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Examination of the kinematic structures in İzmir (Western Anatolia) with repeated GPS observations (2009, 2010 and 2011)

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Examination of the kinematic structures in İzmir (Western Anatolia) with repeated GPS Observations (2009, 2010 and 2011)

Abstract

The Western Anatolia and the Aegean Sea regions are one of the most significant seismically active and rapidly deforming fields in the world. Generally, seismic activities cause deformations and these deformations are monitored with Global Positioning System (GPS) / Global Navigation System (GNSS). In this context, GPS data were used to determine the deformation of İzmir and its surrounding to estimate the relative plate motions. In this study, the kinematic structures of the faults, which control the seismic hazard in İzmir and its surroundings, processing results of the three-year (2009, 2010 and 2011) episodic GPS observations and the estimation of displacements for 21 GPS stations were presented. The aim of this study is to examine interplate motion of the stations and their relations with the tectonic structures, seismicity and paleomagnetism and additionally, to interprete the motions of the study area relative to different block motions. Consequently, the mean motion of the study area was found approximately 25 mm/yr (towards the SSW) in the Eurasia fixed frame solution. The Aegean block fixed frame and the Anatolian block fixed frame solutions were computed relative to Euler vectors. In Aegean and Anatolian block solutions it was determined that the stations move separately, not as a group. In Euler pole solution, some stations are separated from each other and meanwhile some stations are grouped by considering the differences and similarities of the station motions. According to this solution three lines and two regions were described in the study area. The relations between seismicity and paleomagnetic studies and the kinematic structures determined in Anatolian block fixed frame and Euler pole solution were also investigated. When the Anatolian block fixed frame

solution and the earthquakes occurred between the years 1973 and 2011 were evaluated together, it was found that in the high seismically active region especially near to Sığacık bay, the motions of GPS stations were different even though their locations were close to each other. As a result of this, the relationship between the vector directions and active tectonism was determined. Additionally, in the Euler pole solution directions of the motion were found to be coherent with the paleomagnetic results, particularly in Urla and its surroundings. Here, the block fixed frame and Euler pole solutions and additionally, relations of them with seismicity and tectonism were mentioned as difference from previous studies. Besides, in this study, high importance was given to locate each station in main geological formations of the study area.

Keywords: GPS/GNSS, Western Anatolia, İzmir, Tectonic features

1. Introduction

The study region locates in the west side of the Western Anatolia and it is very active extensional area. In this region with the effect of the high seismicity, a N-S trending extensional zone was described as “West Anatolian Extensional Province” by Bozkurt (2001). This zone is bordered by the North Anatolian Fault (NAF) and the Hellenic-Cyprus arcs, in north and south, respectively. (McKenzie, 1972; Le Pichon and Angelier, 1979; Eyidoğan and Jackson, 1985; Jackson and Mckenzie, 1988; Westaway, 1990; Taymaz and Price, 1992; Yılmaz et al., 2000; Bozkurt, 2001; Aktuğ and Kılıçoğlu, 2006) (Fig. 1).

In İzmir Bay and its surroundings, 24 earthquakes (Table 1) that had destructive effects occurred between 17 (AD) and 1883 (Emre et al., 2005). The largest one occurred on 10 July 1688 (Poirier and Taher, 1980) and it damaged grate part of İzmir. The 1739 Foça and 1788 İzmir earthquakes followed this earthquake (Altınok et al., 2005). In the instrumental time-period, the region was shaken with the 1992-Doğanbey (M=6.0), 2003-Urla (M=5.7) and 2005-Sığacık Bay (M=5.7, 5.8, 5.9) earthquakes (Akyol et al., 2006; Benetatos et al., 2006; Zhu et al., 2006; Aktar et al., 2007). The seismicity is described with a weakness zone which is called as the İzmir-Balıkesir Transfer Zone (İBTZ) (Fig. 2) (Sözbilir et al., 2003a , 2003b; Sözbilir et al., 2004; Emre et al., 2005; Özkaymak and Sözbilir, 2008; Uzel and Sözbilir, 2008; Sözbilir et al., 2009). This zone lies throughout the Kuşadası Bay-Torbalı-Kemalpaşa-Akhisar line in eastern side. This line also corresponds to the line where the E–W trending graben system turns into to the NE–SW trending strike slip fault basin.

Dramis and Blumetti (2005) defined two fundamental groups for the structures which are formed by co-seismic and pre-seismic effects, namely, seismotectonic (landforms related to tectonic stress) and seismogravitational (landforms related to the seismic shaking and earth's gravity) structures. The formations associated with the tectonic stresses which are called as seismotectonic structures, are the geothermal fields, the ridges, the faults and, horst-graben systems. The occurred earthquakes up to present have generated the deformation in Western Anatolia, particularly in and around İzmir. Additionally, in the study of Pamukçu et al. (2015a), these relations were investigated with gravity data and in the study of Pamukçu et al. (2015b) realized in the surrounding of Sığacık Bay, the seismic activity of the region was described in details with the GPS/GNSS solutions and the changes on gravity anomalies.

In the study of Nyst and Thatcher (2004) the dissimilarities in the GPS vectors between in and around İzmir and Western Anatolia were identicated. By this knowledge, for monitoring the kinematic motions of the seismically active faults near to İzmir and its surroundings, GPS measurements were realized in 2009, 2010 and 2011 at 21 GPS stations which located in the south of İzmir.

In this study, Eurasia fixed frame solutions, additionally, unlike previous studies (Aktug and Kılıçoğlu, 2006; Dogru et al., 2014) Aegean-Anatolian block fixed frame solutions and interplate motions (Euler pole) were calculated. According to Eurasia fixed frame solutions, the mean motion of the study area was found approximately 25 mm/yr towards the SSW. In Aegean block and Anatolian block fixed frame solutions the velocity directions were generally towards N and S, respectively.

According to the Euler pole solutions two regions were described in the study area by taking account of the similarities of the motion directions. Besides, some stations are separated from each other with three lines by noticing the directional differences of the station motions.

Consequently, the velocity fields observed by GPS measurements were examined with the vector directions of paleomagnetic studies and seismicity based on the distributions of earthquake focal depth.

2. Geologic Settings of Study Area

The study area which covers İzmir and its surroundings, locates in the western part of an area called as "West Anatolian Extensional Province" (WAEP) by Bozkurt (2001) (Fig. 1 and Fig. 2). Additionally, İBTZ which is located around the study area forms the westward of WAEP (Uzel and Sözbilir, 2008; Sözbilir et al., 2009; 2011; Uzel et al., 2012) (Fig. 2).

In the study area, the NE–SW directional dextral strike-slip faults are dominant and among them the most significant faults, Seferihisar fault (SF) and Orhanlı fault zone (OFZ), border the Seferihisar High. The length and wide of SF, which extends along İzmir Bay and Sığacık Bay, is 30 km and 2–5 km, respectively (İnci et al., 2003; Emre et al., 2005; Sözbilir et al., 2009; 2011). OFZ, which is 45 km in length and extends along İzmir Bay and Kuşadası Bay, contains some NE-SW directional faults (Uzel and Sözbilir, 2008). The other dextral strike slip fault is Gülbahçe fault zone (GFZ) and its length is 70 km from N to S. This fault corresponds with the east border of the N-S trending Karaburun Peninsula (Emre et al., 2005). Karaburun fault zone (KFZ) which dominates the southwestern of İzmir Bay is 2–4 km in wide and 25 km in length (Uzel et al., 2013) (Fig. 2). The E–W directional faults are generally normal faults and they are located throughout northern and southern of the inner of the İzmir Bay (Fig. 2). The İzmir Fault (IF), which locates in the southern of the inner of İzmir Bay, is approximately 2–4 km in wide and 40km in length (Sözbilir et al., 2011; Uzel et al., 2012). SF, OFZ, GFZ, KFZ and IF are Holosen faults (Emre et al., 2011; Emre and Özalp, 2011). The other significant fault of the study area is Manisa Fault Zone (MFZ) and it is located in northern side and its length is approximately

10 km (Fig 2). Since Miocene at least three distinct movements reactivated this zone (Özkaymak and Sözbilir, 2008).

3. Processing of the GPS Data

GPS measurements were realized in 2009, 2010 and 2011at 21 stations of the GNSS network which were built in the south of İzmir (Fig. 3). As the first campaign in 2009, The GPS observations were performed in two groups (Day of Year/DOY: 183-185 and 186-190). In each group, 10 stations were observed per session for 10 hours. The station "UZUN" was observed for four days in 2009 campaign. In the 2010-campaign, the observations were performed in three groups (DOY: 184-186, 187-189 and 190-192) with three sessions for 10 hours in each group. In 2010 campaign, UZUN and DU12 stations were observed for nine days. In 2011, 10-hour measurements were realized at 21 stations in three groups, each consisting of three session days (DOY: 183-185, 186-188 and 189-192). During this campaign DU05, DU12 and UZUN stations were observed continuously.

For linking the local network with the ITRF (International Terrestrial reference Frame) global network International GNSS Service (IGS) stations were also included in the processing. These IGS stations allow the estimation of necessary parameters in analysis of the GPS data (station coordinates, earth orientation parameters, atmospheric zenith delays etc.). 12 IGS stations were used to characterize the Eurasia-fixed reference frame; ISTA, TUBI, ANKR (Turkey), ZECK (Russia), NSSP (Armenia), NICO (Cyprus), MIKL, GLSV (Ukraine), BUCU (Romania), PENC (Hungary), WTZR (Germany) and MATE (Italy) (Fig 4a). ITRF2008 coordinates of these IGS

stations were used as reference stations in the computations. The GPS observations were processed by using GAMIT/GLOBK software (King and Bock, 2002; Herring et al., 2010).

Velocity vectors of 3-year GPS campaigns (2009, 2010 and 2011) and displacement vectors of 2009-2010 and 2010-2011 are shown in Fig. 4b. The components of the velocity field of 3 years combined solutions in the Eurasia-fixed frame and 1-sigma (σ) uncertainties are shown in Table 2.

Reilenger et al. (2006) developed an elastic block model for African, Arabian, Eurasia plates for constraining present day plate motions (relative Euler vectors). Besides, Anatolia was separated into 3 blocks (plates) as Anatolian block, Aegean block and Southwest Anatolian block and for determining the block model and the Euler vectors were calculated relative to Eurasia. The Euler vectors are 30.8°N, 32.1°E and 1.231°/Myr for Anatolian and 15.9°N, 52.3°E and 0.563°/Myr for the Aegean block fixed solutions (Reilinger et al., 2006) (Fig. 5). In this study, Aegean and Anatolian block fixed velocity vectors were calculated by using Euler vectors (Reilinger et al., 2006) which represent general kinematics in relative coordinate system (Fig. 6 and Fig.7).

As the last application, a single Euler pole was estimated using these GPS stations and thus the mean motion of these stations was evaluated (Fig. 8). The Euler pole solutions are calculated with a weighted least square solution with the unknown parameters being the rotation rates around the XYZ axes. The partials used in the estimates are;

$$v_x = Z_{wy} - Y_{wz}$$
$$v_y = -Z_{wx} + X_{wz}$$
$$v_z = Y_{wx} - X_{wx}$$

where v_x, v_y, v_z are the station velocities in XYZ frame, wx wy wz are the rotation rates around the XYZ axes. Other quantities are computed using standard analytic formulas and propagation of variance-covariance matrices assuming that the errors in wx, wy, wz are small compared to their estimates.

4. Results and Discussion

In this study, the Eurasia fixed frame, Aegean-Anatolian block fixed frames and Euler pole solutions were calculated for investigating the kinematic structures of Izmir and its surroundings (Western Anatolia). The mean motion of the study area was found approximately 25 mm/yr towards the SSW in Eurasia fixed frame solutions (Fig. 4). In the Aegean block fixed frame solutions, the velocity directions are approximately towards N, NE and NW (Fig. 6) and in the Anatolian block fixed frame solutions, the velocity directions are approximately towards S, SE and SW (Fig. 7). In Anatolian block fixed frame solutions (Fig. 7), an approximately N-S directional transition zone was estimated throughout from UZUN to DU12. The direction of same line was monitored in Aegean block fixed frame (Fig. 6) as NE-NW

According to the Euler pole solutions (Fig. 8) the study area was described by three lines and two regions (Fig. 9). DU09, DU10 and DU16 which had the most important movements relative to other stations (DU01, DU02, DU03, DU04, DU05, DU06, DU07, DU08, DU11, DU12, DU13, DU14, DU15, DU17, DU18, DU19 and UZUN) were showed in the same region called as “region A” (Fig. 9).. The N-NW directed velocity vectors of the stations in “region A” were bigger than DU01, DU02, DU03, DU04, DU05, DU06, DU07, DU08, DU11, DU12, DU13, DU14, DU15, DU17, DU18, DU19 and UZUN (Fig. 9). Therefore, it can be said that the largest

deformation occurs in this area. The displacements of the stations in region A (Fig. 9) show the activation of Karaburun and Menemen basins (Fig. 2). DU01, DU06, DU13 and DU14 were defined in “region B” due to their similar velocity vector directions (Fig. 9). The velocity vectors of these stations were smaller than the stations in “region A”. Additionally; it was seen at Fig. 9 that the stations which are located outside of “region A” and “region B” had different velocities and vector directions.. The region B is seemed coherently with the east and west branched hypothetical fault which is described by Aktar et al. (2007) for Sığacık Bay. In the area of the Line No.1 (Fig. 9) which was drawn by noticing the differences on the directions of velocity vectors of DU06 and DU07, it is thought that this area may have a thrust fault mechanism. The opposite velocity vector directions of DU10 and UZUN (NW and SE, respectively) which were located at eastern side of Karaburun were shown at Line No. 2 (Fig. 9). This line might correspond to the continuation of Gülbahçe fault zone (GFZ) (Fig. 2) It is seen that the velocity vector directions of UZUN and DU16 are different from each other. Therefore, a boundary (Linr No:3, Fig. 9) was determined. This boundary may be related with the NW-SE directed normal fault (Dondurur et al., 2011; Uzel et al., 2012).

If Aegean (Fig. 6), Anatolian block fixed frame (Fig. 7) and Euler pole (Fig. 8) solutions are evaluated together, it can be said that the vectors partially line up because the motion of the stations are transitioning between these blocks i.e. one of the blocks (Aegean or Anatolian) in partially pushing or pulling the stations in its direction.

Additionally, in this study, in order to determine the motion differences between İzmir and the Western Anatolia graben system (Fig 2, İBTZ), DU18 was built. As seen in the Aegean block,

209 Anatolian block and Euler pole solutions (Fig. 6, 7 and 8) the motion of DU18 is different from
210 other 20 stations.
211
212 It is determined that the velocity vector directions of DU09 and DU10 (located in the north
213 of Karaburun Peninsula) (Fig. 3), are different from each other (Figures 6, 7and 8). The existence
214 of KFZ between DU09 and DU10 may effects the kinematic structure of Karaburun. .By noticing
215 the differences on velocity vector directions of DU04, DU11, DU13 and DU14 (Fig. 6 and 7) it
216 can be said that these differences are related with extensional regime of the region.
217
218 In order to investigate seismic activity of the region, the earthquakes which occurred in the
219 study area between 1973 and 2011 were obtained from the USGS (U.S. Geological Survey) (Fig.
220 10) and additionally, the 2005 earthquake series and other earthquakes which occurred in GPS
221 campaigns years (2009, 2010 and 2011) from Boğaziçi University (BU), Kandilli Observatory
222 and Earthquake Research Institute (KOERI) National Earthquake Monitoring Center. These
223 earthquakes with focal depths ranging from 0 to 39.9 km were given with the Anatolian fixed
224 frame solutions in Fig. 11a-c.
225
226 In Fig.10 it is seen that the seismicity was high in the GPS campaigns years (2009, 2010 and
227 2011). In Fig.11.a, it is shown that the earthquakes between the years 1973 and 2011 occurred in
228 the entire region; the earthquake intensity was high particularly in Sığacık Bay and its
229 surrounding. Besides, in the Anatolian block fixed frame solutions, the differences on the vector
230 directions were noticed in Sığacık Bay and its north. In Fig. 11.a, when the earthquakes and GPS
231 solutions are compared together, it is pointed out that although the locations of DU05, DU11 and
232 DU13 are close to each other, these stations show different directional characteristics. It may be

thought that this case can be related with 2005 series of earthquakes which are given in Fig. 11.b, hence there is no earthquake intensity to create this deformation between the years 2009 and 2011 (Fig.11.c). This case cannot be interpreted completely since there is no GPS/GNSS data in the same points before 2009. These approaches are valid for the Aegean block fixed frame (Fig. 6).

In the comparisons of the results of this study with the previous paleomagnetic studies (Kissel et al., 1987; Zanchi et al., 1993) some changes were determined while passing from Karaburun to İzmir city center (Fig. 12). It was noticed that the directions of paleomagnetic rotations (Fig 12) are similar with Euler pole solutions of DU05, DU09 and DU16 (Fig. 8). Kissel et al. (1987) noticed that paleomagnetic rotations were difficult to explain of the global geodynamical evolution of the Western Anatolia and these rotations were most likely associated with the local tectonic regime.

Additionally, according to the field observations, there is a shallow water table at the west side of DU05 and there are geothermal natural outflows at the east side of this station. As a result of the GPS/GNSS observations, it was observed that the horizontal displacement direction of DU05 was different relative to other 20 stations (Figures 4, 6, 7 and 8). This difference can be related with the local tectonic characteristic of the location of DU05 and its surrounding. As a result, the deformation of this station and its surrounding may be shaped by paleomagnetic effects and geothermal features.

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5. Conclusions

In this study, the dissimilarities on the structural elements of Western Anatolia graben system and İzmir and its surroundings were determined and the kinematic mechanism of the study area was presented in detail. Particularly, according to the Anatolian block fixed and Euler pole solutions, the boundaries which control the tectonics of İzmir and its surroundings and the motions of the kinematic structures which are effective on seismic activity of the region were defined. Besides, the border which separates the E-W directional graben system of Western Anatolia from the N-S directional structural elements of İzmir and its surroundings was established. Additionally, due to the similarities between the paleomagnetic rotations and recent GPS velocities, it was pointed out that the movements of some regions in the study area have not changed a lot in long geological time scale.

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References

Aktar, M., Karabulut, H., Ozalaybey, S., Childs, D., 2007. A conjugate strike-slip fault system within the extensional tectonics of Western Turkey. Geophysical Journal International, 171 (3), 1363–1375.

Aktuğ, B., Kılıçoğlu, B., 2006. Recent crustal deformation of Izmir, Western Anatolia and surrounding regions as deduced from repeated GPS measurements and strain field. Journal of Geodynamics, 41, 471- 484.

Akyol, N., Zhu, L., Mitchell, B.J., Sözbilir, H., Kekovalı K., 2006. Crustal structure and local seismicity in western Anatolia. Geophysical Journal International, 166 (3), 1259-1269.

Altınok, Y., Alpar, B., Özer N., Gazioğlu, C., 2005. 1881 and 1949 earthquakes at the Chios Çeşme Strait (Aegean Sea) and their relation to tsunamis. Natural Hazards and Earth System Sciences, 5, 717–725.

Benetatos, C., Kiratzi, A., Ganas, A., Ziazia, M., Plessa, A., Drakatos, G., 2006. Strike-slip motions in the Gulf of Sığacık (western Turkey): Properties of the 17 October 2005 earthquakes seismic sequence. Tectonophysics, 426, 263–279.

Bozkurt, E., 2001. Neotectonics of Turkey a synthesis. Geodinamica Acta, 14, 3-30.

Dogru, A., Gorgun, E., Ozener, H., Aktug, B., 2014. Geodetic and seismological investigation of crustal deformation near Izmir (Western Anatolia). Journal of Asian Earth Sciences, 82, 21-31.

Dondurur, D., Çifçi, G., Drahor, M. G., Coşkun S., 2011. Acoustic evidence of shallow gas accumulations and active pockmarks in the Izmir Gulf, Aegean sea. Marine and Petroleum Geology, 28, 1505-1516.

Dramis F., Blumetti, A.M., 2005. Some considerations concerning seismic geomorphology and paleoseismology. Tectonophysics, 408, 177– 191.

Emre, Ö., Özalp, S., Doğan, A., Özaksoy, V., Yıldırım, C., Göktaş, F., 2005. Active faults and earthquake potential of Izmir and its surroundings. MTA Report No:10754 (in Turkish), 80p. (not published).

Emre, Ö., Özalp, S., Duman, T.Y., 2011. 1: 250,000 scale Active Fault Map Series of Turkey. İzmir (NJ 35-7) Quadrangle, Serial Number(6), General Directorate of Mineral Research and Exploration, Ankara-Turkey.

Emre, Ö., Özalp, S., 2011. 1: 250,000 scale Active Fault Map Series of Turkey, Urla (NJ 35-6) Quadrangle, Serial Number (5), General Directorate of Mineral Research and Exploration, Ankara-Turkey.

Eyidoğan, H., Jackson, J. A., 1985. A seismological study of normal faulting in the Demirci, Alaşehir and Gediz earthquake of 1969−1970 in western Turkey: implications for the nature and geometry of deformation in the continental crust. Geophysical Journal of Royal Astronomical Soc., 81, 569−607.

Gönenç, T., Akgün, M., 2012. Structure of the Hellenic Subduction Zone from Gravity Gradient Functions and Seismology. Pure and Applied Geophysics, 169 (7), 1231-1255 doi: 10.1007/s00024-011-0391-2 online issn: 1420-9136.

Herring, T.A., King, R.W., McClusky, S.C., 2010. Introduction to GAMIT/GLOBK, Release 10.4, Massachusetts Institute of Technology, Cambridge.

İnci, U., Sözbilir, H., Erkül, F., Sümer, Ö., 2003. The cause of the earthquakes between the Urla and Balıkesir is a fossil fault. Cumhuriyet Newspaper Science and Technical Journal (in Turkish).

Jackson, J., Mckenzie, D., 1988. The relationship between plate motions and seismic moment tensors, and the rates of active deformation in the Mediterranean and Middle East. Geophysical Journal of the Royal Astronomical Soc., 93, 45–73.

King, R. W., Bock, Y., 2002. Documentation for the GAMIT GPS Analysis software, Mass. Inst. of Tech., Scripps Inst. Oceanogr., Release 10.0.

Kissel, C., Laj C., Sengör A.M.C., Poisson A., 1987. Paleomagnetic evidence for rotation in opposite senses of adjacent blocks in Northeastern Aegea and Western Anatolia. Geophysical Research Letters, 14, 907-910.

Le Pichon, X., Angelier, J., 1979. The Hellenic Arc and Trench system: a key to the neotectonic evolution of the eastern mediterranean area. Tectonophysics, 60, l-42.

Makris, J., Stobbe, C., 1984. Physical properties and state of the crust and upper mantle of the Eastern Mediterranean Sea deduced from geophysical data. Marine Geology, 55, 347-363.

McClusky, S., Balasdsanian, S., Barka, A., Demir, C., Georgiev, I., Hamburger, M., Hurst, K., Kastens, K., Kekelidze, G., Kotzev, R.K.V., Lenk, O., Mahmoud, S., Mishin, A., Nadariya, M., Ouzounis, A., Paradissis, D., Peter, Y., Prilepin, M., Reilinger, R., Sanli, I., Seeger, H., Tealeb, A., Toksoz, M.N., Veis, G., 2000. Global positioning system constraints on crustal movements and deformations in the eastern Mediterranean and Caucasus. Journal of Geophysical Research, 105, 5695–5719.

McKenzie, D., 1972. Active tectonics of the Mediterranean region. Geop. J.R. Astron. Sot., 30, 109-185.

Nyst M., Thatcher W., 2004. New constraints on the active tectonic deformation of the Aegean. Journal of Geophysical Research, 109, B11406, doi:10.1029/2003JB002830.

Özkaymak, Ç., Sözbilir, H., 2008. Stratigraphic and structural evidence for fault reactivation:The Active Manisa Fault Zone, Western Anatolia. Turkish Journal of Earth Science, 17, 3, 615-635.

Pamukçu, O., Gönenç, T., Çırmık, A., Sındırgı, P., Kaftan I., Akdemir, Ö., 2015 a. Investigation of vertical mass changes in the south of Izmir (Turkey) by monitoring microgravity and GPS/GNSS methods. Journal of Earth System Science, 124, No. 1,137–148.

Pamukçu, O., Gönenç, T., Çırmık, A. Y., Kahveci, M., 2015 b. Investigation of the Sığacık Bay's Displacement Characteristic by using GPS and gravity data in Western Anatolia. Journal of Asian Earth Sciences, 99, 72-84

Poirier, J.P., Taher, M.A., 1980. Historical seismicity in the Near and Middle East, North Africa, and Spain from Arabic documents (VIIth-XVIIIth Century). Bulletin of the Seismological Society of America, 70 (6), 2185-2201.

Reilinger, R., McClusky, S., Vernant, P., Lawrence, S., Ergintav, S., Çakmak, R., Özener, H., Kadirov, F., Guliev, I., Stepanyan, R., Nadariya, M., Hahubia, G., Mahmoud, S., Sakr, K., ArRajehi, A., Paradissis, D., Al-Aydrus, A., Prilepin, M., Guseva, T., Evren, E., Dmitrotsa, A., Filikov, S.V., Gomez F., Al-Ghazzi, R., Karam, G., 2006. GPS constraints on continental deformation in the Africa-Arabia-Eurasia continental collision zone and implications for the dynamics of plate interactions. Journal of Geophysical Research, 111, 2-26.

Sözbilir, H., Erkül, F., Sümer, Ö., 2003a. The Field Data of After Miocene Aged NE-direction accommodation zone between Gümüldür (Izmir) and Bigadiç (Balıkesir), Western Anatolia. 56th Turkey Geological Workshop (in Turkish), Ankara - Turkey, Abstracts book 85-86.

Sözbilir, H., İnci, U., Erkül, F., Sümer, Ö., 2003b. An Active Intermitten transform zone accommodating N-S Extension in Western Anatolia and its relation to the North Anatolian Fault System, International Workshop on the North Anatolian, East Anatolian and Dead Sea Fault Systems. Recent Progress in Tectonics and Paleoseismology, and Field Training Course in Paleoseismology, Ankara- Turkey.

374 Sözbilir, H., Sümer, Ö., Uzel, B., Saygılı, A., Ramazanoğlu, İ., Uysal, E., 2004. Geological and
375 Geomorphological Parameters of Izmir Fault. 8th Meeting of Turkish Active, Tectonic
376 Research Group, Abstracts Book 2 (in Turkish).
377 Sözbilir, H., Sümer, Ö., Uzel, B., Ersoy, Y., Erkül, F., İnci, U., Helvacı, C., Özkaymak, Ç.,
378 2009. The Seismic geomorphology of the Sığacık Gulf (İzmir) earthquakes of October 17 to
379 20, 2005 and their relationships with the stress field of their Western Anatolian region.
380 Geology Bulletin of Turkey, 52 (2), 217-238 (in Turkish).
381
382 Sözbilir, H., Sarı, B., Uzel, B., Sumer, Ö., Akkiraz, S., 2011. Tectonic implications of
383 transtensional supradetachment basin development in an extension-parallel transfer zone: the
384 Kocaçay Basin, western Anatolia, Turkey. Basin Research, 23, 423-448.
385 Taymaz, T., Price, S., 1992. The 1971 May 12 Burdur Earthquake Sequence, SW Turkey: A
386 Synthesis of Seis. and Geo. Observations. Geophysical Journal of International, 108, 589-
387 603.
388 Uzel, B., Sözbilir, H., 2008. A First record of strikeslip basin in western Anatolia and its tectonic
389 implication: The Cumaovası basin as an example. Turkish Journal of Earth Science, 17, 559-
390 591.
391 Uzel, B., Sözbilir, H., Özkaymak, Ç., 2012. Neotectonic evolution of an actively growing
392 superimposed basin in western Anatolia: The inner bay of Izmir, Turkey. Turkish Journal of
393 Earth Science, 21, 439-471.
394 Uzel, B, Sözbilir H., Özkaymak Ç., Kaymakçı, N., Langereis C. G., 2013. Structural evidence for
395 strike-slip deformation in the Izmir-Balıkesir transfer zone and consequences for late
396 Cenozoic evolution of western Anatolia (Turkey). Journal of Geodynamics, 65, 94-116.

397 Wessel, P., Smith, W.H.F., 1998. New, improved version of the generic mapping tools released.
398 American Geosciences Union, 79, 579.
399 Westaway, R., 1990. Block rotation in western Turkey: 1. Observational evidence. Journal of
400 Geophysical Research, 95, 19857–19884.
401 Yılmaz, Y., Genç, S.C., Gürer, O.F., Bozcu, M., Yılmaz, K., Karacık, Z., Altunkaynak, Ş.,
402 Elmas, A., 2000. When did the western Anatolian grabens begin to develop? In: Bozkurt, E.,
403 Winchester, J.A. & Piper, J.D.A. (eds), Tectonics and Magmatism in Turkey and the
404 Surrounding Area. Geo. Soc., London, Special Publications, 173, 353–84.
405 Zanchi, A., Kissel, C., Tapirdamaz, C., 1993. Late Cenozoic and Quaternary brittle continental
406 deformation in western Turkey. Bulletin de la Societe Geologique de France, 164, 507-517.
407 Zhu, L., Akyol, N., Mitchell, B.J., Sözbilir H., 2006. Seismotectonics of western Turkey from
408 high resolutions and moment tensor determinations. Geophysical Research Letters, 33 (7),
409 L07316, doi: 10.1029/2006GL025842.
410 KOERI; http://www.koeri.boun.edu.tr/scripts/lst6.asp
411 USGS; https://earthquake.usgs.gov/earthquakes/search/

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Tables

Table 1. Large historical earthquakes occurred in İzmir and its surroundings (Modified from Emre et al., 2005)

Time	Latitude (N°)	Longitude (E°)	Intensity (I_o)
17	38.40	27.50	X
105	38.90	27.00	VIII
176 and 177	38.60	26.65	VII
178	38.30	27.10	VIII
688	38.41	27.20	IX
1039	38.40	27.30	VIII
20th March 1389	38.40	26.30	VIII
20th May 1654	38.50	27.10	VIII
2nd June 1664	38.41	27.20	VII
1668	38.41	27.20	IX
14th February 1680	38.40	27.20	VII
10th July 1688	38.40	26.90	X
13th January 1690	38.60	27.40	VII
September (October) 1723	38.40	27.00	VIII
4th April 1739	38.50	26.90	IX
24th November 1772	38.80	26.70	VIII
3rd – 5th July 1778	38.40	26.80	IX
13th October 1850	38.40	27.20	VIII
3rd November 1862	38.50	27.90	X
1st February 1873	37.75	27.00	IX
29th July 1880	38.60	27.10	IX
15th October 1883	38.30	26.20	IX
1st November 1883	38.30	26.30	VIII

Table 2: Velocities of Eurasia-fixed frame from 3-year (2009, 2010 and 2011) GPS data and 1-σ uncertainties in ITRF2008 frame (in Fig. 4b).

Station	Longitude(°)	Latitude (°)	v_E (mm/year)	v_N (mm/year)	σ_{vE}[a] (mm/year)	σ_{vN}[a] (mm/year)	ρ_{vEvN}[b]
DU01	27.06	38.39	-21.79	-19.11	1.06	1.30	-0.007
DU02	26.96	38.31	-19.42	-15.94	1.01	1.26	0.053
DU03	26.92	38.31	-18.95	-14.94	0.90	1.14	0.012
DU04	26.82	38.27	-17.47	-19.16	0.99	1.23	0.008
DU05	26.58	38.32	-13.11	-20.60	1.44	1.71	-0.018
DU06	26.47	38.30	-20.37	-22.34	1.00	1.22	0.007
DU07	26.29	38.28	-15.87	-21.37	0.87	1.09	0.038
DU08	26.47	38.39	-19.16	-19.95	0.92	1.14	0.021
DU09	26.40	38.56	-18.15	-15.05	0.93	1.14	0.017
DU10	26.55	38.53	-23.03	-18.16	1.13	1.34	-0.005
DU11	26.69	38.23	-21.98	-18.52	0.95	1.18	0.0013
DU12	26.76	38.35	-19.02	-19.80	0.67	0.89	0.067
DU13	26.61	38.19	-19.84	-21.92	0.99	1.24	0.008
DU14	26.87	38.14	-20.09	-19.40	1.01	1.25	0.007
DU15	27.11	38.21	-18.57	-17.20	1.29	1.56	-0.014
DU16	27.13	38.55	-24.24	-11.94	1.05	1.31	0.010
DU17	27.38	38.55	-20.50	-16.01	1.07	1.32	-0.035
DU18	27.53	38.30	-16.80	-16.14	1.04	1.30	0.002
DU19	27.30	38.32	-22.72	-17.13	1.37	1.66	-0.019
DU20	27.08	38.01	-16.04	-20.48	1.13	1.39	-0.024
UZUN	26.71	38.47	-18.76	-21.77	0.54	0.71	0.153
NSSP	44.50	40.22	3.45	7.30	1.36	1.05	-0.363
ZECK	41.56	43.78	1.67	0.48	0.91	0.52	-0.108
NICO	33.39	35.14	-4.82	2.04	0.52	0.89	-0.484
ANKR	32.75	39.88	-21.90	-2.31	0.79	0.92	-0.131
MIKL	31.97	46.97	0.63	-0.18	0.49	0.63	0.191
GLSV	30.49	50.36	-0.45	0.24	0.44	0.82	0.163
TUBI	29.45	40.78	-3.85	-1.77	0.43	0.55	-0.049
ISTA	29.01	41.10	0.00	-2.39	0.36	0.47	0.001
BUCU	26.12	44.46	-0.06	-1.20	0.43	0.46	-0.074
PENC	19.28	47.78	-0.41	1.54	0.73	0.56	-0.520
MATE	16.70	40.64	-0.48	4.50	0.88	0.55	0.540
WTZR	12.87	49.14	-1.43	0.24	1.09	0.62	-0.531

[a] 1-σ uncertainties

[b] Correlation coefficient between east and north uncertainties

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Figure Captions

Figure 1: The main tectonic framework of the Western Anatolia and its surroundings (Makris and Stobbe, 1984; McClusky et al., 2000; Bozkurt, 2001; Gönenç and Akgün, 2012).

Figure 2: Main geological structure of the Western İzmir (modified from Uzel et al., 2013). Black dotted lines show the borders of İBTZ. Dotted red rectangle shows the study area.

Figure 3: Observed GPS stations in study area which given in Fig 1 with red circle. The high topography is in black color.

Figure 4.a: The locations of IGS stations which were used in processing. **b:** The black vectors show the 3-year (2009, 2010 and 2011) GPS data, red vectors and green vectors show the displacements of 2009-2010 and 2010-2011, respectively with 95% confidence ellipses of the project stations computed in Eurasia-fixed frame from in ITRF 2008.

Figure 5: The red point shows the location of the reference point (15.9°N, 52.3°E given at Reilinger et al., 2006) used in the calculation of Anatolian block fixed frame and the orange point shows the reference point (30.8°N, 32.1°E given at Reilinger et al., 2006) used in the calculation of Aegean block fixed frame (Google Earth was used for creating this figure).

Figure 6: The velocity field with 95% confidence ellipses of the stations computed in the Aegean block fixed frame from 3-year (2009, 2010 and 2011) GPS data.

Figure 7: The velocity field with 95% confidence ellipses of the stations computed in the Anatolian block fixed frame from 3-year (2009, 2010 and 2011) GPS data.

Figure 8: The Euler pole solutions with 95% confidence ellipses.

Figure 9: The interpretation of interplate motions which shown in Fig. 8.

Figure 10: Number of earthquakes occurred in the study area between 1973 and 2011 (obtained from the USGS).

Figure 11: The focal depth distributions of the earthquake occurred in the study area and the velocity vectors of Anatolian fixed frame solutions. **a:** The focal depths of earthquakes ranging from 0 km to 39.9 km between the years 1973 and 2011 in the study area from USGS) **b:** The focal depths of earthquakes ranging from 0 km to 39.9 km in 2005 in the study area (from BU, KOERI, National Earthquake Monitoring Center) **c:** The focal depths of earthquakes ranging from 0 km to 39.9 km between the years 2009 and 2011 in the study area (from BU, KOERI, National Earthquake Monitoring Center). Generic Mapping Tools (GMT) (Wessel and Smith, 1995) was used to create these figures.

Figure 12: The reverse directions were inverted through the origin (modified from Kissel et al., 1987).

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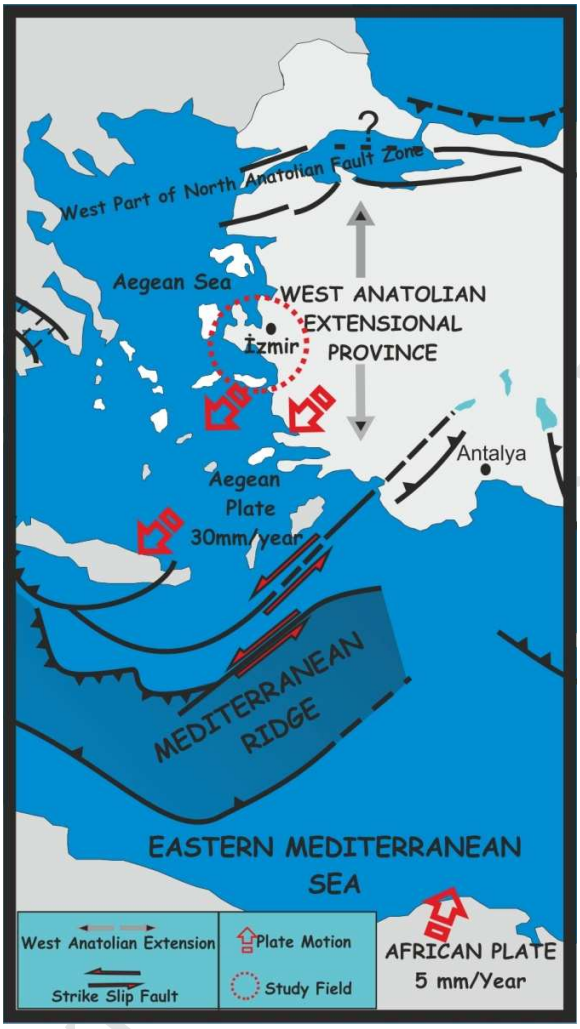


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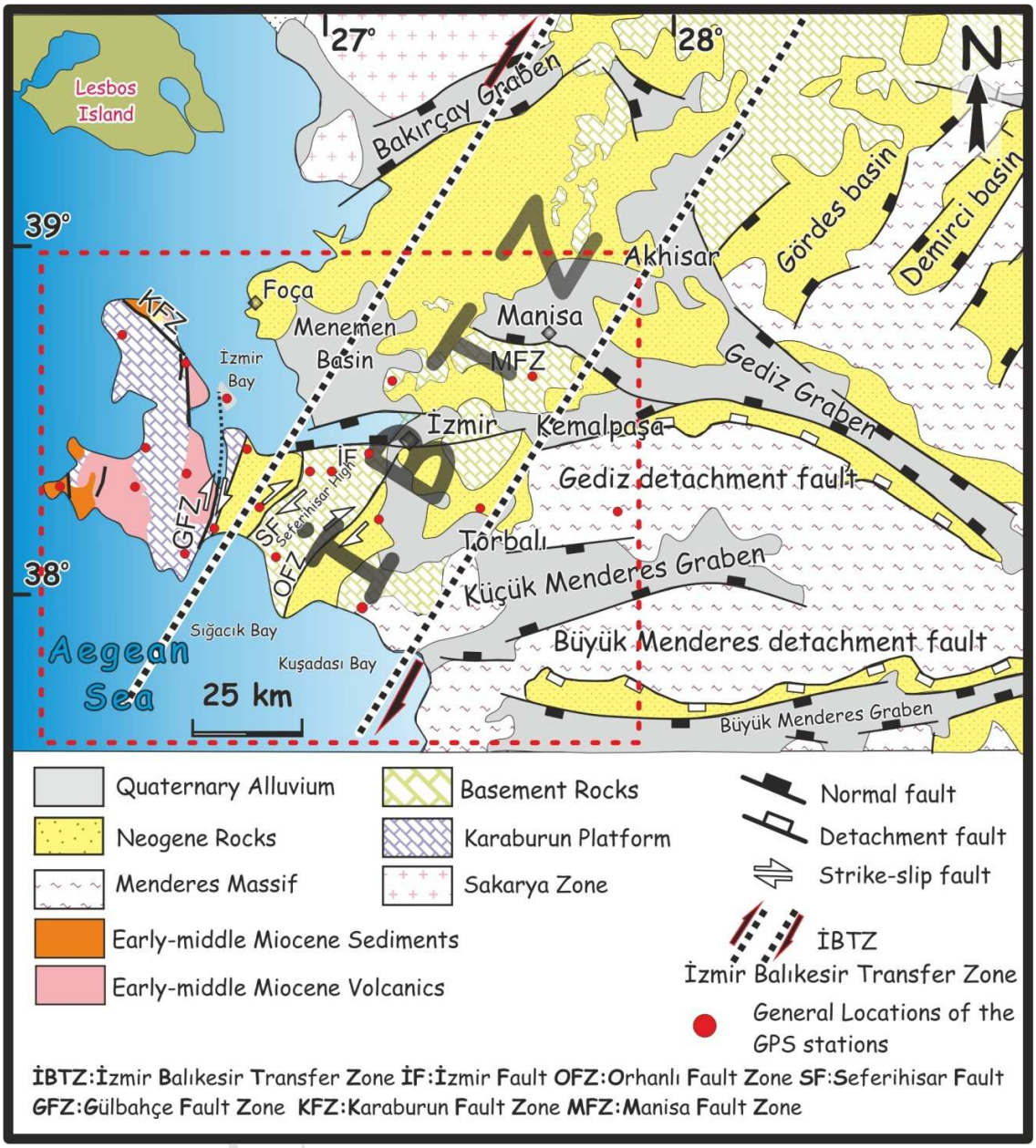


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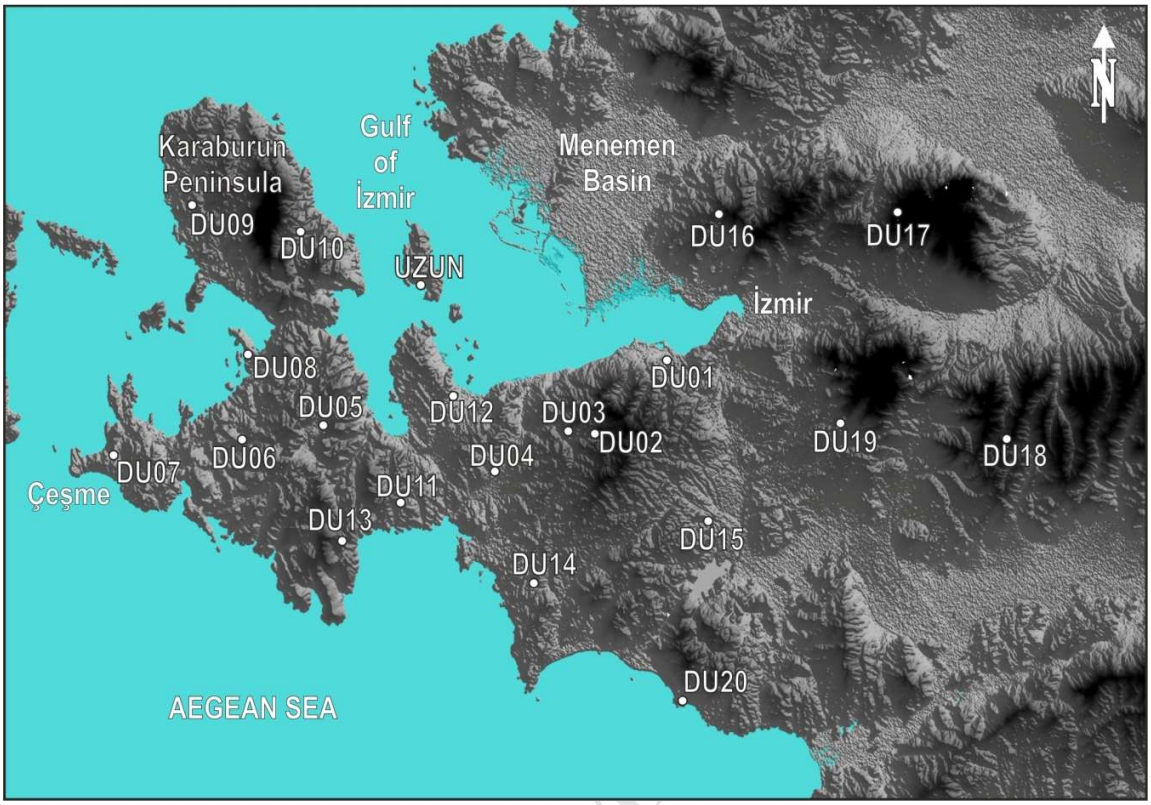


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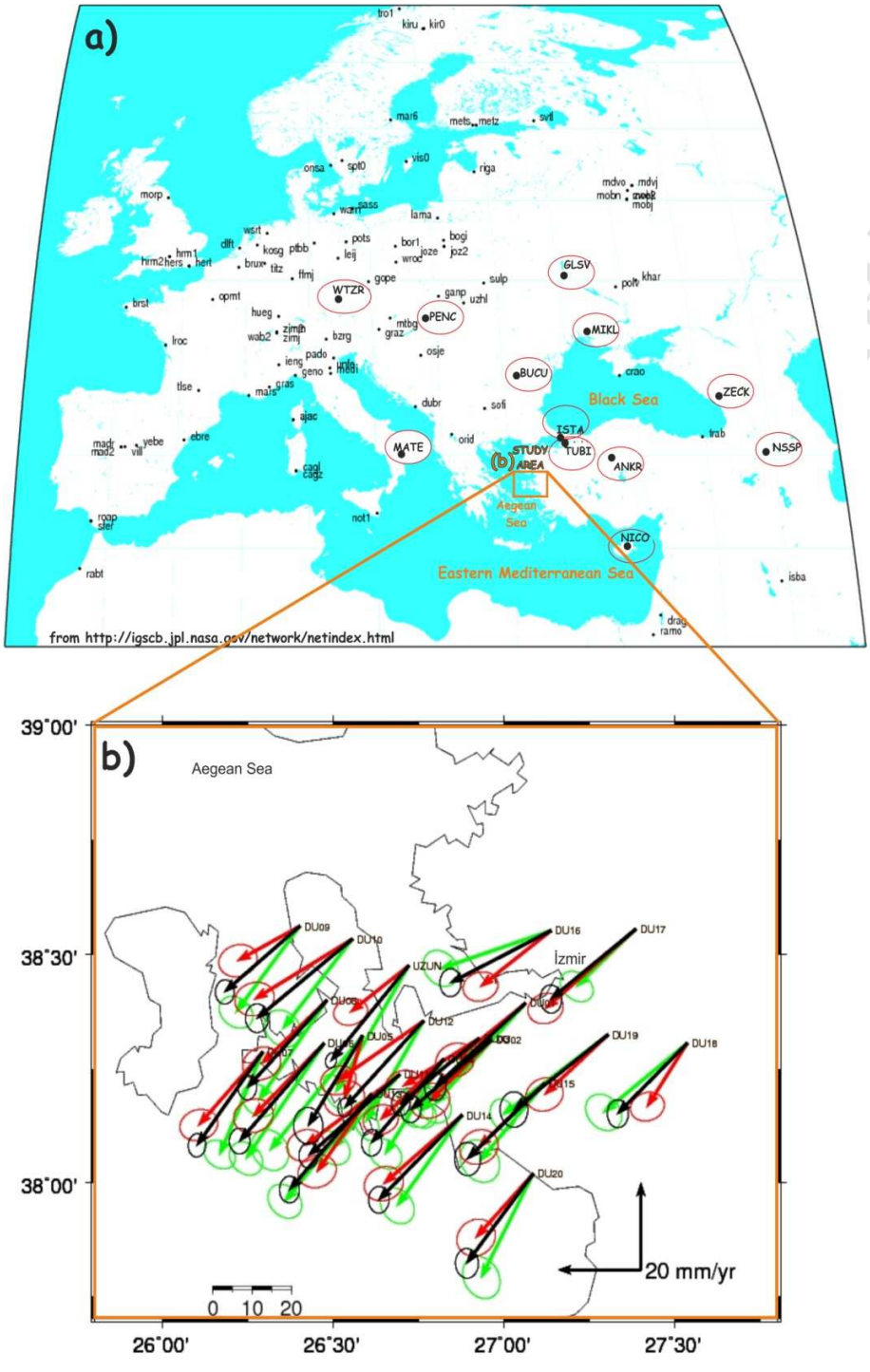


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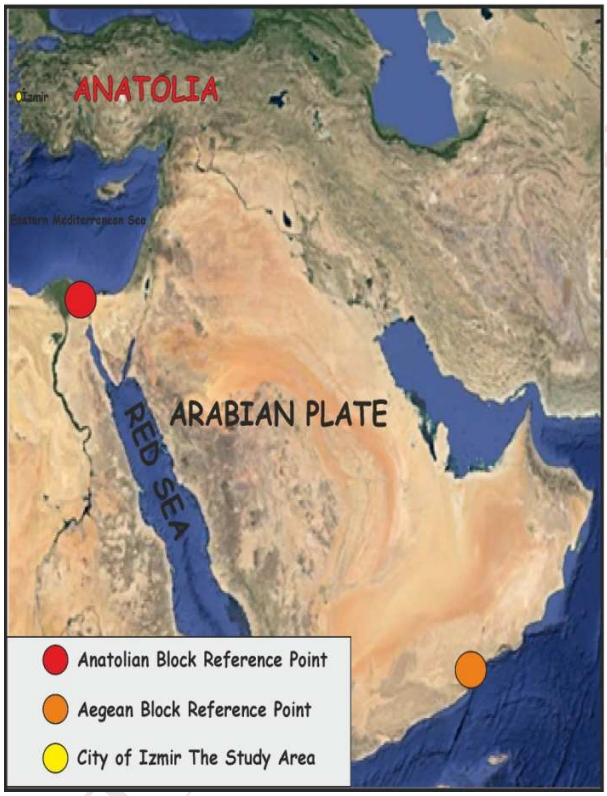


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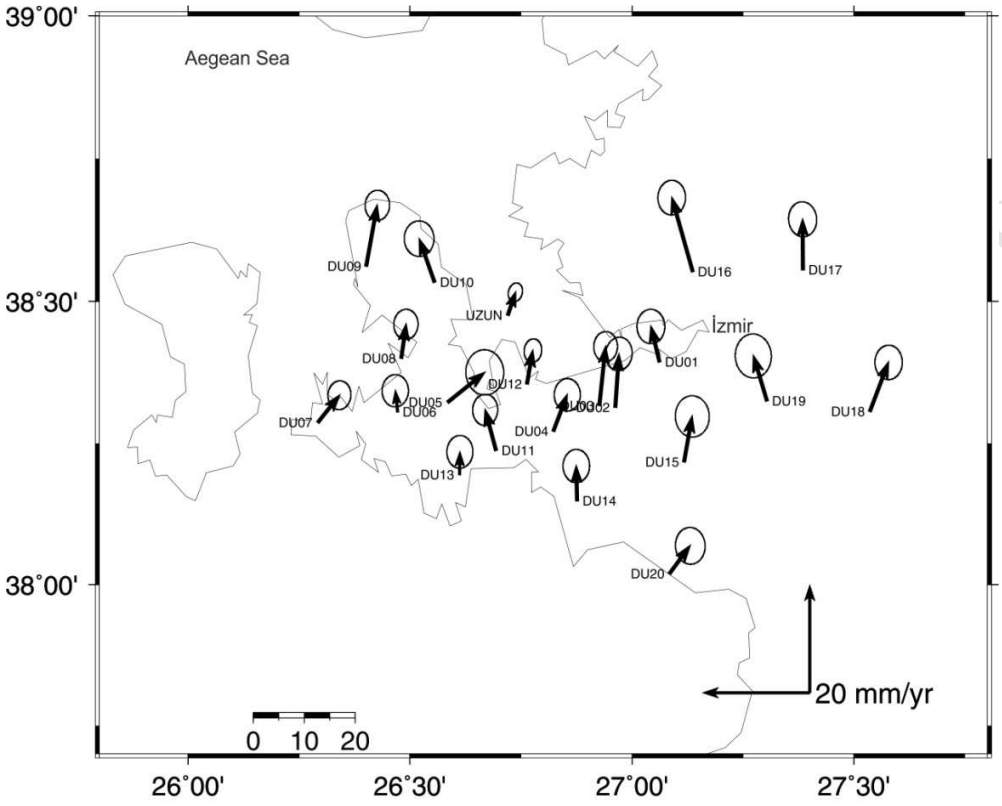


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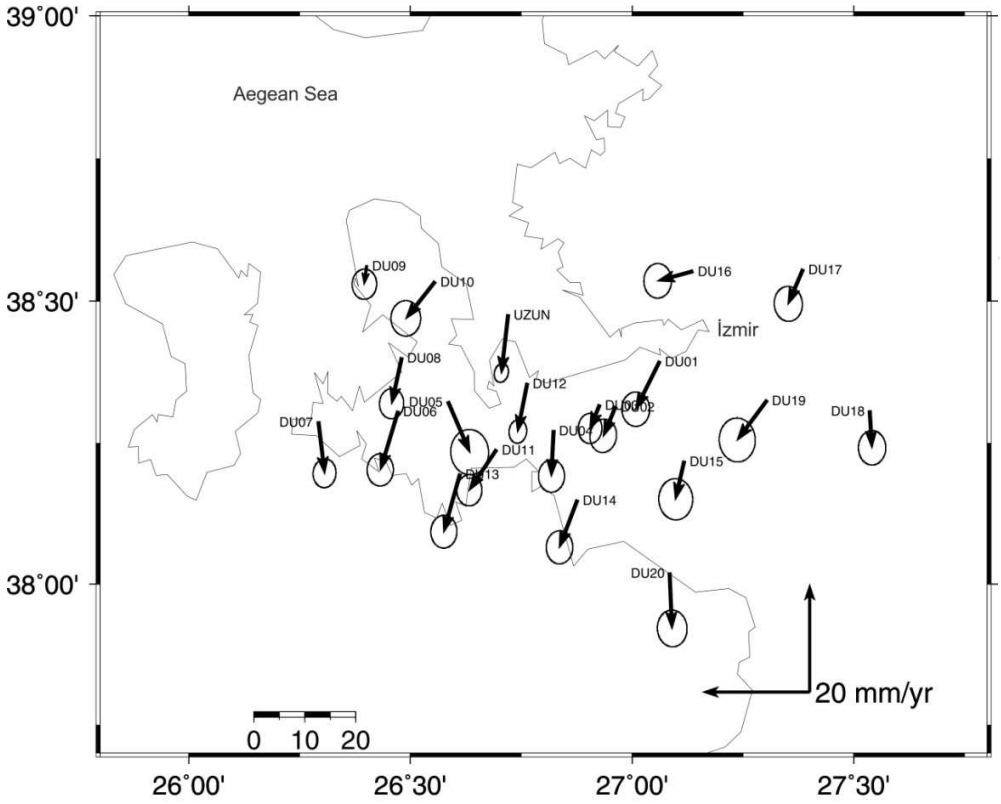


Figure 7: The velocity field with 95% confidence ellipses of the stations computed in the Anatolian block fixed frame from 3-year (2009, 2010 and 2011) GPS data.

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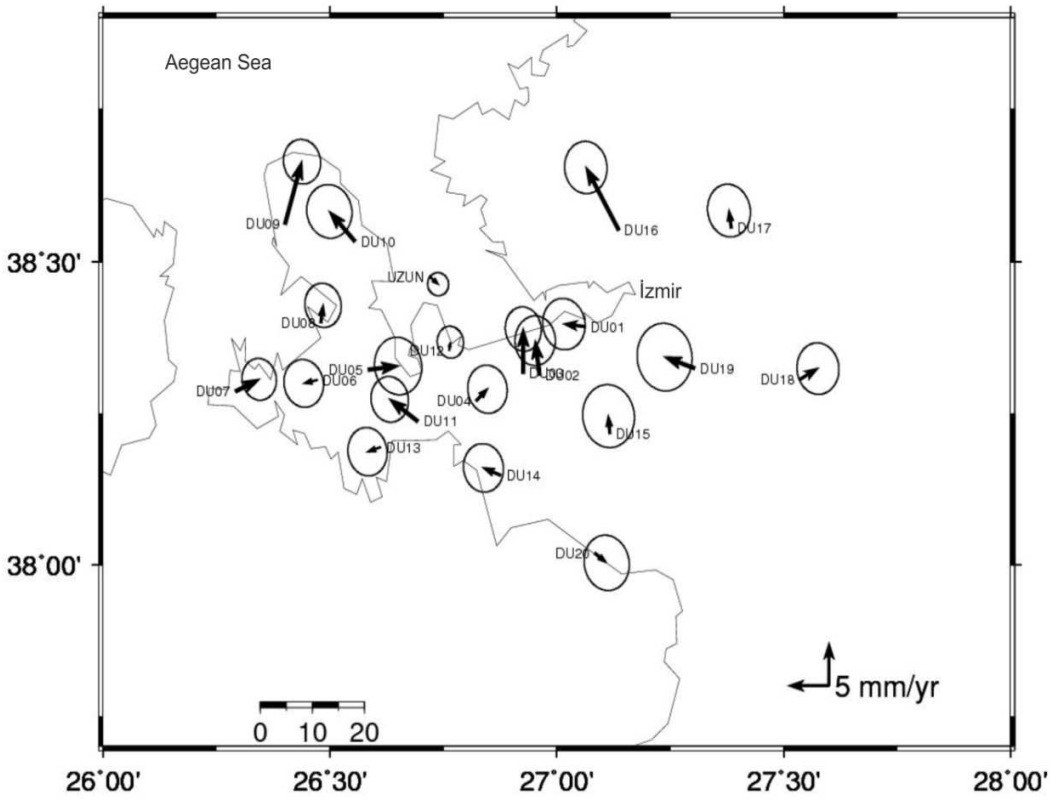


Figure 8: The Euler pole solutions with 95% confidence ellipses.

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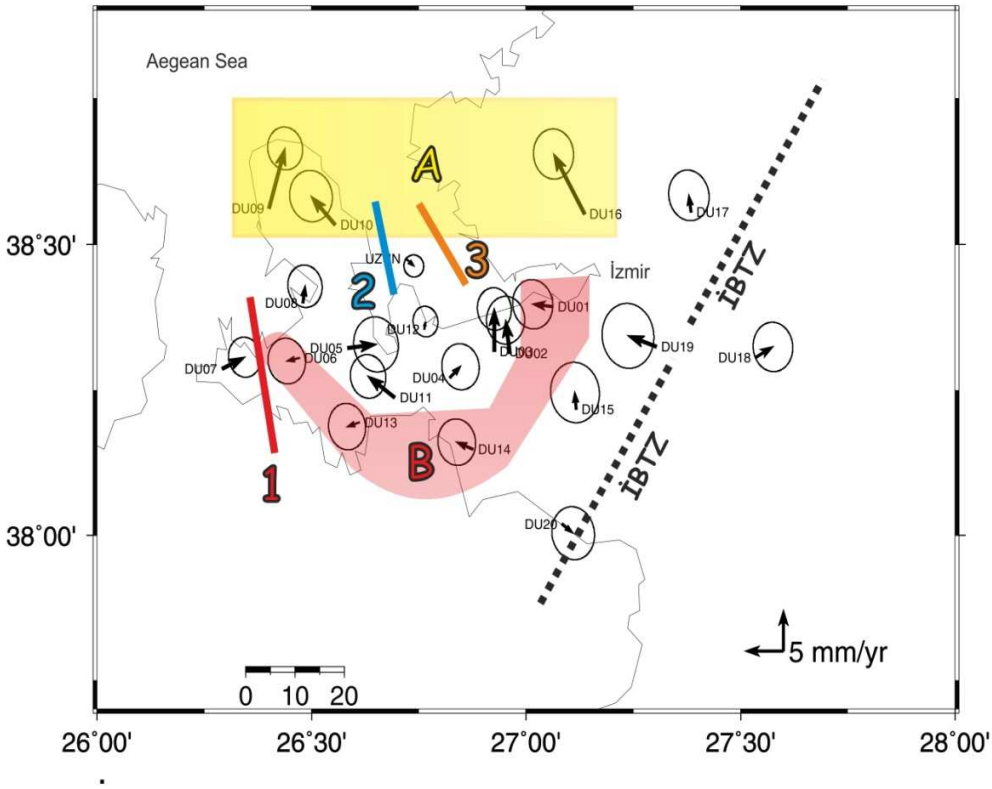


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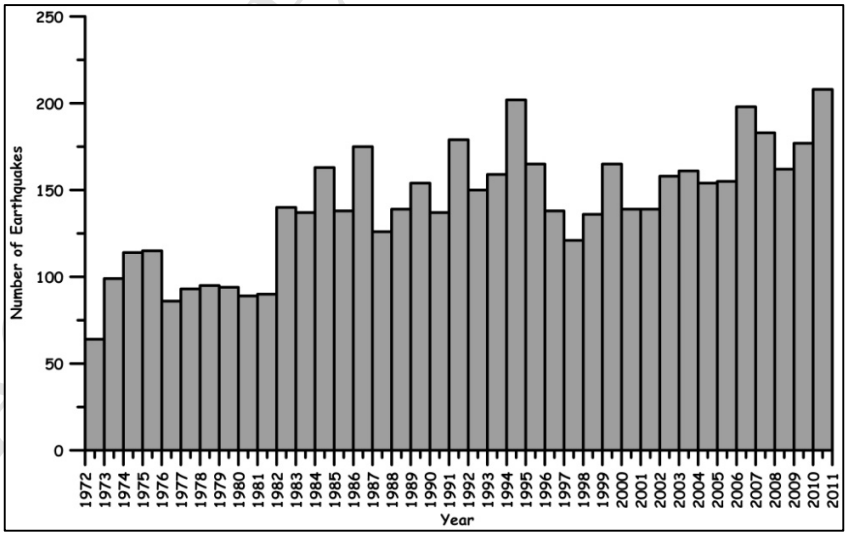
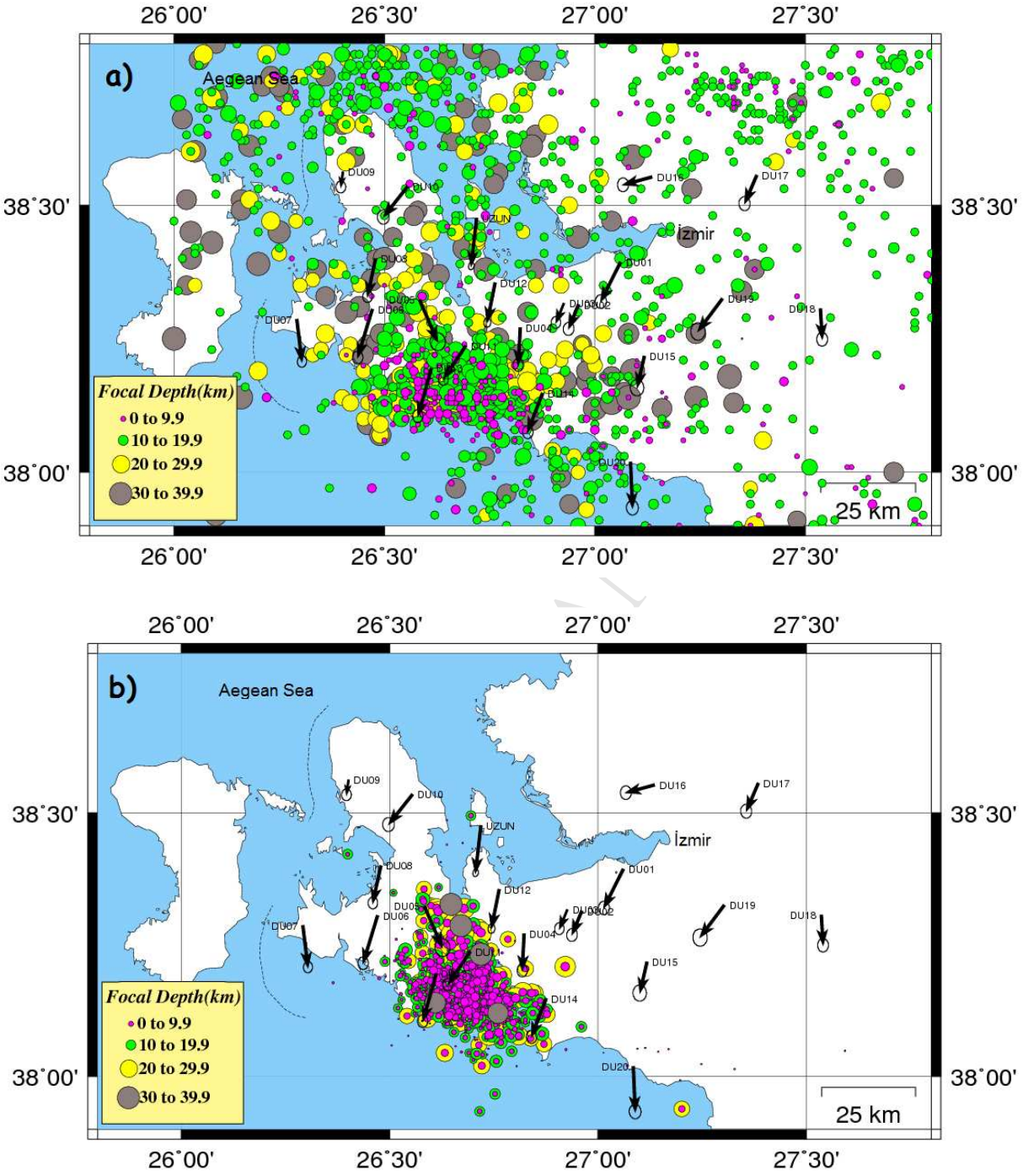


Figure 10: Number of earthquakes occurred in the study area between 1973 and 2011 (obtained from the USGS).


a)
Aegean Sea
İzmir
UZUN
DU01
DU02
DU03
DU04
DU05
DU06
DU07
DU08
DU09
DU10
DU11
DU12
DU13
DU14
DU15
DU16
DU17
DU18
DU19
DU20
Focal Depth(km)
0 to 9.9
10 to 19.9
20 to 29.9
30 to 39.9
25 km
26˚00'
26˚30'
27˚00'
27˚30'
38˚30'
38˚00'
b)
Aegean Sea
İzmir
UZUN
Focal Depth(km)
0 to 9.9
10 to 19.9
20 to 29.9
30 to 39.9
25 km
26˚00'
26˚30'
27˚00'
27˚30'
38˚30'
38˚00'

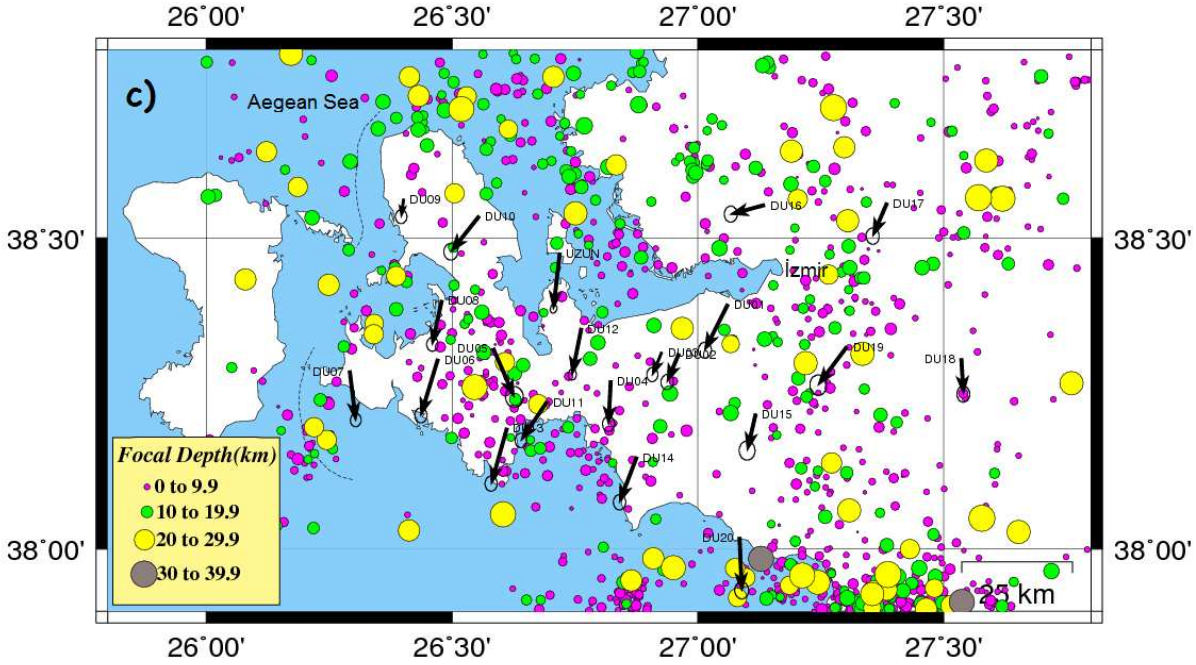


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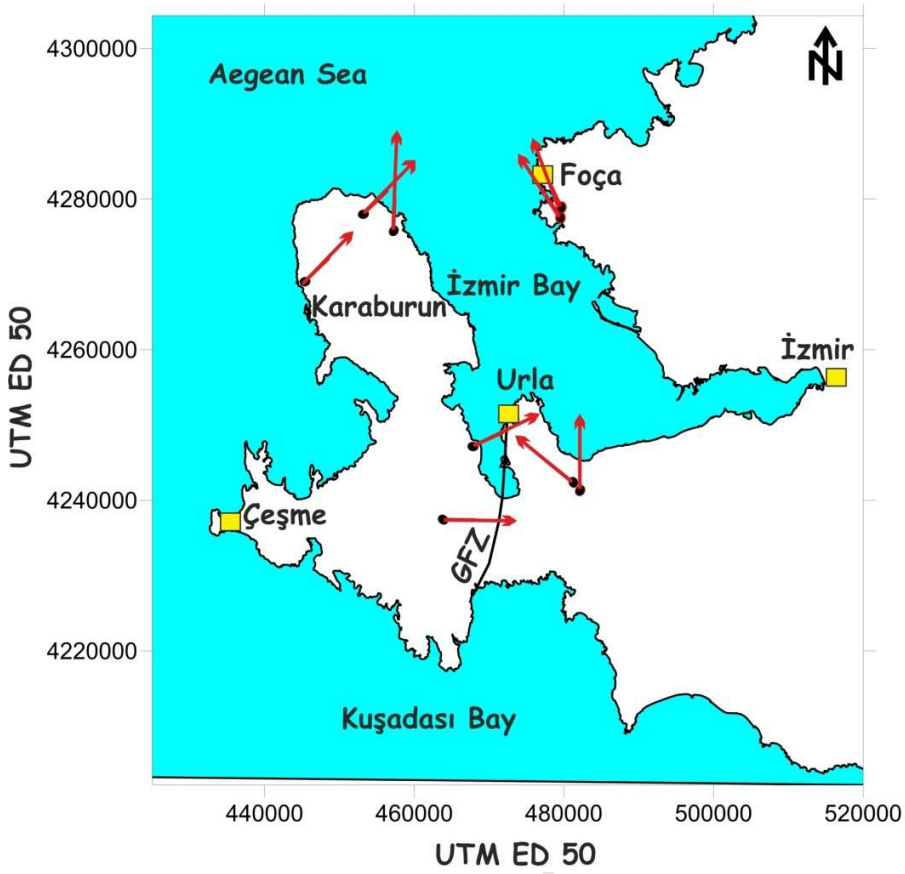


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Highlights

1. The motions of the tectonic structures of İzmir and its surroundings were defined.
2. Processing results of three years GPS campaigns were presented.
3. Aegean and Anatolian block fixed frames were calculated relative to Euler vectors.
4. Three lines and two regions were described in study area by Euler pole solutions.
5. Results of the solutions were compared with seismicity and paleomagnetic studies.

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