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THE FAULT TRACE OF 1953 YENİCE-GÖNEN EARTHQUAKE AND THE WESTERNMOST KNOWN EXTENSION OF THE NAF SYSTEM IN THE BİGA PENINSULA

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ABSTRACT.- Northeast-striking en-echelon faults in the Biga peninsula represent the westernmost known extension of the NAF system. The main faults exhibit a clockwise en-encelon pattern from Manyas-Danişment in the east, Yenice-Gönen in the center and Sarıköy-İnova in the west The NAF system in eastern Turkey developed about 11 my ago and has accumulated a total dextral separation of about 30-40 km. The apparent decrease in displacement to 8 km in the southern segment east of the Marmara Sea corresponds to a change from a single to multiple fault zones. The nature of grabens, as pull-apart basins, during Late Pliocene to Quaternary time in an essentially strike-slip regime has been quantified in the Bursa-Gönen graben apparently moved 3.4 km west-southwest along these faults, while east-west normal faults developed in the graben that account for some 8.2 km of north-to-south extension. No data are available for displacement on the Sarıköy-İnova and Manyas-Danişment faults.

INTRODUCTION

There has been considerable debate over westward continuation of the North Anatolian Fault (NAF) zone east of Marmara Sea. From western termination of the Mudurnu valley through westward; some workers believe that the NAF zone consists essentially of a single strand (Alptekin, 1973; Bingöl, 1976) while others indicate that it sprays into two (Şaroğlu et al., 1987) or three active strands (Dewey and Şengör, 1979; Şengör and Canıtez, 1982; Şengör et al., 1983, 1985; Hancock and Barka, 1983). Some other workers, however, point out that the NAF zone branches and loses its continuity east of Marmara Sea (Koçyiğit, 1984; Kıyak, 1987) or the right-lateral slip of the fault is distributed over a number of grabens with a large component of normal faulting (McKenzie, 1978; Jackson and McKenzie, 1984; Crampin and Evans, 1986).

The Gaziköy-Saros bay fault ** is generally known as the northern arm of the NAF system. The fault extends towards west through the Lake Sapanca, İzmit bay and northern Marmara trough and reaches to northern Aegean trough of the Saros bay. Another branch of the NAF, the middle branch, also extends toward west from the Lake İznik and Gemlik bay to the southern shore-line of Marmara Sea. In addition to the northern and middle branch of the NAF, the third branch from Bursa to Yenice, has been considered. This branch is the result of the structures induced by the 1953 Yenice-Gönen and 1964 Manyas earthquakes.

The main purpose of this paper is to discuss the structural importance of the 1953 Yenice-Gönen earthquake in the regional neotectonic events, based on the field observations along the main earthquake fracture and its northeastward and southwestward extension.

THE FAULT TRACE OF 1953 YENİCE-GÖNEN EARTHQUAKE

A destructive earthquake occurred between Yenice and Gönen on March 18, 1953. The shock was felt over a large area in northwest Turkey. The epicenter of the shock was located approximately 12 km east of Yenice, the magnitude of P wave was 7.4 and focal depth determinations varied from 10 to 12 km (Herece, 1985).

A 50 km-long surface break formed during earthquake. From a study of the aftershocks, Pınar (1953) and Ketin and Roesly (1953) investigated the epicenter area in detail. The Yenice-Gönen fault zone, which includes the fault trace of 1953 event, has been investigated in detail for the first time by Herece (1985).

The fault trace bf 1953 Yenice-Gönen earthquake is shown in Figure 1. The break begins in andesite to the west of Çakmak, then proceeds west displaying continental Neogene and Quaternary deposits to the east of Koru değirmeni, where the fault scarp is still observable. During the earthquake the southern block was displaced approximately 80 cm downward along this fault scarp. The fault can be traced through the alluvial plain of Gönen and westward into the Neogene deposits north of Muratlar. The fault trace is not visible in the alluvial plain. However, approximately 2 km west of the Neogene de-

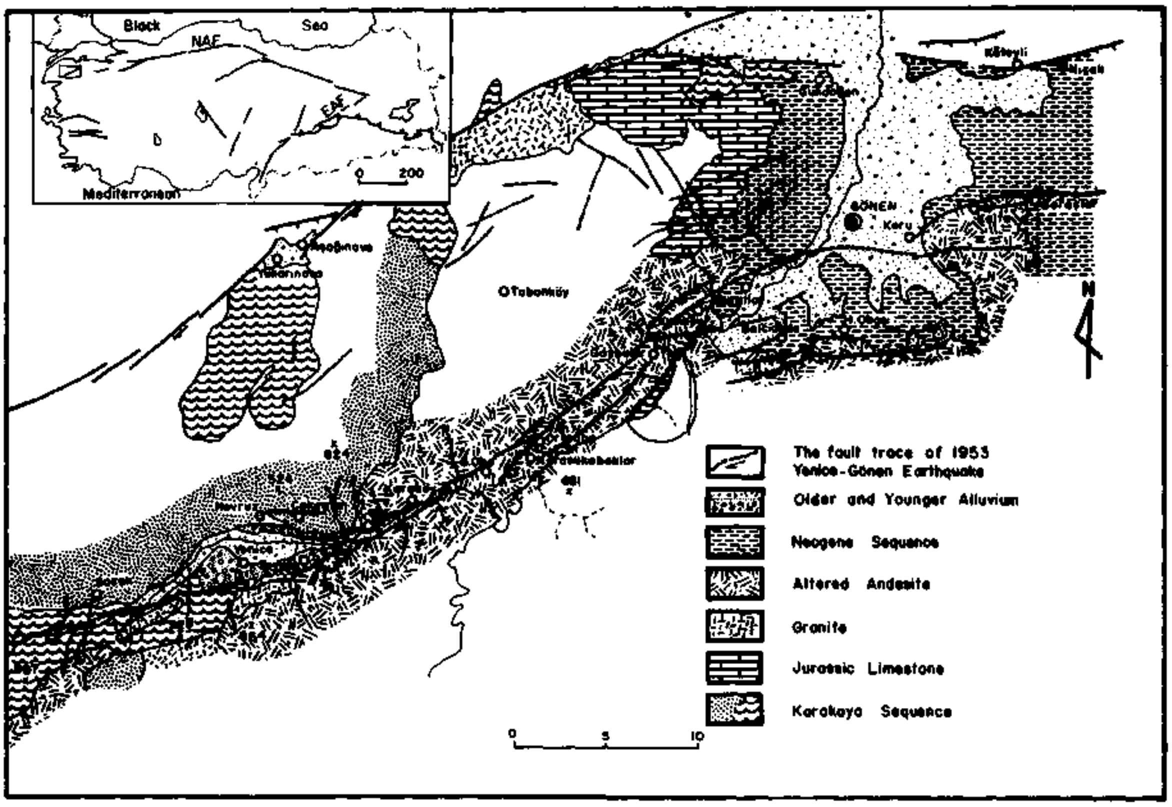

Fig.1- The fault trace of 1953 earthquake between Yenice and Gönen.

posits and the road between Yenice and Gönen, the fault break apparently is visible in the poplar forest and thickets. The trace continues in Neogene deposits trending approximately west-southwest about *2.5* km to the weathered andesites, northwest of Muratlar.

North of Muratlar and Kumköy villages the fault trace is not distinct due to high erosion rates on the mountain slopes and agricultural activities in the valleys. An excavation for dam construction, however, exhibits the fresh fault trace in weathered andesites, and northwest of Gaybular it cuts a small Jurassic limestone outcrop. The fault trace again displaces andesite in continuing southwest from north of Oba. The fault trace there occurs on the north-facing slope of a mountain where the fault scarp apparently developed because of normal dip-slip displacement of the southern block during the earthquake. It forms the boundary between an alluvial plain and andesite east of Çakır.

Northeast of Çakır the fault trace continues for the most pan between alluvium and andesite along the southern border of the valley. It extends to the southwest, cutting the road between Yenice and Kalkım and continues south-southwest of Seyvan.

Between Seyvan and Yenice the fault trace is well exposed as a scarp appoximately 1 m high. Here, the fault break indicates that, in addition to dextral movement, the northern block was displaced downward during the earthquake. The fault trace continues to the west-southwest in the andesite as a very distinctive scarp. It then enters granite, changing its southwesterly direction to westerly south of Yenice (the old town of Yenice originally was located on the fault some 800 m from its present site). The distinct fault trace then makes a southwesterly bend to the south of Yenice and extends through the valley south of Sazak. Here the fault trace marks the southern border of the valley, which is underlain by metamorphic rocks. After almost 4 km, the fault crosses diagonally to the northern side of the valley, displacing the Quaternary deposits in the valley. The fault trace in the northern side of the valley strikes south-southwest into metamorphic rocks for about 5.5 km, and seems to terminate somewhere between Sazak and Zeyberçayırı.

In the more rapidly eroding areas such as the weathered andesites and the rougher terrains associated with higher elevations not all of the faults could be mapped because scarps had been removed by erosion. Mapping faults between Yenice and Gönen was rendered even more difficult by the dense forest cover at higher elevations, and contour plowing and cultivation of the lower slopes. As a result of these factors many fault traces were not continued laterally.

During the mapping of the 1953 earthquake fracture zone between Yenice-Gönen a number of scarp in different stages of erosion were noted. These scarps indicate multiple faulting events during the Quaternary (Herece, 1985).

I would like to discuss about northeast and southwest extension of the Yenice-Gönen fault zone which reactivated by the 1953 Yenice-Gönen earthquake. Neotectonic studies on the northeast extension of the fault zone is utilized by the fault trace developed during 1964 Manyas earthquake. The northeast extension has been considered as a right-lateral strike-slip fault with a minor dip-slip component after the 1964 Manyas earthquake (Ketin, 1966). The field works conducted by Erentöz and Kurtman (1964) and Herece (1985) and the fault plane solutions utilized by McKenzie (1972) and Öcal et al. (1968), however, indicate that the northeast extension of the fault zone is not right-lateral strike-slip motion but it is normal dip-slip movement. This conclusion supports the consideration of the closed depression area between Bursa and Gönen is being a graben (Herece. 1985; 1988).

BURSA-GÖNEN GRABEN

The location of Bursa-Gönen graben is shown in Figure 5. This closed depression begins east of Bursa where it is connected to the NAF system by northeasterly lineaments and closes around Sarıköy and Gönen in the west The graben is as much as 160 km in length and 5-30 km in width.

The depression is bounded by fracture system of different directions to the north and south. In the eastern part of the graben northeast rupture directions predominate while west-northwest trends are seen mostly around Manyas lake in the western sector. The main faults along the borders appear to be parallel in the area between Karacabey and west of Bursa. Both the northern and southern escarpments here trend northeast, but within the graben and in the easternmost and western sectors, as well as on their edges, numerous tilted segments were formed with different orientation.

The graben, in genera, subsided along inward-dipping faults to form a down-faulted, wedge-shaped block (Ekingen, 1972). The main faults along the margins of the graben are normal dip-slip (Fig. 2). Although dips of approximately 70° are indicated on the gravimetric cross-section, scarps on the graben flanks show widely different slope angles due to mass wasting denudation, erosion, and rejuvenation (Herece, 1985).

The elevation of the graben floor is about 0 to 50 meters above sea level. A broad arc may have developped concurrently with graben formation because the shoulders of the bordering block have gently outward dipping slopes. Relief is variable with maximum elevations of 250 and 680 m for the shoulders in the eastern sector and 350 to 450 m in the west. Amounts of subsidence in the graben area apparently differ with shoulder elevation and with thickness of the Quaternary deposits. Present morphotectonic features of the graben have a similar profile to the asymmetric depression (Herece, 1985).

When and how the depositional basin in the Bursa-Gönen graben formed is questionable. Is the stress system (s) that caused the northeast- southwest and northwest-southeast trending faults visible on the Landsat images also responsible for forming this depression? What king of tectonic environment formed this closed basin? Is the basin a dropped keystone block or graben, an extensional depression on listric normal faults, or a "sag-pond" type block associated with an earlier strike- slip regime similar to that prevailing along the NAF today?

Unfortunately, a lack of adequate field data on the Neogene sequences within and around the Bursa-Gönen graben precludes an answer to these questions.

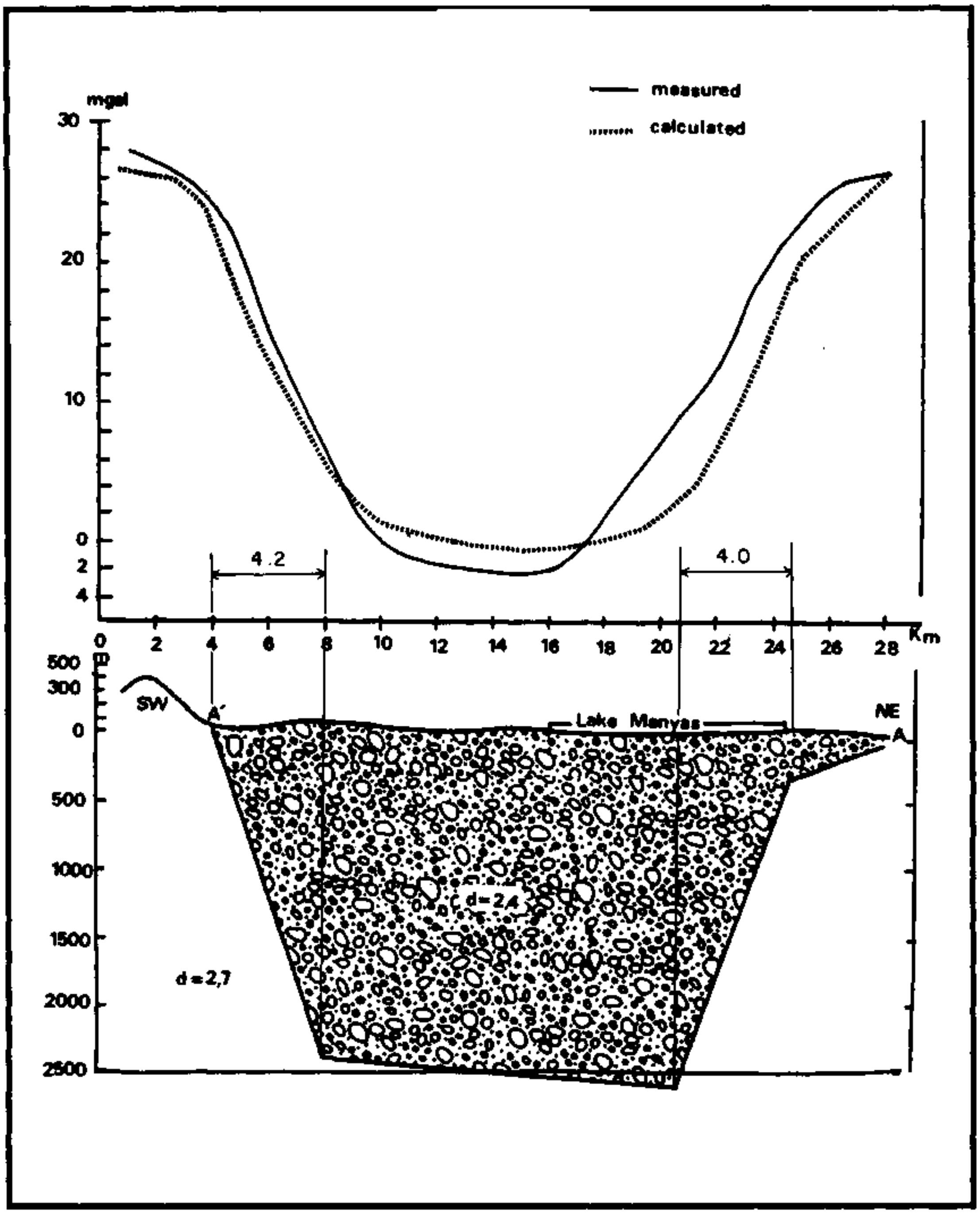

Fig. 2– The separation in the Bursa-Gönen graben, deduced from a gravimetric model.

AGE OF THE NEOGENE SEQUENCE

The age of Neogene sequence in northwest Turkey is questionable because of lack of correlation of Tethys and Paratethys depositional environment. Attemp at correlation of Tethys and Paratethys rocks involves radiometric dating of units interlayered with mammalian faunas in these local sequences (Mein, 1975; Fahlbush, 1976). The Tethys stages have been dated radiometrically (Vaas, 1978) and paleomagnetically (Ryan et al.. 1974; Vaas.1978) and, therefore, can be used for correlation. A tentative correlation of Tethys and Paratethys stages is given in Figure 3 for Neogene deposits on the Biga peninsula.

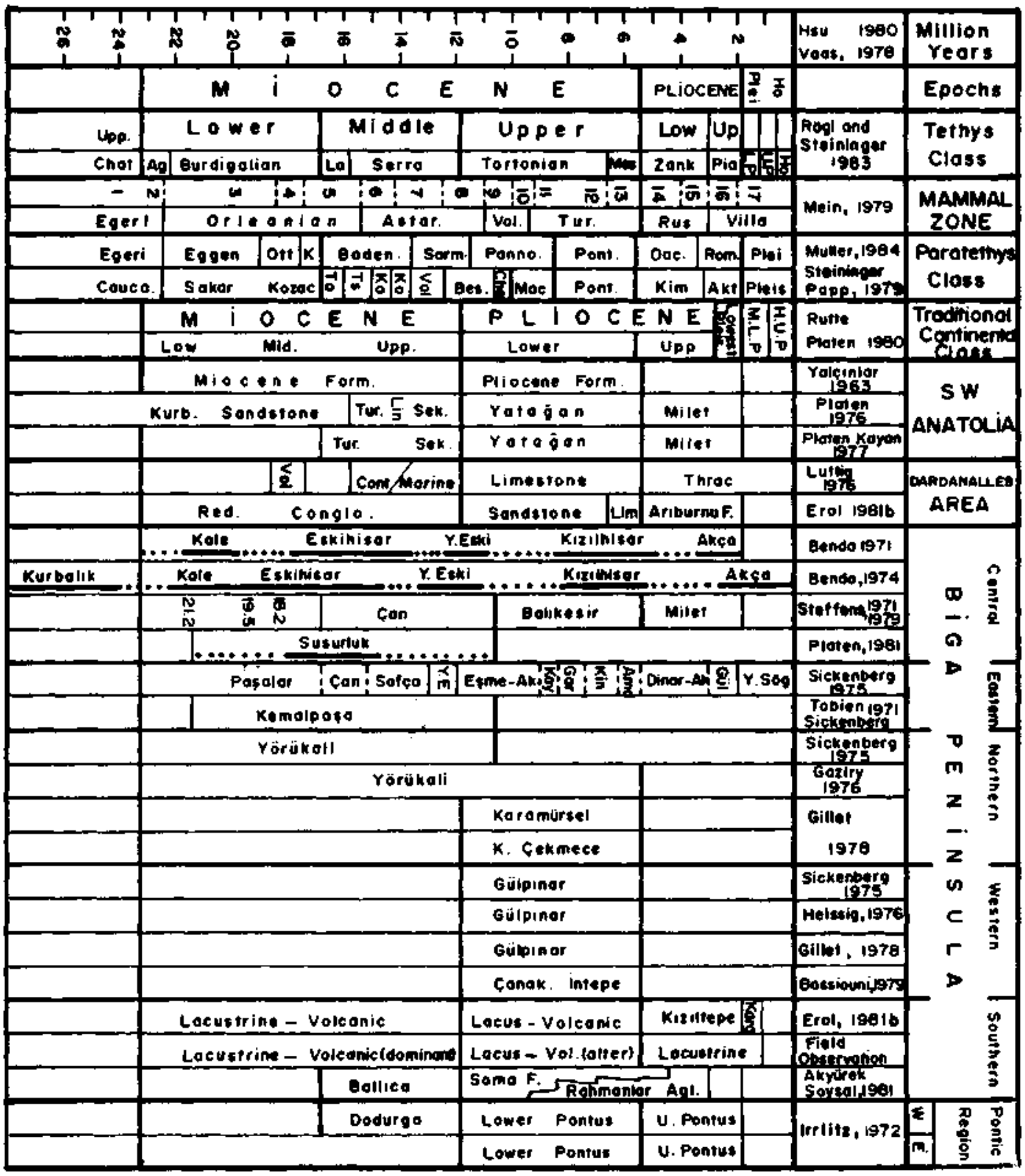

Fig. 3– The age of Neogene sequences in Biga peninsula (Modified from Herece, 1985).

The lignite layers in the Neogene deposits of Biga peninsula are assigned to the "Eskihisar Pollen Assenv age ranging in age from Burdigalian to Lover Serravallian. The viability of the pollen horizons is supported by several other distinctive fossil assemblages and radiometric dates of lavas (Benda et al., 1974). The pollen bearing sediments in northwest Turkey correspond to the lignite between Turgut and Sekköy members of western Turkey.

The fossil assemblages in the Neogene sequence on the northern and western boundaries of the Biga peninsula indicate an exclusively Paratethys (Chersonian) environment in the north. Mixed assemblages are widespread in the Bosphorous and Dardanelles area indicating a transition region between Tethys and Paratethys seas. The sedimentation of Neogene sequence started in Langhian, however, the Late Miocene was a time of extensive tectonic activities. These tectonic movements caused breakup of the landmass and connected Tethys and Paratethys. The Upper Miocene was also a time of extensive volcanic activity during which north- south distension began, thus deepening the sedimentary basin.

On the other hand, there are Upper Miocene lacustrine and fluvial deposits with widespread lignite in the basins (Havza, Ladik, Taşova- Erbaa) located in the area east of Marmara Sea along the NAF zone. To the west of these basins, the Çerkeş-Kurşunlu, Ilgaz and Tosya were developing as parts of final closure of northern Neo- tethys sea along the intra - Pontide suture zone (Şengör and Yılmaz, 1981; Barka, 1984). Andesite, tuff and agglomerate (Devrez and Sivricek formations) were the first deposits of these basins and they were formed as the result of continuing north-south compression during Early Miocene (Barka, 1984). During the deposition of Middle Miocene lacustrine sequences between Kurşunlu and Ilgaz and south of Tosya, the Havza-Ladik and Taşova-Erbaa basins were started to form by the north-south compression at the end of Middle Miocene (Barka, 1984).

During Tortonian time, the lacustrine deposits of lower Pontus formation (Irrlitz, 1972) began to accumulate in all of these basins. The interpretation of syn-sedimentary structures in the lower Pontus formation (Hancock and Barka, 1983) indicates that a broad right- lateral strike-slip motion is initiated at the end of Tortonian (Barka, 1984). These data, however, require that the Anatolian plate should move westward during Upper Miocene. Is the origin of the Upper Miocene basins in the Biga peninsula different than that of the basins in the central portion of the NAF zone. Are those basins formed by the earlier strike-slip regime similar to that prevailing along the NAF today? The answers of these questions are out of scope presently because of lack of some additional field work. The development of the basins in the central portion of the NAF also is related to the westward motion of the Anatolian plate (Hancock and Barka, 1981, 1983; Barka, 1984; Şengör et al., 1985).

No matter what the origin of the Neogene basins, the faults can be recognized from their topographic expression as young scarps that bound the Bursa-Gönen graben. The Bursa-Gönen graben at the least can be explained by the fault systems that surrounded it. It is evident from Landsat images that the diamond-like shape of the graben area is due to east-northeast and west- northwest sets of lineaments. Because only some of the lineaments associated with these Neogene basin margins can be shown to be recent fault scarp, it is suggested that the rest were present as Neogene fractures providing structural control for the developing sedimentary basins. This postulated movement on some lineaments appears to be responsible for deformation of the Neogene sequence in the Biga peninsula.

A tectonic model for the Quaternary (Recent) events in the Eastern Mediterranean incorporates the NAF, EAF, and Hellenic subduction zones, and calls for the Pontide unit, (on the northern side of NAF), to be stationary while the Anatolian plate to the south moves westward (McKenzie, 1972, 1978; Dewey and Şengör, 1979; Şengör and Canıtez, 1982). Assuming this model to be correct, with the northern side relatively fixed with respect to the northeasterly trending Yenice-Gönen lineament, the block south of this lineament must move southwestward if it is to be part of the NAF system. Such a movement was confirmed during the earthquake of Yenice-Gönen in 1953 (Ketin and Roesly, 1953; Herece, 1985).

Besides the Yenice-Gönen line, the Sarıköy-İnova and the Manyas-Danişment lineaments also must represent right - lateral strike-slip faults. The southern side of the Bursa -Gönen graben, therefore, moves west-southwest along these strike-slip traces while the graben area is enlarged north to south by normal faults as shown in Figure 5. This latter movement also is verified by the normal faults of 1964 event (Herece, 1985).

Apparently this closed depression, in which some 3000 m of Neogene sediments are deposited, is bounded by normal faults; elsewhere along the NAF system, right-lateral strike-slip faults are dominant. These contrasting styles can be accomodated in second-order shear models of Lensen (1958).

TOTAL LATERAL DISPLACEMENT IN THE SOUTHERN BRANCH OF THE NAF'S

There are no available data to suggest any displacement for the NAF on Biga peninsula. It is essential to know the depth of the subsidence and the thickness of Quaternary deposits (When and how the graben floor started subsiding). The gravimetric cross-section of the Manyas depression area, however, implies a lateral displacement of the southern branch of the NAF in the Biga peninsula.

As can be seen in Figure 2, the separation in the graben area is about 20.5 km. This represents the maximum separation in the graben, and includes the cumulative strain from both Neogene and Quaternary times. It is difficult to assign incremental displacement with time, because neither the tectonic style nor strain history has been worked out for the Neogene deposits in the graben (Herece, 1985). The Yenice -Gönen, Sarıköy-İnova and Manyas-Danişment faults, therefore, should not be responsible for the total separation if the Bursa-Gönen graben used different fault systems during the Neogene sequence.

The graben has subsided and enlarged since Late Upper Pliocene due to the distinct young faults which bound these sedimentary basins to the north and south. However, there is a possibility to find out what the separation is in the depression area. If the profile of the graben is restored, one can calculate the absolute separation in the graben as 8.2 km since Late Upper Pliocene time (Herece, 1985). It is also possible to determine that there has been combined dextral movement of 8.2 km on the Yenice-Gönen, Sarıköy-İnova and Manyas-Danişment faults. This value of 8.2 km should represent the cumulative lateral displacement on all the faults that constitute the southern branch of the NAF during Quaternary time.

LATERAL DISPLACEMENT ON THE YENİCE-GÖNEN FAULT

By matching up the weathered andesite and granite intrusions on either side of the Yenice valley (Fig. 4) a total horizontal displacement of 1.7-2.8 km is inferred on the Yenice-Gönen fault line. The weathered andesite and younger volcanic rocks overlying the Neogene sequence east of Yenice apparently have been displaced southwestward about 3.4 km, east-west offset of 2.8 km. In contrast, the contact of the granite intrusion in the Yenice basin appears to have been separated (right-lateral) about 2.8 km with an east-west offset of 1.7 km. Assuming the higher of these values as a maximum, lateral displacement can be taken as 2.8 km on the fault line in the Yenice valley.

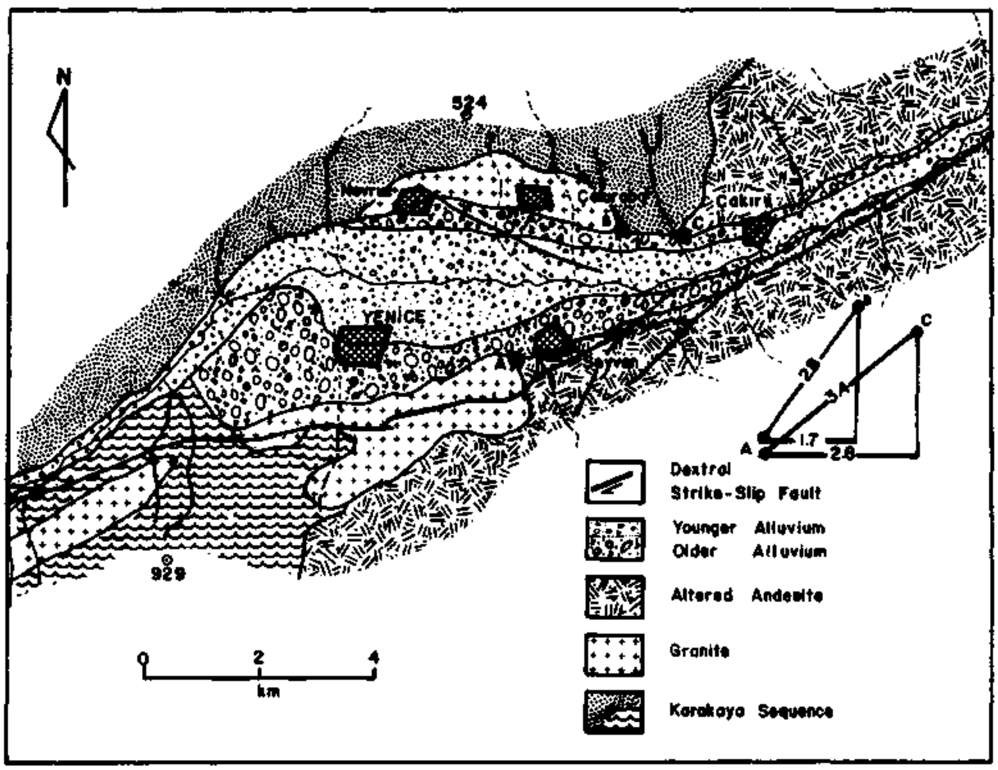

Fig. 4 - The lateral displacement of volcanic units in the Yenice valley (Herece, 1985).

The rest of 5 km offset should be used by Sarıköy-İnova and Manyas-Danişment faults. No data, however, are available for displacement on these faults.

In the current literature, there are discussions on the amount of the lateral displacement of the fault zone as in the westward extension of the NAF zone. Seymen (1975) and Tatar (1975) state a 85±5 km lateral displacement obtained from displaced suture zone in the eastern part of the NAF. This Figure has been widely used in the modelling works. Yılmaz (1985) does not agree with this offset (85±5 km) and he states that this amount of offset must be reconsidered.

Hancock and Barka (1983) indicate that there has been 25±5 km total dextral separation along the NAF since Lower Pliocene. The 25-27 km offset of the Kızılırmak river is in harmony with the value given above. The new data come from the field work around Gerede in 1987. It demonstrates that dextral offset of the NAF in this area is about 18-22 km (Herece, in preparation).

The change in direction of the Sakarya river near Geyve from south-north to easterly, may correspond to the offset of the NAF. This offset is roughly measured as 13-18 km (Herece, 1985).

8 km of the total offset has been used by the faults in the Biga peninsula since the Late Upper Pliocene (in Quaternary). The rest of the offset, the location and the time interval of the remaining displacement of the NAF must be studied. As stated in the current literature the NAF connects the northern Marmara trough to the Saros bay and the Lake İznik-Gemlik bay to the Marmara depression areas. In other words, the Marmara depression area and/or the parts of the enlargement of this area may correspond to the strike- slip component of the NAF. The Gaziköy-Saros bay fault, which runs from the Sea of Marmara to the Saros bay, is a very distinct right-lateral strike-slip fault and it is currently active. The activity of this fault zone is indicated by 1912 and 1928 earthquakes. For the above mentioned reasons, most of the displacement of the NAF might be located in the northern part of the Bursa-Gönen graben.

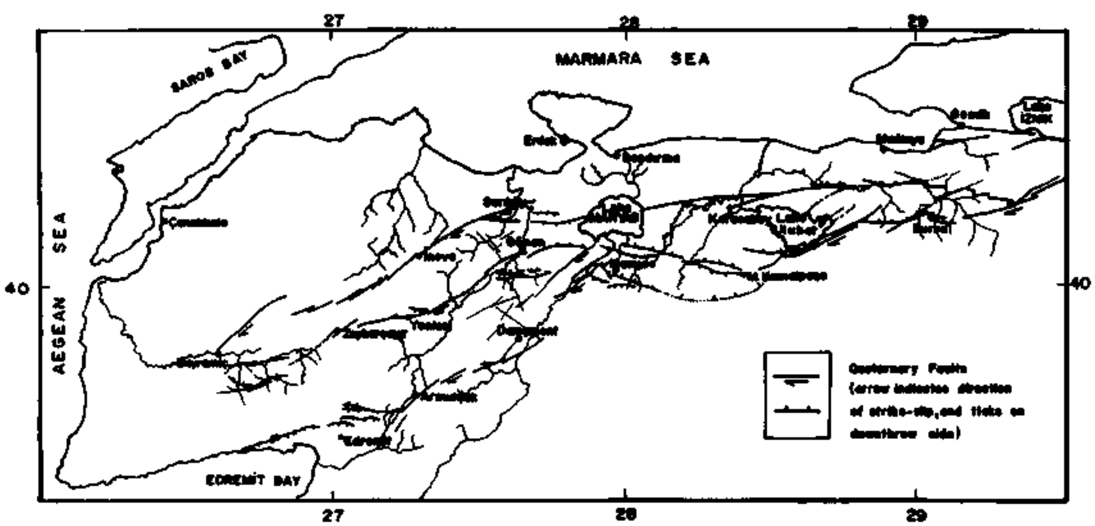

Fig. 5– The major fault lines in Biga peninsula.

WESTWARD CONTINUATION OF THE YENİCE-GÖNEN FAULT

The fault trace of the 1953 earthquake line and other fault breaks caused by previous tectonic activity in the Yenice valley have been mapped as far southwest as Sazak. They appear to diminish in size and even lose their surface expressions farther to the southwest In particular, the lateral movement on the Yenice-Gönen fault zone which appears to be responsible for the opening of the Bursa-Gönen graben needs to be addressed. From here westward, the continuation of the Yenice-

Gönen fault zone is discussed in detail by Herece (1985) and the fault zone is terminated somewhere to the west of Eskiyayla village.

DISCUSSION AND CONCLUSION

The east and central portion of the NAF zone is very distinct morphologically. It branches and becomes less distinctive in Marmara Sea region. Well known dextral strike-slip component of the fault is distributed over a number of depressional areas with a large component of normal faulting. The Bursa-Gönen graben is one of those areas.

The bounding faults, formes the Bursa-Gönen graben, is connected to the NAF zone by northeasterly lineaments in the east of Bursa. Westward, near Gönen and Sarıköy, this graben closes. The main faults along the northern and southern margins of the graben are normal dip-slip with dip angles of 68° - 70° . These dip angles also are very close to the theoretical dip angles of grabens (Heiskanen and Vening Meinesz, 1958). The graben, formed by normal dip-slip faults, is filled with 3 km thick deposits. There is a possibility that these normal faults may extend to a depth of 8 km.

The normal faults along the southern border of the Bursa- Gönen depression, which includes the Lake Manyas, are very distinct; the northern border coincides with the northern shore-line of the Lake. The western and southern parts of the Bursa- Gönen graben apparently move toward west-southwest along dextral strike-slip faults, while the graben area is enlarged by east-west trending normal faults.

It is essential to know the age and nature of the deposits in the graben if deductions on how the graben formed and the graben floor started subsiding are to be made. As stated in the literature (Şengör et al., 1985; Barka, 1984) the acceptance of the tectonic events in the Upper Miocene basins are caused by westward movement of the Anatolian plate brings the possibility that these basins were developed by an earlier dextral strike-slip regime similar to the NAF of today. Because Lower Pontus formation is overlain by the Upper Pontus formation with angular unconformity (Irrlitz, 1971; Barka, 1984). This unconformity may suggest that the deformative tectonic events during deposition of the Lower Pontus formation slowed down or stopped for a while (Herece, 1985). The NAF of today has been active since Late Upper Pliocene time.

In the Bursa-Gönen graben the actual separation in north to south direction has been about 8 km (4 mm/year) during and since the Quaternary. The possible total horizontal displacement along the Yenice-Gönen fault zone, which is one of the key component of the extension, has been about 2.8 km (1.4 mm/year). No data, however, are available for displacement on the Sarıköy-İnova and Manyas-Danişment faults.

The Sarıköy-İnova fault starts from Sarıköy and continues southwestward. The eastwaru continuation of this distinct fault trace is thought to represent the northern boundary of the Bursa-Gönen graben. In other words, this fault does not represent the middle branch of the NAF which runs (Barka, 1983; Barka and Kadinsky-Cade, 1988) from Gemlik bay to Bandırma and Sarıköy to Bayramiç and Ezine and Aegean Sea (Herece, 1985; 1988). The westward continuation of the Yenice-Gönen and Sarıköy-İnova faults terminate somewhere to the east of Bayramiç (Herece, 1985).

The Manyas-Danişment fault caused extensive and complex deformation in its western part. This fault might run over Armutluk to the Edremit bay. The Yenice valley (3-4x7-9 km), which is cut by the fault trace of 1953 event, and İnova depression area (1.5x2.5 km) are "pull-apart" basins (Herece, 1985).

In conclusion, the northeast-southwest trending dextral strike-slip faults in the Biga peninsula are the westernmost known extension of the NAF. Based on this observation the Yenice-Gönen fault zone starts from southwest of Gönen and extends toward Yenice. In other words, northeast-southwest trending fault system, from Muratlar, Kumköy to Yenice, is right-lateral in character. This character implies that it is related to the NAF. East-west trending fault from Muratlar to Çakmak, which has been developed by the 1953 earthquake, is the latest connection of the Yenice-Gönen fault zone to the Bursa-Gonen graben. The fault trace of 1964 Manyas earthquake is not the eastern extension of the fault zone developed partly by the 1953 Yenice-Gönen earthquake. This conclusion debates that of Şaroğlu et al. (1987). The fault zone developed by the 1964 Manyas earthquake is not a right-lateral strike-slip fault but it is a normal dip-slip fault belonging to the Bursa-Gönen graben (Herece, 1985).

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