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The Bolkar Mountains (Central Taurides, Turkey): a Neogene extensional thermal uplift?

Bolkar Dağları (Orta Toroslar, Türkiye): Neojen ekstansiyonel termal bir yükselme mi?

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Abstract

This paper concerns the neotectonics of the Bolkar Mountains, belonging to the Central Taurides in Southern Central Anatolia. The study is based on observations on Synthetic Aperture Radar (SAR) scenes of the European Remote Sensing (ERS) satellite and Digital Elevation Model (DEM images, complemented with field structural analysis. It is revealed that extensional tectonics prevails in the area during the Neogene. In the northern sector, movements trend west and are attributed to the westward escape of Anatolia towards the Aegean basin. Further south, movements turn progressively to the southwest then south and are related to the opening of the Adana-Cilicia basin probably as early as the Late Oligocene-Early Miocene. More importantly, uplift of the Bolkar Mountains occured in the Neogene coeval with this extension. The belt is interpreted as the northern uplifted shoulder of the Adana-Cilicia basin, due to thermal effects of Neogene lithospheric stretching and thinning. This is the consequence of the inception of a backward and downward retreat of the African subducting slab beneath Cyprus in the Late Oligocene-Early Miocene, which has resulted in a wide extension in the overriding plate. Transition between high elevations in the Central Taurides and deep bathymetry in the Cilicia basin suggests that gravitational forces may also contribute to the extension during the Neogene-Quaternary.

Key Words: Central Taurides, Neotectonics, Stress, Strain, Slab retreat

Öz

Bu makale Güney Orta Anadolu'da, Orta Toroslara ait Bolkar Dağlarının neotektoniği ile ilgilidir. Çalışmanın temelini, Avrupa Uzaktan Algılama (ERS) uydusunun Sentetik Apertür Radar (SAR) resimleri ve Sayısal Arazi Modelleri (SAM) gözlemleri oluşturmakta, yapısal arazi analizleri de bunları tamamlamaktadır. Neojen süresince çalışma alanının ekstansiyonel bir tektoniğin etkisi altında kaldığı anlaşılmaktadır. Kuzeyde, hareketler batı yönlüdür ve Anadolu'nun Ege havzasına doğru batıya kaçışına atfedilmektedir. Daha güneyde, hareketler gitgide GB ve G'ye doğru dönmektedir ve Adana-Kilikya havzasının olasılıkla en erken geç Oligosen-erken Miyosen'de açılmasına bağlıdır. Daha da önemlisi, Bolkar Dağları bu ekstansiyonla eşzamanlı olarak Neojen'de yükselmiştir. Bu kuşak, Neojende litosferik çekilme (streetching) ve incelmenin termal sonucu olarak, Adana-Kilikya havzasının yükselmiş kuzey omuzu şeklinde yorumlanmıştır. Bu, geç Oligosen-erken Miyosen'de Kıbrıs'ın altına dalan Afrika slabının geriye ve aşağı doğru çekilmesinin bir sonucudur ve üstte kalan plakada önemli bir ekstansiyon oluşturmuştur. Orta Torosların önemli yükseltilerinden Kilikya havzasının derin batimetrisine geçiş, Neojen-Kuvaterner ekstansiyonunun oluşmasında yer çekimi kuvvetlerinin de rol oynadığını öngörmektedir.

***Anahtar Kelimeler :** Orta Toroslar, Neotektonik, Stres*

INTRODUCTION

The 1300 km long Taurus belt rises along the southern edge of the Anatolian Plateau, between Iraq and the Aegean region. Mountain building in southern Turkey is a consequence of the recent geological evolution of the Tethyan domain. The Taurus region can be divided into three main segments (Blumenthal, 1960; Gutnic, 1968; Özgül, 1983): (1) the Western Taurides, from the Aegean region to the right lateral Kırkkavak fault, (2) the Central Taurides, from the Kırkkavak fault to the left lateral Ecemis fault, and (3) the Eastern Taurides corresponding to the Bitlis suture zone (Figure. 1).

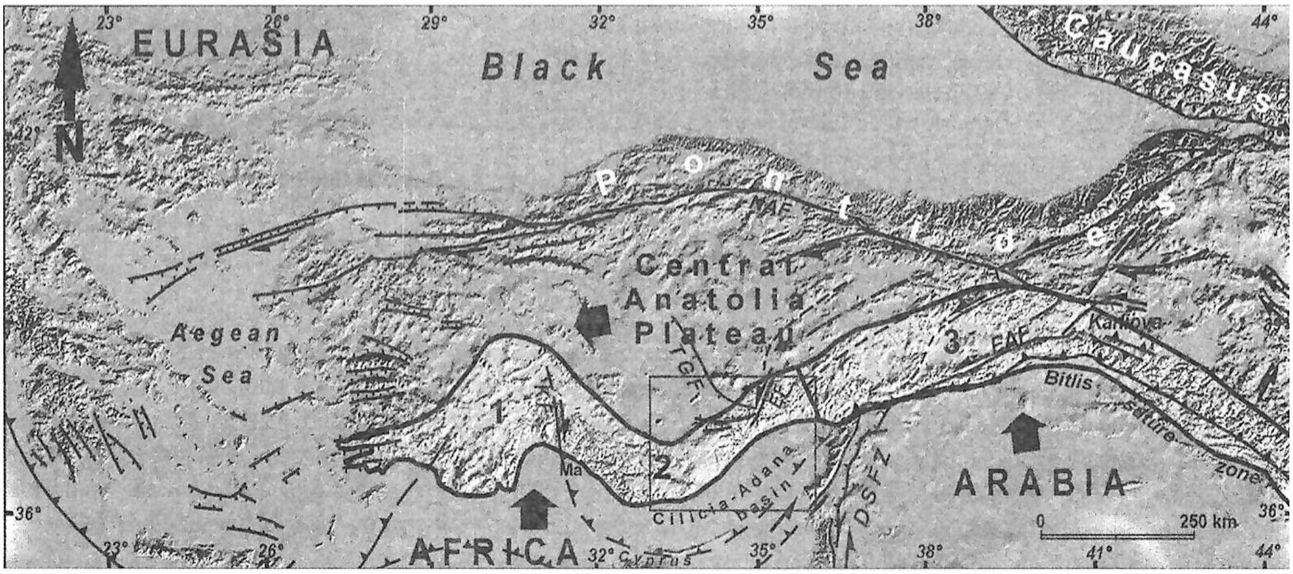


Figure 1. Shadowed image of a Digital Elevation Model of the Eastern Mediterranean showing main tectonic features of the region. Large arrows represent relative plate motions within the Eurasian reference (Reilinger et al., 1997). Bright grey tones represent the Taurus belt divided in: 1, Western Taurides; (2), Central Taurides; and (3), Eastern Taurides. Rectangle = study area. DSFZ = Dead Sea fault zone; EAF = East Anatolian Fault; EF = Ecemis fault; Ma = Manavgat; KF = Kirkkavak fault; NAF = North Anatolian Fault; TGF = Tuz Gölü fault.

The tectonic history of the Taurides has been widely studied (e.g., Brunn et al, 1971; Monod, 1977; Gutnic et al., 1979; Şengör and Yılmaz, 1981; Özgül, 1983; Şaroğlu et al., 1983; Hayward, 1984; Marcoux, 1987; Yılmaz, 1993; Frizon de Lamotte, 1995), but the Central Taurides (Figure 2) have been less described in the frame of the Alpine orogeny. Özgül (1983) and Tekeli et al. (1983) have retraced the tectonic evolution of this central range during the Mesozoic-Paleogene, showing that several compressive events were dominant during this period. In this paper we shall focus on the Neogene history of the eastern part of the Central Taurides, namely the Bolkar Mountains, where occurrence of Early-Middle Miocene sediments now at 2000 m elevation is related to a Late Miocene uplift of the belt.

Digital Elevation Models (DEMs) covering areas at regional scale have been digitally processed to generate images of the topography. These images express "pure" morphology, i.e., not obscured by surface effects such as vegetation, contrarily to satellite images. They display the regional morphology which, in tectonically active zones, is mainly the result of the ongoing deformation. High ground resolution (12.5 m) images acquired by the Synthetic Aperture Radar (SAR) of the European Remote sensing (ERS) satellite (wavelength, 5.6 cm) allow more detailed mapping of the neotectonics because these data are particulary sensible to topographic slope dip and strike variations (Chorowicz et al., 1995).

The Central Tauride Mountains are part of the Central Anatolian region. They lie between the Adana-Cilicia basin in the south and the Central Anatolian Plateau in the north (Figure 1 and 2). The Central Anatolian Plateau has been subjected to Mio-Plio-Quaternary deformation and volcanism (Innocenti et al., 1982; Şengör et al., 1985; Pasquarè et al., 1988; Le Pennec et al., 1994; Aydar, 1992; Temel, 1992; Temel, 1992; Aydar et al., 1993). This region is part of the Anatolian block moving westward by lateral extrusion as a consequence of north-south convergence between Africa-Arabia and Eurasia (McKenzie, 1972; Şengör et al., 1985; Dewey et al., 1986). The aim of this paper is to describe the structures resulting from active tectonics in this area and to understand its tectonic development. We shall argue a new model based on the thermal uplift of the Bolkar Mountains considered to be the northern shoulder of the Adana-Cilicia basin. DEM and radar images will constitute the main data source for regional analysis of the deformation geometry. Our field observations will then assume a full significance within a better known tectonic framework.

REGIONAL STRUCTURAL FRAMEWORK

Geodynamic context

Convergence between Africa-Arabia and Eurasia began in the mid-Cretaceous (Biju-Duval et al., 1977; Livermore and Smith, 1984; Yazgan and Chessex, 1991), inducing Campanian-Maestrichtian southward obductions over Anatolia and Africa-Arabia, and Eocene-Early Oligocene collision and emersion in the Pontides (Şengör and Yılmaz, 1981). Red Sea continental rifting and individualisation of Arabia began at the Oligocene-Miocene boundary (Le Pichon and Gaulier, 1988). In the mid-Miocene, initiation of left-lateral motion along the Dead Sea Fault zone occurred (Joffe and Garfunkel, 1987), coeval with collision in the Eastern Turides (Şengör, 1979; Şengör and Yılmaz, 1981; Görür, 1985; Dewey et al., 1986). Uplift of Eastern Anatolia began in the latest Serravalian-Tortonian time to be assembled more or less to its present configuration (e.g. Dewey et al., 1986; Yılmaz, 1993).

Westward lateral extrusion of Anatolia has been established at c. 13 Ma (McKenzie, 1972; Dewey et al., 1986; Le Pichon et al., 1995) or at c. 5 Ma (Tatar, 1975; Barka and Hancock, 1984; Barka and Kadinsky-Cade, 1988; Koçyiğit, 1989; Barka, 1992; Westaway, 1994; Dhont et al., 1988; Koçyiğit and Beyhan, 1998) together with initiation of motion along the North Anatolian fault. Escape is going on in between the North and East Anatolian faults, toward the Aegean domain where extensional tectonics largely dominates (e.g., Jackson, 1994). The debate is still open concerning the age of initiation of this extension, which ranges between the Early Miocene (~19-20 Ma; Jolivet et al., 1994a; Seyitoğlu and Scott, 1995) and the Late Miocene (12 Ma; Şengör, 1987; Görür et al., 1995). The extension pattern is ascribed to westward lateral motion of the Anatolian block due to Arabia-Eurasia collision in Eastern Anatolia (Şengör et al., 1985; Taymaz et al., 1991; Görür et al., 1995), back-arc spreading (Le Pichon and Angelier, 1981; Gautier and Brun, 1994), slab rollback (Meulenkemp et al., 1988; Lee and Lister, 1992), or gravitational spreading following crustal thickening (Seyitoğlu and Scott, 1995; Meijer and Wortel, 1997).

We shall not discuss possible changes in the geodynamics during the past 13 Ma and consider the Late miocene to present-day time globally taking into account only finite displacements and deformation during this time interval.

Regional geology

Bolkar Mountains

The Bolkar Mountains form a belt with peaks up to 3500 m, lying more or less parallel to the Cyprus arc (Figure 2).

The belt consists of crystalline and Mesozoic-Paleogene southvergent tectonic units affected by folds, thrusts and transcurrent faults resulting from two main tectonic events in the Late Cretaceous and Late Eocene-Oligocene (*e.g.*, Özgül, 1983). The Bolkar Mountains have raised since the Late Miocene (Özgül, 1976) as attested by marine Lower to Middle Miocene sediments now at elevations more than 2000 m, unconformably overlying ophiolitic and platform carbonate rock units which were thrusted during the compressive events. The Late Neogene uplift has been interpreted as resulting from thrusting (Williams and Unlügenç, 1992) or as a wide anticlinal fold (Şaroğlu et al., 1983).

In their eastern part, the Bolkar Mountains are cut by the Ecemis fault zone, striking NNE in its southern part, which may have accommodated about 80 km of left-lateral slip motion since the Eocene (Özgül, 1976; Scott, 1981; Şengör and Yılmaz, 1981).

Adjacent areas

The Central Anatolia Plateau

Extensive volcanism and neotectonic features are widely expressed in this region. Volcanism developed since the Late Miocene (Innocenti et al., 1982; Pasquarè et al., 1988). It is mainly made of calk-alkaline products (Innocenti et al., 1982) and was interpreted as an arc

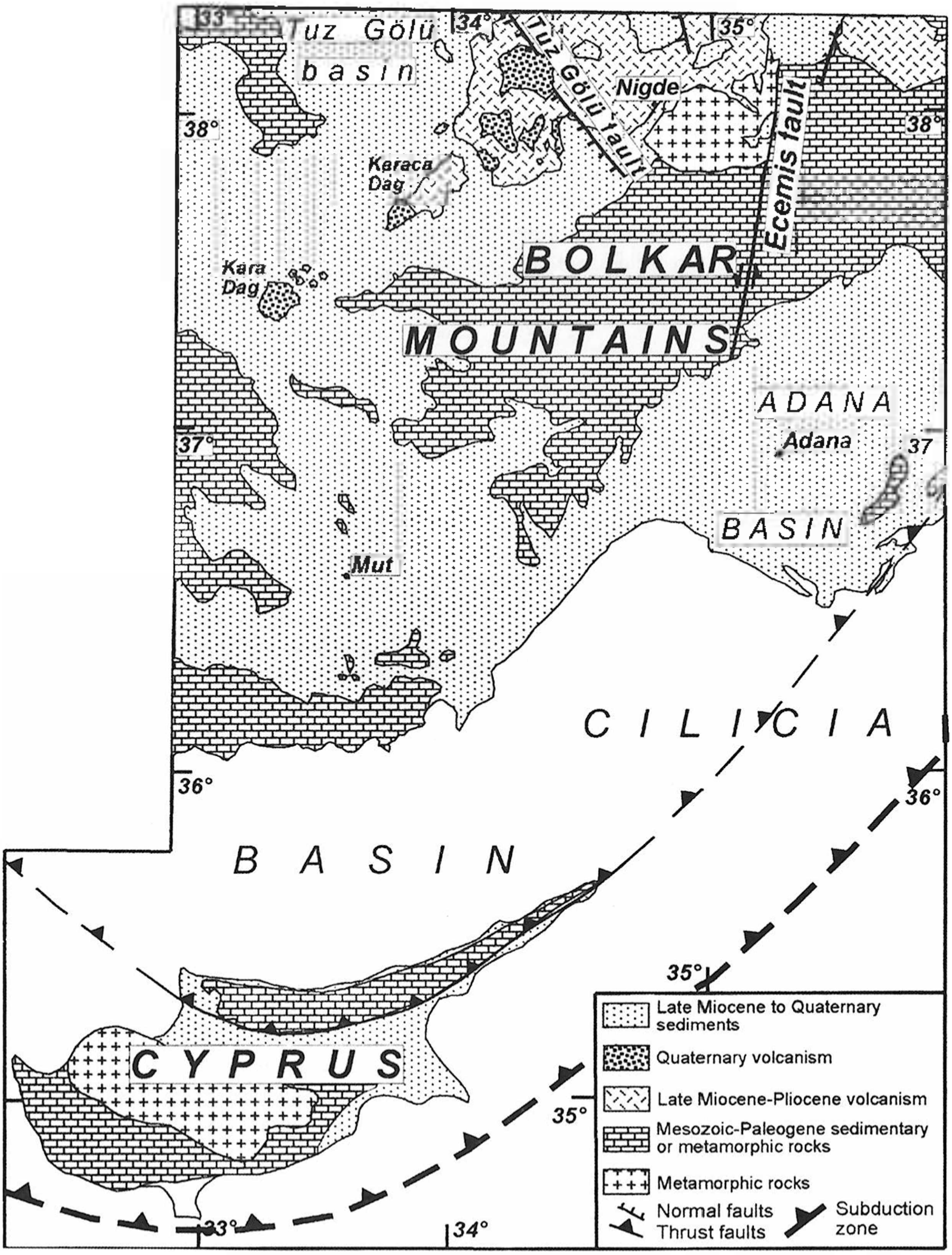


Figure 2: *Geologic sketch map of the southeasternmost part of the Mediterranean region –extending from South-Central Anatolia to Cyprus, compiled from the 1 / 2.000.000 geological map of Turkey (MTA, 1989) and the geological map of Cyprus (Flecker and Robertson, 1995).*

related to the north-dipping oceanic slab of the African plate (Innocenti et al., 1975; Innocenti et al., 1982) or as the record of active faults motion (Koçyiğit and Beyhan, 1998). This volcanism has been considered either to be related to compression (Pearce et al., 1990; Yılmaz, 1990) or to be the consequence of regional tension (Temel, 1992). According to Şengör et al. (1985), the Central Anatolian Plateau presently undergoes a moderate NE-SW trending compression. Koçyiğit and Beyhan (1998) explain the fault pattern and volcanic activity of the region to be related to a regional NNW-SSE-directed shortening yielding a ENE-WSW-directed extension. Barka and Reilinger (1997) shared this opinion by proposing that a flatten slab is presently subducting underneath Cyprus leading to compression in the overriding plate as far as Crimea. However, Pasquare et al. (1988) and Toprak and Göncüoğlu (1993) argued for an Early Pliocene east-west trending tension. Main tectonic features of the Central Anatolian Plateau are the Tuz Gölü and Ecemiş fault zones (Figure 3a and 3b).

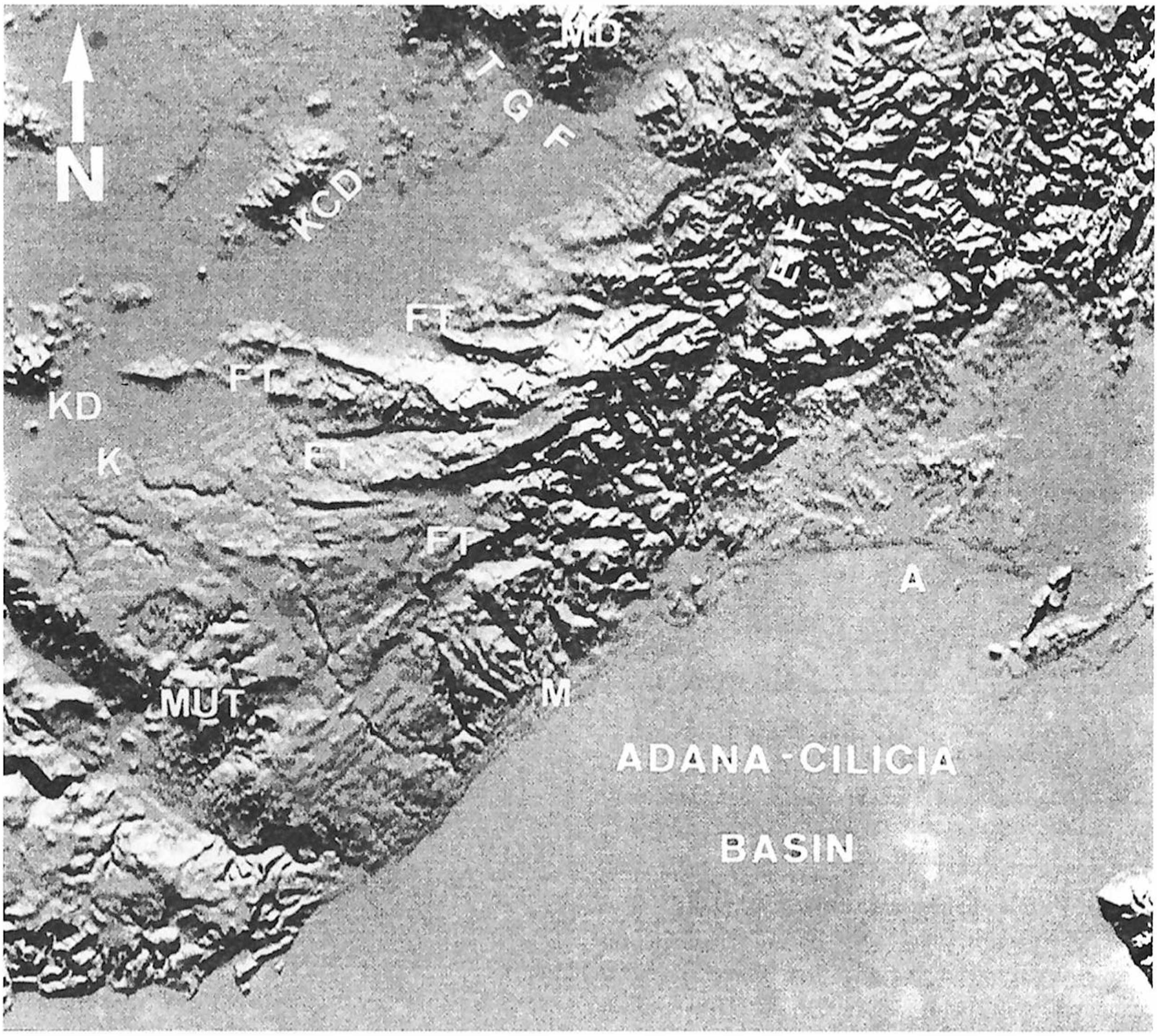


Figure 3: (a) Image of the Digital Elevation Model of the study area, at 500 m ground resolution, artificially illuminated from the North. FT, normal faults of the Central Taurus range; A =Adana; K= Karaman; KCD = Karaca Dağ; KD = Kara Dağ; MD = Melendiz Dağ; M = Mersin; TGF = Tuz Gölü fault. X = the Tuz Gölü fault ends against the Ecemis fault.

The NW-striking Tuz Gölü fault zone is the northeastern boundary of the Tuz Gölü basin (Arikan, 1975; Görür et al., 1984; MTA, 1989), which forms a NE-dipping half-graben, outcropping at mean elevation 1000 m, filled with 2000 m of Neogene sedimentary and volcanic rocks lying above several thousand meters thick Eocene-Oligocene sediments.

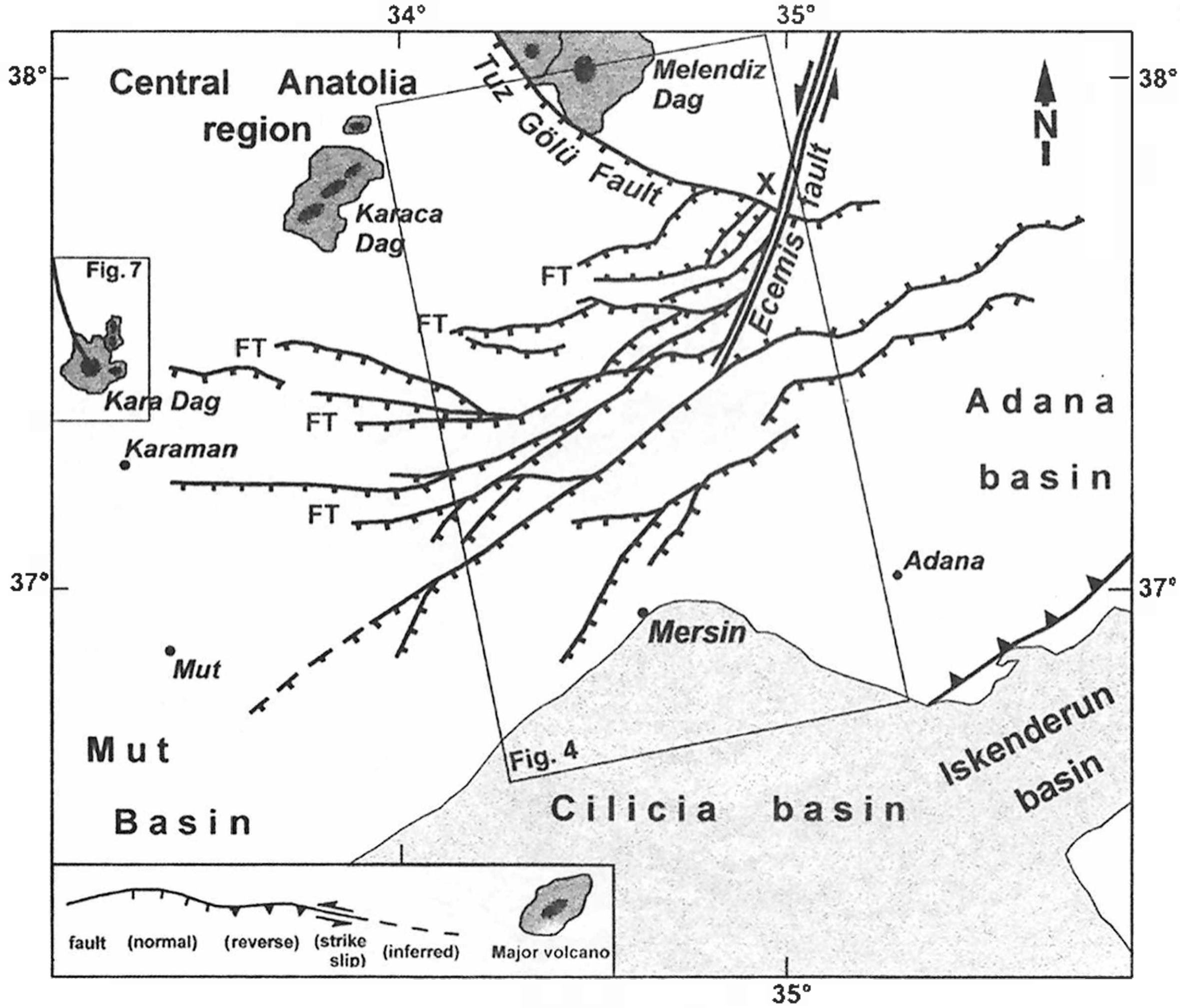


Figure 3: (b) Interpretation of Figure 3a.

The Cilicia-Adana Basin

The Cilicia-Adana basin is located in the easternmost sector of the Mediterranean coast of Turkey and is bounded by the Bolkar Mountains to the north. Southwards it extends up to Cyprus beneath at 1000 m depth as indicated by offshore data (Evans et al., 1978). The Late Cenozoic stratigraphic record of the Adana basin has been revised by Yetiş et al. (1995). The basin is filled with Aquitanian-Burdigalian patch reef rocks drowned in the Late Burdigalian-Early Langhian times causing a sharp transition to deep-marine turbidites (Gürbüz, 1993). During Late Langhian and Serravalian times, the basin was infilled and shoaled, leading ultimately to the deposition of deltaic sequences in the Tortonian and Messinian. The basin emerged in the Quaternary but remains a low plain.

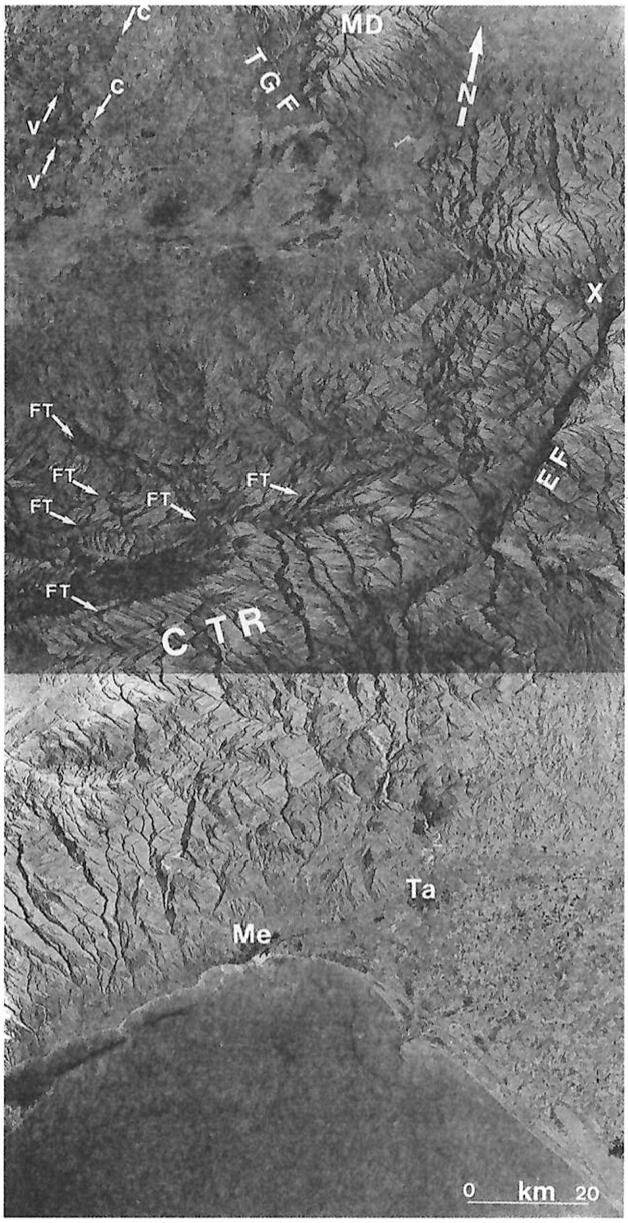
In northern Cyprus, Late Oligocene conglomerates has been interpreted as alluvial fans derived from the Adana basin in the northeast (Robertson and Woodcock; 1986). Fans have prograded across a broad alluvial plain in the Cilicia basin. A thick succession of Early Miocene marine turbidites having their source from the northeast overlies these conglomerates.

The Cilicia-Adana basin has been interpreted as a post-collisional basin originated in the Burdigalian as a consequence of the collision between Arabia and the Anatolia (Williams et al., 1995). In Late Miocene-Plio-Quaternary time, it may be also regarded as a releasing bend basin (Chorowicz et al., 1994) developed along faults which prolongate the left-lateral East Anatolian fault, related to lateral extrusion of Anatolia. Alternatively, it may have opened in the Early Miocene as an extensional fore –arc basin north of the Cyprus trench subduction zone (Jackson and Mc Kenzie, 1984; Eaton and Robertson, 1993; Payne and Robertson, 1995).

DATA AND METHODOLOGY

Data

A Digital Elevation Model (DEM) of the whole area has been interpolated using a kriging method from the digitisation of elevation contour lines of topographic maps at 1/250.000 scale. It covers 230x200 km^2 with 500 m horizontal ground resolution (Figure 3a). The DEM shadowed image yields a synoptic view that permits mapping of large tectonic features. Such data provide an overall better description of a region when they are coupled with satellite images (Chorowicz et al., 1994).We have analysed a mosaic of two ERS-1 SAR images (Figure 4).



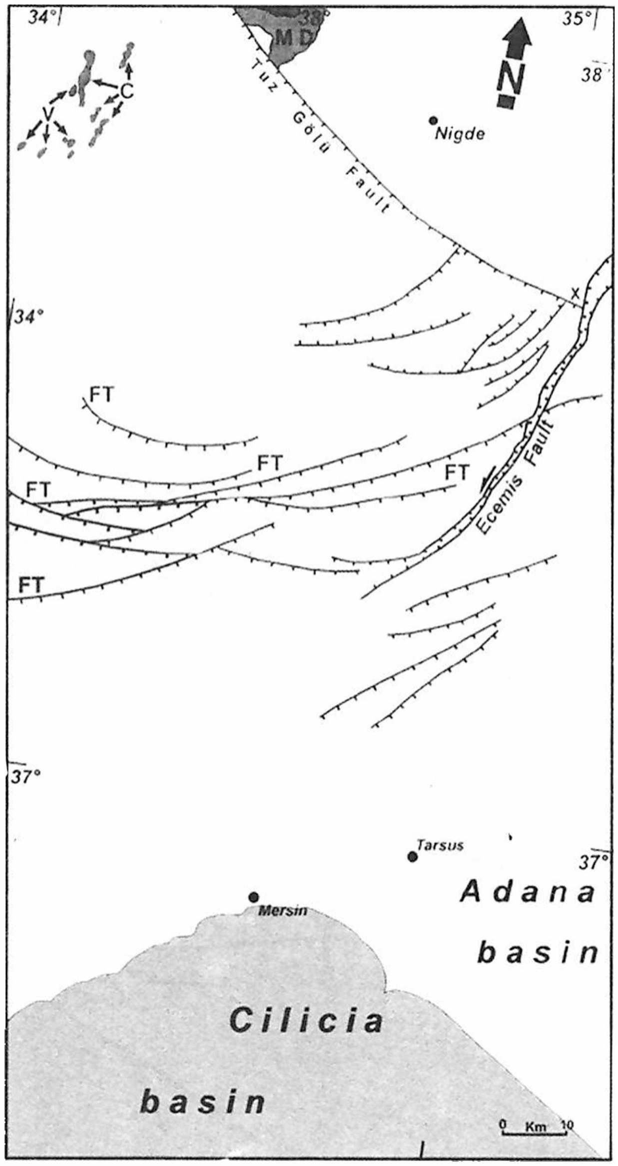


Figure 4: *(a) Mosaic of SAR ERS-1 images (negative view; descending mode, looking east) of part of the Bolkar Mountains. Location on Figure 3b. C = linear clusters and volcanoes; CTR = Cilician Taurus range; EF = Ecemis fault; FT = normal faults; Me = Mersin; MD = Melendiz Dağ; Ta = Tarsus; TGF = Tuz Gölü fault; V = elongate volcanoes; X = termination of the Tuz Gölü fault against the Ecemis fault.*
(b) *Interpretation of Figure 4a.*

Each image was generated from original tape of the digital scene by standart processing including linear stretching. It covers 100x100 km^2 at 12.5 m ground resolution, permiting a detailed mapping of the area. Illumination is from ENE. We have produced negative prints in order to express in black the slopes facing the radar. Detailed information is well exposed by various grey tones on the slopes backing the illumination.

Methodology

Recent faults are determined on DEM and SAR ERS-1 images from their distinct, poorly eroded scarps or because they affect the recent (13-0 Ma) rocks. Our observations have consisted in measurement of tension fractures and orientations and sense of-motion of striated fault planes (Figure 6). Special emphasis has been placed on the striations directly observed on the major mapped fault planes, on which the main part of the regional displacements occurred. This method which privileges one striation set is well demonstrated at site 8 (Figure 5, 7a and 7b). We have also accounted for striations observed on smaller faults paralleling the nearby main one, assuming that in a given local stress field parallel faults have the same mechanism, for a given tectonic phase. We have plotted on the trace of main faults the azimuth plunge of striations, with indication of the movement (Figure 5). Along the major faults we have generally found only one set of striations, supposed to be related with the last displacement.

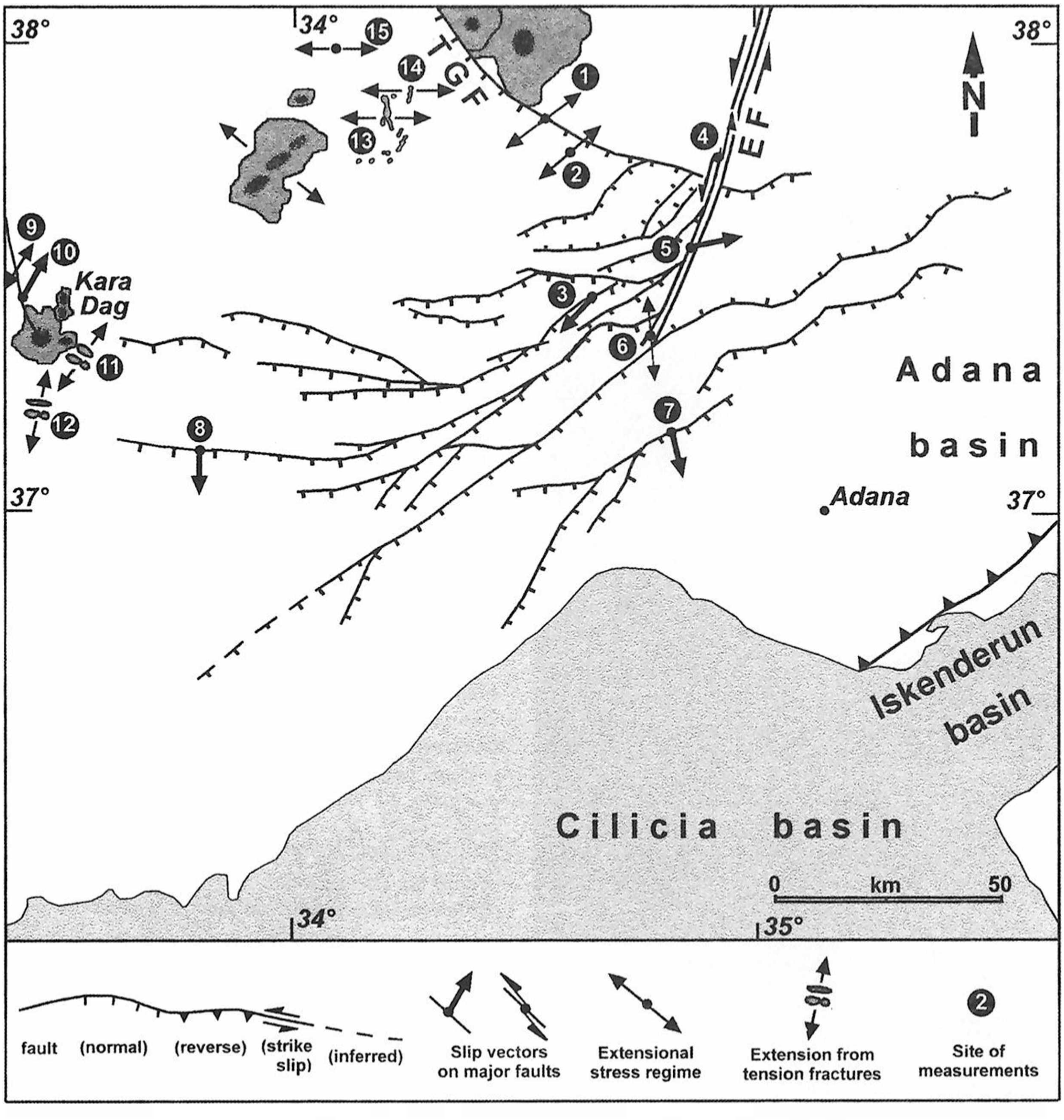


Figure 5: Synthetic map of tectonic features. EF = Ecemis fault; TGF = Tuz Gölü fault. Numbers in circle are sites of structural analysis (see Figure 6).

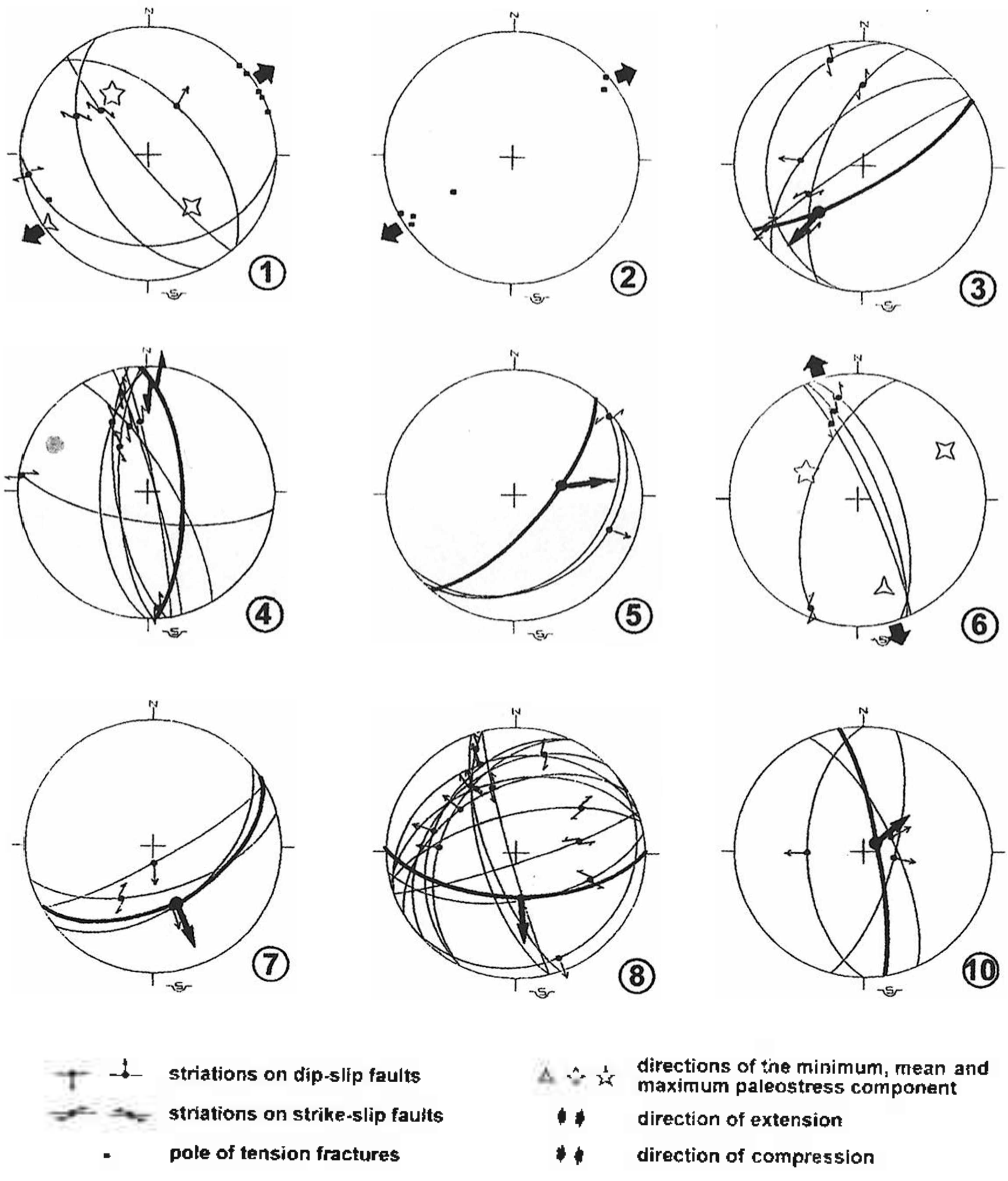


Figure 6: Field structural analysis data. Schmidt nets, lower hemisphere. Thick lines are major (mapped) fault planes and related striations. Sites (number in circle) are located on Figure 5.

In sites not located along major mapped faults, we have used the striations on the various fault surfaces to calculate the orientation of the local paleostress tensor using the Angelier's (1990) method. We admit that local strain due to minor faults is related to local paleostress pattern. Prior to carrying out the data inversion, all structural measurements were recalculated to correct the tilting of the strata. We considered also that all measurements from any one site, which are of the same age, are presumed to be related to a unique paleostress pattern. The fact that the results of our calculations are consistent from place to place throughout the South –Central Anatolian region justifies this hypothesis. When several deformation events were assumed, the measurements were sorted by relative age at each site. To explore superimposed deformations, attested by observation on fault planes of several striation sets, we employed the 4-D method of Angelier (1984). For each striation measurement, the discrepancy with the computed theoretical slip-

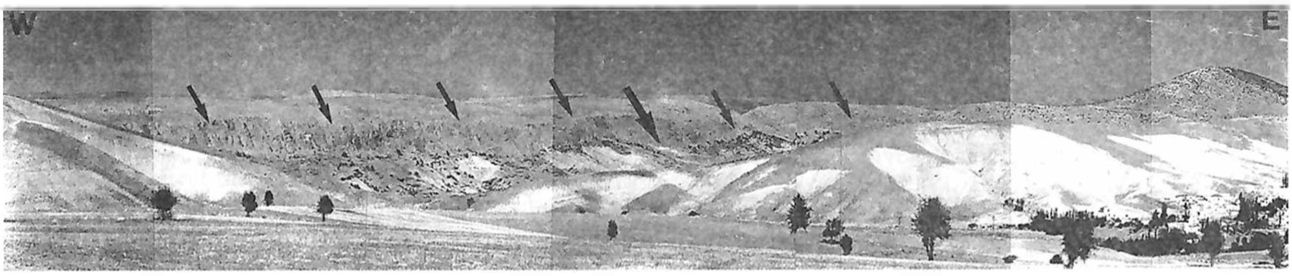


Figure 7: (a) Panorama showing a E-W trending normal fault scarp affecting marine sediments of Early-Middle Miocene age at 1800 m elevation in the Bolkar Mountains (site 8 on Figure 5. And 6). The large arrow indicates the N55^{0}S-dipping striated normal fault mirror (Figure 9b). In the foreground the landscape clearly evidences a north-dipping tilted block resting on the hanging-wall of fault scarp. Measurements were taken (1) directly on the fault mirror, concerning dip-slip corrugations (thick line in site 8 of Figure 6), and (2) in the hanging-wall compartment concerning smaller faults. This is a good example showing that the striations directly observed on the E-W trending major fault plane well describe the regional displacement (southward motion). The other smaller striated fault planes of the hanging-wall compartment develop due to collapse of the block during the main fault activity.

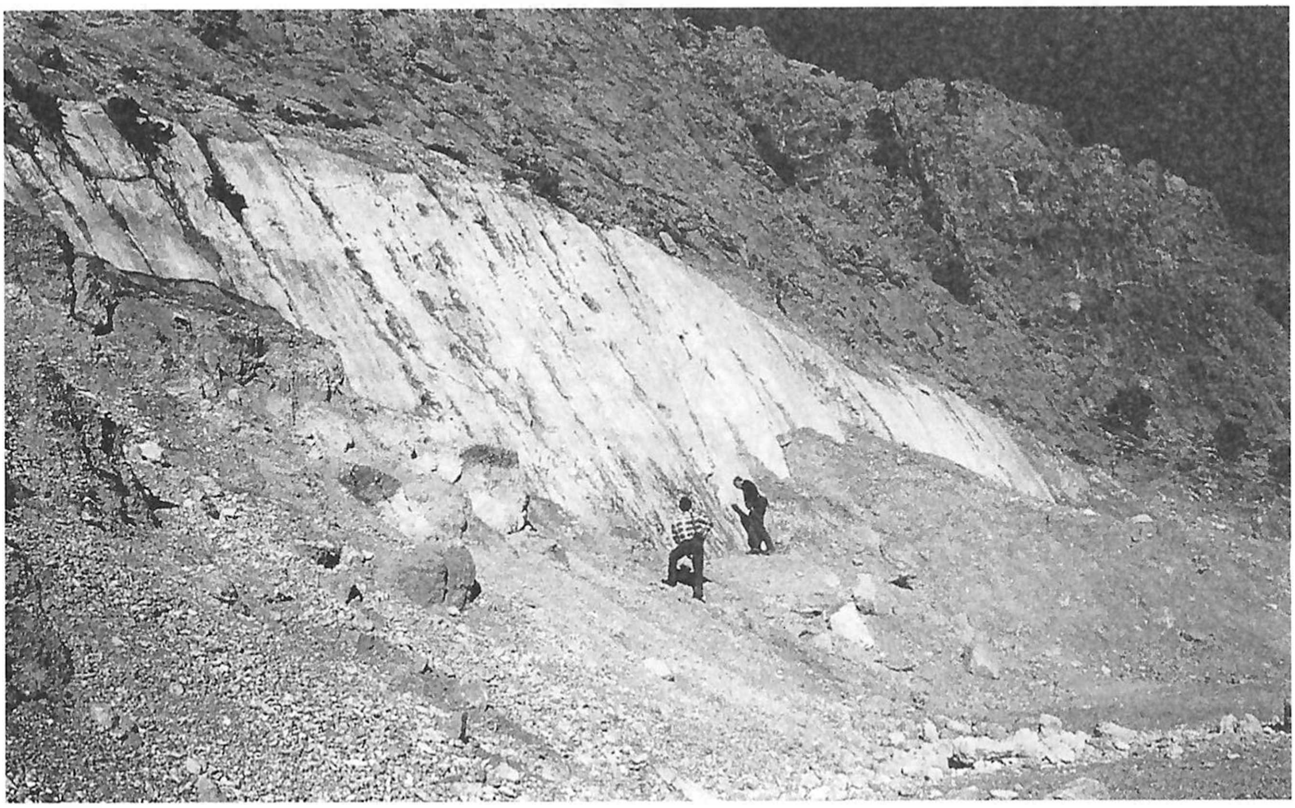


Figure 7: (b) View of the E-W fault mirror (Figure 7a) cleared by countrymen for open quarry working.

vector is estimated in order to appreciate their compatibility either with one slip- vector or with several phases of deformation. To characterise the paleostress at each site, we have used parameter PHI= $(\sigma_2 - \sigma_3) / (\sigma_1 - \sigma_3)$ that ranges from 1 to 0. The stress ellipsoid has three well distinct axes when PHI-values are close to 0.5. PHI-values approaching 0 indicate that norm value of σ_3 is close to σ_2

STRUCTURAL ANALYSIS

Bolkar Mountains

The high mountains of the Central Taurides and major volcanoes are the highest peaks in the region. The Ecemiş fault is well displayed on both DEM (Figure 3) and SAR (Figure 4) images where it cuts the Taurus range to individualise the Central and Eastern Taurides. Site 4, located close to the main fault in Oligo-Miocene conglomerate and reddish clay (Figure 5), indicates left-lateral strike-slip movement showing SSW-directed motion along the Ecemiş fault. Local (collapse?) movements may occur in Quaternary alluvial terrace gravel (site 5) close (100 m) to the Ecemis structural valley, indicating N80^0-directed transtensional displacement.

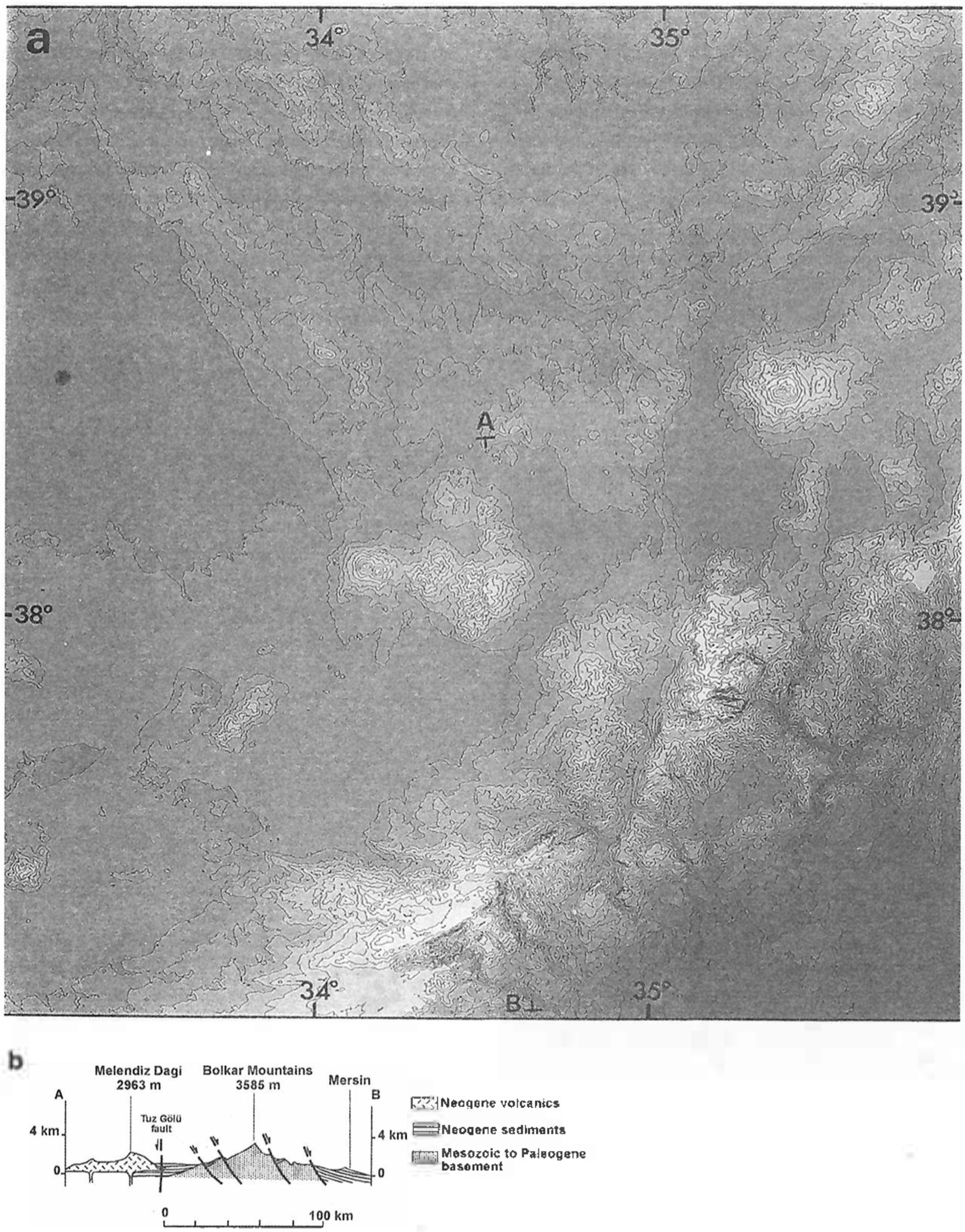


Figure 8: (a) Relative elevation map of the studied area from Digital Elevation Model. The higher altitudes (light tones) are located in the Bolkar Mountains, except for the largest volcanoes. (b) Topographic geological corss-section showing N-dipping tilted blocks and nond faults.

To the southwest, the Ecemiş fault connects in the Central Taurides with a series of faults that die out westward (FT on Figure 3 and 4). These faults have been plotted on a topographic cross-section (Figure 8b). They bound north-dipping tilted blocks and are extensional. In site 8, we have observed a large normal fault affecting the marine Early-Middle Miocene layers and their Mesozoic basement (Figure 5 and 7a and 7b). The normal fault is dip-slip and attests to recent local N-S extension. In site 3, extensional oblique-slip faults reactivate ancient thrust faults and testify to recent SW-directed horizontal displacement (Figure 6).

In site 7, relative extensional displacement is directed N160^{0}E. Measurements in site 6 give a N165^0- trending σ_3. All these measurements show Neogene dip-slip to oblique-slip movement along active faults. No reverse faulting has been documented throughout the area. We conclude that the Mio-Plio-Quaternary Bolkar Mountains, unlike the Eastern Taurides, are not compressive but submitted to tension. Elevations in the Central Taurides are the highest in the studied area (Figure 8a), except for major volcanoes. These high mountains do not result from compression, as is the case in the Eastern Taurides.

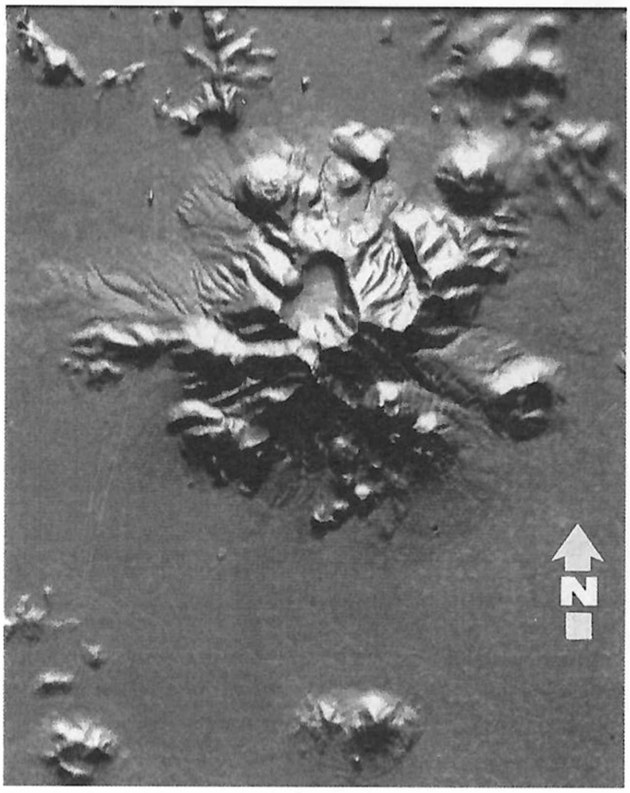
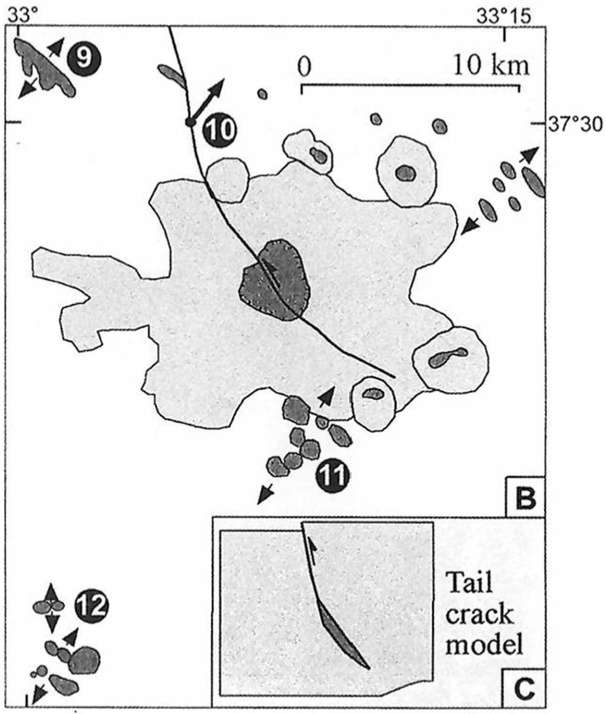


Figure 9: (a) Digital Elevation Model image of the Kara Dağ volcano region, illuminated from north, at 200 m ground resolution. Location on Figure 3b.

Central Anatolia Plateau

The DEM (Figure 3) and SAR images (Figure 4) well express the south-eastern termination of the Tuz Gölü fault where it ends against the Ecemis fault (X on Figure 3 and 4). Microfaults and tension fractures affecting Late Miocene rocks (sites 1 and 2 on Figure 5) indicate ENE- to NE-trending post - Late Miocene extension. No reverse faulting has been recognised in this area, contrarily to Koçyiğit and Beyhan (1998) who have mapped a southeastward thrusting along the Tuz Gölü fault termination.

In the Tuz Gölü basin, a series of small Plio-Quaternary volcanic cones is visible in the northwestern corner of Figure 4. Some are elongated in the N10^{0}E direction (V on Figure 4). Smaller volcanoes adjacent to each other form linear clusters, also trending N10^{0}E (C on Figure 4). The local Plio-Quaternary extension in sites 13 and 14 is consequently oriented N100^{0}E (Figure 5). In the field we have found small (200 m long, 20 m wide) volcanic ridges, a few meters higher than the nearby lava flow surface, trending N-S to N20^{0}E (Figure 10 and site 15 on Fig 5). The volcanic ridges seem related to basalt filling tension fractures which formed within still warm



(Figure 9: (b) Interpretation of the Digital Elevation Model of Figure 9a. Numbers in circle refer to locations cited in the text and plotted on Figure 5. Opposite arrows indicate local extension direction perpendicular to volcanic ridges or linear clusters. The crater shape as well as striations in site 10 (Figure 6) testify to left-lateral slip component along the fault. (c) Vertical view of a tail-crack model.

basalt flows, possibly related with Plio-Quaternary strain, yielding E-trending extension (site 15 on Figure 5).

The Kara Dag volcano is located near the southern termination of a SSE-striking fault, which turns SE at its southern end. The fault cuts the volcano into two parts which are slightly (100 m) left-laterally displaced (Figure

9). The fault is mainly extensional, western side down. In site 10, striations on a small conjugate fault indicate oblique-slip movement with a left-lateral throw component (Figure 6). In site 9 (Figure 9b), a 300 m long and 50 m wide fissure eruption was formed through a tension fracture striking N140^{0}E, indicating N50^0-trending local extension. The Kara Dag is then rooted on a tail-crack feature, which accommodates the horizontal left-lateral throw component at fault termination (Figure 9b and 9c). South and southwest of the volcano, in sites 11 and 12, linear clusters of central volcanoes and fissure eruptions indicate N-S to NE-SW extension.

Figure 10: One of the Plio-Quaternary (?) North-South trending volcanic ridges of site 15, with Hasan Dag volcano in the middle ground.

DISCUSSION

Elevations in the Bolkar Mountains (Figure 8a) progressively decrease westwards, with the dying out of large Neogene normal faults and tilted blocks in the belt. All our observations show that extension was predonant in the belt during the Late Neogene. Neogene uplift of the Bolkar Mountains, documented by marine Lower to Middle Miocene sediments now at elevations more than 2000 m, is coeval in time with the extensional tectonic setting.

Two contradictory tectonic hypotheses can be put forward to explain the Neogene uplift of the Bolkar Mountains: (1) a southward thrusting in the belt resulting in the formation of a foreland basin in the Adana-Cilicia area; or (2) a "roll back" (i.e. the downward and backward migration) of the slab south of Cyprus resulting in the formation of a northerly extensional basin focused in the Adana-Cilicia area and a related marginal uplift in the Bolkar Mountains.

The interpretation of the Adana basin as a foreland basin has been considered by Williams and Ünlügenç (1992) and Gürbüz (1993). Normal faults within the basin have been interpreted as the response to the load-induced flexure resulting from southward thrusting of the Bolkar Mountains. However, we did not observe and map any Late Neogene compressive structures in the area. The Taurus thrusting hypothesis may well explain the Aquitanian-Burdigalian marine transgression in the Adana basin, followed by Middle Miocene rapid subsidence leading to deposition of marine turbidites. However Flecker et al. (1995) have shown that the presence of Early Miocene deepwater turbidites in northern Cyprus indicates a deepening of the southern part of the Cilicia basin at this time. This is contradictory with a the model of a foreland basin which deepens progressively from north to south due to successive imbrications of thrustings in the north. The interpretation of the Neogene extension in the Adana-Cilicia basin as the consequence of the inception of the roll-back of the African slab beneath Cyprus has been suggested by Eaton and Robertson (1993) and Payne and Robertson (1995). In this model, the overriding plate must stretch to meet the retreating slab. We propose that inception of the roll-back process beneath Cyprus started in the Late Oligocene-Early Miocene, coeval with the deposition of the Late Oligocene conglomerates followed by Early Miocene marine turbidites in northern Cyprus. By comparison with the Aegean, Jolivet et al. (1994b) have shown that the thrust front has migrated southward continuously from the Early Miocene to the Present together with the retreat of the Aegean subduction zone. High temperature metamorphic rocks in the Cycladic blueschists yield radiometric ages of 30 Ma (Altherr et al., 1982), indicating that extension started in the Late Oligocene. A lower bound has been put on the timing of the inception of the roll-back in the Aegean, which may be operational since at least the late Eocene (Thomson et al., 1998). Initiation of the roll-back process in the Cyprean region is in keeping with that of the South Aegean, indicating that slab retreat my have started as early as the Late Oligocene-Early Miocene. Extension in the Cilicia-Adana basin has probably followed the same dynamics of the Aegean, with southward migration of the thrust front above the subduction zone located south of Cyprus at Present. Consequently, we interpret the Bolkar Mountains as a consequence of the stretching of the Adana-Cilicia basin which started in the Late Oligocene-Early Miocene time. The belt is regarded as thermal uplifted shoulder of the Adana-Cilicia lithospheric basin, due to upper mantle thinning and subsequent asthenospheric intrusion.

The Manavgat basin, lying 400 km to the west in southwestern part of the Central Taurides, has a stratigraphy similar to that of the Adana basin (Flecker et al., 1995). A Neogene uplift has been documented north of the basin. It has been interpreted as a possible marginal uplift related to the initiation of the "roll-back" of African subducted slab (Flecker et al., 1995) . This result is coherent with our observations further east and means that the whole Central Taurides can result from extension.

From multisource geophysical data, the slab subducting beneath Cyprus has been estimated to dip 40^0N (Kempler and Ben-Avraham, 1987). This is not coherent with the idea of Barka and Reilinger (1997) who have postulated the occurrence of a flattening slab in this area, inducing compression in the overriding plate. However, considering a 40^0N dipping slab, melt generating magma at 100-150 km depth can not account for the volcanism developed in the Central Anatolian region about 350 km to the north.

Volcanic vents in the Tuz Gölü basin area (V and C on Figure 4) are interpreted to be rooted on tension fractures that have given way for the magma. The $\sigma3$ direction inferred from the vents is compatible with that deduced from structural fault analysis in sites close to the vents. All our measurements of the last deformations indicate extension. It is then justified to consider that the open structures have been formed under an extensional regime rather than a compressional one. North of the Bolkar Mountains, extension trends east-west and can be interpreted as the consequence of the westward lateral escape of Anatolia toward the Aegean domain. Such extension has been described around the Niğde massif which has been interpreted as a metamorphic core complex exhumed in the Late Oligocene-Early Miocene. (Whitney and Dilek, 1997). Unroofing of the massif was followed by extension in the Middle Late Miocene, evidenced by intrusion of a 13.7-20 Ma granite in the Niğde metamorphics. Initiation of this extension is coeval with that of the Aegean some 30 Ma ago (Altherr et al., 1982). To the east, near the Africa-Arabia-Anatolia triple junction, Yürür and Chorowicz (1998) have described such extensional tectonics which they have associated to a recent (2 Ma) deformation phase. East-west trending movements turn progressively southwestward and southward when approaching the Taurus belt. This change may be related to the influence of the Cilicia-Adana basin opening, in the frame of N-S directed extension affecting the area north of Cyprus, which is thought to start in the Late Oligocene-Early Miocene. The transition from 3000 m mean altitude in the Bolkar Mountains to 1000 m below sea level in the Cilicia basin suggests that gravitational forces may also contribute to extension during the Neogene-Quaternary.

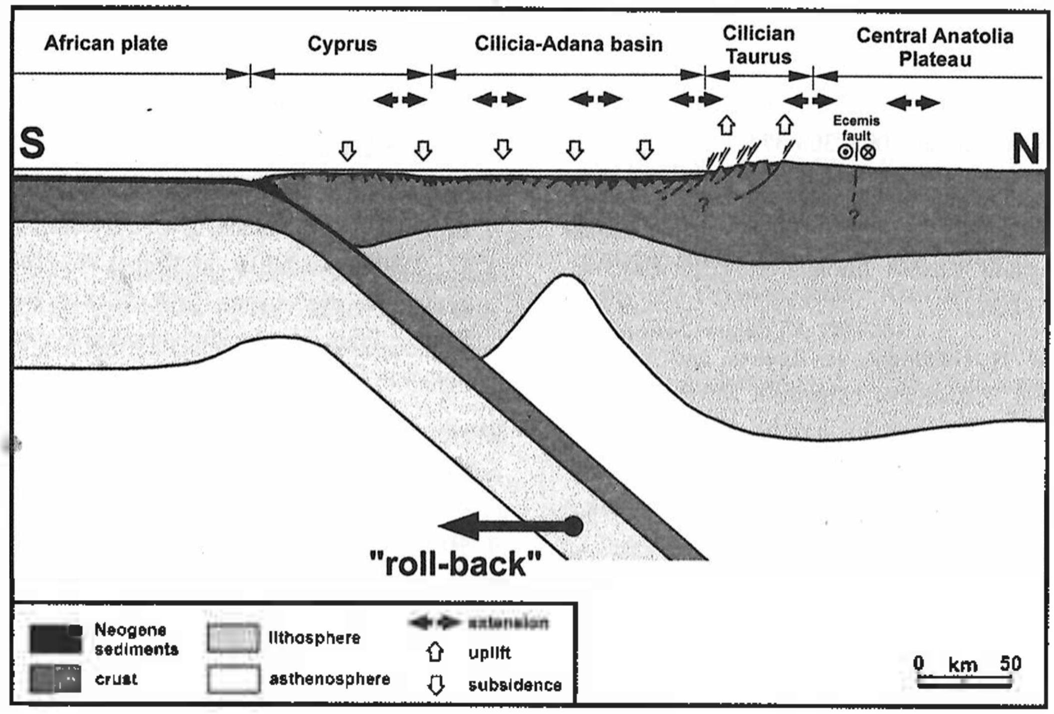


Figure 11: Model of the north-south lithosphere of the Eastern Mediterranean area, along 34° longitude in cross-section without vertical exaggeration, for Neogene. "Roll-back" of the slab subducting underneath Cyprus during this time is responsible for the north-south extension. The Bolkar Mountains are interpreted as the northern thermally uplifted shoulder of the Cilicia-Adana basin due to lithospheric thinning.

CONCLUSIONS

Using radar and DEM imagery, we have described new tectonic features in the Bolkar Mountains in Southern Central Turkey, all observations concur to show that during the Neogene, extension was predominant in the belt. No Late Neogene compressive structures have been observed. We have argued that the uplift of the Bolkar Mountains in the Neogene is associated to extension related to the initiation of the downward and backward migration ("roll-back") of the subducting African slab underneath Cyprus probably as early as the Late Oligocene-Early Miocene. This has resulted in a wide extension in the upper overriding plate, forming the Adana-Cilicia lithospheric scale extensional basin and its related uplifted northern thermal shoulder forming the Bolkar Mountains. Extension trends N-S in the Bolkar Mountains and progressively turns E-W north of belt. This change may be related to the Middle-Late Miocene to Present westward escape of Anatolia toward the Aegean basin.

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