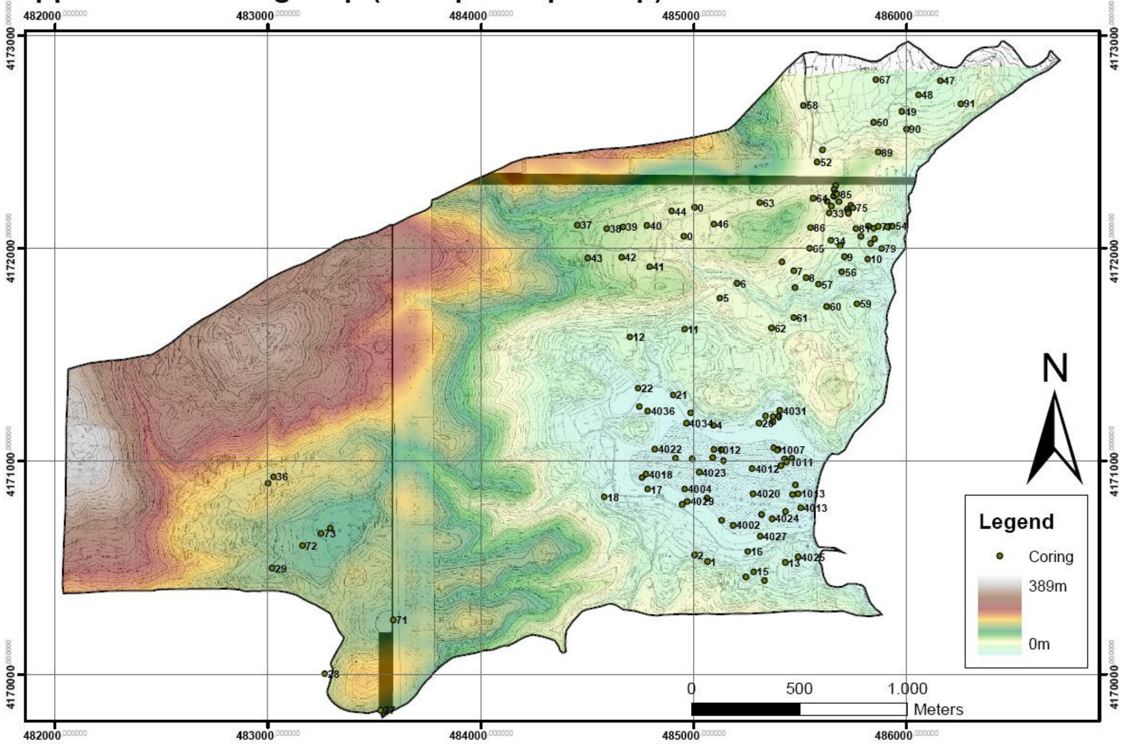
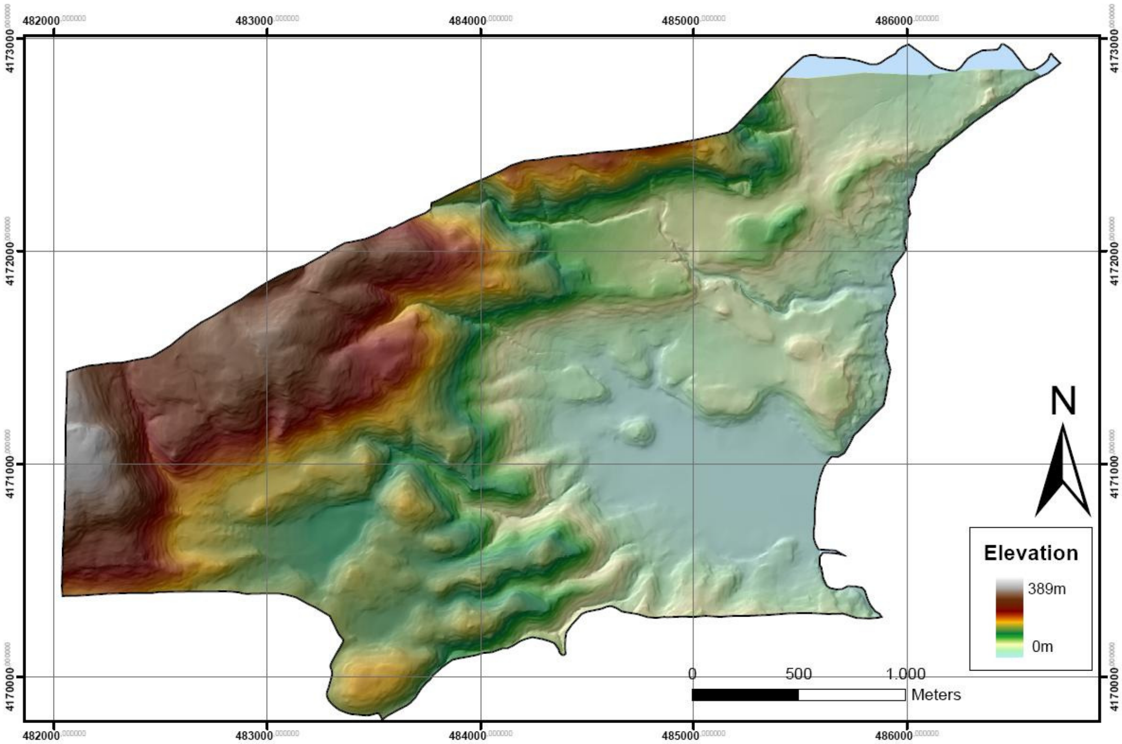
XI. Evolution stages of the swamp based on C14 data.

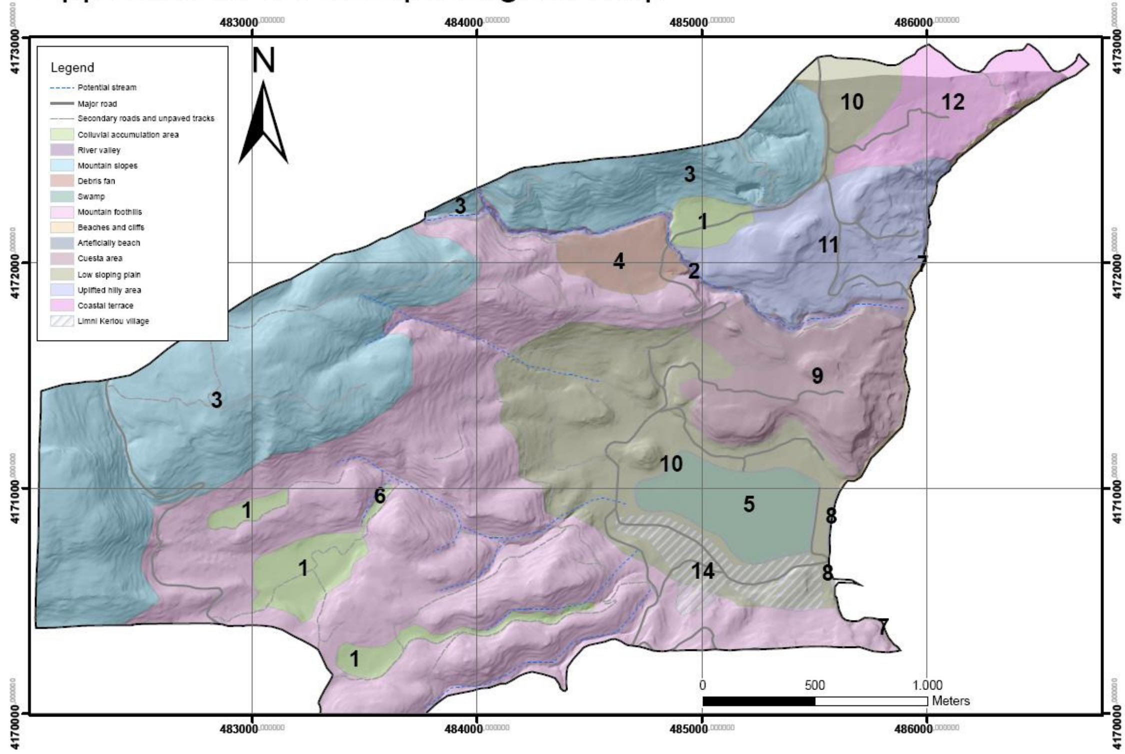
Appendix I: Coring map (on top of topo map)



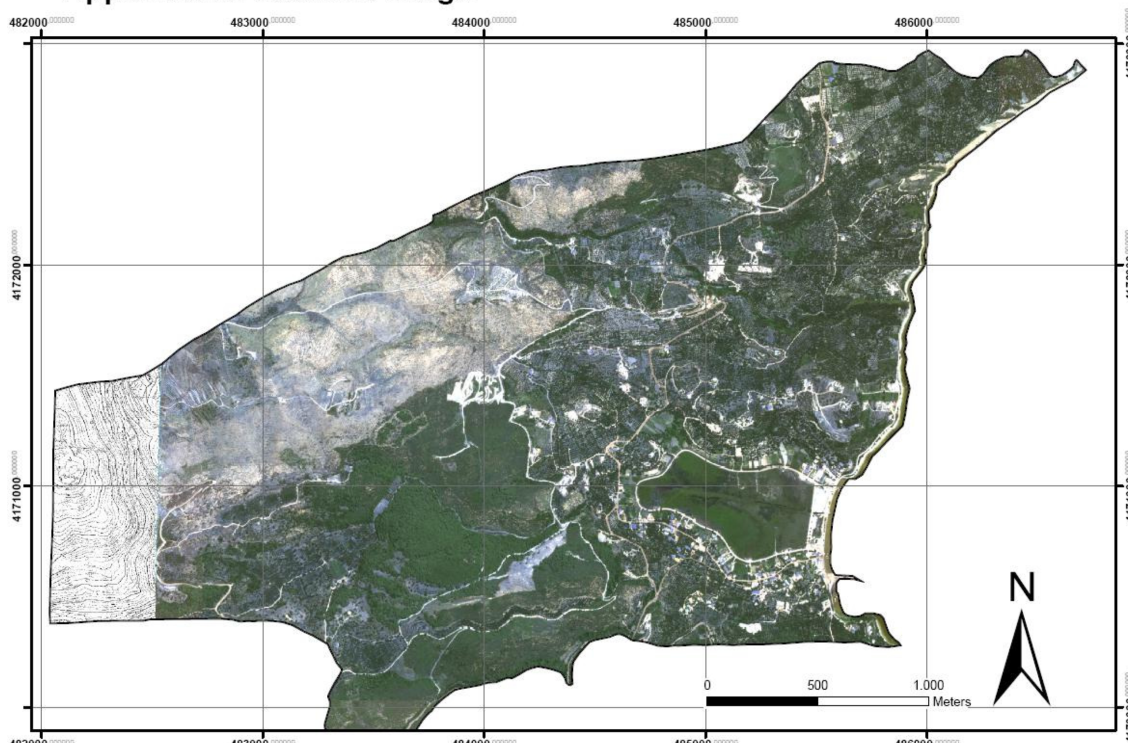
Appendix II : Digital elevation model (modified with hill shaded relief effect)



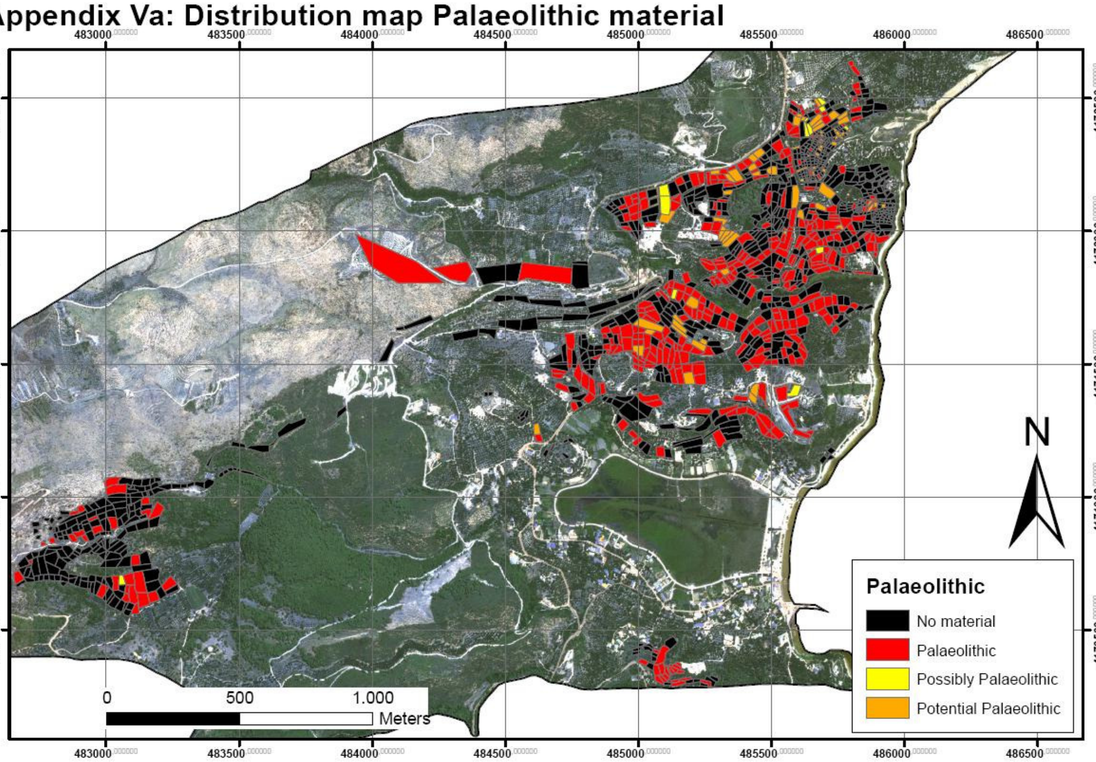
Appendix III: Geomorphological map



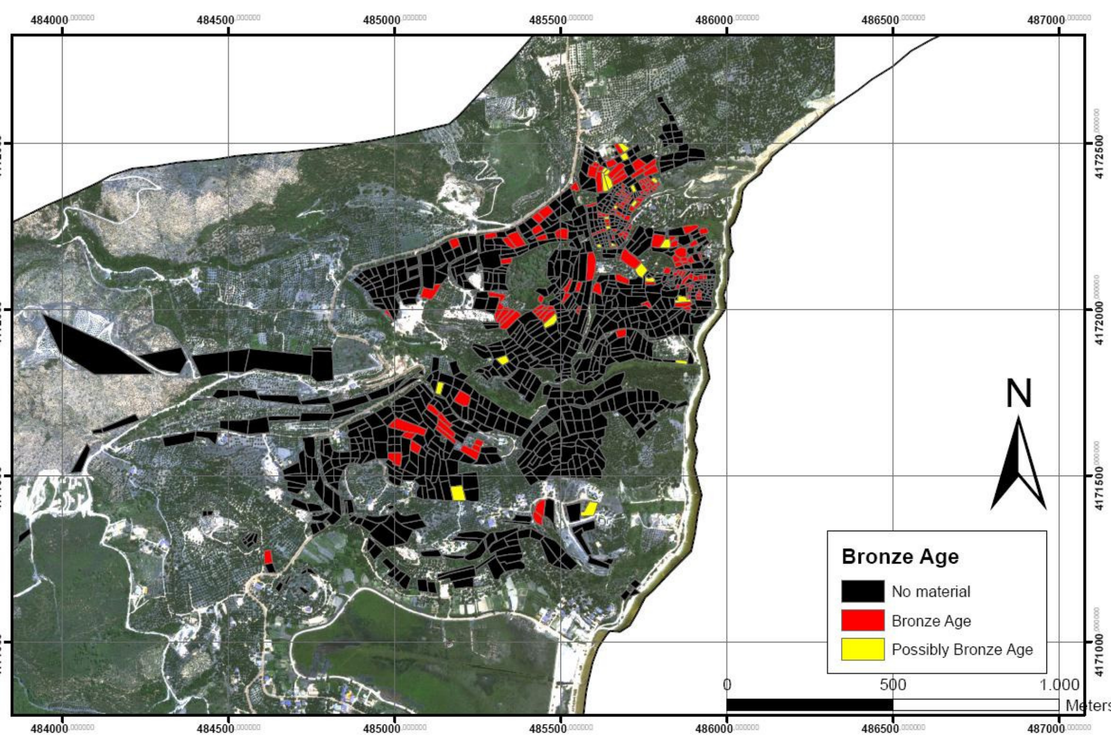
Appendix IV: Satellite Image



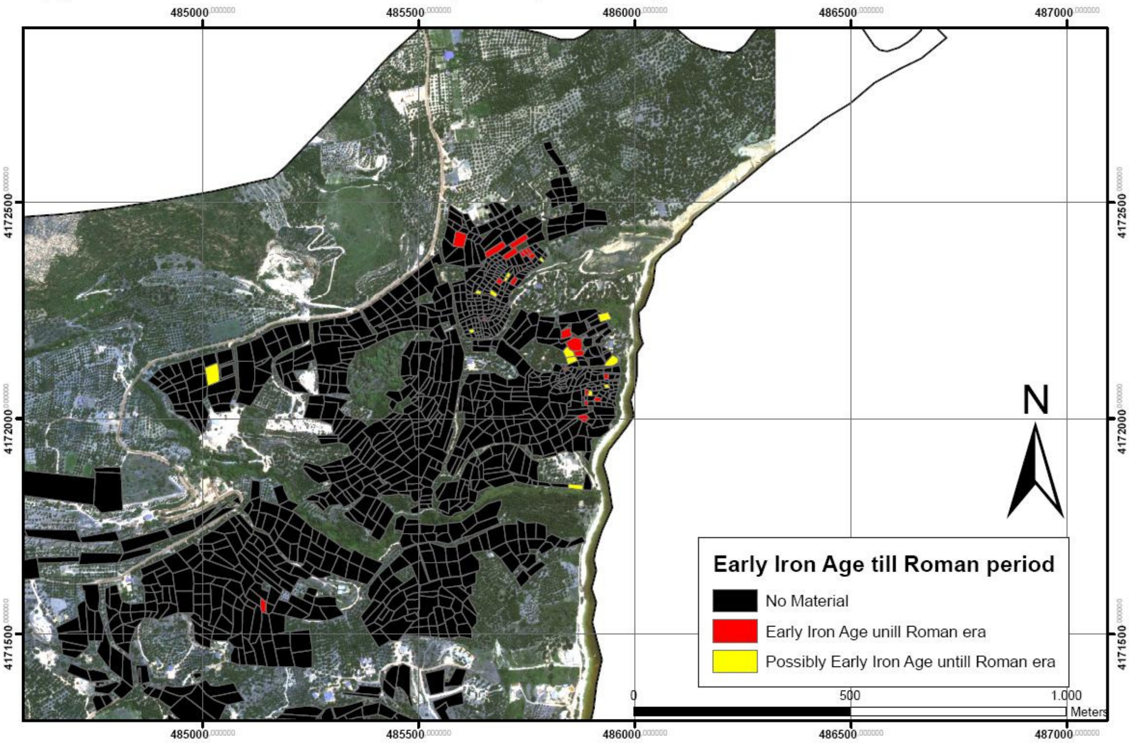
Appendix Va: Distribution map Palaeolithic material



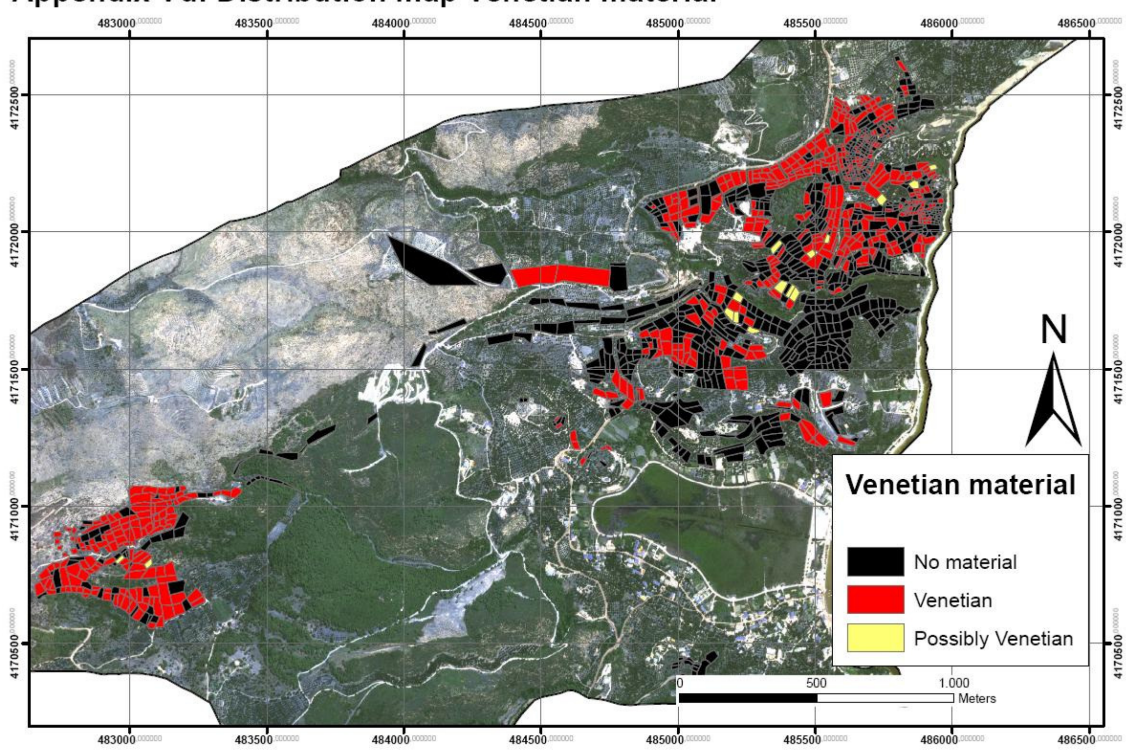
Appendix Vb: Distribution map Bronze Age material



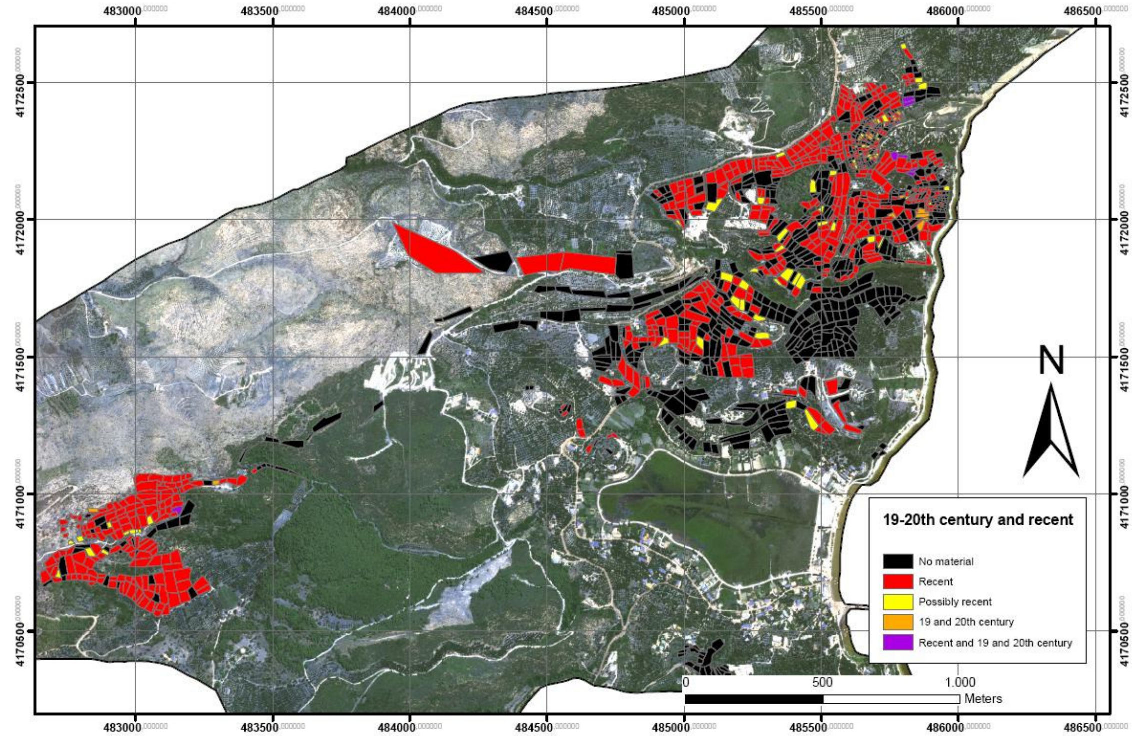
Appendix Vc: Distribution map Early Iron Age till Roman period



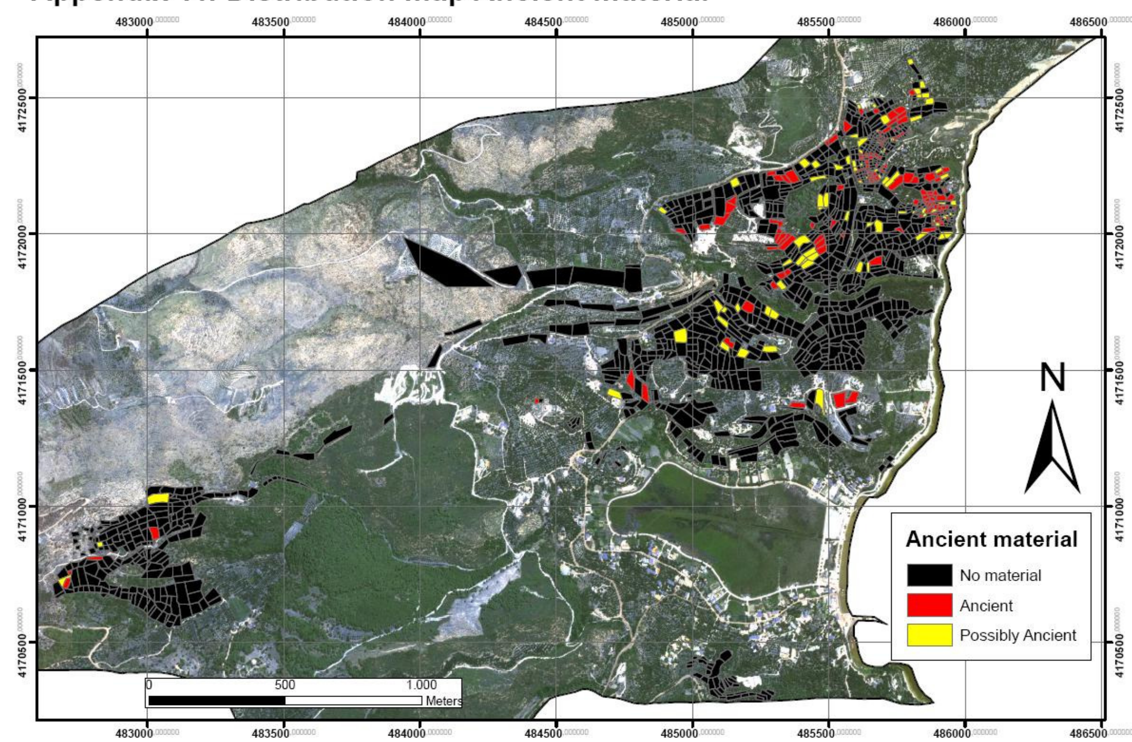
Appendix Vd: Distribution map Venetian material



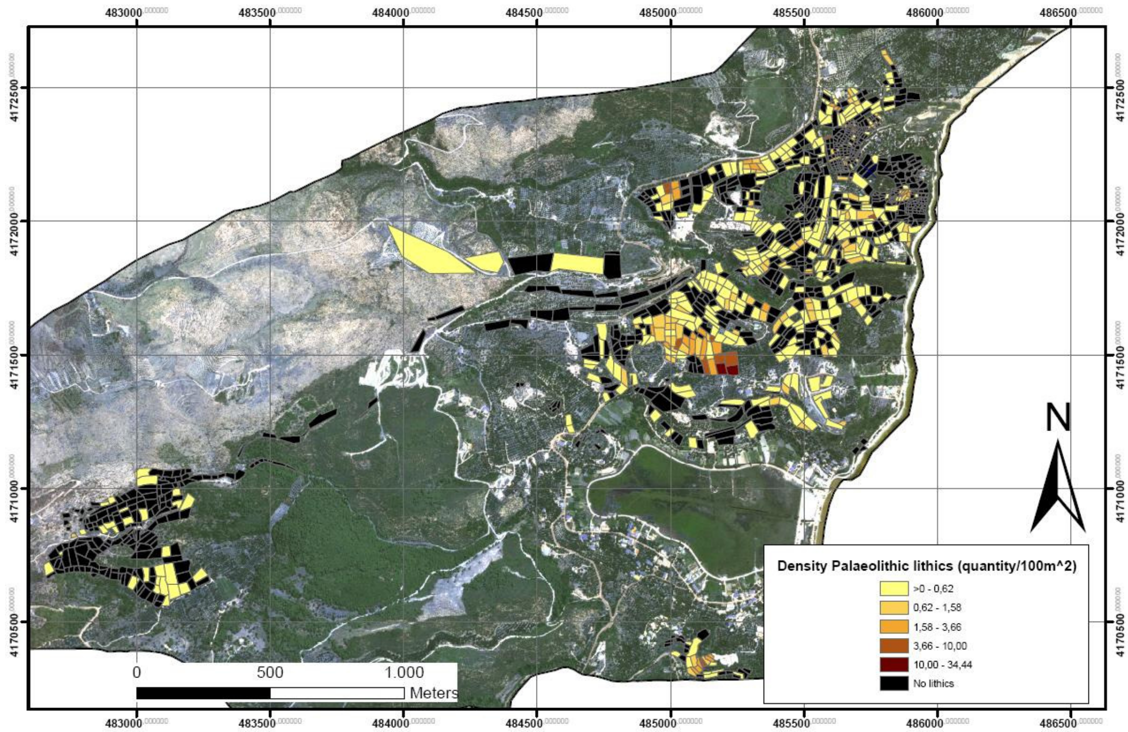
Appendix Ve: Distribution map 19-20th century and recent



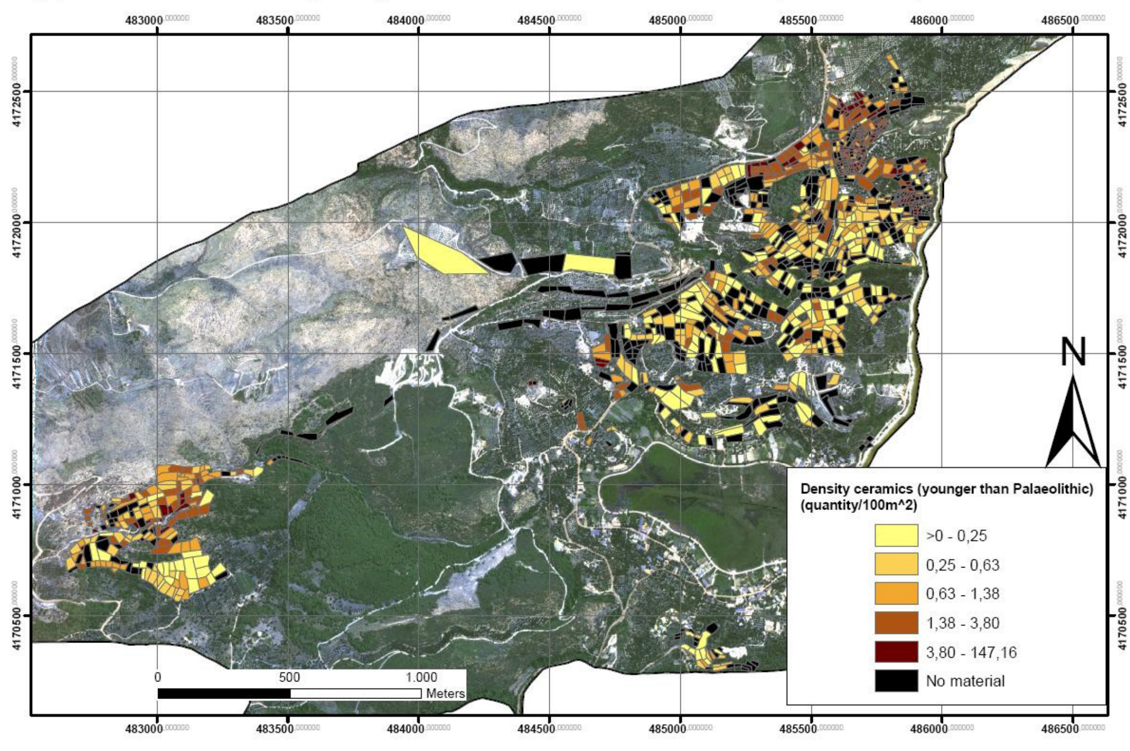
Appendix Vf: Distribution map Ancient material



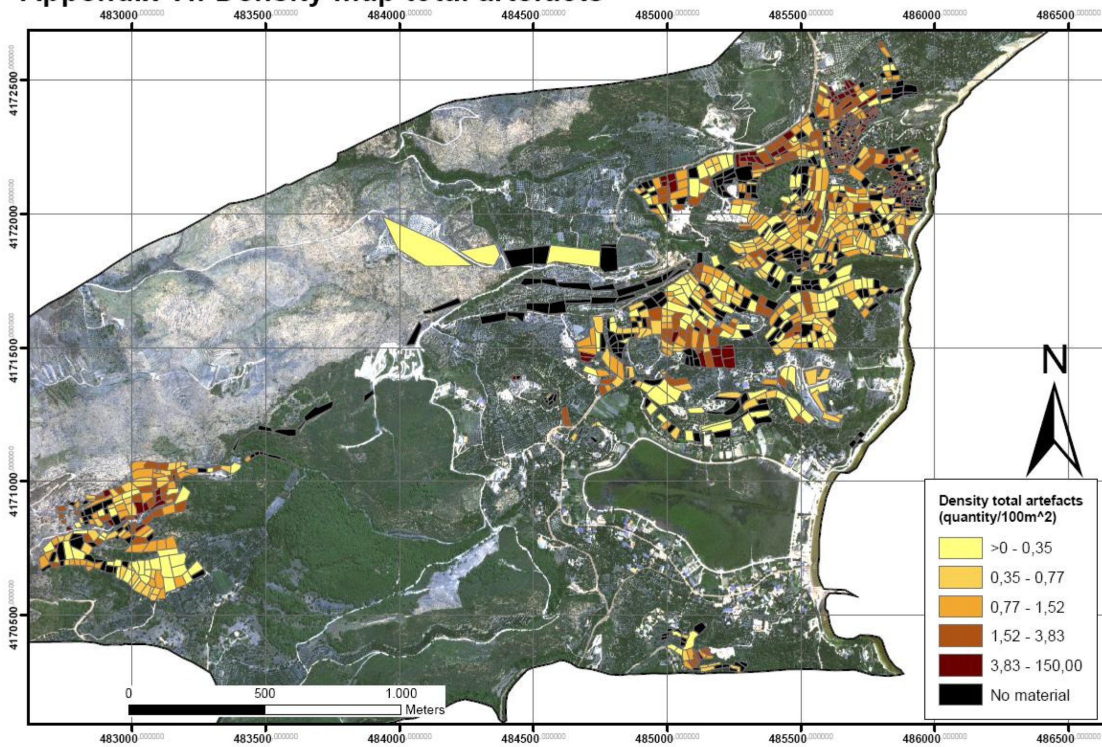
Appendix Vg: Density map Palaeolithic material



Appendix Vh: Density map non-Palaeolithic material (ceramics)



Appendix Vi: Density map total artefacts

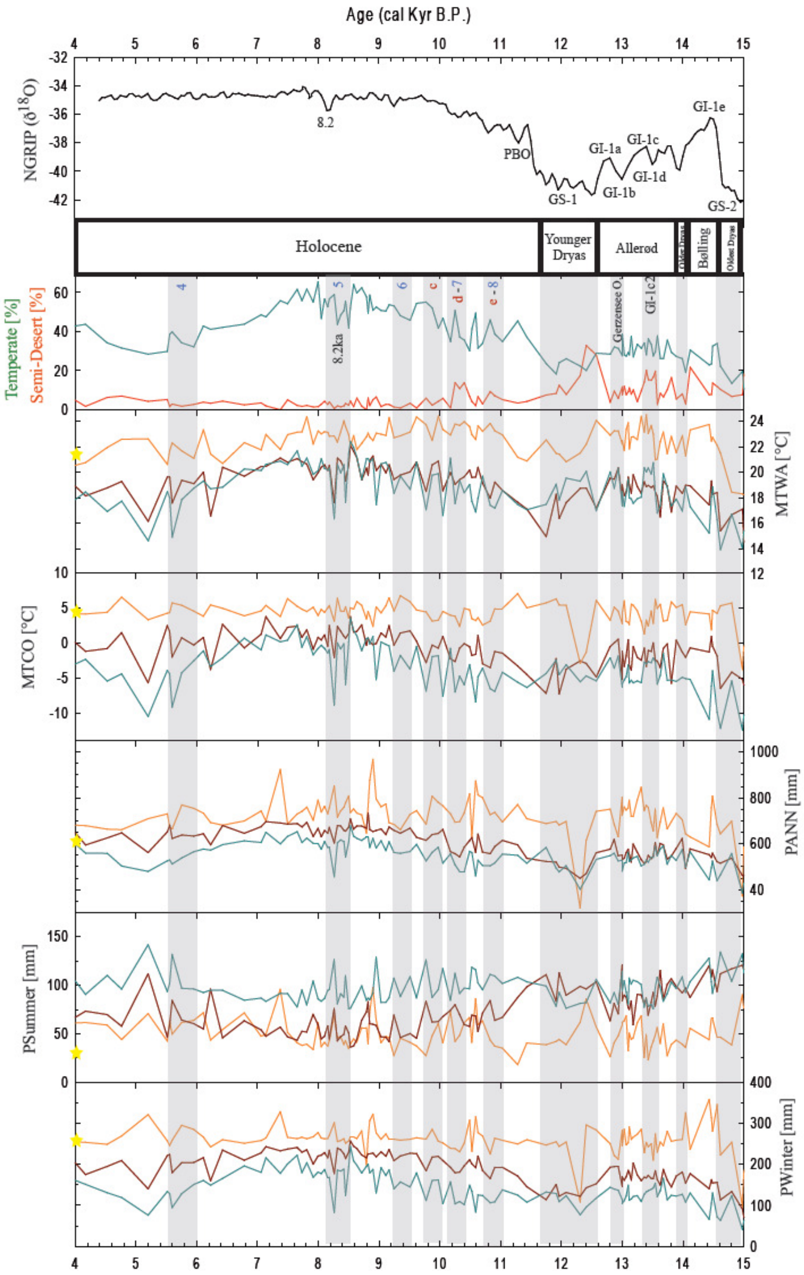


Appendix VI: Geological time scale (after USGS)

ERA	PERIOD		EPOCH		Ma
Cenozoic	Quaternary		Holocene		0.01
			Pleistocene	Late	0.8
				Early	1.8
	Tertiary	Neogene	Pliocene	Late	3.6
				Early	5.3
			Miocene	Late	11.2
				Middle	16.4
				Early	23.7
		Paleogene	Oligocene	Late	28.5
				Early	33.7
			Eocene	Late	41.3
				Middle	49.0
				Early	54.8
			Paleocene	Late	61.0
				Early	65.0
Mesozoic	Cretaceous		Late		99.0
			Early		144
	Jurassic		Late		159
			Middle		180
			Early		206
	Triassic		Late		227
			Middle		242
			Early		248

(in million of years Ma)

Appendix VII: Overview climatic reconstruction (from Dormoy et al., 2009)



Climate reconstructions for the borderlands of the Aegean Sea based on sea core SL 152. Percentages of temperate taxa and semi-desert taxa are marked in green and red, respectively. MTWA=mean temperature of the warmest month, MTCO=mean temperature of the coldest month. Annual (PANN), summer (PSummer) and winter (PWinter) precipitation are indicated as reconstructed with the MAT, NMDS/GAM and PLS methods. Horizontal grey bands correspond to cool climate oscillations (after Dormoy et al., 2009).

Appendix VIII: Laboratory analysis

Grain size Analysis

Grain size analyses were carried out, based on a method by Konert & Vandenberghe (1997). The samples weighted 4 to 5 grams. CaCO3 was removed by addition of 10 ml 32% HCl. Distilled water (30 ml) was added, followed by half an hour of stirring. To remove organic material 25 ml 30% H2O2 was added. Distilled water (50 ml) was added, followed by four hours of stirring. In cases of excess organic matter content samples where first sieved before cooking. The samples were boiled until all H2O2 was removed from the solution. The samples were filled up to 800 ml with distilled water. The samples were left standing overnight to settle. The next day after decantation, 300 mg of Na4P2O7.10H2O was added to separate clay minerals through peptisation followed by one minute of cooking. The remaining particles were injected into a laser analyser (Malvern Mastersizer 2000). Diffraction of laser beams by soil particles allows the analyser to calculate grain sizes.

CaCO3 determination

The amount of CaCO3 was determined for 106 samples. CaCO3 was determined using a Scheibler calcimeter. Per sample 0.250 gr was put into an Erlenmeyer. Distilled water (15 ml) was added. A small plastic bottle filled with HCl was put into the Erlenmeyer (10 ml; 5%). The Erlenmeyer was attached to a closed system. The small bottle of HCl was thrown over inside the Erlenmeyer, thereby letting HCl react with CaCO3 to form CO2. The amount of CO2 released by this reaction is measured, being indicative for the amount of CaCO3 in the sample. The result of each sample is compared to the result of 0.25 gr pure CaCO3, thereby allowing calculation of percentage CaCO3 for each soil sample.

Organic material Determination

The amount of organic material was determined for 106 samples through loss on ignition. A sample of 1-3 grams was put in a little ceramic basket. The basket was put in a stew (105 °C) for one day to remove remaining water. The sample was then put into an oven (450 °C) for 4 hours to remove organic material. The samples were weighted to a thousandth gram before stewing, between stew and oven and afterwards. The differences in weight allow calculation of water content and organic material content.

Appendix IX: Summary Labresults

Grainsize analysis					Organic material	CaCO3 determination
Sample	***Clay %***	***Silt %***	***Sand %***	***Soil type***	***Organic matter content %***	***CaCO3 content %***
1_100	37,7	60,8	1,5	silty clay loam	4,9	45,8
5_60	13,6	41,9	44,6	loam	2,5	49,1
6_130	65,9	32,5	1,6	clay	3,6	33,3
6_190	44,0	55,1	0,9	silty clay	4,5	41,7
8_170	11,6	45,6	42,8	loam	1,5	14,5
8_250	28,9	69,9	1,2	silty clay loam	4,0	32,6
9_130	26,0	54,7	19,4	silt loam	2,4	17,6
10_200	36,4	63,5	0,1	silty clay loam	3,5	19,5
11_70	61,2	38,8	0,0	clay	2,1	73,3
11_110	50,4	48,7	0,9	silty clay	1,5	76,9
13_260	73,2	24,3	2,5	clay	2,6	48,9
16_170	70,3	27,5	2,2	clay	1,8	58,4
20_140	44,9	44,3	10,8	silty clay	2,9	43,3
24_100	44,1	54,3	1,6	silty clay	2,8	44,3
24_150	17,8	68,7	13,6	silt loam	1,8	12,1
28_160	33,7	65,4	0,8	silty clay loam	7,8	0,0
30_180	45,6	50,1	4,4	silty clay	7,9	0,0
33_150	24,2	51,6	24,1	silt loam	3,0	18,5
34_290	17,1	45,0	38,0	loam	1,8	13,9
36_160	35,0	65,0	0,0	silty clay loam	6,6	0,0
36_360	23,0	71,5	5,5	silt loam	7,9	0,0
46_110	27,0	70,2	2,8	silty clay loam	6,7	0,0
46_140	39,2	57,2	3,5	silty clay loam	6,6	0,0
47_90	17,2	42,2	40,7	loam	2,5	0,0
47_170	15,2	33,8	51,1	loam	2,1	21,8
47_280	32,4	54,1	13,5	silty clay loam	1,7	6,2
47_360	41,1	57,7	1,2	silty clay	3,5	16,9
49_1.80	---	---	---	---	3,7	16,4
49_320	14,9	57,6	27,5	silt loam	1,8	13,5
50_170	29,4	69,1	1,4	silty clay loam	4,3	15,4
56_130	24,8	60,6	14,6	silt loam	2,7	16,1
65_60	42,9	53,0	4,1	siity clay	4,7	19,0
72_140	37,3	59,7	2,9	silty clay loam	4,6	19,0
75_90	29,0	59,7	11,3	silty clay loam	6,0	15,9
77_170	39,1	57,6	3,2	silty clay loam	4,2	15,7
77_300	31,3	53,3	15,5	silty clay loam	2,6	13,3

Grainsize classification (according to Konert & Vandenberge (1997):

Clay: < 8 micrometer
Silt: 8-63 micrometer
Sand: >63 micrometer

Sample name refers to the coring number and depth (separated by the underscore).

Appendix Xa: Description of the corings in the swamp.

Although the alternation of the corings in the swamp seems very complex (especially around the mid of the swamp), the corings could be distinguished roughly in four groups (figure Xa.1). There is a group with a peat layer on top of clays, a group of clays on top of peat on top of clays, and finally two groups showing more complex sequences with and without some fine to medium sands between the clays and peat. This sand is particularly found in some of the eastern corings in the swamp.

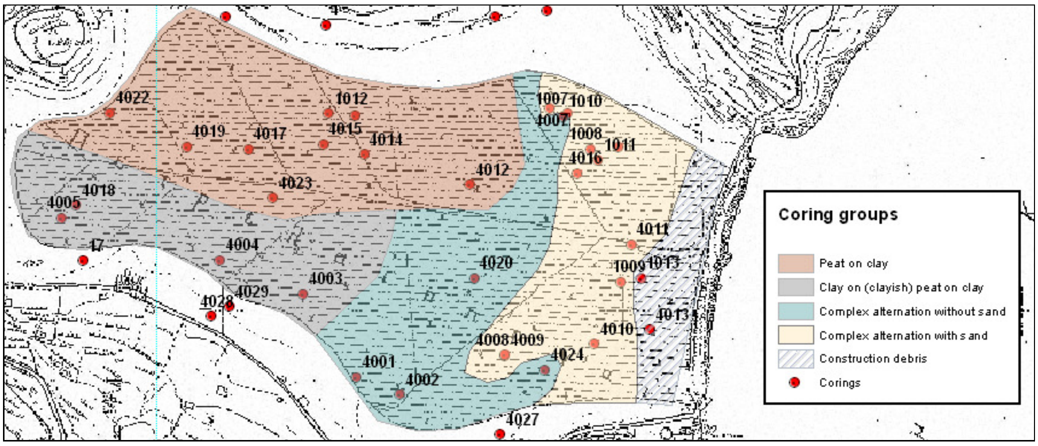


Figure Xa.1: Corings in the swamp.

The first group of corings, i.e. the peat on top of clay sequence, could be clearly seen in the corings along the imaginary eastern directed coring transect in the north western part of the swamp: 4022, 4019, 4017, 4015, 4014 and 4012 (figure Xa.2). Also the nearby corings 4023, 4006 and 1012 showed this sequence. The latter (1012) is one of the plotted corings that were conducted by a pilot study of Rink (2005) and are referred to numbers 1007-1013 in the figures and maps. Although the clay layer was not found in coring 4022, probably as the coring depth did not reach the clay yet, the thickness of the peat layer seems to decrease towards the east. So the clay layer is found less deep towards the east.

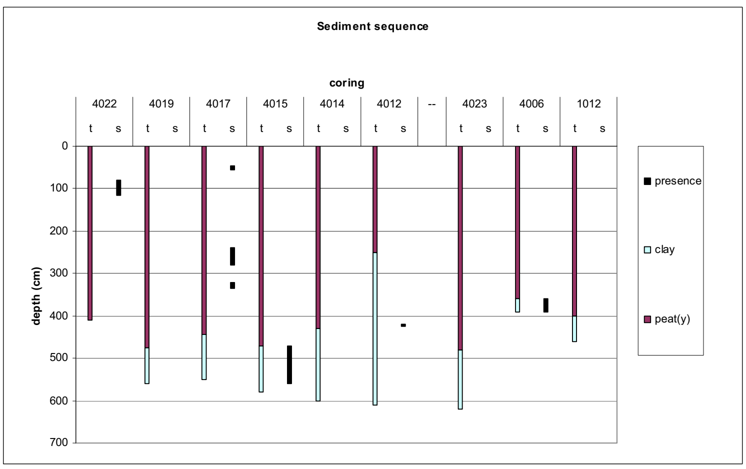


Figure Xa.2.: Sediment sequence in the north western part of the swamp (t=texture, s=shell remnants).

The sequence of the second group of corings can be characterized by a clay layer on top of a peat layer on top of clay. This could be seen in the corings 4005, 4018, 4004 and 4003 in the south-western part of the swamp (figure Xa.3). Just like the northern situated corings the thickness of the peat layer decreases too towards the east. In contrast to the corings more in the centre, the peat layer is thinner. Besides this, the clay layer on top of the peat is again less deep towards the east.

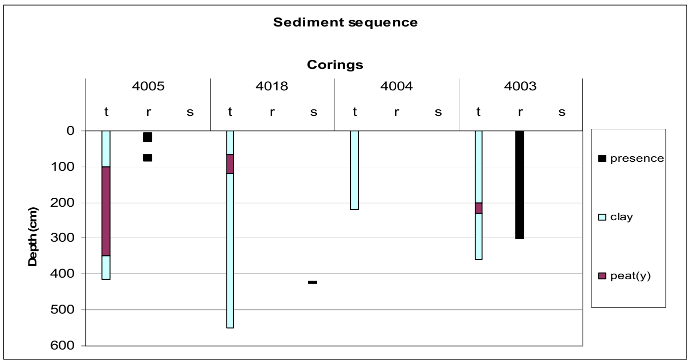


Figure Xa.3: Sediment sequence in the south western part of the swamp (t=texture, r=reed, s=shell remnants).

A third group of corings in the eastern part of the swamp contained more complex sequences (figure Xa.4). A clear prominent observation was the presence of a fine to medium sand layer between the clays and peat. Corings 4016 and 4011 showed a sand layer of respectively 60 and 90 cm. Rink (2005) also found a relative thick sand layer of 100 to 170 cm at roughly the same depths (coring 1011 and 1009). Also corings 4009, 4010, 4021 and 1010, 1008, 1007 contained a single sand layer, although with a smaller thickness. In every coring the sand layer was situated between clays. Besides this prominent presence of sand, this group of corings contained more alternations between clay en peat, both underneath as well as above the sand layer.

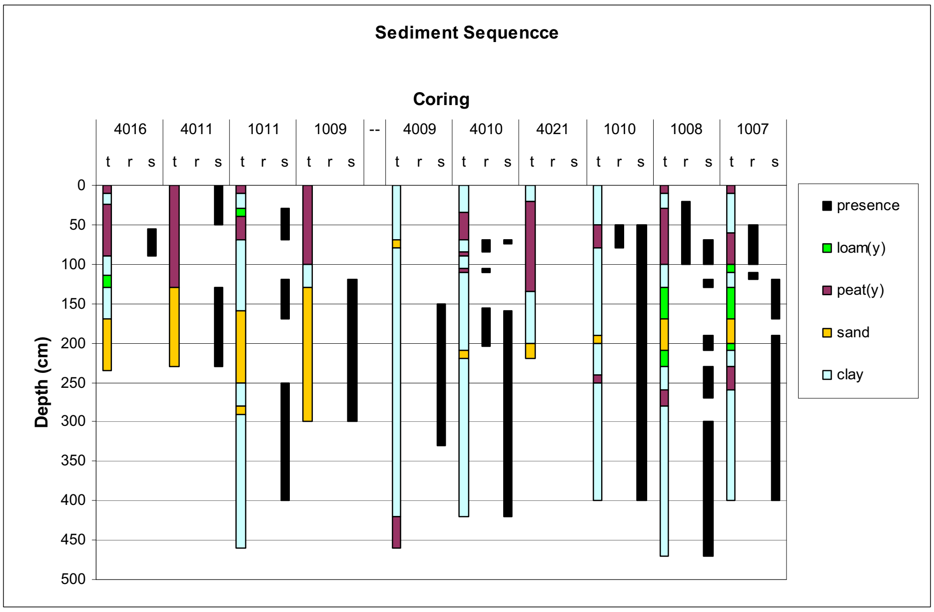


Figure Xa.4: Sediment sequence in the eastern part of the swamp (t=texture, r=reed, s=shell remnants).

The remainder corings in the eastern part of the swamp, 4002, 4020, 4024 and 4007, contained no sand but did contain the complex alternation of clay and peat (figure Xa.5) like the other corings in the mid to eastern part of the swamp. Corings 4013 and 1013 were stagnated on construction debris that is probably part of the artificial road and beach zone (see figure Xa.1).

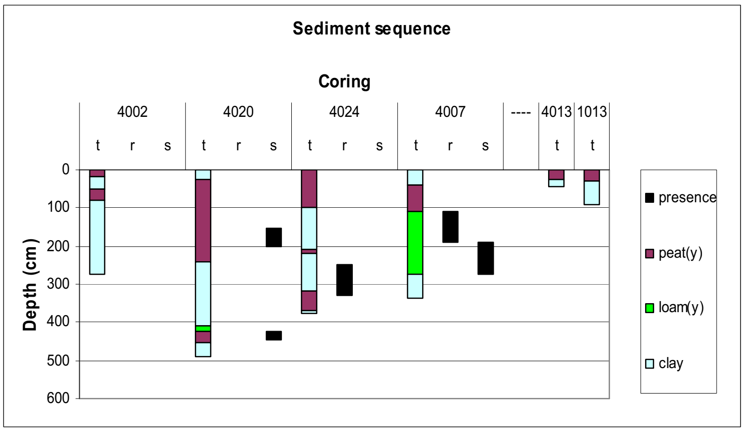


Figure Xa.5: Sediment sequence of the remaining corings in the eastern part of the swamp (t=texture, r=reed, s=shell remnants).

Appendix Xb: Description of the corings around the swamp.

This group of corings could be distinguished within two zones. The first zone comprised of some corings outside but near the swamp (also in the flat part of the town) in a relative flat setting. This relative flat strip surrounds the swamp which is artificially bordered by a small road, and mostly comprises grassy and swampy vegetation. The second zone is situated more on the terraces against the hill slopes. Besides the own corings, also corings conducted by Van der Laan (2010) were used for interpretation.

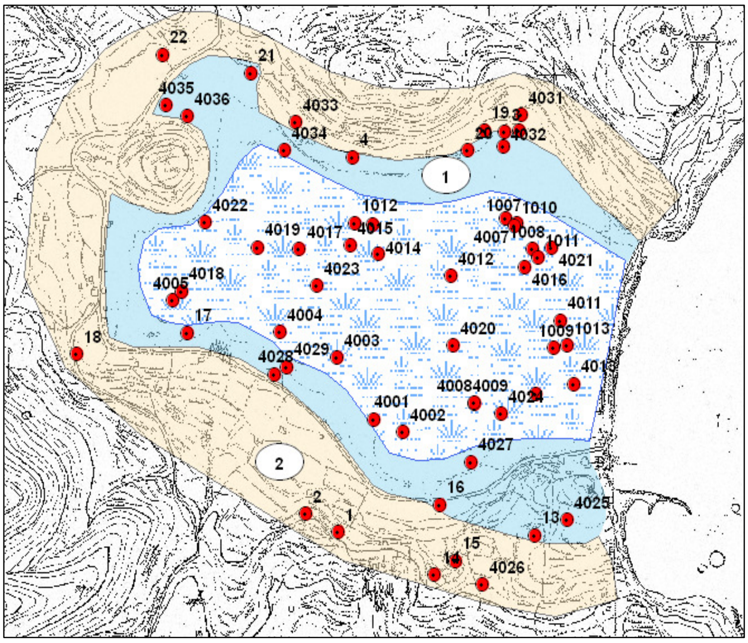


Figure Xb.1: Corings around the swamp within two zones.

The first zone contains the corings 4025, 13, 16, 4027, 4028, 4029 and 17, south of the swamp (figure Xb.2). The depth of these corings varied depending of the accessibility of the often dry and hard soils. Both the corings of Van der Laan (2010) as well as the own corings showed a sequence of silt loams and silty clays. These layers gave several difficulties as these very compact dry silts and clays hardly allowed coring through the layers. Most sediments contained organic matter and some iron content. It is likely that the silty character can be ascribed to a colluvial character as there are also fragmented limestones within these sediments. Besides the colluvial sediments, also some sediments were found that probably refer to the clay sedimentation in the bay and lake (coring 4027 and 4029). Coring 4027 even showed a small sand layer with small gravels between the clays. This sand had the same greyish colour as the sand that is assumed to be part of the sand ridge. Also a bit closer to the swamp, coring 4029 consisted of organic clays that probably belong to the clay settlement in the former lake.

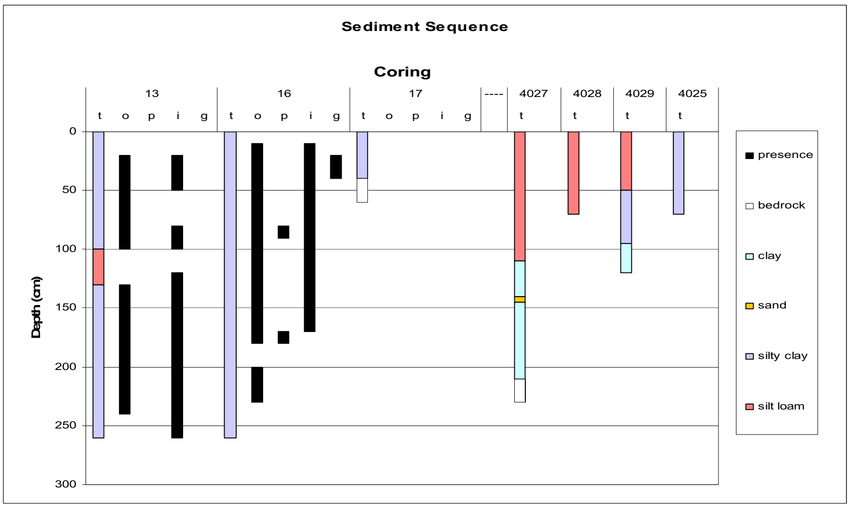


Figure Xb.2: Sediment sequence in the first zone, south of the swamp (t=texture, o=organic matter, p=plant remnants, i=iron, g=gravel).

The thickness of the total sediment bed in this zone varied from east to west. Bedrock was found at 40 cm in the western part (coring 17) and inclines to 210 cm in the eastern part (coring 4027). North of the swamp, the first zone comprises the corings 4035, 4036, 21 4034, 4, 20, 3 and 4032 (figure Xb.3). Just like the southern situated corings in this zone, these corings varied in depth.

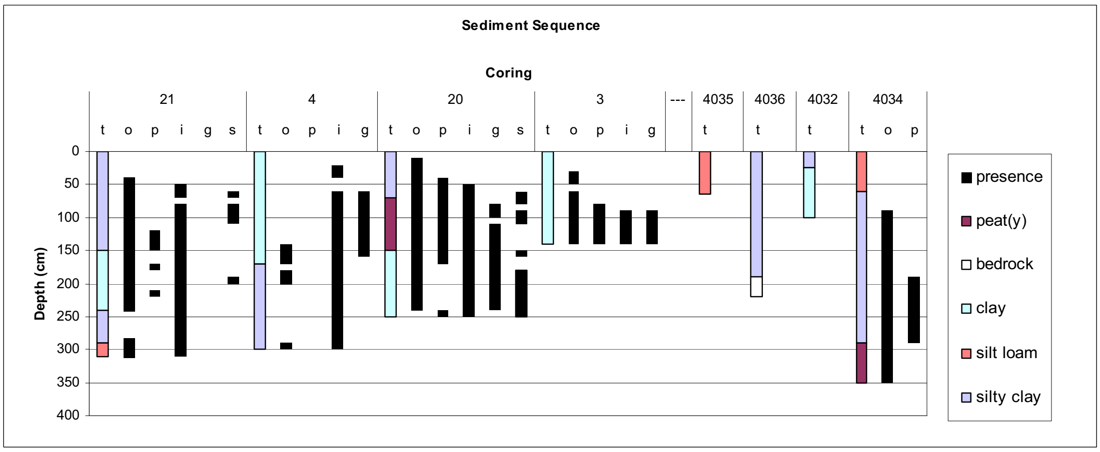


Figure Xb.3: Sediment sequence in the first zone, north of the swamp (t=texture, o=organic matter, p=plant remnants, i=iron, g=gravel, s=shell remnants).

Also in these corings, both colluvial and lake sediments were found. However, more corings displayed sediment from an ancient lake or sea. Apart form corings 4035 and 4036, all corings displayed layers of clay that were mostly covered with colluvial material. Peat was found in corings 34 and 20 which is in agreement with the found peat layer in the north of the swamp. More than the corings south of the swamp, these corings contained significant amounts of shell, plant remnants and gravel. The clays had a high organic matter content and also comprised some limestone fragments. The gravels found in coring 4, 20 and 3 were angular which implies colluvial influence. The hill slopes at this side of the swamp are steeper compared with the southern side which enhances colluvial transport. Coring 4034 is a good example of colluvial sediment on top of the lake or sea sediments. It showed silt loam and silty clays on top of a peaty clay layer. Organic matter content increased with depth in these silty clays till it changed into the peaty character of the clay. Coring 21 showed silty clays on top of (blue) grey clays with a high organic matter content. The organic silty clays in corings 4036 and 4035 together with the clays in coring 21 imply signs of siltation in an already further state than the clays in the swamp. This also implies that this part was also a part of the lake or bay, and it confirms the assumption that siltation started from the west. Just as the corings south of the swamp, the bedrock varied from east to west. The western situated coring 4036, and probably 4035 too, was stagnated on the bedrock, while the eastern corings did not reach the bedrock yet.

Finally the second zone with corings which is located closer to the foothills will be evaluated (zone 2 in figure Xb.1). In the south, it concerns the corings 4026, 15, 14, 1, 2, 13 and 18, while corings 22, 4033, 19, 4030 and 4031 represent the northern corings in this zone. Figures Xb.4 and Xb.5 show respectively the southern and northern situated corings. All corings were conducted in poor developed soils, mostly already on the terraces against the hill slopes. These corings mainly contained silty clays and silt loams with sometimes a sandy character and a lot of limestone fragments. Terracing practices seemed to have disturbed former soils. Coring 1 is a good example which showed a clear layer of organic material and iron concretions between the silty clays at a depth of 160 cm. These iron fragments indicate oxidation and imply former exposure at the soil surface. Besides the presence of these clear iron concretions, the presence of angular gravel and relative young plant remnants in the corings indicates the disturbed soils by terracing.

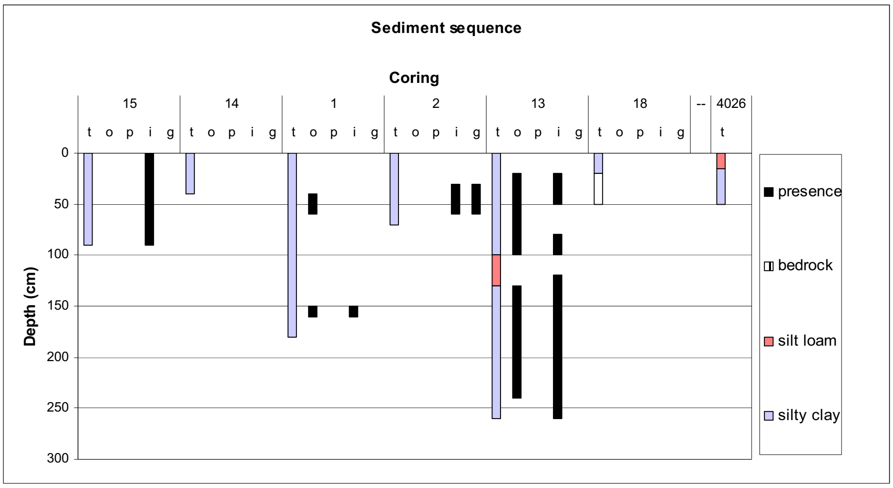


Figure Xb.4: Sediment sequence in the second zone, south of the swamp (t=texture, o=organic matter, p=plant remnants, i=iron, g=gravels).

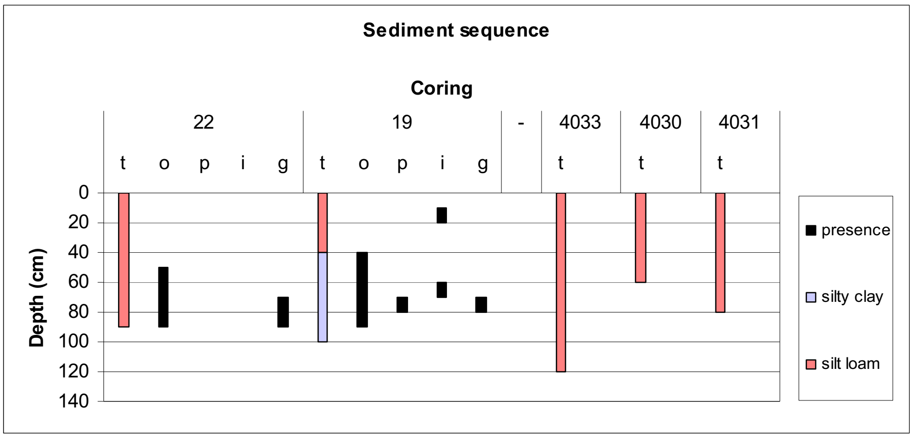


Figure Xb.5: Sediment sequence in the second zone, north of the swamp (t=texture, o=organic matter, p=plant remnants, i=iron, g=gravels).

Appendix Xc: Description of the corings in the western part.

The corings 35, 36, 29, 72, 73, 30 and 71 seemed to be situated in a kind of basin surrounded by the calcareous mountains and hills (figures Xc.1 and Xc.2). Corings 35 and 36 were situated at a clearly elevated basin (154m a.s.l.) separated by a steep ridge (chapter 4).

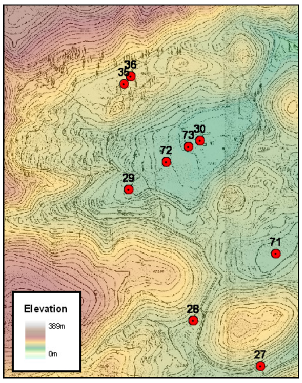


Figure Xc.1: Corings in the western part.

Most corings reached more than 300 cm depth. The higher elevated terrain around corings 35 and 36 gave more difficulties to core. Coring 35 contains 40 cm brown clayish silt with a lot of large limestone fragments which is the reason for the shallow coring depth. Coring 36 comprised 310 cm of sediment and could not be continued because of lack of core length. This coring consisted of a thick layer of dark brown silty clays on top of dry and hard clays. The clay content increased downward. These dry and hard clays were different from the clays found in the eastern part of the study area. Those grey and bluish clays were typically compact marine clays, while these (silty) clays were typically red and very dried out. The colour changed form dark brown to brown-orange to red brown. Also corings 29, 72, 73 and 30, which were cored along a straight transect, showed the silty clays on top of firm red-brown clays. The more south situated coring 28 also contained similar sediments. At this depth calcareous powder was found in the corer which suggests the presence of the bedrock border. Also corings 27 and 71 consisted of the same red brown sediments. Coring 27 reached the bedrock too.

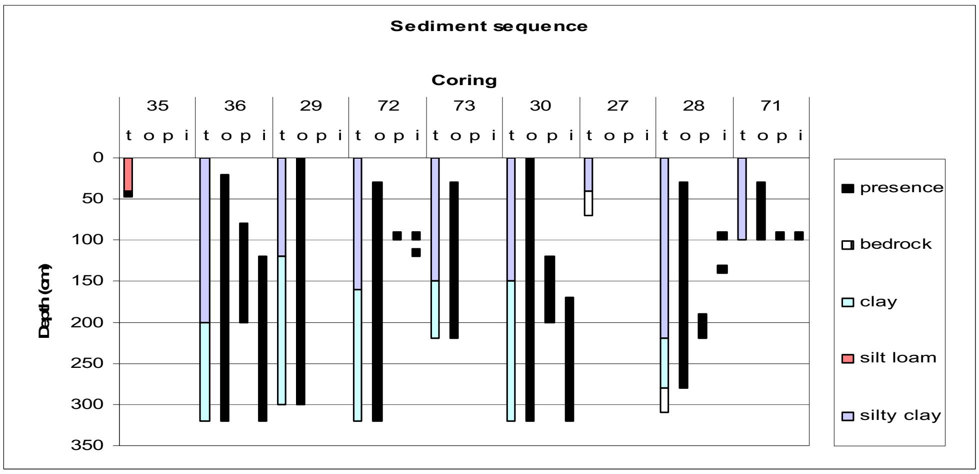


Figure Xc.2: Sediment sequence in the western part of the study area (t=texture, o=organic matter, p=plant remnants, i=iron).

Appendix Xd: Description of the corings in the central north.

The corings in this group can be distinguished in three parts (figure Xd.1). The first part, (corings 37-44, except coring 41) comprised corings within some very shallow soils. All corings contained red brown clayish sandy material with a thickness of 20 cm with a lot of gravels and limestone pebbles. This calcium rich mixed layer was situated on a glued limestone mass. This mass seemed to be a debris fan with on top a small soil layer containing more recent terra rossa. However, this sediment had a more sandy character than the terra rossa found in the west of the study area. Because of the mixed character and the presence of gravels, these soils are probably colluvial and were transported downward from the adjacent hills.

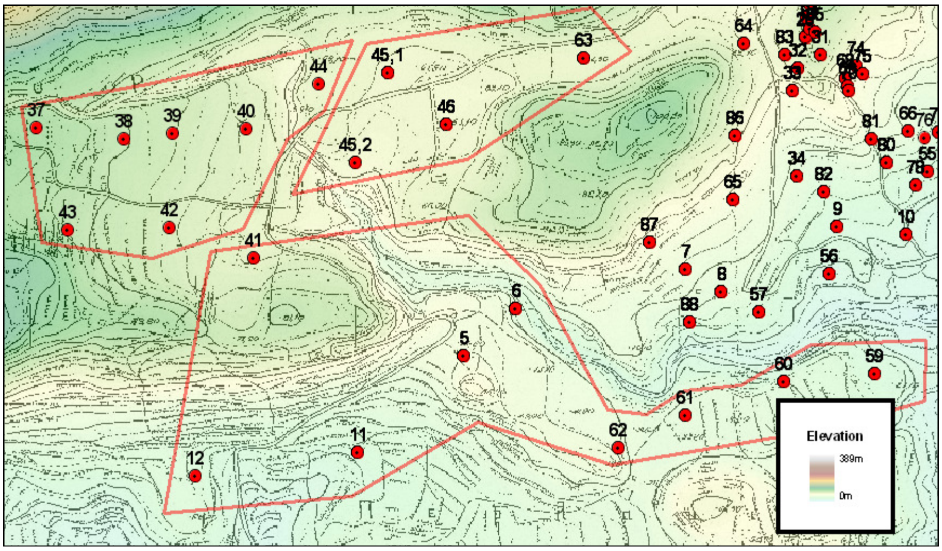


Figure Xd.1: Coring parts within the central north of the study area.

The corings 45a, 45b, 46 and 63 were conducted eastwards of these shallow corings. These corings contained a brown sandy clayish top soil. The main feature is that these corings appeared to suddenly be deeper compared with the shallow coring group 37-44 (figure Xd.2). Especially coring 45a and 46 showed a deep sequence. While in coring 45b and 63 a small sandy clay layer (40-60 cm) was found on top of the bedrock, coring 45a and 46 showed a sandy clay layer on top of a thick clay layer that seemed comparable with the terra rossa accumulation in the western part (chapter 4.4 and appendix Xc). These brown to red- and orange brown (silty) clays were extremely compact and contained a lot of organic matter, plant remnants and iron concretions. At coring 45a the bedrock was found at 270 cm, and coring 46 could not reach further as result of the lack of core length. Just like the corings in the terra rossa in the western part, these corings appeared to be deeper than suspected. Apparently, these (silty) clays were able to accumulate in a depression as the local bedrock was suddenly found deeper. These sediments seemed to have a colluvial character too. Plant remnants and iron could indicate that ancient exposed soils were transported downward from the steep hill slopes north of this area. This suggests a similar deposition area as the area in the western part of the study area (chapter 4.4).

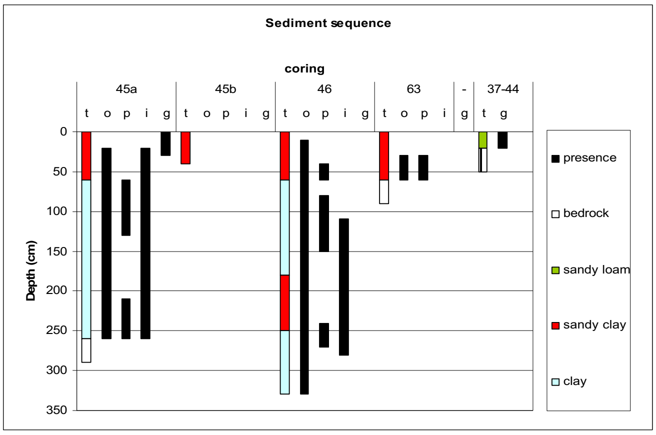


Figure Xd.2: Sediment sequence in the central north of the study area (t=texture, o=organic matter, p=plant remnants, i=iron, g=gravel).

The remaining corings in this group are shown in figure Xd.3 and showed more different sequences. Coring 41 and 12 contained a relative shallow greyish brown silty clay layer with a lot of limestone pebbles on top of the bedrock. These corings were similar to the most western situated corings in the second zone around the swamp (coring 18 and 22). These corings seemed to represent the middle part of the study area where no corings have been done. In this zone, bedrock dominated and very shallow soils were locally observed. The corings 11 and 5 more eastwards contained mostly greyish silt loams and silty clays, and showed indications of disturbed layers as a result of terracing. The corings 59-62, even more eastwards and south of the river valley, comprised of brown sandy clays till 40 to 80 cm which were situated on top op the bedrock. A prominent sediment sequence was found in coring 6. This coring was carried out near the lowest part of the small river valley. It contained a 30 cm thick grey silt layer on top of greyish silty clays till 200 cm. More downward these silty clays changed into more blue greyish and showed a lot of plant remnants, organic matter and iron concretions. These blue grey clays suggest sea influence that probably could come this far because of the lower elevation of this small river valley.

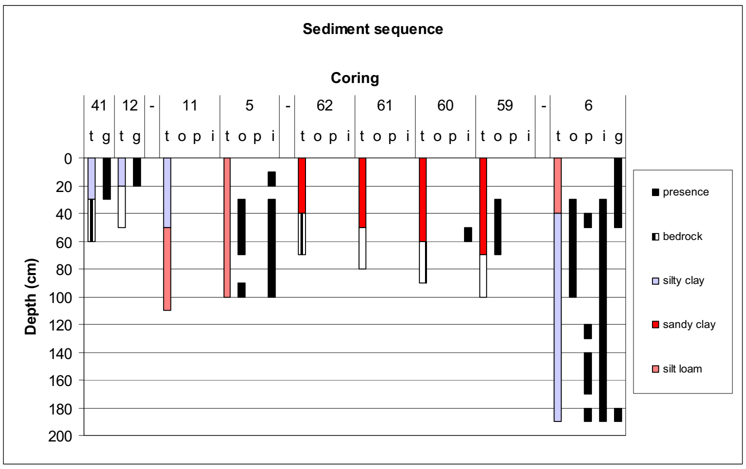


Figure Xd.3: Sediment sequence in the central north of the study area (t=texture, o=organic matter, p=plant remnants, i=iron, g=gravel).

Appendix Xe: Description of the corings in the north eastern area.

This coring group could be divided into two parts (figure Xe.1). The first part comprises corings 58, 67, 50 and 51 (figure Xe.2).

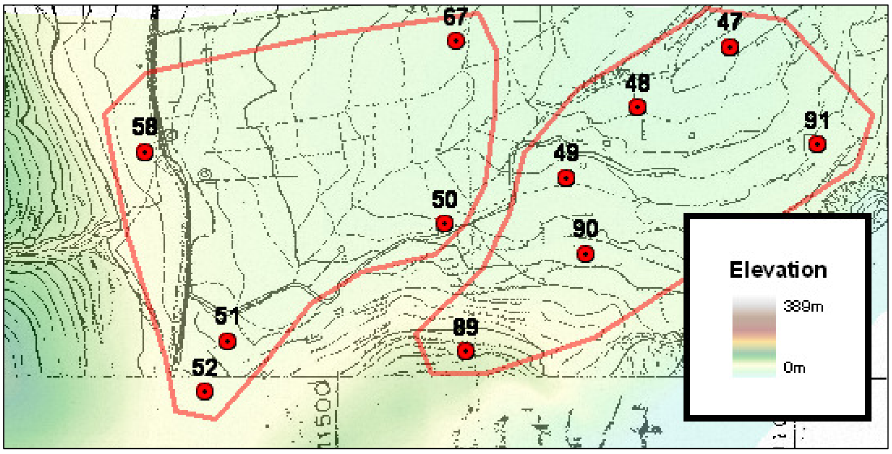


Figure Xe.1: Corings in the north eastern part of the study area.

Coring 58, which is the most western coring in this group, contained silty clays on top of firm silt loams. Despite that this coring was situated close to the steep hill slopes and could be stagnated due to the bedrock, it was the silty character of the soil that caused the core stagnation. In contrast; coring 67 showed a shallow sandy loam layer directly on top of the bedrock. Apparently the bedrock also varied in this north eastern part of the study area. Coring 52 consisted of sandy clays and coring 51 revealed silt loams on top of loamy sands. These very fine sands were situated on top of brown sandy clays with a mixed sand fraction. The very fine sands were moderately rounded, moderately sorted and contained some shell remnants and small clay cubes. These sands and clays were also found in the second part of this coring group.

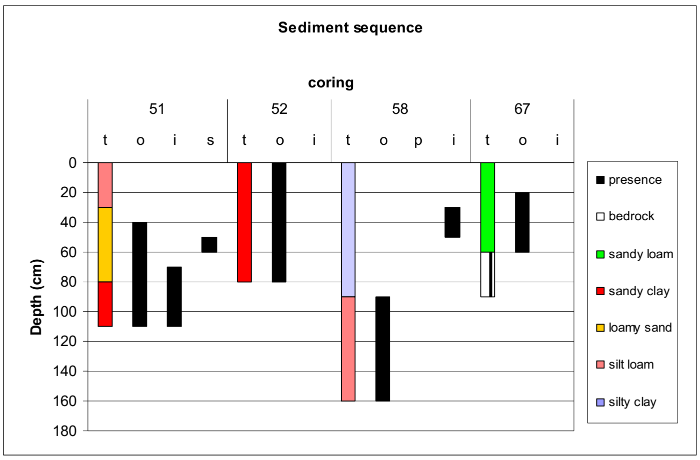


Figure Xe.2: Sediment sequence in the central north of the study area (t=texture, o=organic matter, p=plant remnants, i=iron, s=shell remnants).

This second part comprises the corings 47-50 and 89-91 which were situated in a SW-NE transect parallel to the coastline. All these corings roughly consisted of an alteration of clays and sands (figure Xe.3). In the upper parts, it was more an alteration of sandy loams and sandy clays, but in the lower parts it was an alteration of more pure clays and loamy sands.

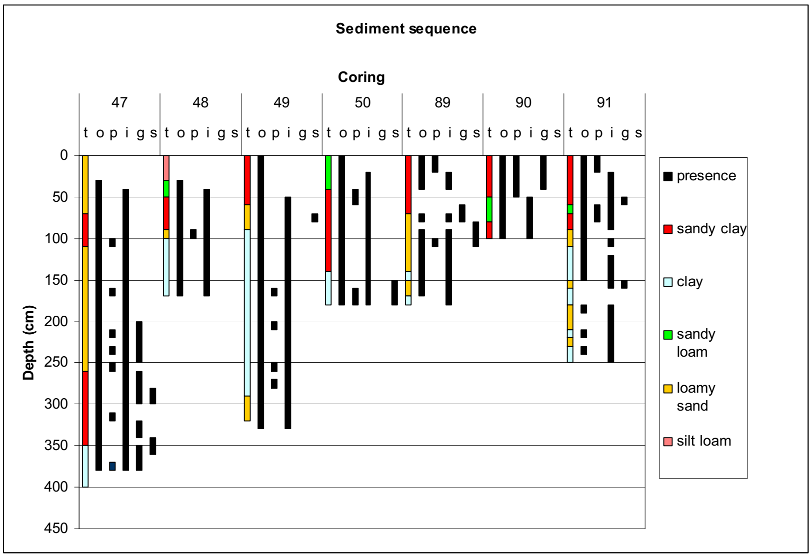


Figure Xe.3: Sediment sequence in the central north of the study area (t=texture, o=organic matter, p=plant remnants, i=iron, g=gravel, s=shell remnants).

The loamy sands consisted mostly of very fine sands that were well sorted and well rounded. The sands were mostly greyish to orange yellow. Overall, the colour of the clays changed downward from brownish to more greyish. Some clays contained sand fragments which were comparable with the sands layers found between the clays. On the other hand, some clay cubes were found between the sands. Besides these mixed textures, also shell remnants were found in the clays and sands.

Appendix Xf: Description of the corings around Kamaroti hill.

This group contains a lot of corings that ranged from the top of Kamaroti hill till the river valley in the south. The group could be divided into four parts based on location, elevation and texture (figure Xf.1).

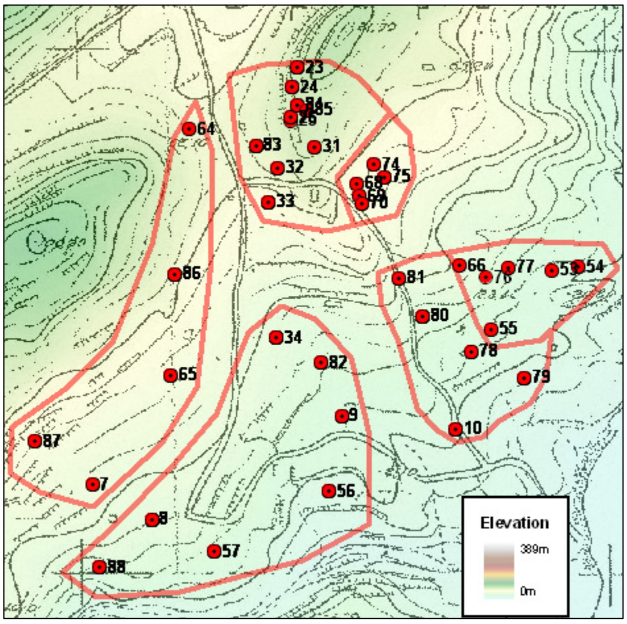


Figure Xf.1: Corings groups around Kamaroti hill.

The first part that was evaluated is the part around the top of Kamaroti hill till the part around the east west directed road south of it. Corings 23-26, 83-85, 31-33, 68-70 and 74-75 were located here (figure Xf.2 and Xf.3). Coring 23 was located near the top and revealed a larger depth than expected. This coring reached a depth of 280 cm and was stagnated on probably bedrock. This coring contained silty clays on top of clays. Interestingly, the silty clays were interrupted twice by a yellow brown layer of very fine well rounded and sorted sand. Also the underneath clay part appeared to be interrupted by such a sand layer. Apparently, sea influence reached also this area around the top. As the area north of this area also revealed the same sands between clays, it is assumable that these sands are the same around the top of Kamaroti hill. Coring 24-26 were located on a lob shaped terrace beneath the top. Both coring 24 and 26, which were located respectively at the base and centre of the terrace, showed this sand material too. Coring 24 contained mainly (silty) clays and was interrupted also two times by an identical sand layer. Although this coring was located two meters beneath coring 23 at the top, the upper sand layer found in this coring seemed to be the same as the sand of coring 23. Coring 26 and 84, which were located on the centre of this terrace, did also show the presence of this kind of loamy sand. Coring 25, at the end of the mentioned lob shaped terrace, appeared to be impossible due to the presence of very large limestone boulders, and even very concentrated archaeological material. Overall, the area around the top displayed an interesting sequence, especially because of the local topography and presence of some loamy sand layers. The presence of (brownish) silty clays on top of grey clays suggests that this hill was reasonable well preserved against erosion processes, and that marine influence played a role here too.

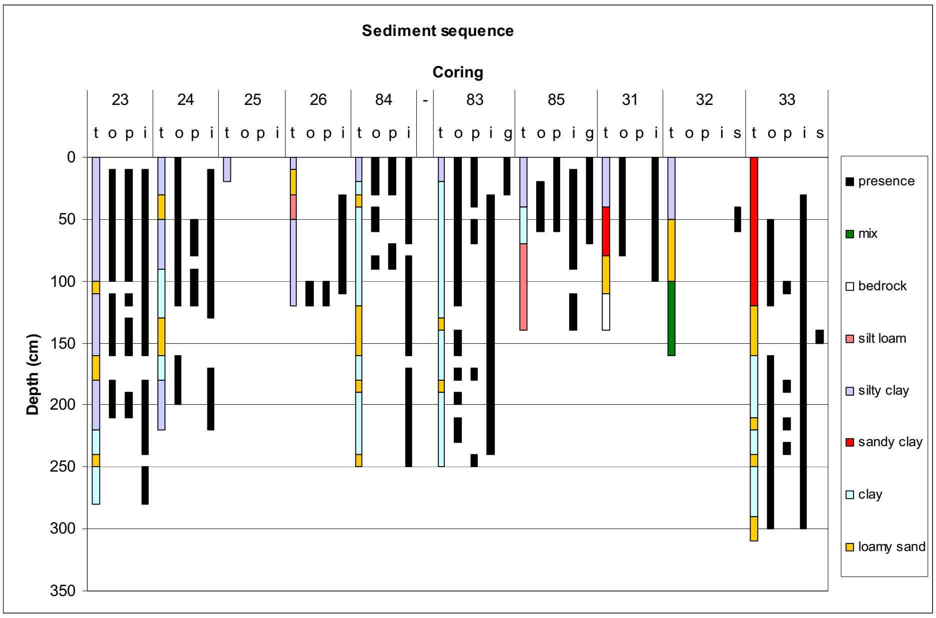


Figure Xf.2: Sediment sequence around the top of Kamaroti hill (t=texture, o=organic matter, p=plant remnants, i=iron, g=gravel, s=shell remnants).

Corings 83, 85, 31 32 and 33 were located on more downward situated terraces and showed a complex sequence of sediments (figure Xf.2). These corings contained silty clays, silt loams, sandy clays and more pure clays. Organic matter, iron content and plant remnants were often found. Also the loamy sands were found again. Especially, coring 33 showed these sands that were found between firm grey clays that also contained small sandy bands themselves. Also some shell remnants were found. This sequence suggests an alternating sea influence that enhanced clay settlement alternating with sand. Coring 32 and 33 also showed the sands. In case of coring 31, these sands were directly found on top of bedrock. Coring 32 seem to be a good example of destruction of soil layers, because this coring comprised a mix of sandy and clayish material with some shell remnants and showed no layering. Terracing is dominating this area which could disturb soil profiles intensively like it was probably the case here.

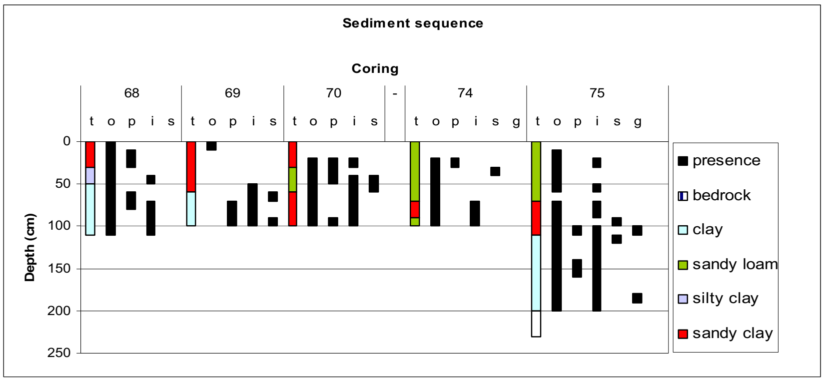


Figure Xf.3: Sediment sequence around the top of Kamaroti hill (t=texture, o=organic matter, p=plant remnants, i=iron, g=gravel, s=shell remnants).

The corings 68-70 were situated on one terrace east of the south directed road. These three corings of 100 cm were located perpendicular to the terrace and contained loamy and sandy material on top of more clayish material (figure Xf.3). Plant remnants, shell remnants, wooden particles and some fine sands were found in these three corings. Especially the corings 69 and 70, that were located on the mid and end of the terrace, showed a more chaotic soil profile with a lot of limestone fragments and pebbles. Coring 74 and 75 were situated nearby on another terrace and showed in particular the loamy, sandy top layer which changed in more clayish material (figure Xf.3). Coring 75 reached the bedrock at 210 cm. This bedrock outcrops at several locations along these southern slopes of Kamaroti hill.

This bedrock was also found in the second part of this coring group that was located more downwards in the south eastern part. Coring 66, 76, 77, 53, 54 and 55 showed a loamy sandy layer of 40- 60 cm on top of the shallow bedrock (figure Xf.4). The depth at which the bedrock could be observed differed locally. At some locations the bedrock outcropped, while on other locations the bedrock was located underneath a soil of 40-60 cm, and sometimes even underneath soils of 120 cm (coring 78). Corings that reached larger depths were corings 79-81 and 10, mostly located along the south directed road. Coring 10 was the most southern situated coring and contained of silty clays on top of greyish blue clays. Coring 79 and 80 contained loamy material on top of greyish brown and blue clays. In coring 80, the very fine sand layer was found again. This part showed the locally different depth of the bedrock, and the influence of the sea that seems to have played a role in this part as well.

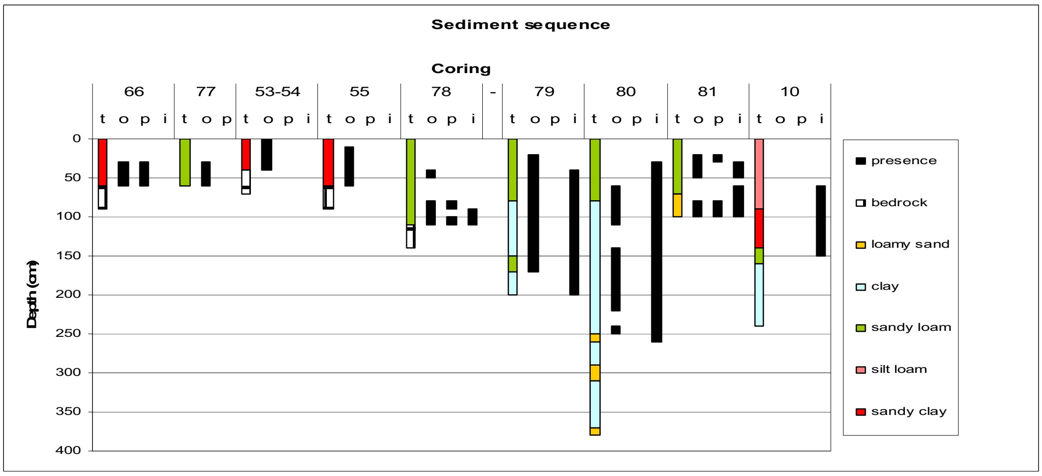


Figure Xf.4: Sediment sequence in south eastern part along the slopes of Kamaroti hill (t=texture, o=organic matter, p=plant remnants, i=iron).

The third part comprises the corings 64, 86, 65, 87 and 7 that were located on the south eastern slopes of the hill west of Kamaroti hill and are shown in figure Xf.5. Most corings consisted of silty or sandy clays on top of clays and bedrock. All these corings contained a lot of limestone matter or pebbles, with sometimes some sharp gravels within the (organic) clays. As these corings were situated along hill slopes, this indicates a colluvial nature.

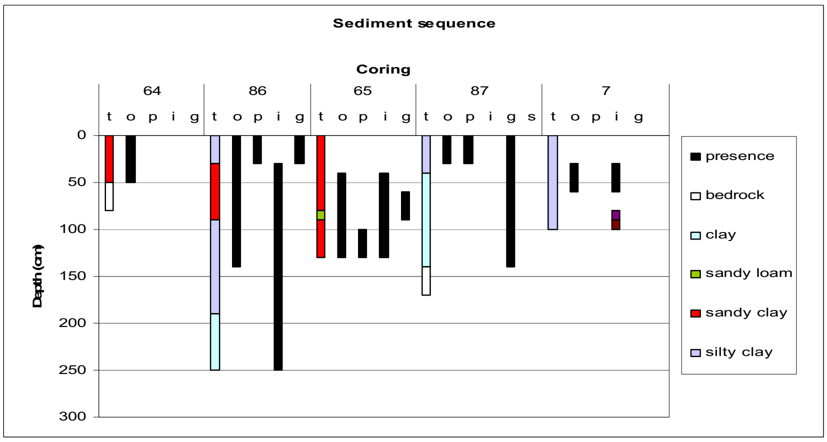


Figure Xf.5: Sediment sequence along the south eastern slopes of the hill west of Kamaroti hill (t=texture, o=organic matter, p=plant remnants, i=iron, g=gravel, s=shell remnants).

Finally, coring 34, 82, 9, 56, 57, 8 and 88 are evaluated (figure Xf.6). Coring 34 contained a thick top layer of sandy material on top of a large firm clay layer. This firm clay layer consisted of many very fine sand bands that were more frequently present with increasing depth. The whole clay layer contained organic material, iron concretions and plant remnants. The colour of the clays were (brown) greyish to blue. From 310 cm, the clays became wetter as result of the water table that should be located slightly lower. Coring 82, more southwards, also contained the brown clays but now with some gravels, shell remnants and clear iron and organic matter concretions. Also coring 9, which was located more southwards too, contained a lot of gravels. The silt loams and silty clays were situated on top of clear peaty clays containing a lot of gravels and small shells. Underneath this peaty clay the bedrock was found. Also corings 56 and 57, which contained mainly sandy clays, revealed the presence of gravels and clear large organic parts. These parts were less peaty than the peaty clays in coring 9, but seem to be part of the same deposits. Looking at the DEM in figure Xf.1, these corings seem to be located in a lower elevated terrain which borders the river valley. It is likely that the sea invaded this part too, which may have resulted in a local closed water system which enhanced peat accumulation later on. Coring 8 and 88 did not show these peaty clayish parts with gravels, but did show a deep sequence. Coring 8 contained silty clays on top of a prominent brown yellow layer with very fine loamy sands that were perfectly rounded and sorted. These sands were found on top of blue and grey clays.

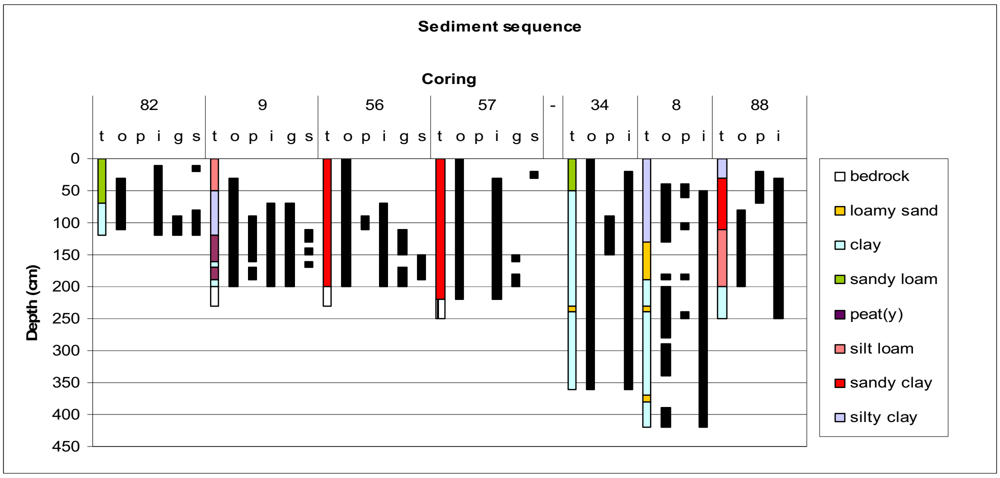
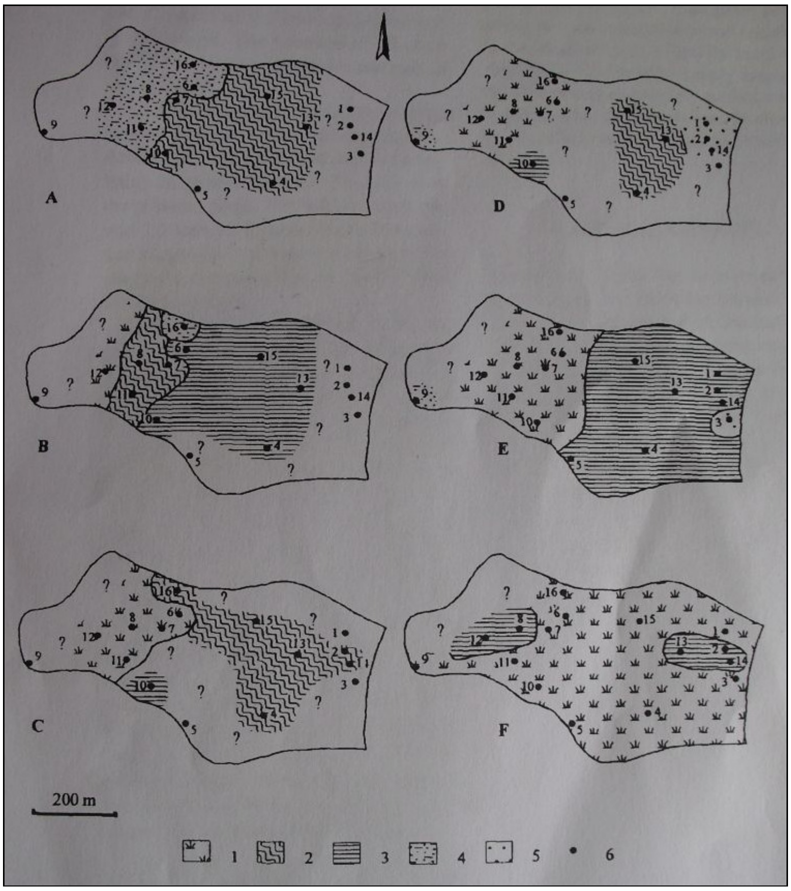


Figure Xf.6: Sediment sequence in the southern part along the hill slopes op Kamaroti (t=texture, o=organic matter, p=plant remnants, i=iron, g=gravel, s=shell remnants).

Appendix XI: Evolution stages of the swamp based on C14 data.



Several stages of the swamp (1:peat, 2: dedrital mud, 3: limnic clay, 4: terrestrial loam, 5: sea sand, 6: coring site) (from Papazisimou et al., 2000).