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The Savcılı Thrust Fault (Kırşehir, Central Anatolia): a backthrust fault, a suture zone or a secondary fracture in an extensional regime?

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Abstract: Large exposures of granitic and metamorphic rocks characterize the geology of Central Anatolia, in Turkey. These basement rocks crop out mainly between the Tuz Gölü and Ecemiş fault zones, two major fractures of strike-slip fault character. During the Neogene, detachment faulting along the Tuz Gölü Fault (TGF) zone caused the deposition of several thousand meters of sediments in the large intracontinental Tuz Gölü Basin. In the western parts of Central Anatolia and near Kırşehir town, another fracture zone runs almost parallel to the SE-trending TGF zone, separated from the TGF by a narrow (~30 km) and rectangular granitic belt. Along this fracture known as the Savcılı Thrust Fault (STF), metamorphic and plutonic rocks overthrust middle Eocene detrital rocks of the sedimentary cover along a relatively narrow (~100 m) crushing zone. In some previous works, this structure is presented as a backthrust of the Anatolian block, or a suture zone along which two continental Central Anatolian blocks were amalgamated. Recent detailed mineral exploration studies reveal that the area at the north of the STF comprises several low-angle normal faults along the surfaces of which the Eocene and the underlying metamorphic rocks moved southwards until they were juxtaposed to southern granitic rocks along steeply or moderately dipping contacts. The fault surfaces are several km long, slips of a few kilometers are clear and ductile deformation is observed in the Eocene clastic rocks. Immediately to the north of the STF, Eocene rocks are asymmetrically folded with a southern vergence, a displacement sense not compatible with the northerly movement observed at the STF zone and suggesting a causal relationship between thrusting and normal faulting. A possible explanation of this extension may be the southwards tilting of the foreland due to the northwards overthrusting and the following gravitational movements. The folding style in the foreland and the very narrow width of the thrust zone, however, preclude such a crustal loading to induce extension in the foreland. In the Savcili area where the thrust fault is observed, we do not see any evidence to account for crustal shortening, as it should be observed in the vicinity of a major compressional structure as previously advanced. How this thrust formed in an extensional regime and how this post-middle Eocene crustal extension is associated with the southern Neogene Tuz Gölü Fault zone remain to be explored.

Key words: Turkey, Central Anatolia, Kırşehir metamorphites, Savcılı Thrust Fault, Tuz Gölü Fault, normal faulting.

Introduction

The structural features of the Anatolian block are the results of geodynamic processes that opened and closed the Tethys Ocean in the Eastern Mediterranean. Ketin (1966) reviewed the previous proposals of the orogenic divisions of this part of the Tethysides. Şengör & Yılmaz (1981) and Şengör and co-workers (Şengör et al. 1985) explained various points of the Anatolian geology. After several decades of geological research that resulted in a large number of papers (regional scale: (Ketin 1966; Brinkmann 1976; Görür et al. 1998); local scale: (Ketin 1955; Ataman 1972; Erkan 1976; Erkan & Ataman 1981; Oktay 1981; Seymen 1981, 1982, 1984, 2000; Göncüoğlu et al. 1991; Aydın & Önen 1999; Whitney & Dilek 1998; Boztuğ 2000; Dirik 2001; Whitney et al. 2001; Gautier et al. 2002; Güleç et al. 2002; Piper et al. 2002; Kuşçu et al. 2002; Genç 2003)), the internal parts of the Anatolian block known as Central Anatolia (Fig. 1) still remain the structurally most poorly understood sector of Anatolian block. Large outcrops of metamorphic and granitic rocks characterize the geology of Central Anatolia, in particular near Kırşehir city (Fig. 2). The non-metamorphic cover begins with the Upper Cretaceous rocks near Kırşehir (Ketin 1955), overlain by Tertiary sediments comprising middle Eocene sedimentary clastic rocks and carbonates, and Neogene detrital rocks (Oktay 1981; Seymen 1982). To the west of Kırşehir and near Savcılı town, the metamorphites tectonically overlie the Eocene rocks along a fracture zone (Oktay 1981), namely the Savcılı Thrust Fault (STF). According to Seymen (1982, 2000), the STF is one of the major fractures of Central Anatolia and extends for about 150 km in a SE–NW direction. Noting that the compression in Anatolia is absorbed by south-verging thrust faults, Şengör & Yılmaz (1981) interpreted the STF as a back-thrust fault of the Anatolian interior. For Görür et al. (1998), two crustal blocks of Central Anatolia were sutured along this structure.

Recent detailed mapping and field observations undertaken for mineral exploration studies (Genç 2004; Genç & Yürür 2004) near this structure indicate, however, a structural setting of extensional character that is highly incompatible with the compressional tectonic interpretations advanced by previous workers for the area considered. In

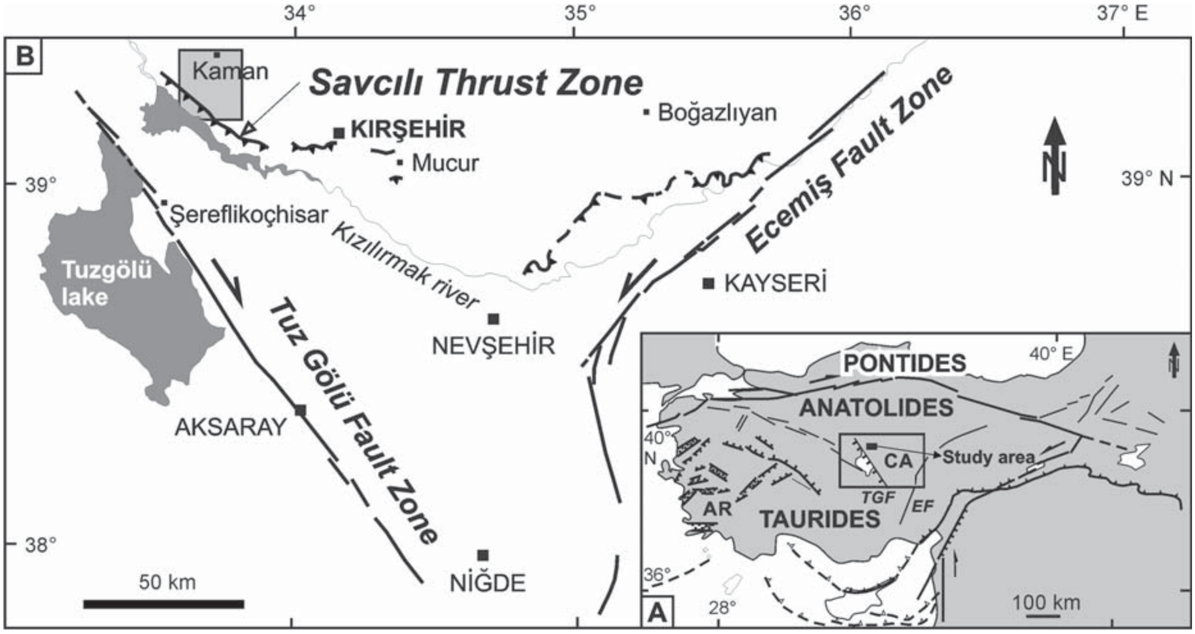

Fig. 1. A — Place of the study area in a generalized tectonic map of Turkey: AR — Aegean Region, CA — Central Anatolia, EF — Ecemiş Fault, TGF — Tuz Gölü Fault. The trace of the Savcılı Thrust Fault is drawn from Dirik & Göncüoğlu (1996). **B** — Map showing the study area, the Ecemiş and Tuz Gölü faults and the Savcılı Thrust Fault.

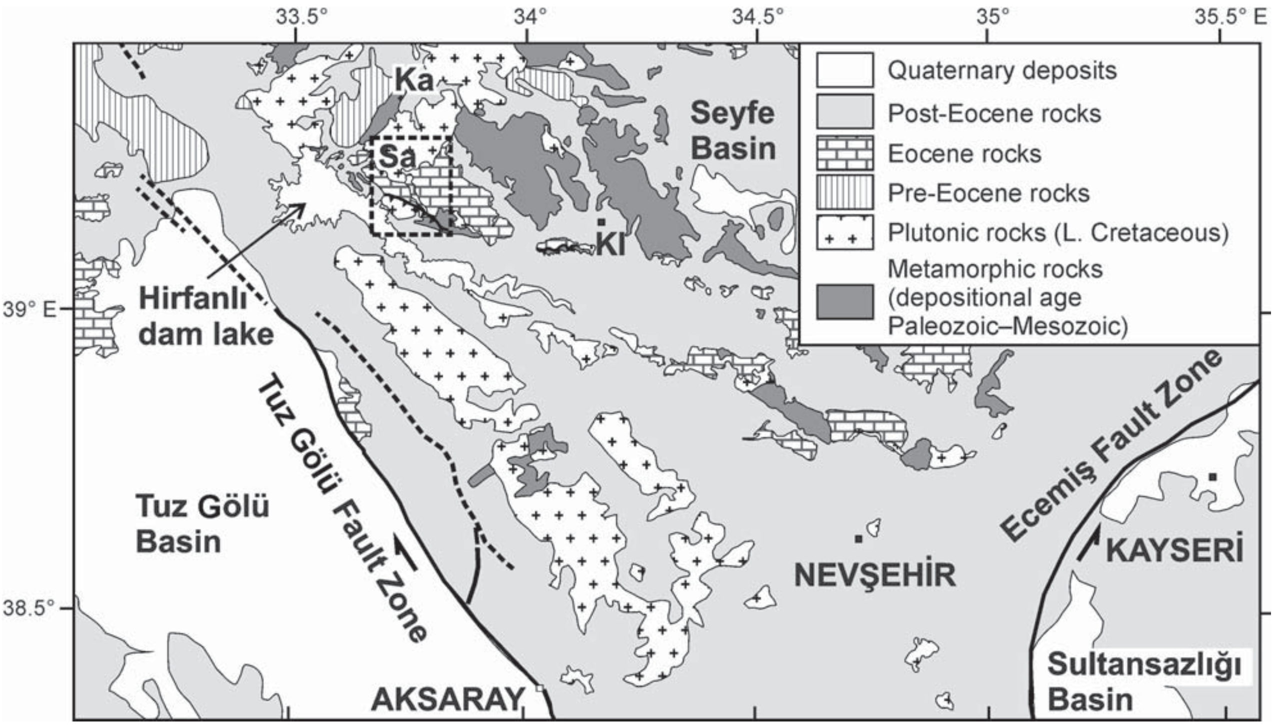

Fig. 2. Geological map of the region surrounding the study area (from the 1:500,000 scale geology map of Turkey, Ankara sheet, MTA, 2002). **Ka** — Kaman, **KI** — Kırşehir, **Sa** — Savcılı.

this paper, we present our observations on the Savcılı Thrust Fault and field evidence of the extensional tectonics that are observed near this structure. We use digital elevation models to present the topographic and morphological features of this area, and geological map and cross-sections of some key areas, the study of which effectively explains the structural characteristics of the area near Savcılı city where this fracture zone is best observed. We then discuss on the spatial relationships between the contractional Savcılı structure and the surrounding extensional tectonic domain to check if both regimes could be parts of the same tectonic phase. We think that deciphering this structural contrast is of great importance to better understand the geological past of this part of the Anatolian Tethysides for which the previous tectonic models are not satisfactorily supported by field observations.

Geological setting

The Fig. 2 illustrates the geology of the area on a regional scale. Near Kırşehir, low- to high-grade metamorphites comprise gneissic rocks, migmatites and various metamorphic rocks (such as mica-schists, calc-schists, marbles, quartzites, etc). The depositional age of these metamorphites is Paleozoic (Genç 2003) whereas controversial ages are proposed for their metamorphism. According to Pollak (1958) and Brinkmann (1971, 1976), metamorphic rocks are the products of a polyphased deformational history. Some workers, however, do not find any trace of pre-Alpine movements in Central Anatolia (Ketin 1966; Erkan 1976; Seymen 1984; Whitney et al. 2001). New petrogenic and radiometric data obtained from metamorphic and plutonic rocks of Central Anatolia indicate a single-phase, Late Cretaceous regional metamorphism related to crustal thickening, and a later high-temperature overprint associated with magmatism, uplift and exhumation (Erkan & Ataman 1981; Seymen 1982; Whitney & Dilek 1998; Whitney et al. 2001). Granitic rock exposures are distributed over a large area in Central Anatolia but the largest outcrop is located to the NE of the Tuz Gölü Fault (see Fig. 2). In the area investigated, granites intrude the metamorphites as shown by the baking of these latter in contact with the plutonic rocks. In the study area, the earliest units of the sedimentary cover are nummulitic middle Eocene clastic rocks with pebbles derived from the metamorphic and granitic rocks, overlain by Eocene limestones. Generally poorly cemented detrital rocks of Neogene age cover the oldest units. Metamorphic foliations generally trend NW–SE, and the Eocene beds usually have gentle dips towards the south. Foliation and bedding surfaces locally become almost vertical near the Savcılı Thrust Fault where the Eocene rocks are folded and also in places where tilting occurred due to detachment faulting. The Neogene strata remain subhorizontal almost in the whole area.

Morphology

As seen in the digital elevation model (DEM) (Fig. 3), the study area is located in a region characterized general-

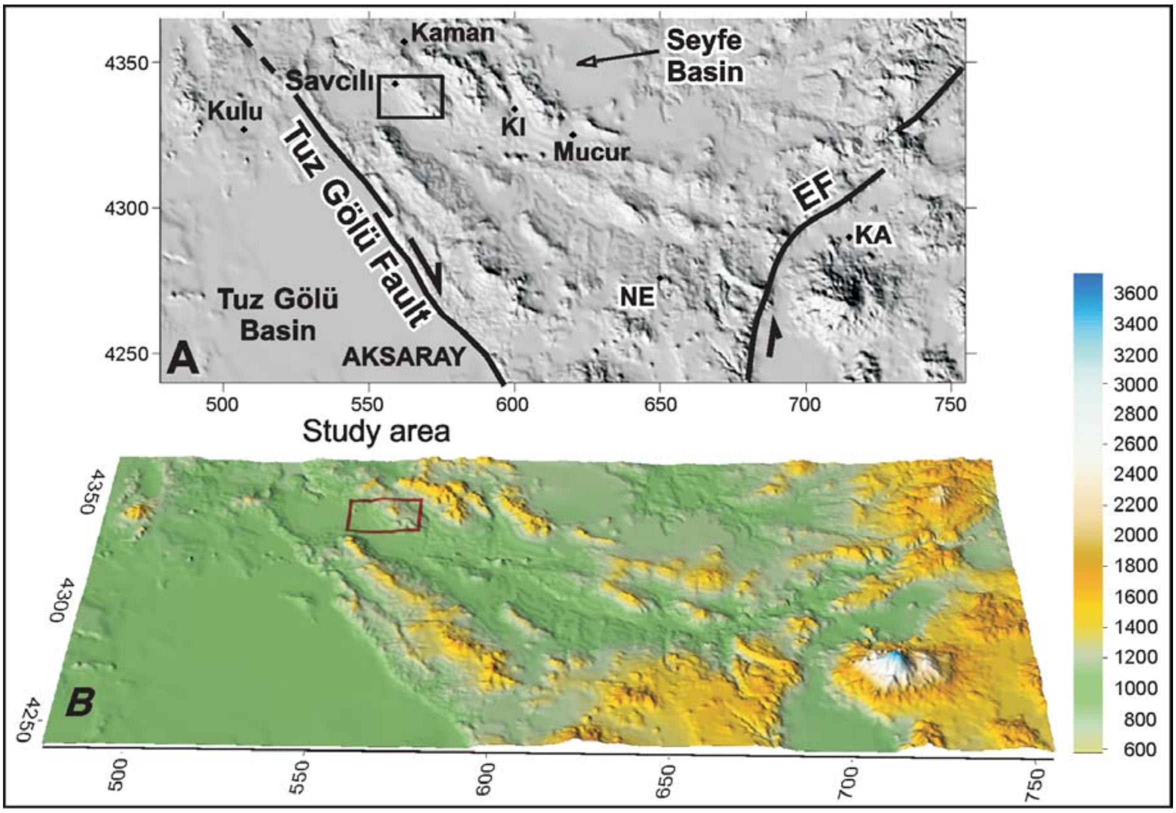

Fig. 3. A — Digital elevation model (DEM) of the region showing the topography of Central Anatolia, prepared using 1:250,000 topographic maps. Artificial lighting from West with a 45° zenith angle. The rectangle denotes the location of Fig. 4. Vertical exaggeration is 2. **EF** — Ecemiş Fault, **KA** — Kayseri, **KI** — Kırşehir, **NE** — Nevşehir. **B** — Block diagram of the DEM with the same lighting and vertical exaggeration parameters.

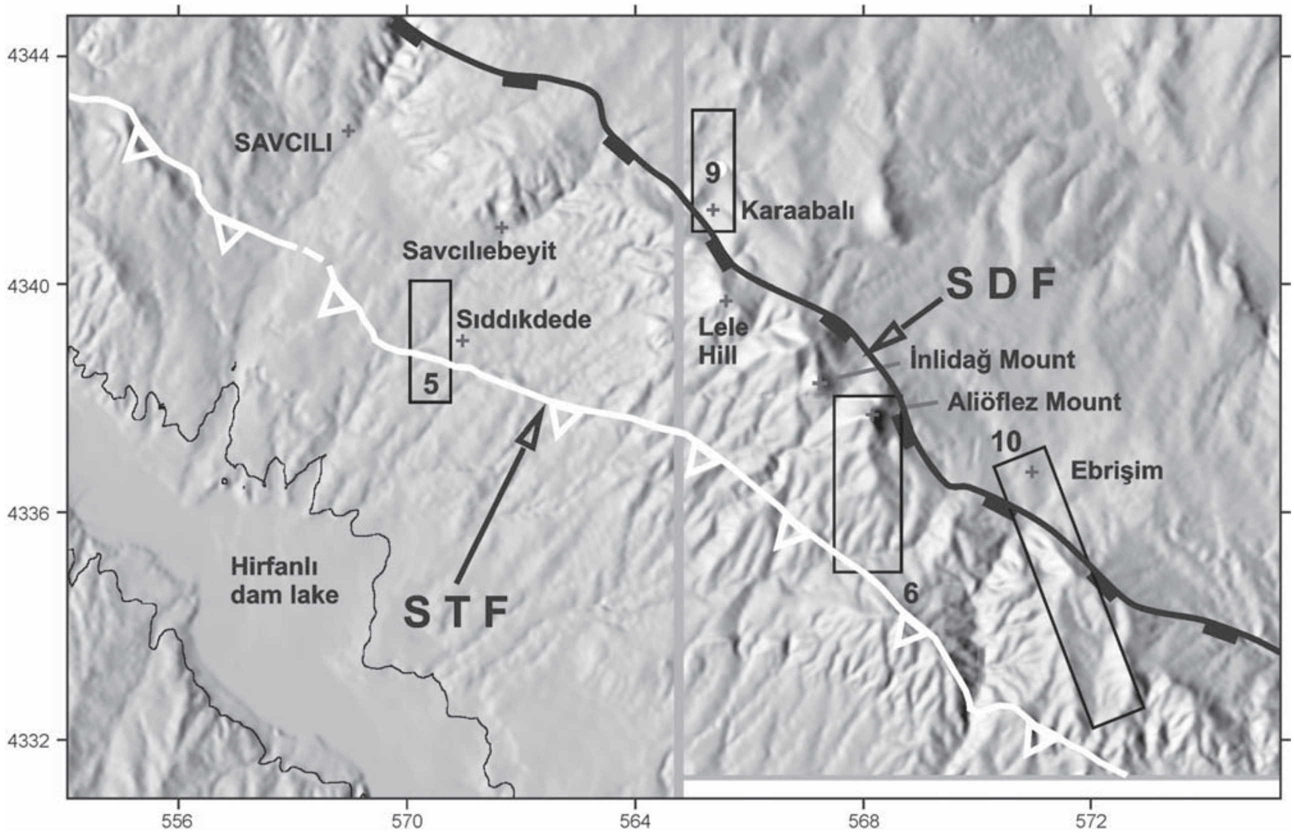

Fig. 4. Digital elevation model (DEM) of the region in the vicinity of the Savcılı Thrust Fault, shown by white line (STF), and the Savcılı Detachment Fault (SDF) drawn by black line. (DEM is prepared based on the digitization of 1:25,000 scale topographic maps.) Vertical exaggeration is 2 and the artificial illumination is from West with a 45° zenith angle. Rectangles and numbers in them represent the locations of Figs. 5, 6, 9 and 10.

ly by a low, gentle rolling topography, with well-pronounced, subparallel alignments of moderate heights trending more or less parallel to the direction of the two major fracture zones, the Tuz Gölü and Ecemiş Faults. Near Kayseri, the well-marked relief is due to the Quaternary Erciyes stratovolcano that developed along the Ecemiş Fault. Although covered in several places by Neogene deposits, these alignments of older rocks, in particular the metamorphic and plutonic rocks of Central Anatolia, appear to create a large curvilinear structure with a southward convexity.

In our study region, this low-relief landscape comprises several large Quaternary depositional areas (such Tuz Gölü Basin, Seyfe Basin). These areas represent basins bounded by strike-slip faults (Şengör 1980; Şengör et al. 1985).

Fig. 4 is a high-resolution DEM of the region around the study area, prepared on the basis of 1:25,000 scale topographic maps. The DEM is displayed with a vertical exaggeration of 2 and artificial lighting from the west, the best direction to emphasize the structural morphology due to shadowing. The DEM shows a generally mild topography disturbed by the NW-SE alignment of numerous hills, like the Aliöflez Mount. To the NE of this alignment, a terrain much subdued in grey tones corresponds to relatively low relief topography. This topographic texture is again expressed far from the hilly terrain and towards the Hirfanlı dam lake to the SW. We will see in the next sections that this hilly alignment delineates the starting line of slices that moved more or less southwards along detachment faults whilst another southern lineament, sub-parallel to this line, corresponds to the trace of the Savcılı Thrust Fault. Almost no topographic signature could be associated to the fault trace in the DEM.

The Savcılı Thrust zone

The Savcılı Thrust Fault (STF) is observed typically near Sıddıkdede (Fig. 4) along a contact between the northern Eocene detrital rocks and the southern metamorphic and magmatic rocks (Fig. 5). Along the faulted contact that dips about 45°, the Eocene strata are reversed and folded. A few hundreds of meters northerly, the Eocene detrital rocks are exposed in a south-vergent asymmetric fold, a folding geometry in contradiction to the northerly thrusting movement. The thrust zone does not affect a zone larger than a few hundreds of meters north of which the Eocene beddings have gentle dips. To the south of the STF, a large area is composed of granitic rocks most of which remain under the Hirfanlı dam lake. Further south,

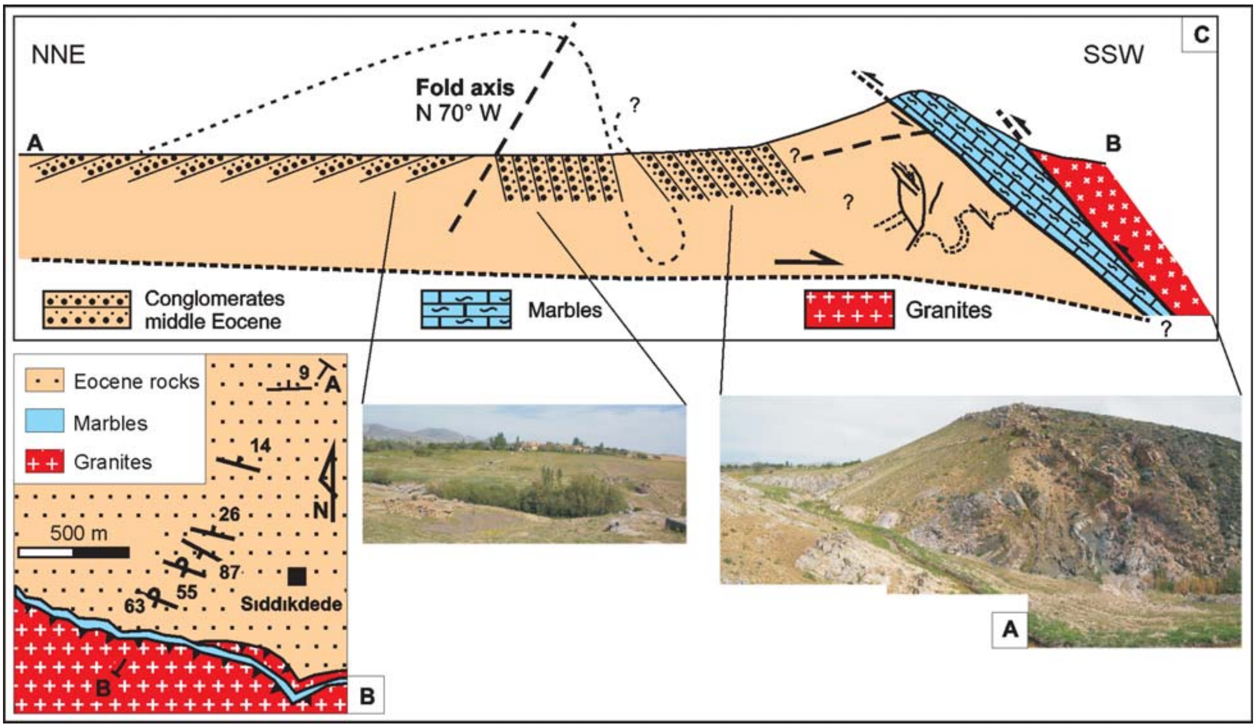

Fig. 5. **A** — Mosaic of photographs showing the Savcılı Thrust Fault near Sıddıkdede locality (see Fig. 4 for its location). **B** — Geological map of the area. **C** — A–B cross-section.

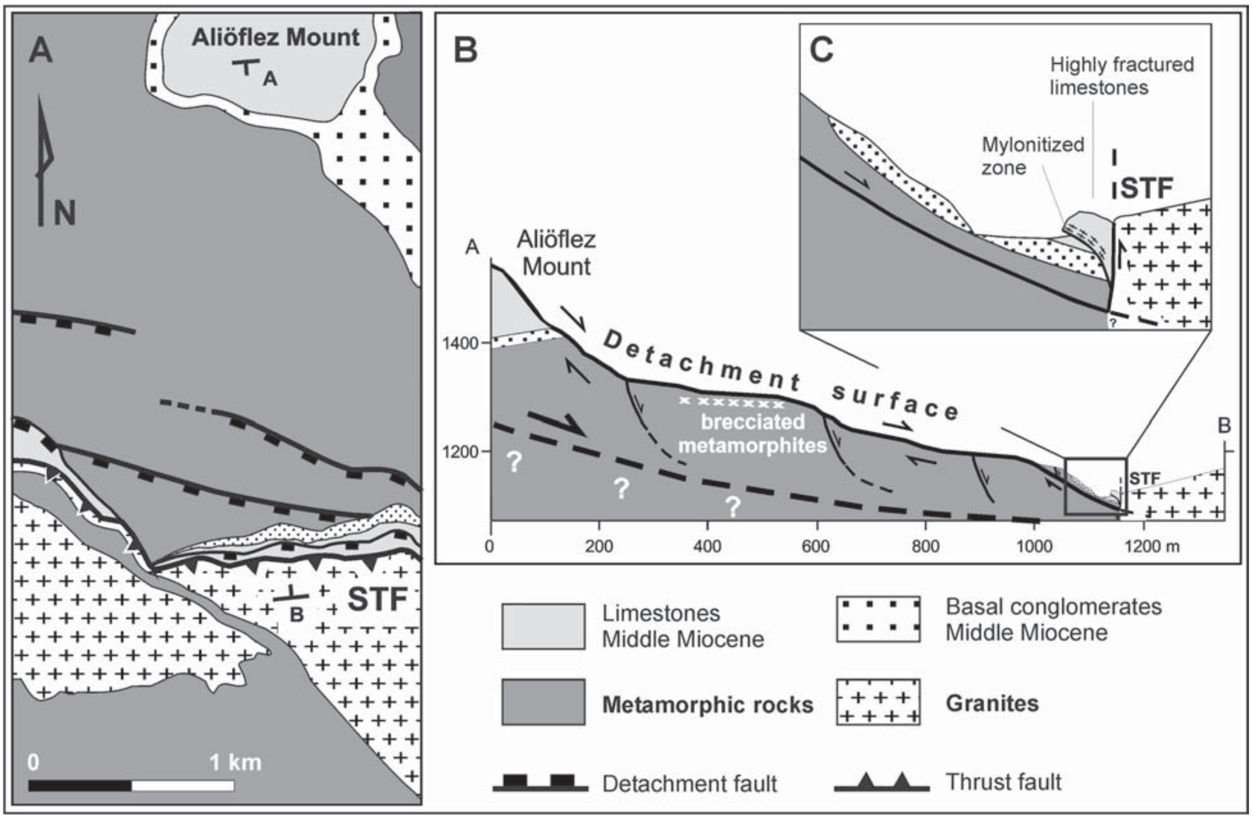

Fig. 6. **A** — Geological map of the area at the south of the Aliöflez Mount, showing the Savcılı Detachment Fault and Savcılı Thrust Fault (see Fig. 4 for its location). **B** — A–B cross-section. Dashed heavy line below the topographic detachment surface denotes the detachment fault that initiates at the northern vicinity of the Aliöflez Mount. **C** — Detail of the thrust fault zone.

plutonic rocks crop out again along the granitic belt that extends up to the Tuz Gölü Fault zone (Fig. 2).

The thrust fault can also be observed on the southern flanks of the SE-trending hills (Figs. 3, 4). One of these topographic highs is the Aliöflez Mount, comprising at the lowest parts wollastonite-bearing calc-silicatic gneisses overlain by Eocene rocks that crop out in the highest parts (Fig. 6). The surface of the southern flank of this mount is an extensional fault that will be described in the next section. The flank ends at a small stream where the sedimentary and metamorphic rocks are juxtaposed to granitic rocks along a subvertical contact. Dips of the beddings/foliations of the sedimentary/metamorphic rocks gradually increase when approaching the contact that appears to be an almost vertical reverse fault along which the southern plutonic rocks overthrusted the northern cover units. The granitic rocks of the contact are highly fractured and have an arenitic appearance. Near the contact and within the granites, subhorizontal tensional fractures filled with few centimeters thick calcite suggest subvertical stretching of the material associated with subhorizontal shortening.

Evidence of extensional tectonics

In the vicinity of the Savcılı Thrust Fault (STF), extensional tectonics are shown by the presence of low-angle normal faults cropping out between the SE–NW trending alignment of hills, such the Aliöflez Mount, at the north, and the thrust zone, at the south. There, metamorphic rock slices capped by Eocene rocks moved downslope and southwards along normal faults from the highest points of these hills, for about 2 km to end up on the thrust zone along and south of which granitic rocks crop out (for geological map and cross-section, see Fig. 6). The Fig. 7 illustrates a general view of the study area in which normal and thrust faulting are shown. In many places, varied mesoscopic structures (Fig. 8) attest to the low-angle normal faulting. Amongst them, there are faulted contacts between Eocene limestones and Eocene clastic rocks (Fig. 8a and b), fault surfaces traced with shear fractures bisected by groove marks, slickenlines and elongated pebbles of the Eocene basal conglomerates due to shearing, found in both the Eocene and metamorphic rocks (locally calc-silicate gneisses) (Fig. 8a,b,c,d,e,f and g). In the topographically highest parts, at the İnlidağ Mount for instance, the movements between gliding slices are accommodated by several N-trending strike-slip faults (Fig. 8d). There, the southern faces of the Eocene rocks are extensively fractured (marked as "stretched rocks" in Fig. 8d), possibly as a result of splitting due to extensional forces that existed between the hanging-wall rocks that slid and those that remained in place. On the gently dipping detachment fault surfaces, slickenlines are clear within Eocene rocks (Fig. 8e). At Lele Hill, normal faulting is obvious at the summit of the hill within metamorphic rocks (Fig. 8i). Downwards and in metamorphic rocks, the fault surfaces display an almost flat geometry when viewed from afar, and in detail, the surfaces are frequently cut by crescent-shaped extensional fractures with downslope concavity, most of them dipping with high angles in the same sense as the surface dips (Fig. 8h). Along these structures, metamorphic rocks are offset for several centimeters downslope so as to generate a step-like morphology on the surface. Again in metamorphic rocks, the transport direction is suggested by groove marks, but also by quartzite fragments embedded in the foot-wall block surface (Fig. 8g). Some elongate-shaped of these accreted objects have their long axes aligned parallel to the groove marks but they are not associated with a channel-shaped tail often observed along fault surfaces, an observation that is used to better determine the shear sense. Near the STF where the hanging-wall blocks can be observed, mylonitization affects the Eocene strata at the bottom parts of these blocks (see the sheared and elongated pebbles of the middle Eocene basal conglomerates in Fig. 8b and f). Further field observations are necessary to establish a detailed rock stratigraphy (undeformed, mylonitic, brecciated mylonitic zones etc.) associated with detachment faulting.

The geometry of the cross-section and kinematic markers observed suggest a general downslope tectonic transport in an approximately N-S direction and towards the south (Fig. 9).The transport is accommodated by normal faults with steeply to moderately dipping surfaces while the dip of the fault becomes almost horizontal in some parts of the flank between the northern heights and the southern STF (see Fig. 6). This geometry of this kilometric low-angle normal fault, where the dip angle of the fault surface decreases away from its topographically high sector, is similar to detachment faults already recognized

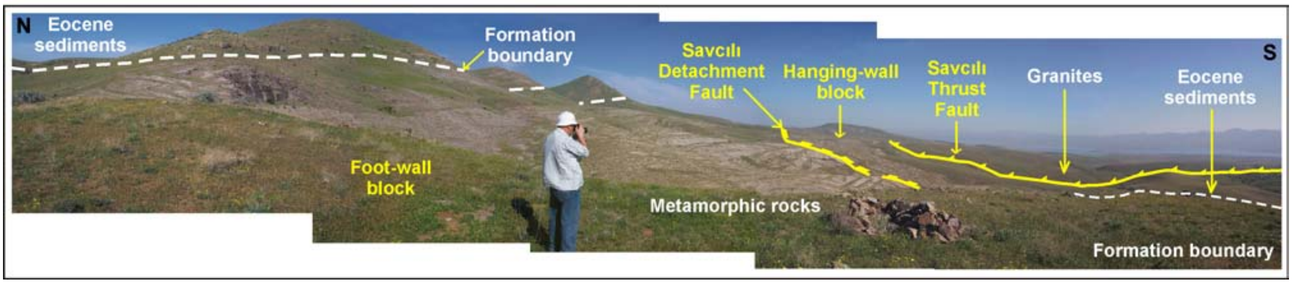

Fig. 7. Mosaic of photographs taken to show the Savcılı Detachment Fault and Savcılı Thrust Fault, in a N-S section at the western vicinity of the Aliöflez Mount.

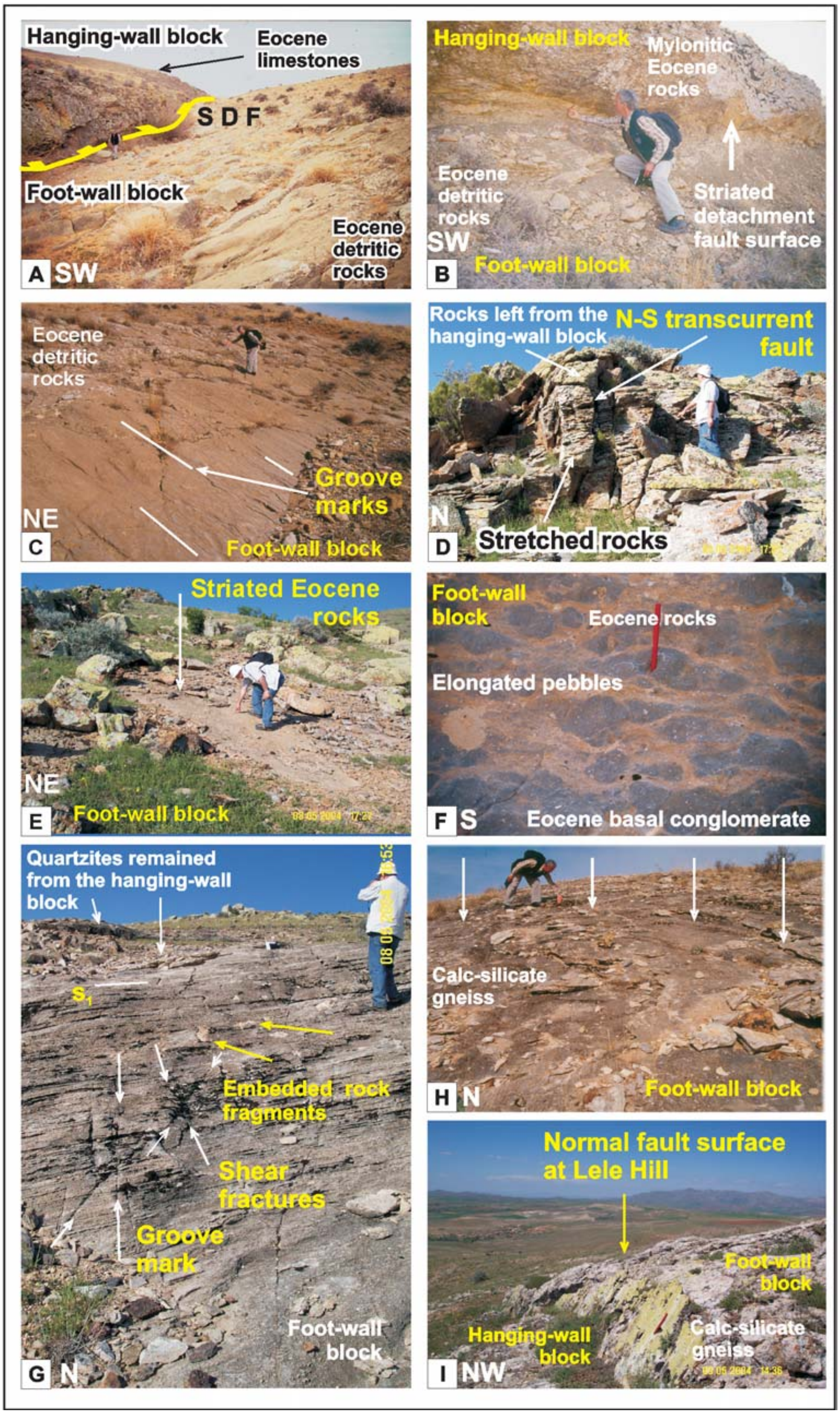

Fig. 8. Several structural aspects of the detachment faulting observed along the section shown in Fig. 7. In each picture, the view direction is given next to the inset letter as well as the lithological and structural elements are written. In (F), the length of the pen scale is 12 centimeters. In (H), the arrows indicate the trace of one of the several crescent-shaped structures observed along the fault surface and in metamorphic rocks.

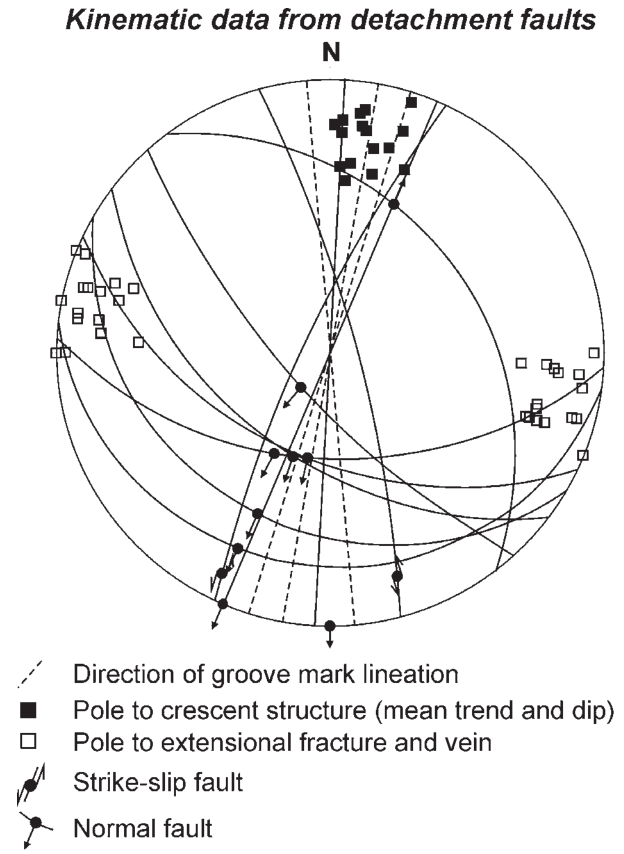

Fig. 9. Lower hemisphere Schmidt projection of structural data collected on and near the Savcılı Detachment Fault surfaces. Normal and strike-slip faults and associated lineations together with kinematic indicators like groove marks, extensional fractures and veins, and southward concave crescent structures suggest a NNE–SSW extension, accommodated by the displacements of hanging-wall units from NNE towards SSW.

from previous studies (e.g. Harris et al. 2002). We therefore call this structure the Savcılı Detachment Fault.

These gravitational movements have generated a gently rolling landscape characterized by the repetition of whitish Eocene outcrops in particular near the hill alignment. A good example can be observed near Karaabalı village where several low-angle normal faults have generated this morphological feature along several kilometers (Fig. 10). Another aspect of these tectonics is the tilting of the Eocene strata to almost vertical (Fig. 11) in the vicinity of Ebrişim village. This is likely the result of block rotations about horizontal axes due to movements along normal fault surfaces.

Significance and cause of thrusting

As seen in digital elevation models, the Savcılı Thrust Fault (STF) is associated with almost no topographic signature, and in the field, its width of not more than a hundred of meters does not suggest the presence of an important crustal structure, as it would be when considering the geotectonic role previously ascribed to this structure (e.g. Görür et al. 1998). Morphologically, the STF is much less pronounced compared to the elements of the surrounding extensional structures.

The field data do not allow us to propose a chronology for the thrust and detachment faulting events in the study area, and these events may well have occurred in different periods. Nevertheless, the folding vergence of the foreland units suggests that the crustal portions that moved by detachment faulting were stopped against the granitic masses to the south. A structural scenario in which the Eocene rocks and their metamorphic basement rocks have moved along detachment faults and were blocked by a southern

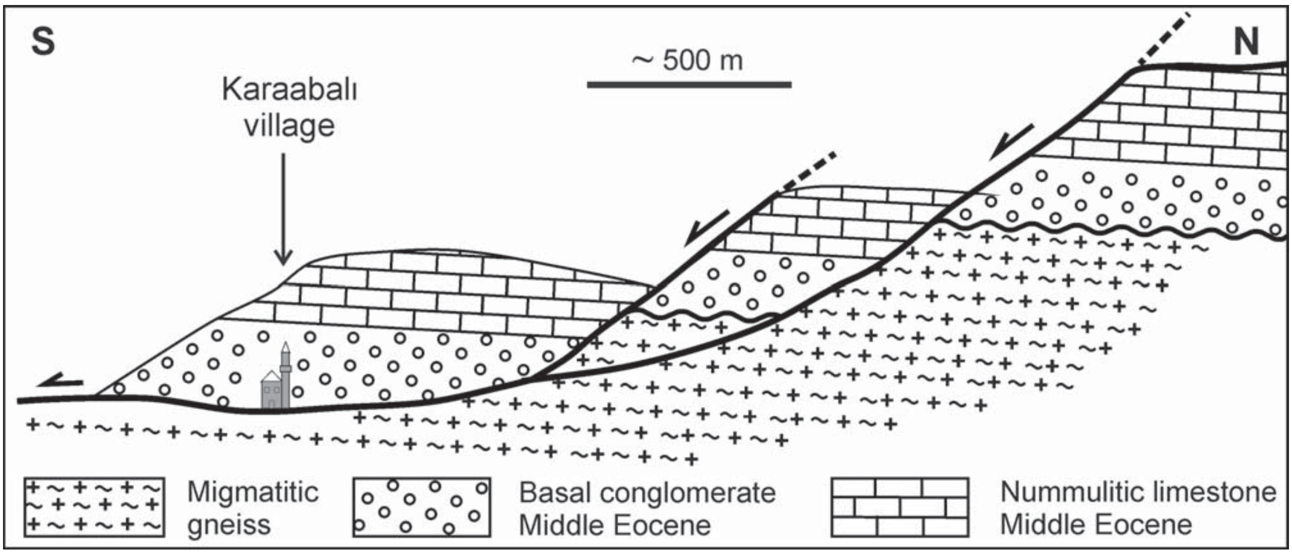

Fig. 10. Geological cross-section around the Karaabalı village (see Fig. 4 for its location). Vertical exaggeration is 2.

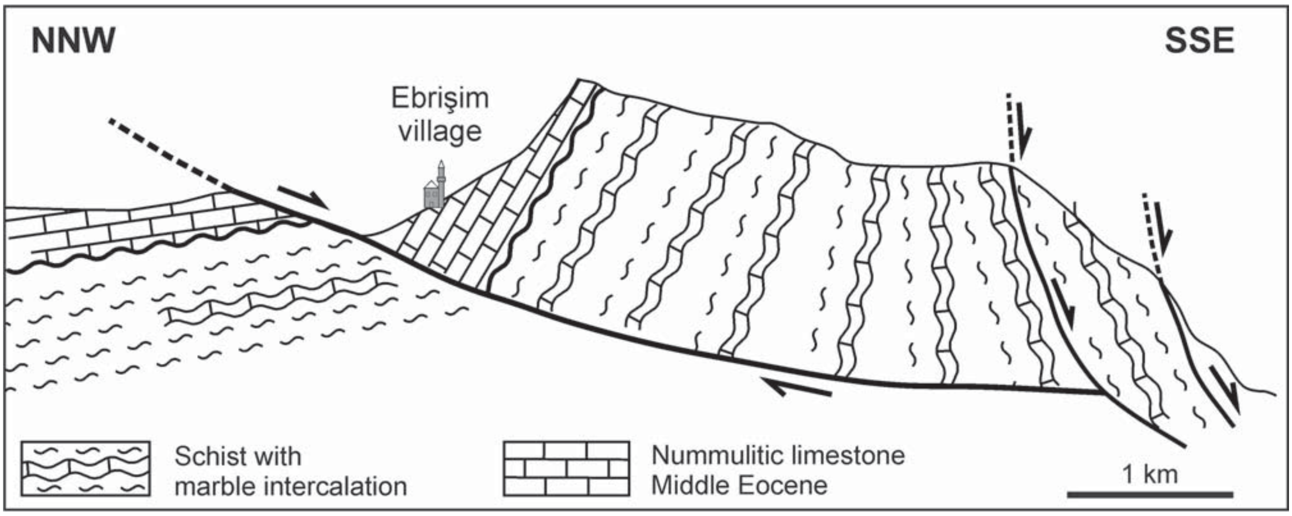

Fig. 11. Geological cross-section around the Ebrişim village (see Fig. 4 for its location).

granitic relief during a post-middle Eocene period is conceivable since the middle Eocene clastic sedimentary rocks comprise granitic pebbles indicating that during Eocene deposition clastic rocks were supplied by material from a subaerial source of granitic rocks. In the Eocene conglomerates, the nature of the clastic material becomes dominantly granitic when approaching the southern granitic exposures. Consequently, it may be proposed that a regional crustal extension was accommodated by detachment faults in the post-middle Eocene time, and that the northern slices could not move further south than the granitic heights. At this point, the question is if the granitic rocks were not affected by these extensional displacements. Alternatively, thrusting may have a structural link with the Neogene activity of the Tuz Gölü Fault (TGF), in the SW of the study area. It may be induced due to the migration of the detachment faulting activity from the study area towards the TGF, a phenomenon that is known from earlier works (e.g. Lister & Davis 1989).

Crustal extension in the study area may have initiated during the Neogene time as in the Neogene activity of the TGF (Dhont et al. 1998; Çemen et al. 1999). On a larger scale, this extension seems to be coeval with the Aegean extension at the west of Turkey (Dhont et al. 1998; Koçyiğit et al. 1999; Bozkurt 2000; Seyitoğlu et al. 2002), a geotectonic event generally attached to subductional processes between the African and Eurasian plates in the Eastern Mediterranean (e.g. Seyitoğlu & Scott 1996).

Conclusions

Field observations undertaken around the Kırşehir city, in Central Anatolia, suggest that the Savcılı Thrust Fault (STF) zone developed in an area that experienced extensional tectonics accommodated by low-angle normal faults, in the post-middle Eocene period. The vicinity and parallelism of the compressional and extensional structures as well as the geometry of the foreland folding suggest a structural causality between the gravitationally moving blocks and the thrusting event. We interpret the STF as a secondary structure developed on the northern flank of a granitic belt due to the collision of this belt front with the southerly gliding metamorphic and sedimentary slices. Further research has to be concentrated to understand how this thrust formed in the extensional regime and how this regime is associated with the southern nearby detachment faulting event along the Tuz Gölü Fault zone.

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