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Holocene stratigraphy and geomorphological evolution of the Aegean coastal plains of Anatolia

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Abstract

Three main stages can be distinguished in the sedimentary development and geomorphological formation of the present delta plains on the Aegean coast of Turkey. The Early Holocene is characterized by post-glacial transgression and dependent sedimentation. The Middle Holocene was the period when sea level reached the present level, and apart from small fluctuations, stopped rising. Alluviation and deltaic progradation were prevalent during this transition period from marine to terrestrial environments. As for the Late Holocene, deltaic progradation slowed down and delta plains were covered by floodplain sediments. These characteristics can be observed in the same sequence throughout the Aegean coast of Turkey.

1. Introduction

Knowledge about the formation and evolution of the present geographical characteristics of Turkey has been growing rapidly in recent times due to the great number of new research projects. Turkey is a large country and consists of different geographical regions, each with different physical characteristics in ancient times as well as at present.

1.1. Long-term geomorphological background

The present geographical characteristics of Turkey have evolved since the Middle Miocene (Fig. 1). Palaeogeographical evidence previous to this time indicates completely different conditions due to the effects of orogenic and post-orogenic tectonic movements. It is generally believed that the geomorphology of Turkey in the Middle Miocene was relatively level and low-lying, unlike today (Erol, 1981). This rather flat relief was under the intense weathering effects of a warm-humid climate. Correlative sediments were generally deposited in wide, shallow lake basins. Before the collision of the Arabian and Anatolian plates, the Mediterranean Sea was in contact with the warm waters of the Indian Ocean to the southeast (Rögl and Steininger, 1984). Accordingly, oceanic and atmospheric circulation provided Turkey with a thickly developed vegetation. The low and flat morphology of Turkey in the Middle Miocene is generally known as the 'Anatolian peneplain'. However, perhaps the 'D1 relief system' of Erol (1981) more suitably describes the Middle Miocene palaeo-geomorphology.

Anatolia started to rise in the Middle Miocene because of the collision of the Anatolian and Arabian plates. This important event marked the beginning of remarkable changes in tectonic development and structural geomorphology as well as new climatological and bio-geographical conditions (MacKenzie, 1970; Dewey and Şengör, 1979; Şengör and Kidd, 1979; Şengör, 1980; Rögl and Steininger, 1984). The first result of the 'Neotectonic' events was the formation of new depressions on the rising Anatolian peneplain. They developed in various forms, such as great basins, grabens and half-grabens, many of which became lake basins.

By the end of the Miocene, the morphology of Anatolia was high and rugged. The climate was continental due to rising mountain belts along the periphery. In addition, the northward movement of the Arabian plate closed the connection of the Mediterranean Sea with warm-water oceans. Thus, the wide sub-tropical region of the Middle Miocene in southeast Turkey became hot and dry instead of the previous warm and humid sea. Under these new arid or semi-arid climatic conditions, the broad older wetlands of Turkey dried up, and torrential rains and sheet-floods formed a 'bolson' morphology, at

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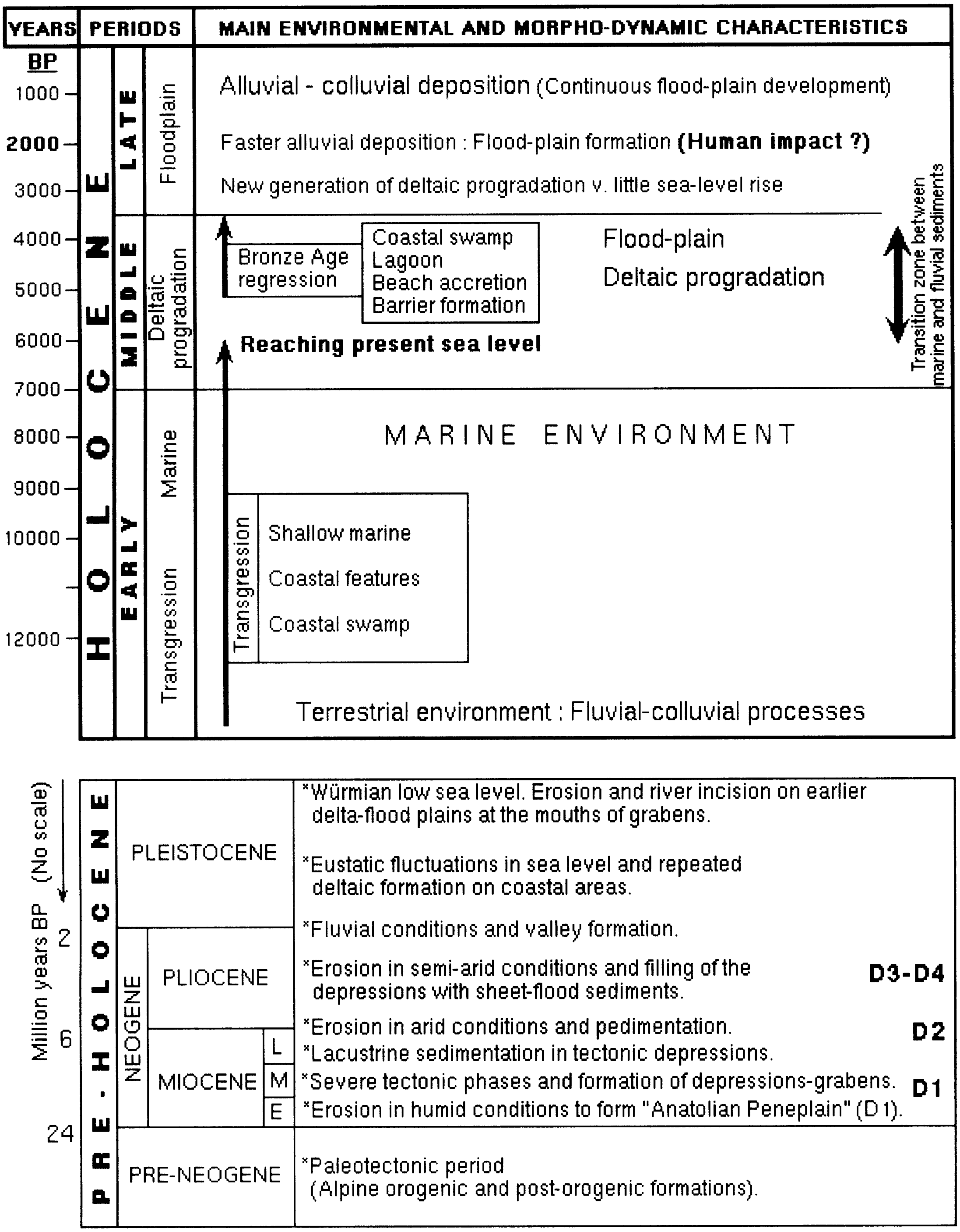

Fig. 1. Palaeogeographical evolution of the Aegean coastal plains of Anatolia. Pre–Holocene development stages refer to a wider region. D1–4 indicate Erol's landform systems (1981).

least in the southern part of the country. This is very clearly seen in many places where sheet-flood deposits overlie earlier lake deposits in depressions. Under these circumstances, biogeographical characteristics also dramatically changed and the previous thick green vegetation changed to a dry steppe vegetation.

Uniform evolution is evident in the Pliocene palaeogeography of Turkey. There is no clear indication that any sudden changes took place in geographical conditions in this period. It is generally accepted that tectonic uplift and terrestrial sedimentation continued. The climatic characteristics of this period are not yet clear. Some colleagues believe that the dry climate at the beginning of the Pliocene and the dependent sheet-flood regime gradually changed to a humid climate, and the Pliocene is represented by fluvial landform development

(Erol, 1981). However, flood sediments are generally not obvious in the Pliocene terrestrial sediments. In many basins, terrestrial deposits consist of thick sheet-flood sediments and the transition between the Pliocene and Pleistocene is unclear, although fluvial processes and river activity were clearly dominant in the Quaternary. Generally, it is accepted that the Pliocene was a period of piedmont formation under more semi-arid conditions, with a gradual transition to fluvial processes on flood-plains in the Pleistocene.

Although fluvial processes were dominant in morphological evolution during the Pleistocene, none of the major valleys of Turkey was formed by river incision alone. The river valleys always formed along weak structural lines or in depressions, grabens and half-grabens. Therefore, the drainage pattern of Turkey has not been formed by superimposition alone, dependent on tectonic uplift. Rather, many major valleys of Turkey have a 'chain-like' morphology in which wider valley elements in tectonic depressions are connected with narrow, deep gorges in bedrock thresholds. Therefore, river erosion and sediment discharge in wider valleys are dependent on slower incision of the thresholds. Consequently, wider parts of valleys could not have been easily eroded and filled with alluvial sediments at first; but, eventually they were cut following gradual river threshold incision. Then, well-developed alluvial terraces were sometimes formed. However, because of their local origin, these terraces cannot be directly correlated to tectonic phases or climatic fluctuations, and they cannot be used for general interpretation of Quaternary palaeogeographies.

Examination of glacial features in Turkey contributes little to the interpretation of Pleistocene palaeogeography. Investigations of glacial features in Turkey are incomplete and a generic scheme is yet to be developed. It is evident that 'pluvial' lakes and their shoreline features, especially high terraces are very important in illuminating the Pleistocene palaeogeography of Turkey. However, here again conclusions vary and a unifying theme evades us; for example, the number of high lake-level stages is still under discussion.

As for the coastal evidence of Quaternary palaeogeography, there are various reasons for vertical and horizontal shoreline changes. Of these reaons, climatic–eustatic sea-level fluctuations are the most important. However, the Holocene transgression prevents us from observing directly and interpreting the older and lower Pleistocene coastlines. They are either destroyed or drowned by the coastal processes of the rising sea. Earlier Quaternary coastal features occurred above present sea level in tectonically uplifted coastal regions; but, it is not easy to separate the tectonic and eustatic components. In coastal delta plains, the most useful data can be obtained by examination of palaeo-environmental characteristics of the alluvial sediment units and their stratigraphical sequence. This is only possible by drilling.

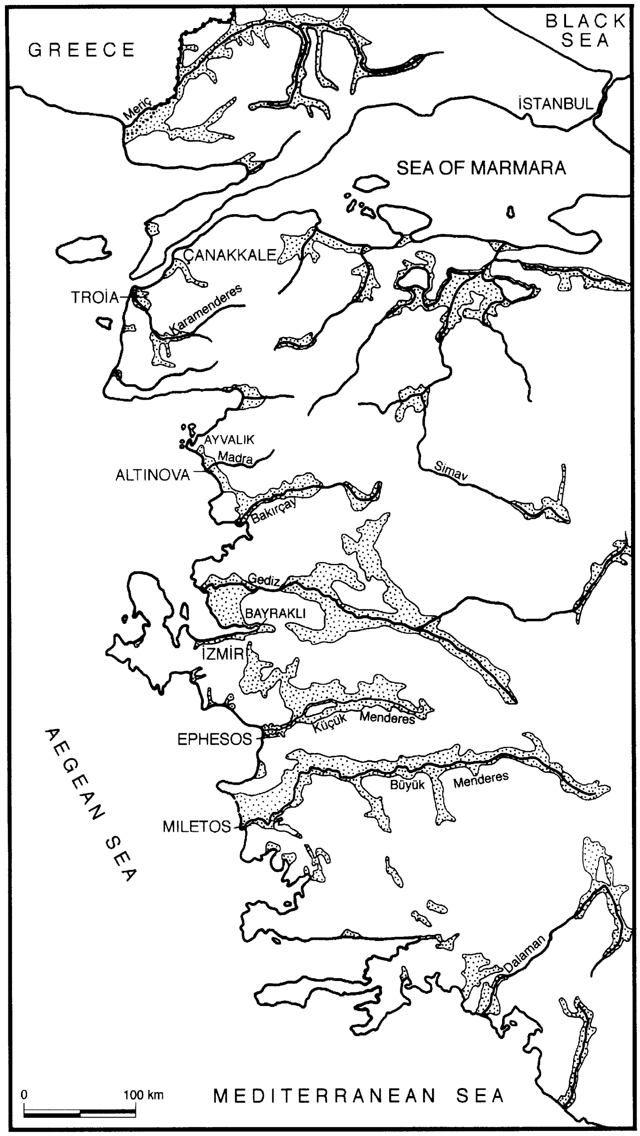

Fig. 2. The Aegean coastal region of Turkey. Major rivers and alluvial plains (dotted) are shown.

2. Holocene stratigraphy of Turkey's Aegean coastal plains

Here I summarize the conclusions of long-term investigations I have undertaken of the Aegean coastal plains of Anatolia. The most extensive drilling research was made on the Karamenderes (Scamander) plain in the north (Figs. 2 and 3). The site of ancient Troia (Troy) occurs on the flank of this plain. Additional subsurface evidence has been obtained by drilling on the Madra çayı, Gediz and Küçük Menderes delta plains.

On the coastal part of the Karamenderes flood-delta plain a pre-Holocene sediment unit occurs below recent alluvium. (Kraft *et al.*, 1980; Fig. 4). The upper surface of this unit is about −30 to −20 m near the Çanakkale Strait (Dardanelles) coastline. Although this unit is

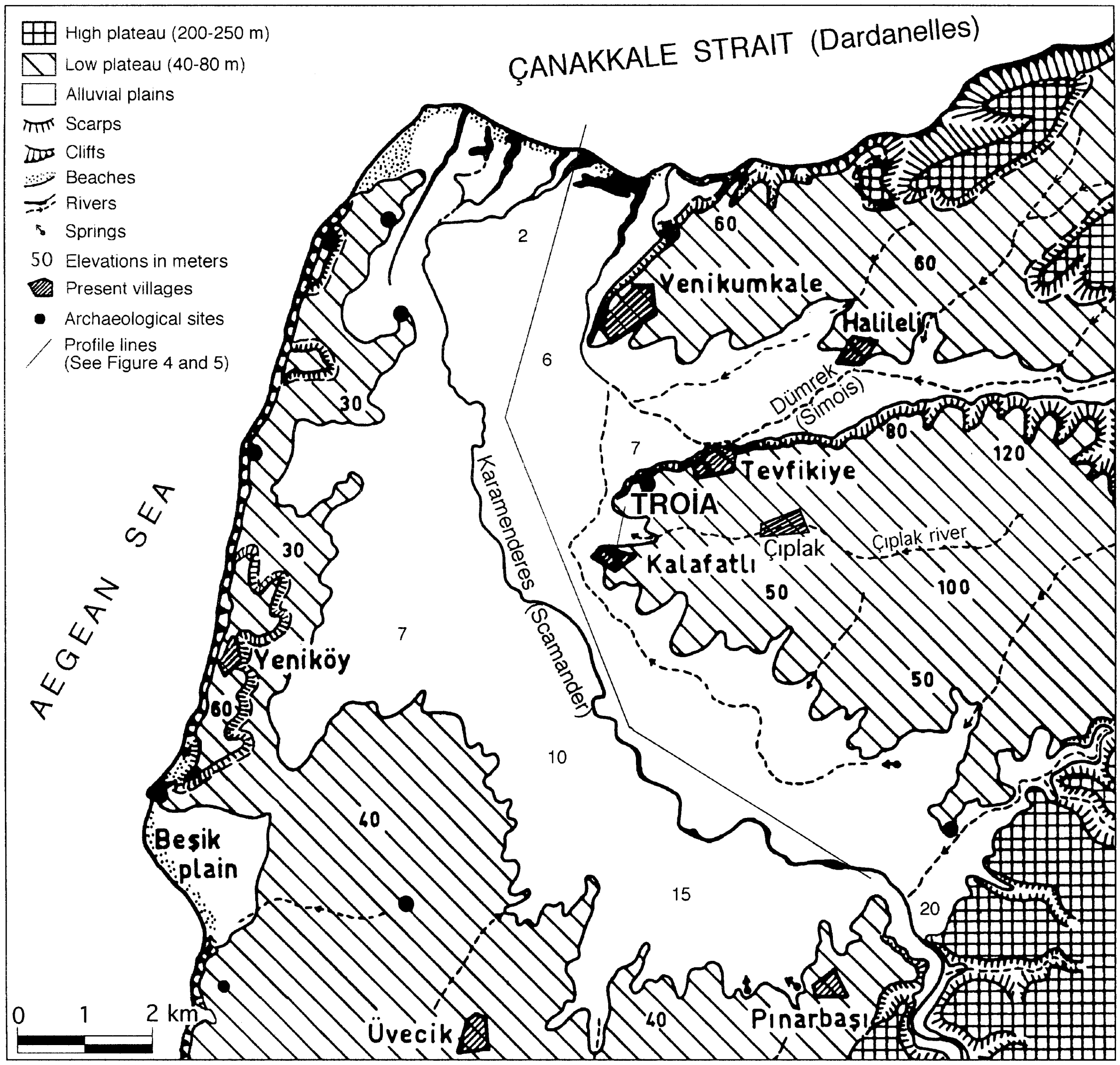

Fig. 3. Geomorphological outlines of the lower Karamenderes–Dümrek flood-delta plain and surrounding area.

marine near the coast, it changes into a terrestrial unit in the lower tributaries. For example, correlative terrestrial sediments fill an old valley incision below the present alluvial cover of the Çıplak valley to the south of Troia (Kayan, 1997b; Fig. 5). The terrestrial unit was encountered by drilling and has no outcrop on the present surface. This pre-Holocene unit fills old valley depressions that were deeply cut by ancestral rivers. Thus, in the old valley depressions of the lower Karamenderes and its tributaries, river incision and infill stages occurred repeatedly. These processes are related to Pleistocene sea-level fluctuations.

^{14}C dating shows that the Early Holocene rising sea intruded into the deeply incised lower part of the Karamenderes valley about 10,000 yr BP. The surface of the pre-Holocene fill was inundated by the sea 8000–7000 BP (Fig. 4). Transgressive sediments start with a coarse sand–gravel lag deposit which contains abundant marine mollusc shells in exposed embayments that were open to strong winds and high wave energy. However, the transgressive deposits start with swamp sediments in sheltered coastal embayments. The sequence of coastal swamp — coastal features — marine sediments can generally be followed on transgression surfaces. For example, this sequence was clearly observed in drilling work on the coastal plains of Troia, Altinova, Izmir and Ephesos (Fig. 6). Marine sediments which were deposited in the lower parts of the major rivers are generally fine grained and very homogenous. They contain many organic colloids, and therefore they are generally dark coloured. These characteristics represent low-oxygen environments and relate to quiet, stable conditions. ^{14}C datings of marine molluscs prove that the rising sea reached its present level in this region about 6000 yr ago (Kayan, 1988, 1991). However, the rate of sea-level rise became slower in the final stage from 7000 to 6000 BP.

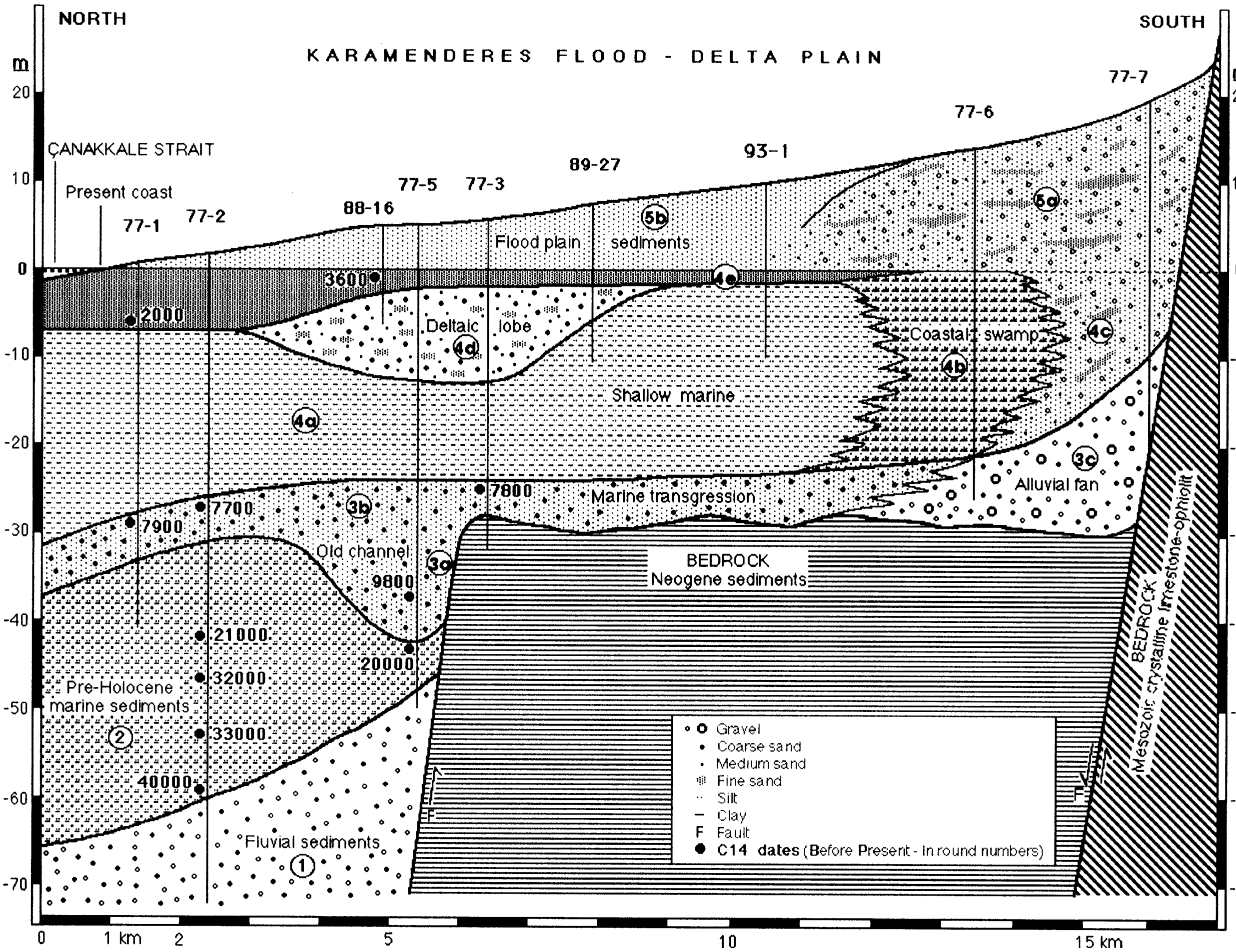

Fig. 4. North–South (lengthwise) cross-section of the Karamenderes plain (modified from Kraft *et al.* (1980) with reinterpretation based on new drilling evidence). Sequence of the stratigraphical units, from older to younger, follows the numbers, respectively. (1) Pre-Holocene (Pliocene or early Pleistocene?) coarse sand–gravel river deposit. (2) Pre-Holocene (Late Pleistocene) fine–medium sandy marine sediments. (3) Early Holocene marine transgression: (a) Marine sediments deposited in the pre-Holocene incision of the Karamenderes river into the Late Pleistocene marine sediments following the latest (Würmian) eustatic sea-level fall. (b) Marine transgression over the Early Holocene bottom of the Karamenderes valley. Sea level reached this surface about 8000 BP and waves reworked coarse material on the surface. (c) Alluvial fan deposits of the Karamenderes river. (4) Early–Middle Holocene marine sediments: (a) Silty–fine sandy marine sediments. (b) Coastal swamp–deltaic progradation. (c) Alluvial fan deposit. (d) Deltaic lobe (marine) of Karamenderes and Dümrek rivers. (e) Transition zone between marine and fluvial sediments. (5) Middle–Late Holocene flood–plain aggradation. (a) Coarser (sand–gravel) alluvium. (b) Finer (fine sand–silt) alluvium

When sea-level rise slowed and stopped about 6000 BP, alluvial aggradation and deltaic progradation began to dominate coastal processes. Barrier-lagoons were not usual in the inner parts of the transgressive embayments. This implies a ‘river dominating deltaic progradation’ about 7000–5000 yr ago at the maximum transgression of the sea into the river valleys. In contrast, ‘marine dominating regressive deltaic progradation’ can be followed by a coastal barrier — lagoon — coastal swamp order of sedimentary environments in the more recent lower parts of deltas.

Old coastal morphologies and sediments and ^{14}C datings of the Troia area as well as archaeological evidence indicate a 2 m sea-level fall between 5000–3500 BP (Kayan, 1995, 1997a). Geomorphological and archaeological evidence of this Bronze Age event can be found along the entire Aegean coast of Turkey. This sea-level fall of about 2 m must have accelerated deltaic progradation. Consequently, the period 7000–3500 BP can be separated from the earlier and faster transgression stage by different geomorphological formations, and attributed to the Middle Holocene (Fig. 2). The Middle Holocene strata represent a transition phase between marine environments and terrestrial conditions, as a great variety of geomorphological and sedimentological features and pervasive swamp environments are found. This transitional sedimentation occurs on a very flat surface on the marine sediment unit. This indicates a continuation of quiet sediment processes, even during the change from transgression to regression at the beginning of the Middle Holocene.

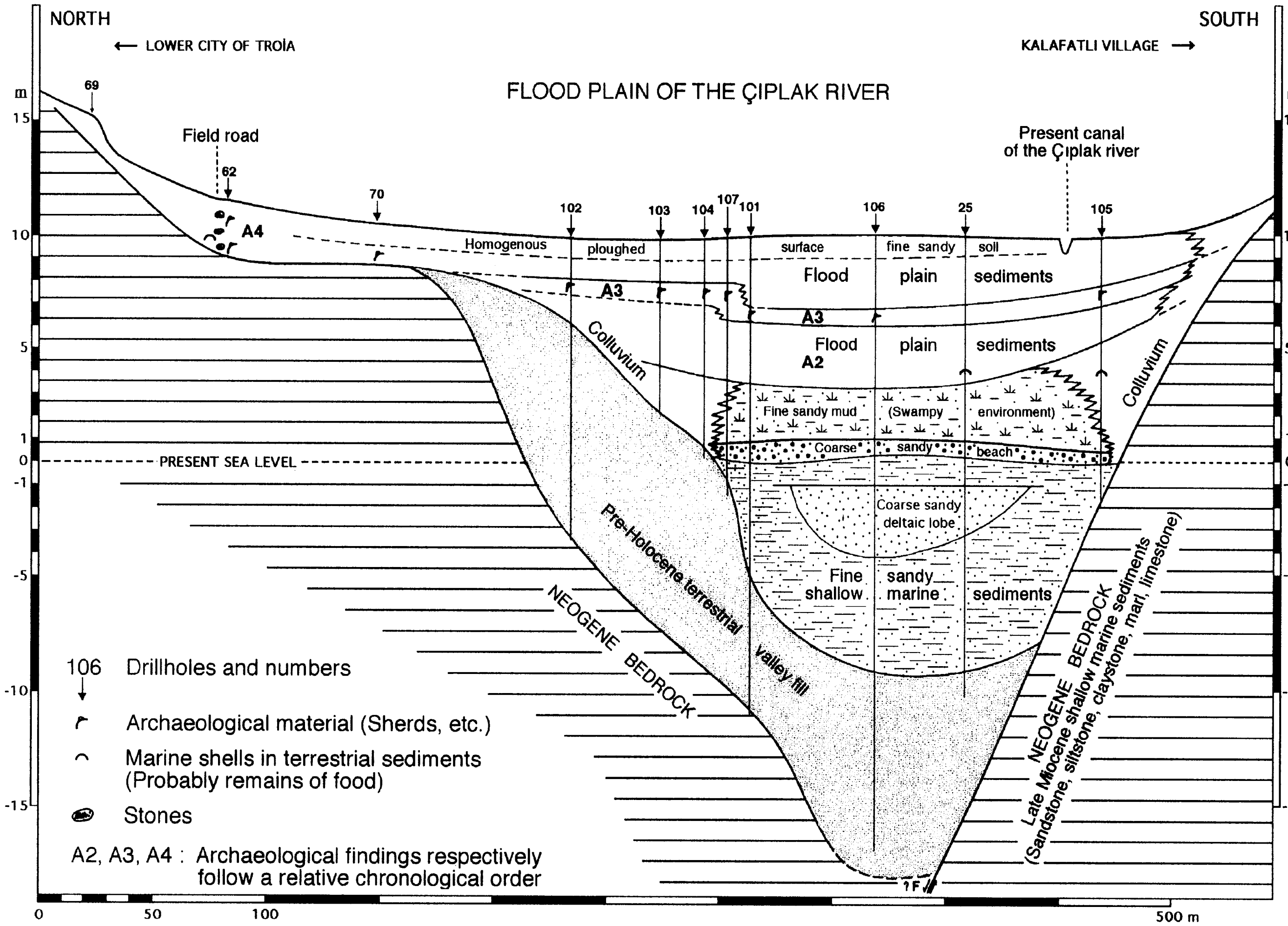

Fig. 5. A cross-section across the lower part of the Çıplak valley between Troia and Kalafatlı village (see Fig. 3). The valley formed in a structural depression and was filled by pre-Holocene terrestrial sediment (corresponding with marine sediment unit 2 in Fig. 4). Then, most likely during the last glacio–eustatic low sea level, it was incised by the ancestral Çıplak river. This new valley has been filled by marine, coastal swamp and finally floodplain sediments during the Holocene.

Deltaic progradation continued in the Late Holocene. ^{14}C datings and archaeological evidence show that the slowly rising sea again reached nearly the present level around the time of Christ. However this rise was slower than deltaic progradation, and marine intrusion was not repeated. Alluvial deposition filled marine embayments at the mouths of the rivers, and delta coasts generally reached open sea during the Late Holocene. Thereafter, deltaic progradation became slower and delta surfaces covered by flood plain sediments aggraded vertically instead. Many sherds and sand-sized grains of archaeological material related to human activity in the regions are found in such thick flood plain deposits. This implies that accelerated erosion due to human impact should be taken into consideration in this period (Kayan, 1996, 1997b and c).

Deltaic progradation seems to have almost stopped today in many of the major delta plains. The reason is not only to be found in the open sea processes, but also perhaps a greater extent in changes in land-use traditions and new drainage–irrigation techniques over the entire river basin. Dam construction on upper tributaries, intensive agricultural activity, and the use of ground water for irrigation on the lower plains have all reduced the volume of water and alluvium reaching the coast, thus preventing natural deltaic progradation. Consequently, a cycle of coastal erosion has been initiated on many of the delta coasts, for example on the coast of the Madra çayı (river) delta.

3. Conclusion

In conclusion, three main stages can be distinguished in the sedimentary depositional and geomorphological evolution of the delta plains on the Aegean coast of Turkey (Fig. 1). The Early Holocene is characterized by post-glacial transgression and resultant sedimentation. The Middle Holocene was the period when sea-level reached present level, and apart from small fluctuations,

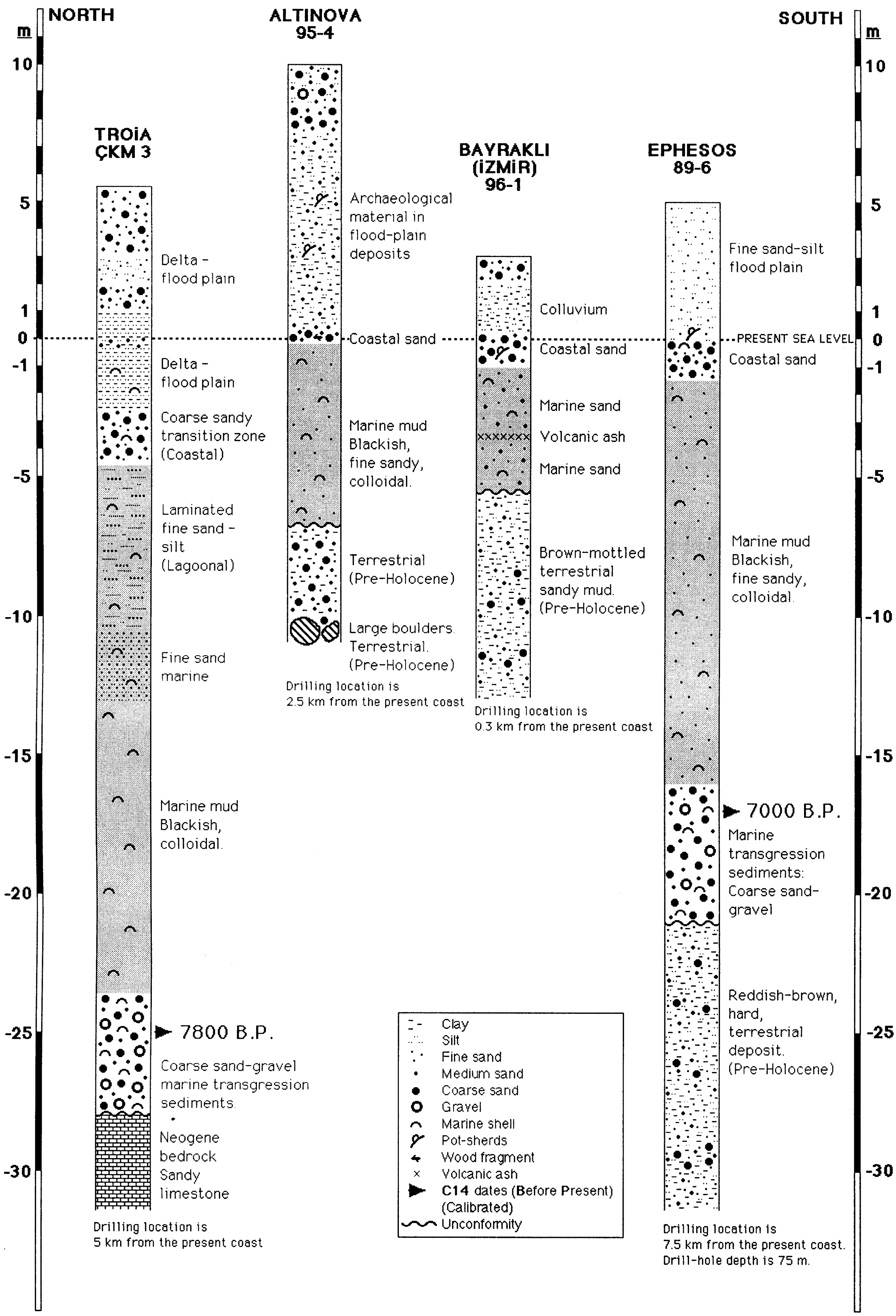

Fig. 6. Typical bore-hole profiles from four Aegean coastal plains of Turkey from North to South (no distance scale). Holocene sedimentary sequences are very similar in all of the examples. Generally, fine grained and colloidal Holocene marine sediments start at the pre-Holocene base with generally coarse sandy lag deposits and end with coastal sand deposits. Then the Late Holocene floodplain sediments cover the surface. Marine sediments have not been found above present sea level at any place. (For the drilling site locations see Fig. 2).

stopped rising. Alluviation and deltaic progradation were prevalent during this transition period from marine to terrestrial environments. As in the Late Holocene, deltaic progradation slowed down and delta plains were covered by flood plain sediments. These sequences of transgression and regression can be observed in this order along the entire Aegean coast of Turkey. In addition, tectonic deformation in the Middle–Late Holocene sedimentary units and geomorphology of the coastal plains has not been observed in spite of tectonic activity in this region. This is one of the more interesting point of our conclusions and is open to further discussion.

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References

Dewey, J. F., & Şengör, A. M. C. (1979). Aegean and surrounding regions: complex multiplate and continuum tectonics in a convergent zone. *Geological Society of America Bulletin*, *90*, 84–92.

Erinç, S. (1973). Geomorphological evidence of neotectonics in Turkey. *Jeomorfoloji Dergisi*, *5*, 11–14.

Erol, O. (1981). Neotectonic and geomorphological evolution of Turkey. (Ed. R. W. Fairbridge). *Zeitschrift für Geomorphologie N.F. Suppl. Bd*., *40*, 193–211.

Kayan, I. (1988). Late Holocene sea-level changes on the Western Anatolian coast. (Ed. P. A. Pirazzoli, & D. B. Scott, Quaternary Coastal Changes). *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology 68*, 205–218.

Kayan, I. (1991). Holocene geomorphic evolution of the Beşik plain and changing environment of ancient man. *Studia Troica 1*, 79–92.

Kayan, I. (1995). The Troia bay and supposed harbour sites in the Bronze Age. *Studia Troica*, *5*, 211–235.

Kayan, I. (1996). Holocene stratigraphy of the Lower Karamenderes–Dümrek plain and archaeological material in the alluvial sediments to the north of the Troia ridge. *Studia Troica*, *6*, 239–249.

Kayan, I. (1997a). Bronze Age regression and change of sedimentation on the Aegean coastal plains of Anatolia (Turkey). In: H. N. Dalfes, G. Kukla, & H. Weiss (Eds). Third millenium BC climate change and old world collapse (Vol. 149, pp. 431–450). NATO ASI series, Berlin: Springer. 431–450.

Kayan, I. (1997b). Geomorphological evolution of the Çıplak valley and archaeological material in the alluvial sediments to the south of the Lower City of Troia. *Studia Troica*, *7*, 489–507.

Kayan, I. (1997c). Efes'te Artemision ile Coresus Kapısı arasında eski kıyı çizgisi üzerine paleocoğrafya araştirmalari. T. C. Kültür Bakanlığı Anıtlar ve Müzeler Genel Müdürlüğü. *XII. Arkeometri Sonuçları Toplantısı Bildiriler Kitabı*. Yayın no: 1876: 77–92. Ankara.

Kraft, J. C., Kayan, I., & Erol, O. (1980). Geomorphic reconstructions in the environs of Ancient Troy. *Science*, *209*, 776–782.

MacKenzie, D. (1970). Plate tectonics of the Mediterranean region. *Geophysical Journal of Research Astronomical Society*, *30*, 109–185.

Rögl, F., & Steininger, F. F. (1984). Neogene Paratethys, Mediterranean and Indo-Pacific Seaways: implications for the paleogeography of marine and terrestrial biotas. In: P. Brenchley, P. (Ed.), *Fossils and climate*. (pp. 171–211). Chichester: Wiley.

Şengör, A. M. C., & Kidd, W. S. F. (1979). The post-collisional tectonics of the Turkish-Iranian Plateau and a comparison with Tibet. *Tectonophysics*, *55*, 361–376.

Şengör, A. M. C. (1980). Türkiye'nin neotektoniğinin esasları (Principles of the Neotectonics of Turkey). *Türkiye Jeoloji Kurumu Konferanslar Serisi*, *2*.