Structural Evolution of the Tuzgölü Basin in Central Anatolia, Turkey

İbrahim Çemen, M. Cemal Göncüoglu,[1] *and Kadir Dirik*[1]

Oklahoma State University, Stillwater, Oklahoma 74078, U.S.A.
(*e-mail: icemen@okstate.edu*)

ABSTRACT

The Central Anatolian segment of the Alpine-Himalayan orogen contains "interior" basins, the largest of which is the Tuzgölü (Salt Lake) basin (>20,000 km^2). It is bounded on the east by the Tuzgölü (Salt Lake) fault zone and on the west by the Yeniceoba and Cihanbeyli fault zones. Structural, stratigraphic, and sedimentologic evidence suggests that the Tuzgölü basin started as a fault-controlled basin during late Maastrichtian tectonism when the present-day northwest-trending faults that bound the basin were initiated. These faults may have been formed as normal faults suggesting extension or strike-slip faults with a normal component of movement indicating a large transtension at the time of their initiation. The late Maastrichtian faults were reactivated as strike-slip faults in response to late Eocene compression in the region that produced the Central Anatolian thrust belt to the north and the late Eocene south-dipping thrust faults of the Ulukişla basin to the south. This reactivation is suggested by structurally repeated and missing Paleocene-Eocene deposits in some of the basin's wildcat wells. The late Eocene regression in the Tuzgölü basin was caused by the combined effects of Eocene shortening and a large environmental change. Late Eocene evaporites suggest that the basin was dry before the start of the Neotectonic period, while during the Neotectonic itself the Tuzgölü fault zone was reactivated again, predominantly as a normal fault with a right-lateral strike-slip component. This is evidenced by (1) a major unconformity between the post-Eocene Koçhisar Formation of the Tuzgölü basin and the underlying Eocene rock units; (2) a well-developed rollover anticline observed on seismic reflection profiles; and (3) a right-step along the Tuzgölü fault zone seen in the field.

Introduction

Central Anatolia contains many intracontinental basins bordered by the Pontides to the north and the Taurides to the south (fig. 1). The Tuzgölü (Salt Lake) basin is the biggest and perhaps the most typical of these. It is bounded by the Tuzgölü fault zone to the east and by the Yeniceoba and Cihanbeyli fault zones to the west (figs. 1, 2). Its northern boundary is the İzmir-Ankara suture zone and associated structures to the north of the town of Haymana, and its southern boundary is the folded and faulted rocks of the Ulukişla basin.

The Tuzgölü basin (fig. 1) has been the subject of numerous studies. Work from the 1960s to the early 1980s (Rigo de Righi and Cortesini 1959; Yüksel 1970; Arikan 1975; Ünalan et al. 1976; Görür and Derman 1978; Derman 1980; Dinçer 1982; Oktay 1982; Uygun et al. 1982) concentrated on the stratigraphy and sedimentology of the basin and examined an approximately 5-km-thick sedimentary succession deposited from the late Maastrichtian to the present. Many of these studies considered the basin an "interior" basin and proposed that sedimentation was interrupted by regression and resumed by transgression from the late Maastrichtian to the Recent.

During the 1980s, field-oriented research, together with the interpretation of available subsurface data in certain parts of the basin, provided a better understanding of the tectonic framework of Central Anatolia and surrounding regions with respect to evolution of the Tethys Ocean (Şengör and Yilmaz 1981; Görür et al. 1984; Robertson and Dixon 1984; Şengör et al. 1985; Göncüoglu 1986; Göncüoglu et al. 1991, 1992). Görür et al. (1984) first interpreted the origin of the Tuzgölü basin in terms of the plate tectonic settings of Anatolia and surrounding regions. They suggested that an ocean, named the Intra-Tauride Ocean, started to form as early as the Jurassic and separated the Tauride-Anatolide platform into two blocks, the Kirşehir block

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[1] Middle East Technical University, Ankara 06530, Turkey.

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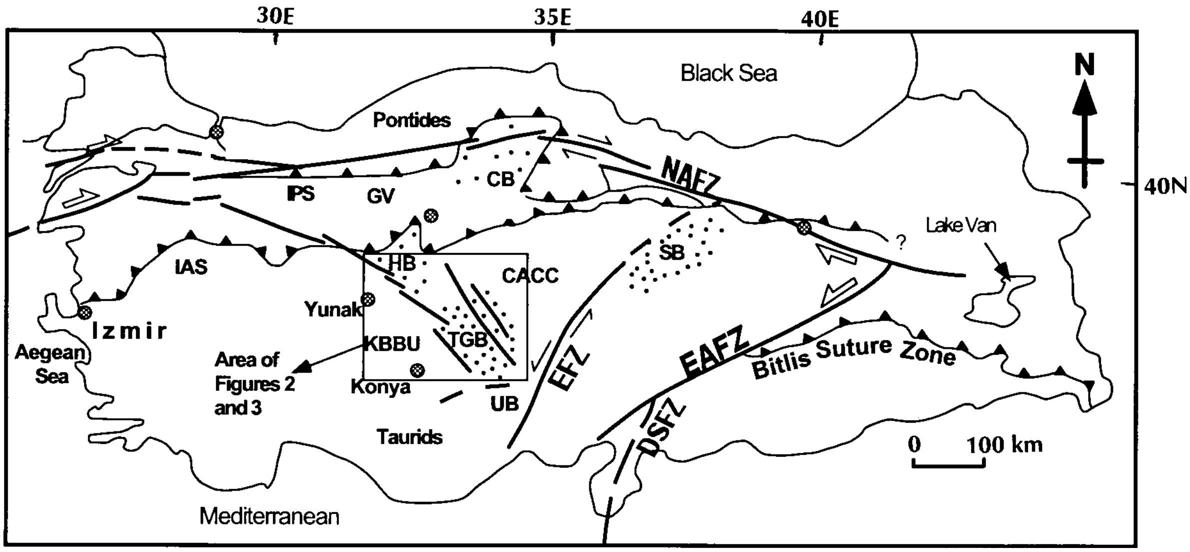

Figure 1. Index map showing major basins and tectonic elements of Central Anatolia. *A* = Ankara; *CACC* = Central Anatolian Crystalline Complex; *CB* = Cankiri basin; *EAFZ* = East Anatolian fault zone; *EFZ* = Ecemis fault zone; *DSFZ* = Dead Sea fault zone; *GV* = Galatian Volcanics; *BB* = Haymana basin; *IAS* = İzmir-Ankara suture zone; *IPS* = Intrapontide suture zone; *KBBU* = Kütahya-Bolkardaği belt units; *UB* = Ulukisla basin; *SB* = Sivas basin; *TGB* = Tuzgölü basin.

to the east and the Menderes-Tauride block to the west. They also suggested that the ocean started to close as a result of a northeast-dipping subduction zone southwest of the Kirşehir block during the Paleocene. By the early Miocene, the closure of the ocean was complete and the Central Anatolian suture zone was formed. Within this tectonic framework, they interpreted the Late Cretaceous to Eocene sedimentary rocks in the Tuzgölü region as deposited in a forearc basin.

The Paleozoic to Late Cretaceous basement rocks of the region have been extensively studied by Göncüoglu (1986), Göncüoglu et al. (1991, 1992, 1993), Akiman et al. (1993), and Türeli et al. (1993), in terms of their original lithologies, degrees of metamorphism, and tectonic settings. Cemen and Dirik (1992) and Çemen et al. (1995) suggested that the Tuzgölü basin may have been formed as an extensional basin over the pre-Maastrichtian basement rocks of the region. Göncüoglu et al. (1991, 1992) interpreted the Central Kizilirmak and Ulukişla basins as extensional basins formed on the southward-migrating ophiolites of the İzmir-Ankara suture zone.

Most of the geological studies of the Tuzgölü basin were conducted because of its oil and gas potential, although to date, no commercial oil or gas has been produced in the basin. However, the basin has several reservoir quality sandstone and limestone units, and the Paleocene to Eocene shale units are considered good quality source rock (Görür and Derman 1978; Dinçer 1982; Dellaloglu and Aksu 1984).

The main purpose of this article is to discuss the structural evolution of the Tuzgölü basin. We will briefly describe (1) the nature and origin of the Paleozoic-Mesozoic basement rocks; (2) the stratigraphy and sedimentology of the Late Maastrichtian to Recent sedimentary succession overlying the basement; and (3) the geometry and structural evolution of the major fault zones that have controlled the sedimentation in the basin. Finally, we also propose a structural evolution model for the basin from the Late Cretaceous to the present.

Following Görür et al. (1984), we consider that the Tuzgölü basin consists of two subbasins, Haymana and Tuzgölü, that evolved independently during the Late Cretaceous to the Eocene. The two basins have been integrated into one basin since the end of Eocene. When we discuss the Late Cretaceous to Eocene rock units and geologic events, we use the term "Tuzgölü basin complex" for the two subbasins together and the term Tuzgölü basin for the Tuzgölü subbasin only. For the post-Eocene rock units and geologic events, we use the term "Tuzgölü basin" for the entire Tuzgölü basin complex.

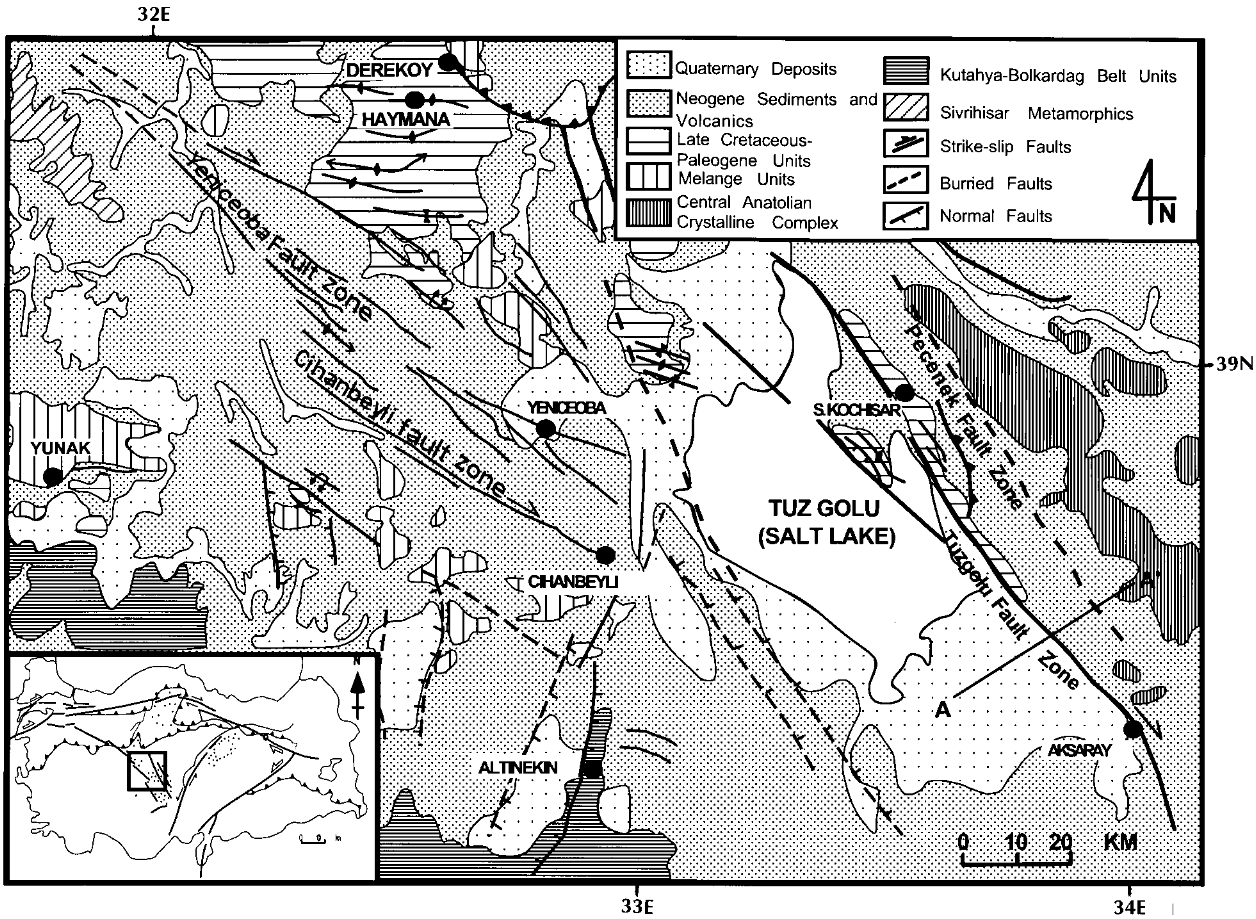

Figure 2. Generalized geologic map showing major rock units and structural features of the Tuzgölü basin and surrounding areas. Line *A-A′* shows approximate location of the seismic profile in figure 7.

Stratigraphy

The sedimentary succession of the Tuzgölü basin unconformably overlies the Paleozoic to pre–late Maastrichtian igneous-metamorphic basement rocks on the eastern and western side of the basin. Based on a seismic refraction study, Gurbuz and Evans (1991) concluded that metasedimentary rocks underlie the Tuzgölü basin sedimentary rocks. Several wildcat wells drilled by the Turkish Petroleum Corporation (TPAO) have penetrated the basement rocks. For a detailed discussion on the nature and origin of the basement rocks, see Göncüoglu et al. (1991, 1992, 1993, 1997).

Basement Rocks. The basement rocks exposed along the eastern and western margins of the Tuzgölü basin are named the Central Anatolian Crystalline Complex (Akiman et al. 1993) and the Kütahya-Bolkardaği belt (Özcan et al. 1990), respectively. Göncüoglu et al. (1991, 1992) concluded that these basement rocks are very similar in lithology and age and, therefore, can be correlated. The base of the two sections consists of the same late Paleozoic metaclastics. The overlying thick carbonate section is highly metamorphosed on the east side; its slightly metamorphosed equivalent is present on the west side within the upper part of the Kütahya-Bolkardaği belt. These similarities led Göncüoglu (1986) and Göncüoglu et al. (1991) to suggest that the Tuzgölü basin was formed over the Paleozoic– to Late Cretaceous–age basement rocks. Although their lithologies are similar, there are differences in the basement rocks along the eastern and western margins of the basin: the basement rocks of the eastern margin were metamorphosed to a higher degree than their western counterpart, and the basement rocks of the eastern margin are cut by collisional type granitic rocks (Türeli et al. 1993) and postcollisional alkaline magmatic rocks.

To date, no fossils have been found in the Central

Anatolian metamorphic rocks. The base of the sedimentary succession overlying the basement is latest Maastrichtian in age (Sirel 1996). Detailed petrologic studies suggest that these metamorphic rocks were subjected to medium- to high-grade metamorphism with temperatures locally reaching partial melting conditions (Göncüoglu et al. 1991). Radiometric age determinations (K/Ar, biotite) indicate that metamorphism took place at about 71–75 Ma during early–Late Cretaceous time (Göncüoglu 1986).

Exposed along the northern and northwestern margins of the Tuzgölü basin (figs. 3, 4) are ophiolitic rock units that have been generally interpreted as an obducted accretionary prism material. The ophiolitic rocks were emplaced as thrust sheets over the Central Anatolian Crystalline Complex and Kütahya-Bolkardaği belt units during the closure of the İzmir-Ankara Ocean. The time of emplacement of the accretionary prism is bracketed as post-Turonian to pre–late Maastrichtian in the Central Anatolian Crystalline Complex but middle to late Maastrichtian in the Kütahya-Bolkardaği belt (Göncüoglu et al. 1991). The rocks in this inferred accretionary complex are composed of blocks and clasts of the Kütahya-Bolkardaği belt and some slope facies deposits. The blocks are mostly of ophiolitic slices that had undergone blueschist metamorphism. Blocks derived from suprasubduction zone–type oceanic crust and fragments derived from oceanic island basalts are also present.

Sedimentary Succession. The composite thickness of the Tuzgölü basin sedimentary succession overlying the basement rocks along the basin's eastern and western margins is about 2500 m (fig. 3). Several wildcat wells have penetrated >3500 m without reaching the basement rocks. Wells drilled on structural-high fault blocks penetrated a thin and incomplete sedimentary succession. The base of the sedimentary succession exposed along the

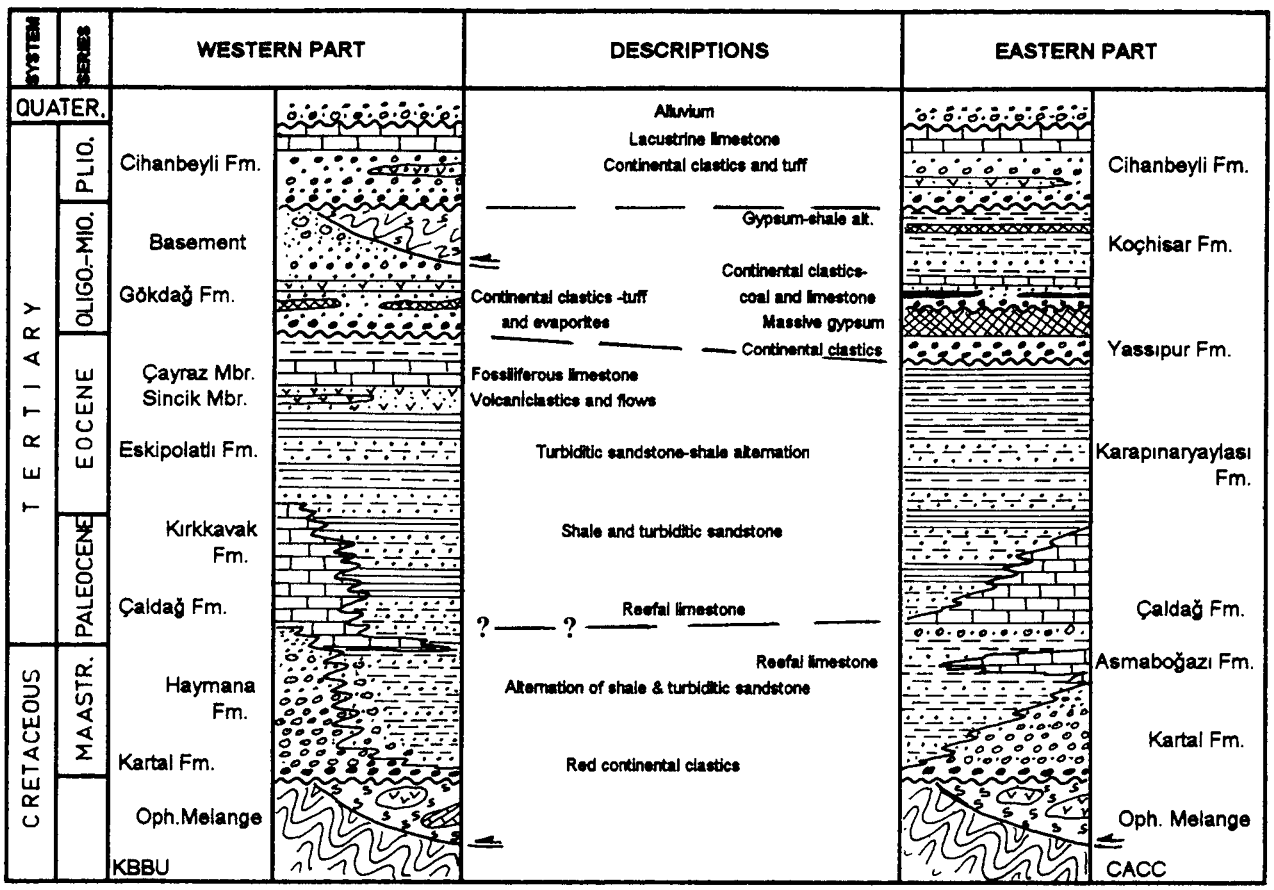

Figure 3. Generalized stratigraphic columns of the sedimentary succession exposed along the eastern and western margins of the Tuzgölü basin. *CACC* = Central Anatolian Crystalline Complex; *KBBU* = Kütahya-Bolkardaği belt units.

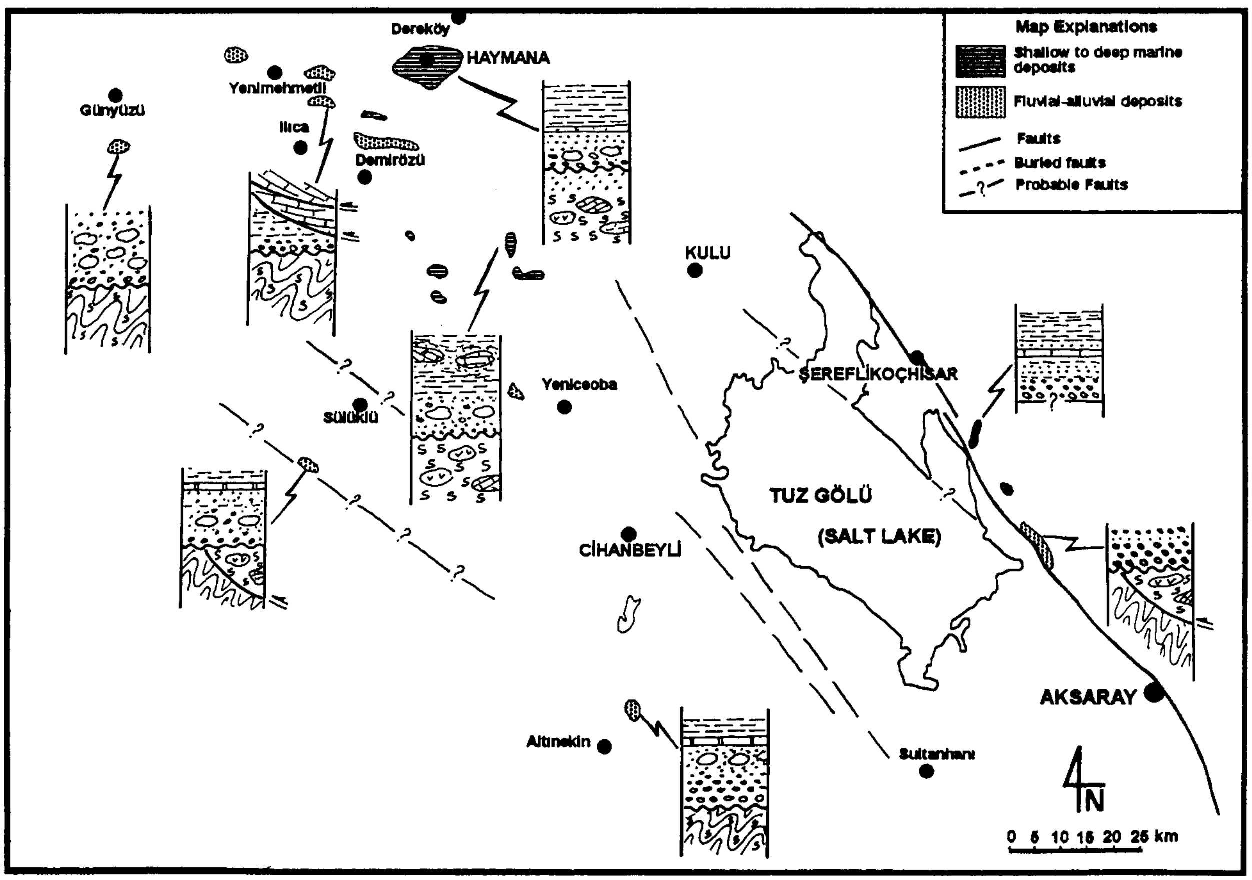

Figure 4. Distribution of Late Cretaceous to Paleogene sedimentary rocks and their simplified columnar sections

basin's eastern and western margins is latest Maastrichtian–early Paleocene in age. Figure 3 is a simplified stratigraphic column showing the rock units exposed along these eastern and western margins and their proposed correlation.

Along the eastern margin, the base of the sedimentary succession is well exposed in several areas north of Aksaray (figs. 3, 4) and contains very poorly sorted red conglomerate and sandstone, with angular to rounded loosely cemented clasts in a red clayey matrix. The angular clasts were derived from the underlying basement rocks and consist of serpentine, gabbro, chert, granite, and metamorphic rock fragments. The matrix is composed of red mudstone and poorly sorted fine- to coarse-grained sandstone. This basal unit has been named the Kartal Formation by previous workers (Rigo de Righi and Cortesin 1959; Ünalan et al. 1976; Görür and Derman 1978; Uygun et al. 1982; Dellaloglu and Aksu 1984; Görür et al. 1984). The Kartal Formation grades laterally and vertically into a limestone unit, the Asmaboğazi Formation (figs. 3, 4), which consists of gray-green, medium- to thick-bedded sandstone, orbitoidal sandstone and sandy limestone in its lower part, and a rudist-bearing (*Hippurites sp.*) reefal limestone in its upper part. The unit grades upward into a medium- to thick-bedded, abundant algae and fossil-bearing limestone unit, usually referred to as the Çaldağ Formation, which contains Upper Paleocene (Tanesian) fossils in its lower part and lower Eocene fossils in its upper part (I. Sezgin, written comm.).

The northwestern margin of the Tuzgölü basin complex within the Haymana subbasin contains a pre–late Maastrichtian section apparently carried with the underlying accretionary complex. Specifically, the ophiolitic basement is overlain by a Late Campanian–early Maastrichtian sedimentary unit of deep marine sedimentary rocks. A conglomerate unit, composed mostly of carbonate rock fragments derived from the Paleozoic to Mesozoic rock units, overlies the marine sediments. The base of the conglomerate contains pebbly conglomerates and calciturbidites grading into olistostromes that, in turn, grade into alternating pelagic red-pink clayey micrite, green marly shale, and turbiditic sandstone. The conglomerate grades laterally and vertically into a typical turbidite sequence composed of a thick shale deposit containing several sandstone bodies. This sequence is referred to as Haymana Formation, which thins southward and overlies the Kütahya-Bolkardaği belt metamorphics.

The Kartal Formation is well exposed at two locations along the western margin of the basin (fig. 4), where it unconformably overlies the basement. At the more southerly of the two exposures, it contains, at its base, red pebble to gravel conglomerate overlying extensively fractured serpentines of the metamorphic basement rocks. The clasts, up to 100 cm in diameter, are radiolarite, pelagic limestone, and, to a lesser extent, syenites. The conglomerate grades into gray clayey limestone interbedded with a pebbly conglomerate containing mostly radiolarite fragments.

The northern outcrop also contains similar lithologies. Its base is a locally derived breccia to conglomerate that contains fragments of the underlying basement rock units. The matrix is carbonate-cemented mudstone and sandstone. Here, the formation also contains evaporites, indicating a dry continental environment. The Kartal Formation of the western margin contains Danien (lower Paleocene) to Tanesian (upper Paleocene) microfossils at the southern exposures and Danien microfossils at the northern outcrop (Sirel 1996). Considering these fossils, the lowermost part of the Kartal Formation must have been deposited earlier than the lower Paleocene; its age can be considered as latest Maastrichtian to upper Paleocene.

The Kartal Formation of the western margin also grades into a limestone unit, the Asmaboğazi Formation, a sandy dolomicrite at its lower part grading into a green interbedded marl-sandstone in its upper part. The Asmaboğazi Formation grades into a light gray to cream, thick-bedded fossiliferous limestone that is the equivalent to the Çaldağ Formation of the eastern margin.

The Asmaboğazi and Çaldağ Formations grade laterally and vertically into a Paleocene-Eocene sandstone, shale, turbiditic sandstone, and limestone interbedded unit along both eastern and western margins of the basin (fig. 3). Along the western margin, this unit is traditionally named the Kirkkavak Formation where it is Paleocene in age but is named the Eskipolatli Formation where it is Eocene in age (Ünalan et al. 1976; Görür and Derman 1978). Along the eastern margin, it is called the Karapinar Yaylasi Formation (Dellaloglu and Aksu 1984). The Paleocene-Eocene clastics cover large areas and are generally composed of alternating sandstone and shale in their lower part; turbiditic sandstone and calciturbidites are common in their middle parts (fig. 3). These formations have varying thicknesses but are>2000 m thick close to the axis of the basin.

Along the eastern margin of the basin, the lower and middle parts of the Paleocene-Eocene formations contain well-developed red-gray to brown, thick-bedded sandstones. In the west, they are mostly composed of interbedded green, highly fossiliferous sandstone-marls. In the east, the upper part of the section contains a coarse-grained sandstone and thick evaporite lenses above an unconformity (e.g., Yassipur Formation; fig. 3). In the west, the upper part contains a volcaniclastic unit and a limestone unit (Sincik and Çayraz members; fig. 3). The volcaniclastic unit (Sincik member) is purple-green-gray and composed of volcanic sandstone, claystone, volcanic breccia, and lava flows. It conformably overlies the green, highly fossiliferous sandstone-marl interbedded uppermost part of the Eocene Eskipolatli Formation (fig. 3). The limestone unit (Çayraz member) overlies the volcaniclastic unit and is made of interbedded Nummilitic limestone, shale, and marl. The shale beds are greenish gray with green sandstone bands and are calcareous. The limestone is dirty yellow and contains *Nummilite* and *Alveolina* fossils. The sandstones are greenish gray with many quartzite, ultramafic rock, and limestone fragments. Along the northern margin of the basin, the limestone unit overlies the basement rocks nonconformably and locally with a fault contact. The fossil content indicates that the limestone is lower-middle Eocene in age.

These lithologies indicate that very similar rock types and sedimentary environments were present along the eastern and western margins of the Tuzgölü basin from the latest Maastrichtian to the Eocene. The presence of locally derived, poorly sorted, very angular to angular, pebble- to boulder-size clasts in a red silty to clayey matrix suggests that the Kartal Formation was deposited as alluvial fans or stream-flow-dominated alluvial fans adjacent to a shallow marine, locally lagoonal, sedimentary environment. The evaporites were deposited during dry periods within the basin. The alluvial fans suggest the presence of nearby faults along the eastern and western margins of the basin. These faults must have been controlling the sedimentation in the basin during the deposition of the Kartal Formation. They were formed as either normal faults or as strike-slip faults with a normal component of movement. The Kartal Formation is a time-trans-

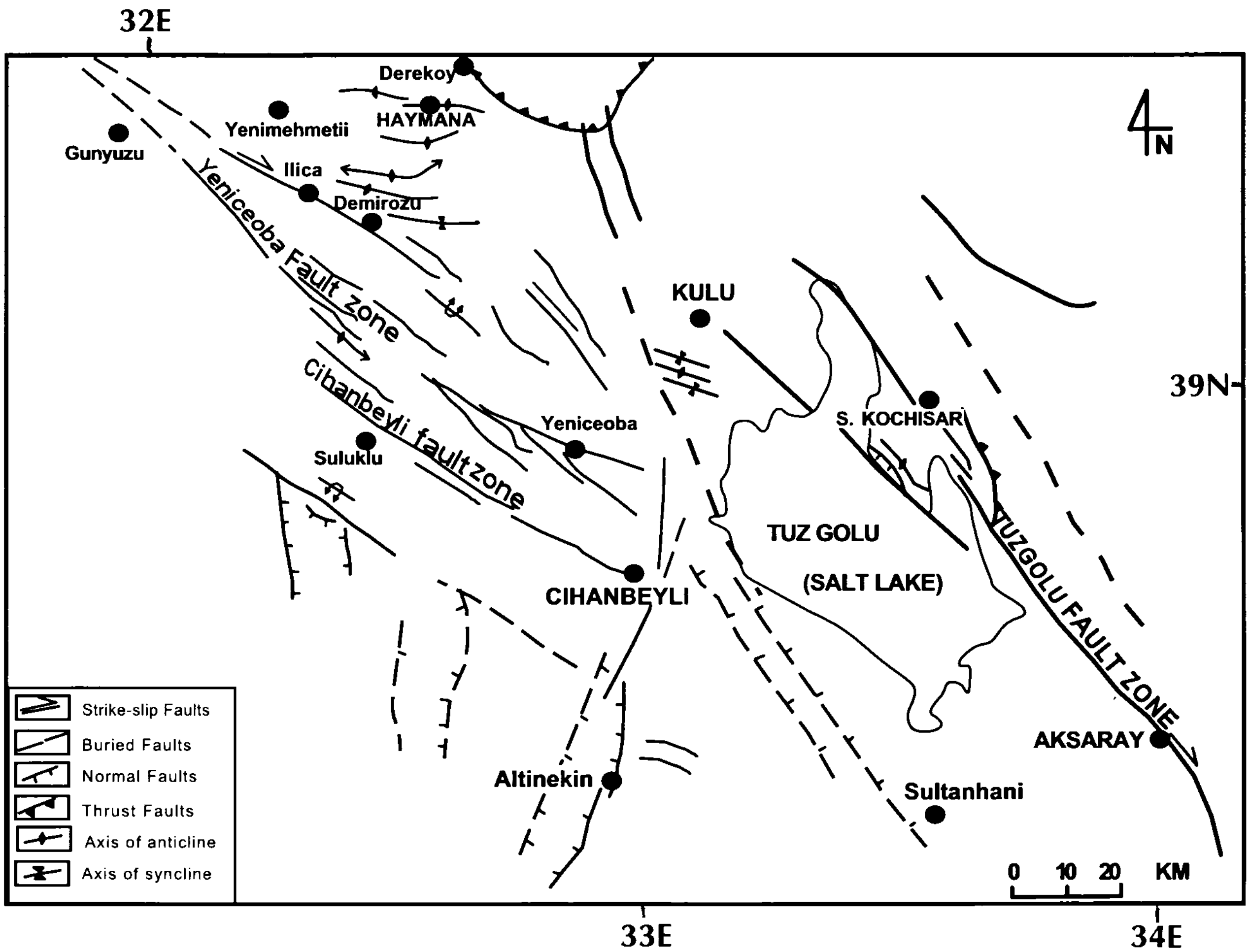

Figure 5. Generalized map showing major structural features of the Tuzgölü basin and surrounding areas

gressive unit. It grades laterally and vertically into latest Maastrichtian to Eocene rock units; therefore, we suggest that the Tuzgölü basin developed as a fault-controlled basin in that time interval.

Unconformably overlying the Eocene units along the eastern margin of the Tuzgölü basin is the Oligo(?)-Miocene Koçhisar Formation, a thick-bedded, red-pink, coarse-grained sandstone in its lower part but a medium- to thick-bedded sandstone higher in the section (fig. 3). The sandstone beds near the base of the unit are composed of both angular and rounded particles of serpentinite, granite, and marble. In the middle part, the sandstones are well-sorted and fine- to medium-grained, alternating with green shales and clayey limestones. Locally, they contain well-developed cross bedding. The upper part of the formation is a variegated-colored fine- to medium-grained, thin- to medium-bedded sandstone, generally interbedded with thin-bedded gypsum, marly gypsum, and gypsum-mudstone. The uppermost part of the succession is characterized by yellow, medium- to thick-bedded sandstone from a granitic source.

The Gökdağ Formation of the western part of the basin is in the same stratigraphic position as the Koçhisar Formation of the eastern margin (fig. 3). The unit is composed of alternating thin- and thick-bedded conglomerate, clayey sandstone, siltstone, and mudstone, generally brick red; yellow to greenish yellow to green colors are also present. Along the northwestern margin, it contains recrystallized limestone blocks. The conglomerates contain gabbro, red chert, schist, dark gray limestone, quartzite, and Nummilitic limestone.

The Mio-Pliocene Cihanbeyli Formation unconformably overlies the older rock units in the plains of the Tuzgölü basin (figs. 2, 4). It is composed of a loosely cemented conglomerate at its base and interbedded brick red or gray sandstone, siltstone, and claystone in its upper part, which also contains volcanic rock fragments. It contains lacustrine limestones in its uppermost part.

The conglomerates are mostly massive and sometimes medium to thick bedded with red, dirty white, gray, and yellow colors. The clasts are composed of quartzite, chert, gabbro, serpentine, limestone, and metamorphic rock fragments. The sandstones contain the same clasts, which are light pink, beige, and white in color. White and dirty white lacustrine limestones are thick to very thick bedded with many dissolution cavities and are sometimes cherty and siliceous.

Structural Geology

Most of the surface area of the Tuzgölü basin is covered by largely undeformed Neogene to Quaternary strata that bury many of the important pre-Neogene structures. However, several northwest-striking faults are present as prominent topographic and structural features (figs. 2, 5).

Northwest-Striking Faults. A northwest-striking fault zone is the most prominent structural feature along the eastern margin of the Tuzgölü basin. Arpat and Şaroglu (1975) have named this the Tuzgölü fault zone. It has also been referred to as the Koçhisar-Aksaray fault (Uygun et al. 1982; Görür et al. 1984) and as the Aksaray-Ş. Koçhisar fault (Şengör et al. 1985). This fault is about 200 km long and can be divided into a northern and southern part at the town of Aksaray (fig. 5).

The time of initiation of the Tuzgölü fault zone has been controversial. Many workers proposed that the fault formed in the Cretaceous (Görür and Derman 1978; Uygun et al. 1982; Görür et al. 1984). However, Dellaloglu and Aksu (1984) suggested that the fault was formed in the Miocene. The latest Maastrichtian-Paleocene Kartal Formation is well exposed along the Tuzgölü fault zone. This distribution of Kartal Formation may simply be erosional and does not suggest that the fault zone was formed contemporaneously with the deposition of the formation in late Maastrichtian time. However, the basement rocks, whose clasts are often seen in the alluvial fan deposits of the Kartal Formation, are present today on the footwall of the Tuzgölü fault zone to the northeast along the eastern margin of the basin. The proximity of the basement rock exposures to the Tuzgölü fault zone, together with the fact that the basement rocks could only have been derived from the footwall of the fault zone, suggest that the Tuzgölü fault zone may have been formed in the late Maastrichtian as one of the faults that controlled sedimentation in the basin along its eastern margin during the deposition of the Kartal Formation.

In the western part of the basin, two parallel fault zones extend from Yeniceoba and Cihanbeyli northwestward. The northernmost of the two faults is called the Yeniceoba fault zone; the southern one is named the Cihanbeyli fault zone (figs. 2, 5). These faults bring Paleozoic basement rocks and the overlying sedimentary succession to the surface. The continental sediments of the Kartal Formation and its vertical and lateral associations (i.e., Asmaboğazi and Çaldağ Formations) are exposed at several locations close to these faults. The Kartal Formation contains, at its base, poorly sorted angular pebble to gravel conglomerate within a red clayey matrix. The clasts, up to 100 cm in diameter,

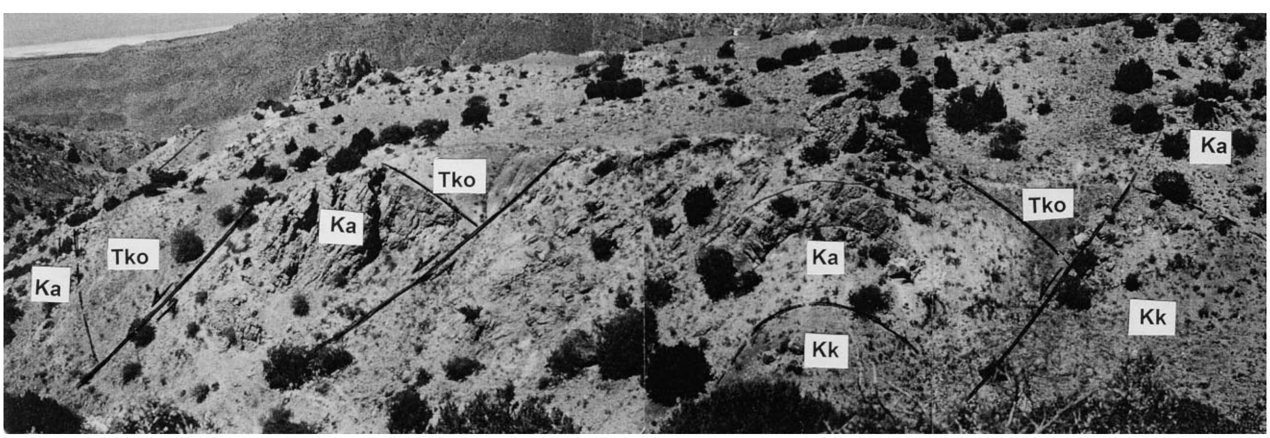

Figure 6. Photo showing down-to-the-west normal faults parallel to the trend of the Tuzgölü fault zone. Looking northwest about 5 km southeast of the town of Şerefli Koçhisar. *Kk* = Cretaceous Kartal Formation; *Ka* = Cretaceous Asmaboğazi Formation; *Tko* = Tertiary Koçhisar Formation.

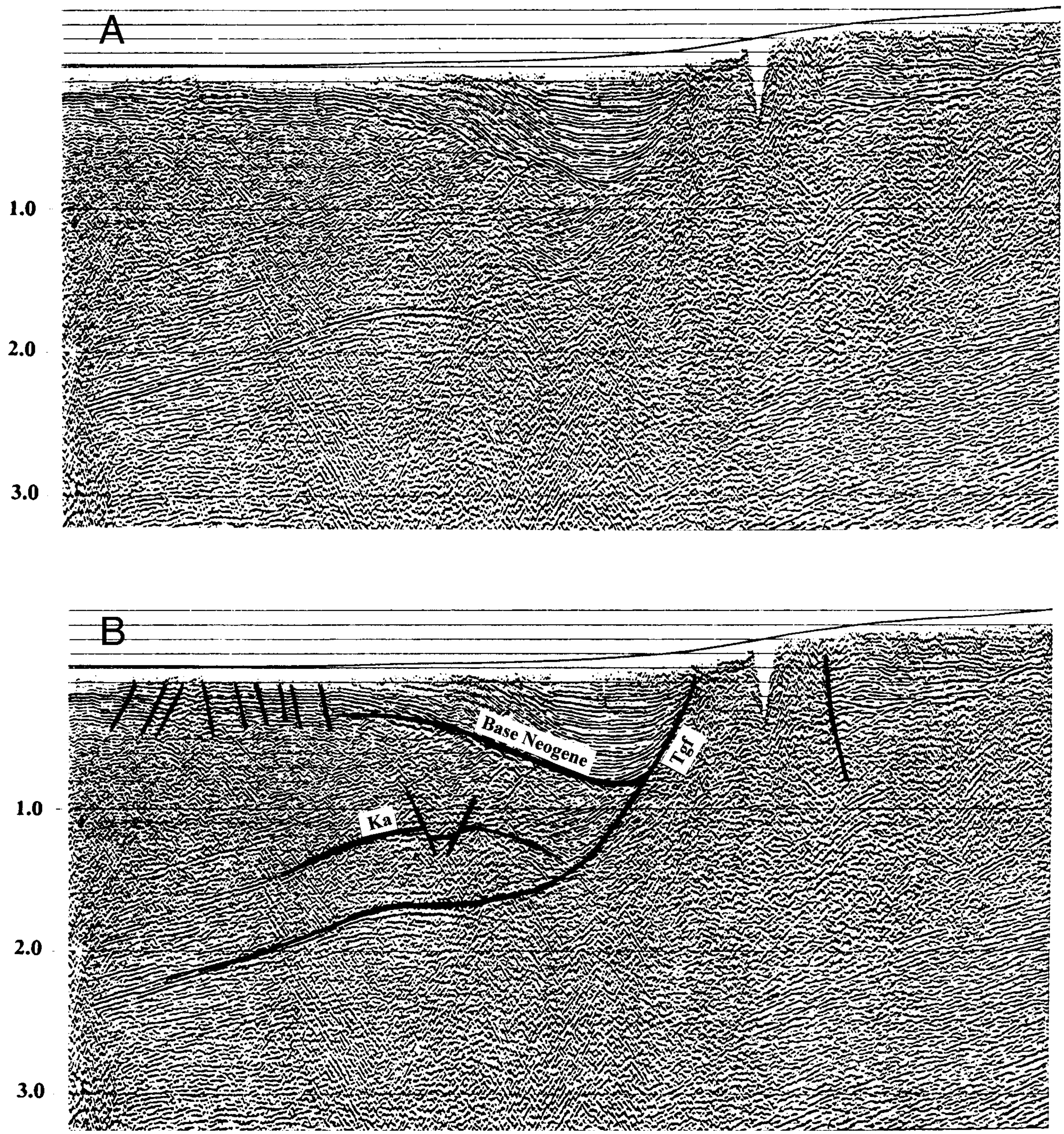

Figure 7. Seismic profile showing the rollover anticline and crestal collapse grabens. Approximate location of the profile is shown as line *A-A′* in figure 2. *A*, Uninterpreted; *B*, interpreted. *Tgf* = Tuzgölü fault; *Ka* = top of the Cretaceous Asmaboğazi Formation.

are mostly radiolarite and pelagic limestone, serpentinite, and metamorphic rock fragments. All these lithologies are present in the adjacent areas on the southwest side (footwall) of the two faults. The Yeniceoba fault zone has been displaced by a northeast striking fault and probably connects to the north- to northwest-striking Sultanhani fault zone (fig. 5), which has been observed in Turkish Oil Company (TPAO) seismic profiles as a major subsurface fault. During the early 1990s, two ex-

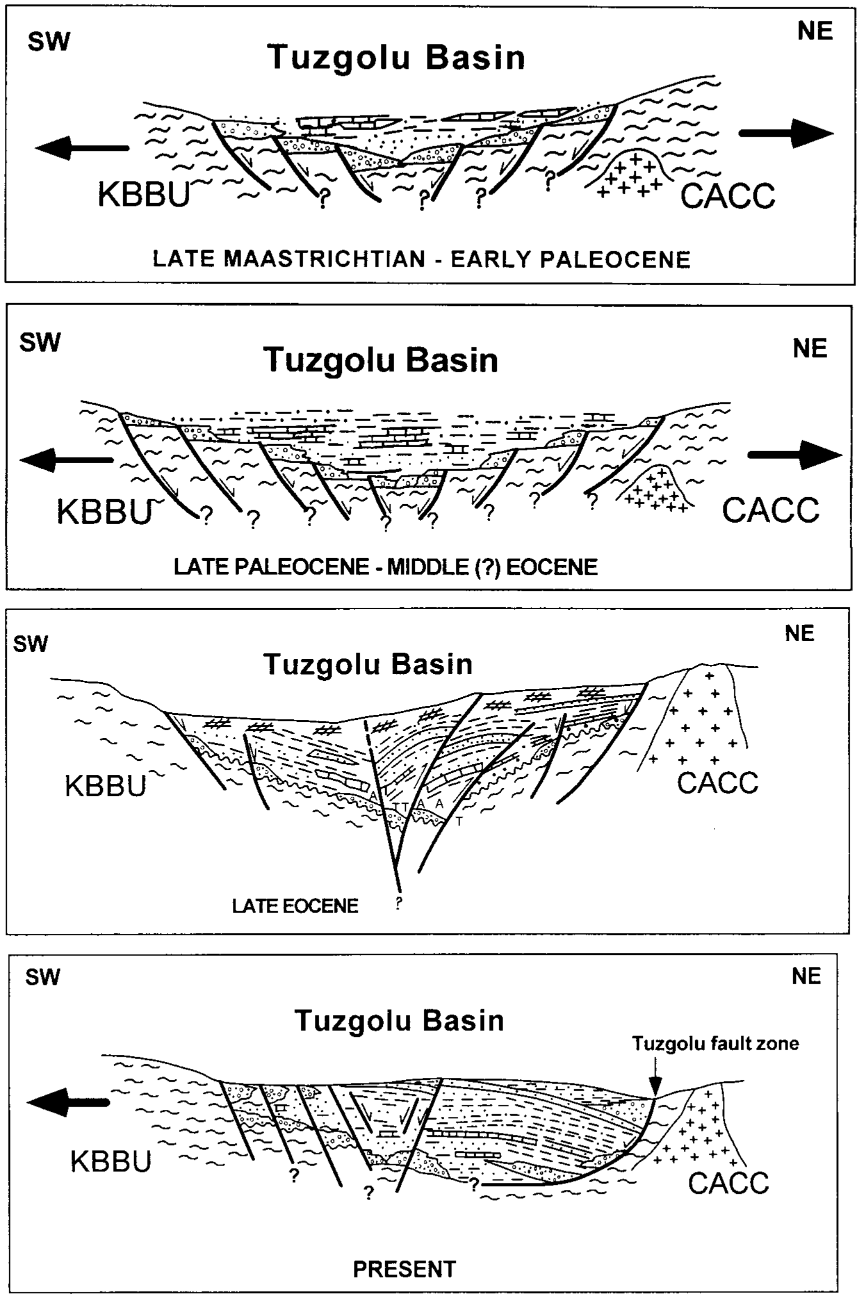

Figure 8. Schematic diagrams (not to scale) showing evolution of the Tuzgölü basin. *CACC* = Central Anatolian Crystalline Complex; *KBBU* = Kütahya-Bolkardaği belt units. *Top*, Late Maastrichtian–early Paleocene: Kartal Formation conglomerates are being deposited as alluvial fans derived from the nearby fault-controlled highlands. The formation grades laterally and vertically into the sandstone and limestone units of the Asmaboğazi Formation. The faults may have been formed as normal faults, which would suggest extensional tectonics, or as strike-slip faults with a normal component, which would suggest a large transtension. Second, late Paleocene–middle (?) Eocene: the same tectonic regime and associated deposition continues. The time transgressive Kartal Formation is being deposited as alluvial fans and stream-dominated alluvial fans well into the Eocene. It grades into the limestones of the Paleocene Çaldağ Formation, which in turn grade into Paleocene-Eocene clastics of alternating sandstone and shale. The faulting at the basin edge continues and produces the late Paleocene to Eocene age syn-extensional Kartal Formation conglomerates. The Tuzgölü basin region was subjected to transgression, caused by a global sea level rise in the Paleocene.

ploration wells were drilled close to the Sultanhani fault zone. The well on the northeast side of the fault penetrated the late Maastrichtian sediments, while the well on the southwest encountered the basement rocks below the Miocene sedimentary rocks.

The proximity of the basement rock exposures to the Yeniceoba and Cihanbeyli faults together with (*a*) the fact that the basement rocks are now present on the southwest sides of these faults and (*b*) subsurface data from the seismic profiles suggest that the two faults were formed in the late Maastrichtian during the deposition of the Kartal Formation and that they controlled sedimentation along the western margin of the basin.

Neogene to Recent movements have been observed along the Tuzgölü fault zone and other northwest-striking faults of the basin. Observations along this fault zone include offset streams and elevated Plio-Quaternary deposits along the northern part of the fault zone and a well-developed right-stepping along the fault zone to the southeast of the town of Ş. Koçhisar (figs. 2, 5). Vertical movement along the northern part of the fault zone is suggested by (*a*) many small-scale down-to-the-west normal faults parallel to subparallel to the main trace of the fault zone in its central part (fig. 6) and (*b*) a 500-m normal separation of the base Eocene sedimentary rocks reported by Uygun et al. (1982) in the vicinity of the town of Aksaray. These observations suggest a predominantly right-lateral strike-slip movement with a southwest-side-down normal component along the Tuzgölü fault zone during the Neogene. Moreover, along the southern part of the fault zone, there are left-lateral antithetic faults formed at a high angle to the main trace of the fault zone, alignment of hot springs, right-lateral offset of lava flows, slickensided surfaces, travertine occurrences, and terrace deposits (Dirik and Göncüoglu 1996).

Several seismic reflection profiles trending normal to the Tuzgölü fault zone suggest that the fault becomes a low-angle detachment surface in the subsurface although it is a high-angle fault along its surface trace (fig. 7). The profiles also suggest that the Neogene sedimentary rocks onlap over a rollover anticline, apparently formed during the Neogene extension because of the rotation of the Tuzgölü fault surface. This unconformity is also observed in the field between the Koçhisar Formation and the underlying Eocene Karapinar Yaylasi and Yassipur Formations (fig. 3).

The northwest-trending faults along the western margin of the Tuzgölü basin also contain evidence for Neogene movement: striated fault planes indicating a strike-slip movement and displaced streams suggesting a right-lateral movement. On the surface, these faults affect the thickness of the Mio-Pliocene Cihanbeyli Formation and control facies changes within the formation along them. We suggest, therefore, that they were active during the deposition of the Cihanbeyli Formation and controlled its deposition. These faults are also observed on the seismic lines (fig. 7). They effect the upper part of the sedimentary section and are formed as crestal collapse graben in the same sense of Ellis and McClay (1988). The presence of these faults suggests that the Neogene extension was active in Mio-Pliocene and was responsible for fault-controlled smaller basins in the Tuzgölü basin, where the Cihanbeyli Formation is substantially thicker than the surrounding areas.

Tatar et al. (1996) determined that Central Anatolia, between 34° and 38° east longitude, has experienced about 33° counterclockwise rotation since the late Eocene. This rotation, which is associated with the westward crustal extrusion of the Anatolian plate (Çemen et al. 1993), was probably responsible for the Neogene movement along the Tuzgölü fault zone and other northwest-trending faults of the Tuzgölü basin area.

Central Anatolian Thrust Belt. The Haymana basin of the Tuzgölü Basin complex (fig. 1) is bounded to the north by the Dereköy thrust fault (fig. 5), which brings Cretaceous ophiolitic rocks on its hanging wall over the Maastrichtian to Eocene

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Third, late Eocene: the Tuzgölü basin is isolated from the sea and extensive evaporates are deposited. Widespread Eocene compression of the region, together with a large environmental change, causes regression and eventual drying up of the basin. This contractional event reactivates the earlier-formed normal faults as strike-slip faults. This reactivation causes structural thickening and thinning of the Paleocene-Eocene rock units and rapid facies changes in the Late Eocene continental to shallow marine to nonmarine deposits. *Bottom*, Present: the start of deposition of the Oligo(?)-Miocene formations, which unconformably overly the Eocene units, marks the beginning of the Neotectonic period. Strike-slip movement with a substantial normal component along the Tuzgölü fault zone and other northwest-trending faults of the basin dominates. This tectonic regime continues during the deposition of the Pliocene Cihanbeyli Formation, which has thick occurrences in the keystone grabens, formed in the late stages of Neotectonic extension.

Haymana basin sedimentary rocks. The thrust fault is part of the Central Anatolian thrust belt formed in the late Eocene during the final closure of the northern branch of the Neo-Tethys as part of the İzmir-Ankara suture zone (Şengör and Yilmaz 1981; Görür et al. 1984). During this closure the Pontide-Sakarya microcontinent collided with the northern edge of the Tauride-Anatolide platform. The late Eocene compressional tectonics caused the formation of the east-west trending anticlines and synclines. To the south of the town of Haymana, major folds are parallel to subparallel to the trend of the Dereköy thrust (fig. 5).

Although the Dereköy thrust fault seems to be the leading-edge thrust of the Central Anatolian thrust fault zone, there are faults showing reverse separation to the west of the town of Yeniceoba. These faults bring ophiolitic basement rocks over the Eocene sedimentary rocks (figs. 2, 5). South of the Tuzgölü basin, south-dipping thrust faults deformed the sedimentary succession of the Ulukişla basin (fig. 1). These thrusts have also been dated as late Eocene in age by Göncüoglu et al. (1991).

Because the present Tuzgölü basin is bounded by the late Eocene north-dipping Central Anatolian thrust belt to the north of the Haymana basin and by the late Eocene south-dipping thrust faults of the Ulukisla basin to the south, it is possible that the compressional systems to the north and south of the basin might have reactivated the earlier basin-controlling faults as strike-slip faults during the late Eocene.

Structural Evolution of the Tuzgölü Basin

The presence of the alluvial fan depositional environments during the deposition of the Kartal Formation suggests a rapid deposition from the nearby fault-controlled highlands. Since the Kartal Formation is late Maastrichtian in age, these faults must have been formed at that time (fig. 8, *top*). The nature of the Late Maastrichtian faulting, however, is open to question. The basin-controlling faults may have been formed as normal faults, which suggests extensional tectonics, or as strike-slip faults with a normal component of movement, which suggests a large transtension (fig. 8, *top*). The Tuzgölü basin might have been formed by one of these extensional processes alone or any combination of them after the formation of the İzmir-Ankara suture zone of Central Anatolia. To solve this problem, complete sedimentological work must be carried out in the Kartal Formation, which is beyond the scope of this study.

The time-transgressive (late Maastrichtian to Eocene) nature of Kartal Formation suggests that late Maastrichtian extension continued well into the Eocene. The formation grades laterally and vertically into the late Maastrichtian Asmaboğazi Formation. In the late Maastrichtian, the conglomeratic alluvial fan deposits of the Kartal Formation were deposited along the margins, whereas alternating, mostly gray-green, medium- to thick-bedded, orbitoidal sandstone–sandy limestone and occasionally polygenic fragmented gravelstone of the Asmaboğazi Formation were deposited in the shallow-marine environments of the basin. The same tectonic regime and associated deposition must have continued during the deposition of the Paleocene Çaldağ Formation since the Kartal Formation also grades into the Çaldağ Formation.

The presence of thick Paleocene marine deposits in the Tuzgölü basin suggests the region was subjected to a transgression, caused by a global sea level rise in the Paleocene. The late Paleocene to Eocene age syn-extensional conglomerates of the Kartal Formation, especially well observed along the western margin of the basin, suggest that the faulting probably continued, in addition to the transgression, well into the early to middle Eocene (fig. 8). The Kartal, Çaldağ, Kirkkavak, and Eskipolatli Formations were deposited along the western margin of the basin while the Kartal, Çaldağ, and Karapinar Yaylasi Formations were being deposited along the eastern margin of the basin from the late Paleocene to the middle (?) Eocene (fig. 3).

The basin must have been isolated from the sea and was dry during the late Eocene. This is evidenced by an upper Eocene sandstone overlain by extensive evaporates (fig. 4). The Eocene compression of the region, together with a large environmental change caused regression and eventual drying up of the Tuzgölü basin in the late Eocene. This compressional event may have also reactivated the earlier formed normal faults as strike-slip faults (fig. 8), in addition to forming the Dereköy thrust as the northern boundary of the Haymana basin of the Tuzgölü basin complex (figs. 1, 5). It appears that this reactivation caused (*a*) tectonically thickened and thinned Paleocene-Eocene deposits in some of the wildcat wells drilled in the basin and (*b*) rapid facies change in the late Eocene continental to shallow marine deposits.

The initiation of the deposition of the Oligo-Miocene Koçhisar Formation, a fining-upward sequence that shows several lateral facies changes, marks the beginning of the Neotectonic period in the structural evolution of the Tuzgölü basin (fig. 8, *bottom*). This period has been dominated by strike-slip movement with a substantial normal component along the Tuzgölü fault zone and other northwest-trending faults in the basin, as evidenced by a large right-step along the Tuzgölü fault zone south of the town of Ş. Koçhisar (figs. 2, 5) and the onlap between the Koçhisar Formation and the Eocene sediments along a rollover anticline formed by the normal (extensional) component of the Neotectonic movement (fig. 7). This tectonic regime must have continued during the Pliocene Cihanbeyli Formation, which has thick occurrences in the keystone grabens formed in the late stages of the Neotectonic extension.

Conclusions

Structural, stratigraphic, and sedimentologic evidence summarized in this article suggest that the Tuzgölü basin began as a product of late Maastrichtian tectonism in Central Anatolia. The faults formed during this event dissected the Central Anatolian continental crust that had been thickened by closure of the north Tethys Ocean in the Cretaceous. The major northwest-trending faults of the Central Anatolian region, such as the Tuzgölü, Cihanbeyli, and Yeniceoba fault zones (fig. 3), were probably formed at that time. Although extensional in nature, the exact geometry of the faults formed during this tectonic event remains in question. Late Maastrichtian tectonism might have been originated by continental rifting or by a large transtensional zone. At present, either of the two extensional processes or a combination of them seem possible. The sustained deposition of syn-extensional conglomerates in the Kartal Formation suggests that the late Maastrichtian tectonics continued well into the Eocene. The distinction between the two proposed extensional processes can be made by a complete surface and subsurface sedimentological study of the sedimentary rocks in the basin from late Maastrichtian to Eocene time. The presence of continental crust basement rocks at the base of the sedimentary succession suggests that the basin never became an oceanic basin.

The late Eocene contractional tectonics seem to have reactivated the older faults as strike-slip faults. This reactivation is probably responsible for rapid facies changes in the late Eocene continental to shallow marine deposits and tectonically thickened and thinned Paleocene-Eocene deposits in some of the wildcat wells. This contractional event, together with a large environmental change, caused regression in the Tuzgölü basin in the late Eocene. Late Eocene evaporites suggest that the basin dried up before the start of Neotectonic period in Central Anatolia.

The Koçhisar Formation of the Tuzgölü basin unconformably overlies the Eocene rock units. This, together with the evidence for strike-slip movement along the Tuzgölü fault zone, suggests that during the Neotectonic the fault zone experienced predominantly strike-slip movement with a substantial normal component. In seismic profiles, the Koçhisar Formation onlaps Eocene sediments along a rollover anticline formed by the normal (extensional) component of the Neotectonic movement. This geometry qualifies the Tuzgölü fault zone as a detachment surface (fig. 7; fig. 8, *bottom*).

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