Geoarchaeological Case Studies in the Bakırçay Valley

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Paleogeography and Human-environmental Interactions in the Chora of Pergamon in Western Turkey

Geoarchäologische Fallstudien im Bakırçay-Tal

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Landschaftsentwicklung und Mensch-Umwelt-Beziehungen
in der Chora von Pergamon in der Westtürkei

Dissertation
zur Erlangung des akademischen Grades
Doktor der Naturwissenschaften (Dr. rer. nat.)
am Fachbereich Geowissenschaften
der Freien Universität Berlin

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Berlin, 2014

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Datum der Disputation:	5. Dezember 2014

Acknowledgements

The thesis was financially, technically and scientifically supported by the Cluster of Excellence 264 'Topoi' funded by the German Research Foundation (DFG).

I would like to express my great appreciation to my first supervisor, Prof. Dr. Brigitta Schütt, for giving me the chance to participate in this project and for the support throughout the years. Furthermore, I would like to offer my special thanks to my second supervisor, Prof. Dr. Helmut Brückner, for the stimulating discussions and for supporting me. I wish to acknowledge the help provided by Prof. Dr. Felix Pirson and his team from the German Archaeological Institute in Istanbul, Prof Dr. Martin Zimmermann and his team from the DFG Priority Programme 1209 'The Hellenistic Polis as a Living Space', and Dr. Barbara Horejs and her team from the project 'Prehistoric Anatolia' funded by the European Research Council.

This thesis would not have been possible without the help of the co-authors. I am particularly grateful to Albrecht Matthaei, who contributed the archaeological part of the studies and who never lost his interest, kindness and patience. I would like to thank Marlen Schlöffel for her great support in fieldwork, laboratory work, as well as for her support in the conception and writing of the papers. I thank Anna Pint (University of Cologne) for the identification of macrofossils, and Wiebke Bebermeier, Daniel Knitter, Mario Kronwald and Moritz Nykamp for their help in the field, the fruitful discussions and their valuable contributions to the papers. Assistance in the field and in the laboratory provided by Dirk Liebisch, Robert Milewski and Nina Strothmann is greatly appreciated. Furthermore, I am grateful to the anonymous reviewers for their comments that helped to improve the papers. I would like to thank Philipp Hoelzmann and his team from the Laboratory for Physical Geography for their support, and Cornelius Meyer from Eastern Atlas for the good cooperation and for providing geophysical data. I am thankful to Tomasz Goslar and the Poznan Radiocarbon Laboratory for the datings.

I would also like to thank the great number of colleagues within Topoi and at the Institute of Geographical Sciences of the Freie Universität Berlin who contributed to this thesis, among them Pasquale Borrelli, Zhyldyz Bostonalieva, Leon van Hoof, Daniel Kelterbaum, Jan Krause, Emmi Krings, Ellen Leipner, Michael Menker Girma, Christiane Reuter, Tilman Rost, Frank Schlütz and Janos Toth. Martin Seeliger (University of Cologne) was a great companion in the field and an excellent partner for discussions on the evolution of the Bakırçay valley. Finally, I would like to thank Anne Beck, Laura Sutcliffe and the Elsevier Language Editing Service for improving the language of the thesis.

Summary

The Bakırçay valley is one of the large east-west trending graben landscapes in western Anatolia. The ruins of Pergamon (modern Bergama), situated at the northern fringe of the valley, are the most outstanding example of the numerous archaeological sites within this old cultural landscape. The Bakırçay valley has not yet been studied from the paleogeographical and geoarchaeological points of view. This study aims at the reconstruction of the middle to late Holocene landscape development in the western hinterland of Pergamon and thus of the western Bakırçay valley. Furthermore, interactions between landscape changes, human settlement and land use activity are investigated. Geomorphological, sedimentological, and geophysical investigations are coupled with archaeological research with close cooperation between the DFG (German Research Foundation) cluster of Excellence Topoi, the Pergamon excavation of the German Archaeological Institute and the DFG Priority Programme 1209 'The Hellenistic polis as a living space'.

Three select landscape compartments of the western Bakırçay valley were investigated in detailed case studies: (i) The surroundings of the ancient polis of Atarneus, a hilltop settlement near the Aegean coast. (ii) The valley of the Geyikli, the westernmost perennial tributary of the Bakırçay. (iii) The environs of the archaeological site 'Teut114' with buried wall structures of unknown function in the central Bakırçay valley.

These case studies revealed approximately four millennia of the landscape and settlement history of the Bakırçay valley. The landscape was remarkably stable during this period. (i) The sedimentary plains surrounding the settlement hill of Atarneus were aggraded by braided and meandering rivers. Colluviation and alluvial fan deposition occurred at the foot-slopes. Sedimentation totalled approximately 5 to 7 m, showing evidence of a "drowning" of the landscape in terrestrial sediments. In general, the depositional system did not change. This striking resistance to the changing settlement and land use intensity is an effect of the modification of the slopes through terracing that countervailed erosion and likewise increased the buffering capacity of sediment storage on the slopes. There is no evidence that landscape deterioration contributed to the abandonment of Atarneus. Rather, socio-economic factors were crucial for the rise and fall. (ii) The Lower Geyikli Valley was inhabited by a braided river with a highly dynamic depositional system. Sedimentation totalled approximately 4 to 6 m. Only in recent times, gravel mining has led to a deformation of the valley floor, and the Geyikli's fluvial terrace has become inactive. (iii) In the middle Holocene, the site 'Teut114' was situated on a depositional piedmont plain, which was protected from the annual Bakırçay floods. Over the past two millennia, the Bakırçay flood plain was continuously aggraded, and the site became prone to flooding.

Zusammenfassung

Das Bakırçaytal zählt zu den großen Grabenlandschaften Westanatoliens. Die Ruinen von Pergamon am nördlichen Talrand sind das prominenteste Beispiel der zahlreichen archäologischen Stätten dieser alten Kulturlandschaft. Die vorliegende paläogeographisch-geoarchäologische Studie widmet sich der Rekonstruktion der mittel- bis spätholozänen Landschaftsgeschichte im westlichen Hinterland von Pergamon, sowie der Erforschungen der Interaktionen zwischen Landschaftswandel, menschlicher Besiedlung und Landnutzungsintensität. In enger Zusammenarbeit des DFG Exzellenzclusters Topoi mit der Pergamon-Grabung des DAI Istanbul und dem DFG Schwerpunktprogramm 1209 werden geomorphologische, sedimentologische und geophysikalische Untersuchungen mit archäologischer Forschung kombiniert.

Drei Landschaftsteilräume des westlichen Bakırçaytals sind Gegenstand detaillierter Fallstudien. (i) Die erste Fallstudie widmet sich der antiken Polis Atarneus, einer Höhensiedlung nahe der Ägäisküste. Die Studie zeigt, dass das Umland von Atarneus in den vergangenen 3500 Jahren von verflochtenen und mäandrierenden Flüssen aufsedimentiert wurde, während an den Hangfüßen Schwemmfächerschüttung und Kolluvienbildung dominierten. Dies führte zum „Ertrinken“ der Landschaft in bis zu sieben Metern terrestrischen Sedimenten, jedoch ohne dass sich das Ablagerungssystem generell veränderte. Die erstaunliche Widerstandskraft der Landschaft gegenüber Siedlungs- und Nutzungswandel resultiert aus der Terrassierung des Siedlungshügels, die zur Erhöhung der Sedimentspeicherkapazität der Hänge führte und zugleich Erosion entgegenwirkte. Anzeichen für eine Aufgabe von Atarneus vor ca. 2000 Jahren aufgrund einer Landschaftsdegradation, wie antike Quellen vermuten lassen, wurden nicht gefunden, vielmehr waren sozio-ökonomische Faktoren ausschlaggebend. (ii) Fallstudie zwei beschäftigt sich mit dem Tal des Geyikli, dem westlichsten perennierenden Tributär des Bakırçay. Der Talauslass befindet sich in einer Geländeposition, die laut antiquer Quellen ehemals einen Meeresbusen beinhaltete. Sedimentologische Untersuchungen zeigen, dass der Talauslass in den letzten beiden Jahrtausenden von einem verwilderten Fluss eingenommen und aufgeschottert wurde. Die Paläo-Meeresarmhypothese konnte somit für diesen Zeitraum widerlegt werden. (iii) Die archäologische Stätte „Teut114“, eine begrabener Gebäudekomplex unbekannter Funktion, ist im zentralen Bakırçaytal gelegen, dessen Landschaftsgeschichte weitgehend unerforscht ist. Die Fallstudie zeigt, dass „Teut114“ im Übergangsbereich eines pleistozänen Piedmonts und der Überschwemmungsebene des Bakırçay errichtet wurde. Im Verlauf der letzten 2000 Jahre wurde die Bakırçay-Schwemmebene kontinuierlich aufgeschottert, und das ehemals geschützt liegende „Teut114“ wurde anfällig für Überflutungen.

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1. Introduction

The large valleys of western Anatolia and their famous ancient cities have been the focus of geoarchaeological research for an extended period. Investigations at ancient Milet in the Büyük Menderes valley (Müllenhoff, 2005; Brückner, 2003), prehistoric Troy in the Karamenderes valley (Kayan, 1995, 1996; Kraft et al., 2003) and ancient Ephesos in the Kücük Menderes valley (Stock et al., 2013, Kraft et al., 2011, Brückner, 2005) are several examples. These studies demonstrate the close connection between the dramatic landscape change following the Holocene warming and sea-level rise and the rise and fall of the cities.

However, the Holocene landscape development in the surroundings of ancient Pergamon in the Bakırçay valley has been treated poorly by researchers. Although intensive archaeological investigations have been conducted since the first excavations at Pergamon started in 1878 (Kästner, 2011), only a small number of studies dealt with the paleogeography of the Bakırçay valley (Sections 2.3.3 and 2.3.4).

The aim of this thesis is to contribute to a better understanding of the landscape development of the Bakırçay valley and its interactions with the settlement history. The study investigates the western hinterland of Pergamon and the archaeological sites within (Fig. 1). The investigations were conducted within the project 'Ancient landscapes in the environs of Pergamon,' which is part of the DFG (German Research Foundation) Cluster of Excellence 264 'Topoi'. The paleogeographical investigations were undertaken in close cooperation with the Pergamon excavation of the German Archaeological Institute in Istanbul and the archaeological project 'The chora of Pergamon' within the DFG Priority Programme 1209 'The Hellenistic polis as a living space'.

Fig. 1. View to the southeast from the summit of Kale Ağılı into the Bakırçay valley.

The Bakırçay valley and its bordering mountains are characterised by a complex geotectonic setting (Section 3.2), a Mediterranean type climate (Section 3.3), soils (Section 3.4) and vegetation (Section 3.5), as well as a seasonal hydrologic regime with only a few perennial rivers (Section 3.6). Furthermore, it is an old cultural landscape that has been settled since the Bronze Age period (Sections 2.2 and 6.1). The interaction of these land-forming factors during the past millennia manifested in geoarchives, such as alluvial, colluvial and fluvial sediments. This study is based on the investigations of these archives and follows the geoarchaeological approach of Brückner and Gerlach (2007; Section 4.1).

The fieldwork for the project was undertaken in three campaigns during the summers of 2009, 2010 and 2011. Three reports in German language (Section 5.1: Schneider et al., 2010; Section 5.2: Schneider et al., 2011; Section 5.3: Schneider et al., 2012) present the approach, methodology and preliminary results of the fieldwork.

The main part of the thesis comprises three case studies that explore different compartments of the Bakırçay valley. The first case study (Section 6.1: Schneider et al., 2014) concentrates on the volcanic butte Kale Ağılı, which is located at the northwestern fringe of the Bakırçay valley near the Aegean coastal plain. The focus is on the reconstruction of the Holocene paleogeography and the settlement history. Furthermore, human-environmental interactions are investigated. One of the crucial questions of the study is if the ancient city of Atarneus, which occupied Kale Ağılı during Antiquity, needed to be abandoned because of landscape degradation, as it is implied by the Greek geographer Pausanias (Pausanias Periegetes VII, 2, 11, see Jones 1933; Section 2.3.1). The investigation couples geomorphological mapping, the evaluation of sediment cores and archaeological investigations.

A long-lasting, but still unsolved discussion between archaeologists and geographers is the initial point of the second case study (Section 6.2: Schneider et al., 2013): Did an inner gulf occupy the lower Bakırçay valley during historic times? Additionally, did the Paleo-Bakırçay – opposite to the modern Bakırçay - have a northern branch that joined the Aegean Sea north of the Kara Dağ Massif? If there was no gulf and no northern Paleo-Bakırçay, this would have consequences for the validity of written historical sources. The description of the Pergamene landscape by the ancient geographer Strabon (Section 2.3.1) cannot be correct if the modern coastlines and river deltas are identical with the ancient ones. The study combines geomorphological mapping, the analysis of sediment outcrops and archaeological methods.

The interior of the Bakırçay valley is investigated through the third case study (Section 6.3: Schneider et al., in press). A minimally invasive geoarchaeological approach is applied to explore a buried archaeological site of an unknown function and age on the Bakırçay valley floor southwest of ancient Pergamon. The site named 'Teut114' had been identified through the analysis of satellite data, which revealed a rectangular structure of approximately 180 x 100 m^2 marked by colour anomalies in freshly ploughed soil. Archaeological survey, geophysical exploration, geomorphological mapping and sedimentological analyses of drilling cores and pre-existing sediment outcrops were applied to reconstruct the settlement history, as well as the paleogeographical situation and the landscape development.

2. State of the Art

2.1 Geoarchaeological research in the Mediterranean and in western Anatolia

The Mediterranean ranks among the classical study areas of geoarchaeological research. Bintliff (2002) summarises important investigations from Claudio Vita-Finzi's path-breaking work 'The Mediterranean Valleys' (Vita-Finzi, 1969) to Van Andels works on the Prehistory of southern and eastern Greece (Pope and Van Andel, 1984; Shakleton and Van Andel, 1986; Van Andel et al., 1990) up to more recent investigations, such as Roberts et al. (1996), on the prehistoric settlement at Catalhöyük in the Konya basin, central Turkey, and Wilkinson (1994) on the economics of Early Bronze Age Mesopotamian dry-farming states. Brückner (1998) presents geoarchaeological studies in Mediterranean river deltas from southern Spain to southwestern Anatolia and northern Egypt. Morhange et al. (2014) review the geoarchaeology of tsunamis with a special emphasis on the eastern Mediterranean, including studies from Israel, the Aegean Sea and Egypt.

The paleogeographical and geoarchaeological research in the western Anatolian coastal regions is summarised in various publications. Grove and Rackham (2003) give an overview of Holocene alluviation and delta development. They outline the sedimentation processes leading to the postglacial silting up of the large Anatolian graben structures and their connection to the rise and fall of famous ancient cities. Additionally, they discuss the causes for the sedimentation in the graben and the delta progradation beyond the human factor. Müllenhoff (2005) and Brückner (1996) synopsise the geoarchaeological studies along the Aegean Coast from Troy in the north to the Dalyan Delta in the south.

2.2 Archaeological investigations in the Bakırçay valley

A summary of the archaeological research on the Bakırçay valley is presented in Section 6.1: Schneider et al., 2014 (Subsection 'Settlement history'). Detailed information on the archaeological investigations in Pergamon and its surroundings are presented, e.g., by Radt (2011a, b), Kästner (2011) and Zimmermann (2011). An overview of the Bakırçay valley as settlement area is given by Pirson and Zimmermann (2011).

2.3 Geoarchaeological and paleogeographical research in the Bakırçay valley

Geoarchaeological research in the Bakırçay valley does not have to start from scratch with this study. There are four types of sources, which constitute the basis on which this investigation was carried out. The most obvious approach to reconstruct the ancient landscape is to evaluate reports of contemporary eyewitnesses. Indeed, even some of the earliest writers in human history have described the Bakırçay valley and its landscape features. Section 2.3.1 reviews the most remarkable texts on the Bakırçay valley in ***ancient literature***.

Already the first generation of modern researchers was interested in the Bakırçay valley, its landscape and the archaeological sites. Excerpts of their ***travel reports*** from the second half of the 19th century and the early 20th century with information on the condition of the landscape are presented in Section 2.3.2.

At the same time, the first geoarchaeological questions on the Bakırçay valley arose. A vivid debate between archaeologists and geographers on how the ancient landscape looked, and where the places mentioned by the ancient authors are situated, followed. These ***early geoarchaeological papers*** are the subject of Section 2.3.3. Finally, Section 2.3.4 summarises the ***modern paleo-geographical and geoarchaeological studies*** in the environs of the Bakırçay valley.

2.3.1 Ancient literature

The Bakırçay valley surely is not among the most prominent and popular of the landscapes described by the ancient authors. Nevertheless, there are a number of passages in ancient literature, which contain information on the landscape, or on the cities and places within. Some of the texts even indicate a remarkably deep insight and understanding of the dynamics and the functionality of the landscape.

A comprehensive summary of ancient texts on the Bakırçay valley is given by Thraemer (1888). In the following, a selection of the most interesting texts is presented, among them texts of Herodotus, Strabon, Nearchus, Ovid and Pausanias. This selection does not claim to be complete, but it is intended to draw a rough picture of the ancient Pergamene landscape. The order of the texts is chronological, following the date of birth of the original author.

Herodotus (c. 485-424 BC), also referred to as the 'father of history', was a historian born in Halicarnassus (modern Bodrum). He travelled huge parts of the ancient world and reported on culture and geography (Meister, 2006). In Herodotus II, 10 (see Godley 1920) he describes his impression that amongst others, the environs of Teuthrania, a city and territory within the lower Bakırçay valley (Fig. 2), were formed by the silting-up of a marine embayment:

> „… *all that lies between the ranges of mountains above Memphis to which I have referred seemed to me to have been once a gulf of the sea, just as the country about Ilion and* **Teuthrania** *and Ephesus and the plain of the Maeander, to compare these small things with great. For of the rivers that brought down the stuff to make these*

lands there is none worthy to be compared for greatness with one of the mouths of the Nile. …"

Herodotus II, 10, see Godley 1920

Nearchos was an officer in the army of Alexander the Great in the fourth century BC. His original written reports are lost, but they were frequently reproduced by other ancient authors (Badian, 2006). In book XV of his Geographica, Strabon quotes Nearchos (Strabon XV, 1.16, see Jones 1930). Expressed in modern words, Nearchus concludes that the floodplains of some rivers, among them the Bakırçay (= Caicus), resulted from fluvial aggradation following erosion in the mountains. Furthermore, he notes the fertility of the floodplain:

„… Nearchus, speaking of the alluvia deposited by the rivers, gives the following examples: that the Plain of the Hermus River, and that of the Cayster, as also those of the Maeander and the Caicus, are so named because they are increased, or rather created, by the silt that is carried down from the mountains over the plains - that is all the silt that is fertile and soft; and that it is carried down by the rivers, so that the plains are, in fact, the offspring, as it were, of these rivers; and that it is well said that they belong to these. …"

Strabon XV, 1.16, see Jones 1930

Strabon, a geographer and historian, most likely lived between 62 BC and 23 AD (Radt, 2006). Several texts in Strabon's Geographica refer to cities and landmarks in the Bakırçay valley. Mostly, these texts are purely enumerative and list the places and landscapes without giving detailed information. Even in early times, archaeologists, as well as geographers, found contradictions in Strabon's descriptions, as well as ambiguities with the translation. At this point, select texts on the Bakırçay valley are not presented in detail, but only listed (Table 1). The debate on the interpretation of Strabon's texts is presented in Section 2.3.3.

The Roman poet **Publius Ovidius Naso (Ovid)** was born in Sulmo in 43 BC and died at Tomi in 17 AD (Kenney, 2006). In book XV of his 'Metamorphoses', he mentions the Bakırçay valley. He describes that a river, the Mysus, abandoned his old streambed and shifted to a new one, which was then called the Caicus (= the Bakırçay). Therefore, Ovid possibly describes a channel shift of the Paleo-Bakırçay. However, it remains unclear when this event took place.

„… They say the Mysus, wearied of his spring and of his former banks, appears elsewhere and takes another name, the Caicus. …"

Ovid, Metamorphosis XV, 277, see More, 1922

Pausanias Periegetes (c. 115-180 AD) was a Greek geographer and author best known for his detailed "Description of Greece" (Donohue, 2006). In book VII of this compendium, he describes the delta progradation in the Meander valley and a following mosquito-plague that caused the abandonment of Miletus. In the next sentence, he states that at Atarneus under Mount Pergamus, the same thing happened:

> *„A small inlet of the sea used to run into their land. This inlet the river Maeander turned into a lake, by blocking up the entrance with mud. When the water, ceasing to be sea, became fresh, gnats in vast swarms bred in the lake until the inhabitants were forced to leave the city. They departed for Miletus, taking with them the images of the gods and their other movables, and on my visit I found nothing in Myus except a white marble temple of Dionysus. A similar fate to that of Myus happened to the people of* ***Atarneus****, under Mount Pergamus."*
>
> *Pausanias Periegetes VII, 2, 11, see Jones 1933*

Table 1

Summary of Strabon's texts referring to the Bakırçay valley.

Original source	Translation	Places within the Bakırçay valley mentioned by Strabon*
Strabon XII, 8.2	Jones, 1961	Pergamene, Elaitis, Caicus, Teuthrania
Strabon XIII, 1.2	Jones 1960	Caicus, Canae, Atarneus, Pitane, Elaitic Gulf
Strabon XIII, 1.6	Jones 1960	Canae
Strabon XIII, 1.51	Jones 1960	Canae, Elaitic gulf, Atarneus, Pitane, Caicus, Elaea
Strabon XIII, 1.67-70	Jones 1960	Pitane, Atarneus below Pitane, Caicus, Elaitic Gulf, Elaea, Pergamum, Cane, Canae, Teuthrania
Strabon XIII, 3.5	Jones 1960	Caicus, Elaea, Elaitic gulf

* spelling according to the translations

2.3.2 Written records from the late 19th and early 20th century

Although some statements of the ancient historians and geographers allow a general view on the ancient landscape, the picture remains quite cloudy. Fortunately, the ancient authors are not the only literature source on the - supposedly more natural - pre-modern landscape. From the second half of the 19th century, when interest in the archaeology of Pergamon and the Bakırçay valley had awakened, several researchers travelled the Bakırçay valley and wrote reports on their observations. In the following, select excerpts from these reports on aspects concerning this study are summarised. The selection of the texts does not claim to be complete.

Ernst Curtius (1814-1896) was a German historian and archaeologist. In 1871, he was head of a Prussian expedition that recorded the surface topography of several archaeological sites on the west coast of Asia Minor, among them Pergamon (Kern, 1903). In his expedition report, Curtius describes the Bakırçay of the year 1871 (Curtius, 1872). He portrays it as a perennial river that floods the plain during the winter months. In summer, the river is about one foot deep and 30 to 60 feet wide. Furthermore, Curtius mentions that the headwater areas of the river were deforested during his visit in 1871:

> *„Eine halbe Stunde von der Stadt [Pergamon] entfernt strömt der Kaikos, dessen Bett 15 Meter unter dem Niveau der Stadt liegt und 25 über dem Meere. Im Winter die Ebene überfluthend, hat er auch im Hochsommer immer einen Fuß Wasser bei 30 bis 60 Fuß Breite. So lange die Quellgebirge ihre Waldung hatten, waren die Verhältnisse ungleich günstiger und da der Fluss von Somah bis zum Meere ein durchschnittliches Gefälle von 1 zu 1000 hat, so konne er in alten Zeiten gewiss auch zur Schiffahrt genutzt werden."*
>
> *Curtius, 1872: 47*

Habbo Gerhard Lolling (1848-1894) was an expert in Greek geography and topography, as well as in epigraphy. He was member of the German Archaeological Institut (DAI) and the author of the first Baedeker traveller's guide on Greece. In 1878, he took part in the Pergamon excavation led by Karl Humann (Wolters, 1894; Richardson, 1894). During this visit of the Bakırçay valley he located the ancient polis of Atarneus. In his report on the visit of Atarneus, he included a remarkably detailed description of the landscape and land use around the ancient city in 1878. Lolling states that Atarneus' ruins are located on a hill with the modern name Kalé-Ağılı, which he translates as 'castle of herds', fitting its actual use as grazing land:

> *„Die Ruinen des alten Atarneus selbst heißen jetzt Kalé-Ağılı oder Ageli.; d.h. das Heerdenschloss, ein sehr bezeichnender Name für die Burgruine, die meist nur von den Hirten mit den Heerden besucht wird und noch von keinem Europäer beschrieben worden ist."*

Lolling, 1879: 6

Lolling also describes in detail the plains surrounding the city hill of Atarneus. He depicts swampy areas at the foot slopes of the city hill, which had the biggest extent during the winter months. The parts of the plains, which were not swampy, were fertile cropland:

„Unter dem etwas höheren Ostabhang sowie unter dem Westfusse [von Atarneus], zu dem sich die Burghöhe in mehreren flachen Absätzen stufenförmig hinunter zieht, breiten sich lange Sumpfstrecken aus, die besonders im Winter eine grosse Ausdehung erlangen. […] Was in der Ebene unter uns nicht von den Sümpfen eingenommen wird, ist fruchtbares Getreideland.“

Lolling, 1879: 7-9

Further, Lolling reports, that after the first rainy days in autumn, extended areas of the Bakırçay plain and the environs of the city hill of Atarneus were flooded:

”Nach den ersten Herbstregen sieht man viele und weite Strecken der Kaikosebene unter Wasser; dann wird auch das engere Gebiet von Dikeli von dem Kale und den nördlicher gelegenen Ortschaften, zunächst Kabakum (wörtlich: «unter dem Sande») durch eine glatte Wasserfläche und weiter einwärts durch die Sümpfe geschieden, die wie bereits erwähnt bis an den Fuss des Kaleberges ausgedehnt sind.“

Lolling, 1879: 9

In the 1880s, **Walther von Diest** (1851-1932), a Prussian officer, received from the ‘Königlichen Akademie der Wissenschaften (Royal Academy of Sciences),’ the order to map the topography around Pergamon in support of German excavations. He surveyed the region between March and November 1886 and published a report in 1889 (Von Diest, 1889). Amongst other things, von Diest describes the road between Dikili and Pergamon. In the March of 1889, parts of the street east of Dikili, where the Geyikli (=Assarbogas-tschai) enters the Bakırçay valley were flooded. This is consistent with the statements of Lolling on the conditions on the plains during the wet season:

„Die Rückfahrt nach Pergamon erfolgte zu Wagen auf der vor 10 Jahren hier unter Humanns Leitung erbauten Kunststraße. Die zweite Hälfte ist leidlich erbalten und sogar auf eine Entfernung von 14 km durchweg mit Brücken versehen. Der Teil nahe Dikeli führt durch die oben beschriebene Niederung des Kainardscha-Göl, ist aber infolge jahrelang vernachlässigter Ausbesserung in der Regenzeit kaum mehr zu befahren. Anfang März passierten wir die Stelle, wo sie der Assarbogas-tschai schneidet; die Pferde mußten fast schwimmen; uns, im Wagen aufrecht stehend, ging das Wasser bis über die Kniee; […]“

Von Diest, 1889: 8

Alfred Philippson (1864-1953) was a long-time Professor for Physical Geography at the University of Bonn and extensively travelled the Mediterranean region (Mehmel, 2001). He also visited the

Bakırçay valley and published several works on the regional geography (Philippson 1910, 1911, 1912). At this point, only one excerpt from Philippson's detailed descriptions shall be presented. In his work 'Reisen und Forschungen im westlichen Kleinasien' ('Voyages and investigations in western Asia Minor'), Philippson elaborately describes the floor of the western Bakırçay valley. He states that near Eğrigöltepe (Fig. 2), the Bakırçay has cut several metres into its own alluvium. He notes that west of Eğrigöltepe and Teuthrania, the Bakırçay split up into two branches. The northern branch collected the slow flowing tributaries from the north. Furthermore, Philippson describes a swampy area connected to thermal springs in the northwestern part of the Lower Bakırçay valley. Most likely, Philippson refers to the hot springs and the surrounding swamp of the thermal field of Kaynarka (Fig. 2). Finally, Philippson documents the land use of the western Bakırçay valley. He found the plain being used for crop cultivation, as well as the cultivation of broad bean and sesame:

> *„… der Fluß strömt zunächst in gesammeltem Bett schneller dahin und hat sich oberhalb Eğrigöltepe etwa 3 m tief in seine eigenen Anschwemmungen wieder eingegraben. Dort, wo die Andesithügel aus der Ebene aufragen, verbreitert sich diese wieder etwas. Der Fluß teilt sich; langsam schleichende Gewässer (Asmak) führen ihm die Zuflüsse der Nordseite zu, nicht ohne dass sich diese vorher in dem Nordwestwinkel der Ebene, am Nordostrand des Kara-Dag, zu einem großen Sumpfdistrikt aufstauen, da dort der Boden den Anschwemmungen am meisten entzogen ist. Auch einige heiße Quellen tragen hier zur Versumpfung bei. Im übrigen ist auch diese Ebene meist angebaut, hauptsächlich mit Getreide, Saubohnen und Sesam."*

Philippson, 1910: 99

2.3.3 Geoarchaeological considerations between 1880 and 1960

The early researchers did not strictly investigate archaeological aspects. Even in early times, paleogeographical and geoarchaeological problems were discussed. Most remarkable is the scientific dispute between Wilhelm Dörpfeld, an archaeologist, and the geographer Alfred Philippson. The starting point of the discussion were the inconsistencies in the description of the ancient Bakırçay valley in Strabon's Geographica. Dörpfeld was firmly convinced that Strabon's descriptions were accurate, and all of the inconsistencies resulted from a landscape change, which occurred after the death of Strabon. He presented and defended his idea in several publications (Dörpfeld, 1910, 1911, 1912, 1928). On the contrary, Philippson vehemently refused this theory and published several papers in response (Philippson, 1911, 1912). A comprehensive overview on the debate, to which also Thraemer (1888), von Diest (1889), Buisson (1917), Leaf (1923), Van Gerkan (1956) and Stauber (1996) contributed, is presented in Section 6.1: Schneider et al., 2014 (Subsection 'Introduction').

2.3.4 Modern paleogeographical and geoarchaeological research

Only a small number of studies deal in detail with the paleogeography or geoarchaeology of the Bakırçay valley and its bordering mountains. Two investigations concern the geomorphological evolution of the Kozak Mountains (i and ii). A seismical study focuses on the development of the Bakırçay delta (iii). Geoarchaeological research has not yet been conducted inside the Bakırçay valley. However, two sites in its direct vicinity are the subject of geoarchaeological investigations: the Madra Cay Delta, north of Dikili (iv), and the ancient harbour city Elaia, south of modern Çandarlı (v).

(i) In 1979, Erol published a geomorphological study on Tertiary and Quaternary erosional cycles in Turkey. He discusses internal and external forces, such as tectonics and climate change, affecting the development of landforms. Erol concludes that in Anatolia, six erosional-depositional cycles occurred since Pliocene times, each cycle comprising erosional surfaces, as well as correlated sediment formations: 1. Pre-Oligocene cycle, 2. late Oligocene cycle, 3. Miocene cycle (tropical climate, peneplain character), 4. lower Pliocene cycle (arid to semi-arid climate, pediments), 5. upper Pliocene cycle (cooler and more humid climate), and 6. cycle of the lowest Pleistocene (Prepluvial Pleistocene). Erol assumes that the main features of the modern drainage system had been established after the fifth cycle. Following the pre-pluvial Pleistocene, according to Erol, six terraces accumulated. He relates the first four terraces to periodic accumulation fluctuations, combined with continuous subsidence during the pluvial Pleistocene (terrace 'S1': Günz, 'S2': Mindel, 'S3': Riss, 'S4' continuous Terraces 'S5' and 'S6' represent the youngest, post-Pleistocene alluvial fills). Concerning the Bakırçay valley and its environs, Erol found erosional surfaces from the second, late Oligocene cycle at 1100-1200 m a.s.l., and from the third Miocene cycle at 600 to 700 m in the Kozak Mountains, the northern bordering mountains of the Bakırçay valley. This researcher does not report on the occurrence of other cycles or terraces in the Bakırçay valley.

(ii) The tectonic development of the Ayvalik-Kozak region was investigated in a geomorphological study by Kuzucuoğlu (1995). She established a relative chronology of Tertiary and Quaternary tectonic and volcanic activities and the implications of these processes on the development of the region's drainage network. Kuzucuoğlu concludes that processes, such as relief inversion, river captures and entrenchments, strongly influenced the river network since the Miocene. She finds that Miocene and Pliocene tectonics and volcanic activities had a stronger influence on the landforms than the Quaternary processes, but that during Quaternary, regional uplift of the horst and sinking of the graben still continued and modified the river network. Opposite to geological papers on the Kozak Horst (Section 2.2.2; Altunkaynak and Yilmaz, 1998), Kuzucuoğlu does not describe a caldera collapse as being the cause for the intramontane basin within the central Kozak Horst.

(iii) The modern Bakırçay has its delta in the Gulf of Çandarlı and therefore, tectonically, in the Çandarlı basin (Fig. 2). The development and position of the deltas of the Bakırçay and the Gediz River during the Pleistocene were studied by Aksu et al. (1987). The study focuses, amongst other questions, on the relationship between the modern seabed and Quaternary delta growth and on the establishment of a chronology of successive delta development stages. The submarine topography was gathered by means of ship-based seismic measurements. A geochronological model was established by radiocarbon dating of material taken from sediment cores. Aksu et al. (1987) identify three depositional sequences in the Çandarlı basin, each of these being the marine equivalent of a delta progradation. The uppermost depositional sequence and delta progradation relates to the postglacial Holocene regression. The marine transgressions are represented by prominent unconformities separating the depositional sequences. Aksu et al. (1987) conclude that the maximum progradation of the Bakırçay delta during the last glacial maximum most likely reached as far as 65 km west from the bedrock head of the Bakırçay valley. Furthermore, they conclude that in the Çandarlı basin, during sea level low stands below 100 m, brackish or lacustrine conditions occurred (Aksu et al., 1987).

(iv) The Madra Cay drains a huge part of the Kozak Mountains. The river delta is situated on the Aegean coastal plain north of Dikili (Fig. 2) and was first studied in 1975 by Erol and in 1992 by Lambrianides, each of them relying on one sediment core. In 1994, Kayan et al. studied the Holocene development of the Madra River Delta as a part of the multidisciplinary 'Madra Cayi delta archaeological project' led by Lambrianides and Spencer. The aim of the study by Kayan, Vardar and Öner (Kayan and Vardar, 2007a, b; Kayan and Öner, 2007) was to reconstruct the paleogeography of a prehistoric settlement site located on the delta plain, the Yeni Yeldegirmeni Tepe, and to detect environmental and geomorphological changes that could have affected settlement and cultural development. The study is based on geomorphological mapping and the analyses of 22 sediment cores. Kayan and Vardar (2007b) found that the Early Holocene was characterised by a rapid rise of the Aegean Sea. The maximum transgression was 6-7 ka BP and reached approximately 2-3 km further inland than today's shoreline. During the middle Holocene, sea level rise came to a halt and deltaic progradation started to outweigh the sea level rise. Finally, in the late Holocene, flood plain aggradation caused by the flooding of rivers dominated. Kayan and Vardar (2997b) conclude that during the early Bronze Age, the prehistoric settlement on the Yeni Yeldegirmeni mound was situated closer to the shoreline. Afterwards, the coastal plain extended and provided more settlement area.

(v) The ancient city of Elaia is located on the coast of the Bay of Elaia, a portion of the Gulf of Çandarlı south of the Kara Dağ Peninsula (Fig. 2). The depositional system of the Bay of Elaia is not connected to the Bakırçay valley. In Hellenistic times, Elaia was the harbour city of Pergamon. Within the DFG Priority Program 1209 'The Hellenistic Polis as a Living Space,' Seeliger et al. (2013; 2014) conducted a geoarchaeological study on the late Holocene coastal changes around Elaia, at the time of the erection of the harbour and the process of its silting up. The investigation is based on geophysical, archaeological and sedimentological methods. 78 sediment cores were obtained from Elaia's harbour and its surroundings. Seeliger et al. (2013, 2014) conclude that the postglacial maximum transgression of the Aegean Sea dates to ca. 4500 BP and reached approximately 900 m further inland than today's shoreline. The closed harbour basin of Elaia was erected in early Hellenistic times and was intensely used until Roman times. Afterwards, the basin slowly silted up, coinciding with the decline of the city in late Antiquity.

3. Regional Setting

The Bakırçay valley is the northernmost and smallest of the large E-W-trending valleys of the West Anatolian Aegean coast. Between 38°50' N and 39°2' N, it extends approximately 50 km inland. Administratively, it is part of the Izmir Province and spreads over the districts Dikili, Bergama and Kınık. Only the easternmost valley portion is part of the Soma District in the Manisa Province. Important cities are Bergama, Soma and Kınık in the interior and Dikili and Çandarlı along the Aegean coast (Fig. 2).

According to Erol's landscape classification (Erol, 1983), the Bakırçay valley is part of the unit 'Mountains and basins of Edremit and Bergama', a subdivision of the 'Aegean Coastal Subregion'. The 'Mountains and basins of Edremit and Bergama' are characterised by a basin and range style geological setting (Section 3.2) with a Mediterranean-type climate (Section 3.3) and soils and vegetation (Sections 3.4 and 3.5). The dominant river is the Bakırçay (Section 3.6).

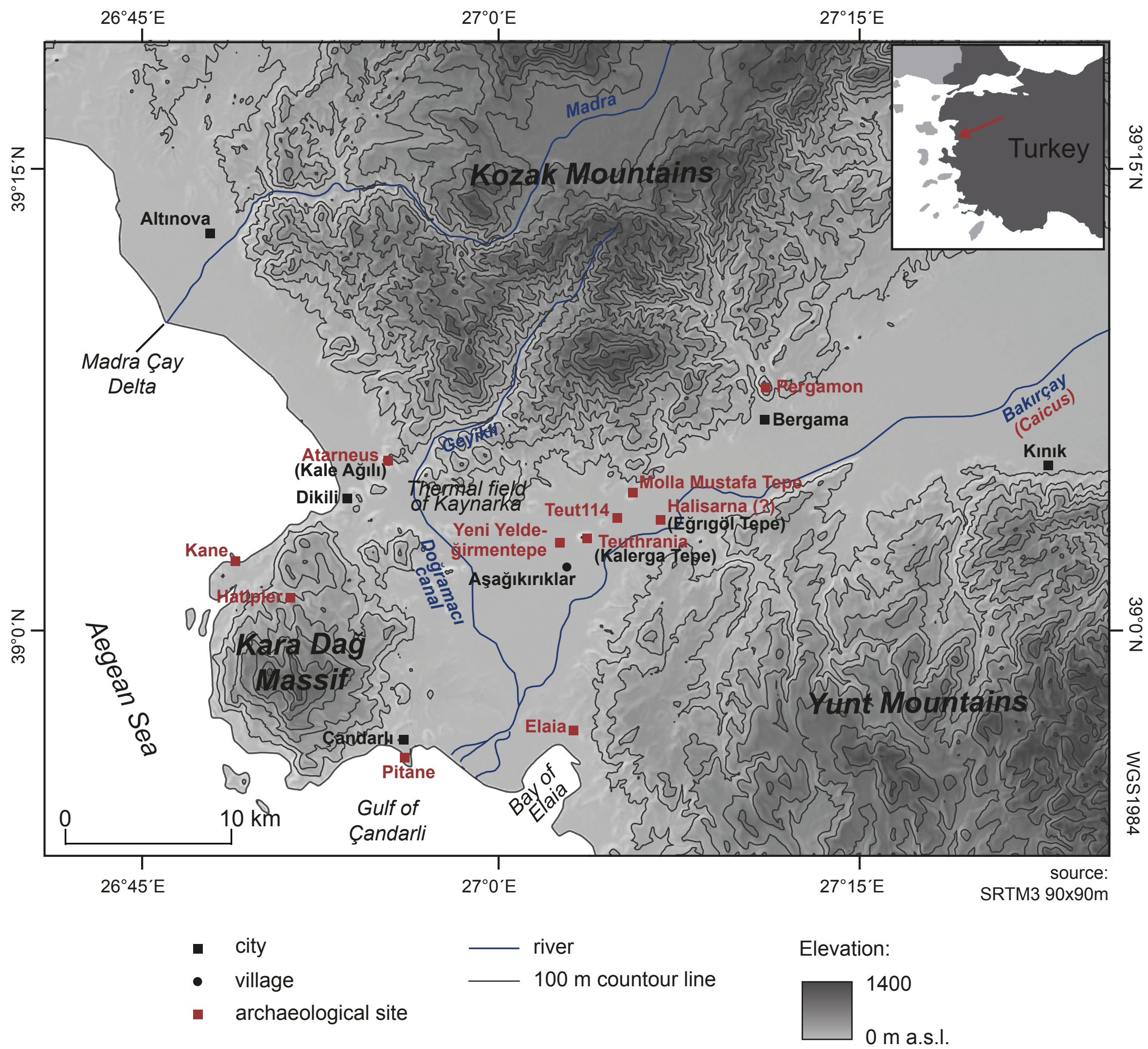

Fig. 2. Topographical map of the western Bakırçay valley.

3.1 Study area

The study area comprises the western portion of the Bakırçay valley, approximately bounded by the triangle of Bergama, Dikili and Çandarlı (Fig. 2). In the north, south and east, the valley is limited by the Kozak Mountains, the Yunt Mountains, the Kara Dağ Massif and the Aegean Sea (Fig. 2). The eastern border is represented by the corridor that connects the western and eastern basins of the Bakırçay valley.

The western basin of the Bakırçay valley has an average width between 10 and 15 km. Two narrow corridors connect it to the Aegean coastal plain: A northern one near Dikili between the Kara Dağ Massif and the Kozak Mountains, and a southern one near Çandarlı between the Kara Dağ Massif and the Yunt Mountains. The Bakırçay valley bottom rises from sea level near the Aegean coast to approximately 20 m a.s.l. in the corridor south of Bergama. The Bakırçay runs along the southern border of the valley and joins the Aegean Sea southeast of Çandarlı. To prevent flooding of the alluvial plain, the Bakırçay was straightened and embanked (Anonymous, 1986; 1987). The artificial Doğramacı canal runs parallel to the eastern fringe of the Kara Dağ Mountains. It collects the waters from the Geyikli valley in the north, as well as the smaller streams from the eastern Kara Dağ Massif. Furthermore, several ENE-WSW-trending smaller canals, which drain the interior of the western Bakırçay valley basin, debouche into the Doğramacı canal. Approximately 7 km east from Çandarlı, the canal joins the Bakırçay.

The Kozak Mountains are the northern border mountains of the Bakırçay valley, separating it from the Havran valley. They rise up to almost 1400 m a.s.l. A Tertiary caldera structure forms their inner part (Section 3.2.3). The Yunt Mountains as the southern border of the Bakırçay valley rise up to 1200 m a.s.l. The Kara Dağ Massif seals the Bakırçay valley like an oversized plug. This constellation with only two narrow connections to the coastal plain makes the Bakırçay valley unique along the Anatolian Aegean coast.

The Bakırçay valley comprises settlements from various periods since prehistoric times. Among the oldest settlements is the prehistoric Yeni Yeldegirmentepe in the centre of the basin (Horejs, 2010a, b; 2011; 2012). Pergamon in the east, Atarneus in the northwest, Elaia in the southwest and Teuthrania in the valley centre rank among the most prominent of the numerous archaeological sites from the historical period (Fig. 2).

3.2 Geotectonic and geological setting

This chapter is an extended and modified version of Section 2.2 Pre-Holocene landscape evolution of the publication Schneider et al., 2014 (Section 6.1).

3.2.1 The tectonic position within Anatolia

Geotectonically, the study area is situated within the Sakarya zone at the southern margin of the western Pontides (Dilek, 2006; Fig. 3). The Pontides are, along with the Anatolide-Taurides in the central portion and the Arabian platform in the southeast, one of the three geotectonic units that form the Anatolian plate.

Anatolia, as a coherent landmass, developed through the collision of several micro-plates. The Pontides, as well as the Anatolides-Taurides, are the remnants of terranes, which, before the Ordovician, formed the northern fringe of the supercontinent Gondwana (Okay, 2008). The Tethys Ocean separated Gondwana from the second supercontinent Laurasia in the north (Cavazza et al., 2004).

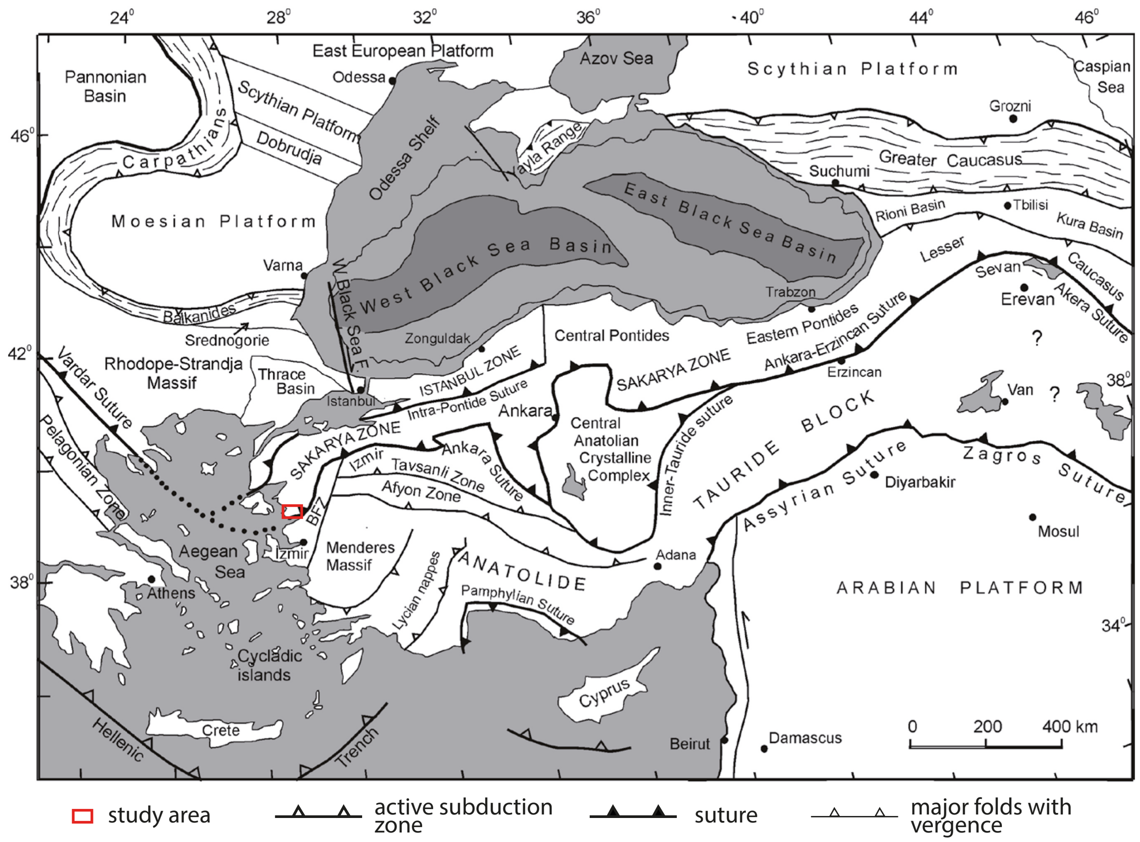

Fig. 3. Tectonic setting of Anatolia and the adjacent regions (modified after Okay, 2008).

The Pontides consist of three terranes: the Strandja, the Sakarya and the Istanbul terrane. The Pontides were rifted off from the northern fringe of Gondwana during the Ordovician (488-444 Ma) (Okay, 2008). In the late Triassic to early Jurassic (220-176 Ma), the Sakarya terrane was accreted to Laurasia in the course of the Cimmeride Orogeny, which followed the closure of the Paleo-Tethys (Pickett and Robertson, 1996). In the Mid Creatceous (c. 100 Ma), the Intra-Pontide ocean, which separated the three terranes, closed, and they were amalgamated into a coherent landmass (Robertson and Ustaomer, 2004).

The Anatolide-Tauride terrane was rifted off from Gondwana in the Triassic (251-200 Ma). The closure of the Neotethys, which separated the Pontide terranes from the Anatolide-Tauride terrane in the middle Cretaceous (100 Ma), led to the collision of the Pontides and the Anatolides-Taurides. This event resulted in the formation of the Izmir-Ankara suture. In the Oligocene (34-24 Ma), the Pontides and the Anatolides-Taurides were completely amalgamated and Anatolia existed as a coherent plate (Okay, 2008).

Finally, in the Miocene, the Arabian platform collided with the Anatolian plate along the Assyrian/Zagros suture, and the modern plate constellation was almost established (Yilmaz et al., in press). Since the Miocene times, and still on-going, two dominant tectonic processes have affected Anatolia: the tectonic 'push' of the northwards moving Arabian plate in the southeast, and the tectonic 'pull' of the southwards retreating Hellenic subduction zone in the southwest (Cavazza et al., 2004). The results of these tectonic movements are, amongst others, the development of the North Anatolian Fault Zone and the still on-going opening of the Aegean Sea.

3.2.2 The development of the study area's basic structures and landforms

The study area is the merging point of several geotectonic structures and geological formations (Fig. 4): The dominant Bergama and Ayvalik-Lesvos grabens bordered by the Kozak Horst, the Maruflar Horst and the Kara Dağ Massif, as well as smaller grabens such as the Zeytindağ/Örenli-Eğiller Graben and the Altınova Graben. These geological structures represent five stages of geological and landform evolution. The initial point of the development of today's landforms was the end of the Eocene when the Sakarya zone was elevated above sea level. It has since been subject to terrestrial erosional and depositional processes (Okay, 2008).

Stage 1: The Aegean Sea, the Kozak Caldera and the Anatolian Peneplain.

In the first stage, during Oligocene and Early Miocene, several tectonic events affected the study area. The Aegean Sea initially started to open (Cavazza et al., 2004), and the granitic Kozak pluton was embedded. Most likely shortly after the emplacement, the region above the pluton underwent a caldera collapse, following the release of volcanic erupta (Altunkaynak and Yilmaz, 1998). At the end of the first stage, the study area was part of the Anatolian peneplain, which had developed under warm and humid, tropical conditions with intense weathering during the Oligocene/Early

Miocene times (Erol, 1979; Kayan, 1999). In detail, the study area was situated at the fringe of a slightly elevated NE-SW-trending chain of volcanic centres in the northwest and a shallow lake basin in the southeast. The lacustrine and volcanic sediments deposited in this environment are known as the Dikili Group (Yilmaz et al., 2000).

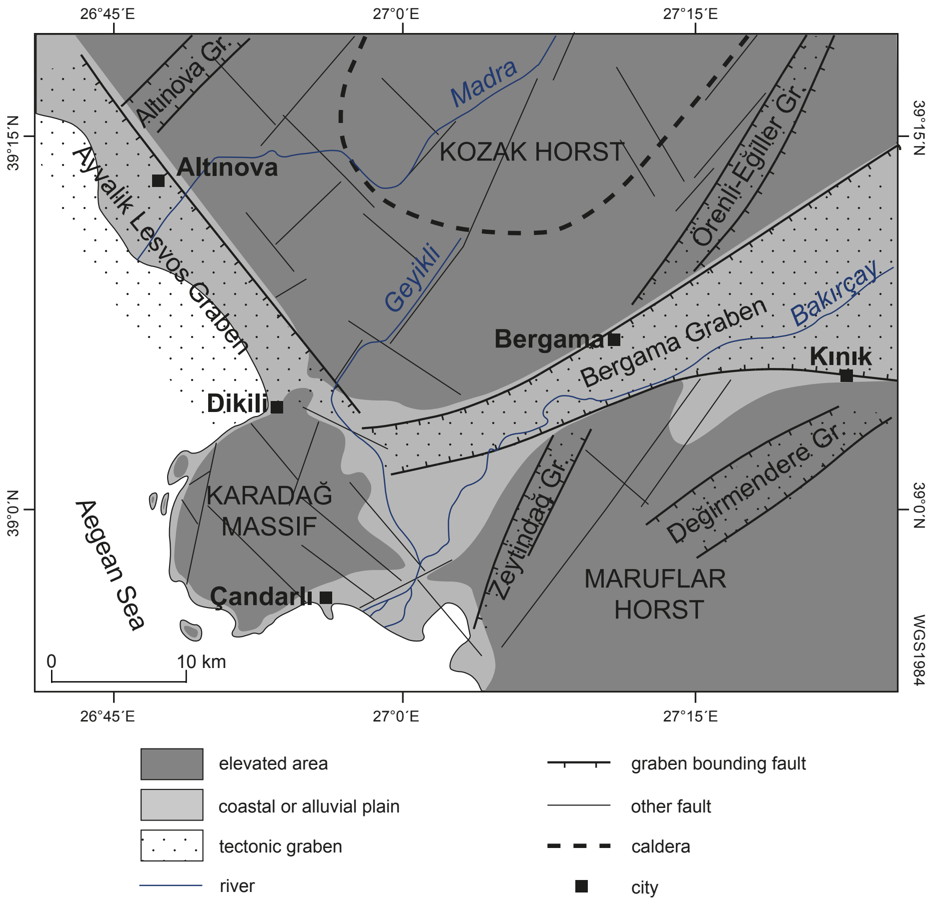

Fig. 4. Scheme of the main tectonic features and morphologic units of the western Bakırçay valley (Schneider et al., 2014; modified after Jeckelmann, 1996; Yilmaz et al., 2000; Agostini et al., 2010).

Stage 2: The Kozak Horst, the Zeytindağ-Örenli-Eğiller Graben and the Altınova Graben.

The second stage of landscape formation occurred during the middle Miocene, coinciding with the opening of NE-SW-trending graben and horst systems (Yilmaz et al., 2001) as result of an E-W-extensional regime. The Örenli-Eğiller Graben and the Altınova Graben developed, separated by the now rising Kozak Horst. The climate became drier and more continental (Kayan, 1999). The newly developed graben filled with the sediments of the Zeytindağ group. At the graben margins, coarse sediments, such as fault scree and fan sediments, were deposited. In the graben centres, fine sediments, such as sand, silt and mudstones, as well as lacustrine sediments, were deposited (Yilmaz et al., 2000).

Stage 3: The Bergama Graben and the Ayvalik-Lesvos Graben and initial pediments

In the third stage, beginning in the late Miocene, the extensional regime changed to a N-S-direction. This change led, in the early Pliocene, to the sinking of the Bergama Graben and the Ayvalik Lesvos Graben (Yilmaz et al., 2001; Agostini et al., 2010) and separated the Kozak Horst from the neighbouring horsts. Climatic conditions changed to more semi-arid and, along the shoulders of the graben, pediments formed (Erol, 1979). Within the graben, fluvial depositional conditions dominated (Kayan, 1999). At the end of the Pliocene, the main tectonic structures of the study area were constituted and the basic structure of the river system had been established (Kuzucuoğlu, 1995).

Stage 4: Alluvial mega fans, graben infill and river incision

The fourth stage of landscape formation comprises the Pleistocene, which brought no changes in the tectonic regime but the cooler climatic conditions of glacial periods, and the warmer, arid to semi-arid conditions of the interglacials (Kayan, 1999). Sea level high and low stands and resultant transgression and regression stages alternated repeatedly. Simultaneously, stages of graben infill followed stages of river incision (Erol, 1979). During the last glacial maximum, the coastline was situated approximately 30 km west of its present position (Aksu et al., 1987; Perissoratis and Conispoliatis, 2003). The Ayvalik Lesvos Graben had fallen dry, and Lesvos was connected to the mainland. Piedmont plains formed by coalescing alluvial fans, which developed on the western border of the Kozak massif (Kayan and Vardar, 2007b). This is also likely for the slope toes within the Bergama Graben.

Stage 5: Deltaic progradation and alluviation

The fifth and last stage of landscape formation began with the Holocene transgression of the Aegean Sea, which was fastest in the early Holocene, slowed in the middle Holocene and stopped with minor fluctuations near today's level between 6,000 and 5,000 BP (Brückner et al., 2010). The Ayvalik Lesvos Graben was flooded supposedly at approximately 10,000 BP. In the Madra River delta, the maximum transgression of the Aegean Sea occurred between 7,000 and 6,000 BP and extended between 2 and 3 km further west of today's shoreline (Kayan and Vardar, 2007b). Seeliger et al. (2013) dated the maximum transgression in the Bay of Elaia south of the Bakırçay delta to approximately 4500 BP. Afterwards, coastlines shifted to the west as a result of deltaic progradation. Alluviation inside the Bergama Graben led to the development of the Bakırçay flood plain in its present state (Kayan, 1999). Climate in the Holocene was not stable. After a relatively wetter period at the beginning of the Holocene, a phase of aridisation occurred in the middle

Holocene (Roberts et al., 2011), coinciding with the establishment of today's typical Mediterranean vegetation (Grove and Rackham, 2003).

3.2.3 The Bergama Graben and the Kozak and Maruflar Horsts

The Bergama Graben trends over approximately 60 km from northeast to southwest. In its central part, it narrows to less than 5 km while it widens to the east and west. In the east, it is limited by the north-south trending Soma Graben, in the west by the Ayvalik-Lesvos Graben and the Kara Dağ Massif (Fig. 4). The graben has an asymmetric profile with a steep northern side against the Kozak Horst and a lower southern side against the Maruflar Horst. At the southern fringe of the Kozak Horst, the main faults dip with more than 70° to the south. The main faults in the south, at the northern fringe of the Maruflar Horst, have lower angles and dip to the north. Both the northern and southern main faults show normal faulting. The thickness of the Bergama Graben infill is estimated to be thicker than 500 m (Yilmaz et al., 2000). The lithology of a borehole in the northern part of the lower Bergama Graben basin revealed an approximately 75 m thick alluvial layer overlying a volcanic basement (Özürlan et al., 2006).

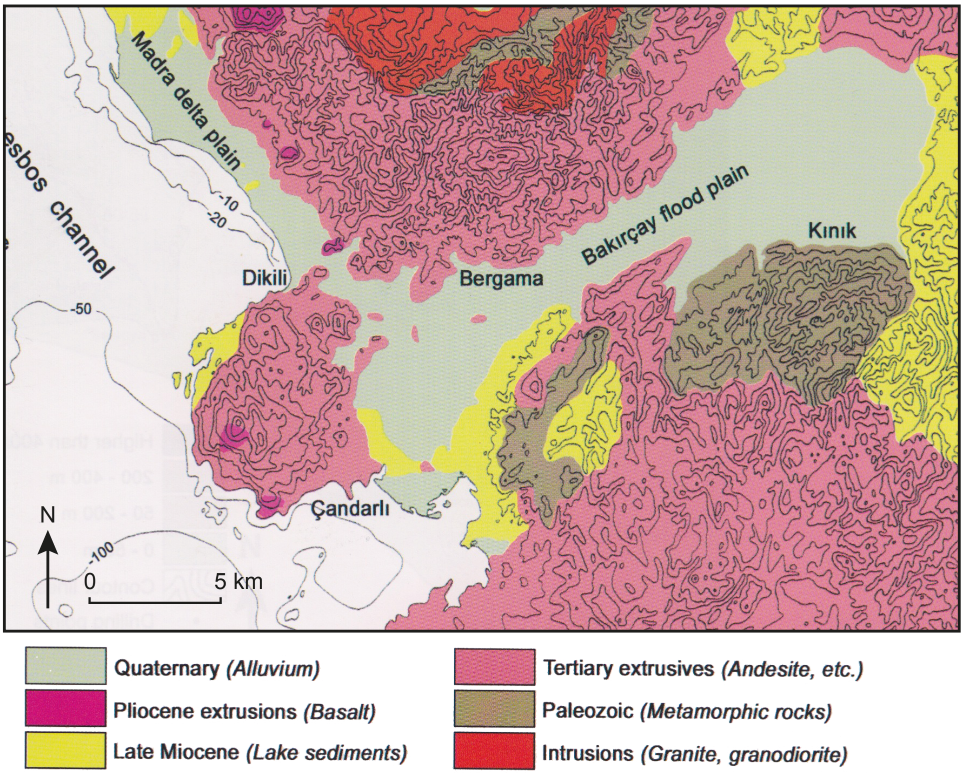

Fig. 5. Cover rocks of the western Bakırçay valley (modified after Kayan and Vardar, 2007a).

The Kozak Horst is the northern rift shoulder of the Bergama Graben. In the east, it is limited by the Örenli-Eğiller Graben, in the west by the Ayvalik-Lesvos Graben and in the north by the Altınova Graben (Fig. 4). The central portion of the Kozak Horst is a collapsed caldera environment over a granitoide pluton (Yilmaz et al., 2000). Along with the granitoide intrusions, the rock association of the Kozak Horst comprises Palaeozoic metamorphic rocks and volcanic rocks from Tertiary and Pliocene extrusions. Additionally, Neogene sedimentary rocks, mostly Miocene lake sediments, crop out occasionally (Fig. 5). The highest elevated parts of the Kozak Horst follow the caldera structure and encircle an intramontane basin (Fig. 2). The Maruflar Horst's geology is similar to the Kozak Horst. Yilmaz et al. (2006) suppose that the Maruflar Horst represents a granitic pluton in a caldera environment, though with more intact cover rocks. A typical caldera structure with an intramontane basin does not occur in the Maruflar Horst (Fig. 2).

3.2.4 Historical earthquakes

The processes that led to the sinking of the Bakırçay valley (Section 2.2.2) are still occurring. Subsidence of the Bergama Graben is continuing at an average rate of 1 cm per 1,000 years (Aksu et al., 1987). This tectonic stress causes earthquakes. For the historical episodes, at least nine earthquakes are documented, which resulted in damages in the Bakırçay valley (Table 2).

Table 2

Historical earthquakes in the Bakırçay valley and its surroundings.

No.	Year	Location	Remarks	Source
1	17 AD	Gediz valley	Signs of destructions in Pergamon	Garbrecht, 2003; Ambraseys and Jackson, 1998;
2	105 AD	Çandarlı	Amongst others, Pitane (modern Çandarlı) was destroyed	Emre et al., 2005
3	106 AD	Western Anatolia	Limited destructions in Pergamon	Garbrecht, 2003
4	178 AD	Western Anatolia	‚Smyrna earthquake'; severe destructions in western Anatolia, amongst others in the Bakırçay valley	Garbrecht, 2003
5	262 AD	Western Anatolia	Destructions in western Anatolia, amongst others in Pergamon	Garbrecht, 2003
6	358 AD	Western Anatolia	Destructions in the Asia Province	Garbrecht, 2003
7	365 AD	Eastern Mediterranean	Severe destructions throughout the eastern Mediterranean	Garbrecht, 2003
8	22.9.1939	Epicenter near Dikili	Dikili: 41 casualties, 1000 houses destroyed, opening of surface cracks, formation of geothermal springs	Emre et al., 2005 Ketin, 1948a, Ketin 1948b
9	2.5.1953	Epicenter in the northern portion of the Karaburun peninsula	Destructions in Bergama	Emre et al., 2005

The potential influence of the earthquakes on the landscape is demonstrated by the Dikili earthquake from 22/09/1939 with a magnitude of 6.6 (surface-wave magnitude scale, M_s). The epicentre was located in the Aegean Sea near Dikili (Zanchi and Angelier, 1993). The earthquake led to the formation of geothermal springs along newly opened surface cracks (Ketin, 1948a, b). In Dikili, 41 people died and approximately 1000 houses were destroyed (Emre et al., 2005).

3.3 Climate

The Bakırçay valley and its border mountains are part of the subtropics with winter rain (Schulz, 2002). According to the Köppen-Geiger system, the region has a Mediterranean type 'Csa' climate with hot, dry summers and mild, humid winters (Fig. 6; Peel et al., 2007).

The seasonality of temperature and precipitation originates in the Mediterranean region's transitional position between the mid-latitude westerlies to the north and the Azores high, a segment of the descending branch of the Hadley cell, to the south (Harding et al., 2009). During the summers, when the Innertropical Convergence Zone (ITCZ) moves north, the influence of the Azores high with warm and dry conditions dominates. During the winters, when the ITCZ shifts to the south, the influence of the westerlies leads to increased rainfalls in the course of extratropical cyclonic activity. Furthermore, in the summer, the region is affected by an extension of the South Asian Monsoon, the 'Basra low-pressure depression' that can cause the intrusion of hot air masses (Erlat, 2007). In the winter, the Siberian high-pressure system influences the region, and arctic air masses intrude from the north (Lionello et al., 2006).

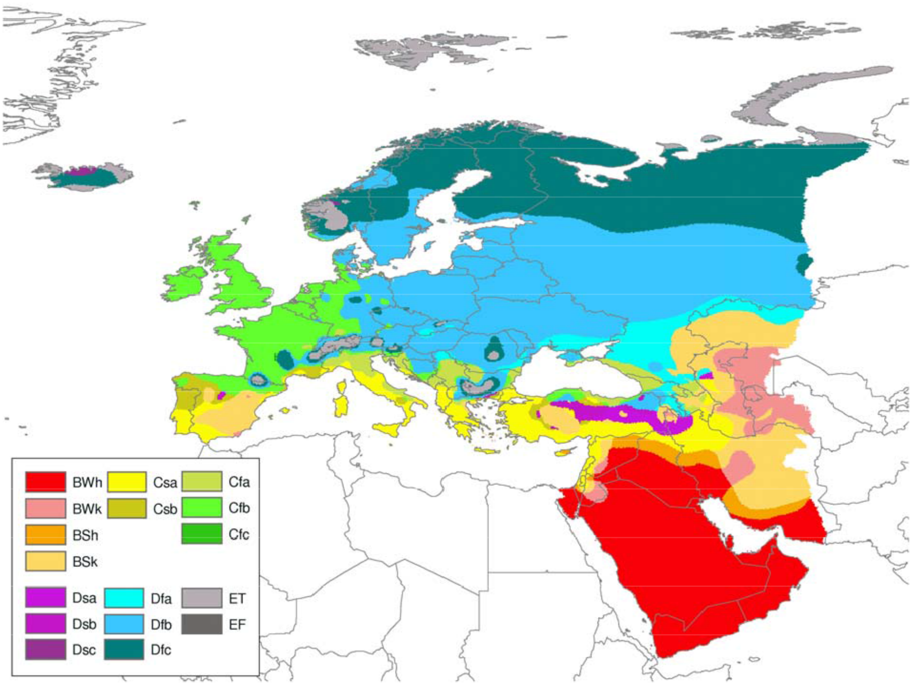

Fig. 6. Köppen-Geiger climate type map of Europe (Peel et al., 2007).

The climate charts of the stations in Dikili and Bergama illustrate the regional climate in the Bakırçay valley (Fig. 7). The mean annual temperature ranges between 16.0 and 16.3 °C. The coldest months are January and December at approximately 11-12°C, and the warmest months are July and August at 24-26°C (mean monthly temperature). Erlat (2007) presents daily temperature data for the climate station in Altınova, a city approximately 20 km northwest of Dikili (period: 1966-1996). Between December and February, the mean daily maximum temperature are 12-13 °C, with the minimum temperature being 2.5-4°C. In July and August, which are the warmest months, the mean daily maximum temperature is 33°C, and the minimum temperature is 17°C (Erlat, 2007).

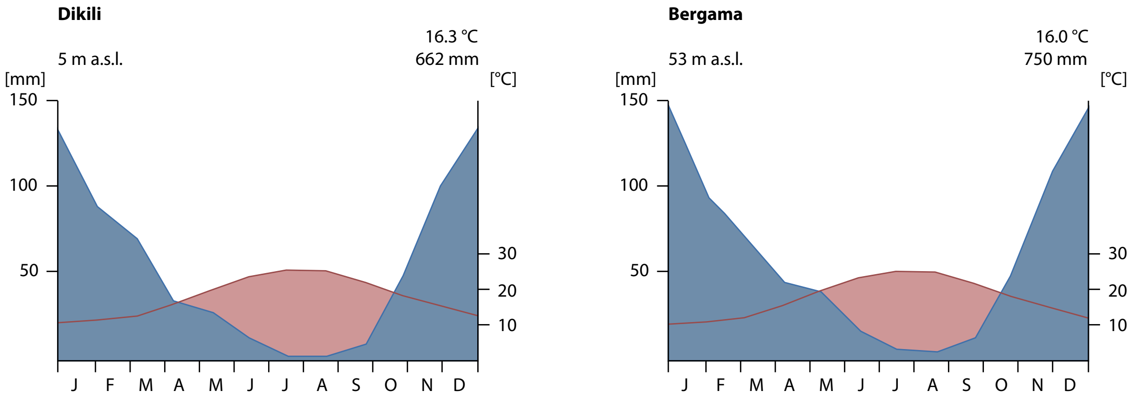

Fig. 7. Climate charts of Dikili and Bergama (modified after Jeckelmann, 1996).

The mean annual precipitation totals 662 mm in Dikili, while in Bergama, it is approximately 90 mm higher (Jeckelmann, 1996). The regional inter-annual precipitation variability is up to 750 mm per year (Erlat, 2007). The difference in mean annual rainfall between Dikili and Bergama demonstrates the strong effect of the orographic position on the meso-scale climate, which is typical for the Mediterranean (Grove and Rackham, 2003) and the Aegean coast (Erlat, 2007). Dikili is situated on the flat coastal plain in the leeward position of the Kozak Horst and the Kara Dağ Massive. Opposite to this, Bergama is situated at the southern fringe of the Kozak Horst and benefits from orographic rainfall (Fig. 2). Mean monthly precipitation in Dikili and Bergama are highest between November and February, with peaks up to almost 150 mm per month. The dry season in Dikili starts in April and lasts until October, while in Bergama, it is delayed by one month. During July and August, the monthly precipitation is distinctly less than 10 mm (Jeckelmann, 1996). The maximum amount of daily rainfall measured at Dikili in the period of 1939-1996 was 183 mm (Erlat, 2007).

3.4 Soils

Pedogenesis in the Mediterranean is characterised by the combination of several factors, which make it special compared to other pedogenetic zones. The seasonal climate with a warm and dry period in summer, the mosaic structure of the relief and the lithology, the emission of dust from the Sahara and the long-term effect of human settlement and land use are among the most prominent factors (Yaalon, 1997). The primary pedogenetic processes in the Mediterranean are decalcification, accumulation of residual clays, clay migration, rubification and caolinisation, as well as soil erosion (Zech and Hintermaier-Erhard, 2002). Consequentially, the most common soils in the Mediterranean are luvisols, calcisols and leptosols, as well as cambisols, vertisols and fluvisols (Jahn, 2000). In semi-arid to arid regions, where evaporation exceeds precipitation, calcrete formation occurs (Khadkikar et al., 1998).

A detailed soil map of the Bakırçay valley and its bordering mountains does not exist. However, it is evident that the relief, the lithology and the vegetation cover/land use are the crucial factors for the pedogenesis. Erlat (2007) states that brown forest soils (cambisols) on granodioritic and volcanic parent material are the most common soils in the region. The calcareous Miocene sediments (Fig. 5) are mostly covered by rendzinas (leptosols). On steep-slopes, soil erosion has area-wide exhumed the bedrock. Colluvial and alluvial soils (fluvisols) have developed on the slope toes and the valley floors (Erlat, 2007). However, intensive agricultural use has intensely modified and degraded the original soil cover. In particular, the valley floors must be regarded as anthrosols.

3.5 Vegetation

The Mediterranean vegetation is a mosaic of different formations, such as sclerophyllous woodlands, evergreen sclerophyllous shrub lands, savannahs, steppe and heathlands (Grove and Rackham, 2003; Wagner, 2001). The plants of these formations are adapted to the seasonality of the climate with hot, dry summers and cool, wet winters (Allen, 2009). Relief and orographic position, altitudinal zoning, lithology, soil cover, fires and human influence are the factors that determine which Mediterranean vegetation formations will develop (Grove and Rackham, 2003).

The Bakırçay valley and its bordering mountains lie within the 'Mediterranean coastal region' of Anatolia. The potential natural vegetation of this region are sclerophyllous woodlands and *Pinus brutia* dry forests below 1000 m a.s.l., and *Pinus nigra* forests above 1000 m a.s.l. (Kürschner et al., 1995).

Sclerophyllous woodlands were originally characteristic for the whole colline altitudinal zone in the Aegean coastal zone of Anatolia. Due to human land use, the woodlands are mostly degraded and often restricted to inaccessible, unused slopes and valleys (Sütgibi, 2007). Characteristic species for the lowest, most thermophilic altitudinal zone up to 300 m a.s.l. are *Olea europaea* var. *sylvestris* and *Ceratonia siliqua*, *Myrtus communis*, *Pistacia lentiscus* and *Rhamnus lycioides*. The shrub layer contains *Arisarum vulgare* ssp. *vulgare*, *Asparagus aphyllus* ssp. *orientalis*, *Capparis spinosa*, *Euphorbia dendroides*, *Piptatherum coerulescens* and *Rubia tenuifolia*. Above 400 m a.s.l. *Quercus cerris*, *Quercus infectoria* ssp. *boissieri* and *Styrax officinalis*, as well as *Phillyrea latifolia*, *Pistacia terebinthus* ssp. *palaestina* and *Quercus cocciferia* play an increasingly important role. Along with the sclerophyllous woodlands, *Pinus brutia* forests cover large areas. They are mostly of anthropozoogeneous origin, resulting from pasturing and afforestation (Kürschner et al, 1995).

Fig. 8. View to the west from the summit of Kalerga Tepe into the western Bakırçay valley and towards the Kara Dağ Massif. The Bakırçay valley floor is used for agriculture. The isolated hills and mountains are covered by sclerophyllous woodlands or shrub lands.

Due to land use, such as firewood harvesting and pasture and resultant soil erosion, those portions of the sclerophyllous woodlands, which were not completely deforested, are degraded to sclerophyllous shrub lands (Sütgibi, 2007). In the maquis formation up to approximately 5 m high, the trees are reduced to the size of shrubs, but the original species composition is still more or less unchanged (Grove and Rackham, 2003). The phrygana formation is more strongly degraded than the maquis and consists of undershrubby vegetation up to 1 m high (Kürschner et al, 1995). Within the Aegean coastal region, the characteristic species are *Sarcopoterium spinosum*, *Calicotome villosa*, *Genista acanthoclada*, *Anthyllis hermanniae*, *Coridothymus capitatus*, *Teucrium capitatum*, and species of *Cistus*, *Erica manipuliflora*, *Thymbra spicata* and *Satureja thymbra* (Kürschner et al, 1995).

Within the study area, the sclerophyllous woodlands and *Pinus brutia* forests, as well as maquis and phrygana are restricted to areas in the Kozak Mountains and the Yunt Mountains. However, also in the mountains, some areas are terraced and serve the cultivation of olive trees. The Kozak plateau (the floor of the intramontane caldera-basin within the Kozak Horst, Section 3.2.3) is covered by a cultivated *Pinus pinea* forest (Erlat, 2007). On the Bakırçay valley floor, natural or quasi-natural habitats do not exist because it is completely used for agriculture, particularly for the cultivation of cotton, sunflowers and vegetables (Fig. 8). Only the sporadic isolated volcanic hills have a cover of maquis and phrygana (Fig. 9).

Fig. 9. The Kalerga Tepe as seen from southeast. Cotton is cultivated in the alluvial plain. Macchie and phrygana cover the isolated volcanic hill.

3.6 Hydrological setting

The hydrologic regime of the Aegean rivers is closely connected to the climatic conditions. The period of maximum discharge is linked to the cyclonic activity under the influence of the westerlies between autumn and spring (Section 3.3). During the dry period in summer, discharge is low, and only the bigger rivers flow perennial. The smaller streams have an intermittent torrential flow regime (Kayan and Vardar, 2007a). In the winter, floods are frequent. The increasing use of water for agricultural irrigation and industrial and domestic supply aggravate the period of low discharge and counteracts groundwater recharge (Akbulut et al., 2009). Furthermore, the construction of dams and water reservoirs influence the natural hydrological regime, such as the maximum discharge and frequency of floods. Vörösmarty et al. (1997) called this effect of the dams, which also affects the sediment transport within rivers, 'neo-Castorisation'.

The Bakırçay drains a basin of approximately 2900 km^2, comprising the Bakırçay valley and areas within the bordering mountains. Hence, it is one of the smaller perennial rivers of the Aegean coast of Anatolia compared, for example, to the Gediz and the Cücük and Büyük Menderes. The Bakırçay's mean annual discharge varies between 19 and 23 m^3s^{-1}. The mean monthly discharge between July and October is distinctly less than 5 m^3s^{-1} (Fig. 10; Aksu et al., 1987). The maximum mean monthly discharge up to 85 m^3s^{-1} occurs in February and March, coinciding with the snowmelt in the headwater areas.

The Bakırçay flow pattern changes from braided in the middle reaches to a transitional braided to meandering pattern in the lower reaches and finally to meandering close to the Bakırçay delta (Fig. 10; Aksu et al., 1987). However, as the entire drainage basin, the Bakırçay is strongly anthropogenically modified. The Bakırçay has been straightened and dams parallel to its course reduce the risk of flooding the valley floor. Furthermore, irrigation and drainage channels have replaced the smaller natural watercourses on the valley floor (Anonymous, 1986).

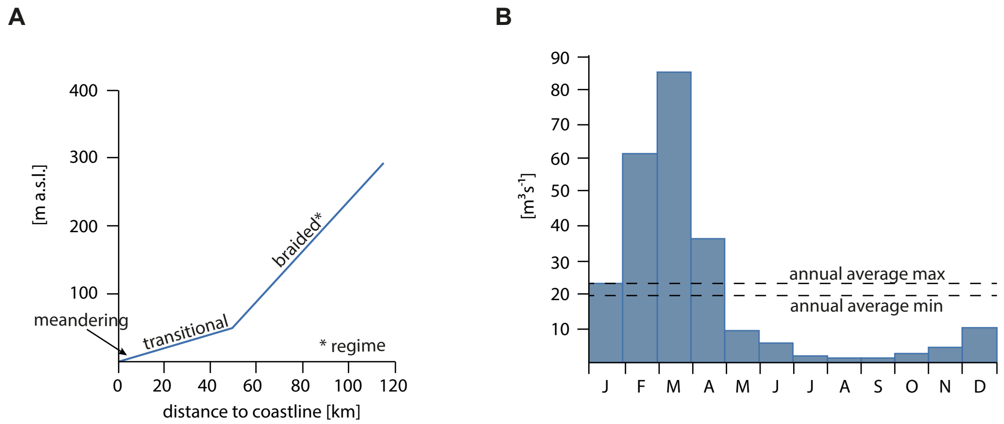

Fig. 10. A: Gradient and regime of the Bakırçay; B: Monthly average discharge of the Bakırçay (modified after Aksu et al., 1987).

4. Approach and Methods

This chapter is an extended and modified version of the 'Methods' sections of the publications Schneider et al. 2010, 2011, 2012, 2013, 2014 and Schneider et al., in press (Sections 5.1-5.3 and 6.1-6.3).

4.1 General approach

Geoarchaeology, as an interdisciplinary science between physical geography/geosciences and archaeology, interfaces a large number of methods to reconstruct paleolandscapes and cultural developments. Roberts (2001) gives an overview of the tools of environmental reconstruction from dating techniques through paleoecological techniques to geological, geomorphological and geoarchaeological techniques. Bork et al. (1998) present a (cultural) landscape reconstruction approach with the main emphasis on pedogenesis and anthropogenic disturbance of soils. The approach aims at identifying Holocene natural and anthropogenic landscape changes and comprises steps, such as the inventory of today's pedogenic and landscape conditions, the detailed reconstruction of the late Pleistocene/early Holocene landscape and the evaluation of undisturbed natural soil profiles (Bork et al., 1998). However, this approach is particularly suited for middle European conditions.

This study follows the geoarchaeological approach of Brückner and Gerlach (2007), which is based on the evaluation of geoarchives, such as river deltas, terraces, colluvial sediments, alluvial fans and lake sediments (see also Brückner, 2003 and Brückner et al., 2005). Figure 11 shows an overview of the approach and the steps undertaken in this study. In the following sections, the methods are explained in detail.

4.2 Analysis of remote sensing data

Prior to the fieldwork, remote sensing data were analysed with the aim to identify archaeological sites and geoarchives. The analyses were based on digital elevation models, satellite images and topographical maps (Table 3). The digital elevation models were analysed for basic features, such as slope, aspect, stream flow and topographical wetness index. The satellite images were used to identify land use and vegetation, as well as signs of paleochannels. See the 'Methods' sections of the case studies presented in Section 6.1-6.3 for more detailed descriptions.

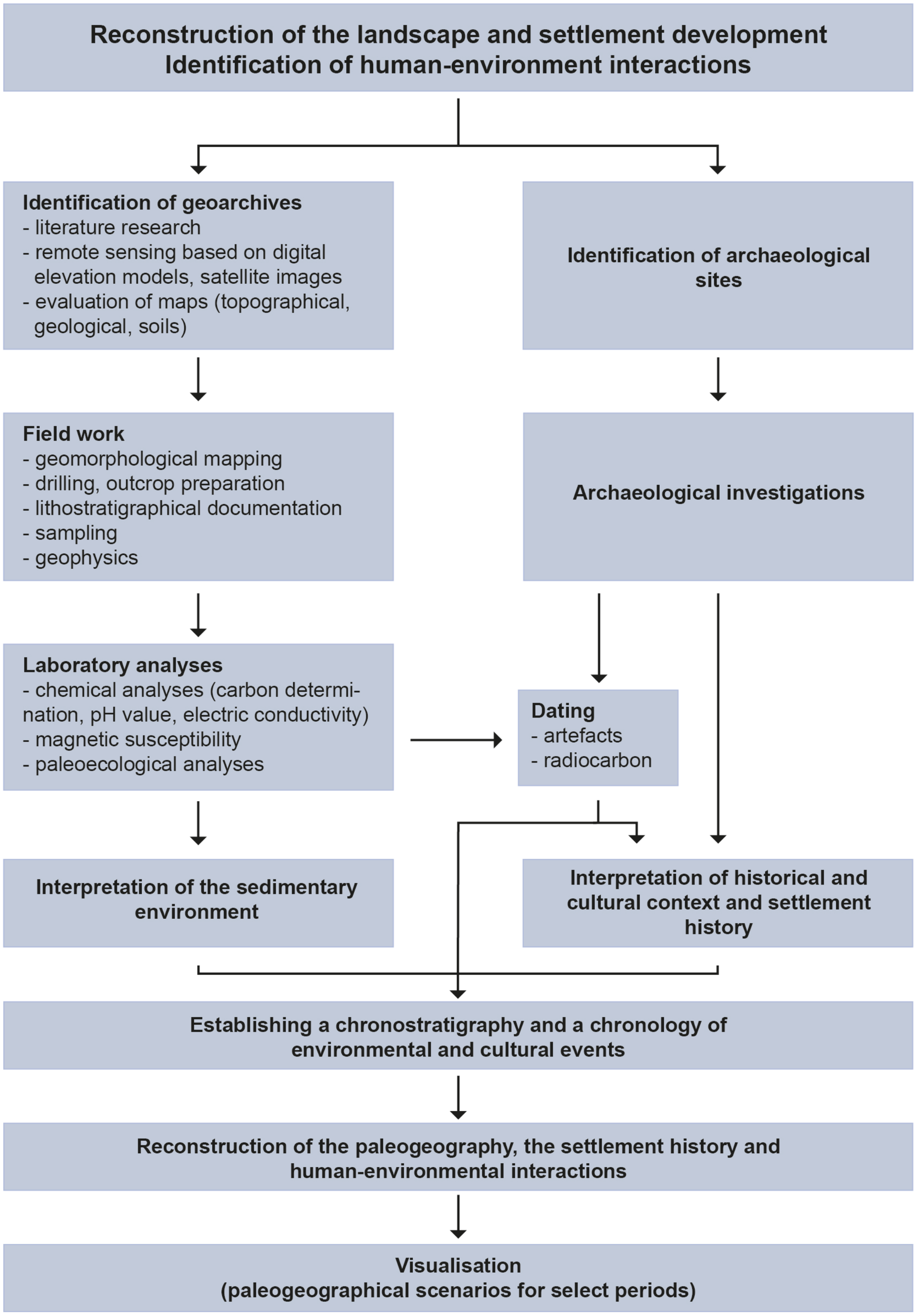

Fig. 11. General approach of the study (modified after Brückner and Gerlach, 2007)

Table 3
Remote sensing data and maps.

Data	Provider/ Source
QuickBird 2 satellite imagery (resolution 0.7 x 0.7 m²; scenes from 3/6/2007, 2/4/2006 and 18/9/2004)	DigitalGlobe
SRTM 90m digital elevation data (version 4.1)	Jarvis et al., 2008
Rapid Eye (orthorectified, 12.7 m CE (circular error at 90% confidence); scene from 15/9/2011)	DLR / RapidEye Science Archive
Soviet Military Topographic Map 1:50.000 (sheets J35-30-Г., J35-31-В)	Office of Geodesy and Cartography of the USSR, Moscow.

4.3 Field work

The fieldwork was conducted in the summers of 2009, 2010 and 2011. The study areas were geomorphologically mapped during surveys following Leser and Stäblein's methodology (1980). Field-based lithostratigraphic recordings were produced for six sediment outcrops. The sediments were sampled from all lithostratigraphic units. Furthermore, 40 sediment cores were obtained using a Wacker vibracoring device (BHF 30 S) with a 5 cm core diameter in open metal drill probes or in closed plastic tubes (Table 4). The position and elevation above sea-level were determined through the differential GPS system Leica SR 20 (Table 4).

Prior to the chemical analyses (Section 4.4), guidelines from the German manual of soil mapping (Ad-Hoc-AG Boden, 2005) were followed to describe the grain size composition of the sediments. Sediment colour was determined using the Munsell soil colour chart. Further, lithostratigraphic features, such as sediment texture, sorting, grading, macroscopic fossil content, charcoal content and hydromorphic features, were documented.

Table 4
Sediment profiles with profile type, location, profile depth and publication information.

No.	drilling		outcrop	Coordinates (WGS84)		Elevation	Profile depth	Published in[c]
	open	closed		Latitude	Longitude	m a.s.l.[a]	m b.s.[b]	
AD01 (11)[d]	x			39° 5' 38.3"	26° 54' 50.4"	7	6.1	1; 5
AD02 (10)	x			39° 5' 40.4"	26° 54' 48.7"	6	5.1	1; 5
AD03 (9)	x			39° 5' 43.4"	26° 54' 46.1"	5	6.1	1; 5
AD04 (13)	x			39° 5' 17.7"	26° 55' 34.0"	11	4.2	1; 5
AD05 (14)	x			39° 5' 15.1"	26° 55' 34.9"	10	6.1	1; 5
AD06 (15)	x			39° 5' 11.0"	26° 55' 34.0"	9	6.1	1; 5
AD07 (5)	x			39° 1' 25.9"	27° 2' 17.8"	10	9.1	1
AD08 (6)	x			39° 2' 10.7"	27° 3' 19.4"	10	12.0	1
AD09 (12)	x			39° 5' 16.1"	26° 54' 32.3"	8	7.1	1
AD10 (8)	x			39° 6' 1.1"	26° 54' 55.2"	11	5.1	1
AD11 (7)	x			39° 5' 57.2"	26° 54' 44.0"	11	7.1	1
AD12 (17)			x	39° 5' 43.32"	26° 56' 49.1"	24	5.5	1; 4
AD13 (16)			x	39° 5' 29.5"	26° 56' 40.0"	23	3.7	1; 4
AD14 (4)	x			39° 2' 49.1"	27° 2' 32.1"	10	7.1	1
AD15 (2)	x			39° 2' 48.2"	27° 2' 0.9"	10	4.8	1
AD16 (1)	x			39° 2' 43.0"	27° 1' 47.1"	10	7.1	1
AD17 (3)	x			39° 2' 46.2"	27° 2' 3.5"	10	6.1	1
AD18	x			39° 2' 49.9"	27° 2' 1.8"	10	8.0	2
AD19		x		39° 2' 50.1"	27° 2' 5.8"	10	7.0	2
AD20	x			39° 2' 51.2"	27° 2' 3.6"	10	7.0	2
AD21	x			39° 2' 50.3"	27° 2' 3.1"	10	8.0	2
AD22		x		39° 2' 50.8"	27° 2' 5.9"	10	9.0	2
AD23		x		39° 4' 12.7"	26° 58' 5.4"	8	6.0	2
AD24		x		39° 4' 4.0"	26° 58' 11.5"	8	6.0	2
AD25 (Sp1)		x		39° 3' 21,96"	27° 4' 43,68"	14	4.0	2; 6
AD26 (SP2)		x		39° 3' 21.40"	27° 4' 44,05"	14	4.0	2; 6
AD27 (SP3)		x		39° 3' 28,28"	27° 4' 48,14"	13	4.0	2; 6
AD28 (SP4)		x		39° 3' 30,23"	27° 4' 49,55"	13	4.0	2; 6
AD29		x		39° 0' 57.8"	27° 0' 30.6"	7	8.0	2
AD30		x		39° 0' 56.7"	27° 0' 32.2"	7	8.0	2
AD31 (SP5)			x	39° 3' 21,86"	27° 4' 52,04"	11	2.0	2; 6
AD32 (Sp6)			x	39° 3' 21,86"	27° 4' 51,71"	11	1.0	2; 6
AD33			x	39° 5' 33.0"	26° 56' 53.4"	24	8.0	2; 4
AD34			x	39° 4' 55.0"	26° 56' 20.9"	20	5.5	2; 4
AD35			x	39° 5' 23.9"	26° 56' 41.7"	20	6.0	2
AD36 (13)		x		39° 5' 15.0"	26° 56' 3.4"	24	3.7	2; 5
AD37 (14)		x		39° 5' 14.0"	26° 56' 5.3"	20	7.6	2; 5
AD38 (15)		x		39° 5' 11.7"	26° 56' 8.8"	19	8.0	2; 5
AD39	x			39° 3' 2.5"	27° 2' 33.7"	10	18.9	3
AD40	x			39° 3' 41.3"	27° 1' 10.4"	11	4.0	3
AD41	x			39° 3' 41.3"	27° 1' 10.4"	11	2.0	3
AD42	x			39° 3' 41.3"	27° 1' 10.4"	11	2.0	3
AD43	x			39° 1' 26.0"	26° 58' 26.6"	9	4.0	3
AD44	x			39° 1' 21.8"	26° 58' 30.4"	9	2.0	3
AD45		x		39° 2' 46.3"	27° 2' 3.4"	10	6.0	3
AD46		x		39° 2' 42.8"	27°2' 5.3"	10	6.0	3

[a] a.s.l. = above sea level; [b] b.s. = below surface; [c] 1: Schneider et al., 2010; 2: Schneider et al., 2011; 3: Schneider et al., 2012; 4: Schneider et al., 2013; 5: Schneider et al., 2014; 6: Schneider et al., in press; [d] in brackets = alternative number used for publication

4.4 Laboratory analyses

The sediments were analysed for the organic and inorganic carbon contents (Section 3.4.1), the pH value and the electrical conductivity of their solutes (Section 3.4.2), as well as the magnetic susceptibility (Section 3.4.3). Prior to chemical analyses, the samples were passed through a 2 mm sieve and dried at 105°C. For the determination of the carbon contents, the samples were additionally homogenised in a vibratory disc mill.

4.4.1 Carbon determination

The organic matter content of soils and sediments consists of dead and transformed remains of plants and animals (Hintermaier-Erhard and Zech, 1997). It is an important characteristic to identify the depositional environment of a sediment. Organic matter consists of approximately 50% carbon (= organic carbon). Thus, it is possible to approximately deduce the organic matter content from the total organic carbon content (Pribyl, 2010).

The enrichment of carbonate minerals in soils and sediments, such as calcite, magnesium carbonate or dolomite, gives evidence of processes, such as calcrete formation (Blume et al., 2002). One component of carbonate minerals - besides other elements such as calcium or magnesium - is inorganic carbon. Therefore, the total inorganic carbon content serves as an approximate measure for the carbonate content of soils and sediments (Dean, 1974; Santisteban et al., 2004).

Three methods were used to determine the carbon content of the samples. The total carbon content (TC) was in part measured with a LECO TruSpec CHN analyser (i) and in part with a Wösthoff Carmhograph C-16 (ii). All of the total inorganic carbon contents (TIC) were determined using a Wösthoff Carmhograph C-16. The total organic carbon (TOC) was calculated by subtraction of TIC from TC. TC and TIC measurements were not conducted for all samples. For the unmeasured samples, carbon contents were estimated through calibration of loss-on-ignition data (iii).

(i) *LECO TruSpec CHN analyser*. The total carbon content was analysed by detecting CO_2 flow by highly selective infrared (IR) and thermal conductivity (detection limit: 0.01 mass-%; Anonymous, 2011).

(ii) *Wösthoff Carmhograph C-16*. The total carbon content was determined using dry combustion at 1000°C in an oxygen atmosphere and subsequent quantification of the evolved CO_2 in 20 ml of a 0.05 N NaOH solution through conductivity (Blättermann et al., 2012). The total inorganic carbon content was analysed using an acid sample treatment (H_3PO_4) and conductometrically detected CO_2 flow (Blättermann et al., 2012).

Table 5
Calibration standards and detection limits of the Wösthoff Carmhograph C-16.

Measured value	Calibration standard	Relative standard deviation	Detection limit
TC	$CaCO_3$ (calcite), 12.01±0.15 mass-%	< 2 mass-%	0.01 mass-%
TIC	$CaCO_3$ (calcite), 12.01±0.38 mass-%	< 4 mass-%	0.01 mass-%

(iii) *Loss-on-ignition* was measured as described by Dean (1974). After oven-drying the sediment to a constant weight (12 h at 105°C), the samples were heated to 550°C and to 880°C for at least four hours in a muffle furnace. To calibrate the loss-on-ignition values, the carbon content that had been measured with the Wösthoff Carmhograph C-16 and the LECO TruSpec CHN analyser was used (Sutherland, 1998).

4.4.2 pH value and electrical conductivity of sediment solutes

The pH value is the negative logarithm of the hydrogen ion concentration in a solution (Allaby, 2008). As a measure of the basicity or acidity, the pH value affects the chemical, physical and biological properties of soils and sediments (Blume et al., 2002). The electrical conductivity of a soil or sediment solution depends on the ion conductivity, the ion concentration and the temperature. It is a measure of the concentration of ionisable dissolved substances and therefore indicates the salinity of a sediment (Barsch et al., 2000; Blume et al., 2002).
To determine the pH values, the samples were immersed in a 0.01 molar potassium chloride solution, and in ultrapure water to determine the electrical conductivity. The samples were measured using handheld devices (pH: Hanna instruments HI 98301; electrical conductivity: HI 98301; Anonymous, 2013a, b). The sediment:solution ratio was 1:2.5.

4.4.3 Magnetic susceptibility

Magnetic susceptibility measurements are a powerful tool to obtain information on various geoarchives, such as sediments and soils, but also archaeological sites. The measurements rely on the fact that materials react differently when exposed to a magnetic field, depending on the content of magnetisable material. Thus, for example, pedogenic iron oxides or oxides created by fire can be identified (Evans and Heller, 2003). The dimensionless magnetic volume susceptibility was measured using the Bartington Instruments MS2C system at 4-cm intervals on closed plastic tubes following the methodology of Dearing (1994).

4.5 Paleoecological analyses

From each outcrop and sediment core, a representative number of samples was analysed according to their microfaunistic (i) and macrofaunistic (ii) components. Furthermore, the pollen content of one sediment core was examined (iii).

(i) For microfaunistic analysis, the samples were immersed in water and passed through 630, 100 and 63 µm sieves. For clayey samples, sodium pyrophosphate ($Na_4P_2O_7$; 50 $g*l^{-1}$) was added as the dispersing agent. Finally, the 100 and 63 µm fractions were examined under a microscope. However, none of the samples contained identifiable microfossils.

(ii) Macroscopic analyses concentrated on the identification of *Bivalvia* and *Gastropoda*. The individuals were collected from the untreated samples. Species identification was conducted by Dipl.-Geol. Anna Pint (Institute of Geography, University of Cologne).

(iii) Profile AD24, a sediment core retrieved from a peat bog (see Table 4 and Schneider et al., 2011: 'Die vermoorten Thermalquellen bei Dikili'), was analysed for its pollen content. Pollen preparation and analysis were conducted by Dr. Frank Schlütz (Lower Saxony Institute for Historical Coastal Research, Wilhelmshaven). However, the small number of pollen and the poor state of conservation did not allow for the creation of a pollen diagram.

4.6 Dating

Samples of charred wood were prepared for AMS (accelerator mass spectrometry) radiocarbon dating (^{14}C) and measured at the Poznan Radiocarbon Laboratory. For the publications by Schneider et al., 2013 and Schneider et al., 2014, the AMS dates were calibrated with OxCal 4.1 (Bronk Ramsey, 2009) and the IntCal09 calibration curve (Reimer et al., 2009). The dates of the publication by Schneider et al. (in press) were calibrated with OxCal 4.2.3 (Bronk Ramsey, 2009) and the IntCal 13 calibration curve (Reimer et al., 2013). For a detailed description of the principles of choosing datable material see Sections 6.1-6.3.

Along with radiocarbon dating, depositional ages were derived from archaeological artefacts found within the sediments. The artefacts were identified and dated by Dr. Güler Ates and Dr. Barbara Horejs (Austrian Academy of Sciences, Vienna).

5. Field work reports

5.1 Summer 2009

Geoarchäologische Untersuchungen im westlichen Kaikostal 2009.

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In:

Pergamon – Bericht über die Arbeiten in der Kampagne 2009.

Pirson, Felix.

Archäologischer Anzeiger 2010 (02)

pp. 183-188

ISBN: 978-3-7774-3081-3
http://www.dainst.org/zeitschriften-alphabetisch
http://www.hirmerverlag.de/

5.2 Summer 2010

Geoarchäologische Untersuchungen im westlichen Kaikostal 2010.

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In:

Pergamon – Bericht über die Arbeiten in der Kampagne 2010.

Pirson, Felix.

Archäologischer Anzeiger 2011 (02)

pp. 160 - 166

ISBN: 978-3-7774-4881-7
http://www.dainst.org/zeitschriften-alphabetisch
http://www.hirmerverlag.de/

5.3 Summer 2011

Geoarchäologische Untersuchungen im westlichen Kaikostal 2011.

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In:

Pergamon – Bericht über die Arbeiten in der Kampagne 2011.

Pirson, Felix.

Archäologischer Anzeiger 2012 (02)

pp. 218 - 222

ISBN: 978-3-7774-5831-1
http://www.dainst.org/zeitschriften-alphabetisch
http://www.hirmerverlag.de/

6. Geoarchaeological case studies

6.1 Case study 1

Late Holocene human-environmental interactions in the Eastern Mediterranean: Settlement history and paleogeography of an ancient Aegaean hill-top settlement

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Quarternary International 324 (2014), pp. 84 - 98

http://dx.doi.org/10.1016/j.quaint.2013.05.023

Abstract

Interactions between settlement history and landscape evolution of a hill-top settlement on the West Anatolian Coast near ancient Pergamon (modern Bergama) were studied by a combination of archaeological and geographical investigations. Ceramics, ancient literary and epigraphic texts, numismatics and architectural remains show that the hill-top had been populated since late Bronze Age times. From the sixth century BC until the change of the eras, the hill was occupied by a Greek polis – Atarneus – and was abandoned afterwards. It was newly populated in the second half of the twelfth and the first half of the thirteenth century AD.

The lithostratigraphy of nine drilling cores, arranged in three transects and dated by AMS radiocarbon dating, shows that during the past 4000 years the sedimentary plains surrounding the settlement hill were aggraded by braided and meandering rivers, while colluviation and alluvial fan deposition occurred at the foot-slopes. Sedimentation totaled about 5–7 m in the past 4000 years, evidencing a „drowning“ of the landscape in terrestrial sediments. Although channels shifted repeatedly and alluvial fan deposition fluctuated, the depositional system did not change in general during the past 4000 years. This striking resistance to the changing settlement and land use intensity is an effect of the distinct modification of the slopes through terracing that countervailed erosion and likewise increased the buffering capacity of the sediment storages on the slopes. There is no evidence that landscape deterioration contributed to the abandonment of the settlement hill. Rather, socio-economic factors were crucial for the rise and fall of the settlements occupying the hill.

6.2 Case study 2

Alluvial geoarchaeology of a small drainage basin in western Anatolia: Late Holocene landscape development and the question of the mouth of the Paleo-Bakırçay

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Quarternary International 312 (2013), pp. 84 - 95

http://dx.doi.org/10.1016/j.quaint.2013.05.043

Abstract

Late Holocene landscape evolution in the Geyikli basin, a sub-catchment of the Bakırçay basin on the West Anatolian Coast, and its implications for the plaeogeography of the environs of ancient Pergamon (modern Bergama), were studied by a combination of archaeological and geographical investigations. The study aims to investigate whether the „Dörpfeld Scenario“ of the paleogeographical situation in the Lower Bakırçay valley is true or not. The scenario postulates that during the Late Holocene, an alluvial fan, fed from the Geyikli valley, progressively closed a topographical constriction between the Aegean Sea and a supposed paleo-gulf that occupied the Lower Bakırçay Valley. Initially, this caused the development of an inland lake, and finally the shift of the mouth of the Paleo-Bakırçay from a northern position to its modern southern position.

The lithostratigraphy of four sediment outcrops in the Lower Geyikli Basin and in the topographical constriction between the Aegean Coastal Plain and the Bakırçay valley shows that during the past ca. 1950 years, the Lower Geyikli Valley was inhabited by a braided river with a highly dynamic depositional system. Sedimentation totalled about 4–6 m in the past 1950 years, indicating a „drowning“ of the landscape in terrestrial sediments. In recent times, gravel mining has led to a deformation of the valley floor, and the Geyikli's fluvial terrace has become inactive. The lack of any sediment related to a Paleo-Gulf or a Paleo-Lake inside the Bakırçay Basin, as well as the lack of any sediments of a northern Paleo-Bakırçay, documents that the „Dörpfeld Scenario“ does not apply for the past 1950 years. Archaeological findings show that the Geyikli Basin was intensively settled in historic times, but there is no evidence that the Geyikli Basin was anthropogenically deformed in a way that could have contributed to the „Dörpfeld Scenario“.

6.3 Case study 3

A geoarchaeological case study in the chora of Pergamon, Western Turkey to reconstruct the late Holocene landscape development and settlement history

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Quarternary International (in press)

http://dx.doi.org/10.1016/j.quaint.2014.07.020

Abstract

This paper investigates the late Holocene landscape development and settlement history of the central Bakırçay valley (the ancient Kaikos valley) in western Turkey, which exemplifies a buried archaeological site approximately 12 km SW of Pergamon. A minimally intrusive geoarchaeological approach was applied by coupling an archaeological survey, geophysical exploration, geomorphological mapping and sedimentological analysis of drilling cores and pre-existing outcrops. The geomorphological and lith- ostratigraphical results imply that in the early and middle Holocene the site was situated on a deposi- tional piedmont plain that was protected from the annual Bakırçay floods. Over the past two millennia, the Bakırçay flood plain was gradually aggraded and the site became prone to flooding. Despite the limitations of non-intrusive archaeological investigations, three scenarios were developed on the func- tion and age of the buried site. Hence, the site was either a sanctuary from the 2nd century AD, a luxurious estate from the 4the8th century AD, or a lime kiln from late Antique/Byzantine times.

7. Concluding Remarks

Approximately 5000 years of landscape development and human-environmental interactions in the Bakırçay valley were investigated in this geoarchaeological study. This is a remarkably short period when compared to the more than 30 million years which formed the region since the area was elevated above sea level at the end of the Eocene (Section 2.2.2; Okay, 2008; Altunkaynak and Yilmaz, 1998). The primary tectonic structures, as well as the basic river systems, had been constituted already at the end of the Pliocene (2.6 Ma) (Erol, 1979; Kuzucuoğlu, 1995). At the end of the Pleistocene (11.7 ka BP), most of today's major landforms were clearly distinguishable. A prehistoric resident of the Aegean coast - if transferred to the modern Bakırçay valley - would most likely easily recognise the region. Therefore, regarded in the geological dimensions, the Bakırçay valley was only slightly modified during the Holocene.

Nevertheless, also the Holocene brought some remarkable landscape changes to the Bakırçay valley. Section 7.1 addresses the question of whether the region has to be regarded as a stable or a dynamic landscape during the late Holocene. In Section 7.2, the landscape changes are discussed in the wider context of established models of Holocene landscape change in the eastern Mediterranean. Finally, Section 7.3 compares the results of the study to the statements of the ancient authors and the reports of the late 19th and early 20th century, which have been presented in Sections 2.3.1 and 2.3.2.

7.1 The Holocene Bakırçay valley – dynamic or stable landscape?

The case studies allow the reconstruction of the middle to late Holocene landscape development for three compartments of the Bakırçay valley landscape: the volcanic hill Kale Ağılı, the Geyikli valley and the central Bakırçay valley. On one hand, the studies imply that landscape was stable during the middle and late Holocene on the regional scale:

- In the immediate surroundings of the volcanic hill Kale Ağılı, which was occupied by the Greek polis Atarneus in the last centuries before the turn of the eras, the sedimentation systems were constant in the past 4,000 years – despite dramatic increases and decreases in settlement activity. Meandering and braided rivers with frequently shifting channels occupied the valley floors and plains surrounding the hill. Alluvial fan deposition and colluviation was dominant on the slope toes. Only in most recent times, most likely due to flood protection and drainage measures, the valley floors became almost inactive, and alluviation strongly slowed down (Section 6.1).
- A braided river occupied the Geyikli valley floor throughout the past 2000 years. Fluvial aggradation most likely has only become inactive in most recent times. There is no evidence

that, in pre-modern times, a significant change in the landscape dynamics occurred (Section 6.2).

- In the central Bakırçay valley, around the archaeological site Teut114, constant fluvial aggradation by the Bakırçay led to the elevation of the flood plain level and the drowning of Pleistocene piedmonts during the middle and late Holocene. Along with the most recent drainage and flood protection measurements, the late Holocene sedimentation system has to be regarded as stable (Section 6.3).

On the other hand, the on-going subsidence of the Bakırçay graben (Section 3.2.2) and the continuous sedimentation led to a distinct modification of the relief on the local scale:

- On the slope toes and valley floors, the ancient land surface has drowned under a five to eight meter thick layer of younger sediments (Sections 6.1-6.3). Correspondingly, the elevated landforms in the mountainous hinterlands must have been worn down by erosion.
- The drowning of the slope toes led to an uphill shift of the borders between the alluvial plain, piedmont plains and mountainous hinterland. An impressive example is the site Teut114 (Section 6.3). In the first century AD, the site was in a flood-protected situation on a piedmont plain. Today, through fluvial aggradation, it has become part of the Bakırçay floodplain, and only modern drainage and flood protection measures prevent it from being affected by the seasonal Bakırçay floods.

In summary, it can be noted that the sedimentation systems of the Bakırçay valley and its surroundings seem to have been stable on the regional scale. Still, the constant erosion and sedimentation led to a modification of the landscape on the local scale. On the slope toes and valley floors, the ancient land surface is buried under a several meter thick cover of young sediments. Therefore, despite the stable landscape dynamics during the late Holocene, today's landscape cannot be taken as a reference for the original geomorphological situation of an archaeological site.

7.2 The case studies before the background of Holocene landscape change in the eastern Mediterranean

The eastern Mediterranean was the subject of intense landscape changes during the Holocene. In addition to the sea level rise after the last glacial maximum (i), temperature and precipitation (ii), as well as vegetation and land use changed (iii). Are the results of the case studies in agreement with the eastern Mediterranean trends?

(i) Most likely the biggest modification of the eastern Mediterranean region was the shift of the coastlines following the sea-level rise caused by the global warming (Vött and Brückner, 2006). Extended areas along the Aegean coast, which had been terrestric during the last glacial maximum,

drowned during the Holocene transgression (Perissoratis and Conispolatis, 2003). The coastline at the outlet of the Bergama graben moved to its present position, which is approximately 30 km further east than during the last glacial maximum (Aksu et al., 1987). Simultaneously, the erosional and depositional system of the coastal regions had to adapt to the new erosion base level.
Although the investigated areas are not in an immediate coastal position, the implications of the Holocene sea level rise are evident. The observed fluvial, alluvial and colluvial aggradation is the consequence of the adjustment of the sediment systems to the elevated erosion base level combined with the ongoing sinking of the Bergama Graben. Because of the lack of marine sediments, the case studies do not contribute to the reconstruction of the Holocene sea level changes and coastline shifts. Nonetheless, the investigation of the surroundings of Atarneus and the lower Geyikli valley (Schneider et al., 2013; 2014; Sections 5.1 and 5.2) exclude the existence of a gulf in the northern connection of the Bakırçay valley during the past two thousand years, approximately.

(ii) Variations in temperature and precipitation affected the Aegean coastal regions throughout the Holocene, although less severe than between the Last Glacial Maximum and the beginning of the Holocene (Dusar et al., 2011). During the late glacial, semi-arid and cool conditions prevailed. The early Holocene brought wetter and warmer conditions, until, after approximately 5 ka BP, a general aridisation trend dominated. Finally, the late Holocene was characterised by significant climate variability (Dusar et al., 2011; Finné et al., 2011).

The case studies show stable landscape dynamics during the past 4000 years and do not imply climate variations, which affected the depositional systems. However, the rather coarse resolution of the fluvial and alluvial sediments – if compared, for example, to the annually layered lake sediments investigated by Woodbridge and Roberts in central Turkey (2011) - as well as the rough resolution of the geochronological model, possibly obscure the effect of short term climate variations. In general, the results of the case studies are not in disagreement with the regional trends.

(iii) Vegetation in the eastern Mediterranean changed simultaneously with the Holocene climate. During the late glacial, open steppe vegetation dominated. Until the fourth millennium BP, the typical Mediterranean vegetation with a mixture of sclerophyllous forests, maquis, phrygana and steppe had been established (Grove and Rackham, 2003). Since the Bronze Age, anthropogenic influence, such as deforestation, agriculture and arboriculture, became more evident and had a first culmination during the Roman period (Dusar et al., 2011). During the early Byzantine period, anthropogenic influence declined and secondary woodlands were established. Finally, from the late Byzantine period, human land use increased again, until the second culmination in the modern period (Dusar et al., 2011).

The geoarchives, which were evaluated for the case studies, do not give direct information on the vegetation and land use in the Bakırçay valley because of the lack of macro- and microfossils. Additionally, the archaeological part of the studies does not allow quantitative or qualitative statements on the extent of the cultivated area during a select period or on the land use intensity.

Anyhow, it seems obvious that a simple model in which increased land use is necessarily connected to increased soil erosion does not apply for the Bakırçay valley. The study of the hill Kale Ağılı and the ancient polis Atarneus demonstrates that the immediate surroundings of the hill were not the subject of a landscape change during the Holocene – despite the variations in settlement activities and land use. In particular, the example of the alluvial fan (Section 6.1: cross profile two) between the city hill and the necropolis hill of Atarneus demonstrates that increased settlement activities are not necessarily connected with increased soil erosion. The sedimentation in the alluvial fan was almost unchanged throughout the past three millennia, approximately, although Kale Ağılı changed from a natural condition to a densely populated polis and back to unpopulated (Section 6.1). It is undisputed that the settlement activity modified the erosion on Kale Ağılı. However, the terracing of the settlement hill countervailed the increased erosion and therefore affected the stability of the sediment system at the foot slope of the volcanic hill.

7.3 The study results in comparison with Ancient and 19th century reports

7.3.1 Ancient authors vs. this study's results

Summing up the select excerpts from ancient texts (Section 2.3.1), it may be concluded that the ancient authors do not describe the Bakırçay valley in detail. Often, events in another place are described and then transferred to the Bakırçay valley in a short subordinate clause without further explanation (e.g., Pausanias Periegetes VII, 2, 11, see Jones, 1933). However, the authors consistently describe the Bakırçay valley as a landscape, which is affected by landscape changes.

Herodotus (Herodotus II, 10; see Godley, 1920) and Pausanias Periegetes (Pausanias Periegetes VII, 2, 11; see Jones, 1933) both mention that the Bakırçay valley was once a gulf, which had been silted up. Pausanias even states that the polis Atarneus had to be abandoned because of a mosquito plague following this process. Furthermore, Strabo's enumerative descriptions of the Bakırçay valley are only consistent if there was a gulf inside the Bakırçay valley and its northern connection with the Aegean Sea (Section 2.3.3; Dörpfeld, 1910, 1911, 1912, 1928).

This study brought no evidence that the Bakırçay valley was once a gulf (Schneider et al., 2013; Section 6.2). However, only the northern connection of the Bakırçay valley was investigated, and the statements only apply for the past two millennia, approximately. Therefore, it is still possible that there was a gulf within the Bakırçay valley and the northern passage before 2 ka BP, or that there was a gulf with a southern connection to the Aegean Sea.

Opposite to this, the study could prove that Atarneus was not abandoned because of landscape deterioration, but rather because of socio-economic factors (Section 6.1). Whether Pausanias Periegetes made a mistake, or if there was another city called Atarneus, remains speculation at this point. Because this study's main focus is sedimentological-paleogeographical, this question shall not be discussed here but shall be left for philologists and historians to investigate.

7.3.2 The landscape around 1900 and the modern landscape – a comparison

The researchers of the late 19th and early 20th century found a landscape that was, in many ways, different from today's (Section 2.3.2). The infrastructure was poor and flood protection measures preventing the flooding of the plains by the Bakırçay were hardly developed. The Bakırçay and its tributaries flooded huge parts of the plain during winter and spring (Lolling, 1879; Von Diest, 1889). The Bakırçay valley as a cultural landscape was already well developed, although its appearance was remarkable different from the modern one. The mountains were mostly deforested and used as grazing land (Lolling, 1879; Curtius, 1872). Today, these areas are either forested or covered by maquis or phrygana. Due to a change in the land use in the past decades, the natural vegetation of this area has apparently partly recovered.

The landscape changes of the past approximately 100 years, including the implementation of new agricultural techniques, flood protection measures as dams and water reservoirs, the expansion of infrastructure and settlements, seem in many ways to be more severe than the summed up landscape changes of the prior two millennia. Only the landscape changes through alluvial and fluvial aggradation seem to have become nearly inactive due to the regulation of the streams and the measurements against flooding of the valley floors.

References

Ad-Hoc-AG Boden, 2005. Bodenkundliche Kartieranleitung. Schweizerbart, Stuttgart.

Agostini, S., Tokcaer, M., Savascin, M.Y., 2010. Volcanic rocks from Foça–Karaburun and Ayvalık–Lesvos grabens (Western Anatolia) and their petrogenic–geodynamic significance. Turkish Journal of Earth Sciences 19, 157-184.

Aitken, M., 1974. Physics and Archaeology. Clarendon Press, Oxford.

Allaby, M. (Ed.), 2008. Dictionary of Earth Sciences. Oxford University Press, Oxford.

Akbulut, N., Şahin, Y., Bayarı, S., Akbulut, A., 2008. Rivers of Turkey. In: Tockner, K.,Uehlinger, U., Robinson, C. (Eds.). Rivers of Europe. Elsevier, Oxford, pp. 643-672.

Aksu, A.E., Piper, D., Konuk, T., 1987. Late Quaternary tectonic and sedimentary history of outer Izmir and Çandarlı Bays, Western Turkey. Marine Geology 76, 89–104.

Alcock, S., Cherry, J., Davis, J., 1995. Intensive survey, agricultural practice and the classical landscape of Greece. In: Morris, I. (Ed.). Classical Greece. Cambridge University Press, Cambridge, pp. 137-170.

Allen, H., 2009. Vegetation and Ecosystem Dynamics. In: Woodward, J. (Ed.). The Physical Geography of the Mediterranean. Oxford University Press, Oxford, pp. 203-229.

Altunkaynak, Ş., Yilmaz, Y., 1998. The Mount Kozak magmatic complex, Western Anatolia. Journal of Volcanology and Geothermal Research 85, 211–231.

Ambraseys, , N., Jackson, J., 1998. Faulting associated with historical and recent earthquakes in the Eastern Mediterranean region. Geophysical Journal International 133, 390-406.

Ambraseys, N., 2008. Descriptive catalogues of historical earthquakes in the Eastern Mediterranean and the Middle East; Revisited. In: Fréchet, J., Meghraoui, M., Stucchi, M. (Eds.). Historical Seismology. Modern Approaches in Solid Earth Sciences 2. Springer, Dordrecht, pp. 25-39.

Anonymus, 1986. Soviet Military Topographic Map 1:50.000 – Sheet J35-30-Г. Office of Geodesy and Cartography of the USSR, Moscow.

Anonymous, 1987. Soviet Military Topographic Map 1:50.000 – Sheet J35-31-B. Office of Geodesy and Cartography of the USSR, Moscow.

Anonymous, 2011. TruSpecCHN/CHNS Carbon/Hydrogen/Nitrogen/Sulfur Determinators – Instruction Manual. Leco Corporation, St. Joseph.

Anonymous, 2013a. HI 98127 / 98128 instruction manual. Hanna Instruments, Smithfield.

Anonymous, 2013b. EC and TDS Testers with ATC. Hanna Instruments, Smithfield.

Ateş, G. (in press). Katalog der Fundkeramik. In: Matthaei, A., Zimmermann, M. (Eds.), Der Survey im Umland von Pergamon. Altertümer von Pergamon.

Aydar, E., 1998. Early Miocene to Quaternary evolution of volcanism and the basin formation in western Anatolia: a review. Journal of Volcanology and Geothermal Research 85, 69-82.

Badian, E., 2006. Nearchus. Cancik, H., Schneider, H. (Eds.). Brill Online: Brill's New Pauly. http://referenceworks.brillonline.com/entries/brill-s-new-pauly/nearchus-e818750. First appeared online 2006, accessed 24 March 2014.

Barsch, H., Billwitz, K., Bork, H., 2000. Arbeitsmethoden in Physiogeographie und Geoökologie. Klett-Perthes, Gotha.

Bauer, G., Wächtler, K. (Eds.), 2001. Ecology and Evolution of the Freshwater Mussels Unionoida. Springer, Berlin.

Bintliff, J., 2002. Time, process and catastrophism in the study of Mediterranean alluvial history: a review. World Archaeology 33 (3), 417-435.

Bittel, K., 1950. Zur ältesten Besiedlungsgeschichte der unteren Kaikos-Ebene. Istanbuler Forschungen 17, 10-29.

Blättermann, M., Frechen, M., Gass, A., Hoelzmann, P., Parzinger, H., Schütt, B., 2012. Late Holocene landscape reconstruction in the Land of Seven Rivers, Kazakhstan. Quaternary International 251, 42-51.

Blott, S., Pye, K., 2001. GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surface Processes and Landforms 26, 1237-1248.

Blume, H., Brümmer, G., Schwertmann, U., Horn, R., Kögel-Knabner, I., Stahr, K., Auerswald, K., Beyer, L., Hartmann, A., Litz, N., Scheinost, A., Stanjek, H., Welp, G., Wilke, B., 2002. Scheffer / Schachtschabel – Lehrbuch der Bodenkunde. Spektrum, Heidelberg.

Böckh, A., 1853. Hermias von Atarneus und Bündnis desselben mit den Erythräern. In: Böckh, A., Ascherson, F., Eichholtz, P., Bratuscheck, E. (Eds.). August Böckh's Gesammelte Kleine Schriften VI. B.G. Teubner, Leipzig, pp. 185-210.

Bork, H., Bork., H., Dalchow, C., Faust, B., Piorr, H., Schatz, T., 1998. Landschaftsentwicklung in Mitteleuropa. Klett-Perthes, Gotha.

Boyer, P., Roberts, N., Baird, D., 2006. Holocene environment and settlement on the Çarşamba alluvial fan, south-central Turkey: Integrating geoarchaeology and archaeological field survey. Geoarchaeology 21, 675–698.

Buisson, E., 1917. Die äolische Westküste Kleinasiens in Strabons Erdbeschreibung. Noske, Leipzig.

Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. Radiocarbon 51 (1), 337-360.

Brown, A., 1992. Slope erosion and colluviation at the floodplain edge. In: Bell, M., Boardman, J. (Eds.). Past and Present Soil Erosion. Oxbow Books, Oxford , pp. 77-87.

Brown, A., 1997. Alluvial Geoarchaeology. Cambrdige University Press, Cambridge.

Brownson, C., 1918. Xenophon: Hellenica I, Books I-IV. Loeb Classical Library, London.

Brownson, C., 1932. Xenophon: Anabasis. Loeb Classical Library, London.

Brownson, C., Todd, O., 1922. Xenophon Anabasis, Books IV-VII and Symposium and Apology. Loeb Classical Library, London.

Brückner, H., 1996. Geoarchäologie an der türkischen Ägäisküste. Geographische Rundschau 48 (1), 568-574.

Brückner, H., 1998. Coastal research and geoarchaeology in the Mediterranean region. In: Kelletat, D. (Ed.). German geographical coastal research – the last decade. Institute for scientific cooperation, Tübingen, pp. 235-257.

Brückner, H., 2003. Delta evolution and culture – aspects of geoarchaeological research in Miletos and Priene. In: Wagner, G. Pernicka, E., Uerpmann, H. (Eds.). Troia and the troad. Springer, Berlin, pp. 121-142.

Brückner, H., Vött, A., Schriever, A., 2005. Holocene delta progradation in the eastern Mediterranean – case studies in their historical context. Méditerranée 104, 95-106.

Brückner, H., Müllenhoff, M., Gehrels, R., Herda, A., Knipping, M. Vött, A., 2006. From archipelago to floodplain – geographical and ecological changes in Miletus and ist environs during the past six millennia (Western Anatolia, Turkey). Zeitschrift für Geomorphologie N.F 142, 63-83.

Brückner, H., Gerlach, R., 2007. Geoarchäologie. In: Gebhardt, H., Glaser, R., Radtke, U., Reuber, P., (Eds.). Geographie. Spektrum, Heidelberg.

Brückner, H., Kelterbaum, D., Marunchak, O., Porotov, A., Vött, A., 2010. The Holocene sea level story since 7500 BP – Lessons from the Eastern Mediterranean, the Black and the Azov Seas. Quaternary International 225, 160-179.

Bull, W., 1977. The alluvial-fan environment. Progress in Physical Geography 1 (2), 222-270.

Cavazza, W., Roure, F., Ziegler, P., 2004. The Mediterranean Area and the Surrounding Regions: Active Processes, Remnants of Former Tethyan Oceans and Related Thrustbelts. In: Cavazza, W., Roure, F., Spakman, W., Stampfli, G., Ziegler, P. (Eds.). The TRANSMED Atlas – The Mediterranean Region from Crust to Mantle. Springer, Berlin.

Chen, X., Bowler, J., Magee, J., 1991. Aeolian landscapes in central Australia: gypsiferous and quartz dune environments from Lake Amadeus. Sedimentology 38, 519-538.

Conze, A., 1887. Teuthrania. Athenische Mitteilungen 12, 149-160.

Curtius, E., 1872. Beiträge zur Geschichte und Topographie Kleinasiens. Abhandlungen der Königlichen Akademie der Wissenschaften zu Berlin 94.

Dean, W., 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: comparison with other methods. Journal of Sedimentary Petrology 44 (1), 242-248.

Dearing, J., 1994. Environmental magnetic susceptibility: Using the Bartington MS2 System. Chi Publishing, Kenilworth.

Dilek, Y., 2006. Collision tectonics of the Mediterranean region: Causes and consequences. Geological Society of America Special Papers 409, 1–13.

Donohue, A., 2006. Pausanias. Cancik, H., Schneider, H. (Eds.). Brill Online: Brill's New Pauly. http://referenceworks.brillonline.com/entries/brill-s-new-pauly/pausanias-e910750. First appeared online 2006, accessed 24 March 2014.

Dörpfeld, W., 1910. Die Arbeiten zu Pergamon 1908-1909. Athenische Mitteilungen 35, 345-399.

Dörpfeld, W. 1911. Zum Elaitischen Golf. Hermes 46, 444-457.

Dörpfeld, W. 1912. Die Arbeiten zu Pergamon 1910-1911. Athenische Mitteilungen 37, 233-276.

Dörpfeld, W., 1928. Strabon und die Küste von Pergamon. Athenische Mitteilungen 53, 117-159.

Driehaus, J., 1957. Prähistorische Siedlungsfunde in der unteren Kaikosebene und an dem Golfe von Çandarlı. Istanbuler Mitteilungen 7, 76-101.

Dunne, L., Hempton, M., 1984. Deltaic sedimentation in the Lake Hazar pull-apart basin, south-eastern Turkey. Sedimentology 31, 401-412.

Dusar, B., Verstraeten, G., Notebaert, B., Bakker, J., 2011. Holocene environmental change and its impact on sediment dynamics in the Eastern Mediterranean. Earth-Science Reviews 108, 137–157.

Eichholz, D., 1962. Pliny: Natural History X, Books 37-38. Loeb Classical Library, London.

Emre, Ö., Özalp, S., Dogan, A., Özaksoy, V., Yildirim, C., Göktas, F., 2005. Izmir yakın Çevresinin diri fayları ve deprem potansiyelleri (Active faults and earthquake potential in the Izmir region). Maden tetkik ve arama genel müdürlüğü (Ed.), MTA Rapor No: 10754.

Eren, M., Kadir, S., Hatipoğlu, Z., Gül, M., 2008. Quaternary Calcrete Development in the Mersin Area, Southern Turkey. Turkish Journal of Earth Sciences 17, 763-784.

Erlat, E., 2007. Climatic conditions in Altınova and the Madra River Delta. In: Lambrianides, K., Spencer, N. (Eds.). The Madra River Delta: Regional Studies on the Aegean Coast of Turkey. The British Institute at Ankara, London, pp. 51-59.

Erol, O., 1975. Ayvalık Güneyi-Altınova çevresinde Madra Çayı deltasının holosen birikintileri ve deltanın gelnşim safhaları (The Holocene deposits and the development of the Madra Çayı Delta, on the Anatolian coast of the north Aegean Sea near Ayvalık-Altınova). Coğrafya Araştırmaları Dergisi 7, 1-43.

Erol, O., 1979. The Neogene and Quaternary erosion cycles of Turkey in relation to the erosional surfaces and their correlated sediments. Jeomorfoloji Dergisi 8, 1-40.

Erol, O., 1983. Die naturräumliche Gliederung der Türkei. Beihefte zum Tübinger Atlas des Vorderen Orients A (13). Reichert, Wiesbaden.

Evans, M., Heller, F., 2003. Environmental maganetism. Academic Press, San Diego.

Fassbinder, J., 2007. Unter Acker und Wadi: Magnetometerpropektion in der Archäologie. In: Wagner, G. (Ed.), Einführung in die Archäometrie. Springer, Berlin, 51-73.

Finné, M., Holmgren, K., Sundqvist, H. S., Weiberg, E., Lindblom, M., 2011. Climate in the eastern Mediterranean, and adjacent regions, during the past 6000 years – A review. Journal of Archaeological Sciences 38, 3153-3173.

Folk, R., Ward, W., 1957. Brazos River bar: a study in the significance of grain size parameters. Journal of Sedimentary Petrology 27, 3-26.

Foxhall, L., 1996. Feeling the earth move: cultivation techniques on steep slopes in classical antiquity. In: Shapley, G., Salmon, J. (Eds.), Human Landscapes in Classical Antiquity: Environment and Culture. Routledge, London, pp. 44-67.

Frank, C., 1987. Aquatische und terrestrische Mollusken (Gastropoda et Bivalvia) aus Nordost-, Ost- und Südostspanien sowie von der Insel Mallorca (Balearen). Linzer biologische Beiträge 19 (1), 57-90.

Fuchs, M., Will, M., Kunert, E., Kreutzer, S., Fischer, M., Reverman, R., 2011. The temporal and spatial quantification of Holocene sediment dynamics in a meso-scale catchment in northern Bavaria, Germany. The Holocene 21 (7), 1093-1104.

Garbrecht, G., 2003. Erdbeben in der Wasserversorgungsgeschichte Pergamons. In: Ohlig, C. (Ed.), Wasserhistorische Forschungen: Schwerpunkt Antike. Schriften der Wasserhistorischen Gesellschaft 2, pp. 119-133.

Glaubrecht, M., 1993. Mapping the diversity: geographical distribution of the freshwater snail Melanopsis (Gastropoda: Cerithioidea: Melanopsidae) with focus on its systematics in the Mediterranean Basin. Mitteilungen Hamburger Zoologisches Museum und Institut 90, 41-97.

Godley, A., 1920. Herodotus – The Persian Wars Books I-II. Loeb Classical Library, London.

Godley, A., 1922. Herodotus – The Persian Wars Books V-VII. Loeb Classical Library, London.

Godley, A., 1925. Herodutus – The Persian Wars Books VIII-IX. Loeb Classical Library, London.

Grove, A., Rackham, O., 2003. The Nature of Mediterranean Europe: An Ecological History. Yale University Press, New Haven.

Grüner, A. Teuthrania. In: Matthaei, A., Zimmermann, M. (Eds.), Der Survey im Umland von Pergamon. Altertümer von Pergamon (in press).

Halfmann, 2003. Stadttypologien im römischen Kleinasien: Pergamon und Ephesos als Modell. Asia Minor Studien 50, 111-126.

Harding, A., Palutikof, J., Holt, T., 2009. The Climate System. In: Woodward, J. (Ed.). The Physical Geography of the Mediterranean. Oxford University Press, Oxford, pp. 69-88.

Hasewaga, K., 1989. Studies on Qualitative and Quantitative Prediction of Meander Channel Shift. In: Ikeda, S., Parker, G. (Eds.), River Meandering. American Geophysical Union, Washington, pp. 215-236.1

Hertel, D., 2011. Das vorklassische Pergamon und sein Siedlungsprofil. Istanbuler Mitteilungen 61, 21-84.

Hintermaier-Erhard, G., Zech, W., 1997. Wörterbuch der Bodenkunde. Ferdinand Enke, Stuttgart.

Horejs, B., 2010a. Bronzezeitliche Besiedlungsmuster im Kaikostal. Interpretationen erster Surveyergebnisse im Umland von Pergamon (Türkei). In: Horejs, B., Kienlin, T. (Eds.). Siedlung und Handwerk – Studien zu sozialen Kontexten in der Bronzezeit. Universitätsforschungen zur prähistorischen Archäologie 194, pp. 47–67.

Horejs, B., 2010b. Yeni Yeldegirmentepe. In: Pirson, F., Pergamon – Bericht über die Arbeiten in der Kampagne 2009. Archäologischer Anzeiger 2010 (2), pp. 164-168.

Horejs, B., 2011. Prähistorische Surveys am Yeni Yeldegirmentepe und im Umland von Pergamon. In: Pirson, F., Pergamon – Bericht über die Arbeiten in der Kampagne 2010. Archäologischer Anzeiger 2011 (2), pp. 146-150.

Horejs, B., 2012. Der prähistorische Umlandsurvey. In: Pirson, F., Pergamon – Bericht über die Arbeiten in der Kampagne 2010. Archäologischer Anzeiger 2012 (2), pp. 204-208.

Hughes, D., Lewin, J., 1982. A small scale flood plain. Sedimentology 29, 891-895.

Hutchinson, M. F., 1989. A new procedure for gridding elevation and stream line data with automatic removal of spurious pits. Journal of Hydrology 106, 211-232.

Jahn, R., 2000. Die Böden der Winterfeuchten Subtropen. Geographische Rundschau 52 (10), 28-33.

Jarvis A., Reuter, H., Nelson, A., Guevara, E., 2008. Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org.

Jeckelmann, C., 1996. Genese lokaler Thermalwasservorkommen in der Region Bergama / W-Türkei. Ph.D. Thesis, Eidgenössische Technische Hochschule Zürich, Suisse.

Jones, H., 1930. The Geography of Strabo 7, Books 15-16. Loeb Classical Library, London.

Jones, H., 1960. The Geography of Strabo 6, Books 13-14. Loeb Classical Library, London.

Jones, H., 1961. The Geography of Strabo 5, Books 10-12. Loeb Classical Library, London.

Jones, W., 1933. Pausanias: Description of Greece 3, Books 6-8.21. Loeb Classical Library, London.

Kadioğlu, M., Tulunay, Y., Borhan, Y., 1999. Variability of Turkish precipitation compared to El Niño Events. Geophysical Research Letters 26 (11), 1597-1600.

Kahya, E., Kalaycı, S., 2004. Trend analysis of streamflow in Turkey. Journal of Hydrology 289, 128-144.

Kästner, U., 2011. 'Ein Werk, so groß und herrlich … war der Welt wiedergeschenkt!' – Geschichte der Ausgrabungen in Pergamon bis 1900. In: Grüßinger, R., Kästner, V., Scholl, A. (Eds.). Pergamon – Panorama der antiken Metropole. Michael Imhof, Petersberg, pp. 36-44.

Kauth, C. (in press). Katalog der Steinfunde. In: Matthaei, A., Zimmermann, M. (Eds.), Der Survey im Umland von Pergamon. Altertümer von Pergamon.

Kayan, I., 1995. The Troia Bay and supposed harbor sites in the Bronze Age. Studia Troica 5, 211-235.

Kayan, I., 1996. Holocene stratigraphy of the lower Karamenderes-Dümrek plain and archeological material in the alluvial sediments in the north of the Troia ridge. Studia Troica 6, 239-249.

Kayan, I., 1999. Holocene stratigraphy and geomorphological evolution of the Aegean coastal plains of Anatolia. Quaternary Science Reviews 18, 541–548.

Kayan, I., Öner, E., 2007. Alluvial geomorphology and paleogeography of the Yeldegirmeni mound and its environs. The Madra River Delta: Regional Studies on the Aegean Coast of Turkey. The British Institute at Ankara, London, pp. 31-37.

Kayan, I., Vardar, S., 2007a. The physical geography of the Madra River Delta. In: Lambrianides, K., Spencer, N. (Eds.). The Madra River Delta: Regional Studies on the Aegean Coast of Turkey. The British Institute at Ankara, London, pp. 23-30.

Kayan, I., Vardar, S., 2007b. Geomorphological formation and development of the delta plain of the Madra River. Lambrianides, K., Spencer, N. (Eds.). The Madra River Delta: Regional Studies on the Aegean Coast of Turkey. The British Institute at Ankara, London, pp. 9-21.

Kazancı, N., Dündar, S., Alçiçek, M. C., Gürbüz, A., 2009. Quaternary deposits of the Büyük Menderes Graben in western Anatolia, Turkey: Implications for river capture and the longest Holocene estuary in the Aegean Sea. Marine Geology 26 (4), 165-176.

Kenney, E., 2006. Ovidius Naso, Publius. Cancik, H., Schneider, H. (Eds.). Brill Online: Brill's New Pauly.
http://referenceworks.brillonline.com/entries/brill-s-new-pauly/ovidius-naso-publius-e902670.
First appeared online 2006, accessed 24 March 2014.

Kern, O., 1903. Curtius, Ernst. In: Historische Kommission bei der Bayerischen Akademie der Wissenschaften 47 (Ed.). Allgemeine Deutsche Biographie 47, pp. 580-597.

Kesgin, B., Nurlu, E., 2009. Land cover changes on the coastal zone of Çandarlı Bay, Turkey using remotely sensed data. Environmental Monitoring and Assessment 157, 89-96.

Ketin, I., 1948a. Die großen anatolischen Erdbeben in den letzten zehn Jahren. Urania-Magazin 11, 230–235.

Ketin, I., 1948b. Über die tektonisch-mechanischen Folgerungen aus den großen anatolischen Erdbeben des letzten Dezenniums. Geologische Rundschau 36, 77–83.

Khadkikar, A., Merh, S., Malik, J., Chamyal, L., 1998. Calcretes in semi-arid alluvial systems: formative pathways and sinks. Sedimentary Geology 116, 251-260.

Kiliçaslan, I., Özbek, M., 2010. Contributions to the knowledge on the distribution of freshwater Mollusca species of Turkey. Review of Hydrobiology 3(2), 127-144.

Knipping, M., Müllenhoff, M., Brückner, H., 2008. Human induced landscape changes around Bafa Gölü (western Turkey). Vegetation History and Archaeobotany 17, 365-380.

Kraft, J., Rapp, G., Kayan, I., Luce, J., 2003. Harbor areas at ancient Troy: Sedimentology and geomorphology complement Homer's Iliad. Geology 31 (2), 163-166.

Kraft, J., Brückner, H., Kayan, I., Engelmann, H., 2007. The geographies of ancient ephesus and the Artemision in Anatolia. Geoarchaeology 22 (1), 121-149.

Kraft, J.C., Rapp, G., Brückner, H., Kayan, I., 2011. Results of the Struggle at Ancient Ephesus: Natural Processes 1, Human Intervention 0. Geological Society, London, Special Publications 352, 27-36.

Kuhnen, H., 2008. Water archaeology indicating changes on landscapes: the Mid-Rhine example. Veröffentlichungen aus dem Deutschen Bergbau-Museum Bochum 161, 355-367.

Kürschner, H., Raus, T., Vetter, J., 1995. Pflanzen der Türkei: Ägäis – Taurus – Inneranatolien. Quelle & Meyer, Wiesbaden.

Kuzucuoğlu, C., 1995. River response to Quaternary tectonics with examples from northwestern Anatolia, Turkey. In: Lewin, J., Macklin, M., Woodward, J. (Eds.). Mediterranean Quaternary River Environments. Balkema, Rotterdam, pp. 45–53.

Lambrianides, K., 1992. Preliminary survey and core sampling on the Aegean coast of Turkey. Anatolian Studies 42, 75-78.

Lambrianides, K., 1993. Preliminary survey and core sampling of the Madra Çay delta at Altınova, near Ayvalık. Araştırma Sonuçları Toplantısı 10, 227-230.

Leaf, W., 1923. Strabo on the troad. Cambridge University Press, Cambridge.

Leeder, M., 1982. Sedimentology: Process and Product. Springer, London.

Leser, H., Stäblein, G., 1980. Legende der Geomorphologischen Karte 1:25 000 (GMK 25). 3. Fassung im GMK-Schwerpunktprogramm. In: Barsch, D., Liedtke, H. (Eds.). Methoden und Anwendbarkeit geomorphologischer Detailkarten. Berliner Geographische Abhandlungen 31, 91-100.

Lionello, P., Malanotte-Rizzoli, P., Boscolo, R., Alpert, P., Artale, V., Li, L., Luterbacher, J., May, W., Trigo, R., Tsimplis, M., Ulbrich, U., Xoplaki, E., 2006. The Mediterranean climate: an overview of the main characteristics and issues. Development in Earth and Environmental Sciences 4, 1-26.

Llasat, M. C., Llasat-Botija, M., Prat, M. A., Porcú, F., Price, C., Mugnai, A., Lagouvardos, K., Kotroni, V., Katsanos, D., Michaelides, S., Yair, Y., Savvidou, K., Nicolaides, K., 2010. High-impact floods in the Mediterranean countries: the FLASH preliminary database. Advances in Geosciences 23, 47-55.

Lolling, H., 1879. Atarneus. Mitteilungen des Deutschen Archäologischen Instituts Athenische Abteilung 4, 1-10.

Marriner, N., Morhange, C., 2007. Geoscience of ancient Mediterranean harbours. Earth-Science Reviews 80, 137-194.

Matthaei, A., in press. Fundstellen in der westlichen Kaikosebene und deren Randbereichen. In: Matthaei, A., Zimmermann, M. (Eds.), Der Survey im Umland von Pergamon. Altertümer von Pergamon.

Mehmel, A., 2001. Alfred Philippson. In: Historische Kommission bei der Bayerischen Akademie der Wissenschaften (Ed). Neue deutsche Biographie 20. Duncker & Humboldt, Berlin, pp. 399-400.

Meister, K., 2006. Herodotus. Cancik, H., Schneider, H. (Eds.). Brill Online: Brill's New Pauly. http://referenceworks.brillonline.com/entries/brill-s-new-pauly/herodotus-e511320. First appeared online 2006, accessed 24 March 2014.

Miall, A., 1977. A review of the Braided-River Depositional Environment. Earth-Science Reviews 13, 1-62.

Miall, A., 1985. Architectural-element analysis: A new method of facies analysis applied to fluvial deposits. Earth Science Reviews 22 (4), 261-308.

Mills, H., 1979. Downstream rounding of pebbles – a quantitative Review. Journal of Sedimentary Petrology 49 (1), 295-302.

More, Brookes, 1922. Ovid. Metamorphoses. Cornhill Publishing, Boston.

Morhange, C., Salamon, A., Bony, G., Flaux, C., Galili, E., Goiran, J., Zviely, D., 2014. Geoarchaeology of tsunamis and the revival of neo-catastrophism in the Eastern Mediterranean. Roma 'La Sapienza' Studies on the Archaeology of Palestine & Transjordan 11, 61-81.

Mouahid, A., Idaghdour, M., Ghamizi, M., Moné, H., 1996. Observation of spawn in Melanopsis praemorsa (Prosobranchia: Melanopsidae). Journal of Molluscan Studies 62, 398–402.

Müllenhoff, M., 2005. Geoarchäologische, sedimentologische und morphodynamische Untersuchungen im Mündungsgebiet des Büyük Menderes. Marburger Geographische Schriften 141.

Okay, A.I., 2008. Geology of Turkey: A synopsis. Anschnitt 21, 19–42.

Oldfather, C., 1950. Diodorus Siculus - Library of History Volume V. Loeb Classical Library, London.

Özürlan, G., Candansayar, M., Şahin, M., 2006. Deep resistivity structure of the Dikili-Bergama region, west Anatolia, revealed by two-dimensional inversion of vertical electrical sounding data. Geophysical Prospecting 54, 187–197.

Peel, M., Finlayson, B., McMahon, T., 2007. Updated world map of the Köppen-Geiger climate classification. Hydrology and Earth System Sciences 11, 1633-1644.

Perissoratis, C., Conispoliatis, N., 2003. The impacts of sea-lvel changes during the latest Pleistocene and Holocene times on the morphology of the Ionian and Aegean Seas (SE Alpine Europe. Marine Geology 196, 145-156.

Philippson, A., 1910. Reisen und Forschungen im westlichen Kleinasien. Petermanns Mitteilungen Ergänzungsband 36 (167).

Philippson, A., 1911. Zur Geographie der Unteren Kaikosebene in Kleinasien. Hermes 46, 254-260.

Philippson, A., 1912. Die Landschaft von Pergamon. Altertümer von Pergamon 1 (1), 43-59.

Pickett, E., Robertson, A., 1996. Formation of the Late Palaeozoic–Early Mesozoic Karakaya Complex and related ophiolites in NW Turkey by Palaeotethyan subduction–accretion. Journal of the Geological Society 153 (6), 995-1009.

Pirson, F., 2009. Pergamon - Bericht über die Arbeiten in der Kampagne 2008. Archäologischer Anzeiger 2009 (2), 168-174.

Pirson, F., 2010. Pergamon – Bericht über die Arbeiten in der Kampagne 2009. Archäologischer Anzeiger 2010 (2), 139-236.

Pirson, F., 2011. Pergamon – Bericht über die Arbeiten in der Kampagne 2010. Archäologischer Anzeiger 2011 (2), 81-212.

Pirson, F., 2012. Pergamon – Bericht über die Arbeiten in der Kampagne 2011. Archäologischer Anzeiger 2012 (2), 175-274.

Pirson, F., Zimmermann, M., 2011. Das Umland von Pergamon - Wirtschaftliche Ressourcen, ländliche Siedlungen und politische Repräsentation. In: Kästner, V., Scholl, A., Geske, I., Grüßinger, R., Laurentius, J. (Eds.). Pergamon: Panorama der antiken Metropole. Imhof, Petersberg. Berlin 2011, pp. 58-65.

Polat, O., Goek, E., Yilmaz, D., 2008. Earthquake hazard of the Aegean extension region (west Turkey). Turkish Journal of Earth Sciences 17, 593–614.

Pope, K., Van Andel, T., 1984. Late Quaternary alluviation and soil formation in the Southern Argolid: its History, Causes and Archaeological Implications. Journal of Archaeological Science 11, 281-306.

Pribyl, D., 2010. A critical review of the conventional SOC to SOM conversion factor. Geoderma 156 (3-4), 75-83.

Price, S., Nixon, L., 2005. Ancient Greek Agricultural Terraces: Evidence from Texts and Archaeological Survey. American Journal of Archaeology 109 (4), 665-694.

Rackham, O., Moody, J., 1990. Terraces. In: Wells, B. (Ed). Agriculture in ancient Greece. Proceedings of the Seventh International Symposium at the Swedish Institute at Athens, 16-17 May, 1990. Astrom, Stockholm, pp. 123-130.

Radt, S., 2006. Strabo. Cancik, H., Schneider, H. (Eds.). Brill Online: Brill's New Pauly. http://referenceworks.brillonline.com/entries/brill-s-new-pauly/strabo-brill130030. First appeared online 2006, accessed 24 March 2014.

Radt, W., 2011a. Pergamon: Geschichte und Bauten einer antiken Metropole. Primus, Darmstadt.

Radt, W., 2011b. 'Die lustigen Zeiten sind dahin!' – Die Grabungen des 20. Jahrhunderts. In: In: Grüßinger, R., Kästner, V., Scholl, A. (Eds.). Pergamon – Panorama der antiken Metropole. Michael Imhof, Petersberg, pp. 50-55.

Reimer, P. J., Baillie, M. G. L., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., Buck, C. E., Burr, G. S., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Hajdas, I., Heaton, T. J., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., McCormac, F. G., Manning, S. W., Reimer, R. W., Richards, D. A., Southon, J. R., Talamo, S., Turney, C. S. M., van der Plicht, J., Weyhenmeyer, C. E., 2009. IntCal09 and Marine09 Radiocarbon Age Calibration Curves, 0-50,000 Years Cal BP. Radiocarbon 51 (4), 1111-1150.

Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Staff, R.A., Turney, C.S.M., van der Plicht, J., 2013. IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0–50,000 Years cal BP. Radiocarbon 55, 1869–1887.

Reinhardt, A. Eğrigöl Tepe. In: Matthaei, A., Zimmermann, M. (Eds.), Der Survey im Umland von Pergamon. Altertümer von Pergamon (in press).

Reuter, H.I., Nelson, A., 2009. Geomorphometry in ESRI Packages. In: Hengl, T., Reuter, H. I. (Eds.). Geomorphometry. Concepts, Software, Applications. Developments in Soil Science 33. Elsevier, Amsterdam, pp. 269-291.

Rheidt, K., 1986. Chliara. Ein Beitrag zur spätbyzantinischen Topographie der pergamenischen Landschaft. Istanbuler Mitteilungen 36, 223-244.

Richardson, R., 1894. H.G. Lolling. Amercian Journal of Archaeology 9, 371-373.

Roberts, N., 2001. The Holocene – an environmental history. Blackwell, Oxford.

Roberts, N., Boyer, P. and Parish, R., 1996. Preliminary results of geoarchaeological investigations at Catalhoyuk. In: Hodder, I. (Ed). On the Surface: Catalhoyuk 1993–95. McDonald Institute for Archaeological Research, Cambridge, pp. 19–40.

Roberts, N., Eastwood, W., Kuzucuoğlu, C., Fiorentino, G., Caracuta, V., 2011. Climatic, vegetation and cultural change in the eastern Mediterranean during the mid-Holocene environmental transition. The Holocene 21 (1), 147-162.

Robertson, A., Ustaömer, T., 2004. Tectonic evolution of the Intra-Pontide suture zone in the Armutlu Peninsula, NW Turkey. Tectonophysics 381, 175-209.

Sallares, R., 2006. Role of environmental changes in the spread of malaria in Europe during the Holocene. Quaternary International 150 (1), 21–27.

Santisteban, J., Mediavilla, R., López-Pamo, E., Dabrio, C., Zapata, M., Garcia, M., Castano, S., Martínez-Alfaro, P., 2004. Loss on ignition: a qualitative or quantitative method for organic matter and carbonate mineral content in sediments? Journal of Paleolimnology 32, 287-299.

Schäfer, A., Utescher, T., Mörs, T., 2004. Stratigraphy of the Cenozoic Lower Rhine Basin, northwestern Germany. Newsletter on Stratigraphy 40, 73-100.

Schazmann, P., Darier, G., 1912. Die Arbeiten in Pergamon 1910-1911. Mitteilungen des Deutschen Archäologischen Instituts Athenische Abteilung 37, 331-343.

Schneider, S., Bebermeier, W., Schütt, S., 2010. Geoarchäologische Untersuchungen im westlichen Kaikostal – Bericht über die Geländearbeiten im Sommer 2009. In: Pirson, F., Pergamon – Bericht über die Arbeiten in der Kampagne 2009. Archäologischer Anzeiger 2010 (2), pp. 183-188.

Schneider, S., Knitter, D., Schütt, S., 2011. Geoarchäologische Untersuchungen im westlichen Kaikostal – Bericht über die Geländearbeiten im Sommer 2010. In: Pirson, F., Pergamon – Bericht über die Arbeiten in der Kampagne 2010. Archäologischer Anzeiger 2011 (2), pp. 160-166.

Schneider, S., Schlöffel, M., Schütt, B., 2012. Geoarchäologische Untersuchungen im westlichen Kaikostal – Bericht über die Geländearbeiten im Sommer 2010. In: Pirson, F., Pergamon – Bericht über die Arbeiten in der Kampagne 2010. Archäologischer Anzeiger 2012 (2), pp. 218-222.

Schneider, S., Nykamp, M., Matthaei, A., Bebermeier, W., Schütt, B., 2013. Alluvial geoarchaeology of a small drainage basin in western Anatolia: Late Holocene landscape development and the question of the mouth of the Paleo-Bakırçay. Quaternary International 312, 84-95.

Schneider, S., Matthaei, A., Bebermeier, W., Schütt, B., 2014. Late Holocene human-environmental interactions in the Eastern Mediterranean: Settlement history and paleogeography of an ancient Aegean hill-top settlement. Quaternary International 324, 84-98.

Schneider, S., Matthaei, A., Schlöffel, M., Kronwald, M., Pint, A., Schütt, B., in press. A minimally invasive geoarchaeological case study in the chora of Pergamon, Western Turkey to reconstruct the late Holocene landscape development and settlement history. Quaternary International.

Schuchhardt, C., 1912. Historische Topographie der Landschaft. In: Conze, A. (Ed.). Stadt und Landschaft von Pergamon. Altertümer von Pergamon 1,1, pp. 61–143.

Schulz, J., 2002. Die Ökozonen der Erde. Ulmer, Stuttgart.

Schütt, B., Berking, J., Frechen, M., Frenzel, P., Schwalb, A., Wrozyna, C., 2010. Late Quaternary transition from lacustrine to a fluvio-lacustrine environment in the north-western Nam Co, Tibetan Plateau, China. Quaternary International 218 (1-2), 104-117.

Schütt, H., 1965. Zur Systematik und Ökologie türkischer Süßwasserprosobranchier. Zoologische Mededelingen 41 (3), 43-72.

Seeliger, M., Schneider, S., Brückner, H., Schütt, B., Horejs, B., Feuser, S., Zimmermann, M., Pirson, F., 2011. Studying Pergamon's Environs – Geoarchaeological Research in Elaia and Bakırçay Valley. In: Önen, E., Mutluer, M., Çetin, N. (Eds.). Proceedings of the International Bergama Symposium, 7th – 9th April 2011, pp. 48-65.

Seeliger, M., Bartz, M., Erkul, E., Feuser, S., Kelterbaum, D., Klein, C., Pirson, F., Vött, A., Brückner, H., 2013. Taken from the sea, reclaimed by the sea: The fate of the closed harbour of Elaia, the maritime satellite city of Pergamum (Turkey). Quaternary International 312, 70-83.

Seeliger, M., Brill, D., Feuser, S., Bartz, M., Erkul, E., Keltermbaum, D., Vött, A., Klein, C., Pirson, F., Brückner, H., 2014. The Purpose and Age of Underwater Walls in the Bay of Elaia of Western Turkey: A Multidisciplinary Approach. Geoarchaeology 29 (2), 138-155.

Shakleton, J., Van Andel, T., 1986. Prehistoric Shore Environments, Shellfish Availability, and Shellfish Gathering at Franchthi, Greece. Geoarchaeology 1(2), 127-143.

Sommerey, K.M., 2008. Die Chora von Pergamon. Studien zu Grenzen, Siedlungsstruktur und Wirtschaft. Istanbuler Mitteilungen 58, 135–170.

Stauber, J., 1996. Die Bucht von Adramytteion. Habelt, Bonn.

Stock, F., Pint, A., Horejs, B., Ladstätter, S., Brückner, H., 2013. In search of the harbours: New evidence of Late Roman and Byzantine harbours of Ephesus. Quaternary International 312, 57-69.

Stumpf, G., 1991. Numismatische Studien zur Chronologie der römischen Stadthalter in Kleinasien, Saarbrücker Druckerei und Verlag, Saarbrücken.

Sütgibi, S., 2007. Land-use patterns in the Altınova area. In: Lambrianides, K., Spencer, N. (Eds.). The Madra River Delta: Regional Studies on the Aegean Coast of Turkey. The British Institute at Ankara, London, pp. 59-63.

Sutherland, R., 1998. Loss-on-ignition estimates of organic matter and relationships to organic carbon in fluvial bed sediments. Hydrobiologia 389, 153-167.

Thraemer, E., 1888. Pergamos: Untersuchungen über die Frühgeschichte Kleinasiens und Griechenlands. Teubner, Leipzig.

Topaloglu, F., 2006. Regional Trend Detection of Turkish River Flows. Nordic Hydrology 37 (2), 165-182.

Van Andel, T., Zangger, E., Demitrack, A., 1990. Land Use and Soil Erosion in Prehistoric and Historical Greece. Journal of Field Archaeology 17 (4), 379-396.

Van Gerkan, A., 1956. Die ursprüngliche Mündung des Kaikos. Nachrichten der Akademie der Wissenschaften in Göttingen 8, 283-299.

Vita Finzi, C., 1969. The Mediterranean Valleys: Geological Changes in Historical Times. Cambridge University Press, Cambridge.

Von Diest, W., 1889. Von Pergamon über den Dindymos zum Pontus. Petermanns Mitteilungen Ergänzungsheft 94, 1-100.

Vörösmarty, C., Meybeck., M., Fekete, B., Sharma, K., 1997. The potential impact of neo-Castorization on sediment transport by the global network of rivers. Human Impact on Erosion and Sedimentation 245, 261-273.

Vött, A., Brückner, H., 2006. Versunkene Häfen im Mittelmeerraum. Antike Küstenstädte als Archive für die Kultur- und Umweltforschung. Geographische Rundschau 58 (4), 12-21.

Wagner, H., 2001. Mittelmeerraum. WBG, Darmstadt.

Waters, M., Field, J., 1986. Geomorphic analysis of Hohokam settlement patterns on alluvial fans along the western flank of the Tortolita Mountains, Arizona. Geoarchaeology 1 (4), 329-345.

Weiss, C., 1988. Fluvii. In: Lexicon Iconographicum Mythologicae Classicae IV. Artemis & Winkler, München, pp. 139-148.

Wilkinson, T., 1994. The structure and dynamics of dry-farming states in Upper Mesopotamia. Current Anthropology, 35, 483–520.

Wójcicki, K., 2006. The oxbow sedimentary subenvironment: its value in palaeogeographical studies as illustrated by selected fluvial systems in the Upper Odra catchment, southern Poland. The Holocene 16 (4), 589-603.

Wolters, P., 189. H. G. Lolling. Athenische Mitteilungen 19, 5-23.

Woodbridge, J., Roberts, N., 2011. Late Holocene climate of the Eastern Mediterranean inferred from diatom analysis of annually-laminated lake sediments. Quaternary Science Reviews 30, 3381-3392.

Yaalon, D., 1997. Soils in the Mediterranean region: what makes them different? Catena 28, 157-169.

Yilmaz, A., Adamia, S., Yilmaz, H. Comparisons of the suture zones along a geotraverse from the Scythian Platform to the Arabian Platform. Geoscience Frontiers, in press.

Yilmaz, H., Oyman, T., Arehart, G. B., Colakoglu, A. R., Billor, Z., 2007. Low-sulfidation type Au-Ag mineralization at Bergama, Izmir, Turkey. Ore Geology Reviews 32, 81-124.

Yilmaz, Y., Genç, S.C., Gurer, O., Bozcu, M., Yilmaz, K., Karacik, Z., Altunkaynak, Ş., Elmas, A., 2000. When did the western Anatolian grabens begin to develop. In: Bozkurt, B., Winchester, J., Piper, J. (Eds.). Tectonics and magmatism in Turkey and the surrounding area. Geological Society, London, pp. 353–384.

Yilmaz, Y., Genç, S.C., Karacik, Z., 2001. Two contrasting magmatic associations of NW Anatolia and their tectonic significance. Journal of Geodynamics 31, 243-271.

Zanchi, A., Angelier, J., 1993. Seismotectonics of western Anatolia: regional stress orientation from geophysical and geological data. Tectonophysics 222, 259-274.

Zech, W., Hintermaier-Erhard, G., 2002. Böden der Welt. Spektrum, Heidelberg.

Zgusta, L., 1984. Kleinasiatische Ortsnamen. Winter, Heidelberg.

Zimmermann, M., 2007. Die Chora von Pergamon. In: Pirson, F. Pergamon – Bericht über die Arbeiten in der Kampagne 2006. Archäologischer Anzeiger, vol. 2, 13-70.

Zimmermann, M., 2009. Archäologische Feldforschungen im zentrallykischen Küstensaum und in der Chora von Pergamon, Marburger altertumskundliche Abhandlungen 1.

Zimmermann, M., 2010. Arbeiten in Atarneus. In: Pirson, F., Pergamon – Bericht über die Arbeiten in der Kampagne 2009, Archäologischer Anzeiger 2010 (2), 174-182.

Zimmermann, M., 2011. Arbeiten in Atarneus. In: Pirson, F., Pergamon – Bericht über die Arbeiten in der Kampagne 2011, Archäologischer Anzeiger 2011. 2, pp. 168-173.

Zimmermann, M., 2011. Pergamon. Geschichte, Kultur, Archäologie. C.H. Beck, München.

Zimmermann, M., 2012. Die Chora von Pergamon: Abschlussbericht des Umlandsurveys 2011. In: Pirson, F. Pergamon – Bericht über die Arbeiten in der Kampagne 2011. Archäologischer Anzeiger, vol. 2, 201-218.

Curriculum Vitae

Der Lebenslauf ist in der Online-Version aus Gründen des Datenschutzes nicht enthalten.

Eidesstattliche Erklärung

Hiermit erkläre ich, dass ich die Dissertation 'Geoarchaeological Case Studies in the Bakırçay Valley – Paleogeography and Human-environmental Interactions in the Chora of Pergamon in Western Turkey' selbständig angefertigt und keine als die angegebenen Quellen und Hilfsmittel verwendet habe. Die Beiträge der Co-Autoren der wissenschaftlichen Veröffentlichungen und technische Hilfe anderer Personen sind im Rahmen der Danksagung (Acknowledgements) dargelegt.

Ich erkläre, dass ich diese Dissertation in dieser oder anderer Form in keinem früheren Promotionsverfahren, sondern erstmalig am Fachbereich Geowissenschaften der Freien Universität Berlin eingereicht habe. Der Inhalt der dem Verfahren zugrunde liegenden Promotionsordnung ist mir bekannt.

Berlin, den 12. Juni 2014