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From archipelago to floodplain – geographical and ecological changes in Miletus and its environs during the past six millennia (Western Anatolia, Turkey)

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with 5 figures and 2 tables

Summary. During the past six millennia, the famous ancient harbour city of Miletus and its environs have experienced major changes in palaeogeography and palaeoecology, related to (a) the progradation of the Büyük Menderes river delta, (b) fluctuations of sea level associated with the post-glacial marine transgression, and (c) the permanent impact of humans on the ecosystem since Late Chalcolithic times. In this paper, we present new results of our geoarchaeological research in and around Miletus examining palaeogeographical changes and their relation to human settlement activities over different historical periods. Palaeoecology of both coastal and terrestrial environments were reconstructed by sedimentological, foraminiferal, archaeozoological and palynological criteria. Analyses of sediment cores collected around the Temple of Athena revealed that sea level reached its highest stand during the Early Bronze Age. A similar pattern is evident on the southern fringe of Lion Harbour embayment around the later Sanctuary of Apollo Delphinius, where cultural debris from the Late Chalcolithic period is covered by shallow marine sediments. In the Middle and Late Bronze Ages, the introduction of the goat by the Minoans was a major factor in the progressive degradation of climax vegetation (open deciduous oak forests) which resulted in increased soil erosion and associated sediment accumulation in the coastal zone. These environmental changes, together with the fall in relative sea level, contributed to the rapid transformation of the Milesian archipelago to the Milesian Peninsula during the second millennium BC. In the 6^{th} century BC, the town centre (agora) with the Delphinium and the surrounding areas was extended by man made infill of the southern part of Lion Harbour embayment. Siltation caused by progradation of the Maeander Delta since Roman Imperial times largely infilled the harbours of the city and subsequently integrated the peninsula into the floodplain.

1 *Introduction*

The ancient cities of Miletus, Priene, Myous, and Herakleia were built on the shores of the Latmian Gulf, a marine embayment which was formed due to a rise of sea level in the late Pleistocene to early Holocene. The decline of the cities was closely related to the progradation of the Büyük Menderes river delta (Maeander, ancient name: Maiandros, see Fig. 2). During past millennia, the marine embayment has been transformed into a delta and alluvial plain (Brückner 2003, Brückner et al. 2002, 2004, Müllenhoff 2005). Similar examples of landscape transformation are known from many former embayments along the Aegean coast of Turkey. The rivers Scamander (Karamenderes) and Kaystros (Küçük Menderes), for example, formed deltas near the famous cities of Troia and Ephesus, respectively (Brückner 1997, 1998, 2005, Brückner et al. 2005, Kraft et al. 2003, 2005).

Several phases of settelement can be differentiated in the development of Miletus (Table 2). The terminology follows that of Parzinger (1989) for Miletus I-II and Niemeier (2005) for Mile-

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tus III-VI. The oldest phase (Miletus I) dates from the Late Chalcolithic period ca. 3500–3000 BC (PARZINGER 1989, NIEMEIER & NIEMEIER 1997, NIEMEIER 2005). Around 1900 BC, during the Middle Bronze Age, the arrival of settlers from Crete marked the beginning of the Minoan-Mycenaean period which ended in 1100 BC with the destruction of the fortification of the city (Miletus III-VI). The Ionian settlement started around 1050 BC. Miletus had its most flourishing time in the Archaic period (7^{th}–6^{th} centuries BC) when "the ornament of Ionia", as it was then called, founded more than 80 colonies, mainly along the shores of the Black and Marmara seas (GORMAN 2001). This phase ended abruptly in 494 BC with the total defeat against the Persians in the naval battle of Lade and the destruction of the city. The Classical-Hellenistic (479/478–64 BC), the Roman (64 BC–4^{th} century AD) and the Byzantine (4^{th} cent. AD–1327 AD) periods followed. Later, Miletus became part of the Ottoman Empire.

This paper examines the palaeogeography and palaeoecology of Miletus from its beginnings. The principal research foci are:

- maximum extent of the Holocene transgression and dating of the highest sea level;
- reconstruction of palaeo-environments and their changes in space and time;
- information about the Delphinium site, one of the most prominent places of the ancient city;
- floral and faunal changes throughout the past six millennia.

The stratigraphy at Miletos was established from vibracores (Cobra mk 1 corer of Atlas Copco Co., diameters of auger head: 6, 5 and 3.6 cm). Position and altitude of the cored sites were measured with differential GPS. Sedimentological and palaeoecological examinations of the cores was subsequently undertaken in the laboratory. The environment of deposition was mainly inferred from microfaunal analysis (ostracods, foraminifers). Palynological investigations provided information about the vegetation history. A chronostratigraphy was established based on artefact analysis and radiocarbon dating. Supplemented by input from archaeology and historical sciences, a reconstruction of the palaeogeographical evolution could then be achieved.

2 *Progradation of the Maeander Delta*

The historic delta growth of the Maeander River is one of the most spectacular cases of delta progradation in the Mediterranean region. It is assumed that the maximum marine transgression during the mid-Holocene reached nearly 60 km inland (BAY 1999b). The subsequent westward shift of the shoreline has been documented in the ancient literature (e.g. Herodotus, Strabo, Pausanias), by archaeological evidence from the former seaports Miletus, Priene, Myous and Herakleia, and by palaeogeographical studies (BRÜCKNER 1997, 1998, 2003, BRÜCKNER et al. 2002, 2004, MACKIL 2004, MÜLLENHOFF 2005). Lake Bafa, a brackish residual lake in the former southeastern part of the Latmian Gulf, also provides evidence of these shoreline changes (MÜLLENHOFF et al. 2004).

2.1 *Facies determination by microfaunal analyses*

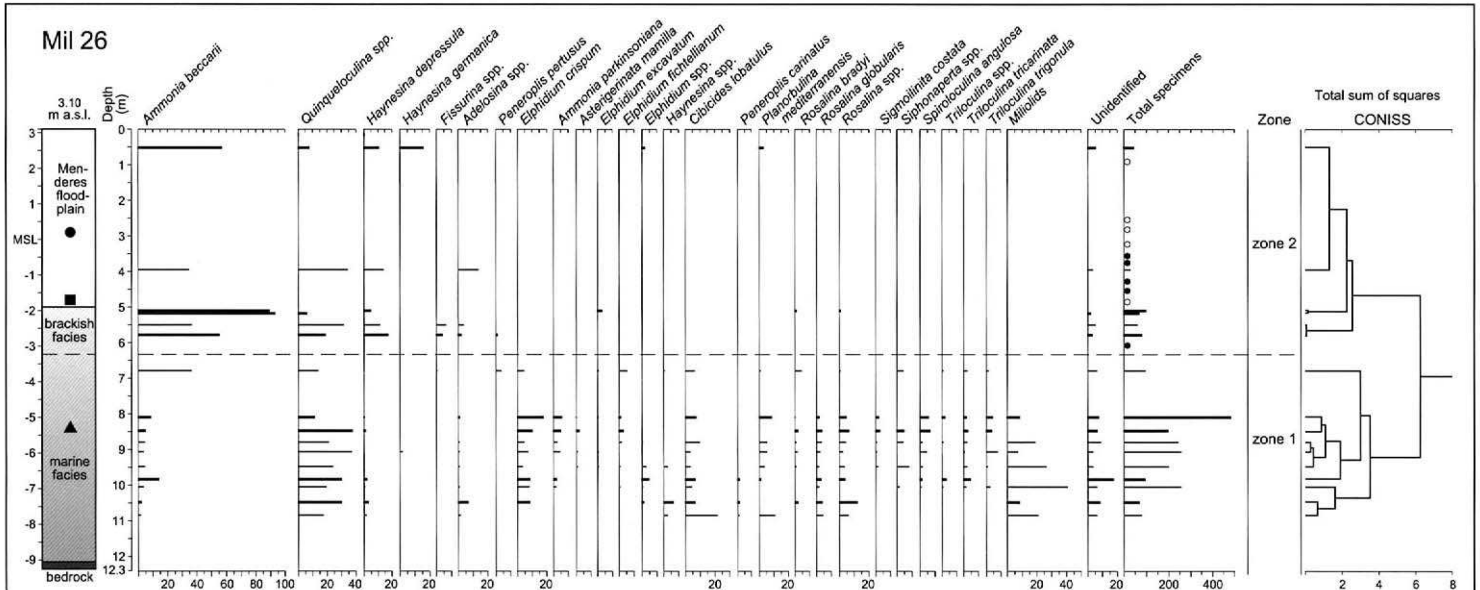
Most cores collected at Miletus show a transgressive stratigraphic sequence in their basal portions from terrestrial through littoral to shallow marine sediments (Brückner 2003, Müllenhoff et al. 2003). The prograding delta, responsible for the regressive overlap in the top sections of the cores, produced major ecological changes. Marine deposition was terminated by a seaward shift of the shoreline due to delta growth which led to the deposition of brackish or littoral sediments. The sequence is capped by fluvial deposits of the Menderes floodplain. Different sedimentary facies, mirroring fluctuating ecological conditions, are best detected by sedimentological and faunal criteria. Handl et al. (1999) identified more than 70 ostracod species from a sediment core from Miletus (Mil 39P) resulting in a clear differentiation of the depositional environments (marine, brackish, limnic). The following example shows that foraminifera are also sensitive indicators of changing sedimentary conditions.

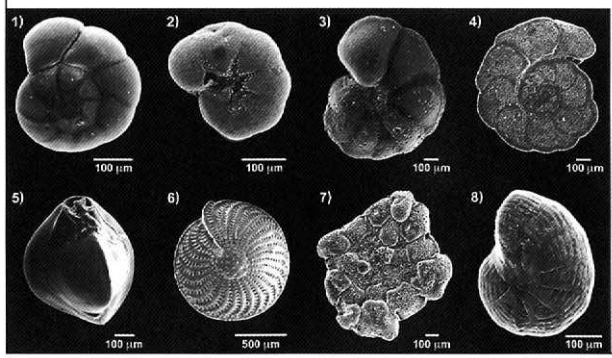
Foraminifera were analysed from a vibracore at the eastern side of the Milesian Peninsula close to the former Menderes River (Mil 26; ground surface at 3.10 m a.s.l. (above present mean sea level), X: 1816.64, Y: 2601.56, according to the coordinates of Bendt's map (Bendt 1968), lat/long: 37°31'44.76"N/27°16'59.20"E). Twenty-seven samples were studied using Cimerman & Langer (1991) as a primary reference for identification. Where possible, at least 200 specimens were picked from the sediment samples. However, low concentrations of foraminifera were found in several samples in the upper half of the core. In these samples all foraminifera were collected from the available sediment. Six samples from the upper part of the profile were entirely barren of foraminifera (Fig. 1).

A constrained cluster analysis (Grimm 1987) reveals a biostratigraphical change in the core at a depth of 6.30 m b.s. (below surface) or 3.20 m b.s.l. (below present mean sea level) (Fig. 1). The lower portion of the core (foraminiferal assemblage zone 1) shows a high species diversity. Apart from those belonging to the genus *Quinqueloculina*, *Triloculina* and other (undifferentiated) miliolids, the most abundant foraminifera are *Elphidium crispum* (Linnaeus 1758), *Cibicides lobatulus* (Walker & Jacob 1798), *Planorbulina mediterranensis* d'Orbigny 1826 and *Rosalina* species. The upper part of the profile (assemblage zone 2) is dominated by *Ammonia beccarii* (Linnaeus 1758), *Haynesina depressula* (Walker & Jacob 1798) and *Quinqueloculina* species. Photographs of representative species are shown in Fig. 1.

We attribute the change in assemblage zones to a reduction in water depth. The high diversity assemblages in the lower part of the core are characteristic of shallow marine nearshore waters (Avsar & Ergin 2001). The presence of typical brackish species (Cundy et al. 2000) in foraminiferal assemblage zone 2 represents a deltaic setting, also shown by sedimentological evidence (topset beds). The border between the two is at 3.20 m b.s.l. The barren sections in the upper half of the core point towards predominantly fluvial conditions (river alluvium). The occurrence of brackish foraminifera in ten samples may indicate short-lived lagoonal conditions, characteristic for a deltaic system.

Three ^{14}C ages are available for the construction of a chronostratigraphic framework. Plant remains at a depth of 5.25 m b.s.l. (8.35 m b.s.) date to 4575–4475 cal BC. A piece of wood at a depth of 1.65 m b.s.l (4.75 m b.s.) is very young: 1650–1950 cal AD. Bivalves (*Cerastoderma glaucum*) at a depth of 0.25 m a.s.l. (2.85 m b.s.) date to 360–175 cal BC (Table 1).





Cluster analyses (Grimm, 1987) identifies two main assemblage zones. In the column labelled "Total specimens", open circles denote levels barren of foraminifera. Filled circles represent samples that contained fewer than 10 specimens. See text for further explanation.

C-14 ages:
- ● bivalves (*Cerastoderma glaucum*): 0.25 m a.s.l. (2.85 m b.s.): 360-175 cal BC (Mil 26/3)
- ■ piece of wood: 1.65 m b.s.l (4.75 m b.s.): 1650-1950 cal AD (Mil 26/5)
- ▲ plant remains: 5.25 m b.s.l. (8.35 m b.s.): 4575-4475 cal BC (Mil 26/9)

1-2: brackish species characteristic of assemblage zone 2. 3-8: shallow marine species characteristic of assemblage zone 1. 1. *Ammonia beccarii* (Linnaeus, 1758), dorsal view. 2. *Haynesina depressula* (Walker & Jacob, 1798), side view. 3. *Cibicides lobatulus* (Walker & Jacob, 1798), dorsal view. 4. *Cibicides lobatulus* (Walker & Jacob, 1798), ventral view. 5. *Triloculina tricarinata* d'Orbigny 1826, side (apertural) view. 6. *Elphidium crispum* (Linnaeus, 1758), side view. 7. *Planorbulina mediterranensis* d'Orbigny 1826, side view. 8. *Peneroplis pertusus* (Forskål, 1775), side view.

Fig. 1. Results of the foraminiferal analysis of core Mil 26

Table 1. Radiocarbon dating results.

Sample	Material	Laboratory Sample Code	$\delta^{13}C$ (‰)	^{14}C Age	Calibrated Age (range ± 1σ)
Baf S1/3D	*C. glaucum*, single valve	UtC 11866	-2.3	2819 ± 38 BP	710–558 BC
Baf S1/6D	*C. glaucum* articulated specimen	UtC 11867	-3.4	3294 ± 38 BP	1240–1126 BC
Mil 26P/3	*C. glaucum*	Beta-121048	3.5	2560 ± 70 BP	360–175 BC
Mil 26P/5	wood	Beta-121049	-25.5	240 ± 40 BP	1650–1950 AD
Mil 26P/9	plant remains	Beta-121050	-16.3	5700 ± 50 BP	4575–4475 BC
Mil 53/7F	marine shells	UtC 6056	0.8	2344 ± 38 BP	36 BC–55AD
Mil 67/7F	marine shells	UtC 6055	-0.5	2216 ± 37 BP	105–197 AD
Mil 153/6H	wood	UtC 11949	-24.3	3365 ± 37 BP	1734–1604 BC
Mil 153/13H	wood	UtC 11950	-23.2	3540 ± 40 BP	1936–1774 BC
Mil 157/15H	wood	UtC 11953	-26.4	2452 ± 45 BP	757–410 BC
Mil 157/18H	olive stone	UtC 11971	-23.4	4321 ± 37 BP	3011–2884 BC
Mil 159/17SG	sea grass	UtC 11972	-14.2	3710 ± 37 BP	1719–1626 BC
Mil 160/9HK	charcoal	UtC 13164	-25.4	2430 ± 33 BP	754–407 BC
Mil 193 13HK	charcoal	UtC 13162	-23.0	2489 ± 36 BP	762–521 BC
Mil 194/6H	wood	UtC 13160	-26.8	2592 ± 38 BP	812–673 BC
Mil 194/14HK	charcoal	UtC 13161	-26.2	4530 ± 40 BP	3353–3103 BC

Calibrated ages according to the radiocarbon calibration program Calib4 (Stuiver & Reimer 1993, Stuiver, Reimer & Reimer 2005). For marine carbonate a reservoir correction of 402 years was applied. Analyses carried out by Dr. K. van der Borg, Utrecht (Netherlands), indicated by UtC, and Dr. M.A. Tamers and D.G. Hood, Beta Analytic Inc., Miami/Florida (USA), indicated by Beta.

The sedimentological and microfaunal evidence and ^{14}C ages indicate that the postglacial marine transgression was well underway by 4500 cal BC. The boundary between shallow marine and lagoonal facies, at a depth of 3.20 m b.s.l. (6.30 m b.s.), contains no datable material, but we know from other cores that this area of Miletus was endangered by siltation in Roman Imperial times (see section 4). An erosional disconformity at 1.90 m b.s.l. (5.00 m b.s.) marks the onset of alluvial deposition by the Menderes River, and the age of 1650–1950 cal AD postdates this transition. The bivalves, dating from late Classical or Hellenistic time, are likely to have been reworked by fluvial processes. This interpretation is supported by the absence of foraminifera in association with this brackish mollusc. The percentage peak of *Ammonia beccarii* in 0.5 m b.s. can be explained as a result of at least intermittent, slightly brackish (almost freshwater) conditions, which prevailed at site Mil 26 until today.

Table 2. Historic and palaeogeographic changes in Miletus.

Time	**Historic changes**	**Palaeogeographic changes**
2^{nd} half of 4^{th} mil. BC (3500–3000 BC)	First settlement, ***Late Chalcolithic*** (Miletus I)	Postglacial sea level rise had formed the Milesian archipelago, climax vegetation dominated by deciduous oak forests
Early Bronze Age (3000–2000 BC)	**Early Bronze Age Miletus** (Miletus II)	Highest position of local sea level, reduction of settlement area
Middle to Late Bronze Age (2000–1100 BC)	***Minoan-Mycenaean Miletus***, founded by settlers from Crete; from Middle Bronze Age (Miletus III) to late Late Bronze Age (Miletus VI); destruction of Mycenaean fortification in 12^{th} century BC	Intense degradation of vegetation due to increasing anthropogenic impact (among others: introduction of the goat), gradual decline of natural fauna, resulting soil erosion together with a slight marine regression initiated transition of the archipelago to the Milesian Peninsula
since 1050 BC	Protogeometric-Geometric ***Miletus***, colonisation due to excellent natural harbours	Definite connection of the archipelago with the adjacent southern flank of the Maeander graben.
7^{th}–6^{th} centuries BC	***Archaic Miletus***, political, economical and cultural prosperity, foundation of more than 80 colonies (Black Sea region etc.); *Thales, Anaximander, Anaximenes, Hekataios*; second half of 6^{th} century BC: enlargement of city-centre around the agora and the Delphinium by man made infill, replanning in a new grid system.	Continued degradation of the ecosystem, palynological analyses prove increase in maquis elements and indicators of human impact, siltation especially north of Kalabak Tepe due to strong erosion and denudation processes
494 BC	Naval battle of Lade, victory of Persians, total defeat, destruction of the city	
after 479 BC	***Classical-Hellenistic Miletus***, building of new city by enlargement of Late Archaic grid system; industrial processing of wood and wool, metallurgic industry	
64 BC–4^{th} century AD	***Roman Miletus***, new economic growth, renovation of theatre in $1^{st}/2^{nd}$ centuries AD, dredging of Theatre Harbour	Vegetation dominated by maquis and phrygana, endangering of Milesian Peninsula by prograding Maeander Delta, accelerated siltation of the Lion and Theatre harbours
4^{th} century AD–1327 AD	***Byzantine Miletus***, Episcopal See, erection of castle; gradual decline	Increased siltation by Menderes alluvium, gradual integration of Milesian Peninsula into the floodplain
1327 AD–beginning of 20^{th} century AD	Miletus part of Emirate of Menteşe, later of ***Osmanic Empire***; total decline of the city	Definite siltation of all harbours, loss of access to the open sea

2.2 *Growth of the Büyük Menderes Delta*

The reconstruction of the prograding Büyük Menderes Delta over time is based on geoarchaeological and palaeoecological data (Fig. 2). The facies change from marine to littoral or brackish conditions was determined by sedimentological and microfaunal criteria as described above (section 2.1). This part of the stratigraphic sequence was dated in other cores to constrain the chronology of the advancing delta front. Several coring transects were established along and across the valley floor. Boreholes were concentrated near the ancient seaports Myous, Priene and Miletus. The chronostratigraphy is based on radiocarbon dating of floral and faunal remains and on the determination of characteristic artefacts found within the sediments. These results were supplemented by archaeological and historical data (for details see BRÜCKNER 2003, BRÜCKNER et al. 2002, MÜLLENHOFF 2005).

3 *Early Settlement Period palaeogeography of the Miletus area*

New results on the early palaeogeography and palaeoecology of Miletus are reported for two key sites of the city: the area around the Temple of Athena, which has been excavated by W.-D. & B. Niemeier since 1995, and the area of the Delphinium, which has been studied by A. Herda since 2002.

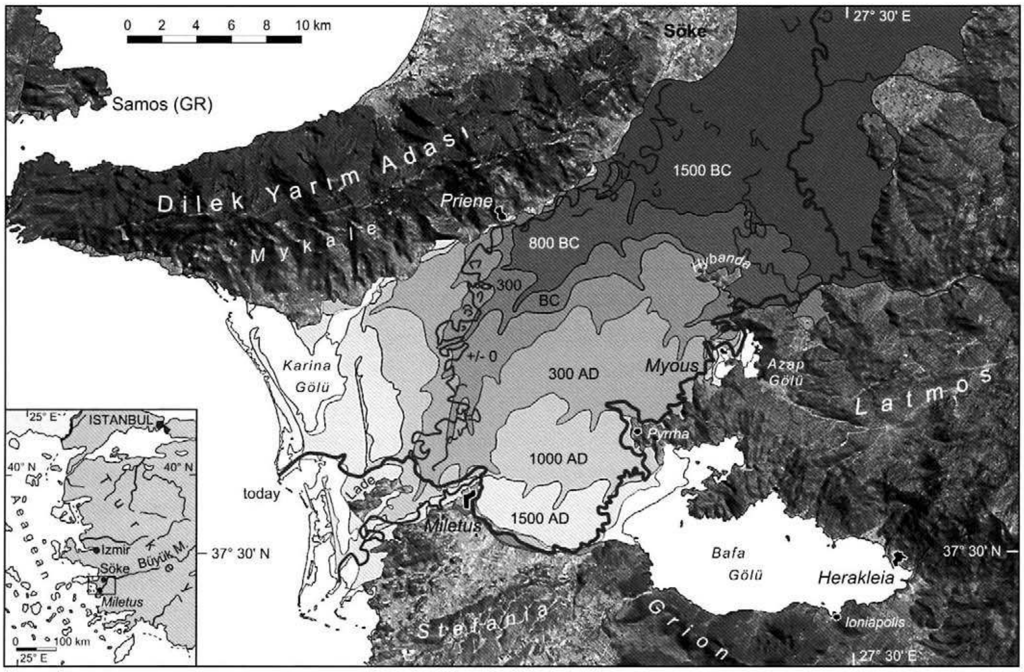


Fig. 2. Progradation of the Büyük Menderes Delta in space and time. Source: MÜLLENHOFF (2005: Abb. 56), slightly changed.

The area of the later city consisted of two larger and several smaller islands during the time of the maximum Holocene transgression. This archipelago was situated several hundreds of metres from the mainland (BRÜCKNER 2003). The main objectives of our studies were to determine when the Aegean Sea reached its maximum level and how far within the area of the later city the transgression extended inland.

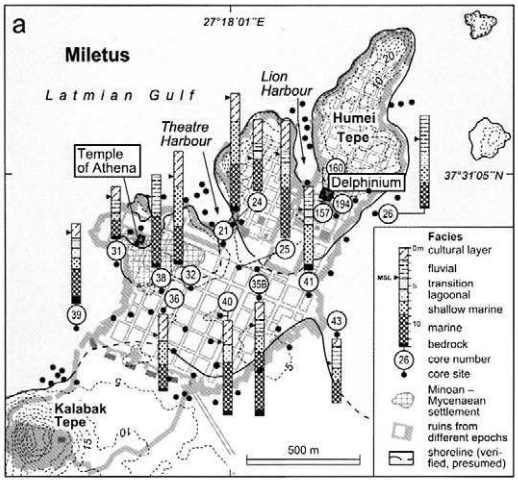
3.1 *Relative sea level changes at the Temple of Athena*

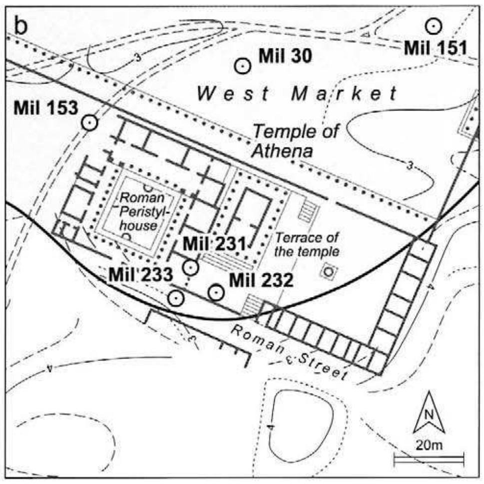
Previous studies revealed that the area south of the (later) Temple of Athena formerly was an island (see the reconstruction of the Milesian archipelago in Fig. 3a) (BRÜCKNER 2003). Hence, this part of the city is a suitable study area to detect and date sediments reflecting the highest sea level during Holocene. From an archaeological perspective this is also important, since near-coastal settlement activities were drastically limited when sea level reached its maximum position. In the area of the Temple of Athena the first settlement (Miletus I) dates from the Late Chalcolithic period ca. 3500–3000 BC (NIEMEIER & NIEMEIER 1997, NIEMEIER 2005). The oldest excavated *in situ* finds of that time are a storage pit, postholes cut into the bedrock and a terrace wall. The deepest finds lie on bedrock at 0.98 m b.s.l. (W.-D. Niemeier, pers. comm., 2004).

Siltation in the area northwest of the temple started as early as 1936–1774 cal BC according to a radiocarbon age of a wood fragment in shallow marine to littoral sediments in coring Mil 153 (sample 13H Fig. 3d). Soon afterwards anthropogenic influence is documented by the occurrence of a grape seed in 2.92 m b.s.l. and a massive cultural layer between 1.75 and 1.37 m b.s.l. Characteristic ceramic fragments date to the early Late Bronze Age (Miletus IV 1700–1450 BC). The littoral facies is truncated at 0.67 m b.s.l. and – confirmed by a dated wood fragment at 0.87 m b.s.l. (sample Mil 153/6H) – not before 1734–1604 cal BC. Cultural layers from Geometric to Hellenistic times comprise the uppermost unit.

Several vibracores (Mil 231, 232 and 233) southwest of the temple yielded the following results (see also Fig. 3). Above the bedrock (lacustrine limestone of the Nergiztepe Formation), we found an anthropogenic setting of stones (local limestone). Based on the associated edged ceramic fragments this setting dates from the first settlement phase (Miletus I, late Chalcolithic

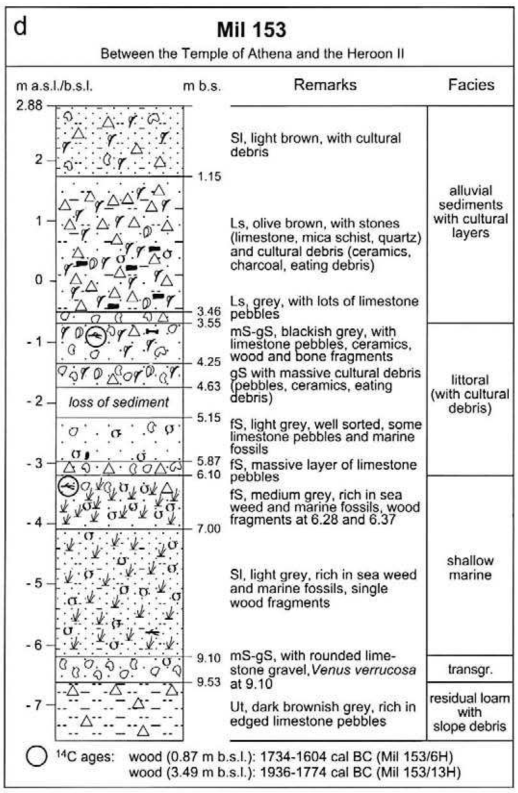
Fig. 3. Environmental changes in the area of the Temple of Athena.
(a) Reconstruction of the Milesian archipelago during the maximum marine transgression around 2500 BC (only some of the more than one hundred corings are shown; source: BRÜCKNER 2003: Fig. 4, slightly changed).
(b) Section of BENDT's topographical map (1968) showing the position of the sanctuary within the city of Miletus, the cored sites mentioned in the text and the maximum marine transgression (shaded area).
(c) Sediment core Mil 231, with interpretation of strata (lower right corner: bottom of core at 5 m b.s.; top of each core segment is to the left).
(d) Details of coring Mil 153, with geology, dating results and facies interpretation.
(e) The so-called temple terrace is the square building in the middleground; the two persons standing in front of it are looking at the Late Minoan Ia and Ib walls (Miletus IV, 1700-1450 BC); in the foreground the area of corings Mil 231-233.
(f) Details of coring Mil 233, with geology, dating results and facies interpretation.
Legend for (d) and (f) see Fig. 4 (p. 75).

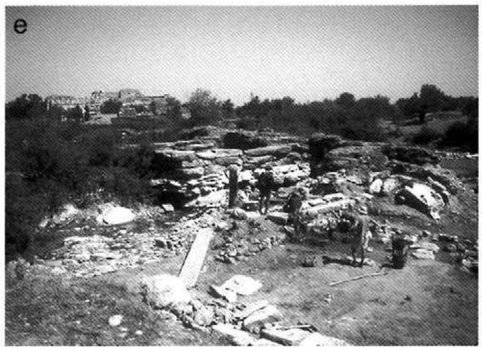


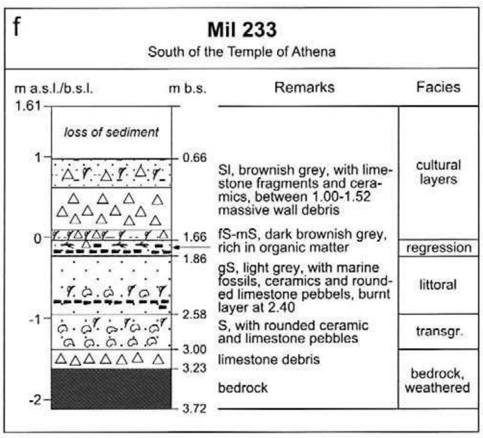


Coring Mil 231, Temple of Athena area

8 Cultural debris
7 Wall (Late Bronze Age, Miletus IV)
6 Semiterrestrial facies
5 Littoral facies, with rounded ceramic fragments (Miletus III)
4 Shallow marine facies, with rounded ceramic frgts. (Miletus II-III)
3 Marine facies
2 Transgression facies, with ceramic fragments (Late Chalcolithic, Miletus I)
1 Bedrock (limestone of the Nergiztepe formation)







period). The structure is covered by layers of well sorted sand and well rounded limestone pebbles. The sediments contain some fragments of marine organisms. These strata are best interpreted as littoral (Mil 232 and 233) and shallow marine (Mil 231) facies. The upper parts contain rounded ceramic fragments dating to the Middle Bronze Age (Miletus III). They are overlain by sediments of the upper littoral and backbeach environments (regressive facies). Walls that were erected on top of them are evidence for a new phase of settlement, starting in the Late Minoan Ia and Ib periods (Miletus IV). They had been excavated in the 1950s by C. Weickert (WEICKERT et al. 1959/60) (see Fig. 3e).

The coring results can be interpreted as follows. During the Late Chalcolithic period, the time of the first settlement of Miletus (Miletus I), it was possible to settle at coring sites Mil 232 and Mil 233. The sites Mil 231, Mil 153, Mil 151 and Mil 30, the latter cored in 1995 inside the West Market near the Temple of Athena (see Fig. 3b), were already drowned by the sea at that time.

Due to the progressive postglacial sea level rise, lower parts of the Late Chalcolithic settlement were flooded by the sea and people had to move to higher grounds. In the Early Bronze Age (Miletus II) at the latest (probably already earlier), the settlement area had turned into an island (see Fig. 3a). We conclude that local sea level reached its highest position during the Miletus II settlement phase (3000–2000 BC). During the periods of Miletus II and III, coring sites Mil 232 and 233 were dominated by littoral conditions, the seaward sites Mil 231 and Mil 30 by a sublittoral to shallow marine environment. The maximum transgression can be reconstructed some 4.50 m south of Mil 233. These results shed new light on the strong wall dating from the Middle Bronze Age that had been excavated by W.-D. Niemeier in former years (cf. NIEMEIER & NIEMEIER 1997, NIEMEIER 2005). This wall may now be interpreted as part of the seaward city wall of the Miletus III settlement. It is situated about 4 m landward of the reconstructed transgression peak. This scenario explains convincingly why it was not possible to settle at sites Mil 231, 232 and 233 during the Early and Middle Bronze Ages (Miletus II and III). Therefore, only rounded ceramic pebbles from those periods were found within the littoral and shallow marine facies.

The early Late Bronze Age wall at the later Temple of Athena belongs to the Miletus IVa period (Late Minoan Ia according to WEICKERT et al. 1959/60). Its deepest part lies at 0.21 m b.s.l. The wall indicates that at 1700 BC it became possible to re-settle at this place (see Fig. 3e). This implies that in the meantime relative sea level had fallen. This is also shown by the regressive facies encountered within the corings Mil 231-233 and the littoral sediments found in Mil 153.

Several conclusions can be drawn regarding local Holocene sea level changes. During Miletus I, relative sea level must have been below its present position. In coring Mil 232, the deepest level of a Late Chalcolithic stone structure lies at 2.52 m b.s.l., maybe even at 2.83 m b.s.l. Sea level reached its highest position during the Early and Middle Bronze Age (Miletus II and III), most probably during Miletus II around 2500 BC. This is confirmed by the Holocene sea level curve for the whole of the lower Büyük Menderes delta and floodplain as it also peaks around 2500 BC (MÜLLENHOFF 2005).

The highest marine strata of that time are beach sediments, which today are found up to 0.30 m b.s.l. Assuming 1 m for the height between mean sea level and beach berm in a moderate wave climate, the highest sea level may be reconstructed ca. 1.30 m b.s.l. However, it can neither be excluded that today's position was influenced by tectonic movements, bearing in mind the position of Miletus at the southern flank of the Büyük Menderes graben, nor that man has levelled the ground so that the highest beach sediments are not preserved anymore. In any case, the wall of Miletus IVa shows that sea level had dropped again by 1700 BC.

3.2 *Geoarchaeological research in the Delphinium area*

Another palaeogeographical key site of Miletus is the Delphinium, the sanctuary of Apollo Delphinius (Fig. 4). Situated southeast of the Lion Harbour next to the agora (the marketplace since at least Archaic times), it was one of the most prominent places of the ancient polis. The Milesian New Year's Festival was celebrated in honour of Apollo Delphinius, ending with a big city procession from here to Didyma (HERDA 2006). The Prytaneion, cultic and political nucleus of the polis, was within the Delphinium. So far, the earliest *in situ* finds in connection with the Apollo Delphinius cult date back to the 6th century BC. From a geoarchaeological point of view, the geographical and ecological setting under natural conditions and during the time of the first settlement are of special interest. Further objectives of the study were to find out which environmental changes took place during the last millennia, to reconstruct the palaeogeography around the Archaic sanctuary and to solve the question of a possible predecessor in Submycenaean or (Proto)Geometric times. Due to its topographic position and the high groundwater table, excavation below the level of the Classical times (5th century BC) is impossible without a costly well point system. Therefore, vibracoring is the most effective tool to unravel the past (see also HERDA 2005). Fig. 4 shows the area of the sanctuary, the cored sites and some representative profiles.

3.2.1 *Evidence of the marine past and the first sanctuary*

Core Mil 160 (Fig. 4d) was collected from the middle of the former Apollo Delphinius altar, the centre of the sanctuary. The marble altar dates to the Late Archaic – Early Classical times. Bedrock was encountered at 5.05 m b.s.l., covered by a thin sandy layer with subangular limestone pebbles and some fragments of marine fossils (transgressive facies?). The latter is separated from the substruction of the altar by 2.80 m thick sediments of a shallow marine facies. We found the same facies in core Mil 157 (Fig. 4e), directly east of the older south hall of the sanctuary. Here, the thickness is only 1.80 m because of the higher position of the bedrock. An olive stone from the lower part of the shallow marine facies at a depth of 2.67 m b.s.l. yielded a ^{14}C-age of 3011–2884 cal BC. A piece of wood from the regressive facies at 1.54 m b.s.l. dates to 757–410 cal BC. The extended 1 sigma error range for this sample is due to the fact that the ^{14}C calibration curve shows a so-called plateau for this time period.

The Delphinium is situated at the south-eastern fringe of the famous Lion Harbour, a natural embayment separating Kale Tepe (with the Theatre) and Humei Tepe. From a palaeogeographical perspective, it is significant that all the cores within the Delphinium complex reveal a shallow marine stratum. This demonstrates that the maximum transgression extended further south than previously assumed. The transgression peak was found in front of the Ionic Hall close to core Mil 242 which still shows half a metre of littoral to shallow marine sediments (Figs. 4a, c).

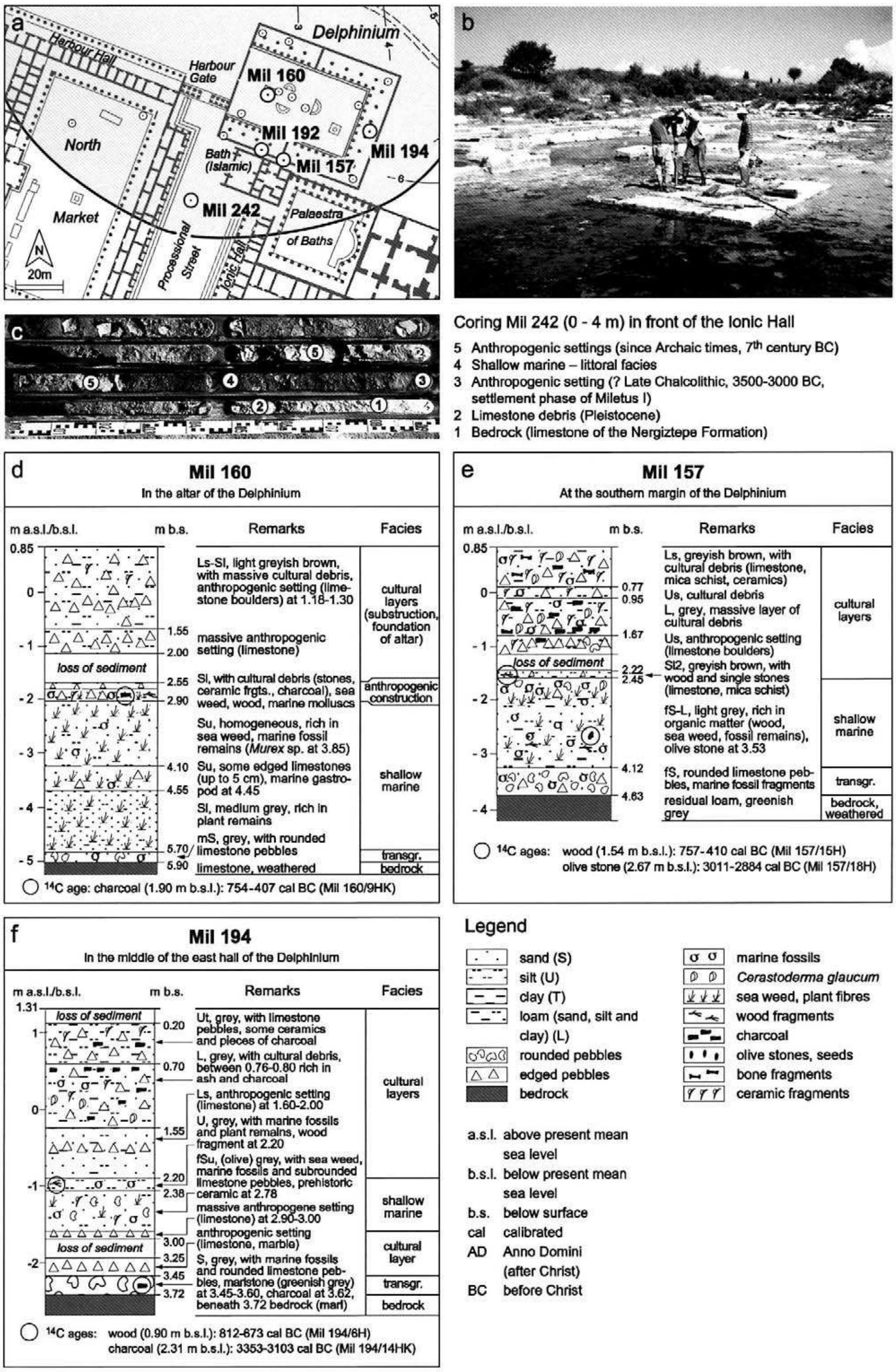
These sediments are covered by layers with massive stone debris (marble, mica schist, limestone), some ceramic fragments and organic remains. In the Delphinium complex, they reach up to 2.35 m (in Mil 160) and (at least) 1.54 m (in Mil 157) below the walking level of Classical times which lies at 0.33 m a.s.l. They are interpreted as infill material in order to consolidate the ground before the erection of the heavy stone architecture. According to characteristic ceramic fragments and numerous marble chips, the anthropogenic setting dates back to the 6th century BC, when the city centre of Miletus with the agora, the Delphinium and the surrounding living quarters was extended by man made infill of the marshy southern parts of the Lion Harbour embayment and subsequently replanned in an new grid system. However, an earlier phase of the sanctuary cannot be excluded (HERDA 2005). For example, in a core from the east hall of the Delphinium (Mil 194, Fig. 4f), a piece of wood from the uppermost shallow marine sediment yielded a ^{14}C age of 812–673 cal BC. A piece of charcoal at the same depth from a parallel coring half a meter to the west dates the first settlement layers on top of the marine stratum to 762-521 cal BC (sample Mil 193/13HK). Therefore, in that area the first settlement or sanctuary (?) after the marine phase may even belong to the Late Geometric Period (8th– early 7th centuries BC).

3.2.2 *Traces of the earliest settlement*

The fact that people settled in the area of the sanctuary as early as in Chalcolithic – most probably Late Chalcolithic – times (Miletus I) is of high importance. Below the marine sediments, artefacts (stone settings and ceramic fragments) were found (cf. Mil 194, Fig. 4f). The stone settings are made of limestone, calcareous sandstone, and marble. The latter is especially of interest since there is no marble outcropping nearby. A few ceramic fragments show the typical graphite-like ware (cf. PARZINGER 1989: 416f.). A *terminus ante quem* for these prehistoric finds is given by the already mentioned ^{14}C age of an olive stone at a depth of 2.67 m b.s.l., ca. 50 cm above the lowermost part of the marine sediments in the Delphinium. It dates to 3011–2884 cal BC (coring Mil 157, Fig. 4e). A piece of charcoal found above the bedrock and directly beneath the lowermost Chalcolithic layer in a depth of 2.31 m b.s.l. gives a contemporaneous date for the Late Chalcolithic settlement (3353–3103 cal BC, sample Mil 194/14HK, Fig. 4f).

So far, the Delphinium is – besides the Temple of Athena (see above), the 'Heroon III' and a site west of the Bouleuterion (cf. PARZINGER 1989: 428 ff.) – the fourth place within the area of the ancient city where traces of the Chalcolithic settlement were discovered. It is in the Delphinium that they are found in the lowermost position (at 3.76 m b.s.l. in coring Mil 192), even deeper than near the Temple of Athena (2.52–2.83 m b.s.l.). The altitudinal differences can be explained by the irregular bedrock topography, generally rising towards the east and the south. In addition, local differences in tectonics cannot be excluded.

Fig. 4. Environmental changes in the area of the Delphinium.
(a) Section of BENDT's topographical map (1968) showing the position of the sanctuary within the city of Miletus, the cored sites (with numbers: those mentioned in the text) and the maximum transgression of the sea around 2500 BC (shaded area).
(b) Coring the strata under the altar (coring Mil 160).
(c) Complete sediment core Mil 242, with interpretation of strata (lower right corner: bottom of core at 4 m b.s.; top of each core segment is to the left).
(d)–(f) Details of corings Mil 157, 160 and 194 with geology, dating results and facies interpretation.
Lower right corner: Legend for Figs. 3 and 4.


a
Delphinium
Harbour Hall
Harbour Gate
Mil 160
Mil 192
Mil 194
Bath (Islamic)
Mil 157
North
Market
Mil 242
Palaestra of Baths
Processional Street
Ionic Hall
20m
b
c
Coring Mil 242 (0 - 4 m) in front of the Ionic Hall
5 Anthropogenic settings (since Archaic times, 7th century BC)
4 Shallow marine – littoral facies
3 Anthropogenic setting (? Late Chalcolithic, 3500-3000 BC, settlement phase of Miletus I)
2 Limestone debris (Pleistocene)
1 Bedrock (limestone of the Nergiztepe Formation)
d
Mil 160
In the altar of the Delphinium
m a.s.l./b.s.l. m b.s. Remarks Facies
Ls-Sl, light greyish brown, with massive cultural debris, anthropogenic setting (limestone boulders) at 1.18-1.30
massive anthropogenic setting (limestone)
loss of sediment
Sl, with cultural debris (stones, ceramic frgts., charcoal), sea weed, wood, marine molluscs
Su, homogeneous, rich in sea weed, marine fossil remains (Murex sp. at 3.85)
Su, some edged limestones (up to 5 cm), marine gastropod at 4.45
Sl, medium grey, rich in plant remains
mS, grey, with rounded limestone pebbles
limestone, weathered
cultural layers (substruction, foundation of altar)
anthropogenic construction
shallow marine
transgr.
bedrock
14C age: charcoal (1.90 m b.s.l.): 754-407 cal BC (Mil 160/9HK)
e
Mil 157
At the southern margin of the Delphinium
m a.s.l./b.s.l. m b.s. Remarks Facies
Ls, greyish brown, with cultural debris (limestone, mica schist, ceramics)
Us, cultural debris
L, grey, massive layer of cultural debris
Us, anthropogenic setting (limestone boulders)
loss of sediment
Sl2, greyish brown, with wood and single stones (limestone, mica schist)
fS-L, light grey, rich in organic matter (wood, sea weed, fossil remains), olive stone at 3.53
fS, rounded limestone pebbles, marine fossil fragments
residual loam, greenish grey
cultural layers
shallow marine
transgr.
bedrock, weathered
14C ages: wood (1.54 m b.s.l.): 757-410 cal BC (Mil 157/15H)
olive stone (2.67 m b.s.l.): 3011-2884 cal BC (Mil 157/18H)
f
Mil 194
In the middle of the east hall of the Delphinium
m a.s.l./b.s.l. m b.s. Remarks Facies
loss of sediment
Ut, grey, with limestone pebbles, some ceramics and pieces of charcoal
L, grey, with cultural debris, between 0.76-0.80 rich in ash and charcoal
Ls, anthropogenic setting (limestone) at 1.60-2.00
U, grey, with marine fossils and plant remains, wood fragment at 2.20
fSu, (olive) grey, with sea weed, marine fossils and subrounded limestone pebbles, prehistoric ceramic at 2.78
massive anthropogene setting (limestone) at 2.90-3.00
anthropogenic setting (limestone, marble)
S, grey, with marine fossils and rounded limestone pebbles, marlstone (greenish grey) at 3.45-3.60, charcoal at 3.62, beneath 3.72 bedrock (marl)
cultural layers
shallow marine
cultural layer
transgr.
bedrock
14C ages: wood (0.90 m b.s.l.): 812-673 cal BC (Mil 194/6H)
charcoal (2.31 m b.s.l.): 3353-3103 cal BC (Mil 194/14HK)
Legend
sand (S)
silt (U)
clay (T)
loam (sand, silt and clay) (L)
rounded pebbles
edged pebbles
bedrock
marine fossils
Cerastoderma glaucum
sea weed, plant fibres
wood fragments
charcoal
olive stones, seeds
bone fragments
ceramic fragments
a.s.l. above present mean sea level
b.s.l. below present mean sea level
b.s. below surface
cal calibrated
AD Anno Domini (after Christ)
BC before Christ

3.2.3 *Implications for sea level reconstruction*

The research in the Delphinium has implications for the reconstruction of the sea level curve for Miletus. Assuming the tectonic impact to be negligible, sea level was more than 3.76 m below its present position, at least until the early time of the first settlement phase (Miletus I), starting ca. 3500 BC. The continuing Holocene marine transgression caused the submergence of this first settlement at the Delphinium site. People had to move to higher grounds, presumably from the end of the 4th millennium BC (cf. age of the olive stone within the marine stratum, Fig. 4e). The small marine indentation, the sediments of which were encountered in all the corings within the Delphinium area, developed later to what was then called Lion Harbour. During the Bronze Age, the marine environment obviously hindered any settlement activities at this site. Sea weed at a depth of 3.10 m b.s.l. from the middle of the shallow marine stratum, a few metres to the northeast of the central altar, dates to 1719–1626 cal BC (coring Mil 159, sample 17SG). This is about the time of the Minoan settlement at the Temple of Athena (Miletus IV). Subsequently, a swampy environment seems to have persisted until the erection of the first sanctuary in the Archaic or even Late Geometric times.

4 *Transformation from archipelago to the Milesian Peninsula and finally to the Maeander floodplain*

The transformation of the archipelago around 2500 BC into the famous Milesian Peninsula known in antiquity was the result of denudation processes from adjacent slopes south of the city. The associated accumulation facies is also found at the foot of the Stefania plateau (Bay 1999a, 1999b). The marine regression in the 2nd millenium BC, coastal dynamics as well as man made infill also contributed to the transformation from the islands to the peninsula. Siltation caused by the advancing Maeander Delta occurred much later (Brückner 2003, Brückner et al. 2002, Müllenhoff 2005).

According to ^{14}C ages of shallow marine strata, the settlement area at the (later) Temple of Athena seems to have still been an island when the Minoan settlers arrived from Crete around 1900 BC. However, it cannot be excluded that by then the island was already connected to the mainland by a sand bar (tombolo). The connection of several individual islands to the Milesian Peninsula most likely occurred before the Ionian Migration, i.e. before 1050 BC (Brückner 1998, 2003: 130f., Greaves 2000: 64f., 2002: 43).

Earlier studies showed that the Milesian Peninsula was endangered by siltation during Roman Imperial times (cf. section 2.1; Brückner 2003: 130ff.). At that time delta growth was especially strong, obviously intensified by human impact on the environment. At the entrance of the Lion Harbour, sedimentation rates rose from 0.6 mm/a during 3875–450 BC and 6.3 mm/a during 450–75 BC to 12.2 mm/a between the 1st century BC and early Byzantine times (75 BC – ca. 400 AD). The Theatre Harbour had to be dredged in Roman Imperial times. Where the fourth harbour of the ancient city, mentioned by Strabo (14, 1, 6), is supposed to be located, i.e. near the Southern Market in a leeward position to northern and western winds (this is also near coring Mil 26 discussed in section 2.1), the area was filled with dump material (stones, debris) during or shortly after Roman Imperial times. It seems that by then the harbour had turned useless due to siltation. At core site Mil 53 (2.17 m a.s.l.; lat/long: 37°31'26.19"N/27°16'1.86"E), west of the peninsula, the shallow marine/fluvial boundary reflecting the foreset/topset contact at 1.68 m b.s.l. dates from cal 36 BC to 55 AD (sample Mil 53/7F). Soon after that time, Roman tombs were built in this area. Since then, their base level has been buried by 1–2 m of alluvium. North of Değirmen Tepe, 2.1 km seawards to the west, this transition dates from 105–197 cal AD (coring Mil 67, sample 7F). Therefore, it is in Roman Imperial times that this site changed to a terrestrial environment (as for details see BRÜCKNER 2003, BRÜCKNER et al. 2002, MÜLLENHOFF et al. 2003).

5 *Floral and faunal changes*

Biogeographical changes reflect either climatic fluctuations or human influence on the environment. The so-called climax vegetation along the Aegean coast of Turkey, that is the natural vegetation without any major human impact, was a sparse deciduous oak forest. For the time around 4000 BC, pollen diagrams show the dominance of *Quercus pubescens* type, but also a significant amount of non-arboral pollen. In some places, the degradation to a maquis-type vegetation can be proven already during the middle of the 2nd millennium BC. Indicators for settlements are very well present in the Archaic epoch while arboreal pollen show a definite decline. The significant increase in *Olea* and *Phillyrea* may also indicate human impact since these species are much more frequent in the maquis than in the natural vegetation. The high amount of *Olea* may also indicate olive groves (cf. WILLE 1995, GROVE & RACKHAM 2001).

5.1 *Floral changes*

In the Delphinium, an olive stone occurs within the transgressive units at 2.67 m b.s.l. dating to 3011-2884 cal BC (sample Mil 157/18H). Several other olive stones occur in a late Chalcolithic layer at 4.48–4.58 m b.s.l. (sample Mil 248/24H) plus a grape seed at 4.18–4.28 m b.s.l. (sample Mil 248/22H). The important question is when the cultivation of olive and vine started in the Miletus area (cf. GREAVES 2002: 25–30) or in the eastern Aegean. For example Homer (Iliad 7,53; 9,579f; 18,561 ff etc.) testifies the cultivation of olive and vine in Greece as early as in Mycenaean times. Our new finds indicate at least a Chalcolithic age which is consistent with archaeobotanical studies in the Levante, where the first cultivation of olive trees is dated to Neolithic times, while vine was introduced in the 3rd millennium BC at the latest (EITAM 1993, HELTZER 1993).

In order to specify the vegetation changes related to early activities of human settlement around the Latmian Gulf, a sediment core was retrieved out of Lake Bafa by means of a floating raft. The coring site is located in the eastern part of the lake at a water depth of ca. 10.50 m. The palynological analysis shows four subsections (Fig. 5, cf. MÜLLENHOFF et al. 2004). The first is characterized by large amounts of deciduous oak (*Q. pubescens* type), probably representing the climax vegetation of the area. Section 2 reveals decreasing values of deciduous oak and pine (*Pinus*), but an increasing amount of maquis elements like *Phillyrea*, *Cistus* and *Ericacea* as well as fruit trees (*Olea*, *Castanea*) and indicators of farming (*Plantago lanceolata* type, *Juniperus* type). The sediments were deposited not long before 1240–1126 cal BC (sample Baf S1/6D), mirroring first major human impact on the ecosystem, most likely due to the Minoan-Mycenaean settlement phase and the introduction of the goat to the Milesia (cf. section 5.2). As a consequence, increased soil erosion is indicated by high amounts of indeterminable and especially resistant

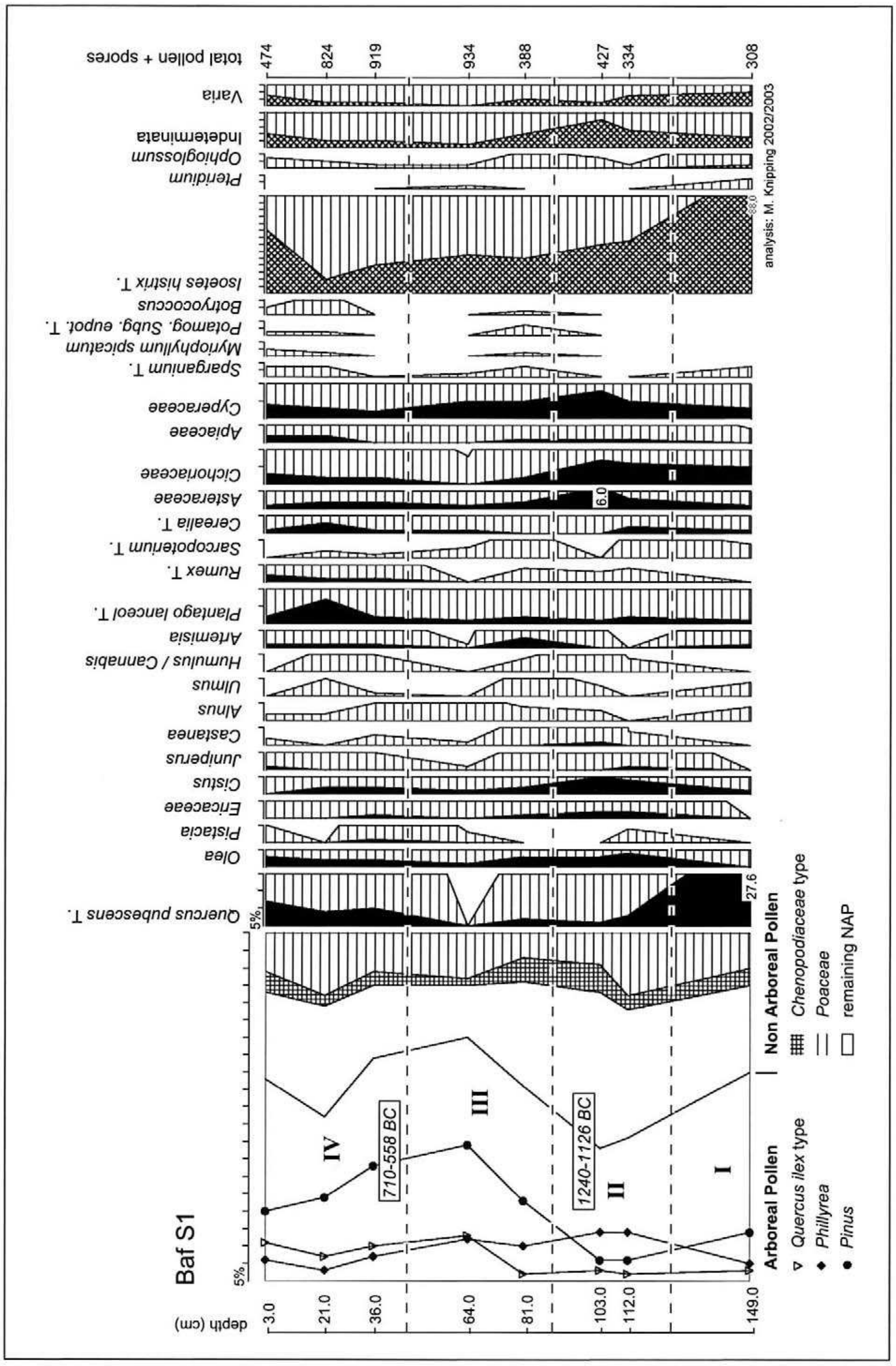


Fig. 5. Percentage pollen diagram of coring Baf S1. Basic sum = terrestrial elements excluding Varia and Indeterminata. Source: MÜLLENHOFF et al. (2004: Fig. 3), slightly changed.

pollen types (*Asteraceae*, *Cichoriaceae*). In the third section, human impact decreases. Higher values of pine and evergreen oak (*Q. ilex* type) exemplify a gradual stabilization of the ecosystem. The increase of *Olea* as well as *Chenopodiaceae*, *Artemisia*, *Rumex* type and *Plantago lanceolata* type in section 4 prove again open vegetation and intensified pasture farming. Furthermore, the *Cerealia* type reaches maximum values, and rye (*Secale*) could be found for the first time. These changes are the result of the strong settlement activities from Archaic to Hellenistic-Roman times, as evidenced by the radiocarbon age of sample Baf S1/3D (710–558 cal BC) in the lowermost part of the section.

The pollen spectra from Lion Harbour in Miletus support the results described above. They show a general decline of forests dominated by deciduous oak species (*Q. pubescens* type pollen) during the period 4000–500 BC (Wille 1995: 331, Lohmann 1995: 303 f., 1997: 291). Ongoing deforestation triggered increased erosion – especially since 500 BC – as shown by sediments at the foot of the Stefania plateau south of Miletus. There, profiles in irrigation wells and several geological corings show colluvial sediments dating from this time (Bay 1999a, 1999b, Müllenhoff 2005).

On top of the limestone plateau, some 6 km south of Miletus, (patches of) oak forests still existed at the end of the 6th century BC and probably even later. A famous epigraphical source from Miletus, the so-called Molpoi decree, mentions an oak forest (δρυμός) when describing the route of the annual procession from Miletus to the Apollo sanctuary in Didyma (cf. Wiegand 1929: 6, 8; Philippson 1936: 14, note 1; Herda 2006: chapter IV. 90). Since a limestone terrain is not favourable for agricultural use, it may well be that deforestation on the Stefania plateau was not as strong as in other parts around Miletus.

5.2 *Faunal changes*

Vegetation changes go hand in hand with faunal changes. Peters (2005) carried out archaeozoological studies of thousands of bones and other faunal macro remains from the Miletus excavations of W.-D. Niemeier. His results show that game is still well present at the beginning of the Minoan times around 1900 BC with the wild boar (*Sus scrofa*), the European fallow deer (*Dama dama*), and even the leopard (*Panthera pardus*). This confirms the idea of sparse oak forests as prevailing vegetation unit. According to their pastoral tradition on the island of Crete, the Minoan settlers preferred the goat to the sheep since goats are better adapted to the scarcity of food related with the Cretan limestone terrain. The introduction of the goat to the Milesia was a major factor why the forest ecosystem degraded to the Maquis/Garrigue-type vegetation. The goat is – next to *Homo sapiens* – the worst enemy of the forest. In post-Minoan times, sheep husbandry grew in importance. During the Archaic period (7th–6th centuries BC), wool from Miletus was a famous article for trading. In summary, Peters' research shows that from Minoan time to the Archaic period there is a considerable decrease in big game and an increase in small ruminants such as the hare (*Lepus capensis*), another indicator for an open landscape. In this context, it is also interesting to note that fishing added considerably to the diet of the Minoans. Some of the fish species are only found offshore, some belong to littoral or lagoonal, some even to fluvial environments such as the freshwater eel (*Anguilla anguilla*, det. H. Manhart, Munich). This implies the use of wooden vessels. Therefore, fishing and sea trading activities also contributed to deforestation.

6 *Conclusions*

The results of our palaeogeographical studies around the Temple of Athena show that during the Late Chalcolithic period (3500–3000 cal BC) the site was not covered by the sea and therefore suited for settlement activities. Around 2500 cal BC, during the Early Bronze Age, local sea level in the Latmian Gulf reached its highest position (about 1.30 m b.s.l.) and created an archipelago-like coastal landscape. This was associated with the maximum landward transgression (see Fig. 3a). When at the same site, some 800 years later, Late Bronze Age walls were built, sea level had already fallen to a lower position.

Chalcolithic findings within sediment cores from the Delphinium, one of the most prominent places of the ancient city, show that sea level in that area was lower than 3.76 m b.s.l. around 3500 cal BC, then rose quickly and produced a shallow marine environment. This lasted at least until the beginning of the 1st millennium BC when anthropogenic settings served as grounding for the first sanctuary in Archaic or even late Geometric times and an extension of the city centre in the later 6th century BC.

Results from both the Temple of Athena and the Delphinium sites clearly show that relative sea level was highest during Early and Middle Bronze Age (Table 2). In contrast to KAYAN (1995) who dates the sea level highstand for the area around Troia some 1000 years earlier, this corresponds with the relative sea level curve as described by MÜLLENHOFF (2005) for several study areas all around the former Latmian Gulf. Nevertheless, it has to be taken into account that the sea level highstand between 3000 and 2000 cal BC may be related to graben tectonics such as the sudden coseismic submergence of the northwestern part of the plain in the course of a major earthquake in 1955. Until today, it has not been possible to separate any tectonic contribution to sea level changes from further triggering factors like eustasy or sedimentary fluctuations. However, our studies evidence the dependencies between sea level, coastline displacements and settlement activities.

When the first settlers arrived in the area around the later Miletus in Chalcolithic times, vegetation was dominated by sparse deciduous oak forests. In the course of the 2nd millennium BC, vegetation began suffering from intense degradation due to increasing anthropogenic impact. Goat grazing since Minoan times and other land use activities led to deforestation and caused the gradual change of the natural fauna. Consequently, anthropogenically induced soil erosion was a main factor for the transition of the Milesian archipelago to a peninsula during Minoan and Mycenaean times (Table 2).

The in-depth study of the microfauna (foraminifers, ostracods) rendered possible the exact determination of the transition from marine *via* brackish to fluvial environments. Thus, the stratigraphy exemplifies the Milesian Peninsula becoming landlocked by the prograding Menderes Delta during Roman Imperial times. At that time, sedimentation rates were extremely high due to the intensification of land use, clearing of forests, and livestock farming. However, the evolution of the cultural landscape during the last millennia was also associated with the cultivation of typically Mediterranean agricultural products such as wine and olives, which probably started in the Milesia as early as in Chalcolithic times.

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