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Post-Collisional Tectonics of Eskişehir-Ankara-Çankırı Segment of İzmir-Ankara-Erzincan Suture Zone (IAESZ): Ankara Orogenic Phase

Ali KOÇYİĞİT*, Asuman TÜRKMENOĞLU*, Ali BEYHAN*, Nuretdin KAYMAKÇI* Erol AKYOL**

ABSTRACT:

After the late Eocene final collision between the Sakarya Continent to the north and Menderes-Tauride to Kırşehir Blocks to the south, the intracontinental convergence of them lasted throughout the Oligocene-Miocene and early Pliocene time interval. This long-term convergence led to the emergence of a broad and NNE-SSW-trending lowland area (molassic trough) in the nature of intramountain basin where a fluvio-lacustrine depositional setting was established, and a thick sedimentary sequence, up to 6 km (outside of study area), was deposited. This sedimentation was also accompanied by a calc-alkali and alkali volcanism. These deposits, in general, are composed mainly of red, coarse clastics at bottom, and yellow-green-blue finer clastics and lacustrine cherty limestone towards the top. They also contain volcanic intercalations, coal seams and bentonitic horizons, in places.

The continued intracontinental convergence dissected early-formed broad and unique molassic trough into several, small-scale depositional settings bounded by thrust fault contact at their one or both margins. At the same time, sedimentary fills of these troughs were intensely deformed by folding and thrust faulting, and thrown into a broad south-vergent imbricate thrust zone and Ankara forced fold zone. This zone characterizes the tectonic architecture of the İzmir-Ankara-Erzincan Suture Zone (IAESZ) in its Eskişehir-Ankara-Çankırı segment.

Based on the newly-gathered palinologic and earlier vertebrate data from the coal seams and surrounding clastics, the youngest age of this penetrative post-collisional compressive regime, which was here called to be the Ankara phase, is late early Pliocene. This age is also supported by the fact that this intensely deformed Upper miocene-Lower Pliocene continental molassic sequence is overlain unconformably by an undeformed, nearly flat-lying fluvial conglomerates of Plio-Quaternary age. Sedimentation of these Plio-Quaternary fan to terrace conglomerates, which sealed the pre-late early Pliocene compressive tectonic regime and related structures, was accompanied by a new tectonic regime as indicated by steeply dipping to vertical faults, fault-bounded depressions and seismicity of region.

* Middle East Tecnhnical University, Geological Engineering Department, Tectonic Research Unit, 06531, Ankara.

** Dokuz Eylül Üniversity, Geological Engineering Department, Bornova-İzmir.

ÖZ:

Kuzeydeki Sakarya Kıtası ile güneydeki Menderes-Toros ve Kırşehir Blokları arasındaki kıta içi yakınsama Oligosen, Miyosen ve erken Pliyosen boyunca sürmüştür. Bu uzun süreli yakınsama, bir dağarası havza niteliğinde, geniş ve KKD-GGB gidişli bir molas çukurluğunun oluşumuna yol açmıştır. Bu çukurlukta, inceleme alanı dışında 6 km kalınlığa erişen kalın bir tortul istif depolanmıştır. Bu depolanmaya aynı zamanda, sırayla kalk-alkali ve alkali volkanizmalar da eşlik etmiştir. Bu tortul istif, genel olarak, tabanda kırmızı ve iri taneli kırıntılılardan, tavana doğru ise sarı-yeşil-

mavi renkli küçük taneli kırıntılı ve çörtlü gölsel karbonatlardan oluşur. İstif ayrıca, yer yer volkanik tüfit-lav, ince kömür damarları ve bentonit gibi anahtar ara düzeyler de içerir.

Uzun süreli kıtaiçi yakınsama, başlangıçta oluşmuş olan büyük boyutlu molas çukurluğunu, bir ya da iki kenarından ters faylarla sınırlanmış birçok küçük depolanma ortamına bölmüştür. Buna koşut olarak, u molas çukurluklarının dolgu istifleri de kıvrımlanma ve ters faylanmalarla yeğin biçim bozumuna (deformasyona) uğramış ve İzmir-Ankara-Erzincan yitim kuşağının (İA-EYK) Eskişehir-Ankara-Çankırı bölümündeki tektonik mimarisini karakterize eden, güneye bakımlı bindirimli ters fay ve alttan itkiyle gelişmiş kıvrım kuşaklarına dönüşmüştür.

Kömür damarları ve çevresindeki kırıntılılardan elde edilen palinolojik ve omurgalı fosil bulgularına göre, burada "Ankara Orojenik safhası" olarak tanımlanan, bu yaygın ve uzun süreli çarpışma sonrası sıkışma rejiminin en son yaşı geç erken Pliyosen'dir. Sıkışma rejimi ile yeğince biçim bozumuna uğramış olan Üst Miyosen-Alt Pliyosen istifi, biçim bozumuna uğramamış, hemen hemen yatay konumlu ve Pliyo-Kuvaterner yaşlı akarsu çakıltaşları tarafından açılı uyumsuzlukla örtülür. Bu gözlem de aynı yaşı doğrulamaktadır. Geç Pliyosen öncesi sıkışma rejimi ve onunla ilgili jeolojik yapılar (kıvrımlar, ters faylar) Pliyo-Kuvaterner yaşlı akarsu çakıltaşları ile örtülür ve mühürlenir. Bu çakıltaşlarının depolanmasına ise, dikçe eğimli, doğrultu bileşeni egemen düşey faylar, faylarla sınırlı çöküntü alanları ve bölgesel depremsellikle karakterize edilen yeni bir tektonik rejim eşlik etmiştir. Bu yeni rejimin başlangıç yaşı da en azından Orta Pliyosen ya da daha gençtir.

INTRODUCTION

Collision and suturing are progressive events lasting for a long period of time. These tectonic events are of three major groups: (1)pre-collisional, (2)syn-collisional, and (3)post-collisional. They determine site, dimension and nature of the suture zones on the dynamic earth. One of the well-known suture zones in Turkey is the İzmir-Ankara-Erzincan Suture Zone (IAESZ) (Şengör and Yılmaz, 1981). It is dominated by a polygenetic, multiple packet of stacked thrust-bounded zones made up of accreted and obducted components in a forearc setting created during the northward oblique subduction of the northern Neo-Tethys ocean (Görür et al., 1984; Koçyiğit, 1991a). Collision and suturing within this zone is diachronic, i.e. they initiated in Maastrichtian and lasted until late Eocene at different locations of the IAESZ (Seymen, 1975; Saner, 1977; Yılmaz, 1981; Şengör and Yılmaz, 1981; Görür et al., 1984; Gözler et al., 1985; Koçyiğit, 1987, 1991a; Tüysüz and Dellaloğlu, 1994).

In general, sutures are geologically complicated domains due to the superimposition of pre-, syn-, and post-collisional events and related structures. Therefore, observing well-preserved structures and rock sequences within the sutures is of great importance for a better understanding of their evolutionary history. One of the type localities where especially the post-collisinal structures are well-exposed is the Eskişehir-Ankara-Çankırı segment of the IAESZ. Most of these studies, however, carried out in this area have been focused on pre-and syn-collisional characteristics of the region (Erol, 1954; Şengör and Yılmaz, 1981; Akyürek et al., 1984; Görür et al., 1984; Koçyiğit, 1987, 1991a: Tüysüz and Dellaloğlu, 1994). In contrast, studies dealing with the post-collisional and the neotectonic nature of the Ankara region are very rare (Nebert, 1958; Erol, 1980; Yağmurlu et al., 1988; Koçyiğit, 1991b, 1992). Therefore, in this area as well as other segments of the IAESZ, the following questions are still open to debate: (1) what was the post-collisional nature of the tectonic regime?, (2) how long has this regime continued?, and (3) what is the commencement age of the neotectonic regime? This study aims to answer these questions.

GEOLOGICAL SETTING

The study area is located near the junction of IAESZ and Inner Tauride Suture Zone (ITSZ), within the Eskişehir-Ankara-Çankırı segment, and approximately 70 km NE of Ankara (Fig. 1). The Sakarya Continent, Kırşehir Block and Tauride-Menderes block were juxtoposed and welded to each other resulting in the Eskişehir-Ankara-Çankırı segment of the IAESZ after the final obliteration of northern Neo-Tethys Ocean in Maastrichtian-late Eocene period (Şengör and Yılmaz, 1981; Görür et al., 1984; Koçyiğit, 1991a). This segment is geologically very complicated. Because, the metamor-

Post-Collisional Tectonics of Eskişehir-Ankara-Çankırı Segment of IAESZ

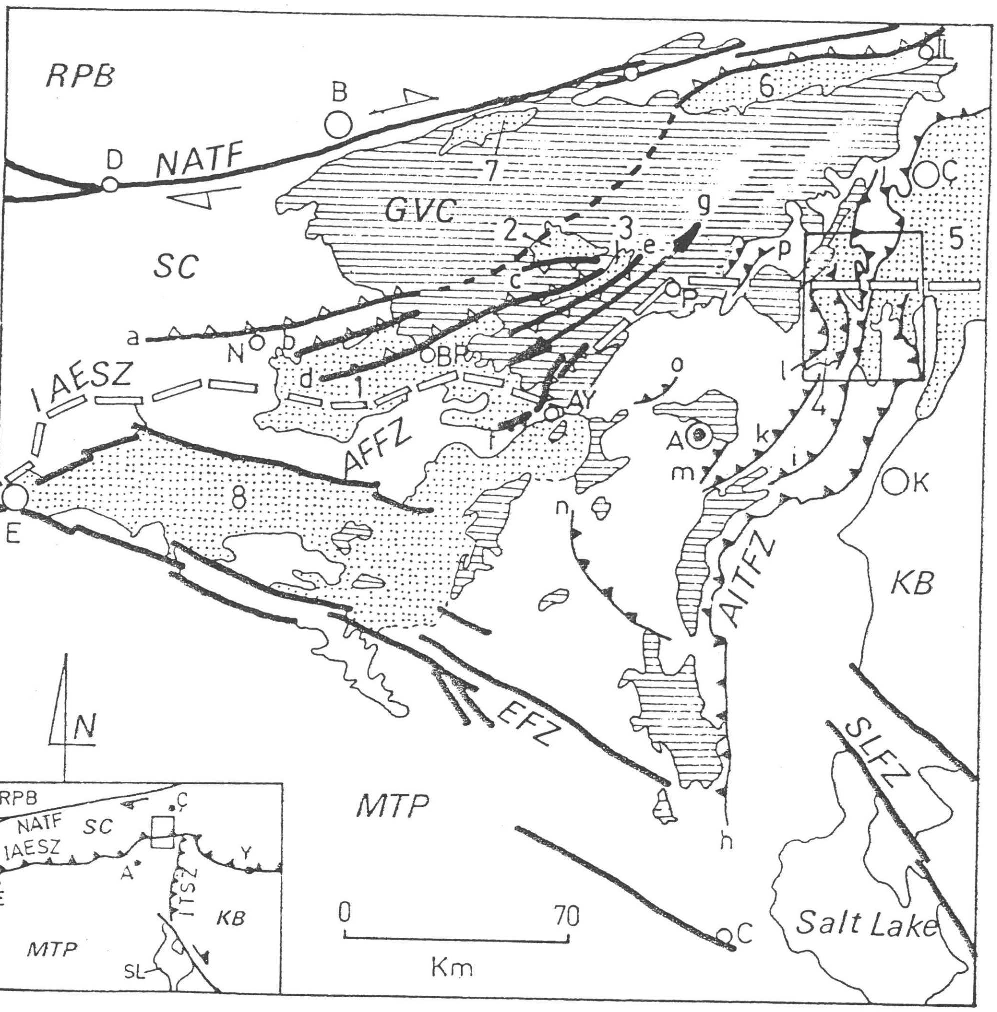


Figure 1. Regonal geologic setting and location map. AFFZ: Ankara forced fold zone (a. Nallıhan high-angle thrust fault, b. Pınarbaşı thrust fault, c. Peçenek high-angle thrust to overturned contact, d. Çayırhan-Beypazarı monocline-high-angle thrust to overturned contact, e. Çeltikçi monocline to high-angle thrust fault, f. Ayaş monocline to high-angle thrust fault, g. Pınaryaka folds), AITFZ: Ankara imbricate thrust fault zone (h. Bedesten thrust fault, i. Elmadağ thrust fault, j. Hancılı high-angle thrust fault, k. Hasanoğlan thrust fault, l. Karacakaya-Haydarköy thrust fault, m. Oran thrust fault, n. Dereköy thrust fault, o. Yuvaköy thrust fault, p. Hacılar thrust fault), EFZ: Eskişehir Fault Zone, GVC: Galatean Volcanic Complex, IAESZ: İzmir-Ankara-Erzincan Suture Zone, KB: Kırşehir Block, MTP: Menderes-Tauride Platform, NATF: North Anatolian Transform Fault Zone, RPB: Rhodop-Pontide Block, SC: Sakarya Continent, SLFZ: Salt Lake Fault Zone; 1. Beypazarı trouhg, 2. Peçenek trough, 3. Çeltikçi trough, 4. Hasayaz-Hancılı trough, 5. Çankırı molassic basin, 6. Çerkeş-Ilgaz molassic to strike-slip basin, 7. Dörtdivan strike-slip basin, 8. Eskişehir trough; A. Ankara, AY. Ayaş, B. Bolu, BP. Beypazarı, C. Cihanbeyli, Ç. Çankırı, D. Dokurcun, E. Eskişehir, IL. Ilgaz, K. Kırıkkale, N. Nallıhan, P. Pazar.

phosed Hercynides, unmetamorphosed Alpides and their volcanic to molassic cover altogether have been superimposed, and even tectonically stacked by two groups of compressional structures, namely the Ankara imbricate thrust fault zone (AITFZ) and the Ankara forced fold zone (AFFZ) (Fig. 1). The AITFZ constitudes the southern side of the IAESZ and is composed mainly of several NNE-SSW trending and south-vergent imbricate thrusts, along which both the Hercynides and Alpides are thrust onto the Upper Miocene to Lower Pliocene fluvio-lacustrine deposits (Koçyiğit, 1991a, 1992). The AFFZ determines the northern side of the IAESZ and is composed mainly of NE-SW trending and south-vergent

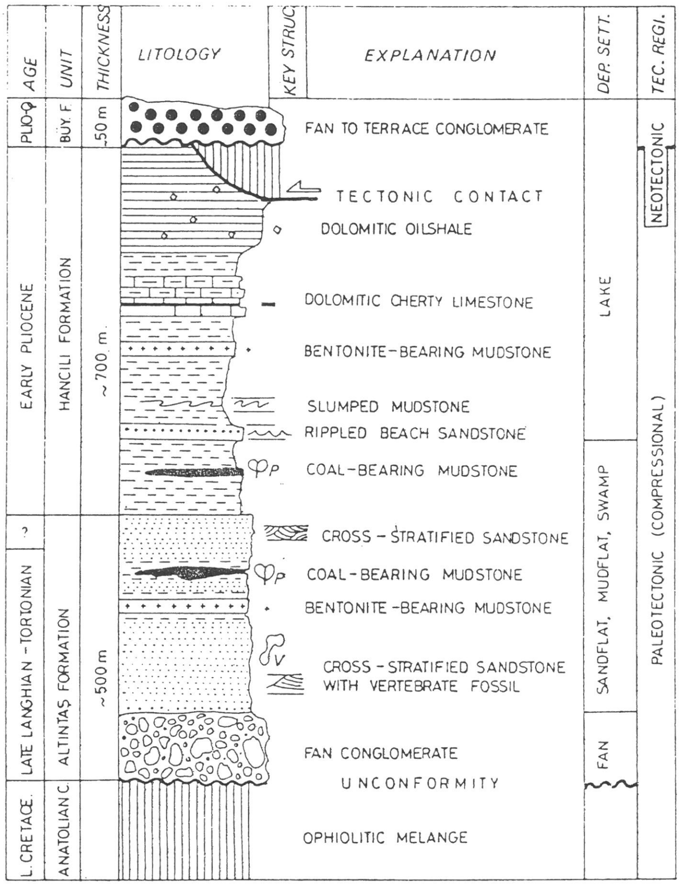


Figure 2. Generalized stratigraphic column of Kalecik-Hasayaz troughs.

monoclinal to overturned folds and high-angle thrust faults such as the Nallıhan thrust fault, Çayırhan-Beypazarı and Ayaş-Pazar monoclinal to-overturned folds (Fig. 2) (Erol, 1954; Yağmurlu et al., 1988).

The study area is made up of Upper Cretaceous ophiolitic melange, the Anatolian Complex, and its Upper Miocene-Pliocene molassic cover, and is shaped by the AITFZ. Their brief stratigraphy and structural to kinematic characteristics will be explained below.

STRATIGRAPHY

Within the study area three type localities, namely the Hancılı-Yurtyenice, Büyükhacıbey and Yeşilöz areas, were chosen. At these type localities two rock assemblages are well-exposed. The oldest rock assemblage constitudes the basement and consists of Upper Cretaceous ophiolitic melange. In contrast, younger rock assemblage forms the cover and is composed of Upper Tertiary continental deposits. They have been subdivided into three rock stratigraphic units. They are, from the oldest to the youngest, the Upper Langhian-Messinian(?) Aslantaş, Lower Pliocene Hancılı and Upper Pliocene-Lower Quaternary Büyükhacıbey formations (Fig. 2). They will be explained in detail below.

Anatolian Complex (Ka)

In general, the Upper Cretaceous ophiolitic melange exposing throughout the IAESZ was previously named as the Anatolian Complex (Koçyiğit, 1991a). It is dominated by the Cenomanian-Lower Campanian ophiolitic melange expelled out from the northward-subducted north Neo-Tethys. In other words, it is a well-preserved remnant of the subduction complex accreted at the S-facing active margin of the north Neo-Tethys during late Cretaceous (Şengör and Yılmaz, 1981; Koçyiğit, 1991a).

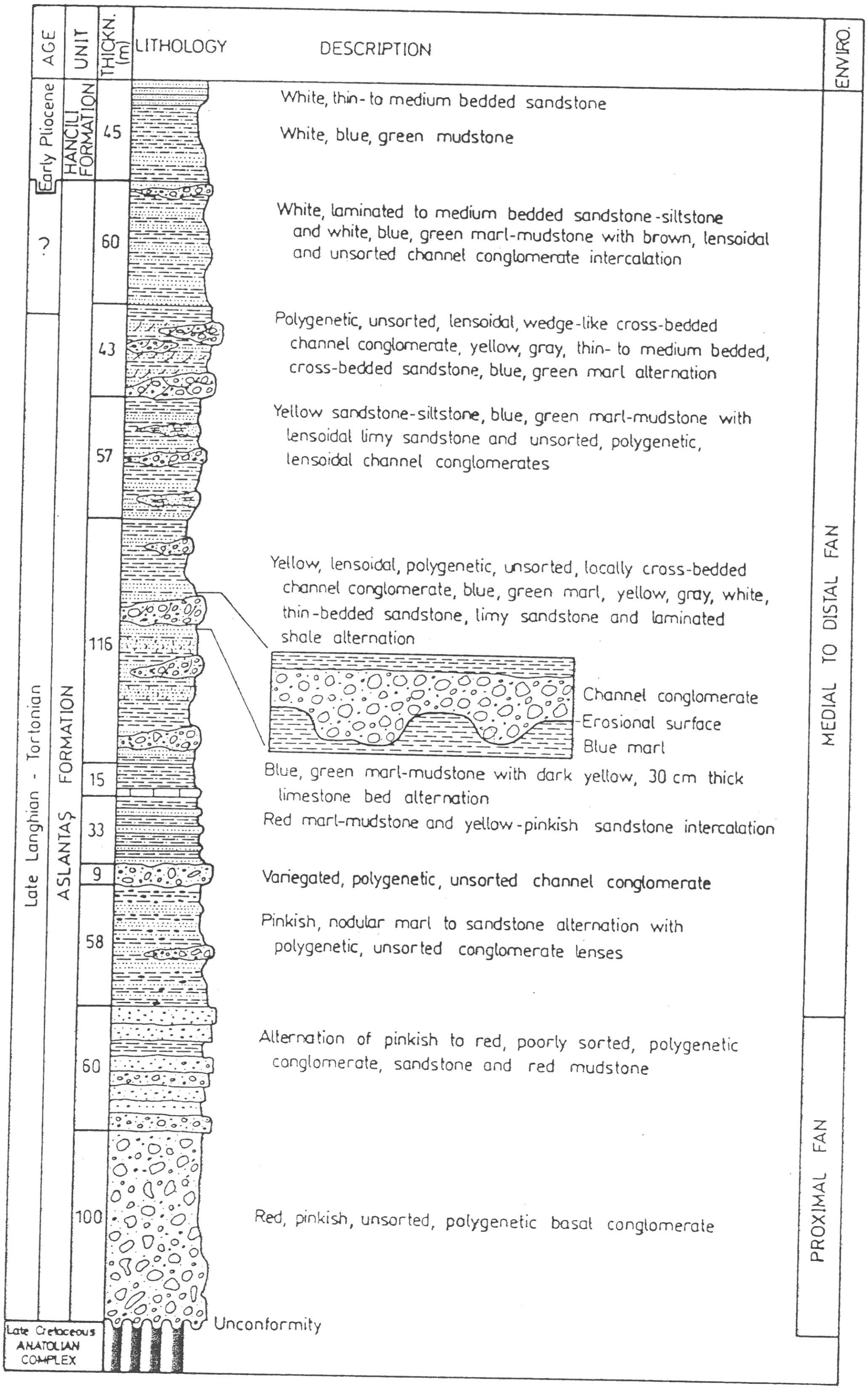


Figure 3. Measured stratigraphical type section of the Aslantaş formation (Type locality: 3 km NW of the Aslantaş village).

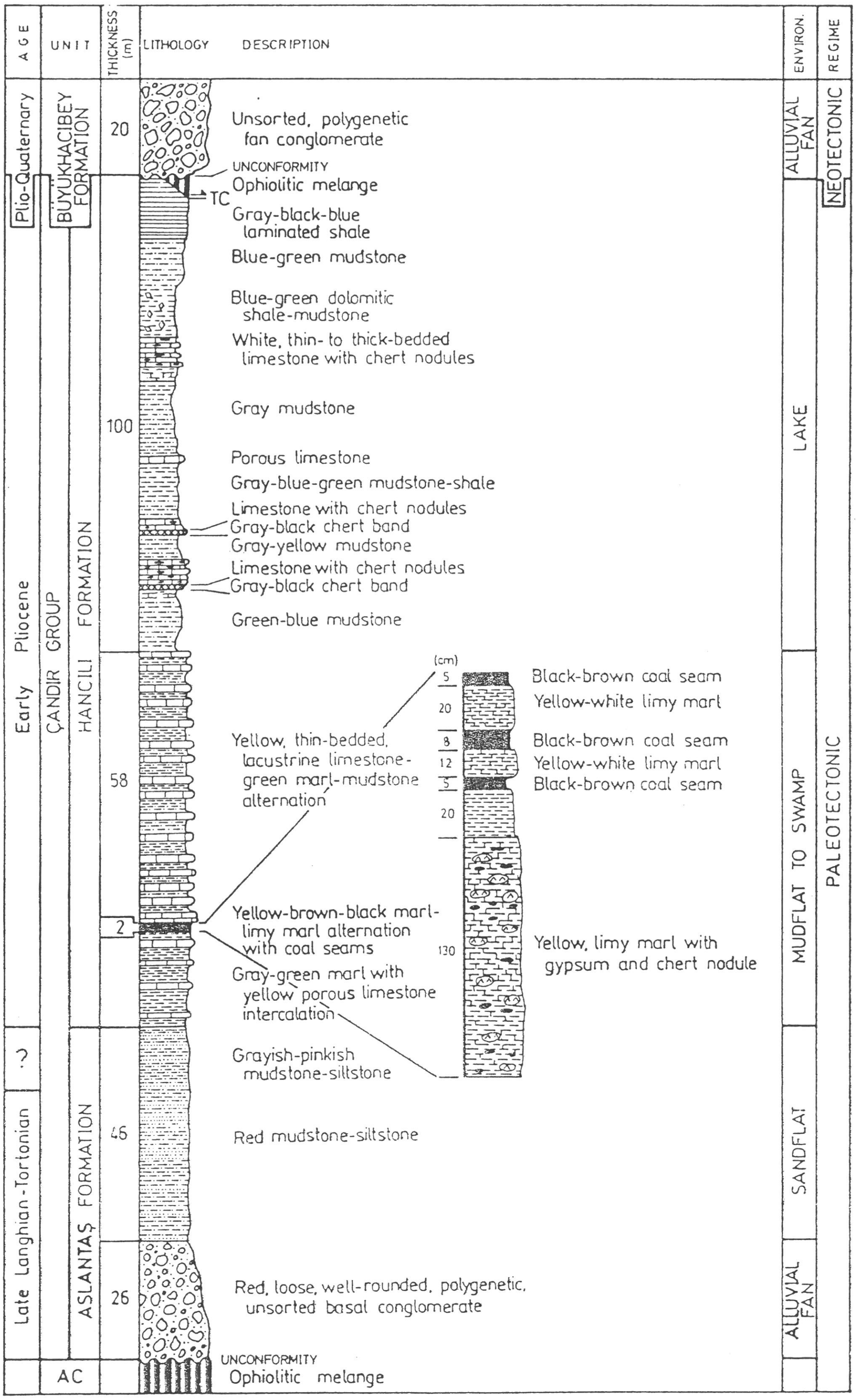


Figure 4. Measured reference section of the Çandır group (Reference locality: 1.2 km NNW of the Yurtyenice village). AC. Anatolian Complex TC. Tectonic contact.

The Anatolian Complex is a chaotic tecto-no-sedimentary mixture of various blocks of dissimilar age, origin, facies and size set in a pervasively sheared, semischistose or milonitized fine-grained matrix composed of sandstone containing dominantly detrital ophiolitic material, shale, turbidite and pelagic mudstone. Blocks range from a few cm to tens of km in size. They are generally lenticular to wedge, rectangular and irregular in shape, and are rootless. Secondary mineralization, such as calcitization and silicification, is most common on the polished and striated block surfaces. Based on their sources, blocks are of four major categories: (1) passive continental margin-derived blocks, which are dominated by carbonate blocks of dissimilar age and facies, (2)active continental margin-derived blocks, which are mostly volcanic to ophiolitic material-rich olistostromes, turbidites and broken formations, (3)ocean floor-derived blocks, namely the peridotite, serpendtinite, gabbro, pyroxenite, spilitic pillow basalt, diabase, manganese-bearing folded radiolarian chert and radiolaria-rich wackestone, Cenomanian Globigerina sp.-bearing pelagic cherty limestone interbedded with red radiolarian chert bands and volcanic breccias, and (4)older basement-derived blocks, such as marble, recrystallized limestone, graywacke, Carboniferous-Permian and Triassic fossiliferous carbonates, and low-grade metamorphics (Koçyiğit, 1992).

Blocks or allochthonous slices are mostly in fault-contact with each other. Some of these fault-bounded slices of dissimilar age, lithofacies and origin occur in fault-parallel strips of contrasting colours which commonly correspond to the internal imbricate thrust structure of the ophiolitic melange, the Anatolian Complex. Pinch and swells, bedding pull-aparts, dispersed phacoids of sandstones and limestones, disrupted beds, hinges and folds (close, upright, overturned, recumbent, isoclinal, disharmonic folds), quartz or calcite-filled shear planes, spaced to axial plane cleaveges, local thrust to normal faults and discrete thrust nappes are the common mesoscopic-scale structures observed within mostly trench-filled turbidites, Globigerina sp.-bearing mudstone of Cenomanian age, radiolaria-rich wackestone, radiolarian cherts and volcanoclastic sedimentary piles. All these features seem to have resulted from a single progressive deformation changing from a ductile flow at early stage to brittle failure at the advanced stage, due to a simple shearing prevailed at the base of inner trench slope during the rapid subduction of a relatively thin trench floor sequence (Moore, 1979; Moore and Karing, 1980; Nelson, 1982).

The apparent thickness of the Anatolian Complex is over 4 km. In addition, the youngest block found in the clastic matrix of the Anatolian Complex is a thin-bedded, pinkish to red pelagic biomicrite of Santonian-early Campanian age (Koçyiğit, 1992). Besides, the Anatolian Complex is overlain depositionally by the Middle Campanian olistostromal levels of the Kızılkaya Formation, that is the lowermost unit of a well-preserved accretionary forearc sequence (Koçyiğit, 1991a). Thus, the uppermost limit of the growth age of the Anatolian Complex, as an accretionary wedge, at the base of S- facing inner trench slope is the pre-middle Companian.

Çandır Group (Tç)

The term "Çandır Formation" was previously used by Tekkaya et al. (1975) to explain stratigraphy of all continental deposits exposing around the Hırsızderesi, N of Çandır county, located at approximately 90 km NE of Ankara. In their study, however, a measured type section was not given. Later on, a measured section was given by Atalay (1981) to identify the Anchitherium auriliense content of the same deposits, but he did not map separately these continental units, although they are mappable at 1:25 000 scale. In addition, the bedded gypsum constituting upper levels of his measured section is disconformable with the yellow to red clastics below. In the same years, a broad area between Kalecik and Eldivan (Çankırı) was studied and mapped by Akyürek et al. (1980). They first subdivided same continental deposits into three formations, namely the Kumartaş, Hancılı and the Karakoçaş formations. But they also did not give a measured type section for each formations. Besides, the name of the Kumartaş village was converted into Aslantaş.

In this study, the term "Çandır Formation" was shifted upward into the Çandır group; the term "Kumartaş" was changed as the Aslantaş, and the term "Hancılı Formation" was preserved due to the above-mentioned explanations.

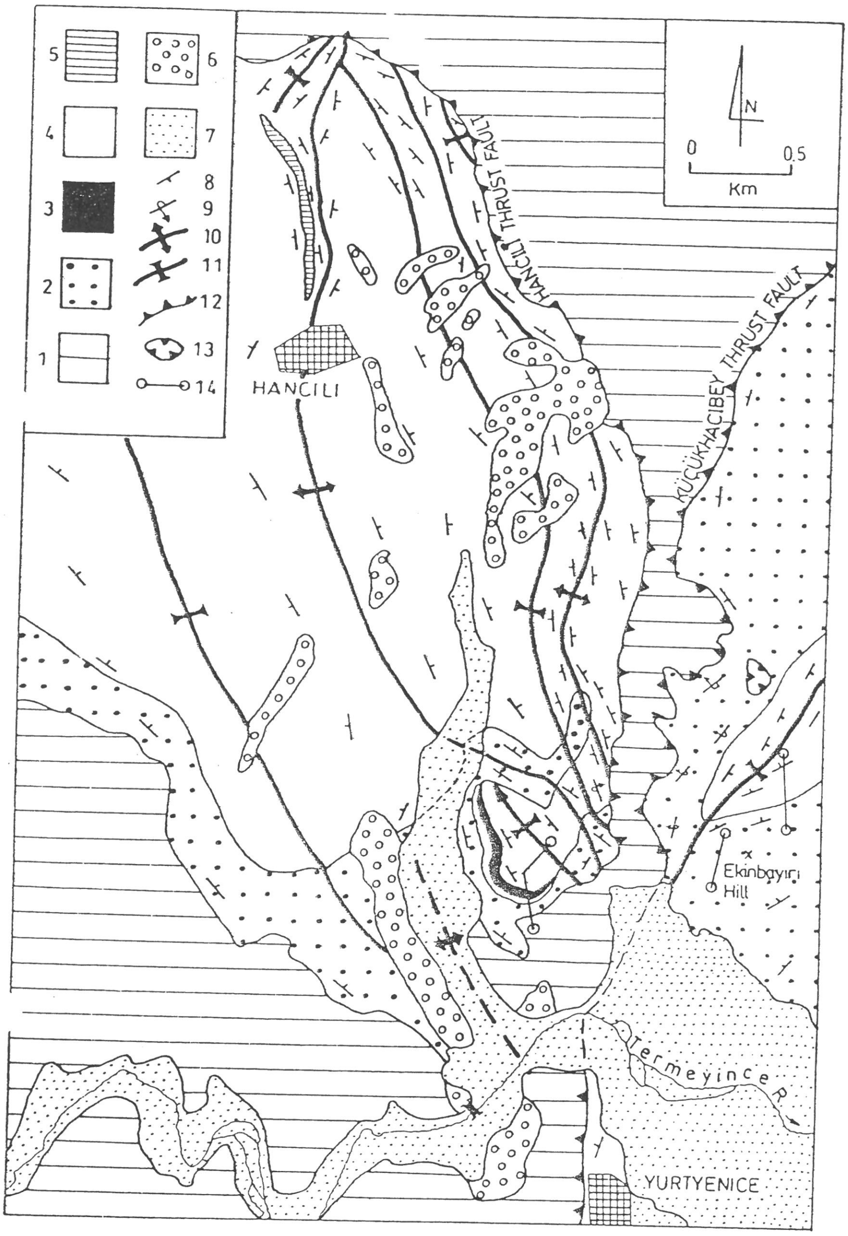


Figure 5. Geological map of the Hancılı-Yurtyenice type area. 1. Anatolian Complex (Upper Cretaceous ophiolitic melange), 2. Upper Langhian-Messinian(?) Aslantaş formation, 3. Lower Pliocene coal seam, 4. Lower Pliocene Hancılı Formation (It was partly differentiated because of the map scale), 5. Lower Pliocene lacustrine limestone included in the Hancılı Formation, 6. Plio-Quaternary Büyükhacıbey formation (mainly fan to terrace conglomerates), 7. Quaternary alluvial sediments, 8. Dip and strike of bedding, 9. Dip and strike of overturned bed, 10-11. Anticline to syncline axes, respectively, 12. Thrust fault, 13. Klippe, and 14. Measured section lines.

Within the study area, the Çandır group rests unconformably on the erosional surface of the Upper Cretaceous Anatolian Complex, and is overlain by the unsorted fan to terrace conglomerates. It is also overlain tectonically by the same basement rocks, in places (Fig. 2). It consists mainly of underlying fluvial red clastics and overlying lacustrine yellow to white deposits. The total thickness of the Çandır group is about 1.2 km.

Aslantaş formation (Ta).

The type section of this formation is located about 3 km NW of the Aslantaş village (Fig. 3). Its reference section, however, was measured 1.2 km NNW of the Yurtyenice (Termeyince) village (Figs. 4 and 5). In this measured reference section, the Aslantaş formation starts with a 26 m thick red, well-rounded, polygenetic and unsorted basal conglomerate on the erosional surface of the ophiolitic melange and continues upward into the red to pinkish mudstone-siltstone alternation. Towards the top, it grades into the green mudstone-limestone alternation of the Hancılı Formation (Fig. 4). Within and outside of the study area, the Aslantaş formation displays frequently lateral facies change and consists of 10 m to 30m

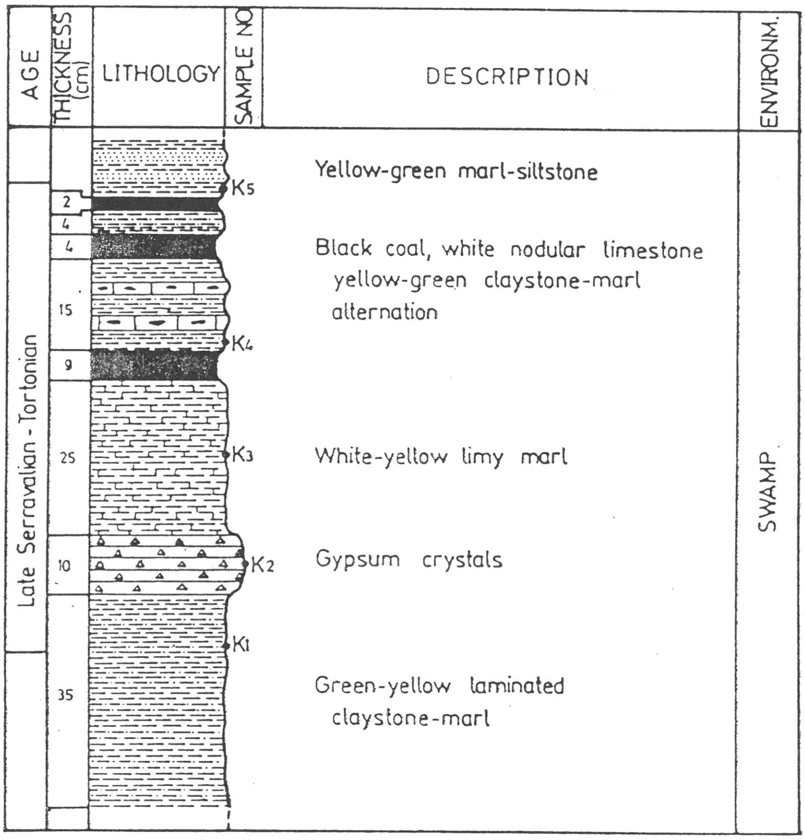


Figure 6. Measured stratigraphical column of the coal seam-bearing part of the Aslantaş formation (Locality: 200 m south of the Kılçak village, outside of the type area).

thick cycles of poorly sorted to masssive conglomerate, cross-bedded conglomerate to sandstone, limy sandstone, marl and limestone including thin coal seams and bentonite occurrences (Figs. 2 and 6). In general, the lowermost facies of cycles which are mostly unsorted polygenetic conglomerates show sharp and erosional contact relationships with the shale-marl below (Fig. 3). The total thicknesses of the formation are 550 m and 72 m in its type and reference sections, respectively (Figs. 3 and 4).

Common sedimentary structures observed within the Aslantaş formation are trough to planar cross-beddings and pebble imbrications. these structures, red colouration and thick unsorted conglomerates indicate that the Aslantaş formation was deposited as a fan conglomerate by both the debris flow and braided river (Collinson, 1986).

In terms of measured section studies carried out at the Kılçak outcrop (outside of the type localities), a rich pollen assemblge of late Serravalian-Tortonian age has been indentified (Fig. 6). Long list of this polen assemblage was given in the final report submitted to the Turkish Scientific and Technologic Research Council (TUBİTAK), therefore, it was not listed in this paper. In addition, some Upper Langhian-Tortonian vertebrate fossils have also been found within the red marls of the Hırsızderesi outcrop of the Aslantaş formation. Based on all these data, a late Langhian-Tortonian age was assigned to the lower fossiliferous part of the Aslantaş formation.

Hancılı Formation (Th). This unit was first named by Akyürek et al. (1980), but they did not give its type section. The type section of the Hancılı Formation has been well-preserved within a southward overturned syncline, namely the Ekinbayırı syncline, approximately 2 km NE of the Yurtyenice village (Fig. 5).

In general, the Hancılı Formation consists mainly of blue-green-yellow-white, swamp to lacustrine deposits of early Pliocene age (Fig. 2). At the Ekinbayırı type section, which will not be given here, the Hancılı Formation starts with a blue-green marl, shale alternation on the pinkish-yellow nodular limestone of the underlying Aslantaş formation, and continues upward with the alternation of blue-green-yellow-black marl, shale, small-scale cross-bedded siltstone-sandstone, slumped mudstone, and well-developed large-scale rippled sandstones. This 53 m thick lowermost part of the formation was deposited at the coastal zone as indicated by the well-developed wave ripples (Fig. 2). On the northern overturned limb of the syncline, the rippled beach sandstone is alternated by pinkish-yellow, thick, lensoidal and unsorted conglomerates of the underlying Aslantaş formation which reveals the transgressing and regressing lake due to the climatic variations.

This lowermost part of the Hancılı Formation is followed conformably by the 95 m thick alternation of black-blue, thin-bedded to laminated shale, marl,argillaceous limestone, carbonaceous shale and siltstone. At the topmost, it is overlain unconformably by the gray, unsorted, polygenetic fan conglomerate of the Plio-Quaternary Büyükhacıbey formation.

The reference section of the Hancılı Formation is well exposed approximately 1.2 km NNW of the Yurtyenice Village, where it starts with a gray-green marl, yellow,brown-black marl with coal seams and gypsum crystals and thin, yellow lacustrine limestone alternation of about 80 m thickness (Fig. 4). This lowermost package of the formation was deposited in a backswamp environment as indicated by coal seam ocurrence (Figs. 2 and 4). Later on, the Hancılı Formation continues upward with the alternation of green-blue mudstone, gray-black chert bands, thin bedded to laminated cherty limestone, blue-green dolomitic oil shale of approximately 100 m thickness. at the topmost, it is overlain tectonically by the Cretaceous Anatolian Complex, and unconformably by the Plio-Quaternary Büyükhacıbey formation (Fig. 4). To the further west, around both the Kınık and Ödek villagees, the Hancılı Formation contains andesitic tuffite and bentonite intercalations, up to 5 m. Measured thicknesses of the Hancılı Formation both on the type and reference sections are 148 m and 180 m, respectively. Indeed it is about 700 m thick outside of the type locality (Fig. 2).

The pollen assemblage obtained from the coal seam and adjacent marls at the lowermost level of the Hancılı Formation is younger than Miocene (Prof. Dr. Erol Akyol, personal communication, 1994). In addition, some vertebrate fossils, such as **Testudo** sp., **Gazella gaudryi** and **Paleotragus** sp. have also been found within the Hasayaz, Yeşilöz (Minkati) and Yüzbeyli outcrops of the Hancılı Formation, and the early Pliocene age was given to the formation (Tekkaya et al., 1975). The combination of our palinologic data and vertebrate fossil findings of Tekkaya et al. (1975) indicates that the Hancılı Formation is early Pliocene in age.

Consequently, both the underlying Aslantaş and overlying Hancılı formations have been deposited in a well developed fluvio-lacustrine environment made up of fan, sand- to mudflat, backswamp and lacustrine depocenters as indicated by some key features and facies, such as the unsorted debris flow conglomerate, vertebrate-bearing cross-bedded sandstone, coal seams with gypsum crystals, wave rippled beach sandstone, slumped mudstone, dolomitic cherty limestone and oilshale (Collinson, 1986; Allen and Collinson, 1986) (Fig. 2).

Büyükhacıbey formation (TQb). It is a widespread unit sealing the pre-late Pliocene compressional regime in Ankara region. It occurs in cap-like discontinuous outcrops of various size ranging from a few square meters to several square kilometers. It rests unconformably on the erosional surface of the pre-late Pliocene rocks comprising mostly upthrown blocks of both the normal and vertical young faults (Fig. 6). Two of areas where the Büyükhacıbey formation is well-exposed are the Hancılı-Yurtyenice and Büyükhacıbey type areas (Figs. 5 and 7). The type locality of the formation is also the Büyükhacıbey village. At approximately 1 km N of the Büyükhacıbey village, yellow, thick-bedded (up to 2 m) to massive, unsorted, polygenetic conglomerates, which were previously termed to be the "Hacıbey Upper Pliocene Pebble Series" by Erol (1961), overlie unconformably the folded fine clastics of the Upper Langhian-Messinian(?) Aslantaş formation and include pinkish-yellow sandstone to mudstone wedges. Well-rounded to subrounded pebbles of these conglomerates range from a few cm to 3 m in diameter, and consist mostly of ophiolitic rocks, andesitic

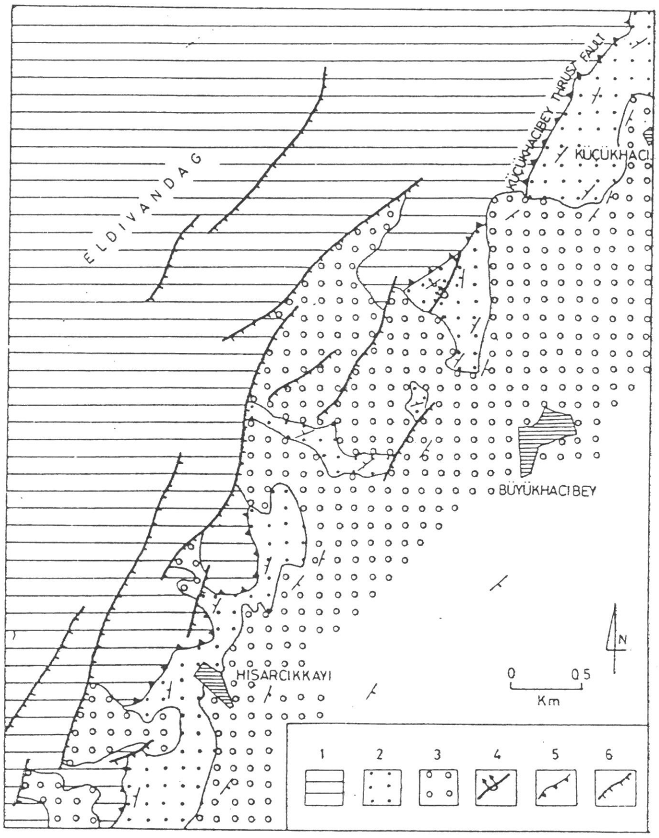


Figure 7. Geological map of the Büyükhacıbey type area. 1. Anatolian Complex (Upper Creaceous ophiolitic melange), 2. Upper Langhian-Messinian (?) Aslantaş formation, 3. Plio-Quaternary Büyükhacıbey formation (mainly fan to terrace conglomerates), 4. overturned anticline axis, 5. thrust fault, 6. steeply dipping to vertical faults (gravity collapse structure).

volcanics and older continental red clastics. They are embedded in a yellow-pinkish sandy matrix. These conglomerates constitute the proximal part of a large and well-developed fan, namely the Büyükhacıbey alluvial fan, and grade laterally into sandstone to silststone and mudstone representing medial to distal parts of the same feature. At approximately 2 km S of the Büyükhacıbey village distal parts of the fan overlie unconformably the slightly folded gypsiferous beds of the Pliocene Elmapınarı formation outside of the type locality. Measured thickness of the Büyükhacıbey formation is about 50 m, however, it ranges from a few m to 70 m in and outside of the study area.

Within the study area no fossil could be found within the Büyükhacıbey formation. In contrast, within the Sinaptepe (northwestern margin of the Kazan depression) and Akdoğan-Üçbaş (15 km S of Kızılcahamam) outcrops of the Büyükhacıbey formation, a rich vertebrate fossil assemblage has been identified, and these outcrops have been dated to be late Pliocene-early Quaternary in age (Ozonsoy, 1957; Şenyürek, 1960; Erol, 1961). In addition, at margins of Beypazarı-Ayaş, Kazan (Mürted), Ankara-Etimesgut, Gölbaşı-Kurakçöl, Edige-Kayadibi (Elmadağ) and kalecik-Hasayaz depressions, nearly horizontal to gently dipping up to 6°, fan to terrace deposits rest unconformably on the thrusted and folded Lower Pliocene continental deposits (Erol, 1952, 1953, 1954, 1955, 1961; Koçyiğit, 1991b, 1992). Thus, the Büyükhacıbey formation is late Pliocene-early Quaternary in age based on both their vertebrate fossil content and contact relationships.

RECORDS OF POST-COLLISIONAL COMPRESSIONAL TECTONIC REGIME

After the final (late Eocene) closure of north Neo-Tethys and suturing of the Sakarya Continent with the Menderes-Tauride Block (Şengör and Yılmaz, 1981; Görür et al., 1984; Koçyiğit, 1991a), the post-collisional convergence and approximately N-S directed com-

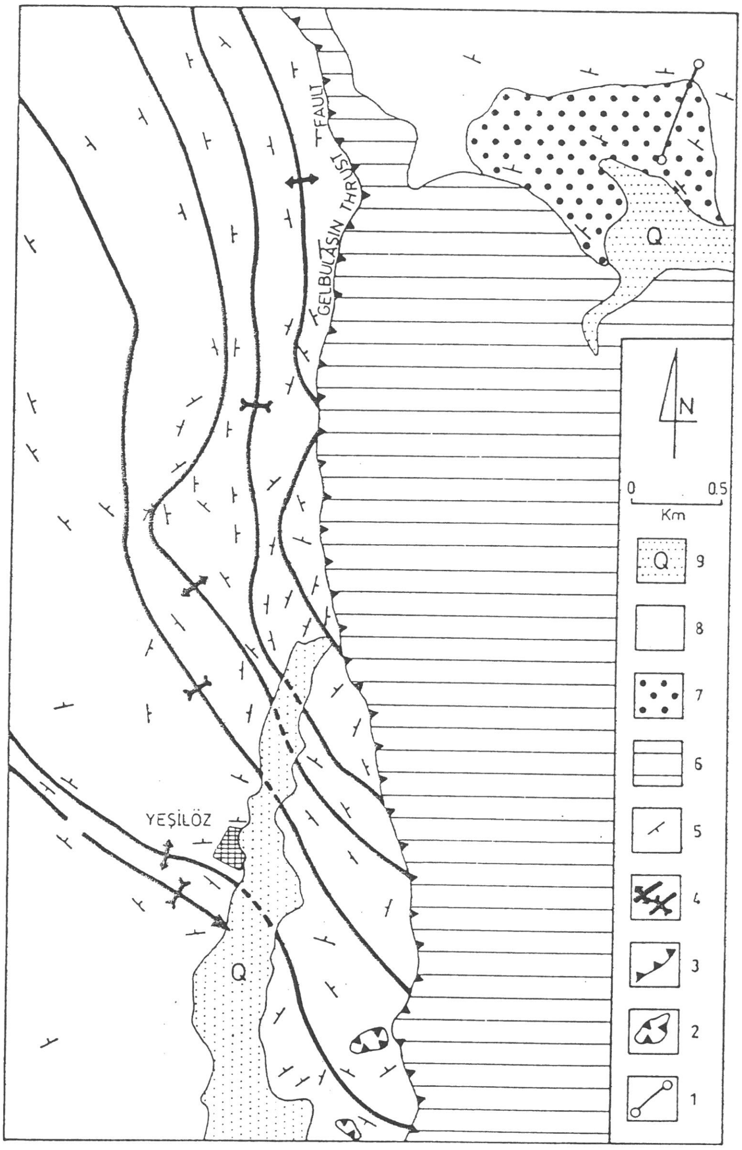
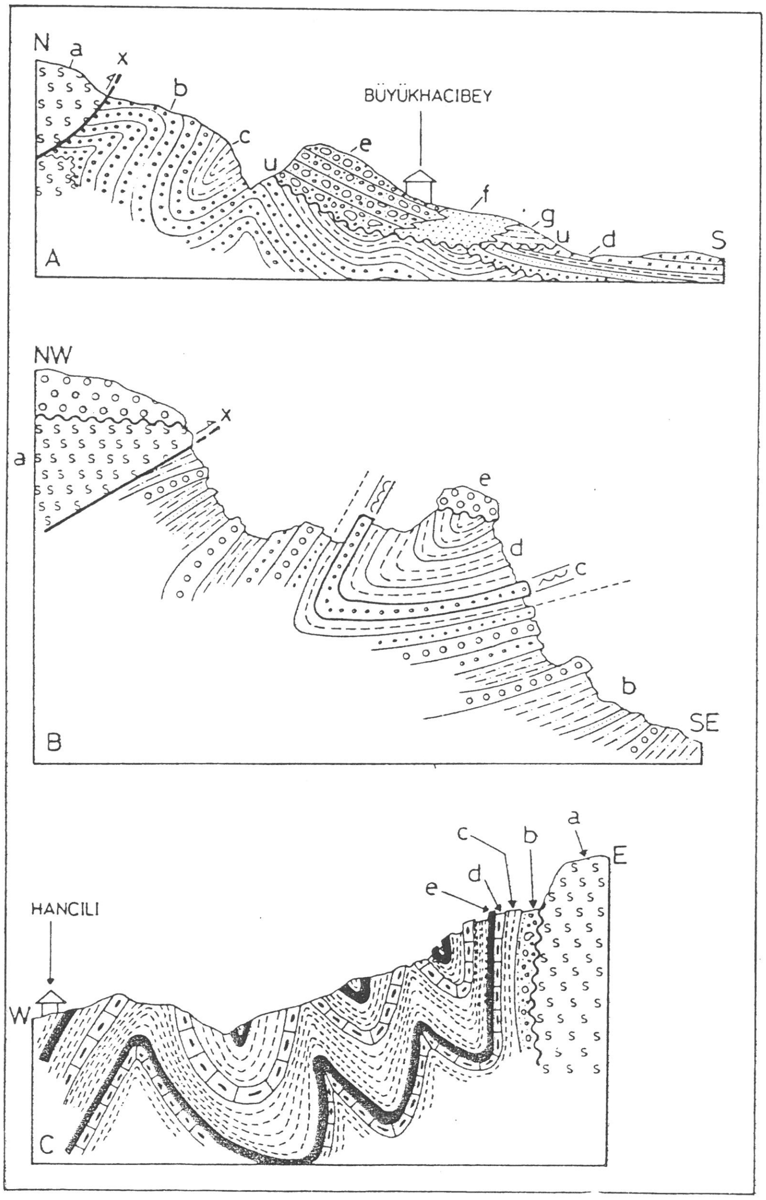


Figure 8. Geological map of the Yeşilöz type area. 1. Measured section line, 2. Klippe, 3. Thrust fault, 4. Anticline to syncline axes, 5. Dip and strike of bedding, 6. Anatolian Complex (Upper Cretaceous ophiolitic melange), 7. Upper Langhian-Messinian (?) Aslantaş formation, 8. Lower Pliocene Hancılı Formation, and 9. Quaternary alluvial sediments.

pressional tectonic regime lasted throughout the IAESZ until the end of early Pliocene, although it has been reported to be pre-Tortonian by Şengör and Yılmaz (1981) Görür et al. (1984). This long-term post-collisional compressional tectonic regime dissected the early-formed large and unique molassic basin fills by creating various folds and thrust faults approximately parelleling the basin margins (Figs. 5 and 7).

Type localities of the study area fall in the Ankara imbricate thrust zone (Fig. 1), which determines the Eskişehir-Ankara-Çankırı segment of the IAESZ, and include well-preserved records of late early Pliocene compressional tectonic regime. These are various tight, asymmetric to overturned folds, high-to low-angle thrust faults, klippen and conjugate shear joints with calcite to quartz infillings.

Figure 9. Sketched geological cross-sections depicting folded-thrust faulted Upper Langhian-Lower Pliocene continental deposits (Aslantaş and Hancılı formations) and their undeformed Plio-Quaternary cover (Büyükhacıbey formation). A: a. Anatolian Complex (Upper Cretaceous ophiolitic melange), b. Upper Langhian-Messinian(?) continental red clastics (Aslantaş formation), c. Yellow-white-blue marl with bentonite (Lower Pliocene Hancılı Formation), d. Pinkish basal conglomerate, yellow mudstone and gypsum alternation of early Pliocene age (Elmapınarı formation), e. f and g. Proximal, medial and distal parts of the Plio-Quaternary Büyükhacıbey fan, u. Angular unconformity, and x. Thrust fault; B: a. Anatolian Complex (Upper Cretaceous ophiolitic melange), b. Upper Langhian-Messinian(?) Aslantaş formation, c. rippled beach sandstone, d. Lower Pliocene Hancılı Formation, and e. Plio-Quaternary Büyükhacıbey formation (2 km NE of Yurtyenice village); C: a. Anatolian Complex (Upper Cretaceous ophiolitic melange), b. Basal conglomerate, c. Green-blue marl-mudstone alternation, d. cherty limestone, and e. chert band.



Folds

Folds occur mostly with their axes parelleling to basin margins (Figs. 5, 7 and 8). Degree of basin fill deformation by folding decreases towards the depocenters. Therefore, folds are widespread, closely-spaced, tight, assymmetric, and even overturned at margins (Figs. 9A, B, and C). Unlike this, they are rare and open near and at depocenters.

Amplitudes and lengths of folds range from mesoscopic scales to the 10 km and 30 km, respectively. Although they are same in age, orientations of their axes vary from E-W to the N-S direction and thus, reflect the general syn- to post-collisional deformation pattern of the "Ankara Knot" (Şengör and Yılmaz, 1981).

Age of the youngest basin fill deformed by assymmetrical to overturned folding is late

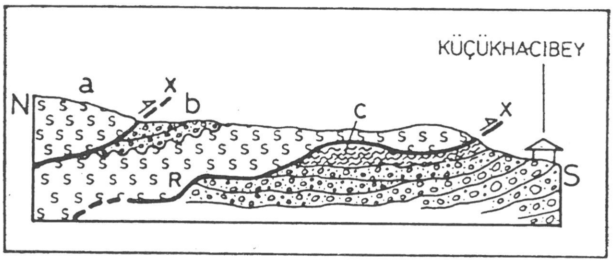


Figure 10. Sketched geological cross-section showing the thrust fault (x) with ramp segments (R). a. Anatolian Complex (Upper Cretaceous ophiolitic melange), b. Upper Langhian-Messinian(?) Aslantaş formation, c. crushed and sheared zone.

early Pliocene. Therefore, age of folding is older than late early Pliocene, but younger than late Pliocene, because undeformed Upper Pliocene-Lower Quaternary fan to terrace conglomerates rest unconformably on the thrust faulted-folded Lower Pliocene basin fill (Figs. 9A and B).

Thrust faults

As in the case of folds, thrust faults also occur approximately parallel to basin margins (Figs. 5, 7 and 8). They are main elements of :e IAESZ, along which older basement rocks, mostly the ophiolitic melange of the Upper Cretaceous Anatolian Complex, are thrust onto the molassic continental deposits of late Eocene-early Plicene age (Erol, 1961; Akyürek et al., 1984; Koçyiğit, 1991a, 1992). They dip N, NW, W and result in a SSE ward-vergent imbricate thrust fault zone ranging from a few hundreds m to 40 km in width (Fig. 1). Individual thrust fault within this thrust zone also ranges from an overturned contact (Fig. 9) to the low-angle thrust fault with ramp segments (Fig. 10). Cataclasites (fault breccia and gauge), conjugate shear joints with secondary mineral infillings, younger units dipping beneath the older basement rocks, axial plane cleavege and drag folds are most common field indicators of thrust faults.

As to the age of thrusting, they are also at least late early Pliocene in age, but they are relatively younger than folding, because especially around the Yeşilöz village, both the bedding planes of the Lower Pliocene deposits and the fold axes within them are truncated by the thrust faluts (Fig. 8).

Klippen

These are the erosional remnants of allochthonous units transported and emplaced onto the younger basin fill by the low-angle thrust faults. Three klippens covering an area of approximately 1 square km were observed. Two of them are well-exposed 1 km SE of the Yeşilöz village (Fig. 8) and one 2 km NNE of Yurtyenice village (Fig. 5). Outcrop distances to the main body of the allochthonous unit reveal at least 200 m to 500 m horizontal tectonic transportation during late early Pliocene or just after early Pliocene but before late Pliocene.

Conjugate shear joints

These are also widespread compressional features occuring within the young basin fill. Especially the brittle facies,namely the conglomerates, sandstone, limestone and coal seams, of the basin fill has been subdivided into parellelogram-shaped blocks of diverse size by shearing. They mostly occur as calcite-, quartz- or iron oxide-bearing veins of maximum 2 cm width and 10 m length.

Any measurement of shear joints has not been done for stress analysis, because folds and thrust faults were enough to identify the orientation of principal compressive stress axis which is responsible for the deformation of basin fill.

Consequently, the post-collisional compressional tectonic regime deforming the Upper Langhian-Lower Pliocene continental deposits within the Eskişehir-Ankara-Çankırı segment of the IAESZ by folding and thrusting, and sealed by the undeformed Upper Pliocene-Quaternary coarse clastics was here named as the **Ankara orogenic phase.**

RECORDS OF NEOTECTONIC REGIME AND ITS COMMENCEMENT AGE

In the Ankara region, the undeformed Plio-Quaternary clastics (fan to terrace conglomerates) of the Büyükhacıbey formation area key unit sealing the pre-late Pliocene post-collisional compressional regime and related structures, and recording neotectonic regime. Common and widespread records of this new regime are as follows:(1) steeply dipping to vertical faults, (2) fault-bounded depressions

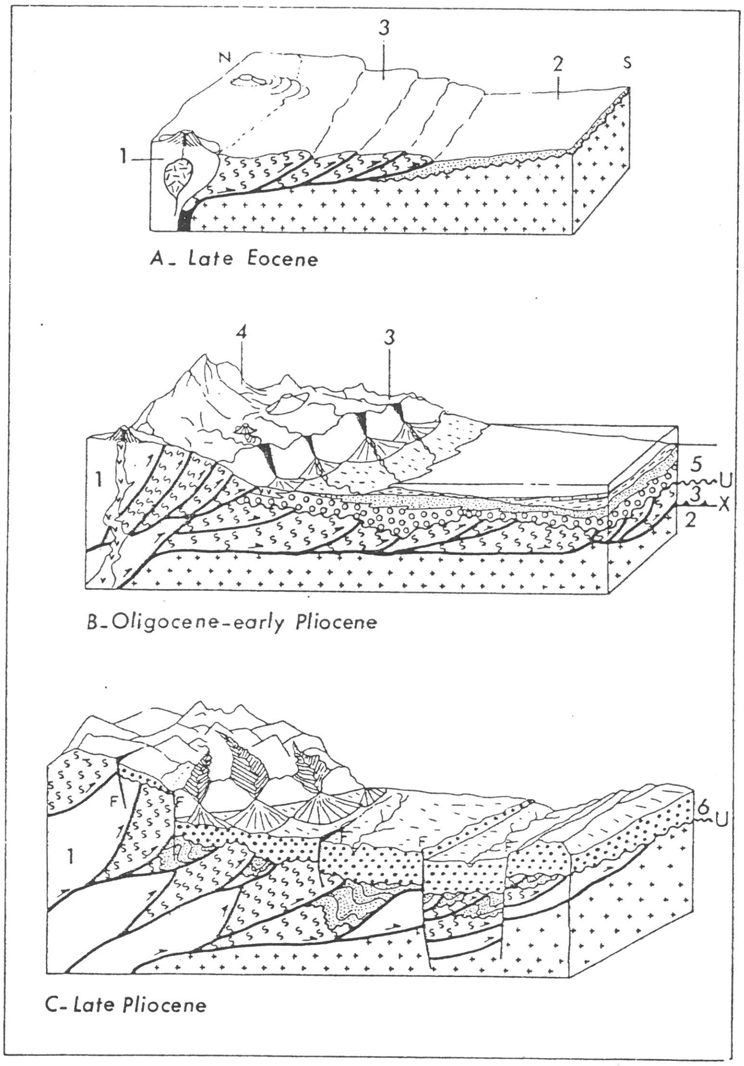


Figure 11. Model depicting the late Eocene-late Pliocene geologic history of the Kalecik-Hasayaz molassic troughs. 1. Pre-Jurassic Arc massive intruded by granitoids, and overlain by Galatean Volcanic Complex, 2. Passive continental margin, 3. Advancing ophiolitic thrust sheet (Upper Cretaceous Anatolian Complex:accretionary complex), 4. Highland sediment source, 5. Fill of Oligocene-Lower Pliocene molassic trough (Piggy-back basin), and 6. Upper Pliocene fan to terrace deposits sealing the pre late Pliocene post-collisional compressive tectonic regime and related features, u. Angular unconformity, x. Thrust faults, f. gravity collapse structures of neotectonic period.

accompanied by incised meanders, (3) hanging valleys, (4) dissected and uplifted outcrops of alluvial fan to terace conglomerates, and (5) seismicity. Some of these will be discussed briefly below.

Steeply dipping to vertical faults

These faults occur along the thrust-faulted to folded margins of late Eocene-early Pliocene molassic basins (troughs), and determine the fault-bounded margins of newly developing depressions. Therefore they run parallel to the general trends of older compressional structures, but cut and displace them (Erol, 1961; Koçyiğit, 1991b). These faults range from a few hundred meters to 20 km in length and display step-like outcrop pattern (Fig. 7).

Fault-parallel alignment of cold to hot water springs and newly forming alluvial fans, dissected and elevated older alluvial fans to terrace conglomerates adjacent to faults, hanging drainage system and seismicity such as the

1974 Yenimehmetli, 1985 Köşker and 1989-1994 Ankara earthquakes are major evidences of these faults and their activeness.

These steeply dipping to vertical faults running parallel to the general trend of earlier compressional structures can be interpreted to be gravity collapse features formed as a natural response to the extreme crustal shortening and thickening because of the long-term post-collisional compressional regime.

Fault-bounded depressions

Several long, narrow, deep, fault-bounded and mostly NE-SW trending depressions occur within the Eskişehir-Ankara-Çankırı segment of the IAESZ. Some of them, from west to east, are Çeltikçi, Temelli-Kazan, Çubuk, Ilıcaözü, Kurakçöl-Mogan, Karaali-Edige-Kayadibi, Kayaş-Lalahan, Kalecik-Hasayaz and Orta-Kurşunlu depressions. These depressions are covered by about maximum 100 m thick unconsolidated Plio-Quaternary sediments made up of debris flow to braided river conglomerates at margins and sand-silt-mud at central parts. They are also accompanied and drained by major tributaries of both the Sakarya and Kızılırmak rivers, such as the Hamamçayı-Koca River, Ankara-Ovaçayı, Çubukçayı, Ilıcaözüçayı, Kapalıboğaz stream, Balabançayı, Kayaşçayı, Termeyinceçayı and Devrezçayı,respectively (Erol, 1961). Most of these drainage systems have cut deep into their beds leaving a terrace conglomerate at different elevations above their present channels (Koçyiğit, 1991b). Throughout the above-mentioned depressions, most of these rivers of incised meander character have also shifted their channels. These observations, therefore, can be attributed to the activeness of their fault-bounded margins (Erol, 1961; Koçyiğit, 1991b).

Dissected and elevated fan to terrace conglomerates

These are mostly the Plio-Quaternary terrace conglomerates of the Büyükhacıbey formation. They occur in dissected outcrops at different elevations. They are well-exposed at different margins of the Kalecik-Hasayaz depressions, such as the Hancılı, Büyükhacıbey and Kılçak localities (Figs. 5 and 7). One of these outcrops is located to the west of Erenler hill (outside of study area) where the Koca River has cut deeply into its bed, leaving a terrace conglomerate 125 m above its present-day channel (Koçyiğit, 1991b). Similar outcrops are also occur at the margins of the Temelli-Kazan, Çubuk, Mogan, Balaban and Kurakçöl depressions and mark an active tectonic uplift in the Ankara region.

Seismic activity

Some earthquakes of small magnitudes, up to 4.7, have been recorded recently. These are 1974 Yenimehmetli earthquake of magnitude 4, 1985 Köşker earthquake of magnitude 4.7, and 1989-1994 Ankara earthquakes of magnitudes 3.9, 3.5. In addition, during field studies, villagers living in villages located at margins of Temeli-Kazan, Çubuk, Edige-Kayadibi and Kalecik-Hasayaz depressions stated that they have been experiencing frequently weak earth shakings. All of these reveal that the Ankara region is tectonically active.

DISCUSSION AND CONCLUSION

After the late Eocene final closure of north Neo-Tethys ocean (Görür et al., 1984; Koçyiğit, 1991a, 1992), the convergence between the Sakarya Continent to the N and Menderes-Tauride platform and Kırşehir Block to the S continued until late early Pliocene. Accordingly, older basement rocks (Arc Massif) and active marginal deposits of the Sakarya Continent, and the ophioltic melange accreted to it, altogether, were transported as thrust sheets towards south onto both the Menderes, Tauride Platform and Kırşehir Block (Fig. 11A). This southward tectonic transportation was accompanied by Oligocene-early Pliocene continental molassic sedimentation in a piggy-back basin and post-collisional volcanic activity throughout the Galatean Volcanic Complex (Fig. 11B). During this tectonic transportation, all of these rocks and their Oligocene-Lower Pliocene molassic cover, collectively, were deformed, thickened, stacked and put into a south-vergent imbricate stack by folding and thrust faulting (Fig. 11C). Diagnostic records of this long-term post-collisional compressional regime in the Eskişehir-Ankara-Çankırı segment of the IAESZ are the Ankara forced fold and imbricate thrust zones (Fig. 1) which were studied in detail at different type localities as mentioned in foregoing sections.

At least at the end of late early Pliocene, extreme shortening, thickening and uplift led, from one hand, to a rapid erosion and continental sedimentation, from other hand, to the emergence of a new tectonic regime because of the addition of the earth's gravity force to this increasing overload. Thus, Plio-Quaternary fan to terrace conglomerates of the Büyükhacıbey formation were deposited along the erosional surface of older and intensely deformed rocks, and sealed earlier post-collisional compressive regime and its records, such as the thrust faults, tight to overturned folds. This young sedimentation was accompanied by mostly strike-slip faulting, under the control of which a series of approximately NE-SW trending and fault-bounded depressions drained by the incised meanders developed (Fig. 11C). In the present day, same tectonic regime is still going on as indicated by the seismicity of the region.

Consequently, nature of the tectonic regime prevailing since the final collision among the Sakarya Continent, Menderes-Tauride Platform and the Kırşehir Block is compressive, and it lasted until at least late early Pliocene, Which is also the commencement age of the Neotectonic regime in Turkey.

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