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Nature, Provenance and Relationships of Early Miocene Palaeovalley Fills, Northern Adana Basin, Turkey: Their Significance for Sediment-Bypassing on a Carbonate Shelf

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Abstract: The Gildirli Formation is the oldest Neogene rock unit in the Adana Basin and was formed prior to the regionally extensive Early Miocene marine transgression. These coarse clastic red-beds provide important evidence about the causes and early phases of filling in this large trough, because the Gildirli Formation sediments fill an irregular palaeotopography carved out of Palaeozoic and Mesozoic basement rocks.

Detailed study of the Gildirli Formation reveals the existence of at least two alluvial fans supplied from different source areas. A northeastern fan, exposed around Gildirli Village, was fed by streams draining an area of ophiolitic mélange, Mesozoic and older limestones, and fills an irregular palaeomorphology around and northeast of Gildirli. The southwestern fan, in the Nergizlik area, is dominated by debris flow and sheet flow rudites derived from an area of entirely carbonate bedrock. The lower part of the southwestern fan is characterised by well-bedded carbonate breccias and conglomerates that occupy deep, steep-sided palaeovalleys with approximate E–W trends (parallelling the main basin-margin), whereas higher parts of this fan are muddier and show channelised fluvial and floodplain attributes. The two fans display different provenance characteristics and evidently were fed into an intervening pre-existing depression, probably tectonically controlled.

The Lower to Middle Miocene sediments that succeed the Gildirli Formation fan clastics on this basin margin form a mosaic of facies associations, partly contemporaneous and partly diachronous. These include a mixed clastic-carbonate unit (Kaplankaya Formation) of mainly shallow marine character, a reefal to platform carbonate unit (Karaisalı Formation), and a coarse clastic submarine fan system (Cingöz Formation) together with its coeval deep-marine shales (Güvenç Formation). The limestone bodies of the Karaisalı Formation in this area display clinoformal geometries that accord with a backstepping pattern and also attest to pre-existing fault control of the steep basin margin.

The western part of the partly contemporaneous Cingöz Formation submarine fan system has been supplied through a feeder-channel that now occupies the palaeovalley depression inherited from pre-Gildirli Formation times. The palaeovalley system shows a margin-parallel trend and might have been developed before the deposition of the Gildirli Formation by extensional tectonics. Thus the location, geometry and orientation of this sector of the mid-Miocene submarine fan appears to have been determined by the tectonically mediated pre-Miocene/Early Miocene palaeomorphology.

Key Words: Adana Basin, alluvial fan, submarine fan, palaeovalley, sediment bypassing, sequence stratigraphy

Erken Miyosen Yaşlı Eski Vadi Dolgusunun Tabiatı, Sediman Kaynağı ve İlişkileri: Bunların Karbonat Şelfinden Sediman Esgeçişi İçin Önemi

Özet: Gildirli Formasyonu Adana Havzası'ndaki Neojen yaşlı en eski kaya birimidir ve bölgesel olarak geniş yayılım gösteren Erken Miyosen denizel transgresyonundan önce gelişmiştir. Kaba taneli kırmızı renkli katmanlar bu geniş çanağın erken dönem dolgusunun sebepleri hakkında önemli ipuçları sağlar, zira Gildirli Formasyonu sedimanları Paleozoyik ve Mesozoyik yaşlı temel kayaları üzerinde açılmış olan eski topografyayı doldurmaktadır.

Gildirli Formasyonu'nu üzerinde yapılan ayrıntılı çalışmalar farklı kaynaklardan beslenen en az iki alüvyon yelpazesinin varlığını göstermektedir. Gildirli civarında yüzeyleyen kuzeydoğu yelpazesi ofiyolitik melanj, Mezozoyik ve daha yaşlı kireçtaşlarından türeyen malzemenin yüzeylendiği alandan beslenmektedir ve Gildirli Köyü ve civarındaki eski topografyanın düzensizliklerini doldurur. Nergizlik alanındaki güneybatı yelpazesinde ise, tamamı kireçtaşlarından oluşan ve temeli oluşturan bir kaynak alandan türeyen moloz akması ve yaygı sellenmesi çakıltaşları hakimdir. Güneybatı yelpazesinin alt seviyeleri yaklaşık D–B gidişli (havzanın kenarına koşut) dik yamaçlı eski vadileri dolduran düzenli katmanlı karbonat çakıltaşlarından oluşur, buna karşılık yelpazenin üst kısımları daha çamurludur ve kanallı akarsu ve taşkın ovası özellikleri gösterir. Bu iki yelpaze farklı kaynak alan karakteristikleri gösterir ve olasılıkla tektonik olarak kontrol edilen yelpazeler arasındaki daha önceden var olan yayvan alanları doldurmaktadır.

Gildirli Formasyonu kırıntılılarını takip eden havza kenarındaki Alt–Orta Miyosen çökelleri kısmen eşyaşlı, kısmen zamandan bağımsız fasiyes topluluklarının bir mozayiğini oluşturur. Bu mozayiğe esas olarak sığ denizel karakterli kırıntılı-karbonat karışımı birim (Kaplankaya Formasyonu), resifal platform karbonat birimi (Karaisalı Formasyonu) ve kaba kırıntılı denizaltı yelpaze sistemi (Cingöz Formasyonu) ile birlikte eş zamanlı derin denizel şeyler (Güvenç Formasyonu) dahildir. Karaisalı Formasyonu'nun kireçtaşı topluluğu bu alanda çökelme öncesi fayların varlığını gösteren karaya doğru tırmanan bir depolanma örneği sunar ve öneğimli (havzaya doğru eğimli) geometrilere sahiptir. Kısmen eşyaşlı olan Cingöz Formasyonu denizaltı yelpazesinin batı kısımları, Gildirli Formasyonu zamanı öncesinden beri süregelen eski vadinin olduğu alandan beslenmiştir. Bu vadiler havza kenarına paralel uzanırlar ve Gildirli Formasyonunun çökeliminden önce gelişen genişleme tektoniği ile gelişmiş olabilirler. Bu nedenle Orta Miyosen yaşlı denizaltı yelpazesinin bu kısmının gidişi, geometrisi ve yeri tektonik olarak oluşan Miyosen öncesi/Erken Miyosen paleomorfolojisi tarafından kontrol ediliyor görünmektedir.

Anahtar Sözcükler: Adana Havzası, alüvyon yelpazesi, denizaltı yelpazesi, Miyosen eskivadiler, sediman esgeçmesi, istif stratigrafisi

Introduction

The aim of this paper is to present new data relating to the early history of the northwestern segment of the Adana Basin margin, the possible origin of the submarine canyon feeding the western part of the mid-Miocene fan and the relations between the submarine canyon fill and the carbonate platform. Our observations confirm suggestions that this canyon may be a relict feature, reflecting pre-existing topography and that clastic supply to the submarine fan system was channelled through this old valley during sea-level lowstands, whereas carbonate sedimentation prevailed on the shoulders of the valley during transgressive and highstand intervals.

The Adana Basin is one of a number of Neogene troughs located in southern Turkey. The basin is bordered by the Misis-Andırın strike-slip fault zone that forms the boundary between the Arabian and Anatolian plates to the east (Gökçen *et al.* 1988; Karig & Kozlu 1990), by the Ecemiş Fault Zone that lies within the Anatolian plate to the west (Yetiş 1968; Koçyiğit & Beyhan 1998; Westaway 1999; Jaffey & Robertson 2001, 2005) and by the Taurus Mountains to the north (Yalçın & Görür 1984; Ünlügenç *et al.* 1993; Williams *et al.* 1995) and opens into the Mediterranean Basin to the south (Figure 1). These boundaries were developed by interaction between the African-Arabian and Anatolian plates (Barka & Kadinsky-Cade 1988; Karig & Kozlu 1990; Westaway 1999; Jackson & McKenzie 1998; Robertson 1998). The basin has a complex basement structure and stratigraphy, and the nature and relations of all the basement units have not been fully resolved as yet. Wells drilled in the basin have penetrated several units that are not exposed within or on the margins of the basin. This complexity has stimulated efforts to understand the basin, its evolution, play type and the characteristics of reservoirs within the basinal framework. In particular, the Tertiary sediments of the Adana Basin have been the object of many economic studies due to its hydrocarbon prospectivity. Mobil geologists published the first detailed stratigraphic framework (Schmidt 1961). Most of the following studies were concerned with the stratigraphy, sedimentological and tectonic evolution of the basin (e.g., İlker 1975; Görür 1979, 1992; Lagap 1985; Yalçın & Görür 1984; Yetiş & Demirkol 1986; Yetiş 1988; Ünlügenç & Demirkol 1991; Nazik & Gürbüz 1992; Gürbüz 1993; Gürbüz & Kelling 1993; Şafak 1993; Şafak & Ünlügenç 1993; Ünlügenç *et al.* 1993; Özçelik & Yetiş 1994; Yetiş *et al.* 1995; Williams *et al.* 1995; Gürbüz *et al.* 1998; Satur *et al.* 2000).

Görür (1979, 1992) divided the Gildirli Formation into two members: red-coloured, non-fossilliferous, continental conglomerates, sandstone and siltstone below (Çakmak Member) and yellowish grey coloured, fossiliferous, marine conglomerate, sandstone and siltstone above (Kabalaktepe Member). Later Yetiş & Demirkol (1986) named this the Kaplankaya Formation and included the marine part of the Gildirli Formation (Kabalaktepe Member of Görür 1979) within it (Yetiş & Demirkol 1986; Yetiş 1988). The Cingöz Formation was defined by Schmidt (1961) and consists of conglomerate, sandstone and shale. It was divided into three members: Köpekli shale member at the bottom, Ayva member in the middle and Topallı member at the top. Görür (1985) interpreted the Ayva member as proximal, and the Topallı member as distal turbidites.

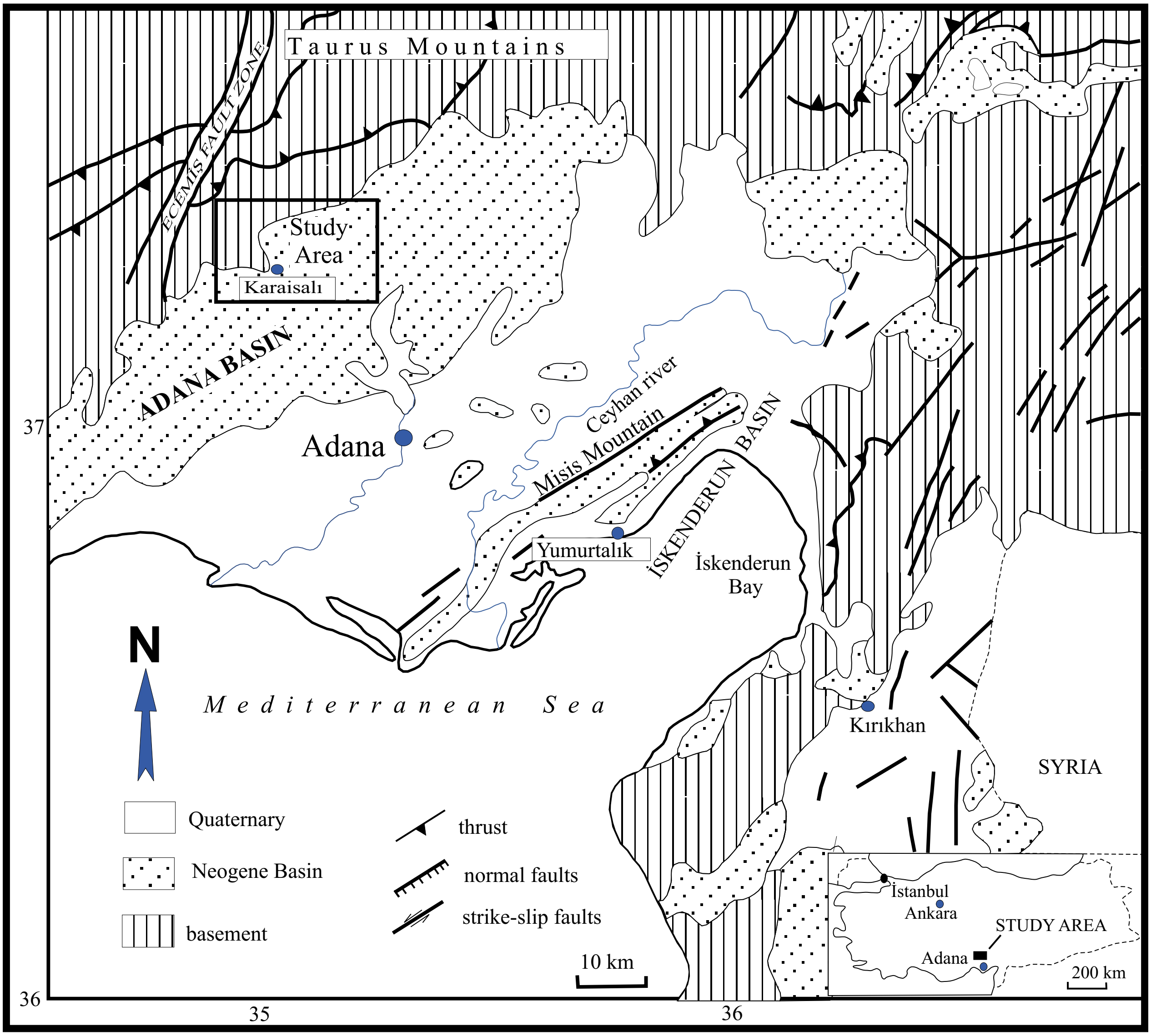

Figure 1. Location of study area on a tectonic map of the Adana Basin (modified from Gürbüz & Kelling 1993).

Moreover, some earlier studies suggested that the Cingöz Formation turbidites represented deep-water lobes (Yetiş & Demirkol 1986) but Gürbüz (1993) first described and elucidated the details of this submarine fan system, developed along the northern margin of the basin. Gürbüz & Kelling (1993) showed that these fans were fed from northerly sources. Satur *et al.* (2000) claimed that the clastics supplied to the submarine fan systems bypassed a contemporaneous shallow-marine carbonate shelf and slope through steep-sided canyons and concluded that coarse deep-water sediments within the canyon and fan were supplied from alluvial fans and fan deltas in the most proximal sectors of the system. Cronin *et al.* (2000) detailed the lateral and vertical relationships between broadly coeval reefal carbonates, slope facies and turbidites on the northern margin of the Adana Basin, east of the study area described herein.

Geological Background

Late Cretaceous ophiolites constitute a significant component of the eastern Mediterranean region and tectonically overlie Mesozoic platform carbonate and Palaeozoic rocks of the Tauride Belt (Şengör & Yılmaz 1981; Dilek & Moores 1990; Dilek *et al.* 1999). Continued subduction of the Neotethyan ocean floor, following the emplacement of ophiolites, resulted in the terminal closure and amalgamation of the bounding continental fragments and termination of marine deposition by Late Eocene (Şengör & Yılmaz 1981; Clark & Robertson 2002; Kelling *et al.* 2005). The Adana Basin is located on the southern flank of the Taurus Mountains. Therefore the basement of the Adana Basin is formed by a complex suite of rocks including ophiolitic mélange, Mesozoic carbonates and Palaeozoic rocks. Before the Miocene transgression, movements on the Ecemiş Fault Zone (Yetiş 1968; Koçyiğit & Bayhan 1998; Westaway 1999; Jaffey & Robertson 2001, 2005) and the Misis-Andırın Fault System (Gökçen *et al.* 1988; Karig & Kozlu 1990), both of which display left-lateral strike- slip, may have led to extension within the Adana Basin and the observed margin-parallel faults may result from this extension. The Gildirli Formation sediments also may be the products of these extensional tectonics.

The oldest Tertiary rock unit in the study area is the Gildirli Formation, which rests directly on pre-Tertiary basement (Görür 1992). The Gildirli Formation was defined by Schmidt (1961) as Lower Miocene sediments deposited under continental and tidal influence, filling canyons and bays that existed before Miocene sedimentation commenced (Figure 2). Schmidt described the Gildirli Formation sediments as unsorted, poorly bedded red or varicoloured siltstone and sandstone with thick interbeds of red mudstone. Görür (1992) interpreted the bulk of the Gildirli Formation as alluvial fan deposits.

The Gildirli Formation is most commonly overlain by a succession of yellow to cream hued sandstones, pale grey argillaceous limestones, shales and local conglomerates yielding shallow marine fossils and termed the Kaplankaya Formation (Yetiş & Demirkol 1986; Figures 2 & 3). This formation is succeeded by different lithostratigraphic units in different locations. To the southeast of Çukurköy Village (Figure 2) Kaplankaya Formation sediments are overlain by shales of the Güvenç Formation (Burdigalian–Langhian: Özçelik & Yetiş 1994), whereas east of the same village there is a passage up into limestones of the Karaisalı Formation (Figure 2). South of Çukurköy Village, the Kaplankaya Formation is partly overlain by deep-water clastics of the Cingöz Formation (late Burdigalian–Serravallian: Şafak 1993). Biostratigraphic evidence from Karaisalı Formation limestones and Cingöz/Güvenç Formation clastics indicate that these sediments represent at least partly contemporaneous shallow-marine carbonates and their basinal equivalents respectively.

However, disagreement persists as to the stratigraphic relations of the Gildirli Formation with these overlying units (Figures 2 & 3). Schmidt (1961) considered that Gildirli Formation sediments locally grade upwards into the Köpekli Shale member (part of the re-defined Kaplankaya: Yetiş & Demirkol 1986) and Karaisalı Formation limestones. Görür (1979) and Yetiş (1988) interpreted the Kaplankaya Formation as formed during the first transgression during Early Miocene time. Görür (1979) considered that the Gildirli Formation grades upward into the Cingöz and Güvenç formations. Despite the continental character of the Gildirli Formation, Yetiş (1988) considered that the Gildirli Formation grades upward into other marine units. Şafak & Ünlügenç (1992) reported that the Kaplankaya Formation conformably overlies the Gildirli Formation and grades laterally and vertically into Karaisalı Formation limestones. Elsewhere Kaplankaya Formation sediments rest with angular discordance on the Demirkazık Formation (Late Cretaceous) and the Karsantı Formation red-beds (Oligocene: Şafak 1993). Our field observations and careful study of published geological maps of the area indicate that the Kaplankaya, Karaisalı and Cingöz formations abruptly succeed Gildirli Formation red-beds in different areas (Figure 2). All these data indicate that Gildirli Formation sediments were deposited prior to the Early Miocene marine transgression. Subsurface data also support this interpretation since Gildirli Formation sediments have not been encountered in the deeper Adana Basin where Early Miocene marine sediments directly overlie Mesozoic and metamorphic rocks (Bulgurdağ, Bekirli-1 and 2 and Emelcik-1 wells: unpublished Petroleum Affairs Directorate archive).

Sedimentology and Depositional Environments of Lower and Middle Miocene Units

Gildirli Formation

Sediments traditionally assigned to the Gildirli Formation are almost confined to that sector of the northwestern

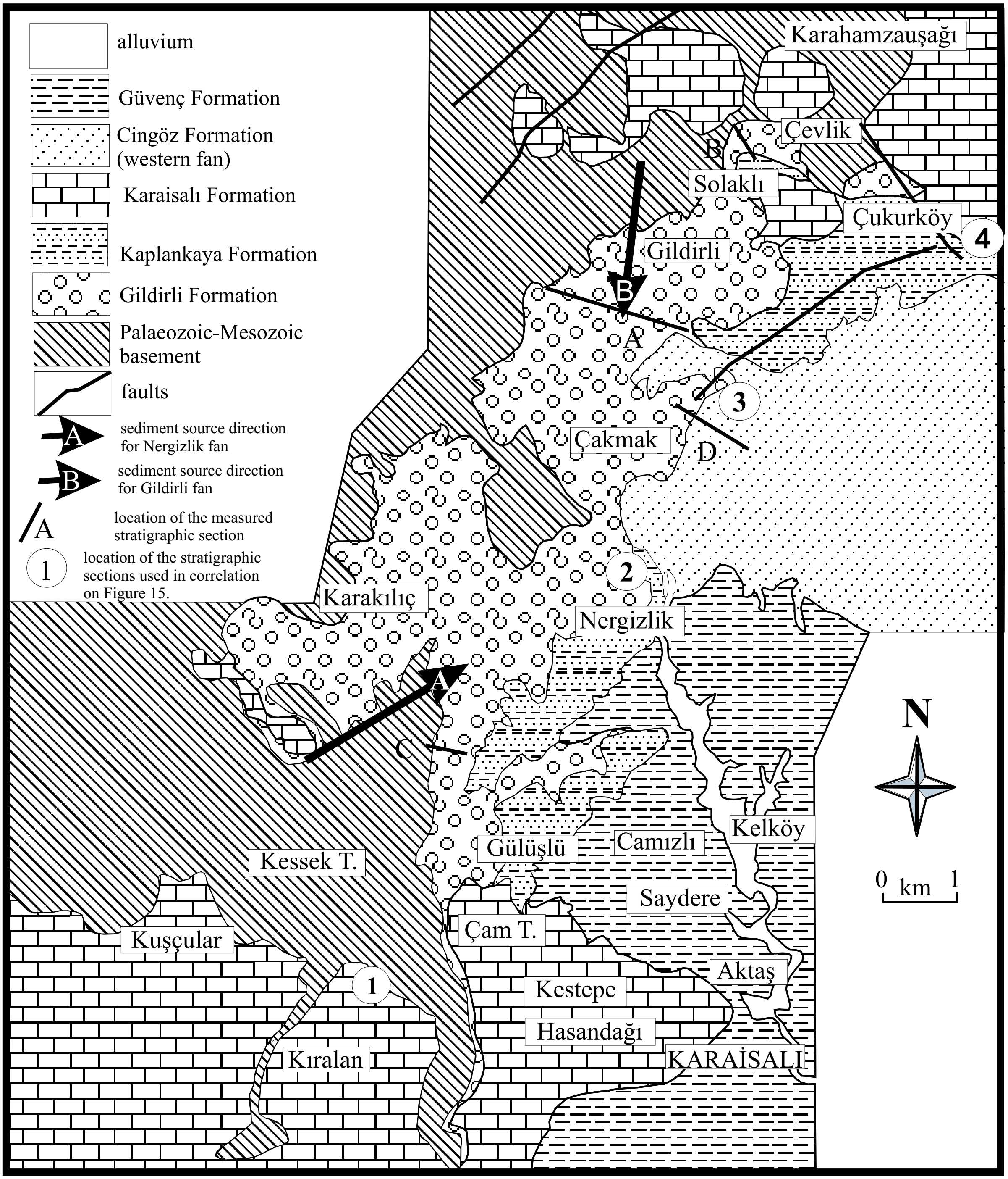

Figure 2. Geological map of the study area (compiled from Görür 1985; Lagap 1985; Yetiş & Demirkol 1986).

margin of the Adana Basin around Gildirli and Nergizlik villages. Descriptions of the characteristics in different locations are given below:

Gildirli Area: Two sections have been measured to show lateral and vertical changes within the Gildirli area: one at the type locality of the Gildirli Formation and the

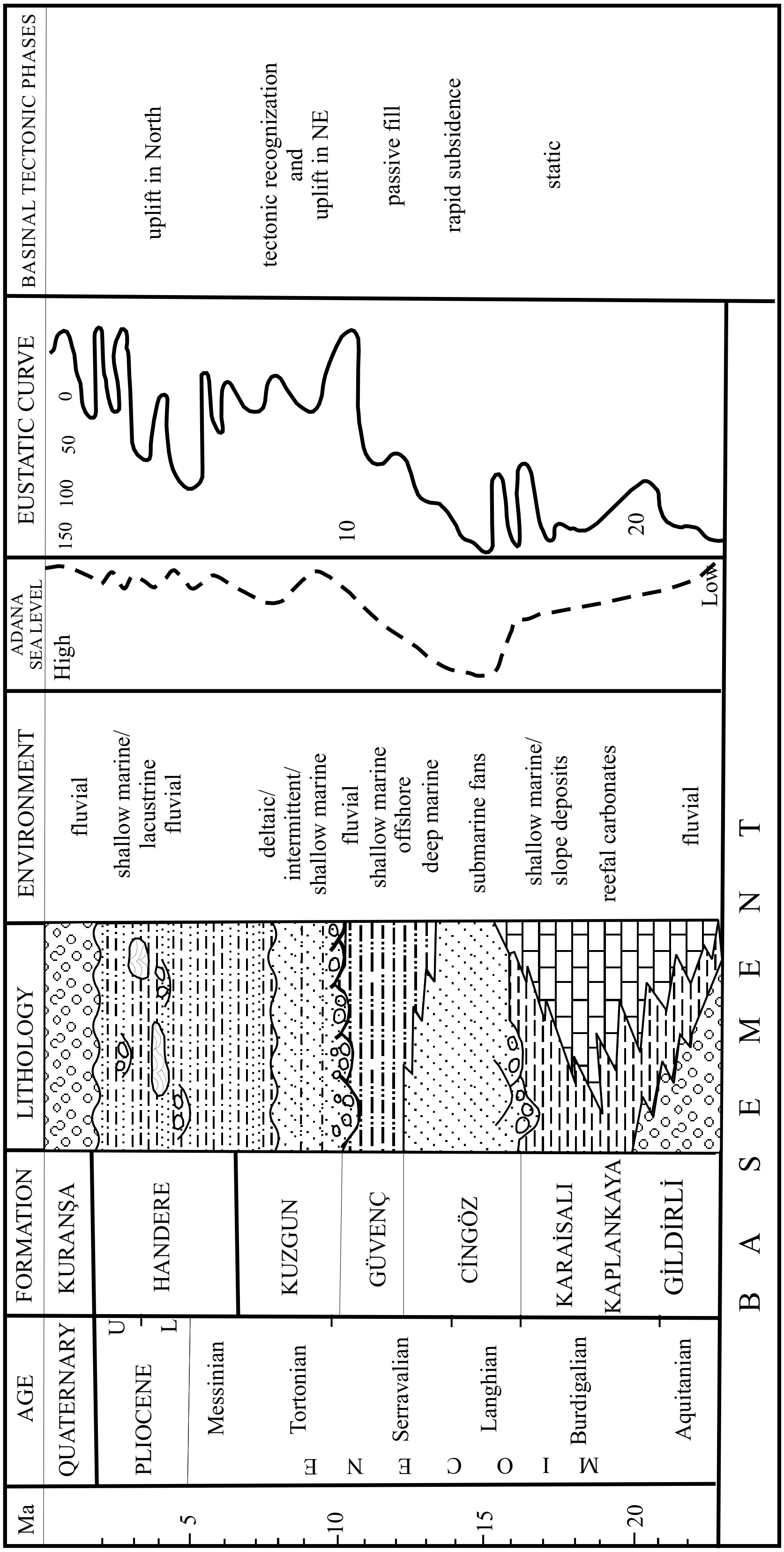

Figure 3. Generalized stratigraphic column of the study area (from Gürbüz & Kelling 1993).

second at a location about six kilometres to the east of Gildirli Village and about five kilometres to the north of Çukurköy Village.

At the type locality, the Gildirli Formation (up to 100-metres thick) consists of red conglomerates, sandstones and mudstones (Figure 4). The cobble- and pebble-grade conglomerates are red to brownish, polymict (with moderately to well-rounded limestone, chert, igneous and ophiolitic clasts), very thick bedded to massive, poorly sorted, and crudely cross bedded (Figure 5a). Imbrication is common and the larger clasts are supported by an argillaceous or sandy matrix. The red sandstones are regularly bedded, polymict (carbonate, chert, quartz, igneous and ophiolitic fragments), and poorly sorted with an argillaceous matrix. The sandstones are thinner and laterally more extensive than the conglomerates and the ratios of conglomerates to sandstones are laterally variable. For example, southwest of Gildirli Village the formation comprises a very thick pile of conglomerate and sandstone with little mudstone (Figure 5b). Bedding here is more regular (planar) and widespread, forming a stacked succession of conglomerates and subordinate sandstones. Individual beds are crudely size-graded.

To the east and west of Gildirli Village, Gildirli Formation conglomerates abut against a steeply inclined surface of the basement. The steep surface at this locality has a roughly E–W trend (Figure 5c). The thickness of the Gildirli Formation decreases rapidly away towards the south from this onlapping contact. The grain size decreases (from 20 cm to 1 cm) away from this site towards the east, south and west. The conglomerates and sandstones show more lenticular geometries (due to basal scouring: Figure 5a) in the same directions, accompanied by increasing proportions of mudstone. Locally very poorly sorted, argillaceous, matrix-supported conglomerates with non-erosive bases followed by sandy and silty mudstones are observed to the west of Gildirli Village. These sandy and silty mudstones appear to be poorly bedded but a few calcrete horizons give a spurious impression of bedding.

At the second locality, the Gildirli Formation is mud rich and contains root traces and calcrete horizons (Figures 6 & 7a). Conglomerates have poorly defined channel geometries; scouring is present, but not so well defined (Figure 7b). Coarse-grained material contains much argillaceous matrix.

The Gildirli Formation is successively overlain (from south to north) by submarine fan clastics of the Cingöz Formation (near Cakmak, south of Gildirli Village), by Kaplankaya Formation clastics (around Çukurköy Village and about six kilometres to the east of Gildirli Village) and by Karaisalı Formation limestones (north of Gildirli and north of Çukurköy Villages). The observed contacts between the Gildirli and the Kaplankaya/Karaisalı formations are sharp (Figure 5d). To the north of Gildirli Village and north of Çukurköy, the Karaisalı Formation directly overlies basement rocks with no Gildirli Formation present.

Nergizlik Area: Gildirli Formation sediments exposed in the Nergizlik area reveal characteristics that differ significantly from those seen in the Gildirli area. The most striking differences are the well-bedded and parallel-sided nature of the breccias and conglomerates, the dominance of carbonate clasts, and the presence of only a few, very thin red mudstone interbeds in the lower part of the formation (Figures 8 & 9a). However, the upper part of the unit is dominated by red mudstones accompanied by thin calcrete layers and lenticular, monomict carbonate-conglomerates (Figure 8).

The rudites in this succession are white, grey or dark grey, moderately to poorly sorted, clast-supported but carbonate-cemented or containing a sandy matrix. Clasts are very angular in the lower part of the succession but upwards they become subangular, moderately to well rounded and almost exclusively composed of limestone. The rudites contain well-rounded intraformational boulders, cobbles and pebbles (Figure 9b). The clasts are well cemented and lithified. Both normal and inverse grading are observed. Coarser- and finer-grained materials alternate within the sedimentary succession. Conglomerate beds can be traced to the likely source area, dominated by Cretaceous limestones, but the contact between this basement and the overlying carbonate-conglomerates can sometimes be difficult to identify because of similar cementation. Individual conglomerate beds tend to become thinner with distance from the basement contact and there is a concomitant lateral decrease in maximum clast size. Conglomerates onlap the walls of the V-shaped valleys (Figure 9a). Here regular bedding of the rudites is evident from the floor of the valley up to the present-day rim. At this level the lithology changes to mudstone-dominated lithologies with lenticular conglomerates (Figure 9c).

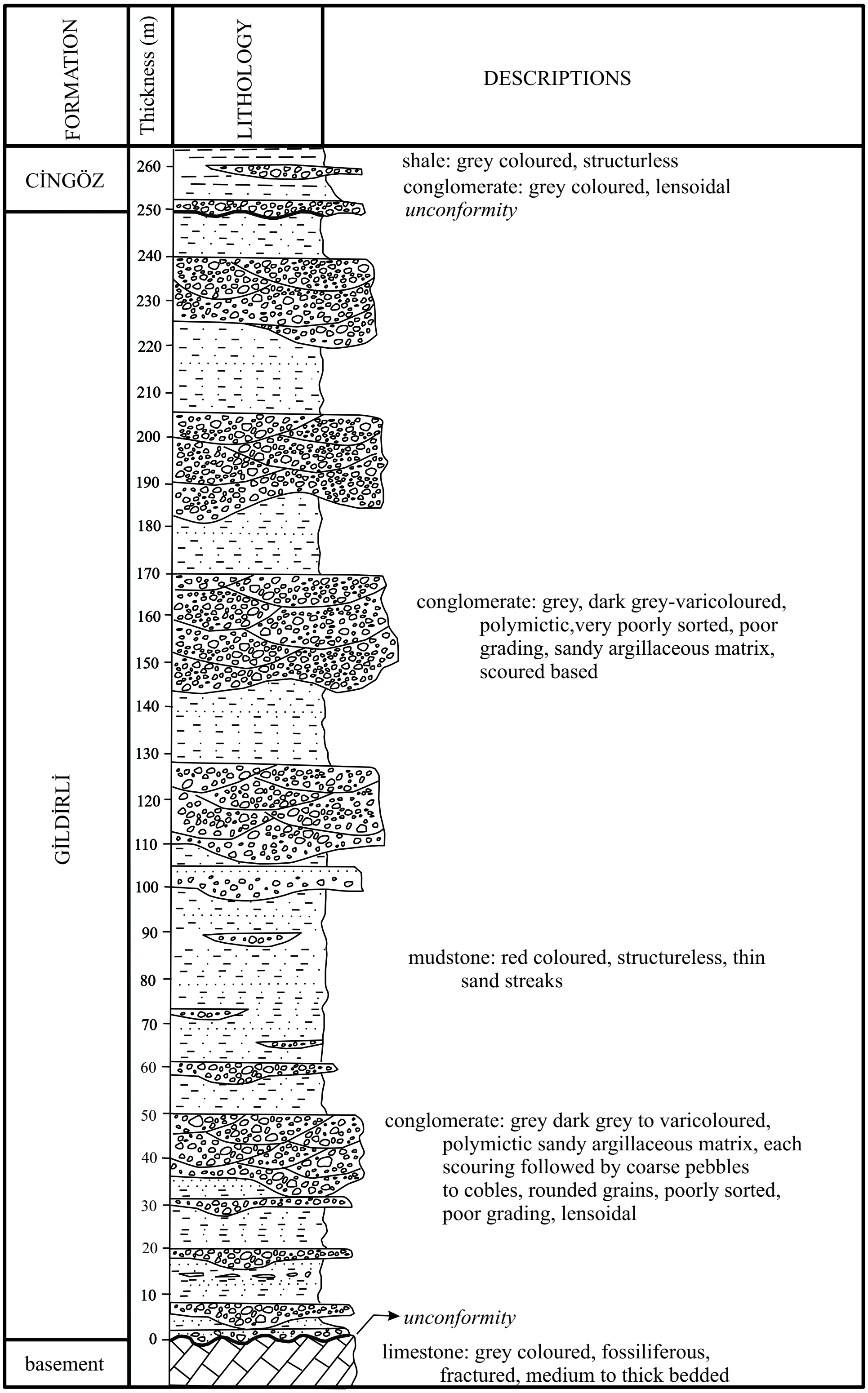

Figure 4. Stratigraphic section of the Gildirli Formation measured along the creek to the southwest of Gildirli Village (Location A on Figure 2).

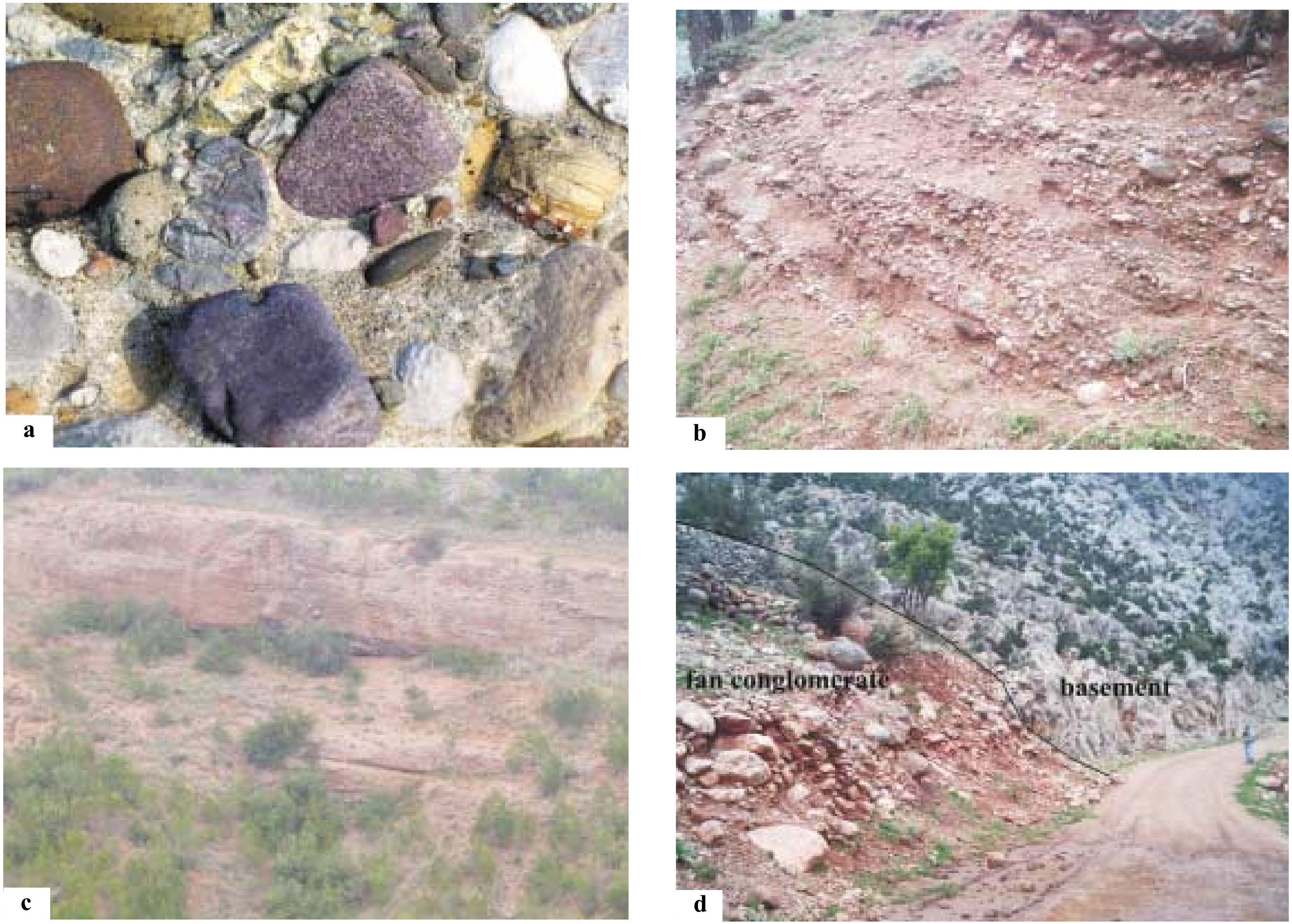

Figure 5. Facies characteristics of the Gildirli Formation in the Gildirli area: **(a)** Conglomerates are polimict (clasts of limestone, sandstone, marble, basic rocks and chert with sandy matrix) probably indicating derivation from a complex source area, some conglomerates have muddy matrix and crude cross bedding suggesting deposition probably from unconfined debris flow. **(b, c)** Conglomerates to the southwest of Gildirli village are massive, very coarse grained and sandy matrix supported probably representing the main feeder channel of the fan-head area. **(d)** The coarsest fraction of the conglomerates is concentrated in the proximal areas, in contact with the basement.

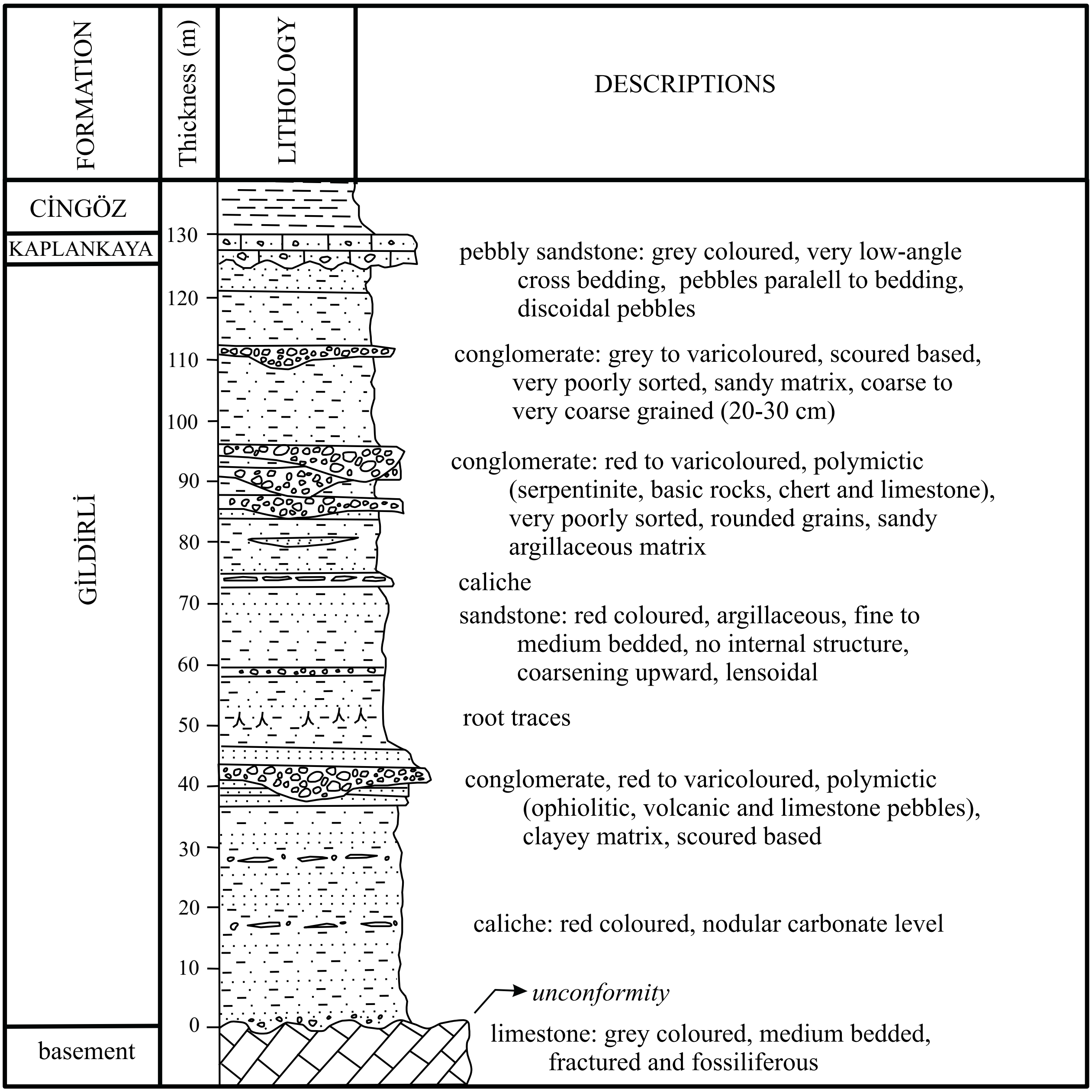

Figure 6. Measured stratigraphic section from the Gildirli Formation near Çevlik Village (Location B on Figure 2).

Outside and above these V-shaped valleys mudstones are dominant in the Gildirli Formation, but coarse blocky, lenticular limestone-clast conglomerates are observed locally. The topmost part of the succcession here is characterised by lenticular bodies of conglomerate enclosed in red to brick-red mudstones with well-developed calcrete horizons (Figure 9d) and root traces. Anomalous, isolated large blocks within the mudstone occur in a few areas.

Lateral changes in the thickness of the Gildirli Formation are conspicuous in the Nergizlik area. The formation is very thick (up to 100 metres) in the palaeovalleys but much thinner (10 to 20 metres) on the shoulder or in the inter-valley areas. The carbonate-

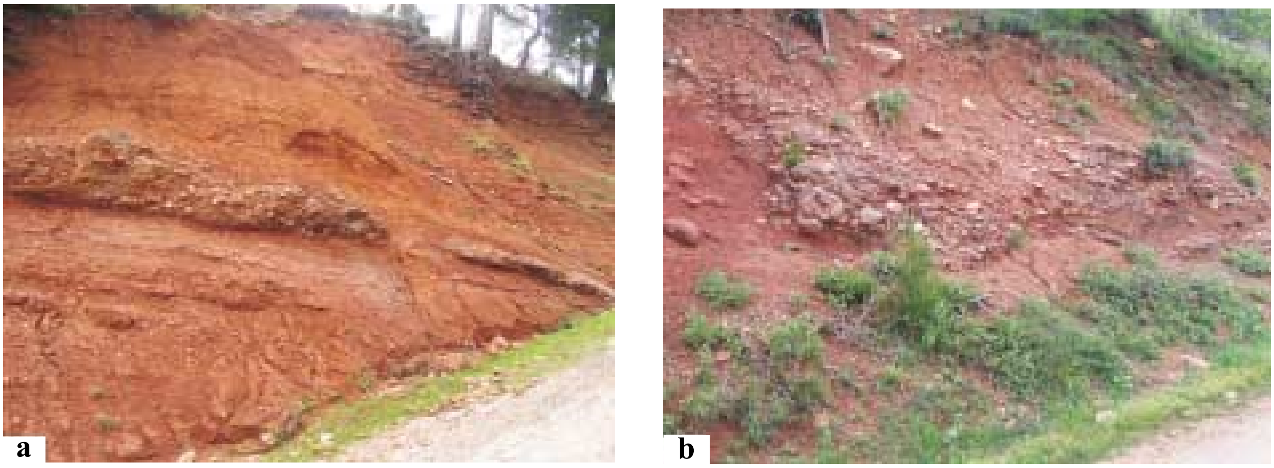

Figure 7. Gildirli Formation is mud dominated in the section (shown in Figure 6) near Çevlik Village. (a) Minor conglomerates show channel geometry. (b) Some channel conglomerates show poor sorting, mud matrix and inverse grading suggesting deposition from debris flow.

conglomerates wedge out towards the west, where limestones of the Karaisalı Formation directly overlie the Mesozoic carbonate basement.

Interpretation: The general lithological characteristics of the Gildirli Formation (red colour, lenticular geometries, calcrete levels, absence of marine fossils and presence of rootlet horizons) indicate deposition in a broadly terrestrial environment.

The orientation and steepness of the basement surface against which Gildirli Formation coarse clastics are banked is suggestive of fault-controlled morphology (Figure 5d). Certainly the pre-Gildirli Formation topography was irregular, as indicated by the rapid thickness variations (see sketches on Figures 5d & 9a) and the wedging-out and onlapping relations of these red-beds with the basement. The general distribution of facies types and the lateral fining trends for clasts (Figures 5c & 7a) indicate that the Gildirli Fan faced toward the southwest. The regular changes in clast size and in the thickness of the formation and individual beds away from the onlapped basement contact surface also is consistent with the alluvial fan interpretation. The observed thickness variations and gross geometry of the unit in the Gildirli area suggest a fan morphology, supporting Görür's (1979) interpretation. The lenticular geometry, cross bedding and imbrication in the conglomerates are consistent with deposition in fluvial channels while the red mudstones with calcrete horizons may represent flood plain deposits (Allen 1965, 1974). Local development of very poorly sorted, argillaceous matrix with a non-erosive base may represent debris flow deposits and the pebbly and sandy mudstones may indicate mudflow deposition on the fan surface (Figure 7b).

The concentration of coarse-grained material, non-channelised nature of conglomerates and sandstones, and scarcity of mudstones in the area southwest of Gildirli Village (Figure 5c) suggest that this represents a fan-head area (Prothero 1990) while mud-dominated facies with conglomerates containing much mud matrix represent the areas away from the feeder area (Figure 7a, b).

The clast compositions of the conglomerates from the Gildirli area (Figure 6a) indicate supply from sources made of Palaeozoic and Mesozoic carbonates, ophiolitic material, chert and volcanic rocks. These materials are exposed in areas to the north of the study area.

Gildirli Formation sediments in the Nergizlik area differ significantly from those seen near Gildirli Village. The monomict nature of the conglomerates at Nergizlik indicates that clasts supplied to this area came from a different, entirely carbonate source (Figure 9b). Angular clasts at the lower level indicate deposition on a steeply inclined surface and a short transport distance. Increased rounding towards the top suggests a decrease in depositional slope angle as the sediment fills the base of

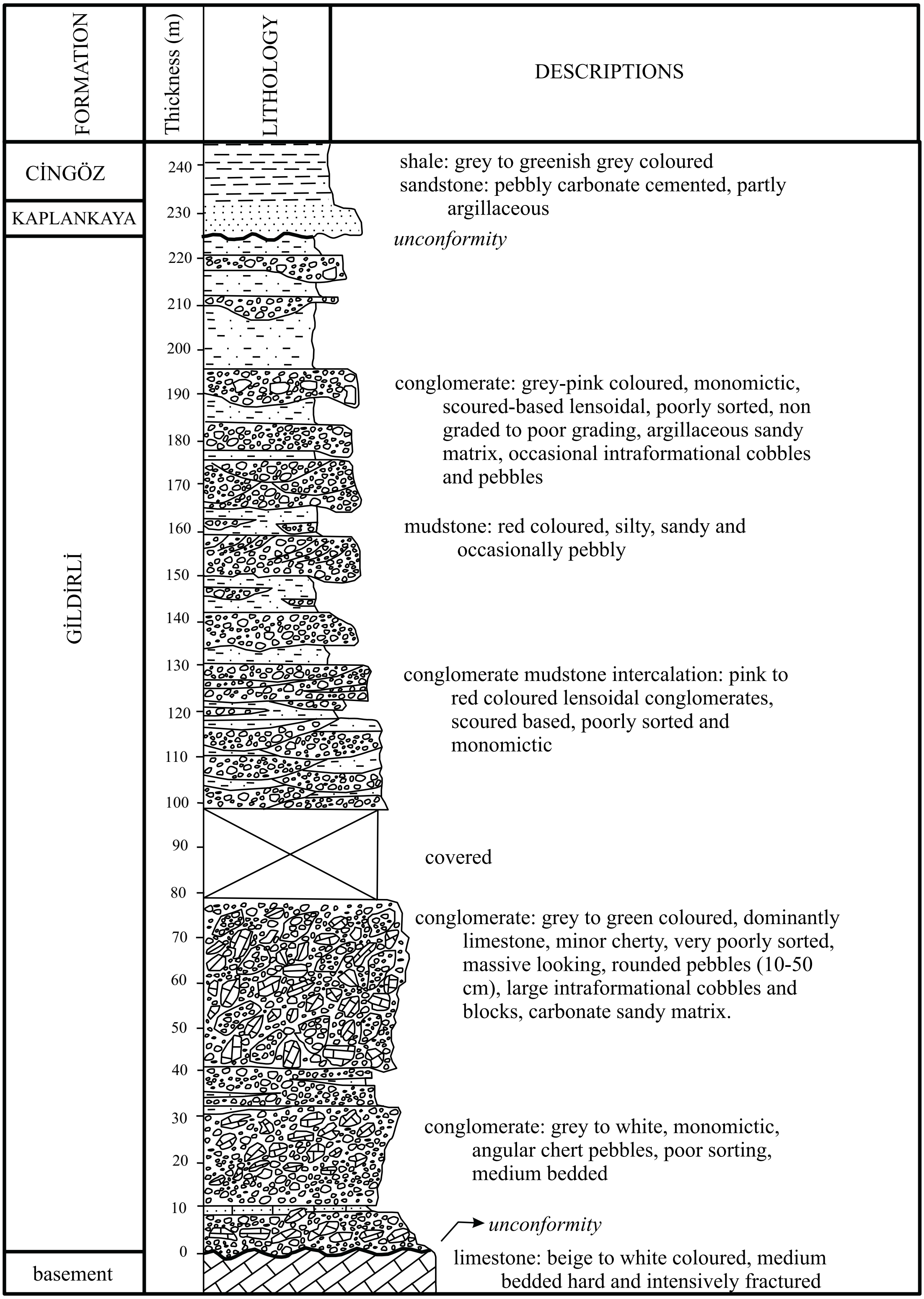

Figure 8. Measured stratigraphic section from the Gildirli Formation to the southwest of Nergizlik Village (Location C on Figure 2).

the slope area. Synsedimentary conglomerate clasts indicate erosion and deposition of the fan material. This might be due to uplift and erosion of the previously deposited and lithified material (Figure 9b). This may imply that valley bounding faults were active during deposition. The well-bedded and parallel-sided character of the rudites forming the thick conglomerate body here also indicates that it was either fed by a line source or else the flows entering this region were strongly confined. In the lower part of the Nergizlik succession the well-bedded nature of the conglomerates, presence of reverse and normal grading, lack of muddy matrix, and carbonate cementation all indicate deposition from sheetflows, with tractional reworking, in a setting where deposition was largely controlled by palaeotopography. However, in the upper part of the Nergizlik succession the red, mud-dominated nature of the sediments indicates that topographically lower areas had been filled, enabling sediment to spill out of the valleys. The lenticular geometry of conglomerates and sandstones in these upper parts of the succession is attributed to strongly channelized flows, probably from ephemeral streams (Figure 9c). Southeasterly depositional dips from the conglomerates indicate that around Nergizlik the palaeoslope was towards the southeast, contrasting with the southwest slope deduced from deposits in the Gildirli area. The nature of the clasts in Gildirli Formation sediments of the Nergizlik area points to very local sources, namely the adjacent Mesozoic basement limestones.

Previous authors have assigned the Gildirli Formation to alluvial fan, fluvial and shallow marine settings (Schmidt 1961; Görür 1979; Yetiş 1988). Recently part of the formation (reassigned to the Kaplankaya Formation; Yetiş & Demirkol 1986) has been re-interpreted as a prograding alluvial fan, fluvial and fan delta system, feeding into a submarine canyon head (Satur 1999; Satur *et al.* 2000, 2005).

Kaplankaya Formation

The Kaplankaya Formation is the most widespread unit seen in contact with the Gildirli Formation red-beds. This formation is lithologically very diverse, comprising fossiliferous sandstones, pebble and cobble conglomerates, siltstones, marls and sandy limestones (Yetiş & Demirkol 1986; Ünlügenç *et al.* 1993). Conglomerate-rich sections of the Kaplankaya Formation may be confused with Gildirli Formation rudites. The clast-composition of conglomerates and sandstone in these formations is very similar but Kaplankaya Formation rudites are distinguishable by their grey colour, more rounded clasts, fossil content and their carbonate cement as opposed to red colour, the sandy or argillaceous matrix and non-fossilliferous nature of Gildirli Formation conglomerates (Figure 10a). Kaplankaya Formation sandstones are fine- to coarse-grained, well cemented and well bedded. Alternations of sandstone and siltstone dominate the lower part of the formation and the proportion of carbonate increases upward. It is absent where the Karaisalı Formation directly overlies the basement carbonates especially to the north of Çukurköy. The marls, argillaceous limestones and some sandstones contain abundant shallow-marine fossils (echinoids, bivalves, small benthic forams, algae, corals).

The Kaplankaya Formation is not present in the area east of Çakmak Village (Figure 2) where the Gildirli Formation is in erosive contact with the Ayva member (submarine fan sediments) of the Cingöz Formation (Figure 10b). However, along most of the northern margin of the Adana Basin the Kaplankaya Formation grades upwards into the Karaisalı Formation, except where the Kaplankaya Formation is not developed. In these areas the Karaisalı Formation directly overlies the basement rocks.

The upper levels of the Kaplankaya Formation have yielded foraminiferal assemblages of Burdigalian age (Yetiş *et al.* 1995), while foraminiferal and ostracod assemblages reported in Ünlügenç *et al.* (1993) and in Cronin *et al.* (2000) indicate a late Burdigalian–early Langhian age range for this formation.

Interpretation: The Kaplankaya Formation contains a wide range of sediment types and facies. The sedimentological and biological evidence summarised above indicates that most of these sediments were formed in a shallow-marine environment during the initial stages of the Early Miocene marine transgression, a major eustatic sea-level rise (Yetiş 1988; Görür 1992). In his study of the Gildirli Formation, Görür (1992) concluded that his Kabalaktepe member (now considered the equivalent of the Kaplankaya Formation) was

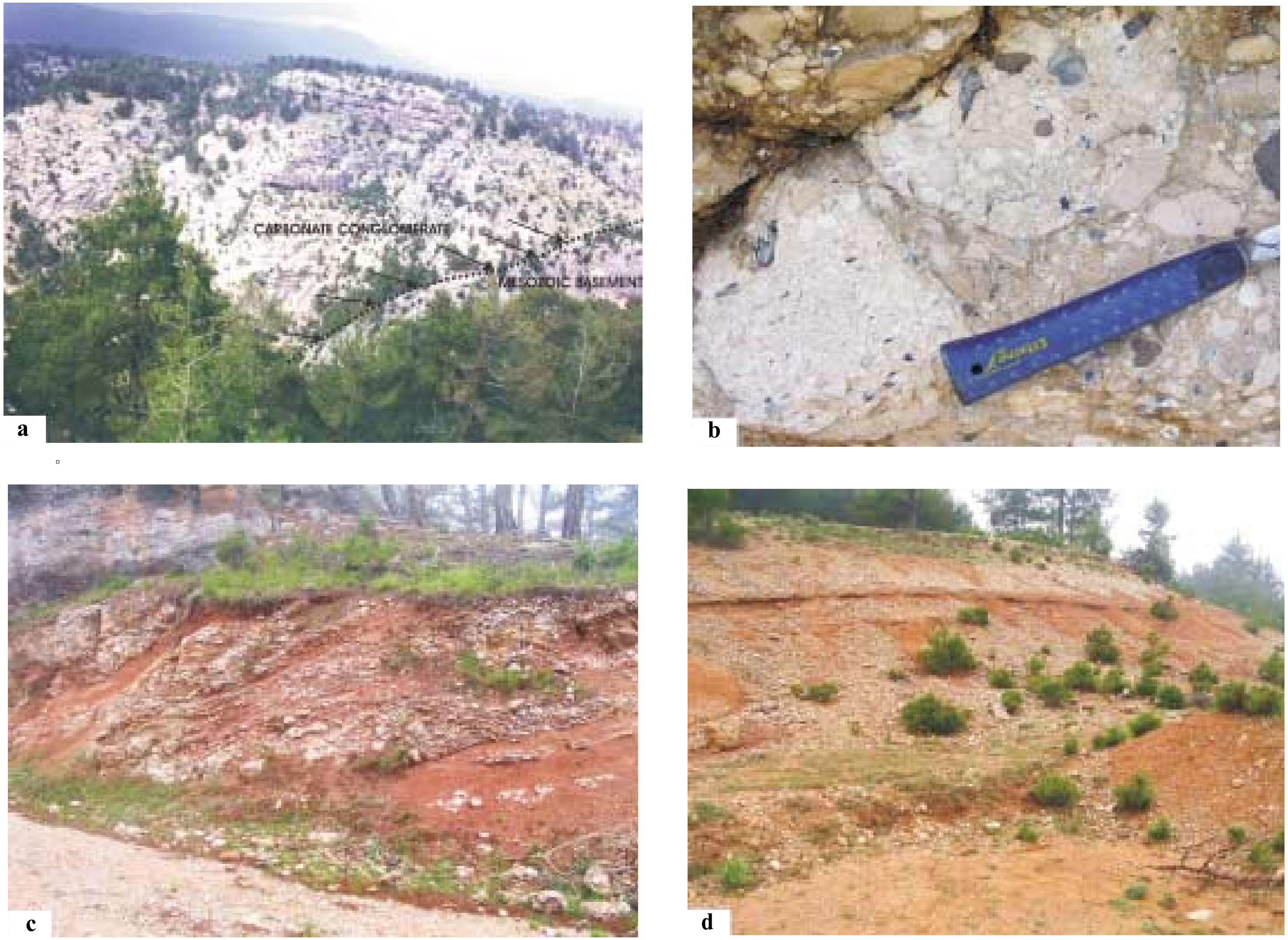

Figure 9. General characteristics of the Gildirli Formation in the Nergizlik area: (a) Both the carbonate breccias near the base and the succeeding carbonate conglomerates fill V-shaped valleys. These conglomerates show parallel bedding up to the rim of the valley. (b) Here, conglomerates are made up of carbonate clasts of variable size. Grains are moderately to well rounded and poorly sorted. Angular grains are also present. Some of the large and well-rounded conglomerate clasts indicate reworking of previously deposited material. (c) Above the rim of the valleys lensoid conglomerates with scoured bases enclosed in red mudstone are present. (d) Uppermost part of the sequence is dominated by red-coloured mudstone with well-developed calcretes.

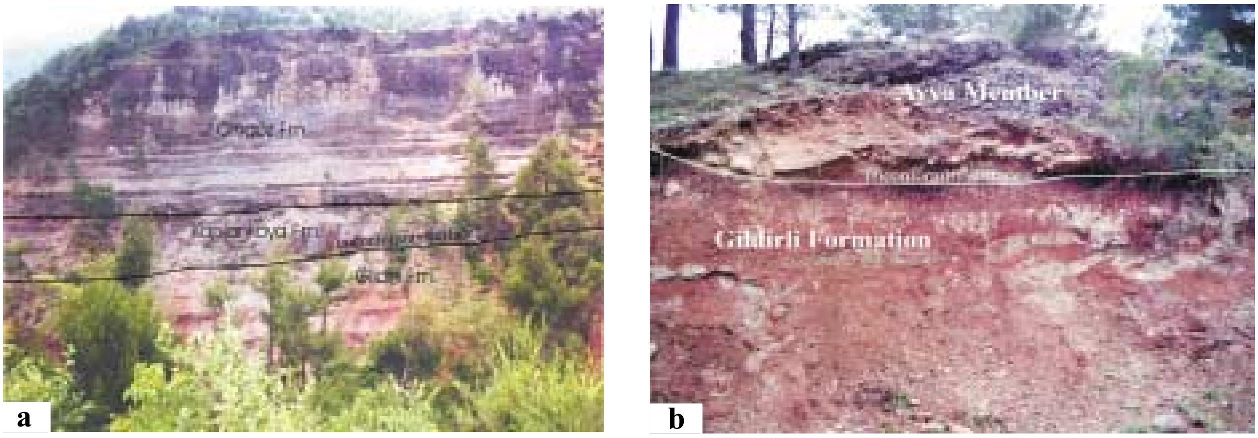

Figure 10. (a) The contact between the Gildirli and Kaplankaya formations is sharp. In Çukurköy Village the Gildirli Formation is overlain with a sharp contact by the Kaplankaya Formation which is in turn overlain by the Ayva Member of the Cingöz Formation, suggesting an unconformity, since the Gildirli Formation is continental, the Kaplankaya Formation is shallow marine and the Ayva Member of the Cingöz Formation is deep marine. (b) Near Çakmak Village, however, conglomerates of the Ayva Member of the Cingöz Formation directly (unconformably) overlies the Gildirli Formation with a sharp contact.

deposited in beach and nearshore environments, including a fan-delta setting. Ünlügenç *et al.* (1993) recognised a somewhat wider range of shallow-marine and coastal settings. Satur (1999) also included within the Kaplankaya Formation some thick, deeply incised bodies of limestone-conglomerate exposed near Çakmak Village (and here considered to lie within the Gildirli Formation). These he assigned to alluvial fan and fan-delta settings. Along the basin margin to the east of Çukurköy, Cronin *et al.* (2000) have described thick Kaplankaya Formation shales, marls and sandstones displaying major slumps and other mass-wasting features, which they described as a reef-front slope sequence, onlapped by younger Cingöz Formation turbidites.

The marked lateral and vertical variations in lithology and thickness within the Kaplankaya Formation appear to have been determined by the pre-existing palaeotopography and by the nature and volumes of carbonate and clastic detritus supplied to the deepening basin margin. The very well-rounded nature of intraformational pebbles and cobbles in the conglomerates results, at least in part, from reworking of the underlying Gildirli Formation conglomerates. Absence of the Kaplankaya Formation in areas where Karaisalı Formation carbonates directly overlie the basement also supports that it was developed on an irregular morphology. Hence it may be considered (as Yetiş 1988 and Görür 1992 interpreted) the product of the Miocene transgression (basal conglomerate of the Miocene sea). Since carbonate deposition continued from Burdigalian to Langhian as sea level rose and climbed a rough palaeotopography, the Kaplankaya Formation might have been developed only where conditions were suitable. Therefore it has a variable thickness from metre to tens of metres.

Most previous studies favoured a gradational passage from the Gildirli Formation into the Kaplankaya Formation (Schmidt 1961; Görür 1979; Yetiş 1987; Ünlügenç *et al.* 1993). However, the field relations and total absence of marine intercalations in the upper parts of the Gildirli Formation indicate that the contact is not gradational but sharp and probably unconformable (Figure 10a).

Karaisalı Formation

Karaisalı Formation limestones are local representatives of a widespread carbonate unit of Early to Middle Miocene age found in the marginal areas of broadly coeval basins that occur throughut south-central Turkey, from Antalya in the west to Kahramanmaraş in the east. This formation is almost continously exposed along the northern margin of the Adana Basin except for a few places where it is interrupted by the palaeovalleys that fed the mid-Miocene submarine fan systems (Gürbüz & Kelling 1993; Cronin *et al.* 2000; Satur *et al.* 2000).

Near Çukurköy Village and in areas south of Karaisalı Town these limestones can be traced laterally (to the south) into basinal shales (Figure 3), but to the north of the main basin margin they display onlapping relations against a steep ancient slope formed by basement rocks (Figure 11).

The Karaisalı Formation is almost entirely composed of white to pale grey, medium- to thick-bedded, locally massive limestones. Traced downslope (to the south) the limestones become more argillaceous, with marls, and contain abundant planktonic foraminifera (Nazik & Toker 1986). Limestones in the northern (nearshore) outcrops, and in the younger sections, contain abundant corals, algae, forams, echinoderms, molluscs, bryozoa and worm tubes.

Local exposures of the Karaisalı Formation show two different types of morphological feature, but with broadly similar internal organisation.

Just east of Çukurköy, the limestones form a steep basin-margin slope and display a vertical stacking pattern of limestone bodies or bed-packages (Figure 11). Near Çukurköy Village the lowest level shows relatively steep depositional dips, sloping toward the south and passing laterally downslope (southwards) into basinal shales. These basal limestones, underlain by a few metres of grey Kaplankaya Formation conglomerates, lap onto the basement rocks and the upper surface of this body is erosively truncated. The second package also shows an onlapping basal contact onto basement (Figure 11) and internally this displays two massive areas, laterally separated by well-bedded parts. The massive elements appear to be reefal facies while the intervening well-bedded parts may represent inter-reefal areas. These features mark the inception of the margin of a carbonate shelf. The third package is thicker but again the lower limestone beds continue to onlap the relatively steep basement surface to the north. This body seems to represent a well-developed shelf margin with a more subdued slope. The topmost package seen in this area has a subhorizontal, probably erosional, top (Figure 11), but also onlaps the basement. It has a well-developed reefal platform margin. Further north, the succeeding body also shows a flat top and a steep reefal margin (Figure 12). This body was deposited landwards (north of) the main basin-margin on the basement carbonate without Gildirli Formation clastics. All these features confirm the strong palaeotopographic control on carbonate deposition and accumulation in this area, through the phases of aggradation, progradation and retrogradation seen in Figures 11 & 12.

To the west of Nergizlik and north of Karaisalı area, the Karaislı Formation shows similar onlapping relations with the basement. It can be divided into packages each of which shows a lower carbonate followed by an upper siliciclastic sediments (Figure 13). Each siliciclastic package is made up of grey-coloured carbonate conglomerate, dominantly carbonate sandstone and mudstone. 0.5–2-metres-thick carbonate interbeds are present within siliciclastic packages. Sandstone and conglomerate show locally lenticular geometry. Plant fragments are common in the mostly bioturbated mudstones. These siliciclastic levels mark the boundary between packages (Figure 13). Both lithologies lap onto the carbonates of the Mesozoic basement and each package backsteps. The Palaeoslope seems to be gentler than in the Gildirli area. The Gildirli Formation is not present in this area and the Karaisalı Formation directly overlies either Mesozoic or Palaeozoic basement. The area between Nergizlik and Gildirli villages is devoid of any Karaisalı Formation carbonates.

The Karaisalı Formation limestones gradationally succeed the Kaplankaya Formation around Çukurköy Village and in areas to the east, but elsewhere they are in direct, erosive, contact with both Mezozoic basement carbonates and Gildirli Formation red-beds, often separated by a thin layer of conglomerate. Moreover, more gently inclined backstepping Karaisalı Formation/basement contacts can be traced for more than 7 km northwards from the faulted margin of the Adana Basin (Görür 1979; Yalçın & Görür 1984; Ünlügenç *et al.* 1993).

Throughout this region the evidence from foraminifera and ostracods indicates a late Burdigalian to late Langhian age-range for the Karaisalı Formation (Ünlügenç *et al.* 1993), although it may extend into the Serravallian (Yetiş 1988). It is absent in the area between Gildirli and Nergizlik villages. Where present its thickness varies from a metre to more than 300 metres.

Interpretation: Carbonate sediments are very sensitive to environmental factors such as water depth, salinity, light, suspended matter, water temperature and other factors that control living condition of carbonate-

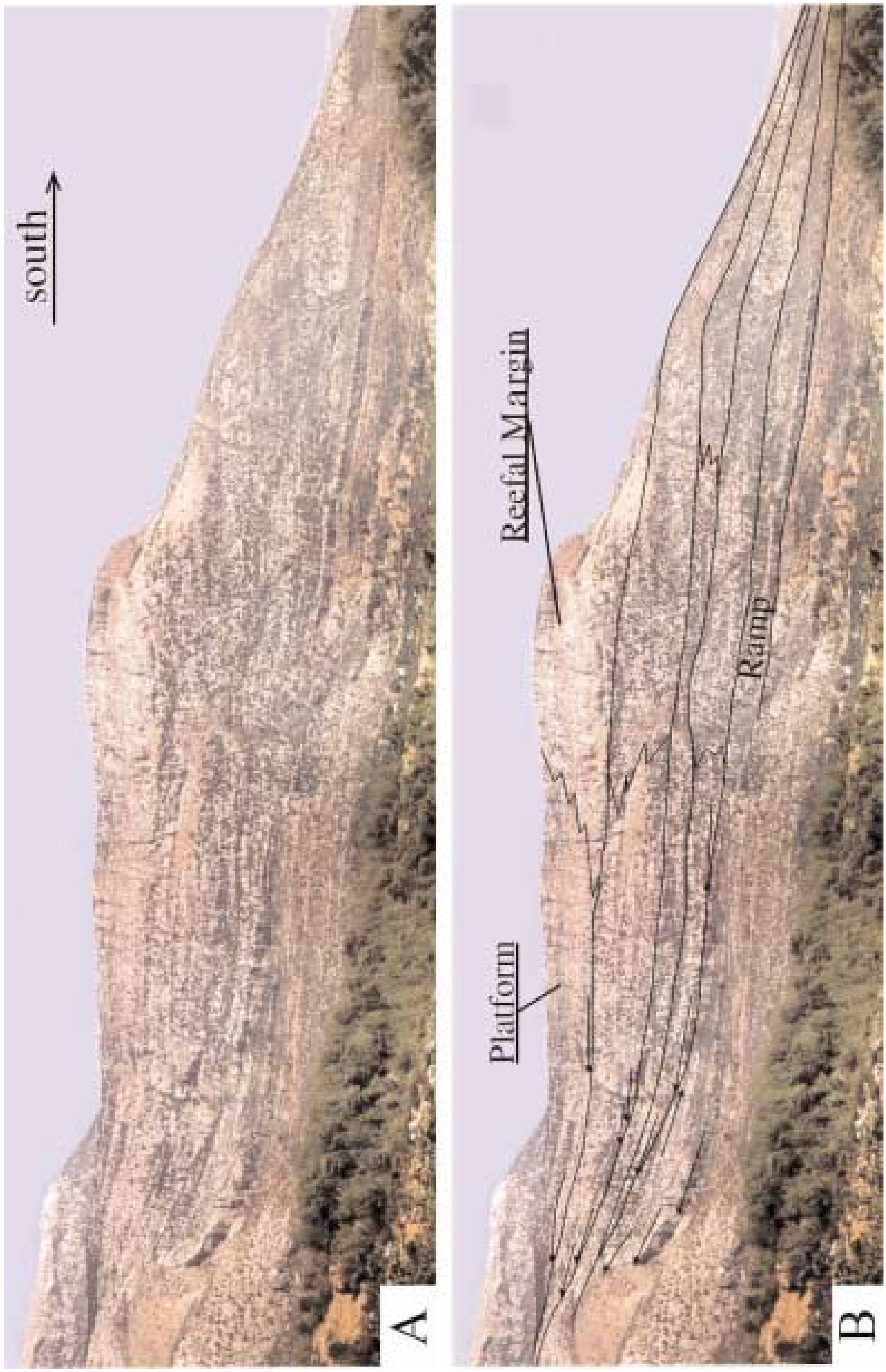

Figure 11. Field view (a) and interpretation (a) of stacking pattern and stratigraphic relation of the Karaisalı limestone in the Çukurköy area that indicates more than one sequence separated by unconformity surfaces (continuous lines). Note that the reefal margin gradually develops at the edge of the platform which was probably a ramp at the beginning of deposition. Each sequence is defined by marked onlaps and/or truncation surfaces.

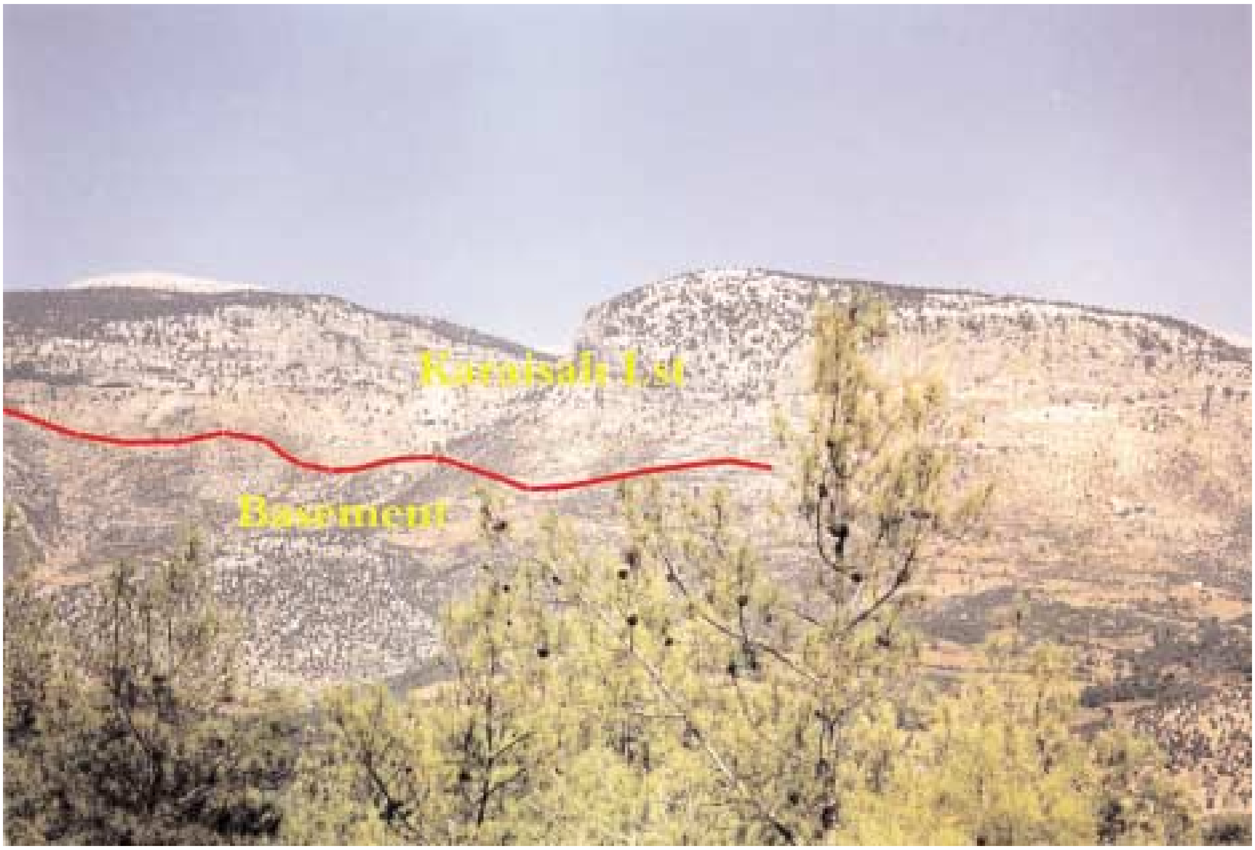

Figure 12. This photograph demonstrates the back-stepping stratigraphic relation of the Karaisalı Formation (forming the topmost sequence) and the basement. Note the horizontal position and contact with the basement rocks. No Gildirli Formation is present here.

secreting organism and direct precipitation of carbonate mineral (Bathurst 1971; Milliman 1974; Wilson 1975; James 1984a, b). Since carbonate sediments are produced mainly in shallow water, change in the type of facies indicate changes in environmental conditions, bathymetry and paleotopography (James 1984b). Therefore stratigraphic and facies relations are very important to understand the development history of the valley system after the deposition of the Gildirli Formation and during the deposition of the Karaisalı Formation. In order to define whether the Karaisalı Formation was deposited and eroded in the area that is now occupied by a valley or whether it was not deposited at all due to water depth within the valley and/or suspended matter (brought by currents bypassing the carbonate platform) preventing carbonate deposition, the stratigraphic relations of the Gildirli, Kaplankaya and Karaisalı formations should be carefully analysed.

Görür (1979) described the Karaisalı Formation as mainly composed of bioclastic limestones and defined six microfacies while Yetiş *et al.* (1995) emphasized the reefal character of this formation.

The Karaisalı Formation generally has been interpreted as a platform carbonate succession with significant reefal elements (Görür 1979). The evidence cited above demonstrates that the lateral distribution of the Karaisalı Formation limestones was controlled by the palaeotopography of the margin (probably fault-controlled), while the vertical stacking pattern may have been controlled by sea-level fluctuations. The gross relations of the beds, the truncation surfaces and clinoform geometries observed in bed-packages all strongly suggest that the packages can be tentatively interpreted as depositional sequences. Moreover, the stratigraphic relations of these packages (sequences) with the Mesozoic basement indicate that at least during early

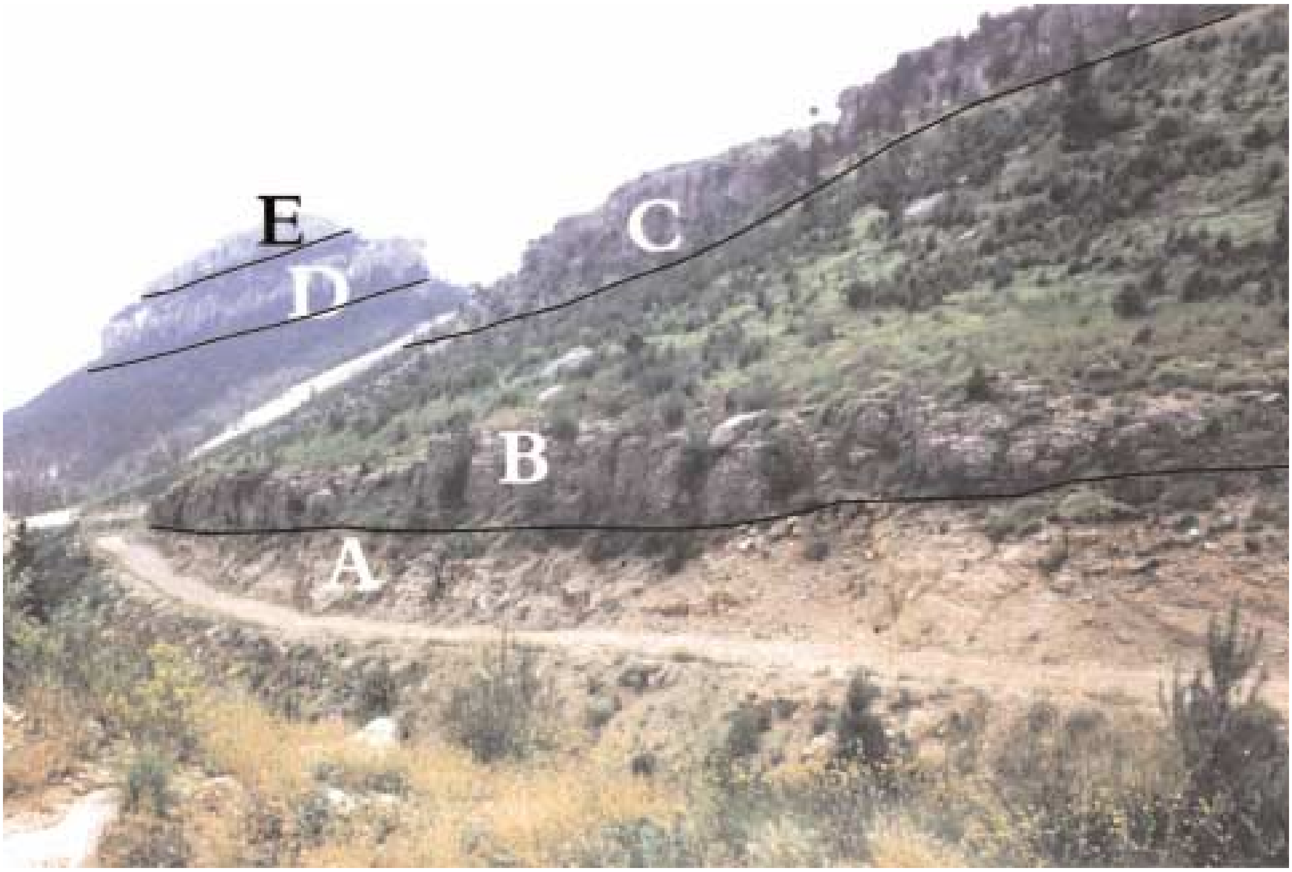

Figure 13. The Karaisalı Formation limestone laps onto the basement to the north of Karaisalı. It locally begins with a conglomerate containing marine fossils (A). Conglomerate is seen along the road cut, together with overlying Karaisalı limestone (B). Note other levels of limestone which are overlying the first one (C, D and E).

stages of Karaisalı Formation deposition (late Burdigalian– ?early Langhian) the main basin margin around Çukurköy and to the east was a steep surface and was free of Gildirli Formation sediment cover. This cliff-like morphology confined early carbonate accumulation to a narrow, NE–SW-trending marginal zone. Only after deposition of package 5 (Figure 11) was it possible for carbonates to spread northwards across the more subdued palaeosurface of Tauride basement rocks (Figure 12). West of Karaisalı town a broadly similar pattern of basement onlap and backstepping is observed (Figure 13).

The stacking pattern of Karaisalı Formation limestone packages observed to the east of Çukurköy Village indicates that deposition started on a sloping ramp which evolved into a narrow shelf with a steep frontal slope. Relative sea-level changes and sea-floor topography determine the areal extent and productivity of the carbonate factory (Pomar 2001). This control is very evident in the exposures portrayed in Figures 11 & 12. Steeper slopes are more easily maintained in carbonate accumulations since lithification is more rapid and frame-building organisms can grow on steeper slopes (Kenter & Schlager 1989; Kenter 1990; James 1980, 1983; James & Mountjoy 1983). One important point to be considered is that at present we see only two dimensional exposures. Knowledge of the morphology in the third dimension may alter our interpretation.

The absence of the Karaisalı Formation only from areas occupied by the Gildirli Formation indicates that those areas were not suitable for deposition of carbonate sediments. If limited deposition occurred, it must have been eroded before the deposition of Cingöz Formation clastics.

Cingöz Formation

The Cingöz Formation was originally defined by Schmidt (1961). It is divided into three members: grey to greenish grey shale of the Köpekli member at the bottom; yellowish grey, pebbly, medium- to coarse-grained feldspathic lithic arenite of the Ayva member in the middle; and olive green, coarse- to fine-grained sandstone-shale of the Topallı member at the top. The Cingöz Formation grades upward into the Güvenç Formation. Görür (1985) interpreted the Ayva member as proximal turbidite sediment, and the Topallı member as a distal part of the same system. Yetiş (1988) followed Görür (1985)'s interpretation.

The Cingöz Formation, locally in the marginal areas, starts either with poorly bedded, often channelized, conglomerates or sandstones. The conglomerates and sandstones either wedge out or grade into sandstone-shale interbeds. Gürbüz & Kelling (1993) defined two submarine fan systems within the Cingöz Formation: western and eastern fans with respect to their relative geographic location. Lithological characteristics of the member are given in detail by Gürbüz (1993), Gürbüz & Kelling (1993) , Gürbüz *et al.* (1998), and Satur *et al.* (2000, 2005) will not be repeated here.

Conglomerates of the Cingöz Formation in the Gildirli area directly overlie either the Gildirli Formation (Figure 10a) and/or basement carbonates along the Yayla road (where Cingöz Formation conglomerates are present as erosional remnants), or they overlie Kalkankaya Formation conglomerates, for example to the south of Çukurköy Village (Figure 10b). South of Gildirli Village, Cingöz Formation conglomerates directly overlie Gildirli Formation conglomerates as shown in the measured stratigraphic section (Figure 14).

Foraminiferal assemblages from the Cingöz Formation yield a Late Burdigalian–Serravalian age (Nazik & Gürbüz 1992). Its thickness varies from 1000 metres to 3200 metres (Yetiş *et al.* 1995).

Interpretation: Cingöz Formation clastics were interpreted as deposited in a submarine fan environment (Yetiş 1988; Gürbüz 1993; Gürbüz & Kelling 1993; Satur 1999; Satur *et al.* 2000, 2005). It was interpreted that they represent the proximal part of a submarine fan which developed as an axial system, trending parallel to the basin margin (Satur *et al.* 2005). This interpretation is also consistent with the concept of a palaeotopographic feature (margin parallel valley) that existed before the deposition of the Cingöz Formation. This topographic feature may be the reflection of the palaeotopography that controlled the distribution and deposition of the Gildirli Formation as well as the Cingöz Formation. The Cingöz Formation occupies the area where carbonate sediments of the Karaisalı Formation are absent. It extends and grades laterally into basinal sediments of the Güvenç Formation.

Güvenç Formation

The Güvenç Formation occupies the basinal part of the mid-Miocene system. It was first defined by Schmidt (1961) and is dominated by olive green shale-thin sandstone intercalation with an abundant open-marine fauna. It grades downwards and laterally into the Cingöz Formation. The Güvenç Formation was deposited during Burdigalian–Serravalian time (Özçelik 1993; Özçelik & Yetiş 1993). Its thickness is around 2100 metres.

Interpretation: Görür (1985) considers the Güvenç Formation as the basinal equivalent of the Cingöz Formation (Görür 1985). Yetiş *et al.* (1995) interpreted the Güvenç Formation as deep-marine sediment and probably a distal part of the Cingöz submarine fan system. Intercalation of shale-thin sandstone, sedimentary characteristics and gradation into the Cingöz Formation support a distal fan interpretation (Yetiş 1988; Yetiş *et al.* 1995).

Summary of Stratigraphic Relations of Early & Middle Miocene units

The complex stratigraphic relationships between the units described above in the northwest part of the Adana Basin are best illustrated by a comparison of measured successions from four locations in this area (Figure 15).

Around location 1 (west of Karaisalı town, Figure 2), Karaisalı Formation limestones are separated from the eroded basement surface by a thin conglomerate containing marine fossils (thus distinguishing it from Gildirli Formation conglomerates) (Figures 2 & 10a, b). To the northeast (near Çevlik and Karahamzalı villages), thin Gildirli Formation red-beds intervene between the Karaisalı Formation and basement carbonates. The

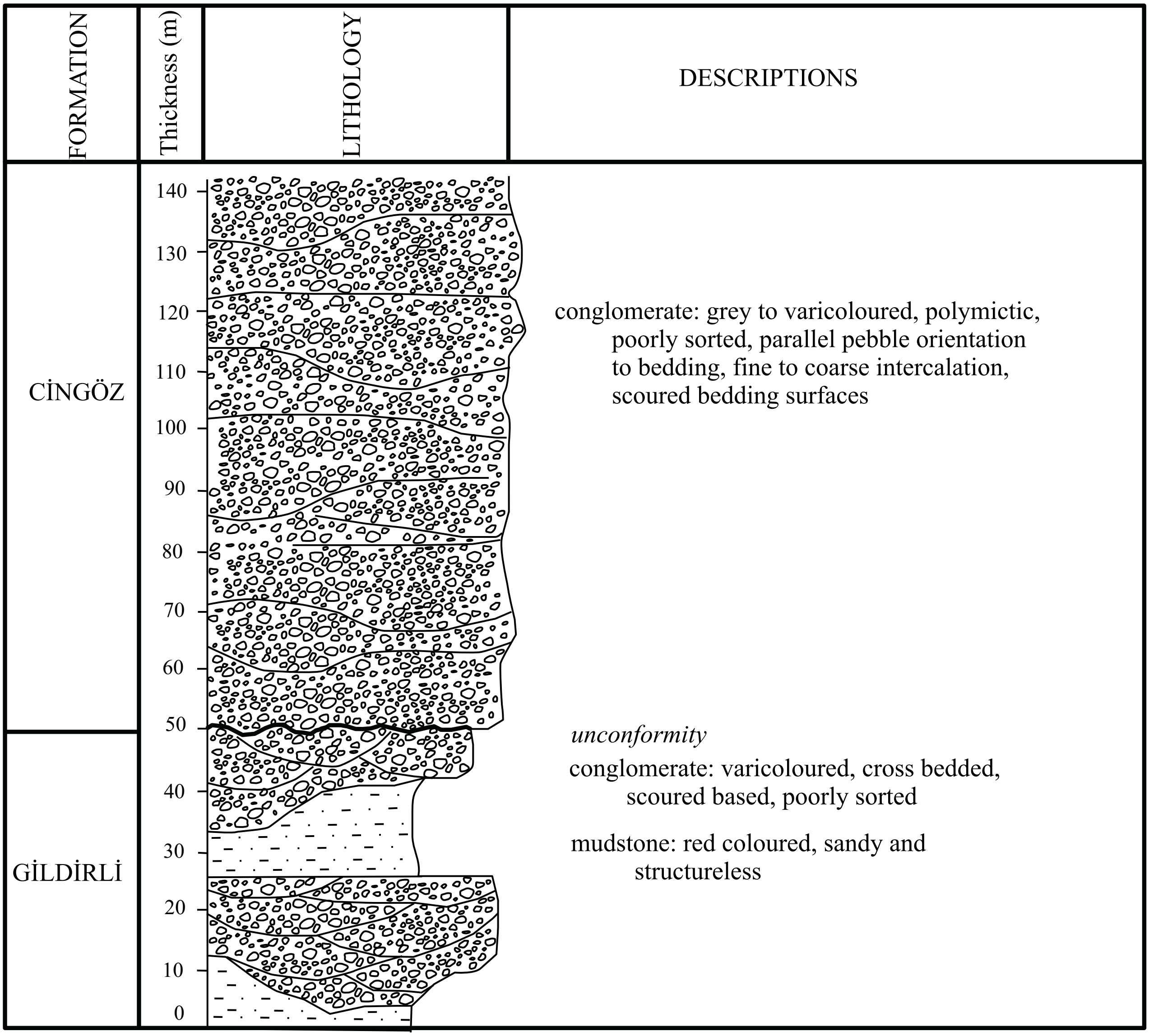

Figure 14. Measured stratigraphic section near Çakmak Village where conglomerates of the Ayva Member of the Cingöz Formation directly overlie red continental clastics of the Gildirli Formation. The Kaplankaya and Karaisalı formations are not present here, indicating an unconformable relationship (Location D on Figure 2).

Karaisalı/Gildirli formations contact here is sharp (Figure 10a) and the red-beds thicken rapidly to the west and southwest. The architecture of Karaisalı Formation limestone bodies in these western outcrops indicates that the carbonate deposits become progressively younger upslope and landward, with successive basement-onlapping packages of limestone backstepping progressively farther north.

At location 2 (northwest of Nergizlik), coarse Gildirli Formation units occupy deep palaeovalleys previously cut into the Mesozoic basement (Figures 2 & 9a). The red-beds are succeeded by the Kaplankaya Formation and in turn by turbiditic sandstones and shales of the Cingöz member.

Around location 3 (northeast of Çakmak, Figure2), coarse Gildirli Formation sediments again rest with

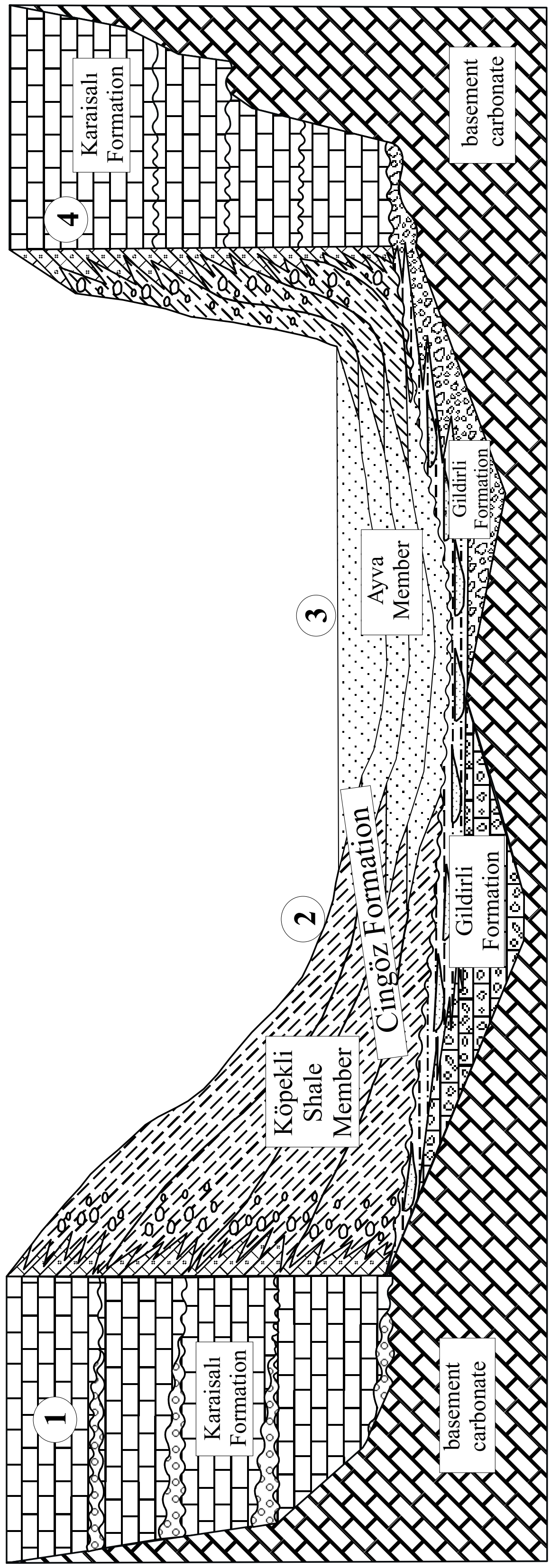

Figure 15. Stratigraphic relations, correlation and depositional model for the Gildirli and Kaplankaya formations, Karaisalı limestone, Cingöz clastics and submarine fan sediments (Ayva Member) in the study area.

strong discordance on the Mesozoic basement (Figures 2, 4 & 5d). In turn these red-beds are erosively succeded by coarse submarine canyon-fill sediments of the Cingöz Formation (Figures 8, & 10b).

At location 4 (Gildirli-Çukurköy area) different stratigraphic successions can be identified, proceeding from north to south. These represent a down-palaeoslope traverse. In the north (upslope), Karaisalı Formation limestones rest directly and discordantly on the Mesozoic basement (Figures 11 & 12). Downslope (farther south), Gildirli Formation conglomerates and the red-beds are sharply succeeded by Kaplankaya Formation shallow-marine sediments (Figure 10a). In turn, the Kaplankaya Formation grades upwards into Karaisalı Formation limestones. Farther downslope, to the south, basement is not exposed. Here Gildirli Formation red-beds are again sharply overlain by Kaplankaya Formation marls and shelly sandstones which grade upwards into 'submarine slope shales' with numerous slide and slump features (Cronin *et al.* 2000). Gildirli Formation red-beds, Kaplankaya Formation clastics and slope shales are all onlapped by submarine fan clastics of the Cingöz Formation.

General Discussion

The observed field relations, stratigraphic and palaeoenvironmental evidence all show that the Gildirli Formation was the initial Neogene unit to be deposited in this area [probably in the latest Oligocene to earliest Miocene time interval (cf. Görür 1992)]. These sediments accumulated under terrestrial conditions on a topographically irregular surface carved out of Palaeozoic and Mesozoic basement rocks. Differences in the clast-contents of Gildirli Formation conglomerates in the Gildirli and Nergizlik areas indicate that these rudite bodies were supplied from different sources. Conglomerates and sandstones exposed around Gildirli Village are interpreted as an alluvial fan derived from an area dominated by Palaeozoic and Mesozoic carbonates and ophiolitic mélange. To the west, the Nergizlik conglomerates, however, were deposited in a fan that was fed from a source entirely composed of older carbonates and devoid of ophiolitic material. This western limestone-clast dominated fan-complex rests on an east-facing depositional slope, while the eastern, more polymict, fan formed on a depositional slope facing west and south. It thus appears that both fans funnelled coarse detritus into an intervening major depression. The sediments of the two fans may have intermixed within this valley. The associated V-shaped palaeovalleys may reflect margin-parallel faults in the basement that controlled and shaped the main basin margin prior to deposition of the Gildirli Formation. Angular clasts in the lower part of the Nergizlik fan show initial deposition on the stepped slope, while upwards progressive rounding of clasts indicates increasing transport distance of the material and probably decreasing slope angle on the fan surface with time. Angular clasts show short whereas rounded clasts show relatively longer transport distance. Well-rounded and well-cemented clasts of intraformational conglomerate may be interpreted as indicating syndepositional movement on the bounding fault and partial uplift of previously deposited fan material.

During Gildirli Formation times (?earliest Miocene), two alluvial fans prograding toward an intervening depression, developed on an irregular landscape (Figure 16a). With the inception of the Burdigalian marine transgression, carbonate sediments began to accumulate on more elevated and shallow parts of the basin margin during intervals of higher sea-level, while fine-grained material (marine shales and marls) fed by a siliciclastic source were deposited on frontal slopes and in lows. During lowstand intervals, coarse clastic material was transported into deeper parts of the basin through the V-shaped valley and any previously deposited fine-grained material within the valley was removed by erosive flows. This long-lived depression was occupied by deeper waters during much of the Early and Middle Miocene, whereas the shoulders of this valley, covered by a shallow sea, remained largely free of clastic input, allowing near-continuous accumulation of carbonate sediment whereas the valley itself remained the site of siliciclastic deposition. Thus coarse Ayva member sediments were brought into direct erosive contact with older Miocene deposits, including the Gildirli Formation due to submarine erosion. Carbonate sediments along the margin also were partly eroded during lowstand intervals (Vail 1987; McMillen 1991). The next sea-level rise then covered previously exposed areas and marine sediments lapped onto the unconformity surface (Figure 16b). In the feeder valley of the submarine fan, stacked sandstone and conglomerate bodies were developed and these conglomerates and

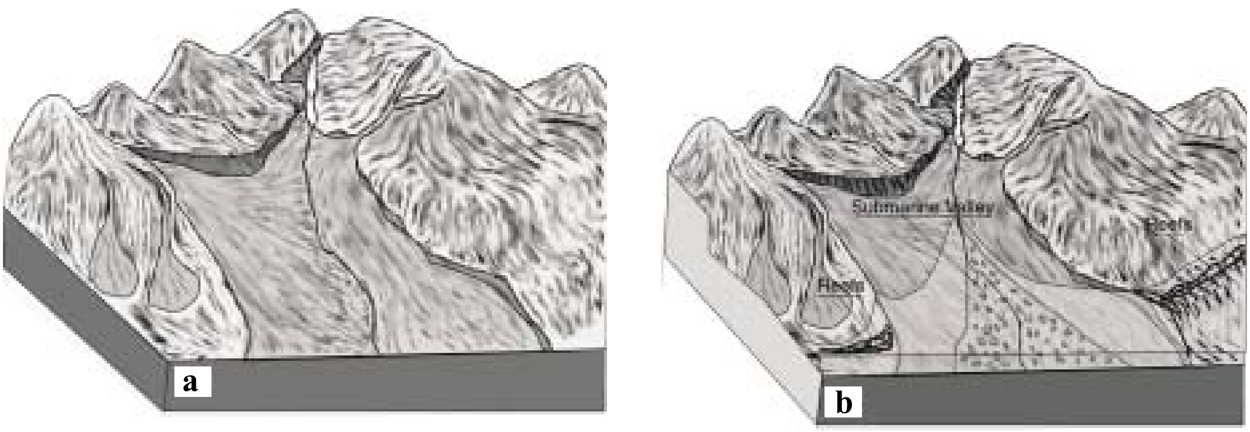

Figure 16. Proposed model for Gildirli Formation deposition and the following period. The palaeovalley is first filled by two alluvial fans of the Gildirli Formation (a). With the advance of the sea, existing palaeotopography is submerged by the sea and the deeper part of the area becomes the site of deposition for finer-grained siliciclastic material, probably formed in estuaries; meanwhile, along the shoulders of the valleys carbonate deposition took place. During sea-level lowstands the palaeovalley acted as passage for coarse siliciclastic material to feed the submarine fan system (b).

sandstones are separated by more shale-rich intervals, probably formed also during highstands in the distal part of the fan towards the south (Satur *et al.* 2005).

The nature and distribution of Kaplankaya Formation sediments were largely controlled by the availability of clastic materials and the pre-existing topography. Thus the Kaplankaya Formation is more conglomeratic in those areas (such as the palaeo-depressions) where Gildirli Formation rudites were available for reworking and re-deposition. Moreover, Kaplankaya Formation sediments formed in front of the early Karaisalı carbonate platform are more shaley, richer in carbonate and display clear attributes of basinal slope facies (Cronin *et al.* 2000). The Kaplankaya Formation, however, is absent where clastic material was not available (as to the north of Çukurköy Village).

The coincident location and stratigraphic relations of the Gildirli alluvial fans and palaeovalleys with the feeder-system for the western part of the Ayva member strongly suggests that supply to the submarine fan system was also controlled by the pre-existing palaeotopography since the submarine fan system shows an alignment parallel to the basin margin.

During the widespread Early Miocene rise in sea-level the irregular palaeotopography of both Gildirli Formation red-beds and the basement rocks was inundated. The early Karaisalı Formation limestones were formed on more elevated areas of the sea floor, suitable for deposition of carbonates as indicated by Bulgurdağ oil field where carbonates were deposited on a basement high (Mobil Oil Co. report, Petroleum Affairs archive), while fine-grained pelagic, open-marine marls and limestone was deposited within the lows surrounding the elevated areas (as in the Bekirli-1 and 2 wells, petroleum affairs archive). When the sea reached the marginal areas, coastal and shallow-marine mixed clastic/carbonate facies (Kaplankaya) and patch reefs, ramp and narrow platform limestones (lowest part of the Karaisalı Formation) were deposited. Currently available biostratigraphic evidence, cited earlier, indicates that the diverse facies represented in the Kaplankaya and Karaisalı formations are broadly contemporaneous, although the higher parts of the latter unit are probably younger and overlap with deposition of the Cingöz and Güvenç formations deep-marine clastics. As a consequence, both the Kaplankaya and Karaisalı formations unconformably overlie the Gildirli Formation clastics.

The presently observed geometry of the Karaisalı Formation clinoformal apron (Figure 11) along the northern basin margin demonstrates that there was as much as 200 metres difference in water depth between the platform edge and the base of the marginal slope of the Adana Basin in the Early to Middle Miocene, attesting to rapid subsidence and/or presence of an irregular topography prior to the marine transgression. Moreover, the absence of a break in slope in the lowest preserved limestone package and the basinward transition from thick limestone to marl demonstrate that initially Karaisalı Formation deposition took place on a highly inclined ramp. The vertical change from a ramp to a reefal margin may be related to various factors (Pomar 2001). Fluctuating sea level, which forces physical, biological and chemical processes to migrate laterally and vertically, controls the internal pattern within the shelf (Hine & Mullins 1983). It may also be related to differential rates of carbonate sedimentation (Wilson 1975). There must have been subtle differential relief on the sea floor that localized the shelf-slope break. Higher in the section, reef bodies developed along the platform edge, the shelf-break became more pronounced and the slope angle increased. Slumps and slides within the basinal equivalents of Karaisalı Formation carbonates indicate that the frontal slope was steep, leading to frequent failure of sediment deposited on the slope and its accumulation along the base of slope (Handford & Loucks 1993; cf. Cronin *et al.* 2000). The abundant neritic shell debris found in these base-of-slope shales, associated with planktonic forams (Görür 1979), strengthens this conclusion.

The geometry and onlapping style of the bed-packages forming the Early Miocene Karaisalı carbonate ramp attest to the influence of inherited tectonic structures and/or palaeotopography as controls on subsidence on the northern margin of the Adana Basin. The stratigraphic relations between Karaisalı Formation carbonates and the basement along the margin near Çukurköy and to the north of Karaisalı Town (portrayed in Figure 11) provide further evidence for the influence of inherited palaeotopography in this region. However, the stacking pattern of the later Karaisalı Formation packages is most readily interpreted as the result of fluctuations in relative sea-level. The shoreline position of each package indicates a general rise in sea level, but the onlapping pattern and occurrence of truncation surfaces indicates that there were also periods of sea-level fall (Posamentier & Vail 1988). The sedimentary response to relative sea-level change is frequently expressed by a predictable succession of facies forming a systems tract. Thus it is likely that surfaces delimiting the major Karaisalı limestone packages represent sequence boundaries (Handford & Loucks 1993).

The available biostratigraphic evidence demonstrates that Cingöz/Güvenç Formation submarine canyon and fan systems (Ayva Member) came into existence (in the late Burdigalian or early Langhian) and remained active while reefal and skeletal carbonates were being deposited along much of the narrow ramp and/or platform. The great volume of deep-water clastics (more than 3 kilometres thick in total) that subsequently accumulated in the basin was therefore conveyed by some form of bypassing across this carbonate zone. Only two major entry points for this Cingöz Formation clastic (Ayva Member) influx have been identified on the northern margin of the Adana Basin, one of which is a submarine canyon located near Çakmak Village, in our study area (Gürbüz 1993; Satur 1999; Satur *et al.* 2000). This feature clearly has considerable relief, since it juxtaposes coarse Cingöz Formation canyon fill-sediments (Ayva Member) against underlying Miocene formations, including Gildirli Formation red-beds (Figure 15) and basement rocks.

The event that initiated the development of this submarine fan system is unclear but is probably a result of tectonic activity in the hinterland (Satur *et al.* 2005) and/or a period of sea-level fall within the overall Miocene marine transgression or both.

Satur (1999), Cronin *et al.* (2000) and Satur *et al.* (2000) interpreted that this fan was fed by a single canyon which bypassed the laterally extensive carbonate shelf and argillaceous slope apron. If this canyon or valley was created by a sea-level fall, its relief may have been limited to the amount of sea level change. From the onlapping relation, the amount of sea-level change can be predicted. In the present case the onlapping relation indicates that the feeder valley was much deeper than the valley that might be ascribed to a sea-level fall. Therefore some kind of early feature must have existed in the area. The most likely mechanism is that the valley was created by early extensional faulting along the basin margin. In the area where the submarine fan was developed, limestone and basinal equivalent marls were not developed, probably indicating that the conditions were not suitable for carbonate deposition. This was probably due to the water depth in the area and/or siliciclastic input that prevented carbonate deposition. Alignment of the submarine fan system with the basin margin also suggests the control of basin-margin parallel faults.

Sandstone and conglomerate packages described by Satur (1999) and Satur *et al.* (2000, 2005) show tongue-shaped geometries. Each tongue-shaped sandstone body is enveloped by a siltstone-rich unit up to 50 metres thick. These packages may represent lowstand deposits of each sequence that developed following a highstand period. Vertical changes from conglomerates to silty units and conglomerates again may be related to sea-level changes.

The absence of high-resolution biostratigraphic correlation obscures whether this and similar features were formed by initial deep incision and long occupation or whether it represents a long-lived depression in the contemporary shelf that acted as an intermittent cross-shelf pathway for clastic material, presumably during minor lowstand intervals within an overall transgressive episode. Some evidence, however, favours the presence of V-shaped palaeovalleys that controlled the passage of the coarse-grained material toward the basin. If the valley formed through incision of the carbonate platform, one would expect a relationship of the coarse-grained material to the carbonates (which is not seen) and multiple incision within the carbonate packages. If these valleys were developed by incision of the river system and/or sea-level lowering, they probably would have formed perpendicular to the basin margin. Available data, however, suggest that these coarse clastics followed a margin-parallel path, probably a trough that was inherited from previous tectonic extension (Satur *et al.* 2005). These data themselves suggest that a pre-existing bottom topography controlled the distribution, geometry and characteristics of the fan and its feeding system.

Conclusions

Facies characteristics, environmental criteria, stratigraphic relations and internal structures of the sediments suggest that the Gildirli Formation was formed by two different alluvial fan systems and that these fans were feeding the same low area. The distribution of coarse fraction and V-shaped valley fills indicate that faults controlled the topography before Gildirli Formation deposition. Reworked conglomerates within the Nergizlik fan material indicate that some of the faults were probably active during the deposition and supplied material from the uplifted block.

During subsequent evolution of the northern margin of the Adana Basin pre-existing palaeotopography basically controlled the facies types; carbonates were deposited on high and stable areas and siliciclastic material in the lows and basinal areas. This indicates that pre-existing palaeotopography exerted a very strong control on both the distribution and type of facies developed in any one area. It also may have controlled the location of the feeder systems of the submarine fans and therefore fan was confined to the valley.

The palaeo-low inherited from Gildirli Formation time controlled the deposition and location of the submarine-fan clastics. The interplay between sea-level fluctuation and sediment supply controlled the deposition of carbonates and submarine-fan clastics: carbonates were deposited during transgressive and highstand times while submarine-fan clastics were deposited during lowstand times. Previous tectonic movements also had a strong control on the distribution of the fan system. If the basin-margin parallel fault system existed due to extension, it may have funnelled the material towards the basin along the margin.

Although facies and stratigraphic relations are clear and direct observation can be made, additional studies are needed to determine the facies characteristics along the sequence boundaries, the biostratigraphy of the carbonates and the basinal sediments related both to carbonate and submarine fan sediments (the Cingöz Formation) to define adequately and correlate the facies types during highstand and lowstand times.

Acknowledgements

The authors wish to thank the management of TPAO for permission to publish this paper. Editing and helpful suggestions by Prof. Gilbert Kelling greatly improved the quality of the paper. Authors also wish to thank Maurice Tucker, Alaistair Robertson and Atilla Çiner for carefully reviewing the manuscript. Gilbert Kelling also helped with the English of the final text.

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Received 03 January 2006; revised typescript received 03 September 2006; accepted 10 October 2006