Turkish Journal of Earth Sciences

Volume 32
Number 3 *SI-3*

Article 1

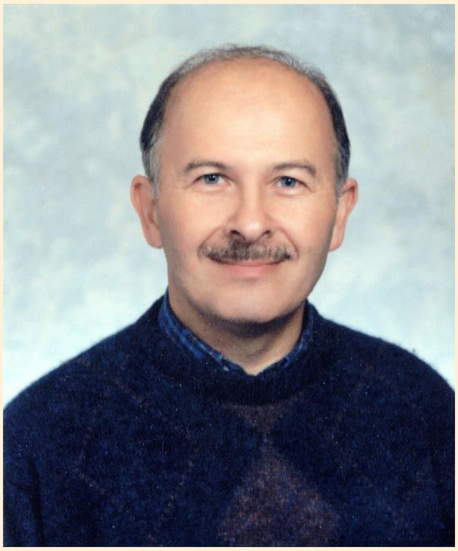
1-1-2023

Cover and Contents

SPECIAL ISSUE
VOLUME 32 | ISSUE 3 | YEAR 2023
ISSN 1300-0985 • E-ISSN 1303-619X

TURKISH JOURNAL OF EARTH SCIENCES

http://journals.tubitak.gov.tr/earth/



From coseismic surface rupture to long-term behavior of faulting: a tribute to A. Aykut Barka

Guest Editors:
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Published by the Scientific and Technological Research Council of Turkey
TÜBİTAK

TURKISH JOURNAL OF EARTH SCIENCES

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VOLUME 32 • ISSUE 3 • 2023
ISSN 1300-0985 • E-ISSN 1303-619X

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- The Turkish Journal of Earth Sciences is published electronically 6 times a year by the Scientific and Technological Research Council of Turkey (TÜBİTAK).
- It is an international English-language journal for the publication of significant original recent research in a wide spectrum of topics in the earth sciences, such as geology, structural geology, tectonics, sedimentology, geochemistry, geochronology, palaeontology, igneous and metamorphic petrology, mineralogy, biostratigraphy, geophysics, geomorphology, palaeoecology and oceanography, and mineral-deposits.
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- Submitted papers should have regional implications and attract international interest as the journal aims to provide a medium for interdisciplinary papers that would be of interest to many different specialists.
- Specialized papers can be submitted if they illustrate significant progress in that specific area of the earth sciences. In addition to original and review articles, we are also interested in publishing discussions of papers that have already appeared in recent issues of the journal.
- The journal also publishes thematic sets of papers on topical aspects of geology or special issues of selected papers from conferences.
- Short articles (6 printed pages maximum) for rapid publication reporting a significant advance in the earth sciences with regional impact are welcome. Contribution is open to researchers of all nationalities.

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CONTENTS

From coseismic surface rupture to long-term behavior of faulting: a tribute to A. Aykut Barka

Guest Editors: *Gülsen Uçarkuş, Serdar Akyüz, Ziyadin Çakır, Robert Reilinger, Mustapha Meghraoui, and Orhan Tatar*

Preface

A. Aykut Barka (1952–2002) was a renowned Turkish geologist in earthquake research, a flagbearer in cultivating the active tectonic studies in Turkey, and founder of the "Active Tectonics Research Group" of Türkiye (ATAG). His contributions, including furthering our understanding of the behavior of the North Anatolian Fault Zone (NAFZ), using GPS studies to measure directly tectonic deformation throughout the Eastern Mediterranean Region, emphasizing the role of stress transfer and triggering along NAFZ and advancing public awareness of earthquake hazards in Turkey are exemplary. Barka's studies were focused on understanding the temporal and spatial evolution of active faulting through geologic, geodetic, and seismic observations; he, therefore, adopted a multidisciplinary approach. His highly cited "Slip Distribution Along the North Anatolian Fault Associated with the Large Earthquakes during 1939–1967" paper (1996) pioneered stress transfer calculations for the NAF based on his detailed slip distribution work for the 6 large earthquakes of the 20th century that ruptured the NAF east to west. Later on, Barka and Stein used these slip-rates to calculate the stress triggering along the NAF by Coulomb modeling in their 1997 paper. The overall results of this study showed that the İzmit city and the surrounding regions were under a big earthquake risk. Two years after their published work, in 1999, NAF pursued its westward propagation not only one but with two earthquakes, Mw 7.4 İzmit earthquake and Mw 7.2 Düzce earthquake, respectively. Barka was not only concerned by the number of lives lost because of these two earthquakes, but he also knew the next earthquake risk was now over the biggest city of Türkiye, İstanbul, at the western continuation of NAF in the Marmara Sea. He gathered a vast international earth science community to work on different aspects of 1999 earthquakes, as well as the rather unknown part of the offshore segments of the NAF in the Marmara Sea.

Aykut Barka embodied the highest calling of science in service to the public. He passionately dedicated the last 2 years of his life to create awareness for the potential earthquake disaster awaiting İstanbul, in public and parliamentary level. Twenty years after his passing, this special issue is prepared as a tribute to Aykut Barka's dedication to earthquake research, his enduring curiosity on seismic behavior of faulting and his long-term dream of protecting the Turkish people from the losses they have suffered from earthquakes for many centuries.

"From coseismic surface rupture to long-term behavior of faulting" special issue aims to seek new insights related to faulting processes within a single seismic cycle and/or multiple cycles over longer time periods obtained from geologic, geodetic, and seismic observations. Assessing the characteristics of future fault ruptures associated with large earthquakes is essential for understanding the fault behavior and associated hazard. While a combination of parameters, including fault geometry and segmentation, fault slip history, and dynamics of faulting at seismogenic depth, provide the framework for fault interactions and models for temporal and spatial slip behavior of active fault systems, several questions persist related to the strain buildup variability of active faults through the seismic cycle and on larger timescales.

The eleven papers within this special issue addresses some of the phenomena mentioned above. The first three papers deal with plate interaction and crustal deformation around Aegean and Anatolia based on new GNSS observations. *Ergintav et al.* present an updated GNSS velocity field for the Anatolia-Aegean region and surrounding areas by developing local reference frames for the Aegean and east Anatolia in order to better resolve subtle variation of motions within such rapidly moving (i.e. with respect to Eurasia) regions. With this approach, they investigate the role of Nubian lithosphere subduction along the Hellenic-Cyprus subduction zone, and continental collision between Arabia and eastern Anatolia. Two key results of this study show that the seismogenic crust (above approximately 15 km depth) deforms elastically, with a very broad area bounded by the North Anatolian Fault (NAF) and East Anatolian Fault (EAF) rotating with negligible internal strain; second, increasing rates of motion directed towards the Hellenic trench supports models in which foundering of the subducting Nubian slab along the Hellenic subduction zone is the principal driver of western Anatolia-Aegean motion and internal deformation.

Floyd et al. discuss recent GNSS results for the Aegean region, with a focus on the active deformation of the Hellenic subduction zone and its relationship to coupling on the plate interface and processes within the subducting Nubian plate. They use GNSS secular velocities and shallow earthquake locations to determine an upper plate reference frame with low internal deformation (<2 mm/year) that includes a large area of the central and western Aegean. Their interpretation suggests upper plate deformation as resulting from stronger coupling on the subduction plate interface beneath western Crete than on the western or eastern segments of the Hellenic subduction zone.

Kurt et al. present new GNSS observations from 186 sites together with existing dataset using homogeneous processing of time-series for a single reference system and reestimate the velocity field from 836 sites with an average interstation distance of 37 km to obtain an improved coverage of the velocity field to calculate strain accumulation on the North and East Anatolian Faults. Their modelled slip rates vary between 20 and 26 mm/year and 9.7 and 11 mm/year for the North and East Anatolian faults, respectively.

Güvercin examines the upper crustal structure beneath the eastern segments of The East Anatolian Fault Zone (EAFZ) using an improved seismicity catalog compiled from 26,000 earthquakes from Kandilli Observatory and Earthquake Research Institute, in order to resolve the details of the seismogenic part of crust (<15 km). Computation of 3D seismic velocity variations present the tomographic model for the large velocity contrast across the EAF and the variations of dip angle along the fault. Together with the obtained velocity model, the relocated hypocenters indicate that the dip of the EAFZ is not uniform.

Coşkun and Pınar determine the focal mechanisms of small earthquakes in order to identify the transtensional and transpressional features along the North Anatolian Fault beneath the Sea of Marmara. They use two different seismological datasets to investigate these features, broadband stations data from KOERI used for small-to-moderate-sized events and 15 OBS seismic stations of JAMSTEC within the Sea of Marmara used for the microseismic activity. Their results indicate that extensional and strike-slip style deformation dominates the region, while contractional features are rare. Complementing the seismic dataset, processed GPS data are used to interpret the faulting and strain rates. Accordingly, the highest values of 24 × 10–8/year, are deduced in Çınarcık Basin, while the lowest values, 11 × 10–8/year, are observed in Central Marmara.

The next two papers present results from two different subduction margin settings in the world, one from Sunda megathrust in Sumatra and the latter from Marlborough Fault System, New Zealand within the vicinity of Hikurangi subduction zone. *Nalbant et al.* model the stress evolution of the Mentawai section of the Sunda megathrust using a list of thirty M ≥ 7.0 earthquakes that occurred on the megathrust between 1797 and 2022. Their model explains the reasons for the partial rupture of this section in the recent sequence of events, suggesting that coseismic slip on the Mentawai segment is controlled by stress shadows left over from previous ruptures.

Berryman et al. discuss a very complex and debated seismological event, the 2016 Mw 7.8 Kaikōura earthquake which occurred in the Marlborough Tectonic Domain of New Zealand. The event was considered complex due to its setting within comprehensively imbricated, steeply-dipping Pahau Terrane crust that exhibits numerous tectonic overprints with diverse faulting styles as well as rupture complexity and rupture propagation. They examined the 2016 surface rupture complexity in three sections; i) comparison of the 2016 rupture with other historic fault ruptures that occurred in the region; ii) evaluating the geological structures that may have contributed to rupture complexity comparable to other global large earthquakes; iii) assessing the possibility of similar future multifault rupture complexity. They conclude that multifault ruptures may be enhanced in the Kaikōura region where the Australian plate crust is thinner than farther west and the plate boundary deformation transfers between closely spaced faults with acute changes in surface geometry and with diverse rupture characteristics.

Zabcı et al. present new geologic slip rates from the Malatya-Ovacık Fault Zone (MOFZ) which is a NE-striking sinistral fault zone that splays from the North Anatolian Shear Zone (NASZ) near Erzincan. They use cosmogenic 36Cl ages of offset alluvial fan and terrace deposits along the the Ovacık Fault (OF) of MOFZ, as well as paleoseismological studies from the other 'internal' structures of Anatolia, in order to make a synthesis to understand the nature of the rigid or semirigid behavior of this block. They demonstrate that their geologic slip-rate estimates simply exceed the geodetic rates of the OF or other velocities deduced along the NE-striking sinistral strike-slip faults of Anatolia, and the Malatya Fault (MF). They conclude that the geological configuration and relative motion of these secondary faults delimiting the Malatya-Erzincan, Cappadocian, and Central Anatolian slices, well explain the velocity difference between their result on the OF and the very long-term slip-rate of the MF and other structures of internal Anatolia. Their slip-rate analysis together with previous slip-rate estimates show a significant internal deformation for Anatolia, especially along its subparallel strike-slip faults.

Aksoy et al. present new paleoseismological data from the central section of the Ganos fault segment of North Anatolian Fault. They discuss results from a total of five trenches which were excavated between 2006 and 2008 near Yeniköy and Yörgüç sites in Western Türkiye. Faulting events that are found at these trench sites together with earlier paleoseismic studies on the Ganos fault suggests that the historical earthquakes of 1912, 1766 or 1659, 1354 or 1343, and 1063 ruptured the entire Ganos fault onland section. Using the 46 ± 1 m offsets on a stream channel, they calculate a geologic slip rate of 16.9 ± 0.7 mm/year for the last 2732 ± 119 years on the Ganos segment of NAF. Based on paleoseismic trenching and geomorphological offsets, they propose a recurrence interval of 283 ± 89 years and an average slip rate of 17.1 ± 0.9 mm/year for the Ganos segment of the NAF.

Balkaya et al. discuss the earthquake history of the Sürgü and Çardak faults which splay from the East Anatolian Fault zone (EAFZ). Their study shed light on two important fault segments and their unknown paleoseismic history. They present data from four paleoseismologic trenches, two trenches from the Sürgü Fault and two trenches from the Çardak Fault. Along the Sürgü Fault, at least two paleoearthquake events were discovered, one event around 3400 BCE and the second event between 2085 ± 65 BCE and 790 ± 20 BCE. Their trenching results from the Çardak Fault, indicate two surface rupturing paleoearthquakes between 10520 ± 95 BCE and 5780 ± 65 BCE, and between 3215 ± 125 BCE and 825 ± 55 CE, respectively. They also proposed that Sürgü and Çardak faults has different paleoseismic histories and they were not broken together in the past. During the review process of the paper by Balkaya et al., a magnitude Mw 7.6 earthquake ruptured the Çardak fault on February 6th, 2023. Their trench site along the Çardak fault were offset laterally by 5.4 ± 0.3 m. This unprecedented geologic event has been added in the supplementary of this paper.

The final paper of the special issue is by *Nozadkhalil et al.,* who demonstrate surface deformation in the Thrace region of Turkey by mapping the surface motions using the Sentinel-1 Synthetic Aperture Radar (SAR) data. They deduce a large-scale subsidence (approximately 110 × 60 km) with rates reaching up to 10 ± 1.5 mm/year based on analysis of the SAR data acquired between 2014 and 2020. They relate this deformation to natural gas reservoir operations, such as gas exploitation and extraction activities that have been taking place in the region. They suggest that although the Coulomb stress changes caused by this volume change is insignificant, the large-scale subsidence needs to be taken into consideration when assessing hazards for the infrastructures and settlements in case of a large earthquake in the Marmara Sea.

During the evaluation process of this special issue, two large earthquakes struck Eastern Türkiye, rupturing a 350 km portion of East Anatolian Fault with a Mw 7.7 earthquake and the 150 km of Çardak fault with a Mw 7.6 earthquake on February 6th, 2023, nine hours after the initial event. The earthquake doublets were a striking reminder of the importance of fault interaction and associated hazard. Consequences of the 2023 Kahramanmaraş Earthquakes were reminiscent of the 1999 İzmit and Düzce earthquakes and Barka's persistent efforts for creating earthquake hazard awareness in Türkiye.

The guest editors would like to thank the authors for their valuable scientific contributions to this special issue, the reviewers for their careful evaluations, and the Editor-in-Chief of Turkish Journal of Earth Sciences, Prof. Orhan Tatar, for proposing to dedicate this issue to our beloved friend A. Aykut Barka.