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Late Cenozoic Sedimentary Evolution of the Antalya Basin, Southern Turkey

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Abstract: The Late Cenozoic Antalya Basin developed unconformably on a foundered basement comprising Mesozoic autochthonous carbonate platform(s) overthrust by the Lycian Nappes, the Antalya Nappes and the Alanya Massif metamorphics within the Isparta Angle, southern Turkey. The present configuration of the basin consists of three distinct parts, referred herein as the Aksu, Köprüçay and Manavgat sub-basins, respectively, which are divided by the north–south-trending Kırkkavak Fault and the westward-verging Aksu Thrust.

The Miocene fill of each sub-basin is characterized by thick accumulations of non-marine to marine clastics with locally developed coralgal reefs and reefal shelf carbonates. Based on lithostratigraphic and chronostratigraphic considerations, integrated with previously established data, the Miocene fill of the Antalya Basin is reorganized into nine formations and twelve members. A total of nineteen facies have been distinguished within this stratigraphic framework. The stratigraphic organization and the time and space relationships of these facies indicate contrasting styles of sedimentation characterized by several facies associations representing deposition in colluvial and alluvial fan/fan delta with coralgal reefs, reefal shallow carbonate shelf, base of fault-controlled fore reef slope and clastic open marine shelf environments in the tectonically active sub-basins. The coralgal reefs, which occur as small, isolated patch reefs developed on progradational alluvial fan/fan delta conglomerates, and the reefal shelf carbonates represent small to large scale, transgressive-regressive cycles which are closely associated with the complex interaction between sporadic influxes of coarse terrigeneous clastics derived from the tectonically active basin margins and/or related to the eustatic sea level changes during Late Burdigalian–Langhian and Late Tortonian–Messinian times.

With regard to structural history, the Antalya Neogene basins exhibit contrasting behaviour according to their position within the Isparta Angle. West of Antalya, the Lycian Basin is linked to the eastwards advance of the overlying Lycian Nappes up to the Burdigalian; in the centre of the Isparta Angle, the Aksu and Köprüçay sub-basins are younger (Serravalian–Tortonian) and exhibit intense deformation, reflecting west-directed compressional events of Late Miocene to Lower Pliocene age. In contrast, the Manavgat sub-basin situated further east is only weakly deformed, and even farther east, the Ermenek and Mut basins are almost undeformed. Thus the evolution of the Neogene Antalya basins highlights the fundamental structural asymmetry of the Isparta Angle.

Key Words: stratigraphy, basin analysis, facies, coralgal reefs, fan delta, tectonics, palaeoenvironment, Isparta Angle, Taurides, Turkey

Geç Senozoik Antalya Havzası'nın Çökel Dolgu Evrimi

Özet: Isparta Dirseği'nde yeralan Geç Senozoyik yaşlı Antalya Havzası Miyosen çökel dolgusunun stratigrafisi, fasiyes düzeni ve çökelme ortamları, tektonik olarak aktif bir bölgedeki havza oluşumunun, evriminin ve deformasyonunun anlaşılmasına katkı koymak amacıyla irdelenmiştir. Çalışma özellikle havza çökel dolgusunu oluşturan çökelme ortamlarının gelişimlerini denetleyen tektonik, iklimsel ve östatik kökenli etkenleri tartışmayı ve bunların Isparta Dirseği'nin kapanmasının son dönemlerinin açıklanmasına getireceği katkılar bakımından önemlerini ortaya koymaya yönelik olarak geliştirilmiştir.

Antalya Havzası, Isparta Dirseği'nde Mesozoyik yaşlı paraotokton karbonat platform(ları) ile allokton birimlerden (Likya ve Antalya napları ile Alanya Metamorfik Masifi) oluşan bir temel üzerinde, genişleme-sıkışma tektonizması etkinliğinde, uyumsuz olarak gelişmiş bir geç orojen sonrası havzadır. Bu havzanın Miyosen yaşlı çökel dolgusu, yerel olarak gelişmiş resifler ve resifal karbonatlar içeren, kırıntılı egemen kalın çökel birikimi ile temsil edilmektedir. Antalya Havzası'nın bu Miyosen çökel dolgusu, kronostratigrafik ve litostratigrafik bulguların daha önceki çalışmalar tarafından ortaya konulmuş veriler ile birlikte değerlendirilmesi sonucu olarak dokuz formasyon ve oniki üye kapsamında ele alınarak tanımlanmıştır. Bu stratigrafik çatı kapsamında toplam ondokuz fasiyes tanımlanmıştır. Fasiyesler arası yatay (mekan) ve düşey (zaman) ilişkileri koluviyal yelpaze, alüvyon yelpazesi, yama resifleri içeren yelpaze deltası, delta önü-açık kırıntılı şelf, yamaç tabanı-havza düzlüğü yelpazesi, resifal karbonat şelf ve fay-denetimli resif önü yamacı ortamlarında gerçekleşen çökelimi yansıtan değişik fasiyes topluluklarının varlığını göstermektedir.

Antalya Havzası Geç Miyosen şıkışma tektoniği deformasyonu nedeniyle parçalanarak üç alt havzadan oluşan günümüzdeki konumunu kazanmıştır. Birbirlerinden kuzey–güney uzanımlı Kırkkavak Fayı ve batı yönlü Aksu Bindirmesi ile ayrılan alt havzalar, bu çalışmada Aksu, Köprüçay ve Manavgat alt havzaları olarak tanımlanmışlardır.

Doğuda yeralan kuzeybatı–güneydoğu uzanımlı Manavgat alt havzası, Burdigaliyen–Langiyen yaşlı alüvyon yelpazesi, yama resifleri içeren yelpaze deltası, resifal karbonat şelfi, Geç Langiyen–Serravaliyen yaşlı fay denetimli resif önü yamacı ve yamaç tabanı-havza düzlüğü yelpazesi ve Tortoniyen–Messiniyen yaşlı yelpaze deltası ortamlarına özgü çökeller ile temsil edilen bir çökel dolgu içermektedir. Hafif deformasyona uğramış bu alt havza olasılıkla Adana Havzası ile bağlantılıdır.

Diğer taraftan kuzey–güney uzanımlı Köprüçay ve Aksu alt havzaları yoğun tektonizma geçirmişlerdir. Köprüçay alt havzası egemen olarak Burdigaliyen–Langiyen yaşlı koluviyal yelpaze, alüvyon yelpazesi, yama resifleri içeren yelpaze deltası ve delta önü-açık deniz çökelme ortamları ile resifal karbonat şelfi ortamına özgü çökel dolgulardan oluşan bir istif ile temsil edilmektedir. Fasiyes ilişkileri ve yaş bulguları, kuzeyden güneye doğru alüvyon yelpazesinden, yelpaze deltası ve sualtı fasiyeslerine doğru bir geçişin varlığını ve Kırkkavak Fayı'na doğru bir derinleşmenin gerçekleştiğini göstermektedir. Bu fay boyunca izlenen kaba taneli kireçtaşı breşi (kısmen Langiyen yaşlı) çökelme ile eşzamanlı tektonik etkinliğe işaret etmektedir. Ayrıca havzanın batı kenarındaki Langiyen ve daha genç yaşlı yelpaze deltası çakıltaşlarının havza tabanındaki resifal şelf karbonatlarının (Oymapınar Kireçtaşı) üzerine belirgin bir şekilde aşmalı olarak gelmesi, havza gelişiminin erken aşamasında eğimlendiğini göstermektedir.

Aksu alt havzası çökel dolgusu Serravaliyen–Tortoniyen yaşlı alüvyon yelpazesi, yama resifleri içeren yelpaze deltası ve delta önü-açık deniz ortamları ile Messiniyen–Erken Pliyosen yaşlı resifal karbonat şelfi ortamı ile temsil edilen çökel istiflerden oluşmaktadır. Geç Tortoniyen yaşlı Aksu Bindirmesi'nin önünde batıya doğru gelişmiş bindirmeler bulunmaktadır. Eskiköy yakınındaki Pliyosen yaşlı çakıltaşlarında izlenen bir genç bindirme Isparta Dirseği'nin kapanmasının son dönemini yansıtmaktadır.

Algli mercan resifleri, her üç alt havzada da, Miyosen yaşlı kırıntılı çökel istifler içerisinde yaygın olarak bulunmaktadırlar. Bu resifler Akdeniz çevresi mercan faunası ile oldukça benzerlik sunan mercan toplulukları ile temsil edilmektedirler. Bu resiflerin bileşimleri ile fasiyes ve ortamsal konumları, Miyosen stratigrafisinin daha iyi kavranmasına ve tektonik olarak aktif bir havzadaki resiflerin zaman ve mekan içerisindeki gelişimlerinin anlaşılmasına katkı koymak amacıyla ayrıntılı olarak irdelenmişlerdir. Masif, küçük boyutlu yama resifleri olarak bulunan bu resifler, Erken–Orta Miyosen (Burdigaliyen–Langiyen) ve Geç Miyosen (Tortoniyen–Messiniyen) dönemlerinde ilerleyen yelpaze deltası çakıltaşları ve transgresif şelf karbonatları olmak üzere iki farklı zaman aralığında ve çökelme ortamında gelişmişlerdir.

Bu alt havzaların oluşumları ve deformasyonları Anadolu mikrolevhasının güneydoğu Anadolu'da gerçekleşen Miyosen çarpışmasını izleyen dönemdeki batıya doğru kaçışı ile bağlantılı olarak açıklanabilir. Isparta Dirseği, Burdigaliyen–Langiyen sırasında halen tümüyle açık bulunmaktadır ve bu dönemde burada gerçekleşen sıkışma kökenli deformasyona ilişkin herhangi bir bulgu bulunamamıştır. Aksine bu dönemde, yeni oluşan Manavgat alt havzası ile Kıbrıs'ı Anadolu karasından ayıran Mut ve Adana havzalarının da açılması gerçekleşmiştir. Langiyen'de Kırkkavak Fayı'nın yeniden harekete geçtiği bu fay boyunca izlenen kireçtaşı breşlerinin varlığı ile kanıtlanmaktadır. Bunun sonucu olarak Köprüçay alt havzası asimetrik olarak derinleşmiştir. Taban birimini oluşturan Oymapınar Kireçtaşı'nın doğuya doğru eğimlenmesi ve bunun üzerine Langiyen–Serravaliyen yaşlı kırıntılı çökellerin aşmalı olarak gelmeleri bu olayın diğer kanıtlarıdır. Bu deformasyon Serravaliyen sırasında batıya doğru göç ederek Isparta Dirseği'nin kapanmasına ve Isparta Dirseği'nin ekseni boyunca bir sıkışma havzası olarak Aksu alt havzasının oluşmasına neden olmuştur. Aksu alt havzası güney kesiminde, günümüzde 100 km daha güneydoğu'da bulunan Alanya Masifi'nden türemiş yüksek basınç-düşük sıcaklık koşullarına özgü metamorfik çakıllar bulunmaktadır. Alt Tortoniyen sırasında gerçekleşen son transgresif dönem, Kırkkavak Fayı'nın normal aktivitesinin sona erdiğini belirtir. Tortoniyen sonunda Anadolu mikrolevhasının, saatin ters yönünde rotasyona uğrayan Likya Napları'na karşı, batıya doğru göç etmesi olasılıkla Aksu alt havzasındaki Miyosen çökellerinin bindirmeler oluşturmasına ve Kırkavak Fayı'nın ters fay olarak işlemesine neden olmuştur. Isparta Dirseği günümüzdeki konumunu bu dönemde kazanmıştır. Pliyosen sırasında Aksu alt havzasındaki Pliyosen akarsu çakıltaşları üzerine Miyosen çökellerinin bindirmesi, Isparta Dirseği ekseninde batıya doğru yaşanan son sıkışma dönemini göstermektedir. Bu olay sonrasında Anadolu mikrolevhasının genel yükselimi gerçekleşmiştir.

Anahtar Sözcükler: stratigrafi, havza analizi, fasiyes, mercan resifi, yelpaze deltası, tektonik, paleoortam, Isparta Açısı, Toros Dağları, Türkiye

Introduction

The Late Cenozoic Antalya Basin, represented by the Aksu, Köprüçay and Manavgat sub–basins, is located within the Isparta Angle, a conspicuous syntaxis situated between the Mid Miocene Aegean and Lycian arcs and the Late Eocene Taurus arc within the Alpine chain in southern Turkey (Figure 1). The sedimentary fill of the Antalya Basin is characterized by a relatively thick succession of Miocene and Pliocene clastics, coralgal reefs and reefal shelf carbonates and extensive travertine deposits, with locally developed internal deformation and intrabasinal unconformities, in a tectonically active region in the Antalya Gulf.

Over the past decade the origin of the Antalya Basin has been subject of considerable interest and several works have been directed (Flecker 1995; Flecker *et al.* 1995, 1998, 2005; Glover 1995; Glover & Robertson 1998; Karabıyıkoğlu *et al.* 2000, 2004, 2005; Poisson *et al.* 2003a; Deynoux *et al.* 2005; TPAO and Nordysk Research Teams) to investigate the formation, evolution and deformation of the Late Cenozoic Antalya Basin.

This paper is a synthesis of previously published works on Köprüçay and Manavgat sub-basins from our group (Karabıyıkoğlu *et al.* 2000, 2005; Deynoux *et al.* 2005) but also integrates additional data from the Aksu sub-basin and a general discussion on the Antalya Basin. The aim is to evaluate stratigraphy, facies architecture and depositional systems of the Miocene sedimentary fill of the Antalya Basin in order to provide a synthesis that contributes towards a better understanding of basin formation, evolution and deformation within the context of post-collisional tectonics and relative sea level changes.

Geological Setting and Stratigraphy

The Antalya Basin developed unconformably on a foundered basement, comprising Mesozoic autochthonous carbonate platforms (the Beydağları platform to the west and the Anamas-Akseki platform to the east), overthrust by allochthonous units (Lycian Nappes, Antalya Nappes and Alanya Massif) during an interval of time lasting from Late Cretaceous to Pliocene (Figure 1), within the Isparta Angle in the western Taurides (Monod 1977; Akay *et al.* 1985; Dilek & Rowland 1993; Flecker 1995; Flecker *et al.* 1995, 1998, 2005; Glover & Robertson 1998; Karabıyıkoğlu *et al.* 2000, 2005; Monod *et al.* 2002; Robertson *et al.* 2003; Poisson *et al.* 2003a).

The present configuration of the Antalya Basin consists of three distinct components, divided and bounded by the north–south-trending Kırkkavak Fault and Late Miocene Aksu Thrust (Dumont & Kerey 1975; Poisson 1977; Akay *et al.* 1985), which are here simply referred as the Manavgat, Köprüçay and Aksu sub-basins (Figure 1). Since the early work of Blumenthal (1951) much has become known about the Late Cenozoic stratigraphy of the Antalya Basin as a result of numerous local and regional geological studies (e.g., Brunn *et al.* 1971; Bizon *et al.* 1974; Poisson 1977; Monod 1977; Poisson *et al.* 1983, 1984, 2003a, b; Akay *et al.* 1985; Robertson 1993; Flecker 1995; Flecker *et al.* 1995, 1998, 2005; Glover 1995; Glover & Robertson 1998; Karabıyıkoğlu *et al.* 2000, 2005; Tuzcu & Karabıyıkoğlu 2001; Deynoux *et al.* 2005; İşler *et al.* 2005). The Late Cenozoic fill of the basin is represented by non-marine to marine, clastic-dominated Miocene sediments with subordinate coralgal reefs and reefal shelf carbonates, and Pliocene to Recent marine and terrestrial clastics, and travertines.

Previously, Poisson *et al.* (1983, 1984) and Akay *et al.* (1985) have provided the most comprehensive accounts of the Antalya Basin. Based on the foraminiferal and nannoplankton biostratigraphy as well as lithostratigraphic considerations, they have divided the Late Cenozoic deposits broadly into ten formations: (1) Aksu Formation (Upper Oligocene–Tortonian conglomerates), (2) Oymapınar Limestone (Langhian shelf carbonates), (3) Çakallar Formation (Langhian limestone breccias and marls), (4) Geceleme Formation (Serravalian marls), (5) Karpuzçay Formation (Tortonian shales, sandstones and conglomerates), (6) Taşlık Formation (Lower Messinian clayey limestone with limestone and conglomerate blocks), (7) Eskiköy Formation (Messinian sandstones and conglomerates), (8) Gebiz Limestone (Messinian reefal carbonates), (9) Yenimahalle Formation (Pliocene limely claystone and sandstone) and (10) Alakilise Formation (Upper Pliocene sandstone with volcanic tuffs and conglomerate).

Flecker (1995) and Flecker *et al.* (1995, 1998) provided additional biostratigraphic data and introduced strontium isotope methods for dating the Oymapınar carbonates and the overlying Geceleme marls, and thus proposed a revised stratigraphy for the Lower Miocene formations of the Antalya Basin. In their stratigraphic revision, the previous Aksu Formation was divided into

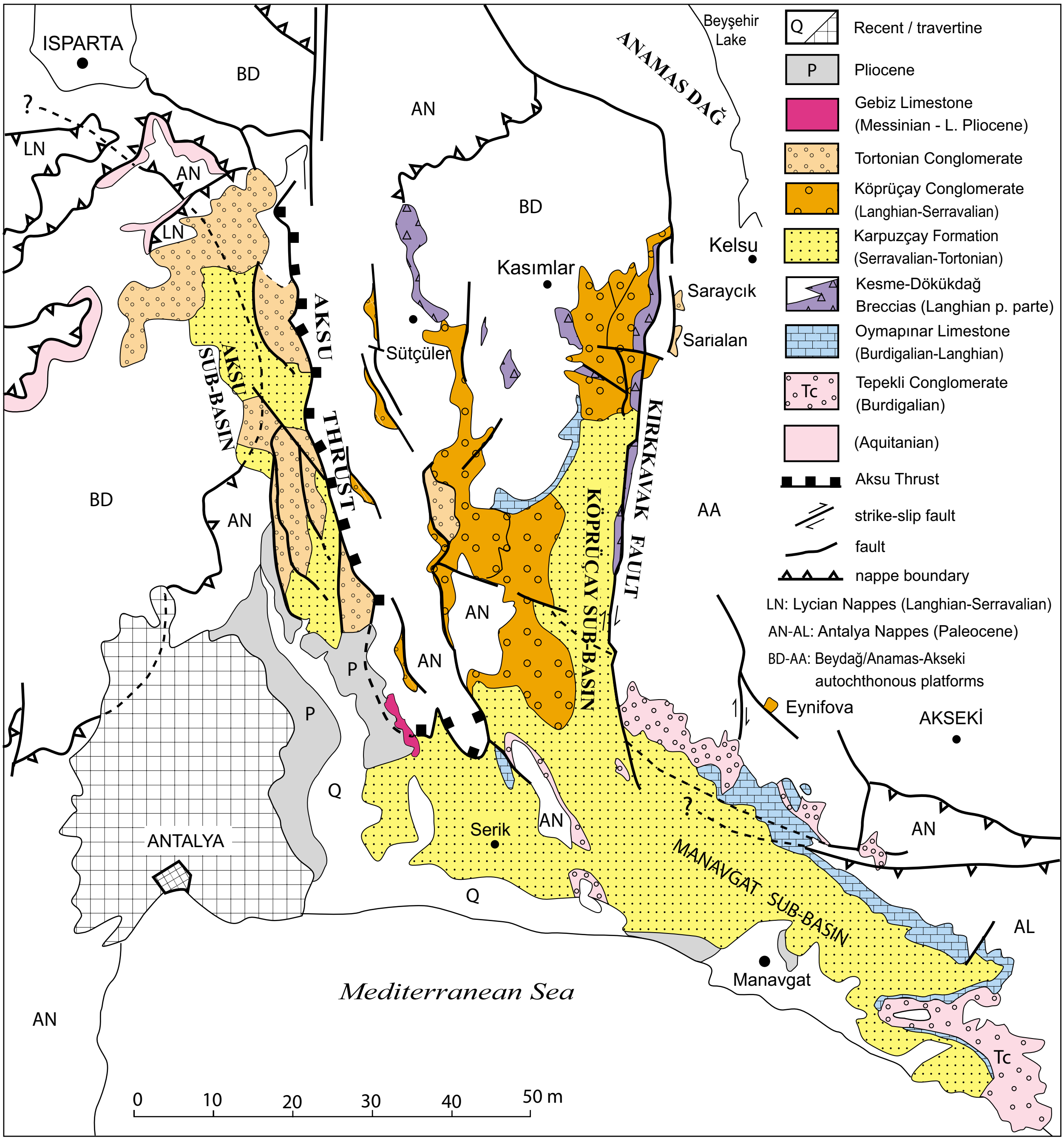

Figure 1. Geological and stratigraphical setting of the Antalya Basin. Inset shows the location of the study area. Modified from Deynoux *et al.* (2005).

two new formations: the Kızıldağ Formation (Burdigalian conglomerates) and the Aksu Formation (Tortonian conglomerates).

Recently particular attention has been directed to the composition and distribution of coral reefs and the associated reefal fauna as well as the benthic-planktic foraminiferal associations and ostracodas as complementary data to contribute towards developing a constrained biostratigraphy (Karabıyıkoğlu *et al.* 2000, 2005). Although the Miocene corals have a rather poor stratigraphical value, with some of them ranging from Oligocene to Pliocene, the composition of the coral assemblages of these reefs together with reef-associated fauna, combined with complementary biostratigraphical and lithostratigraphical findings, have provided a useful proxy data base for establishing a reliable stratigraphy for the conglomerate-dominated basin margin clastics comprising coralgal reefs.

In this study, based on these lithostratigraphic and biostratigraphic findings as well as the integration of previously established data, the clastic-dominated Miocene stratigraphy of the Antalya Basin is revised and reorganized into nine formations and twelve members (Figures 1 & 2), considered in more detail in the following relevant sections. Here, a brief summary of the stratigraphy is outlined below.

The reorganization of the Miocene fill of the *Manavgat sub-basin* consists of the Tepekli Conglomerate (Burdigalian–Early Langhian), Oymapınar Limestone (Late Burdigalian–Langhian), Geceleme Formation with Çakallar Member (Late Langhian) and Karpuzçay Formation (Serravalian Tortonian–Messinian).

The Miocene fill of the *Köprüçay sub-basin* comprises the Kesme Breccia (?Burdigalian), Oymapınar Limestone (Late Burdigalian–Langhian), Köprüçay Conglomerate with İbişler, Yeşilbağ, Sarıkök, Yaka, Selge, Bozburundağ members (Burdigalian–Langhian–?Serravalian), Karpuzçay Formation (Langhian/Serravalian), and Sarıalan Formation (Lower Tortonian).

The Miocene fill of the *Aksu sub-basin* consists of the Aksuçay Conglomerate with Kargı, Karadağ and Kapıkaya Conglomerate members (?Tortonian), Karpuzçay Formation (Serravalian–Tortonian) and Gebiz Limestone (Upper Miocene–Lower Pliocene).

Facies Description and Interpretation

The clastic-dominated Miocene fill of the Antalya Basin is represented by a thick succession of non-marine to marine breccia, conglomerate, sandstone, siltstone, mudstone and claystone with subordinate coralgal reefs, reefal shelf carbonates and marls. Several detailed clastic and carbonate facies and their environmental interpretations have already been advanced for the Miocene fill of the Manavgat, Köprüçay and Aksu sub-basins (for a comprehensive review, see Flecker 1995; Flecker *et al*. 2005; Karabıyıkoğlu *et al*. 2000, 2005; Deynoux *et al*. 2005).

In this study for the sake of simplicity, the Miocene fill of the entire Antalya Basin is considered in terms of a total of nineteen facies on the basis of main sedimentary characteristics comprising lithology, geometry, texture, sedimentary structure, faunal content and colour (Figures 3 to 6 and Table 1). The facies architecture in time and space indicates small- to large-scale transgressive and regressive sequences characterized by six depositional systems representing deposition in (1) colluvial scree/colluvial fan, (2) coastal alluvial fan, (3) fan delta with patch reefs, (4) reefal shallow carbonate shelf, (5) base of fault-generated fore reef slope, and (6) clastic shallow to deeper open marine environments in the tectonically active sub-basins. Each facies is named descriptively following the schemes developed by Miall (1978) and Pickering *et al*. (1986, 1989) for continental and marine clastics, and Dunham (1962) and Wilson (1975) for carbonates.

Miocene Stratigraphy and Depositional Evolution of the Antalya Basin

Manavgat Sub-basin

Lithostratigraphy

In this study the Burdigalian–Messinian fill of the Manavgat sub-basin is interpreted in terms of four formations, which are designated as from base to top: Tepekli Conglomerate (Burdigalian, Early Langhian) composed of terrestrial to marine clastics, Oymapınar Limestone (Late Burdigalian–Langhian) made up of reefal shelf carbonates, Geceleme Formation (Serravalian) and Karpuzçay Formation (Tortonian–Messinian) composed of deeper or shallower marine clastics. This stratigraphy broadly conforms to that of Akay *et al*. (1985) and Flecker *et al*. (1995, 2005). However, the Çakallar Formation of Akay *et al*. (1985) is considered here, as in Karabıyıkoğlu *et al*. (2000), as a member within the Geceleme Formation, since it refers to lithological bodies of limited local extent.

Facies Architecture and Depositional Environments

A large-scale deepening-upward to shallowing-upward sequence representing transgressive and regressive episodes of sedimentation characterizes the sedimentary succession of the Manavgat sub-basin fill.

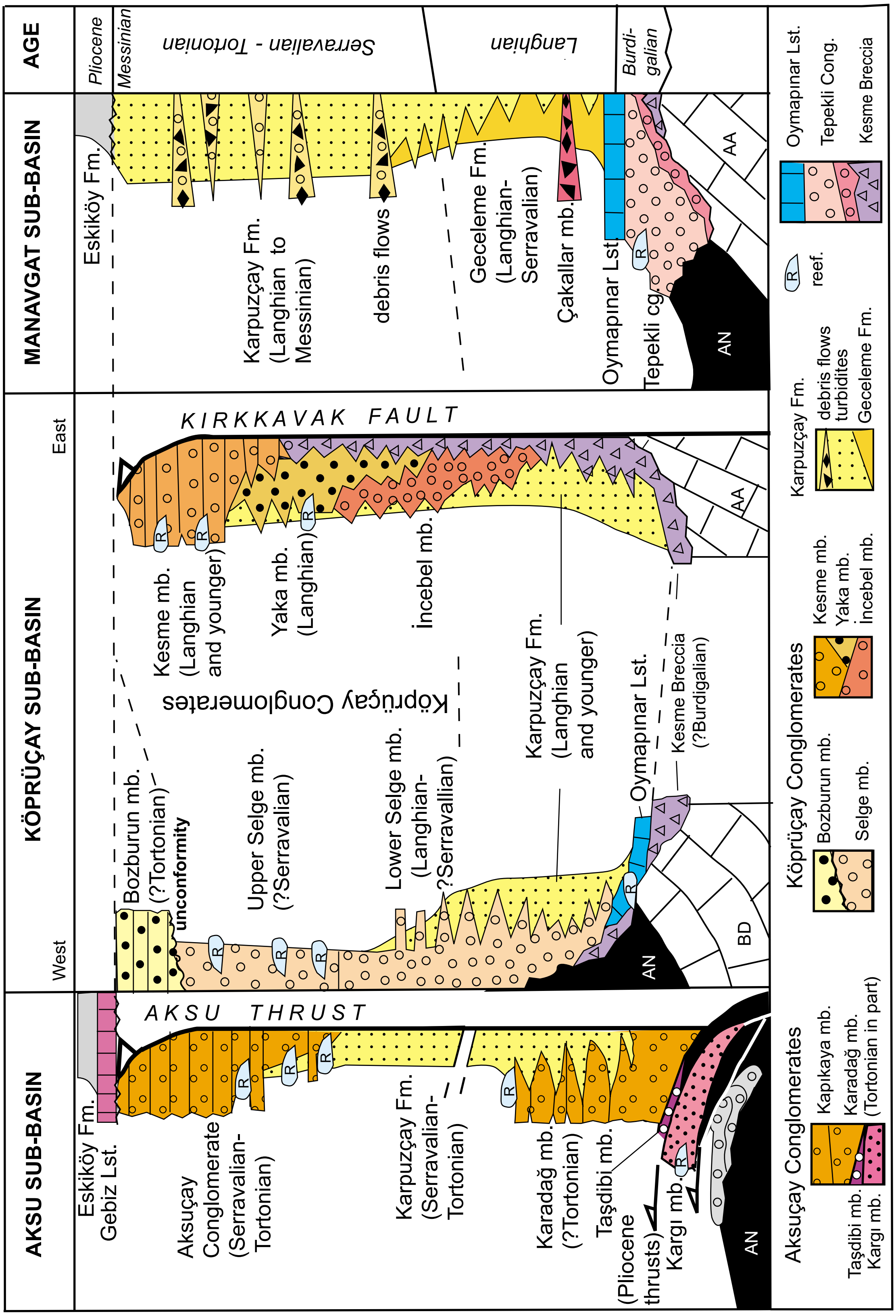

Figure 2. Comparative Miocene stratigraphy of the Antalya sub-basins.

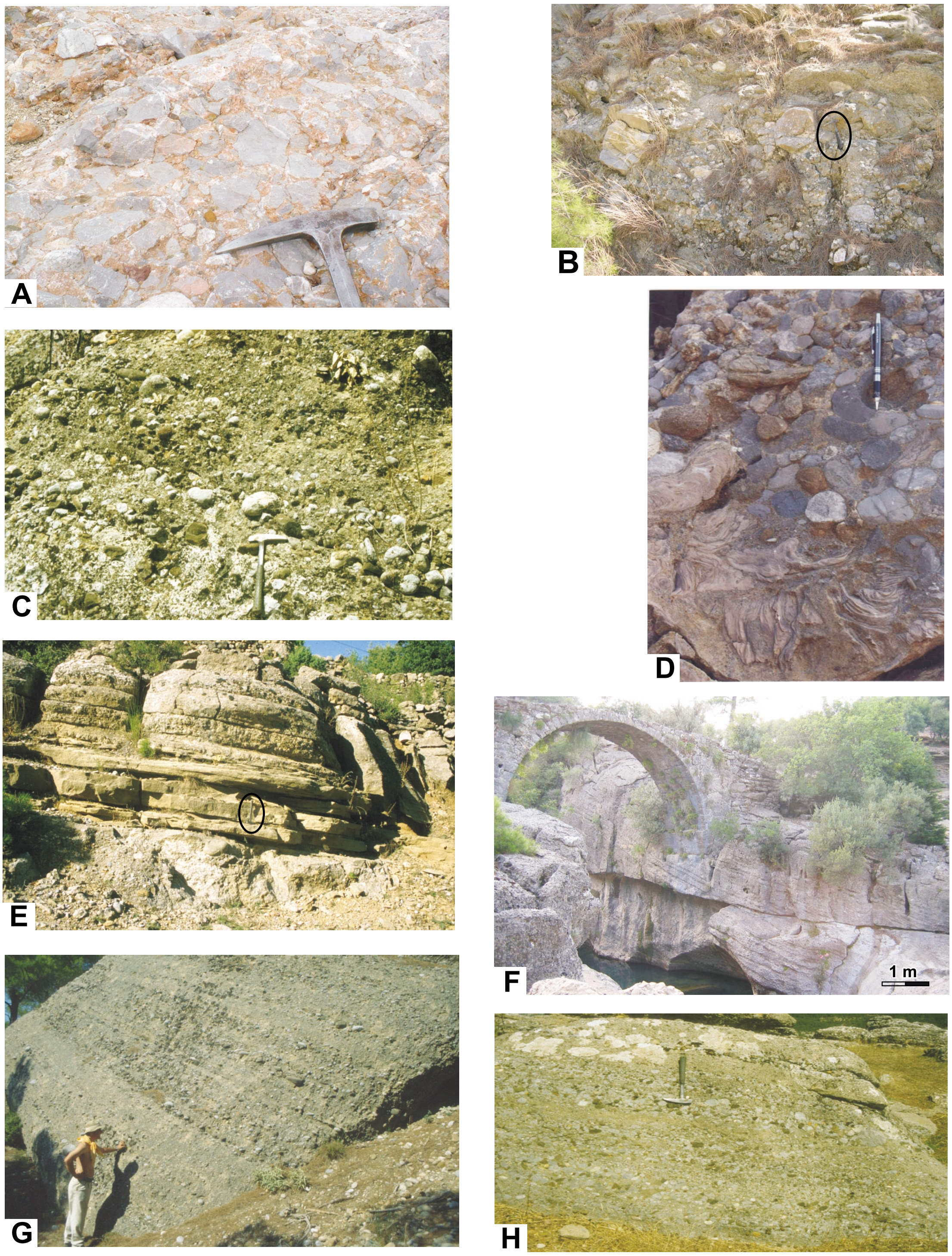

Figure 3. (A) Limestone breccia facies (F1). (B) Matrix-supported conglomerate facies (F2) with a disorganized fabric. Poorly sorted, red, matrix-supported bouldery conglomerate of subaerial origin. (C) Clast-supported conglomerate facies (F3) characterized by poorly- to moderately-sorted, massive- to crudely-bedded, pebble-cobble conglomerate with (D) occasional disarticulated bivalves. (E) Parallel-stratified conglomerate facies (F4) characterized by laterally continuous tabular beds of pebble-cobble conglomerate. (F–H) Examples of large-scale tabular-planar cross-stratified conglomerate facies (F5) characterized by high-angle oblique-parallel foreset beds with angular lower contacts and crudely developed pebble orientation. 2nd Century Roman bridge in picture (F). All pictures are from Köprüçay Conglomerates in Köprüçay sub-basin.

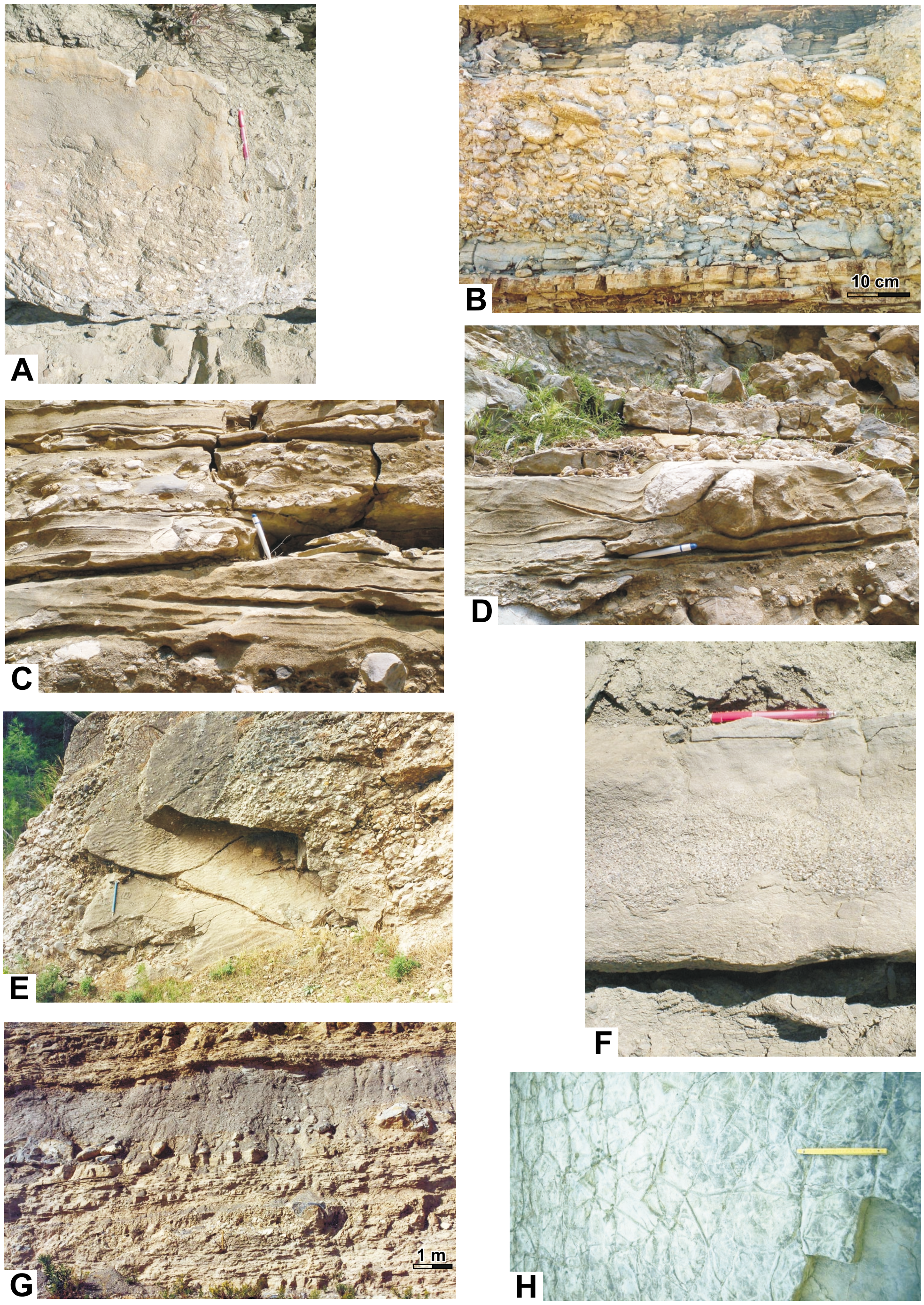

Figure 4. **(A)** Graded conglomerate facies (F6) showing normal graded with erosive base and **(B)** reverse graded beds. **(C)** Massive to parallel-laminated gravelly sandstone (F7) characterized by thinly interbedded fine sandstone and **(D)** with stringers of well-rounded coarse gravels. **(E)** Wave rippled sandstone interbeded with conglomerates (F8). **(F)** Normal graded sandstone facies (F9) with a well-developed Bouma sequence. **(G)** Massive pebbly mudstone facies (F10) with well-rounded to sub-angular gravels and ripped-up mudstone clasts of various sizes floating randomly in a muddy matrix. **(H)** Graded siltstone and mudstone (F11) facies with bioturbations on top of the mudstone bed. Pictures A, B, C, D & E– Köprüçay Conglomerate in Köprüçay sub-basin; F– Aksuçay Conglomerate in Aksu sub-basin; G– Karpuzçay Formation in Manavgat sub-basin; H– Karpuzçay Formation in Köprüçay sub-basin.

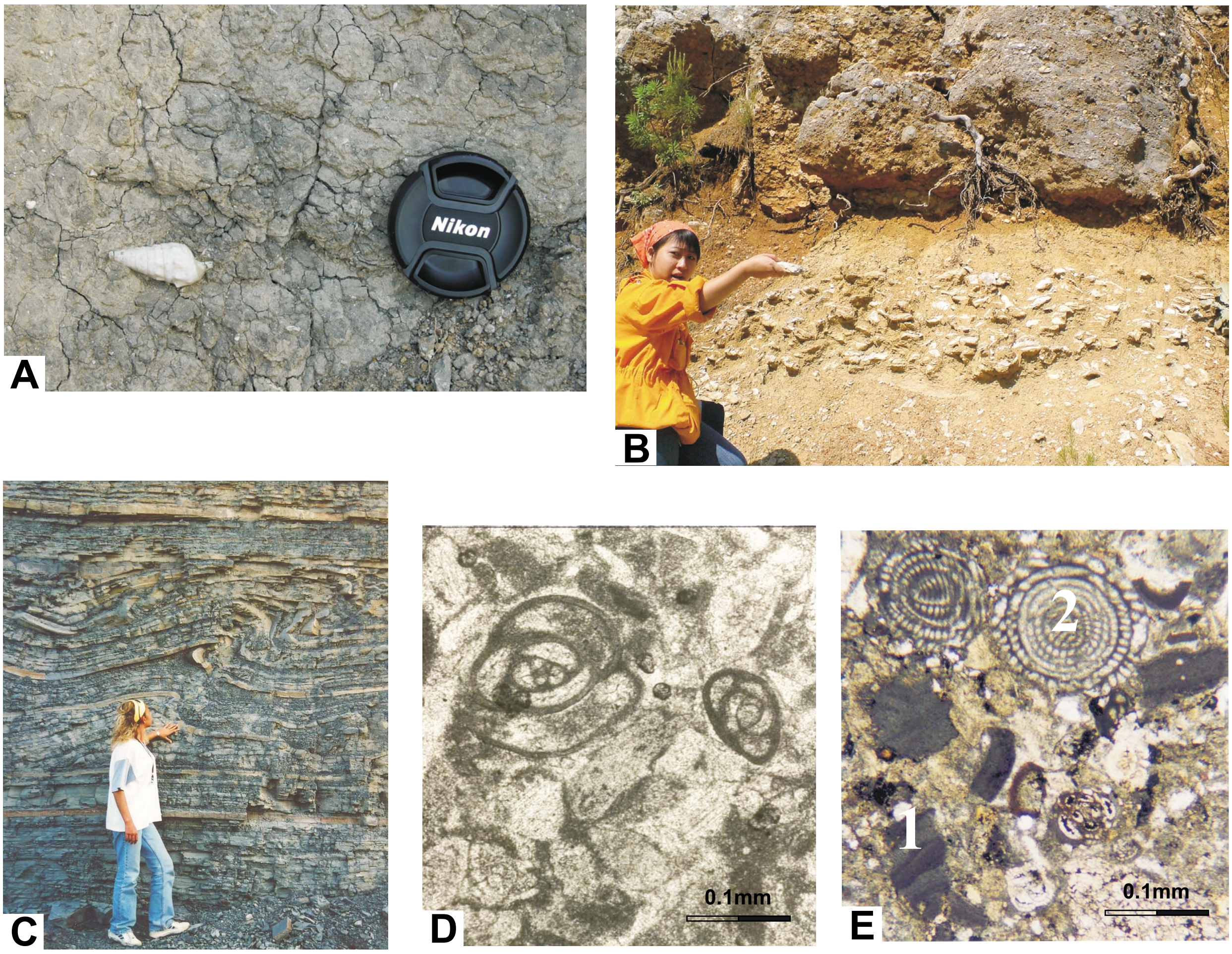

Figure 5. Massive to parallel-laminated siltstone-mudstone facies (F12) overlain by a reef core. **(A)** Gastropods- and **(B)** *Ostrea*-bearing green mudstones. **(C)** Chaolically folded and brecciated facies (F13). **(D)** Photomicrograph of miliolid wackestones (F15) representing restricted inner shelf/lagoon environment. **(E)** Photomicrograph of massive to well-bedded algal, benthic foraminiferal wackestone-packstone facies (F16) with angular fragments of coralline algae (1) and well-preserved *Borelis melo* (2). All pictures are from Karpuzçay Formation in Köprüçay sub-basin.

The Tepekli Conglomerate: Burdigalian–Early Langhian Alluvial Fan/Fan-Delta Complex. The Tepekli Conglomerate is a pebble-cobble dominated clastic formation, which is exposed along the northwestern and southeastern margins of the basin. The spatial distribution, overall geometry and the facies changes within the conglomerate bodies reflect two distinct depositional environments: (1) stream-flow-dominated coastal alluvial fan(s), and (2) southward prograding fan deltas.

In the northwestern part of the basin, the Tepekli Conglomerate is characterized by a variable thickness, locally reaching up to 600 m (Figure 7). The dominant facies consists of clast-supported pebble-cobble conglomerate (F3) with well-rounded clasts. It occurs as a few meters thick, laterally extensive amalgamated tabular units, or as thick channel fills intercalated with relatively thin red mudstones (F12A). This succession is interpreted as an alluvial fan environment characterized by shallow braided streams. Up section and southward (e.g., 2.5 km southwest of Sırtköy, Figure 7) large coralgal patch reefs (F19) embedded within winnowed clast-supported conglomerates (F3) indicate the passage from braided stream-dominated coastal alluvial fan to wave-modified marine fan delta deposits.

In the southeastern part of the basin, a 180-m-thick section is exposed below the Alarahan Castle and represents the upper part of the Tepekli Conglomerate

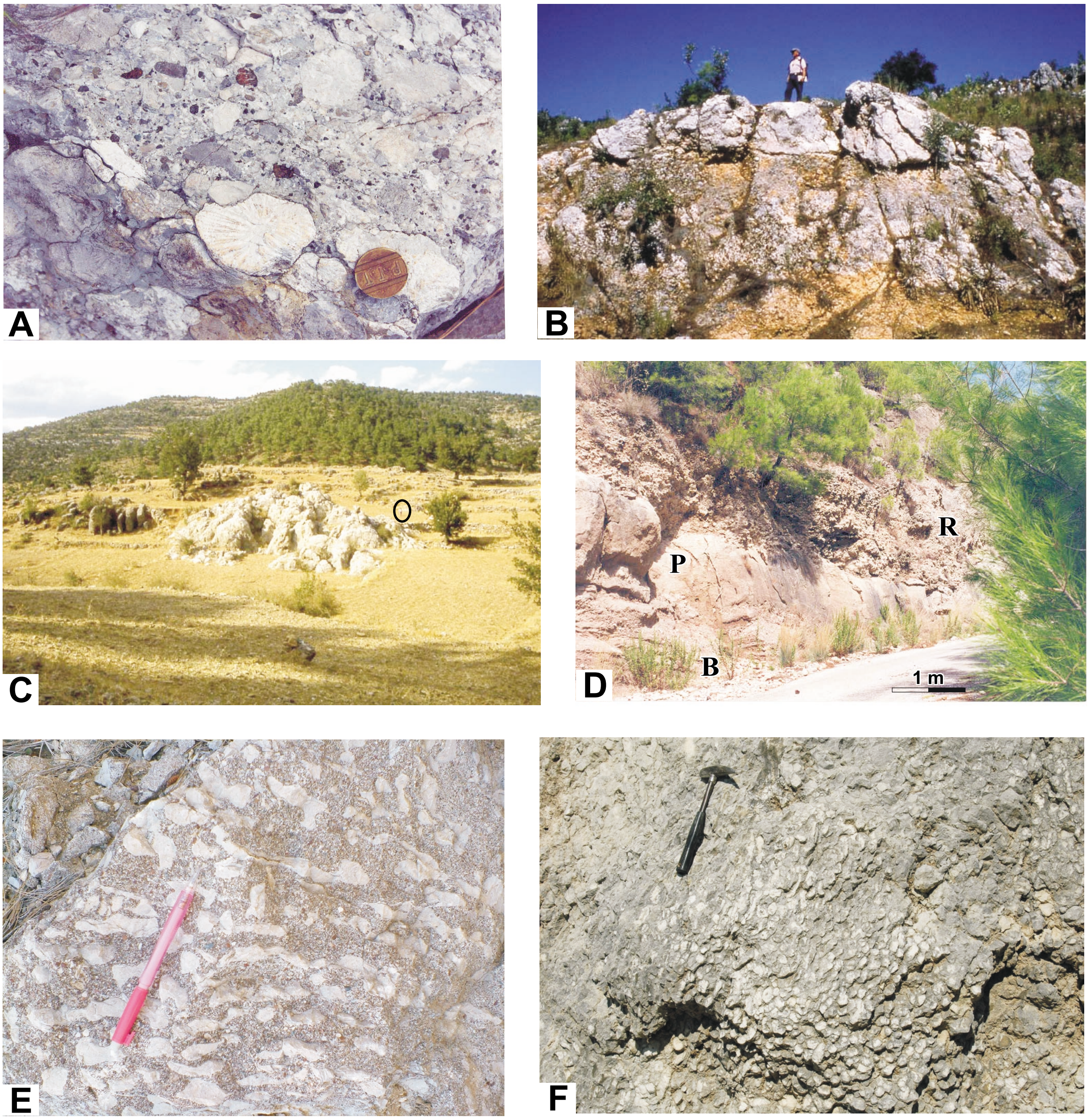

Figure 6. **(A)** Photomicrograph of algal, coral grainstone-rudstone facies (F18) representing lithoclast coral *(Lithophyllia)* rudstone. **(B–C)** Field characteristics of massive coral-algal boundstone facies (F19). Massive and mound-shaped coral-algal limestones developed on coarse conglomerate beds representing isolated patch reefs. **(D)** General view of the transition from braided stream conglomerate (B) through benthic foraminiferal packstone (P) to reef core facies (R). **(E–F)** Details of the reef core facies comprising massive and thick finger-like forms of *Porites* and *Tarbellastraea*. Pictures A & B– Tepekli Conglomerate in Manavgat sub-basin; C– Köprüçay Conglomerate in Köprüçay sub-basin; D, E & F– Aksuçay Conglomerate in Aksu sub-basin.

that is truncated by the overlying transgressive Oymapınar Limestone. The Alarahan section is basically composed of thickly-bedded low-angle clinoforms of clast-supported polymict conglomerates (F3 and F5), with coralgal patch reefs (F19) and rare foraminiferal wackestone/packstone (F16) interbeds, and represents a coarse clastic, stream-dominated fan delta.

Table 1. Description and suggested interpretation of the facies of the Antalya Basin.

Facies	Description	Occurrence *	Suggested Processes and Environment of Deposition
F1: limestone breccia	fine to coarse, poorly sorted, very angular to sub-rounded extraclast limestone (Figure 3A). Thin- to very thick-bedded tabular units with sharply defined flat bases and tops; occasional normal grading; clast- to matrix-supported with red mud or carbonate matrix locally comprising *Microcodium* or shallow marine fauna comprising mixed benthic foraminifers (i.e. miliolids, *Amphistegina, Textularia*), coralline algae and molluscan bioclasts, pelloids, minor coral fragments echinoid plaques and spines. Locally intercalated with conglomerates and pebbly sandstones	Vc in K C in M not observed in Aksu	gravity-driven, subaerial and/or subaqueous mass transport including grainflows, rock falls/avalanches (debris falls), slides and high concentrated debris flows; climatic and/or fault-generated colluvial cone and/or colluvial fan-delta (Blirka & Nemec 1998; Nemec & Kazancı 1999); red matrix-supported and *Microcodium*-bearing breccias represent a terrestrial origin, whereas the breccias with the fossiliferous carbonate matrix indicate deposition in a shoreline environment resulting from reworked coastal colluvium/screes
F2: matrix–supported conglomerate	massive to thick bedded, very poorly sorted, sub-angular to rounded pebble-boulder conglomerate with outsized clasts up to 2 m in diameter (Figure 3B); reddish, yellowish or greyish muddy matrix with varying mixtures of granule to clay-sized material; disorganized gravel fabric with floating/protruding clasts at the top; amalgamated tabular and lenticular units with sharply to faintly defined flat bounding surfaces; occasional scoured bases	Vc in K Vc in M C in A	gravity-induced subaerial and/or subaqueous mass flow deposits from high-viscosity flows (cohesive debris flows) (Middleton & Hampton 1976; Nemec & Steel 1984; Nemec & Postma 1993). Rapid sedimentation en masse in a proximal alluvial fan/fan-delta or high gradient braided stream
F3: clast–supported conglomerate	thin to very thick amalgamated beds with massive to crude stratification; poorly to moderately sorted, sub-rounded to rounded pebble-boulder conglomerate with outsized clasts up to 2 m diameter (Figure 3C); disorganized gravel fabric with occasional weak imbrication in places; tabular, lenticular or channel-fill geometry with sharply defined, flat to erosional bounding surfaces; open or closed framework with red to grey muddy, sandy or granular matrix; occasional coral fragments and disarticulated bivalves (Figure 3D)	Vc in K Vc in M Vc in A	subaerial to subaqueous hyperconcentrated flows such as cohesive and cohesionless debris flows and/or tractive stream flows (Middleton & Hampton 1976; Rust 1978); deposition in a high gradient braided stream and alluvial fan/subaerial fan-delta environments as longitidunal bars; fossillifereous conglomerates indicate wave-reworked nearshore deposition
F4: parallel stratified conglomerate	laterally continuous thick tabular pebble-cobble conglomerate beds (0.5–3 m thick) with sharp and flat bases and tops (Figure 3E); horizontal to sub-horizontal parallel beds characterised by moderatly to well sorted, clast supported, well segregated, sub-rounded to very well rounded pebbles with calcarenitic intergranular matrix; locally well developed preferred imbrications with maximum projection planes down dipping	Vc in K Vc in A R in M	laminar flows with tractive bed load in a wave modified fan-delta front; wave reworking might have also been responsible for the development of gravel segregation locally
F5: large–scale cross–stratified conglomerate	solitary or stacked, large-scale, pebble-cobble conglomerate comprising sigmoidal to oblique parallel foresets (up to 30 m high clinoforms) with fine to coarse intergranular sandy matrix; moderate to well sorted, sub- to well-rounded clasts showing parallel orientation to the bedding plane mostly with imbrications (Figure 3F–H). Angular to tangential contacts with the underlying beds might form downlap geometries	Vc in K R in M R in A	unidirectional subaqueous flows and/or avalanches; fan delta/Gilbert–type delta foresets
F6: graded conglomerate	normal-, inverse-, inverse- to normal-graded conglomerate, pebbly sandstone and sandstone; tabular, lenticular or channelised beds (1 to 4 m thick) with sharp or erosive bases and flat tops; occasional rip-up mud clasts, flute and groove casts, burrows and mixed shallow and deeper marine fauna (Figure 4A, B). Well-developed and normally-graded conglomeratic beds with massive basal parts grading upwards into pebbly sandstone/sandstone; inversely graded conglomerates are clast- to matrix-supported with muddy to sandy matrix	Vc in K Vc in M Vc in A	gravelly high- or low-density turbidity currents (Bouma 1963); cohesionless or cohesive subaqueous debris flows with locally developed slope turbidite channels associated to fan deltas; the inverse grading is the result of turbulent and intense grain interaction or debris flow in a relatively cohesive matrix

Table 1. (Continued)

Facies	Description	Occurrence *	Suggested Processes and Environment of Deposition
F7: massive to parallel stratified gravelly sandstone	thin- to thick-bedded, massive to parallel laminated, fine to coarse sandstone/gravelly sandstone with occasional gravel stringers; laterally extensive (up to several hundreds meters long) and well-defined tabular units with sharp flat bases and tops; erosive-based sandstone interbeds (Figure 4C, D). Occasional ripple marks, well-developed bioturbation, plant debris, bivalves, coral fragments and benthic foraminifers	Vc in K Vc in M Vc in A	massive beds probably resulted from high- or low-density turbidity currents and/or sandy debris flow/grain flow (Lowe 1982), whereas parallel laminated sandstone represents deposition from tractive currents in upper flow regimes; the stringers of boulders are interpreted to have been rolled into the sandstone
F8: cross-stratified conglomerate and sandstone	low and high angle tabular-planar and trough cross-stratified, fine to coarse, moderately well-sorted sandstone, pebbly sandstone and pebble conglomerate with thin parallel foreset beds; occasional wave-rippled and hummocky cross-stratified sandstone up to 20 cm thick (Figure 4E)	C in K R in M R in A	low-angle inclined beds imply deposition by swash-back swash processes representing wave modified beach; high-angle tabular to trough cross-stratified beds are formed by wave originated unidirectional currents in the shoreface; hummocky cross-stratified sandstones represent storm-generated flows
F9: normal graded sandstone	pebbly sandstone and very coarse to fine sandstone (Figure 4F) with bed thickness between 30–50 cm and up to 1m. Flat to irregular bases with decimetric scours; a few cm long flute and groove casts at the base of some of the beds; planar to wavy bed tops; common vertical and horizontal burrows. Typical normal grading with Bouma divisions of Ta and Tb, and/or with frequent development of Tc and Td (a complete Bouma sequence (Ta-Te) is rare). Extrabasinal and/or intrabasinal clastics including well-rounded bioclastic fragments of calcareous algae, foraminifers, bivalves and corals	Vc in K Vc in M Vc in A	rapid deposition from highly concentrated turbidity currents, followed by deposition from suspension fall-out during normal quiet-water conditions after the density flow event (Bouma 1963)
F10: massive pebbly mudstone	1 to 5 m thick, laterally continuous (several hundreds of meters) tabular beds consisting of poorly sorted pebbly mudstone with sharp to erosive bases and irregular tops (Figure 4G); angular to well-rounded clasts and rip-up mudstones randomly floating in the clay-rich muddy matrix; variable matrix to pebble ratio (generally 1:3); shelf derived mixed fauna (benthic and planktic foraminifers and coral-algal fragments)	Vc in M C in K R in A	cohesive subaqueous muddy debris flows (Pickering *et al.* 1986); rip-up mudstone clasts imply erosion of the lower muddy beds; the mixed fauna indicate reworking
F11: graded siltstone and mudstone	thin- to thick-bedded, laterally continuous siltstone/mudstone alternation (ratio around 1:1); sharply defined flat bases and tops; locally organic-rich material, bioturbation, starved-ripples, wavy bedding and obscure varve-like normal grading from silty mudstone to mudstone (Figure 4H).	Vc in K Vc in M Vc in A	low-density turbidity currents (Pickering *et al.* 1986, 1989), suspension fall out and/or oscillating flows in pro-delta to shallow shelf
F12: massive to parallel laminated siltstone-mudstone	A– red mudstone: thin to medium (up to 30 cm), massive to parallel laminated, flat bedded, tabular to lenticular beds alternating with fine sandstone/siltstone including rare asymmetrical ripples B– mollusc-rich mudstone: green to dark grey coloured and massive to faintly laminated clayey mudstone including thin and thick-shelled gastropods, bivalves and rare coral, algal fragments (Figure 5A, B); allocthonous thin coal seams and carbonised plant fragments are common C– planktic foraminiferal mudstone: laterally extensive, thinly interbedded (1 to 10 cm) grey siltstone and mudstone with variable carbonate content; sharply defined bases and tops. Shelf derived mixed fauna and/or *in-situ* planktic foraminifers, mainly globigerinids and pteropods (thin shelled gastropods)	Vc in K Vc in M C in A	A– subaerial deposition from flood-generated overbank flows B– suspension deposition in a shallow stagnant brackish water body to low energy, normal salinity shallow shelf C– sedimentation in a relatively deep clastic open shelf from suspension fall-out and/or low-density turbidity currents

Table 1. (Continued)

Facies	Description	Occurrence *	Suggested Processes and Environment of Deposition
F13: chaotically folded and brecciated deposits	thick chaotic mixture of coherently folded and contorted sandstone-siltstone and mudstone beds (Figure 5C); brecciated and balled strata and rip-up clasts randomly floating in a muddy matrix or concentrated at the upper levels of the beds. Overlying and underlying deposits are generally parallel stratified with occasional channel fills	Vc in K Vc in M Vc in A	slump or slide generated hydroplastic deformation and/or debris flows (Pickering *et al.* 1986, 1989); coherently folded and contorted beds imply hydroplastic deformation; brecciated and rip-up clasts indicate erosion of the underlying beds and considerable internal deformation
F14: reefal debrites and isolated blocks	fine- to very coarse-grained, angular to rounded, clast- and/or matrix-supported reefal debrites with occasional isolated and outsized blocks (up to 8 m) embedded in a very fine-grained and parallel-stratified deposit; thin to very thick beds with flat to scoured bases and flat tops; massive to normal graded	Vc in K Vc in A C in M	reef flanks; fault-generated, reefal shelf derived debrites, olistoliths and calciturbidites (Cook & Mullins 1983); outsized blocks represent rock falls recognised by the underlying deformed beds or rock slides (Pickering *et al.* 1986; 1989)
F15: pelloidal fossiliferous lime mudstone-wackestone	thick, parallel bedded, very fine-grained and moderately well-sorted, fossiliferous lime mudstone-wackestone (Figure 5D); commonly pelloidal with disarticulated to well-preserved gastropods, bivalves, echinoids, miliolid-*Borelis* dominated benthic foraminifers comprising *Borelis*, *Archaias, Elphidium, Textularia*, *Heterostegina*, *Amphistegina, Rotalia*, Miliolid, bryozoa and coralline algae fragments; rare to common quartz grains, carbonised plant, lignite fragments and fromboidal pyrite	Vc in M Vc in K Vc in A	low energy inner shelf/shelf lagoon with restricted water circulation; carbonised grains may suggest transportation from a nearby marshy (peat) environment that might have been subjected to peat development; the clays and quartz grains might have been introduced into the depositional site by currents and/or eolian processes; fromboidal pyrite suggest reductive environment.
F16: algal, benthic foraminiferal wackestone-packstone	poorly- to moderately-sorted, massive to thickly parallel-bedded, white coralline algal, benthic foraminiferal wackestone-packstone; rich and diverse bioclasts comprising both small (*Borelis, Textularia, Elphidium, Gypsina,* Rotalid and Miliolid) and large benthics (*Heterostegina*, *Operculina, Acervulina, Miogypsina*, *Amphistegina*, *Archaias,* Peneroplid and Victoriellid), coralline algae (*Lithothamnium, Lithophyllum, Mesophyllium*), bivalves, gastropods, echinoids, bryzoa and hermatypic coral fragments; well-developed oncoliths and rhodolites, serpulid (*Ditrupa*) tubes, Dasycladacean algae (*Halimeda*) (Figure 5E)	Vc in M Vc in K Vc in A	rich and diverse fauna of benthic foraminifers with coated, abraded, micritized bioclasts and rounded intraclasts indicate low to moderate energy, normal salinity shallow shelf close to wave-base; miliolid- and *Borelis*-rich wackestone-packstone represent shelf lagoon with restricted water circulation; large benthic foraminifer-bearing wackestone-packstone indicates relatively deeper water open shelf; oncoliths and rhodoliths are limited to protected shelf lagoons and turbulent environments on the margin of the open shelf.
F17: algal, benthic foraminiferal packstone-grainstone	well-sorted, fine- to medium-grained packstone-grainstone; flat to low-angle inclined accretionary beds with rare to abundant *Callianassa* burrows; occasional wave ripples; rich and diversified benthic fauna comprising Miliolid, *Borelis*, *Archaias, Heterostegina* with rare *Amphistegina*, *Textularia*, Rotalid and rare planktic Globigerinid; some bioclasts, including fragments of bivalves, gastropods, *Ostrea* and *Porites*, lithoclasts and peloids	Vc in M Vc in K Vc in A	high energy beach and shoal environment of an open shelf with a normal salinity
F18: coral-algal grainstone-rudstone	thin- to thick- bedded, poor to moderately sorted, algal, coral grainstone-rudstone, with well-rounded limestone- and ophiolite-derived extraclasts, large overturned corals and rodaliths (Figure 6A)	Vc in M Vc in K Vc in A	high energy, reef flat to off-reef; extraclasts indicate reworking from a nearby clastic nearshore setting
F19: massive coral-algal boundstone	small, isolated, massive mound-like limestone bodies made up of *in situ* coralgal framework (Figure 6B–F) consisting of high to low diversity hermatypic coral colonies (mainly *Tarbellastraea, Heliastraea, Favites, Favia, Caulastraea, Aquitanastraea*, *Cladocora, Acanthastraea, Porites*, and *Stylophora*), with coralline algae (*Lithothamnium, Lithophyllum, Mesophyllum*), encrusting foraminifera *Acervulina*, and minor solitary corals (*Lithophyllia*, *Syzygophyllia*, Mussidae) in places. sediments filling the spaces between the frame-builders locally varies from clayey lime mudstone to fine to coarse-grained bioclastic wackestone and packstone with overturned and fragmented corals	Vc in M Vc in K Vc in A	development of isolated coralgal reef growth (patch reefs) in a warm, well aerated shallow marine shelf (photic zone) with low to moderate energy level and normal salinity in general; the low-diversity coral framework suggests stressed environment; the local presence of solitary corals may represent a relatively deeper bathymetry

*Vc– very common; C– common; R– rare. M, K, A– Manavgat, Karpuzçay and Aksu sub-basins.

The coralgal reefs in the fan delta deposits are mainly characterized by rich and diverse coral assemblages, mainly composed of massive domal, spherical and subspherical coral frameworks, reflecting a relatively shallow, moderate-energy, normal salinity marine environment. The coral framework is characteristically composed of densely packed, *in-situ* coral assemblages dominated by *Tarbellastraea, Heliastraea, Porites* and *Stylophora*, with some large massive coral colonies reaching up to 60 cm in size. Some broken and overturned colonies are observed within the framework, which is bounded by encrusting coralline algae (*Lithothamnium, Lithophyllum*). The reef bodies are flat-based domal forms exhibiting flat, irregular to smooth convex-up upper surfaces, without any distinct coral zonation (Figure 6).

A tentative reconstruction of the Manavgat sub-basin during the deposition of the Tepekli Conglomerate is shown on Figure 9. Two fan delta complexes are present, separated by an elevated area ('*Alanya High*') attested by the locally preserved terrestrial scree deposits extending from Oymapınar Dam to the south of Fersin. In the NW, the alluvial fan recorded in the Sırtköy-Sevinç area extends southwards into a large fan delta, with a narrow branch coming from the area of Kepez village. In the SE, the Alarahan fan delta was mainly fed from the east and locally from the north according to clast composition, current direction, and facies distribution (Karabıyıkoğlu *et al*. 2000).

The coarse-grained Tepekli Conglomerate, represented by southwards prograding coastal alluvial fan/fan delta deposits, indicates a marked increase in the supply of coarse clastic sediments eroded from the northern/northeastern sources, implying that the northern margin of the Manavgat sub-basin was characterized by an area of considerably high relief resulting from a regionally formed tectonic uplift (Monod *et al*. 2006).

The Oymapınar Limestone: Late Burdigalian–Langhian Reefal Carbonate Shelf. The Oymapınar Limestone is best observed in the Manavgat sub-basin and outcrops as a NW–SE-trending narrow belt that onlaps the Tepekli Conglomerate and the Alanya Massif northwards (Figures 7 & 8). It is a 20–150-m-thick, deepening-upward shallow marine carbonate shelf succession and represents an initial extensive marine transgression in the basin.

At the southeastern end of the basin, the Oymapınar Limestone overlies the Alarahan fan delta deposits with a sharp flat contact. It is mainly composed of coarse-grained large benthic foraminiferal wackestone-packstone (F16) containing small isolated coral reefs (F19). The overall sequence suggests carbonate deposition in a relatively deeper-water outer-shelf environment.

To the northwest along the road to Ahmetler village (Figure 7), the Oymapınar Limestone directly overlies the meta-carbonates of the Alanya Massif. Here, the Oymapınar Limestone is dominated by a succession of parallel bedded benthic foraminiferal wackestone-packstone (F16) and packstone-grainstone (F17) with shallow, mound-like stacked buildups of algal, benthic foraminiferal wackestone packstone and small coral reef patches (F19), which grade laterally (basinwards) into mixed benthic-planktic foraminiferal wackestone-packstone and marl (F12C). The details of the bedding configuration and facies characteristics reveal the presence of a shelf margin algal mound complex with well-developed basin- and shelfward-dipping beds interfingering with horizontally stratified inter-mound beds (Figure 10).

Further northwest, at the Oymapınar Dam site (Figure 11), the Oymapınar Limestone overlies the metamorphic rocks of the Alanya Massif unconformably, where a vertical sequence of up to 30-m-thick *Microcodium*-bearing basal breccia (F1) (see inset in Figure 11) grades vertically through pebbly to sandy miliolid limestone to reefal shelf carbonate. This sequence represents a locally developed subaerial slope scree or small colluvial cone evolving into shallow, wave-reworked coastal colluvium at the initial stage of the transgression of the carbonate shelf.

A tentative palaeoenvironmental reconstruction of the Oymapınar Limestone and the Tepekli Conglomerate is presented along a synthetic 2D view (Figure 12). In the NW, the Tepekli Conglomerate is represented as a subaerial alluvial fan filling deeply incised valleys, as seen in the Sevinç area. To the south, the conglomerates progressively pass into a fan delta environment indicated by patch reefs. Silty clays (F12C) appear in the south easternmost section (Örenşehir) and are interpreted as a deeper and distal facies of the Tepekli Conglomerate. Above, the distribution of patch reefs and algal mounds in

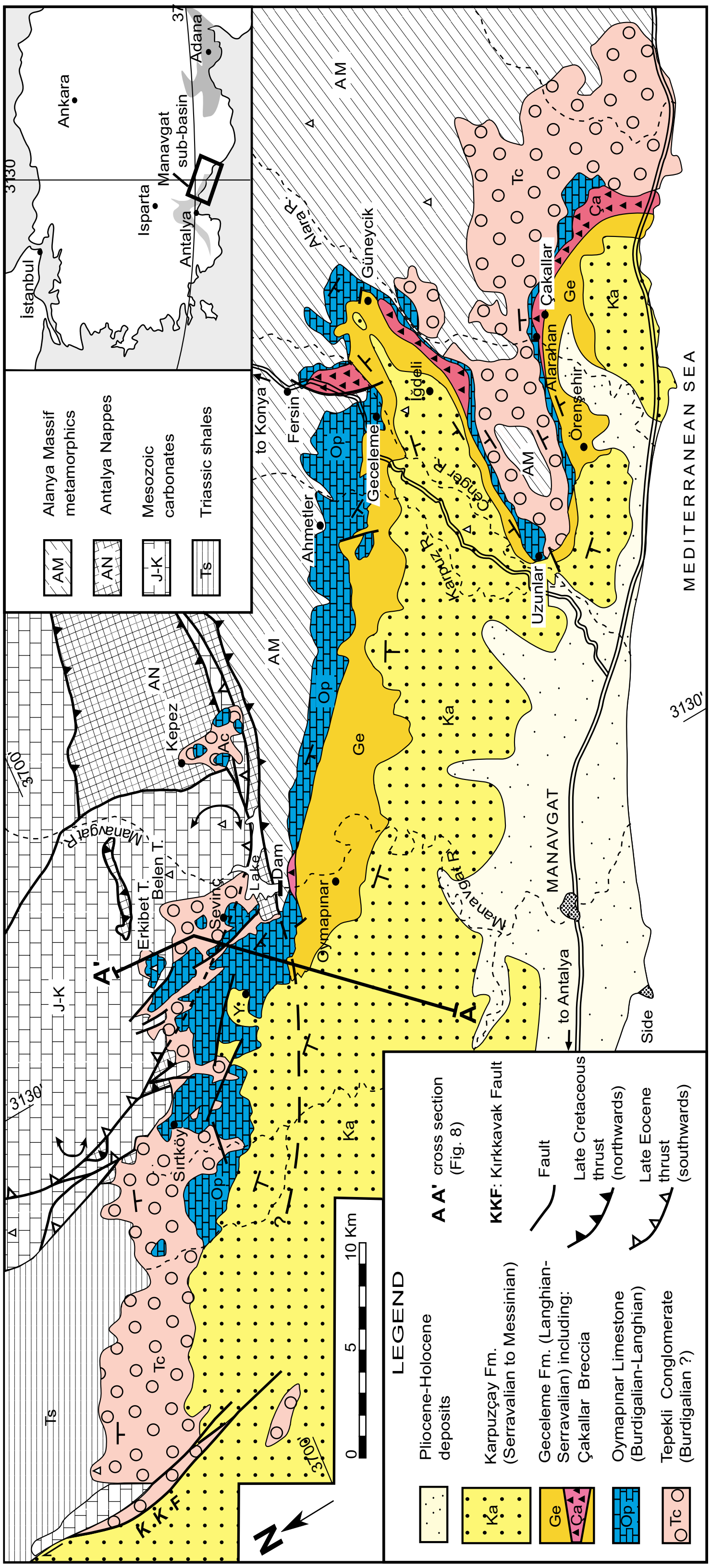

Figure 7. Geological map of the Manavgat sub-basin. Modified from Karabıyıkoğlu *et al.* (2000).

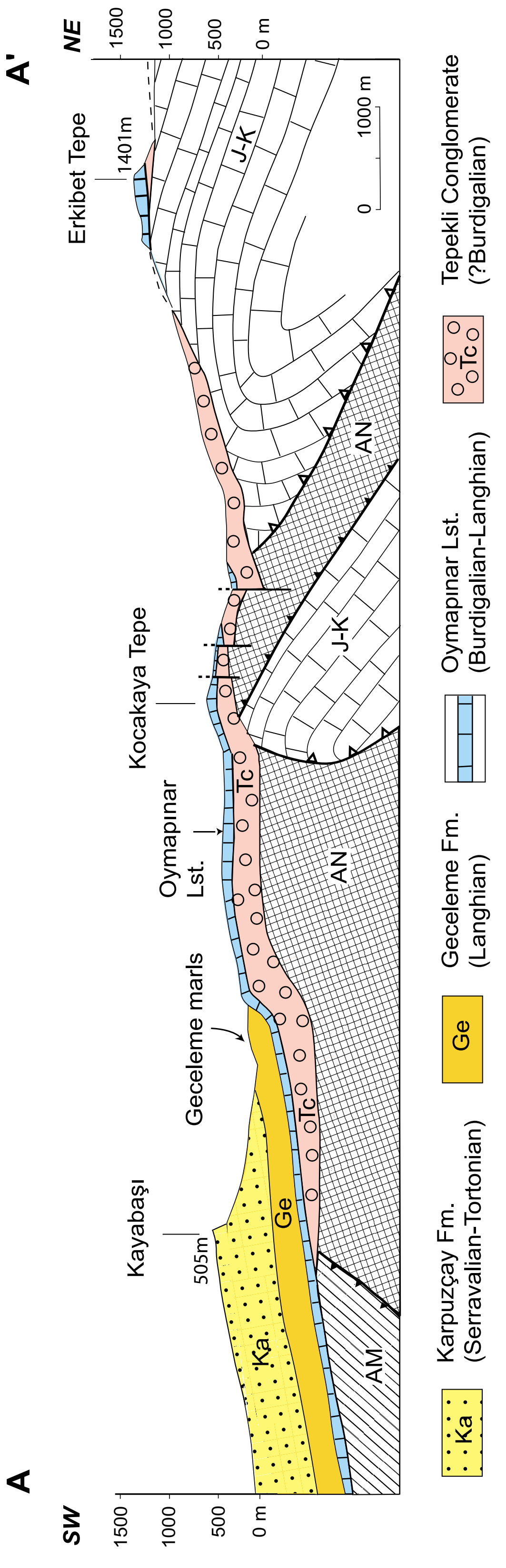

Figure 8. Representative cross-section from the Manavgat sub-basin. Location in Figure 7. Modified from Karabıyıkoğlu *et al.* (2000).

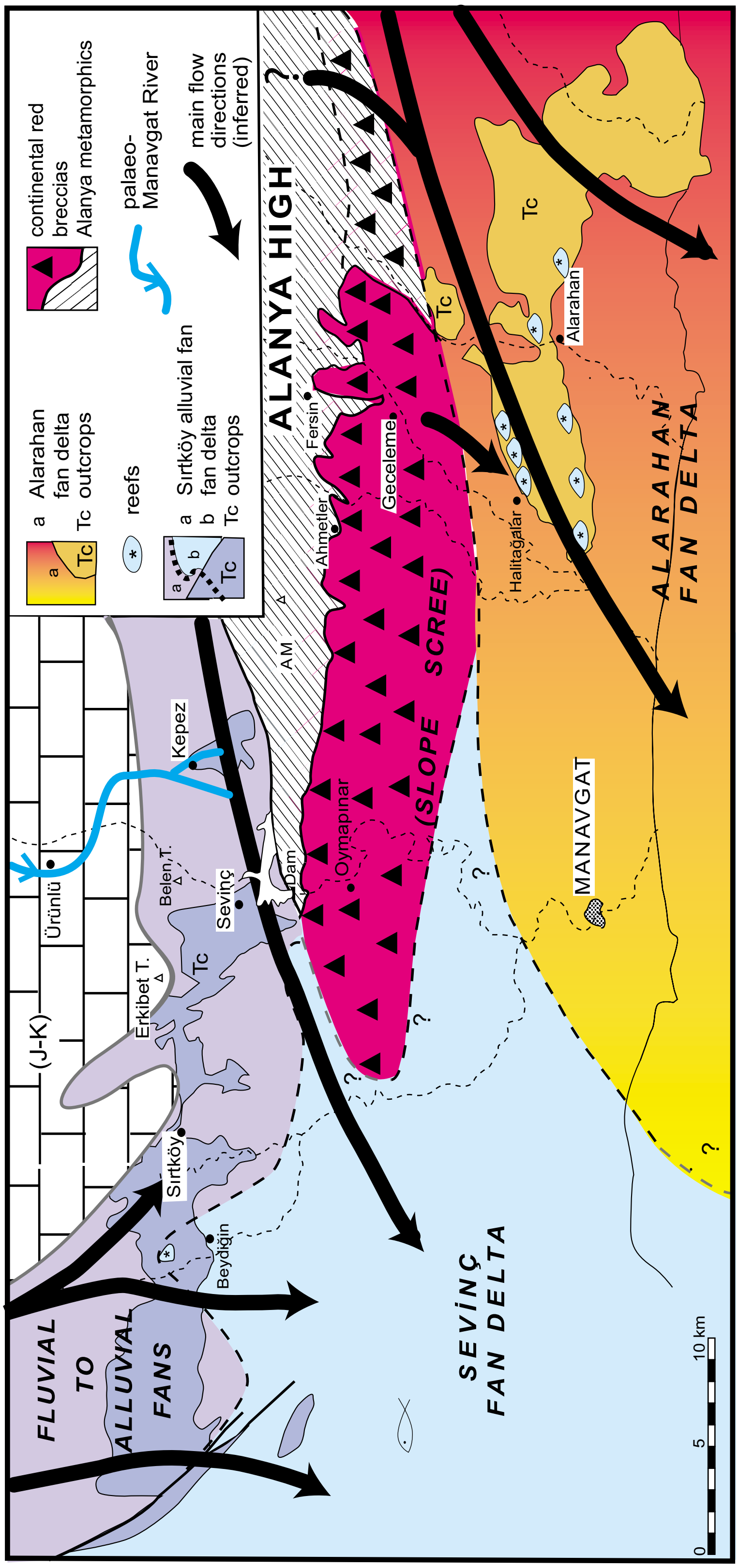

Figure 9. Probable distribution of palaeoenvironments during the deposition of the Tepekli Conglomerate (Tc, Burdigalian). Modified from Karabıyıkoğlu *et al.* (2000).

Figure 10. Field view of the basinward prograding (clinoformal) algal-mound complex of the Oymapınar Limestone (O) at Ahmetler. Note the onlapping relation of the Geceleme Formation (G) mudstone. Dotted lines represent large-scale bedding configurations. The section is approximately 30 m thick. From Karabıyıkoğlu *et al.* (2000).

the Oymapınar Limestone suggests a shallow marine carbonate shelf deepening and thinning to the south and southeast (Örenşehir), with a relatively shallower inner shelf characterized by algal, foraminiferal wackestone-packstone facies and rarer patch reefs in the north (Sevinç area).

The Geceleme Formation: Late Langhian–Serravalian Base of Slope-Basin Floor Fan. The Geceleme Formation is composed of interbedded marl, mudstone, siltstone and very fine sandstone, characterized by a rich planktic microfauna (F11 and F12C), occasional chaotic deposits and isolated reefal blocks (F13 and F14). It is exposed in the central and eastern parts of the Manavgat sub-basin where it conformably overlies the Oymapınar Limestone (Figures 7 & 11). It is overlain by the coarser Karpuzçay Formation. Reef-derived breccias (F14) that are locally present in the lower portion of the Geceleme Formation form the Çakallar Member (see below). Abundant planktic foraminifera belonging to the *Orbulina universa* and *Globigerina nepenthes* biozones indicate Lower and Upper Serravalian, respectively.

The overall hemipelagic character of the sedimentation, with occasional calciturbidites, slumps and rock falls as well as the local occurrence of the Çakallar Member (see below) suggests deposition in a locally fault-bounded base of slope setting.

The Çakallar Member: Fault-Generated Breccia. Karabıyıkoğlu *et al.* (2000) considered locally occurring coarse polymictic breccias as a member within the lowermost part of the Geceleme Formation, even though it was defined as the Çakallar 'Formation' by Akay *et al.* (1985) (Figure 7). Along the main road from Manavgat to Konya, about 2 km south of the Fersin village, the Çakallar Member is nearly 110 m thick and directly overlies the Oymapınar Limestone. It is represented by a succession of sharp flat based or channelized, chaotic and disorganized polymictic breccias containing metamorphic

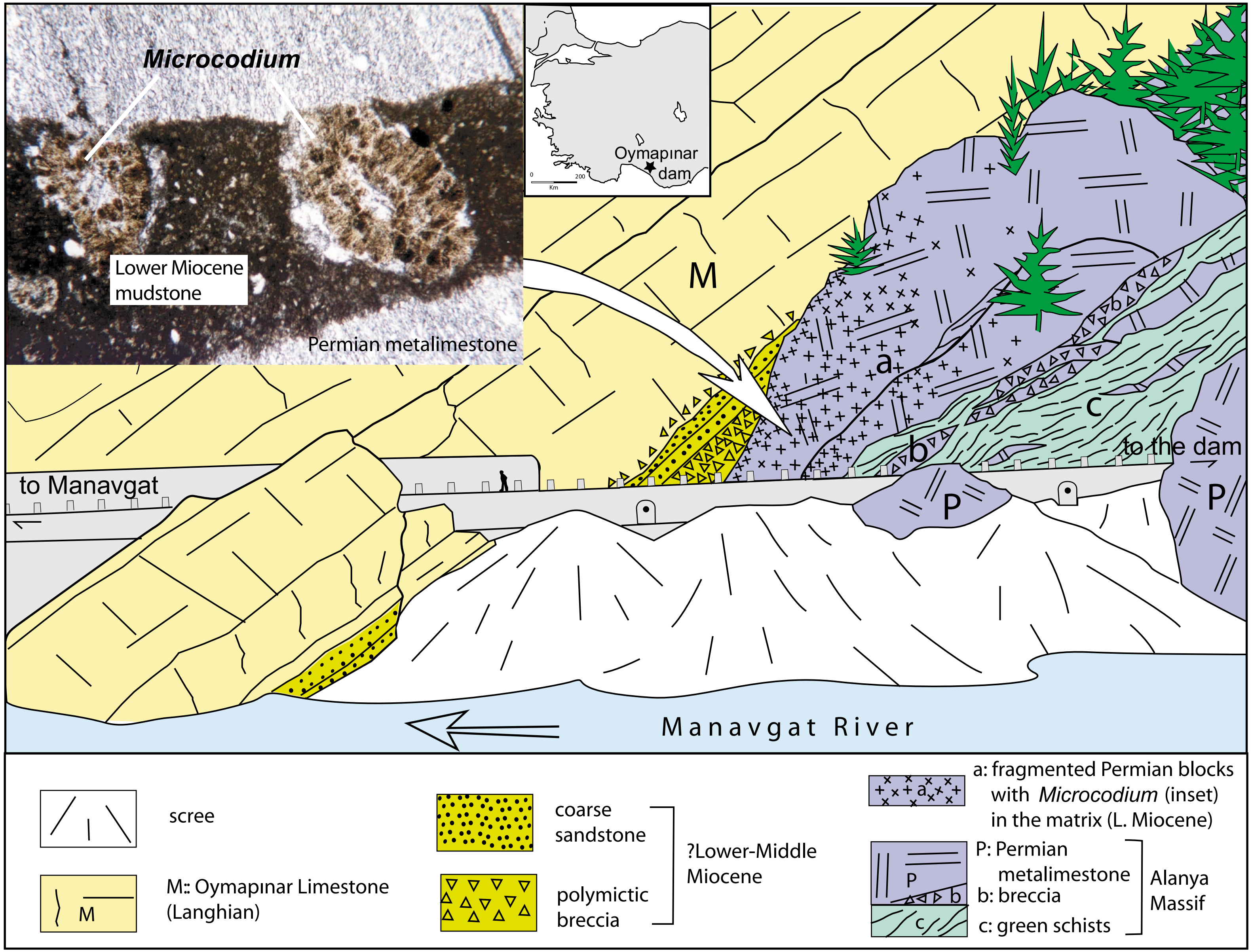

Figure 11. Oymapınar Dam site: field sketch showing the transgression of the Oymapınar limestone upon *Microcodium*-bearing continental breccias overlying the Permian metalimestones of the Alanya Massif. Inset: two *Microcodium* sections in the Miocene mudstone filling the fractures of a metalimestone block. Scale: 0.25 mm.

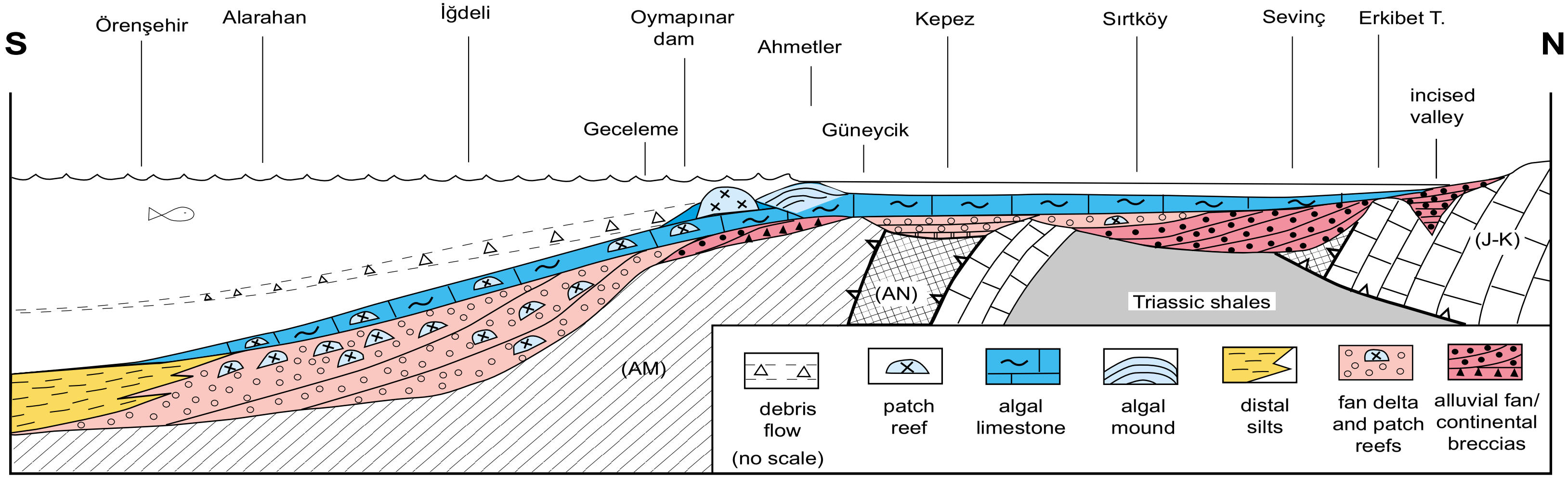

Figure 12. An interpretative N–S cross-section across the eastern part of the Manavgat sub-basin showing facies distribution of the Tepekli conglomerate and the Oymapınar limestone as a synthetic 2D section, representing an overall transgressive succession from alluvial fan/fan delta complex to narrow reefal shelf carbonate and talus slope. Modified from Karabıyıkoğlu *et al.* (2000).

blocks up to 8 meters long (F1 and F14), interbedded with sandstones and mudstones (F9 and F11). These chaotic deposits thin out within a few km southwards into the Geceleme Formation mudstones.

The northwestern boundary of the Çakallar Member outcrop is a conspicuous fault scarp, which can be traced over 2.5 km south of Fersin village and offsets the Oymapınar Limestone by more than 400 m. The continuation of this fault loses displacement within the Geceleme mudstones, and the overlying Karpuzçay Formation is not affected (see map Figure 7). Further south, on both sides of the Örenşehir anticline, the Çakallar Member thins out and disappears westwards. The limited extent of the Çakallar Member and the northward increase in size of the blocks towards the syn-sedimentary Fersin fault (Figure 13) are best interpreted as the result of the proximal redeposition of blocks fallen from the upthrown Oymapınar shelf and Alanya Massif basement, during deposition of the Geceleme mudstones.

The Karpuzçay Formation: Serravalian–Tortonian –Messinian Fan-Delta Complex. The Karpuzçay Formation outcrops as a large, continuous belt across the Manavgat sub-basin (Figure 7) and extends westwards into the Köprüçay sub-basin. It consists of almost 300 m of interbedded calciturbidites, mudstones and siltstones (F7, F9, F11 and F12C) commonly interrupted by erosive-based matrix- to clast-supported conglomeratic horizons a few to several meters thick (F2 and F3), and occasional chaotic deposits (F13 and F14). Plant debris, groove casts and Bouma sequences are common in the sandstone-mudstone couplets. This formation represents the final stage of filling in the Manavgat sub-basin during the Tortonian–Messinian. It is unconformably overlain by the fluvial deposits and marine marls of the Eskiköy Formation (Lower Pliocene).

The Karpuzçay Formation calciturbidites reflect a long-ranging phase of tectonic activity, which caused uplift of the Taurus hinterland and the shelfal area north of the basin. The coarser facies encountered occasionally within the Karpuzçay Formation can be interpreted in terms of tectonically generated mass-flow processes, including high-density turbidity currents, slumps and debris flows in and around a fan delta environment.

Formation and Evolution of the Manavgat Sub-basin

The Tepekli Conglomerate represents the initial infill of a pre-existing topography that marks a long period of uplift and subsequent erosion of the Western Taurus from Early Oligocene to earliest Miocene. Two major coastal alluvial fan/fan delta systems have been identified: the Sevinç coastal alluvial fan-fan delta in the NW and the Alarahan fan delta complex in the SE. Between these two major drainage systems, a mountainous region is implied by the discontinuous presence of red monomict breccias of terrestrial origin (scree), implying steep slopes in the immediate vicinity. According to the clast provenance, the Sevinç and Alarahan fan deltas were the output of two major drainage systems tapping into source areas in the newly created mountainous area to the N and NE, in the western Taurus (cf. Monod *et al.* 2006). The fan delta complexes prograded as conglomerate-dominated bodies into a shallow shelf area. Globigerinid-bearing mudstone and siltstone beds (Burdigalian) accumulated as pro-delta deposits in the deeper shelf area, indicating a gently southward inclined ramp-like open marine system.

A sharp rise of relative sea level and a decreasing rate of sediment supply due to the progressive denudation of relief resulted in the deposition of the transgressive Oymapınar Limestone (Late Burdigalian to Langhian). It onlaps the fan delta deposits and the basement, with a gentle southward deepening trend documented by the distribution of the reefs.

After this tectonically quiescent episode, a sudden deepening is documented by the onset of fine-grained deposition of the Geceleme Formation (Langhian–Serravalian) with pelagic fauna overlying the patch-reefs of the Oymapınar shelf carbonates. The Çakallar Member breccias and debris flows that locally appear in the lower part of the Geceleme Formation substantiates the tectonic origin of this sudden deepening. Syn-sedimentary faulting can be documented in places (Fersin, Oymapınar Dam) by interbedded fragments derived from the Oymapınar shelf carbonates, by the distribution of the breccias and by the identification of the fault planes themselves, all implying the fragmentation and sinking of the Oymapınar carbonate shelf.

The succeeding sedimentation consists of the filling of the newly created accommodation space with an overall coarsening-upward succession from the Geceleme to

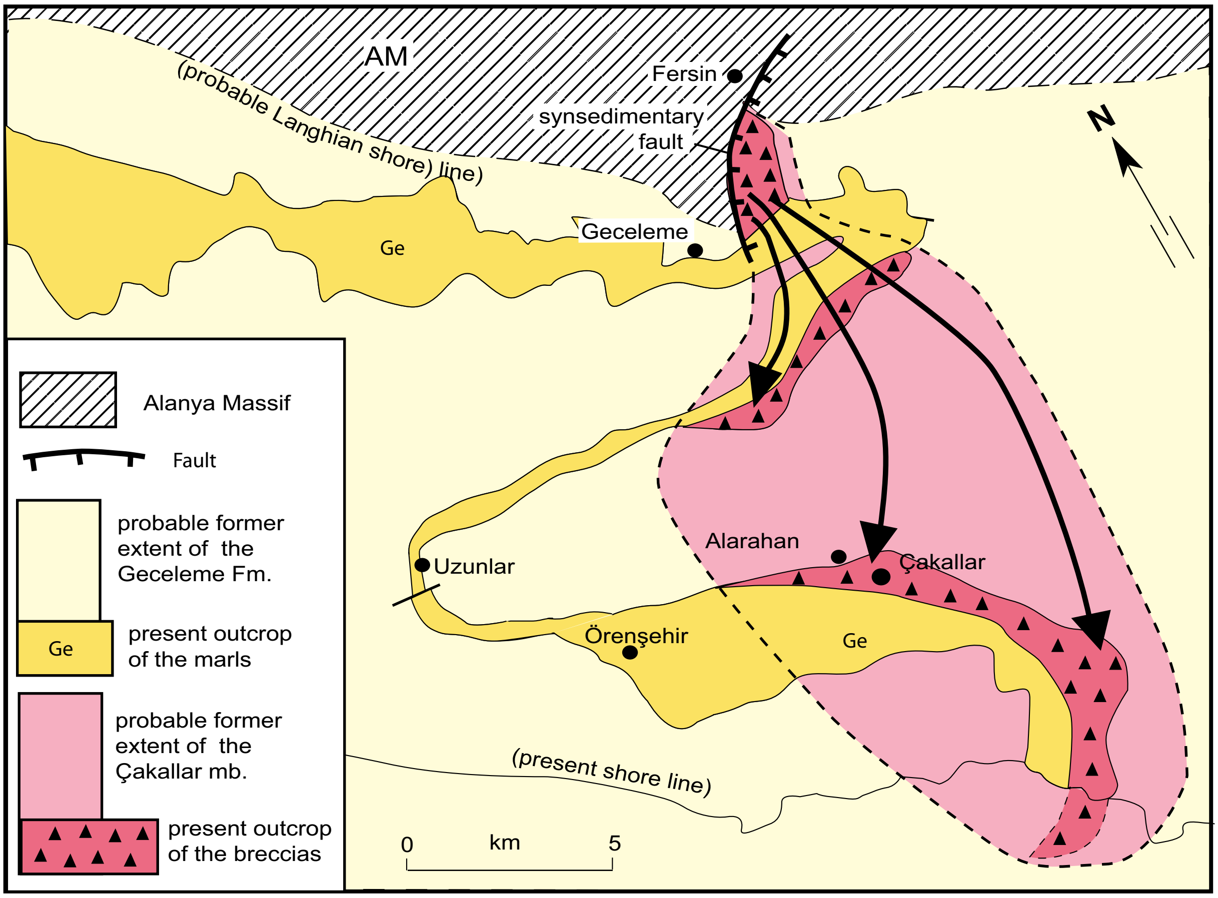

Figure 13. Extension of the Çakallar breccias generated by the syn-sedimentary Fersin fault, within the Geceleme Formation. Modified from Karabıyıkoğlu *et al.* (2000).

Karpuzçay formations. The gravity-induced character of most of the Karpuzçay Formation, the sharp passage from high-density currents and debris flows to turbulent coarse-grained fan delta, suggests that the sedimentation was largely controlled by repeated uplifts of the hinterland during Late Miocene. A differential uplift may be inferred from clast composition of the debris flows, which implies strong erosion of the Alanya Massif and its Miocene carbonate cover in the east (Alarahan area). In contrast, Mesozoic limestone clasts predominate in the west of the basin, reflecting a larger uplift in this part of the Taurus chain. Although discontinuous, the presence of debris flow deposits throughout the Karpuzçay Formation implies repeated influx of coarse material from nearby sources, and suggests a persistent elevation inland until the end of Miocene (Flecker *et al.* 1995; Monod *et al.* 2006). The filling of the Manavgat sub-basin ended with Messinian (Bizon *et al.* 1974) and a weak N–S compression subsequently produced large open folds in the Miocene deposits before the deposition of the undeformed Pliocene fluvial conglomerates and marine marls (Eskiköy Formation).

Köprüçay Sub-basin

Structural and Stratigraphic Setting

The Köprüçay sub-basin occupies a central position within the Antalya Basin. It is separated from the Aksu sub-basin by the promontory of the Late Miocene Aksu Thrust, but to the south it communicates openly with the Manavgat sub-basin. It is bounded by the Beydağları autochthon to the north, the Antalya Nappes to the west and the Kırkkavak Fault (KKF) and the Anamas-Akseki autochthon to the east (Monod *et al.* 2000, 2001)

(Figures 1 & 14). Blumenthal (1951) and Dumont & Kerey (1975) carried out local studies in the southern and northern parts of the basin. The stratigraphy and structure of the southern part of the Köprüçay sub-basin was first described in detail by Poisson *et al.* (1983), and Akay *et al.* (1985) provided a comprehensive study. Later on, Flecker (1995) and Flecker *et al.* (1995) provided an account of the main sedimentary processes. Recently, Deynoux *et al.* (2005) gave a detailed description and interpretation of the facies in the central and northern parts of the basin.

The sedimentary fill of the Köprüçay sub-basin is characterized by locally developed reefal shelf carbonates (Oymapınar Limestone), the mudstones and turbiditic sandstones of the Karpuzçay Formation, and the Köprüçay Conglomerate that formed along the northern and western rims of the basin (Çiner *et al.* 2003). According to the spatial distribution of the coarse sediments of the Köprüçay Conglomerate, three distinct sets of axially and transversally derived alluvial fan-fan delta complexes (AFD) are recognized, which are subdivided into members (see Figure 14): (1) the Selge AFD in the Beşkonak-Selge-Bozburun area; (2) the Kesme AFD in the Yeşilbağ-Kesme-İbişler area; (3) the Yaka AFD in the İncebel to İkizpınar area.

Facies Architecture and Depositional Environments

At the base, the Burdigalian–Tortonian fill of the Köprüçay sub-basin is represented by reefal shelf carbonates (Oymapınar Limestone) which are overlain by fluvial to marine coarse basin margin clastics (Köprüçay Conglomerate), followed by finer-grained marine clastics (Karpuzçay Formation) that filled up the deeper and distal parts of the basin.

The Oymapınar Limestone: Burdigalian–Langhian Reefal Carbonate Shelf. It is locally exposed along the northwestern rim as a NE–SW-trending narrow belt between Ballıbucak and Değirmenözü (Figure 14). This formation dips eastwards (5 to 35°), toward the basin centre and rests westward on the limestones of the Beydağları autochthon. In a 100–150-m-thick section near Ballıbucak village, about 20–30 m of clast-supported breccia (F1) with red to yellow muddy matrix occurs between the Mesozoic basement and the Oymapınar Limestone. The breccia contact on the basement is sharp and erosional, whereas the passage to the limestones appears transitional. Between Bolasan and Değirmenözü, the Oymapınar Limestone is directly overlain by the fine-grained sandstone-mudstone alternations of the Karpuzçay Formation. On the other hand, to the southeast of Bolasan, the Köprüçay Conglomerates locally onlap onto the Oymapınar Limestone (Figure 15).

The reefs recognized within the shelf limestones are developed on algal benthic foraminiferal wackestone-packstone (F16) and are composed of *Porites, Tarbellastraea, Heliastraea, Aquitanastraea, Favites, Favia*, *Plesiastraea, Mussismilia*, *Turbinaria* and *Oxypora*, indicating a shallow normal salinity carbonate shelf. However, near Ballıbucak, a local occurrence of solitary corals *(Lithophyllia* and *Syzygophyllia),* suggests a relatively deeper marine environment, within the subphotic zone.

The Karpuzçay Formation: Serravalian–?Tortonian Open Marine Clastic Shelf. This formation consists of thin parallel-bedded to laminated mudstone and decimetre thick alternations of normally graded calcareous sandstone with sharp flat bases and occasional rippled tops (F9, F11 and F12C). Thickening-up successions of sandstone beds wedging out laterally over hundreds of metres occur locally. These sandy alternations become frequent in the upper part of the formation, and some individual beds show typical Bouma sequences. Large- to small-scale fold and slump structures (F13) as well as internal unconformities suggest syn-sedimentary instability and post-depositional deformation (Figure 5C).

The Karpuzçay Formation indicates sedimentation mainly from suspension fall out in a quiet offshore marine environment, with sandy rippled intercalations, representing distal turbiditic flows. Samples contain shelf derived debris and *in-situ* planktic foraminifera, mainly globigerinids, indicate a pelagic environment.

The Köprüçay Conglomerate: Langhian–?Tortonian Alluvial Fan/Fan-Delta Complex. All conglomeratic facies (F2 to F8) described in Table 1 are present in the Köprüçay Conglomerate. A more detailed description of the facies and their depositional environments is given by Deynoux *et al.* (2005). The conglomerates correspond to specific subenvironments of three distinct alluvial fan-fan delta systems (AFDs) that developed along the tectonically active northern and eastern margins of the basin.

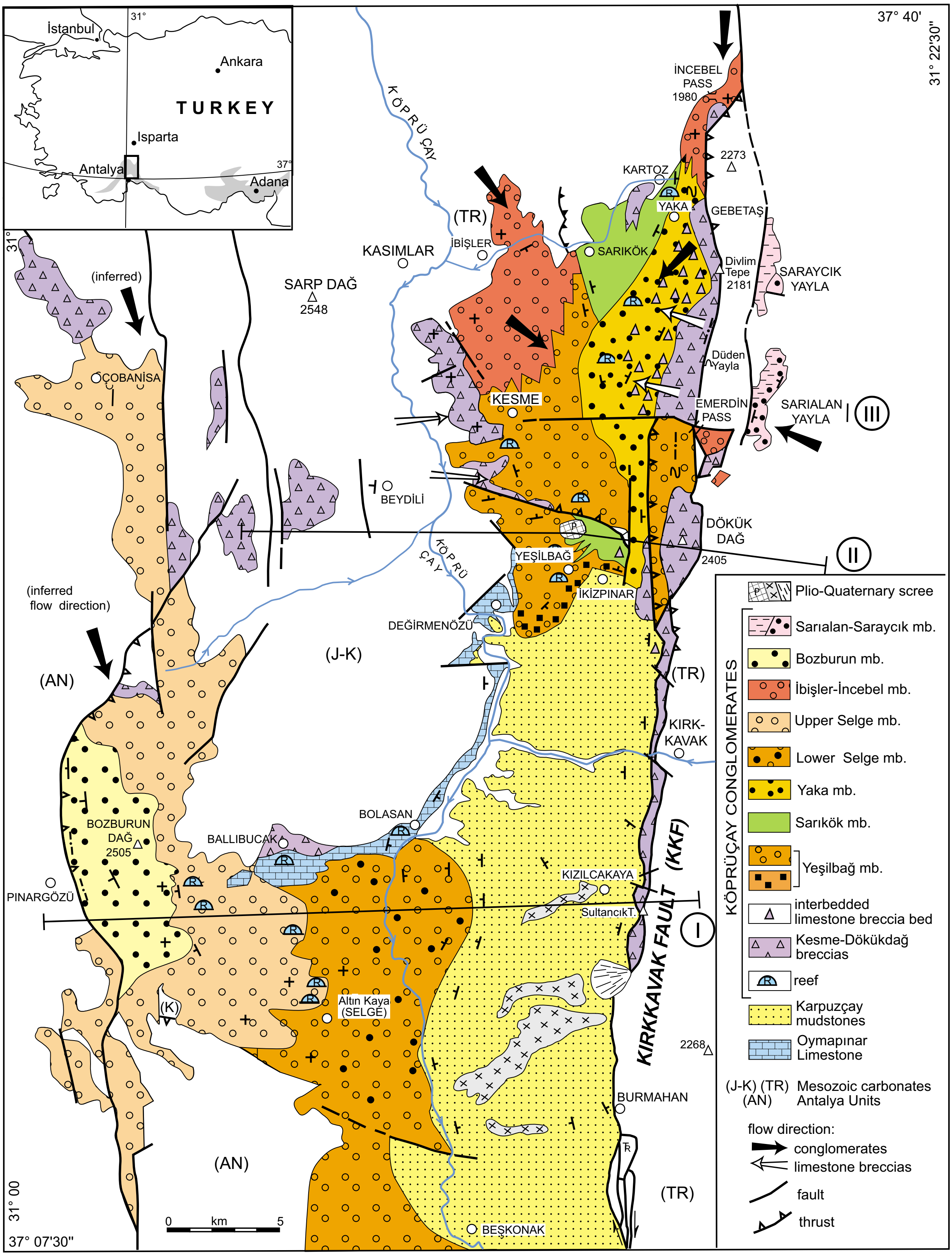

Figure 14. Geological setting and Miocene facies map of the northern part of the Köprüçay sub-basin. Modified from Deynoux *et al.* (2005).

Figure 15. Onlap of Köprüçay Conglomerates onto the Oymapınar Limestones near Bolasan.

Facies represented by hyperconcentrated density flow and cohesive debris flow deposits were both encountered at the transition between the Karpuzçay Formation and the Köprüçay Conglomerate. They correspond to the lower reach of fan delta systems whose slopes and fronts are respectively represented by Gilbert-type subaqueous foresets, consisting of subaqueous water flow and cohesionless debris flow deposits. The superposition of several fan delta systems forms the bulk of the Köprüçay Conglomerate. Where preserved, the upper part of a fan delta system contains patch reefs mainly characterized by hermatypic colonies of *Porites Tarbellastraea, Heliastraea, Heliastreopsis, Favites, Favia*, *Plesiastraea, Mussismilia*, *Stylophora*, *Leptastraea*, *Caulastraea*, and *Aquitanastraea* with rare solitary corals (*Lithophyllia, Syzygophyllia* and *Leptomussa*).

Formation and Evolution of the Köprüçay Sub-basin

The Köprüçay sub-basin evolution can be subdivided into three main periods: the first period (pre-basin sequence) is represented by the transgressive Oymapınar Limestone (Upper Burdigalian to Lower Langhian), which overlies a substratum that was tectonised during the emplacement of the Antalya Nappes in the Late Cretaceous. This carbonate deposition is shelfal in facies with a roughly constant thickness around 100 m, indicating uniform but weak subsidence across the entire area.

The second period, corresponding to the main detrital infilling of the basin, was preceded by a major eastward tilting of the Oymapınar carbonate platform, resulting from a rapid and asymmetric subsidence of the basin along the KKF. This is documented by the distribution of the shallow facies, mostly present in the northern and the western borders, whereas distal mudstones of the Karpuzçay Formation are thickest along the KKF. Most significantly, this syndepositional tilting is demonstrated by the conspicuous onlap of the horizontal conglomerates of the lower Selge Member upon the 10° to 20° eastward dipping Oymapınar Limestone (Figures 15 & 16).

The syn-sedimentary activity of the KKF, at least for its normal component, is an essential characteristic of the Köprüçay sub-basin during the Middle Miocene (Monod *et al*. 2000). It is best demonstrated along the eastern border of the basin where massive carbonate breccias outcrop along the faulted boundary over 40 km, and are interbedded with conglomerates and mudstones basinwards. These breccias indicate that in the Taurus hinterland, a constantly rejuvenated ridge, due to tectonic activity along the KKF, was shedding Mesozoic carbonate fragments into the basin, at least during the Middle Miocene (cf. Langhian dating, east of Kesme).

Detrital infilling of the Köprüçay sub-basin probably persisted into the Tortonian, although no sediments of that age have been identified in the central part of the basin. However, along the eastern footwall of the KKF, in the Sarıalan and Saraycık areas (Figure 14) thin pelagic marls and associated conglomerates have been precisely dated as Early Tortonian by micro- and nanno-fossil associations (Deynoux *et al*. 2005). This shows that regional subsidence finally led to a large eastward overspill of the Köprüçay sub-basin during the Tortonian, possibly as far east as the Kelsu locality, where lagoonal ostracods and large oysters are present in the Miocene marls (Babinot 2002). Moreover, this locality exhibits Triassic limestones perforated by conspicuous borings of Miocene age, very similar to those recently described from the Mut Basin (Uchman *et al*. 2002). Inside some of these the boring bivalve (*Lithophaga* or *Teredo*) is still preserved in living position (Figure 17), thanks to the Late Miocene muds (with globigerinids) which quickly filled the cavity and killed the trapped bivalve. Lastly, the absence of breccias associated with the Lower Tortonian deposits suggests that the relief was minor, and hence that tectonic activity on the KKF had ceased by then.

The uppermost part of the Köprüçay sub-basin is represented by 500 m of undated conglomerates now culminating at the summit of Bozburundağ (2505 m, Figure 14), which reflect a strong regional subsidence. These conglomerates lie unconformably upon the upper Selge Member, tilted 5° to 10° westwards (Figures 16 & 18). This implies that a former uplift and local erosion of the area had to occur before the deposition of the Bozburun conglomerates. More precisely, the toplaps upon the upper Selge strata, dipping westwards away from the Köprüçay sub-basin, indicate that tilting had already occurred before erosion started. We therefore interpret this uplift as reflecting a blind syn-sedimentary ramp produced at the inception of renewed convergence (Deynoux *et al*. 2005), possibly early in Tortonian times. Maximum convergence, however, occurred late in the Tortonian, as demonstrated by movements on the Aksu Thrust (Poisson 1977), and led to the final closure of the Isparta Angle. This major compressive event is reflected in the Köprüçay sub-basin by multiple folds, by the inversion of the KKF as a reverse fault in the north (İncebel Pass, Figures 14 & 16), and by several pop-up like structures farther south (cf. Deynoux *et al*. 2005).

The Köprüçay sub-basin can be interpreted as a syn-tectonic fault-bounded basin, with a strongly asymmetric subsidence centered along the KKF fault line. During the Early Tortonian, activity on the KKF had already ceased, and a shallow-marine transgression covered much of the nearby Taurus chain. Along the eastern border, convergence in the Late Tortonian eventually inverted the KKF into a reverse fault, along with folding and imbrications within the Köprüçay sub-basin, as the Isparta Angle closed to its present shape.

Aksu Sub-basin

Structural and Stratigraphic Setting

The Aksu sub-basin is a north–south-extending basin that lies obliquely in front of the northeast–southwest-trending Lycian Nappe and is bounded by the Early Tortonian Aksu Thrust to the east (Figure 19). To the west, a younger imbrication involves Pliocene conglomerates (Figure 16) near Eskiköy, indicating a further stage of closure of the Isparta Angle (Poisson *et al*. 2003b).

The sedimentary fill of the basin is mainly characterized by coarse conglomerates, sandstones, mudstones and reefal carbonates which have been previously described and interpreted in terms of three formations, the Aksu Formation, the Karpuzçay Formation and the Gebiz Limestone, representing Upper Miocene and Lower Pliocene deposits (Akay *et al*. 1985;

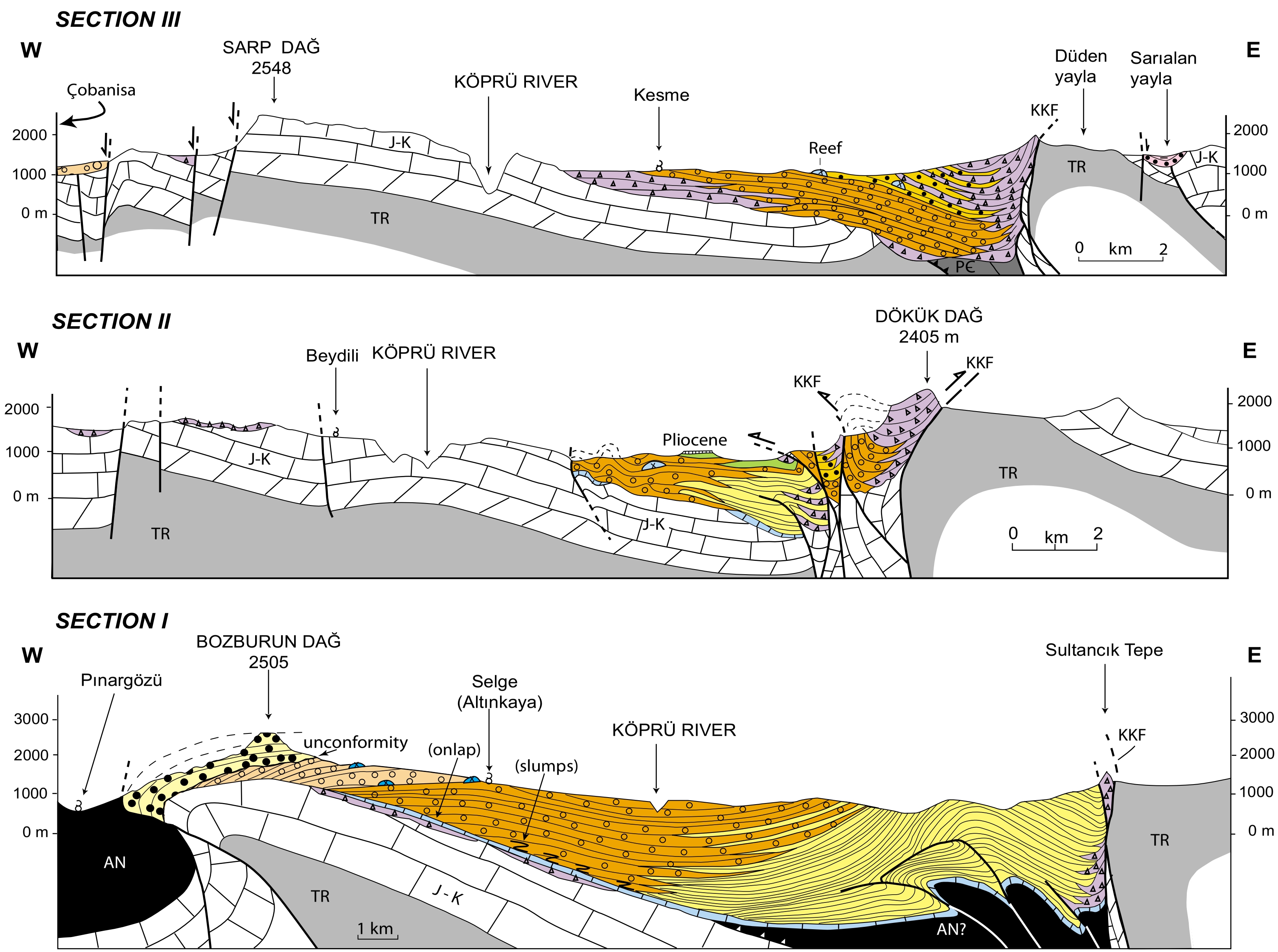

Figure 16. Three sections across the Köprüçay sub-basin showing the distribution of the main facies and members of the Selge, Kesme and Yaka alluvial fan-fan delta complexes. Position of sections in Figure 14. Modified from Deynoux *et al.* (2005).

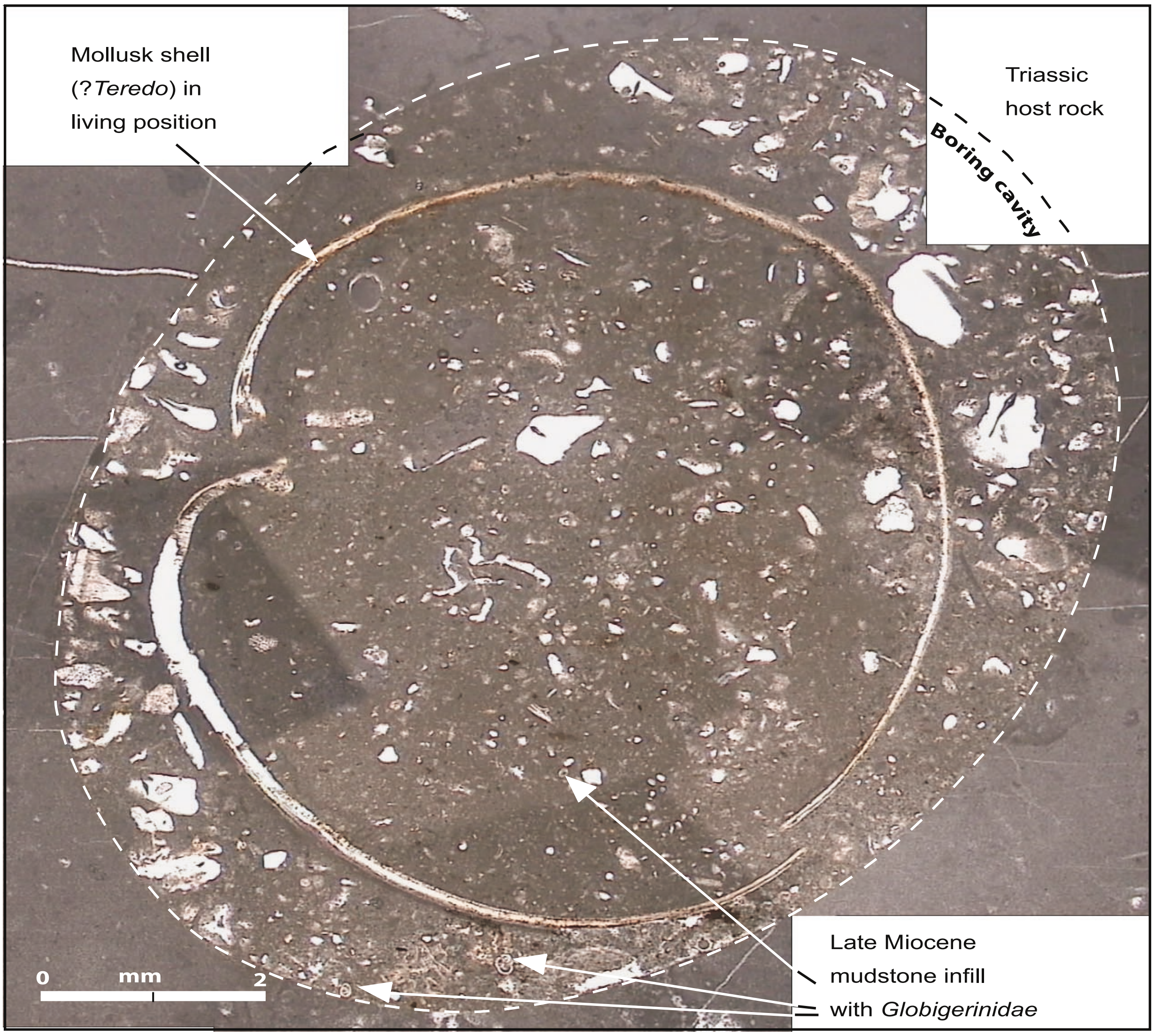

Figure 17. Transverse section of a Miocene boring in a Triassic limestone (Kelsu locality). The cavity is inhabited by its host (*Lithophaga* or *Teredo*) in living position, and was filled by Late Miocene mudstone with microfauna (Globigerinidae), which buried it.

Karabıyıkoğlu *et al.* 1997, 2005; Tuzcu *et al.* 1997). Flecker *et al.* (1995, 1998) and Glover & Robertson (1998) suggested a Tortonian age for the Aksu Formation and a Tortonian–Messinian age for the Gebiz Limestone. Poisson *et al.* (2003a, b) consider the Gebiz Limestone to be Early Pliocene in age. The controversy concerning the age of the Gebiz Limestone is further discussed below.

In this study the Aksu Formation has been designated the Aksuçay Conglomerate, comprising three Members: (1) Kapıkaya Conglomerate, (2) Karadağ Conglomerate, and (3) Kargı Conglomerate. Above these units the Aksu sub-basin includes a thick turbiditic formation, which is probably equivalent to the upper part of the Karpuzçay Formation, as defined in the Manavgat and Köprüçay sub-basins.

To the north, the Kapıkaya Conglomerate (Cg1) overlies the Lycian Nappes units, as already proposed long ago (Gutnic *et al.* 1979). Intercalated reefs within the higher part of the conglomerates have been studied near Taşyayla village. In these reefs, only a limited variety of coral genera are present (*Porites, Tarbellastraea, Siderastrea*), and this restricted faunal assemblage may be attributed to Upper Miocene (?Tortonian), in global

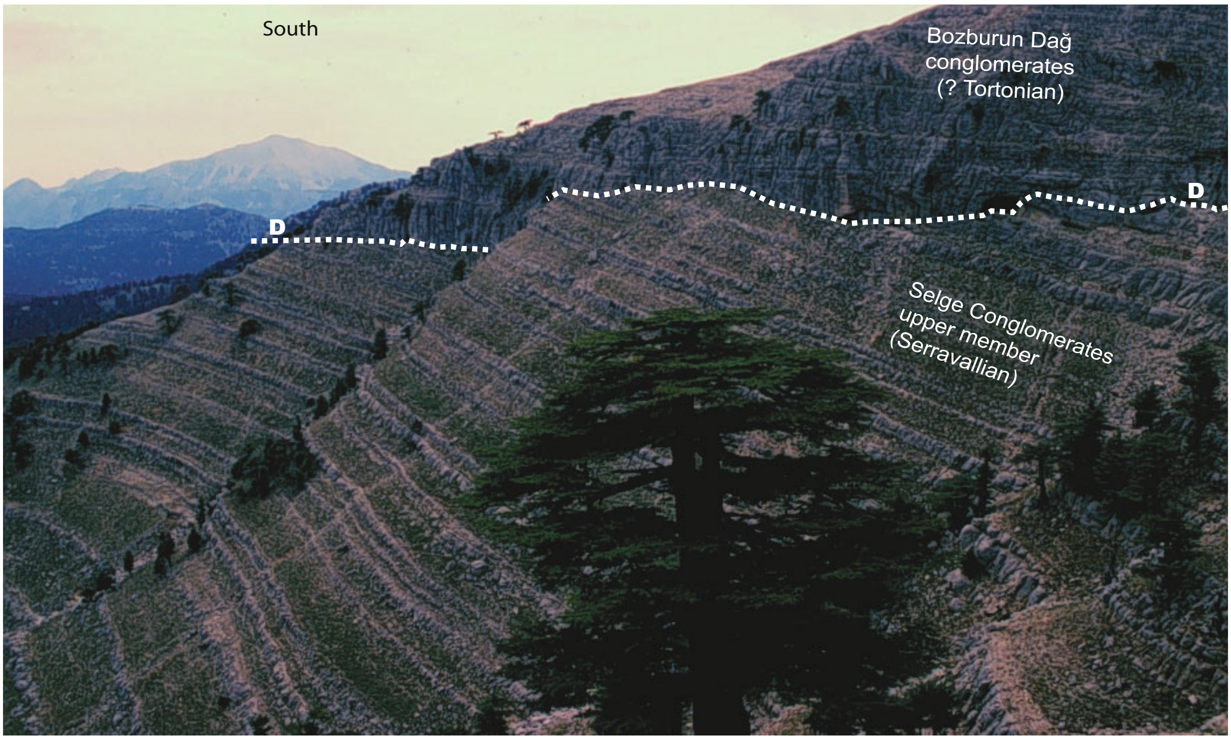

Figure 18. Angular unconformity (D) between upper Selge Member and Bozburun Member conglomerates at Bozburun Dağ eastern side.

agreement with microfaunas and nannos situated in interbedded marls within the Kapıkaya Conglomerates, which yielded Serravalian to Tortonian ages west of Aşağı Gökdere (Akay *et al*. 1985). On the map (Figure 19), this member also includes the conglomerates situated along the road from the Aksu valley (Karacaören) to Bucak, which may have the same origin and age, although no specific data are available.

Further south in the Aksu sub-basin, tectonic imbrications have disrupted and isolated several conglomeratic bodies but precise correlations are not possible, owing to the lack of sufficient stratigraphic control within each of these sub-units. Nevertheless, two conglomerate members have been distinguished on the map and sections (Figures 19 & 20).

The Karadağ Conglomerate (Cg2) includes the conspicuous conglomeratic cliffs, over 500 m high, facing the Kargı Dam lake, and extends up to the north of Çandır on the one hand, but should also comprise the large conglomerate body west of Kozan village, 30 km farther east. Within the Karadağ Conglomerate coral reefs are rare. A rapid sampling of one of the reefs exposed about 5 km south of Aşağı Gökdere includes *Stylophora, Tarbellastraea, Porites, Plesiastraea*, which are not diagnostic enough for precise dating.

The base of the Karadağ unit is usually missing, owing to the Late Tortonian thrusting of this unit over the turbidites of the Karpuzçay Formation, as shown on the map (Figure 19). However, special attention was given to a very peculiar conglomerate facies, which contains abundant metamorphic pebbles and found at the base of the Karadağ cliffs. These unusual conglomerates were first reported by Akay *et al.* (1985). In fact, the outcropping area of this facies is quite large, and extends about 7 km south of the Kargı Lake forming an elongated wedge, 500-m-thick at most (Taşdibi unit, Monod *et al.* 2006). Metamorphic pebbles are abundant (up to 20%) and consist of white marble, quartzite, green schist and amphibolite. However, the most amazing feature is the abundance of pebbles and blocks (up to 50 cm) of high pressure-low temperature blueschist facies, with angular shapes, suggesting short transportation. Among various HP–LT facies, A. Okay (in Monod *et al.* 2006) has recognized typical glaucophane calc-schists, with sodic amphibole, quartz, calcite, phengite, and garnet blueschists, deriving from former metabasites, such as

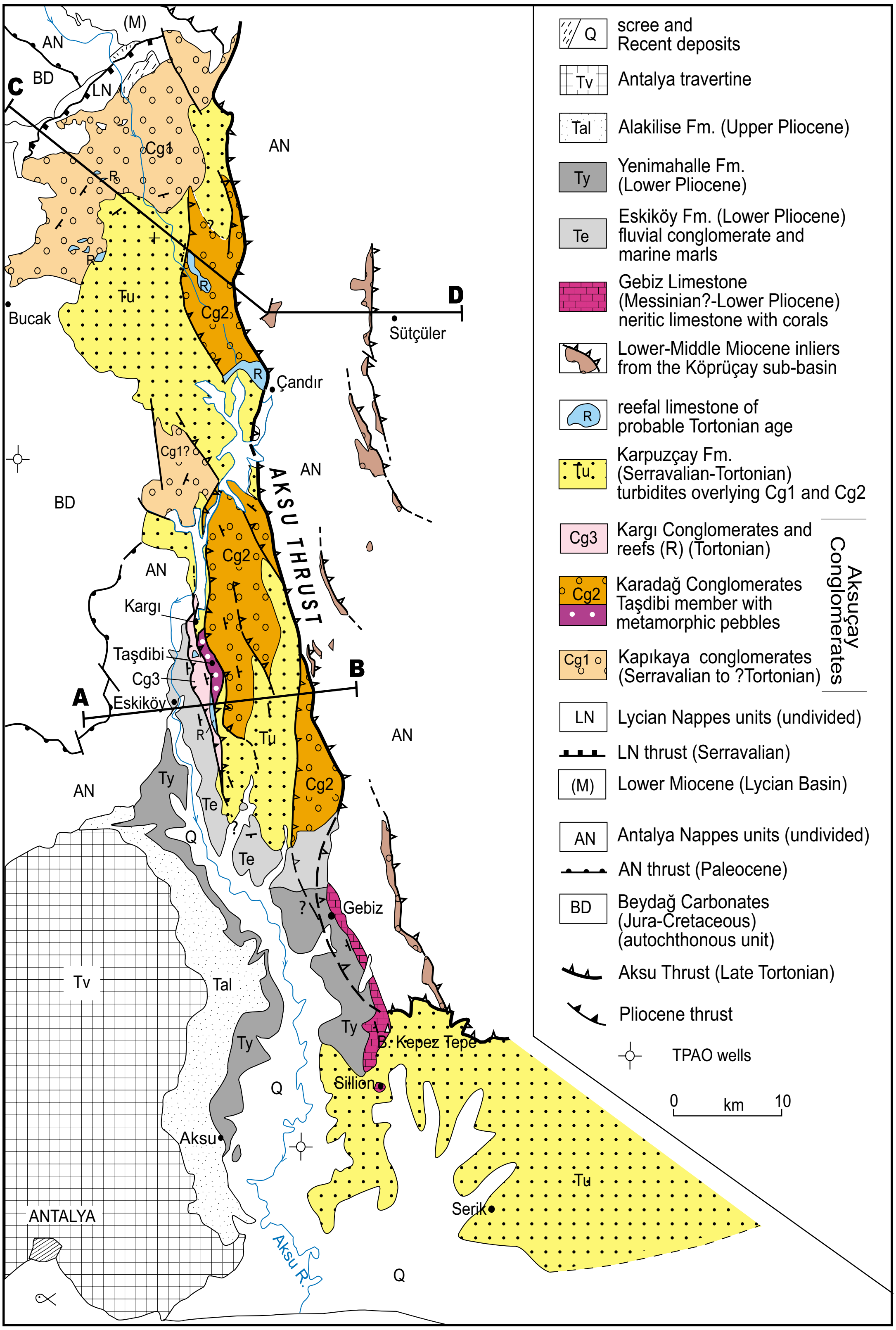

Figure 19. Geological setting and distribution of the Miocene formations in the Aksu sub-basin. Complementary information from Poisson (1977, 2003), Akay *et al.* (1985) and Şenel (1997, 2002).

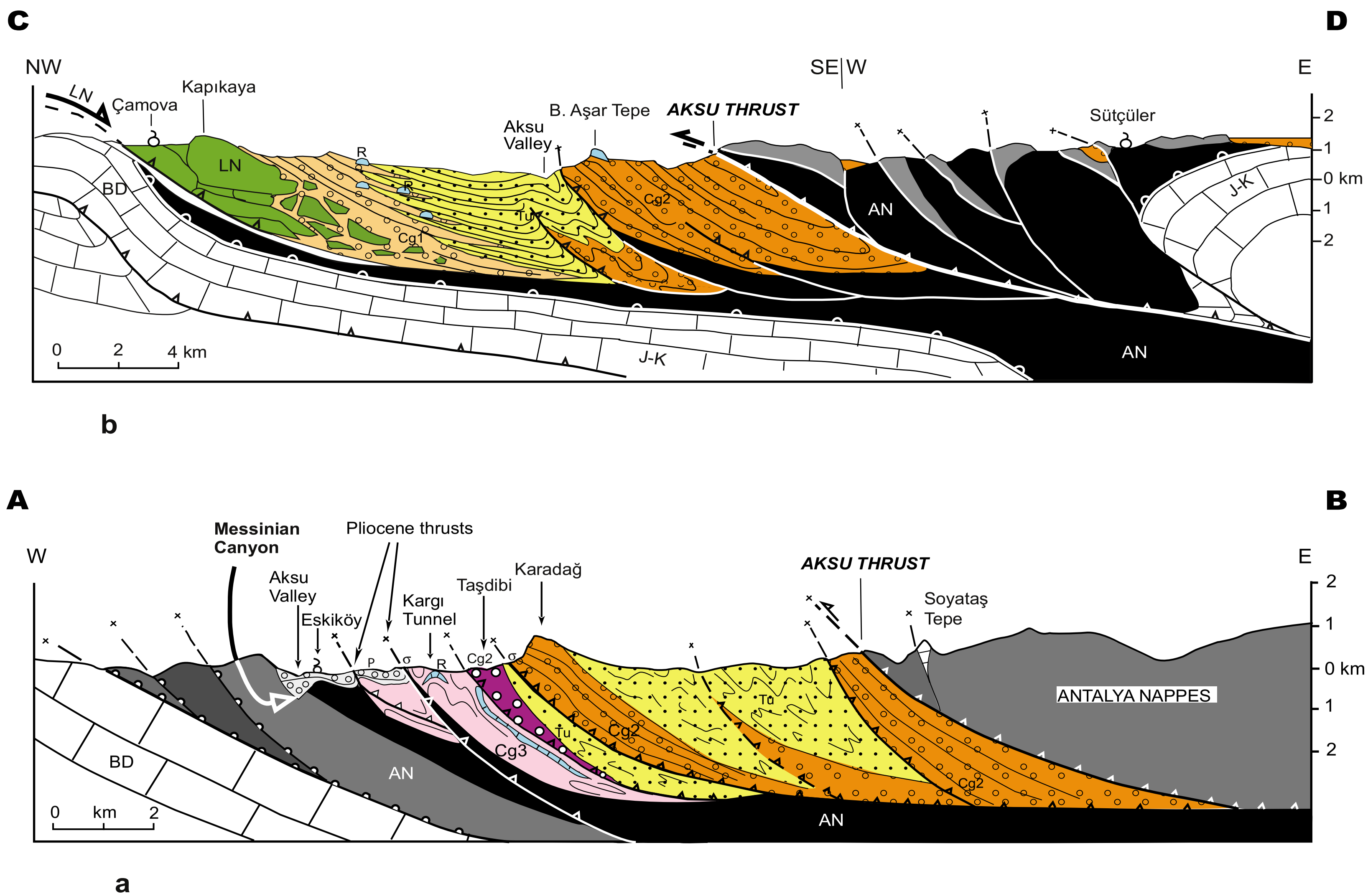

Figure 20. Two schematic sections across the Aksu sub-basin showing multiple imbrications of Late Miocene and Early Pliocene age. See Figure 19 for location and lithostratigraphic legend. (A–B) Aksu sub-basin section (south) and (C–D) Aksu sub-basin section (north).

those in the Sugözü Nappe of the Alanya Massif (Okay & Özgül 1984).

The probable origin of the metamorphic detritus is the Alanya Massif, as previously suggested by Akay *et al.* (1985). This origin is most surprising since the present outcrop of the Alanya Massif is over 100 km to the southeast, and this is inconsistent with the proximal source needed for the angular blocks. Moreover, the abundance of the blueschist pebbles compared with the other metamorphic facies of Barrovian type implies a very large erosional area of the HP–LT rocks. Finally, as seen above, the nearest part of the Alanya Massif is normally buried by marine conglomerates of Burdigalian age in the Manavgat sub-basin, and this rules out fluvial transport of the Alanya material into another marine basin later in the Miocene. Facing these constraints, Monod *et al.* (2006) concluded that the metamorphic pebbles of the Aksu sub-basin could not have come from the present day Alanya Massif, and suggested that, during Miocene times, the Alanya Unit extended westwards possibly as far as Antalya and was there predominantly made of high-pressure rocks. Remnants of this part of the Alanya Massif have now been entirely eroded away, except for two small inliers as noted by Akay *et al.* (1985): one is located 7 km north of Taşağıl (siltstone and fossiliferous Permian metacarbonates), and the other one is 5 km northwest of Gebiz. These inliers provide supporting evidence for the former extension of the Alanya Massif, although HP–LT rocks are not present at outcrop.

The Kargı Conglomerate (Cg3) forms a narrow unit of reddish conglomerates and mudstones, which is well exposed along the Antalya-Isparta new road, and is cut through by the Kargı Tunnel, south of Kargı Lake (Figure 21). In the upper part, the Kargı Conglomerate contains well-preserved patch-reefs, which have been studied in detail by Flecker (1995), Tuzcu & Karabıyıkoğlu (2001) and Karabıyıkoğlu *et al.* (2005). The corals are mostly *Porites* and *Tarbellastraea* (including *T. siciliae*), and the age of the reefs is attributed to the Tortonian. Both upper and lower boundaries of the Kargı Conglomerate are tectonic. The lower thrust is readily visible along the main Antalya-Isparta road, 1 km south of the Kargı tunnel: the red Miocene Kargı Conglomerates are truncated by dark green serpentines up to 50 m thick, which are thrust upon the loose conglomerates of the Eskiköy Formation (Pliocene). The upper limit of the unit also is a thrust, passing 200 m east of the Kargı tunnel against the Taşdibi unit.

Facies Architecture and Depositional Environments

The Aksuçay Conglomerate: ?Serravalian–Tortonian Alluvial Fan/Fan-Delta Complex. The Kapıkaya Conglomerate (Cg1) is interpreted as a coastal alluvial fan that evolved into a fan delta. The reefal interbeds with a limited variety of coral genera that have been studied near Aşağı Yumrutaş and Taşyayla villages suggest a shallow marine environment.

The thick (>1000 m) succession of Karadağ Conglomerate (Cg2) exposed in the central area, is mainly composed of polymict, thickly bedded subaqueous debris flows (F2, F3, F7 and F9) with rare sandy beds, and marl intercalations at the top. Imbricated pebbles are very rare, as well as oblique stratifications. Reworked materials include mainly white and grey Mesozoic limestones, dark sandstones, red and green radiolarites and ophiolitic pebbles, and also include rare reef limestone blocks with Burdigalian–Langhian corals (*Stylophora, Heliastraea, Plesiastraea, Favia, Tarbellastraea, Porites*) (Yukarı Çukur Yayla). Above, two large reefs (F19) concordantly overlie the Karadağ Conglomerate: one near Çandır and the other one 5 km south of Aşağı Gökdere. These reefs are characteristically represented by low-diversity hermatypic corals, which are commonly made up of finger-like branching forms and/or lamellar, plate-like and massive domal forms of *Porites* and *Tarbellastraea* with subordinate *Siderastraea*, minor *Favites, Plesiastraea* and *Platgyra* and indicate normal salinity shallow marine environment. Although the base of the Karadağ unit is not observed, owing to the Late Tortonian thrust, the facies characteristics of the Karadağ Conglomerate indicate proximal alluvial fan-fan delta complex. The metamorphic clasts indicate that the lower part of the Taşdibi conglomerates was partly sourced from the Alanya Massif prograding northwards.

The lower Kargı Conglomerate (Cg3) is characterized by a succession of matrix- to clast-supported lenticular conglomerates (F2 and F3) with red mudstone (F12A) and sandstone interbeds (F7 and F8). The upper succession is composed of tabular, lenticular and tabular cross-stratified conglomerates (F4, F5 and F8) with locally developed coral-algal reef and sandstone and mudstone interbeds. The Kargı Conglomerate initially appears to have been formed as shallow braided stream and overbank deposits that developed on a medial alluvial fan. The upper succession with patch reefs indicates a sharp transgression over the alluvial fan, which in turn,

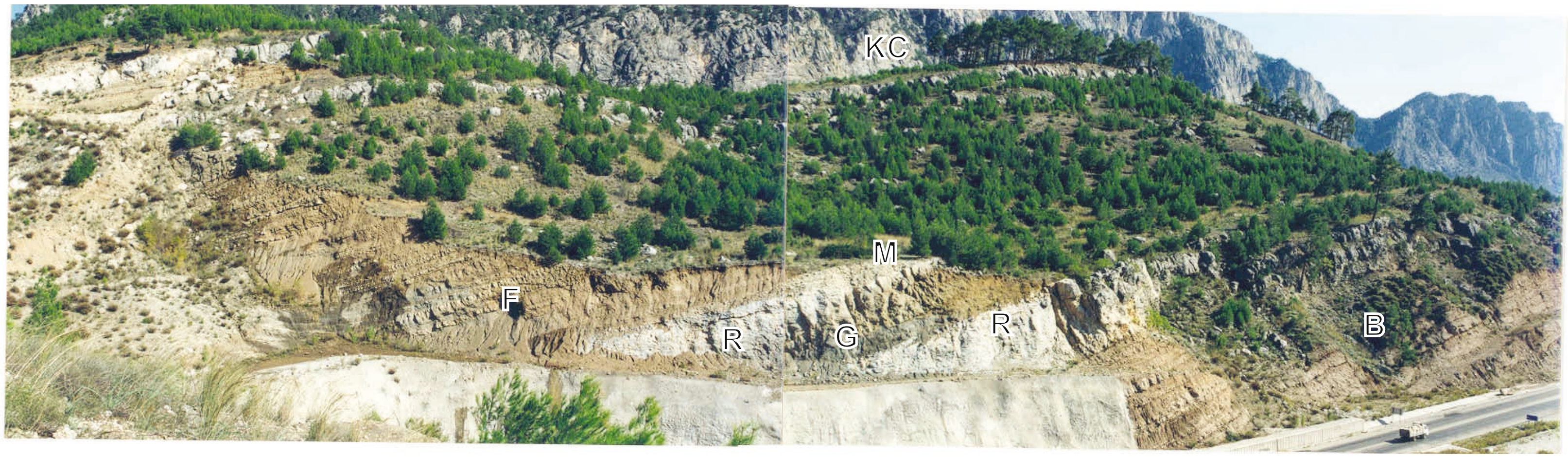

Figure 21. Panoramic view of the Kargı reefs (R) looking westwards. Note the sharp transition from braided stream deposits (B) to reef core (R) interbedded with fan delta slope deposits (F), reef talus deposits (M) and gastropod bearing mudstones (G) in between two reef cores. Steep background is the frontal part of Karadağ Conglomerates (Cg2 on Figure 19). Truck on the right bottom for scale.

led to the development of a fan delta. Facies patterns indicate that the fan delta deposits prograded north–northeastwards (Flecker 1995).

The Karpuzçay Formation: Serravalian–Tortonian Open Marine Clastic Shelf. The Karpuzçay Formation is characteristically composed of sandstone-mudstone alternations (F7, F9, F11 and F12C) forming small- to large-scale coarsening- to fining-upward sequences. Interbeds of muddy coarse conglomerates (F10) are locally present. The sandstones are characterized by laterally continuous thin to thick tabular units with sharp lower and upper contacts. Plane-parallel and graded beds are common sedimentary features. The mudstones are massive to parallel laminated and form laterally extensive units with sharp and planar bases and tops. The facies characteristics of sandstones and mudstones are very similar to those of the Karpuzçay Formation exposed in the Köprüçay sub-basin. Therefore, this formation is also interpreted as offshore marine sediments.

The Gebiz Limestone: Late Miocene–Early Pliocene Fringing Reefal Carbonates. The Gebiz Limestone, situated to the east of the town of Gebiz in the southern Aksu sub-basin, extends as a thin (20-m-thick on average), narrow NW–SE-trending belt at the eastern basin margin, unconformably overlying the Antalya Nappes and the Serravalian–Tortonian Karpuzçay Formation (Akay *et al.* 1985). It is mainly represented by a succession of reefal shelf carbonates, consisting of isolated patches of low-diversity coral reefs, flat-bedded bioclastic limestones and subordinate marls and clays. The reefal and the bioclastic limestones include mollusks, echinoids, benthic foraminifers (peneroplids, miliolids, rotalid, *Borelis melo melo*, *Dendritina*, *Elphidium*, *Heterostegina*, *Textularia*), bryozoa, corals and red algae (Tuzcu & Karabıyıkoğlu 2001; Karabıyıkoğlu *et al.* 2005), whereas the overlying marls and clays contain both shallow and deep water fauna, including both benthic and planktic foraminifers and nannoplankton of deeper open marine conditions (Poisson *et al.* 2003b).

The reefal shelf carbonates are locally well exposed at the Büyük Kepez Tepe and the Aşar Tepe (the ancient city of Sillion) sections, about 8 and 10 km south of Gebiz. These sections, though two kilometers apart, are commonly characterized by a lower and an upper facies association. The lower facies association is represented by isolated patches of *Tarbellastraea* and *Porites* dominated reefs (up to 6 m thick) (F19) comprising minor *Sideastraea*, *Plesiastraea*, *Favites* and *Platygyra* (including species of *Porites calabricae* and *Siderastraea crenulata*), associated with horizontal to gently inclined algal benthic foraminal lime mudstone (F15), wackestone and packstone (F16). Symbiont-bearing foraminifera, *Borelis melo melo* and *Dendritina*, miliolids, large gastropods, echinoids, serpulid tubes, bioturbations and burrowings are common within the reef frameworks and the associated algal foraminiferal limestones. The overlying facies association is generally composed of westwards- to northwestwards-inclined, thin- to thick-bedded, algal benthic foraminiferal wackestone, packstone (F16) and rare grainstone (F17) with moderate to rich shallow marine fauna (Tuzcu & Karabıyıkoğlu 2001; Karabıyıkoğlu *et al.* 2005), which suggest a moderate to high energy open outer shelf environment. At both sections, the lower facies association overlies the planktic foraminifera bearing fines of the Karpuzçay Formation (F12c). At the Büyük Kepez Tepe section, a sharp, flat to slightly erosive contact is revealed at the base of the reefal facies association, along an east–west-oriented exposure (about 300 m long) which runs almost parallel to the depositional dip. The planktic foraminifera content of the uppermost 20 cm of the underlying Karpuzçay Formation exposed at this section yielded a fauna association indicative of Early to Middle Tortonian age, which consists of *Globorotalia acostaensis, G. continuosa, G. obesa, G. bulloides, G. falconensis, Globigerinoides ruber seigliei, G. bulloides, G. obliquus obliquus, G. trilobus trilobus, G. quadrilobatus, Globoquadrina dehiscens dehiscens* and *Turborotalia quinqueloba* (det. A. Hakyemez, in Tuzcu & Karabıyıkoğlu 2001). In contrast to the southeastern part, the northwestern extent of the reefal Gebiz Limestone rests directly on the radiolarites of the Antalya Nappes and is transitionally overlain by marls and fine clastics rich in mollusks, benthic and planktonic foraminifers and nannoplankton, representing open marine conditions (Poisson *et al.* 2003b). The reefs are considered to be fringing reefs developed along the higher grounds of the eastern margin of the Pliocene Aksu sub-basin (Poisson *et al.* 2003b).

Although the depositional setting of the Gebiz Limestone is well understood, the age of the Gebiz Limestone is controversial since it lacks precise biostratigraphic markers. A precise age for the Gebiz Limestone is needed to better constrain the timing of the Aksu Thrust, and hence the closure of the Isparta Angle. Therefore, a further consideration is given here for a brief review of the stratigraphy of the Gebiz Limestone.

The Gebiz Limestone was initially recognized as Lower Pliocene neritic limestones and marls representing post-thrust sedimentation (Poisson 1977). Later, based on the lithostratigraphic and biostratigraphic considerations, Akay *et al.* (1985) suggested a Messinian age, whereas Glover (1995) and Glover & Robertson (1998) inferred a Tortonian age and Poisson *et al.* (2003b) proposed an Early Pliocene age. A Late Tortonian to Messinian age has also been suggested by Tuzcu & Karabıyıkoğlu (2001) and Karabıyıkoğlu *et al.* (2005).

This suggestion is based on the large-scale correlation of the low-diversity coral genera and the associated benthic foraminifera assemblage of the reefal carbonates with those of the Late Miocene Mediterranean reefs. Indeed, *Porites* and *Tarbellastraea* dominated low diversity coral reefs, in some cases associated with benthic foraminifers *Dendritina* and *Borelis melo melo*, are common features in the Late Miocene sequences throughout the circum-Mediterranean (Esteban 1979; Dabrio *et al.* 1981; Grasso *et al.* 1982; Rouchy *et al.* 1982; Martin & André 1992; Buchbinder *et al.* 1993; Bossio *et al.* 1996; Buchbinder 1996; Martin & Cornée 1996; Betzler & Schmitz 1997). However, it should be pointed out that the low diversity may also result from unfavorable palaeoecological factors and therefore does not necessarily indicate a particular age. Yet the coral species and the associated large benthic foraminifera *Borelis melo* and *Dendritina sp.*, suggest a Tortonian–Messinian age. Furthermore, it should be pointed out that *Tarbellastraea*, one of the main framework builders on Miocene Mediterranean reefs, has a limited stratigraphic range (Chevalier 1961). This genus evolved from Oligocene and extended up to Late Miocene with only a few wide-ranging species before it became extinct prior to Pliocene (Budd *et al.* 1996), implying that the reefal Gebiz Limestone cannot be regarded as younger than the Late Messinian in age. Yet Poisson *et al.* (2003b) presented detailed biostratigraphic data, based on nannoplankton and planktic foraminifera content of the lower beds of the Gebiz Limestone exposed in the Gebiz area and concluded an Early Pliocene age for the reefs in the Gebiz Limestone. The nannofossil content of lowermost interbedded limestones and marls yielded an assemblage of the NN12 Zone (*Amaurolithus tricorniculatus* Zone of Martini 1971), indicating the transition from Messinian to Zanclean (Early Pliocene), whereas the marls immediately above the lower beds belong to the *Globorotalia margaritae* Zone of Early Pliocene age (for further details see figure 3 and tables 1 and 2 in Poisson *et al.* 2003b).

In short, we suggest that the Gebiz Limestone represents a westwards- to northwestwards-deepening and younging sequence, mainly characterized by reefal shelf carbonates, with well-developed fringing reefs and patch reefs, which are, in turn, transitionally overlain by the Early Pliocene open marine marls and fine clastics. Alternatively, it may be suggested that the Gebiz Limestone represents a gently basinward (westwards to northwestwards) inclined carbonate ramp characterized by reefal carbonates of inner ramp, distally overlain by open marine carbonates and the fine clastics of mid-outer ramp to deeper outer ramp (Early Pliocene).

Both models indicate that the southeastern margin of the Aksu sub-basin evolved from a locally developed shallow reefal carbonate shelf to a deeper open marine shelf with a fine siliciclastic input, during the time interval of Messinian to Early Pliocene. The reefal carbonates suggest an initial transgression following a Late Miocene regression in the area, resulting from the sea level drop associated with the Messinian crisis. This is followed by an influx of finer clastics that finally drowned the reefal carbonate shelf during Early Pliocene. The transgression represents the onset of Pliocene flooding of the Mediterranean.

Formation and Evolution of the Aksu Sub-basin

The Aksu sub-basin was probably initiated later than the Köprüçay sub-basin (Serravalian vs. Langhian) and records the final stages of the closure of the Isparta Angle. It was fed from the north and northwest resulting in the formation of a southward prograding coastal alluvial fan-fan delta complex (Kapıkaya Conglomerate, Serravalian–Tortonian), and also from the west, leading to the formation of an eastward to northeastward prograding alluvial fan-fan delta complex (Kargı Conglomerate, ?Tortonian). In addition, the Karadağ Conglomerate, containing metamorphic detritus derived from a distinct source area indicative of a former extension of the Alanya Massif to the west, represents an alluvial fan-fan delta complex supplied from the east and southeast. A westward propagating Late Tortonian thrust ('Aksu Thrust') has probably reduced the basin width by 30 to 50%, and was followed by a later westward compression locally affecting the Lower Pliocene deposits.

Conclusions

One of the aims of the present study was to provide a detailed description and interpretation of the various clastic and carbonate facies associated in an alluvial fan-fan delta setting within a tectonically active basin. Interpretations are tentative owing to the complex interactions and rapid lateral changes of physical processes acting during transport and deposition of such highly heterogeneous materials. In many cases, the observed sedimentary structures alone are not sufficient to unequivocally assert the mode of deposition, and in places comparison with models described in the literature may even be misleading. However, in spite of syn- and post-sedimentary deformations, the relative position of the facies, and associated patch reefs or shelly fossils, could be traced along complete transects, from the mudstones of the deepest part of the basin up to the proximal alluvial deposits and source areas. Sediments were transported by braided streams to the strand area where they accumulated as alluvial fans or fan deltas, in some cases forming Gilbert-type fan deltas. The coarseness of the delta foresets, and the recurrent intercalations of carbonate breccias, reflect the proximity of the source areas. When preserved, lagoonal deposits and associated patch reefs mark the stacking pattern of successive Gilbert-type deltas (a few meters up to 10's of meters thick), suggesting stepwise relative sea level changes.

This study also provided an insight into the depositional environments of the coralgal reefs in the Antalya Basin. The Miocene coral reefs developed as small, isolated patch reefs in two contrasting depositional systems, progradational fan delta complexes and shallow marine carbonate shelves, during time intervals of the Late Burdigalian–Langhian and Late Miocene to Early Pliocene, representing the changing style of reef accommodation from tectonically controlled, terrigeneous basin margin clastics to transgressive shelf carbonates in time and space.

Another significant point concerns the formation and evolution of the entire Antalya Basin. Flecker *et al.* (1998) suggested that the load of the Lycian Nappes arriving in the western part of the Antalya Gulf may have induced flexural loading effects in the lithosphere. Such effects should have influenced the Neogene sedimentation in the three sub-basins situated in front of the Lycian Nappes (Aksu, Köprüçay and Manavgat), as is suggested by contrasting drainage patterns in the first two sub-basins, although their orientation is oblique relative to the Lycian Thrust front. The influence of the advancing nappes is clear and indisputable in the Lycian and Kasaba basins situated along the thrust-front (Poisson 1977; Hayward 1984; Flecker *et al.* 2005), and it may be considered to some extent in the Aksu and Köprüçay sub-basins, some 30 to 60 km away.

However, the case of the Manavgat sub-basin is more questionable, owing to its orthogonal orientation, and its distance to the front of the Lycian Nappes, presently more than 100 km away. The Manavgat sub-basin is weakly deformed, with a continuous deposition from Burdigalian to Messinian. The overall stratigraphy and the ages of the main formations as well as the depositional evolution of the Miocene fill of the Manavgat sub-basin are best compared with the northern part of the Adana Basin where a very similar evolution is reported (cf. Görür 1992; Williams *et al.* 1993; Gürbüz 1999; Satur *et al.* 2005).

In contrast, the Köprüçay and Aksu sub-basins are strongly tectonised. In the Köprüçay sub-basin, facies analysis and dating show that the northern and western parts of the Köprüçay sub-basin are occupied by rather thick and extensive conglomerate-dominated alluvial fan-fan delta systems that prograded south to southeastward and eastward and graded laterally (towards the KKF) into thicker pelagic mudstones representing deeper parts of the basin. The asymmetric facies distribution of the clastic succession in the Köprüçay sub-basin strongly indicates differential subsidence and tectonic activity that was mainly controlled by the KKF, along which sediment thickness is the greatest. Furthermore, the conspicuous onlap of the Selge Conglomerates (Langhian and younger) upon the basal Oymapınar Limestones implies an early eastward tilting of the Oymapınar Limestone towards the KKF, whereas the subsequent Tortonian compressions were directed westwards. The importance of the tectonic activity of the KKF during the sedimentation of the

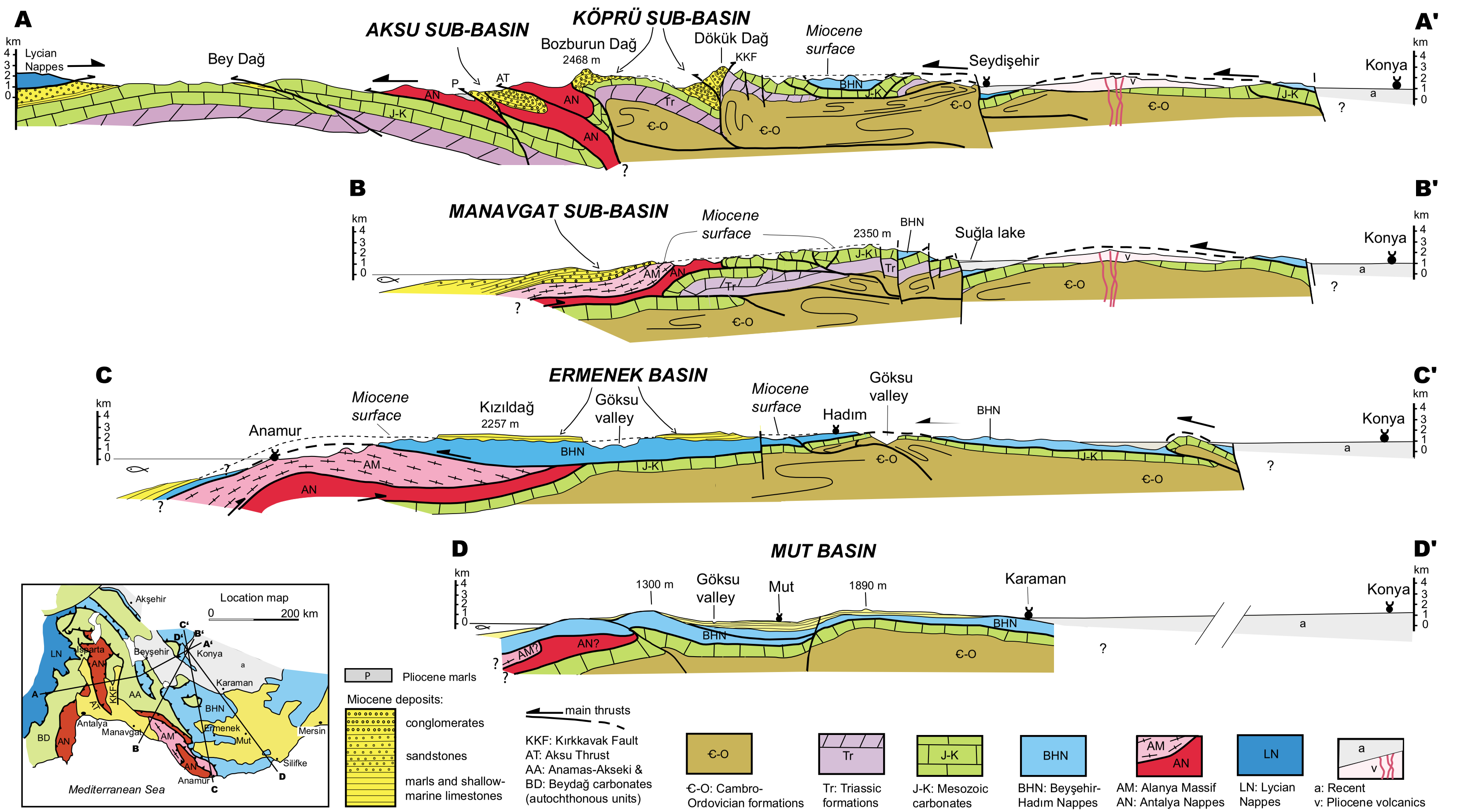

Figure 22. Four synthetic sections in the Neogene basins in southern Turkey. This figure illustrates the contrasting structural behaviour of the Miocene sub-basins in the Antalya area and the striking asymmetry of the Isparta angle: **In section AA'**, on the western side of the Isparta Angle, the Lycian Nappes largely overlie the Lycian Basin (Aquitanian–Burdigalian) on top of the Beydağları; in the centre, the Aksu sub-basin (Serravalian–Tortonian) which overlies the Lycian Nappes as shown in Figure 20a, is strongly imbricated westwards by the Late Miocene Aksu Thrust (AT) and Pliocene thrusts (see Figure 20b); next to it, the Köprü sub-basin also was strongly tectonised during Late Miocene, especially along the deeply rooted Kırkkavak Fault (KKF, see Figure16). Both sub-basins are situated in the central part of the Isparta Angle and their strong deformations reflect the intensity of the Late Miocene and Lower Pliocene westward compressions which led to the closure of the Isparta Angle. On the opposite, the next three sections situated farther east show little or no deformations of the Miocene cover. **In section BB'**, the Manavgat sub-basin (Burdigalian to Messinian) is only flexured along its eastern border (see Figure 8), but the Miocene palaeosurface extends eastwards on top of the Taurus Range and is almost undeformed (cf. Monod *et al.* 2006). **In section CC'**, the Ermenek Basin (Burdigalian–Serravalian) is much thinner and extends horizontally above 2000 m on top of the Taurus nappes (BHN) and the Alanya Massif. It is only affected by normal or wrench faults of limited importance (cf. Ilgar & Nemec 2005). **In section DD'**, from Silifke to Karaman, the Mut Basin (Oligocene–Serravalian) is much thicker but also lies horizontally, and exhibits only limited faulting (Şafak *et al.* 2005). The three last sections demonstrate the overall stability of the Taurus belt on the eastern side of the Isparta Angle during Neogene.

Köprüçay sub-basin is directly evidenced by the carbonate breccias that interfinger with the basin infill during the Langhian and Serravalian. Early in the Tortonian, activity on this fault ceased and a reduced subsidence rate allowed the overspill of the basin upon the Taurus Range. The strongest deformations occurred in Late Tortonian, when the KKF motion was inverted into reverse faulting and westward thrusting, possibly related to an early westward motion of the Anatolian block, which closed the Isparta Angle to its present shape.

Contrary to the expected timing of a flexural loading resulting from the advancing Lycian Nappes, the Aksu sub-basin is probably younger than the Köprüçay sub-basin (Serravalian vs. Langhian) and records the final stages of the closure of the Isparta Angle, showing several west verging thrusts in front of the Aksu Thrust (Late Tortonian). Younger imbrications, involving Pliocene conglomerates and Lower Pliocene marls again may tentatively be related to the westward escape of the Anatolian microplate due to the continental collision occurring in eastern Turkey.

It is also noted that the contrasting structures of these three Miocene sub-basins illustrate the asymmetry of the syntaxis of the Isparta Angle, with a western branch strongly deformed from Langhian to Pliocene, while the eastern side remains almost undeformed. This relative stability allowed preservation of an ancient topography in the higher karstic areas, still visible between Beyşehir and Akseki (Monod *et al*. 2006).

Four structural sketches (Figure 22) illustrate the contrasting position and structure of the Miocene deposits in southern Turkey, from west to east: the Lycian Basin (Aquitanian–Langhian) is a foreland basin largely overthrust by the Lycian Nappes; in the central part of the Isparta Angle, the Aksu sub-basin and the Köprüçay sub-basin are strongly imbricated with the underlying Antalya units and platform carbonates, in Late Miocene and Early Pliocene; farther east, the Manavgat sub-basin (Burdigalian–Messinian) is only flexured late in the Miocene against the Taurus chain. Yet farther east, beyond the Isparta Angle, the Miocene rocks of the Ermenek and Mut basins rest horizontally upon the Central Taurus units and are almost deformation-free except for minor normal or wrench faults (Bassant *et al*. 2005; Ilgar & Nemec 2005).

In the broader context, the final deformation of the Neogene Antalya sub-basins may be understood in part as a consequence of the westward escape of the Anatolian microplate. In the earliest stage (Lower–Middle Miocene) there is no record of compression in southern Turkey: on the contrary, extension prevailed from the Adana Basin to the Mut and Manavgat basins, separating the Anatolian interior from Cyprus. In contrast, furher west, the Lycian thrusts were already advancing southwards, thus creating an initial, wide open, Isparta Angle. During the Late Miocene, southwards expansion in the Aegean Sea induced a further rotation of the Lycian Taurus, and the deepening of the Aksu and Köprüçay sub-basins in the axis of the Angle. The end of Miocene times was marked by jamming of the westward-displaced Anatolian block against the rotated Lycian block: newly created thrusts (such as the Aksu Thrust) imbricated Miocene sediments with basement rocks and closed the Isparta Angle to its present shape. During the Pliocene and Quaternary, west-directed compression resumed, coincident with general uplift of the Anatolian microplate.

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