Stratigraphy and sedimentology of Neogene mammal bearing deposits in the Akkaşdağı area, Turkey

Nizamettin KAZANCI
Ankara University, Engineering Faculty, Dept. of Geological Engineering, TR-06100 Tandoğan, Ankara (Turkey)
and Gebze Institute of Technology, TR-41400 Gebze, Kocaeli (Turkey)

Levent KARADENIZLI
General Directorate of Mineral Research and Exploration, TR-06520 Ankara (Turkey)

Gürol SEYITOĞLU
Ankara University, Department of Geological Engineering, Tectonics Research Group, TR-06100 Tandoğan, Ankara (Turkey)

Sevket SEN
Muséum national d'Histoire naturelle, Département Histoire de la Terre, UMR 5143 du CNRS, Paléobiodiversité et Paléoenvironnements, case postale 38, 8 rue Buffon, F-75231 Paris cedex 05 (France)
sen@mnhn.fr

Mehmet C. ALÇIÇEK
Pamukkale University, Dept. of Geological Engineering, TR-20100 Denizli (Turkey)

Baki VAROL
Ankara University, Engineering Faculty, Dept. of Geological Engineering, TR-06100 Tandoğan, Ankara (Turkey)

Gerçek SARAÇ
Yavuz HAKYEMEZ
General Directorate of Mineral Research and Exploration, Natural History Museum, TR-06520 Balgat, Ankara (Turkey)

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ABSTRACT
The Akkaşdağı area, situated in the southern margin of the Tertiary Çankırı-Çorum Basin, Central Anatolia, Turkey, includes a 280 m thick, mostly continental sediment sequence that overlies either marine Palaeogene transgressive deposits or metamorphic rocks of Kırşehir Massif. From bottom to

top the sequence can be divided into units of Deliceırmak Fm. (alluvial fan deposits) and Ceritkale member (marine fan-delta and shelf carbonates) of mid-upper Eocene, Güvendik Fm. (gypsum) of Oligocene, and Akkaşdağı Fm. (fine to coarse-grained alluvial clastics and lacustrine limestone) of upper Miocene-lower Pliocene. A granitic intrusion was emplaced into the basin after late Eocene. The Neogene succession includes mammalian fossils and the lithological composition of the succession is rather different from its equivalences in other parts of the basin. By facies analysis the Neogene infill could be categorised into alluvial fan deposits (facies association I), fluvial deposits (facies association II), lacustrine deposits (facies association III) and pyroclastic flow deposits (facies association IV). Facies association I is dominant and the others are observed inside as alternating sequences. The facies architecture and facies associations suggest that a structural depression existed in the area and was filled with sediments of distal alluvial fans, flood plains and lakes receiving deposits of distal or terminal alluvial fans and flood plains, and occupied partly by lakes.

KEY WORDS
Stratigraphy,
facies association,
late Miocene,
Akkaşdağı Formation,
Central Anatolia,
Turkey.

RÉSUMÉ

Stratigraphie et sédimentologie des formations néogènes à mammifères dans la région d'Akkaşdağı, Turquie.

La région d'Akkaşdağı se situe dans la marge sud du bassin de Çankırı-Çorum en Anatolie Centrale (Turquie) et contient une succession sédimentaire, essentiellement d'origine continentale, épaisse d'environ 280 m. Ces dépôts recouvrent en discordance les roches métamorphiques du massif de Kırşehir. De la base au sommet, il s'agit de la Formation de Deliceırmak (dépôts de cône alluvial) et du membre de Ceritkale (dépôts deltaïques et carbonates côtiers), les deux datant de l'Éocène moyen-supérieur ; de la Formation de Güvendik (évaporites, probablement d'âge Oligocène) et de la nouvelle Formation d'Akkaşdağı (fluvio-lacustre) d'âge Miocène supérieur-Pliocène. Une intrusion granitique recoupe les formations éocènes. La succession néogène contient un niveau très riche en mammifères fossiles. Sa lithologie est assez différente de ses équivalents dans les autres secteurs du bassin. L'analyse des faciès de dépôts néogènes montre qu'il s'agit des sédiments deltaïques et de plaine d'inondation (groupe de faciès I), de dépôts fluviatiles (groupe II), de carbonates lacustres (groupe III) et de coulées pyroclastiques (groupe IV). Le groupe I domine de loin la sédimentation de cette succession et inclut les autres en séquences alternées. Cette architecture de faciès et l'abondance relative de divers groupes suggèrent qu'une dépression structurale recevant les sédiments de cônes alluviaux et constituée de plaines d'inondation et de lacs temporaires a été l'environnement principal de ce bassin.

MOTS CLÉS
Stratigraphie,
association de faciès,
Miocène supérieur,
Formation Akkaşdağı,
Anatolie Centrale,
Turquie.

INTRODUCTION

The Neogene fossil bearing deposits at the Keskin-Kaman area form the southern part of the large Çankırı-Çorum Basin (ÇÇB) in central Turkey (Figs 1; 2). This basin is one of the important Tertiary sedimentary basins of Anatolia with an infill about 3500 m thick and with a sediment distribution over 25000 km^2 (Fig. 1). The Palaeogene part of the infill is most-

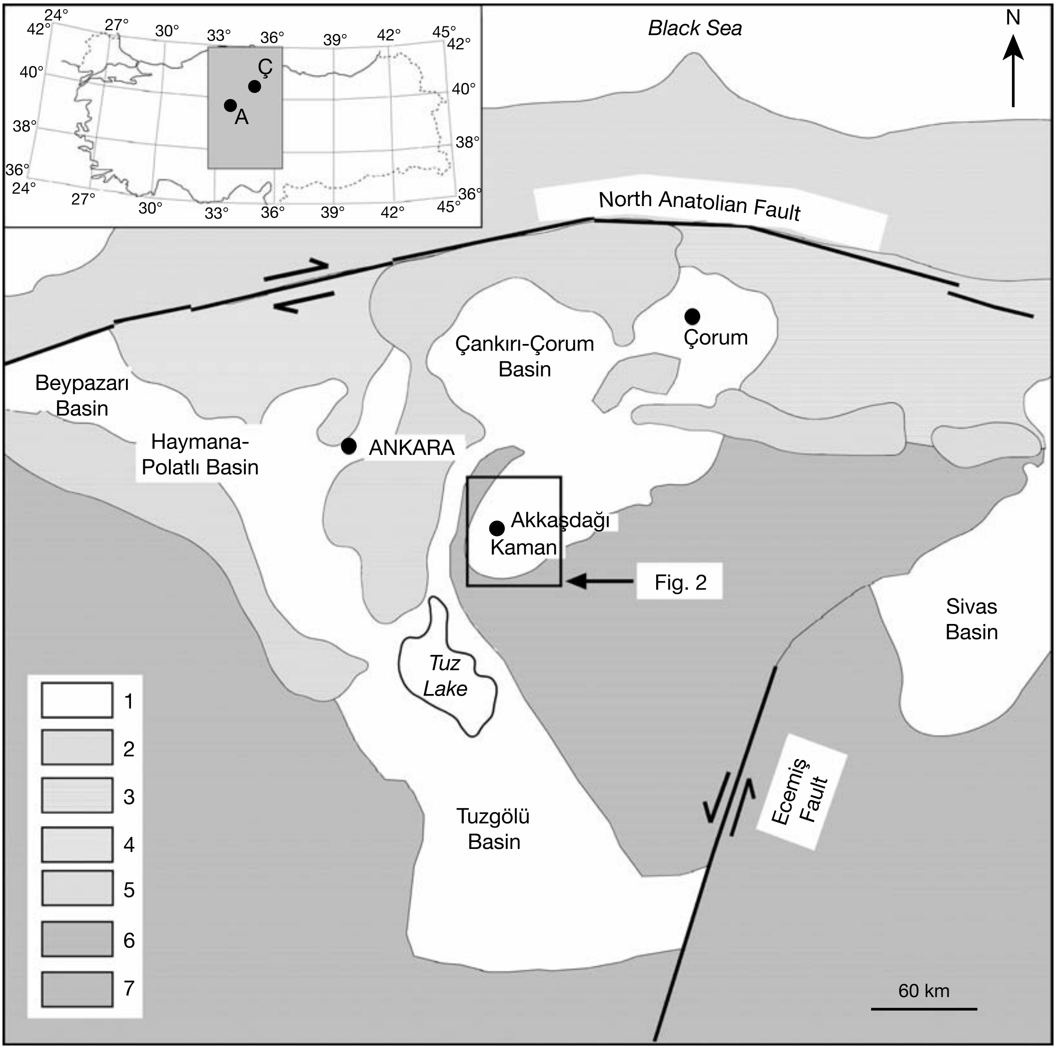


FIG. 1. — Primary geological elements of Central Anatolia and location of the study area; **1**, Tertiary sedimentary basins; **2**, Rodop-Pontid block; **3**, Sakarya continent; **4**, Galatian volcanic complex; **5**, Ophiolitic melange; **6**, Kırşehir continent; **7**, Taurus block (see text for details). **A**, Ankara; **Ç**, Çorum (map modified from Karadenizli 1999).

ly marine, however, the Neogene part is continental (Birgili *et al.* 1975; Hakyemez *et al.* 1986; Karadenizli 1999). In spite of a number of studies conducted, the origin and type of the basin are still debated (i.e. Görür *et al.* 1984; Koçyiğit 1991; Tüysüz & Dellaloğlu 1994; Erdoğan *et al.* 1996). The ÇÇB was largely affected by both syn- and post-orogenic events and hence discontinuity of sedimentary units and frequent lateral facies changes are common. In addition, a relatively poor fossil record, particularly within the Neogene units gave rise to an incomplete stratigraphy of the basin-fill. Therefore, every new paleontologic information is highly important for local stratigraphy and basin evolution studies. Consequently the rich fossil beds at Akkaşdağı form an important marker horizon for the stratigraphy of ÇÇB (Fig. 2). These fossil beds occur in continental Neogene deposits, immediately upon a tuff layer and contain a well diversified mammalian fauna (Kazancı *et al.* 1999). Taxonomic diversity, fossil richness and radiometric dating of the tuff layer provide a special importance to the Akkaşdağı locality for both local stratigraphy and palaeoecology of this Central Anatolian basin. The aim of this study is to present briefly the sedimentological characteristics of fossil bearing Neogene deposits. In order to replace it in its geological context, a basin wide stratigraphy is summarized here.

METHODS OF STUDY

The study area covers a surface area about 900 km^2 in the southern part of the ÇÇB, *c.* 80 km SE to Ankara (Fig. 1). Keskin, Kaman and Çelebi are the main towns and the fossil locality Akkaşdağı (Akkaş hill) is situated just in the centre of this area (Fig. 2).
The study area was mapped by Birgili *et al.* (1975) at first, describing the units as Quaternary, Neogene cover (= Kızılırmak Fm.) and metamorphic basement. Later on all studies followed the same division. For the present study, geology of the area has been revised and remapped at scale of 1:25000, and stratigraphic units have been re-named correlatively to their lateral equivalent in the central and northern parts of the basin. The Neogene deposits in the area are generally loose and erodible and thus they produced a large cover of soil and/or alluvium that prevents access to parent rocks. Consequently, the outcrops for significant stratigraphic sections are rare. Five sections have been measured in Neogene deposits using tape meter and compass (Figs 2; 4). Sediment thickness was calculated by a graphic method ($t = \sin \alpha \times l$; t: thickness, α: surface dip, l: surface length) using field data in Figure 4, as units are nearly horizontal. To interpret depositional sequences, the method of facies analysis was applied following definitions of Miall (1984). This method needs descriptions of individual bed contacts, primary and secondary sedimentary structures, texture, mineralogical composition, grain size, colour, etc., for each facies within the succession measured. Standard laboratory techniques were used for description of lithologies (Folk 1974). The location of the measured sections was determined using a portable hand GPS (Figs 2; 4).

GEOLOGICAL SETTING

The Çankırı-Çorum Basin is one of the Anatolian Tertiary basins in north central Turkey (the others are Sivas Basin to the east, Tuzgölü Basin to the south, Haymana-Polatlı Basin to the west) (Fig. 1). It has a circular geometry according to outcrop distribution of the infill that is both Palaeogene and Neogene in age, although the latter is relatively prominent.
The ÇÇB was initially a depositional depression surrounded by the Kırşehir Block to the south, Mesozoic ophiolites to the west and north and the Sakarya Block to the east (Fig. 1). Its geological history, like that of the other Central Anatolian basins, started in the Late Cretaceous-Early Tertiary by the closure of the Neotethys Ocean; these basins gained individual characters after the closure of the Neotethys in Eocene (Şengör & Yılmaz 1981; Görür *et al.* 1998). A different evolution in each of the Central Anatolian sedimentary basins resulted from a complex movement history between the Sakarya and Kırşehir blocks (Şengör & Yılmaz 1981; Görür *et al.* 1984; Erler & Göncüoğlu 1996). Due to increasing intensity of tectonism, marine realms in Central Anatolia decayed since Oligocene, and nearly came to end in the early Neogene, except for some small areas in eastern and southeastern Turkey (Koçyiğit 1991; Tüysüz & Dellaloğlu 1994; Görür *et al.* 1998). Separate, continental, most commonly lacustrine basins and some upland areas existed in Central Anatolia during the Neogene. The present geographic pattern of Anatolia has been formed in the late Miocene. The geological evolution during the Tertiary is well documented in the ÇÇB where both magmatic, metamorphic and sedimentary rocks and structures are well preserved, particularly in the southern part of the study area, as previously described by Seymen (1984), Bilgin

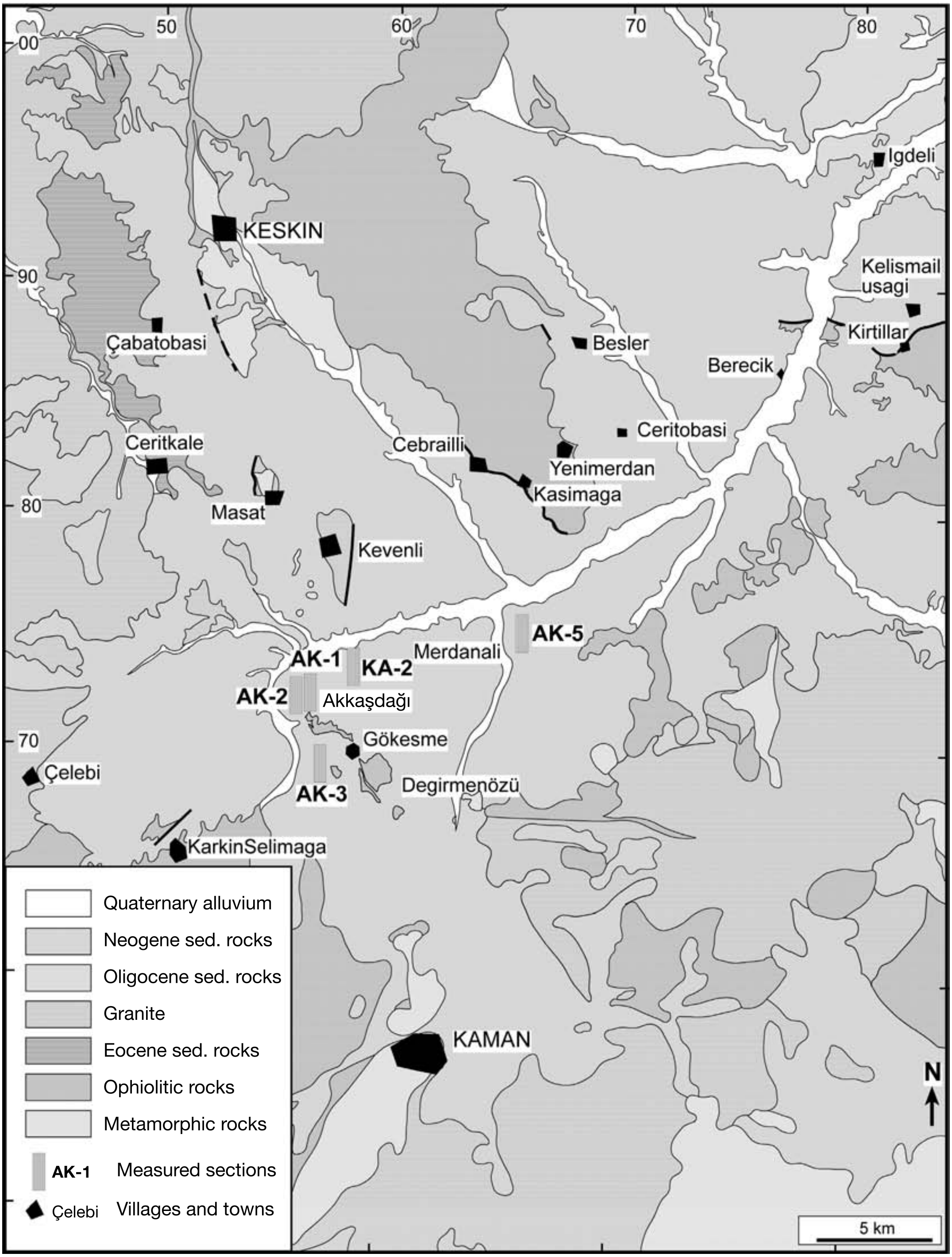


FIG. 2. — Geological map of the study area (from Seyitoğlu *et al.* 2005). See Figure 1 for location.

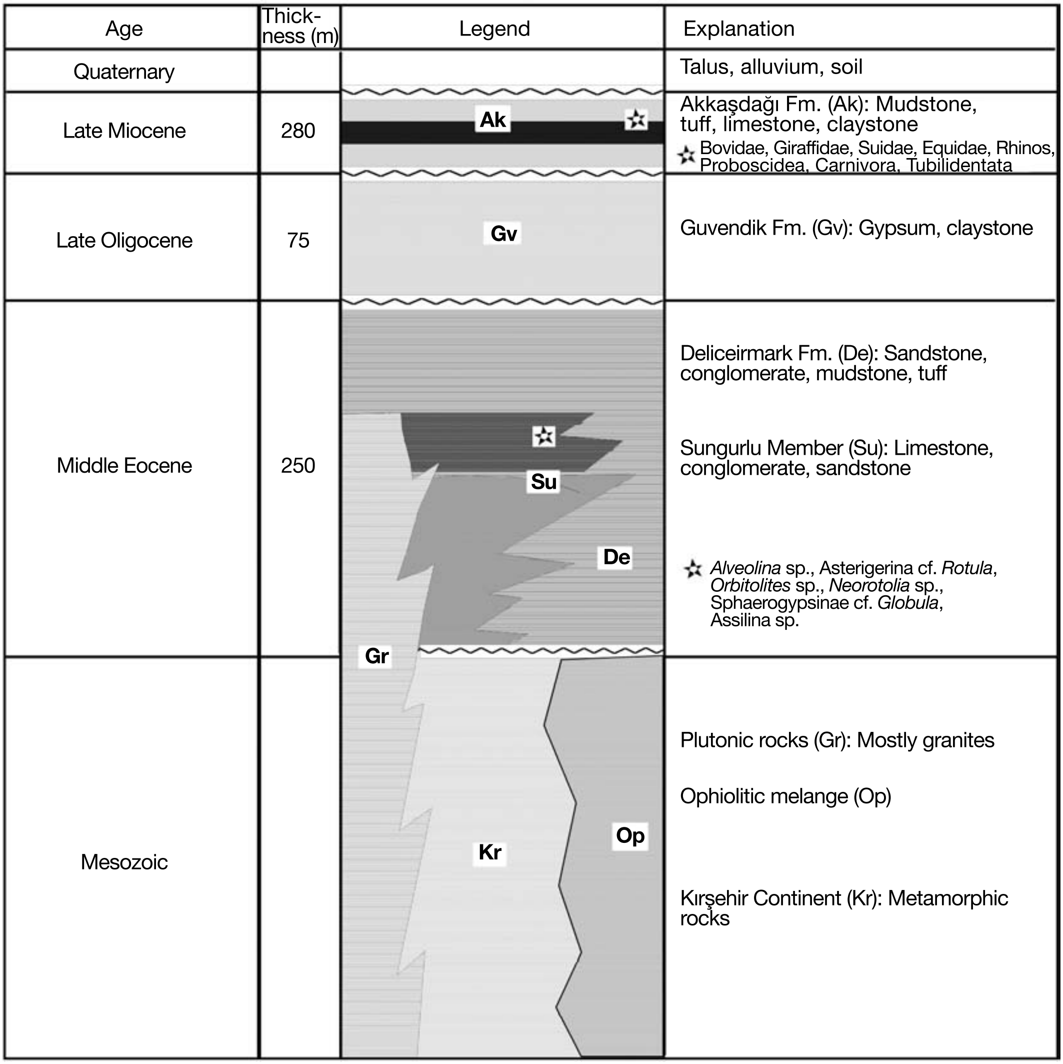


FIG. 3. — Generalized stratigraphy of the Kaman-Keskin area. Names of the lithostratigraphic units are from previous studies mostly from Birgili *et al*. (1975).

et al. (1986), Göncüoğlu *et al*. (1997) and Karadenizli (1999). It should be re-emphasized that intensity of tectonic deformations is significantly different in Palaeogene compared to Neogene units. The presence of an intrabasinal high in the Kaman-Keskin area, between these two series is a prominent feature of the basin. It is generally thought that the ÇÇB was a forearc basin in the Palaeogene (see discussion and references in Görür *et al*. 1984, 1998), whereas its character during the Neogene is still debated. Intracontinental convergence due to the closure of Neothetys Ocean is suggested to continue until Pliocene (Koçyiğit *et al*. 1995). However, Seyitoğlu *et al*. (1997, 2000) proposed that this compression gives way to an extensional tectonics due to the orogenic collapse in the early Miocene. Following to the Pliocene, the western margin of ÇÇB was under the NW-SE compression that was created by North Anatolian and Kırıkkale-

Erbaa fault zones (Seyitoğlu *et al.* 1997, 2000). An extensive discussion on this controversy is given in Seyitoğlu *et al.* (2004). It is noteworthy that the most recent basin interpretations were based on relative stratigraphy of the basin-fill without any reliable chronology. Nevertheless, the ÇÇB has a continuous stratigraphic record from Late Palaeocene to Pliocene in its central and northern parts whereas the Palaeogene is missing in the southern part. Neogene deposits are mainly composed of red alluvial clastics and to a lesser extent lacustrine marls and evaporites. These sediments directly overlie bedrock in the southern part of the basin whereas they overlie marine Palaeogene sediments in the northern part of the basin (Figs 2; 3).

STRATIGRAPHY OF THE AKKAŞDAĞI AREA

A simplified geological map of the southern Çankırı-Çorum Basin (ÇÇB) including Akkaşdağı fossil locality is shown in Figure 2. In the southern part of the ÇÇB, the bedrock is relatively well exposed compared to the northern part of the basin. The mapable geological units herein are mainly metamorphic and plutonic rocks, in addition to conglomerates and sandstones, multicoloured mudstones and gypsum of Palaeogene and coarse alluvial clastics, tuff and lacustrine limestones of Neogene. A modern soil 0.5-1.5 m thick covers the Neogene units and together they form low relief and plain-like morphologies. The area of recent alluvium is limited due to ephemeral nature of streams (Fig. 2). The bedrock types, basin-fill and cover deposits recognized in the southern part of the ÇÇB are briefly described below starting from the base.

THE PALAEOZOIC-MESOZOIC BEDROCK

These rocks are mainly metamorphic cropping out as patches throughout the mapping area, although large bedrock bodies are seen around the towns of Kaman and Keskin (Fig. 2). Their main lithologies are gneiss and phyllites, and according to Seymen (1984), their age of formation (= metamorphism) is Palaeozoic-Early Mesozoic. This metamorphic rock suite belongs to Kırşehir Massif representing rocks of an old continent and marks the early stages of evolution of Anatolia during Mesozoic and Cenozoic times (Seymen 1981; Göncüoğlu *et al.* 1994; Erdoğan *et al.* 1996). In the mapping area, Neogene units largely cover these metamorphic rocks (Figs 1; 3). They also are cut by granitic intrusions of Tertiary age (Erler *et al.* 1991) (Fig. 2).

MAGMATIC INTRUSIONS

Granitic rocks

The main granitic rock unit of the mapping area is best exposed in Hamitköy-Bayındır-Eldelekli area to the southeast and in Çelebi-Behrekdağı-Keskin region to the west where a number of separate granitic intrusions cut metamorphic rocks (Fig. 2). The granitic rocks are mainly composed of monzogranite, quartz monzonite and granodiorite (Erler & Göncüoğlu 1996; Kadıoğlu 1996). Seymen (1984) originally described these Central Anatolian granitoids and suggested that they belong to Kırşehir Massif. The age of these plutons is not precisely known. Based on the relative stratigraphical position of these plutonic rocks, various ages from Triassic to Late Cretaceous to Middle Tertiary have been proposed (Şengör & Yılmaz 1981; Erler *et al.* 1991; Göncüoğlu *et al.* 1994, 1997). In the field we observed that these rocks cut and thermally deformed the middle Eocene limestones of the Sungurlu member (see below) near Ceritkale village. Based on this observation it is tought that the age of this particular intrusion was later than Bartonian.

Volcanic rocks

Volcanics occur as individual tuff layers within the Neogene basin-fill. The thickest layer is a white, whitish grey pyroclastic flow bed, 5-7 m thick, in the Akkaşdağı Formation at the Akkaşdağı hill (Figs 2; 5). The mammalian fossil locality is also situated above this bed on the southern flank of Akkaşdağı. The origin and source of mentioned tuff layer is debated (Karadenizli *et al.* 2005), however, the presence or intrusion of volcanics into the infill of ÇÇB started in the late Eocene and continued in the Neogene as lava flows, pyroclastic flows, air fall tuff and/or epiclastic sediments (volcanic clasts or

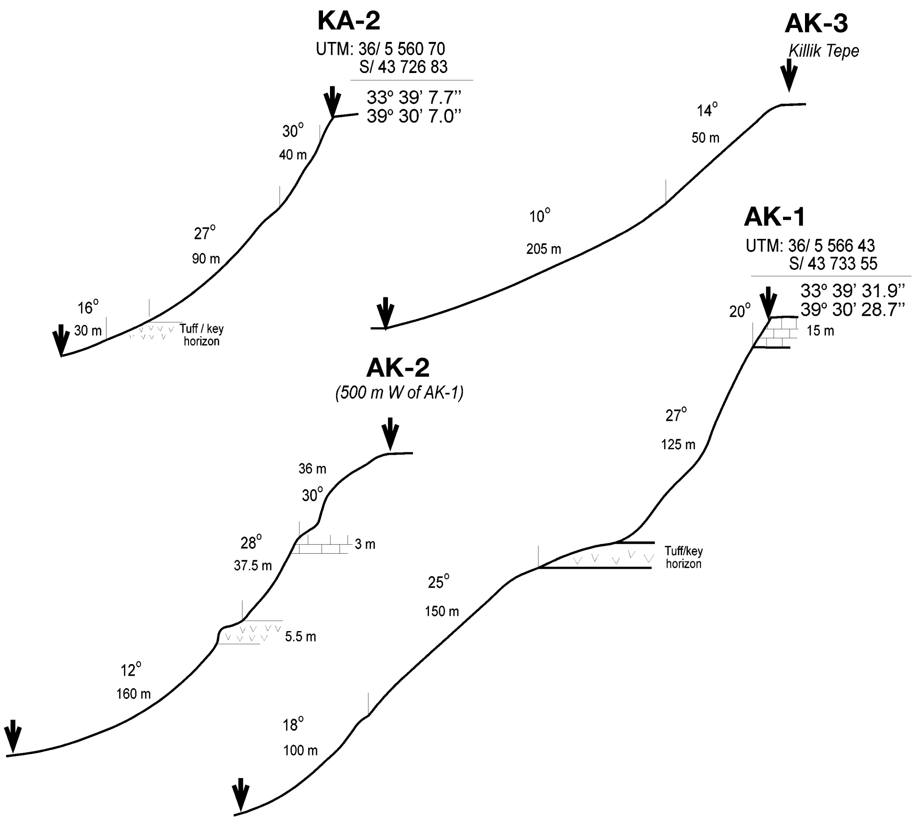


FIG. 4. — Shematic topographies of the measured sections. Thickness of the facies has been calculated by graphic method from the related profiles. Numbers show surface dip (degree), length (m) and coordinates as Universal Transverse Mercator (UTM) and grid systems.

tuffite beds) (Birgili *et al.* 1975; Karadenizli 1999). Moreover, the Galatian volcanic complex to the north of Ankara and the Capadoccian volcanic complex (Fig. 1) to the east of the study area also intercalate with the upper part of ÇÇB infill. The occurrence of these two complexes resulted from continental collision of Afro-Arab and Eurasian plates in late Miocene (Innocenti *et al.* 1975; Pasquaré *et al.* 1988). However, the Galatian volcanic complex has recently been reinterpreted as a consequence of extensional tectonics (Seyitoğlu *et al.* 1997; Wilson *et al.* 1997).

THE TERTIARY BASIN-FILL

The Tertiary sedimentary rocks in the mapping area are grouped into three geological units called Deliceırmak Fm., Güvendik Fm. and Akkaşdağı Fm. in ascending stratigraphic order. The names and chronostratigraphic positions of the first two are after Karadenizli (1999) while the Akkaşdağı Fm. is defined for the first time in this study.

Middle Eocene

Deliceırmak Fm. This is the oldest sedimentary unit in the study area with limited outcrops in the northwest (Fig. 2). It is underlain by metamorphic bedrock and is overlain unconformably by Güvendik Fm. of late Oligocene (Fig. 3). The unit lithology is mostly composed of red, thick-bedded conglomerates, sandstones and mudstones with rare tuff interbeds. Its thickness is *c.* 250 m in the area. Clasts are mainly originated from metamorphic rocks and limestones. The clast size is generally between coarse cobble to medium pebble. Vertical and lateral grading occurs within the conglomerate beds.

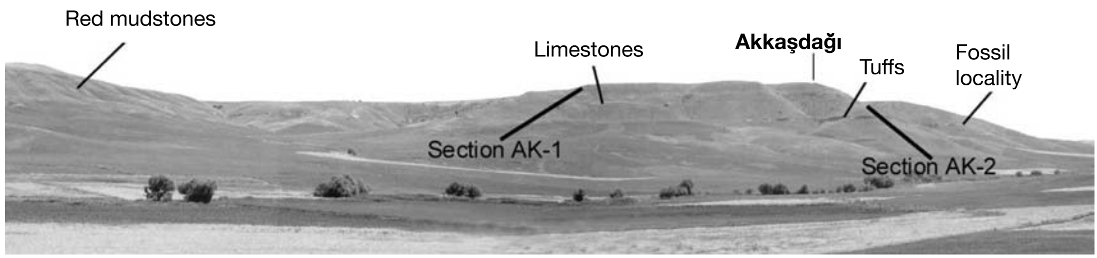


FIG. 5. — Field appearance of the type section of the Akkaşdağı Fm.

Sedimentary characteristics, i.e. bedding type, presence of reverse and normal grading, matrix support, lateral clast grading and red colour suggest that this unit was deposited in an alluvial-fan environment (Karadenizli 1999). Laterally alluvial fans pass into a shallow marine environment as revealed by the presence of marine fossiliferous limestone beds. These limestones are defined as Sungurlu member (see below).

The Deliceırmak Fm. was initially described by Kara & Dönmez (1991) around Yozgat and Kırşehir towns as late Eocene in age. Its type section is near Deliceırmak village far north from the present mapping area. Based on its lateral relation with the Sungurlu member and its fossil content, Karadenizli (1999) revised the stratigraphical position of the Deliceırmak Fm. and assigned it to the middle Eocene (Fig. 3).

Sungurlu member. It is exposed in the western part of the mapping area occurring as a long wedge in N-S direction. The largest outcrops and best sections are located near the villages of Ceritkale and Çatobası (Fig. 2). In this area thickness of the unit is *c.* 80 m and sediments consists of conglomerates, sandstones and limestones. The latter are interfingered with, and underlain conformably by the gravel-rich deposits suggesting that deposition took place in the same environment. The limestones contain foraminiferas such as *Alveolina* sp., *Asterigerina* cf. *rotula* Koufmann., *Orbitolithes* sp., *Neorotalia* sp., *Sphaerogypsina* cf. *globula* (Reuss), *Assilina* sp. (determinations by Dr. Ercüment Sirel) suggesting a shallow marine environmental setting during the late middle Eocene (Bartonian) age (Karadenizli 1999) (Fig. 3). The member was first described by Bilgin *et al.* (1986) as a separate formation (Ceritkale Fm.). However, Karadenizli (1999) showed that it has a strong similarity in both succession and fossil content with the Sungurlu member of the Deliceırmak Fm. outside from the frame in Figure 2.

Late Oligocene

Güvendik Fm. This unit outcrops only in the NE part of the study area (Fig. 2). It is *c.* 75 m thick and consists of thick-bedded gypsum. However, well exposed, up to 300 m thick sequences of this unit are also seen further, around the Kırşehir town in the northeast of the study area (Karadenizli 1999). The Güvendik Fm. is underlain by the middle Eocene deposits unconformably and is overlain by the Akkaşdağı Fm. of late Miocene, hence its stratigraphic position is relative (Fig. 3).

Late Miocene-early Pliocene

Akkaşdağı Fm. This is the most extensive unit of the mapping area (Fig. 2). Its thickness is *c.* 280 m. It mainly consists of multicoloured mudstones and sandstones and to a lesser extent conglomerates. Limestone beds and tuff layers are minor lithologies of the unit, and, they are key horizons with white colours and hard bed notches in the landscape. The Akkaşdağı fossil site lies within this formation. The strata are nearly horizontal. The age of the tuffs is given by both radiometric dating (7.1 Ma) and mammalian fossil records (zones MN 12) (Karadenizli *et al.* 2005).

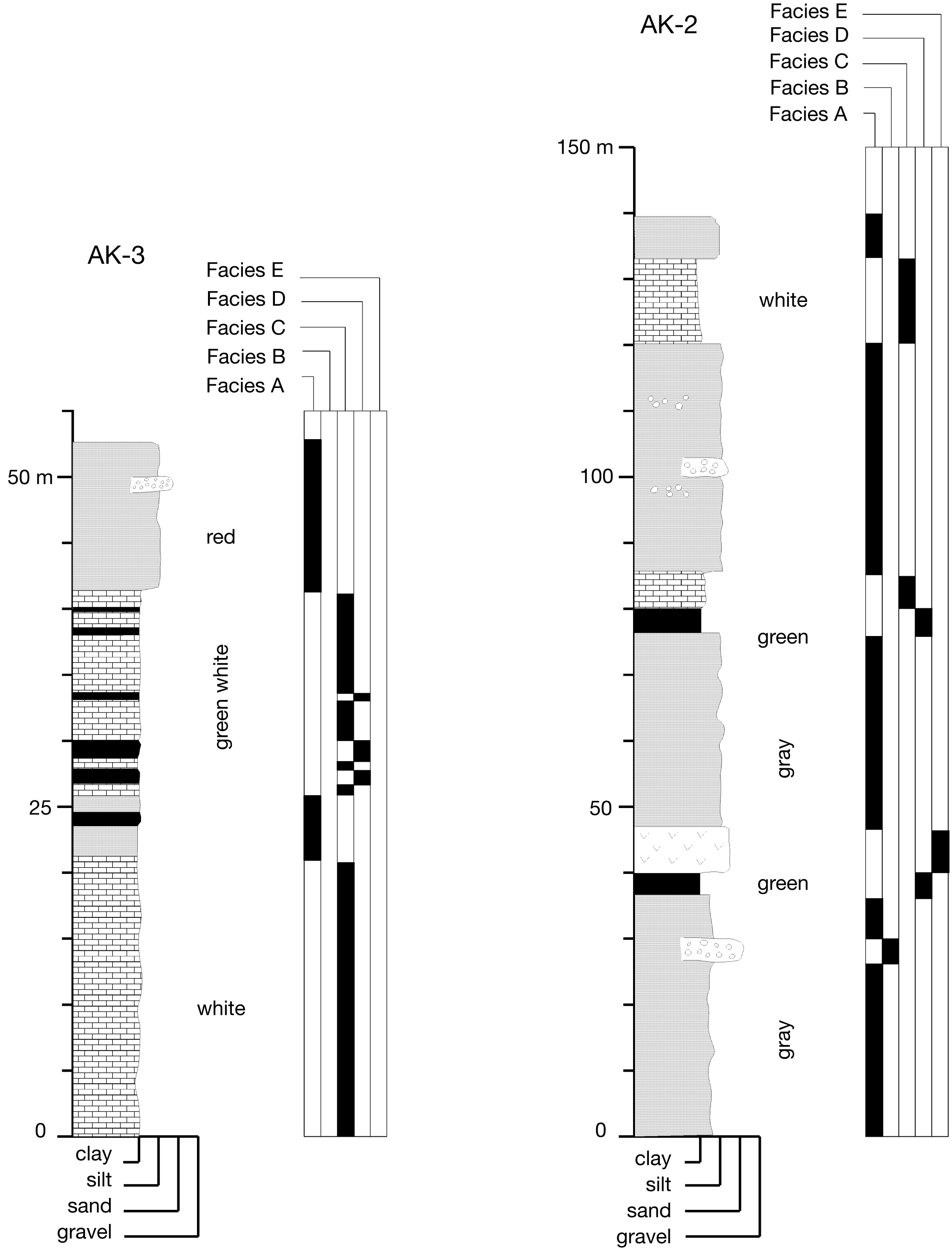


FIG. 6. — Details of the measured sections. Columns at right show the dominance of the facies throughout the successions.

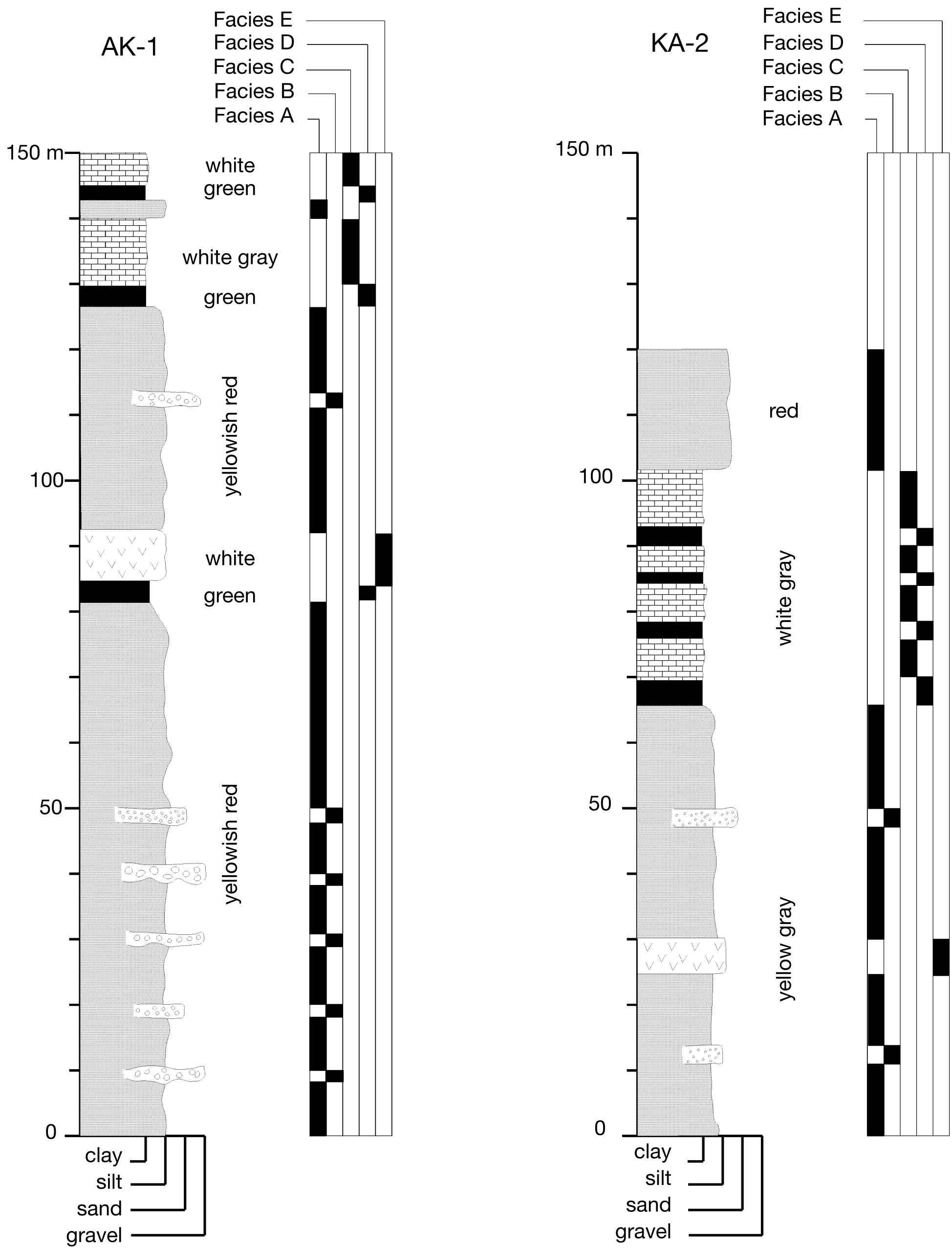


FIG. 6. — Continued.

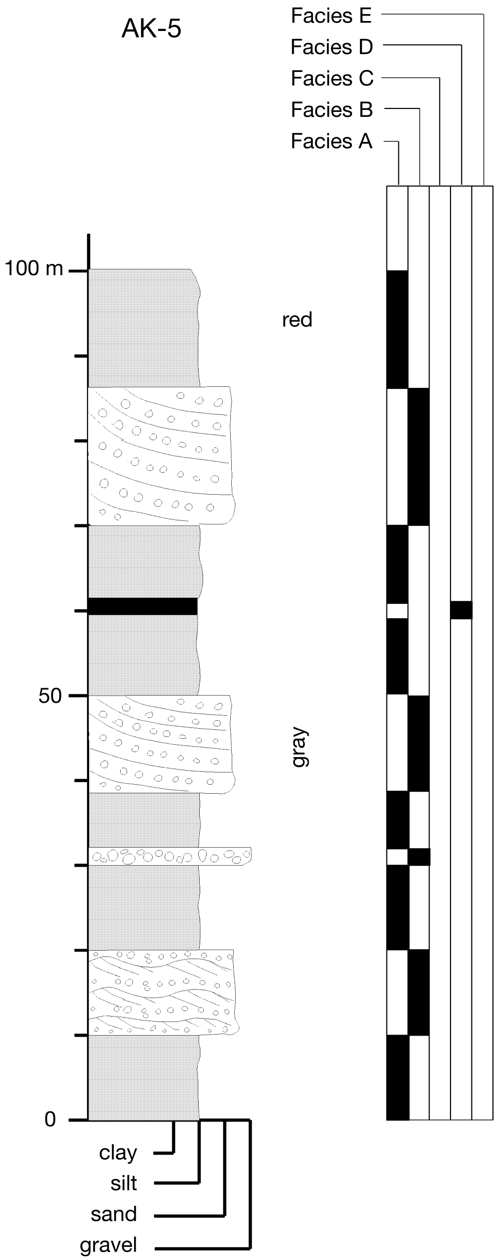


FIG. 6. — Continued.

Previously, these deposits in the study area have been named as Kızılırmak Formation by Birgili *et al.* (1975) inferring late Miocene age and alluvial fan environment for the sediments. However the type locality of the Kızılırmak Fm. is in the central part of the basin, *c.* 100 km further north around Kızılırmak town and the lithology in that locality principally consists of dark red coloured mudstones and sandstones. In order to check the stratigraphy of the study area, the Kızılırmak Formation has been re-studied in its type area near Kızılırmak town and we found significant geological differences between two regions; first, the lithology and sedimentary characteristics of the deposits in this area is totally different from that of Akkaşdağı area, and secondly, the type area deposits yielded late Oligocene mammals (Saraç 2003; Antoine *et al.* pers. comm.). Therefore, it is unlikely that the deposits in both areas belong to the same formation. The stratigraphical outlines of the Akkaşdağı Fm. are as follows:

Type area: a mesa-type hill, Akkaşdağı (Figs 2; 5).

Type section: located north of Akkaşdağı (measured section AK-1; Figs 2; 5; 6) where sedimentary succession represents the lower part of the formation. The upper part of the unit is better exposed near the village Merdanali (measured section AK-5; Figs 2; 6).

Lithology: the lower part of the unit is formed by mudstones intercalated with sandstones, limestones and tuff beds, passing upward to gravely sandstones (Fig. 6).

Thickness: total thickness 280 m of which 150 m represented in the type section (Fig. 6).

Boundaries and age: the unit overlies unconformably the Güvendik Fm. of the late Oligocene and is overlain by Quaternary sediments. The lower part of the unit includes a tuff horizon dated to 7.1 Ma and mammal zone MN 12. Based on these data the lower part of the unit is of late Miocene age at the type locality. There are no radiometric or fossil data from the upper part of the formation that represent nearly half of the sediment sequence. Consequently, it is suggested that the time span of this formation may cover the time interval between the late Miocene-early Pliocene.

QUATERNARY SEDIMENTS

The Quaternary sediments in the mapping area are mainly modern soil, talus and alluvium, and

TABLE 1. — Summary of facies occurrence in the Akkaşdağı Formation.

	Characteristics	Interpretation
Facies A	Multicoloured mudstone, massive and laminated, most commonly red and brown. Bed thickness varies from a few mm to 2 m. Facies A includes individual beds of facies B, gravel lenses, caliche nodules and coal seams. It includes sub-facies Aa and Ab (see text for details).	Sub-facies Aa: distal alluvial fan deposits. Sub-facies Ab: flood plain deposits.
Facies B	Gravely sandstone. Individual beds are 15-150 cm thick with erosional base boundaries. Sandy beds are occasionally intercalated with lense-like gravel beds. Normal grading is usual. Max. clast size is 4 cm. Some beds are cross-stratified and these features form sub-facies Ba-Bc (see text for details).	Fluvial bars.
Facies C	White and yellow limestone. Limestone beds are 30-100 cm thick. Nodular, brecciated and tuffa-type textures are present at different localities. Marl intercalations are common. Freshwater algae are the only fossils found in these limestones.	Freshwater lacustrine carbonates.
Facies D	Laminated claystone, mostly associated with facies B. The facies colour is bluish green, including plant debris and coal seams.	Lacustrine muds.
Facies E	Tuffs, white coloured and fine-grained. Some lithic clasts (dmax. = 3 cm) are randomly scattered. The thickest bed is 5-7 m and lower part of this bed includes gas-escape pipes. Mammal fossils have been discovered just above this unit.	Pyroclastic flow deposits.

only the latter could be presented on the Figure 2. Probably due to a low relief, semi-arid climate and ephemeral streams, the recent deposits are limited (max. 15 m thick) and mostly Holocene in age.

SEDIMENTOLOGY

Sedimentary characteristics of late Miocene deposits, i.e. the fossiliferous Akkaşdağı Fm., are presented here by using facies analysis method of Miall (1984). The sedimentary succession in the Akkaşdağı Fm. is dominantly composed of mudstones, limestones and sandstones with subordinate amount of conglomerates and tuff. Mudstones occur throughout the study area whereas tuffs and limestones are well exposed to the southern part (Akkaşdağı and Değirmenözü, sections AK-1, 2) while sandstones and conglomerates occur mainly in the northern part of the study area (Merdanali, section AK-5) (Figs 2; 4; 6). Five facies and sub-facies (A to E) and four facies associations (I to IV) were distinguished within the late Miocene sediment succession. They are described below in order of their relative abundance (Table 1).

Facies A: mudstones

This is the most common or "host" facies and it forms nearly 3/5 of the whole succession studied (Table 1; Fig. 6). Two sub-facies are differentiated.

Massive mudstones (Aa). This sub-facies forms the main sediments of facies A. Massive and thick beds up to 2 m are the distinguished sedimentary features. Colour of the sub-facies is red or yellowish red. Because of broad lateral extent, it includes different features in places such as pedogenic caliches, granules and pebbles up to 15 cm irregularly scattered, and gravel lenses. Abundance of the coarse-grained sediments increases towards the end of extent, particularly in the east-southeast of the study area. XRD analyses displayed that the main clay mineral of the mudstones is montmorillonite. Fine particles of quartz and feldspar are also abundant in the composition. Such massive and red mudstone facies are interpreted as having been deposited in environments of distal alluvial fans (Miall 1977; De Feyter & Molenaar 1984). Pedogenic caliche layers may indicate that climate was generally arid during deposition of the facies sediment (Kraus & Bowen 1993; Kraus 1997).

FIG. 7. — Close-up of the facies B (sandstones) at a road cut near Merdanali village (between 70-87 m of section AK-5; see Figure 6). Some beds of the facies are unconsolidated and cross-stratified. Dark dots on the exposure are nest holes of birds.

Laminated mudstones (Ab). This sub-facies is characterized by laminated and 15-60 cm thick beds of mudstones. Laminae are commonly continuous and parallel. Facies colour is dark red and brown. The sub-facies includes thin coal layers, coalified plant debris and rare, 2-15 cm thick sandstone-siltstone beds. Most of the sandstone beds are homogeneous but some are planar cross-laminated with foresets inclined towards the south. The sub-facies occurred abundantly in the north-northeastern part of the study area (Figs 2; 6). Such laminated mudstone facies are commonly deposited in flood plain environments (Flores 1981, 1984). Presence of silty and sandy beds within laminated mudstones suggests association of overbank and crevasse splay deposits such a floodplain environment (cf. Bridges 2003). It is clear that depositional environment of sub-facies Ab excludes that of sub-facies Aa, however sediments of both are mainly mudstone. These two sub-facies are included into different facies associations (see below).

Facies B: gravely sandstones

This facies is particularly common in the Merdanali section (AK-5; Figs 2; 6), in addition to thinner sandstone beds hosted in laminated mudstones of facies Ab. The facies B is composed of loose or compacted clay-free sandstones. Colour varies from grey to brown depending on weathering. The individual bed thickness is 15-100 cm and they are nearly horizontal (Fig. 7). Maximum and mean grain sizes are 4 cm and 0.3 mm respectively. Normal grading is a common feature apart from cross stratification. Mineralogically, they are composed of quartz and feldspar and lithic grains. Petrographically, sediments of the facies are arkose with carbonate cement and arkosic wacke (Folk 1974). Three sub-facies can be defined according to the bedding type (Table 1):

Planar cross-bedded sandstones (Ba). They form major beds within facies B. Their bases are generally erosive. Bed thickness is between 15 and

30 cm with apparent dips of 10-12°, with foreset 5-8 mm thick (Fig. 7). Foreset dips are generally towards the south. Beds are generally cut by 10-20 cm thick gravel sheets. Such gravely sandstones are formed commonly by lateral migration of bedforms (Rust 1978). Planar cross beds and clay-free texture are common in sandy longitudinal or lingoid fluvial bars (Miall 1977; Rust 1978) or transversal bars in riverine systems (Todd 1996).

Trough cross-bedded sandstones (Bb). They are not as common as the previous one within facies B, although they are the most common structures encountered in the Merdanali section (Figs 6; 7). Lithology, texture and other characteristics are the same as in other sub-facies except for stratification type. Lateral continuity of troughs is limited to a few meters and trough depths are between 25-55 cm. Inverse grading also occurs occasionally. These features are typical for fluvial channel-fills or scours (cf. Miall 1977; Tyler & Ethridge 1983). A turtle full carapace (*c.* 75 cm) was found within beds of this sub-facies.

Homogeneous sandstones (Bc). It occurs in the middle part of the upper Miocene succession as relatively thick (0.5-2.5 m), compacted and massive multi-storey sandstones. Individual thinner beds of this sub-facies are also accompanied with sediments of sub-facies Ab. Base boundaries are erosive to non-erosive. Individual bed thickness is 25 to 45 cm; bed surfaces are parallel with a lateral extent of several tens of meters. Mean grain size is medium sand. Gravel grains are scattered irregularly and sorting is very poor when their abundance reaches up to 10% volumetrically within the sub-facies. Grading is rarely visible. Lithology may change from arkose or arkosic wacke to lithic wacke. The content of ferric oxides and carbonate is much more than that of sandstones of sub-facies Ba and Bb. Lateral extent of beds and presence of clay particles in the texture may indicate that this sub-facies has been deposited as sand sheets in flood plain environments (cf. Rust 1978; Todd 1989; Maizels 1993).

Facies C: limestones

This facies is found typically at Akkaşdağı sections and Killik Tepe section as two and four separate beds (units) respectively (Figs 5; 6). The thickness of individual units is between 5 and 30 m (Table 1; Fig. 8), and the lateral thickness change is not significant. The aerial position of the limestone beds is close to horizontal or dipped to N-NW with maximum 5°. The facies colour is generally grey, grey white and sometime yellow as a result of alteration. It is thickly bedded (30-100 cm). Mezoscopically it has a nodular and brecciated appearance and locally it has gained a structure of caliche or calcrete (Fig. 8). The latter occurs as a few tens of centimetre layers within the facies beds. In places the facies beds are intercalated with marl laminae. Texturally, this facies is composed of micrites and/or carbonate mudstones. Microcracks and dissolution vugs are the only prominent features. Apart from freshwater algae, it does not contain any biogenic remain.

Facies C represents freshwater lacustrine carbonates. Thick bedding, marl intercalations, muddy texture, nodular structures and fossil free lithology indicate that they have been deposited in shallow (< 10 m deep), freshwater lakes (e.g., Platt & Wright 1991). Calcretes here are not primary pedogenic features (cf. Tucker & Wright 1990). They probably represent pseudo-calcretes resulted from exposure of the soft lake sediments when water level dropped.

Facies D: laminated claystones

This facies is the least abundant in the sections studied. It occurred immediately below the tuff and some limestone facies units as thin layers (10 to 40 cm thick) and also as two 0.5 m and 1.5 m thick beds in the upper part of the sediment succession (Figs 6; 9A). These thick claystone beds include thin iron oxide layers and nodules probably produced as a result of weathering. The laminated claystone is generally green or green grey in colour and coal seams and tuff laminae are interbedded within this facies. XRD analyses indicate that claystone is composed of illite- and smectite-type clay minerals.

The laminated nature and coal seams of the unit together with their occurrence with limestones, show that these clays were laid down into watery areas. Generally it can be assumed that clays

FIG. 8. — **A**, contact between facies C (limestone) and D (claystone) beds, hammer is 35 cm for scale; **B**, thick bedded and travertine-like texture of the limestones, lens cap in the circle is scale; **C**, horizontal field position of limestones covered by red mudstones of facies A at Killik Tepe (measured section AK-3); **D**, thin bedded and nodular natures of the limestones, hammer is 35 cm for scale.

accumulated in lake margin plains, ponds or ephemeral lakes (Hardie *et al.* 1978).

Facies E: tuffs

Tuffs occur in the lower parts of the Akkaşdağı sections 2 and 3. This facies appears as a massive, 5-7 m thick bed/unit only at one locality, the areal position of which is 80°W, 10°N (Figs 4; 5). It is supposed that it is dealt with the dip of strata and topography of the area. Tuff bed is easy to recognize in the section since its colour is white and it forms distinct edges that stick out from the

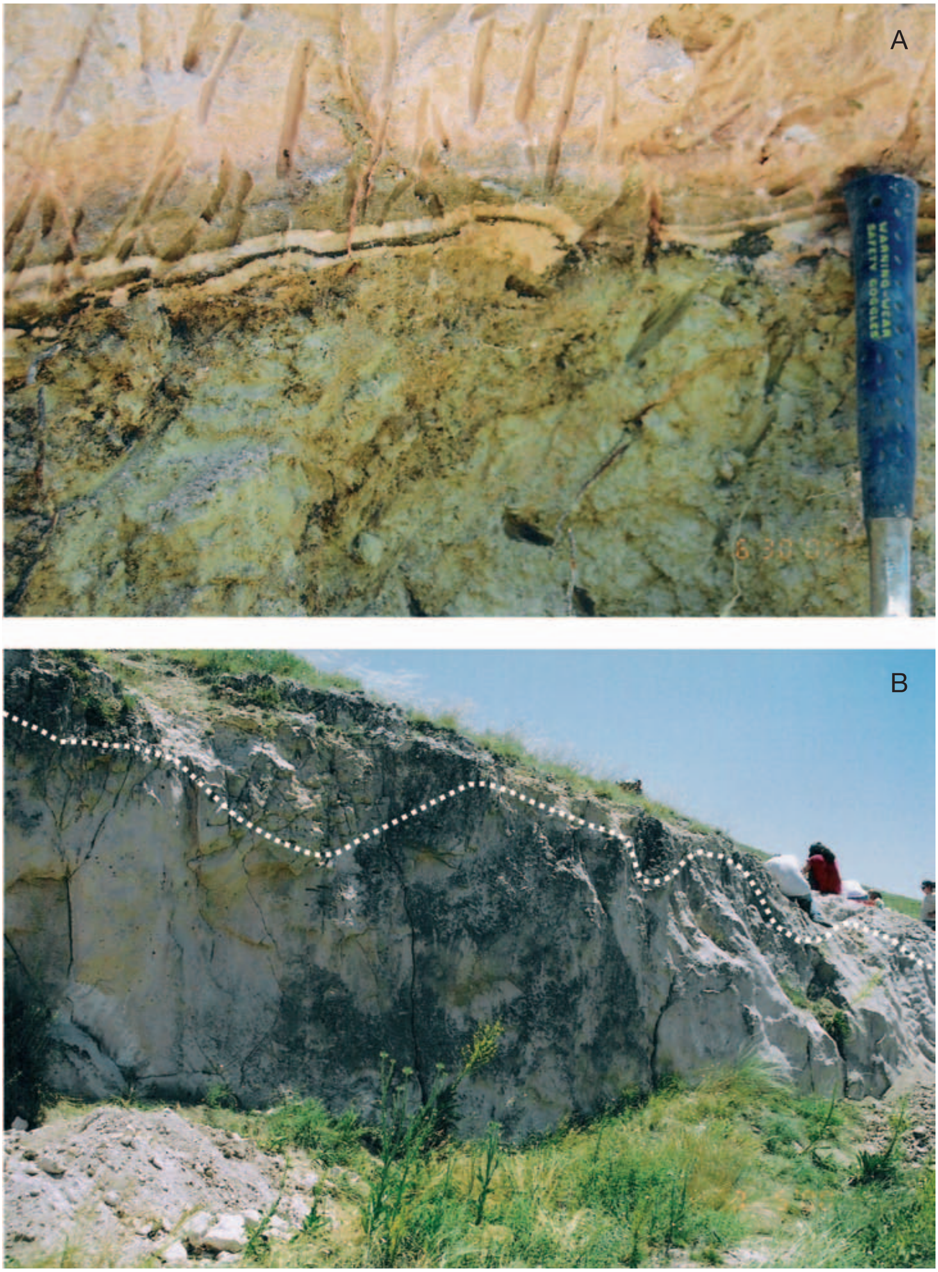


FIG. 9. — Facies E (tuff); **A**, sharp base boundary of the facies with claystones at measured section AK-1, scours are artificial; **B**, the massive nature of the tuff, the uppermost 1 m layer (dashed) contains mammal fossils. Picture is from AK-2. Geologists at right are digging for fossils. Scale: A, visible part of the hammer is 30 cm.

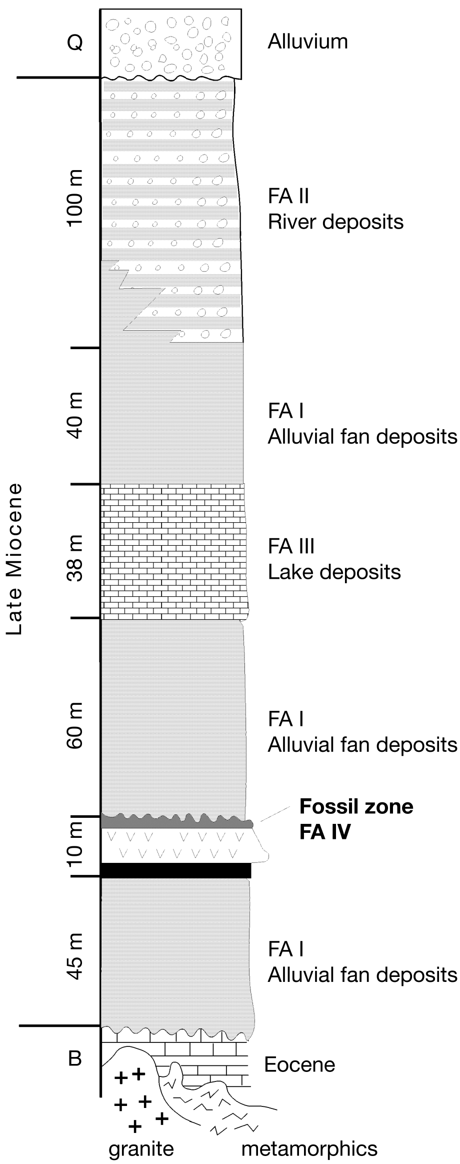


FIG. 10. — A generalized vertical arrangement of facies associations (FA) through the Akkaşdağı Formation (280 m thick), note the upper part is made up by river deposits. Abbreviations: **B**, bedrocks; **Q**, Quaternary.

outcrops. The base boundary of the tuff unit is rarely exposed due to modern soil and plant cover. However, at one site in section 2 the base boundary is sharp whereas its upper boundary is sharp and locally uneven (Fig. 9). The basal, 45 cm thick layer of this unit is pink which changes gradationally into white colour upward. Texturally, the facies could be separated into two parts. The lower part, *c.* 5 m is massive and fine-grained glassy tuffs consisting of vitric material (80-90%) and lithic clasts (10-20%). Crystals are nearly absent. Lithic clasts (max. 3 cm) are mostly pumice and to a lesser extent andesitic rock fragments, and all lithic clasts are concentrated at the base. Some vertical veins with full of red coloured sand or fine gravel size lithic clasts (0.1 to 8 mm) cut the tuff bed. The veins are of millimetric scale at the base but they become bigger up to 8-10 mm towards the middle part of the unit. It is noteworthy that these veins are seen only around the fossil site near Gökeşme village (Figs 5; 9). Such veins are interpreted here as gas escape pipes formed during the hot and rapid emplacement of pyroclastic flows (cf. Cas & Wright 1988). A thermally altered *c.* 15 cm thick mud layer below the tuff is observed at the measured section AK-1 (Figs 5; 9). Moreover, the pink layer at the base probably resulted from oxidation of ferric elements in tuffs during the hot emplacement (Fischer & Schimincke 1984).

The second, uppermost *c.* 1 m thick part of the facies is rather different from the lower part; it is deformed by bioturbation and oxidation, even though the boundary between the two parts of the facies is not sharp. The colour in the upper part changes from white to grey and to reddish grey, most probably due to moderate pedogenesis and presence of organic matter. This part also includes vertebrate, abundant mammal bones scattered randomly or appears as clusters (Fig. 5). Lithology of this facies part includes rare non-volcanic particles and under the microscope it is seen as tuffite probably as a result of the bioturbation.

The absence of a distinct bedding boundary between these two parts suggests that the whole tuff sequence was laid down as a result of only one flow. After the emplacement, the upper 1 m was bioturbated or deformed by mammals. Geochemical analysis shows that composition of facies E as a whole is rhyolitic, indicating a probable relationship with the Central Anatolian volcanic province (Karadenizli *et al.* 2005).

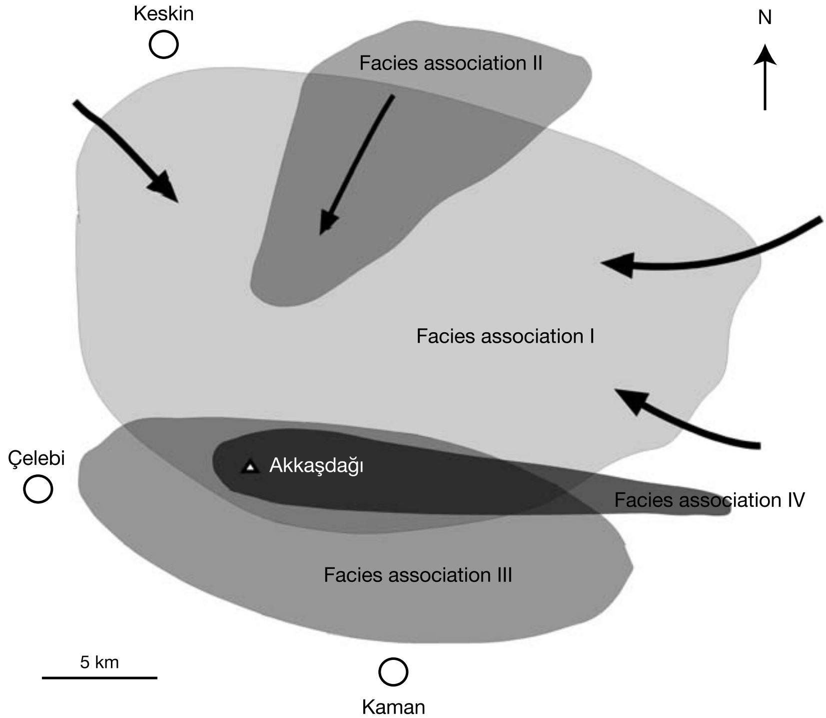


FIG. 11. — Areal distribution of the facies associations, to be compared with Figure 2. Lacustrine deposits (facies association III) are very close to the bedrock in the south. Arrows show possible sediment transport directions.

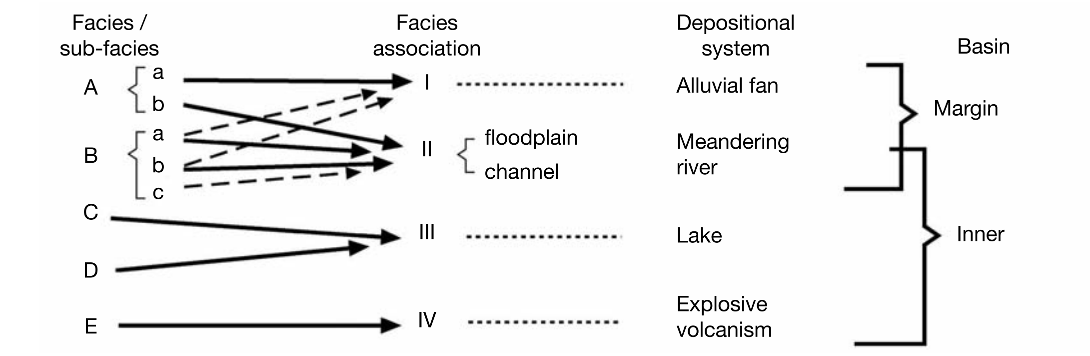
FACIES ASSOCIATIONS

A facies association is an assemblage of lithologies of one or more facies that originate from the same or similar depositional environments and so it represents a depositional system of a sedimentary basin (Miall 1978, 1984). Based on this definition, the described facies within the Akkaşdağı Formation could be compiled into four associations (Table 2). However, close spatial connections of facies of each association provided stratigraphical unit-appearance for associations (Figs 6; 10). They are briefly presented below in order of abundance in the succession.

Facies association I: alluvial fan deposits

This association mainly consists of sandy but massive mudstones (sub-facies Aa) and some individual beds of gravelly sandstones (sub-facies Bb) (Table 2). It forms nearly 3/5 of the sediment succession (Figs 6; 10). Such thick and widespread mudstone-dominated sequences are generally found at distal parts of alluvial fans (cf. Collinson 1996; Miall 1996). However, coarse-grained sediments in an alluvial-fan system represent deposition in environments close to margins of the basin; in our case gravely deposits are seldom and distributed irregularly in muddy deposits (see facies description). Caliche or carbonate nodules in mudstones present that deposition ceased from time to time, and climate was fairly arid during these periods (cf. Nami & Leeder 1978; Miall 1996). The possible muddy alluvial plains existed in or next to the centre of the basin, but the sediment of association I was derived from alluvial fans entered into the basin from different directions, possibly from the east and southeast based on relative abundance of coarse material (see above). In the relevant literature, depositional alluvial plains that are far away from the basin margins are called as "terminal

TABLE 2. — Facies associations in the Akkaşdağı Formation and related possible depositional systems of the southern Çankırı-Çorum Basin.



fans" (Mukherji 1976; Friend 1978; Parkash *et al.* 1983; Kelly & Olsen 1993).

Facies association II: fluvial deposits
It includes two sub-associations. The first one is mainly composed of laminated mudstones (sub-facies Ab) and to a lesser extent sandy deposits of sub-facies Bc, and together they form a flood-plain sub-association (Table 2). Thin coal seams and coal debris in this sub-association show that the depositional environment included plants. Plants are usual occurrences of ponds and marshes of a floodplain, and they may be preserved as thin coal layers and plant fragments in these palaeoenvironments (Flores 1984; Miall 1988). The second one is a channel sub-association that consists of rich sandstones (facies B, sub-facies Ba-c) and a few thin beds of laminated mudstones (sub-facies Ab) (Table 2). This sub-association is hosted in the previous muddy sub-association, forming sandy units (Fig. 7). The lower boundaries of these units are erosive but the upper ones are transitional. The facies of this sub-association represents clearly fluvial channel environments, although similar formations could be observed in medial part of alluvial fans (cf. Stanistreet & McCarthy 1993; Collinson 1996; Miall 1996). The fluvial channels might belong to meandering rivers, however epsilon cross-bedding that reflect the point bars of such streams could not find in the studied sections. Intercalations of channel and floodplain sub-associations present a fluvial system placed in the northeastern part of the study area and water flowing in this system was most probably from north to south, towards the basin centre (Fig. 11).

Facies association III: lacustrine deposits
This association is composed by limestones (facies C) and laminated clays (facies D) and represents a lake environment (Table 2). Massive to stratified nature of limestones and lack of evaporitic formation indicate that lake was open and non-saline. Diagenetic brecciation and absence of macrofossil may be referred to shallow water depth (< 10 m) and to its ephemeral character (Platt & Wright 1991; Alonso-Zarza *et al.* 1992). Massive mudstones could be found in mudflats or in muddy lake deposits (cf. Hardie *et al.* 1978). Laminated clays and signs of weathering in lake sediments may also indicate a muddy lake flat which was subject to pedogenesis (cf. Platt 1989).

Facies association IV: pyroclastic flows
This is a small but an important association due to its volcanic origin. It consists of tuffs of the facies E (Table 2). Its texture and structure indicate a close source and pyroclastic hot flow settlement, which suggests an explosive volcanism in or near the basin, although any eruption centre could not be detected in the basin during the study.

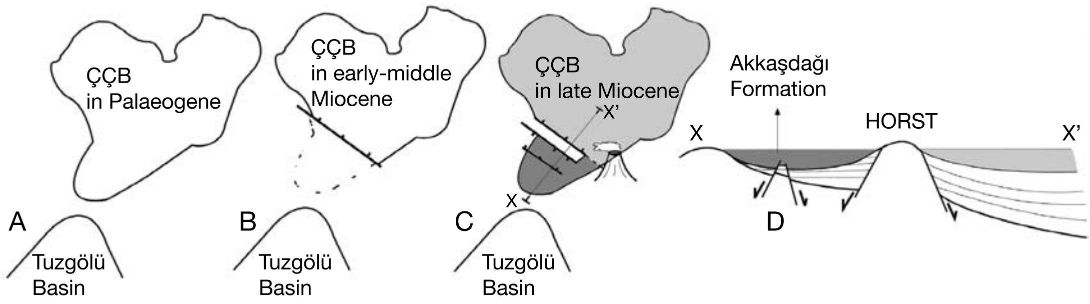


FIG. 12. — Geological evolution of the southern part of the Çankırı-Çorum Basin (ÇÇB); **A**, the large ÇÇB in Palaeogene (see Figure 1 for location); **B**, the southern part uplifted and the ÇÇB was diminished during early-middle Miocene; **C**, because of a horst-graben system, a sub-basin in which the Akkaşdağı Formation began to form developed in late Miocene, X-X' is section line; **D**, a cross section (X-X') for positions of the sub-basin and the main ÇÇB. Figure not to scale.

VERTICAL AND LATERAL DISTRIBUTIONS OF THE FACIES AND FACIES ASSOCIATIONS

Together with measured sections, detailed field observations during the mapping provided reliable data on the extent and spatial relationships between individual facies and facies associations in the study area (Fig. 6). Tuffs of facies E and limestones of facies C were the key horizons for correlations (Figs 4; 8C). Figures 10 and 11 show the stratigraphic and aerial distributions of the associations respectively. Basal boundaries of association are commonly sharp but they do not represent any stratigraphic discordance. The host character of the deposits of association I is typical in vertical distribution while those of association II are the youngest part of the succession (Fig. 10). In addition, they are partly interfingered each other in-between Ceritobasi-Besler villages (Figs 2; 10; 11). Association I occurs everywhere but typically in the south and north of the lines Ceritkale-Cebrali-Kasımağa and Kaman-Çelebi respectively (Fig. 11). Along these lines topography is higher presently and bedrock is exposed (Figs 2; 11). Association II was commonly encountered in the north while association III in the south of the study area. The latter, carbonates of association III form two sub-units, and they are interbedded with massive mudstones of association I (Fig. 6). Such a vertical position of an association indicates that the depositional lake environment was rejuvenated. Associations II and III are not met aerially and spatially probably due to basinal evolution in time (Figs 10; 11). Association IV is seen only in the middle part of the study area, typically at Akkaşdağı (Figs 2; 11). The limited extent of this association maybe resulted from local palaeotopography. Three associations (I, III and IV) form a succession in this locality where the type section of the Akkaşdağı Formation was measured (see above). Toward the further south, the oldest deposits that cover the basement are the younger unit of lacustrine carbonates of association III. In other words, the lower half part of the succession is missing in the south margin. The bedrock (metamorphics, granites and Eocene limestones) is overlain directly by the younger deposits of Akkaşdağı Fm. (carbonates of association III) in the region of Çelebi-Karkınselimağa and Bayındır villages (Figs 2; 11). This may indicate that the lake environment, relatively deepest part of the basin, moved towards the south in time. Later on, however, terminal alluvial fans re-occupied the area. This depocentre migration maybe resulted from syn-depositional tectonism that gave rise to progressive enlargement of the basin, even though this interpretation is open to debate (Fig. 12).

DISCUSSION AND CONCLUSIONS

The study area covers the southern end of the main Tertiary Çankırı-Çorum Basin (ÇÇB)

(Fig. 1). Three lithostratigraphic units of the infill of ÇÇB, Delicеırmak Fm. of the middle Eocene, Güvendik Fm. of the late Oligocene and Akkaşdağı Fm. of the late Miocene are exposed there, however, the latter being aerially predominated (Figs 2; 3). The Akkaşdağı Formation has been described in this study instead of the Kızılırmak Formation of Birgili *et al.* (1975) due to both lithological and stratigraphic discrepancies between the study site and type locality of the former unit. Recent studies have already indicated that Kızılırmak Fm. included a rich late Oligocene fauna (Saraç 2003; Antoine *et al.* pers. comm.). The Akkaşdağı Fm. on which the present study is focused on is *c.* 280 m thick and it overlies previous units and the metamorphic bedrock horizontally or with a 5-10° dip towards the north, while the first two units of the ÇÇB were folded (Figs 5; 7; 8C). The late Miocene age is attributed to the Akkaşdağı Formation due to the presence of a rich mammalian assemblage of zone MN12 and an isotopic dating of 7.1 Ma from the tuffs (Kazancı *et al.* 1999; Karadenizli *et al.* 2005). The relatively slight deformation of this formation, combined with an unconformity between Akkaşdağı Formation and previous units, may indicate that the southern part of the main ÇÇB was re-formed as a continental sub-basin in the beginning of late Miocene (Fig. 12). Three local horsts occured in the Neogene in the northern part of the study area (Seyitoğlu *et al.* 2005) might be a reason for this basin formation. What is more, sub-basin development in the ÇÇB is not unusual. Its northern and central parts were also divided by palaeohighs during early late Miocene resulting various sequences (Karadenizli & Kazancı 2000). It is noteworthy to know that middle Miocene was already tectonically active time period of Anatolia and the neighbour Tuzgölü Basin was also deformed by an overthrusting during the same time (Görür *et al.* 1984, 1998).

The Akkaşdağı Fm. includes seven lithofacies and four facies associations each of them representing a depositional system. They are alluvial fan (FA I), fluvial (FA II), lacustrine (FA III) and pyroclastic (FA IV) deposits (Figs 6-10; Tables 1; 2). The last two associations are relatively localized, however, the FA I is the host and most extensive deposits of the basin-fill (Figs 6; 10; 11). The association FA I was deposited in terminal and/or distal alluvial fans, mostly derived from source rocks in the east-southeast and in the northwest to the depositional basin (Figs 11; 12). Presence of caliche, paleosol, and mammal fossils in sediments of the association FA I in addition to two other associations (FA III and IV) suggests a relatively slow deposition in the alluvial fans. However, the development of such relatively thick, muddy distal fan deposits require a tectonic control (Mukherji 1976; Parkash *et al.* 1983; Miall 1996). Deposition in terminal fans ceased from time to time, and apart from emplacement of a pyroclastic flow (FA IV), at least three lacustrine phases had been formed in the south central part of the sub-basin (Figs 10; 11). These phases produced the carbonates and lacustrine mudstones of association III. Lack of any evaporatic sediment within these deposits, contrary to infills of the main ÇÇB and Tuzgölü Basin, indicates that lakes of the sub-basin were open, mostly freshwater environments. It was connected most probably to the main ÇÇB and also Tuzgolü Basin, because lake environments and the depocentre of the sub-basin were very close to both the main ÇÇB and to the northern margin of the mentioned basin (Figs 1; 11; 12).

An explosive volcanism became active in the beginning of the late Miocene in or near the sub-basin. The volcanic source area situated not far from the depositional centre of the sub-basin, and it is therefore possible that volcanic material erupted spread (FA IV) into a limited area around the volcanic source due to flat and/or convex palaeomorphology (Figs 2; 11; 12).

A fluvial system of meandering rivers and floodplains occurred in the final stage (early Pliocene) of the sub-basin. It produced facies association IV, the youngest part of the basin fill (Fig. 10). Water flowing in this system was dominantly from the northeast to southwest while previous alluvial fans prograded toward the west (Figs 11; 12). Possible change of the basin bottom topography could be the result of synsedimentary tectonism in early Pliocene, although it is open to debate.

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