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EXTENTS OF THE NORTH ANATOLIAN FAULT IN THE İZMİT, GEMLİK AND BANDIRMA BAYS

İZMİT, GEMLİK VE BANDIRMA KÖRFEZLERİNDE KUZEY ANADOLU FAYININ UZANIMLARI

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Abstract

High resolution shallow seismic reflection profiles, surveyed by MTA Sismik-1 in the İzmit, Gemlik and Bandırma bays, in 1984, were re-examined in order to understand geometry and kinematics of the northern and middle strands of the North Anatolian Fault. We used the pull-apart model to detect the course of the strands. We concluded that this approach fits well with the fault patterns and all three strands seems to have identical fault geometry and kinematics. GPS measurements geomorphology, bathimetry and tickness of sediment in the basins, and historical earthquake records in the easten Marmara Sea region show that slip rate is higher along the northern strand than the middle strand suggesting higher earthquake risk along the northern strand of the North Anatolian Fault.

Introduction

The North Anatolian Fault is the most prominent active fault in Turkey and it extends from Eastern Anatolia to Greece through northern Anatolia, the Marmara Sea region and North Aegean Sea. The fault zone splays into three strands in the Eastern Marmara region. The northern strand crosses the İzmit bay and it forms the northern Marmara Sea basins. The middle strand splays from the Mudurnu valley and forms the Geyve-Pamukova pull-apart basin then it extends between Mekece and Gemlik Bay going through the south of İznik lake (e.g. Barka and Kadinsky-Cade 1988; Barka 1991, 1992, 1993). Barka and Kadinsky-Cade (1988) proposed a pull-apart model for the Marmara Sea region to account for the kinematics of the strands of the North Anatolian Fault. To create their model, they combined fault geometry, pattern of seismic activity, geomorphology, fault plane solutions and offshore seismic profiles. This model has been generally accepted with small modifications (e.g. Wong et al., 1995; Ergün and Özel, 1995; Akgün and Ergün, 1995; Koral and Öncel, 1995). Barka (1992) further investigated the extent of the active strands of the North Anatolian Fault beyond west of the Marmara Sea toward the North Aegean Sea and he suggested that the three strand crosses the Marmara Sea and North Aegean region with identical geometrical pattern (Fig. 1).

In this paper, by using seismic profiles obtained by MTA Sismik-1 in 1984, we studied İzmit, Gemlik and Bandırma Bays. Even though, these profiles were already studied (Kurtuluş, 1984; Özhan et al., 1985; Kavukçu, 1990; Akgün and Ergün, 1995), we reinterpreted the data through the light of the pull-apart model for the Marmara Sea region.

Interpretation of Seismic reflection profiles in the Izmit Bay area.

MTA Sismik-1 research vessel surveyed the Izmit bay area to obtain high resolution shallow seismic reflection profiles. Interpretations of these profiles were published by Özhan (1986), Kavukçu (1990) and Akgün and Ergün (1995). They recognized two grabens, Çınarcık and Karamürsel basins which were separated by the Hersek Delta. Kavukçu (1990) pointed out that the Hersek Delta sits on a shallow basement rock. Figure 2 and 3 show two seismic profiles taken from Özhan et al., (1985), indicating fault controlled basins east and north of the Hersek Delta. In fact, the İzmit bay consists of three separate basins, namely, Izmit, Karamürsel and Çınarcık basins. The Izmit basin occurs at the eastern end of the bay. The Karamürsel basin is approximately 18 km long, 10 km wide and 200 m deep. It occurs between Yarımca and Hersek Delta. The Çınarcık basin is the largest basin in the Marmara Sea .

In pervious studies, structural models accounting for the origin of the İzmit bay area were based on either a simple graben structure (i. e. Crampin and Evans 1986) or a single southern strike-slip fault with vertical component (i. e. Şaroğlu et al 1987, Ketin 1990). However, Barka and Kadinsky-Cade (1988) introduced the pull-apart model which explains the structures in the İzmit bay area better than other proposed models, as it does in other parts of the Marmara Sea region. This pull-apart model has been confirmed by Akgün and Ergün (1995) Akgün (1987), and by Koral and Öncel (1995). In this study we used the same basic model in which right stepping en echelon strike-slip fault segments were described to open small basins, İzmit, Karamürsel and Çınarcık basins, as pull-apart structures (Fig. 2). In this model we combined the data by using, a) geometry of the shore lines, b) batymetry, c) offshore seismic reflection data made by MTA Sismik-1 (Kavukçu, 1990), d) borehole data of DSI (State Water Works), e) local and regional geology, and f) seismicity pattern (Fig. 2).

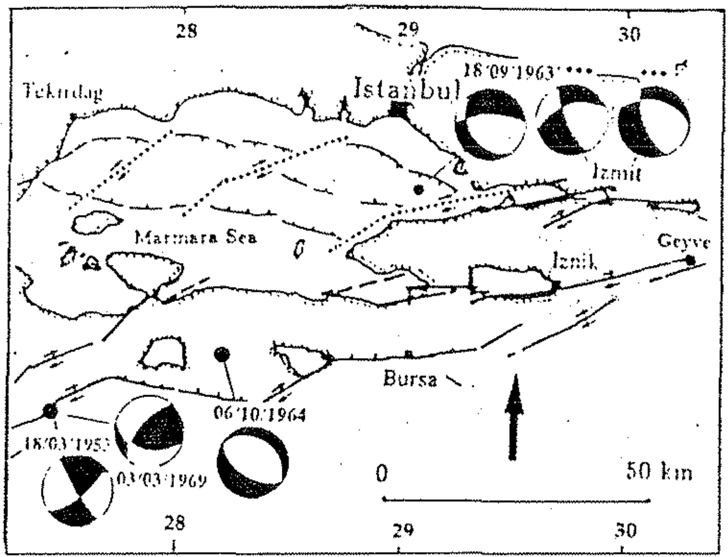

Figure 1 Active strands of the North Anatolian Fault in the Marmara Sea region and fault plane solutions of major earthquakes (from Barka, 1992) Two solutions in the İzmit area are based on composite solutions done by Crampın et al , (1985).

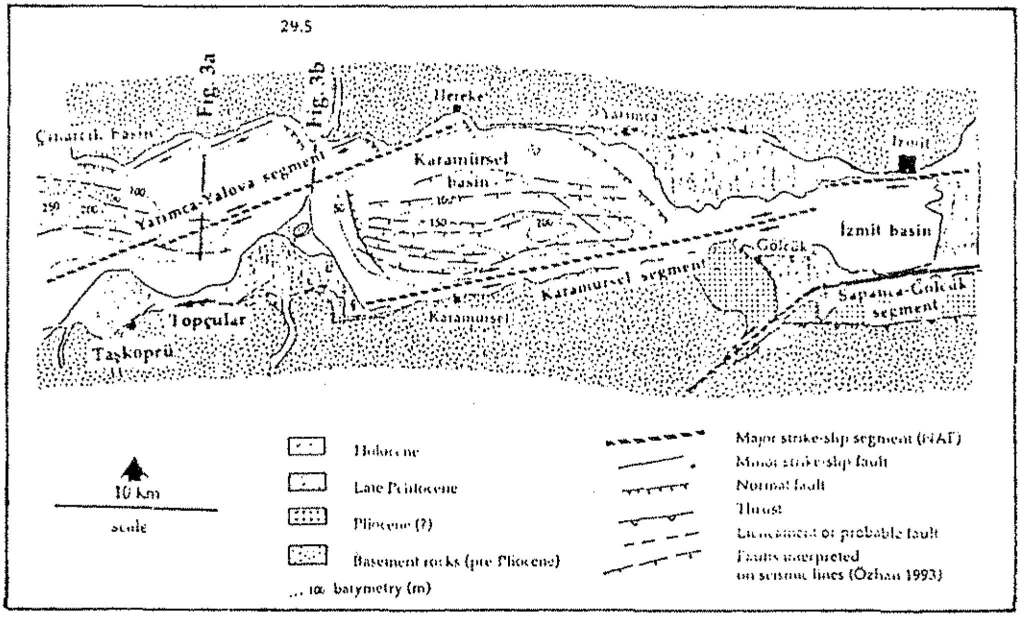

Figure 2. Neotectonic map of the İzmit bay Notice the pull-apart opening of the İzmıt, Karamürsel and Çınarcık basins. Data compiled from (Akartuna, 1968; Ozhan et al., 1985; Sakınç and Bargu, 1989; Barka and Gülen, 1986. Kavukçu, 1990, Barka, 1992).

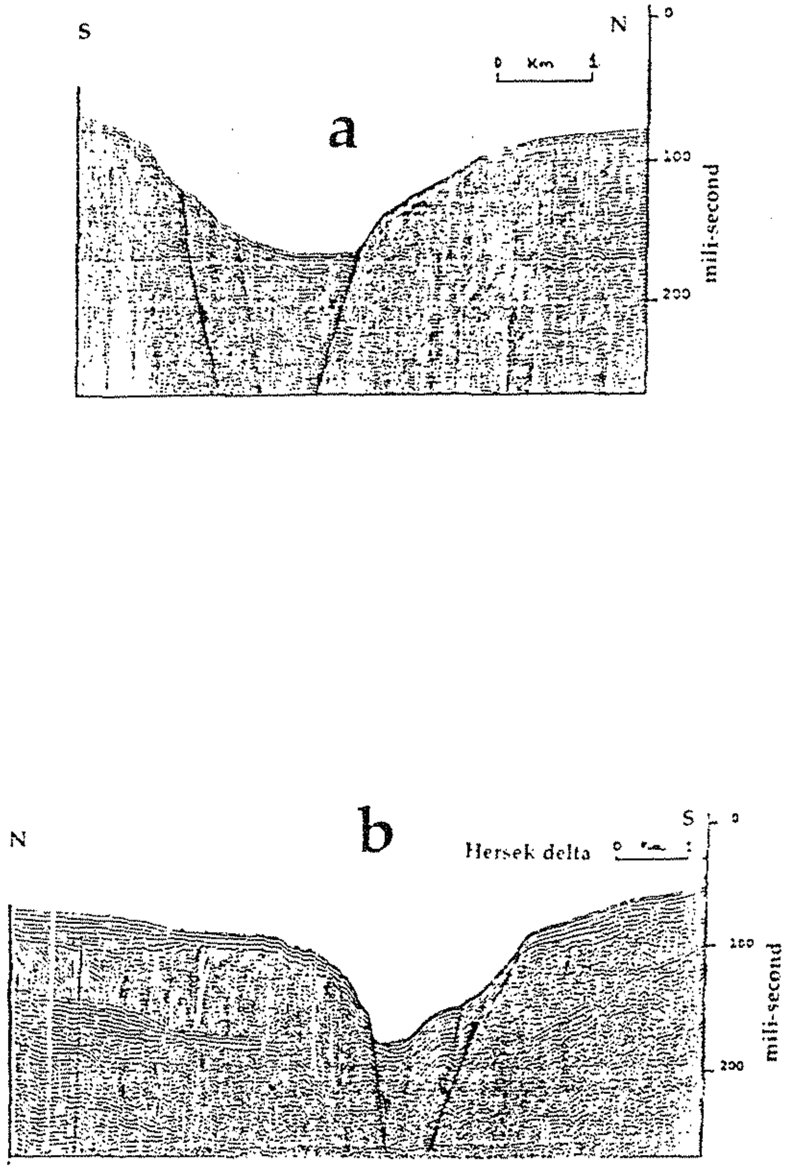

Figure 3. Two examples of seismic reflection profiles obtained by the MTA Sismik-1 west (a) and north (b) of the Hersek Delta (Özhan et al., 1985). Locations are shown in Figure 2. Both sides of the bains is controlled bay normal faults.

The Izmit basin opens between Sapanca-Gölcük and Karamürsel segments. The E-W trending Sapanca-Gölcük segment of the İzmit basin extends along the southern margin of the basin and it changes direction abruptly to southwestward south of Gölcük. The high elevations in the southern block is probably related to this NE-SW trending Gölcük segment. These mountains are also the main source of the Hersek Delta. The shore line between Hersek Delta and Gölcük is very straight indicating a near offshore strike-slip fault. This segment is named the Karamürsel segment and it initiates nearby the City of Izmit and it extends until the southeastern corner of the Hersek Delta. A 1/35.000 and 1/10.000 scale areial photograph study revealed that the Karamürsel segment may not extend to the west of the Hersek Delta. Along the southern margin of the delta, it steps to the north and continues to the west as discontinuous small segments . Near Topçular strike-slip (with thrust component) morphology is well developed for short distance and this extends to Taşköprü village. However, the elevations of the late Pleistocene shallow marine deposits on the Hersek Delta and south of Altınova are comparable (27/20-30 m) indicating that the major fault segment should occur north of the delta. A "State Water Work"' s borehole near Altınova cut the bedrock at 46 m, indicating that the basement under the delta is shallow. Thus this may suggest that the delta moves with the southern block otherwise we could expect a greater depth for the bedrock under the delta.

The northern margin of the Karamürsel basin is formed by the Yarımca-Çınarcık segment. East of Yarımca, this segment consists of small faults trending approximately E-W. Between Yarımca and Hereke the shore is fairly straight trending again E-W and aerial photographs illustrate many triangular facets along the shore line. This segment, then trends WSW-ENE and extends towards Çınarcık delimiting northern apex of the Hersek Delta. The NE-SW trending shore line between Hereke and Gebze suggests that the shoreline may be formed by secondary en echelon strike-slip faults

Interpretation of seismic reflection profiles in the Gemlik Bay area

The geometry and kinematics of the middle strand between Geyve and Gemlik have been studied fairly well through earthquake research projects (e.g. Tsukuda et al., 1989, Honkura and Işıkara, 1991; Barka 1993). However, geometry and kinematics of the section which lies between the Gemlik and Bandırma bays, of the middle strand has not been known in detail. The Gemlik bay area was studied by Kurtuluş (1985) who interpreted the structures from high resolution shallow (effective until 300 m) seismic reflection profiles which were obtained by MTA Sismik-1 in 1984. The batymetric map was created by echo-sounder measurements (Atlas Deso 10) and it had accuracy of 5-10 cm. According to the batymetric map, the maximum depth was about 110 m and its located NE of Mudanya. The long axis of the low area trends NW-SE (Fig. 4).

Kurtuluş (1985) categorized faults in the Gemlik area into three types; a) boundary faults, b) fault which are inactive but cut the sediments, and c) faults which cut the sediments and the sea bottom. (Fig. 5 and 6). In this study, the bathymetric

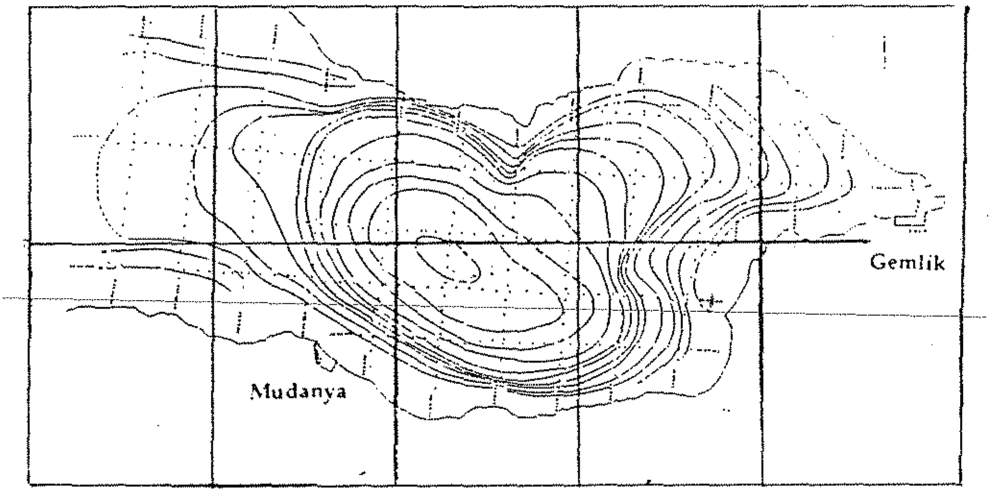

Figure 4. Bathimetry of the Gemlik bay from Kurtuluş (1985).

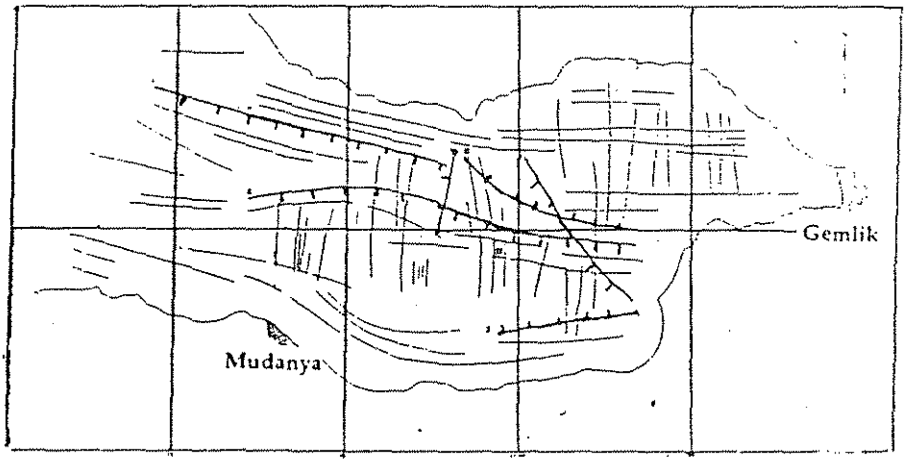

Figure 5. Fault map of the Gemlik bay interpreted from seismic reflection profiles, from Kurtuluş (1985).

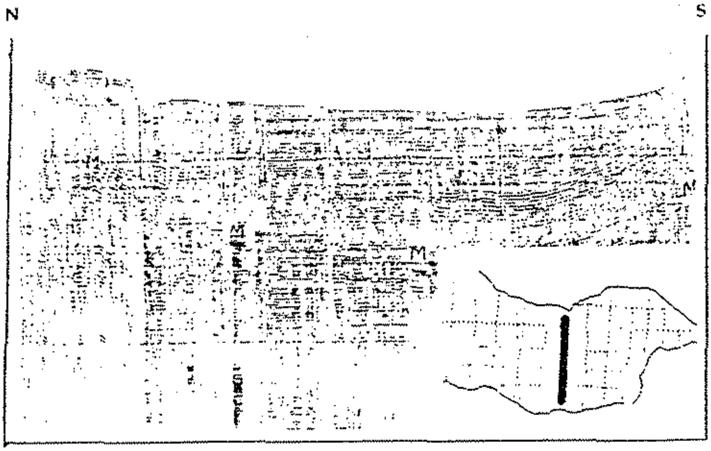

Figure 7. Active fault map of the Gemlik bay interpreted during present study Seismic profiles were the same as Kurtuluş (1985), from MTA Sesmik-1.

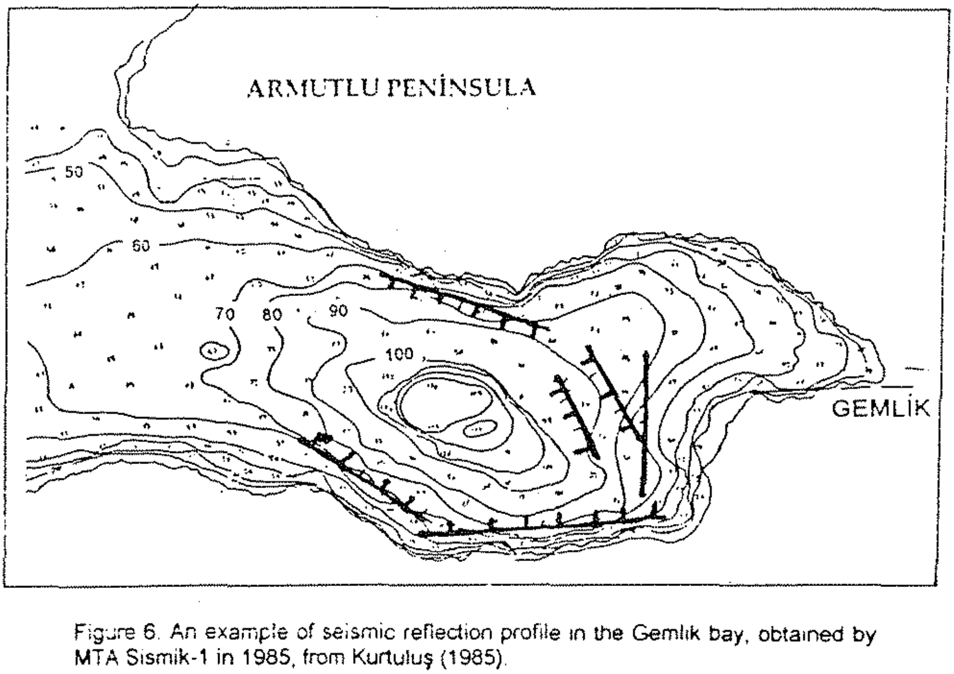

Figure 6. An example of seismic reflection profile in the Gemlik bay, obtained by MTA Sismik-1 in 1985, from Kurtuluş (1985).

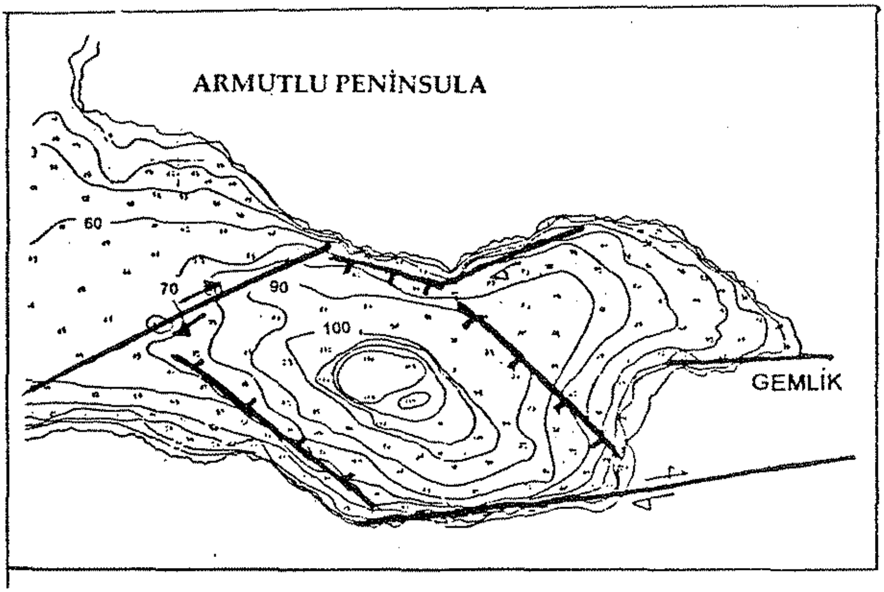

Figure 8. Active segments of the middle strand between Gemlik bay and İznik lake, from Tsukuda et al , (1989).

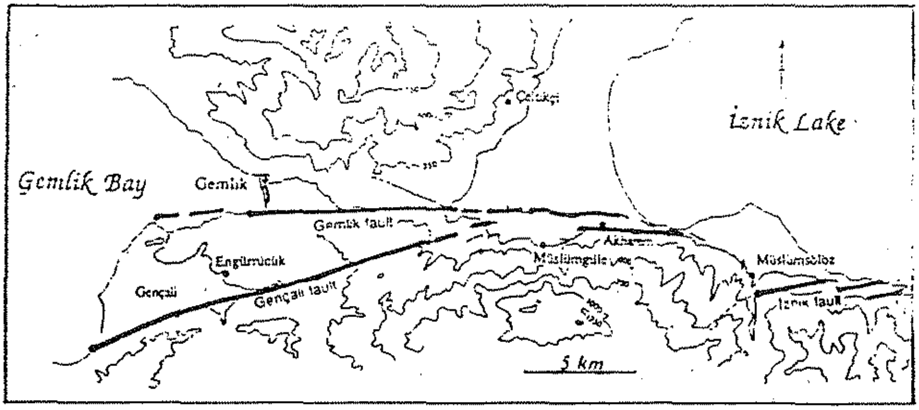

Figure 9. Active fault map of the Gemlik bay area obtained by the combination of onshore and offshore faults.

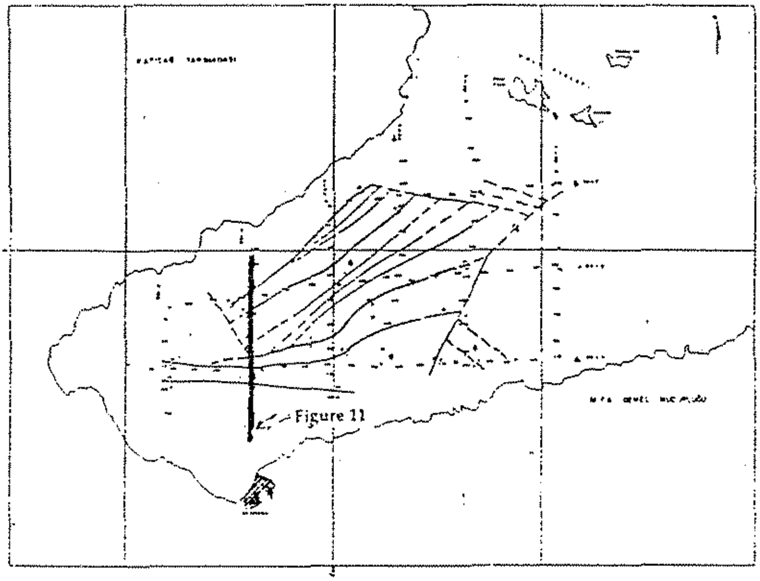

Figure 10 Offshore fault map of the Bandırma bay interpreted from seismic reflection profiles obtained by MTA Sismik-1, from Kavukçu (1990).

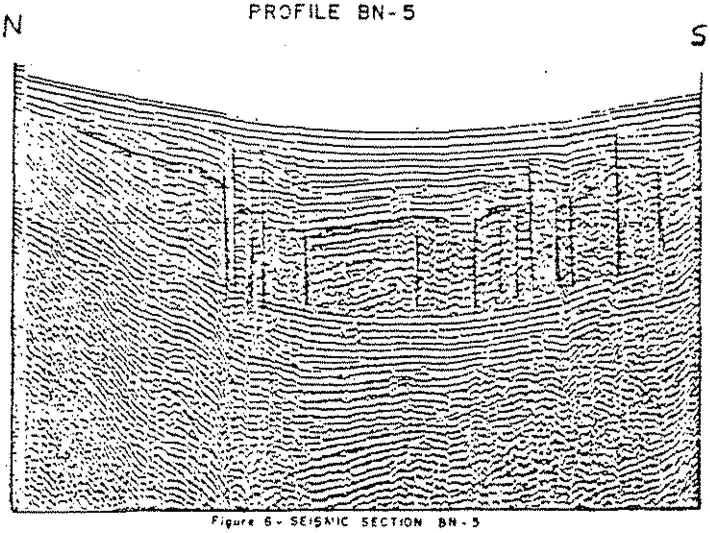

Figure 11. An example of seismic reflection profile in the Bandırma Bay, from Kavukçu (1990). Its location is indicated in Figure 10.

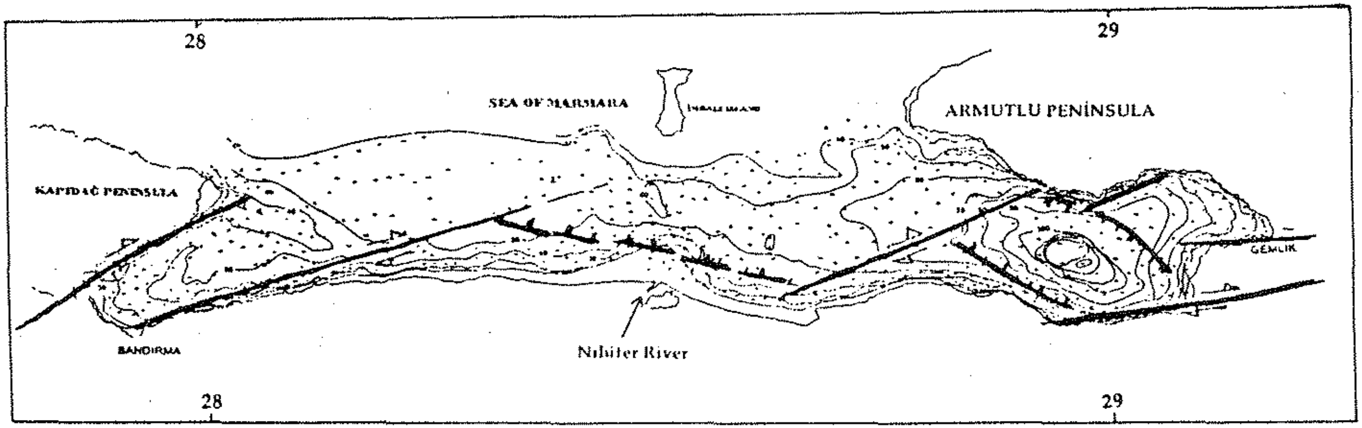

Figure 12. Geometry and extent of the active fault segments of the middle strand of the North Anatolian fault between Gemlik and Bandırma bays. Compare this pattern with the northern and southern one in Figure 1.

contours are re-ploted and the MTA's seismic profiles (Kurtuluş, 1984) reinterpreted (Fig. 7). In Figure 7, we consider only the active faults that deform the sea bottom. Figure 8 show the geometry and distribution of the segments of the middle strand of the North Anatolian Fault between İznik and Gemlik. The fault strand has two segments in the Gemlik area, one E-W direction going through the town of Gemlik and the other one trends ENE-WSW and extends towards Mudanya. The NW-SE trending faults have larger vertical offset and they are interpreted has normal faults. The general pattern of active fault segments both being interpreted from seismic profiles in Gemlik bay and onshore areas and offsets along them suggest that the Gemlik bay area is a pull-part structure. Figure 9 shows a simplified tectonic map of the Gemlik bay area.

Seismic reflection profiles in Bandırma Bay

Figure 10 shows distribution of active faults which were observed on high resolution seismic reflection profiles (Kavukçu 1990). Kavukçu (1990) recognized a complex pattern of the faults where two sets of faults, trending NE-SW and E-W were dominant. He suggested that the basin was collapsing inwards and still active (Fig. 11). The geometry of Bandırma bay (cost line) and the observed pattern of the active fault in the region we suggest that the Bandırma basin can be interpreted also as pull-apart basin (Fig. 10).

An E-W trending normal fault provide connections between Gemlik and Bandırma bays forming a large pull-apart similar to the Manyas-Mustakemalpasa segment of the southern strand and southern margin of the Çınarcık basin of the northern strand. However, the morphologic expressions of this normal fault are obscured by the thick deltaic deposits of the Nilüfer River (Fig. 12).

Discussion and Conclusions

High resolution shallow seismic reflection profiles surveyed by MTA Sismik-1 in 1983, in the Izmit, Gemlik and Bandırma bays provided valuable data to identify the geometry and kinematics of the northern and middle strands of the North Anatolian Fault. Active fault pattern obtained from multiple approach including seismic reflection profiles, bathimetry, onshore morphology and distribution of late Quaternary deposits, reveals that pull-apart model is consistent with the overall data. The available data also clearly illustrates that along the northern strand, not only the size of the basins are larger, but also morphological expressions of the active fault segments are better developed than the middle strand indicating that the slip rate along the northern strand is higher than middle strand. This is confirmed by both recent GPS measurements and historical earthquake records. Figure 13 shows direction and size of velocity lines in the Eastern Marmara region (Straub, 1996). Distribution of GPS vectors relative to northern and middle strands shows that only a few mm/yr slip rate can be detected along the middle strand while more than 10 mm/yr slip rate can be attributed to the northern strand.

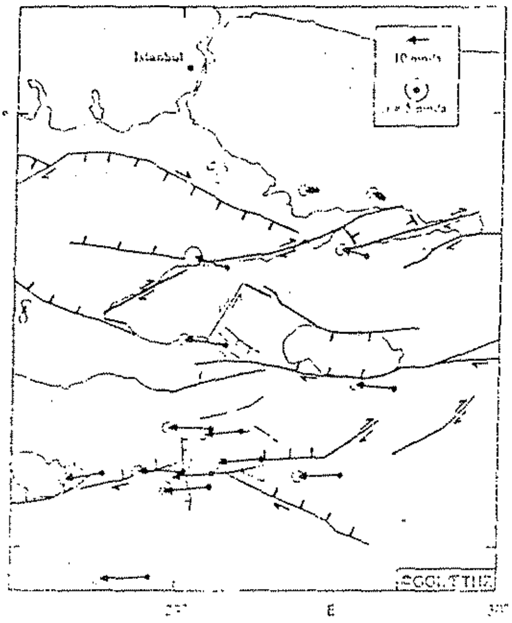

Figure 13. Distribution of GPS velocity vectors in the Eastern Marmara Sea region, from Straub (1996). Notice that a very high percentage of the motion is taken up by the northern strand.

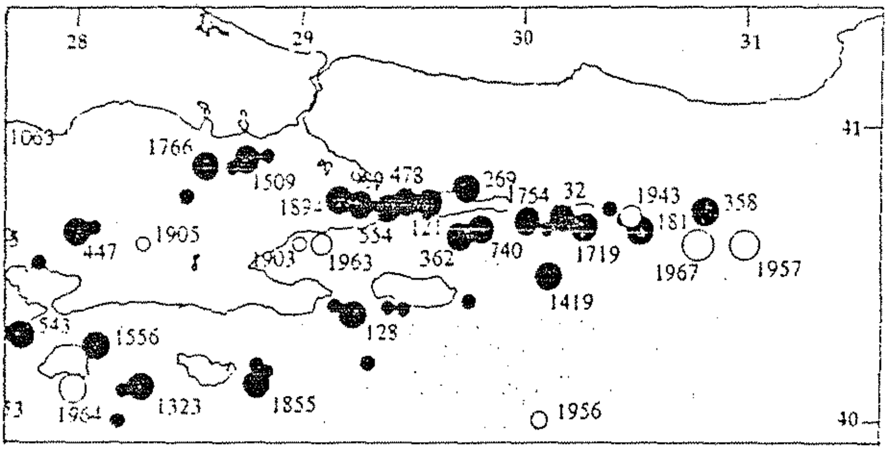

Figure 14. Distribution of historical earthquakes in the eastern Marmara Sea region, from Ambraseys and Finkel (1991). Notice that most of the earthquakes occurred along the northern strand which is consistent with the GPS result.

Distribution of historical earthquakes (Ambraseys and Finkel 1991), (Fig. 14) and trench studies along the middle strand (e.g. Barka 1993, 1996; Yoshioka and Kuşçu 1994) are in good agreement with the result obtained from GPS measurements.

Özet

MTA Sismik-1 gemisi tarafından 1984 yılında yapılan etüdlerden elde edilen yüksek ayrımlı sığ sismik yansıma kayıtlarının yeniden incelenmesi ile Kuzey Anadolu Fayı'nın kuzey ve orta kollarının geometrisi ve kinematiğine ilişkin yeni bulgular elde edilmiştir. Bu amaçla pull-apart modeli uygulanmış, bu modelin fay paternine çok uygun olduğu; her üç kolunda eş fay geometrisi ve kinematiğine sahip olduğu sonucuna varılmıştır. GPS ölçümleri, jeomorfoloji, batimetri, havzalardaki çökel kalınlıkları ve doğu Marmara Denizi bölgesinin tarihsel deprem kayıtyları, fayın kuzey kolundaki atımın orta kolda gözlenenden daha fazla olduğunu, başka bir değişle kuzey kolda deprem riskinin daha yüksek olduğunu göstermektedir.

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References

Akartuna, M. (1968). Armutlu yarımadasının Jeolojisi. Ist. Üni. Fen Fak. Monog. 20, 105pp.

Akgün, M. (1987). Izmit Körfezinin jeofizik yöntemlerle incelenmesi. MSc. Thesis, DEU, Izmir.

Akgün, M. and Ergün, M. (1995). İzmit Körfezinin yapısı ve Kuzey Anadolu fayı (KAF) ile ilişkisinin irdelenmesi. *Jeofizik*, 9: 1-2, 71-78.

Ambraseys, N. N. and Finkel, C. F. (1991). Long-term seismicity of İstanbul and of the Marmara region. Engin. Seis. Earthq. Engin.Report 91/8, Imperial College.

Barka, A. A., (1991). İstanbul'un Depremselliğini oluşturan tektonik yapılar ve İstanbul için bir mikro-bölgelendirme denemesi. "İstanbul ve Deprem Sempozyumu" Inşaat Müh. Odası.

Barka, A. A. and Kadinsky-Cade, K. (1988). Strike-slip fault geometry in Turkey and its influence on earthquake activity. *Tectonics*, 7: 663-684.

Barka, A. A. and Gülen, L. (1988). New constraints on age and total offset of the North Anatolian Fault Zone: Implications for tectonics of the eastern Mediterranean region. Spec. Publ. Middle-East Techn. Univ. Ankara, Turkey. .

Barka, A. A. (1992). The North Anatolian Fault. Annales Tectonicae, 6: 164-195.

Barka, A. A. (1993). Kuzey Anadolu Fayının Sapanca- İzmit ve Geyve- İznik Kolları Üzerinde Paleosismik Araştırmalar. Proje No: YBAG-4/7551.

Crampin, S. and Evans, R, and Üçer, B. (1985). Analysis of records of local earthquakes: Turkish dilatency project. *Geophys.* J. R. Astr. Soc. 83: 1-16.

Crampin, S., Evans, R, (1986). Neotectonics of the Marmara Sea region of Turkey. *J. Geol. Soc.* London, 143: 343-346.

Ergün, M. and Özel, E. (1995). Structural realtionship between the sea of Marmara basin and the North Anatolian Fault. *Terra Nova*, 7: 278-288.

Honkura, Y. and Işıkara, A. M. (1991). Multidisciplinary research on fault activity in the western part of the North Anatolian Fault Zone. *Tectonophysics*, 193: 347-357.

Kavukçu, S. (1990). Active fault investigation in Izmit Bay, Bandırma Bay and Erdek Bay of Marmara Sea. Preceedings " Historical seismicity and seismotectonics of the Mediterranean region", Turkish Atomic Energy Authority. 238-266.

Koral, H. and Öncel, A. O. (1995). İzmit körfezinin yapısal ve sismolojik özellikleri. *Jeofizik* 9: 1-2, 79-82.

Kurtuluş, C. (1985). Gemlik Körfezi yüksek ayrımlı sığ sismik etüdü raporu. MTA, Jeofizik Etüdler Dairesi. 735, 6 pp.

Özhan, G., Kavukçu, S., Çete, M., Kurtuluş, C. (1985). Marmara Denizi İzmit Körfezi, yüksek ayrımlı sığ sismik etüdü raporu. MTA, Jeofizik Etüdler Dairesi.

Sakınç, M. and Bargu, S. (1989). İzmit körfezi güneyindeki Geç Pleyistosen (Tireniyen) çökel stratigrafisi ve bölgenin neotektonik özellikleri. *TJK Bült.* 32: 51-64.

Şaroğlu, F. Boray, A. and Emre, O. (1987). Active faults of Turkey. Mineral Res. Explor. Inst. Turkey. Unpubl. Report 8643, 394 pp.

Straub, C. (1996). Recent crustal deformation and strain accumulation in the armara Sea region, NW Anatolia in ferred from GPS Measurements. PhD Thesis, ETH, 122pp.

Tsukuda, E., Herece, E. and Kuşçu, I. (1988). Some geological evidence on activity of the western North Anatolian Fault, Geyve, İznik, Gemlik area. ITIT project 8513, 68-91.

Wong, H. K., Lüdman, T., Uluğ, A., Görür, N. (1995). The sea of Marmara: a plate boundary sea in an escape tectonic regime. *Tectonophysics*. 244: 231-250.

Yoshioka, T. and Kuşçu, İ. (1994). Late Holosen faulting events on the İznik-Mekece fault in the western part of the North Anatolian Fault Zone, Turkey. *Bull. Geol. Surv.* Japan, 45: 677-685.

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