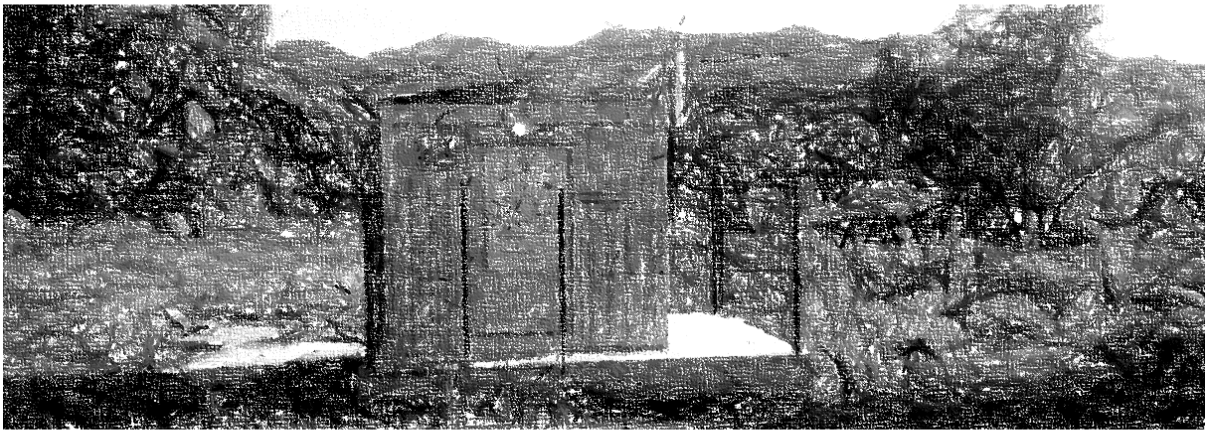

TURKISH-GERMAN SYMPOSIUM ON SEISMOTECTONIC RESEARCH IN THE MARMARA REGION

ABSTRACT BOOK

Organizers

Republic of Türkiye
Ministry of Interior
Disaster and Emergency
Management Authority (AFAD)
&
Helmholtz Centre Potsdam
GFZ German Research Centre for
Geosciences

16-17 August 2022
İstanbul
Türkiye

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Foreword

Governor Yunus SEZER AFAD President

Türkiye is located in a seismically active region in the world and has been exposed to earthquakes throughout history. 17 August 1999 Marmara and 12 November 1999 Düzce Earthquakes were noticed as one of the biggest disasters of the 20th Century in terms of human losses, damage to property and economy in the history of Türkiye.

Türkiye has had several ongoing collaborations with different institutions worldwide in the field of earthquake research. As one among them, Türkiye and Germany have a long history since the 1980s. In order to mark the more than 40 years Turkish-German partnership in the field of earthquake research, AFAD and GFZ gathered the most prominent earthquake researchers not only from Türkiye and Germany and from different parts of the world.

I wish the outcomes of the symposium will shed a light on the earthquake researchers of both countries on how to further the existing cooperation with novel techniques and studies in order to minimize earthquake losses in the Marmara Region and worldwide. We would like to thank GFZ for their valuable cooperation in the long-lasting earthquake researches.

Prof. Dr. Susanne Buiter GFZ Scientific Executive Director and Spokesperson of the Executive Board

As geoscientists we need to deal with extreme events that cause thousands of deaths and heavy losses in infrastructure, such as the Izmit-Kocaeli earthquake of 1999. This event raised the awareness for the seismic risk near Istanbul enormously and led to an even closer cooperation between Türkiye and Germany. In the Turkish Disaster and Emergency Management Authority AFAD, the German Research Centre for Geosciences GFZ found a strong partner with whom we have been closely and very successfully collaborating since 2011.
Earthquake prediction remains a long-term goal in seismology that will require continuing research efforts. We are very optimistic that with the current and planned monitoring infrastructure in the Marmara region, we can contribute towards an improved hazard and risk assessment. This will help towards achieving the ultimate goal of minimizing the impact of a future large earthquake in this region.

The Symposium in Istanbul of August 2022 celebrated four decades of collaboration between Türkiye and Germany in seismotectonic research. We warmly thank AFAD for the fruitful and important interactions of the past years and look forward to our future cooperation over the years to come.

Aim and Objectives of the Symposium

Turkish-German cooperation in the field of earthquake risk mitigation and seismology has long been successfully implemented by Research Institutions and Governmental Authorities on both sides since the early 1980s. The very first cooperation dates back to 1984 with the establishment of nine micro earthquake stations deployed over the Western Segment of the North Anatolian Fault Zone between Adapazarı and Mudurnu within the frame of the 'Turkish–German Joint Project for Earthquake Research'. In the frame of the Turkish and German joint project on earthquake prediction, in the western part of the North Anatolian fault zone, around the İzmit-Bolu area, a multidisciplinary earthquake research study was carried out since 1984. Since then, the collaboration has been intensified and expanded to many geoscientific disciplines with a focus on earthquake research. These activities ultimately led to implementing the downhole Geophysical Observatory at the North Anatolian Fault (GONAF) in the eastern Marmara region.

The Symposium has celebrated four decades of joint Turkish-German seismotectonic research collaboration. The international partnership and joint achievements has been reviewed, current efforts has been presented and discussed, and future challenges of seismotectonic and seismological studies in the Marmara region has been envisioned. The symposium serves to present and discuss novel research results and identify knowledge gaps in order to define the objectives for future geoscientific research in this region. The Symposium offers a good venue and opportunity for creating synergies between Turkish, German and international scientists.

The technical sessions held during the Symposium addressed the key topics covering, among others, studies to characterize the overdue Main Marmara fault to improve quantitative seismic hazard, and risk assessments, lessons learned from the last major earthquake in the region, the August 17, 1999, Kocaeli/İzmit Mw 7.6 earthquake. Participants has discussed further research topics and possibilities in the field of seismotectonics, monitoring seismic and aseismic deformation, earthquake physics, geodesy, seismic hazard assessment, earthquake engineering, and ultimately earthquake risk mitigation.

Dr. Murat NURLU
AFAD

Prof. Dr. Marco BOHNHOFF
GFZ

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OPENNING SESSION: Seismotectonic Setting of the Marmara Region and Current Monitoring Efforts

TURKISH-GERMAN COLLABORATION on EARTHQUAKE RESEARCH: LONG TERM SUSTAINED PARTNERSHIP

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ABSTRACT

Turkish-German research activities in earthquake sciences extend beyond the 1980s. In addition to earthquake research, there also has been an extensive collaboration between Turkish and German researchers in the field of geodesy (Altan, 1995) and geology with the contributions of Walther Peck (Özçep, F, 2018). In the 1980s, there had been several studies on earthquake studies between Turkish and German Researchers (Zchau et. al., 1981 and Zchau et.al., 1982). In 1989, a project called the "Turkish German Earthquake Research Project" was started between the Turkish General Directorate of Disaster Affairs (later named Disaster and Emergency Management Authority of Türkiye – AFAD) and the German Research Center for Geosciences (GFZ). An area covering the Sakarya and Bolu Provinces was selected as the Project area where multi-parameter stations were established in order to investigate the earthquake phenomena in the North Anatolian Fault Zone of Türkiye (Woith, 2009). Several types of stations including micro-earthquake sensors, tiltmeter, groundwater observation stations, and radon stations were set up in the project area. In 1996, the studies were continued within the frame of the SABONET Project with instrumentations that are more technical in order to analyse and evaluate micro-earthquake activity precisely. Turkish-German Earthquake Research Project and SABONET were among the most important international Projects on earthquake research of Türkiye in the 1990s.

Studies of the Turkish-German Earthquake Research Project were discussed at the two symposiums organised in 1989 and 1996. With the establishment of the Disaster and Emergency Management Authority in 2009, ongoing collaboration between Türkiye (AFAD) and Germany (GFZ) was moved one important step ahead within a protocol called "Protocol of Intentions for the Turkish-German Earthquake Research Cooperation" signed in 2011. Within the frame of the new Protocol, a Project called "Geophysical Observatory at the North Anatolian Fault (GONAF)" has been initiated with a concept of monitoring the seismic activity along the Marmara Sea and extended region with deep borehole observation technology. The collaboration between AFAD and GFZ has been strengthened with a protocol called "Protocol for Real-Time Seismological Data Exchange".

By utilising the experiences and expertise gained through the Turkish-German Earthquake Research activities, AFAD has been continuing to focus on Marmara Region in terms of earthquake risk management for years. İstanbul has the highest population density while having the highest share in all all-economic activities except agriculture and other service activities in Türkiye (TUIK, 2021 and 2022). Marmara Region has a rapidly growing industry and service sector outgrowth of the high population and economic activities. Considering the importance of the role of İstanbul in Türkiye's economy, AFAD has carried out many substantial projects in Marmara Region to minimize the cascading effects of earthquakes. In this regard, MEDRAP (Earthquake Risk Reduction Project in the Marmara Region) is one of the recent projects conducted by AFAD in collaboration with the municipalities, universities,

and NGOs. MEDRAP aims to achieve reducing the loss of life and property caused by an earthquake that may occur in the Marmara Region while keeping the damage to the critical infrastructures at the minimum level. Within the scope of the project, hazard and risk analysis are to be performed to address all the components of a disaster to create a resilient society by building smart cities. To ease the process, AFAD regularly increases the earthquake monitoring capacity.

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SEISMOTECTONIC SETTING of the NORTH ANATOLIAN FAULT ZONE in the ISTANBUL-MARMARA REGION

Marco Bohnhoff[1,2], Patricia Martínez-Garzón[1], Murat Nurlu[3] and the GONAF research team

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ABSTRACT

Joint Turkish-German research in the field of seismotectonics and earthquake risk mitigation focussed on the Istanbul-Marmara region celebrates 40 years of successful, thrustful and efficient collaboration. Over the last decade, these activities have been intensified and expanded to many geoscientific disciplines with a focus on earthquake research. These activities ultimately led to implementing the downhole Geophysical Observatory at the North Anatolian Fault (GONAF, www.gonaf-network.org) in the eastern Sea of Marmara region.

Partitioning of deformation in space and time along active fault zones is a key factor affecting hazard and risk models and requires distinct monitoring concepts for optimized detection of deformation transients. The Marmara section of the North Anatolian Fault zone (NAFZ) in NW Türkiye is late in its seismic cycle and expected to produce a large (M7+) earthquake in direct vicinity to the Istanbul metropolitan region. The efforts to image, characterize and monitor the offshore NAFZ segment and its individual branches were substantially intensified after the 1999 Izmit M7.4 earthquake. Here we present and review what is known (and not known) in terms of fault branching, deformation partitioning, interaction between slow and seismic slip, faulting kinematics, and spatiotemporal distribution of seismicity.

Near-fault monitoring along large portions of the offshore Marmara fault section are challenging, especially at the western part. However, the seismicity features now allow to identify distinct seismically active and inactive fault branches. The observation of seismic repeaters suggest that the western portion of the NAFZ below the Sea of Marmara may be creeping to a substantial extent. In contrast, the central and eastern Marmara segments are largely locked, thus accumulating a slip deficit likely since its last activation in 1766. Geodetic monitoring remains limited due to only very few near-fault islands posing thresholds to derive tectonic loading rates for individual fault branches.

The Sea of Marmara represents a large pull-apart basin. In line with regional tectonics and the GPS-derived velocity field, the crustal stress field from earthquake focal mechanisms shows overall transtension. Local fault kinematics allow identifying distinct local normal or strike-slip segments, likely reflecting the overall close proximity of the largest and intermediate principal stress magnitudes.

Recently implemented borehole-based multi-sensor deployments focus on the eastern Marmara section immediately south of Istanbul in the frame of the GONAF project. There, the Princes Islands segment (to the North) and the Armutlu fault (to the South) bound the Cinarcik pull-apart depocenter. The main aim here is to detect slip transients over the entire frequency band and to image deformation partitioning and fault interaction. We observe distinct slow-slip transients detected by borehole strainmeters that occur in conjunction with local moderate (M>4) earthquakes. Furthermore, reducing the observational

gap towards lower magnitude-detection thresholds now allows identifying systematic preparation processes leading to M>4 mainshocks as well as extended aftershock sequences complementing postseismic slow slip.

These observations show that further reducing the observational gap and broadening the signal frequency bandwidth allows to decipher deformation processes that previously remained undetected, now providing means for improved seismic hazard and risk models for the Istanbul metropolitan region.

SESSION 1: Deformation Features Along the Main Marmara Fault

DEFORMATION MECHANISMS ALONG the MAIN MARMARA FAULT

Magdalena Scheck-Wenderoth[1,2] , Mauro Cacace[1], Oliver Heidbach[1], Marco Bohnhoff[1,3], Murat Nurlu[4], Naiara Fernández[1], Juan Bott[1] and Ehsan Gholamrezaie[5]

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ABSTRACT

We present the starting point for a new project focused on the Main Marmara Fault (MMF) in NW Türkiye south of Istanbul, a segment of the North Anatolian Fault Zone (NAFZ). https://www.gfz-potsdam.de/en/section/basin-modeling/projects/3d-marmara
Several well-documented strong (M7+) earthquakes along this segment of the right-lateral continental transform fault indicate that the MMF is a mature active fault with high seismic hazard that poses a great risk to the Istanbul metropolitan region. Along the MMF a 150 km long stretch represents a seismic gap and historical records indicate that the fault is overdue. So far it is unclear whether the seismic gap will rupture in a single large earthquake or several smaller ones and if the next large earthquake would nucleate in the west and propagates towards Istanbul or the other way around. Therefore, a main objective of our work is to assess how the rheological configuration of the lithosphere in concert with fluid dynamics may influence the stress and strain accumulation along the MMF in the Marmara Sea region. We use different numerical tools to follow a workflow of data integration and process simulations for which more details are available at:
https://www.gfz-potsdam.de/en/scientific-infrastructure/research-software
https://www.gfz-potsdam.de/en/section/basin-modeling/infrastructure

Previous work indicates that the seismic gap is related to the mechanical segmentation along the MMF which originates in the rheological configuration of the crust and lithosphere. Integrating publicly available data, a first 3D model of the Marmara Sea lithosphere has been developed. This first digital twin resolves a heterogeneous crustal configuration with respect to variations in density, temperature and rheology and indicates a relationship between variations in long-term strength and deformation mechanisms. In a newly funded project within the ICDP priority program of the German Science Foundation (DEMMAF) we assess what mechanisms control the deformation along the MMF, using data collected at the ICDP GONAF observatory (International Continental Drilling Programme – Geophysical Observatory at the North Anatolian Fault) and a combined work flow of data integration and process modelling to derive a quantitative description of the physical state of the MMF and its surrounding crust and upper mantle. Seismic and strain observations from the ICDP-GONAF site will be integrated with regional observations on active seismicity, on the present-day deformation field at the surface, on the deep structure (crust and upper mantle) and on the present-day stress and thermal fields. Numerical simulations of coupled thermo-hydraulic-mechanical processes based on the observation-derived 3D models will complement the work flow to evaluate the first order controlling factors for seismic hazard.

A NEW SEISMOTECTONIC FRAMEWORK of the MARMARA SEA in the LIGHT of 3D FAULT MAP and 3D COULOMB STRESS ANALYSIS

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ABSTRACT

Within the Sea of Marmara, there is a morphologically complex structure consisting of troughs and ridges that are not observed anywhere on the North Anatolian Fault. During the investigation of this structure after the 1999 earthquake, multi-beam bathymetry data in the trough and shelves and seismic sections affecting very different depths were collected by the researchers. All studies focused on only a single fault model and the assumption that it was composed of fragments, and avoided explaining the Sea of Marmara as a whole. In our study, seismic data collected over 22 thousand km at different times were brought together and a 3D fault map (Figure 1) of Marmara was made for the first time in the entire sea area. In the map revealed as a result of this study, it was revealed that there is a multi-segment fault system that we can define as a horsetail pattern. In the northern and southern shelf areas, all the structural elements of the NAF-SE Thrace Eskişehir Fault Zone (Middle-late Miocene), which existed before the NAF and are known to exist on land, were mapped. In this state, it was understood that the structural elements of two different tectonic periods in Marmara acquired different characters with the inversion tectonics or that the ones suitable for the new structure continued to exist. It is necessary to question the studies made with the 3D map produced in this study and the single fault model produced with a limited number of sections in Marmara. This study reveals the true location of all sea and land faults. The 3D fault map is a new framework that will lead to a review of previous studies on single fault and single fault fragmentary models with insufficient 3D (Figure).

There are records of 248 earthquakes in the last 1500 years in the Marmara Region. 38 earthquakes destroyed more than two ancient settlements, and there are records of death and injury in these settlements. Especially in these historical earthquakes (Figure), the destruction and damage area shows the westward migrating series. The last series occurred in 1719 İzmit Fault, 1509 East Marmara Fault, 1754 Central High Fault, 1766-1 Kumburgaz Fault, 1766-2 Western High Fault, 1659 Ganos Fault, 1756 Saroz Fault before the 1999 earthquake. After the Ganos in 1912 and Izmit in 1999 were broken, the other segments have not been broken since 1509, 1754, 1766-1, 1766-2, and 1756, respectively. According to the Coulomb analysis and the calculation made within the framework of the historical earthquake, the East Marmara Fault (1509) and the East Marmara Ridge Middle Fault (1754) appear to have exceeded the average coulomb stress of the past earthquakes. Kumburgaz Fault (1766-1) and West Marmara Fault (1766-2) have approached 95% of the coulomb stress accumulation as a result of comparing the past averages with the present accumulation.

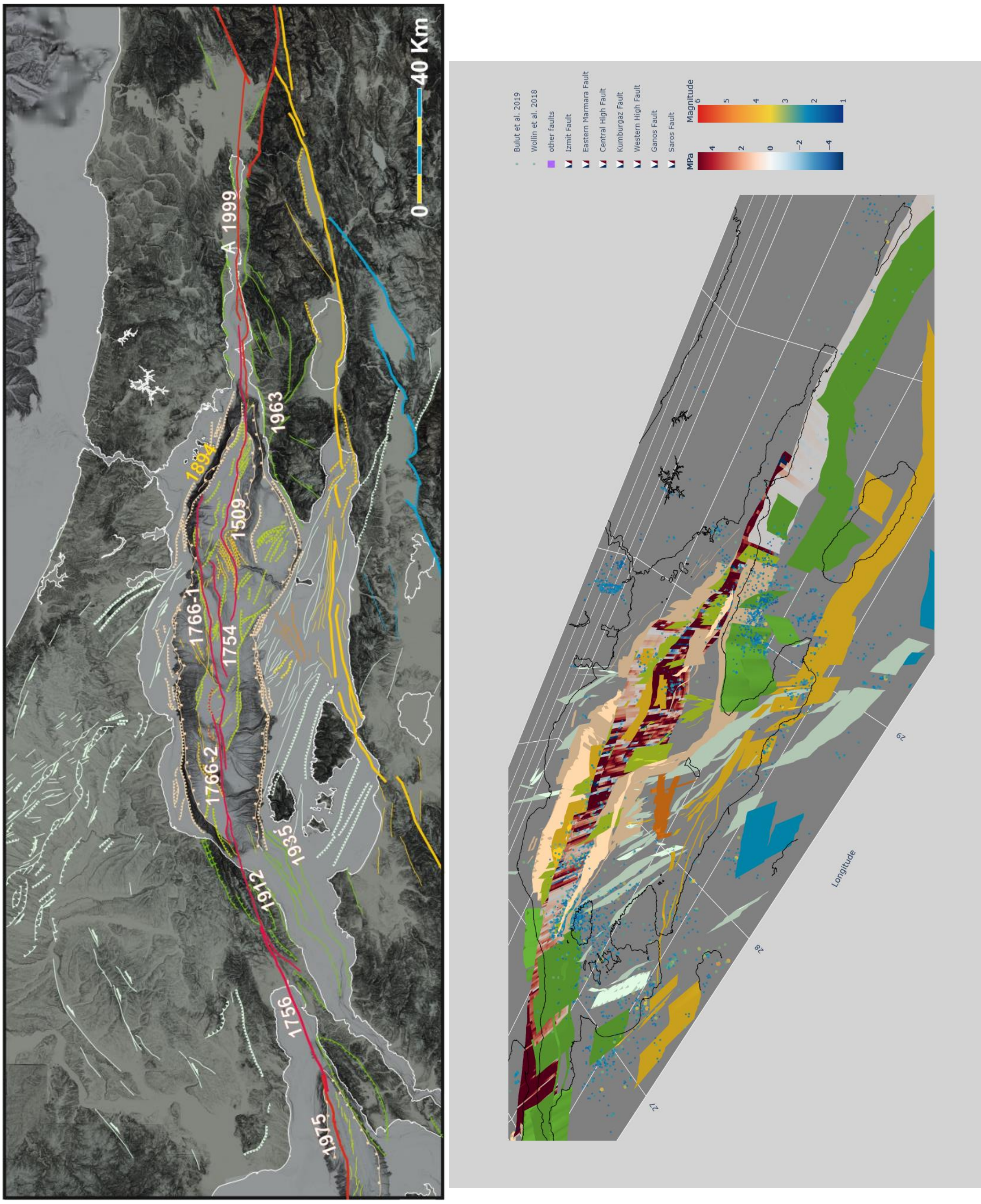

Figure 1. Marmara region active fault map and last earthquakes on northern segments (upper map). Marmara 3D fault map and coulomb stress on Northern segments (Lower map)

SEISMIC and ASEISMIC FAULT SLIP DURING the INTERSEISMIC PERIOD: OBSERVATIONS from the MARMARA REGION of the NORTH ANATOLIAN FAULT

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ABSTRACT

During the inter-seismic period, faults accumulate tectonic strain which is then released through slip transients of different duration from seismic to aseismic. Imaging creeping fault patches and constraining their depth extent could allow identifying fault segments with larger strain accumulation. The Marmara segment of the North Anatolian Fault (NAFZ) currently represents a seismic gap with a high probability for an M>7 earthquake in direct proximity to Istanbul. In the eastern Sea of Marmara region of the NAFZ, the GONAF borehole observatory is fully operating since 2015, providing the means to monitor earthquake nucleation and crustal deformation over the entire frequency band. In this study, we investigate the spatio-temporal distribution of seismic and aseismic deformation in the Marmara region and the implications for the nucleation of a large earthquake compiling information derived from extended identification of earthquake repeaters and analysis of continuous strainmeter and geodetic recordings. At the eastern portion of the Marmara segment, a fully locked fault segment was identified from absence of microseismicity and from GPS data (Bohnhoff et al., 2013; Ergintav et al., 2014). Towards the western part, shallow fault creep was reported based on sea-floor geodesy (Yamamoto et al., 2018) and the occurrence of repeating earthquakes (Schmittbuhl et al., 2016; Bohnhoff et al., 2017) in specific areas. We generated a new 15-year homogenous seismicity catalog for the Marmara region (2006-2021) unifying the data from the main Turkish seismic agencies AFAD and KOERI and including the GONAF borehole network. A total of 13.876 events were of sufficient quality to obtain non-linear hypocenter locations. We utilized this catalog to search for earthquake repeaters along the entire Main Marmara fault segment as well as the southern Marmara and Armutlu fault segments. Centering at the Western High segment of the Main Marmara fault, a spatial transition eastward and westward from partially creeping to fully locked is observed based on the amount and magnitude of earthquake repeaters and the estimated creeping rate. No other sequence of repeaters is found in any other part of the Marmara region. Analysis of strainmeter continuous recordings revealed two slow slip events connected with the occurrence of two M4+ earthquakes in the region in 2016 and 2018 and lasting for at least 30 days. Coulomb forward modelling combined with seismicity analysis suggests that the fault source of these slip transients could be the shallower portion of a local normal fault structure in the Armutlu Peninsula favorably oriented with respect to the local stress field orientation. All together, these results suggest that aseismic slip is occurring in some segments and different depth extent within the Marmara section of the NAFZ and that aseismic slip has a role in earthquake triggering and nucleation in the region. Still, further studies combining seismological and geodetic data are needed to determine the exact amount of slip-partitioning, particularly with depth.

HETEROGENEOUS INTERSEISMIC COUPLING ALONG the MAIN MARMARA FAULT

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ABSTRACT

Measuring interseismic crustal deformation offshore is a challenge in the sea of Marmara. Thus, little is known about the properties of the main faults in the sea of Marmara. In order to overcome the problem of sparse data on land, we extended the existing GNSS network (Ergintav et al., 2014), by new continuous GNSS stations and historical GPS survey points, which have been measured yearly in the last 15 yrs. In addition, we derived PSInSAR velocity maps using SENTINEL 1A/B data. These new data allow to better constrain parameters of the off-shore fault-system in the sea of Marmara.
Here, we present probabilistic models of strain accumulation along the northern branch of the North Anatolian Fault from İzmit to Ganos, including the Main Marmara Fault (MMF). Our new model provides strong evidence for aseismicly slipping zones along the MMF and, henceforth the state of seismic hazard in the region needs to be re-evaluated.

SPATIAL VARIATIONS of TECTONIC and POSTSEISMIC FAULT CREEP ALONG the MARMARA SEISMIC GAP, NORTH-WESTERN TÜRKİYE, BASED on HIGH RESOLUTION ANALYSIS of REPEATERS

Dirk Becker[1], Patricia Martínez-Garzón[1], Christopher Wollin[1], Tuğbay Kılıç [2] and Marco Bohnhoff[1,3]

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ABSTRACT

We use a newly compiled, homogeneous, high-resolution earthquake catalog of the Marmara region spanning the time period 2006-2020 and containing more than 13,000 events to search for earthquake repeaters along the Main Marmara Fault (MMF). Our search criteria identify a total of 30 repeater sequences with up to 9 members. These sequences are observed along the Western part of the MMF from the Tekirdag Basin in the West up to the Kumburgaz Basin in the East. No repeater sequences are identified offshore Istanbul in the Princess Island segment or along the Ganos segment in the West. From the cumulative slip of the repeater sequences we derive a longitudinal variation in the fraction of creep along the MMF with maximum values of up to 40% in the Western High and Central Basin and lower values towards the West and East. The absence of repeater sequences in the Princess Island and Ganos segments indicates a locked plate contact in these areas. We also observe a well-defined postseismic response of a repeater sequence in the Western High to a nearby M5 earthquake indicating postseismic deformation of the creeping patch around the asperity.

SESSION 2: Seismic Hazard and Risk Assessment in the Marmara Region

GROUND MOTION SIMULATION EFFORTS in TÜRKİYE and ENGINEERING EXTENSIONS

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ABSTRACT

The ultimate objective of seismic hazard and risk studies in urban environments is to attain seismic resilience. Naturally, most of the earthquake research are disaggregated: The detailed focus is either on earthquake sources, wave propagation, site response, ground motion modeling or building response. However, it is well known now that integrated approaches are necessary for studying seismic resilience as a whole. With the advance of computers and computational approaches, it is now possible to study the effects of earthquakes from sources to structures through physical models of earthquake ground motions also known as ground motion simulations. There are alternative methods for ground motions simulations which include deterministic, stochastic and hybrid methods.

In this talk, initially ground motion simulations of recent past earthquakes which occurred in and around Türkiye are presented. These events include the 1992 Erzincan, 1999 Düzce, 2002 Çay and 2020 Samos earthquakes. Stochastic and hybrid methods are employed for these simulations where source, path and site factors are validated for each event (e.g.: Ugurhan and Askan, 2010, Can et al., 2021). It is also noted that, not only past events but also scenario earthquakes are modeled in order to use in engineering applications for evaluating the seismic resilience of the areas of interest.

Next, use of ground motion simulations in earthquake engineering applications are presented. These applications include modeling of historical earthquakes through macroseismic intensity validations, single- and multi-degree-of-freedom structural analyses with simulated versus recorded ground motions and a city-scale loss estimations study as shown in Figure 1. (e.g.: Karimzadeh et al., 2018).

The results in terms of the fit of the simulated data to the corresponding recorded data, accuracy of the observed structural responses and losses are promising. The main challenges encountered are the lack of well-defined source and velocity models in areas of interest, data regarding building models and exposure. Future studies aim to study these points as well as extensive uncertainty analyses.

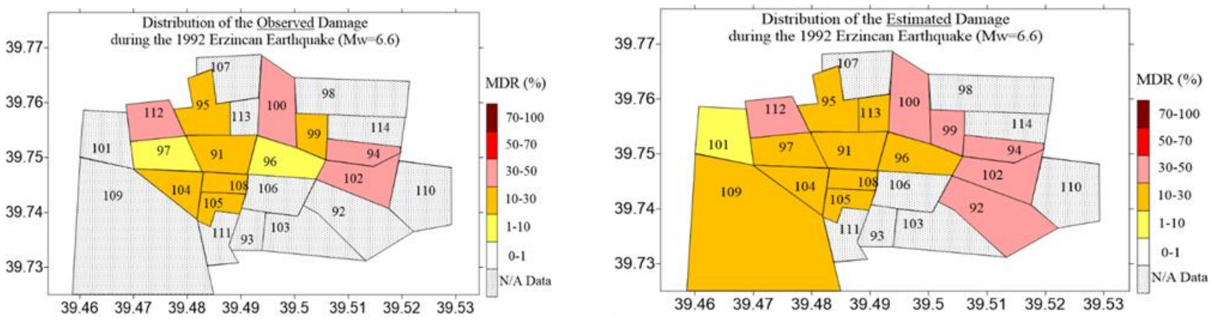

Figure 1. Comparison of observed and estimated damages (in terms of mean damage ratio, MDR) in Erzincan after the 1992 Erzincan earthquake using locally-derived damage functions based on simulated motions
Reference: Figure is adopted from Karimzadeh et al., 2018

TOWARDS BETTER PREDICTIONS of FUTURE GROUND-MOTIONS and THEIR VARIABILITIES: LESSONS LEARNED from “BIG-DATA” ANALYSIS and the DEVELOPMENT of NEW GENERATION of EUROPEAN SEISMIC HAZARD and RISK MODELS

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ABSTRACT

One of the major evolutions of ground-shaking modelling is due to the fact that many records per station and earthquake are now available. This increase of data per station/event is a major game changer since it gives the opportunity to extract the source, path and site contribution of ground-motions, evaluate the site/event specific adjustments relative to the median prediction of a Ground-Motion Predictive Model, refine the evaluation of ground-motion variability and finally move from ergodic to partially ergodic (site specific) ground-motion modelling.

Using the scientific opportunity offered by “big” ground-motions datasets and the increased number of records per station and event we have recently developed new pan-European models of ground-motions (e.g. Kotha et al. 2020) and regional site amplifications (Weatherill et al., 2020). These new models have been used to finalize the next generation of European Seismic Hazard and Risk models (ESHM20 and ESRM 20, models available on www.efehr.com).

The aim of the presentation will be to present the new models but also discuss the emergence of new techniques and strategies to 1) predict seismic motion (calibration of seismic motion variability at a site, development of machine learning methods and questioning of classical 1D methods to estimate site effects (e.g. Zhu et al. 2022)) and 2) detect the temporal evolutions of fault properties (e.g. Piccozzi et al., 2022).

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EARTHQUAKE HAZARD MAP of TÜRKİYE

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ABSTRACT

Previous Earthquake Zoning Map of Türkiye that came into force in 1996 was prepared based on the peak ground acceleration (PGA) contour map that was constructed by Gülkan et al. (1993) using probabilistic seismic hazard analysis methodology for a return period of 475 years. Five earthquake zones were defined based on the estimated PGA values as follows: 1st degree—PGA ≥ 0.4g; 2nd degree—0.3g ≤ PGA < 0.4g; 3rd degree—0.2g ≤ PGA < 0.3g; 4th degree—0.1g ≤ PGA < 0.2g; 5th degree—PGA < 0.1g.

In order to revise the previous map, the project entitled as "Revision of Turkish Seismic Hazard Map" (Akkar et al., 2018) was initiated in 2013. The project was supported within the scope of National Earthquake Research Programme which is conducted by Disaster and Emergency Management Authority (AFAD). It was also supported by Turkish Natural Catastrophe Insurance Pool (TCIP). In the project, earthquake hazard maps in terms of peak ground acceleration (PGA), peak ground velocity (PGV), 5%-damped pseudo-spectral accelerations at 0.2 sec and 1.0 sec periods (SS and S1) for a reference rock site [(VS)30 = 760 m/s] for return periods of 43, 72, 475 and 2475 years were produced.

Earthquake Hazard Map of Türkiye shown in Figure 1 was prepared using the results of "Revision of Turkish Seismic Hazard Map" project. It was published in the Official Gazette on 18th of March, 2018 and came into force on 1st of January, 2019. Different from the previous map which shows earthquake zones, this map shows PGA values having 10 % probability of exceedance in 50 years (return period of 475 years). In addition to the map, the data including PGA, PGV, SS and S1 values with 68%, 50%, 10%, 2% probabilities of exceedance in 50 years (corresponding to return periods of 43, 72, 475 and 2475 years, respectively) were published in the Official Gazette. A GIS-based interactive web application was developed to view and query earthquake hazard maps prepared based on this data in web environment. This web application provides earthquake ground motion parameters obtained from these maps for the sites specified by the users as well as horizontal and vertical elastic design spectra calculated according to Turkish Building Earthquake Code which came into force on 1st of January, 2019.

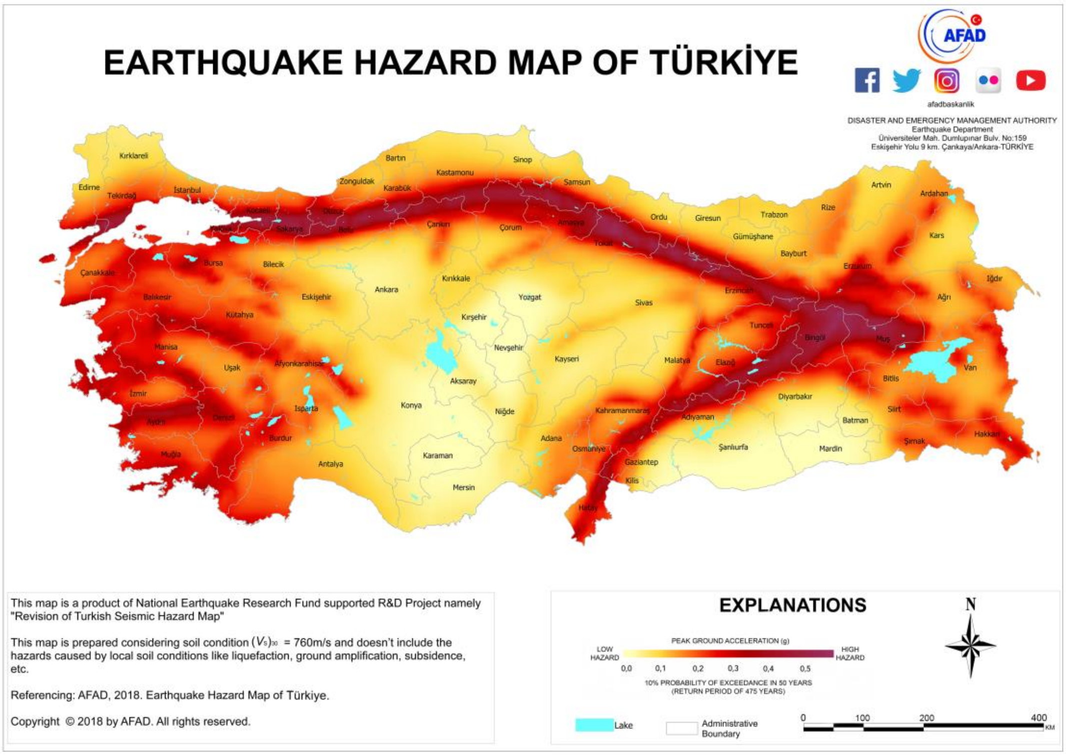

Figure 1. Earthquake Hazard Map of Türkiye

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FACTORS INFLUENCING FAULT STRENGTH and ITS LONG-TERM INTERSEISMIC BEHAVIOUR - CONSTRAINTS FROM 3D THERMO-HYDRAULIC-MECHANICAL MODELLING

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ABSTRACT

This contribution is intended as a digression about physical processes likely to exert a first-order control on the long-term interseismic behaviour of natural fault zones, with a specific focus on the Main Marmara Fault (MMF).

There is not yet a consensus about the interseismic evolution of the MMF, especially regarding its frictional state and its inter-to-pre-seismic behavior. On the one hand, it is possible to envisage the MMF as having a heterogeneous interseismic coupling with an alternation of creeping versus locked segments. Alternatively, the observed asymmetry in strain localization around the MMF can be structurally linked to a heterogeneous off-fault crustal and sedimentary rheological configuration.

Inspired by previous works by some of the co-authors (O. Heidbach) on the MMF, we present some preliminary results from forward dynamic simulations aiming at pinpointing the space and time scales arising from these different concepts of the MMF. We show how, within a rate-and-state formalism, along-strike variations in the interseismic strain accumulation and average earthquake recurrence timing can be explained by a heterogeneous fault frictional parameterization, with rate-weakening (locked) patches neighbouring rate-neutral (creeping) segments, within an overly elastic and homogeneous 3D bulk composition. Considering a functional behavior of frictional properties in terms of the resolved slip velocity can help to widen the conditions under which slow slip transients can develop. The caveat here is the hyper-dimensional parameter space, which is hard to be constrained at the scale of the whole MMF based on available geodetic and seismological constraints. An alternative to narrow down the dimension in the phase-space is to integrate details of the bulk crustal rheology in these forward modelling attempts. Our results from purely elastic against viscoelastic runs highlight a first order role from crustal rheology to modulate the synchronization and recurrence time of events, as well as their basic source parameters (i.e. shear stress changes). We found a positive correlation between lateral variations (across-strike) in crustal viscosity and the inter-to-pre-seismic strain localization, which we consider as indicative of the additional role from bulk damage on the fault behaviour. Based on these, albeit preliminary, results, we favor a hybrid model to explain the interseimic behavior of the MMF, and we call for augmenting our current knowledge of the geological archive around the Sea of Marmara region alongside geodetic and seismological observations.

PHYSICS-BASED REAL-TIME GROUND MOTION MODELLING

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ABSTRACT

When earthquake ground motion is recorded at one specific site, it is influenced by many factors, such as source mechanism, propagation path of the seismic waves, as well as local site conditions that may involve complex surface geology and irregular topography. Many earthquake early warning systems are designed to predict the strength of seismic ground motions (peak ground acceleration, peak ground velocity, or seismic intensity) based on rapidly estimated source parameters (the source-based method), such as hypocentral location, origin time, magnitude, and extent of fault rupture. Recently, wavefield-based (or ground-motion based) methods have been developed to predict future ground motions based directly on the current wavefield, i.e., ground motions monitored in real-time at neighboring sites, skipping the process of estimation of source parameters. Hereon, we present a filter for the real-time prediction of waveforms at target sites. The approach is particularly beneficial for short lead times like Istanbul. The time series modelling is based only on the observations at a single site close to the epicenter and no additional geological information is required. The evaluations indicate that the model is able to adequately estimate the real-time ground-motion time series and their spectral content for frequency ranges that are most relevant for earthquake engineering applications.

ANALYSIS of the Mw 5.8 SILIVRI EARTHQUAKE GROUND MOTIONS: EVIDENCE of SYSTEMATIC AZIMUTHAL VARIATIONS ASSOCIATED with DIRECTIVITY EFFECTS

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ABSTRACT

The main Marmara fault (MMF) in Western Türkiye extends for 150 km through the Sea of Marmara and forms the only portion of the North Anatolian fault zone that has not ruptured in a large event (Mw > 7) for the last 250 yr. Accordingly, this portion is potentially a major source contributing to the seismic hazard of the Istanbul region. On 26 September 2019, a sequence of moderate-sized events started along the MMF only 20 km south of Istanbul and were widely felt by the population. The largest three events, 26 September Mw 5.8 (10:59 UTC), 26 September 2019 Mw 4.1 (11:26 UTC), and 20 January 2020 Mw 4.7 were recorded by numerous strong-motion seismic stations and the resulting ground motions were compared to the predicted means resulting from a set of the most recent ground-motion prediction equations (GMPEs). The estimated residuals were used to investigate the spatial variation of ground motion across the Marmara region. Our results show a strong azimuthal trend in ground-motion residuals, which might indicate systematically repeating directivity effects toward the eastern Marmara region.

SESSION 3: 23rd Anniversary of the 17 August 1999 Marmara Earthquake & Studies on NAFZ

LESSONS LEARNT from 17 AUGUST 1999 MARMARA EARTHQUAKE: HOW TÜRKİYE PROGRESSED on EARTHQUAKE RISK MANAGEMENT

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ABSTRACT

Our world; is living in an age where the number and effects of natural hazards and man-made disasters are increasing. Since 1980, the number of natural hazards has quadrupled. In addition to events such as earthquakes, and excessive or insufficient rains; existing hazards and risks such as rapid and irregular urbanization, population growth, climate change, and infectious diseases pose a threat to societies living in a safe environment.

Türkiye locates in a highly dangerous geography that is heavily affected by disasters due to its geological and geographical structure and climatic characteristics. However, today, together with the effects of climate change, we see events such as sudden and strong floods, tornadoes that reach the land and tropical storms. A natural event that can turn into a disaster in our country can happen at any time. Earthquakes are, of course, the most important ones.

Türkiye is a country that has developed its system by learning from bad experiences in the past. However, the change was always the result of a great disaster and pain. It was like this in 1939 and it was like that in the 1999 Marmara Earthquakes. The response to the 17 August 1999 earthquake was carried out by teams with insufficient equipment, training and personnel. In the first moments, communication and transportation could not be provided, a crisis management centre could not be established, shelter and hot food could not be provided, and security could not be established. Even on the 50th day, the number of people who lost their lives could not be determined. The provision of education and health services could not begin. Damage assessment of public buildings was incomplete. AFAD was established in 2009, in place of 3 institutions dealing with disasters, from the experience of the 1999 earthquakes, to take proactive measures and to break this cycle, so that the “incident” does not turn into a disaster.

Since AFAD was founded, Türkiye's focus on disaster management has been risk management. AFAD implements risk-oriented integrated disaster management in Türkiye, concentrating most of its energy and work on pre-disaster prevention, risk reduction and preparedness.

As Türkiye's disaster management agency, AFAD; plans, directs, supports and coordinates disaster management activities. With the Türkiye Disaster Management System, it has built, it works to prevent disasters and emergencies before they occur, and to reduce risks and damages. It intervenes by providing effective coordination during disasters and quickly completes post-disaster recovery works in integrity. It maintains and updates the system together with the upper plans such as the Türkiye Disaster Risk Reduction Plan, National Earthquake Strategy and Action Plan, Türkiye Disaster Response Plan and local plans such as the Provincial Disaster Risk Reduction Plans and Provincial Disaster Response Plans, its physical infrastructure, teams, vehicle fleet, software and communication systems, technological equipment and logistics organization. This system also includes the coordination function covering

public institutions, the private sector and NGOs. In other words, it organizes and allows them to act as one body.

At the same time, AFAD reached 56 million citizens in 2021 within the scope of the awareness campaign it started, and it aims to carry out more than 54 thousand exercises in 2022 within the scope of the exercise campaign. On the other hand, AFAD, which has approximately 500 thousand AFAD Volunteers, continues to strengthen its community-based disaster management.

AFAD will continue to increase Türkiye's disaster resilience with its 81 provincial directorates, 11 search and rescue unit directorates and approximately 6 thousand personnel.

ESTIMATING EARTHQUAKE SOURCE PARAMETERS in the SEA of MARMARA

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ABSTRACT

Earthquake source parameters are of great significance for both understanding earthquake physics and evaluating seismic hazard. One of the fundamental source parameters, stress drop, plays a key role in impacting the frequency content of ground motion, which is of significance for the seismic hazard assessment, especially near the densely populated region like Istanbul. Utilizing the ground and borehole seismic recordings, we estimate the earthquake source parameters for seismicity in the Sea of Marmara. Using a spectra fitting approach, we constrain the quality factor, corner frequency, and seismic moment, and calculate the earthquake stress drop using a Brune source model for 1244 earthquakes in the Marmara region during 2006-2020. Most of the stress drop range from 1 to 10 MPa, with a median value of 2.6 MPa. We observe spatial variations of stress drop values along the Main Marmara Fault; earthquakes in the east of the Main Marmara Fault near Istanbul show relatively larger stress drop values, which is corresponding to the locked section on the fault. In the creeping section, the stress drop values of repeating earthquakes show similar values compared to the surrounding regular earthquakes. Constraining earthquake source parameters would contribute to our knowledge of source scaling and earthquake characterization, and provide information on seismic hazard.

CHARACTERISTICS of SOUTH MARMARA ACTIVE FAULT SEGMENTS of the NORTH ANATOLIAN FAULT

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ABSTRACT

The "Updating the Active Fault Map of Türkiye" study conducted by the General Directorate of Mineral Research and Exploration (MTA) was completed in 2011 and the results of the study were published in 2013. In order to reduce earthquake hazards, long and short term slip rate, earthquake recurrence interval, depth and width of the rupture zone, the maximum amount of displacement that can occur in a single earthquake, as well as the earthquake history of the active faults should be revealed. "Turkish Paleoseismology Research Project (TURKPAP)" was initiated by the MTA in 2012 within the scope of the National Earthquake Strategy and Action Plan (UDSEP-2023) in line with the aim of reducing earthquake hazards. This project aimed at investigation of the paleoseismological behaviour of the active faults in the mainland of Türkiye by utilizing the information on the "Active Fault Map of Türkiye".
This study evaluates the findings obtained by the field studies that carried out in Southern Marmara in 2013 and 2014 within the scope of TURKPAP. The importance of Southern Marmara comes from the abundance of active faults as well as the dense population and industrialization. In the study area, faults developed by strike-slip mechanism are generally accompanied by reverse and normal components. Of these, the Yenice-Gönen fault (67-km-long), which consists of six sub-segments, and the Sarıköy fault (66-km-long), which is divided into two main segments with a distinct pull-apart structure, are pure right-lateral strike-slip. Bekten fault (19-km-long), which is semi-parallel to these faults, is a transfer structure. The normal component of the Manyas fault zone (40-km-long) observed as a splay of the Yenice-Gönen fault, which is a dominant right-lateral strike-slip fault. The Pazarköy fault (42-km-long), which is divided into two sub-segments by a compressional structure, shows a similar fault character with the Yenice-Gönen Fault. The Gündoğan fault (24-km-long) is located at the eastern end of the Sarıköy fault, stepping to the right. The reverse component predominates on the Sinekçi (26-km-long), Orhaneli (30-km-long), Mustafakemalpaşa (47-km-long), Ulubat (44-km-long) and Evciler (46-km-long) faults. Earthquakes that caused surface ruptures during the instrumental period in the research area occurred on the Yenice-Gönen fault in 1953 and Manyas fault in 1964.

Paleoseismological trenches were dug on these fault segments. Earthquakes that caused surface rupture in the Quaternary period on the trench walls were determined in the light of sedimentological and structural records and supported by geochronological dating methods. It is evident that five events occurred on the Yenice-Gönen fault in the Late Pleistocene-Holocene period before 1953 earthquake, and three events occurred on the Manyas Fault Zone including the 1964 earthquake. It has been clearly observed that Sarıköy and Bekten faults caused at least three earthquakes in the Holocene period. There are geological records of two different earthquakes on Orhaneli and Mustafakemalpaşa faults through Holocene with a reverse faulting mechanism with a strike-slip component. At least three earthquakes occurred on the Ulubat and Gündoğan faults with similar mechanisms and time intervals. It has been

documented that the Evciler, Pazarköy and Sinekçi faults are responsible of at least an earthquake caused one surface rupture in the Holocene period.

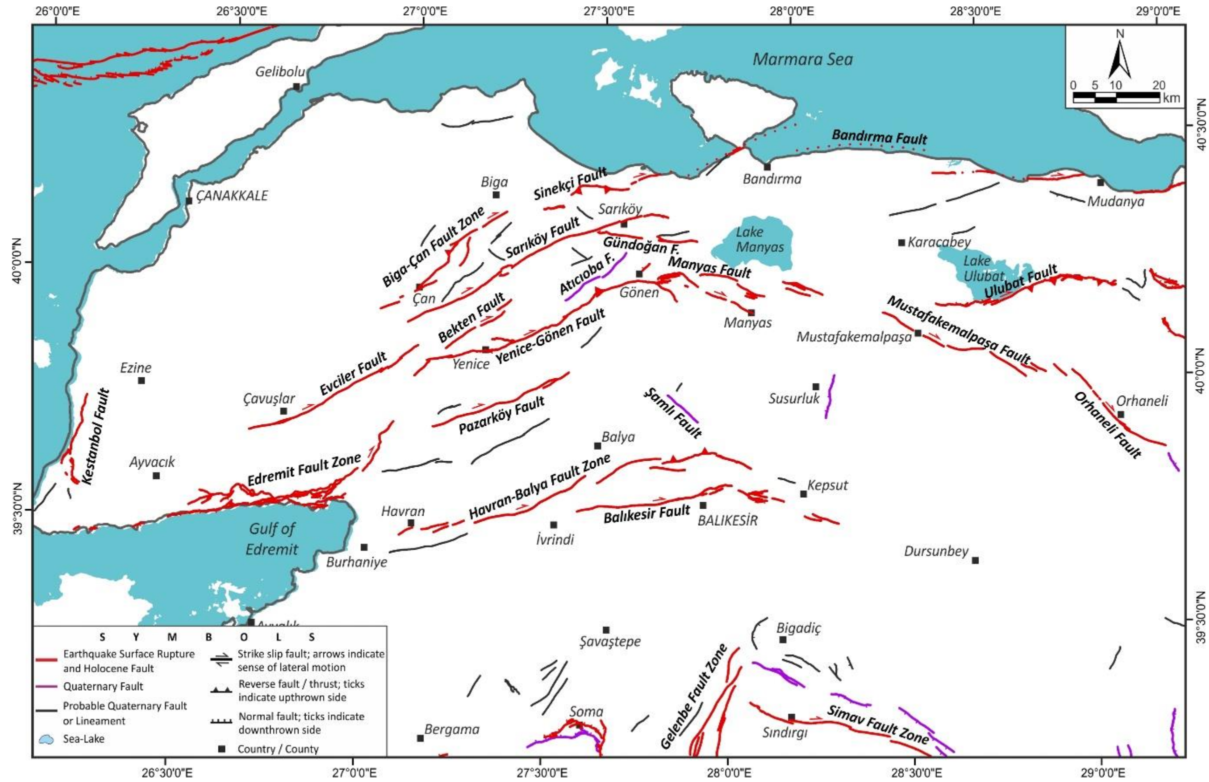

Figure 1. Map showing active faults of the Southern Marmara region
Reference: Simplified from Emre et al., 2013

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EARTHQUAKE FAULTING COMPLEXITY in the SEA of MARMARA: Mw 5.7 SILIVRI EARTHQUAKE

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ABSTRACT

The Sea of Marmara, in northwestern Türkiye, is surrounded by densely populated towns and highly advanced industrial facilities. Additionally, it hosts the Main Marmara Fault along which major earthquakes are generated throughout history. On 26 September 2019, a Mw5.7 earthquake occurred offshore Silivri (Istanbul) stimulating the discussions on a future major earthquake. Seismic agencies reported focal mechanisms indicating departures from shear faulting with a dominant thrust faulting component. In this study, we demonstrate that the mainshock consisted of two distinct subevents (fault segments of different orientation) by analyzing non-DC mechanisms, inverting waveforms into multiple DC point models. We found out that the Silivri earthquake has consisted of two shear faulting events; the first one starting as strike-slip faulting in accordance with the character of the Main Marmara Fault and continuing as a thrust faulting event. Further details on this study can be found in Turhan and Acarel et al., 2022, SRL (accepted).

SPATIO-TEMPORAL EVOLUTION and STRESS PERTURBATION of the SEPTEMBER 2019 SİLİVRİ EARTHQUAKES on the SEMI-REALISTIC 3D FAULT SURFACES ALONG the NORTHERN BRANCH of the NAFZ

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ABSTRACT

The northern branch of the North Anatolian Fault Zone in the Marmara Sea has been a subject of scientific research and has been rigorously studied for the last couple of decades. Numerous studies have been conducted to study in detail and assess this branch's seismic potential since the previous two destructive known earthquakes occurred in both east and west extremities of the Marmara Sea in 1912 and 1999, respectively. Additionally, based on the historical earthquake data and available fault patterns between these two events that took place in the 20th century, the fault beneath the central section of the Marmara Sea was defined as a seismic gap that has not generated a destructive earthquake since the 18th century.

The largest earthquake (M5.8) since the 1999 Izmit earthquake (M7+) was recorded on September 24, 2019, at offshore Silivri town, located in the west of Istanbul. The 2019 Silivri events occurred north of the main fault segment, which generated the last devastating earthquake in 1766. Despite the relentless efforts to put into research the faults beneath the Marmara Sea, it is seen that the currently used fault maps do not have sufficient resolution to explain the fault geometries that caused recent earthquakes. To identify the causative fault(s) of recent earthquakes and to assess the effects on the main fault segment, we conducted research based on seismic reflection and seismicity data. The seismic reflection data consists of profiles that penetrate up to 0.25–10 seconds, and the total seismic profile length is over 650 km for the study area (28–28.4 E and 40.775–40.925 N). The seismicity data consist of ~200 M1.3+ earthquakes that occurred in 2019. The research was executed by following these steps; i) interpretation of the seismic reflection sections and high-resolution bathymetric mosaics (identification of the faults surfaces), ii) domain conversion of the mapped fault surfaces by using available 1D crustal models, iii) generation of 1x1 km patched semi-realistic fault surfaces in 3D, iv) relocation of the hypocenters, v) determination of the kinematic features of the fault surfaces and correlation between current stress regime vi) assessment of the seismicity with 3D fault surfaces, vii) Coulomb-stress modeling on 3D fault surfaces in response to M4+ earthquakes.

One of the outcomes of this research is that a fault system had been identified in the north of the main fault zone from seismic reflection profiles, and the 2019 Silivri earthquakes occurred within this fault system between three different fault surfaces. The M5.8 earthquake occurred NE–SW–striking 70SW–dipping dextral oblique–thrust fault. Moreover, the earthquakes M4+ have caused a total 3 bars stress increase in the main fault zone, corresponding to 10% of the current stress budget of the main fault zone.

SPATIO-TEMPORAL VARIATIONS of SEISMIC COUPLING ALONG the WESTERN SEGMENT of the NORTH ANATOLIAN FAULT, TÜRKİYE

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ABSTRACT

The Marmara Sea Fault forms a major segment of the North Anatolian Fault just south of Istanbul. It hosts a seismic gap causing high seismic hazard and associated risk for the Istanbul metropolitan area. Here we estimate seismic coupling i.e. the ratio of seismic strain rate to tectonic strain rate. This ratio indicates the fraction of total strain accumulated per time that is released seismically identifying fault segments that represent a larger seismic threat. We estimated seismic coupling along distinct portions of the Marmara region, and compared the results from a historical seismicity catalog and a detailed instrumental catalog. We found that seismic strain rates from the historical catalog are of the same order than the geodetic strain rates. In contrast, coupling estimates based on seismic data from the instrumental catalog result in estimates up to three orders of magnitude smaller pointing towards significant fluctuations during the seismic cycle. For example, we observed significant variation of seismic coupling before and after the 1999 M>7 Izmit and Düzce earthquakes. Finally, the comparison of the temporal evolution of the seismic strain rates to the Izmit and Düzce postseismic deformation showed that the first seems driven by the later.

SESSION 4: Disaster Management in the Marmara Region

DEVELOPMENT of EARTHQUAKE EARLY WARNING SYSTEM: BURSA CASE STUDY

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ABSTRACT

Türkiye is located on the Alpine-Himalayan active tectonic zone, which is very active in terms of earthquakes. The North Anatolian Fault Zone (NAFZ) on this zone has been producing destructive and damaging earthquakes for thousands of years.

Bursa province is one of our provinces with a high earthquake risk as it is located on this active zone and has faced many destructive earthquakes until now. After the August 17, 1999 Kocaeli earthquake, some geoscientists agreed that the next major earthquake would be on active faults located at the southwest end of the 1999 earthquake rupture.

Bursa province and its vicinity are home to more than 4 million people and many heavy industry and historical buildings. One of the most important ways to reduce earthquake damage is the establishment of an earthquake early warning system. The purpose of such a system is to detect the location and magnitude of the earthquake by making use of the primary waves of the earthquake, which is quickly detected in the event of a damaging earthquake, and by creating a warning signal before the damaging secondary waves reach the settlements, closing the electricity-natural gas valves and slowing down/stopping transportation vehicles such as rail systems to prevent secondary disasters that may occur.

Within the scope of the project, an early warning signal was obtained by combining the seismometers and accelerometers of Kocaeli University Earth and Space Sciences Research Center, Bursagaz and Disaster and Emergency Management Authority (AFAD), which are installed in the region, under a single software. Within the scope of this project, ElarmS (EPIC), an earthquake early warning software that is widely used in the world, was used and adapted for our country.

WHY DO WE HAVE the NORTH ANATOLIAN FAULT?

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ABSTRACT

The North Anatolian Fault (NAF) is a major right-lateral strike-slip fault that starts from the Karlıova Junction, runs parallel to the Black Sea Coast, crosses the Sea of Marmara and extends towards Greece within the Aegean Sea with a length of 1600 km (Figure 1). It splits into three branches to the west of the 31°E longitude exhibiting horsetail structure. The North Anatolian and the East Anatolian Faults (EAF) form the tectonic boundaries of the Anatolian Block. The Anatolian Block escapes westward with a counter-clockwise rotation and with a maximum slip rate of 24 ± 1 mm/yr. along the NAF (McClusky et al., 2000). The age of the NAF is about 11 my. (Barka and Gülen, 1988; Şengör et al., 2004).

The origin of the NAF was attempted to be explained by 1- The continental collision between the Arabian and the Eurasian plates along the Bitlis-Zagros Suture Zone and the continued continental convergence, 2- Slab roll-back along the Hellenic Trench, 3- The gravitational body forces due to the elevation difference between the west and east Anatolia. Although all these three explanations have somewhat contributed to the formation of the NAF, a very important and a major cause was somehow overlooked. That is presence of the Black Sea oceanic lithosphere which is situated in the north.

The Black Sea is a trapped oceanic basin between the Eurasian Plate and the Anatolia. Under the 10-15 km. sedimentary cover, ocenic crust is mapped by seismic reflection studies (see Figure1, Finetti et al., 1988; Nikishin et al., 2015).

The NAF runs subparallel to the Black Sea coast and together with the Strandja (SF) and the North East Anatolian Faults (NEAF), they surround the southern Black Sea margin. Based on the measured GPS velocities with respect to fixed Eurasia, the continental margin along the southern Black Sea coast (north of the NAF) is decoupled from the westward moving Anatolian Block along the NAF. This suggests that about 100 km. wide strip of the Black Sea continental margin is overthrust northwards onto the Black Sea oceanic lithosphere, because the trapped, rigid Black Sea oceanic lithosphere cannot deform easily (Gülen, 1999; Gülen et al., 2002).

The Black Sea oceanic lithosphere was imaged by seismic tomographic studies. Gülen and Kuleli (1995) obtained the first glimpse of it. A steeply southward dipping high velocity zone in the uppermost mantle exists beneath the northern Marmara Sea and they interpreted it as the passive consumption of the Black Sea oceanic lithosphere. The presence of the current, passive southward subduction of the Black Sea oceanic lithosphere was subsequently confirmed by the seismic tomographic studies of Zor (2008), Papaleo et al.(2017), and Kaban et al.(2018) along the entire southern Black Sea margin.

In a global survey of major intracontinental strike-slip faults, including the NAF, Molnar and Dayem (2010) concluded that most of the major intracontinental strike-slip faults are situated adjacent to relatively strong regions such as oceanic lithosphere or Precambrian shields. They also suggested that such faults form adjacent to discontinuities in strength, because strain in a continuous medium must consantrate near such strong regions.

Thus, as suggested by Gülen(1999) and Gülen et al., (2002) the geometry and the kinematics of the North Anatolian Fault (NAF), the North East Anatolian (NEAF), and the Strandja Faults (SF) and the main reason why they were formed can be explained by the lithospheric strength contrast between the high strength Black Sea oceanic lithosphere in the north, and the relatively easy deforming continental lithosphere in the south, under roughly north-south compression and oblique convergence.

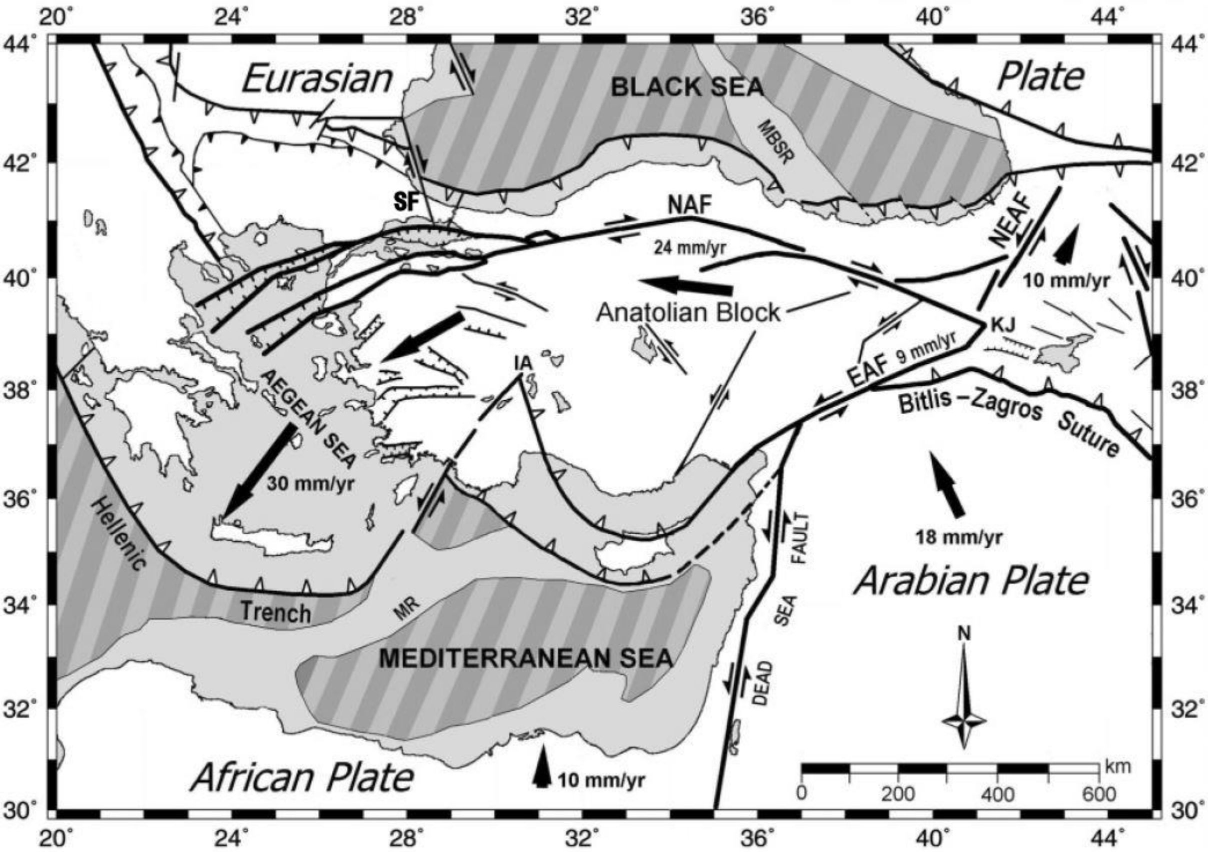

Figure 1. Simplified tectonic map of the eastern Mediterranean region (modified after Gülen et al., 2002). Plate/block motions are shown with thick arrows. Oceanic crusts are indicated with a striped pattern. NAF:North Anatolian Fault, EAF:East Anatolian Fault, NEAF:North East Anatolian Fault, SF:Strandja Fault, KJ:Karlıova Junction, IA:Isparta Angle.

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AFAD-RED: RAPID EARTHQUAKE DAMAGE and LOSS ESTIMATION SYSTEM

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ABSTRACT

Following the establishment of AFAD in 2009, within the framework of Public-Academic collaboration, a Preliminary Damage and Loss Estimation Software (AFAD-RED) was developed. AFAD-RED is a national software developed by the AFAD Earthquake Department in collaboration with scientists, with the aim of estimating the potential losses of an earthquake occurring in Türkiye and also for earthquake scenarios. The main outputs of AFAD-RED are structural damage, the number of casualties, the need for temporary shelter service, estimated seismic intensity, peak ground acceleration (PGA), peak ground velocity (PGV) maps, servicaability of critical structures and infrastructures and more. AFAD-RED software contributes to the mitigation (preparation of national and local mitigation plans), preparedness (capacity development and needs analysis, Provincial Disaster Risk Reduction Plan - İRAP) and response (national and local response plans) phases of the disaster management cycle. The software is also compatible with National Disaster Management Decision Support System of Türkiye.

AFAD-RED uses automatically the first earthquake parameters calculated by the National Seismological Observation Network (Magnitude, depth, coordinates) and estimates the first loss and damage data in real time. The outputs of AFAD-RED isalso used on scenario-based disaster risk management applications especially on planning for disaster preparedness drills, mitigation plans, etc. Provincial AFAD directorates can easily integrate AFAD-RED outputs to their projects from Turkish National Disaster Decision Support System Portal called AYDES.

AFAD-RED uses several databases of different institutions such as administrative information (district boundaries), population information, building information (number of buildings and more), information on geology (active faults), USGS Vs30 speed map data, and Vs30 velocity information from AFAD acceleration stations. Working principles of the AFAD-RED is given below.

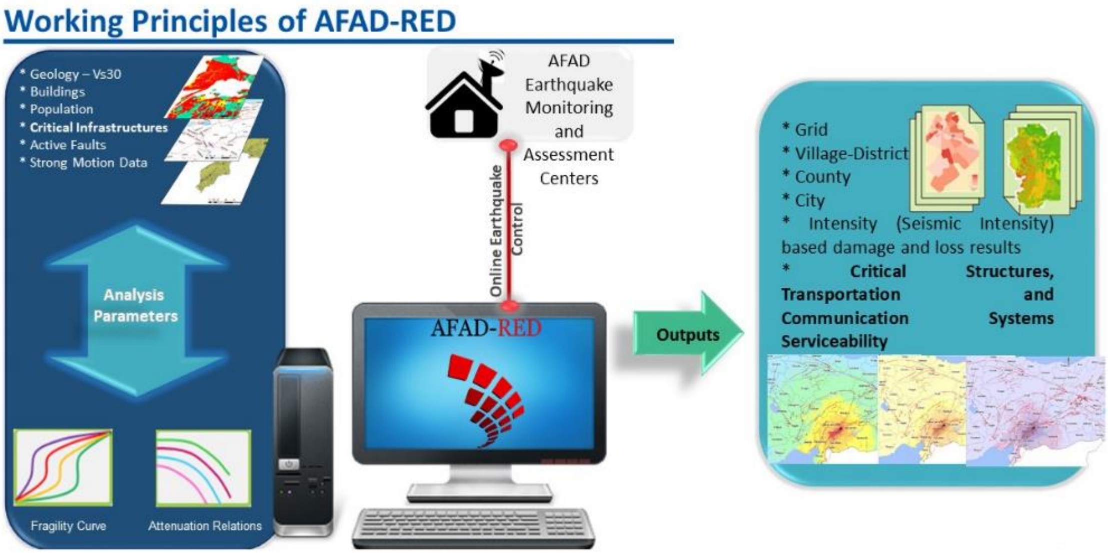

Figure 1. Working principles of AFAD-RED

TSUNAMIS in the MARMARA REGION

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ABSTRACT

According to the historical documents, more than 30 tsunami events have impacted the coasts of the Marmara Sea in the last two millenniums (Altınok et al., 2011; IMM-METU, 2018 and IMM-METU, 2019). 120/128, 24.08.358, 06.11.447, 14.12.557, 10.989, 12.02.1332, 14.10.1344, 10.09.1509, 05.04.1646, 22.05.1766, 10.07.1894, 17.08.1999 are the dates of major tsunamis in Marmara Region selected. After 17 August 1999 Kocaeli Earthquake, the experts have indicated the possibility of a large magnitude (at least M=7.2) earthquake to occur in the Marmara Region. There are numerous possibilities of tsunami generation mechanisms in the region, which requires proper investigation and analysis for reliable estimation of the tsunamigenic fault characteristics and other tsunamigenic non-seismic mechanisms.

In order to evaluate tsunami risk properly from the perspectives of hazard assessment and vulnerability analysis, the collection and processing of high-resolution data and using them in the tsunami numerical modeling are necessary. In this regard, in Marmara region, numerous marine surveys have been performed to collect the data and interpret for identification of fault characteristics (Yaltırak, 2002; Pichon et al., 2003; Armijo et al., 2005; SATREPS-MARDiM, 2018; Bulut et al., 2019). On the other hand, Géli, Henry, Çağatay, (2021) reviewed 20 years Turkish–French collaboration in marine geoscience research in the Sea of Marmara. Parallel to tsunami source characterizations, different numerical studies have been conveyed to investigate the tsunami generation, propagation and coastal amplification in the Marmara Sea (Yalciner et al., 1999, Yalciner, Altinok, Synolakis, 2000; Yalciner et al., 2002; Hebert et al. 2005; Latcharote et al., 2016). Furthermore, a complete project on tsunami modeling, vulnerability and hazard analysis for Marmara coast of Istanbul Metropolitan Municipality has been performed with the illustrative outcomes of tsunami risk maps (IMM-METU, 2018) together with structural and non-structural solutions. Later, tsunami evacuation maps and tsunami action plan for 17 coastal districts of Istanbul Metropolitan area bordering Marmara Sea are developed and publicized (IMM-METU, 2019).

Critical structures such as Haydarpaşa, Ambarlı, Tuzla, Yenikapı ports and critical areas such as Yenikapı and Maltepe coastal reclaimed areas, entrances of Metro stations such as Marmaray Kazlıçeşme, Yenikapı, Sirkeci, Üsküdar, Ayrılık Çeşmesi stations are analyzed in more detail to produce possible measures to reduce the tsunami effects.

Overall, it is believed that the data from marine surveys, outputs of the studies will help increasing preparedness of the megacity İstanbul against possible tsunamis in the Marmara Sea and enable tangible actions to foster resiliency of the city not only Istanbul but also other coastal communities near Marmara Sea and also in other coastal locations near the seas surrounding Türkiye.

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ISTANBUL is GETTING READY for the BIG ONE: REINFORCEMENT ACTIVITIES of SCHOOLS and HOSPITALS STUDIES of ISMEP

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ABSTRACT

Istanbul is the most vulnerable city in Türkiye given its seismic-prone location on the North Anatolian Fault, and its high population and commercial/industrial densities. The JICA study (JICA and IMM, 2002) estimates that an event similar to the Marmara earthquake (1999) could result in up to 87,000 fatalities, 135,000 injuries and heavy damage to 350,000 public and private buildings. In order to prepare the city against a possible earthquake, Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP) has been established under the roof of Governorship of Istanbul and conducted by Istanbul Project Coordination Unit (IPKB). ISMEP, which has started its studies in 2006 with the budget of 310 million Euros funded by World Bank, has now reached the budget of 2.4 billion Euros with the additional funds provided from World Bank (WB), European Investment Bank (EIB), Council of Europe Development Bank (CEB), Islamic Development Bank (IDB), German Development Bank (KfW), Asian Infrastructure Investment Bank (AIIB) and ECO Trade and Development Bank (ETDB).
The Project was designed by a national and international team of specialists as one of the largest and most comprehensive disaster preparedness project in the world while the 1999 Marmara Earthquake Emergency Reconstruction Project (MEER) was being implemented under Turkish Prime Ministry. Different from the previous post-disaster operations, ISMEP was based on a proactive approach by combining disaster emergency preparedness and disaster risk reduction activities. The implementation focus was at sub-national level in Istanbul scale which exhibits the highest earthquake risk, implying a significant impact on the whole region. Since all disasters are locally experienced, the fundamental utility of any emergency management system depends upon the ability, organization, skills and commitment of a community-its government officials, private industry and NGOs to prepare for emergency situations. Therefore, ISMEP takes into account the principle that efforts should be locally based and managed consistent with national/provincial programs and regulations.

The project is comprised of three technical components plus a fourth one providing the management service and function for the project. These components were:

Component A: Enhancing Emergency Preparedness
The component enhanced the effectiveness and capacity of the provincial public institutions and organizations in Istanbul to prepare for, respond to and recover from significant emergencies and disasters, especially those arising from earthquakes by improving emergency communications systems, establishing an emergency management information system, enhancing the institutional capacity of Istanbul AFAD, upgrading the emergency response capacity of first responder public agencies and raising public awareness and conducting disaster preparedness trainings.
During the last decade, ISMEP has helped improving capacity for disaster and emergency management public agencies at the provincial level through building new command, control and coordination centers, providing equipment and vehicles for first responder public agencies and Istanbul AFAD emergency communication and information management systems, training search and rescue units and enabling

Istanbul to be the first in Türkiye receiving INSARAG '"Heavy Search and Rescue" certificate showing that they could operate under UN framework in case of a disaster globally.

Component B: Seismic Risk Mitigation for Public Facilities
The component aimed to support a well-designed risk reduction program to minimize human and physical losses that would be suffered in the event of an earthquake by targeting critical public facilities in order to save lives and ensure their continued functioning by retrofitting or reconstruction of priority public facilities such as hospitals, polyclinics, schools, administrative buildings, dormitories and social service buildings where residential buildings were kept outside ISMEP's scope and undertaking risk assessments for cultural heritage buildings. In connection with the latter risk assessments activity, an inventory of cultural heritage buildings was planned to be developed under the jurisdiction of Ministry of Culture and Tourism together with retrofitting designs.

- ISMEP has reduced vulnerability of public buildings in Istanbul to earthquakes through retrofitting or reconstructing 1332 school buildings (1134 campuses), 18 hospital campuses (54 buildings), 13 dormitory campuses (38 buildings), and 141 other high priority public buildings.

- In total, with the entire budget available, ISMEP has retrofitted and /or reconstructed 1565 public buildings in Istanbul to be safer which serves for about 2 million direct beneficiaries.

Component C: Enforcement of Building Codes
The component supported innovative measures on a pilot basis for monitoring and improvement of building codes and land use plans enforcement through data collection on land use and building inventory; enhancement of the technical and institutional capacity of the pilot municipalities, data digitization and computer equipment to help district municipalities render the process of issuing building permits more efficient and transparent and training/awareness raising for municipal authorities and local communities on seismic risks and the need to take this into account in land use planning and construction and voluntary training of engineers in new legislation involving retrofitting of buildings.
Based on the engineering experience, the project has developed guidelines for better implementation of the Earthquake Code. The project also supported developing a GIS based inventory of cultural heritage buildings and prepared retrofitting and renovation designs for three major cultural heritage assets. Working with two pilot municipalities of Pendik and Bagcilar; ISMEP has demonstrated better enforcement of building codes through improving efficiency and transparency in land use planning and building permit issuance processes, establishing help desks and hot lines.

Component D: Project Management
This component supported the Istanbul Governorship to implement the project efficiently and transparently, and build institutional capacity to sustain the seismic risk mitigation program beyond project life. The project was implemented within the Istanbul provincial boundaries.

Implementation records on health facilities under ISMEP
Kartal Dr. Lütfi Kırdar, Göztepe Prof. Dr. Süleyman Yalçın and Okmeydanı Prof. Dr. Cemil Taşcıoğlu City Hospitals, which were equipped with base isolators for the continuity of operations during an earthquake were opened and also serve as pandemic hospitals. In order to ensure reconstruction of the new hospitals in a single stage, a provisional buildings was constructed to relocate existing hospital's emergency and policlinic departments. Thus, the new hospitals were constructed to provide health services to its patients with their bed capacities according to international quality and comfort standards, without interrupting functionality of the existing hospital.

Okmeydanı Training and Research Hospital, now known as Prof. Dr. Cemil Taşcıoğlu City Hospital was reconstructed according to smart and green building concept features seismic isolator technology. New Okmeydanı Training and Research Hospital is planned to be reconstructed in 2 phases. Phase I started admitting patients by 30 March 2020. The project will proceed with reconstruction operations under Phase II following demolition of the old hospital building which is not resistant to earthquake. The hospital, where 1.5 million policlinic patients and 700K emergency patients will receive treatment and 45K operations will be performed on a yearly basis, was reconstructed using seismic isolator technology. 385 seismic isolators will absorb 90 percent of the load during an earthquake, allowing the building to move slightly or in a well-balanced manner. Thus the hospital will be able to continue providing service with full capacity during and after an earthquake. The number of seismic isolators used in the hospital will be 503 following completion of Phase II. Having started admitting patients, Okmeydanı Training and Research Hospital's Phase I has a service area of 180K square meters. Following completion of the remaining 20 percent part, the hospital will provide service on an area of 259K square meters. Though Phase I of the project was reconstructed to have 750 beds, currently only 600 beds, 81 of which are intensive care beds, can be used due to Covid-19 outbreak.

Reconstructed under the Istanbul Seismic Risk Mitigation and Emergency Preparedness Project (ISMEP) Kartal Dr. Lütfi Kırdar City Hospital was officially opened in July 2020. Consisting of 5 blocks with a covered area of 303K square meters, the hospital has 193 policlinics with 1.105-bed capacity, providing a comfortable environment both for patients and persons accompanying them with its car park, green spaces, and other amenities. Designed to be fully earthquake-resistant, the hospital building has total 855 seismic isolators allowing the hospital to continue providing uninterrupted service during a probable earthquake or disaster.

One of the top-ranked hospitals of Istanbul in terms of the number of patients admitted, Göztepe Training and Research Hospital now known as Prof. Dr. Süleyman Yalçın City Hospital has been planned to be completed in total 2 phases. Total 385 seismic isolators have been used in the first phase which has already been completed and put into the service. With a covered area of 250K square meters and 1188-quality bed capacity, the hospital has been designed as an energy-efficient and environmentally-friendly building, providing uninterrupted service during a probable earthquake or disaster. Attracting attention with its energy-efficient and environmentally-friendly design, Göztepe City Hospital, designed in accordance with the green building concept, is a candidate for the Leed Gold Certificate.

Last but not least, one of the biggest and most important healthcare complexes in the Asian Side of Istanbul Marmara University Prof. Dr. Asaf Ataseven Hospital is renowned as the world's biggest hospital retrofitted against earthquake under the Istanbul Seismic Risk Mitigation and Emergency Preparedness Project. The hospital has total 827 seismic isolators to provide uninterrupted service even during an earthquake. Having a covered area of 113K square meters, the hospital is designed to provide service with 28 operating rooms and total 535 beds consisting of 155 policlinic beds, 60 intensive care beds, and 304 single-bed rooms. In April, the hospital was partially opened as a specific pandemic centre for fighting the novel coronavirus (Covid-19), providing service to Covid-19 patients.

Overall, ISMEP has been an exemplary showcase of capacity building for emergency and disaster risk management as well as physical risk reduction.

Social Aspects

İSMEP has carried out a proactive training and awareness raising strategy through developing training modules which then informed national programs as well as children friendly materials, board games, computer games and even a theatre play. ISMEP has provided regular information and social guidance to project beneficiaries, especially to those who occupy or use buildings to be retrofitted or reconstructed.

Public awareness campaigns were funded to raise awareness in the public about preparedness for seismic risk and risk mitigation measures, as well as the training of students, community volunteers and private sector. As observed in other examples of good practices in the world support for voluntary efforts constitute a very important aspect within that these activities have included in the scope of ISMEP where accomplishment included. as of 1st of September, training activities and campaigns of the project reached to 1, 6 million beneficiaries.

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SESSION 5: Geomechanical Models of the Crust and Lithosphere

SEISMIC VELOCITY CONTRAST on the GANOS SEGMENT of the NORTH ANATOLIAN FAULT ZONE

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ABSTRACT

The 9 August 1912 Mürefte earthquake (M7.4) ruptured a section of the North Anatolian Fault approximately 140 km long, starting from the Gulf of Saros and extending into the Sea of Marmara. The eastern part of the 1912 rupture shows quite different seismicity characteristics compared to the central and western parts. While the Marmara Sea section has a very active seismicity, the land and Saros section almost do not produce earthquakes. Besides, the Ganos Fault forms a bimaterial fault structure on the land. While the northern block of the Ganos Fault consists of older and harder units, the southern block consists of relatively younger and looser units. In order to investigate this different seismicity and fault structure of the Ganos Fault, seismic data were collected for 3 years with a small array (MONGAN) consisting of 40 seismometers. Numerous micro-earthquakes have been discovered that the national networks have not been able to detect. The findings indicate that the land part of the Ganos Fault is also quite in terms of micro-seismicity compared to the part in the Marmara Sea. The seismic wave phases arrive the stations on the northern block much earlier than those on the south, showing the different seismic velocity structure in the fault blocks (Figure 1). Noise tomography analyses obtained using the stations in the north and south blocks separately indicate a velocity contrast of approximately 27% between the two blocks up to 2km depth.

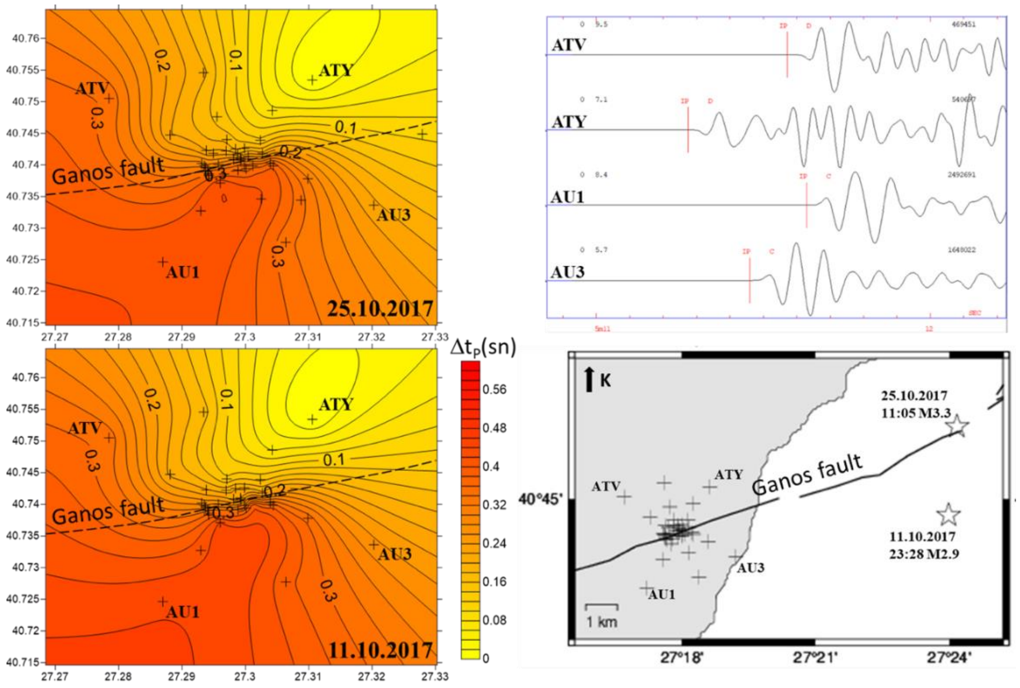

Figure 1. P wave delays (left) at the MONGAN array stations (right below) for two different earthquakes (stars).

KINEMATICS and MECHANICS of the NORTH ANATOLIAN FAULT in the SEA of MARMARA: COMBINING LAND and SEA DATA

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ABSTRACT

Defining accurate scenarios for future large earthquakes requires understanding the kinematics and mechanics of fault networks. This presentation emphasizes, with two examples of studies on the offshore part of the North Anatolian Fault system, the importance of combining monitoring from land and at sea. GPS data acquired around the Sea of Marmara led several studies to revisit the initial assumption that the northern strand of the North Anatolian Fault (Main Marmara Fault, MMF) was fully locked during the interseismic period, but uncertainties on the distribution of locking remain large because the fault lies 5-to-10 km from the coast. Conversely, seafloor acoustic ranging experiments indicated that the MMF is creeping at about ½ plate velocity at one location on its western segment but locked at another location on the central (Istanbul-Silivri) segment. A block model inversion (Özbey et al., 2021) obtained a distribution of locking compatible with on land and offshore constraints and confirms the contrasting behaviors of the western and central segments. In the other example, short (8 m long) piezometers set in the sedimented sea floor within the MMF damage zone recorded enigmatic pore pressure variations, apparently associated with two earthquakes (11/27/2013 Mw 4.8 local earthquake and 05/24/2014 Mw 6.9 Aegean Sea). Combining this observation with land GPS time series allowed to demonstrate these variations are related to an aseismic dilatant creep event lasting for the 6-months-interval between these two earthquakes (Sultan et al., 2022). This finding also shows that it may be possible to use arrays of free fall piezometers deployed in an offshore fault zone to monitor aseismic creep, as a complement to land based or seafloor geodetic methods.

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COMPOSITE PULL-APART STRUCTURE DEVELOPMENT and CROSS-BASIN FAULT GENERATION AROUND BURSA ALONG the SOUTHERN BRANCH of the NORTH ANATOLIAN FAULT ZONE

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ABSTRACT

This study presents a different fault pattern than the current active fault map of Türkiye in southern Marmara around Bursa. Our geological and geophysical findings indicate that composite pull-apart basins (Bursa-west, Bursa-east, and Yenişehir basins) around Bursa have a well-developed cross-basin fault (Kayapa-Yenişehir Fault-KYF) which is a part of the southern branch of North Anatolian Fault Zone (Seyitoğlu et al. 2021). The position of Bursa-west and Bursa-east composite pull-apart basins with the cross-basin fault of KYF give us a clue about the initial fault geometry of this composite pull-apart basin which is the "30° underlapping releasing step model" (Liu and Konietzky 2021). There is also an interesting similarity between the analog model of Rahe et al. (1998) and basin-bounding faults of the Bursa-west, Bursa-east, and Yenişehir pull-apart basins in which the cross-basin fault, the KYF is developed.

The KYF, determined by surface observations in four different locations and seismic reflection data in eleven different lines, cross-cuts the pull-apart basins and it has slip rates of a maximum 8.8 mm/year and a minimum 3.0 mm/year according to GPS-based block modeling. The KYF is the best candidate for the last destructive 1850 and 1855 earthquakes around Bursa. The damage distribution of these earthquakes (Coburn and Kuran 1985) allows speculation that the western part of the KYF was ruptured but the eastern part of KYF remains unruptured. The slip rates obtained from block modeling indicate that a 5.5 m displacement already accumulated and nearly 50 km long eastern KYF is capable to produce an earthquake with a magnitude of 7.0 or greater.

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3D LITHOSPHERIC STRUCTURE BELOW the MARMARA SEA from GRAVITY MODELLING: SEISMIC TOMOGRAPHY and THERMO-MECHANICAL MODELLING

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ABSTRACT

In this contribution we present the first results of the new project Deformation Mechanisms along the Main Marmara Fault (DEMMAF) funded by the German Science Foundation.

Previous lithospheric-scale gravity and thermo-mechanical modelling studies of the Marmara Sea region revealed that crustal heterogeneities have a strong influence on the present-day thermal state and the long-term crustal strength of the region. The rheological configuration of the crust and lithosphere likely influences the long-term seismic behavior of the Main Marmara Fault (MMF) and its along-strike mechanical segmentation. Therefore, constraining the 3D structure of the deeper crust and upper mantle below the Marmara Sea is crucial to better assess the mechanical stability of the MMF in the study area. While the 3D geometry of sedimentary basins below the Marmara Sea is relatively well-resolved and publicly available, the deep crustal structure is less well-constrained and several Moho models exist. In this study, we make use of the most recent tomography-based Moho models together with forward and inverse gravity modelling to constrain the deeper structure (e.g. upper to lower crust interface) of the Marmara Sea region. In our new 3D model, a crustal block corresponding to the Istanbul Zone geological unit is differentiated. This crustal block has a lower ratio of upper-to-lower crustal thickness and relatively higher crustal densities. In addition, a thermodynamic-based mineral-physics approach was used to convert tomographic shear velocities of the upper most mantle to temperatures and to derive the 1300 C isotherm, which we interpret as the Lithosphere Asthenosphere Boundary (LAB). This thermal LAB indicates a colder lithosphere beneath the central Marmara Sea and a hotter lithosphere beneath the eastern Marmara Sea. We then use our new 3D model and the tomography-derived thermal LAB as the basis for thermal and rheological modelling. The new numerical modelling results suggest that the depth of the 450 C isotherm (proxy of the brittle to ductile transition for an average crust) varies across the study area, being a few kilometers shallower in the eastern than in the central and western Marmara Sea. In addition, the rheological modelling suggests spatial variations of the long-term crustal strength and viscosity, especially between the Istanbul Zone crustal block and the rest of the study area.

The obtained bulk rheological configuration will be the basis for a new dynamic forward modelling approach where the links between the frictional properties of the fault and the long-term seismic behavior will be studied.

DECIPHERING ASEISMIC DEFORMATION ALONG SUBMARINE FAULT BRANCHES BELOW the EASTERN SEA of MARMARA (TÜRKİYE): INSIGHTS from SEISMICITY, STRAINMETER and GNSS DATA

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ABSTRACT

The recently observed slow transients in the Sea of Marmara are important to quantify the seismic hazard and risk for the greater Istanbul metropolitan region. In this study, we analyze and characterize a slow slip event that occurred in the Eastern Sea of Marmara in 2016. To characterize the temporal history and the location of this event, we combine for the first time in this region different types of geodetic data (strainmeters and GNSS stations) and seismicity. We propose two interpretations to explain the observations: either the slow event initiated on the western part of the Armutlu fault and then propagated approximately 40 km eastward, or it initiated on the western section of the Armutlu fault, and then jumped onto a perpendicular fault after propagating ca. 15 km. We deduce these interpretations from forward modeling of the strain and displacement data. In addition, our results also suggest that this slow event triggered seismicity on a neighboring perpendicular fault.

SESSION 6: Fault-zone Characterization Based on Novel Seismic Processing Techniques

REAL-TIME SEISMOGEODETIC EARTHQUAKE OBSERVATION STUDIES in TÜRKİYE: POTENTIAL and CURRENT PRACTICES

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ABSTRACT

In Türkiye, monitoring of earthquakes is realized via the velocity and acceleration waveforms obtained from seismometers. It is also possible to determine the earthquake parameters from GNSS observations. Furthermore, GNSS system provides higher sensitivity than seismometers at low frequencies and allows to determine high accuracy permanent displacements in ground base fixed system which cannot be obtained from seismometers.

We developed a Seismogeodetic Earthquake Analysis System (SIDAS) which consists of several modules for real-time retrival of data from individual GNSS stations and RTK Networks, real-time retrieval of accelerometer data from Seedlink Server, real-time retrival of IGS Ephemeris and IGS SSR data. Real-time data processing module which processes GNSS data streams, and main processing module which uses Kalman Filtering to combine GNSS and accelerometer data. The current capabilities of SIDAS are but not limited to : archiving time series in an Oracle/PostGreSQL Database, real-time generation of SG waveforms at sampling freq. of accelerometers at co-located sites through Kalman Filtering, fully multi-threaded implementation with virtually unlimited number of stations, magnitude scaling of seismogeodetic waveforms for 3s, 5s or whole waveform amplitudes which is useful for Earthquake Early Warning Systems, permanent offset calculation from seismogeodetic waveforms, finite source inversion of permanent offsets (Simulated Annealing + BFGS), suitable for real time operational usage (missing data detection, automatic reinitialition, connection resetting etc.), pooling third party corrections (real time satellite clocks and orbits) for bandwidth saving.

While SIDAS is fully functional, the work is still in progress of increasing the stations and spatial resolution, in particular free data acquisition from paid RTK Services still requires a lot of red-tape and negotiations and high computational power is needed in particular for verbose GNSS data. The spatial resolution of network is variable and is limited in many regions (~ 100 km). Nearby stations are needed for moderate size earthquakes.
In Türkiye, monitoring of earthquakes is realized via the velocity and acceleration waveforms obtained from seismometers. It is also possible to determine the earthquake parameters from GNSS observations. Furthermore, GNSS system provides higher sensitivity than seismometers at low frequencies and allows to determine high accuracy permanent displacements in ground base fixed system which cannot be obtained from seismometers.

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Filtering, fully multi-threaded implementation with virtually unlimited number of stations, magnitude scaling of seismogeodetic waveforms for 3s, 5s or whole waveform amplitudes which is useful for Earthquake Early Warning Systems, permanent offset calculation from seismogeodetic waveforms, finite source inversion of permanent offsets (Simulated Annealing + BFGS), suitable for real time operational usage (missing data detection, automatic reinitialition, connection resetting etc.), pooling third party corrections (real time satellite clocks and orbits) for bandwidth saving.

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SPATIAL and TEMPORAL DISTRIBUTION of ASEISMIC SLIP ALONG the CENTRAL NORTH ANATOLIAN FAULT

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ABSTRACT

The central North Anatolian Fault has been known to be slipping aseismically since at least the last large earthquake that ruptured this section in 1944. Following this Mw 7.3 earthquake, reports of offset structures such as railroad tracks and masonry walls pointed to an unusual activity of the shallow portion of the fault. Later geodetic measurements revealed extensive aseismic slip along a 50 to 70 km long section, although restricted to the shallower portion of the fault plane, from the surface down to a depth of about 6 km. The seismic activity in the area is not strong enough to explain the amount of slip observed along the fault, hence slip is mostly aseismic. Following early measurements from creepmeters in the 1980's, InSAR data and new creepmeter data revealed that slow slip events also occurred along this section of the fault. However, the full extent of the section has not been completely explored and the precise spatio-temporal evolution of slip at the surface remains to be described.

Here, we processed 6 years of Radar data acquired by the Sentinel 1 constellation (ESA) to derive a time series of surface displacement. We compute interferograms using the ISCE software (JPL/CalTech) and use a parameterized Kalman filter method to derive surface displacements. Our LOS velocity maps and time series confirm the presence of a 60 km-long aseismic section along the North Anatolian Fault with slip rates reaching 10 mm/yr, half of the expected plate rate at this position along the NAF. We then invert for the depth-distribution of slip along the fault plane and show that aseismic slip extends down to 6-8 km with rates up to 20 mm/yr. Below this aseismic slipping segment, we observe a 3-5 km-wide locked portion along the NAF and a shallow locking depth at about 10-12 km-depth. We observe 2 slow slip events, confirmed by creepmeter measurements, extending over 10 to 20 km along strike. These slow slip events are similar to the one described in 2013 and should extend over 4-5 km at depth. Total slip during these events reach up to 1 cm over a few days, suggesting accelerations up to 300 times the average slip rate. It is important to realize that, in between these events, the fault is locked and no slip is detected at the surface.

The whole aseismic section does not experience such slow events, as the easternmost section slips steadily with no detectable variations of slip rate. We note that the section that experiences slow slip events also shows significant vertical differential motion across the fault, up to 10 mm/yr, and corresponds to an area with significant subsidence (~5 mm/yr). Comparing our measurements with earlier data from creepmeters, GNSS campaigns and InSAR data, we infer that aseismic slip is showing a rather constant behavior, at least since the 1980's. Potential slow down was observed following the 1944 earthquake as a postseismic transient, although this observation must be taken with caution as ambiguities in the data discard strong conclusions on the matter.

As a conclusion, the spatial and temporal behavior of the creeping section of the NAF is characterized by 1. shallow slip from the surface down to 6 km-depth with 2. slip accelerations over the westernmost part of the creeping section where vertical motion is observed, 3. steady aseismic slip over the rest of the section and 4. a shallow locking depth of about 10-12 km-depth. Further investigations are now

required to explain the mechanical behavior of this section but the fine description of aseismic slip should provide food-for-thought to explore potential spatial variations of fault rheology or the presence of fluids within the fault zone.

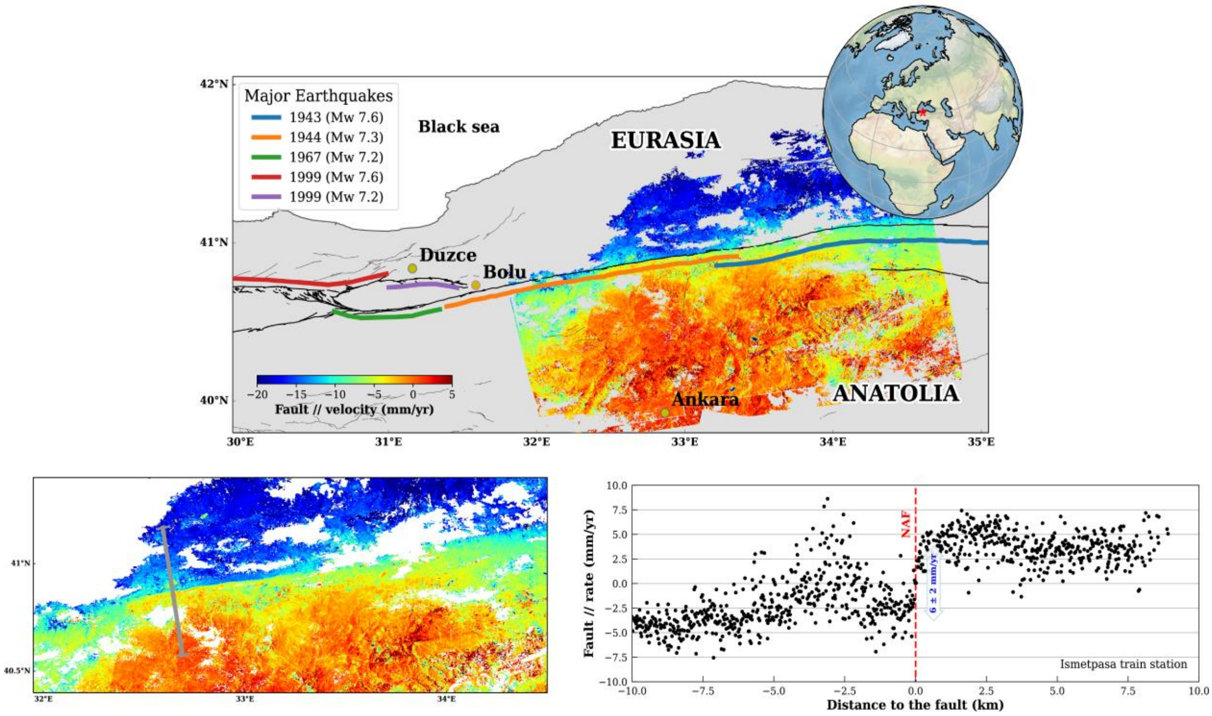

Figure 1. Surface displacement along the Central section of the North Anatolian Fault — **Top:** Map of the surface deformation rate in the direction parallel to the NAF derived from 6 years of Sentinel 1 data. Red indicates westward rate of motion. Black lines are the main NAF system. Colored lines indicate the extent of past historical ruptures. **Bottom left:** Zoom on the surface displacement over the creeping section. Colormap is the same as for the top panel. The grey line indicates the location of the profile shown on the right. **Bottom right:** Fault perpendicular profile of fault parallel rate of motion. The location of the NAF is indicated with a red dashed line.

THE USE of FIBRE OPTIC CABLES as GEOSENSORS-APPLICATIONS and POTENTIAL of DISTRIBUTED ACOUSTIC SENSING (DAS)

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ABSTRACT

Efficient crustal exploration and natural hazard prediction benefit from dense surveys. Seismological techniques provide ground-motion data, while active seismics aims at structural imaging and increasingly on physical properties determination. Dense networks exist in hydrocarbon exploration plays, but rarely in urban and coastal areas where data acquisition is more challenging. This is now becoming possible: dynamic strain determination can be carried out with conventional fibre optic cables used for telecommunication (see review articles by Masoudi & Newson 2016; Martin et al. 2017, Reinsch et al. 2021).

Distributed fibre-optic sensors enable continuous measurement of environmental parameters with high spatial resolution along the measuring fibre (metre scale) and with a high temporal sampling rate (> kHz) over large distances (several km). The physical measuring principle is based on different scattering phenomena of light within the fibre (e.g. Brilloin, Rayleigh, Raman), depending on the interrogation technique. Thus, characteristic properties can be measured by interrogating the light properties (e.g. intensity, phase, travel time, polarisation) (see Wu et al. 2015, Zhu et al. 2015, Liehr et al. 2020). This new tool is lately strongly developed worldwide and provides key records for understanding subsurface dynamics, especially in coastal and urban areas that still experience measurement gaps.

Geophysical applications, here with an emphasis on own work, include vertical seismic profiles in boreholes (Mestayer et al. 2011, Martuganova et al. 2021, 2022), monitoring of microseismicity during hydraulic stimulations (Karrenbach et al. 2017, Lellouch et al. 2020), monitoring fluid flow (e.g. Lipus et al. 2021), earthquake detection (Lindsey et al. 2017, Marra et al. 2019, Currenti et al. 2021, Jousset et al. 2022), and exploration of the structure of the Earth's crust (Jousset et al. 2018, Ajo-Franklin et al. 2019) and also in urban areas (Krawczyk et al. 2019, 2021a, 2021b, Wollin et al. 2021).
Especially the detection of blind faults (c.f., Jousset et al. 2018) and the connection of terrestrial and marine compartments are subject of further developments and applications towards smart cities and hazard mitigation for wider societal benefit.

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SEISMIC DATA ANALYSIS SYSTEMS of AFAD

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ABSTRACT

AFAD is the sole governmental organization responsible from the monitoring and communicating of earthquake information to the public in Türkiye The National Earthquake Monitoring and Assesment Center (NEMAC) is the National seismic monitoring branch of AFAD responsible from the national and regional earthquake observation. The main tasks of this center are; to observe and analyse earthquakes mainly focused on Türkiye and neighbouring countries, to inform government organisations, public and media. The center operates total 1143 seismic stations including broadband, accelerometer, borehole and GNSS. The Center supports the open data policy in seismology and all waveform data are available to the public for scientific and public use.

The Center uses different softwares and platforms for data analysis, storage and distribution. Earthquake Data Center System of Türkiye (AFAD-TDVMS) collects the data obtained by both AFAD and other partner institutions including governmental agencies, universities, local authorities and NGOs (19) carrying out similar studies and all data obtained is shared with users via website (http://tdvms.afad.gov.tr/) free of charge. All national and international researchers have access to the data. 500 researchers downloaded 2000 waveform data between 2013 and 2022.

Accelerometric Database and Analysis System of Türkiye (TADAS) is another platform developed by AFAD. This web based platform and software is open source service based application, full-fledged strong motion data analysis, full compatibility with other commonly used softwares.

The waveform data routinely processed manually for event location and magnitude determination by using a specific software called Earthquake Parameter Estimation and Analysis System (DEKAS). DEKAS can calculate hypocenter for multiple crust models at the same time and offers the user the opportunity to choose the most suitable solution and can also analyse parameters such as earthquake magnitude and location and the focal mechanism solution through the same interface. DEKAS has multithreading feature. In this way, it can display the data collected from hundreds of stations in a very short time and make it available for analysis. DEKAS uses also GIS based database and visualisation. When the earthquake parameters are calculated, it is possible to view the faults in the earthquake region and their metadata.

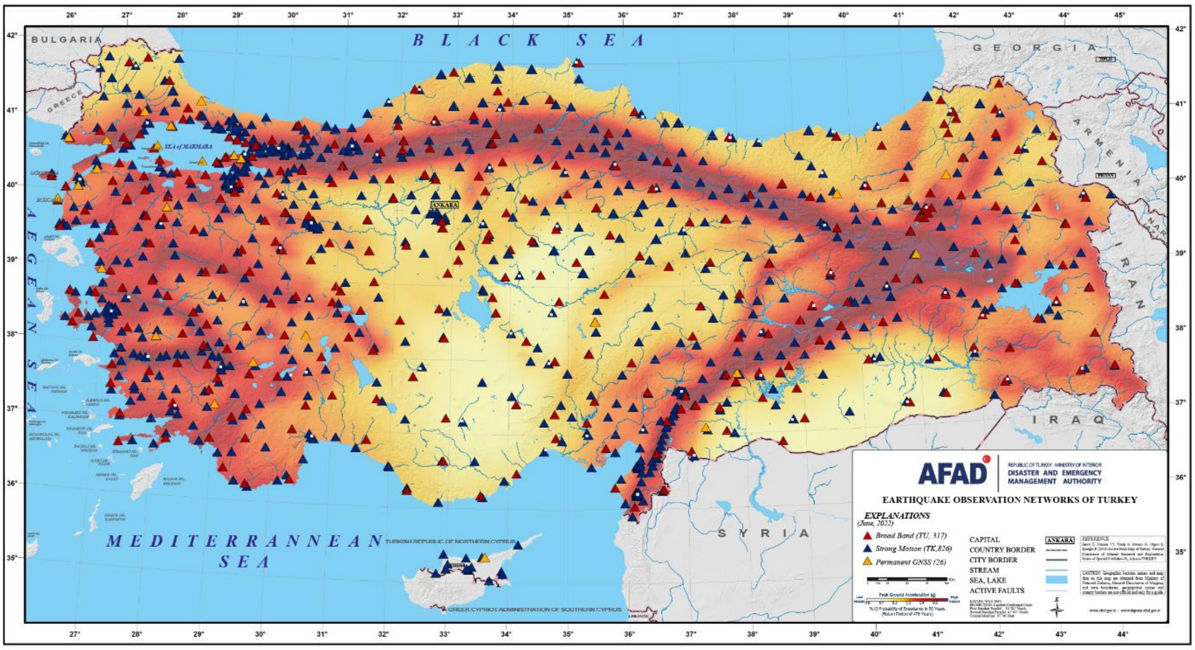

Figure 1. Türkiye National Seismic Observation Network

THE FUTURE of STRAINMETER TECHNOLOGY

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ABSTRACT

Strainmeters have been a valuable tool to understand signals on faults and in volcanic systems that can not be resolved using other geodesic and seismic tools. Strainmeters can also be used to generate a rapid magnitude estimate. Unfortunately, legacy strainmeters have a high cost and power requirements. An example is the Gladwin tensor strainmeter. When produced they cost more than 95k euros and have a power draw of 25-40W. Another issue is that the GTSM and Sacks-Everston strainmeters are no longer produced. UNAVCO currently has 18 deployable strainmeters and the last Sack-Everston instrument will be deployed in fall 2022. Fortunately a new generation of strainmeters are being developed. One promising instrument is the Tensor Optical Fiber Strainmeter (TOFS) developed at Clemson University. This strainmeter has no active downhole electronics, is low power (~2W), and about one-quarter the cost. The TOFS also has a similar resolution to legacy borehole strainmeters. Currently four TOFSs have been deployed to study subsurface water flow in petroleum reservoirs in Oklahoma, USA, and two for hydrothermal well stimulations in Utah, USA.

CLOSING REMARKS

The Symposium was a great success in bringing together three important communities to discuss, including,

1. Scientists dedicated to fault-zone monitoring with a focus on seismotectonic and physics of earthquakes,
2. Scientists calculating the seismic hazard and assessing the seismic risk in the Marmara Region,
3. The authorities that are responsible for disaster management and mitigation.

Communication between these three groups proved to be very important to identify key remaining challenges for earthquake preparedness in the Marmara Region.

To close the observational gap and ensure optimal monitoring of the Marmara Region, it is essential to get as close as possible to the fault zone(s) in order to improve the signal-to-noise ratio conditions. In a submarine area, this is a challenge that can be approached with different possibilities:

- ➔ Permanent onshore deployments are as close as possible to the fault, both at the surface and, preferably, on boreholes (i.e. GONAF).
- ➔ Permanent offshore deployments including OBS systems at the seafloor, or, alternatively, boreholes.
- ➔ Including data processing from fiber-optic cables (Distributed Acoustic Sensing - DAS)

In addition to improved data acquisition, the new developments in data processing including artificial intelligence, allow providing a refined perspective of the seismotectonic of this area by revising previous data. In this area, some of the most important aspects are:

- ➔ Applying novel signal-detection techniques to enhance the seismicity catalogues and obtaining a more detailed picture of the seismicity behavior.
- ➔ Testing novel physics-based earthquake forecasting approaches aiming at detecting earthquake preparatory processes.

In the final discussion with all participants at the conference, possible future research directions and activities were discussed. The remaining remarks included:

- ➔ Collecting all studies already done in the Marmara region with different methods in a white paper/review, and identify common and diverging results, to pose key future research questions.
- ➔ Involving structural geologists to interpret fault processes and the underlying dynamics.
- ➔ Maintaining fruitful discussions between AFAD, GFZ, and other partners and improving the data exchange to obtain better structural 3-D models of the Sea of Marmara, e.g. from active seismic experiments.
- ➔ From the seismic hazard and risk perspective, there is a need to integrate more data that is becoming now available into mechanical modelling. These improvements could include an improvement of site amplification calculation beyond the application of simple Vs30 maps, the inclusion of directivity effects as well as the inclusion of higher frequencies in the models. These factors could lead to better predictions of seismic shaking and thus better hazard assessments.
- ➔ With respect to disaster management, it would be helpful also to include international disaster management community in addition to the the German and Turkish parts. Also, a close exchange between disaster management and the scientific community will benefit each others' experiences.

AGENDA of the SYMPOSIUM

Openning Speeches

Gov. Mr. Yunus SEZER (President, AFAD)

Prof. Dr. Susanne BUITER (Director, GFZ)

Gov. Mr. Ali YERLİKAYA (Governor of İstanbul)

H.E. Mr. Süleyman SOYLU (Minister, Republic of Türkiye, Ministry of Interior)

Openning Session: Seismotectonic setting of the Marmara region and current monitoring efforts

- Dr. Murat NURLU (Head, AFAD Earthquake Department)
- Prof. Dr. Marco BOHNHOFF (Head, Geomechanics and Scientific Drilling at GFZ)

Session 1: Deformation Features along the Main Marmara Fault

Chair: Prof. Dr. Leni SCHECK-WENDEROTH (GFZ)

- Deformation mechanisms along the Main Marmara Fault (Prof. Dr. Leni Scheck-Wenderoth & Dr. Mauro Cacace, GFZ)
- A new seismotectonic framework of the Marmara Sea in the light of 3D fault map and 3D Coulomb stress analysis (Prof. Dr. Cenk YALTIRAK, Istanbul Technical University)
- Seismic and aseismic fault slip during the inter-seismic period: Observations from the Marmara region of the North Anatolian Fault (Dr. Patricia Martinez-Garzon, GFZ)
- Heterogeneous interseismic coupling along the Main Marmara Fault (Prof. Dr. Semih ERGİNTAV, BOUN-KOERI)
- Spatial variations of tectonic and postseismic fault creep along the Marmara Seismic Gap, North-Western Türkiye, based on high-resolution analysis of earthquake repeaters (Dr. Dirk Becker, GFZ)
- DISCUSSION

Session 2: Seismic Hazard and Risk Assessment in the Marmara Region

Chair: Prof. Dr. Ayşegül ASKAN GÜNDOĞAN (METU)

- Ground motion simulation efforts in Türkiye and engineering extensions (Prof. Dr. Ayşegül ASKAN GÜNDOĞAN, METU)
- Toward better predictions of future ground-motions and their variabilities: Lessons learned from “big-data” analysis and the development of the new generation of European seismic hazard and risk models (Prof. Dr. Fabrice Cotton, GFZ)
- Earthquake Hazard Map of Türkiye (Dr. Nazan KILIÇ, AFAD)
- Factors influencing fault strength and its long-term seismic behavior-constraints from 3D thermo-hydraulic-mechanical modelling (Dr. Mauro Cacace, GFZ)
- Physics-based real-time ground motion modelling (Dr. Marco Pilz, GFZ)
- Analysis of the Mw 5.8 Silivri Earthquake Ground Motions: Evidence of Systematic Azimuthal variations associated with directivity effects (Elif Türker, GFZ)
- DISCUSSION

Invited Speech

- Artificial Intelligence (AI) in seismology (Prof. Dr. Greg BEROZA, STANFORD UNIVERSITY)

Session 3: 23rd Anniversary of the 17 August 1999 Marmara Earthquake & Studies on NAFZ
Chair:Prof. Dr. Levent GÜLEN (Sakarya University)

- Lessons learnt from 17 August 1999 Marmara Earthquake: How Türkiye progressed on earthquake risk management (Hamza TAŞDELEN, AFAD)
- Estimating earthquake source parameters in the Sea of Marmara (Dr. Xiang Cheng , GFZ)
- Characteristics of South Marmara active fault segments of the North Anatolian Fault (Dr. Selim ÖZALP General Directorate of Mineral Research and Expl. MTA)
- Earthquake faulting complexity in the Sea of Marmara: 2019 Mw 5.7 Silivri earthquake (Dr. Diğdem Acarel, Gebze Technical Univ.)
- Spatio-temporal evolution and stress perturbation of the September 2019 Silivri Earthquakes on the semi-realistic 3D fault surfaces along the Northern Branch of the NAFZ (Dr. Murat ŞAHİN, Istanbul Technical University)
- Spatio-temporal variations of seismic coupling along the Western Segment of the North Anatolian Fault, Türkiye. (Amandine Amemoutou, GFZ)
- DISCUSSION

Session 4: Disaster Management in the Marmara Region
Chair: Dr. Murat NURLU (AFAD)

- Development of Earthquake Early Warning System: Bursa case study (Dr. Süleyman TUNÇ, Kocaeli University)
- Why do we have the North Anatolian Fault? (Prof. Dr. Levent GÜLEN, Sakarya University)
- AFAD-RED: Rapid Earthquake Damage and Loss Estimation Software (Bekir Murat TEKİN, AFAD)
- Tsunamis in the Marmara Region (Prof. Dr. Ahmet Cevdet YALÇINER, METU)
- Istanbul is getting ready for the Big One: Reinforcement activities of schools and Hospitals Studies of ISMEP (Kazım Gökhan ELGİN, İstanbul Project Cord. and Imp. Unit.)
- DISCUSSION

Session 5: Geomechanical Models of the Crust and Lithosphere
Chair: Dr. Patricia MARTÍNEZ-GARZÓN (GFZ)

- Seismic velocity contrast on the Ganos Segment of the North Anatolian Fault Zone (Eşref YALÇINKAYA, Cerrahpaşa University)
- Kinematics and mechanics of the North Anatolian Fault in the Sea of Marmara: Combining land and sea data (Prof. Dr. Pierre HENRY, CEREGE, France)
- Composite pull-apart structure development and cross-basin fault generation around Bursa along the southern branch of North Anatolian Fault Zone (Dr. Korhan ESAT, Ankara University)

- 3D lithospheric structure below the Marmara Sea from gravity modelling: Seismic tomography and thermo-mechanical modelling (Dr. Naiara Fernandez, GFZ)
- Deciphering aseismic deformation along submarine fault branches below the Eastern Sea of Marmara (Türkiye): Insights from seismicity, strainmeter, and GNSS data (Dr. Virginie Durand, ETH Zurich)
- DISCUSSION

Session 6: Fault-Zone Characterization Based on Novel Seismic Processing Techniques
Chair: Prof. Dr. Fabrice COTTON (GFZ)

- Real-time seismogeodetic earthquake observation studies in Türkiye: Potential and current practices (Prof. Dr. Bahadır AKTUĞ, Ankara University)
- Spatial and temporal distribution of aseismic slip along the Central North Anatolian Fault (Prof. Dr. Romain Jolivet (Ecole Normale Superieur, France)
- The use of fibre optic cables as geosensors-applications and potential of Distributed Acoustic Sensing (DAS) (Prof. Dr. Charlotte Krawczyk, GFZ)
- Seismic data analysis systems of AFAD (Meltem TÜRKOĞLU, AFAD)
- The future of strainmeter technology. (Dr. Wade Johnson, Dr. Dave Mencin (UNAVCO, USA)
- DISCUSSION

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