



universität
wien

MASTERARBEIT

Titel der Masterarbeit

„The Quaternary sediments of NW-Antiparos (Aegean):
Lithostratigraphy and depositional environment“

Verfasser

Bakk. rer. nat Bickel Lukas

angestrebter akademischer Grad

Master of Science (M.Sc.)

Wien, 2011

Studienkennzahl lt. Studienblatt:

A 066 815

Studienrichtung lt. Studienblatt:

Masterstudium Erdwissenschaften

Betreuerin / Betreuer:

PD Mag. Dr. Erich Draganits

Ao. Univ. Prof. Mag. Dr. Susanne Gier

Acknowledgments

First of all I would like to thank my supervisors Susanne Gier and Erich Draganits for their sweeping, maximum possible assistance in bringing this thesis into concrete existence. First and foremost I would like to thank them for backing my fieldwork in July 2009. It was a great time I had there and the experience I gained in the field is priceless. Of course I also want to thank Peter Krois who joined me for some days.

Special thanks go to the University of Vienna who sponsored my field trip with the scholarship “Kurzfristiges wissenschaftliches Arbeiten im Ausland”.

Further I want to thank Bernhard Grasmann and Christoph Iglseder who both helped me to understand (so I believe) the metamorphic samples in thin section. And of course I’m thanking Andras Zamolyi a thousand times, who brought light into the dark jungle of old Hellenic military coordinates to rectify my topographic maps. Moreover Ulrike Exner deserves thanks for instructing me in the use of the Trimble GPS correctly.

I also want to express my gratitude to Edmund Gittenberger who kindly gave his expert opinion on sampled terrestrial gastropods. Furthermore thanks go out to Richard Lein who taught me how to prepare conodont samples and Antonello Briguglio for determining the foraminifera in thin section. Also Franz Ottner deserves thanks for helping with the interpretation of the paleosol and Christian Baal for assisting on the SEM. Additionally I thank Christian Stocker for some awesome photographs and Leopold Slawek, Sigrid Hrabe and Claudia Beybl for the preparation of the thin sections.

Big thanks to all my fellow students and friends who were there for discussion, lending a helping hand, fooling around on field trips or just having a good time – especially Geri Hofer, Alex Kopecný, Andrea Schicker, Magda Bottig, Jonas Weil, Johannes Steinbrener, Bernhard Bretis, Clemens Porpaczy, Clemens Pfersmann, Helga Zeitlhofer, Olga Wronska, Cornelius Tschegg, Hubert Domanski, Otto “Otti” Burtscher, Danilo “Egitte” Grieco and Kofli.

I’m indebted to my parents Margret and Emil who supported and encouraged me to their fullest during my years of study and my brother Philip who’s game for everything.

The deepest thanks go out to Sandra who loved, coped and endured me and my moods during this time and always gave me support when I needed it the most.

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List of abbreviations

a.s.l.	<u>a</u>bove <u>s</u>ea <u>l</u>evel
AMS	<u>a</u>ccelerator <u>m</u>ass <u>s</u>pectroscopy
Bt	biotite
Cal	calcite
Chl	chlorite
cS	coarse sand
fS	<u>f</u>ine <u>s</u>and
HI	halite
Illt	illite

Kfs	K-feldspar ¹
Kln	kaolinite
L xxx xx	Lineation dipping xxx with xx°
LGM	<u>l</u> ast glacial <u>m</u> aximum
m.d.s.l	<u>m</u> odern <u>d</u> ay <u>s</u> ea <u>l</u> evel
mS	<u>m</u> edium <u>s</u> and
Ms	muscovite
Pl	plagioclase
Qz	quartz
SEM	<u>s</u> canning <u>e</u> lectron <u>m</u> icroscope
Sf xxx xx	Foliation dipping xxx with xx°
S_{for} xxx xx	cross stratification (foresets) dipping xxx with xx°
Sme	smectite
SS xxx xx	stratification dipping xxx with xx°
XRD	X-ray diffractometry

¹ Mineral abbreviations according to Whitney & Evans (2010)

Zusammenfassung

Bei Geländearbeiten im Juli 2009 wurden 6,4 km² im Nordwesten von Antiparos (Zentrale Kykladen, Griechenland) kartiert und beprobt. Ziel der Masterarbeit war es eine lithostratigraphische Einordnung der quartären Sedimente von Antiparos zu erhalten, deren Ablagerungsmechanismus zu erörtern und eine geologische Karte des bearbeiteten Gebietes im Maßstab 1:10.000 zu erstellen.

Das Hauptaugenmerk der Arbeit liegt auf der Untersuchung von pleistozänen Kalkareniten (lokal auch „Lithos Poros“ genannt), über deren Ablagerungsmechanismus noch nichts Genaues bekannt war. Bei diesen Sedimenten handelt es sich um gelbliche Sandsteine, die meist als grainstone zu klassifizieren sind und sich zumeist entlang der Küste auftreten, können aber auch in Gräben mehrere hundert Meter weit im Inland aufzufinden sein. Ihre Ausdehnung als auch ihre vertikale Verbreitung ist sehr unterschiedlich (max. 2-3 ha, von 0m - 80 m Meereshöhe anzutreffen). Sie füllen häufig topographische Depressionen oder liegen hangparallel in dünnen Lagen, ohne morphologisch eigenständige Terrassen zu entwickeln. In vielen Aufschlüssen überlagern sie Paläoböden. In vielen Kalkarenitaufschlüssen ist die Bildung von Calcrete bzw. Calcretisierung von Kalkareniten zu beobachten, was zu starker Verschleierung der ursprünglichen sedimentären Strukturen führen kann. An vielen Aufschlüssen konnten jedoch sedimentäre Strukturen wie Pinstripe Lamination und seltener steile Schrägschichtungen festgestellt werden. Ebenfalls wurden pedogenetische Überprägungen wie alveolare Strukturen und Rhizolite beobachtet. Zwischengeschaltet existieren Horizonte und Rinnenfüllungen mit groben (<30cm) Kristallinkomponenten. Des Weiteren wurden Säugetiertrackways und -tracks entdeckt und vermessen. Sie sind der bislang älteste Nachweis von Paarhufern auf Antiparos.

Marine Bioklasten, die verschiedenen Lebensräumen zuzurechnen sind, machen den Großteil der Kalkarenite aus. Siliziklastische Komponenten übersteigen selten 40% am Gesamtanteil. Bei den Bioklasten handelt es sich um Foraminiferen (benthisch und in geringerem Maß planktonisch), Echinodermen, Corallinaceen, Grünalgen, Bryozoen und Gastropoden. Terrestrische Gastropoden konnten in gut erhaltenen Aufschlüssen gefunden werden. Diese in den Kykladen rezent vorkommenden Gastropoden ergeben ein Alter von 32472 ± 900 a cal. BP und datieren somit in eine Kaltphase der letzten Eiszeit. Während dieser lag der Meeresspiegel um ca. 100 m tiefer als heute und somit das kykladische Plateau trocken lag. Dies

bedeutet, dass die erhaltenen Kalkarenitablagerungen zum damaligen Zeitpunkt bis zu 10 km von der Küstenlinie entfernt waren.

Die sedimentären Strukturen, der Mix von Schalenresten aus verschiedenen Lebensräumen, das Vorhandensein von terrestrischen Gastropoden und das Auftreten von Säugetiertrackways zeigen eine Ablagerung durch Windtransport an was auch gut im Einklang mit dem tiefen Meeresspiegel zur Zeit ihrer Ablagerung steht. Diese Kalksandsteine können deshalb als „Eolianite“ bezeichnet werden. Die charakteristischen grobklastischen Lagen deuten an, dass sie als „sand ramp deposits“ zu klassifizieren sind.

Abstract

During fieldwork in July 2009 6.4 km² of the northwestern part of Antiparos (Cyclades, Greece) were mapped and samples were taken. The objectives of this master's thesis were to classify the quaternary sediments of Antiparos in a lithostratigraphic sense, ascertain the depositional environment and to create a geological map of the working area at the scale of 1:10.000.

The main focus of the thesis lies on the characterization of Pleistocene calcarenites (locally called "lithos poros"). The depositional mechanisms of these yellowish grainstones have not been investigated yet. They can be found mostly along the coastline but also up to a few hundred meters inland. Their areal extent (<2-3 ha) as well as their vertical location (0-80 m a.s.l.) are very variable. They preferably fill topographic depressions or form thin slope parallel sheets without forming discrete morphological terraces. On many sites they overlie paleosols. Many calcarenite outcrops are affected by calcretization, masking the primary sedimentary features. Also pedogenetic overprints such as alveolar structures and rhizolites have been recorded. Often intercalated are horizons and channels with coarse gneiss and quartz clasts (up to 30 cm). Tracks and trackways found in two outcrops are the oldest evidence of artiodactylous mammals living on Antiparos.

The calcarenites comprise marine bioclasts originating from various water depths - siliciclastics rarely exceed 40%. The bioclasts consist of foraminifera (benthic and to a lesser extent planktonic), echinoderms, coralline red algae, green algae, bryozoans and gastropods. Land snails have also been found in well preserved outcrops. Most of them still can be found in the Cyclades. They show an age of 32472 ± 900 a cal. BP, thus the calcarenite has been deposited during a late stage of the Würmian glaciations. At that time the mean sea level was approximately 100 m lower than present day, exposing the Cycladic plateau. Consequently the calcarenite outcrops, which are now found near the sea today, have been some 10 km away from the sea during their formation.

The sedimentary structures, the mixture of shell fragments from different habitats, the terrestrial gastropods and the existence of artiodactyl trackways indicate a formation of the calcarenites by wind. This is also supported by the desiccation of the Cycladic platform.

These sediments are commonly referred to in literature as “eolianites” or “carbonate eolianites” which have been deposited as “*sand ramps*”.

1 Introduction

The Cycladic Islands have been a traditional area of earth science research but most of the studies focus on volcanism, structural geology and metamorphic petrology [[*Jolivet and Brun, 2010; Lister and Forster, 2007; Pe-Piper and Piper, 2002; Ring et al., 2010; Ring, 2007*]]. So far no detailed sedimentological study has been carried out on Antiparos. This thesis focuses mainly on the investigation of the lithostratigraphy and depositional environment of Quaternary calcarenites (Figure 1) found in scattered patches in northwestern Antiparos. Before the start of this thesis several possibilities of depositional mechanism have been discussed including marine environments, eolian deposits and even tsunamiites.



Figure 1: Calcarenite outcrop south of Livadia bay at about 60m a.s.l. The bedding of these lithologies is generally dipping parallel to the slope. At this outcrop artiodactyl trackways have been found (see chapter 5.4.6).

Locally this rock is called “lithos poros”, in the geological literature first used by *Cayeux* (1907). It is also common on other Cycladic Islands (e.g. Andros, Tinos, Mykonos, Delos, Naxos, Paros, Antiparos, Despotiko, Keros, Schinoussa and Ios) and is also found in coastal areas of the Greek mainland [*Fytrolakis and Papanikolaou, 1977*]. Occurrences on Antiparos have been mapped by *Anastopoulos* (1963) and mentioned by *Fytrolakis and Papanikolaou* (1977). Abundant small occurrences on Despotiko Island (southwest of Antiparos) were described by *Draganits* (2009). Unfortunately “poros” is an ill-defined term because it includes all rocks with high porosity and has been applied for sandstone, travertine and porous volcanic rocks as well [*Draganits, 2009*]. Therefore in this study the term “poros” will be avoided.

This thesis was initiated by Erich Draganits aiming for a comparison of the Quaternary sediments of Antiparos with similar sediments on Despotiko. Fieldwork on Antiparos has been carried out during four weeks in July 2009 and the samples have been further analyzed at the University of Vienna (see chapter 4).

2 Geological Setting

The geodynamic evolution of the Mediterranean is strongly dominated by the collision of the African and the Eurasian and Anatolian plates during the Mesozoic and Tertiary [Golonka, 2004] and the closure of the Tethys ocean basins which gave rise to the Hellenic orogen [Kiliyas et al., 2002] (Figure 2). The Aegean Sea represents a Mediterranean back arc basins [Jolivet and Brun, 2010].

The Hellenic orogen itself incorporates 3 orogenic belts: the Cimmerian internal belt with the Carboniferous-Early Cretaceous subduction of the Paleotethys, the Alpine orogenic belt with the Cretaceous-Tertiary subduction of the Neotethys and the Mesogean orogenic belt with the underplating of the Mesogea-Africa plate under the Alpine-Cimmeria-Eurasia plate [Mountrakis, 2006].

The Hellenides were formed by four orogenic cycles as described by [Jacobshagen, 1987; 1994] from the Paleozoic until today. Three main tectonic units can be recognized in the Hellenides: the Western Hellenides, the Central Hellenides and the Median Crystalline Belt which include Mesozoic volcanics and sediments as well as ophiolites [Papanikolaou, 2009].

The Cyclades belong to Attic-Cycladic metamorphic complex which links the crystalline rocks of mainland Greece with the Anatolian Menderes Massif [Matthews and Schliestedt, 1984]. Within the Attic-Cycladic metamorphic complex, two main metamorphic events can be distinguished [Jacobshagen, 1987]:

1. Eocene high-pressure blueschist regime
2. Early Miocene extensional greenschist metamorphism

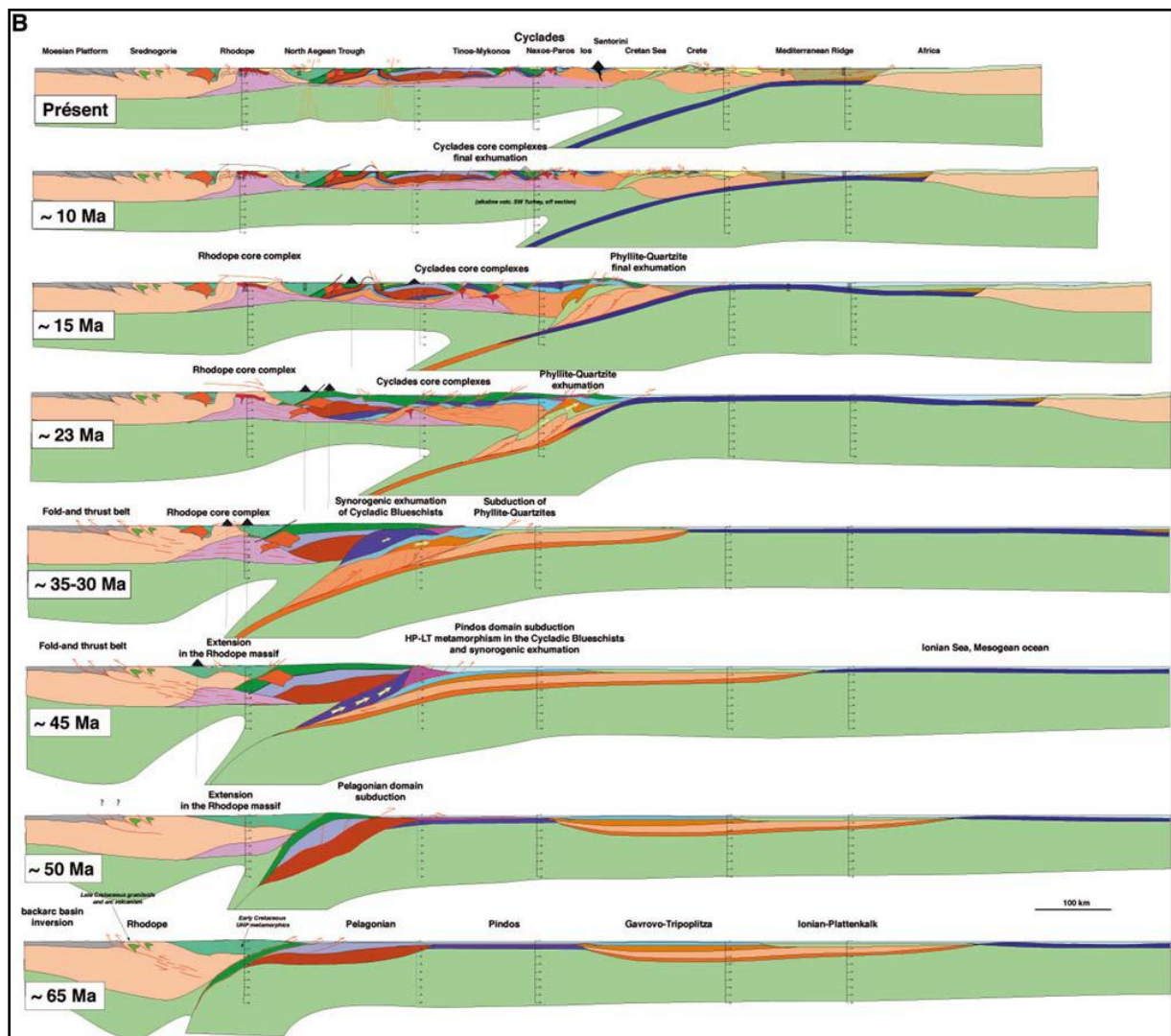


Figure 2: Plate tectonic profiles (Central Europe – Greece – Eastern Mediterranean – Africa); 65 Ma - present [Jolivet and Brun, 2010]

The HP/LT blueschist metamorphism is related to the early Eocene to the late Eocene subduction of the Pindos Ocean and its marginal terranes (Figure 2). No high pressure rocks could be found in the working area on Antiparos. At the Eocene/ Oligocene boundary the subduction zone drastically changed its movement direction: the beforehand northward directed movement reversed southward [Jolivet *et al.*, 2003]. During the early Miocene times exhumation took place in metamorphic core complexes leading to regional greenschist-amphibolite facies metamorphism. In the eastern Cyclades NE-dipping detachments with top-to NE sense of shear have been observed [Sánchez-Gómez *et al.*, 2002; Jolivet and Brun, 2010], while in the western Cyclades top-to SW directed detachments exist [Grasemann and

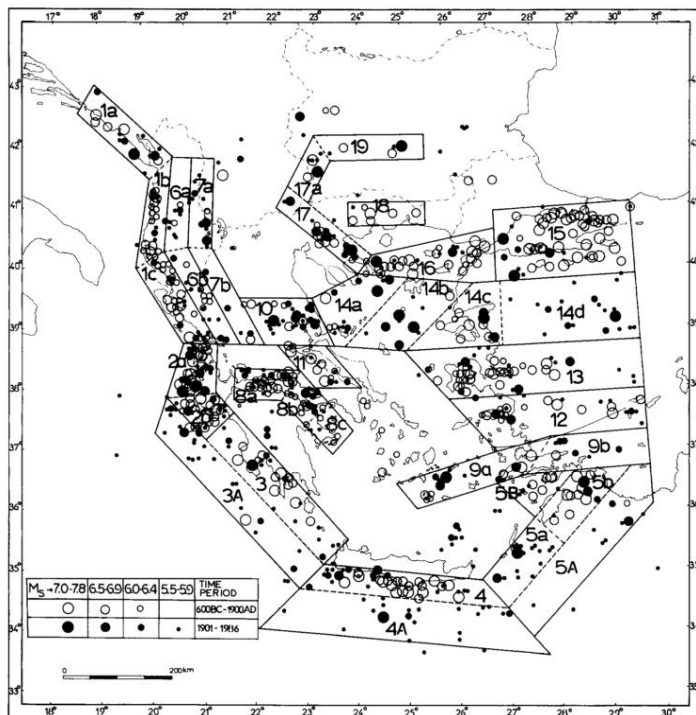


Figure 3: Seismicity of the Aegean region (shallow earthquakes) [Papazachos, 1990]

Petrakakis, 2007; Iglseder, 2010].

Around 4 Ma a calc-alkaline volcanic arc started to form in the Southern Aegean Sea (South Aegean volcanic arc). The southernmost part of Antiparos and parts of Despotiko are made up by rhyolitic volcanic geochemically similar to other rhyolite of the South Aegean volcanic arc [Clapsopoulos, 1998].

Compared to many other parts of the Aegean, the Cyclades show low seismicity (Figure 3) [Papazachos, 1990].

3 Antiparos Island

3.1 Geographic position, general geology and geomorphology

Antiparos is part of the Cycladic Islands of the South Aegean Sea with a surface area of approximately 45 km². Characteristic of Antiparos is the rather flat northern part of the island (Figure 4) and the quite mountainous middle to southern part reaching up to 300 m at Mt. Elias (profitis ilias). The island consists mostly of amphibolite facies orthogneiss and calcite as well as dolomite marbles.



Figure 4: Overview of the working area. Viewing direction NNE with Livadia beach in the middle ground.

These lithologies can be correlated with similar rocks in lower structural levels on Paros [Hannapel and Reischmann, 2005; Papanikolaou, 1978]. In some parts of the island some ore mineralizations such as galena, sphalerite and iron sulfides can be found which have been mined in the last century [Anastopoulos, 1963b]. The southern part of the island is made up of Pliocene volcanic rocks. The metamorphic lithologies are described from structural lower levels to upper levels in the following chapters. The field names used in the descriptions are shown in the map sketch in figure 5.

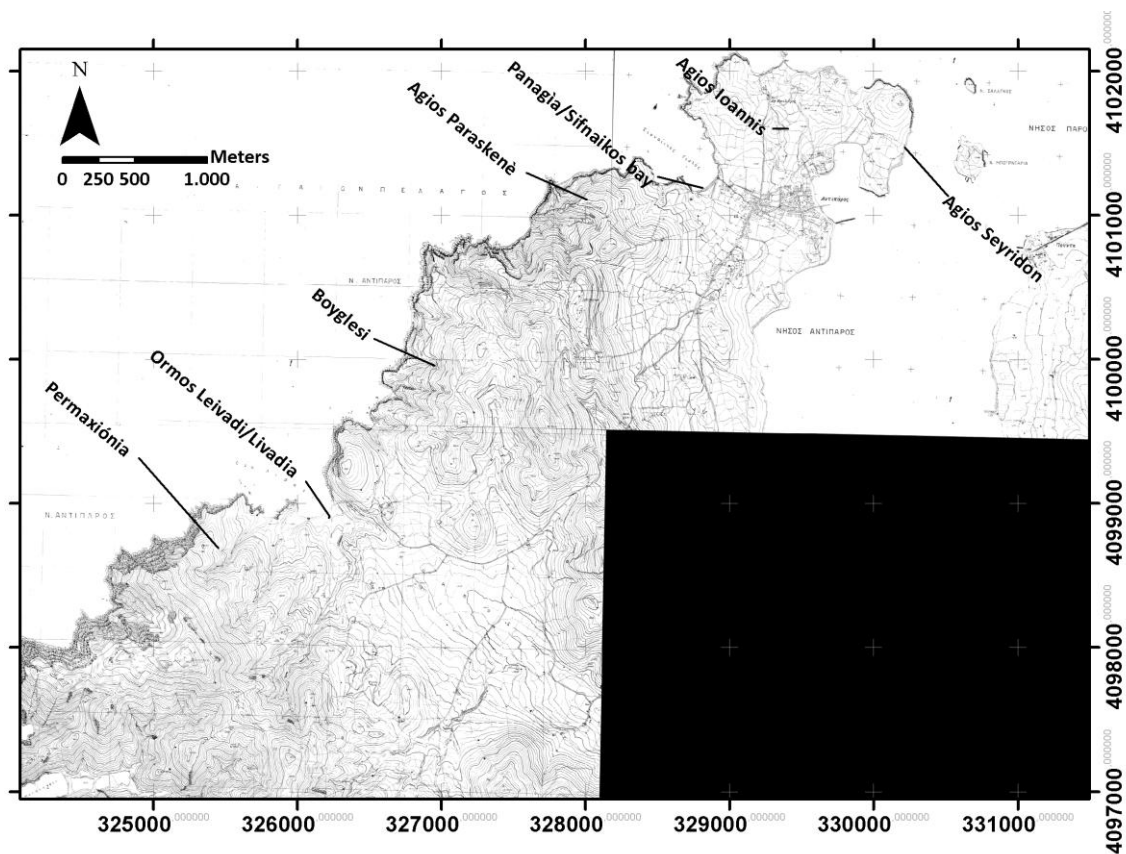


Figure 5: Antiparos field names derived from the geological map of Anastopoulos (1963)

3.1.1 Metamorphic rocks

3.1.1.1 *Bt-Ms-gneiss (granite gneiss)*

Coarse grained, grey granite gneisses (Figure 6) can be found in large parts of Antiparos. A characteristic feature of this gneiss are the feldspar “Augen” and its distinct L-fabric.



Figure 6: Outcrop view of coarse Bt-Ms-Gneiss with Qtz veins near Sifnaikos bay (see Figure 5).

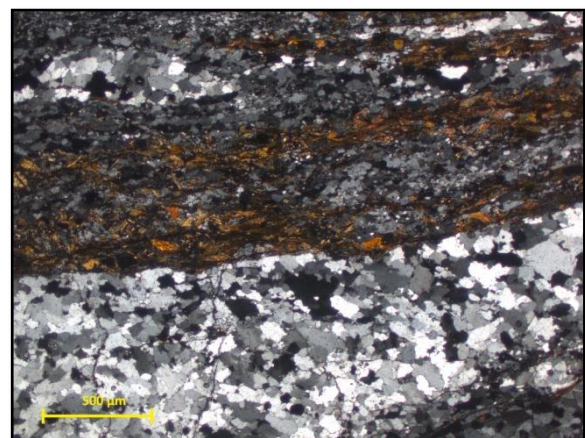


Figure 7: Thin section view of Bt-Ms-Gneiss with alternating layers of quartz and mica.

Biotite and muscovite are generally oriented parallel to the foliation of the rock. Within the biotites two different types can be differentiated: a reddish Fe-rich biotite and a greenish Mg-rich biotite. The peraluminous mineral assemblage indicates a granitic protolith. Pegmatites are abundant and most of them are rotated parallel to the foliation. The deformation microstructures of quartz show greenschist facies during deformation (Figure 7). Shear sense is indicated by the shape preferred orientation of quartz, Kfs-sigma clasts and shear bands with top to NE shear sense. The general orientation of the foliation and lineation is shown in Figure 8.

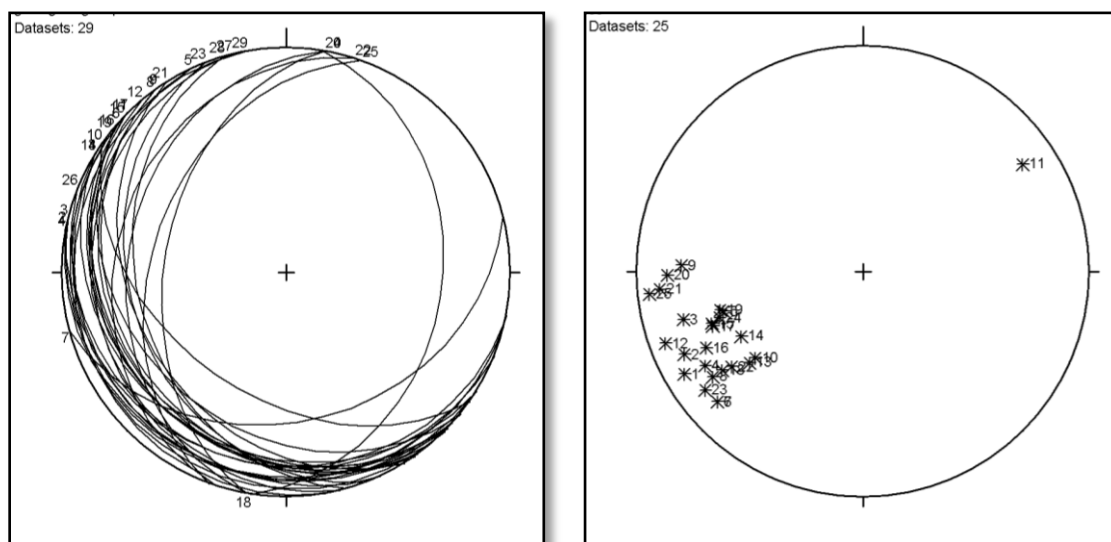


Figure 8: Orientation of the foliation and lineation of Bt-Ms-gneisses

3.1.1.2 *Ms-gneiss mylonite*

White to light greyish well foliated gneiss (Figure 9) occurs exclusively occurs between the coarse grained Bt-Ms-gneiss below and marbles above. In comparison to the previously mentioned gneiss, they are finer grained, show mylonitic foliation and rarely exceed a few meters thickness. SCC'-textures and mica fish show top to NE shear sense (Figure 9).



Figure 9: Close up view of Ms-gneiss mylonite near Ay. Ιωάννης/Ag. Ioannis (see Figure 5)

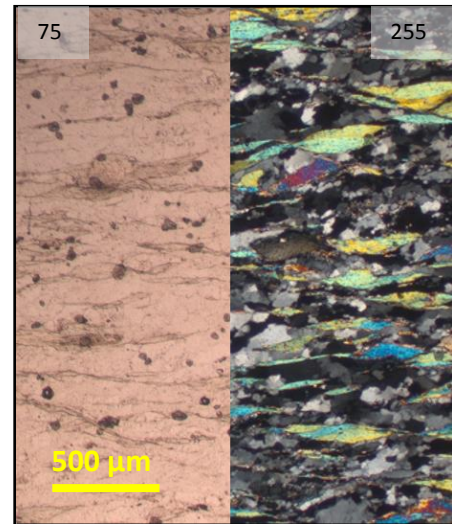


Figure 10: Mica fish in mylonitic gneiss. Thin section view in polarized light (left) and with crossed Nichols (right).

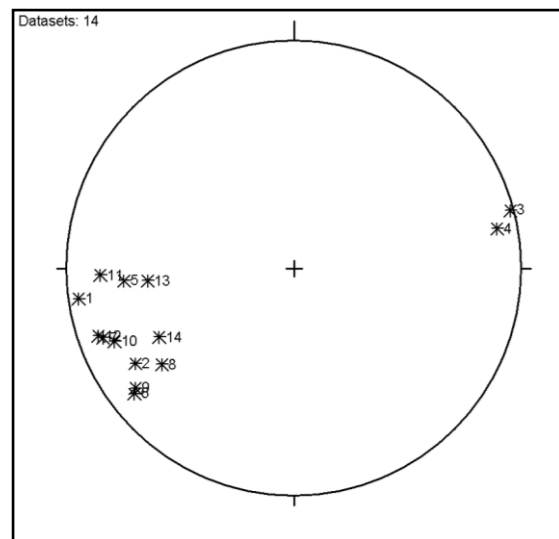
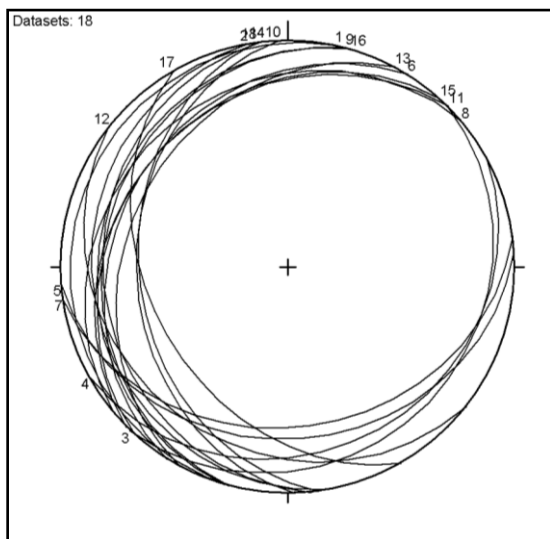


Figure 11: Orientation of the mylonitic gneiss foliation and lineation

3.1.1.3 Marbles

In the map of *Anastopoulos* (1963a) he distinguished two different types of marbles: calcitic (sometimes ankeritized) and silicified marbles. In the geological mapping of this study, calcitic marble (Figs. 12 and 13) could be recognized, however no silicified marble have been found (at least in the working area). Instead large areas with dolomitic marble could be mapped. It is possible that *Anastopoulos* (1963a) derived his interpretation because of the primary non-reaction of dolomite with hydrochloric acid. During this study it could be shown

that fine powder of dolomitic marble does react with hydrochloric acid. In some areas the marbles show impact of karstification as shown by the large Antiparos cave with a depth of some 70m [Shaw, 1992].

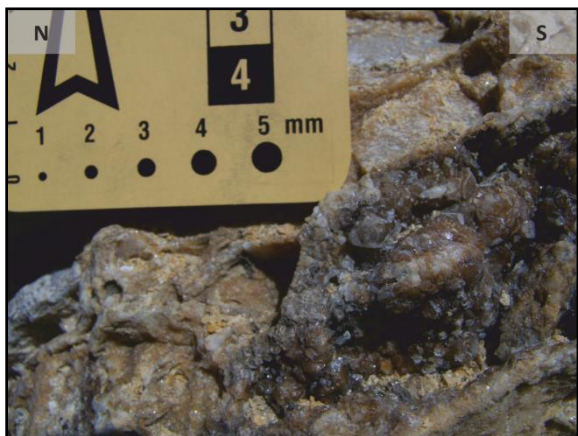


Figure 12: Coarse grained calcite crystals in hollows of calcitic marble near Sifnaikos bay.

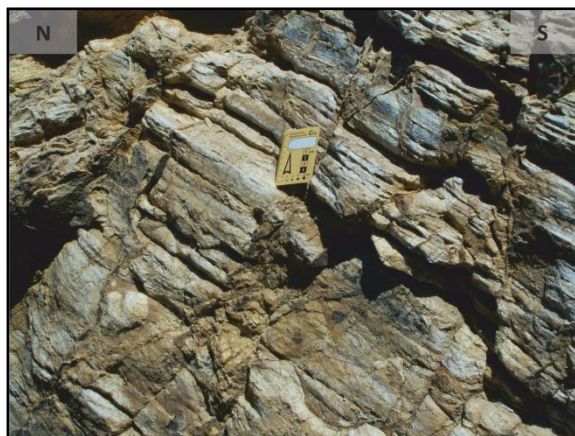


Figure 13: Outcrop view of foliated calcitic marble with fractures near Sifnaikos bay.



Figure 14: Calcitic marble with ore mineralizations. Found near Βούγλεση/Boyglesi at the northwestern coast.

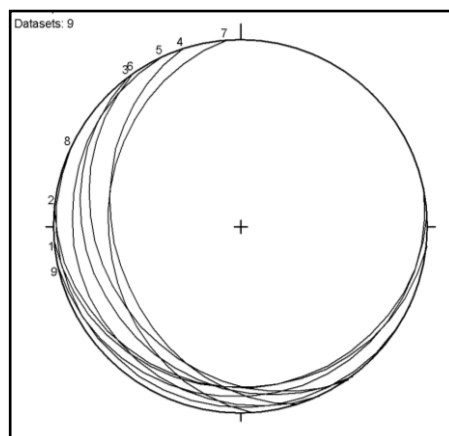


Figure 15: Orientation of the marble foliation.

Grain sizes of the marbles can vary between 0.3 and 0.8 mm. In general the dolomitic marbles are finer grained than the calcitic marbles. The general foliation is SE/ESE (Figure 15). Remains of slag are witnesses of ore mining in bygone times. On site remains of pyritic mineralization have been found near Livadia bay, now completely altered to limonite (determined by Dr. Götzinger; Figure 14)).

3.1.1.4 Marble cataclasite

In the geological map of *Anastopoulos* (1963a) marble cataclasites have been mapped as black micro- to cryptocrystalline fossiliferous limestone of upper Permian age. *Gymnocodium* *sp.* and *Staffella* *sp.* have been used for stratigraphic classification [*Papanikolaou*, 1978]. Thin-section analyses of several samples did not confirm these observations, instead these lithologies represent cohesive matrix supported marble cataclasite to ultracataclasite without any recognizable fossils (Figure 17). The rock is characterized by compaction (stylolites) and dissolution precipitation processes (*Passchier and Trouw*, 2005; see Figure 17). It occurs as thin lenticular intercalations within the calcitic marble at the NE-end of the island (Figure 16).



Figure 16: Outcrop view of the calcitic marble cataclasite. Characteristic are the calcitic veins that penetrate the cataclasite.

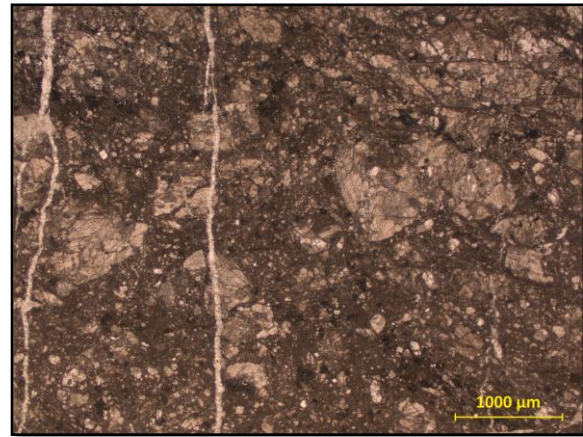


Figure 17: Thin section photo of the calcitic marble cataclasite (sample ED10/AP/5). Stylolites related to pressure solution can be seen as well as calcitic veins that cut through.

3.1.2 Sediments

3.1.2.1 Paleosols



Figure 18: Outcrop view of the paleosol horizons near Sifnaikos bay on top of granitic gneiss with some lenses of calcrete in between. Angular gneiss components are scattered throughout the paleosol.

Some outcrops show striking red layers of clay-rich sediments containing abundant angular fragments of the underlying metamorphites. This layer is found directly on top of the more or less weathered underlying metamorphic rocks. Sometimes some irregular layers or nodules of calcrete do occur within the paleosol (Figure 18). The paleosol is usually covered by calcarenite or calcrete.

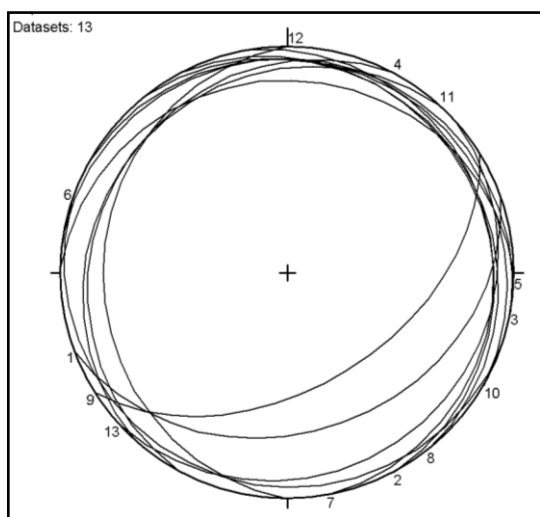


Figure 19: Orientation of the sedimentary bedding of the calcarenites

3.1.2.2 Calcareous sandstone

This sandstone is a highly porous, weakly cemented Quarternary calcarenite with a yellowish to beige color. It is also known from Mykonos [Varti-Mataranga and Piper, 2004] and many other Cycladic islands [Fytrolakis and Papanikolaou, 1977]. On Antiparos, its outcrops are found scattered over the island in small patches (maximum area 2-3 ha) from below sea level up to 80 m above sea level. Best outcrops of this sand-

stones can be found at the coast in morphological depressions or with its bedding parallel to the slope (Figure 19). It can hardly be found in internal parts of the island.

Grain sizes can reach up to 2 mm. Usually the largest clasts are fossils i.e. shell fragments, foraminifera and red algae. In a few cases marine terrestrial snails have been found. The calcarenite will be discussed in detail in chapter 5.4.

3.1.2.3 Calcrete

Calcrete (a combination of **caliche** and **concrete** [Gardner, 1972]) is *“a near surface, terrestrial, accumulation of predominantly calcium carbonate, which occurs in a variety of forms from powdery to nodular to highly indurated. It results from the cementation and displacive and replacive introduction of calcium carbonate into soil profiles, bedrock and sediments, in areas where vadose and shallow phreatic groundwaters become saturated with respect to calcium carbonate”* [Wright and Tucker, 1991]. Calcrete may occur in a variety of shapes ranging from layers, nodules to crusts [Wright and Tucker, 1991]. It is estimated that nearly 13 % of the total land surface (20 million km²) is made of calcrete [Wright and Tucker, 1991]. Its predominant occurrence is in regions where precipitation exceeds evaporation only for a few months per year. Therefore calcrete presents a good indicator for semi-arid (paleo-) climate.

3.1.2.4 Modern day dune sands

At present only a few eolian dunes exist in the northwestern part of Antiparos at Livadia, Sifnaikos (Figure 20) and at the beach near Antiparos camping place. They consist mainly of medium grained, well sorted, primarily siliciclastic sand (see 0). The overgrowth by vegetation indicates that all of these dunes are currently inactive.



Figure 20: Recent wind dunes near Sifnaikos bay with vegetation overgrowth. Size of the yellow Trimble recon GPS device: 16 cm

3.1.2.5 Modern beach sands

The coastal line of Antiparos is characterized by mostly steep cliffs with rare embayments with sandy beaches. The ratio between steep cliffs (approximately 75%) and flat coastal plains (approximately 15%) equals roughly the ratio described for Paros by *Evelpidou et al.* (2002).

4 Lithologies & Methodology

4.1 Samples

During the field survey in July 2009 71 samples have been taken in total. Together with four more samples taken by Erich Draganits in June 2010, there exist 75 samples (unconsolidated and consolidated rock). For detailed sample listing and sample localities see appendix.

4.1.1 Calcarenite, calcrete and calcretized calcarenite

Calcrete and Calcarenite samples have been taken in sizes of around 7 cm x 7 cm x 7 cm with their upright orientation indicated.

4.1.2 Unconsolidated sediment

Samples (c. 300-600 g) of all recent/subrecent sand dunes have been taken for grain size analysis and determination of remains of organisms. Samples of beach sand have been taken from several beaches with the sampling point in the swash/backwash zone (Figure 21).



Figure 21: Sampling method for beach sediments in this thesis. The dotted line represents the line of swash-backwash; the triangles indicate the sampling point.

4.1.3 Paleosol

Samples of red paleosol (200-500 g) have been collected from outcrops which are mainly exposed directly at the coast or faces of abandoned quarries.

4.1.4 Fossils

Recent and fossil shells have been collected from beach sands as well as from the calcarenite. The remains consist of sub recent marine shell debris (gastropods, bryozoans, corals, bivalves,...) and fossil terrestrial snails (see section 5.4.3).

4.1.5 Metamorphic rocks

Representative oriented samples from all metamorphic rocks in the area of investigation have been taken. The samples include calcitic marble, dolomitic marble, mylonitic Ms-gneiss, coarse grained Bt-Ms-gneiss and marble cataclasite.

4.2 Methodology

4.2.1 Geological mapping of the working area

Geological mapping included the documentation of the various lithologies and deformation as well as sedimentary structures. A GPS (Trimble Recon) and print outs of satellite images (Quickbird images derived from Google maps) have been used for the compilation of the geological map at the scale of 1:10,000 as well as recording outcrops in detail. Five outcrops are displayed in detail (see 5.1).

4.2.2 Thin section microscopy

36 thin sections have been produced in the thin-section laboratory of the Department of Geodynamics and Sedimentology by Sigrid Hrabec, Claudia Beybel and Leopold Slawek. Usually calcarenites have been cut perpendicular to the sedimentary bedding (where possible) and in XZ-orientation for the metamorphic samples. The sedimentary thin sections also were classified regarding microfacies in terms of *Flügel* (2010). A list of thin sections is attached in the appendix.

4.2.3 Scanning electron microscopy

Three gold sputtered samples (calcarenite, calcrete and calcretized calcarenite) were investigated using a Jeol JSM 6400F scanning electron microscope at the University of Vienna. The samples were analyzed with 10 kV and a working distance between 17 mm and 21 mm.

4.2.4 XRD analysis of paleosol samples

Powder X-ray diffractometry is based on specific diffraction patterns of X-ray beams on atomic crystal lattices. The diffracted beams can be used to deduce the lattice spacing and from this determine the mineral [*Snyder and Jenkins*, 1996].

4.2.4.1 Preparation of the paleosol samples

A PANalytical X'Pert Pro X-ray diffractometer (CuK α -radiation, 40 kV, 40 mA, step size 0.0167, 5 s per step) was used to derive a qualitative analysis of the mineralogical composition of the samples AP0912, AP0918, AP0919, AP0932 and AP0933 and also the weathered gneiss mylonite of sample AP0937, which originates from top of a mylonitic gneiss at the coast near Agios Paraskenè. First the mineralogy of the bulk sample was analyzed and in a second step only the clay fraction (<2 μ m) of the sample was examined. Philips X'Pert HighScore software was used to interpret the data obtained from the bulk mineralogy. Philips X'Pert Data Viewer was used to arrange and layout the obtained XRD plots.

The bulk samples were prepared by powdering the samples in an automated grinder and refine the powder by hand with an agate mortar. The clay fraction was separated by adding a 1:1 hydrogen peroxide/deionized water mixture to each sample to remove the organic matter. The samples had to react for a few days until the reaction was finished. Subsequently the samples were dispersed using an ultrasonic homogenizer at 400W for 10 minutes.

The <2 μ m fraction was separated with an Atterberg cylinder which separates particles upon their settling velocity [Kovács *et al.*, 2004]. After the addition of sodium polyphosphate to prevent coagulation of particles and a settling time of 24 hours and 33 minutes [Köster, 1964] only the grain sizes <2 μ m were left in the water column. This suspension was dried at 60°C. The dried sediment was further homogenized with an agate mortar.

4.2.4.2 Analysis of the paleosol samples

About 10mg of each <2 μ m sample were dispersed in 1 ml deionized water with an ultrasonic homogenizer and subsequently the homogenous suspension was applied on a circular glass slide. After a first series of measurements each sample was saturated with ethylene glycol to determine the possible presence of expandable-lattice clay minerals. Another series of measurements was undertaken with KCl₂ and MgCl₂ saturated samples whereupon the K saturated sample was treated with ethylene glycol and the Mg saturated sample was treated with glycerol to distinguish between smectite and vermiculite. Additionally the samples were heated to 550°.

4.2.5 Grain size analysis

4.2.5.1 Sieve analysis

Eight samples of modern recent eolian dune and beach sands (from the swash-backwash zone) were analyzed regarding grain size distribution by sieve analysis.

Prior to sieving approximately 110 to 140 g of each sample were alloyed with a 1:1 mixture of deionized water and hydrogen peroxide to eliminate the impact of organic matter on the analysis and treated with ultrasonic for disaggregation. Afterwards excess liquid was removed without draining any sediment material. Subsequently the samples were dried, weighed and wet-sieved whereas the mesh sizes used were: 2.0 mm, 1.0 mm, 0.5 mm, 0.25 mm, 0.125 mm and 0.63 mm. Each grain fraction was collected, dried and weighed again. The percentage of the finest grain fraction ($<63 \mu\text{m}$) was deducted by back-calculation, as the finest fraction was not collected.

For the calculation of the grain size distribution and statistics GRADISTAT v. 6.0 by Simon Blott was used. GRADISTAT displays mean, sorting, skewness and kurtosis of the grain distribution for the method of moments (geometric, arithmetic and logarithmic) and for the Folk and Ward (1957) parameters (in μm and ϕ).

4.2.5.2 Image analysis of thin sections

For analyzing the thin sections, JMicroVision 1.2.7 [Roduit, 2007] was used. This freeware application was used to determine porosity distribution and perform point counting on

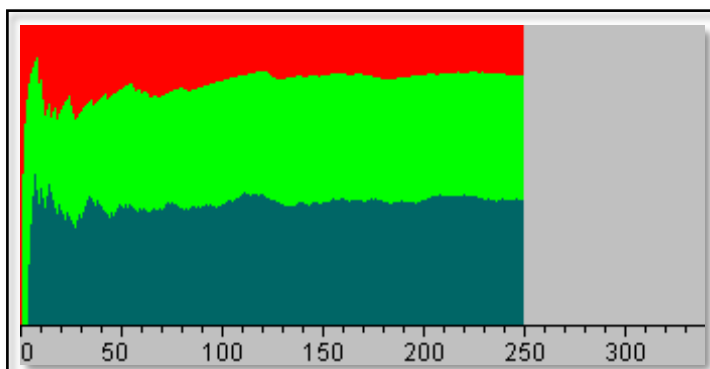


Figure 22: Example point counting evolution plot of AP0914. Dark green = bioclasts, light green = lithoclasts, red = porosity

screen. The spots of point counting were chosen by the random generator of the software. 250 points were counted in all sections at the same scale to maximize comparability and to ensure a flat and stable evolution curve (Figure 22).

4.2.6 Terrestrial snails

The taxonomy of the gastropod samples (AP0959, AP0963A, AP0963B, and AP0963C) which have been found in the calcarenite has been analyzed by Prof. Edmund Gittenberger of the Museum of Natural History in Leiden, Netherlands.

4.2.7 Radiocarbon dating

Radiocarbon analysis is a wide spread method for dating samples containing carbon younger than 62,000 BP [Plastino *et al.*, 2001]. The radioactive isotope ^{14}C is produced in the stratosphere by the interaction of cosmic rays and ^{14}N . The newly formed ^{14}C quickly gets oxidized to CO_2 which enters the food chain through absorption of plants via photosynthesis [Bowman, 1990]. Three basic assumptions are important [Bowman, 1990]:

1. The ^{14}C half life is known.
2. The concentration is equal for all parts of the system.
3. There is no more accumulation of ^{14}C after the organism's death.

The terrestrial snail sample AP0963A was selected for ^{14}C dating by Accelerator Mass Spectroscopy (AMS) and sent to the “AMS and radiocarbon dating facility” at the University of Lecce (Italy) where the analysis was carried out. According to their laboratory procedure, macro containments were removed from the samples by mechanical handpicking under an optical microscope. Furthermore the sample was chemically treated with H_2O_2 (30%) in an ultrasonic bath to remove any possible source of contamination. The purified sample material was then converted to carbon dioxide by combustion in sealed quartz tubes at 900° for 8 hours. The obtained carbon dioxide was converted to graphite at 550°C by using ultra-high purity Hydrogen as reducing agent and 2mg iron powder was used as catalyst. The sample yielded enough graphite to allow accurate determination of the radiocarbon age by AMS. Calibration was done using the software Calib 6.0.2 [Stuiver and Reimer, 1993] with the INTCAL09 database [Reimer *et al.*, n.d.].

5 Results

5.1 Lithostratigraphic sections²

This section shows detailed lithostratigraphic sections 5 different outcrops of Quaternary sediments in northwestern Antiparos. Locations of each section can be seen in Figure 23. A larger version of the geological map (scale 1:10,000) is attached in the appendix. Lithologies, orientation of the metamorphic foliation, brittle faults and location of mass movements are documented in the geological map. Also the location of 3 geological profiles (see appendix) are drawn in the map.

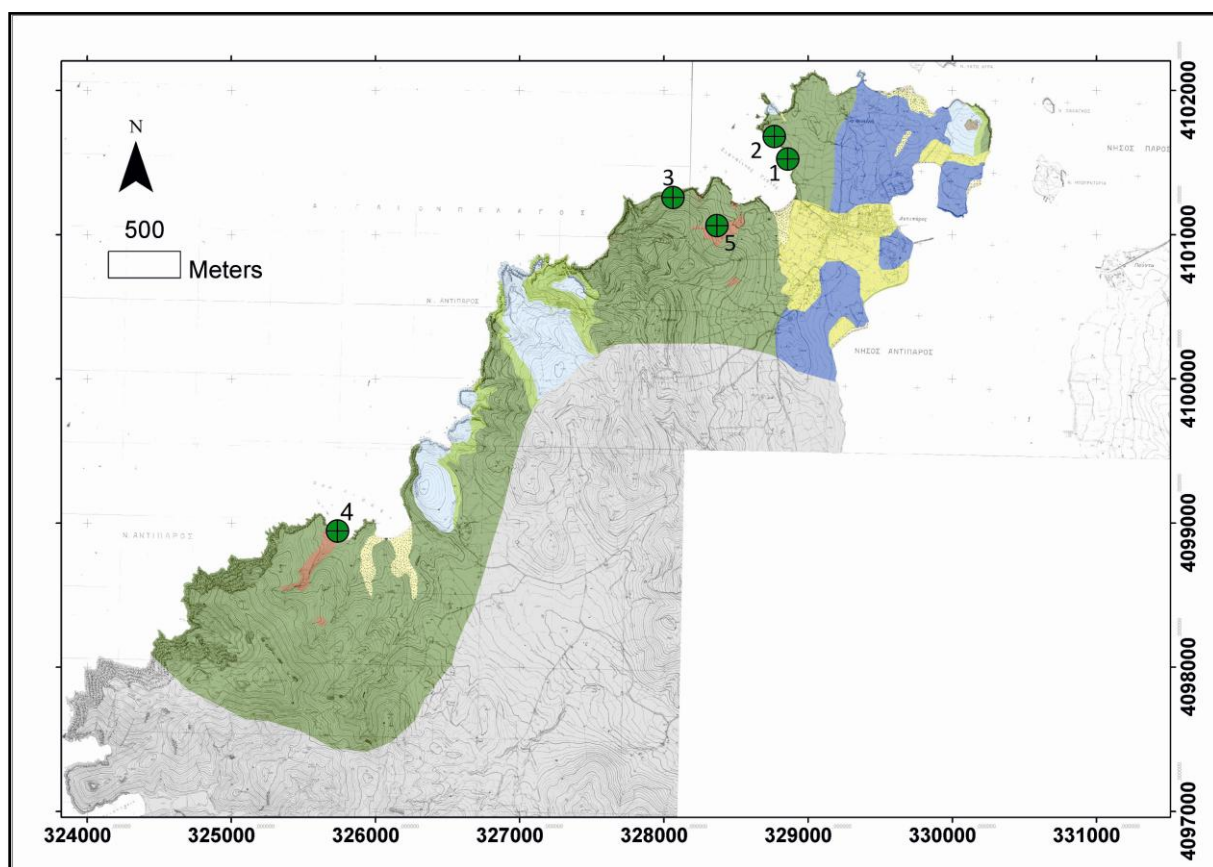


Figure 23: Locations of measured sections in outcrops. Numbers represent section numbers. The green colors represent the Bt-Ms-gneiss and Ms-gneiss mylonite. Purple and light blue are dolomite marbles and calcitic marbles. The brownish patch in the northeastern part represents marble cataclasite. Dune and beach sands as well as undifferentiated alluvium are yellowish. The calcarenites are red.

² All profiles were recorded and are described from bottom to top.

5.1.1.1 Section 1 (Figure 24; E 4101492.691, N 328891.354)

Section 1 (Figure 24 and 25) is situated directly at the coast, approximately 40 m north of the “Sunset Bar” near the Sifnaikos beach at W-Antiparos (Figure 23). The vertical section comprises a 260 cm thick sedimentary succession, resting unconformable on coarse Bt-rich granite-gneiss. Above the gneiss a strongly weathered layer (30-90 cm thick, bed 1) consists mostly of gneissic components, floating in weathered matrix parallel to sub-parallel to the metamorphic foliation. The fine grained (Si-fs) matrix mainly consists of carbonate material, giving the bed yellowish beige to almost white color. Generally the grain size in this layer rarely exceeds 3 mm in diameter. Nevertheless there are platy, angular gneiss components of up to 25 cm. In the upper-most 15-20 cm of this bed the coloration changes in patches from yellowish beige to reddish brown color.

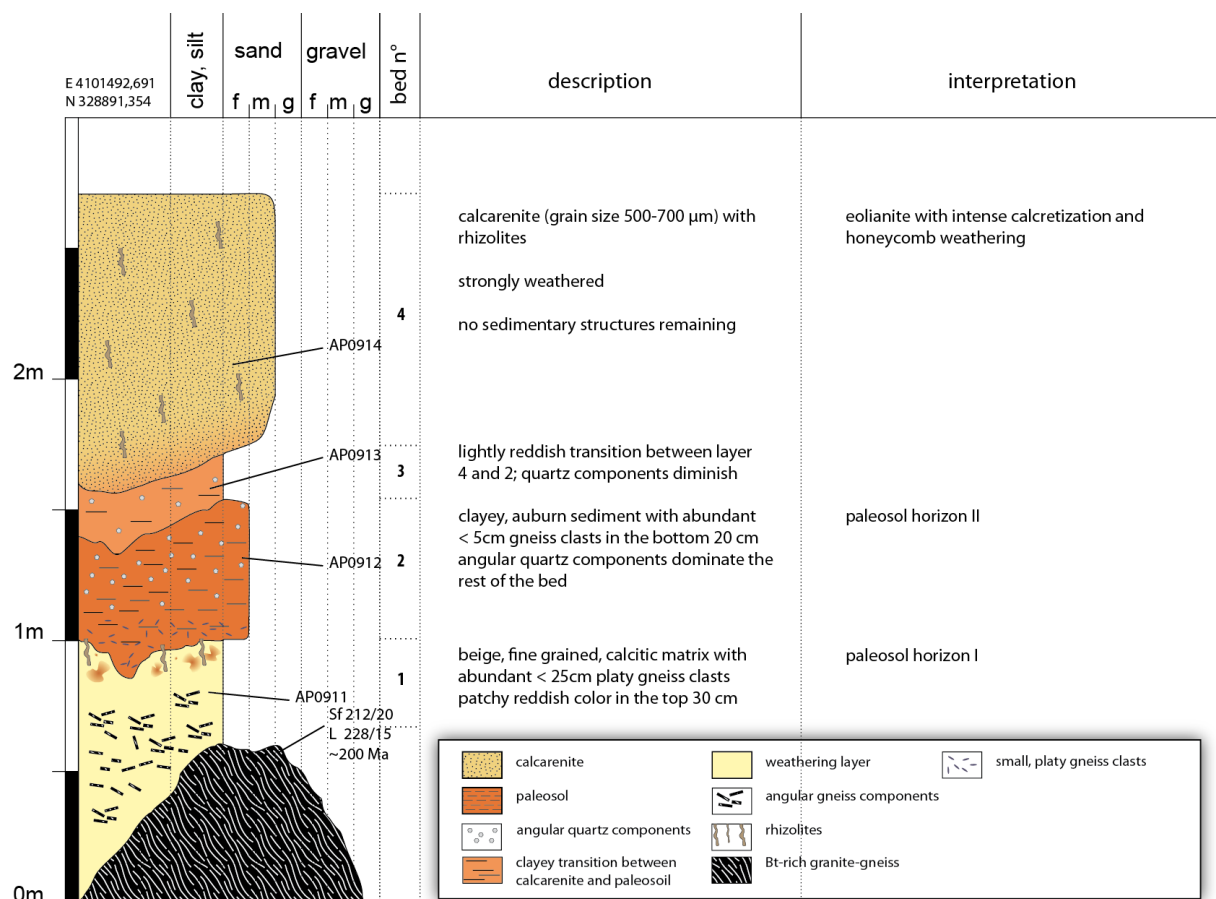


Figure 24: Section 1 located near Sifnaikos bay. The Bt-Ms-gneiss is overlain by a succession of paleosol horizons and a bed of calcretized calcarenite with abundant rhizolites. In Figure 20 a photograph of the section is shown.

The contact to bed 2 above is sharp and very irregular with a probable erosive relief of up to 15 cm. Bed 2 is a red to auburn, 35-58 cm thick layer with a silty to fine sandy matrix with

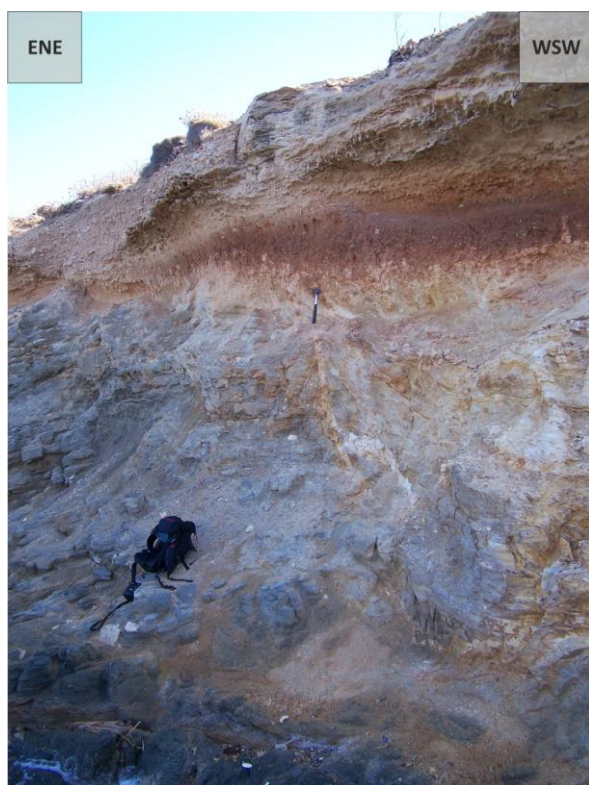


Figure 25: Outcrop of section 1 near Sifnaikos bay. 2 paleosol layers can be seen in this picture. Also note the abundant rhizolites in the topmost calcretized calcarenite.

distinct clay content. Larger angular clasts (approx. 1 cm Ø), are floating in this layer. Most of these clasts are dominated by angular quartz (for mineralogy of this layer see section 5.3.1 → XRD). Bed 3 is an 18 cm thick layer with gradual contacts to bed 2 and bed 4. This layer is characterized by the decrease in the contents of clay as well as pebbly clasts and also the change in color to a brighter brownish red. The matrix is finer than in bed 2 with a constant content of fine sand. In the upper third of the layer, coarse (approx. 2 cm Ø), angular quartz components can be found.

Above bed 3 follows about 120 cm of strongly altered calcarenite. Because of the strong weathering of this layer, it was not possible to distinguish between different layers in this lithology. In the first 20 cm there's a gradual decrease in the reddish coloration of bed 3, changing to a yellowish beige. This still lightly red, fine grained (approx. 100 µm) part of the layer is only slightly cemented. The top of layer 4 consists of calcarenites with well preserved quartz and poorly preserved bioclastic components. Grain sizes range from 500 to 700 µm. A very characteristic feature of this layer is the abundance of rhizolites.

5.1.1.2 Section 2 (Figure 26; E 4101682.127, N 328737.365)

Section 2 is situated 300 m north of the “Sunset Bar” directly at the coast (Figure 23). The outcrop displays a sedimentary succession of about 3 m thickness (Figure 26 and 27).

The sedimentary deposits lie unconformably above dark, coarse grained, biotite-rich granitic-gneiss (sf 099/31; L 056/16) with distinct quartz layers. Towards the top of the gneiss weathering becomes more and more pronounced with fine grained calcitic veins penetrating into the metamorphic rock. The weathered top of the gneiss is covered unconformably by a brownish red, clayey horizon (bed 1) ranging between 22 and 45 cm in thickness with abun-

dant, floating mS components. Some larger clasts exceed 2 cm. The larger components are almost completely made up of angular gneiss components. In bed 2 (27 cm thickness) a decrease of the sand particles to fS and a decrease of the clayey matrix can be observed. Angular gneissic components (4-5 mm Ø) are common in this layer.

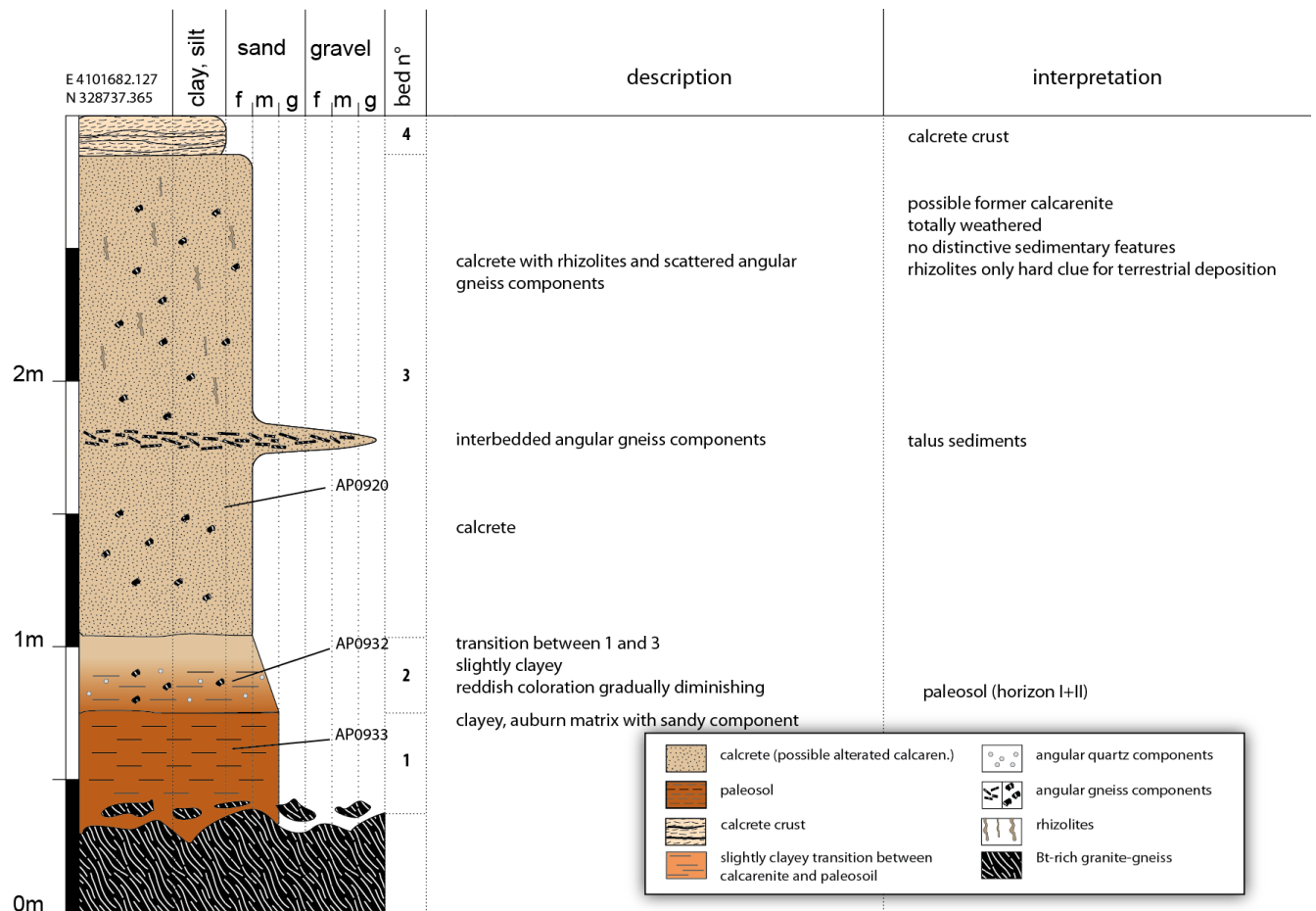


Figure 26: Profile section 2 located 300m north of the Sunset bar (Sifnaikos bay). Again two paleosol horizons are overlain by calcretized calcarenite with scattered coarse gneiss components. Also rhizolites were recorded in the top 1.3 m. For a photograph of the section see Figure 22.



Figure 27: Outcrop of section 2; 300 m north of Sifnaikos beach. The thickness of the calcretized calcarenite diminishes towards north. The section is capped by a calcrete crust.

A massive, beige horizon (232 cm) lies conformably on top of layer 3. Due to excessive re-crystallization and obliteration of former sedimentary structures by calcrete it can only be speculated, that this part of the section represents former calcarenite. A distinct band of coarse, angular gneiss components at about 170 cm of the section indicates traces of the former bedding and is interpreted as talus sediments. Some rhizoliths could be observed. The top of the section is formed by horizontally layered calcrete crusts with rhizoliths.

5.1.1.3 Section 3 (Figure 28; E 4101279.608, N 328084.361)

Section 3 is located east of Panagá bay (Figure 23) where the Quaternary sediments fill up a small morphological depression with maximum thickness in the lowest parts and gradually smaller thickness laterally (E-W). The base of the almost 6 m thick profile is situated about 30 m a.s.l. The base of the sedimentary succession is made up of coarse, biotite-rich granite-gneiss with macroscopic visible L-fabric. The top of the gneiss is strongly weathered. Above follows bed 1, reddish to brown-red fine to medium sand with probable clay matrix³. At the basal 20-30 cm of bed 1 very coarse (<25 cm), platy, angular and poorly sorted gneissic components are common. At about 50 cm of the profile base a lenticular calcrete crust lies within bed 1. Bed 2 consists of a very fine grained calcarenite with lenticular bed morphology. A thin section sample (AP0941) was taken from this bed at 5 cm (Figure 28).

³ It wasn't possible to take a sample from this layer, as it was directly situated at a steep cliff.

Above follow about 430 cm of porous calcarenite which can be subdivided into 6 individual beds (bed 3-8). Bed 3 is medium grained, cross-bedded sandstone with foresets dipping with 9° towards the slope. In the uppermost part of bed 3 the cross stratification gradually changes to a more or less horizontal pin stripe lamination (distance of the lamina 2-3 mm) which continues in bed 4 and 5. These two layers are finer grained (fS-mS) than bed 3 and expose animal tracks in a vertical section (see section 5.4.6 for further detail) with increasing number of tracks towards the top. Sample AP0942 was taken from bed 4. Bed 6 is a 95 cm thick calcarenite with few distinct sedimentary features due to intense weathering. Succeeding bed 7 (120 cm) again exposes abundant animal tracks. Samples AP0943, AP0944 and AP0945 were taken from this bed.

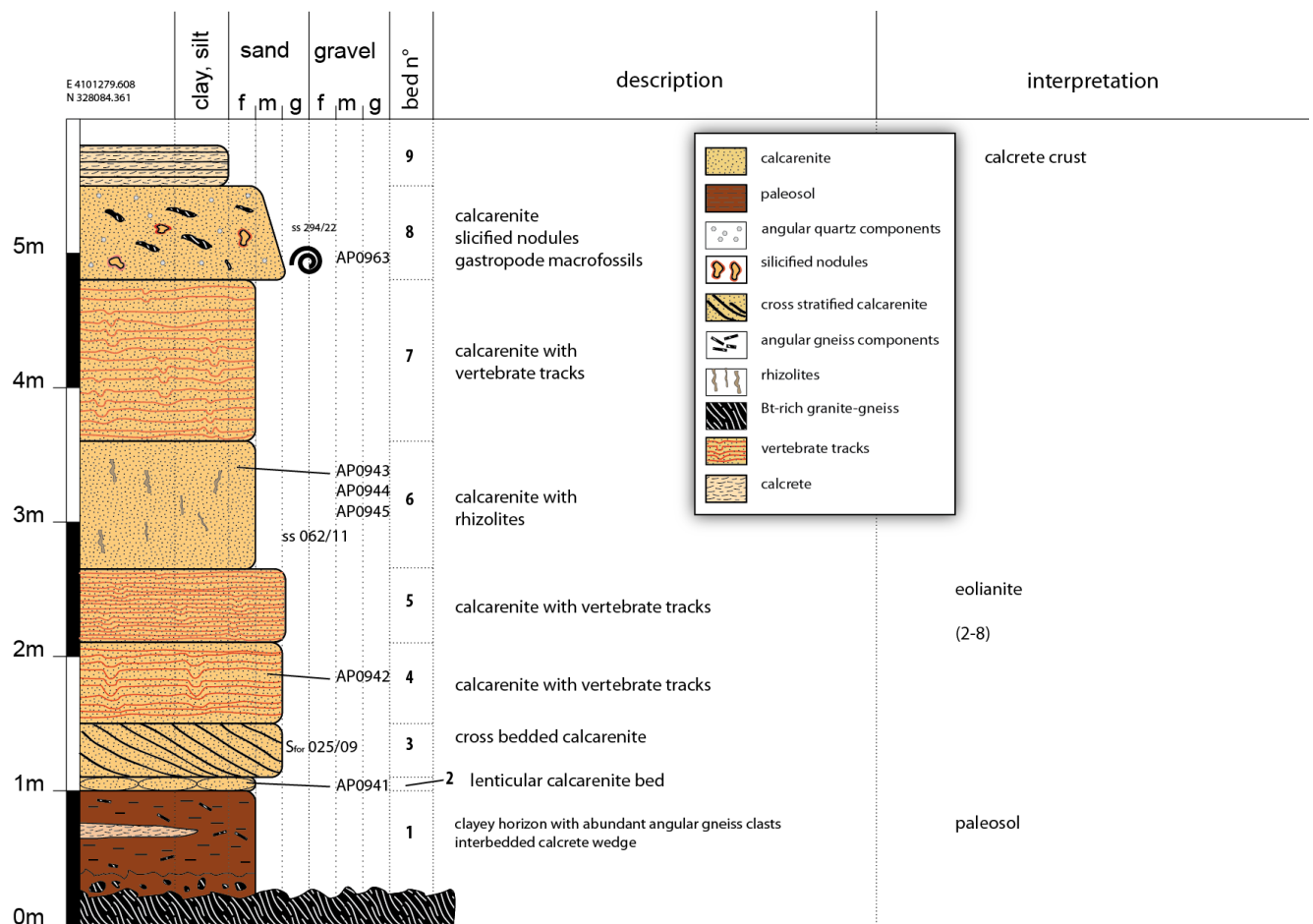


Figure 28: Profile section 3 east of Panagá bay. In this section vertebrate tracks are abundant in beds 4, 5 and 7. Also terrestrial snail shells were found.

The top most layer of the calcarenite succession is a strongly weathered, relatively coarse grained (mS-cS), laminated (SS 001/16) calcarenite at the base. It shows fining upwards grain-sizes and increasing alteration into calcrete towards the top.. Some parts in this layer

the calcarenite/calcrete show silicified nodules (Figure 28). Additionally, bed 8 contains coarse, poorly sorted, sub-rounded clasts (reworked, reddish calcarenite; quartz; granitic gneiss ranging from 7-40 cm in diameter), oriented more or less parallel to the slope. The size of the clasts is clearly decreasing laterally in eastwards direction. A 30 cm thick calcrete crust (bed 9) with horizontal to sub-horizontal layering is developed at the top of the sedimentary succession.

5.1.1.4 Section 4 (Figure 29; E 4098923.086, N 325743.630)

Section 4a is situated to the North of “Permaxiónia (Περμαχιόνια)” and to the west of the bay of “Ormos Leivadi (Όρμος Λειβαδι)” directly at the coast (Figure 23). The Quaternary sediments are deposited parallel to the underlying relief and can be traced even below present sea-level (Figure 30). At this location two profiles (4a and 4b) were recorded, because the sedimentary strata are accessible from the eastern as well as the western side. The western side allowed a more detailed investigation of the sedimentary structures due to lesser weathering. In General it was very difficult to properly recognize sedimentary layering in detail at section 4a.

The profile base consists of 40 cm of beige, coarse grained, carbonate sandstone with mainly angular gneiss clasts (up to 15 cm) floating in the sandy matrix. The mostly platy, larger components show slight imbrications towards the sea. Bed 2 (26 cm) is made up of coarse grained, carbonate sandstone but in contrast to the lower layer, large angular gneiss clasts are missing. In this layer the coarse gneiss components range between one and two centimeters in size. In fact it appears that bed 1 and 2 display a fining upward concerning the coarse, angular gneiss and quartz components.

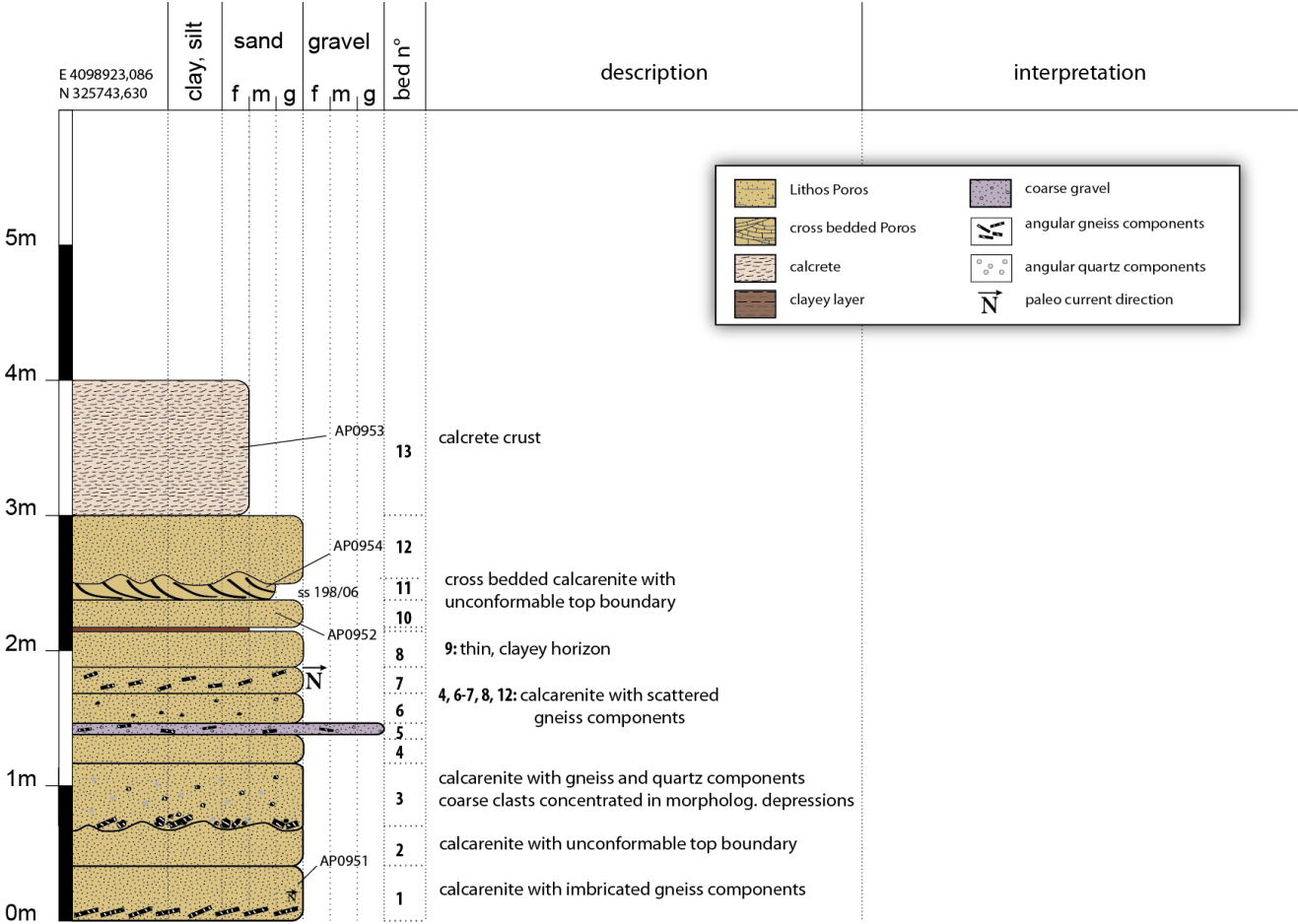


Figure 29: Profile section 4a north of Permaxiónia. The sedimentary succession of calcarenite can be subdivided into 12 beds. Bed 3 and 12 lie unconformably on top of bed 11 (with cross bedding) and bed 2. In bed 3 the troughs of this unconformity are filled with coarse material which is showing fining upward (channel infill). The succession is capped by 1 m of calcrete. See Figure 25 for a photograph of this section.

Layer 3 (26-50 cm) lies unconformable on top of bed 2, eroding into the lower bed. It shows small channels where coarse gneiss and quartz components are accumulated. The coarse components float again in a coarse sandy matrix. Bed 4 (22 cm) consists of coarse carbonate sandstone with floating angular sub-centimeter gneiss clasts. Again, the sedimentary succession of bed 3 and 4 gives the impression of a fining upward of the coarse grained clasts. Layer 5 (9 cm) again consists mostly of up to 10 cm large, platy, angular gneiss clasts in a sandy matrix overlain by layer 6 with 3-4 cm large gneiss clasts.



Figure 30: Outcrop of section 4 near Livadia beach.

The same applies to bed 7 and 8 (20 and 28 cm) where the grain size of the gneiss and quartz components decreases from 12 cm to 0,8 cm and less. Bed 9 is atypical in this profile succession, as the predominantly coarse sandy grain size drastically decreases to a fine sandy grain size with a distinct clay component, giving the layer a slightly red coloring and appearance. This 3 cm thin layer is quite soft and less weathering resistant compared to other beds. Bed 10 comprise coarse sandy matrix with imbricated (towards north → down slope), 1 cm large, gneiss components. Bed 11 (18 cm) shows low angle cross-stratification (198/06) in the finer grained matrix (mS). Angular gneiss and quartz components are rare. Channel deposits of bed 12 (50 cm) cut unconformably into the lower stratum. The matrix changes from mS to gS again. Near the top bed 12 becomes finer grained and gradually changes into 1 m thick massive calcrete (bed 13) with a crust on top of it.

5.1.1.5 Section 5 (Figure 32; E 4101028.850, N 328333.150, 23.7 m a.s.l.)

Profile 5 (Figure 32, Figure 31) is located near the chapel “Agios Paraskenè (Αγ. Παρασκευή”



Figure 31: Outcrop of section 5 near Agios Paraskenè. A 95 cm bed of calcrenite with gastropod macrofossils is overlain by coarse talus material.

at 24 m above sea level facing towards the South (Figure 23). It probably represents an old quarry for calcrenite, as indicated by the quarry face (Figure 31) and some blocks left.

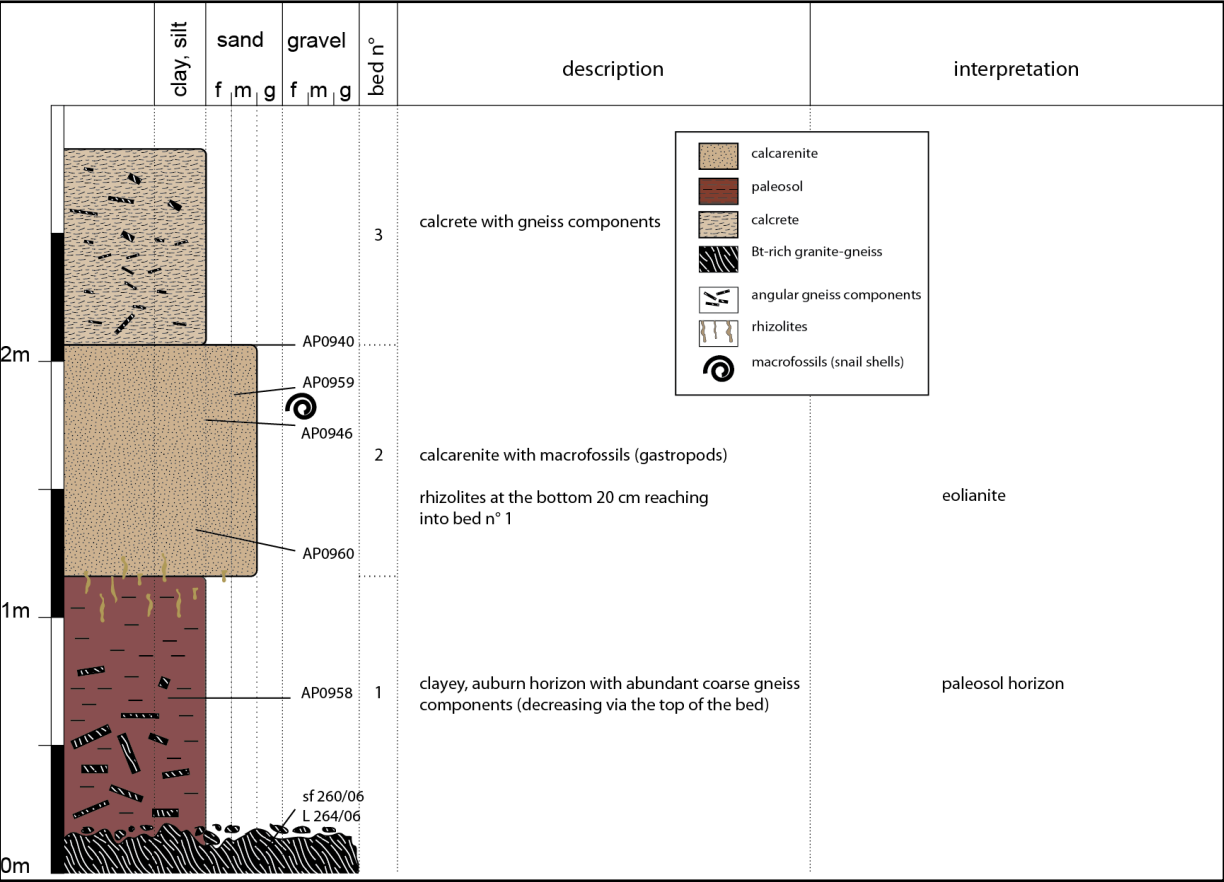


Figure 32: Profile section 5 near Agios Paraskenè. Coarse grained calcarenite overlies a reddish-brown layer with abundant coarse angular gneiss clasts. Terrestrial gastropods have been found in this section (see section 5.4.3). See Figure 26 for a photograph of the recorded section.

The base of the section is formed by coarse grained Bt-rich granitic gneiss as before (S 260/06, L 264/06). The sections starts with a brownish red, clayey layer (bed 1) with coarse, platy gneiss clasts up to 30 cm length without recognizable preferred orientation. Towards the top of this bed, the coarse gneiss components almost disappear and calcarenite with rhizolites is found at the upper bed boundary. Bed 2 (95 cm) consists of mS calcarenite filling the topography of the underlying clayey layer. No sedimentary structures are visible due to strong weathering. Bed 2 contains remains from terrestrial snails which have been sent to Prof. Gittenberger at the Museum of Natural History, Leyden, Netherlands. The top of the sedimentary succession (bed 3) is made up by abundant coarse, angular talus material (granite-gneiss) with no distinct orientation and fine grained carbonatic matrix. The chaotic texture of this layer may be due to former agricultural activities as indicated by plowed fields nearby.

5.2 Modern beach sand and dune sands



Figure 33: Overview of Livadia bay with beach sands (highlighted in red) and inactive eolian sand (highlighted in blue). The steep cliffs behind the bay are made of calcite marbles lying on top of granite gneiss.

Seven samples of loose modern day beach and dune sands (Figure 33) have been taken (4 beach samples and 3 dune samples) for grain size analysis by manual sieving. Sampling locations are shown in Figure 34. A complete sample map is attached in the appendix.

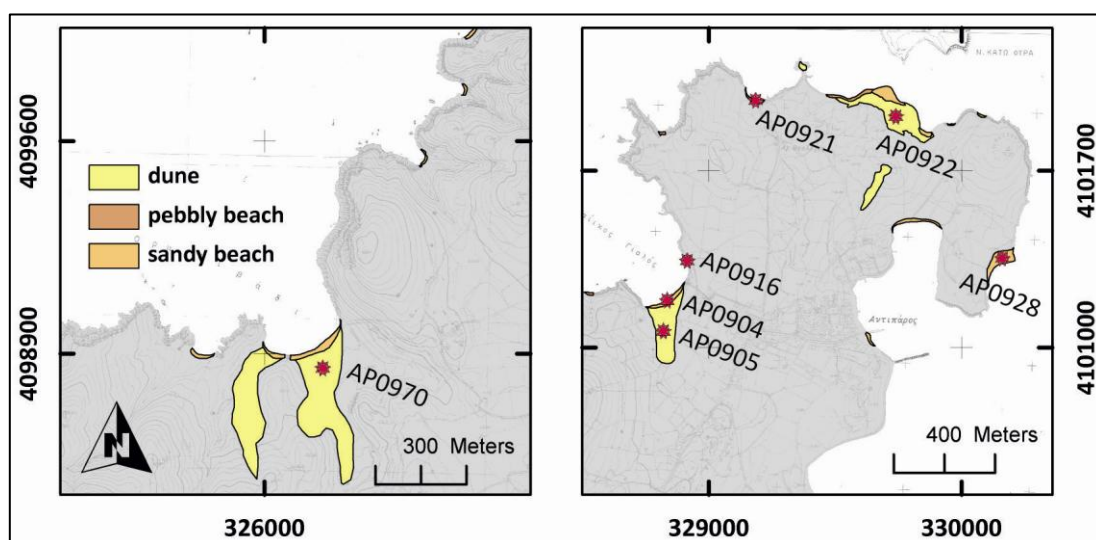


Figure 34: Sample locations of analyzed beach and dune sands.

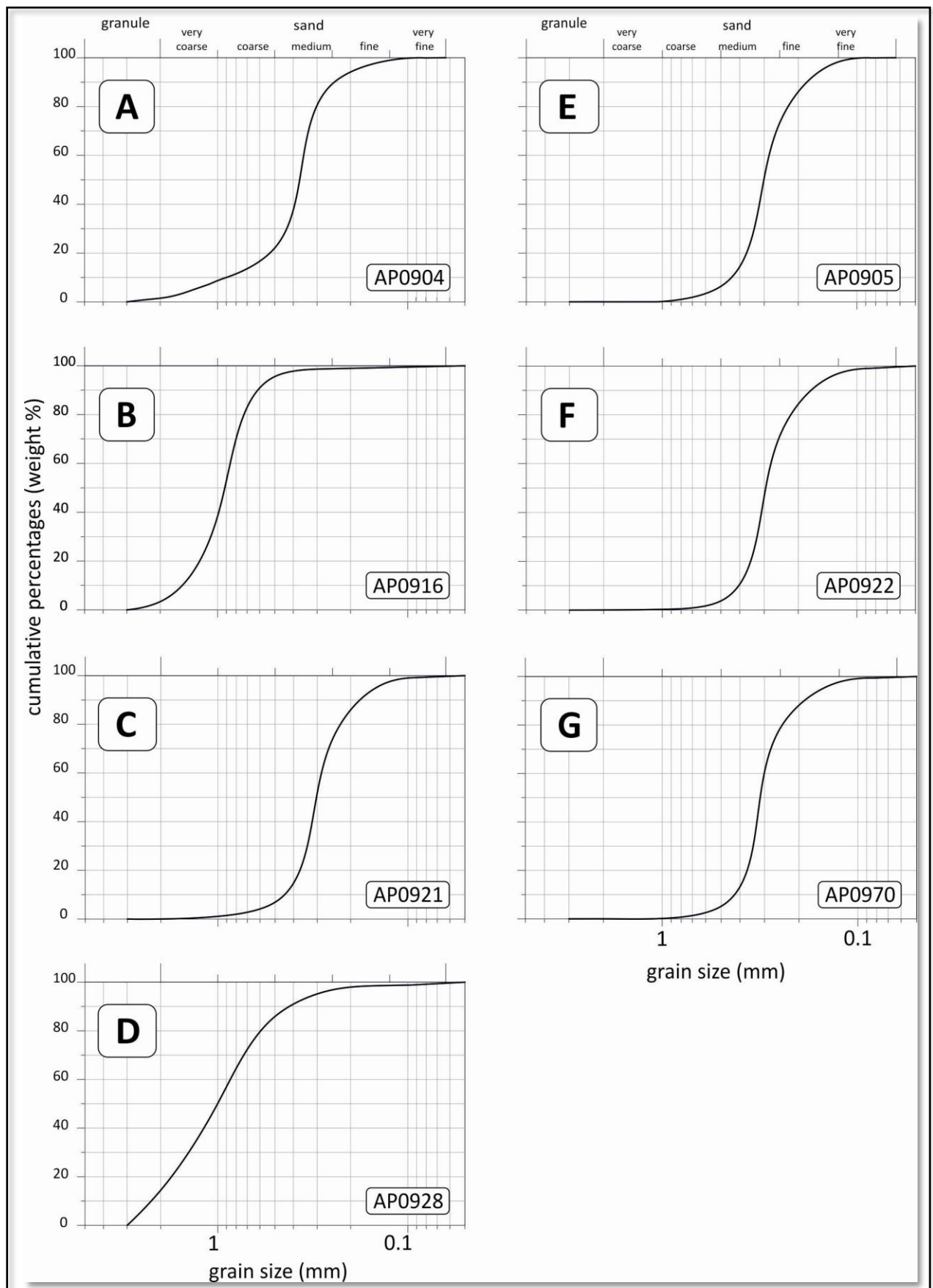


Figure 35: Cumulative grain size curves for beach sands (A-D) and dune sands (E-G) of northern Antiparos.

5.2.1.1 Beach sands

Sandy and pebbly beaches are scattered all along the coast of Antiparos. Larger bioclasts (shell fragments, bryozoans, corals...) are rare, one example is e.g. at the eastern coast (west of Agios Seyridon/Αγ. Σηυριδον). In general the siliciclastic components account for up to 70% of the clastic material. The rest consists of variably preserved bioclastic material, like foraminifera (e.g. Spiroloculina), marine gastropods, bivalves, corallinacean red algae and fragments of bryozoans.

		AP094	AP0916	AP0921	AP0928
	ANALYST AND DATE:	LB, 9/10/2010	LB, 9/10/2010	LB, 9/10/2010	LB, 9/10/2010
	SIEVING ERROR:	0,9%	1,0%	0,6%	1,2%
	SAMPLE TYPE:	Bimodal, Moderately Sorted	Bimodal, Moderately Well Sorted	Bimodal, Moderately Well Sorted	Polymodal, Moderately Sorted
METHOD OF MOMENTS Arithmetic (μm)	MEAN ($\bar{x}_a$):	455,9	865,4	293,5	1039,6
	SORTING (σ_a):	454,7	413,7	142,8	650,8
	SKEWNESS (Sk_a):	3,291	1,694	3,525	1,018
	KURTOSIS (K_a):	13,75	6,871	23,99	3,111
METHOD OF MOMENTS Geometric (μm)	MEAN ($\bar{x}_g$):	354,4	774,5	265,7	840,8
	SORTING (σ_g):	1,806	1,540	1,486	1,917
	SKEWNESS (Sk_g):	1,482	0,169	0,319	-0,279
	KURTOSIS (K_g):	5,719	4,083	4,695	2,880
METHOD OF MOMENTS Logarithmic (f)	MEAN ($\bar{x}_l$):	1,497	0,369	1,912	0,250
	SORTING (σ_l):	0,853	0,623	0,572	0,939
	SKEWNESS (Sk_l):	-1,482	-0,169	-0,319	0,279
	KURTOSIS (K_l):	5,719	4,083	4,695	2,880
FOLK AND WARD METHOD (μm)	MEAN (M_G):	360,3	763,0	248,1	894,6
	SORTING (σ_G):	1,708	1,434	1,505	1,788
	SKEWNESS (Sk_G):	0,454	0,481	-0,294	-0,269
	KURTOSIS (K_G):	3,432	0,594	2,293	1,106
FOLK AND WARD METHOD (f)	MEAN (M_Z):	1,473	0,390	2,011	0,161
	SORTING (σ_I):	0,773	0,521	0,589	0,838
	SKEWNESS (Sk_I):	-0,454	-0,481	0,294	0,269
	KURTOSIS (K_G):	3,432	0,594	2,293	1,106
FOLK AND WARD METHOD (Description)	MEAN:	Medium Sand	Coarse Sand	Fine Sand	Coarse Sand
	SORTING:	Moderately Sorted	Moderately Well Sorted	Moderately Well Sorted	Moderately Sorted
	SKEWNESS:	Very Coarse Skewed	Very Coarse Skewed	Fine Skewed	Fine Skewed
	KURTOSIS:	Extremely Leptokurtic	Very Platykurtic	Very Leptokurtic	Mesokurtic

Table 1: Grain size parameters of sampled beach sands. Sample locations can be found in Figure 34.

Figure 35 A-D and Figure 35 show the cumulative grain size curves and statistical grain size parameters of the beach sands. AP0916 and AP0928 are classified as coarse sands, AP0904 as medium sand and AP0921 as fine sand.

The sorting as a measurement of the root mean square deviation [Folk and Ward, 1957] ranges from moderately sorted to well sorted. The skewness (a measurement of the asym-

metry of a grain distribution [Folk and Ward, 1957]) for samples AP0904 and AP0916 is very coarse whereas for AP0921 and AP0928 it is slightly fine skewed.

The kurtosis measures the sorting in the ends of the grain size distribution curve in relation to the sorting in the center part of the curve. It's a measure of the "peakedness" of the curve in the central part in contrast to the shoulder [Tucker, 1996].

5.2.1.2 Dune sands

The general appearance of dunes on Antiparos is that of inactive sand dunes. They are almost completely covered by vegetation. Areas without vegetation are probably related to recent human activity. They can be found to the south of the beach near the camping site in the northernmost part of Antiparos (2 ha), Sifnaikos bay (2 ha) and Livadia bay (7.3 ha). At Livadia bay the dune sediments are separated by a ridge of granite gneiss (see Figure 34) and form thin strips of sand thinning out towards the interior of the island.

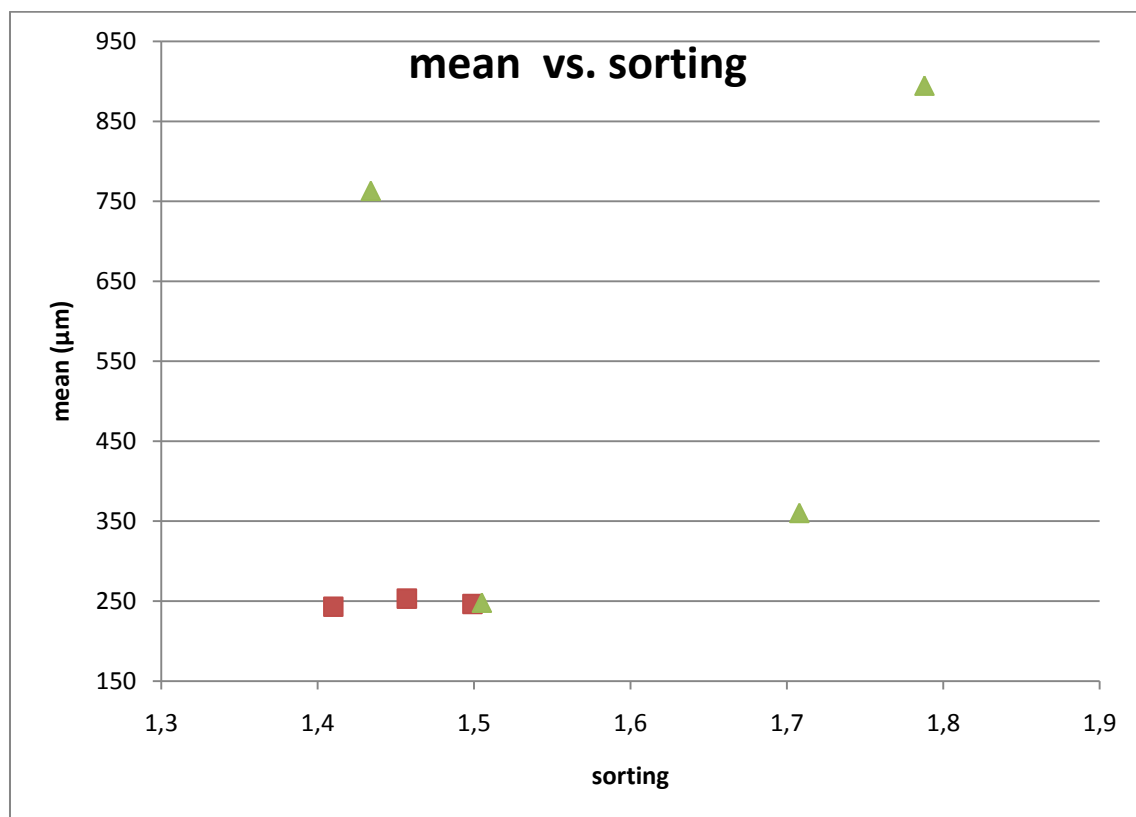


Figure 36: Plot of mean vs. sorting. The dune sands (red squares) are rather uniform with well sorted grain size. The beach sands (green triangles) are much more heterogenic concerning their grain size and sorting.

The eolian sand dunes south of the beach at the camping site does not form long tongue shaped sand accumulations like the occurrences at the west coast, but forms a more or less coast parallel sand body with scattered small sand dunes to the South of it.

Both, dune sands as well as beach sands mostly consist of siliciclastic material. Dune sand additionally contains organic material roots, wood fragments, etc.

		AP0905	AP0922	AP0970
	ANALYST AND DATE:	LB, 9/10/2010	LB, 9/10/2010	LB, 9/10/2010
	SIEVING ERROR:	0,9%	2,0%	1,9%
METHOD OF MOMENTS Arithmetic (μm)	MEAN ($\bar{x}_a$):	284,0	274,1	289,0
	SORTING (σ_a):	113,4	113,1	104,0
	SKEWNESS (Sk_a):	2,253	4,579	2,857
	KURTOSIS (K_a):	19,26	64,72	32,32
METHOD OF MOMENTS Geometric (μm)	MEAN ($\bar{x}_g$):	260,6	251,7	268,6
	SORTING (σ_g):	1,458	1,457	1,411
	SKEWNESS (Sk_g):	-0,117	-0,329	-0,400
	KURTOSIS (K_g):	3,520	4,422	4,674
METHOD OF MOMENTS Logarithmic (f)	MEAN ($\bar{x}_\phi$):	1,940	1,990	1,896
	SORTING (σ_ϕ):	0,544	0,543	0,497
	SKEWNESS (Sk_ϕ):	0,117	0,329	0,400
	KURTOSIS (K_ϕ):	3,520	4,422	4,674
FOLK AND WARD METHOD (μm)	MEAN (M_G):	246,4	243,0	253,1
	SORTING (σ_G):	1,499	1,410	1,457
	SKEWNESS (Sk_G):	-0,308	-0,543	-0,341
	KURTOSIS (K_G):	0,965	0,666	2,305
FOLK AND WARD METHOD (f)	MEAN (M_z):	2,021	2,041	1,982
	SORTING (σ_I):	0,584	0,496	0,543
	SKEWNESS (Sk_I):	0,308	0,543	0,341
	KURTOSIS (K_G):	0,965	0,666	2,305
FOLK AND WARD METHOD (Description)	MEAN:	Fine Sand	Fine Sand	Medium Sand
	SORTING:	Moderately Well Sorted	Well Sorted	Moderately Well Sorted
	SKEWNESS:	Very Fine Skewed	Very Fine Skewed	Very Fine Skewed
	KURTOSIS:	Mesokurtic	Very Platykurtic	Very Leptokurtic

Table 2: Grain size parameters of sampled dune sands. Sampling localities can be found in the appendix.

Figure 35 and Table 2 are displaying the cumulative grain size curves and statistical grain size parameters from the three dune sand samples derived from GRADISTAT 6.0. According to this calculations the dune sands are bimodal, moderately well to well sorted, which can also be seen in Figure 35. The mean grain size lies between 246 and 253 μm resulting in a fine to medium sand. All dune samples show a highly positive skewness indicating a dominance of finer sands. The kurtosis has a wide range from very platykurtic to very leptokurtic.

5.3 Paleosols

Red to brownish red paleosols comprising fine sandy silt with a considerable amount of clay can be found in several outcrops. Generally they are covered either by calcarenite or calcarenite altered to calcrete.

The matrix grain size ranges from clay to silt (fine sand in some cases); in some samples the clay component clearly dominates. This matrix contains coarse grained, angular gneiss and quartz components ranging from granule up to cobble size. Some outliers even reach boulder size. The thickness of these red beds ranges between 0.5 and 1 m.

Red paleosols in the Mediterranean region have been mentioned in the literature (e.g. [Brooke, 2001; Le Guern, 2004; Yaalon, 1997] as well as in other regions (e.g. Bahamas, Texas, Australia,... [Carew and Mylroie, 2001; Chafetz and Butler, 1980; Le Guern, 2004; Le Guern and Davaud, 2004]). Also Varti-Mataranga and Piper (2004) describe a red muddy layer in their profiles on Delos and Mykonos (Cyclades) – interpreted as debris-flow deposits in their work.

5.3.1 XRD analysis

Seven samples of paleosols and weathering layers of northern Antiparos have been analyzed by x-ray diffraction (XRD). The bulk mineralogy shown in Figure 37 mainly represents the underlying metamorphic rocks with high amounts of quartz, orthoclase, plagioclase (albite), muscovite and calcite. Smaller contents of kaolinite, chlorite and hematite are indicated. The brownish red to reddish brown color of the paleosols results mainly from fine scattered hematite. The contents of feldspar and calcite are variable. All XRD-measurements were qualitative and give no evidence of absolute percentages.

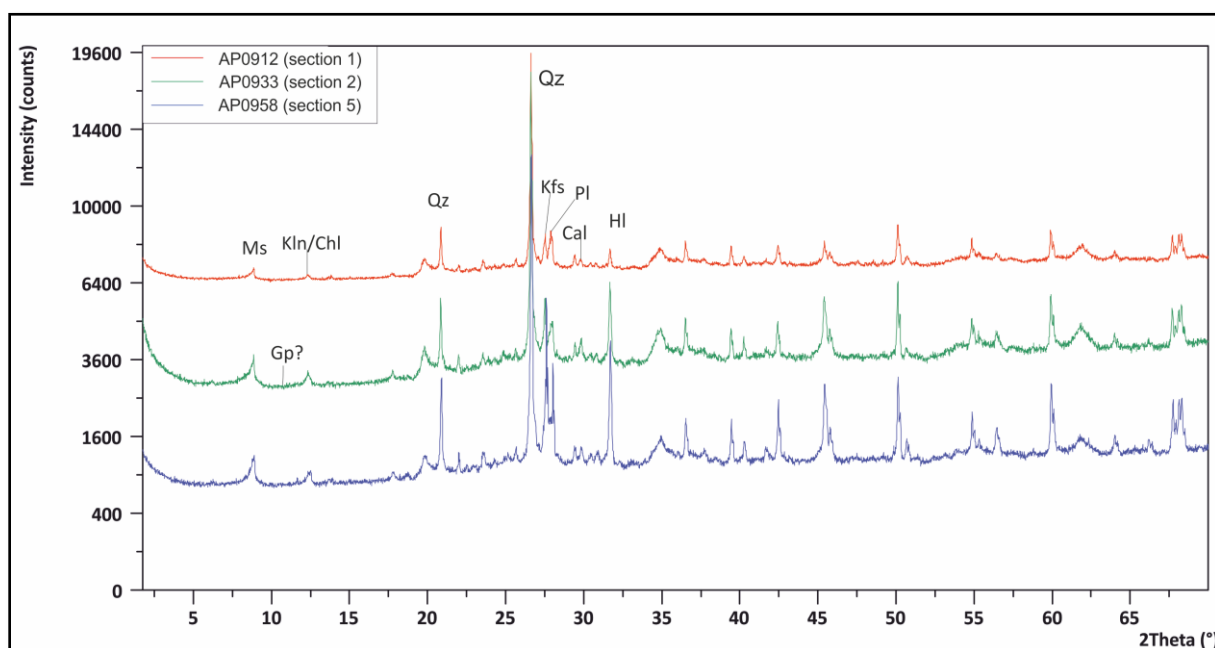


Figure 37: Bulk mineralogy of three paleosols samples from northern Antiparos. The bulk mineralogy of the samples consists of Qz, Kfs, Plag, Ms, Kln, Chl, Cal, and Hl.

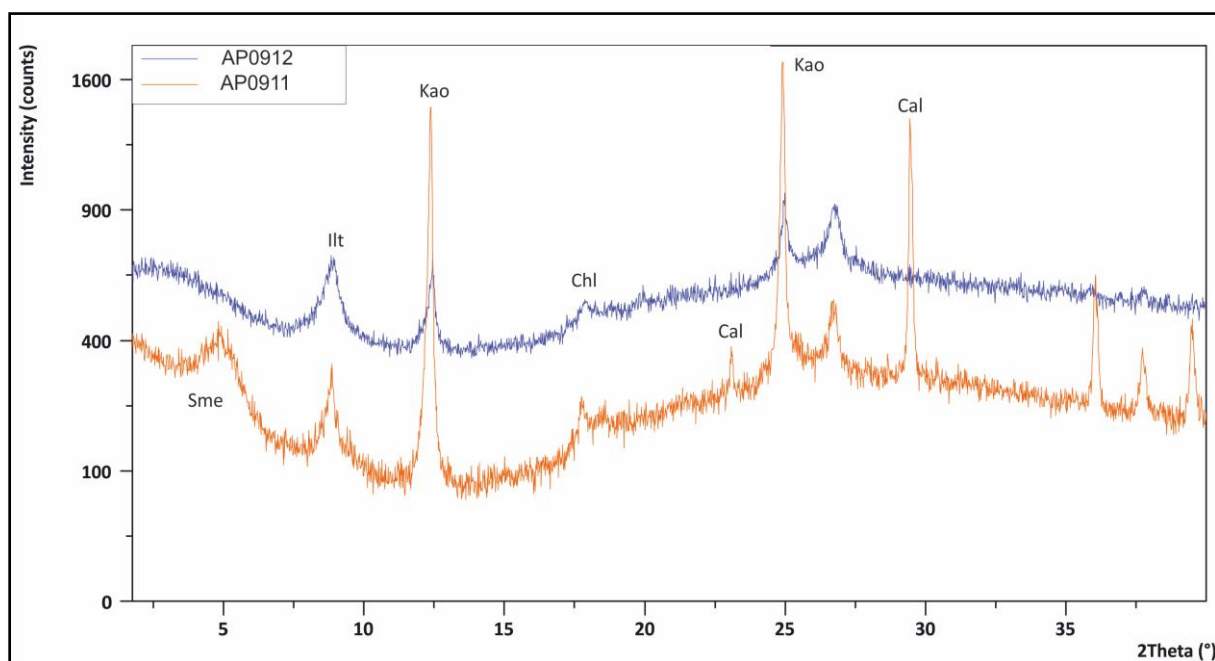


Figure 38: Clay mineralogy of the paleosol samples AP0911 (orange) and AP0912 (blue) in section 1 (Figure 19). The samples have been saturated with Mg and glycerin. Note the high Cc and Kao peaks in AP0911.

Selected samples have been further investigated by analyzing the $<2\ \mu\text{m}$ fraction to investigate the clay mineralogy. In Figure 38 and Figure 39 the XRD-results from four samples (AP0911, AP0912; AP0933, AP0932; saturated with magnesium and glycerin) from two different outcrops were compared. The upper blue line in Figure 38 and Figure 39 represents the stratigraphic top layer of the soil section whereas the orange line represents the lower of

the two layers (Figure 38 and Figure 39). The orange layer shows strong peaks of kaolinite, calcite and smectite with minor amounts of illite and in Figure 39 also indicates a small amount of chlorite. The blue layer in contrast shows a dominant illite peak, a smaller kaolinite peak and traces of chlorite. Smectite and calcite are missing completely in the upper layers.

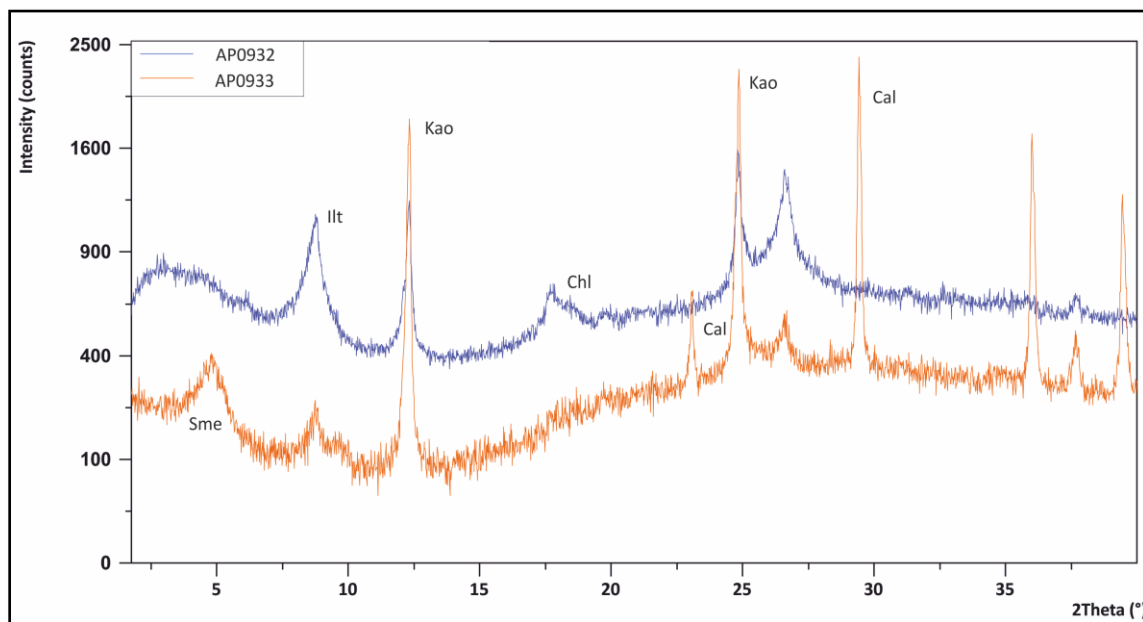


Figure 39: Clay mineralogy of the paleosol succession in section 2. The samples have been saturated with Mg and glycerin. Note the Cc and Kao peaks in AP0933 and the complete absence of Cc in AP0932.

5.3.2 Interpretation

Such paleosol formations are widespread and are typical for interglacial periods [Hearty *et al.*, 2000; Tarnocai and Smith, 1989] or interstadials [Ruhe *et al.*, 1961] and are also well known interbedded in eolianite formations [Brooke, 2001]. The clay mineralogy of the two horizons is typical for a paleosol. The kaolinite rich lower layers (samples AP0911 and AP0932) with lower amounts of illite compared to the upper layer indicate advanced weathering (Figure 33 and 34). This mineralogy, which indicates that lower parts show stronger weathering than the upper levels, is difficult to explain in a single, undisturbed soil. In a single pedogenetic process the weathering sequence should be contrary to the one found in the northern Antiparos outcrops. A possible explanation for the XRD results is that the investigated paleosols (section 1 and 2; Figs. 37, 38, 39) did not form in a single soil forming event but may include more than one soil forming process. Vertical dislocation of clay minerals seems unlikely. Thus the lower, light colored, smectite-rich, calcite-containing paleosol hori-

zon is interpreted as older soil formation, covered by the brownish red illite-rich paleosol which probably belongs to a younger soil forming event. The contact between these two horizons is probably erosional.

5.4 Calcarenites

Calcarenite outcrops are wide spread across the island. They vary considerably in areal extent, their vertical position and also the thickness (Tab. 3 and Figure 41). Most of the outcrops are situated at the coast, but may also show variable distance from the sea (Tab. 3). The largest occurrence at Livadia Bay (outcrop number 1 in Table 3 and Figure 41, section 4 in chapter 5.1.1.4) can be traced from below sea-level up to 80 m a.s.l.

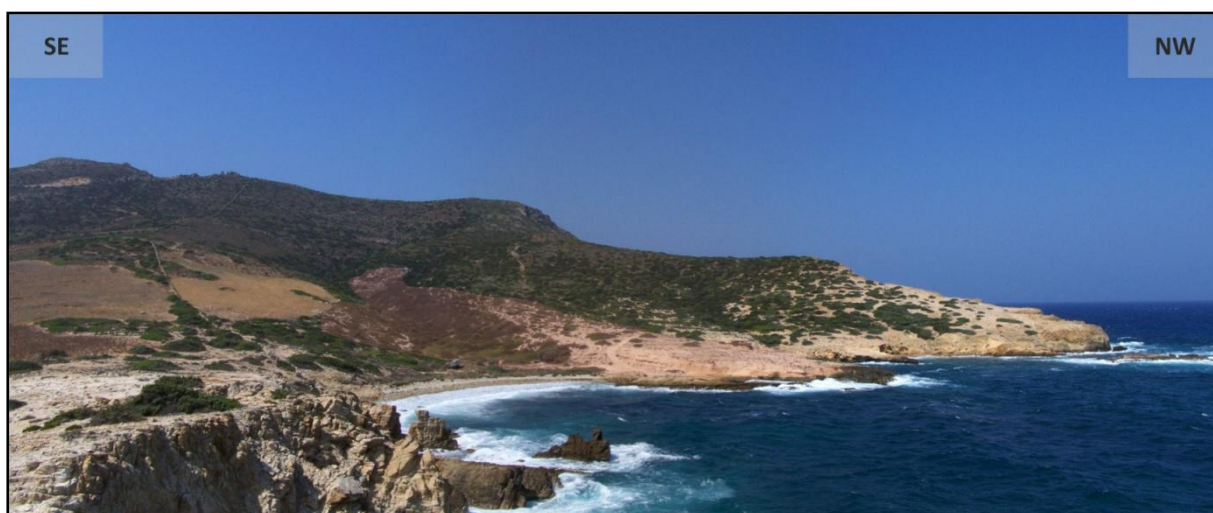


Figure 40: Overview of the calcarenite site west of Livadia bay. Extent of the calcarenite is shaded in red.

Generally the calcarenite can be found as thin sheets covering hill slopes and especially filling topographic depressions without building any distinct terraces. Its occurrences are mainly controlled by its preservation (many thin deposits have probably been eroded), by outcrop conditions (many occurrences are covered by younger sediments and vegetation, as well as by erosion which exposes eolianites (mainly in small valleys)). The calcarenite is usually deposited slope parallel following the underlying relief. In a few cases cross-bedding can be found, commonly dipping towards the slope. Calcarenite occurrence 1 (Figure 40 and 41) follows the underlying relief with slope angles up to 48° which represent the steepest beds of this investigation.

Outcrop N°	Area (m ²)	vertical extent (m)	min. distance from sea (m)	max. distance from sea (m)	thickness (m)
1	47097	0-80	0	572	4
2	3290	44-67	566	632	2-3
3	288	21-30	48	67	1.5
4	3075	40-50	506	574	unknown ⁴
5	30880	8-65	66	380	2.8
6	922	20-32	11	69	4.5
7	739	16-22	8	49	unknown ⁴
8	1367	0-9	0	42	2.5
9	3777	0-8	0	84	1.8

Table 3: Geometrical data of calcarenite occurrences in northern Antiparos. Values from GPS measurements, 1:5000 military maps and GIS project.

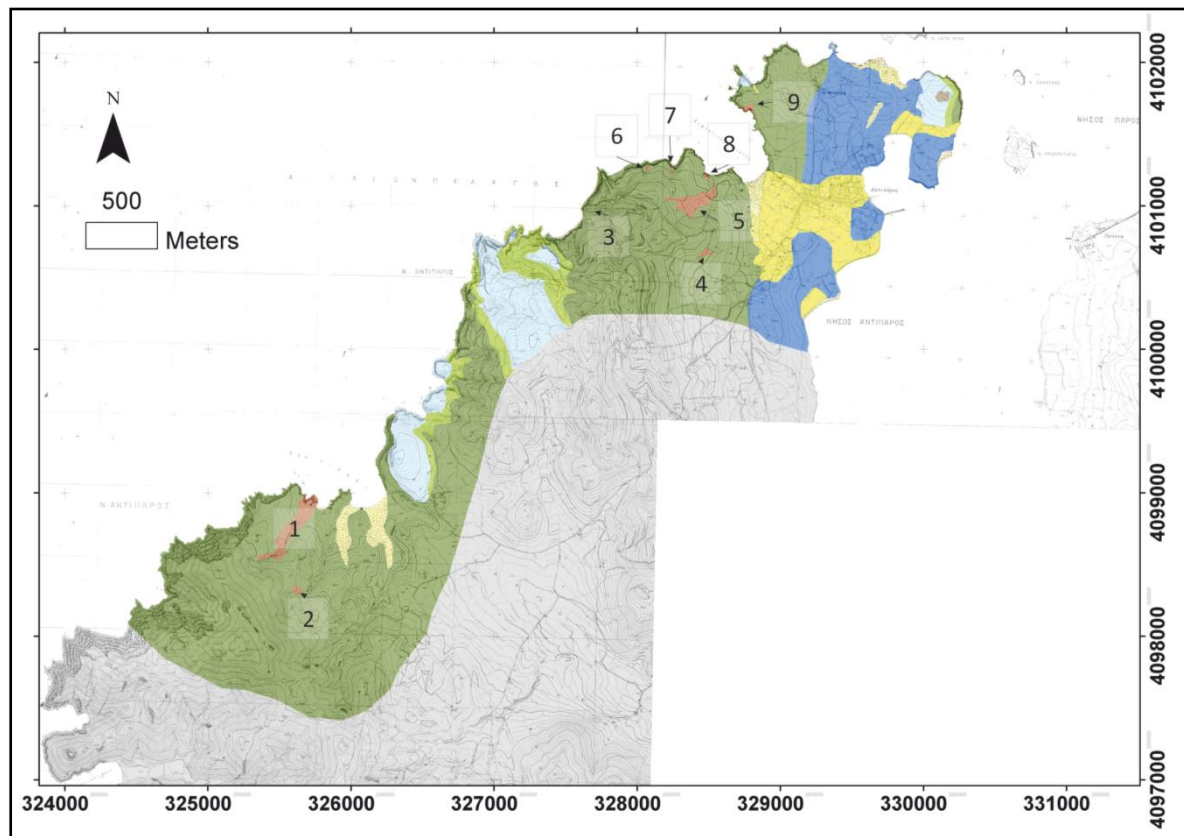


Figure 41: Location of calcarenite occurrences of northern Antiparos in red.

⁴ Thickness measurement not possible due to poor outcrop conditions.

The calcarenites of Antiparos show variable grain sizes. Grain sizes range between 0.5 and 1 mm in mean but may also reach up to 2 mm at some sites. The sorting of these lithologies is mainly good. But if one takes the scattered granule to cobble sized clasts of angular rocks from the underlying crystalline (in rare cases boulder sized; <30cm) lithoclasts, sorting can vary substantially. Assumed that the calcarenite and the coarse, angular material were caused by two different processes, one must look at the sorting from two different angles.

The calcarenites are composed of carbonatic bioclastic material (see chapter 5.4.2) with a percentage of siliciclastica rarely exceeding 30%.

5.4.1 Sedimentary Structures

Sedimentary structures are very important for the understanding of depositional environ-



Figure 42: Calcarenite affected by calcretization and honeycomb weathering near Sifnaikos bay

ments. They are one of the best indicators for the depositional mechanism as they directly result from depositional processes. Well preserved calcarenite occurrences that show hardly any alterations into calcrete, sedimentary structures are clearly visible. In contrast, sedimentary structures are completely obliterated where the calcarenite has been altered into calcrete and additional honeycomb weathering took place (Figure 42).

Cross bedding has been observed in several calcarenites of northern Antiparos; they represent important indicators for paleo-transport directions. The dip angles of the cross beds range between 10° and 35° (see Figure 43).

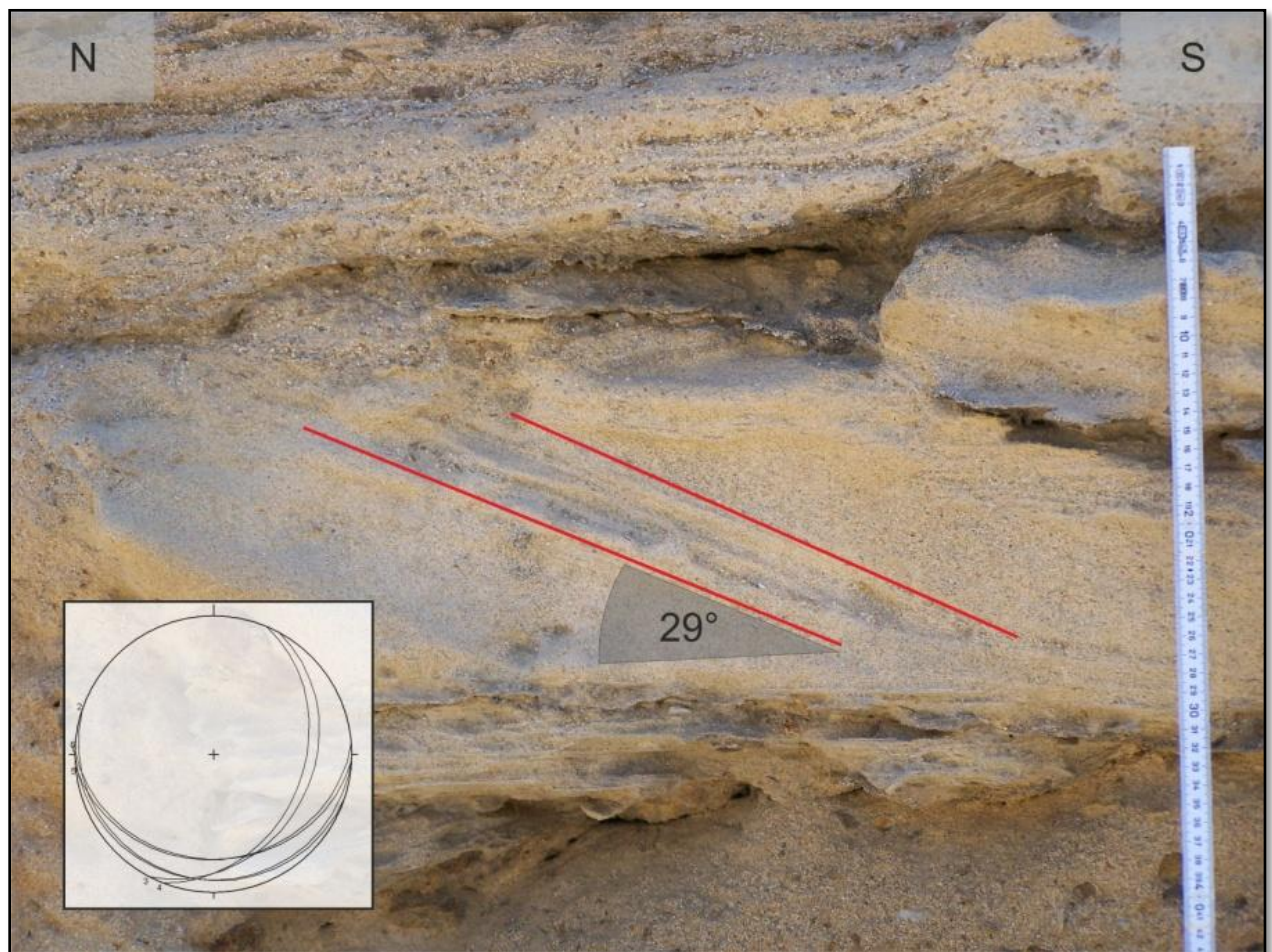


Figure 43: Cross bedding in calcarenite near Livadia bay, dipping at 29° landwards. Dip and dip directions for other recorded cross beddings are shown in the great circle plot.

Another very dominant and distinct feature is the fine lamination (mm scale) with inverse grading (Figure 44) found preferably at the outcrops near Livadia bay. They are most commonly found in pure calcarenites with good sorting.

Another distinct sedimentary features found particularly in outcrops west of Livadia bay (see outcrop 1 in Figure 41) are small, erosive channels within the calcarenite. These channels are characterized by fining upward fills (Figure 45). The coarse-grained (up to 20 cm) components, mainly granite gneiss from the underlying crystalline show imbrications indicating down slope transport, towards the sea. Apart from these channel fills there are several more or less slope parallel horizons within the calcarenite with accumulations of coarse-grained, angular lithoclasts. These lithoclasts mainly comprise metamorphics from the underlying crystalline, but also re-worked calcarenite (Figure 46).

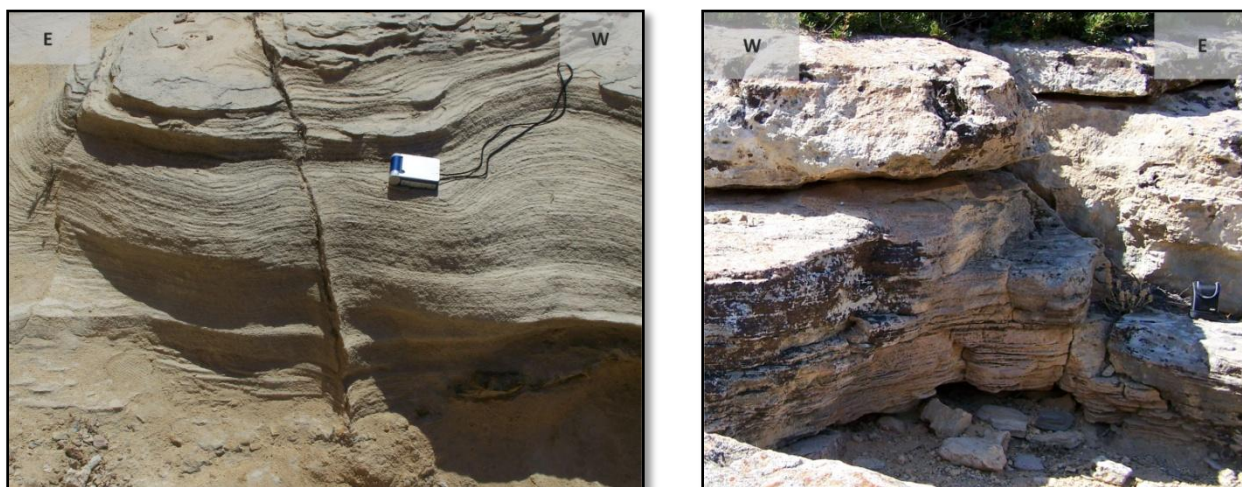


Figure 44: Pinstripe laminations in Quaternary eolian sandstones. **Left:** Pin stripe lamination in eolianite west of Livadia bay; note the fracture cutting through the rock, possibly indicating Quaternary tectonics on Antiparos. **Right:** Pinstripe laminations in an abandoned eolianite quarry (outcrop 2 in Figure 36). Scattered potsherds indicate former human activity.

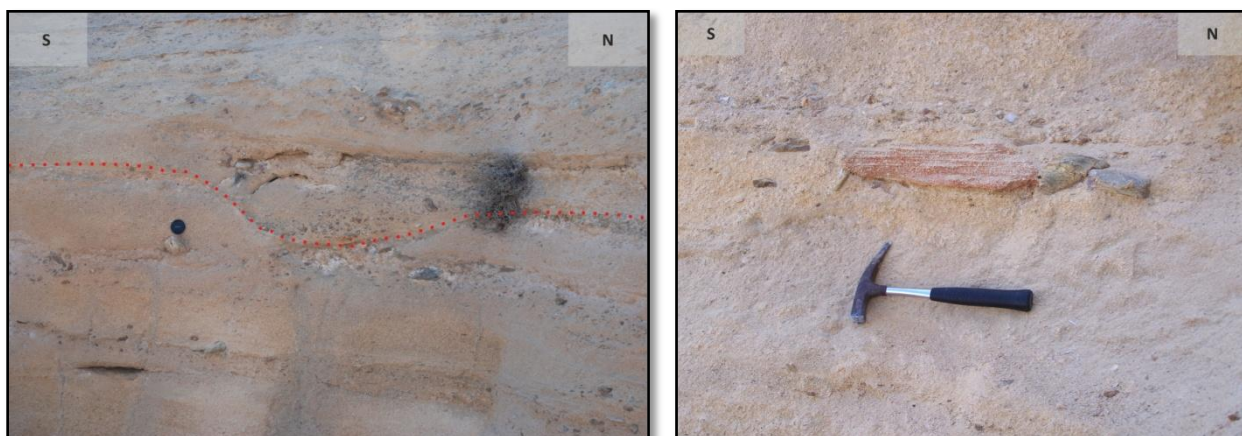


Figure 45: Left: Small channel in the calcarenite west of Livadia bay. Note the characteristic intercalation of well-sorted eolian sandstone and coarse-grained poorly sorted talus sediments – typical for sand-ramp deposits [Lancaster and Tchakerian, 1996; Draganits *et al.*, 2010]. Right: Coarse-grained components embedded in calcarenite aligned parallel to the slope. The reddish component represents a re-worked clast of a calcarenite.

Typical sedimentary structures found both in outcrop (Figure 46) and thin section scale are remains of bioturbation by roots (rhizogenetic structures). On a macroscopic scale these structures are represented by rhizolites – fossil root marks originated by accumulation and/or cementation around, cementation within, or replacement of higher plant roots by mineral matter [Klappa, 1980]. The sampled rhizoliths are casts of former roots filled by mainly calcitic sediment plus cryptocrystalline cement with minor percentage of siliciclastic material (rhizolite type: root cast [Klappa, 1980]). The marginal areas of the rhizolites show increased cementation in contrast to the central parts.



Figure 46: (left) Rhizolites at the contact between bed 1 (paleosol) and bed 2 (eolian calcarenite) of section 5 (chapter 5.1.1.5); (right) Rhizolites in a calcarenite bed 6 of section 3 (see chapter 5.1.1.3)

5.4.2 Thin section and SEM analysis

Twenty-one thin sections of calcarenite and calcretized calcarenite have been investigated in respect to grain composition, microfauna and diagenetic properties (porosity, cements,...).

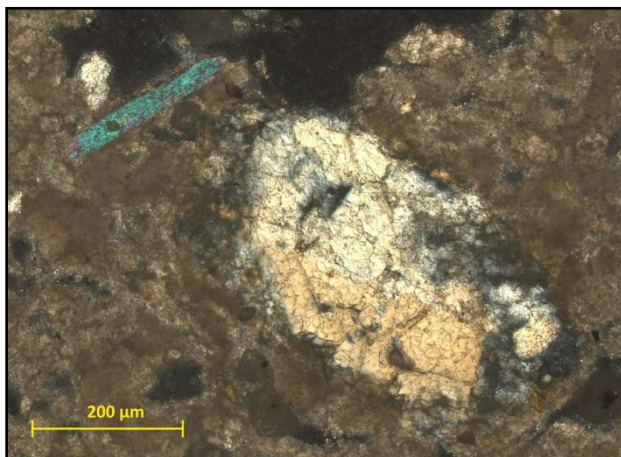


Figure 47: Mica and polycrystalline quartz lithoclasts of AP0902 with crossed Nichols. The anomal interference color is due to the rather thick polished thin section. (AP0902)

The calcarenites of northern Antiparos are mainly composed of lithoclasts and bioclasts. The lithoclasts dominantly originate from gneiss and can make up to 25% of the lithoclastic material. Polycrystalline quartz and occasionally remains of white mica (see Figure 47) and biotite occur. Only polycrystalline quartz has been observed. Sometimes grains of marble origin are present and can make up to 25% of the lithoclastic material. Feldspar (Kfs and Pl) has been

noticed in thin-section but only in small amounts. The grain composition has been investigated by point counting ($n=250$) of thin sections with the software JMicroVision 1.2.7. Points were categorized by 3 classes: lithoclasts, bioclasts and porosity. In most of the samples the carbonate bioclastic grains dominates by far (Tab. 4). Applying the classifications by *Dunham* (1962) and *Folk* (1959; 1962) the calcarenites can be classified as grainstones or biosparite, respectively.

The mean grain size of the calcarenites ranges between 0.5 and 2 mm; the carbonatic particles account for the coarsest fractions. Rounded quartzes are mostly considerably smaller than the carbonate particles but angular quartz and gneiss lithoclasts can exceed the grain sizes of the carbonatic components by far. Sorting of the calcarenites can vary strongly from medium to very good. The bioclastic particles are well to very well rounded (Figure 48). Lithoclasts are present showing both, little rounding and as well as well rounded. The cementation of the calcarenites is rather weak and a big portion of the original porosity has been preserved.

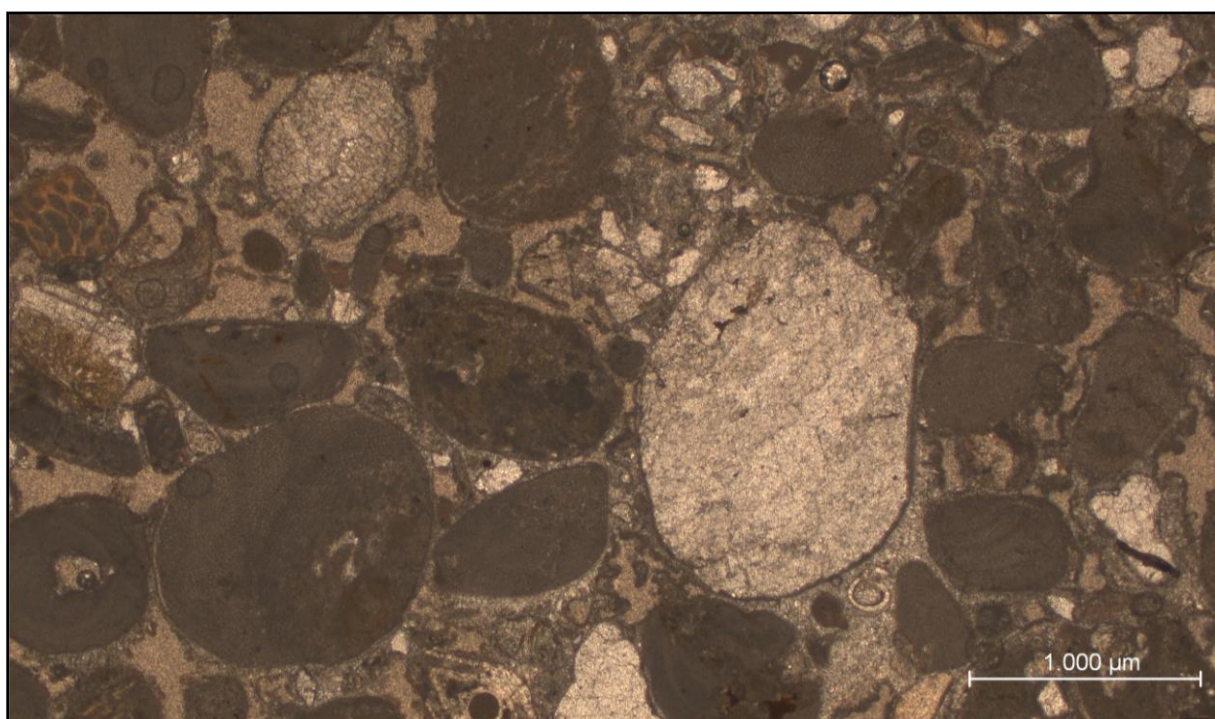


Figure 48: Thin section photo of AP0962. Sorting is poor to medium with bioclasts and most lithoclasts being well to very well rounded. Some smaller lithoclasts show poor to medium rounding. Note the thorough cementation in former confined pore spaces. Bioclasts are mostly represented by corallinacean red algae.

sample n°	porosity	bioclasts	lithoclasts	description
AP0907	22%	57.23%	42.77%	calcarenite
AP0914	16.8%	50.05%	49.95%	calcretized calcarenite
AP0937	19.2%	77.23%	22.77%	calcarenite
AP0972	26.4%	59.78%	40.22%	calcarenite
AP0962	24.4%	74.3%	25.7%	calcarenite

Table 4: Porosity and grain composition of selected thin sections. The percentages of bioclasts and lithoclasts were calculated without involving the porosity.

Cements of the sparitic meniscus and pendant type are prevailing (Figure 49 and 52 e),f)) and indicate precipitation under vadose conditions [Flügel, 2010]. Drip stone cements, which are characterized by cement accumulation underneath grains, are less frequently found than the meniscus cements. In very small pore spaces also isopachous coatings of columnar cements growing perpendicular to the grain surface can be found (radial fibrous cement [Flügel, 2010]). Botryoidal aragonite cements has been observed only rarely (e.g. sample AP0910).

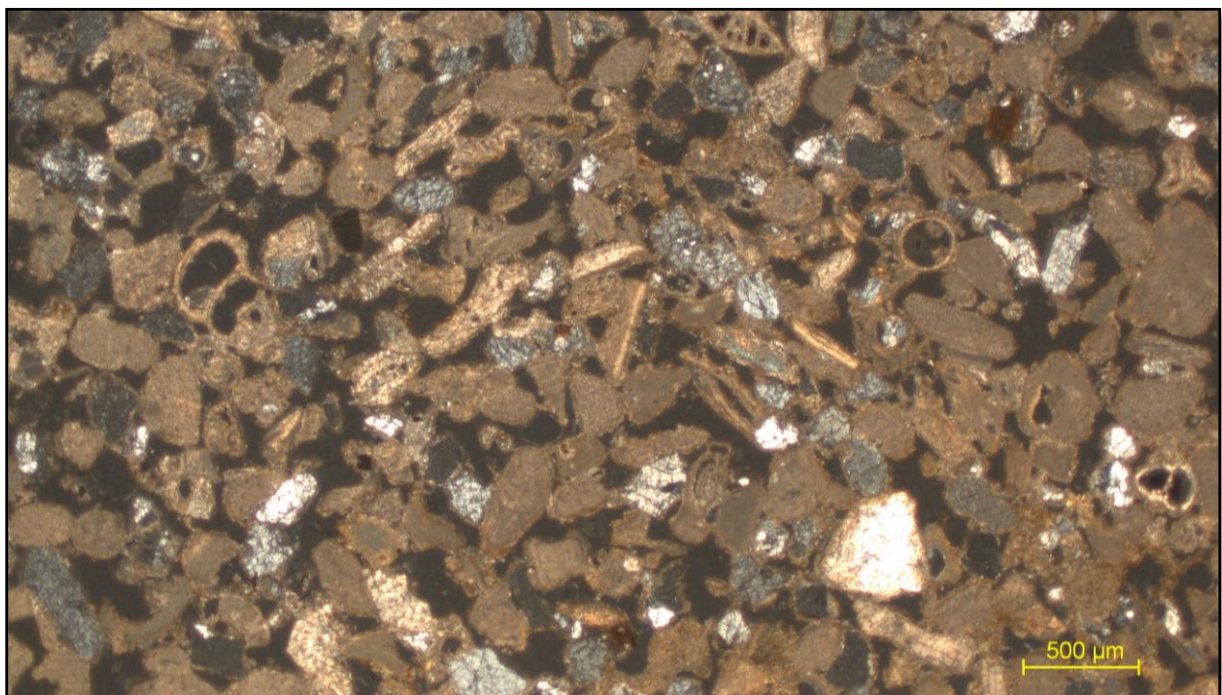


Figure 49: Thin section overview of AP0907. Meniscus cements prevail. The grains are coated by a post-depositional iron oxide rim. The carbonate particles are rounded to well-rounded whereas the crystalline components are poorly rounded.

The bioclastic components are mainly marine bioclasts including foraminifera, echinoderms, gastropods, corallinacean red algae, green algae, bryozoans and shell fragments of bivalves (Figure 51 and Figure 52). Additionally, terrestrial snails have been found. The foraminifera tests are mostly benthic and for the interpretation of the depositional environment it is very important, that they represent a mixture of diverse habitats. The porcellaneous foram tests of *Elphidium* (Rotaliida) and *Quinqueloculina* (Milolida) are indicators of high energy conditions and shallow water. Encrusting foraminifera also suggest a high energy habitat. In contrast, the occurrence of the benthic biserial foraminifera *Nodosaria* and *Stilostomella* represent deeper water – low energy milieu. Planktonic foraminifera have been found rare-

ly. Generally, the shells of the foraminifera are shattered and broken. The porcellaneous foraminifera observed (e.g. Miliolids) usually are better preserved than hyaline tests (Rotaliids). Reworked tests of foraminifera and corallinacean red algae in thin sections can be found unexpectedly well preserved in reworked clasts with their intra particle porosity is filled by micrite. Tests coated by micrite have also been observed (see d) in Figure 52).

Pedogenetic structures like rhizoliths have been observed in calcarenite both, at outcrops as well as thin section scale (Figure 50). They are more common in calcretized calcarenites and calcrete. Additionally to rhizoliths (root cast type) some alveolar structures (Figure 50) have been recorded. Alveolar structures are tubular to irregular pores filled with sparite and separated by “interconnecting bridges of micrite” interpreted as calcified root hairs [Flügel, 2010].

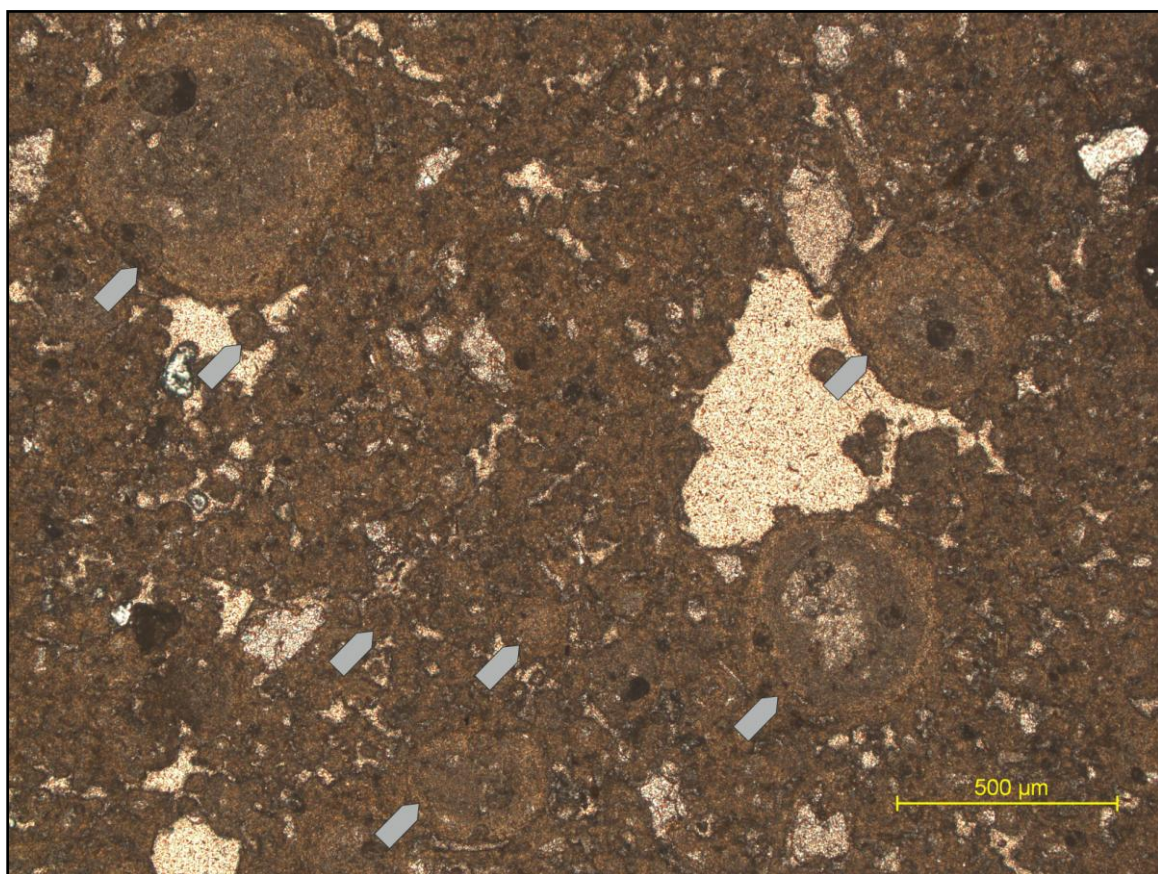


Figure 50: Pedogenetic features in this calcarenite thin section (AP0910). Grey arrows point out root casts. Note the abundance of alveolar structures throughout the thin section.

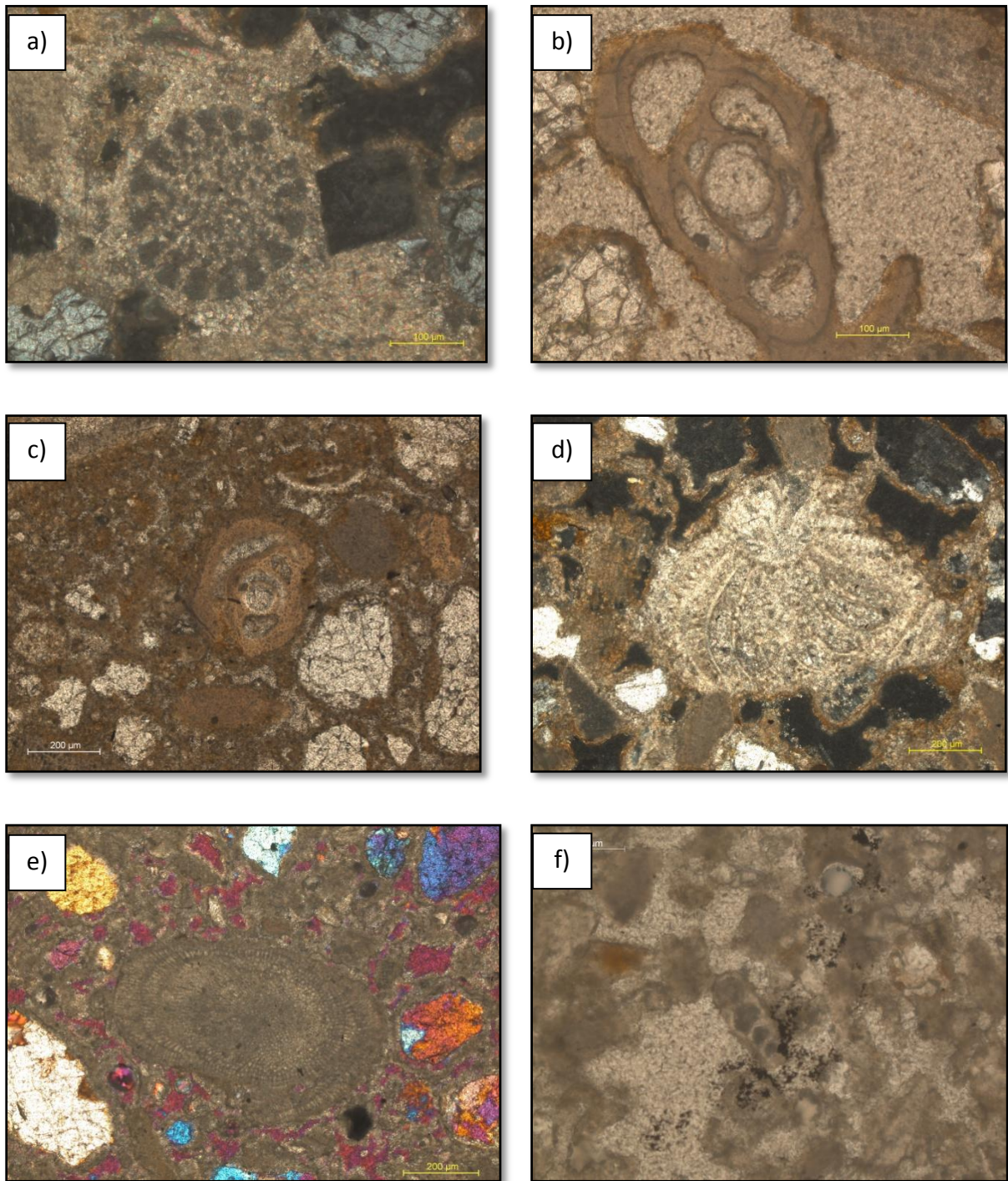


Figure 51: Microfaunal content of calcarenites or calcretized calcarenites. a) sea urchin spicula (AP0907 calcarenite), b) ferruginous miliolid foraminifera (AP0907 calcarenite), c) ferruginous miliolid foraminifera (AP0934 calcretized calcarenite), d) *Elphidium* (foraminifera) (AP0907 calcarenite), e) corallinacean red algae (AP0914 calcarenite), f) *Nodosaria* (benthic foraminifera) (AP0902 calcarenite);

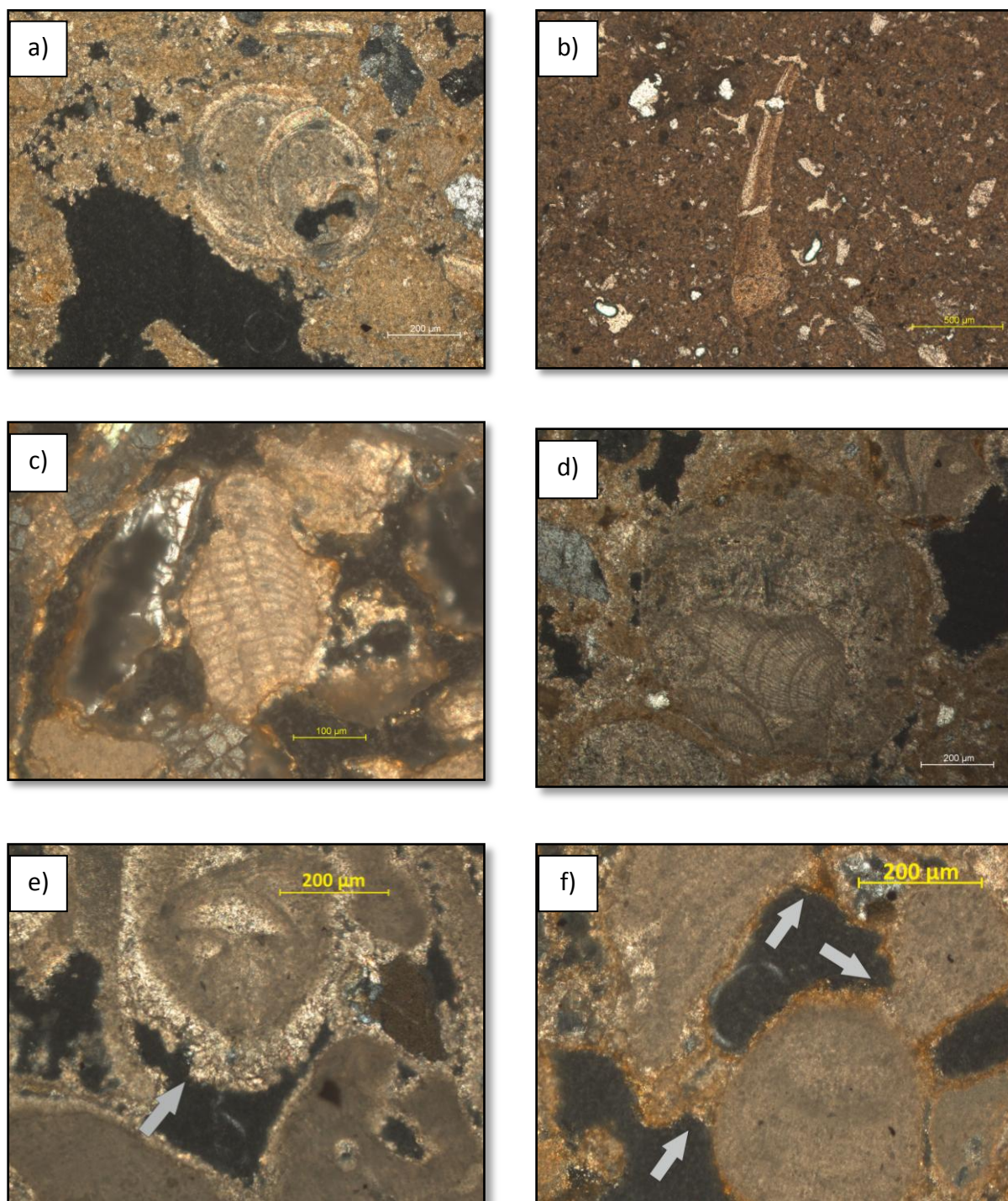


Figure 52: Microfaunal content of calcarenites or calcretized calcarenites a) marine gastropod (AP0934 calcretized calcarenite), b) shell fragment of a bivalve (AP0910 calcretized calcarenite), c) bryozoans (AP0907 calcarenite), d) re-deposited fragments of corallinacean red algae cemented by marine cements (AP0934 calcretized calcarenite), e) drip stone cements (AP0937 calcarenite), f) meniscus cements (AP0907 calcarenite);

A calcarenite, two calcretized calcarenites and one calcrete sample have been investigated by scanning electron microscopy at the University of Vienna. Coatings of Fe-oxide or Fe-oxyhydroxide cover all grains in calcarenite sample AP0907 (Figure 53 a) which can also be observed in thin sections (see Figure 51 d) and Figure 52 c), d)).

The calcretized samples show coarse sparitic calcite cements between the primary components and a secondary micritic cementation related to the alteration into calcrete which results in decreased porosity (see Figure 53 c) and d)). Also calcified fungal hyphen can be found frequently indicating a terrestrial formation [Verrecchia, 2000].

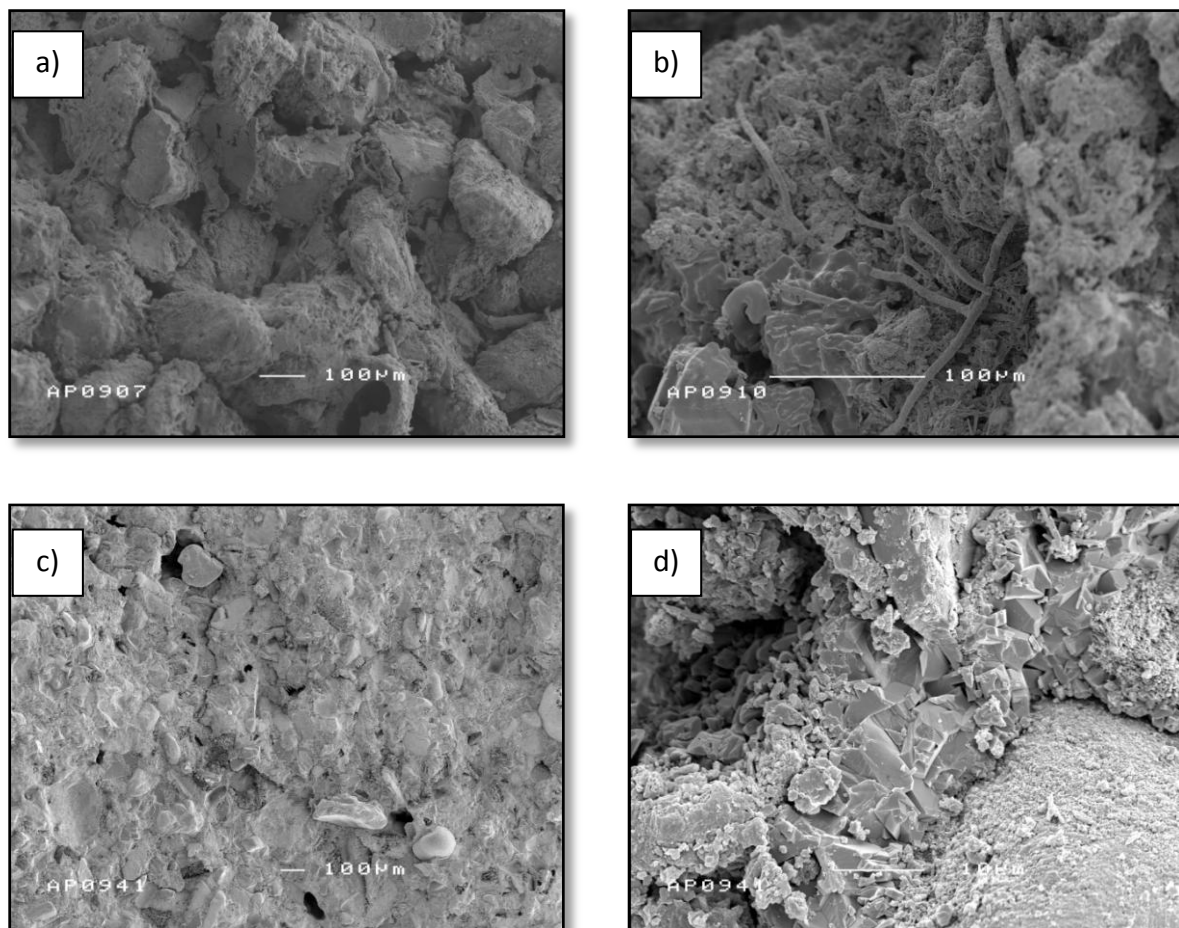


Figure 53: a) calcarenite sample AP0901 (100x magnification); bioclasts with irregular Fe-oxide or Fe-hydroxide coatings, b) fungal hyphen in calcretized calcarenite sample AP0910 (350x), c) overview of calcretized calcarenite sample AP0941 (50x); note the low porosity in comparison with the calcarenite in Figure 48a); d) detail (2000x) of the cementation between two components from the lower left corner in Figure 48c); The primary cementation between the components is sparitic; the micritic cementation is related to the alteration into calcrete.

5.4.3 Terrestrial snails

Five terrestrial snails (Figure 54, 55, 56 and 57) have been found in two different outcrops and sent to Prof. Edmund Gittenberger of the Museum of Natural History in Leiden, Netherlands for identification and possible biostratigraphic classification. The samples are not perfectly preserved but without any noticeable re-crystallization of the calcitic shell. The identifications are supported by the PhD thesis of Mylonas (1982) which includes a list of the modern day terrestrial snails of Antiparos Island.



Figure 54: Possibly *Xeropicta krynickii* (Krynicky, 1833) or *Cerneuella virgata* (da Costa, 1778); sample AP0959



Figure 55: *Xeropicta krynickii* (Krynicky, 1833) or *Cerneuella virgata* (da Costa, 1778); sample AP0963C



Figure 56: *Mastus etuberculatus* (Frauenfeld, 1876); sample AP0963B



Figure 57: *Xeropicta krynickii* (Krynicky, 1833) or *Cerneuella virgata* (da Costa, 1778); sample AP0963A

Sample AP0959 (Figure 54) which originates from section 5 (see chapter 5.1.1.5 and Figure 23) is difficult to identify, because only the helicid shape and the opened umbilicus of this specimen are preserved. The most likely species are *Xeropicta krynickii* (Krynicky, 1833) or *Cerneuella virgata* (da Costa, 1778).

The following three terrestrial snails all derive from section 3 (see chapter 5.1.1.3 and Figure 23). AP0963A (Figure 57) and AP0963C (Figure 55) are according to their umbilicus, shape, size, remains of the periostracum and sculpture either *Xeropicta krynickii* (Krynicky, 1833) or *Cerneuella virgata* (da Costa, 1778). AP0963B is *Mastus etuberculatus* (Frauenfeld, 1876; Figure 56).

All four samples represent land snails that can also be found today on Cycladic islands. *Cerneuella virgata* is a widespread species in the Mediterranean and Western Europe and probably originated from the western Mediterranean and was introduced to the eastern Mediterranean by man [Hausdorf and Sauer, 2009]. *C. virgata* is a heat resistant species and prefers sandy, calcareous substrate like dunes [Romaniello et al., 2008]. *X. krynickii* is distributed widely in the eastern Mediterranean region [Hausdorf and Sauer, 2009]. Just like *C. virgata* this species is very heat resistant and lives in open habitats but can also be found in forest and sandy habitats and preferably live on limestone substrate [Welter-Schultes, 2007; Örstan et al., 2005]. *M. etuberculatus* is known from Bulgaria [Irikov and Eröss, 2008], the Aegean and Turkey [Kebapçı, 2007]. It lives mainly on limestone substrate in open, slightly inclined habitats [Kebapçı, 2007].

5.4.4 Radiocarbon dating

The radiocarbon isotopic composition of sample AP09636A has been determined by AMS in

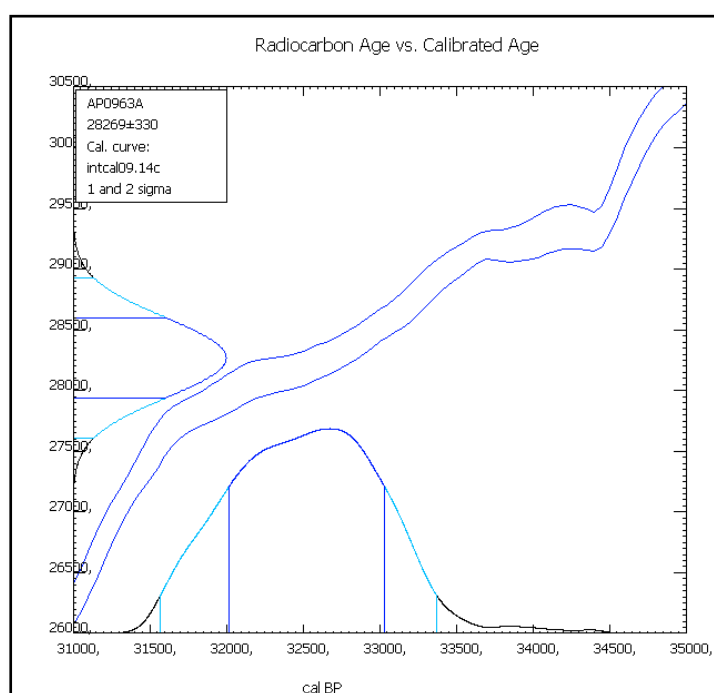


Figure 58: ^{14}C calibration: radiocarbon age vs. calibrated age (BP). Dark blue are 1σ errors; 2σ errors are light blue;

the Centro di Datazione e Diagnostica in Lecce (Italy). The “conventional radiocarbon age” was calculated with a $\delta^{13}\text{C}$ correction based on $^{13}\text{C}/^{12}\text{C}$ ratio measured directly by the accelerator. For the estimation of the measurement uncertainty (standard deviation) both the radioisotope counting statistics and the scattering of the data have been taken into account.

sample name	radiocarbon determi- nation	$\delta^{13}\text{C}$ (‰)	cal BP 1 σ	cal BP 2 σ
AP0963A	28269 $\pm$ 330	-7.4 $\pm$ 0.5	32526 $\pm$ 505	32472 $\pm$ 900

Table 5: Measured radiocarbon values

The calibration with Calib 6.0.2 (Figure 58) results in a calibrated age of 32472 $\pm$ 900 years BP (2.77% error). This means that these calcarenites probably have been deposited during the uppermost Pleistocene period/Tarantian stage (MIS 3). As the terrestrial snails have got into the sediment during the time of deposition or slightly later, their radiocarbon age represents a minimum age for the deposition of the calcarenites. As these sediments likely cemented quite fast the age probably is very close to the age of deposition.

5.4.5 Sea level evolution of the youngest Pleistocene stage

The calcarenites have been deposited during the youngest Pleistocene (around 32472 $\pm$ 900 years cal. BP) this means that the mean sea level of the Mediterranean was much lower than today due to huge amounts of water being bound in continental ice caps and also due to the thermal shrinkage of the water because of low temperatures [Alley *et al.*, 2005; Poulos *et al.*, 2009]. Caputo (2007) published an overview of various sea level curves for the last 450 ka shown in Figure 59.

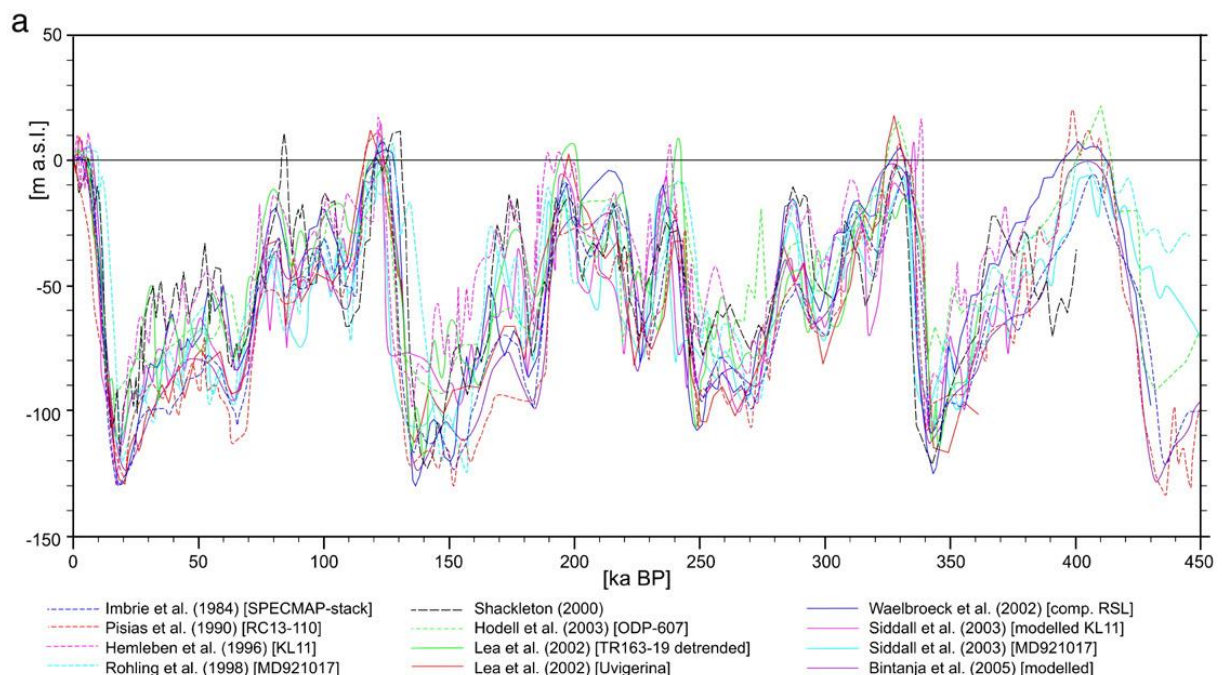


Figure 59: Sea level curves for the last 3-4 glacial cycles during the last 450 ka [Caputo, 2007]

Sea-level reconstructions for the age of the eolianite deposition show considerable variations ranging between sea-levels around -100 m [Imbrie *et al.* 1984, Lea *et al.* 2002] and -55 m below present sea-level [Hemleben *et al.*, 1996; Shackleton, 2000]. New results show that a sea-level of -100 m below present one may be more realistic [Rohling *et al.*, 2009].

On the basis of the sea level curve of Lambeck (1996) a sea level model for the Aegean region was made using a bathymetry & coastline shapefile from the *Hellenic Center for Marine Research* (<http://arch.her.hcmr.gr/downl.htm>) into ArcMap 10.0 and calculating past sea levels via raster calculator (Figure 60).

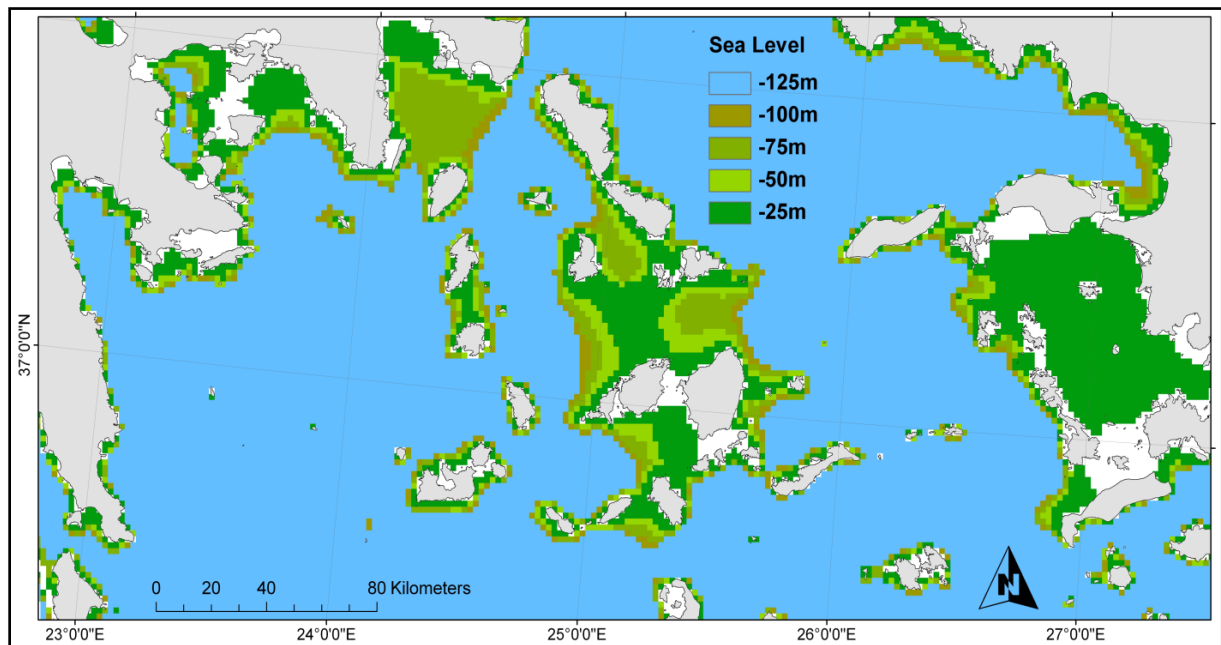


Figure 60: Various sea levels during the latest Pleistocene. The blue area represent areas below the LGM sea level of -125 m. White areas range from 0 to -25m below present sea-level. Vertical tectonic movements were not considered.

For the last glacial maximum, which lasted from 22 ka to 19 ka [Yokoyama *et al.*, 2000] a sea level of -125 m below present one is assumed [Stanford *et al.*, 2010]. Particularly striking is that a sea level drop of 25 m is sufficient to form a large emergent Cycladic platform. Lowering the sea-level to -50 m, -75 m and -100 m would result in shifting the coastline in some 10-12 km distance to Antiparos and its calcarenite occurrences. . Even a drop of only -25 m would move the former coastline 5-8 km from Antiparos. Considering these sea-level reconstructions a marine depositional environment of this sandstone is virtually impossible.

5.4.6 Tracks and trackways

At two localities vertebrate tracks and trackways respectively have been observed (see Figure 41, sites [1] and [6]). At the outcrop [6] near Sifnaikos beach tracks (section 3 in chapter 5.1.1.3) have been investigated in a vertical section (see Figure 61 and 62), while at outcrop [1] the trackways have been recorded on bedding surfaces (see Figure 63, 64 and 66). The tracks at site [6] could not be measured and studied in detail due to the restricted accessibility because of its location at a steep cliff. The trackway at site [1] was studied in detail and the geometrical properties of each track and its relationship to the surrounding tracks has been recorded and a detailed map (Figure 63) has been created.



Figure 61 and 62: Abundant trackways exposed in vertical section, N of Agios Paraskéne. Limbs sunk up to 9 cm into the substrate.

The term “tracks” is the impression of an animal foot or hoof on the “tracking surface” [Fornós *et al.*, 2002; Milàn *et al.*, 2007]. The original track is called “true track” whereas deformations of the substrate by the radial pressure of the animals’ foot below the tracking surface are called “undertracks” [Lockley, 1991]. Furthermore the radial pressure of the foot may create a crest of displaced sediment around it [Milàn *et al.*, 2007]. The geometry of this track crests depend strongly on the moving direction of the track maker. If the track gets filled with sediment, the shape of the true track diminishes by gradually shallower fill. The subsequent track infill is termed “ghost track” [Fornós *et al.*, 2002]. A sequence of consecutive tracks is called trackway [Sarjeant, 1990].

The tracks near Sifnaikos beach are abundant and they are concentrated to certain beds. The depth of track impressions decreases towards the top, which might be related to different track makers, or different sizes of track makers or variations in the properties of the sand

during track formation. Most of the tracks are about 10 cm wide and 5 cm deep. The track walls are shallow inclined and hardly any morphological details of the track makers limb are visible.

South of Livadia bay at site [1] at about 80 m a.sl. nine tracks on a single bedding surface of coarse-grained (<2 mm) calcarenite have been found. The tracks possibly belong to at least 2 separate trackways. Trackways can be traced for about 1.5 m. The measurements of each track are listed in Table 6.. The stride was measured from track center to track center and ranges between 56.1 cm and 40 cm (Table 7).

The interpretation of pes and manus is very challenging, because the bedding surface is intensely weathered and additionally pes and manus commonly overlap to form compound tracks [Fornós *et al.*, 2002]. The recognition and measurement of stride and pace are difficult because of the relative short length of the trackways with the two traceable trackways, 185 cm and 101 cm, respectively.

track #	long axis	short axis	crest height ⁵	track depth ⁶	particularities
1	118 mm	100 mm	370 mm	130-150 mm	slightly convex center
2	110 mm	77 mm	250 mm	70 mm	
3	106 mm	101 mm	180 mm	--	slightly convex center
4	103 mm	85 mm	260 mm	150 mm	
5	86 mm	85 mm	150 mm	70 mm	slip track?
6	96 mm	86 mm	270 mm	130 mm	cloven hoof
7	130 mm	111 mm	100 mm	70-120 mm	crest abraded
8	79 mm	79 mm	--	--	crest gone
9	87 mm	75 mm	--	--	crest gone

Table 6: Measurements of the recorded tracks south of Livadia bay.

⁵ crest height was measured from the track center to the top of the crest

⁶ track depth was measured perpendicular from the bedding plane to the center of the track

Track X-Y	distance	Track X-Y	distance
9-3	42.6 cm	2-4	56.1 cm
3-5	53.4 cm	4-6	44.8 cm
5-7	49.5 cm		
7-8	41.0 cm		

Table 7: Track distances for trackway A (left side) and trackway B (right side). See Figures 58 and 59.

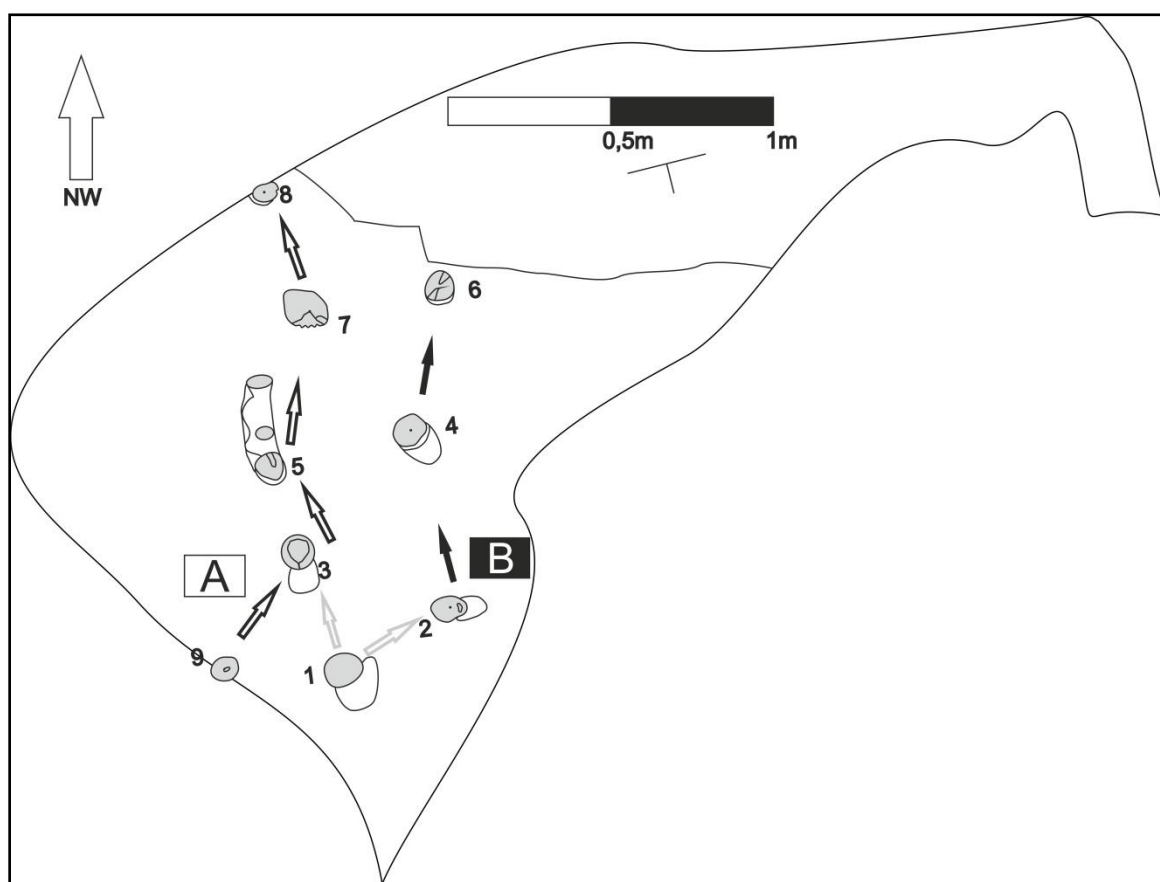


Figure 63: Map of the tracks south of Livadia bay. Weathering and the limited number of tracks make the recognition of trackways difficult, but probably two trackways can be recognized. White arrows belong to trackway A, black arrows to trackway B. The position of track 1 in this sequence remains unclear.

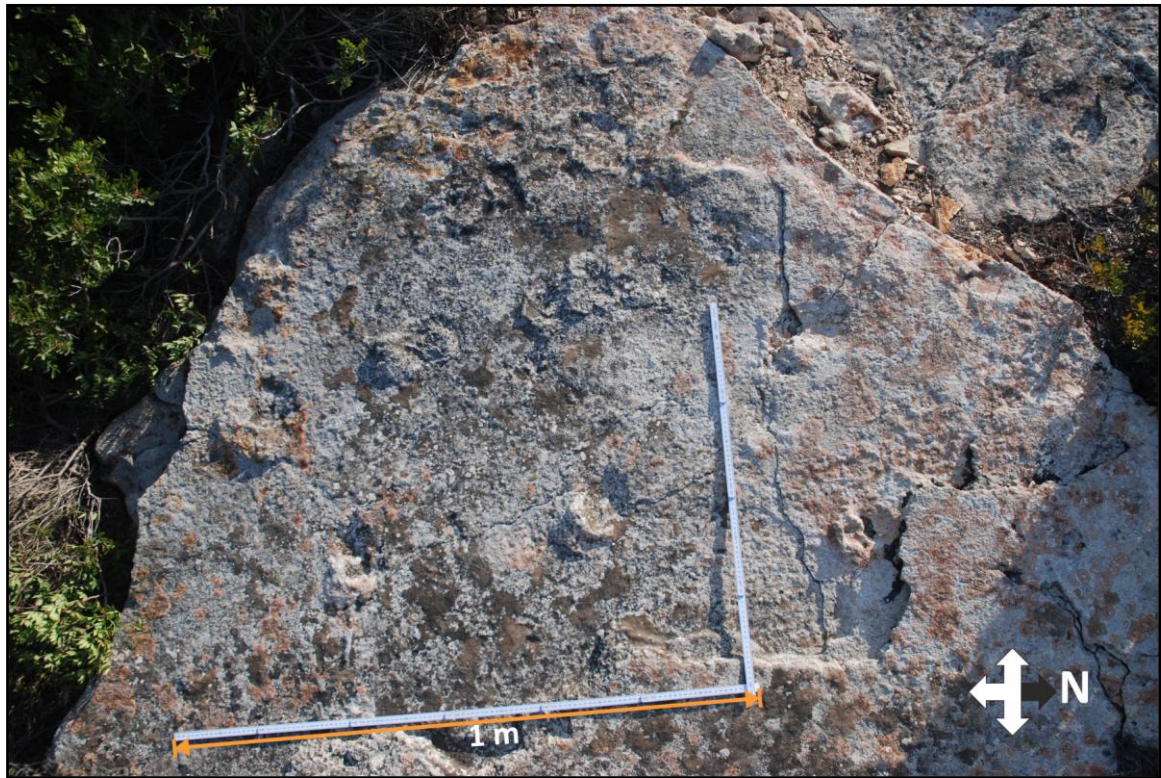


Figure 66: Overview photo of the trackways. They are interpreted as surface tracks.



Figure 64: Oblique view of the trackways beautifully showing push-back mounds.



Figure 65: The only track where details of one track indicating a cloven hoof and thus an *Artiodactyla* track maker (track 6)

The longer of the two trackways (A in Figure 63) includes track 9 continuing to 3, 5, 7 and 8 for a length of 185.5 cm. The measured values for the stride range between 53.4 cm and 41 cm (see Table 7). Track 5 is very interesting as it seems that it represents a slip track meaning the Trackmaker slipped while walking in the unconsolidated sediment and dragging the track down slope for 26 cm. If this assumption is true then this is the only part of the two track-

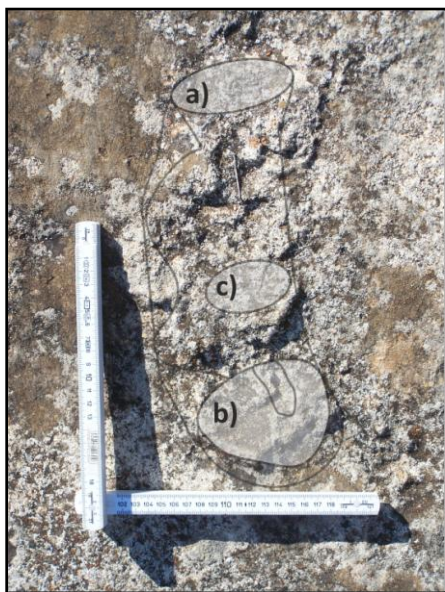


Figure 67: Slip trackway (#5) of trackway A. a) and c) are manus tracks. b) is the pes track. Outlines of the tracks for improved visibility.

ways where pes and manus differentiation is possible. The animal would have started its step with the left manus (Figure 67 a)), slipped (Figure 67 b)) and in the course of movement set the left pes in the slipping surface (Figure 67 c)). The movement direction of the animal must have been upslope because of the arrangement of tracks in track 5.

It is very likely that three tracks (2, 4 and 6) belong to one trackway. The stride measurements (Table 7) of this trackway indicate that the trackmaker must have been of a similar size as the trackmaker of trackway A.

An important observation for the determination of the trackmaker is track 6 (Figure 65) where the imprint of a cloven hoof has been conserved therefore indicating that the track has been produced by an artiodactyl.

6 Discussion

The depositional environment of the calcarenites is highlighted by several characteristics and observations mentioned in the previous chapters. An important argument for the reconstruction of the depositional environment is the Pleistocene paleo-sea level evolution (chapter 5.4.5). During the time of the sedimentation of the calcarenites – interpreted from radiocarbon data (chapter 4.2.7) – the sea-level was about 100 m lower than today [Rohling *et al.*, 2009], therefore strongly suggesting a non-marine deposition. The distance of the sandstone to the sea during their formation is probably even larger considering the long term general subsidence of the central Cyclades at least during the late Pleistocene and Holocene [Draganits, 2009; Kapsimalis *et al.*, 2009; Poulos *et al.*, 2009]].

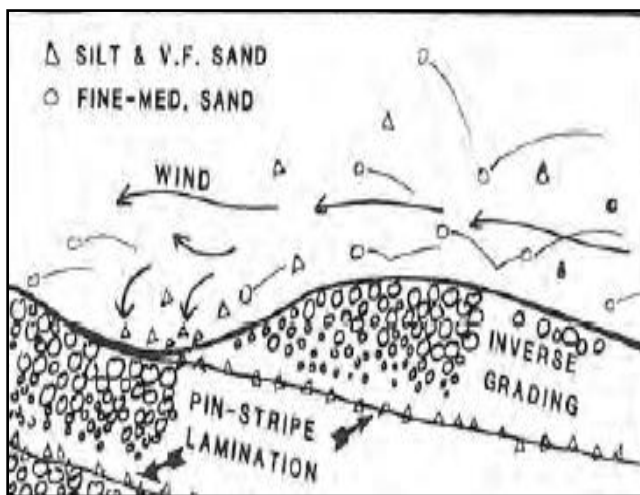


Figure 68: Formation of pinstripe lamination by accumulation of finer grains in the ripple trough [Fryberger and Schenk, 1988].

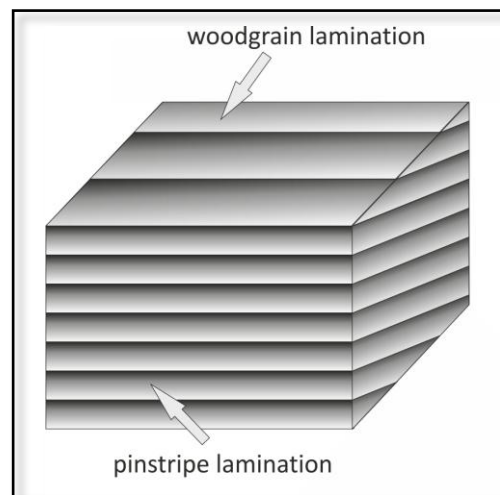


Figure 69: pinstripe and wood grain lamination in a schematic sketch (after Loope and Abegg, 2001).

Additionally several sedimentary features indicate terrestrial depositional environments. A commonly observed and distinct sedimentary feature in the outcrop is the inversely graded lamination which is interpreted as pinstripe lamination (Figure 69) – resulting from the deposition by translational wind ripples [Fryberger and Schenk, 1988]. This type of lamination and beds results from small-scale processes ripple migration and sedimentation. They are formed by the preferred deposition of finer grain sizes in ripple troughs and coarser grain sizes in upper parts of the lee side as well as luv side of ripples (Figure 68).

Eolian sand deposits generally show steeper foresets than sub aquatic deposited sand sediments. Several foreset orientations have been measured, without exception they dip from

the sea towards the interior of the island (see 5.4.1), indicating mainly south to south-east directed paleo-wind directions similar to the present predominant wind directions of the central Aegean region [Chronopoulou *et al.*, 2010]. The measured dip angles of the foresets range between 10° and 35°. Landward dipping foresets are common in modern day as well as ancient eolian sandstones [Loope & F. E. Abegg, 2001; Frébourg *et al.*, 2008].

Pedogenetic processes may also support the recognition of subaerial environments. Additionally rhizolites are useful paleo-environmental indicators both at outcrop scale and in thin section [Frébourg *et al.*, 2008]. Frébourg *et al.* (2008) stated that on a mobile substratum only big root remnants would be preserved by sediment infill. SEM studies for in the present study have also documented calcified fungal hyphen at µm-scale which also may indicate subaerial environments (see chapter 5.4.2).

Grain-size parameters of sand-sized sediments are important indicators for depositional environments. Eolian sediments usually are – like beach sands – well-sorted and well-rounded [Tucker, 2003]. Of course these parameters heavily depend on the source material. Calcarenites consist of heterogeneous carbonate particles (foraminifera, gastropods, corallinacean red algae, etc.) with highly variable particle shapes and intraparticle porosity. Thus particles of different sizes can be transported and deposited. Abegg *et al.* (2001) state that although the mineral density of quartz is slightly lower than that of calcite, high intraskeletal porosity can considerably reduce the density of carbonate particles [Yordanova and Hohenegger, 2007] and thereby also lower their critical shear velocity [Frébourg *et al.*, 2008]. Consequently it is not quite uncommon to find coarse carbonate particles together with smaller quartz grains. This depositional behavior can completely obscure potentially existing pinstripe laminations [Frébourg *et al.*, 2008].

The faunal composition of the calcarenites may evidence their depositional environment. For instance the foraminifera found in the thin sections originate from different habitats (e.g.: *Stilostomela/Nodosaria* → deeper water, low energy; *Elphidium* → shallow water, high energy). The origin of the foraminifera from a variety of different habitats supports the model of an eolian origin of the calcarenites [Frébourg *et al.*, 2008]. According to Frébourg *et al.* (2008) reworked marine bioclasts with micritic filled chambers are also typical indicators for eolian transport as micrite cannot occur in grainstones without being reworked. In the present study the preservation condition of the shells is variable but is fairly bad in most

cases. According to *Frébourg et al.* (2008) bioclasts are commonly strongly fractured and abraded because of high velocity collisions of particles in the wind. During sub aquatic transport staining and pitting are common [*Frébourg et al.*, 2008]. The well-preserved terrestrial snails as well as the trackways are additional strong arguments for an eolian deposition of the calcarenite [*Loope and Abegg*, 2001; *Milàn et al.*, 2007].

Although wind direction is comparable to the present day directions, wind speeds must have been much higher 33 ka ago than today. This is indicated on the one hand by the grain sizes in (sub)recent wind dunes which are much finer grained than the eolianites (see 5.2.1.2) and on the other hand by the location of deposition. The recent dunes are directly located behind beaches as can be seen in Figure 33 and Figure 34 whereas the eolianites have been deposited several kilometers inland, according to the lower sea-level at the time of formation. Big distances between the provenance area and the final deposition are also described from India where the deposits can be up to 80 km from the coast [*Dasgupta and Bandyopadhyay*, 2008].

Concluding above mentioned arguments, the investigated calcarenite on Antiparos is interpreted as “eolianite” or “carbonate eolianite”. The sandstone is very similar to many other eolianites described from the Mediterranean. Well studied examples include those from NW Sardinia [*Andreucci et al.*, 2010 and references therein] and Mallorca [*Fornós et al.*, 2002].

Carbonate Eolianites

According to *Abegg and Loope* (2001) and *Brooke* (2001) carbonate eolianites are sandstones deposited by wind with more than 50% carbonate grains [*Abegg and Loope*, 2001]. There are two main types of depositional environment of eolianites: **coastal** eolianites and **inland** eolianites [*Frébourg et al.*, 2008]. Inland eolianites, as described by *Abegg and Hanford* (2001) result from a large-scale deflation of exposed carbonate shelves and the accumulation of the carbonatic particles in the hinterland, filling up continental depressions in scattered patches. In contrast coastal eolianites are deposited in coast-parallel elongated sand accumulations originating from the deflation of beach deposits and subtidal sediments [*Abegg and Hanford*, 2001]. Carbonate eolianites are mainly known from the Pleistocene [*Brooke*, 2001], with only a few from the Mesozoic and Paleozoic stages [*Abegg and Loope*, 2001].

Brooke (2001) distinguishes between continental coast and island eolianites: continental coast eolianites build up deposits of far larger volumes and represent the accumulation of vast quantities of shallow-marine carbonate. The island of Antiparos can be assigned to the continental shelf island type [Brooke, 2001] because of its location on the central Cycladic platform. The depositional environment of the eolianites found on Antiparos is interpreted as “**sand ramp deposits**” [Lancaster and Tchakerian, 1996], which is eolian sand accumulated in front of topographical obstacles e.g. mountain fronts and are interlayered with coarse layers of talus sediments and paleosols [Tchakerian, 1991].

Although the eolianites on Antiparos hardly exceed some meters thickness, carbonate eolianites may reach huge sizes. Carew and Mylroie (2001) described up to 63 m thick eolianite dunes on Cat Island of the Bahamas at an average elevation of 20 to 30 meters. The Western Australian Island of Dirk-Hartog and the Edel Peninsula (Shark Bay) are formed by Pleistocene eolianite with an active dune field on the Edel Peninsula with more than 36km length and 2 km width [Le Guern, 2004]. Eolianites can build huge porous aquifers along the present day coasts and due to their properties (well-sorted, high porosity) they are also high quality reservoir rocks [Frébourg et al., 2008].

Figure 70 shows the worldwide locations of Quaternary eolianite (modified after Brooke, 2001 and Frébourg et. al, 2007). It is clearly visible, that most of the eolianite occurrences are located between 20° and 40° northern and southern latitude. Most of the world's eolianite is situated in the southern hemisphere [Brooke, 2001]. Preferable conditions for the formation of eolianites are warm climate favoring carbonate production and sediment-mobilizing onshore winds [McKee and Ward, 1983]. This kind of climatic conditions are found in the 20° to 40° latitude zone. The island of Antiparos is located at 37° northern latitude (Figure 70).

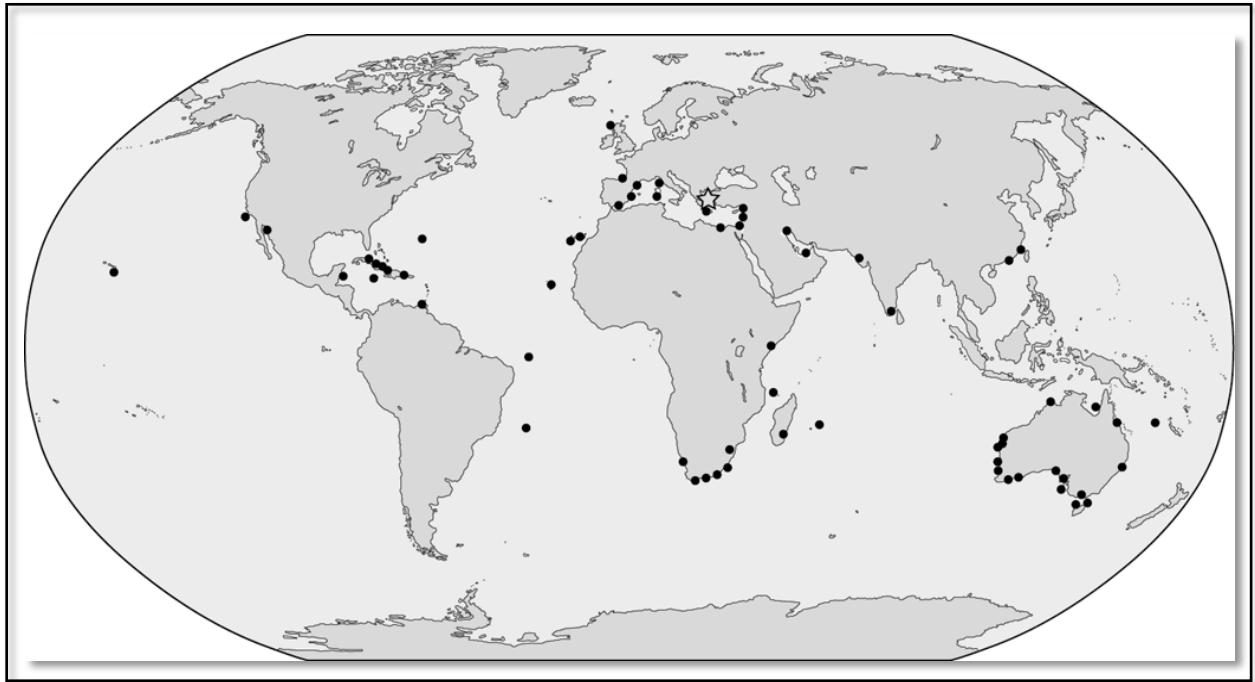


Figure 70: Global distribution of Quaternary eolianites (modified after Brooke, 2001 and Frébourg et al., 2007). The star marks the location of the investigated eolianite on Antiparos.

Pleistocene and Holocene colonization of the Aegean

Until recently the occurrence of chipped tools made of Melian obsidian in upper Palaeolithic layers in the Franchthi cave on the Peloponnese represented the oldest evidence for early seafaring as well as contacts between mainland and the Cyclades [see summary in *Renfrew and Aspinall*, 1990] and the Late Neolithic settlement on Saliagos [*Evans and Renfrew*, 1968], a small islet between Paros and Antiparos has been regarded the oldest remains of permanent settlement in the Cyclades [*Zachos*, 1996]. New discoveries and excavation have moved the date of human contact and occupation further into the past. For example on Kythnos island Mesolithic house structures and graves have been excavated dating between 8263 B.C. to 7668 B.C. [*Sampson*, 2008]. Late-breaking archaeological survey results from SW Crete may even indicate late Paleolithic human presence in this area, representing one the oldest evidence of human sea faring [*Strasser et al.*, 2010].

Possible trackmaker in the context of island colonisation

Potential trackmakers of the observed trackways in the eolianites on Antiparos are constrained by the values of stride measurements (40-50 cm) and the presence of a cloven hoof track. Thus artiodactyl mammals of the size of goats or deer represent the most plausible candidates. Similar trackways have been described from eolianites. Those on Mallorca have

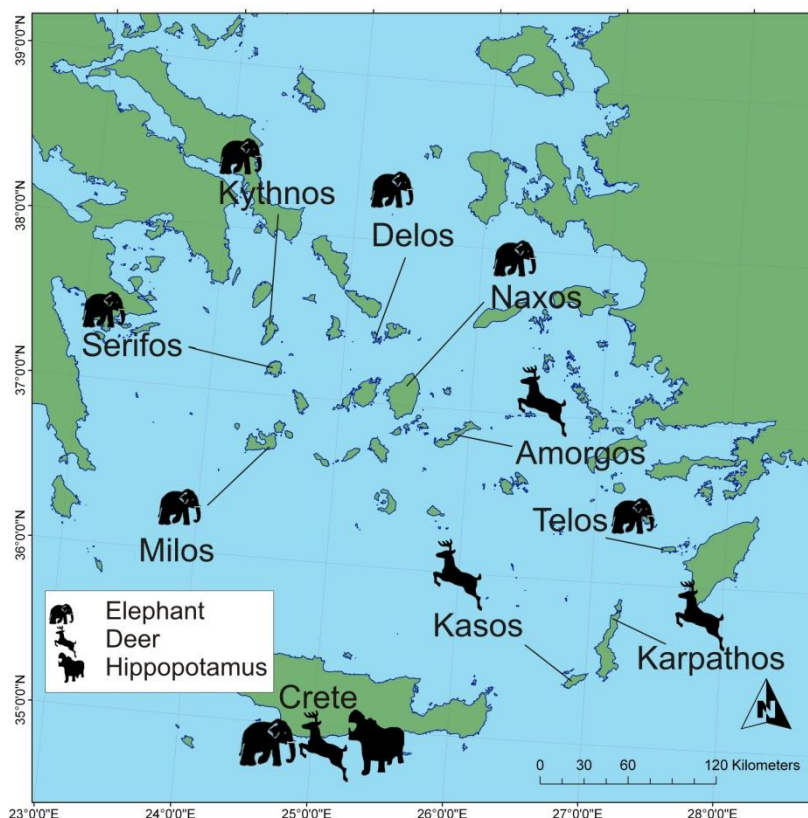


Figure 71: Distribution of late Pleistocene mammal remains in the Aegean (redrawn after *Masseti* (2003; 2009) and *Raia and Meiri* (2006)).

been attributed to a Pleistocene goat – *Myotragus balearicus* Bate (1909) [*Fornós et al.*, 2002] and those from NW Sardinia to a deer – “*Praemegaceros cazioti*” (Deperét 1897) [*Fanelli et al.*, 2007]. On Antiparos bones of fallow deer have been found during rescue excavation in the Antiparos Cave, proving the presence of fallow deer on Antiparos at least in the Neolithic [*Psathi*, 2006]. If we take into account that the sea level

during the formation of these sediments in the late Pleistocene was considerably lower than today’s sea level and various land connections between the Cycladic islands allowed faunal interchange with other islands. Holocene endemic deer are known from Amorgos, Crete, Kassos and Karpathos [*Masseti*, 2003]. In Figure 71 the distribution of endemic mammals of the Aegean are shown according to [*Masseti*, 2003; 2009a; *Raia and Meiri*, 2006]. Considering the low sea-level during the cold periods of the (Figure 60) Amorgos was possibly connected with other Cycladic islands. Additionally, deer besides elephants and hippopotami are known as excellent swimmers (Figure 72) among land living mammals [*Masseti*, 2009a]. They can cross sea narrows up to 20 km [*van Der Geer et al.*, 2010]. Thus faunal exchange between the Greek mainland and the Cycladic Islands wouldn’t have been impossible as the

distance between Evvia and Andros Island is just around 10 km during lower sea-levels in glacial periods. *Fornós et al*, (2002) mention in their paper about trackways of *Myotragus balearicus* preserved in Pleistocene eolianites, that the tracks were made in a moist substrate thus suggesting that they were made during wet periods i.e. winter. The same might be true also for the Antiparos trackways.



Figure 72: Roe deer swimming between two islands of the Andaman archipelago (Bay of Bengal). This is a recent example of deer passing a sea barrier to get to another island. (Photo: Kai Hendry)

According to present knowledge there is not a single evidence for the presence of goats in the Cyclades [*Masseti*, 2003; 2009b]. Goats probably have been introduced by humans possibly during the Neolithic. Thus concerning the size and shape of the tracks and trackways most probable track producer for the traces observed in the eolianites on Antiparos is a fallow deer (*Dama dama*). Additionally, bones of fallow deer have been reported from Neolithic layers from Antiparos cave [*Psathi*, 2006].

7 Conclusions

The Quaternary sandstone occurrences on Antiparos have been interpreted as eolian carbonate sand ramp deposits. Radiocarbon dating on terrestrial gastropods shows that the eolianites were deposited around 32472 ± 900 years BP (95% confidence interval) in a period of considerable lower sea-level than today when Antiparos was part of the landmass of the Central Cycladic Platform. The eolianites of Antiparos are defined by the following observations and analytical results:

- Sedimentary features
 - Pinstripe lamination; cross bedding with steep, landward dipping foresets
- Diagenetic features
 - Vadose cements (pendant and meniscus)
- Pedogenetic overprints
 - Alveolar structures, calcretes, rhizolites
- Bioclasts are a combination of (micro-)fauna from different habitats
- Terrestrial gastropods
- Vertebrate trackways
- Medium to well-sorted (heterogeneity of particles)

Summarizing these observations the calcarenites of northern Antiparos are interpreted as Pleistocene eolianites deposited above paleosols of probably last interglacial age.

Track and trackway morphologies suggest an artiodactyl trackmaker. Based on the lack of pre-Neolithic remains of goats in the Cyclades in the literature, but the quite common occurrence of cervids, the tracks probably have been produced by a deer.

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Appendix

List of samples

Sample N°	Outcrop N°	Description
AP091	2	dark granitic Bt-gneiss
AP092	7	calcrete
AP093	7	calcified gneiss
AP094	8	beach sand
AP095	9	dune sand
AP096	14	calcrete
AP097	14	Poros
AP098	16	calcrete
AP099	16	auger shells
AP0910	22	calcretized calcarenite
AP0911	25-2	weathering zone
AP0912	25-3	red clay layer
AP0913	25-4	bleached reddish layer
AP0914	25-5	alternated Poros?
AP0915	26	Vermetus
AP0916	26	beach sand
AP0917	33	pegmatite
AP0918	37-2	red horizon
AP0919	37-3	transition zone
AP0920	37-4	calcrete
AP0921	53	beach sand
AP0922	66	dune sand
AP0923	68	beach sand
AP0924	75	mylonitic gneiss
AP0925	?	
AP0926	76	shell fragments
AP0927	76	beachrock
AP0928	79	beach sand
AP0929	85	calcite marble
AP0930	85	cataclasite
AP0931	14	rhizolite
AP0932	37	red soil
AP0933	37	weathering zone
AP0934	94	beachrock + shell fragments
AP0935	96	cataclasite
AP0936	96	cataclasite
AP0937	98	weathered gneiss mylonite

AP0938	100	calcarenite (fine grained + pebbly components)
AP0939	101	gastropod in calcarenite
AP0940	101c	Calcrete --> Calcarenite
AP0941	103-3	Calcrete crust/fine grained Poros
AP0942	103-4b	calcarenite (fS-mS)
AP0943	103-4d	calcarenite - calcrete
AP0944	103-4d	calcarenite - calcrete
AP0945	103-4d	calcarenite - calcrete
AP0946	104	calcarenite
AP0947	109	calcarenite
AP0948	110	marble + Fe-ore
AP0949	112	crust taken in creek bed
AP0950	119	calcarenite fS
AP0951	121-2	calcarenite gS
AP0952	121-8	calcarenite fS-mS + clay
AP0953	121-12	calcrete
AP0954	121-10	calcarenite mS
AP0955	125	calcarenite
AP0956	127	calcarenite
AP0957	128	beach sand
AP0958	101 + 104	clayey layer
AP0959	101 + 104	gastropod
AP0960	101 + 104	calcarenite (lower 1/3)
AP0961	103f	coarse grained calcarenite
AP0962	103f	coarse grained calcarenite with crust
AP0963	103f	gastropods in calcarenite
AP0964	103f	silicified calcarenite
AP0965	121	Altered pyrite
AP0966	121-6	calcarenite component in layer n° 6
AP0967	121b-4b	calcarenite mS-gS
AP0968	125A	calcarenite
AP0969	125A	calcarenite
AP0970	143	dune sand
AP0971	144	calcarenite
AP0972	37-5	calcrete + rhizolite
AP0973	145	dolomite marble
ED10/AP/3		mylonitic gneiss
ED10/AP/4A		coarse Bt-gneiss
ED10/AP/4B		coarse Bt-gneiss
ED10/AP/5		cataclasite

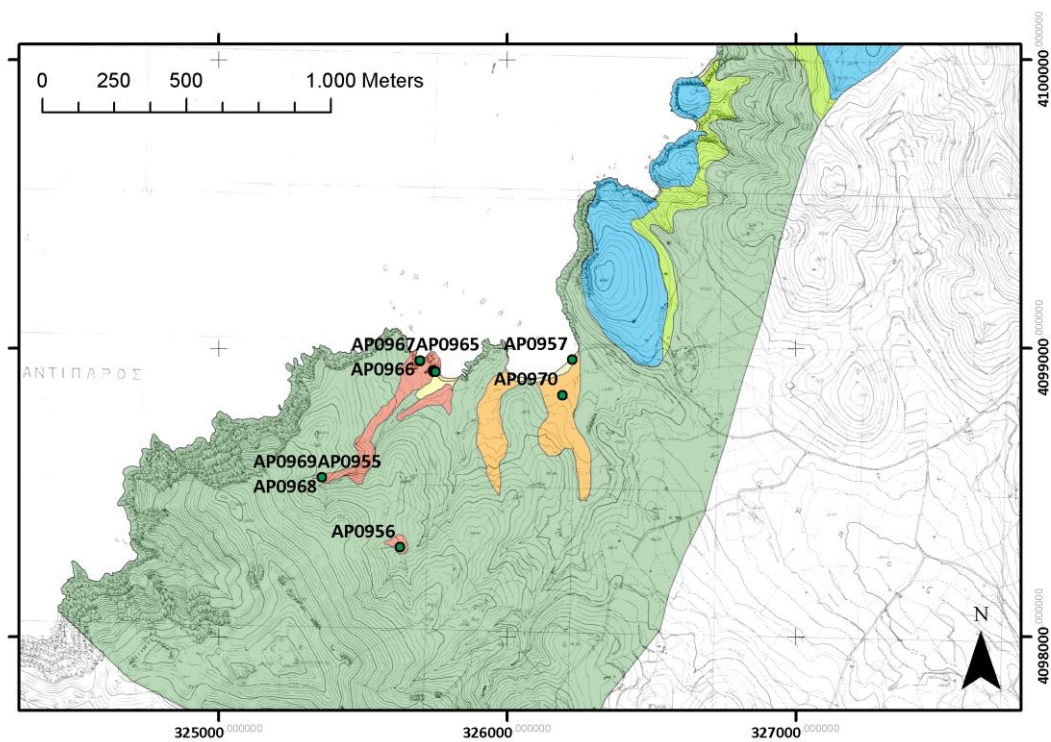
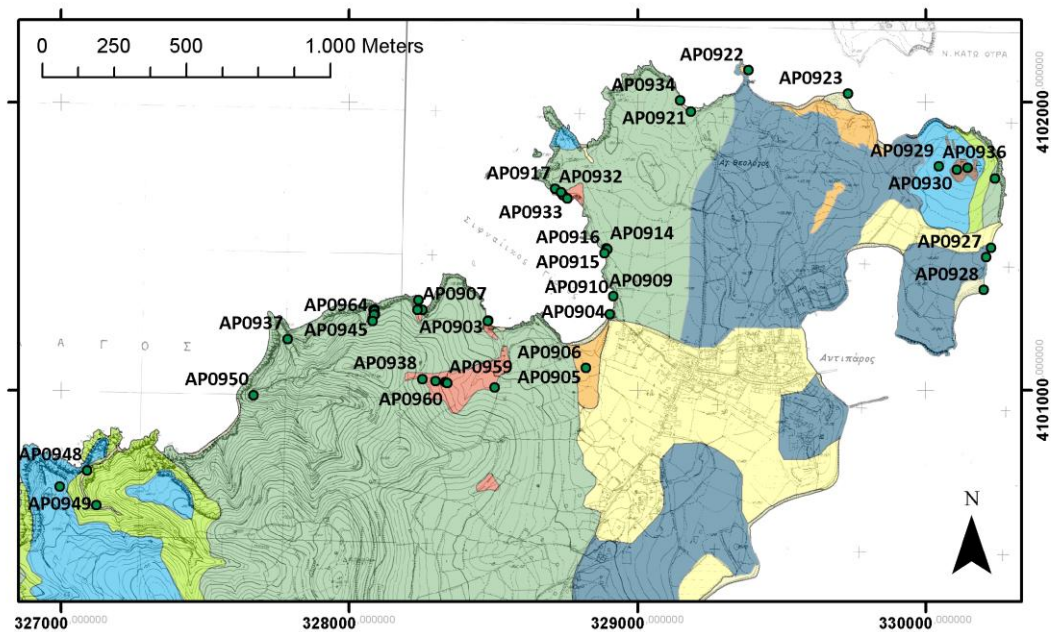
List of thin sections

Sample N°	Outcrop N°	Description
AP0902	7	calcretized calcarenite
AP0907	14	calcarenite
AP0910	22	calcrete
AP0914	25-5	calcretized calcarenite
AP0917	33	pegmatite
AP0920	37-4	calcrete
AP0924	75	mylonitic gneiss
AP0934	94	calcarenite
AP0935	96	cataclasite
AP0936	96	cataclasite
AP0938	100	calcarenite
AP0939	101	calcarenite
AP0941	103-3	calcrete
AP0942	103-4b	calcarenite
AP0943	103-4d	calcarenite
AP0944	103-4d	calcrete
AP0945	103-4d	calcarenite
AP0946	104	calcarenite
AP0947	109	?
AP0951	121-2	calcarenite
AP0951A	121-2	calcarenite
AP0953	121-12	calcarenite
AP0954	121-10	calcarenite
AP0955	125	calcarenite
AP0961	103f	calcarenite
AP0962	103f	calcarenite
AP0962A	103f	calcarenite
AP0964	103f	calcretized calcarenite
AP0971	144	calcarenite
AP0972	37-5	calcarenite
ED10/AP/3		mylonitic gneiss
ED10/AP/4A		granitic gneiss
ED10/AP/4B		granitic gneiss
ED10/AP/5		cataclasite

Detailed grain size analysis of present day beach and dune sands

SAMPLE STATISTICS		beach	beach	beach	beach
		AP094	AP0916	AP0921	AP0928
	ANALYST AND DATE:	LB, 9/10/2010	LB, 9/10/2010	LB, 9/10/2010	LB, 9/10/2010
	SIEVING ERROR:	0,9%	1,0%	0,6%	1,2%
	SAMPLE TYPE:	Sorted	Sorted	Sorted	Sorted
	TEXTURAL GROUP:	Slightly Gravelly Sand	Slightly Gravelly Sand	Slightly Gravelly Sand	Gravelly Sand
	SEDIMENT NAME:	Slightly Very Fine Gravelly Medium Sand	Slightly Very Fine Gravelly Coarse Sand	Slightly Very Fine Gravelly Medium Sand	Very Fine Gravelly Very Coarse Sand
METHOD OF	MEAN	455,9	865,4	293,5	1039,6
MOMENTS	SORTING	454,7	413,7	142,8	650,8
Arithmetic (μm)	SKENNESS	3,291	1,694	3,525	1,018
	KURTOSIS	13,75	6,871	23,99	3,111
METHOD OF	MEAN	354,4	774,5	265,7	840,8
MOMENTS	SORTING	1,806	1,540	1,486	1,917
Geometric (μm)	SKENNESS	1,482	0,169	0,319	-0,279
	KURTOSIS	5,719	4,083	4,695	2,880
METHOD OF	MEAN	1,497	0,369	1,912	0,250
MOMENTS	SORTING	0,853	0,623	0,572	0,939
Logarithmic (ϕ)	SKENNESS	-1,482	-0,169	-0,319	0,279
	KURTOSIS	5,719	4,083	4,695	2,880
FOLK AND	MEAN	360,3	763,0	248,1	894,6
WARD METHOD	SORTING	1,708	1,434	1,505	1,788
(μm)	SKENNESS	0,454	0,481	-0,294	-0,269
	KURTOSIS	3,432	0,594	2,293	1,106
FOLK AND	MEAN	1,473	0,390	2,011	0,161
WARD METHOD	SORTING	0,773	0,521	0,589	0,838
(ϕ)	SKENNESS	-0,454	-0,481	0,294	0,269
	KURTOSIS	3,432	0,594	2,293	1,106
FOLK AND	MEAN:	Medium Sand	Coarse Sand	Fine Sand	Coarse Sand
WARD METHOD	SORTING:	Moderately Sorted	Moderately Well Sorted	Moderately Well Sorted	Moderately Sorted
(Description)	SKENNESS:	Very Coarse Skewed	Very Coarse Skewed	Fine Skewed	Fine Skewed
	KURTOSIS:	Extremely Leptokurtic	Very Platykurtic	Very Leptokurtic	Mesokurtic
	MODE 1 (μm):	302,5	605,0	302,5	1200,0
	MODE 2 (μm):	605,0	1200,0	152,5	605,0
	MODE 3 (μm):				2400,0
	MODE 1 (ϕ):	1,747	0,747	1,747	-0,243
	MODE 2 (ϕ):	0,747	-0,243	2,737	0,747
	MODE 3 (ϕ):				-1,243
	D ₁₀ (μm):	179,8	520,1	144,6	322,3
	D ₅₀ (μm):	307,5	663,0	284,7	1007,3
	D ₉₀ (μm):	690,6	1314,9	349,7	2223,1
	(D ₉₀ / D ₁₀) (μm):	3,840	2,528	2,419	6,898
	(D ₉₀ - D ₁₀) (μm):	510,8	794,8	205,1	1900,8
	(D ₇₅ / D ₂₅) (μm):	1,296	2,001	1,293	2,264
	(D ₇₅ - D ₂₅) (μm):	79,88	570,0	73,35	709,4
	D ₁₀ (ϕ):	0,534	-0,395	1,516	-1,153
	D ₅₀ (ϕ):	1,701	0,593	1,812	-0,010
	D ₉₀ (ϕ):	2,475	0,943	2,790	1,634
	(D ₉₀ / D ₁₀) (ϕ):	4,635	-2,387	1,841	-1,417
	(D ₉₀ - D ₁₀) (ϕ):	1,941	1,338	1,274	2,786
	(D ₇₅ / D ₂₅) (ϕ):	1,247	-4,303	1,228	-2,409
	(D ₇₅ - D ₂₅) (ϕ):	0,374	1,000	0,371	1,179
	% GRAVEL:	4,0%	3,4%	0,0%	14,6%
	% SAND:	96,0%	96,6%	100,0%	85,4%
	% MUD:	0,0%	0,0%	0,0%	0,0%
	% V COARSE GRAVEL:	0,0%	0,0%	0,0%	0,0%
	% COARSE GRAVEL:	0,0%	0,0%	0,0%	0,0%
	% MEDIUM GRAVEL:	0,0%	0,0%	0,0%	0,0%
	% FINE GRAVEL:	0,0%	0,0%	0,0%	0,0%
	% V FINE GRAVEL:	4,0%	3,4%	0,0%	14,6%
	% V COARSE SAND:	4,9%	35,3%	1,1%	36,2%
	% COARSE SAND:	13,3%	57,8%	5,9%	36,2%
	% MEDIUM SAND:	67,7%	3,2%	68,2%	11,1%
	% FINE SAND:	9,8%	0,2%	24,4%	1,8%
	% V FINE SAND:	0,2%	0,1%	0,3%	0,1%
	% V COARSE SILT:	0,0%	0,0%	0,0%	0,0%
	% COARSE SILT:	0,0%	0,0%	0,0%	0,0%
	% MEDIUM SILT:	0,0%	0,0%	0,0%	0,0%
	% FINE SILT:	0,0%	0,0%	0,0%	0,0%

Sample locations



Geological map (1:10,000) + geological sections

Attached in the back!

Curriculum Vitae

PERSÖNLICHE ANGABEN

Lukas Bickel



lukas.bickel@gmx.at
geboren 1984 in Feldkirch, Österreich
Ledig

STUDIUM

- | | |
|-------------------|--|
| 10/2002 - 10/2003 | Universität für Bodenkultur
Diplomstudiengang Kulturtechnik und Wasserwirtschaft |
| 10/2003 - 10/2007 | Universität Wien
Bakkalaureatsstudiengang Erdwissenschaften
Thema der Bakkalaureatsarbeit: „Sedimentologie und Geomorphologie des Nord-östlichen Neusiedlerseegebietes“
Abschluss: Bakk.rer.nat (mit Auszeichnung) |
| 10/2008 - 03/2011 | Universität Wien
Masterstudiengang Erdwissenschaften
Schwerpunkt Geologie
Thema der Masterarbeit: „The Quaternary sediments of Antiparos (Aegean): Litho-stratigraphy and depositional Environment“
Abschluss: M.Sc. |

PRAKTIKA & TUTORIEN

- | | |
|-------------------|---|
| 06/2003 – 07/2003 | Ferialpraktikum beim Amt der Vorarlberger Landesregierung
Landeswasserbauamt Bregenz |
| 08/2008 - 10/2008 | Geologische Bundesanstalt Wien
Abteilung Landesaufnahme
Feinseparation von Gesteinsproben und Erstellung von Zirkonpräparaten für U/Th/Pb-Datierung
Klassifikation der Zirkonkristalle nach Pupin & Turco (1981) |

11/2008 – 04/2009	Universität Wien Department für Geodynamik und Sedimentologie Wissenschaftlicher Mitarbeiter des Projektes „Ägäische Kernkomplexe“ (Leiter Univ.- Prof. Mag. Dr. Bernhard Grasemann) Grob- und Fenseparation von Gesteinsproben für die Datierung von Zirkon (U/Th/Pb), Granat (Sm/Nd) und Hellglimmer (Ar)
SS 2009	Tutor der Lehrveranstaltungen „Kartierung im Gelände (BA19) (PI)“ und „Sedimentologie, Fazieskunde (BA17) (PI)“ an der Universität Wien Tutor der Lehrveranstaltung „Geologische Übungen für Bauingenieure“ an der Technischen Universität Wien
WS 2009/2010	Tutor der Lehrveranstaltungen „Sedimentologie (GP0_28_07) (PI)“ und „Stratigraphie (GP0_28_08) (PI)“ an der Universität Wien
SS 2010	Tutor der Lehrveranstaltungen „Geologische Kartierung (W0_28_46) (PI)“ und „Sedimentologie, Fazieskunde (BA17) (PI)“ an der Universität Wien
seit 11/2008	Geologische Bundesanstalt Anstellung auf Werkvertragsbasis Feinseparation von Gesteinsproben und Erstellung von Zirkonpräparaten für U/Th/Pb-Datierung

SCHULE

09/1994 - 06/2002	Bundesrealgymnasium Feldkirch Abschluss: Matura
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BESONDERE KENNTNISSE

IT-Kenntnisse:

ArcGIS
MS Office
JMicroVision
Corel Draw X5
Golden Software Grapher
Adobe Illustrator
Adobe Lightroom 3

Sprachkenntnisse:

Englisch in Wort und Schrift
Französisch Maturaniveau
Spanisch rudimentäre Kenntnisse

Führerschein B

KURSE

Friedrich-Alexander-Universität Erlangen-Nürnberg (02/2009)
Interuniversitärer Karbonatfazieskurs („Flügel-Kurs“)

MITGLIEDSCHAFTEN

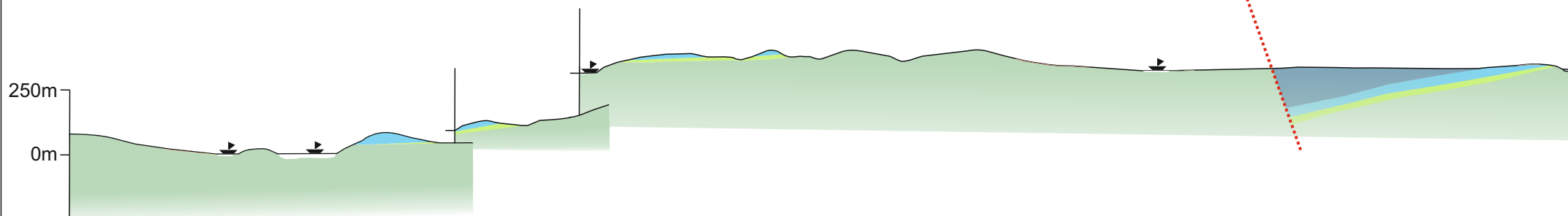
Österreichische Geologische Gesellschaft
International Association of Sedimentologists

0 500 1,000
Meters

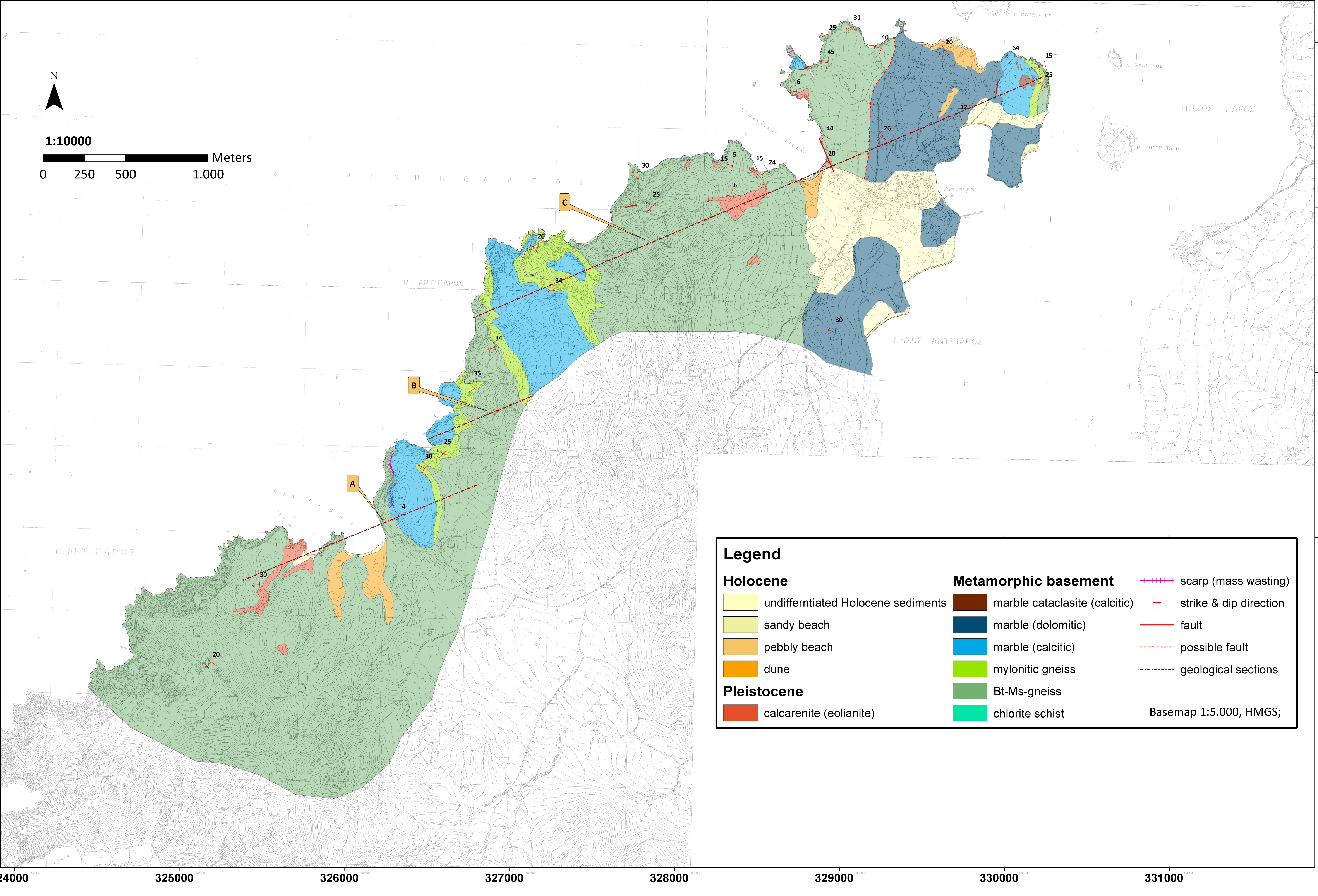
A

B

C



Geological map of northern Antiparos (1:10,000)



Legend

Holocene

- undifferentiated Holocene sediments
- sandy beach
- pebbly beach
- dune

Pleistocene

- calcarene (eolianite)

Metamorphic basement

- marble cataclasite (calcitic)
- marble (dolomitic)
- marble (calcitic)
- mylonitic gneiss
- Bt-Ms-gneiss
- chlorite schist

- scarp (mass wasting)
- strike & dip direction
- fault
- possible fault
- geological sections

Basemap 1:5.000, HMGS;