Neotectonic evolution of the northwestward arched segment of the Central Anatolian Fault Zone, Central Anatolia, Turkey

Kadir Dirik*

Tectonic Research Unit, Geological Engineering Department, Middle East Technical University, 06531 Ankara, Turkey

Received 5 April 1999; accepted 21 February 2000

Abstract – Central Anatolia has undergone complex Neotectonic deformation since Late Miocene–Pliocene times. Many faults and intracontinental basins in this region were either formed, or have been reactivated, during this period. The eastern part of central Anatolia is dominated by a NE–SW-trending, left lateral transcurrent structure named the Central Anatolian fault zone located between Sivas in the northeast and west of Mersin in the southwest. Around the central part, it is characterized by transtensional depressions formed by left stepping and southward bending of the fault zone. Pre-Upper Miocene basement rocks of the region consist of the central Anatolian crystalline complex and a sedimentary cover of Tertiary age. These rock units were strongly deformed by N–S convergence. The entire area emerged to become the site of erosion and formed a vast plateau before the Late Miocene. A NE–SW-trending extensional basin developed on this plateau in Late Miocene–Early Pliocene times. Rock units of this basin are characterized by a thick succession of pyroclastic rocks intercalated with calcalkaline–alkaline volcanics. The volcanic sequence is unconformably overlain by Pliocene lacustrine–fluviatile deposits intercalated with ignimbrites and tuffs. Thick, coarse grained alluvial/colluvial fan deposits of marginal facies and fine grained clastics and carbonates of central facies display characteristic synsedimentary structures with volcanic intercalations. These are the main lines of evidence for development of a new transtensional Hırka–Kızılırmak basin in Pliocene times. Reactivation of the main segment of the Central Anatolian fault zone has triggered development of depressions around the left stepping and southward bending of the central part of this sinistral fault zone in the ignimbritic plateau during Late Pliocene–Quaternary time. These transtensional basins are named the Tuzla Gölü and Sultansazlığı pull-apart basins. The Sultansazlığı basin has a lazy S to rhomboidal shape and displays characteristic morphologic features including a steep and stepped western margin, large alluvial and colluvial fans, and a huge composite volcano (the Erciyes Dağı).

The geometry of faulting and formation of pull-apart basins can be explained within the framework of tectonic escape of the wedge-like Anatolian block, bounded by sinistral East Anatolian fault zone and dextral North Anatolian transform fault zone. This escape may have been accomplished as lateral continental extrusion of the Anatolian Plate caused by final collision of the Arabian Plate with the Eurasian Plate.

1. Introduction

It has become apparent during the last ten years that both the Tuzgölü fault zone (TFZ) and the Ecemis fault zone have played an important role in controlling neotectonic processes including deposition in fault-controlled intracontinental basins, volcanism, and landscape changes in central Anatolia [1]. Most studies in this region undertaken in the southern part of central Anatolia have concentrated on volcanism [2–5] and tectonic controls on the volcanism [6–10]. The general neotectonic characteristics of central Anatolia have been discussed by Dirik and Göncüoğlu [1]. They pointed out the importance of the NW-trending dextral Tuzgölü fault zone, the NE-trending sinistral Ecemis fault zone, and the NE–NW-trending conjugate fault system between them. They have resulted from NNE–SSW directed compression and have controlled the Neogene–Quaternary basins. The Ecemis fault zone, a long sinistral intracontinental transcurrent structure, has been studied and described by Koçyiğit and Beyhan [11], and renamed the Central Anatolian fault zone. Morphologic and structural characteristics of the Kızılırmak segment of this fault zone around Sul-
The main purpose of this study is: 1) to outline the stratigraphy of the (Pliocene) Hırka–Kızılkızırmak and (Plio-Quaternary) Sultansazlıği basins located in the northwestward arched segment of CAFZ (figure 1), and 2) based on these studies, to discuss neotectonic evolution of the region.

2. Stratigraphy

The rock units exposed in the study area may be grouped into six divisions, namely pre-Upper Miocene basement rocks, an Upper Miocene–Lower Pliocene volcanic sequence, Pliocene deposits of the Hırka–Kızılkızırmak basin, Pliocene volcanics, Plio-Quaternary volcanics and the Sultansazlıği basin fill.
2.1. Pre Upper Miocene basement rocks

The pre-Upper Miocene basement is exposed in northern and eastern parts of the study area (figure 2) and comprises the Central Anatolian crystalline complex (CACC) in the north, the Bünayan metamorphics (BM) in the south, and their sedimentary cover. The metamorphics are overlain by an Upper Cretaceous ophiolitic olistostrome overthrusted by ophiolites. In the northern section, the metamorphics and ophiolites are intruded by Lower Cretaceous granitoides and syenitoides [23, 24]. The uppermost Maastrichtian–Paleocene continental to shallow marine units, Upper Cretaceous–Paleocene siltstone, shale, pelagic limestone, volcaniclastics and basic volcanic rock intercalations all unconformably overlie older units. The volcanics have a within-continental-plate eruptive setting [25]. Upwards, this unit grades into an Upper Paleocene–Eocene transgressive sequence characterized by sandstone–conglomerate–calciturbidite intercalations and local reefal to pelagic limestones. The presence of red continental clastics interbedded with bedded to massive gypsum of Late Eocene–Oligocene age at upper levels of the sequence is evidence for emergence during this period. The entire area became the site of erosion to form a vast plateau before the Late Miocene [25].

2.2. Upper Miocene–Lower Pliocene volcanic sequence

The southern part of central Anatolia is covered by a thick Upper Miocene–Pliocene volcanosedimentary sequence including calcalkaline–alkaline volcanics [3]. This unit is a continuous succession in most parts and named the Ürgüp formation by Pasquare [2]. In the study area however, this sequence is not continuous and an angular unconformity is observed between an Upper Miocene–Lower Pliocene lower volcanic sequence and overlying Pliocene units of the Hirka–Kızılçınak basin. This sequence constitutes the oldest member of the cover succession and was extruded in a backarc environment, and interpreted to be the first product of volcanism initiated by consumption of a detached lithospheric
slab beneath the southern part of central Anatolia [26] about 10 Ma ago [3]. In the study area, this unit crops out north-east of Erkilet and west of Hurka (figure 2). It unconformably overlies pre–Upper Miocene basement rocks and is characterized by a thick succession of calcalkaline–alkaline lavas and pyroclastics. The pyroclastic rocks are represented by medium thick-beded agglomerate, volcanic breccia, epiclastics and thin-beded tuffs with a thickness of about 200 m. Epiclastic levels consist of cross-beded, poorly cemented sandstone. Massive to columnar jointed basaltals are occasionally intercalated with the pyroclastics. The sequence was deformed by NNW–SSE directed compression as evidenced by ENE–WSW-trending tight folds.

2.3. Hurka–Kızılrmak basin fill

The Upper Miocene–Lower Pliocene volcanic sequence is unconformably overlain by lacustrine–fluvitae deposits of the NE–SW-trending Hurka–Kızılrmak basin formerly named the Emmiller–Hurka basin by Uygun [27], and deposition is considered to have continued between Late Miocene and Pleistocene times in this basin. However, an extension of the basin to the northeast, parallel to the contemporary Kızılrmak River and towards Sivas, has been observed in the present investigations justifying the renaming of this basin as the Hurka–Kızılrmak basin. Although the southern and northern margins are concealed by younger deposits, the basin fill displays two characteristic sedimentary facies, namely marginal (figures 3A, B and F) and axial plain facies (figures 3C, D and G). Along the front of the northern margin (north of Hurka) the deformed underlying volcanic sequence is overlain by gently dipping fluvial to lacustrine deposits. This unit is represented by sandstone, ostracod– and gastropod-bearing marl, claystone and shale alternating with diatomite-tuffaceous sand-claystone and marly limestone. The sandstone is moderately to poorly cemented and cross-beded. Upwards, this sequence grades into poorly sorted and bedded conglomerates. The size of angular to sub-angular clasts ranges from gravel to block, but decreases southward, and grades laterally into sand to clay. The Vali-baba Tepe ignimbrite [2] interfingers with the sequence at the top (figure 3A). Marginal facies of the basin around the northern part of Sultanejkisi are represented by polygenic conglomerates with sandstone alternations at the base grading upwards into poorly sorted conglomerate with angular to subangular clasts. Laterally it grades into gravely sandstones, red siltstones and claystones. The uppermost levels of the marginal facies and the boundary with the basement rocks are concealed by recent alluvial fan-talus deposits (figure 3F). In the central part, the axial plain deposits of the Hurka–Kızılrmak basin unconformably overlie volcanics north of Erkilet. The sequence starts with thin, fine conglomerate and continues upward with graded sandstone, laminated and occasionally fossiliferous marl-claystone, cross-beded sandstone, a thick tuffite bed and thick bedded lacustrine limestone interbeds (figures 3C and D). This lime-

— 150 —

stone member is about 10 m in thickness. It is followed by a sequence consisting of thick cross bedded and occasionally graded, loosely-cemented sandstone with conglomerate alternations. The upper level is represented by medium-bedded and occasionally brecciated limestone. Pliocene plateau basalts and the Valibaba ignimbrite unconformably overlie the sequence. The lower part of axial plain facies of the Hurka–Kızılrmak basin around Sultansekisi and west of Tuzla Gölü is represented by fluviatile deposits (figures 3F and G). The pre-Upper Miocene basement is unconformably overlain by this sequence without volcanics. It starts with cross bedded, polygenetic conglomerates, grading upward into poorly cemented sandstones with occasional conglomerate lenses and caliche levels, and continues with intercalations of cross-beded sandstone, parallel laminated sandstone–siltstone, and channel fill conglomerates. In the upper levels this sequence grades into white claystone, clayey limestone and porous gastropod-bearing limestone.

Thick, coarse grained alluvial/colluvial fan deposits of marginal facies and fine grained clastics and carbonates of distal facies with volcanic intercalations are the main evidence for development of a tensional (Hurka–Kızılrmak) basin in Pliocene times (figure 4). The border faults of this basin were probably triggered by westward escape of the wedge-shaped Anatolian Plate between NATFZ and EAFZ [28–30].

2.4. Pliocene volcanics

These consist of andesitic domes and stratovolcanoes, plateau basalts and ignimbritic sheets. The andesitic domes are located southwest of Erkilet and the stratovolcanoes to the southeast of Kayseri (figure 1). They are aligned parallel to the border faults of the Sultansazlıği basin. Basaltic lava overlies fluviatile facies of the Hurka–Kızılrmak basin and is overlain by a welded and vesicular ignimbritic sheet, 8–10 m thick and black to dark grey in colour. Under the microscope it displays a hypocrystalline structure of augite, plagioclase and olivine embedded in a glassy matrix. The youngest member of this overlying sequence is a widely distributed ignimbrite sheet named the Valibaba Tepe ignimbrite by Pasquale [2]. This is a grey to dark violet–red coloured, massive andesitic tuff displaying flow structure and composed of plagioclase, augite phenocrysts and glassy matrix. Although the thickness is only about 5–15 m, its distinctive character makes it an important marker bed in this region. According to radiometric age data these volcanics range from 5.1 Ma to 2.8 Ma (Early Pliocene) [3].

2.5. Plio-Quaternary volcanics

These volcanics are the product of the Erciyes stratovolcano and occupy the central part of the Sultansazlıği depression (figures 1 and 2). The stratovolcano comprises basaltic–andesitic lavas interlayered with dacitic pyroclastics, pumice and ash deposits, and has evolved in five stages [2]. The first
Figure 3. Stratigraphic columns of the Hirka–Kizilirmak and Sultansazlığı basins.
stage was characterized by formation of a lava shield of andesitic–basaltic lavas coeval with initial sinking of the Sultansazlığı depression. It was followed by collapse of the lava shield and development of a stratovolcano during this collapse accompanied by emplacement of dacitic–rhyodacitic dykes. Dacitic–rhyodacitic domes developed in the third stage. Olivine basaltic lavas and dacitic pyroclastics were emplaced during a fourth stage, and dacitic lavas with pumiceous ash deposits were formed in the last stage. The geochemical composition of these volcanics is calcalkaline, and their age is Plio–Quaternary [2, 3, 5].

2.6. Sultansazlığı basin fill

The sedimentary fill of the lazy S to rhomboidal shaped Sultansazlığı basin consists of coarse grained marginal and fine grained axial plain deposits showing both vertical and lateral gradations. Conglomerates constitute coarse grained marginal sediments deposited as talus-alluvial fans along the foot of the steep and elevated western margin of the basin. They are poorly lithified and sorted, mostly embedded in sandy matrix, and polygenetic in composition. Fine grained axial plain deposits consist of siltstone, marl, claystone and mudstone. Dune sands are the characteristic sediment of the eastern part of Erkilet. The thickness of the sedimentary fill increases toward the south and attains a maximum of 300 m south of the Erciyes volcano.

3. Structural geology

3.1. Folds

Two types of fold sets occur in the study area. The first occurs in pre–Miocene–Pliocene units and the second in Mio-Pliocene units. The first set is represented by tight to overturned folds consisting of a series of anticlines and synclines with axes trending in a NE–SW direction (figure 2). These folds are overturned and N-verging near the thrust-faults but become tight and doubly-plunging away from them. A second fold type occurs within the Mio-Pliocene units with NE–SW-trending axes; these are open folds in contrast to folds developed in the Upper Miocene–Lower Pliocene volcanics. They are evidence for a pre-Late Pliocene compressional regime in the region. Pliocene basalt lavas and Valibaba ignimbrite lie horizontally on the underlying folded structures.
3.2. Strike-slip faults

The study area is located in a lazy S- to rhomboidal-shaped depression at the northwest arched segment of the CAFZ. The latter is a 35 km wide and 120 km long depression bounded by strike-slip faults with a normal-slip component. It was first named the Sultansazlığı depression and interpreted as a pull-apart basin by Pasquere et al. [6], Dirik and Gönçoğlu [7] accepted this term although the Kayseri–Yeşilhisar and Erciyes names have also been used [9, 11]. The term Sultansazlığı depression has priority and is used here. The CAFZ is approximately 730 km long and 2–80 km wide. It is a NE-trending, active sinistral strike-slip fault zone [11]. The arched central part is controlled by the Kızılrmak, Erkilet, Yeşilhisar, Gesi and Develi subfaults. The Kızılrmak segment is a 5- to 10-km-wide, 140-km-long, and N40°–50°E-striking sinistral fault zone (figure 1) which runs parallel to the Kızılrmak stream and forms the eastern margin of the CACC. The old deposits of the Kızılrmak River have been faulted and elevated by this fault zone which terminates northwest of Tuzla Gölü. The Erkilet segment starts to the southwest of Tuzla Gölü and continues in a SW direction determining the western margin of Sultansazlığı depression. Due to left stepping between the Kızılrmak and Erkilet subfault zones around Tuzla Gölü, a pull-apart basin at Tuzla Gölü with a half graben character [11] has also developed. Large alluvial fans aligned parallel to faults with step-like morphotectonic features displaying steep fault scarp are an important evidence for the Erkilet segment. The Valıbaba ignimbrite has been faulted and downthrown to the floor of the depression by this fault segment indicating considerable vertical displacement along the fault zone. North of İncesu it bends towards the south at about 45°, and forms the Yeşilhisar fault segment [11]. The Yeşilhisar fault segment also displays steep fault scarp with a step-like pattern and determines the western margin of the depression. The Gesi fault segment starts to the south of Tuzla Gölü. It tectonically juxtaposes Plio-Quaternary volcanics and pre-Miocene units and determines the easternmost margin of the Sultansazlığı depression towards the southeast (figure 2).

To the east of Kayseri it bends south at about 25° forming a new subfault, the Develi fault segment [11]. It is about 100 km long and a NNE-striking oblique-slip normal fault zone displaying well developed fault scarps with a step-like pattern determining the eastern margin of the depression. Pliocene volcanics were deformed and faulted along this margin.

The presence of earthquake epicenters around Kayseri, Yeşilhisar, Sarıoğlan (east of Tuzla Gölü), southwest of Felahiye, and Bünyan with magnitudes greater than 4.2 smaller than 6.0 shows that the boundary faults of these basins are still seismically active [1] (figure 1).

4. Tectonic evolution

Major tectonic events in the tectonic evolution of the northwest arched segment of the CAFZ can be summarized in age sequence as follows:

4.1. Middle–Late Miocene

During this period collision of the Pontides with the CACC was completed. The entire area emerged and became the site of erosion to form a vast plateau before Late Miocene times (figure 5A) [25].

4.2. Late Miocene–Early Pliocene

In the southeastern part of Turkey, the Bitlis Ocean closed by collision of the Eurasian Plate with the Arabian Plate during late Middle Miocene times [28] and these two plates welded along the Bitlis Suture Zone (figure 7A). Field observations show that Upper Miocene–Pliocene volcanic-volcanosedimentary sequence of the study area, previously named the Uğur formation, did not result from uninterupted geologic events as indicated by previous studies [2, 3, 11, 27]. Instead, Pliocene lacustrine–fluvialite deposits rest on erosional surfaces of older basement rocks and Upper Miocene–Lower Pliocene volcanics with angular unconformity. The underlying volcanics resulted from consumption of a detached lithospheric slab beneath the southern part of central Anatolia related with the continuous convergence between the Eurasian Plate to north and the Arabian Plate to the south (figure 7A). The convergence lasted until the Late Miocene and was replaced by a new tectonic regime dominated by escape tectonics [29]. During this period, two important structures have formed, namely the dextral North Anatolian transform fault zone (NATFZ) and sinistral East Anatolian fault zone (EAFZ) (figure 7B). Between these faults Anatolia is being extruded to the west. Apart from these two main structures there were probably intracontinental strike-slip faults parallel to the main structures, and the westward escape initiated formation of transtensional basins in central Anatolia including the NE–SW-trending Pliocene Hırka–Kızılrmak basin in the study region (figures 5B and 7B).

4.3. Middle–Late Pliocene

Lacustrine to fluvialite deposition continued until the Late Pliocene and the region was then entirely covered by volcanics (plateau basalts and the Valıbaba ignimbrite) which formed a vast volcanic plateau in the Late Pliocene (figures 5C and D). However, the most important feature initiated at this time is the southward bended and left stepped fracture of the CAFZ, the youngest intracranontial structure in the region. The CAFZ, with which several andesitic domes and stratovolcanoes are aligned, was probably formed by the reaction of an older zone of weakness (figure 6A).
Figure 5. Schematic diagrams showing evolution ofırka–Kızılırmak and Sultansazlıği basins.
Figure 6. Schematic block diagrams illustrating the evolution of the Sultansazlığı and Tuzla basins (the idea for this figure is partly inspired from Pasquare et al. [6] and Toprak [9]).
Figure 7. Evolution of the central Anatolia since Late Miocene. BSZ: Bitlis Suture Zone, NATFZ: North Anatolian Transform Fault Zone, TFZ: Tuzgölü Fault Zone, CAFZ: Central Anatolian Fault Zone, EAFZ: East Anatolian Fault Zone, DTF: Dead SEA Transform Fault, HKB: Hirka–Kızılırmak Basin.

— 156 —
4.4. Late Pliocene–recent

The continued westward escape of Anatolia has caused sinistral movement along this fracture (figure 7C). As a result of this motion, transtensional areas have been formed around left stepping and southward bending regions of the fault zone. In these transtensional areas, two characteristic strike-slip structures, namely the Tuzla Gölü and the lazy S to rhomboidal Sultansazlıği pull-apart basins (SPB) have been initiated during formation of the Pliocene volcanic plateau (figures 5D, E and 6B). During the widening of the SPB, the Erciyes stratovolcano has also evolved by basaltic eruption, followed by andesitic volcanic activity [2] in the depression (figures 5F and 6C).

5. Conclusion

The present landscape of central Anatolia was shaped by the escape tectonics which emerged during the Late Miocene following the ending of continuous N–S convergence. The North Anatolian and East Anatolian transform fault zones are two important features formed during this period. The subfault zones zipping off from the NATFZ are second order features and deform the eastern part of central Anatolia. One of these features is the CAFZ, a NE–SW-trending, active sinistral intracontinental transtensional structure [11].

The transtensional Hıkr–Kızılirmak basin of Pliocene age is the first product of this escape tectonism and has developed on both an Upper Miocene volcanic sequence and pre–Upper Miocene basement. The lacustrine to fluviatile deposition continued up to Middle Pliocene times when the region was entirely covered by plateau basalt and ignimbrite in the latest Middle Pliocene (~2.8 Ma).

The CAFZ is the important structure initiated in the middle Pliocene. The left stepping around Tuzla Gölü and the releasing type of bending on the CAFZ around the central section has formed transtensional areas and resulted in initiation of two depressions, the Tuzla Gölü and Sultansazlıği pull-apart basins. The recent earthquake epicentres strongly suggest that these structures are still active.

Acknowledgements. The author wish to express his gratitude to the Turkish Petroleum Corporation (TPAO) for financial support during fieldwork, and special thanks to Cemal Gönçüoğlu for his continuous interest and contribution related to the studies carried out on the tectonics of central Anatolia.

References


