Turkish Journal of Earth Sciences (Turkish J. Earth Sci.), **Vol. 15**, 2006, pp. 1-23. *Copyright ©TÜBİTAK*

A Miocene Palaeovalley Network in the Western Taurus (Turkey)

OLIVIER MONOD[1], CATHERINE KUZUCUOĞLU[2] & ARAL İ. OKAY[3]

[1] ISTO, UMR 6113, Université d'Orléans, 45067–Orléans, France
(E-mail: o.monod@neuf.fr)
[2] Laboratoire de Géographie Physique, UMR 8591, 1 pl A. Briand, 92195–Meudon, France
[3] İstanbul Technical University, Eurasian Institute of Earth Sciences, Ayazağa, TR–80626 İstanbul, Turkey

Abstract: Lower Miocene conglomerates in the Köprü and Manavgat basins contain pebbles that can be confidently traced back to their source areas, owing to their distinctive lithologies. Among others, are the green Huğlu volcanics (Late Trias), known only in allochthonous units from the Beyşehir region, or the Alanya blueschists, restricted to the Sugözü unit in the Alanya Massif. The problem is to find out how this detrital material could have travelled about eighty kilometres through the Taurus calcareous units during the Miocene. Fortunately, the present drainage system is not yet fully reorganised in the Taurus, and large areas of the chain still retain fossil morphologies. These may be seen in the upper karstic areas of the chain, where a large part of a high surface (1500–2200 m) is preserved. On this surface several dry valleys, some of them 400 m deep, with meanders and tributaries, have been recognised. They are disconnected from the present drainage, and represent fragments of a former network directed NE–SW, at right angles to the structures of the Taurus chain. The age of this network may be attributed indirectly to the Early Miocene. On the other hand, the presence of blueschist fragments in conglomerates of the Aksu Basin cannot be explained through a NE–SW-directed drainage system, and implies instead that the Alanya Massif extends to the west below the Miocene cover of the Antalya Gulf. Later, Late Miocene faulting fragmented the high surface and disrupted the drainage system. Uplift of the Taurus chain followed in the Pliocene and Quaternary, and is responsible for the extensive karstic circulation seen today, which left aside remnants of the ancient morphology of the chain.

Key Words: fluviatile network, tracer pebbles, Miocene morphology, karst, Taurus, Turkey

Batı Toroslar'da Miosen Yaşta Bir Akaçlama Sistemi

Özet: Köprü ve Manavgat havzalarında bulunan Alt Miyosen konglomeralarının kaynak alanının saptanması, çakılların karakteristik litolojik özellikleri nedeni ile kolaydır. Örneğin, bazı çakıllar sadece Beyşehir bölgesindeki allokton birimlerden bilinen, Erken Triyas yaşta yeşil Huğlu volkanitlerinden, veya Alanya Masifi'nin Sugözü Napı'nda tanımlanan mavişistlerden oluşmuştur. Bu klastik malzemenin Miyosen'de Torosların karbonat birimleri üzerinden akarsular ile nasıl 80 km taşındığı önemli bir sorundur. Bu konuya ışık tutabilecek bir gözlem, Toroslarda günümüz akaçlama sisteminin tam gelişmediği ve geniş alanlarda akaçlamanın fosil özellikler taşıdığıdır. Fosil akaçlama bilhassa Torosların yüksek kısımlarında (1500–2200 m) korunmuştur. Bu yüzeylerde, yer yer derinlikleri 400 metreye ulaşan, yan kolları bulunan menderesli kuru vadiler yer alır. Bu eski vadiler modern akaçlama sisteminden izole olmuş, Toros dağ silsilesi yönüne dik, KD–GB gidişli eski bir akaçlama sisteminin artıklarını oluşturur. Dolaylı veriler eski akaçlama sisteminin yaşının Erken Miyosen olduğunu gösterir. Köprü ve Manavgat havzalarından farklı olarak Aksu Havzası konglomeralarındaki mavişist çakıllarını KD–GB gidişli bir akaçlama sistemi ile açıklamak mümkün değildir. Aksu Havzasındaki mavişist çakıllarının varlığı, Alanya Masifi'nin Antalya Körfezi Miyosen örtüsünün altından batıya doğru uzandığına işaret eder. Geç Miyosen'deki faylanma ile yüksek düzlükler parçalanmış, ve KD–GB gidişli akaçlama sistemi bozulmuştur. Toros dağ silsilesinin Pliyosen ve Kuvaterner'de tekrar yükselmesi sonucunda bugünkü kapsamlı karstik akaçlanma gelişmeye başlamış, ve eski akaçlama sistemi ancak izole olarak bazı yüksek bölgelerde korunmuştur.

Anahtar Sözcükler: akaçlama sistemi, kılavuz çakıllar, Miyosen morfolojisi, karst, Toroslar, Türkiye

Introduction

In southern Turkey, Miocene deposits generally unconformably overlie pre-existing structures of Late Cretaceous to Late Eocene age (Blumenthal 1951; Gutnic *et al.* 1979; Koçyiğit *et al.* 2000; Şenel 2002). Within the western Taurus range, this disposition implies that a period of exhumation and erosion occurred before the Miocene marine transgression, as shown by polymict conglomerates which are usually present at the base of the Miocene basins (Blumenthal 1951; Monod 1977, 1979). These conglomerates are irregularly distributed from Adana to Antalya and reflect a rugged topography (Akay *et al.* 1985; Flecker *et al.* 1995; Ocakoğlu 2002). Clast composition suggests that the pebbles were generally derived from the surrounding mountains, typically made up of Mesozoic carbonates, or from overlying nappes, which often include ophiolitic rocks. In most cases, however, the exact origin of the Miocene pebbles cannot be assigned more precisely, owing to the ubiquity of neritic carbonates and the widespread distribution of ophiolitic units in the Taurus range. Only a few particular lithologies can be recognised unambiguously among the pebbles, and these crop out in such restricted areas of the western Taurus that it is possible to identify their origin with a good precision. Among them, the Precambrian diabases of Bozburun Dağ, red Carboniferous sandstones of Dipoyraz Dağ, metamorphic limestones and blueschists of the Alanya Massif and the green Huğlu volcanics (Trias) are excellent source indicators (Figure 1). The problem is to find out how these materials travelled across the Taurus chain early in the Miocene. The aim of this paper is to point out ancient morphological features still preserved in the western Taurus and, with the help of these markers, to reconstruct and date the river network which brought detrital material from the Miocene catchment areas down to the Antalya Basin.

Evidence for Fossil Morphological Features Preserved in the High Western Taurus

The Present Drainage System

Superficial drainage in the western Taurus exhibits many irregularities, showing that its evolution is far from complete. A simplified topographical sketch (Figure 2) shows five major drainage basins, with two different base levels: to the south, the Mediterranean receives water from three major fluviatile basins (Köprüçay River, Manavgat River and Alaraçay River), whereas to the north – the other base level – at about 1000 m altitude, corresponds to an endoreic depression in central Anatolia, where the Beyşehir and Suğla lakes are situated. In addition to these catchment areas, the drainage of a large surface of the Taurus chain (HS in Figure 2) is not yet connected to any organised surficial system. Due to this disposition, this high, isolated area is itself subdivided into a number of closed depressions, and includes the two largest poljes (Kembos Ova and Eynif Ova, cf. Louis 1956) of the chain. The high surface is almost entirely comprised of Mesozoic carbonates (Jurassic–Cretaceous) and exhibits an intense karstic morphology. Surprisingly, although no organised drainage exists in this part of the Taurus, many large, dry valleys are present on the high surface (Figure 3). As shown below, we suggest that these fossil valleys are remnants of a former fluviatile network situated upon a Miocene erosion surface.

The High Palaeosurface

The general topography of the high surface (HS) of the Taurus, at present between 1500 m and 2000 m altitude, is rather smooth, albeit intensively karstic (cf. Nazik 1992; Ekmekçi 2003), but is not a structural surface, as shown by the various underlying carbonate formations ranging in age from Late Trias to Late Cretaceous. Limiting the high surface, very steep slopes generally result from regressive and differential erosion or younger faulting (Figure 3). To the south, the Karpuz River, the Alara River and the Manavgat River have carved extremely steep gorges (over 1000 m deep) through Mesozoic carbonates, demonstrating the young uplift of the Taurus chain. The Manavgat River, in particular, flows down through three deep gorges, and near Üzümdere village a sharp bend at a right angle to the NW probably reflects a former capture (Figure 2). To the northeast, the high karstic surface is limited by high calcareous cliffs above Seydişehir (Figure 3), which probably reflect an important fault line, as suggested by Birot & Dresch (1956). Last but not least, Miocene to Recent normal faulting has uplifted or lowered parts of the Taurus chain and has thus fragmented this surface, which rises to 2250 m in Burmahan Dağ, but disappears at 1100 m under Pliocene sediments along Beyşehir Lake. Thus, owing to the importance of Pliocene–Quaternary erosion and tectonics (cf. Koçyigit & Özacar 2003) only

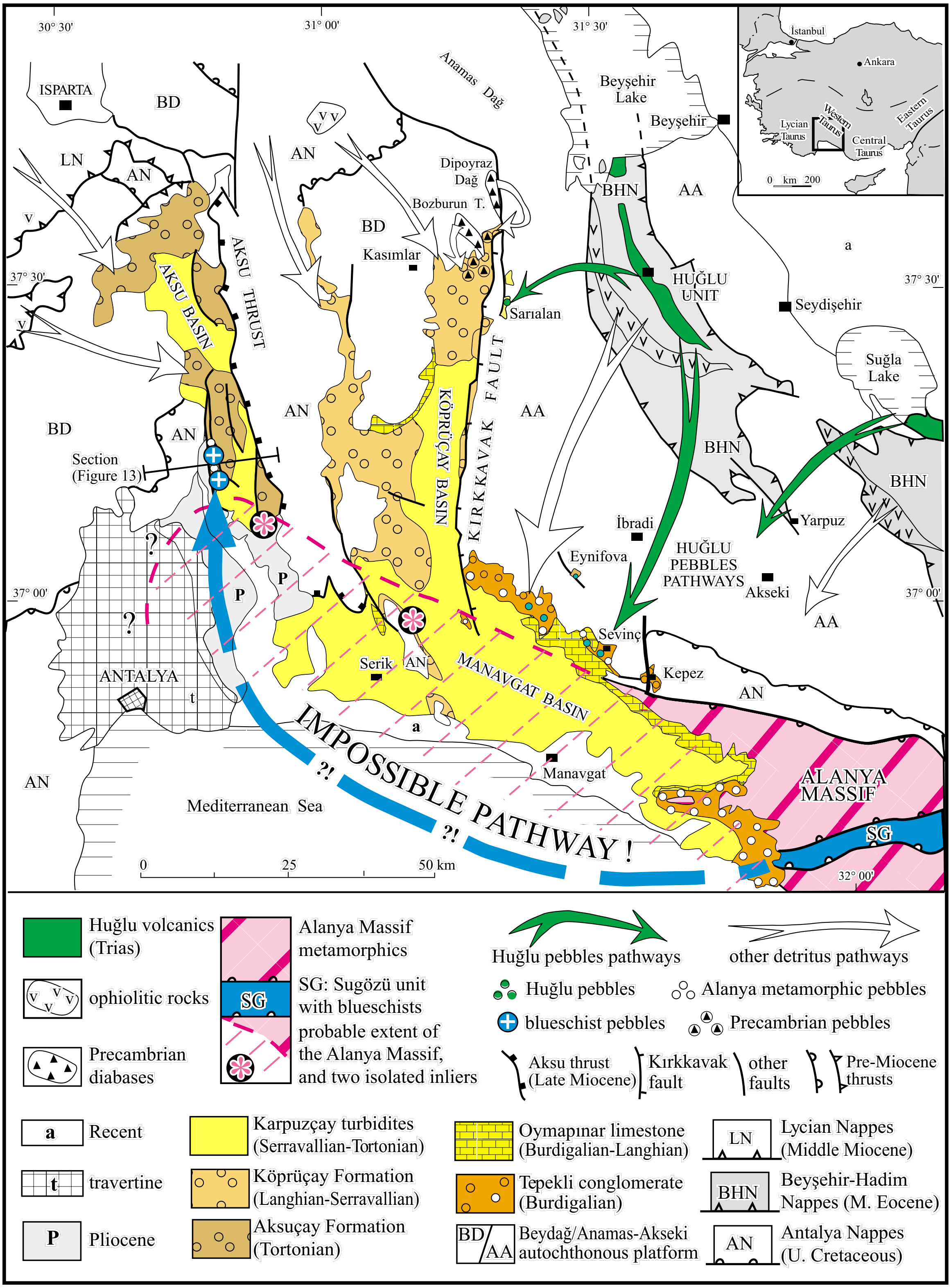

Figure 1. Sketch map of the Antalya Miocene basins showing distribution of the main conglomeratic bodies, with their source rocks and locations of derived pebbles.

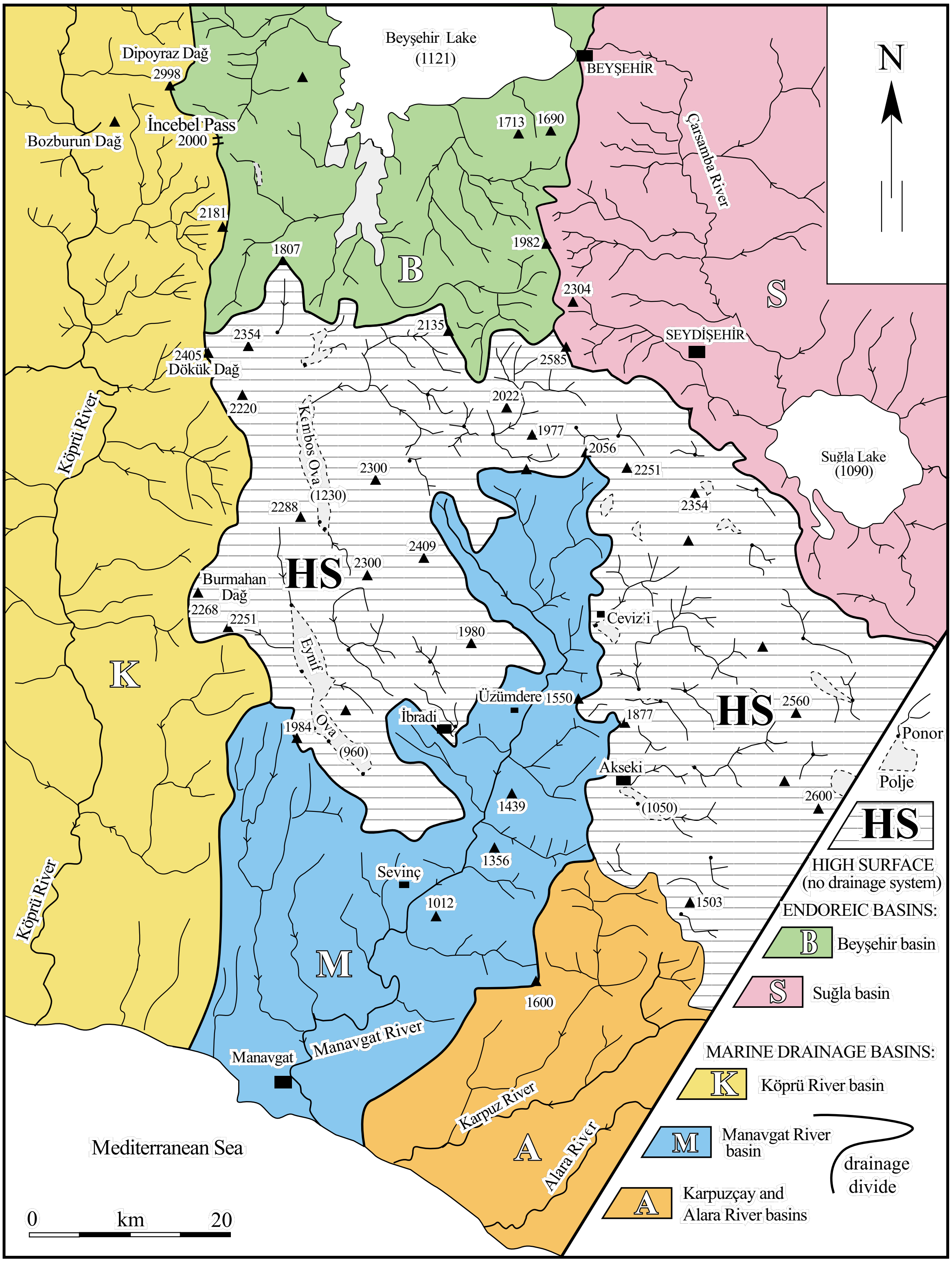

Figure 2. Map of the catchment areas in the western Taurus; the white area (HS) in the centre has no surficial drainage towards the present rivers, but only through underground circulation in this highly karstic area. It contains remnants of a palaeosurface where most of the fossil morphological features are present.

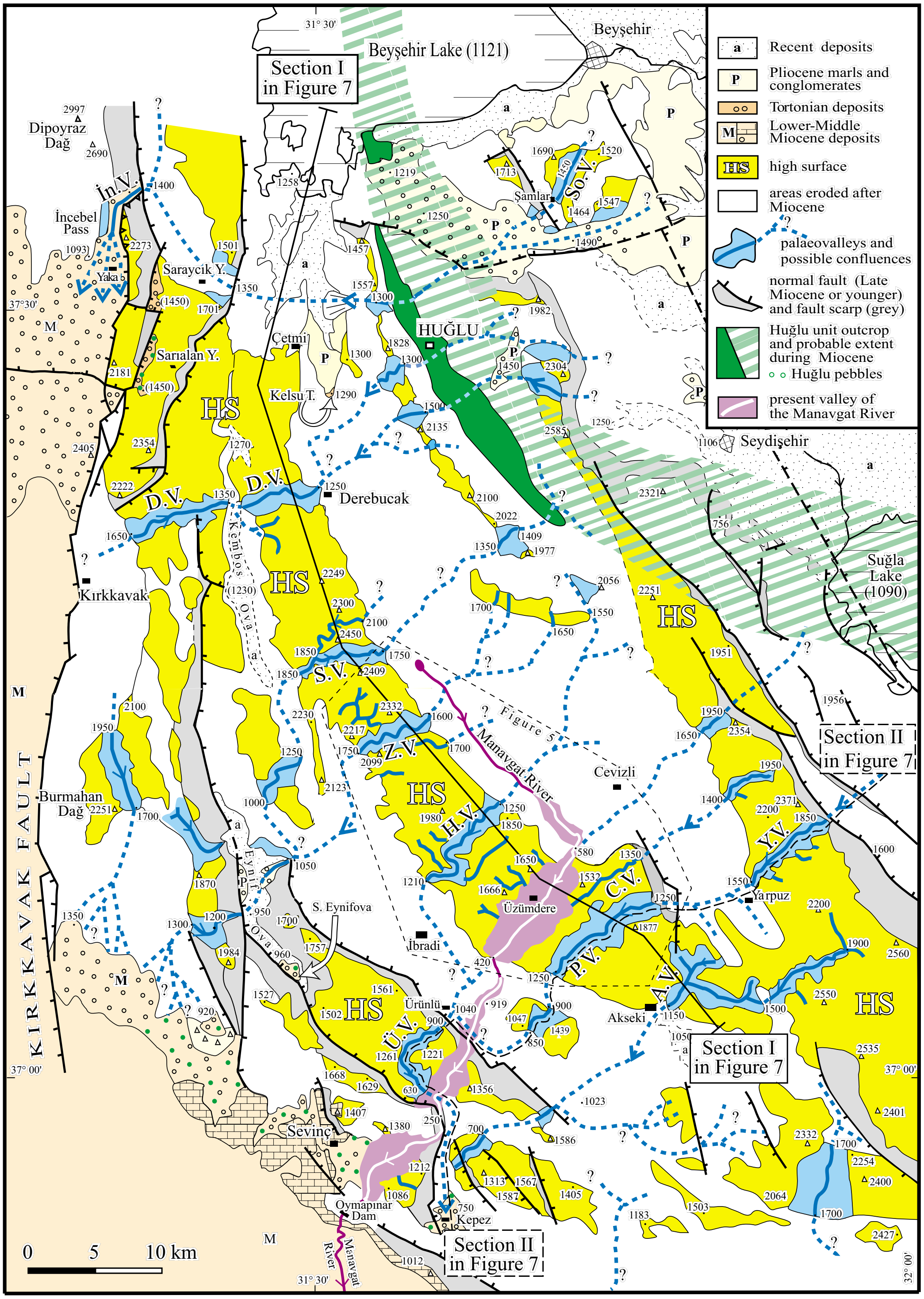

Figure 3. Reconstructed Early Miocene drainage network in the western Taurus. The main palaeovalleys are in blue: **A.V.**– Akseki Valley; **D.V.**– Derebucak Valley; **H.V.**– Hallaç Valley; **In.V.**– İncebel Valley; **P.V.**– Piser Valley; **S.V.**– Sultançukuru Valley; **So.V.**– Sobova Valley; **Ü.V.**– Ürünlü Valley; **Y.V.**– Yarpuz Valley; **Z.V.**– Zimmet Valley. Arrows indicate the present slope. Remaining parts of the high surface **HS** are in yellow. Normal faults figured here are Late Miocene or younger, with fault scarps in light grey. Manavgat River gorge (purple) is younger (Plio–Quaternary).

disconnected fragments of the high surface may now be recognised (HS in Figure 3).

The fragments outlined in Figure 3 were delineated on 1/25000 topographical maps, partly directly and partly with a digital elevation model (DEM); they are defined as remnants of an upland morphology where no significant slopes are steeper than 25°. In most cases, these areas are sharply delimited by a conspicuous break of slope due to Quaternary regressive erosion, as in the Manavgat valley, or to the denudation of a former, steeply inclined structural slope, as south of Derebucak village. In most cases, however, the break of slope reflects younger faulting, as exemplified west of İbradi or south of Seydişehir. Areas displaying imprecise boundaries when mapping the high surface are few. As a result of this cartography (Figure 3), the high surface appears now as a disconnected puzzle of remnant morphologic pieces of limited size and variable altitudes which were parts of a larger, evolved surface, including not only high points but also deep valleys, as shown below.

Streamless Hanging Valleys

Across several remnants of the high surface, a striking feature is the presence of large, streamless valleys, which are well preserved in spite of the karst in the calcareous areas (cf. Nazik 1992). These valleys are conspicuous in the field (Figure 4) as well as on satellite pictures, and some are followed for a few kilometres by roads crossing the Taurus range. A common characteristic of these valleys is their abrupt interruption at both ends, hanging from one to four hundred metres above the present-day drainage. Another typical feature is the karstic morphology of the hanging valleys, which are paved with adjacent dolines and sinkholes.

On 1/25000 topographic maps (Figure 5), the hanging valleys can be delineated with precision. The main palaeovalleys may reach 1 to 1.5 km in width (Zimmet Valley), 250 to 400 m in depth (Hallaç Valley), and 10 km in length (the longest being Piser Valley). Most are oriented NE–SW (Figure 6), and some exhibit clear meander morphologies (Hallaç Valley) with well-preserved meander necks. A few tributaries may be noted on both sides (Figure 5), in spite of the very rough karstic landscape. Interestingly, the tributaries are not deeply incised into the high surface (150–200 m); thus, their connection with the main fossil valleys occurs not on the valley floor, but always on a valley shoulder about 200 to 250 m higher (cf. Zimmet valley). This general disposition (Figures 6 & 7-Section I) implies that the meandering river network was initially created with a weak slope on the high surface, and was succeeded by two or more cycles of erosion with rapid karstic developments following each fall of base level in the main valleys (cf. Ford & Williams 1989).

The dry valleys are typically V-shaped with rather steep flanks (from 30° to 40°) in the deepest valleys, indicating a very rapid rate of incision within the carbonates, but a limited time for lateral erosion to enlarge the width of the valley floors (cf. de Broekert & Sandiford 2005). The steeper slopes are found preferentially to the SW (Ürünlü Valley), whereas much smoother shapes are recorded in the NE (Sobova Valley, near Beyşehir). As a rule, the directions of the palaeovalleys trend NE–SW and the tributaries, when not at right angles to the main valleys, suggest a southwesterly direction of flow. Although complete profiles cannot be drawn precisely, owing to their discontinuous preservation, some of the palaeovalley fragments are long enough to suggest that the original slope was weak: for instance, the Hallaç Valley (8 km) and the Piser Valley (10 km) exhibit roughly the same altitude at both ends. However imprecise, where several segments can be connected to one another, a realistic picture of a 70-km-long palaeovalley emerges (Figure 7-Section II), with a source about 2000 m high to the NE, and a base level at 750 m altitude to the SW, as demonstrated by the deltaic deposits near Kepez (Karabıyıkoğlu *et al.* 2000). However, in most of the reconstructed profiles of the palaeovalleys, such a picture is not obtained, and the river profiles show sharp discontinuities, or even slope reversals, that we interpret as reflecting later tectonic events (mainly faulting) which disrupted the original profile of the valleys.

Reconstruction of a Palaeodrainage System

Once recognised, the palaeovalleys appear as isolated fragments scattered all over the high surface of the Taurus. In order to restore the shape of the palaeodrainage network, we assume that all the fossil valleys belong to a single drainage system, although this certainly is questionable. First, due to complete

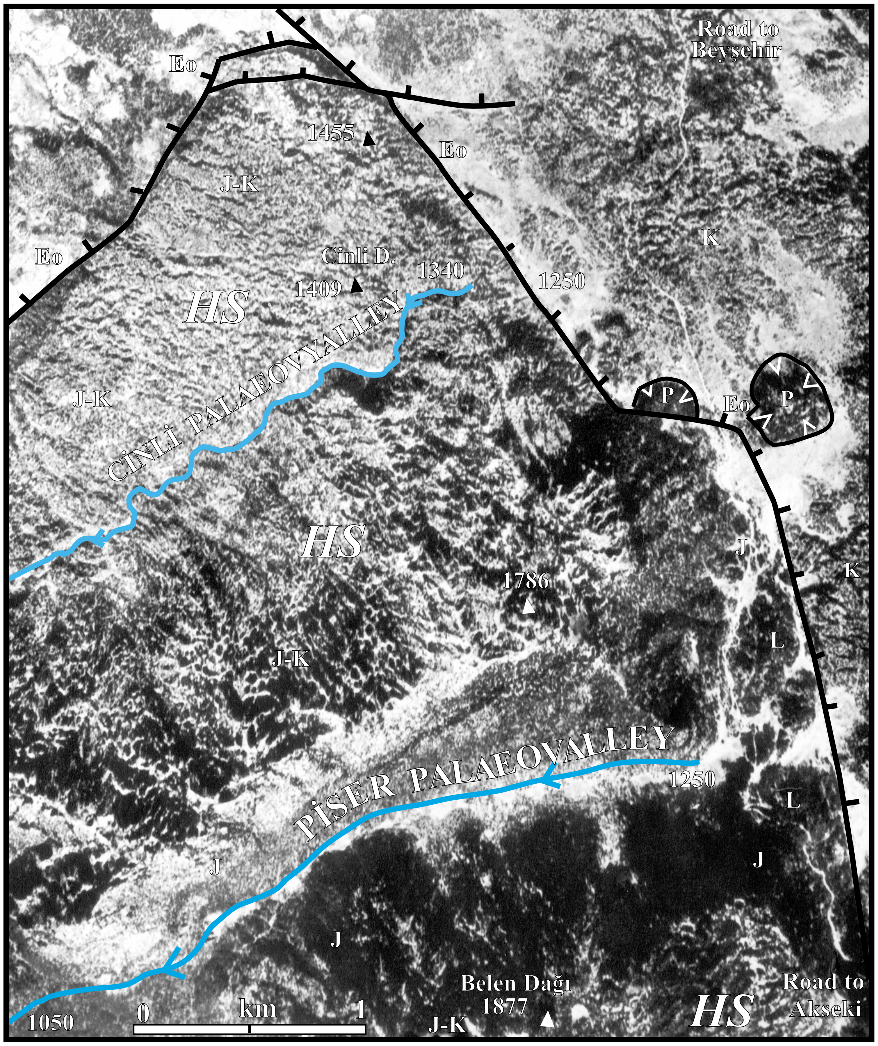

Figure 4. Aerial view north of Akseki showing the high surface (**HS**) incised by the Cinli palaeovalley inclined southwestward, and the much deeper Piser palaeovalley. The sun is to the south. **P**– Permian isolated klippe from the Beyşehir-Hadim Nappes; **Eo**– Eocene limestone and flysch; **J–K**– Upper Jurassic to Upper Cretaceous carbonates, displaying a highly karstic morphology; **J**– Middle Jurassic dolomite; **L**– Liassic shales and sandstones. Location given in Figure 5.

denudation of the slopes and, in most cases, the absence of valley fill, the age of each valley cannot be directly known. Second, the present shape of the valleys results from a succession of erosion cycles, which cannot be identified individually. Third, the relative altitude of the different fragments may have been changed by later tectonic events, as shown by slope reversals along the profile of several valleys. Last but not least, Plio–Quaternary erosion has removed parts of the softer formations (Eocene flyschs, Palaeozoic and other allochthonous units) which had overlain the Mesozoic carbonates, so that the locations of the original confluences are now lost.

However, the size of the main fossil valleys suggests a much larger catchment area than the present one, and therefore implies that the fossil fragments were somehow connected to one another, forming an extensive drainage system throughout the Taurus chain. A tentative sketch is presented (Figure 3), in which the nearest connections have been drawn, based on the orientations

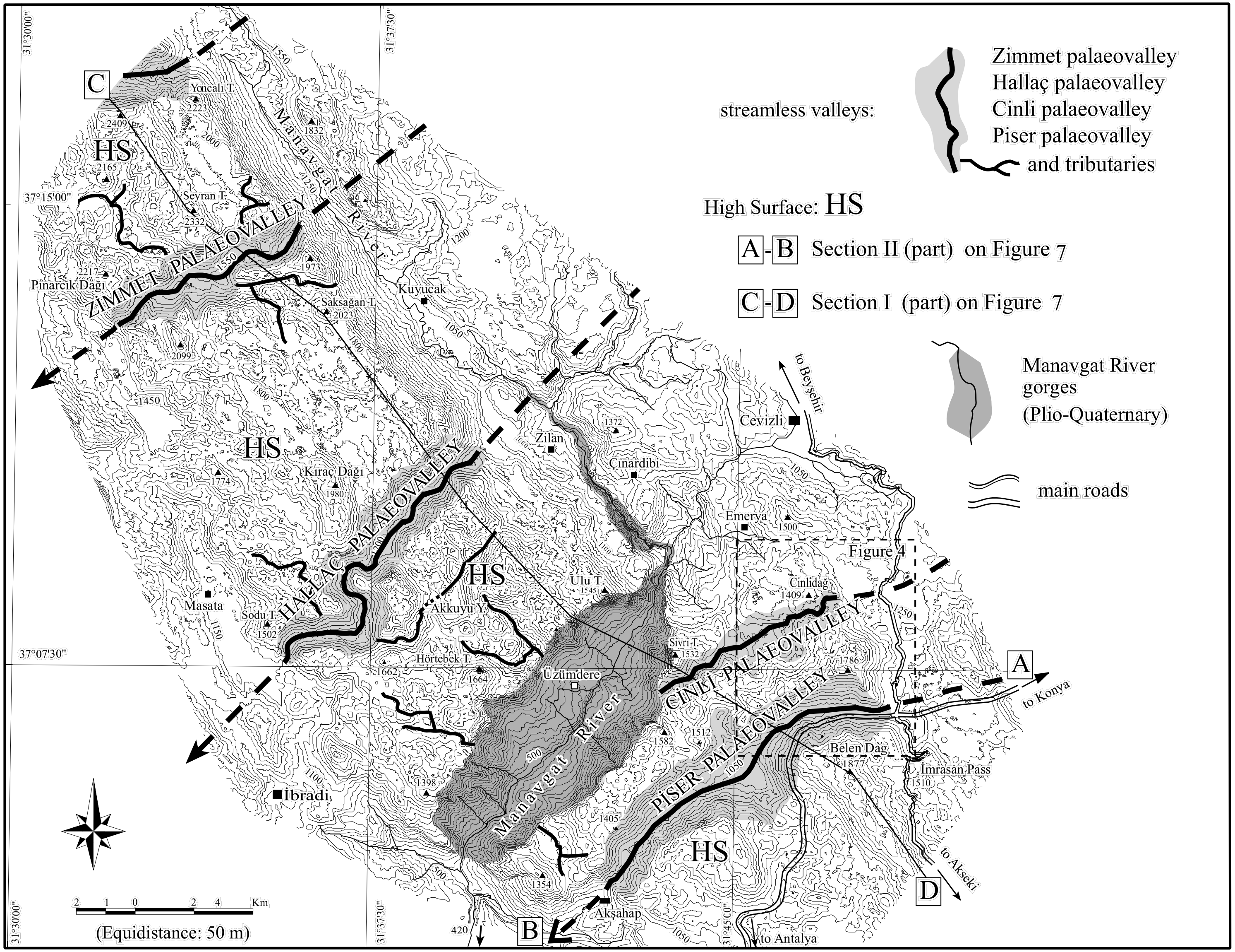

Figure 5. Detailed map of the topography of the Taurus NW of Akseki showing several hanging dry valleys (light grey) incised into a high karstic area of the Taurus (**HS**). Entrenched meanders in the Hallaç palaeovalley and a few hanging tributaries are still recognisable. The present drainage (Manavgat River) flows in the deepest gorge (dark grey) incised during the Plio–Quaternary. **A-B**, **C-D** part of sections I & II in Figure 7. Location given in Figure 3.

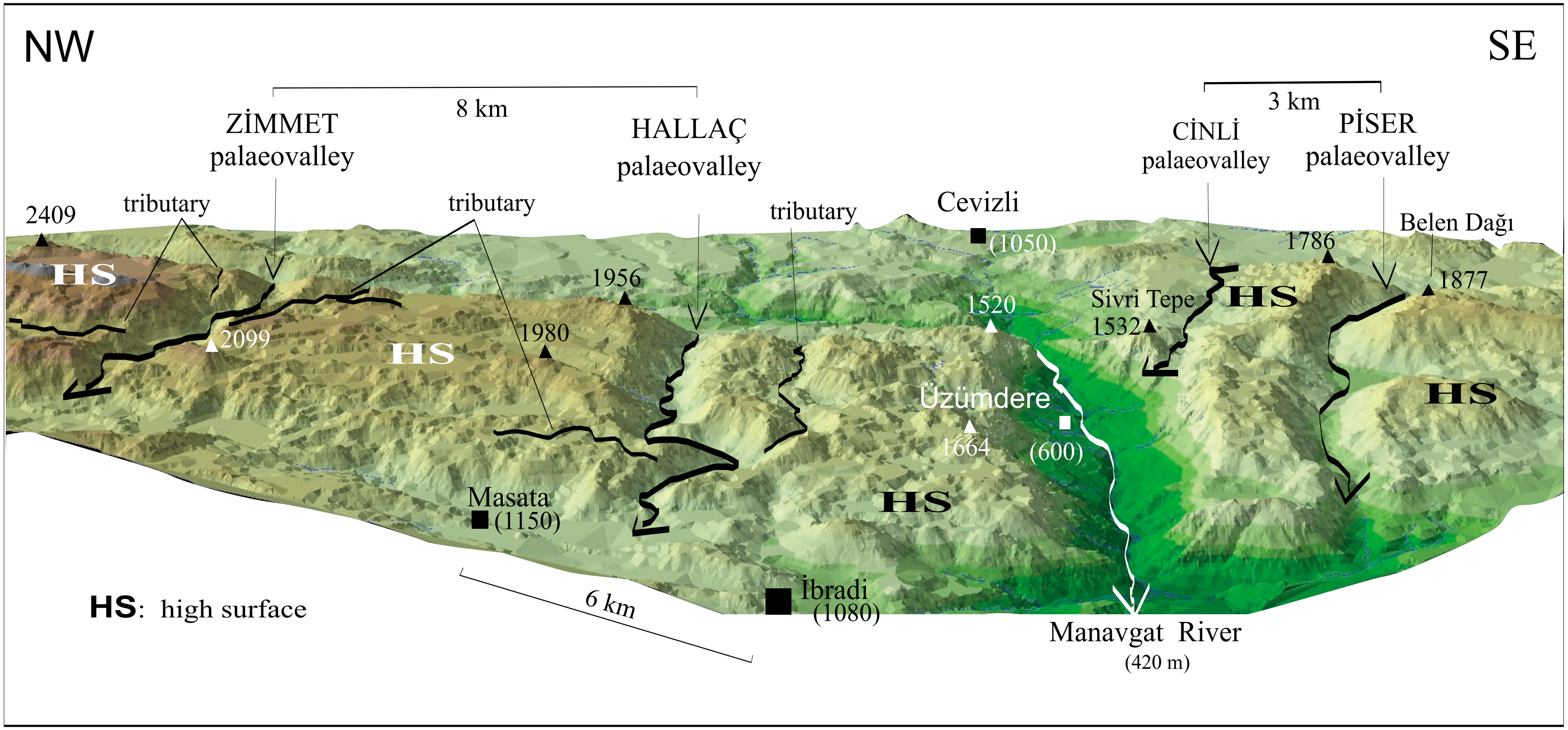

Figure 6. Digital Elevation Model (DEM) picture of the Taurus seen from the south, showing the hanging position of several dry valleys (note the meandering Hallaç palaeovalley) with tributaries, and the much deeper gorge (at Üzümdere) through which the Manavgat River is now flowing. Sun is to the west. Location given in Figure 5.

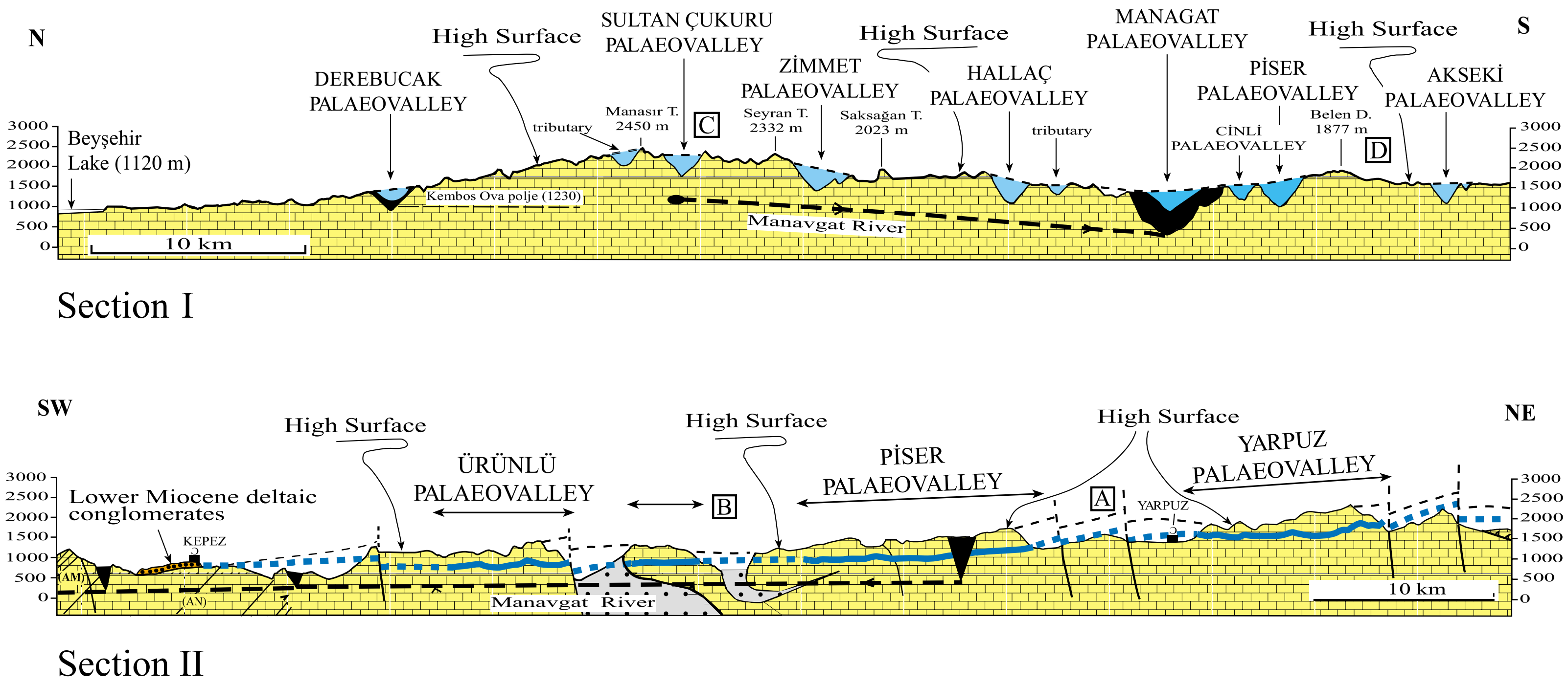

Figure 7. Two morphological profiles (heights x 2) across the Taurus chain (location and **A-B C-D**, in Figure 5). Geological structures are not detailed within the Mezosoic carbonates. **Section I** extends N–S from Beyşehir Lake to Akseki and shows the incisions of the main palaeovalleys (in blue) and those of the present rivers (in black) into the high karstic surface. The high surface is deformed and culminates at 2450 m (Manasır Tepe). **Section II** follows the course of the palaeoriver (dark blue line) which ran from the top of the Yarpuz palaeovalley (1850 m) down to Kepez (750 m) where lie the deltaic Tepekli conglomerates at the base of the Manavgat Basin. The depth of incision of the palaeovalley is relatively uniform (300 to 400 m) throughout the seventy kilometres of its course, but younger faulting has disrupted the former profile in several places. The projected profile of the Manavgat River is about 500 m lower than the fossil valley, hence draining a huge karstic underground circulation today, nearly 1000-m deep, through the carbonates of the Taurus. Dashed lines indicate where the softer formations of the Taurus (flysch and allochthonous units) were eroded after the Early Miocene. Hatched area: Antalya Nappes (AN) and Alanya Massif (AM). In grey with black dots: Eocene flysch.

of the palaeovalleys, independently of their present altitude. The branching of the valleys remains hypothetical upstream, and several river courses are equally conceivable in places where their former trace has been eroded. Whatever the case, the resulting network shows a general drainage trend from NE to SW, with rivers cutting the calcareous ridges at right angles, with junctions in the softer formations running parallel to the structures, thus forming a bayonet-like pattern, resembling that of the Jura Mountains today.

Dating the Palaeotopography on the Taurus Heights

The age of the high palaeosurface into which the valleys were incised is: (i) more recent than the youngest, underlying strata, of Late Eocene age; and (ii) older than the earliest Neogene deposits covering this surface. In the regions of Ermenek and Mut (Figure 15), although Oligocene lacustrine carbonates have been dated locally, an Early Miocene age is attributed to the first extensive brackish to marine deposits lying above the Mesozoic basement (Ilgar & Nemec 2005; Eriş *et al.* 2005). This leaves a large span of time (from Early Oligocene to the earliest Miocene) for erosion to build the surface.

Concerning the palaeodrainage system, a minimum age could be estimated by dating the valley infills (cf. de Broekert & Sandiford 2005; Zilberman 1992). Sediments occupying palaeovalleys have allowed Eriş *et al.* (2005) in the Mut region, and Ocakoğlu (2002) north of Adana, to date a lower Miocene palaeotopography. However, the method is not applicable in this part of the Taurus chain, insofar as most of the palaeovalleys do not contain any infill. Fortunately, a notable exception concerns the conspicuous Miocene deposits situated below the İncebel Pass (2000 m) south of the Dipoyraz Dağ (*In.V.* on Figure 3). In this locality (Figure 8), thanks to a younger offset of the Kırkkavak Fault cutting through the İncebel palaeovalley, a 750-m-thick infill of horizontal, fluviatile conglomerates is clearly exposed (Deynoux *et al.* 2005). Interestingly, on the western side of the İncebel Pass, near Yaka village, these fluviatile conglomerates interfinger with shallow marine sediments of the Köprüçay Basin (Figure 3) which contain pelagic micro- and nannofaunas of Langhian age (NN5) (Deynoux *et al.* 2005). Albeit indirectly, owing to the distance (9 km) separating the fossiliferous locality from the fluviatile deposits of the İncebel Pass, this age strongly suggests that the İncebel palaeovalley was incised before, or at most during, the early–Middle Miocene. As suggested by the apparently coherent palaeodrainage pattern, the uniform morphologic shapes of the valleys and the broadly similar altitudes of the valley floors in this part of the western Taurus, we infer that most of the palaeovalleys should be of about the same age.

Latest Miocene and Younger Morphotectonic Events

The Messinian Crisis: No Evidence in the Taurus Heights

Could the incision of the palaeovalleys be related to the Messinian crisis? Messinian morphology usually corresponds to a regressive erosion process that is best expressed by deep canyons in the lower parts of the valleys. This is probably the case in the lower Aksu Basin (Figure 13), where the incision of a narrow canyon filled by Lower to Middle Pliocene marine deposits has been attributed to the Messinian by Poisson *et al.* (2003). By contrast, the palaeovalleys are situated in the highest parts of the western Taurus, far upstream from the marine basins, and their incision could not have been triggered by the Messinian crisis, the effects of which are not noticeable at such altitudes.

Hanging Valleys

The hanging of the large Miocene fossil valleys over today's river network can be attributed to Mio–Pliocene and Quaternary uplift of the Taurus, followed in turn by: (i) karstification with the development of a large underground network (Ekmekçi 2003), and (ii) differential erosion and incision by superficial waters of today's surficial river network. Surprisingly, however, many of the fossil tributaries are also in a hanging position above the main palaeovalleys (Figure 5), and could result either from glacial erosion during the Quaternary, or from an older step succession induced by the drop of the water base-level in the karst.

Impacts of the Quaternary Glaciations? With the conspicuous exception of Dipoyraz Dağ (2998 m), where several recent glacial valleys and lateral moraines have been recorded (Monod 1977; Şenel 2002), no significant remains of glacial imprint are present on the high surface. The obvious reasons are its insufficient mean altitude and,

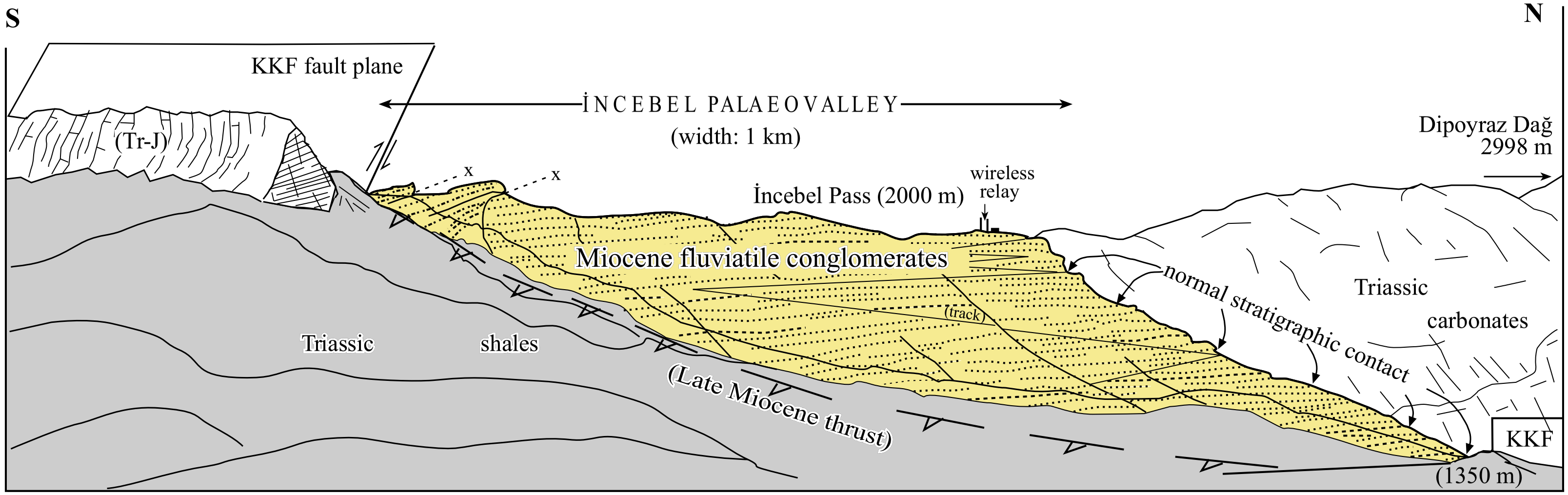

Figure 8. İncebel Pass, viewed from the east, and showing the 750-m-thick fluviatile conglomerate infill of the İncebel palaeovalley resting on Triassic carbonates. On the western side of the pass, near Yaka village, these conglomerates interfinger with marine deposits of Langhian age (Deynoux *et al.* 2005). Location on Figure 3.

in the higher areas, the lack of large, high summits from which ice could accumulate and flow. By contrast, immediately east of the present study area and in a very similar carbonate landscape, Arpat & Özgül (1972) and Çiner *et al.* (1999) have described widespread moraines at about 2000 m and several U-shaped valleys around the Geyik Dağ (2875 m). Except for a very limited cirque west of the Kembos Ova (Çeşgar Tepe 2288 m), no glacial morphology could be detected in the surveyed area. It can thus be confidently ruled out that the small tributaries winding on the high surface and hanging over the main dry valleys resulted from Quaternary glacial erosion.

Abandoned Tributaries: Successive Karstic Stages? The hanging tributaries most probably result from the drop of the underground network, as described in accounts of heavily karstic areas (Ford & Williams 1989). Each successive uplift of the Taurus resulted in a sudden lowering of base level, which was rapidly reached through karstic dissolution, hence abandoning the former tributaries as soon as the main valleys were deep enough. The fossilised valleys and their hanging tributaries now remain remarkably well preserved in the Mesozoic limestones, in spite of the rugged karstic landscape of the high surface (Figure 4).

Tectonic Deformation of the High Surface

If the Early Miocene age of the river network described above is accepted, the reconstructed fossil morphology may be used as a guide to infer the age of several tectonic features which later disrupted the high surface and its drainage system. As a whole, the central part of the study area seems little affected, as shown by the coherent altitudes of both ends of the hanging valleys (***AV, PV, CV, HV*** on Figure 3), with a weak slope oriented to the SW. However, a continuous rise of the high surface (Figure 7-Section I), from Beyşehir Lake (1121 m) to Manasır Tepe (2450 m) and a decrease east of Akseki (1500 m) may reflect a blind, deep-seated thrust of Late Miocene age.

In contrast, the western and eastern borders of the surveyed area are strongly affected by late Miocene and younger faulting. To the west, the Kırkkavak Fault (Dumont & Kerey 1975) and several associated N–S trending faults have elevated several horsts above 2000 m (Figure 3), foundered grabens or half grabens (Eynif Ova, 950 m; Saraycık and Sarıalan Yayla, 1450 m), and inverted the profile of several palaeovalleys towards the NE (***DV, ZV***, and those west of Eynif Ova). The age of these faults is clearly post-early Tortonian (at Sarıalan), and pre-Pliocene (at Eynif Ova) (Deynoux *et al.* 2005). On the eastern side of the area, block faulting also occurred and is conspicuous south of Seydişehir (Figures 3 & 14) with a normal offset exceeding 1000 m. The result was the raising of the dry valley floors to 1900 m, with steeper westward slopes. The lacustrine Plio–Quaternary deposits near Beyşehir seem unaffected, thus constraining the age of these faults to the Late Miocene–Early Pliocene (cf. Koçyigit & Özacar 2003).

Miocene Palaeomorphology in the Western Taurus: New Evidence from Tracer Pebbles

A first study by Flecker (1995) showed that significant variations in composition of the pebbles reflected the parent lithologies surrounding the Miocene conglomerates. This is especially clear around the metamorphic Alanya Massif, which is surrounded by Burdigalian conglomerates containing abundant metamorphic pebbles derived from the Massif. Another case of close relationship is found in the northern part of the Köprüçay Basin, where abundant pebbles of pre-Cambrian diabase and red Carboniferous sandstone may be easily traced to their source rocks in the neighbouring Dipoyraz Dağ (Figure 1). Other lithologies, however, pose more problems, as no convenient source rocks are available in the neighbourhood. Such are the green tuffites of Huğlu, which are good tracers to reconstruct and date the Miocene fluvial network above, and the Alanya blueschists which suggest a much larger extent for the Alanya Massif during the Miocene than now.

Huğlu Pebbles in the Antalya Basin: Dating the Palaeoriver Network of the Western Taurus

Dark green tuffites of Late Triassic age, associated with dacitic lava flows form the bulk of the Huğlu unit in the western Taurus (Monod 1977; Gökdeniz 1981; Andrew & Robertson 2002). Among the various lithologies present in the green tuffites (Figure 9), some exhibit distinctive facies which are readily recognizable. Especially noticeable are the facies that include small green chlorite speckles, 1 to 3 mm across, scattered in a finer chloritic matrix containing small quartz and feldspar grains, and

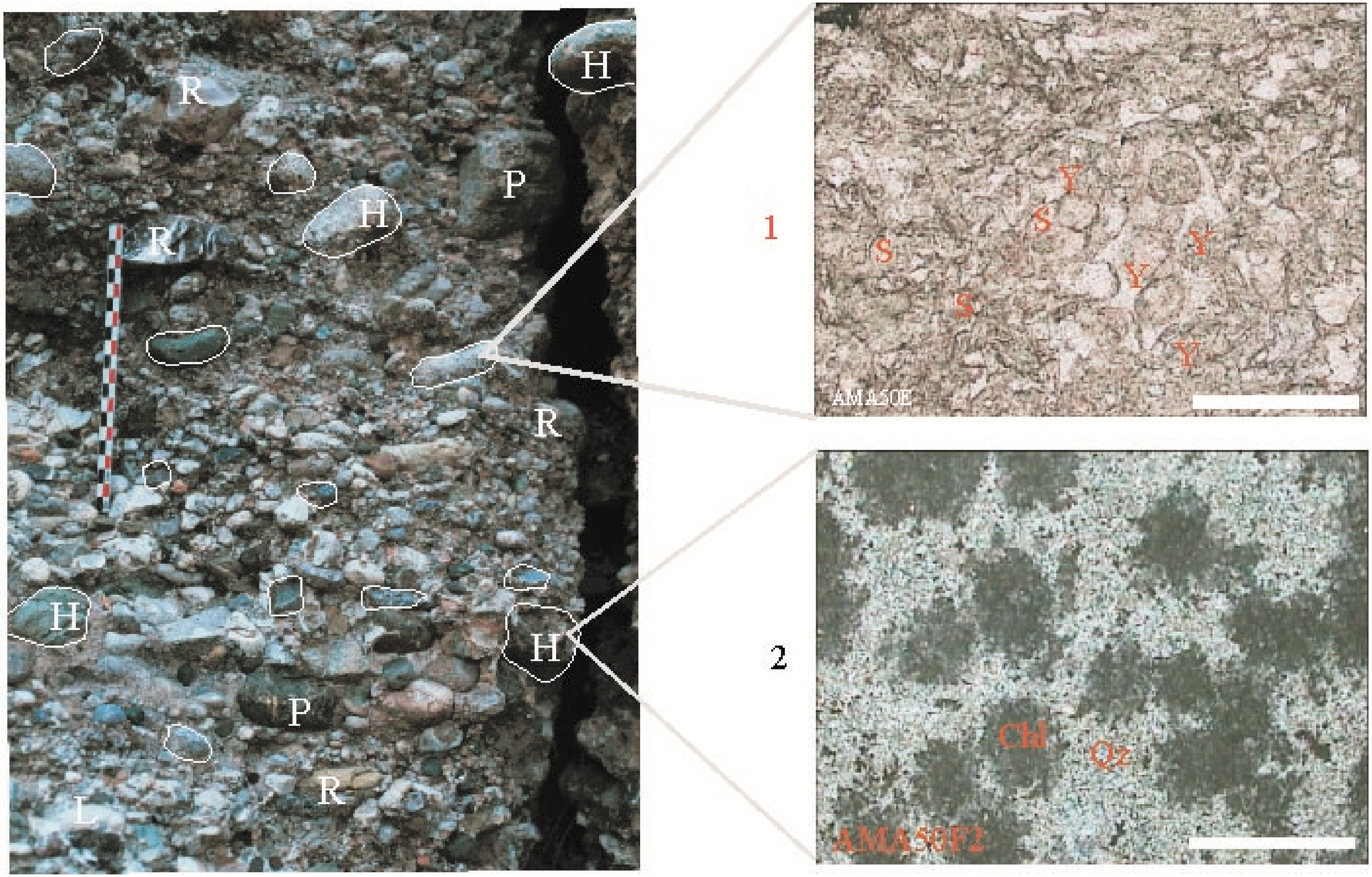

Figure 9. Huğlu tuffitic pebbles (circled) in the Tepekli Dere conglomerate (Burdigalian) near Sevinç (Manavgat Basin, see Figure 3). The other pebbles (not circled) include peridotite (P), radiolarite (R) and carbonates (L). Two thin sections from Huğlu pebbles show: 1– Tuffite with glassy shards with "Y"-branching in a green chloritic matrix (AMA50E); 2– Typical tuffitic facies with chloritic specks dispersed in a finely quartzose matrix (AMA50F). Scale bar: 0.25 mm.

typical glassy shards with curved shapes and Y-shaped branches. Other facies in the Huğlu unit include green volcaniclastic rocks and dacitic breccias. These siliceous facies are hard enough to produce resistant, conspicuous pebbles which are found in great numbers in the conglomerates that lie either at the base of the Manavgat Basin (Tepekli Dere near Sevinç, Burdigalian) (Figure 9), or at the top of the Köprüçay Basin (Sarıalan Yayla, lower Tortonian) (Figure 3). The distance separating the source from their depositional area is over 80 km for the former and about 50 km for the latter.

Thus the pre-Langhian age of the network suggested by the İncebel palaeovalley infill is compatible with that of the Huğlu tracer pebbles found in Burdigalian conglomerates of the Manavgat Basin (Karabıyıkoğlu *et al.* 2000). However, at Sarıalan Yayla, east of the Köprü Basin, the age of the conglomerate containing the Huğlu pebbles is clearly younger (early Tortonian; Babinot 2002) and reflects the latest and highest Miocene transgression which extended landwards as far as the Kelsu locality near Beyşehir Lake, probably through the pre-existing ria of the İncebel palaeovalley (Figure 11). In any case, once eroded from their source area, alluvial pebbles can easily be reworked during another or several other phases of erosion and transportation affecting the earlier deposits. This possibility leads us to select a Burdigalian age for the establishment of the Neogene palaeo-network preserved on the western Taurus heights, in agreement with the presence of Huğlu pebbles in the İncebel Pass infill and in the Tepekli Dere conglomerate.

Alanya Blueschists in the Aksu Basin: Nearby or Distant Sources?

In the lower part of the Miocene Aksu Basin, the occurrence of metamorphic pebbles, including typical blueschist with high pressure-low temperature amphiboles, poses an intriguing problem as it cannot be interpreted (“IMPOSSIBLE PATHWAY” on Figure 1) as a result of transport by a palaeodrainage system as described above. The presence of metamorphic pebbles in the Aksu Basin was already noted along the Sinne Dere by Akay *et al.* (1985). In the course of a survey of the Antalya Neogene basins (Deynoux *et al.* 2005), rapid mapping of the area disclosed the presence of an imbricated tectonic unit, 7-km long and 500-m thick at most, near Taşdibi village (cgt in Figures 12 & 13). This unit is composed of polymictic conglomerates of Middle to Late Miocene age, containing pebbles of metamorphic rocks, sandstone, limestone and spilite. About 20% of the pebbles consist of metamorphic rocks, which include white and dark marble, calc-schist, garnet-quartz mica schist and more importantly blueschist metabasite. The primary mineral assemblage in the blueschist metabasite is garnet + crossite + clinozoisite + phengite + rutile. Garnet porphyroblasts, up to 2 mm across, are set in a fine-grained matrix of sodic amphibole, clinozoisite and phengite. Crossite is rimmed by barroisite and garnet is partly replaced by chlorite. Some of the calc-schist pebbles also contain sodic amphibole along with calcite, quartz and phengite. Lithologically and petrographically the blueschist metabasite, calc-schist and garnet-quartz mica schist pebbles are very similar to those from the Sugözü nappe of the Alanya Massif (Okay & Özgül 1984). As there is no other unit of such blueschists in the western Taurides, the metamorphic pebbles in the Miocene conglomerates must have been derived from the Alanya Massif, 100 km to the southeast. The problem is that, during the Miocene, it is impossible that any drainage system could have existed between the Sugözü nappe and the Aksu Basin, as they were separated at that time by large marine expanses (namely, the Manavgat and Köprüçay basins). Moreover, the size of the rock fragments (up to half a metre) and their poor rounding

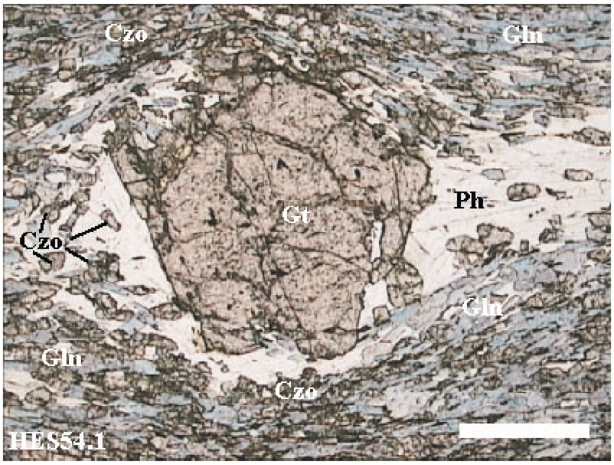

Figure 10. Blueschist pebble in the Aksu basin from Taşdibi unit (Serravallian–Tortonian), location on Figure 12. A typical HP-LT Alanya facies containing large, rotated garnet (Gt) surrounded by phengite (Ph, clear), embedded in a schistose matrix of sodic blue amphibole needles (Glaucophane-barroisite) (Gln), and clinozoisite smaller crystals (Czo). (HES54.1). Scale bar: 0.25 mm.

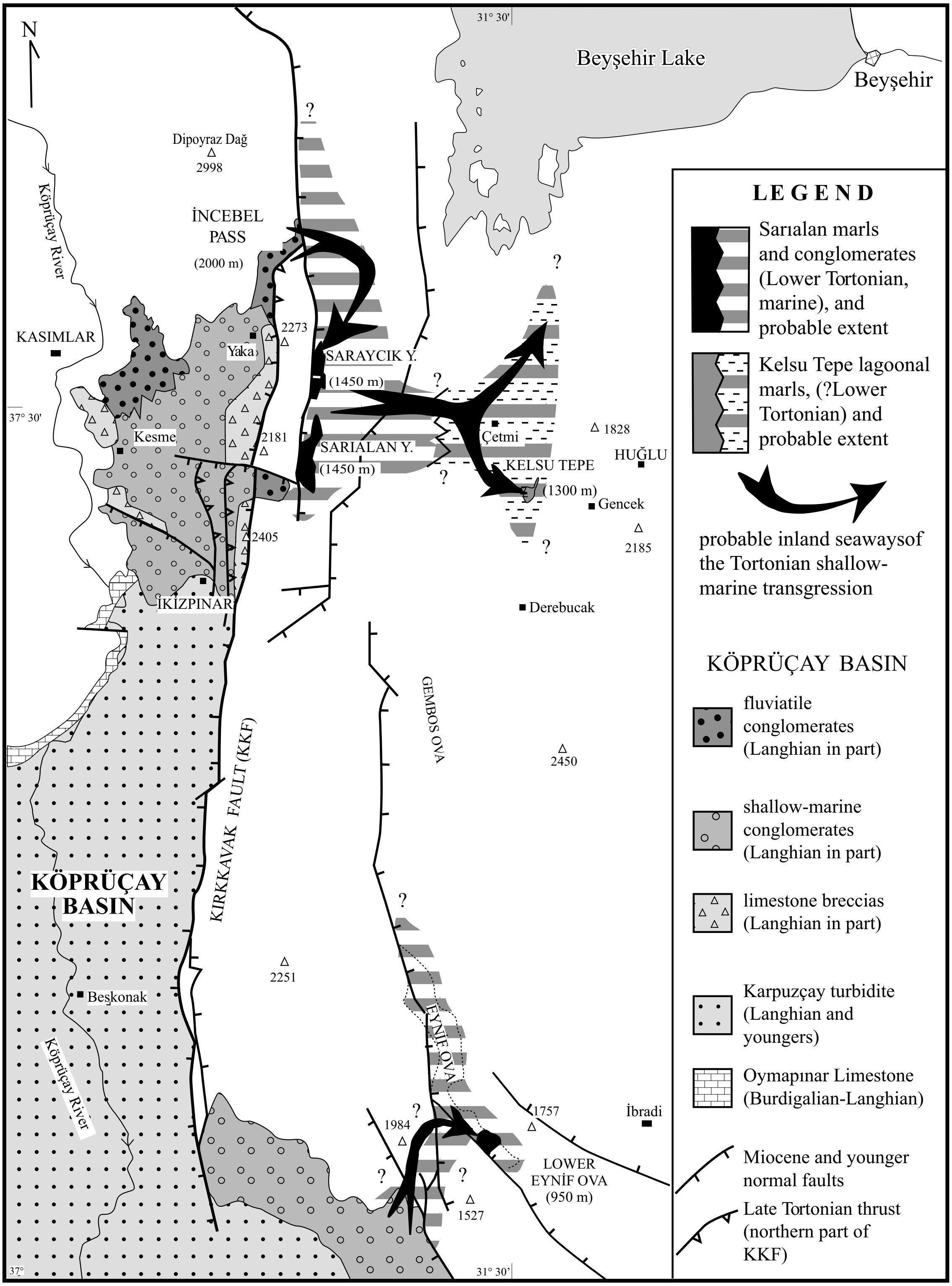

Figure 11. Sketch map of probable Tortonian seaways into the western Taurus. One is in the north, through the ancient ria of the İncebel palaeovalley and accounts for the Lower Tortonian marls in the Saraycık, Sarıalan and Kelsu localities. Another seaway may have been situated south of the Eynif Ova polje, but is not documented.

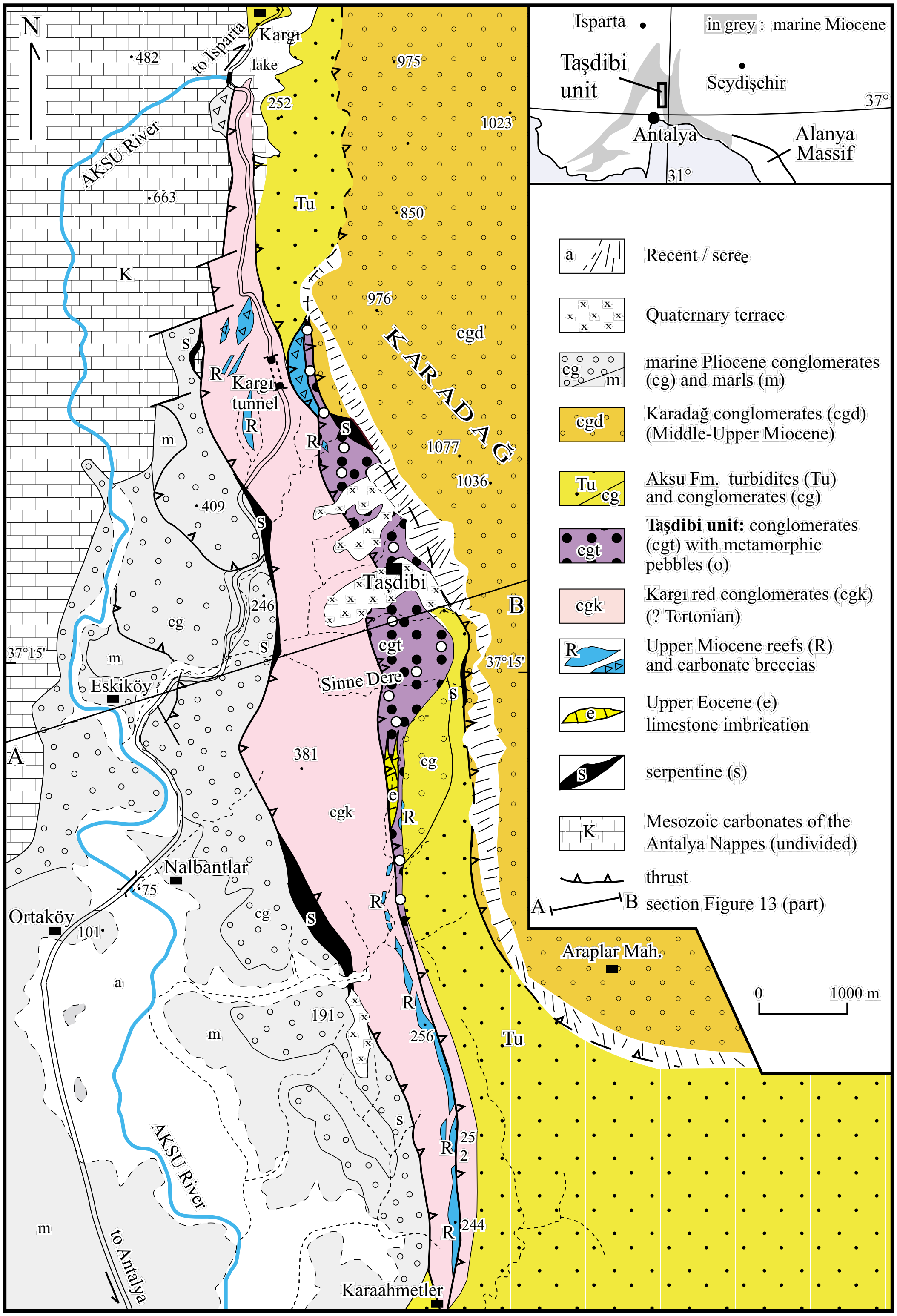

Figure 12. Map of the southern part of the Aksu valley showing the tectonic position of the Taşdibi inlier containing metamorphic pebbles (white circles) derived from the Alanya Massif. A-B: part of the section in Figure 13.

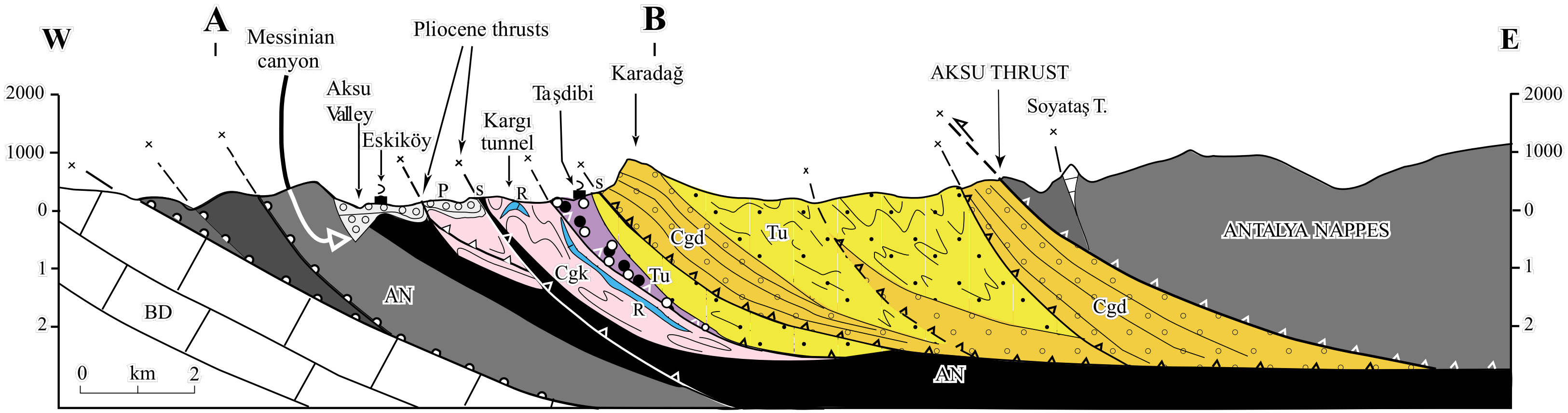

Figure 13. Section of the Taşdibi unit. Explanation as for Figure 12. White circles – metamorphic pebbles (including blueschists) in the Taşdibi conglomerates (cgt, Middle–Late Miocene). Location given in Figure 1.

preclude lengthy transport. A westerly origin, from the HP-LT rocks of the Lycian nappes can be excluded, owing to the distance and the distinct facies with abundant carpholite of the high-pressure units surrounding the Menderes Massif (Rimmelé *et al.* in press).

We must therefore conclude that, during the Miocene, the metamorphic Alanya Massif extended much farther westward, probably as far as Antalya, as shown in Figure 1. This conclusion is further supported by two small inliers (less than one kilometre long) of typical metamorphic rocks of the Alanya Massif situated in an intermediate position (two stars on Figure 1), that were already noted on Akay's map (1985). Erosion of the Sugözü nappe took place first, as indicated by the greater abundance of HP-LT pebbles in the lowest part of the Taşdibi conglomerates, in agreement with the higher tectonic position of the Alanya Massif atop the Antalya units. Subsequent erosion affected the underlying Antalya nappes and progressively produced the usual polymictic facies of the Miocene conglomerates in which metamorphic pebbles become quite scarce.

Conclusions

Morphotectonic Evolution of the Western Taurus during the Neogene

Although highly speculative in places, several steps may be proposed in deciphering the morphotectonic evolution of the western Taurus:

- During the Oligocene and earliest Miocene (Figure 14A), erosion prevailed and partly levelled the recently (Late Eocene) structured Taurus chain, resulting in a somewhat irregular, but low topography, which was cut into either calcareous or softer formations. Most of the tracer pebbles (Huğlu tuffites) were transported and deposited at that time. As suggested by the meanders of several palaeovalleys flowing from NE to SW, the regional topography displayed a weak slope. This pattern also suggests the probable absence of significant karstic circulation, which would have disrupted the river flows.
- Subsequent rise of the Taurus belt resulted in deep incision of the valleys (Figure 14B) which could, however, maintain their former shapes, hence producing entrenched meanders through the calcareous ridges, with hanging tributaries due to the rapid onset of underground circulation in the karstic areas.
- During the Late Langhian, a rapid rise of sea level (Karabıyıkoglu *et al.* 2000) induced a short-lived transgression which allowed deltaic sedimentation at the mouths of the rivers, as vividly exemplified by the thick accumulation of Langhian fluviatile to marine conglomerates in the Incebel Valley (Deynoux *et al.* 2005).
- During the Middle and early Late Miocene, although no direct evidence is available, the drainage system of the Taurus was still continuously active, as suggested by the abundance of polymict coarse detrital materials shed into the Manavgat and Köprü basins during that interval (Karpuzçay formation, Karabıyıkoglu *et al.* 2000).
- Early in the Tortonian, a final transgression brought shallow-marine influences far into the chain (Figure 11) through a few narrow rias corresponding to the main palaeovalleys, as shown by the deltaic conglomerates and shallow-marine marls in the Sarıalan, Saraycık, Kelsu and (possibly) Eynif Ova localities (Figure 3).
- Late in the Tortonian, the fluvial network of the Taurus was suddenly disrupted by major tectonic events, which resulted in a series of normal and reverse faults in the western part of the chain (Figure 3). Some of the faulted blocks were elevated, and rapid development of karstic circulation through the carbonate rocks prevented further erosion of the former fluviatile morphology, thus preserving the fossil valleys in the higher parts of the Taurus.
- In the nearby Aksu Basin, strong uplift during the Late Miocene is indicated by the complete erosion of the neighbouring metamorphic Alanya Massif, which was situated atop the Antalya nappe pile, and the coeval deposition of metamorphic pebbles in a shallow-marine environment. This uplift was probably induced by a compressional event such as the Aksu Phase (Poisson *et al.* 2003), which is responsible for most of the westward imbricated structures in the Aksu Basin (Figure 13).
- During the Pliocene and Quaternary (Figure 14C), major uplift of the western Taurus as a whole subjected the chain to intense erosion, renewing karstic circulation in the carbonate rocks, removing part of the softer terrains, and so destroying the ancient fluviatile morphologies there. Plio–Quaternary coarse detrital materials accumulated in the endoreic

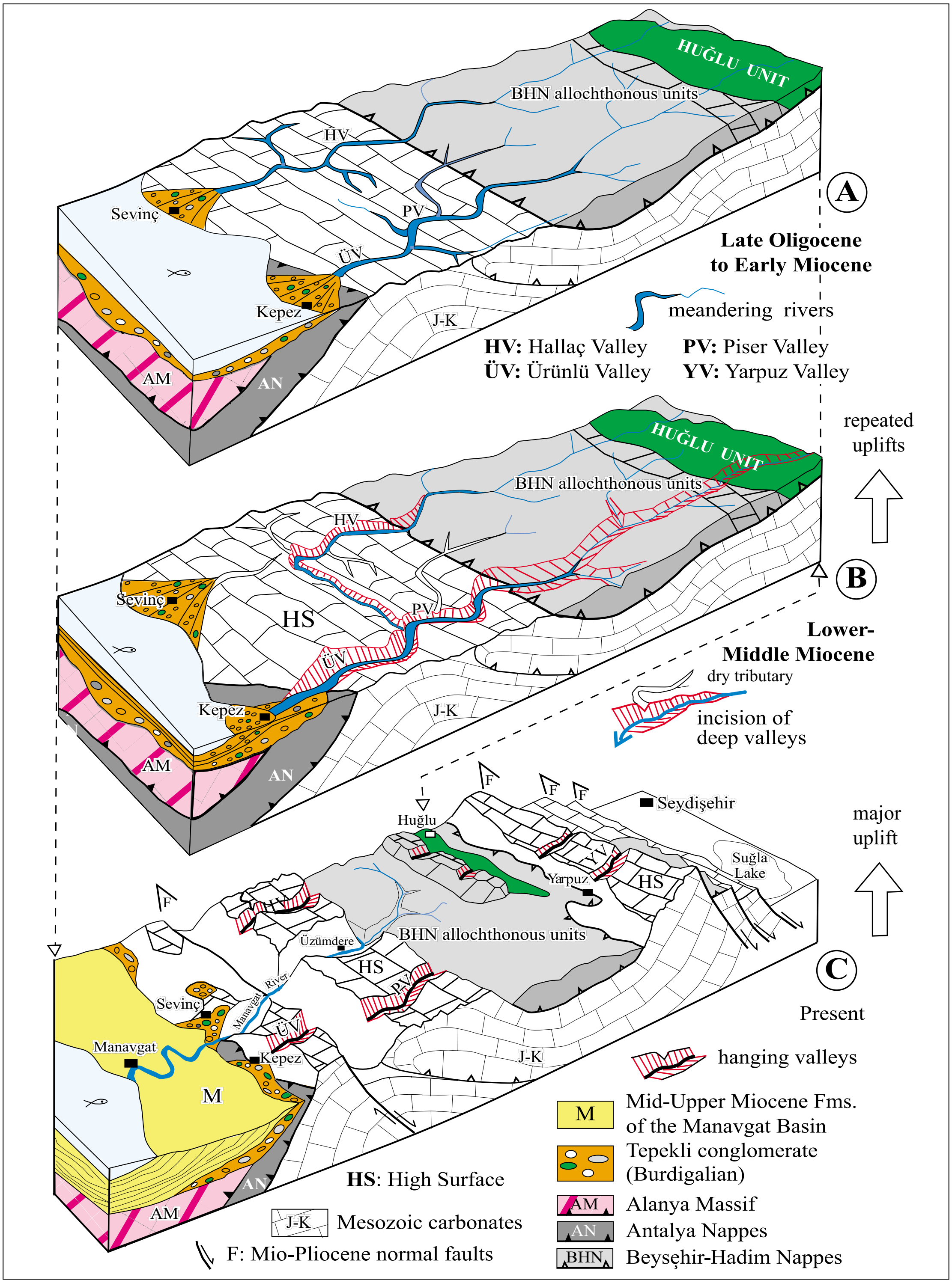

Figure 14. Three cartoons illustrating the morphologic evolution of the western Taurus from Oligocene to Present. (A) A flat morphology in the western Taurus during the Oligocene and Early Miocene; (B) Uplifting and incision of deep valleys (in red) into the high surface (HS) during Lower–Middle Miocene; and (C) Present aspect of the Taurus chain with isolated remains of the High Surface and several fragments of the former drainage system (“hanging valleys”).

basins (Beyşehir depression) but mostly seawards (Belkis conglomerates, Blumenthal 1951).

- On a larger scale, the fossil drainage identified here (Figure 15) embraces only part of a much wider area of southern Turkey which was exposed during the Neogene, shedding materials mostly towards the Mediterranean. Because it escaped the main Miocene deformations, this area has preserved its original palaeogeographic framework. In addition to the area discussed above, between Beyşehir and Manavgat, a rough DEM map (Figure 15) illustrates the probable extent of the Miocene aerial surface in the Taurus,

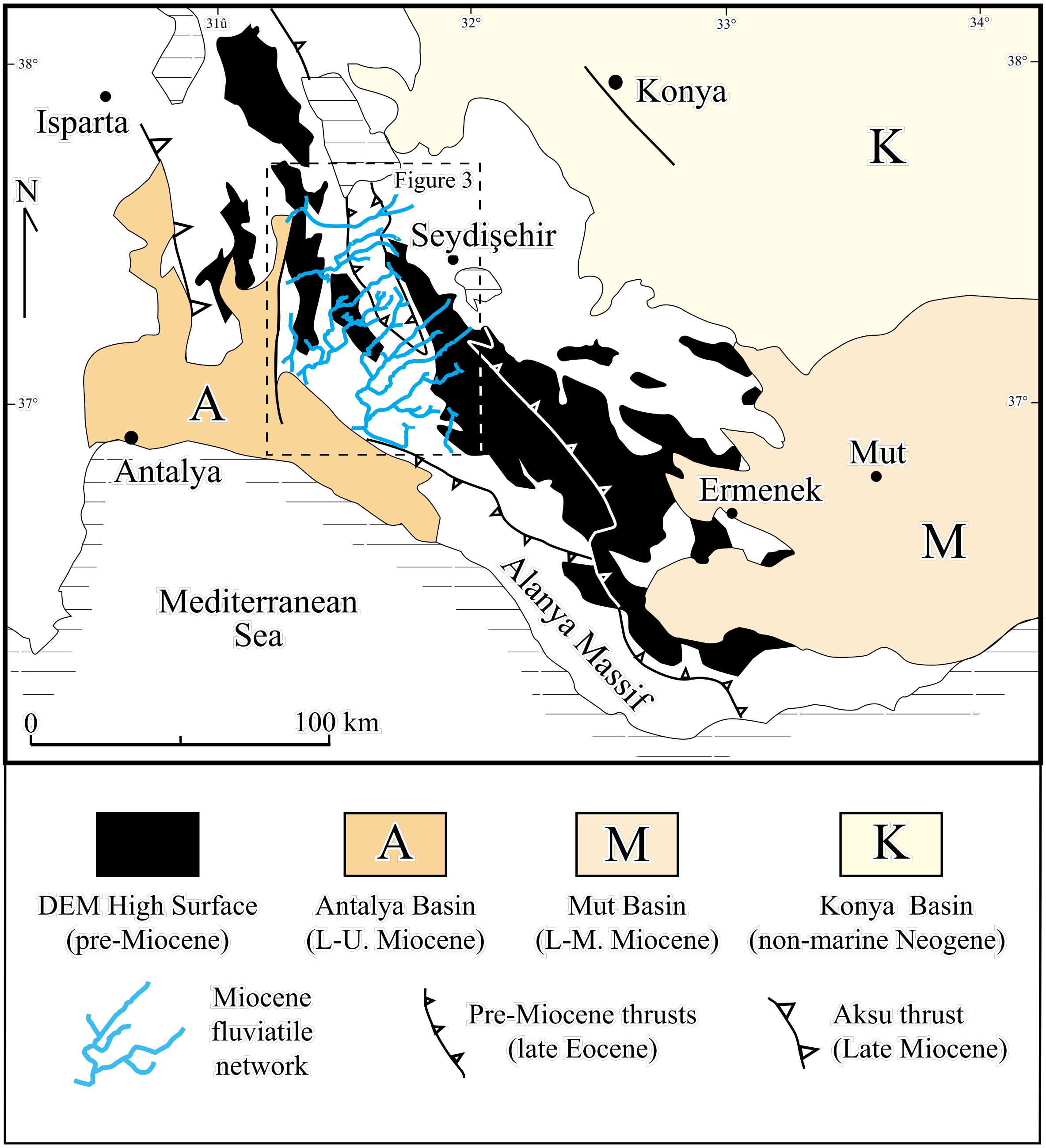

Figure 15. Extent of the High Surface (in black) as shown by a Digital Elevation Model (DEM) of the western and central Taurus, and the three surrounding Neogene basins (Antalya, Mut, Konya). In blue, situation of the fossil drainage network described above.

thus showing where other ancient morphologic features could be preserved. Delimitation of this vast area is only approximate, and additional fossil features have still to be identified and dated where possible, to refine the shape of the oldest morphology of the Taurus chain.

Acknowledgements

O.M. is grateful to M. Karabıyıkoğlu, M. Deynoux and A. Çiner for numerous hot discussions in the field on the Miocene detrital materials, to M. Bakalowicz for fruitful information on the karstic processes, to B. Vigier for producing a DEM map of part of the Taurus, and N. Rouchon for the figures. W.T. Dean very kindly corrected the English text. The authors acknowledge the Turkish Academy of Sciences, the French Ministry of Foreign Affairs (MAE), ISTO-CNRS (Orléans) and MTA (Ankara) for financial support, exchanges and fieldwork facilities. The authors thank A. Koçyigit and K. Dirik for their useful suggestions. This work formed part of the TÜBİTAK-CNRS joint project N° 5785.

References

AKAY, E., UYSAL, S., POISSON, A., CRAVATTE, J. & MÜLLER, C. 1985. Stratigraphy of the Antalya Neogene Basin. *Bulletin of the Geological Society of Turkey* **28**, 105–119.

ANDREW, T. & ROBERTSON, A.H.F. 2002. The Beyşehir-Hoyran-Hadim nappes: genesis and emplacement of Mesozoic marginal and oceanic units of the Northern Neotethys in southern Turkey. *Journal of the Geological Society, London* **159**, 529–543.

ARPAT, E. & ÖZGÜL, N. 1972. Rock glaciers around Geyik Dağ, Central Taurides. *Mineral Research and Exploration Institute of Turkey (MTA) Bulletin* **78**, 28–32.

BABINOT, J.-F. 2002. Ostracodes miocènes de séries annexes aux bassins de Köprüçay et de Manavgat, région d'Antalya (sud Turquie). Revue Paléobiologie, *Genève* **21**, 735–757.

BIROT, P. & DRESCH, J. 1956. *La Méditerrannée et le Moyen Orient*, t. 2, 526 p.

BLUMENTHAL, M. 1951. *Recherches géologiques dans le Taurus Occidental dans l'arrière-pays d'Alanya.* Mineral Research and Exploration Institute of Turkey (MTA) Publications D5, 134 p.

ÇINER, A., DEYNOUX, M. & ÇÖREKÇIOĞLU, E. 1999. Hummocky moraines in the Namaras and Susam Valleys, Central Taurides, SW Turkey. *Quaternary Science Reviews* **18**, 659–669.

DE BROEKERT, P. & SANDIFORD, M. 2005. Buried inset-valleys in the eastern Yilgarn Craton, western Australia: geomorphology, age, and allogenic control. *The Journal of Geology* **113**, 471–493.

DEYNOUX, M., ÇINER, A., MONOD, O., KARABIYIKOĞLU, M., MANATSCHAL, G. & TUZCU, S. 2005. Facies architecture and depositional evolution of alluvial fan to fan-delta complexes in the tectonically active Miocene Köprüçay Basin, Isparta Angle, Turkey. *Sedimentary Geology* **173**, 315–343.

DUMONT, J.-F. & KEREY, E. 1975. Kırkkavak fayı: batı Toroslar ile Köprüçay Baseni sınırında kuzey–güney duğrultu atımlı fay [Kırkkavak fault: A N–S-trending strike-slip fault at the contact between the western Taurides and Köprüçay Basin]. *Bulletin of the Geological Society of Turkey* **18**, 59–62 [in Turkish with English abstract].

EKMEKÇI, M. 2003. Review of Turkish karst with emphasis on tectonic and palaeogeographic controls. *Acta Carsologica* **32**, 205–218.

ERIŞ, K., BASSANT, P. & ÜLGEN, U. 2005. Tectono-stratigraphic evolution of an Early Miocene incised valley-fill in the Mut Basin, southern Turkey. *Sedimentary Geology* **173**, 151–185.

FLECKER, R., ROBERTSON, A.H.F., POISSON, A. & MÜLLER, C. 1995. Facies and tectonic significance of two contrasting Miocene basins in south coastal Turkey. *Terra Nova* **7**, 221–232.

FORD, D.C. & WILLIAMS, P.W. 1989. *Karst Geomorphology and Hydrology.* Unwin Hyman, London, 583 p.

GÖKDENIZ, S. 1981. *Recherches géologiques dans le Taurus occidental entre Karaman et Ermenek. Les séries à Tuffites vertes triasiques.* PhD Thesis, Université Paris-Sud, Orsay, 202 p [unpublished].

GUTNIC, M., MONOD, O., POISSON, A. & DUMONT. J.-F. 1979, Géologie des Taurides occidentales. *Mémoire Société géologique de France* **137**, 1–112.

ILGAR, A. & NEMEC, W. 2005. Early Miocene lacustrine deposits and sequence stratigraphy of the Ermenek Basin, central Taurides, Turkey. *Sedimentary Geology* **173**, 233–275.

KARABIYIKOĞLU, M., ÇINER, A, MONOD, O., DEYNOUX, M., TUZCU, S. & ÖRÇEN, S., 2000. Tectonosedimentary evolution of the Miocene Manavgat Basin, Western Taurids, Turkey. *In*: BOZKURT, E., WINCHESTER, J.A. & PIPER, J.A.D. (eds.), *Tectonics and Magmatism in Turkey and the Surrounding Area.* Geological Society, London, Special Publications **173**, 475–498.

KOÇYIĞIT, A. & ÖZACAR, A. 2003. Extensional neotectonic regime through the NE edge of the outer Isparta Angle, SW Turkey: new field and seismic data. *Turkish Journal of Earth Sciences* **12**, 67–90.

KOÇYIĞIT, A., ÜNAY, E. & SARAÇ, G. 2000. Episodic graben formation and extensional neotectonic regime in west Central Anatolia and the Isparta Angle: a case study in the Aksehir-Afyon Graben, Turkey. *In*: BOZKURT, E., WINCHESTER, J.A. & PIPER, J.A.D. (eds.), *Tectonics and Magmatism in Turkey and the Surrounding Area.* Geological Society, London, Special Publications **173**, 405–421.

LOUIS, H. 1956. Die Enstehung der Poljen und ihre Stellung in der Karstabstragung, auf Grund von Beobachtungen im Taurus. *Erdkunde Archiv für wissenschaftliche Geographie* X, 33–53.

MONOD, O. 1977. *Recherches géologiques dans le Taurus Occidental au sud de Beyşehir (Turquie)*. PhD thesis, Université Paris-Sud Orsay, 442 p [unpublished].

MONOD, O. 1979. *Carte géologique du Taurus Occidental au sud de Beysehir et Notice explicative*. Editions du CNRS, Paris, 60 p.

NAZIK, L. 1992. *Beyşehir Gölü Güneybatısı ile Kembos Polyesi Arasının Karst Jeomorfolojisi* [Karst Geomorphology of the Area between Kembos Polye and SW Beyşehir Lake]. PhD thesis, İstanbul Üniversitesi, 298 p [in Turkish with English abastract, unpublished].

OCAKOĞLU, F. 2002. Palaeoenvironmental analysis of a Miocene basin in the high Taurus (southern Turkey) and its palaeogeographical and structural significance. *Geological Magazine* **139**, 473–487.

OKAY, A.İ. & ÖZGÜL, N. 1984. HP/LT metamorphism and the structure of the Alanya Massif, southern Turkey: an allochthonous composite tectonic sheet. *In*: ROBERTSON, A.H.F. & DIXON, J.E. (eds.), *The Geological Evolution of the Eastern Mediterranean.* Geological Society, London, Special Publications **14**, 429–439

POISSON, A., WERNLI, R., SAGULAR, E.K. & TEMİZ, H. 2003. New data concerning the age of the Aksu Thrust in the south of the Aksu Valley, Isparta Angle (SW Turkey): consequences for the Antalya Basin and the Eastern Mediterranean. *Geological Journal* **38**, 311–327.

RIMMELÉ, G., OBERHÄNSLI, R., CANDAN, O., GOFFÉ, B. & JOLIVET, L. (in press) The wide distribution of the HP-LT rocks in the Lycian belt (W Turkey): implications for the accretionary wedge geometry.

ŞENEL, M. 2002. *Geological Map of Turkey (1/500000), Konya Sheet.* Mineral Research and Exploration Institute of Turkey (MTA) Publications, Ankara.

ZILBERMAN, E. 1992. Remnants of Miocene landscape in the central and northern Negev and their paleogeographical implications. *Israel Geological Survey Bulletin* **83**, 1–54.

Received 23 April 2005; revised typescript accepted 12 June 2005