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Stress States at the end of the North Anatolian Fault Zone, Marmara Region

Yasemin KORKUSUZ ÖZTÜRK[1] (yasemin.korkusuz@boun.edu.tr) and **Nurcan MERAL ÖZEL**[2] (Nurcan.Meral.Ozel@ctbto.org)

1 - Boğaziçi University, Kandilli Observatory and Earthquake Research Institute, Department of Geophysics, Çengelköy, Üsküdar, İstanbul, 34684, Turkey

2 - CTBTO, International Monitoring System Division, Vienna International Centre, P.O. Box 1200, 1400 Vienna, Austria

Vienna - Austria, SnT2017 - CTBTO

ABSTRACT

Extensional focal mechanism solutions are mostly observed in the Central Marmara by this comprehensive research although the main Marmara Fault, the western branch of the North Anatolian Fault Zone (NAFZ), is dominated by a right lateral strike-slip regime.

As a result of the western motion of the NAFZ, Marmara Region is prone to a large earthquake and a seismically very active area. Therefore, the analysis of the Marmara Sea is significant.

This research aims to define the locations and the branches of fault structures and their geometrical orientations.

In this study, earthquakes are located using hypocenter program. We have reached six clusters of earthquakes location in the region and next, they are submitted to the stress tensor inversion procedure and their simultaneous focal mechanism solutions are obtained. Besides, they are relocated once again using HYPODD relative location technique.

Consequently, from the comparison of relocation results of hypocenter and HYPODD programs, it is found out that most of the relocations have the same orientations due to the usage of a high quality data set. Dipping angles of the segments of the Main Marmara Fault could not be observed; on the other hand, important information is discovered about seismogenic zones. Besides, mostly NE-SW oriented extensional stress structures are found in the five regions, while a right lateral strike-slip stress structure is found in the most western Marmara. Further, our sensitive relocation and stress analyses will make an important contribution to a better understanding of the movements in the Sea of Marmara, and shed light on earthquake rupture analyses for heterogeneous stress states and other seismological studies.

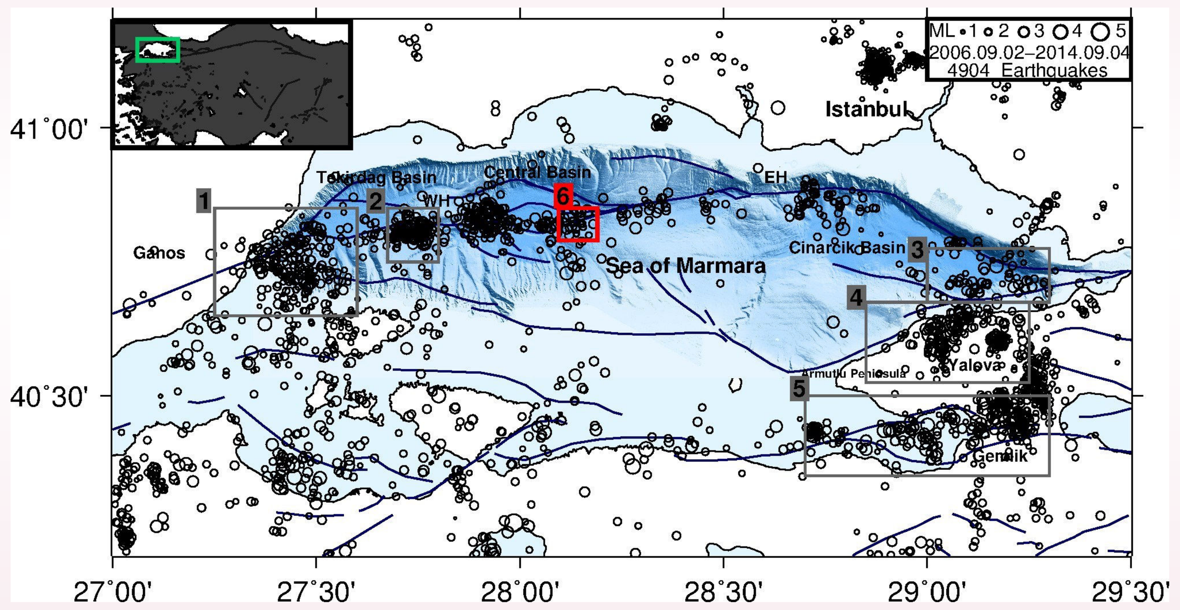


Figure 1. Recent seismic activity of the Marmara Region for a time period between 2006.09.02 and 2014.09.04 from the earthquake catalogue of TUBITAK-MRC (Fault geometry, Seeber *et al.*, 2004). All circles are events with ML≥1.0. Black rectangles including colored circles are visible earthquake clusters; Eastern Ganos Offshore (1-EGO), Eastern Tekirdağ Basin (2-ETB), Eastern Çınarcık Basin (3-ECB), Yalova (4-Y), Gemlik clusters (5-G) and Eastern Central Marmara Basin (6-ECMB, red). The red circle is the main study area of this work. Fault traces are from Armijo et al., 2002, and bathymetry data are from Rangin et al., 2001.

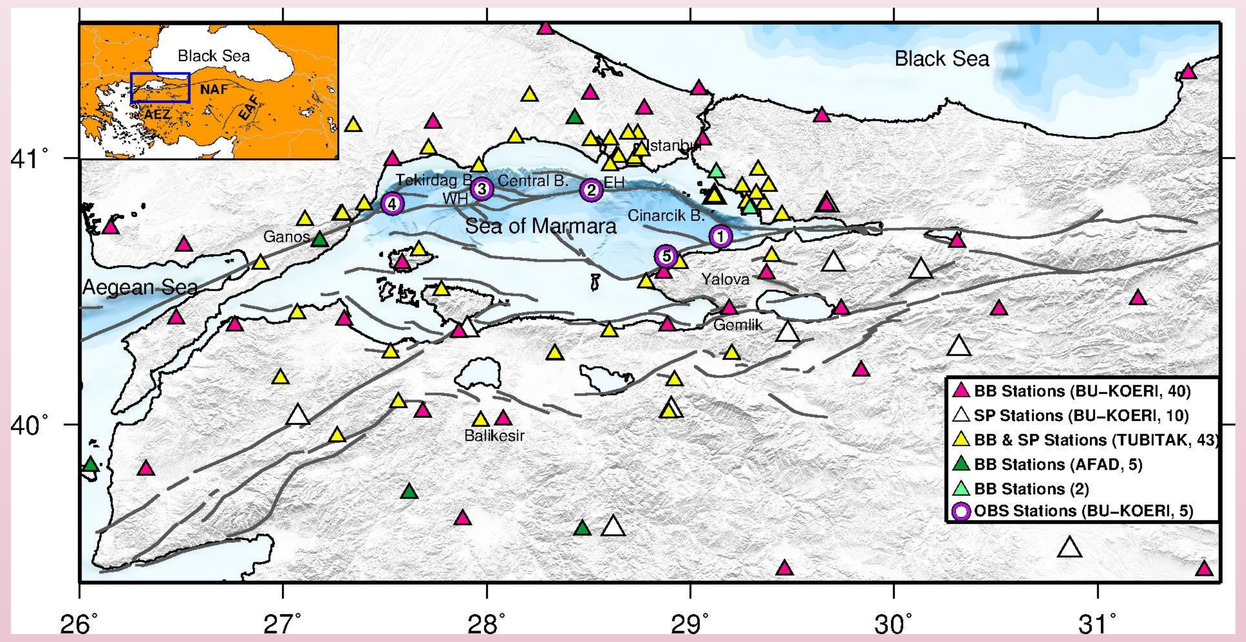
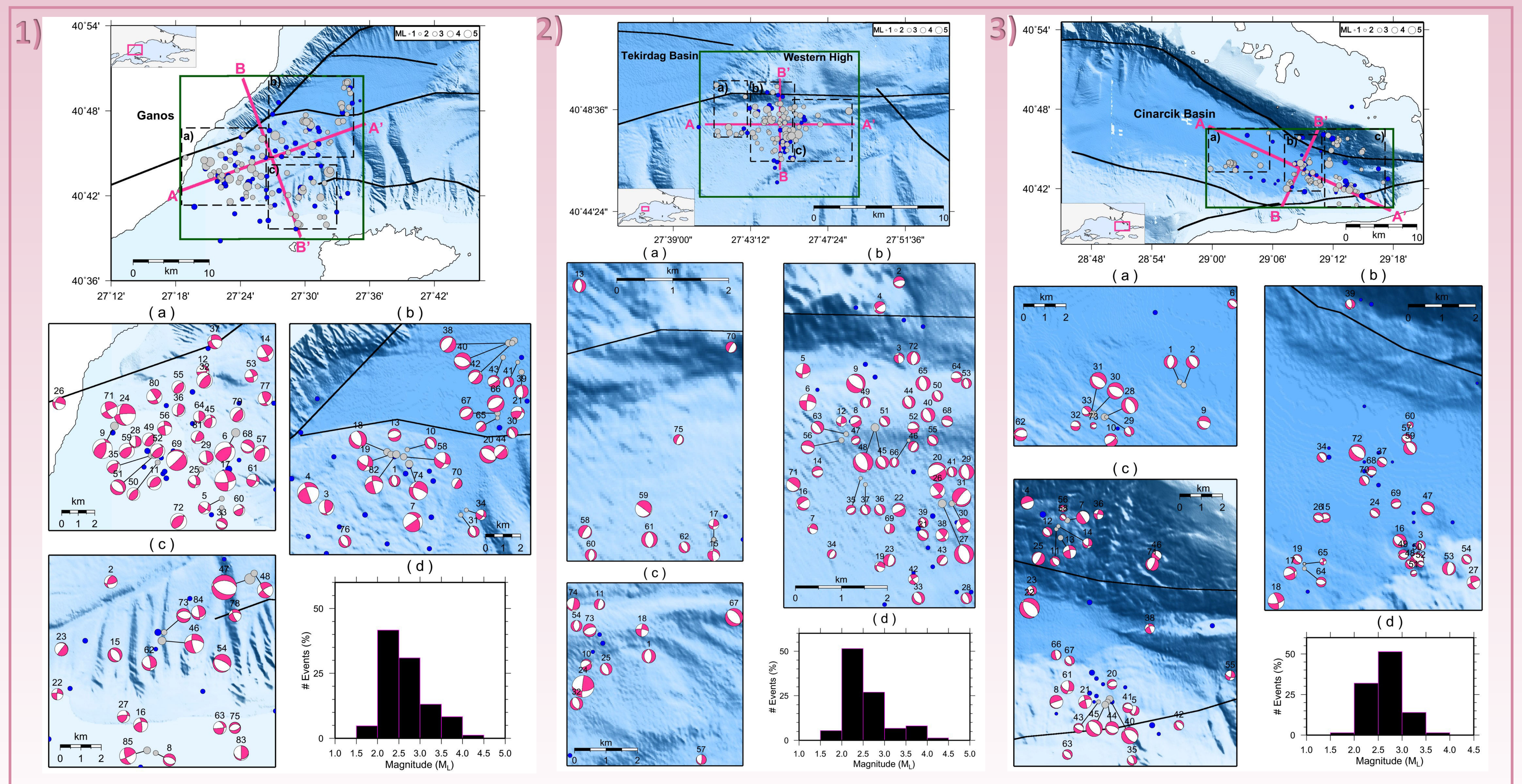


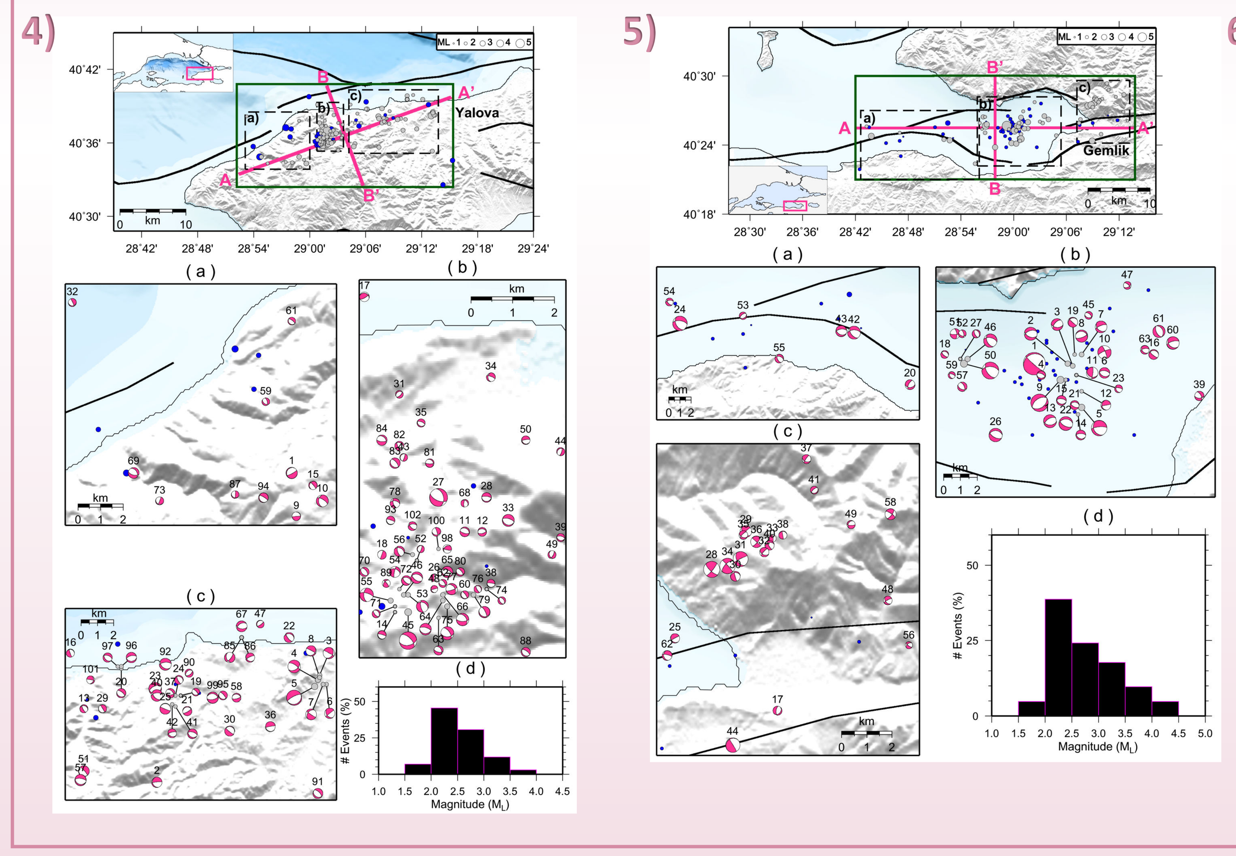
Figure 2. The seismic station distribution map of the study.

DATA AND METHODS

- 425 of 642 clustered earthquakes with ML≥1.5 are selected; as a result of, individual locations and focal mechanisms of earthquakes form the re-identifications of P and S phases and P-wave first motion polarities. The selection critera are each earthquake must have minimum 10 P-wave first motion polarities and maximum 1 inconsistent station (Korkusuz Öztürk *et al.* 2015).
- 5 degree grid search is used in order to determine maximum, intermediate and minimum principal stress axes and also discriminate fault planes from auxiliary planes (Horiuchi *et al.*,1995).
- 425 earthquakes are subjected to the hypoDD program to obtain double-difference locations (Korkusuz Öztürk *and Meral Özel, submitted*). SVD (Singular Value Decomposition) is used to solve the system Waldhauser and Ellsworth (2000).

RESULTS-1





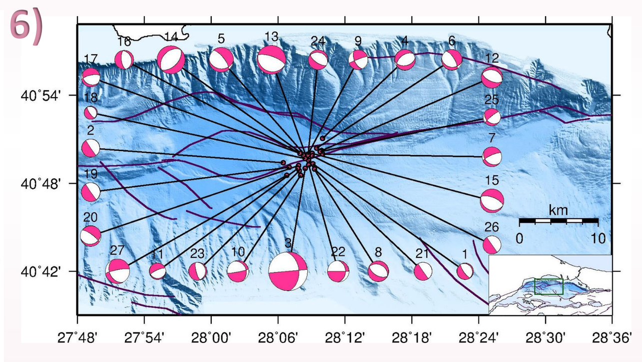


Figure 3. Epicenters of relocated (beachballs) and eliminated (blue dots) earthquakes are shown for the Eastern Ganos Offshore, Eastern Tekirdağ Basin, Eastern Çınarcık Basin, Yalova, Gemlik and Eastern Central Basin clusters, (from 1 to 6) respectively. Earthquakes are enumerated time dependently. Dark green rectangles are study areas and percentage distributions of local magnitudes of the selected earthquakes are shown in subplots (d).

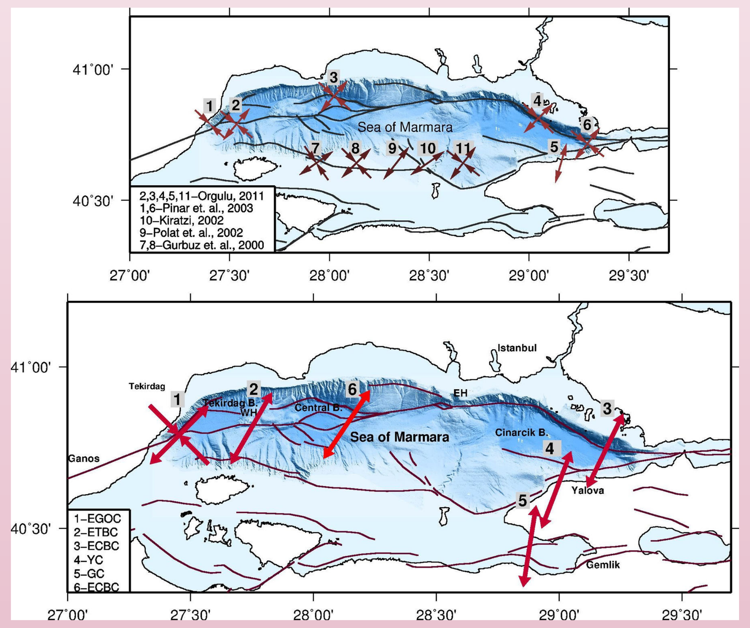


Figure 4. The map on the top is the representation of orientations of the maximum horizontal stress axes from previous studies; 2,3,4,5 (light brown) for local areas in the Sea of Marmara; 1 and 6 (light brown) for the whole western and the whole eastern Marmara areas; and 7,8,9,10,11 (dark brown) for the whole region of Marmara (Gürbüz et al., 2000; Kiratzi, 2002; Polat et al., 2002; Pınar et al., 2003; Örgülü, 2011). The below map represents horizontal stress alignments for the Eastern Ganos Offshore (1), Eastern Tekirdağ basin (2), Eastern Çınarcık basin (3), Yalova (4), Gemlik (5) and Eastern Central Marmara basin (6) clusters(Korkusuz Öztürk et al., 2015; Korkusuz Öztürk and Meral Özel, submitted).

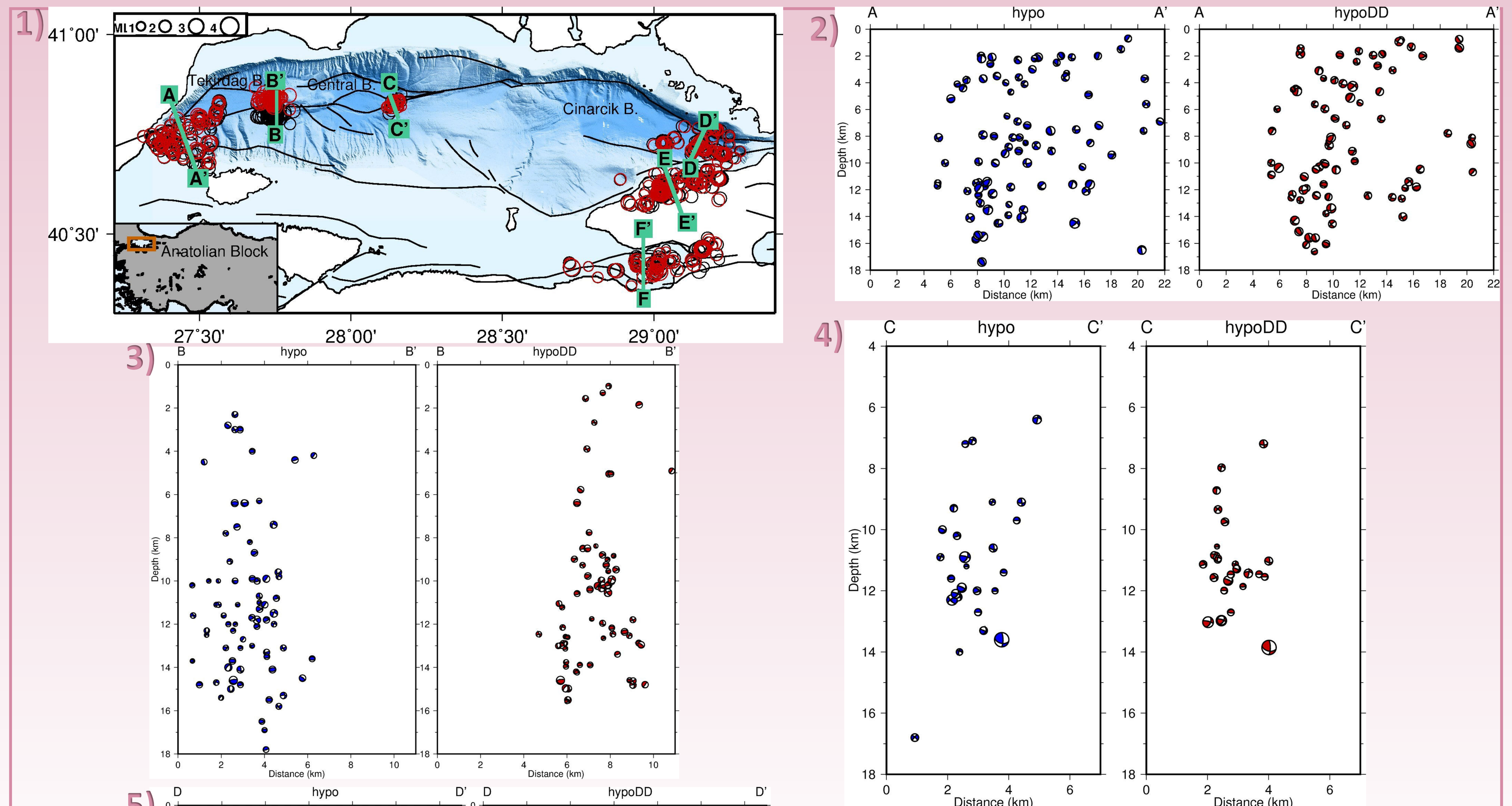
Table 1. The summary of average error amounts from relocations and fault plane solutions.

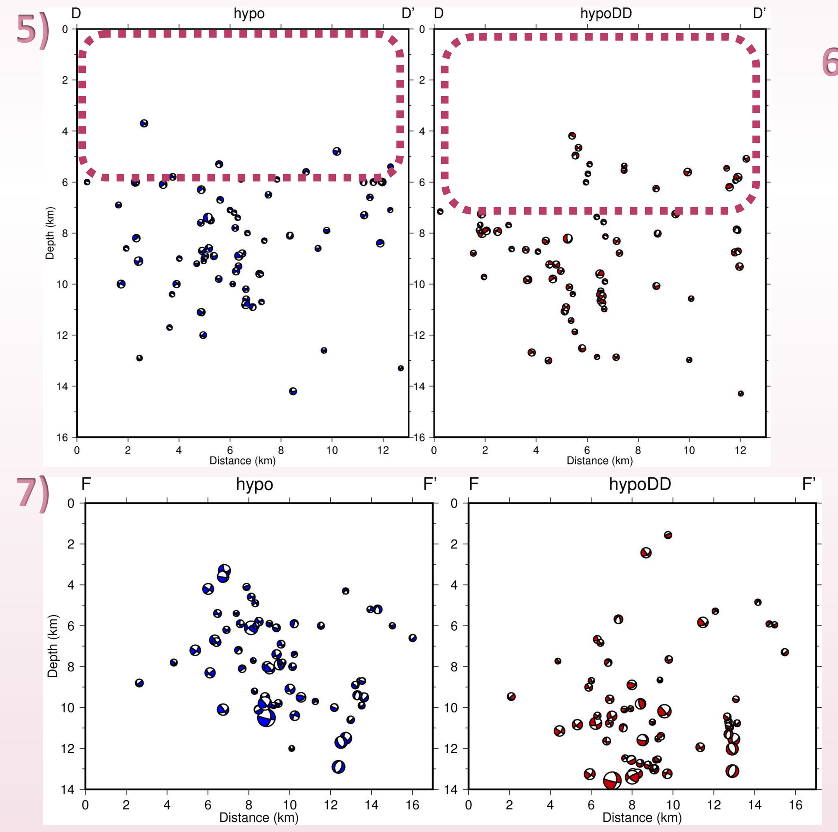
Cluster	Av-GAP (°)	Av-Erdp (km)	Av-Erlt (km)	Av-Erln (km)	Min/Max/Av/Tot-Polarity	Misfit Polarity
1-EGOC	65±21	2.6±0.93	1.0±0.23	1.2±0.32	10/58/21/1768	22
2-ETBC	58±23	3.1±0.85	1.2±0.21	1.4±0.29	10/65/28/2063	28
3-ECBC	64±22	2.8±0.69	0.8±0.16	1.2±0.22	10/44/20/1494	12
4-YC	55±22	2.5±0.85	0.9±0.23	1.2±0.24	10/63/23/2336	23
5-GC	75±39	3.0±0.80	1.1±0.32	1.4±0.28	11/61/25/1565	19
6-ECMBC	67±29	3.2±1.04	1.3±0.30	1.3± 0.36	10/45/21/574	7
TOTAL	63±25	2.8±0.84	1.0±0.23	1.27±0.27	10/65/23/9800	111

Table 2. Stress tensor inversion results via the program of Horiuchi et al. (1995).

Cluster	Used/All Events	Az-Pl	Az-Pl	Az-Pl
1-EGOC	85/144	315-35	141-50	221-7
2-ETBC	75/105	293-70	143-30	30-0
3-ECBC	73/116	123-80	298-10	206-5
4-YC	102/124	285-75	115-7	201-2
5-GC	63/100	102-58	285-30	189-5
6-ECMBC	27/53	90-79	304-3	214-5

RESULTS-2





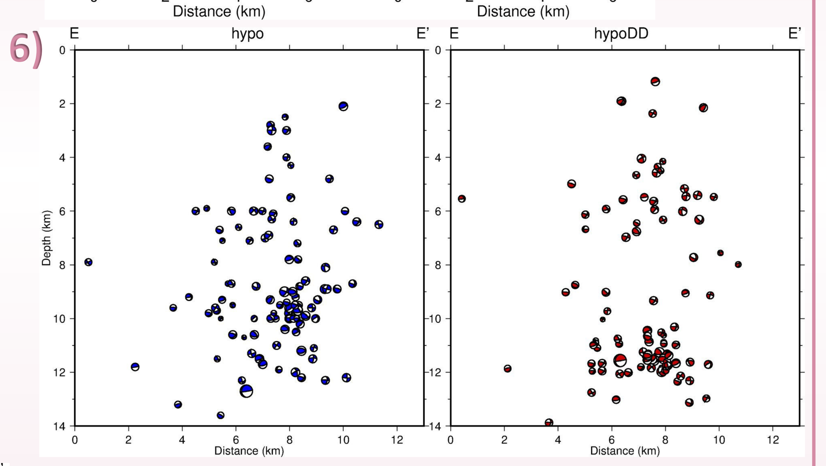


Figure 5. Epicenters of earthquakes selected within the six visible clusters for individual (black circles) and relative (red circles) locations. Green profiles are for the fault perpendicular cross sections which are shown from figures 2 to 7.

The left figures are for individual locations obtained via Hypocenter software, while the right ones are derived by using the Hypodd relative location technique.

DISCUSSION AND CONCLUSION

- In this study, we analyze seismotectonics of the Sea of Marmara for the time span between 2006 and 2014 by merging data sets from KOERI and TUBITAK-MRC.
- P and S phases of 642 ML≥1.5 earthquakes are re-identified, and 425 of them are selected for the further process.
- Selected events are located, their fault plane solutions are obtained. Thus, alignments of maximum, intermediate and minimum principal stress axes are calculated.
- A dominant NE-SW extension is found out in the ETB, ECB, YC, G and ECMB clusters through the SHmax alignments, while a right lateral strike-slip stress structure is obtained in the EGO region.
- Hypodd relative locations are derived from our joint data sets for the six clusters in the Sea of Marmara. Therefore, we find that the seismogenic zone extends over ~17 km depth in the EGOC and the number of the earthquakes is few or almost none within the top 2 km depth, the sedimentary area. ETBC, might be creeping above ~10 km depth. Hence, this segment may not be capable of creating large earthquakes, as the loaded stress might be releasing via moderate size earthquakes that occur with a few months or around one year recurrence interval depending on their magnitudes. Furthermore, the upper part of the ECMBC may be creeping above ~10.5 km or the most upper part may be totally locked above ~7 km depth, the zone between ~7-10.5 km is creeping and the zone between ~10.5 and 14 km is seismically active. The ECBC that have an extensional stress state might be locked above ~7 km or ~10 km depths, and this segment of the main Marmara Fault may be loading stress to create a large earthquake, considering the last largest event occurred in 1766. The YC hosts a large number of small earthquakes up to ~14 km depth. On the other hand, a ~2 km thick silent zone might exit between ~7-9 km depths, and the shallow activity ~6 km depth might come from the existence of the hot springs. Moreover, in the GC the seismogenic zone is observed between ~5-13 km depths.

References

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