Holocene coastal evolution of western Anatolia – the interplay between natural factors and human impact

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Since the Last Glacial Maximum ca. 20,000 years ago, the Mediterranean coasts have undergone substantial changes in their geographical and geomorphological setting. The transgression of the Mediterranean Sea from ca. –120 m to its present level around six millennia ago, created marine embayments. Many of them have silted up in the meantime, partly or in the whole, because of strong delta progradation. This process was often considerably sped up due to human impact on the environment in the adjacent hinterland. As one major result, former harbour cities lost their connection to the open sea.

As for the Aegean coast of Turkey, the strongest coastline changes during the Holocene occurred in delta regions, particularly in those of Karamenderes (Scamandros), Gediz (Hermos), Kücük Menderes (Kaystros), Büyük Menderes (Maiandros) and Dalyan (Kalbis). A paper summarizing the geoarchaeological research in these areas and its link with historical sources was published by Brückner (1997). The present paper focuses on the evolution of the Büyük Menderes delta and its effects on the former harbour cities Myous, Priene and Miletos, thereby looking upon the interplay between natural factors (such as tectonic activity, sea-level fluctuations, climatic and hydrologic changes) and human impact (such as deforestation and animal husbandry).

In this context, the following topics are of special interest:

- Are there indicators for a neotectonic uplift or subsidence?
- What is the shape of the sea-level fluctuation curve for the Holocene, especially the position of sea level around 6-5 ka BP?
- When and to what extent did the human factor dominate natural changes?
- Is there a synchronic or a diachronic evolution of the Aegean coastal areas of Turkey?
- Are there indicators for catastrophic events, like tsunami and volcanic deposits?
- How does sedimentological and geological evidence match the human records?

1 - Indicators for neotectonic and volcanic activities

As for the general tectonic setting, it is widely accepted that the collision between the African/Arabian plates and the Eurasian plate is the reason for the westward displacement of the Anatolian microplate (see also Altunel, this volume). The strong seismic activity of the North Anatolian Fault (NAF) as well as many historic reports of earthquakes are impressive witnesses of this ongoing drift. One result is the graben/horst structures in Western Anatolia. The grabens are the guidelines for the lower courses of the major rivers.

The subduction of the Anatolian Plate below the Aegean Plate can be proven by geomorphological criteria: in the whole of the Mediterranean, the last interglacial marine terrace (MIS 5.5) is an excellent indicator for neotectonic movements since its glacio-eustatically 'normal' position is around 4-6 m above the present sea level. So far, a MIS 5.5 site has not yet been reported from the west coast of Anatolia. This is a strong argument for tectonic subsidence during the Late Quaternary. The only exception might be Kömür Adasi in the Gulf of Akbük with lithophagae borings on a Middle Helladic wall, up to 75 cm above present mean sea level. This find is, however, very questionable.

As for tephrochronology, which may render a good event stratigraphy, the only volcanic ash layer that has been found in the west coast region of Turkey to date is that of the Thera (Santorini) eruption in 1642 B.C. It occurs in a former lake east of Izmir and in Lake Köycegiz near Kaunos; it was also unearthed during the excavation of the Minoan-Mycenaean Miletos (see also Nomikou, this volume).

2 - Outlines of the geoarchaeological approach

The major purpose of geoarchaeological research in delta- and floodplain areas is to trace the maximum extension of the Holocene transgression ca. 5,000-6,000 years ago, and to decipher the shifts in the shoreline during the following regression caused by delta progradation. The main tool is percussion corings with a Cobra drilling device, reaching average depths of 10-20 m. The general stratigraphy of the strata is like this: On top of the abraded bedrock lies the transgression deposit (often pebbles in sandy matrix), indicating the 1st transition of the shoreline during the course of the Holocene sea-level rise. The littoral facies then grades into a marine one. Depending on the sedimentation rate, this stratum may be several metres thick. The 2nd transition of the shoreline occurs during the following regression. It is indicated either by another littoral facies (e.g. beach sand) or by a lagoonal layer (mostly silt and clay). The latter is evidence of the fact that meanwhile a sand bar or barrier beach developed seaward of the cored site. The lagoonal facies may change into that of a freshwater lake. The uppermost sedimentary units are deposits of the delta top and the river floodplain (river gravel, sand or fine grained alluvium).

For establishing a chronostratigraphy, the most suitable material in the drill cores are macrofloral remains (e.g. grape seed, olive stone, peat), articulated mollusc shells (although the reservoir effect is a pending problem) and, of course, characteristic, datable ceramic fragments. The different environments of deposition (marine, littoral, lagoonal, lacustrine, fluvial) have to be detected by microfauna analysis (e.g. ostracods; Handl *et al.*, 1999) or by geochemical parameters (Vött *et al.*, this volume). Given a high number of corings and datings, the data set may be used to map the position of the shoreline during different times. The reconstruction of the former sea-level fluctuations is tricky since there are seldom good indicators in the sediment cores. The best are: (a) the transgression facies at the base of the core; (b) the change from marine to littoral facies in the upper part of the core, which may be detected by sedimentological and faunal criteria; (c) coastal peat. This information must then be supplemented by archaeological criteria, like drowned ruins.

In order to decipher the impacts of natural as well as human factors, the above mentioned data must render a chronostratigraphy with high resolution, clear results from pollen analysis must be available, and the archaeological and historical information must be included.

3- Case study: progradation of the Maeander delta

In the following, the link between the archaeologic, prehistoric and historic sciences on the one side and geoarchaeology/palaeogeography on the other shall be demonstrated by the example of the Maeander (in antiquity: Maiandros; modern name: Büyük Menderes). The data set is also suitable for the extraction of information about the changes of the natural factors throughout the past millennia and for the evaluation of the human impact.

3.1. Literary evidence

During the peak of the Holocene transgression, the Büyük Menderes graben was partly filled with a marine embayment, the later so-called "Latmian Gulf". Meanwhile, the environment has completely changed and the harbours of the ancient cities Myous, Priene and Miletos have totally silted up (cf. Bay, 1999; Brückner, 1996, 2003; Brückner *et al.*, 2002). The following synopsis of the literary evidence is based on Brückner (2003: 122 ff.).

Conclusions for the historical progradation of the Maeander delta in space and time may be drawn from ancient writers like Herodotus (484-425 B.C.), Strabo (ca. 63 B.C.- ca. A.D. 24) and Pausanias (ca. A.D. 110 - after A.D. 180) as well as from historical documents found in monasteries and from travellers' reports. These sources do not, however, allow an unambiguous scenario.

Schröder (1998: 94) suggests that the city later known as "Magnesia on the Maeander" may originally have been a harbour city when it was founded in the course of the Ionian colonisation and that the delta front reached the city around 800 B.C. Herodotus (5.36 and 6.8) mentions Myous, Priene and Miletos as harbour cities. (Note that Herodotus refers to the Archaic Priene) In the 7th century B.C., the delta front ran northeast of Hybanda (modern name: Özbasi), then probably still an island, since gneiss blocks from a quarry in the area north of Myous were transported to Miletos by ship for the erection of the Archaic city wall (cf. Schröder and Bay, 1996: 66). From Herodotus (5.36) we may conclude that Myous still had an open harbour around 500 B.C. According to Grund (1906), the northern branch of the Maeander river was then more active so that the northern part of the Latmian Gulf silted up more rapidly during that time. When Alexander the Great freed the region from the Persians in 334 B.C., the harbour of Myous was of some strategic importance (Brinkmann *et al.*, 1991: 9). An Early Hellenistic inscription testifies to a still well accessible harbour in Myous. Schröder (1998: 96) assumes that the city was deserted approximately 280 B.C.; according to the Eirenias inscription it was 169/150 B.C. (cf. Tuttahs, 1998: 157). There are no Roman ruins in Myous. In the 2nd century A.D., Pausanias (7.2.11) reports that the inhabitants had left the city because of unbearable swarms of mosquitos and had moved to Miletos. Pausanias (7.10.11) also describes a small marine embayment near the former city which had been cut off by the Maeander – most likely the predecessor of the present Lake Azap. In the early 1st century A.D., Myous was 30 stades (ca. 5.9 km) inland from the shoreline and the mouth of the river was between Priene and Miletos, about 50 stades (ca. 9.8 km) away from Pyrrha (Strabo 14.1.10). Around A.D. 100 the level of the pavement in the streets in the lower parts of Miletos had to be raised (Eisma, 1978: 71); this was probably due to a rise in sea level.

According to Erol (1996), the Büyük Menderes started to accumulate its delta in the centre of the Latmian Gulf; its northward shift after 500 B.C. finally resulted in the filling up of the harbour(s) of the Archaic Priene. The author assumes that when Priene was founded anew in the middle of the 4th century B.C., it was situated at a northern marine embayment, south of which the delta had already developed. When the Büyük Menderes had silted up this embayment, Priene's harbour(s) became landlocked and had to be shifted.

Philippson (1936: 10) assumes a complete silting up of the area around Miletos in the 6th century A.D. Miletos gradually lost its importance as a port city. Between A.D. 600 and 700, the former island of Lade was integrated into the delta-plain (Aksu *et al.*, 1987: 233). In A.D. 1560 a Greek sailor reported that the coast was ca. 8 km away from the city (Wiegand, 1929). The question of how he had measured this distance (along the river?) remains open.

The scenarios of the historic delta growth published so far are mostly based on evidence from literature. This is especially true for the ones of Eisma (1978) and Erinç (1978). Aksu *et al.* (1987) add evidence from sedimentology, Erol (1996) uses the interpretation of aerial photographs as a further source of information, and Schröder and Bay (1996) excerpt information from drillings for water wells, as well. It is evident that these sources leave quite some space for different interpretations. This is also true for the latest approach by Tuttahs (1998: 153 ff.). He interprets the filling up of the Latmian Gulf in three phases: (I) the Maeander delta prograded from Söke to Priene along the north-west coast at the foot of Mykale mountains; (II) it turned south from Priene to Miletos; (III) the still open parts in the east and the south of the gulf silted up from Myous to Miletos along the south-east coast. The author places the transition from phase I to phase III around 300-250 B.C. Phases II and III ran parallel ca. 300 B.C. - 0 B.C./A.D.

3.2. Geoarchaeological evidence

By geoarchaeologic means, potential Archaic to Classical Greek harbour sites were identified in the embayments west of the Myousian peninsula, i.e. between Castle hill and Settlement hill, and south of Settlement hill. In the vicinity of Myous, the transiton from marine to lacustrine facies must have occurred already in Hellenistic times. Lagoonal conditions prevailed in Hellenistic-Roman times. In the southwest, the lacustrine environment started in the 1st or 2nd century A.D. and partially prevailed until Modern times. In the east, the brackish and shallow Lake Azap is what remains of the former marine embayment.

Priene was founded anew in Late Classical time around 350 B.C. Under palaeogeographic perspective the most interesting question is that of the harbour site(s), a topic whereof the historic sources remain silent. Potential areas are the eastern and western embayments at the foot of the promontory of Priene. Ceramic and ^{14}C stratigraphies of drill cores led to the following conclusions: In the eastern embayment, marine conditions prevailed at least until the 13th/12th century B.C. Thereafter, a slight regression can be proven by a peat dating from the second half of the 2nd millennium B.C. In the mid-4th century B.C, this embayment had already turned into a freshwater lake. For that time, a potential harbour site can be ascertained in the western embayment where water depth was still several metres and a lagoonal environment existed until the beginning of the Roman Imperial era. Definitely freshwater milieu did not exist before the 3rd century A.D. This embayment was filled with sediments more slowly than its eastern counterpart since it was sheltered from alluviation by the river due to the leeward position behind the promontory of the Priene rock.

During the peak of the Holocene transgression, the area of the later city of Miletos was composed of islands. One of them hosted the earliest settlement in the area of the later Athena Temple dating from the second half of the 4th millennium B.C. When the Minoan settlers arrived around 1900 B.C. this island topography is likely to have persisted; however, hints of an already existing connection with the adjacent mainland by a sandbar (tombolo) cannot be neglected. The palaeogeographic setting changed to a peninsula during the Minoan-Mycenaean occupation phase. The sediments were mobilized by coastal longshore drift and human-induced denudation from the adjacent slopes. It is at least since the Archaic period that the Milesian peninsula extending into the Latmian Gulf is known from literary sources and archaeologic evidence (city wall). The Roman time – and especially the Roman Imperial era – witnessed strong siltation processes around Miletos. It was then that the southeastern part of the Latmian Gulf was cut off, thereby creating the “Milesian lake” out of which the still brackish Bafa Gölü developed.

Tradition has it that the Milesian peninsula had four harbours, of which only the Lions’ Harbour and the Theatre Harbour have been definitely identified to date. Our research in the Lions’ Harbour showed an enormous increase in siltation between the 1st century B.C. and ca. A.D. 400, when the average sedimentation rate was doubled compared to the centuries in Classical Greek and Hellenistic times. It was even 21 times higher than during the period 4th-2nd millennia B.C. The corings within the Theatre Harbour unearthed no artifacts older than the Roman Imperial era; therefore, it must have been dredged in the 1st or 2nd century A.D. when also the theatre was renovated. The geoarchaeological approach also revealed that a good natural setting for the third harbour was provided close to the earliest settlement near the later Athena Temple. Another potential harbour most likely existed to the east of the Milesian peninsula, in a leeward position to winds from the west (see below).

The data set of archaeological and ^{14}C ages from the lower alluvial plain and the delta region of the Büyük Menders is suitable for the establishment of a locally valid sea level fluctuation curve for the Holocene. It seems to have a relative peak around 6-5 ka BP, after the strong late Pleistocene – Holocene sea level rise, and a relative low around 3 ka BP. This shape of the curve is similar to Kayan’s (1995) sea level curve established at Troia. However, in our case this glacio-eustatic curve is shifted downward by a factor of 0.7 m/ka due to the ongoing subsidence of the Menderes graben. In several other regions of the Mediterranean, sea level reached its highest position during the Holocene only today and was definitely lower around 5 ka BP (e.g. Silvan, this volume, for the coast of Israel; Collina-Girard, this volume, for the French coast in Provence).

3.3. Including and cross-checking geophysical data

Within the spectrum of geoarchaeological tools, the geophysical ones are a good supplement to the above described methods. Geoelectric measurements may provide information about the hardrock/softrock contact even at great depths. This may help to a better understanding of the filling of the embayments during the late Pleistocene-Holocene period. Geomagnetics and georadar render valuable information about the subsurface strata and about anthropogene structures up to depths of ca. 5 m. The interpretation of these two-dimensional images must then be verified/falsified either with corings or excavations – the latter being much more expensive and time consuming than the former and nearly impossible below the groundwater table. The following paragraph presents some examples of the integration of geophysical methods – in this case carried out by Dr. H. Stümpel, University of Kiel (Germany) – into geoarchaeological research.

On several sites of the former city of Miletos, a feature on the geomagnetic images was interpreted as a city wall at a depth of 4-5 m below present surface. This was ascertained by geologic corings and later proven by the excavation. It dates to the Archaic period. The assumption of a harbour situation near the Southern Market was based on geophysical measurements. Corings confirmed an excellent natural setting for a harbour; its use seems to have ended in the Roman Imperial era. According to geomagnetic data another harbour was presumed at the foot of Kalabak Tepe, the prominent hill in the southwestern part of the Archaic city. Our research verified a former marine embayment; however, it was always of shallow water depth. While it may have been of some use in the Archaic time, the “harbour” had silted up in the early Roman era, mostly due to colluviation from the adjacent slopes. Corings in the famous Lions’ Harbour falsified the geophysically interpreted harbour jetties; these features are brick and tile debris which was most likely intentionally deposited in order to relocate the marble statues of the lions when the area had already turned into a swamp.

4 - Floral and faunal changes

Various pollen spectra show that along the Aegean coast of Turkey the climax vegetation, i.e. the natural vegetation without human impact during the peak of the Holocene (around 5,000 years ago) was a sparse deciduous oak tree forest. This is evidenced by high values of *Quercus pubescens*-type pollen grains on the one side and a fair amount of non-arboral pollen grains on the other. Already during the middle of the 2nd millennium B.C., the degradation to a macchia-type vegetation can be proven in some places. In the Archaic epoch the potential indicators for settlements are well present while the arboreal pollen shows a definite decline. The significant increase in *Olea* and *Phillyrea* pollen may indicate human impact since these species are much more frequent in the macchia than in the natural vegetation. The high amount of *Olea* may also indicate olive groves (cf. Wille, 1995).

The vegetation changes are also mirrored by the faunal changes. Peters (in press) identified bone fragments from Minoan, Mycenaen and Archaic periods of Miletos. While game was still well present during Minoan times, it significantly decreased thereafter. The occurrence of wild boar (*Sus scrofa*) and European fallow deer (*Dama dama*) confirms the presence of sparse deciduous oak tree forests. Another indicator for that biotope is the leopard (*Panthera pardus*). One characteristic aspect of the Minoan culture was the preference of goat as compared to sheep; the settlers obviously brought with them this pastoral habit when emigrating from Crete to Miletos. The predominance of goat keeping is one major factor in the degradation of the forest ecosystem to a Macchia/Garrigue-type vegetation. In post-Minoan times, however, sheep husbandry became the mainstay of small livestock exploitation; it is well known that during the Archaic period the Milesian wool was a famous article for trading. In summary, from the Minoan time to the Archaic period, deforestation is evidenced by the decrease in big game on the one hand and the increase of small ruminants and of hare (*Lepus capensis*) – an open landscape indicator – on the other. There is archaeo-zoological evidence that fishing added considerably to the diet of the Minoan site inhabitants. Some of the identified species can only be found offshore, implying the use of vessels. Fishing and sea trading activities may therefore have contributed to the deforestation of the Milesian hinterland, too.

5- VISUALIZING THE SCENARIO OF THE LANDSCAPE EVOLUTION

One of the major goals of the paleogeographic-geoarchaeologic research linked with archaeological and (pre-) historical sciences is to develop a scenario of the landscape evolution including the human impact in space and time. This is exemplified by Fig. 1 which shows the latest synopsis of the geomorphological evolution of the Büyük Menderes delta, presented in several time slices. The palaeogeographic scenario is based on ca. 200 percussion corings and their geoarchaeologic interpretation as well as on data from archaeology and historical sciences. A future step will be the production of a video sequence including a digital 3D elevation model derived from ERS Tandem radar data and satellite images.

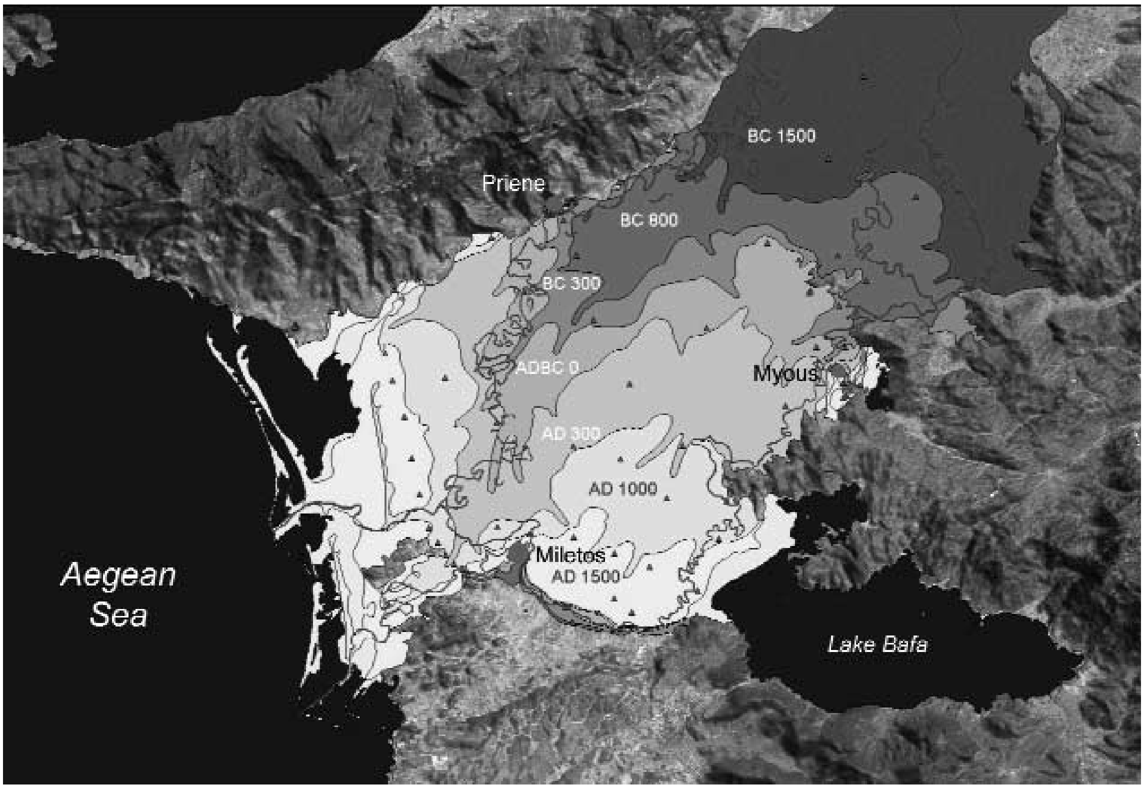

Fig. 1. Scenario for the progradation of the Büyük Menderes delta during the past millennia. During the peak of the Holocene ca. 6-5 ka BP, the marine embayment extended much further to the east covering the whole area of the floodplain visible in this figure. A given age refers to its nearest seaward coastline.