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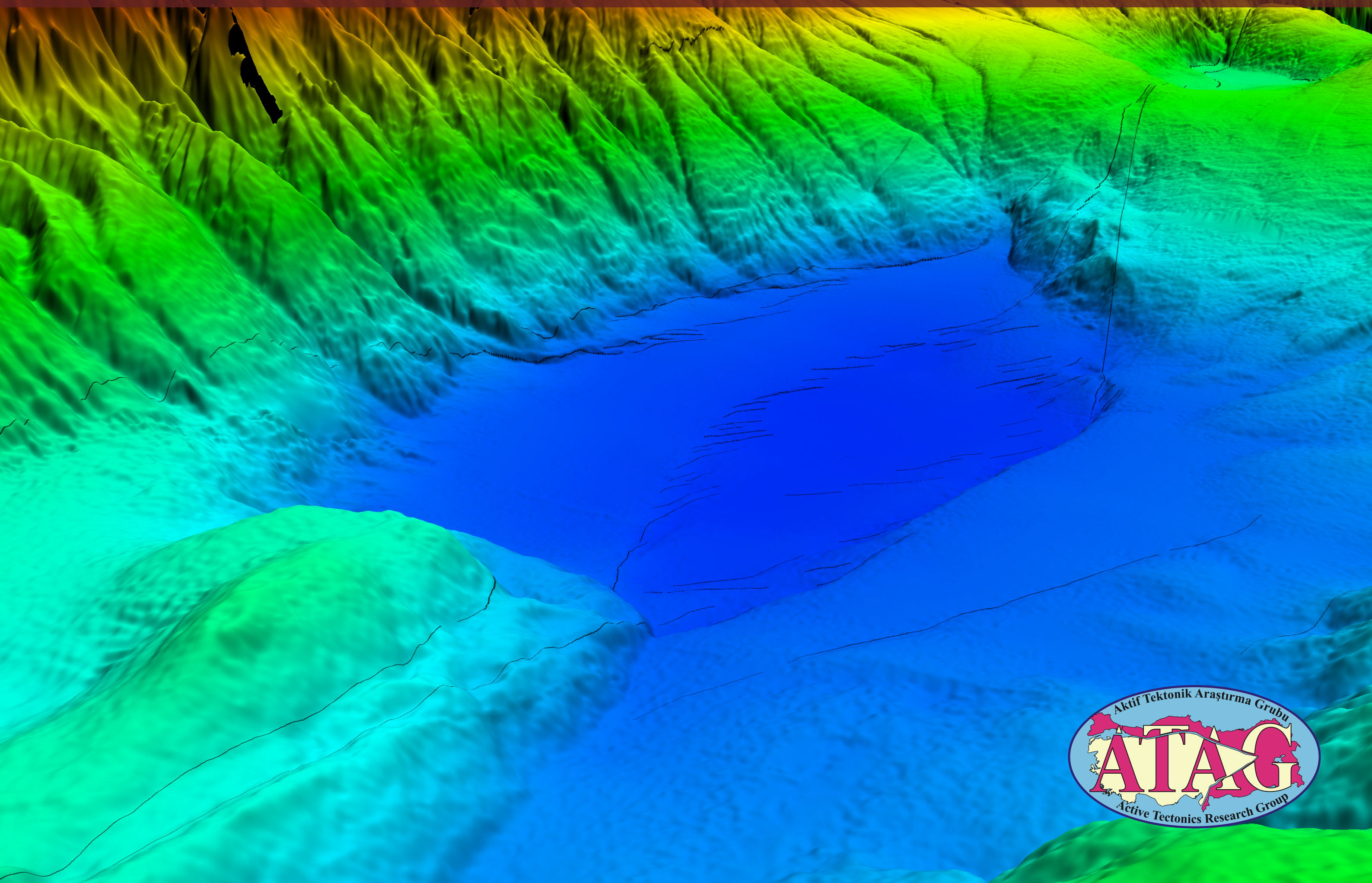
ATAG23
20th Anniversary of the 1999 Marmara Earthquakes

15-18 October 2019 Istanbul

ABSTRACT BOOK



Aktif Tektonik Araştırma Grubu
ATAG
Active Tectonics Research Group

20th Anniversary of the 1999 Marmara Earthquakes: 23rd Active Tectonics Research Group Meeting

ABSTRACT BOOK

15-18 October 2019
İstanbul Technical University (İTÜ)
Süleyman Demirel Convention Center
Maslak İstanbul TURKEY

We would like to thank Istanbul Technical University Rectorate
for the financial support.

PREFACE

It gives me a great pleasure to welcome you to the scientific program of the 23rd Meeting of the Active Tectonics Research Group (ATAG). ATAG, founded by late Prof. Aykut Barka, organizes annual meetings since 1997 to gather earth scientists and students, studying active tectonics of Turkey and neighbouring regions.

As the year 2019 marks the 20th anniversary of the 1999 Mw 7.4 İzmit and Mw 7.2 Düzce earthquakes, this year ATAG meeting aims to bring together international earth science community to share the knowledge and experience gained in active tectonics not only in Turkey but also in other parts of the world.

Following the 1999 earthquakes there have been numerous seismological, geodetic and marine studies carried out in order to better understand the characteristics of the North Anatolian Fault offshore. Consequently, the special themed "20 Years after the 1999 Marmara Earthquakes: Active Tectonics of Marmara Sea" session is devoted to the review of research conducted for the last 20 years. The following sessions cover active tectonic and seismological studies from Anatolia and all around the world such as Aegean Basins, Mediterranean Basins, Dead Sea Fault, San Andreas Fault, Chaman Fault System, Caucasus region, Carpathians, Greece, Central Italy, Japan, Indonesia and so on.

The meeting starts with keynote lectures given by Prof. A. M. Celal Şengör, Prof. John Dewey, Prof. Xavier Le Pichon and Prof. Dan McKenzie. Istanbul Technical University senate will present Honorary Doctorate Degrees to distinguished Professors Dewey, Le Pichon and McKenzie for their contributions to development of geosciences on the morning of October, 15th, 2019.

Keynote lectures will lead the way to a three-day technical program with 70 oral and 49 poster presentations organized under 7 sessions:

TH1 - 20 Years after the 1999 Marmara Earthquakes: Active Tectonics of Marmara Sea
TH2 - Active tectonics of Anatolia and the adjacent regions
TH3 - Paleoseismology
TH4 - Seismology - Seismotectonics
TH5 - Tectonic Geodesy

TH6 - Monitoring and Modelling Crustal Deformation
TH7 - Tsunamis

This year, for the first time in ATAG meetings, poster sessions will be complimented with lightning introduction talks at the end of the sessions. With the encouragements of organizing committee and contribution of the participants, this year the poster session carries more significance than previous years with its rich scientific content.

We have two invited speakers Prof. Thomas Rockwell and Prof. Michel Bouchon in sessions 2 and 4,
respectively. Prof. Rockwell will give a talk titled “Rupture Sequences on the North Anatolian and Dead Sea Faults: Are Perceived Segment Boundaries Real?”. Prof. Bouchon will talk about “The mechanics and faulting characteristics of supershear earthquakes”.

This year the meeting also includes 15th Barka Lecture that will be given by Prof. Roger Bilham. The lecture title is “The dangerous southern edge of the Eurasian Plate: a collision of earthquakes and corruption”.

I believe that 23rd ATAG meeting will advance our knowledge of the various aspects of tectonics of Turkey and surrounding regions by providing a platform for exchange of ideas and international collaborations. I also would like to express my gratitude to all participants for their invaluable contribution to this meeting.

I wish you all a pleasant time in Istanbul and a successful meeting.

On behalf of the organizing committee of the 23rd ATAG meeting

Prof. Ziyadin ÇAKIR
Istanbul Technical University

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KEYNOTE LECTURES

20 Years After: From the viewpoint of neoctectonics of the Eastern Mediterranean

A. M. Celâl Şengör (1)

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An Arabic proverb says that without shedding tears great deeds cannot be accomplished. The Sea of Marmara and its surroundings became one of the best-known corners of the world geologically, as a consequence of the tragic 1999 earthquakes that killed about 20,000 people and left countless others homeless. This immense progress we owe to our European friends, who provided not only much of the finance but also the technical expertise. Xavier Le Pichon took an immediate interest (literally the day after the 17th August İzmit earthquake) and organised a large-scale research programme that still continues. Dan McKenzie had come earlier to study the then little-known Southern Shelf of the Marmara Sea and had long been interested in the neotectonics of Turkey. John Dewey has been involved in Turkish neotectonics since 1976. All three also trained Turkish students who are now faculty members in this university. Both McKenzie and Dewey were good friends of İhsan Ketin, the nestor of Turkish geology. Our gratitude to them can hardly be expressed in mere words.

My task today is to introduce this symposium. Consequently, I decided to look at the factors governing the neotectonics of Turkey. The structures that disrupt the older orogenic framework in Turkey all became active since about 11 Ma ago. This date also coincides with the beginning rise of the Turkish-Iranian Plateau out of the waters of the sea (then about 30 m higher than today). At the time, western Turkey and the Aegean were about 3 to 3.5 km high as judged from the metamorphism of their crust and the flora of their surface. North and East Anatolian faults formed at this time and Ketin's Anatolian block came into existence and began its westerly journey with respect to Eurasia. Models relying on topographic potential energy to trigger these events cannot account for the observation that the Anatolian Block began moving from an area of low topography towards an area of high topography. Boundary forces must have been responsible. Could they have been sufficient? When one looks at the placement of the two major strike-slip faults bounding the Anatolian Block, one sees that they follow old sutures, i.e., lithosphere-scale planar structures lined with serpentinite and flysch. These are ideal conditions to form weak faults. Stratigraphic and geochronological work along the North Anatolian Fault has suggested that it propagated from east to west and accelerated its rate of motion. That acceleration may be a function of the rising topography in the east and sinking topography in the west and the contribution of the Hellenic Subduction. The Anatolian Block is falling apart internally. In the Aegean and western Turkey, this is expressed by north-south stretching and the formation of east-west rifts. In central Turkey the motions are much slower and it has been difficult to paint an overall strain picture. In eastern Turkey, east of the Anatolian Block, north-south shortening dominates. One thing we have learnt during the last two decades is how much older geology influences the neotectonics of Turkey. Rock types in the crust, geological

structures, thermal regime and the history of the lithosphere are the main controls on how the boundary and body forces shape the neotectonics of Turkey.

Keywords: neotectonics, Eastern Mediterranean, Anatolia, deformation

Transtension in the brittle field; Implications for volcanism, hydrology, and geothermal power

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A major and difficult problem of structural geology is how general strains in the brittle upper crust are effected by fault systems, that is what fault systems, domains, and arrays achieve particular biaxial, uniaxial, and triaxial bulk strains, Transtension generates non-coaxial constriction and poses difficult problems of wrench/normal fault-combination block rotation and strain. In transtension, all faults, except those that are vertical and parallel with the zone boundary (line of no infinitesimal strain) or the transport direction, rotate either with or against vorticity. Except for faults parallel with the zone boundary line of no finite strain or the transport direction, faults rotate and lengthen/shorten Normal faults rotate around vertical and horizontal axes to give oblique slip, and wrench faults rotate around vertical axes. Kinematic problems arise because blocks of varying size and shape, bounded by normal and wrench faults, rotate at different rates about vertical and horizontal axes while shortening or lengthening. This causes serious compatibility problems between adjacent blocks that may be solved by block margin deformation, by bulk block strain, by buckling of faults, by volume increase with holes opening at block intersections, by alternating periods of normal and wrench faulting, by discrete arrays of normal and wrench faults, or by a combination of some or all of these. If domains of conjugate wrench faults form on surfaces of maximum shear stress, and rotate in opposite senses to minimum shear/normal stress ratios, fault slip and block rotation cease, and new faults must form if bulk deformation continues. Three major compatibility problems arise, the zone shortens parallel with its boundary, widens by different amounts for each domain, and, if the normal fault blocks remain rigid, the zone lengthens then shortens. Alternatively, if the conjugate wrench faults are rotated as "passive" markers to maintain complete compatibility of zone length and width, the blocks change shape, involving substantial internal deformation. This strain is reflected in the negative log normal relationship between earth magnitude and number, and in fault and fracture scaling. Although the bulk instantaneous strain/stress field determines the wrench/normal fault regime at infinitesimal or very small strains, compatibility dictates their rotation, slip-sense, buckling and intersection relationships. Therefore, slip directions and senses and stress patterns are dictated by block rotation and, as faults lock at unfavorable intersections and orientations, new fault systems increase fracture penetration to decrease block size. This implies an increase in fracture porosity and fluid flow in contrast to simple, orthogonal biaxial extension, where rigid block rotation is "allowed".

The Coso region, in southern California is, perhaps, the best place on Earth to study transtension in the brittle regime; it is active and well-mapped, the horizontal strain rates are high, the exposure is excellent, there is a well-described young stratigraphy upon which the transtension is superimposed, and there is a huge amount of seismic, heatlow, fluid flow, and general geologic data from boreholes and surface, arising from the Geothermal Program. The Central Basin and Range between the Sierra Nevada is transtensional in contrast to the bulk biaxial extension of the

Northern Basin and Range. Although earthquakes occur across the Central Basin and Range, strain is concentrated mainly in a narrow zone (East California "Shear" Zone). In the Coso Region, between the Sierra Nevada and the Argus Range, the transport direction (from GPS) is roughly NNW at about 10 mm/yr. This generates triaxial constriction with an instantaneous stretching direction roughly WNW and a horizontal strain rate of about 10^{-14} sec^{-1}. Constriction can be modeled by a combination of NNE normal faults, NE wrench faults, and WNW folds and thrusts, which rotate clockwise with vorticity, and N wrench faults that rotate counterclockwise against vorticity. This predicted pattern of faulting, folding, and bulk strain is recorded closely by fault slip data from earthquakes and field observations. A nascent core complex generates part of the extension. In both transtensional and transpressional zones, GPS and moment tensor sum data indicate very smooth velocity fields, which in turn means that the commonly accepted view of the rotation of large rigid blocks cannot be correct; instead, the upper crust behaves as a "continuum rubble" of very small "blocks". An artesian geothermal water system is developed by flow from the Sierra Nevada and Argus Range into the Coso Valley where it is heated in a thin crust with a high geothermal gradient, and by shallow silicic magma chamber between 5 and 8 kilometres. The base of an array of 2000 metre boreholes is at 340°C generating dry steam and 300 MW of geothermal power. Volcanic conduits are controlled by areas of structural complexity at intersections of fault systems with block size reduction and void development.

Keywords: transtension, brittle deformation, geothermal, volcanism

Continental collisions and the origin of subcrustal continental earthquakes

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The existence of subcrustal continental earthquakes beneath the Alpine-Himalayan Belt was recognized more than 60 years ago. There is general agreement that most of those beneath the western part of the belt in the Mediterranean result from the subduction of oceanic lithosphere. There is less agreement about the origin of those beneath Vrancea in Romania, the Hindu Kush and the Pamir. Because there is little evidence for the former existence of oceanic lithosphere beneath these regions, many authors have argued that these seismic zones result from the separation of the mantle part of the continental lithosphere from the crust before it sinks into the mantle. However, this model has become steadily less satisfactory. Detailed studies of the depth of earthquakes beneath all stable regions of continents have shown that substantial subcrustal earthquakes, with magnitudes greater than 5.5, are rare. We show that this distribution is controlled by temperature, with material hotter than 600_C being aseismic. This simple rule accounts for the distribution of almost all earthquakes in oceanic and continental lithosphere, including those in subduction zones. We argue that the subcrustal continental earthquakes must also result from the subduction of oceanic lithosphere. This proposal is not new, but has generally been dismissed because of the lack of surface geological evidence that suitable pieces of oceanic lithosphere existed. However, the depth distribution of continental earthquakes makes it steadily harder to avoid.

Keywords: Continental seismicity, subduction, continental sutures, Vrancea, Hindu Kush, Pamir

The Marmara Sea and the formation of the Anatolia-Aegea northern boundary

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Although we have progressed a great deal during the last twenty years on this subject, two major concepts that appear to me to be essential to its full understanding are still ignored by many. The first concept, which was presented more than fifty years ago, concerns the fact that the Anatolia-Aegea northern boundary exists because of the formation of an Anatolia Aegea block since Miocene and that one cannot understand its formation if this genetic link is ignored. Yet, the progress in unravelling the geology of the last 60 Myr has led to many recent interpretations of Aegea as a huge composite accretionary prism produced by subduction of a single continuous slab, its tectonics being dominated by the roll-back of the slab. In these interpretations, the formation of the Anatolia-Aegea block appears to be an epiphenomenon of secondary significance. The second concept emerged when it was discovered that the Anatolia-Aegea boundary has a decreasing age from east to west and that its structure changes progressively with age. The youngest portion, to the west, corresponds to the Gulf of Corinth asymmetric rotating extensional rifts, oblique to the direction of motion, without the presence of any strike-slip fault. The oldest portion to the east corresponds to pure strike-slip. If this is so, it becomes reasonable to assume that the evolving structure from west to east may actually reflect a genetic sequence that we should have in mind when considering the formation of the Marmara Sea. The assumption used by many that a single type of structure might explain the whole evolution of the Marmara Sea then would not be correct. Rather, the coexistence of normal and strike-slip features in it would reflect a still evolving structure from an initial Corinth stage to the future pure strike-slip boundary that has not yet been completely achieved. I will try to show that using both concepts gives the proper framework to understand the evolution of what I consider to be one of the most fascinating tectonic areas on our globe.

Keywords: Anatolia, Aegea, Marmara Sea, strike-slip
.

INVITED TALKS

The mechanics and faulting characteristics of supershear earthquakes

Michel Bouchon (1), Hayrullah Karabulut (2), Jean Schmittbuhl (3), Marie-Paule Bouin (4), Martin Vallée (4), Mustafa Aktar (2), Nafi Toksöz (5), Michel Dietrich (1), Ares Rosakis (6)

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The1999 Izmit and Düzce earthquakes have changed our understanding of rupture dynamics. In both earthquakes a large part of the fault broke at a speed faster than the shear wave velocity of surrounding rocks. The inferred speed close to 5km/s was astonishing. The results were first met with skepticism but were consistent with theoretical studies in fracture dynamics. In the same year, the first measurement of the rupture velocity of a crack tip in a laboratory experiment was achieved. The measured value was $\sqrt{2}$Vs, remarkably close to the value observed during the Izmit and Düzce earthquakes. In the following years, supershear speed was observed during several earthquakes on strike-slip faults with characteristics similar to the North Anatolian Fault. The most impressive supershear rupture (~300km in length) occurred during the 2001 Kunlun earthquake in Tibet, an event which produced the longest rupture ever observed for an earthquake on land. The most recent one is the Palu (Indonesia) earthquake, the largest continental earthquake of 2018. One important aspect of supershear earthquakes, not encountered in other events, is their radiation of a shock wave, similar in nature to the sonic boom of a supersonic airplane. The presence of this shock wave necessarily impacts the damage caused by the earthquake. We will review the observations of supershear earthquakes and assess their faulting characteristics.

Keywords: supershear, earthquakes, North Anatolian Fault, 1999 Izmit and Düzce earthquakes

Rupture sequences on the North Anatolian and Dead Sea Faults: Are perceived segment boundaries real?

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The North Anatolia (NAF) and Dead Sea (DSF) faults are relatively simple plate boundary systems with long historical records and abundant paleoseismic data that allow for an assessment of long-term strain release and resilience of perceived segment boundaries. 1200 km of the NAF ruptured in a sequence of at least nine major earthquakes (>M7) between 1939 and 1999. Previous major rupture sequences initiated in the 17th, 13th, 10th, and 5th centuries CE, filled in with smaller sequences to the west. Paleoseismic studies agree well with the historical record, and fill in for areas that are sparse in historical data. Of note is that the sequence initiated in 1668 appears to have ignored some of the rupture boundaries expressed in the 20th century sequence, including the major releasing step at Niksar Basin, suggesting soft section boundaries. Asymmetry in fault zone structure appears to have played a role in both nucleation and propagation of ruptures, resulting in complex section interaction over time.

The DSF, of similar length, has likely sustained similar sequences during the past two millennia, although details of paleoearthquakes are mainly known for the southern 500 km section of the DSF south of the Lebanese restraining bend. Along this section of the fault, the most recent sequence of large earthquakes occurred in the 13th century. Two other sequences are well documented that ruptured the entire length of the southern section of the DSF during the 8th and the 4th centuries, respectively. Similar to the NAF, successive past earthquakes along the southern DSF had variable rupture length, suggesting that no fault section boundary is permanent, although the question remains open for the major Dead Sea releasing step, as no through-going rupture has been documented yet. With a long-term slip rate of ~5 mm/yr, and a seismic quiescence lasting for almost 7 centuries along some sections of the faults, the occurrence of the 1995 M7.2 Aqaba earthquake might signal the beginning of a new seismic sequence, making the DST currently one of the most hazardous seismic sources in the Middle East.

Keywords: North Anatolian Fault, Dead Sea Fault, segment boundaries, paleoseismology

TH-1
20 YEARS AFTER THE 1999 MARMARA EARTHQUAKES: SPECIAL THEME ON ACTIVE TECTONICS OF MARMARA SEA

An overview of 20 years of submarine investigations conducted within the French/Turkish cooperation in the Sea of Marmara since the devastating earthquakes of İzmit and Düzce in 1999

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The devastating earthquakes of İzmit and Düzce in 1999, triggered an unprecedented effort from the scientific community to unravel the geology of the submerged sections of the North-Anatolian Fault System within the Sea of Marmara. Since 2000, no less than eight major oceanographic cruises were conducted using large research vessels, through active collaborations between France and Turkey:

- The MARMARA cruise (in 2000 with *R/V Le Suroît)* provided the first bathymetric and active fault maps of the Sea of Marmara below -100 m water depth *(e. g. Le Pichon et al., 2001; Rangin et al., 2001*).
- The SEISMARMARA seismic cruise (in 2001 with R/V *Nadir)*, helped determine the deep structure below the Sea of *Marmara (e. g. Carton et al, 2007; Laigle et al., 2008; Bécel et al., 2010; Bayrakci et al, 2013).*
- The MARMACORE (in 2002, with R/V *Marion-Dufresne)* provided more than 230 m of giant sediment piston cores that allowed the study of paleoseismicity and paleoenvironments during the Late Pleistocne-Holocene (Beck et al., 2007; *Vidal et al., 2010; Çağatay et al., 2015a*).
- The MARMARASCARPS (in 2002 with *R/V L'Atalante* and ROV Victor), provided the fine-scale mapping of active fault scarps, cores for paleoseismological studies and the first visual observations of cold seeps along the fault (*e. g. Armijo et al, 2005, Zitter et al., 2007;Uçarkuş et al., 2011; Drab et al., 2012*).
- The MARMARA VT cruise (in 2004 with *R/V Marion-Dufresne)* provided indications on the influence of sea level changes on water circulation within the upper sediment layers and paleoceanographic history and shelf evolution during MIS 2-5 (*Eriş et al., 2007; Çağatay et al., 2009; Aloisi et al., 2015*).
- The MARNAUT Cruise (in 2007 with *R/V L'Atalante* and *Nautile* submersible), provided *in-situ* gas samples, leading to the discovery that the North Anatolian Fault was cutting through a gas and oil system of the Thrace Basin natural gas field (e.g. *Géli et al, 2008; Bourry et al, 2010; Tryon et al, 2010*; *Şengör et al., 2014; McHugh et al., 2014*).
- The Marmesonet cruises (in 2009 with R/V Le Suroit and in 2010 with R/V Piri Reis) were site-surveys prior to the implementation of seafloor observatories, which revealed the relation between active faulting and gas emissions (e.g. (e.g. *Çağatay et al, 2015b*; *Thomas et al, 2012*; *Dupré et al, 2015; Géli et al, 2018*).
- The MARSITE Cruise (in 2014 with *R/V Pourquoi pas?*) investigated cold-seep dynamics in relation to seismicity the context of a major active strike-slip fault and paleoaceanographic evolution (e.g. *Ruffine et al, 2018; Henry et al, 2018; Çağatay et al., 2018, 2019*). In addition, submarine, geodetic data collected with

support of the EU-funded MARSITE Programme (*e.g. Özel et al, 2015*) suggest complete fault locking in the Central part of the Sea of Marmara, offshore metropolitan Istanbul (*Lange et al, 2019*).

These collaborative studies have transformed the Sea of Marmara from a poorly known marine area to a well-known important natural laboratory for tectonics, seismological, sedimentological and paleoceanographic studies.

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Keywords: Sea of Marmara, French/Turkish cooperation, submarine investigations

20 years of Italian-Turkish scientific cooperation for marine geological studies of the submerged portions of the North-Anatolian fault in the Sea of Marmara and the NE-Aegean Sea

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The submerged portions of the North-Anatolian Fault (NAF) in the Sea of Marmara and the NE-Aegean Sea are sites of large magnitude earthquakes, that leave diagnostic geological "signatures" in the sedimentary record in the form of mass-wasting deposits, turbidites, and fluid and gas escape features. This is due to the interplay of seismic-shaking, mass- and turbidity flows, sediment resuspension and fluids circulation in relatively small sub-basins with a complex paleo-oceanography, steep slopes, high rates of deformation, and diffuse fault-controlled gas and fluid seeps. To unravel the complex interrelations of these phenomena during earthquake cycles, we carried out paleoseismological studies at several key locations. Here, we report results of these studies, carried out onboard the R/V Urania over almost 20 years starting soon after the Mw 7.4, 1999 İzmit earthquake.

Our work included high resolution mapping of active faults through multibeam bathymetry and high resolution seismic reflection profiles, multi-parameter analysis of sediment cores, as well as seafloor observations using sensors mounted on remotely-operated vehicles (ROV). The main objectives were to map active faults, determine slip-rates and earthquake recurrence times along major fault strands, and assess connections between fault deformation and fluid activity. We mapped fault geometry in the gulfs of İzmit, Gemlik and Saros, showing the trans-tensive nature of these depressions. The average slip-rates for the last ~10 ka was found to be ~10 mm/y in the gulfs of İzmit and Saros, at the eastern and the western ends of the NAF northern strand, and 3-4 mm/yr in the Gulf of Gemlik, along the middle strand of the NAF. These rates, integrated over 10 ka of NAF activity, are smaller than those determined by the GPS geodetic measurements.

Submarine paleoseismological studies in the Gulf of İzmit detected the sedimentary records of earthquakes for the last 2.4 ka, suggesting an average recurrence time of 300 years for major events. Multisensor observations and monitoring of the seafloor have shown widespread emissions of gas and fluids along the submerged part of the NAF, associated with reduced black sediments; we investigated their possible connection with the earthquake cycle.

Keywords: Sea of Marmara, North Anatolian Fault, submarine paleoseismology

20 years of geodetic observations around the Marmara Region: Implications on the behaviour of the NAF

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After the 1992 Lander CA earthquake, the 1999 Izmit earthquake was one of the first large events whose surface deformation was captured by GPS, which allowed researchers to infer its rupture parameters in fine detail. Following the 1999 Izmit earthquake, all the attentions have been drawn to the Marmara region, mostly Istanbul, where the next big earthquake is expected to occur by breaking the section of the North Anatolian Fault (NAF) between the 1999 Izmit rupture to the east and the 1912 Mürefte rupture to the west under the Sea of Marmara. As a result, both continues and campaign type of GPS sites have been established since then all around the Sea of Marmara not only by our group but also various other research groups. Today, we monitor a large GPS network composed of both continuous and campaigned type sites established by our group and various other institutions (e.g. Municipalities, Cadastral Office, TÜBİTAK, etc.). Named as MEGA, the network consists of 90 GPS sites. Of these 70 are continuously recording stations. The critical section for on land geodetic measurements is the northern coastlines of the Sea of Marmara between Princes's Islands and Tekirdag since the NAF runs close to this side of the sea. 6 new continuous GPS stations were constructed between Tekirdağ and Küçük Çekmece in 2018. These new GPS measurements will allow us to determine spatial extend of the creeping section under the Sea of Marmara which is deduced from GPS observations.

In order to monitor its postseismic deformation, a new network consisting of 35 GPS concrete pillars was established between Izmit and Adapazari. Both GPS and Synthetic Aperture Radar (Envisat and Sentinel) observations demonstrate that the central section of the 1999 Izmit has been creeping for 20 years since the earthquake.

In addition to GPS, there has been a catalogue of 5-year Sentinel 1A/B TOPS data accumulated since 2014. These are 250 km-wide swaths of SAR images, some of which cover entire Marmara Sea in one frame (e.g. track 36). Preliminary analysis of Sentinel 1 images reveals promising results concerning the variation of interseismic strain along the northern coast.

In addition, we established a gravity network in order to clarify the systematic relations between vertical movements and mass changes with using absolute and relative gravity measurements between 2006 - 2011 in the Marmara Region. These measurements help us to determine the anomalies about the vertical crustal deformation in the Marmara Region. Also, the absolute gravity measurements are carried out for the first time using the only A10 meter in the country after 17 August 1999 Izmit earthquake in the Marmara Region.

Keywords: NAF, GNSS, InSAR, gravity, deformation

Paleoseismicity in the Sea of Marmara: new insights from turbidite and authigenic carbonate crust studies

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Long-term paleo-earthquake history of faults over several seismic cycles is important for probabilistic earthquake risk assessment. Mass-flow (turbidite) sedimentary units triggered by seismic activity and authigenic carbonate crusts and mounds located along the submerged North Anatolian Fault System (NAFS) constitute important archives of paleoseismic activity.

A considerable part of the sedimentary succession of the deep Marmara basins consists of mass-flow units that are mainly triggered by earthquake shaking. These units were studied in tens of cores recovered from various locations along the different segments of the NAF's northern branch (the Main Marmara Fault), using high resolution digital X-Ray Radiography and µ-XRF Core Scanner, MSCL physical properties and grain-size analyses. The chronology was determined using AMS radiocarbon and radionuclide methods. The mass-flow deposits triggered by earthquakes, including the 1999 İzmit Earthquake record in the İzmit Gulf, essentially consist of a turbidite (T) part characterized by multiple sand-silt laminae above a sharp and often erosional base and a homogenite (H) part consisting of homogenous mud, with the two parts forming a turbidite-homogenite unit (THU). The basal turbidite parts of the THUs have high gamma density and magnetic susceptibility, and are often enriched in one or more elements indicative of coarse detrital input (Si, K, Fe, Zr, Ti) and/or high carbonate shell content (Ca, Sr).

Radionuclide and radiocarbon dated THUs in different basins of the SoM can be confidently correlated with historical earthquake records. The sedimentary records measured over more than 5000 yrs provide average earthquake recurrence time between 200 and 300 yrs for the various segments of northern branch, and 1000 yrs for the middle NAF branch in the Gemlik Gulf. These results are compatible with GPS velocities. However, the intervals between two consecutive events vary widely between 90 to 1500 years for the different northern NAF segments. The western High and Central Basin records suggest that the 1912 earthquake rupture is unlikely to have reached beyond Western High into the Central Basin.

The NAFS in the SoM is characterized by extensive seafloor authigenic carbonate crusts, which occur as pavements, mounds and chimneys. They are often covered or surrounded by patches of black Fe sulfide-rich sediments and fluid emissions. The fluids are hydrocarbon-rich gas and brackish-water in the deep basins and saline formation waters and thermal hydrocarbon gas and oil from mud volcanoes and anticlines on the compressional highs. Various lines of evidence indicate that the seafloor authigenic carbonates are formed by the anaerobic oxidation of methane (AOM) at or near the seafloor, as result of high methane flux, possibly during periods of high seismic activity. Although, the available U/Th ages of carbonate crusts along the NAFS cannot be specifically matched with the historical earthquakes authigenic carbonates can be considered as paleoseismic archives, provided that they are sampled in detail, with a careful consideration to the paragenetic relationships and with each phase separately analysed for U/Th dating and isotope and biomarker analyses.

Keywords: Paleoseismology, Sea of Marmara, North Anatolian Fault, homogenites

Active faults and their seismogenic potential along the submerged portion of the North Anatolian Fault in NW Turkey

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Using high-resolution multibeam and seismic reflection data collected during several cruises onboard R/V Urania, we compiled a new morphotectonic map of the submerged portion of the North-Anatolian Fault system (NAF) in Sea of Marmara and NE Aegean Sea, NW Turkey. Data analysis allowed us to recognize the active fault segments and their activity over the last 12.5 ka, taking the base of the latest marine ingression as a stratigraphic marker horizon. In fact, this event is marked in the sedimentary record by a clear stratigraphic boundary, since the Sea of Marmara was a fresh water lake during the late glacial, and switched to a marine environment after the Holocene transgression, as demonstrated by stratigraphic analysis of numerous sediment cores and observed in high-resolution seismic profiles. Considering the average recurrence time (0.2-0.3 ka) of major (M>=7) earthquakes along each segment of the NAF, the time interval of 10 ka includes several earthquake cycles and should be considered representative of the seismotectonic behaviour of the fault at geological time scales. Given the relatively high deformation rates relative to sediment supply, active tectonic structures often display a morphological expression at the seafloor. This allowed us to correlate deformations between seismic sections. However, in areas densely covered by seismic reflection profiles, we used pseudo-3D techniques to image the complex fault geometries typical of strike-slip tectonic environments, and produced "time-slice" representations at different stratigraphic levels. Fault strands unaffecting the Holocene sequence were considered inactive. Three types of deformation patterns were observed and classified: almost purely E-W oriented strike-slip segments; NE-SW oriented transpressional structures; NW-SE trending trans-tensional features. The Gulf of Saros, in the NE Aegean Sea and the Gulf of İzmit in the eastern Sea of Marmara, the sites of major destructive events in the past century, delimit a series of pull apart basins in the north of the Sea of Marmara. Here, the most active northern NAF branch, the so-called Main Marmara Fault, appears segmented, and the length of each segment controls the maximum expected magnitude of future earthquakes affecting the Istanbul Metropolitan area. Segmentation of the Main Marmara Fault in the Sea of Marmara develops along three main right-lateral oversteps delimiting three major fault branches, from E to W: the transtensive Çınarcık segment; the Istanbul (East and West) segments; and the westernmost Tekirdağ segment. For each segment, a quantitative morphometric analysis was carried out, in order to define the prevailing deformation style and cumulative length. These data were used as inputs in empirical relationships to calculate the maximum expected Moment Magnitude for each NAF segment, obtaining values in a range from 6.82 to 7.14 for the Istanbul segment, and 6.85 and 7.08 for the Çınarcık and the Tekirdağ segments, respectively. Such estimates are in agreement with historical earthquake record of the Sea of Marmara region.

Keywords: Sea of Marmara, North Anatolian Fault, active faults, seismogenic potential

The slip deficit along the North Anatolian Fault (Turkey) in the Marmara Sea: Insights from paleoseismicity, seismicity and geodetic data

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The North Anatolian Fault experienced large earthquakes with 250 to 400 years' recurrence time. In the Marmara Sea region, the 1999 (Mw = 7.4) and the 1912 (Mw = 7.4) earthquake ruptures bound the Central Marmara Sea fault segment. Using historical-instrumental catalogue and paleoseismic results (≃ 2000-year database), the mapped fault segments, fault kinematic and GPS data, we compute the paleoseismic-seismic moment rate and geodetic moment rate. A clear discrepancy appears between the moment rates and implies a significant delay in the seismic slip along the fault. The rich database allows us to identify the size of the seismic gap and related fault segment and estimate the moment rate deficit. Our modeling suggest that the locked Central Marmara Sea fault segment even including a creeping section bears a moment rate deficit $\dot{M}_d$ = 6.4*10^{17} N.m./yr. that corresponds to Mw ≃ 7.4 for a future earthquake with an average ≃ 3.25 m coseismic slip. Taking into account the uncertainty in the strain accumulation along the 130-km-long Central fault segment, our estimate of the seismic slip deficit being ≃ 10 mm/yr implies the size of the future earthquake ranges between Mw = 7.4 and 7.5.

Keywords: North Anatolian Fault, Paleoseismicity, earthquake catalogue, geodesy, slip deficit

Dynamics and radiation of earthquake rupture on multi-scale geometrically complex faults

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Geological faults comprise large-scale segmentation and small-scale roughness that govern earthquake processes and associated seismic radiation. Standard techniques for seismic hazard assessment for such faults (or fault systems) are insufficient, but numerical simulations for multi-scale geometrical complex faults help to shed light on rupture dynamics and seismic radiation of such systems.

In my presentation, I will discuss recent work to understand effects of large-scale segmentation and small-scale roughness on rupture evolution and near-source shaking. Using numerical simulations, we find that rupture incoherence due to fault roughness leads to high-frequency spectral decay consistent with observations. Waveform characteristics and comparisons with empirical ground-motion relations show that rough-fault rupture simulations generate realistic synthetic seismogram that can be used for engineering applications. We also show that for segmented faults, the spatial distribution of the regional stress is of critical importance as it determines the initial stress on the fault system. Similarly, the rupture nucleation point has significant impact on the resulting rupture process and earthquake size. Consequently, seismic hazard assessment for such fault systems must include more earthquake physics to capture the possible near-source shaking levels of future earthquakes.

For future earthquakes in the Marmara Sea, we expect large-magnitude events that may rupture two or more fault segments. I will review the work of Oglesby and Mai (2012) and others to better understand the dynamic rupture and seismic radiation for a set of selected scenarios occurring inside the Marmara Sea. In the light of recent work on rough-fault dynamic ruptures I will outline future research needed to better quantify the possible shaking levels for Istanbul and around the Marmara Sea.

Keywords: earthquake physics; earthquake rupture dynamics; seismic radiation; seismic hazard

Fluid emissions at the seafloor and their relationship with strain and damage along faults

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Faults are known to focus the emissions of fluids (gas, interstitial water and/or oil) through the seafloor. Our objective is to understand whether, and how, these emissions could relate to damage processes around faults. In order to characterize the influence of faults, the distribution of distances between emission sites and faults is compared to the distribution of distances for a uniform distribution of points (generated through a Poisson process) associated with the same faults. This analysis was performed with acoustically detected gas plumes in the water column along the North Anatolian fault zone in the Sea of Marmara and with pockmarks in a gravity driven system on a part of the Niger prodelta affected by listric faults and mud diapirism. In both cases, the fraction of seeps that are closer to fault outcrops than expected from a uniform distribution is 20 to 25%. However, the distance to the fault defining the zone where seeps are more abundant varies between locations, being 1 km in average in the Sea of Marmara and 200 m on Niger prodelta. Along the North Anatolian Fault, the width of the fluid emission zone relates with the width of the zone were seafloor deformation is observed in high-resolution geophysical surveys (seismics and AUV seafloor mapping). These zones are typically wider than crustal damage zones for which half-width rarely exceeds 500 m. On the Niger prodelta, pockmarks associated with listric faults are systematically found on the footwall rather than on the fault outcrop suggesting gas escapes straight up from the fault through the last few hundred meters of sediment beneath the seafloor. Another important observation is that focussed emissions are found on fault segments that creep aseismically, suggesting that progressive deformation is as effective as earthquakes to maintain fault zone permeability. In contrast, the locked segment off Istanbul, which has not ruptured since at least 1776 has very few associated fluid emissions. Observations also suggest that the width of the zone around faults in which permeability is increased is wider in marine sediments than at crustal level and that its width may depend on sediment properties as well as fault throw. On the other hand, if the permeability difference between the fault damage zone and the formation decreases toward the seafloor, fluid channelling within the fault zone would become inefficient above some depth, and this could contribute to widen the zone of fluid emissions at the seafloor. Nevertheless, a parallel may tentatively be drawn with co-seismic deformation and surface damage observed on land after earthquakes. Maps of surface damage produced from SAR data by ARIA JPL team or maps of surface ruptures obtained by field mapping or image correlation methods delineate a deformation zone of variable width along the rupture zone of the Ridgecrest earthquake. This zone has a typical width of about 2 km in the flat lakebed of Indian

Wells Valley, comparable to the width of seafloor deformation zones in the Sea of Marmara. The zones of deformation may also be compared with the distribution of shallow aftershocks observed after earthquakes both in the Sea of Marmara and Ridgecrest case.

Keywords: fluid emissions, fault permeability, damage zone, seafloor deformation zone

The significance of episodic creep within the fault zones of Anatolia and California

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In 1972, a few years after it had been discovered in California, aseismic surface slip was found to have offset the North Anatolian Fault at Ismetpasa. The smoking gun was a 13 cm offset of an otherwise perfectly straight wall constructed across the 1944 Bolu Mw=7.5 surface rupture, 13 years after the earthquake. A sub-pixel analysis of sequential photos of this iconic offset taken by visitors in the past 45 years reveals that the wall is now offset 52 cm but that the rate of aseismic slip has reduced from 10 mm/yr to roughly 6.5 mm/yr, most of which occurs in 2-3 mm creep events at monthly to yearly intervals. Creep has offset numerous other cultural features in the village of Ismetpasa, buckling the steel crash-barrier of the newly constructed road, severing houses, and offsetting field boundaries. Episodic creep with 1-5 mm amplitudes has now been quantified at 6 locations in Ismetpasa and for tens of km to the east. The 1999 Izmit rupture continues to creep episodically in small events and a strainmeter array surrounding Istanbul shows episodic creep occurs on submarine faults beneath the Sea of Marmara, south of the city.

Numerous similarities are apparent between surface creep processes on the Anatolian faults and faults of the San Andreas system in California. Creep occurs on some fault segments and not on others irrespective of their seismogenic potential: creep events suggest slip to depths of a few km, creep events occasionally propagate along the fault and creeping segments in California and in Anatolia are both frequently associated with serpentinite. But there are differences. As yet triggered slip has not equivocally been reported from the Anatolian faults although it is common in California.

Recent results from California suggest that fault zone foliation may control episodic creep properties, and that the details of strike slip faults are poorly modeled as two elastic blocks bounding a narrow gouge zone. Following the 2019 Ridgecrest earthquakes creep events were associated with contraction of the fault zone. Phacoidal foliation with lozenge-shaped 1-20 cm clasts bounded by polished surfaces)in the California fault zones may have developed as a result of cyclic shear strains associated with episodic creep. It is also possible that this foliation is responsible for moderating episodic creep. Phacoidal foliation has been found in the Ismetpasa region. Given the difficulties of laboratory studies of macroscale foliation the surface fault zones of Turkey and California provide in-situ laboratories for the study aseismic slip processes.

Keywords: Aseismic slip, Creep, North Anatolian Fault, San Andreas Fault

Creeping and locked segments along the Main Marmara Fault

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The North Anatolian Fault (NAF) poses a significant hazard for the large cities surrounding the Marmara Sea region particularly the megalopolis of Istanbul. Indeed, the NAF is presently hosting a long unruptured segment below the Sea of Marmara. This seismic gap is approximately 150 km long and corresponds to the Main Marmara Fault (MMF). We analyzed here in detail the seismicity along the Main Marmara Fault (MMF) below the Marmara Sea. First, we studied the 2007-2012 period and, from high precision locations, we showed that seismicity is strongly varying along strike and depth providing fine details of the fault behavior that are inaccessible from geodetic inversions. The activity strongly clusters at the regions of transition between basins. The Central basin shows significant seismicity located below the shallow locking depth inferred from GPS measurements. Its b-value is low and the average seismic slip is high. We also evidenced nine long-lasting strike-slip seismic repeaters below the Central Basin within the seismogenic zone, in a 10 km region consistently with a deep creep domain along the MMF. The typical recurrence time of the repeaters is 8 months during the 2008–2015 period. Their cumulative slip appears to be compatible with the regional geodetic slip rate if they are assumed to be part of a large single asperity (10 km). The repeaters also exhibit short-term crises and are possibly related to bursts of creep. The Kumburgaz basin at the center of the fault shows on the contrary, sparse seismicity with the hallmarks of a locked segment. The assessment of the locked segment areas provide an estimate of the magnitude of the main forthcoming event to be about 7.3 assuming that the rupture will not enter significantly within creeping domains. In the eastern Marmara Sea, the seismicity distribution along the Princes Island segment in the Cinarcik basin, is consistent with the geodetic locking depth of 10km and a low contribution to the regional seismic energy release. Second, using a template matching technique, during the 2009-2014 period, we enriched the description of the time and space evolution of the seismicity in the Marmara Sea region. The template database is shown to be a new framework for the long term monitoring of specific remanent structures like seismic swarms or repeating earthquakes. We confirmed the existence of both families of repeaters: a first family that typically belongs to aftershock sequences and a second family of long lasting repeaters with a multi-month recurrence period. The new catalog confirms the strong contrast of behaviors along the Main Marmara Fault (MMF): deep creeping to the west (Central Basin), fully locked in the center (Kumburgaz Basin) and dominated by fluid and off-fault activity to the east (Cinarcik Basin).

Keywords: Long-term seismicity monitoring, seismic repeaters, template matching

Seismic tomographic image of the ruptured fault during the 1999 Marmara Earthquakes

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The broken segments of the NAF during 1999 Marmara earthquakes show significant complexities but also provide new insights on the mechanics of the interactions, geometry and dynamics of the rupture process. The local seismic tomography of the ruptured fault segments during 1999 Marmara earthquakes is an attempt to decipher some of the observations such as aftershock seismicity, supershear rupture, strain partitioning and termination of the ruptures. Can we relate some of these observations to seismic velocity distribution (lithology) and the fault zone parameters (thickness and shear modulus) ? Can these inferences help us better characterize the unbroken segment of NAF beneath the Marmara Sea ?

We re-compiled the seismic data during 1999 aftershock periods from various agencies and research groups. More than 290 seismic stations and 15,000 earthquakes are relocated along 200 km long ruptured fault. We computed P wave velocity distribution within 20 km range of the fault zone. Large velocity perturbations are observed from local basins. Preliminary results show relatively large velocity contrast across the supershear segment of the Izmit rupture. The thickness of the fault zone is varying along the 200km rupture zone. The terminations of the Izmit rupture take place at geometrical devitiations of the fault trace which is correlated well with the lithologic variations.

Keywords: Marmara, Seismic Tomography

Relation of seismicity and interseismic strain accumulation along the North Anatolian Fault in the Marmara Region

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The recent studies based on geodesy and seismicity reveal number of evidences that the interseismic strain accumulation along the North Anatolian beneath the Marmara Sea is heterogeneous. One critical question is how the background seismicity relates to the strain accumulation and whether seismicity maps can be used to infer seismic gaps. The 2014, Mw6.9 Gökçeada-Samothraki earthquake provides an opportunity to compare co-seismic slip with the seismicity during the interseismic period and the post-seismic period. The comparison shows that the seismicity during the interseismic period surrounds the coseismic slip showing that asperities persist during the seismic cycle and locked regions do not generate significant amount of seismicity.

This creates an opportunity to use the seismicity as a proxy for interseismic behavior on the Main Marmara Fault. On that regard, we built a finite-element model of the Marmara region considering the 3D nature of the faults and structure. Using the geodetic data and constraints from seismicity, we infer that there is a possible zone of partial creep along the Tekirdag Basin while Ganos segment is fully locked. On the other hand, with the current datasets it is more challenging to constrain the strain accumulation along Eastern Marmara. Finally, we performed spontaneous dynamic rupture scenarios based on the historical earthquakes and strain accumulation after the last event using previous calculations of slip rates and interseismic locking.

Keywords: Marmara, Strain accumulation, Interseismic Seismicity, Earthquake Slip Distribution, Dynamic Rupture

Highlighting the triggering of seismicity in the Eastern Sea of Marmara: What are the possible mechanisms?

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Different types of earthquake interactions and triggering are commonly observed, involving different temporal (e.g. short-term or delayed) and spatial scales (e.g. regional or remote), and in some cases involving slow energy release. The short-term and short distance triggering, the best example of whom being the aftershocks, is well explained by an increase of the Coulomb stresses produced by the main earthquake rupture. However, few observations of the other types are yet available, and thus their mechanisms are not yet well understood. To better comprehend the mechanisms driving the triggering of seismicity and earthquake interaction around the Eastern Sea of Marmara, we combine different types of available observations, including seismic data, GPS and strainmeter measurements.

This study reveals the existence of seismicity triggered by both distant earthquakes and by localized slow slip events in the Eastern Sea of Marmara region. First, a clear increase of the seismicity rates and moment release is observed following two M>6 earthquakes in Greece in 2008, and a M6.9 earthquake in the Eastern Aegean Sea in 2014. A first hypothesis is that these events could have triggered a large-scale slow deformation episode that had in turn triggered seismicity remotely, while propagating. Interestingly, the seismicity from the Western part of the Marmara Sea does not exhibit any sensitivity to these earthquakes. In the Eastern Sea of Marmara, the Middle Branch of the North Anatolian Fault (NAF), west of the Izmit rupture, and the Armutlu Peninsula are the more responsive regions.

The seismicity from these regions appears also to be sensitive to local slow-slip events. We observe an increase of the seismicity mainly on the Middle Branch concomitant with two slow slip events in June and November 2016 (Martinez-Garzon et al. 2019 and Aslan et al. 2019). We also reveal an increase of seismicity on the Armutlu Peninsula and on the NAF branch south of Istanbul in October 2016, raising the question of the migration of the June slow slip event, or the existence of a third slow slip event in the region not detected previously. Finally, computing the focal mechanisms of the largest triggered events (M>4) we highlight that normal faulting events are more responsive to seismic and aseismic excitation than strike slip ones.

The different response of various regions in the Marmara Sea to remote earthquakes and slow slip events is really intriguing. One hypothesis is that depending on the state of the faults in their seismic cycle, the seismicity in these regions is more or less responsive to small excitations. Understanding the mechanisms of earthquake triggering and their link with the proximity of the faults to failure is particularly important to better assess seismic hazard in a given region.

Keywords: earthquake triggering, slow slip

A synthesis on fault geometry, earthquake rupture and fault creep along the Main Marmara Fault

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The westward propagation of eight M>7 earthquakes along the North Anatolian Fault (NAF) since 1939 is one of the most well-known rupture series of an active continental transform fault within the instrumental period. This well-known sequence is now pending on its western end where the Mw 7.4 1999 Izmit earthquake rupture ended offshore within the Sea of Marmara. High-resolution geophysical and bathymetric data reveal that northern NAF is segmented within the crustal scale Sea of Marmara basin. Transtensional submerged segments of the NNAF (also known as Main Marmara fault), control a number of basins and highs (Çınarcık, Kumburgaz, Central and Tekirdağ basins; Eastern and Western Highs) creating different segment boundaries for rupture propagation. Recent seismological studies (especially the seismic repeaters) suggest that while the Western segment crossing the Central and Tekirdağ basins is creeping, Central High and Princes Island segments are in a locked status. Such a scenario may review the earthquake rupture assessments made for the NNAF for several reasons: 1) Can creeping sections of the Main Marmara fault provide a barrier for the locked segments? 2) Can creeping section accumulate stress to be released in future large earthquakes or postpone their probability by releasing stress aseismically?

To better estimate if a creeping segment will participate in large seismic events, it is crucial to assess reliable paleoseismic records associated with past rapid slip events. Most well-known M>7 historical earthquakes associated with Main Marmara fault are 1509, 1719, May 1766, August 1766, 1894 and 1912 Ganos earthquakes. Previous rupture scenarios associated the 1912 and August 1766 earthquakes with the Western segment, 1509 and May 1766 with Central High segment, and 1894 with Princes Island segment. Our observations based on high-resolution microbathymetry and sediment cores with C^{14}, Pb^{210} dating show evidence of the 1912 and August 1766 earthquakes rupturing the Western segment up to the Central Basin. Well preserved submarine fault scarps that are mapped along this segment combined with records of earthquake triggered sediments (seismoturbidites) propose an eastward continuation for the 1912 Ganos rupture. Since this section of the Main Marmara fault suggested to be creeping, geologic evidence of large earthquake ruptures show that large slip events can still occur along potentially creeping segments. Similar to Ismetpasa section of the NAF fault which is also creeping prior to 1944 earthquake, observed micro-seismicity along the Western segment can be an afterslip effect of the 1912 earthquake hence pointing out to interseismic creep. On the contrary to Western segment, Central High segment exhibit no exposure of fresh fault scarps and has sparse micro-seismicity. Analysis of seismoturbidites from interface sediment cores from Kumburgaz Basin provide the record of the 1509 event in this section.

This study aims to discuss the distribution of paleoseismic sediment records along different fault segments combined with current understanding of segment boundaries of the Main Marmara fault based on several geological, geophysical and geodetic datasets.

Keywords: North Anatolian fault, Marmara Sea, segment boundaries, fault creep, seismoturbidites

Dynamics of geofluids along the seismically active North-Anatolian Fault Network (Sea of Marmara, Turkey)

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The North Anatolian Fault (NAF) Network, *i.e.* NAF and inherited faults, correspond to a highly active continental plate boundary, and is characterized by significant emissions of geofluids from different sources. The geofluids are gas or pore waters with, locally, a minor component of liquid hydrocarbons. The gas emissions are made of numerous gas streams of variable flowrates, and have a heterogeneous spatial distribution. It has been shown from visual observations during ROV dives that the inception, lifetime and intensity of the gas streams may be strongly influenced by small perturbations like the landing of the ROV or the sampling operations. Thus, it is likely that stronger perturbations, like those induced by the seismic activity of the faults, have significant impacts on the gas emissions.

Besides, the chemical nature of the pore waters is strongly affected by both sediment/ pore-water and gas/pore-water interactions. In the sedimentary column, processes like clay dehydration, Anaerobic Oxidation of Methane (AOM), sulfate reduction, organic matter degradation are taking place, depending on the availability of the species and their related fluxes.

Geofluids collected at several segments of the North Anatolian Fault Network have been analysed to decipher gas sources, fluxes of discharges at the seafloor, and the geochemical reactions that leads to very diverse pore water compositions. Here, we present the geochemical results and their interpretations. An attempt to draw possible relationships between fluid activity and seismic history of the area is also proposed.

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Keywords: North Anatolian Fault Network, Sea of Marmara, geofluids

Buoyed observatory for permanent, sustainable monitoring of geological hazards in the Sea of Marmara: The MAREGAMI Concept

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A new concept of seafloor observatories for geohazard monitoring in the Sea of Marmara is proposed with the ANR/Tubitak* collaborative project, which consists in 3 components: i) a sea-surface « buoy » for data transmission to land and for the permanent production of electrical power (50 W-24h/24) from solar panels ; ii) three mooring lines and an umbilical for electrical power and data transfer from sea-bottom to surface; iii) a central node equipped with a broad band OBS and one bottom pressure gauge, connected to 4 remote, short-period OBSs, located 5 km away. Each Maregami system allows the deployment of 5 (4+1) seismic stations of the seafloor, covering a circular area, having a radius of ~ 10 km. This concept thus allows the development of networks of networks, which results in the multiplication of seismic sensors, at relatively low costs compared to the fully cabled observatories. In contrast, the deployment of the « buoy » option could be limited by possible interactions with maritime traffic in the Marmara Sea. Critical issues, on regulation constraints and funding possibilities, will be addressed by the Turkish partners during the second the second phase of the Maregami Project.
Here, we describe the specific marine operations required for the lay-out of up to 10 km long cables on the seafloor.

ANR Reference: ANR- 16-CE03-0010 ; Tubitak Reference: 116Y371

Keywords: Sea of Marmara, OBS, seafloor observatories

Tsunami scenarios for the Sea of Marmara based on dynamic rupture simulations

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Seafloor displacements from three different dynamic rupture simulations are used to numerically model Tsunami waves in the Sea of Marmara. The dynamic ruptures scenarios are based on a finite-difference algorithm and a 3D model of the local crustal structure is used in the simulations. Characteristics of probable earthquake scenarios are strongly dependent on the hypothesized level of accumulated stress, in terms of a normalized stress parameter. Up to now, almost all models for Tsunamis in the Sea of Marmara have been based on hypothetic sources rather than physics-based earthquake cycle models. We treat the sources as "instantaneous" and model the resulting nonlinear wave field using a finite-element shallow-water algorithm through a triangular mesh.

Keywords: Marmara, Tsunami, Finite Element

Probabilistic tsunami hazard assessment for Tuzla, Istanbul in the case of Prince Islands Fault Rupture

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Tuzla is one of the coastal district of megacity Istanbul. The region is important not only it contains several residential areas but also it has the biggest shipyard area in whole Marmara Sea region. Moreover, proximity of the Prince Islands to the Tuzla region, increases the earthquake and tsunami vulnerability of the region. The North Anatolian fault zone controls the main part of the seismicity in the region and the main characteristic of the fault zone is earthquakes systematically propagates from east to west. After the 1999 Izmit Earthquake, the around 160 km long part of the northern branch of the North Anatolian Fault Zone ,inside the Marmara Sea, has been accumulating energy since the 1766 event (Ambraseys, 2002, Bohnhoff et al., 2013, Bulut et al., 2019). This fault zone generates an earthquake with the recurrence interval of about 250 years and rupture possibility of this fault was estimated 35-70% in the following 30 years in 2004 (Parsons, 2004). Recent studies revealed that PIF, which is around 33 km long part of silent of NAF, is most likely to generate an event with the magnitude M > 7.0 (Ergintav et al., 2014).

The historical documents show that the Marmara Sea region has been experienced 35 tsunami events in the years between BC 330 and 1999. Due to the these circumstances, Istanbul with the 16 million population is under the threat of high damage because of this possible big earthquake and triggered tsunamis.

This study associates the probabilistic approach with tsunami numerical modelling. In the light of the previous studies, related with the geometry and the fault parameters of the PIF, some estimations have been done and tsunami numerical modelling has been performed. The results of the study show that tsunami wave heights up to 1 m have 65% probability of exceedance for the next 50 years and this value reaches up to 85% in Tuzla region for next 100 year. Moreover, probabilistic inundation maps are revealed that probability of exceedance of 0.3 m wave height, ranges between 10% and 75% and the maximum inundation distance calculated among entire earthquake catalogue is 60 m in this test site. The results at the synthetic gauge points, which are selected along the western coast of the Istanbul by including Tuzla coasts, show high probability exceedance of 0.3 m wave height, which is around 90%, for the next 50 years while this probability reaches up to more than 95% for the next 100 years.

Keywords : PTHA, Marmara Sea, Tsunami Numerical Modelling

Preliminary results on the September 26th, 2019, Mw 5.8 Marmara Earthquake

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The September 26, 2019 earthquake (Mw 5.8) in the Marmara Sea occurred near the transition zone from the partially creeping segment of the Central Marmara to the locked segment of Kumburgaz. The preliminary earthquake mechanism is primarily strike-slip with a significant reverse component. The aftershock distribution appears to be~ 4 km on the north of the Main Marmara Fault fault trace observed at the sea bottom topography. The activity lasted few days and faded out.

We revised the earthquake source mechanism solutions using regional waveforms and relocated main shock and aftershocks. The mainshock has a strike-slip source mechanism with a dip angle of ~70^{o} toward north with a reverse component. The analysis indicates that the earthquake is close to the western end of the Kumburgaz segment but not on the Main Marmara Fault. The aftershock locations and the sea floor morphology show that the mainshock and the related aftershock activity took place on the northern flank of the Central Basin, approximately sub-parallel to the MMF. The strike of the earthquake and aftershock distribution have an orientation of WNW-ESE consistent with the geometry of the northern flank of the basin. Based on the aftershock distribution and near field seismic data it is concluded that the earthquake ruptured unilaterally toward the east. Considering a causative fault plane based on seismicity distribution and using scaling laws for slip and area, calculation of Coulomb stress change on the Main Marmara Fault shows both regions of stress decrease and increase.

Keywords: Creep, Fault Locking, Stress Perturbation, Stress Increase

Locking behavior of the active Main Marmara Fault during interseismic period

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During the last century, the North Anatolian Fault (NAF) produced series of M>7 earthquakes that mostly migrated to the west, but the only region that did not break during this period is beneath the Sea of Marmara. The Main Marmara Fault, the northern branch of the North Anatolian Fault in the Marmara Region, is the most active one in this region. The main Marmara Fault's interseismic behavior under the Sea of Marmara in terms of estimation of locking depth and fault slip rate provides information about the moment deficit that may occur during a future earthquake, and thus the seismic risk of Marmara Region, which has a population of 24 million, can be evaluated.

In this study, we modeled the interseismic locking of MMF by utilizing interseismic GPS velocities and applying 3D finite element analysis. Our kinematic model has a realistic 3D fault geometry and each fault section slides at a fault slip rate below a locking depth of 0 (unlocked) to 20 km. By simply changing the depth of interseismic locking, we improve the model estimated velocities with the GPS velocity data. Preliminary models reveal that a difference in locking depth is required between the Central Segment and the eastern end of the Ganos Segment entering the Sea of Marmara. This result, which is consistent with seismicity studies and other previous studies using 1D profiles, shows that the strain accumulation under western Marmara is less and that the locking depths or couplings are not similar in these two segments. For the Princes' Islands Segment, further analysis is required due to complexity in the GPS data. Our results show that in most cases the change in the seismicity of each component is consistent with the interseismic behavior associated with its fault locking.

Keywords: Interseismic, Locking, Marmara

Recording and modeling of water column oscillations in the Sea of Marmara

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Resonant oscillations (also known as seiches) in closed basins may be triggered by earthquakes and landslides and result in larger tsunamis amplitudes that in the open ocean. Moreover, seiches cause oscillatory currents at the seafloor that can influence sediment resuspension and deposition after earthquakes. In the Sea of Marmara, the periods of the resonant oscillations typically fall in the range of long period sea waves (5-200 min), which suggests smaller amplitude ones may be triggered by meteorological events. In order to better constrain tsunami models, an attempt to detect resonant oscillations and measure their frequencies, amplitudes and decay time, was planned as part of MAREGAMI ANR-TUBITAK collaborative project and EMSO-France activities. A bottom pressure recorder and a doppler current meter are being deployed at successive locations in the Sea of Marmara for periods of about 6 months. We here present results of our first two deployment session (Feb. 2018 to Aug. 2018 in Kumburgaz basin, Nov. 2018 to May 2019 in Cinarcik Basin) and re-examine data from an older record in Tekirdag basin. Tidal oscillations with ≈12 hours and ≈24 hours dominant periods are observed with maximum amplitudes of 10 cm (10 hPa) crest to crest as well as 1-to-5-days intervals with higher frequency oscillations of centimeter amplitude. The frequency spectra differ depending on sensor location. Common peaks are found at periods ca. 185, 145, 107, 78, 48, 40 minutes. These periods match some of the resonance modes previously determined by numerical experiments (Yalciner and Pelinovsky, 2007). We will present the newly acquired data and discuss their interpretation based on their correlation with atmospheric data and on 3D numerical modelling implemented using the code CROCO.

Keywords: hydrodynamics, bottom pressure records, seiche, standing waves

Holocene earthquake history of central high segment of the NAF in the Sea of Marmara: A comprehensive approach to turbidite paleoseismology

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Acquisition of long-term earthquake records on active fault systems is essential for hazard assessment and fundamental in active tectonic studies, and paleoseismic datasets provide crucial information to extend these records beyond historical knowledge. The field of submarine paleoseismology has been rapidly evolving in the recent years with increasing interest for earthquake-triggered turbidite deposits (seismoturbidites). However, distinguishing the homogenite part of seismoturbidites deposits from background sediments can be rather a difficult task. In this study, we examined sediment cores using multi-parameter proxies, including anisotropy of magnetic susceptibility in order to provide distinctive characterization of the seismoturbidites. The anisotropy method allows to determine more accurately the boundaries between turbidite-homogenite (TH) units and background sediments and to construct more reliable age-depth models for correlation with historical earthquake records. Moreover, magnetic susceptibility lineation can be an indicator of paleo-flow orientations. Here, a complete Holocene TH history is examined for the first time for the Central High Segment of the Northern North Anatolian Fault (NNAF) based on a 21-m-long calypso core (MRS CS-14) which was recovered from Kumburgaz Basin (~-833 m) in the Sea of Marmara during MARSITE Cruise in 2014. CS-14 covers a Late Pleistocene (~15 ka BP) and Holocene succession of lacustrine and marine facies. The lacustrine-marine transition is observed at ~18 m and lower and upper Holocene sapropels between 8-14 m and 2-6 m respectively. Core CS-14 consists of continuous “background” hemipelagic/lacustrine sediments that are interrupted by 71 TH units. The marine sequence contains 63 TH units and 8 of the TH units are detected within the lacustrine section. An event free age-depth model of the core produced by using 4 AMS ^{14}C ages and 5 stratigraphic horizons (L-M transition, onsets and termination of Holocene sapropels) suggests ~200-250 years of earthquake recurrence interval. These 71 seismoturbidite units that are deposited in the Kumburgaz basin resulted from the triggering effect of the earthquakes produced by Central High Segment or adjacent fault segments of the NNAF, showing the intense and continuous activity of the NNAF in the last ~15 ka BP.

Keywords: North Anatolian Fault, Kumburgaz Basin, Seismoturbidites, Anisotropy of Magnetic Susceptibility

New block and continuum models for the Sea of Marmara kinematics using GPS, geologic slip rate and underwater geodetic data

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The Sea of Marmara has been the focus of numerous marine-geophysical studies during the last couple of decades. These efforts were very instrumental in shedding light on the geometry of the principal fault system of this region. While the geologic slip rates are largely unknown within the sea, they became somewhat better known on land, to the east and to the west of the Sea of Marmara during the last decade. Recently two under-water geodetic studies were carried out and, although they did not provide additional kinematic data with respect to an absolute frame of reference, they did produce some clues about the the state of the fault locking in two different locations. Lack of geodetic data forced researchers to produce mostly very simple one-dimensional kinematic models of single fault segments using on-shore GPS measurements. In this study we are using two different groups of block architectures to obtain a best-fitting kinematic field of the region using both geologic slip rates (where they are available) and GPS measurements. We also use recently-available locked-versus-creep arguments for two separate fault segments, coming from the underwater geodetic measurements, to further constrain the inversions. We then compare these results with a group of continuum kinematic models where the strain rates are allowed to vary spatially.

Keywords: Marmara, Kinematic Models, GPS, Underwater Geodesy

Characteristics of the North Anatolian Fault on the Hersek Peninsula based on integrated onshore and offshore investigations

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The northern branch of the North Anatolian fault (NAF) presents the greatest natural hazard for the Marmara Megapolis and specifically the İstanbul Metropolitan area. The Sea of Marmara section of the NAF is a ~180-km-long seismic gap bound by the M7.4 1912 Mürefte earthquake rupture in the west and M7.4 1999 İzmit earthquake rupture in the east. Terminations of these ruptures define the length of the seismic gap and consequently the magnitude and rupture extent of the expected Marmara earthquake. This study focuses on the western termination of the M7.4 Izmit surface rupture and integrates high-resolution onshore and offshore data from Hersek Peninsula and its vicinity in İzmit Bay to assess the seismic hazard risk for the Marmara region. Detailed geologic and geomorphic mapping, paleoseismic trenching, geophysical and geotechnical subsurface data and archeoseismologic investigations demonstrate that the M7.4 1999 İzmit earthquake did not rupture the surface and possibly died off at or east of the Hersek Peninsula due to structural complexity of the NAF at this location. A restraining bend and bifurcation of the NAF at Hersek peninsula suggests that this location might be a persistent asperity forming a surface rupture segmentation point since Pleistocene. Surface ruptures documented in paleoseismic trenches north of the Hersek Lagoon and an offset 6th century Byzantine aqueduct; however, suggests that this section of the NAF has ruptured the surface multiple times in the past and is highly likely to rupture again during the expected Marmara earthquake. The Byzantine aqueduct which crosses the projection of the NAF is offset 14 +/-1 meters and yields 13.6 +1/-3.5 mm/yr dextral slip rate indicating that the northern branch of the NAF accrues and releases the majority of the stress between Eurasia and Anatolian block in the Marmara region. If the ~180-km-long seismic gap between the 1912 and 1999 ruptures during a single event the expected Marmara earthquake can range between M7.3 and M7.6.

Keywords: North Anatolian Fault, Hersek Peninsula, Paleoseismology, Offshore geophysics, Archeoseismology

Isotopic characteristics of organic matters in the sediments from the Sea of Marmara

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Isotopic and elemental analyses have been conducted in core sediments from the Western High and the Çınarcık Basin in the Sea of Marmara, to investigate the origin of organic matter and their possible use in paleoceanographic studies.

δ18Obulk carbonate in the core MRS-CS-13 from the Western High increases steeply upward from -7.7‰ VPDB to -0.61‰ VPDB , indicating the incursion of the Mediterranean; while the comparatively uniform values of δ18Obulk carbonate (~ 0.92‰ VPDB) in the core MRS-CS-17 from the Çınarcık Basin implies that this site did not experience the lacustrine/marine transition.

High C/N ratios and light δ13Corg values in the sediment interval of 700 - 500 cmbsf of Core MRS-CS-13, which deposited in the period of transgression, suggest a high terrestrial input. The C/N decrease and δ13Corg increase upward indicate that the marine productivity grew toward the top of the lower sapropel. In the upper sapropel of this core, increasing C/N ratio and decreasing δ13Corg revealed more input of the terrestrial component. In the Unit 1 of core MRS-CS-17, gradual C/N ratio decrease and δ13Corg increase throughout the core imply growing in marine components.

Keywords: Sea of Marmara, palaeoceanography, lacustrine/marine transition

Geological structures in shallow marine sediments

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Geological structures, the deformations and ruptures, developed in shallow marine sediments are well recognized but not systematically reviewed. In this study, three kinds of structures in shallow marine sediments are summarized through literature investigation, including overpressure associated structures, sediment deformations, and sediment ruptures. The seepages, pockmarks and gas pipe are the structures associated with overpressure, which are generally induced by gas and/or fluid accumulation, migration and emission. The mud diapir and salt diapir are sediment deformations, driven by gravity slide, gravity spread, and differential compaction. The landslides, polygonal faults and active faults are sediment ruptures, which are developed by gravity, compaction force, and tectonic force, respectively. These structures are generally developed in the depth less than 1000 meters below seafloor (mbsf), being considered of playing significant role in the migration, accumulation and emission of hydrocarbon gas and fluid, as well as the formation of gas hydrate. Their formation mechanisms can be accredited to sediment diagenesis, compaction, and tectonic activities. The relationships between different structures, between structures and gas hydrate, and between structures and authigenic carbonates are also discussed.

Keywords: sediment deformations, landslides, faults, shallow marine

Analysis of the Northern Marmara Shelf by seismic data

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In 2007, multichannel seismic data and subbottom profiler were collected along the northern Marmara Sea by Dokuz Eylül University, Institute of Marine Sciences and Technology, aboard the R/V K. Piri Reis research vessel. In order to define the morphology, stratigraphy, recent sedimentation and structural geology of the northern shelf, 224 km of multichannel high-resolution seismic, 338 km of Chirp subbottom profiler data have been collected along the shelf. A 600 m long, 96 channel digital seismic streamer with a 6.25 m group interval and a generator–injector gun was used to obtain high-resolution seismic data. The Chirp data were collected using an over-the-side-mount transducer system operating at 2.75–6.75 kHz frequency band.

The high-resolution seismic datasets were used to define the recent sedimentation and Plio-Quaternary stratigraphy of northern Marmara shelf. Seismic data indicate that a thin cover of Plio-Quaternary unit (termed Unit 1) overlies the Miocene/Oligocene age older sediments (termed Unit 2). An erosional surface between Unit 1 and Unit 2 as a regional unconformity for the shelf formed during the last sea level low stand has been distinguished. Depending on the Chirp subbottom profiler data, Unit 1 is subdivided into two sub-units as Unit 1a for Holocene deposits accumulated after the last glacial maximum (LGM) and Unit 1b for fluvial sediments deposited during the last lowstand of the Marmara Sea. The thickness of the Holocene sediments is maximum at SW of Bosphorus outlet reaching approximately 32 m, in the Büyükçekmece Bay and along the coastal area between Silivri and Büyükçekmece.

After Holocene, average sedimentation rate of the entire northern shelf is calculated as 0.4 m/1000 yr for the last 12,000 yr. Acoustic data indicates that there are four depressions in the western part of the shelf, which are interpreted to correspond to palaeolakes during the LGM filled by Plio-Quaternary sediments. Analysis of Chirp subbottom profiler data suggests that the transition from lacustrine to marine conditions within the palaeolakes occurred when the Marmara Sea level exceeded −62 m threshold depth during the sea level rise following the LGM at approximately 12,500–13,000 yr before present (BP).

Keywords: Seismic stratigraphy, Neogene–Quaternary sedimentation, palaeolakes, Marmara Sea

TAMAM (Turkish American Marmara Multichannel) Project in Marmara Sea

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The Marmara Sea is composed of a set of submerged basins along the North Anatolian Fault (NAF) in Turkey. This 1500-km long fault is a major continental transform that ruptured in a series of destructive earthquakes in the 20th century. The only remaining seismic gap is the Marmara Sea near Istanbul, which constitutes a major seismic hazard.

TAMAM (Turkish American Multichannel Project) is a collaboration between several US and Turkish research institutes to study the tectonics of the Marmara Sea. First seismic data were acquired in 2008 in the frame of TAMAM and second data were collected in 2010 in the frame of TAMAM-2 (PirMarmara) onboard R/V K.Piri Reis. In the scope of TAMAM project a total of more than 3000 km high resolution multichannel data were collected. Multichannel seismic reflection profiles were collected in 2008 and 2010 using 72 and 240 channels of streamer with a 6.25 m group interval. The generator-injector airgun was fired every 12.5 or 18.75 m and the resulting multichannel seismic data has 10-230 Hz frequency band. To investigate the tectonic history of the Marmara Sea we undertook a research cruise on the Turkish research vessel to collect high resolution multichannel seismic data that we are using to obtain detailed images of the faults and the layers of sediment that record the tectonic history of the Marmara Sea. Although deep and shallow seismic data have been collected in the Marmara Sea in the past, high resolution seismic data with medium depth penetration was needed. With this project, it was possible to map the faults divided into different branches at medium penetration both inside the basin and in the whole Marmara Sea.

Keywords: Marmara Sea, North Anatolian Fault, seismic, TAMAM project

TH-2
ACTIVE TECTONICS OF ANATOLIA AND THE ADJACENT REGIONS

Distributed late Quaternary active faulting along the Southern Shelf of the Sea of Marmara, Central Branch of the North Anatolian Fault, Turkey

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The North Anatolian continental transform fault (NAF) is made up several branches composed of groups of fault strands. Most of the right-lateral plate motion has been accommodated on the Northern Branch (NAF-N) in northern Marmara Sea, relatively close to the city of Istanbul. Theoretical models for evolution of strike-slip faults suggest that a broad zone of faulting and folding eventually focuses on a single narrow zone. Some publications suggested that a single fault zone and rapid motion on the Northern Branch started only 200 ka as a result of this process. This model was used to hypothesize that fault strands of the Central Branch of the NAF, on the Southern Shelf of Marmara Sea, had been abandoned and were "dead", with activity focusing solely on the Northern Branch.

We investigate the activity on the Southern Shelf utilizing new high-resolution seismic reflection data, and a late Quaternary age model. A dense dataset of 2D high-resolution seismic reflection data, sparker seismic data, CHIRP sub-bottom profiller data, as well as multibeam bathymetry, acquired in 2008, 2010, 2013 and 2014 during TAMAM and SOMAR cruises, primarily in the southern shelf of the Sea of Marmara We correlate reflections using our stratigraphic age model for the last 540 ky, through high-resolution seismic reflection data from a slope basin up onto the southern shelf of Marmara Sea. This seismic stratigraphic correlation allows examination of the history of deformation of the many fault strands forming the Central Branch of the NAF. The data reveal that all of the offshore faults in the South Marmara Sea have been active after 540 ka, and many deform the Last Glacial Maximum (LGM) unconformity where it is present below the sea floor.

The vertical component of displacement increases downward through the late Quaternary section on many Southern Shelf faults suggesting continued growth and activity. The vertical component of displacement also increases downward to pre-Late Quaternary stratigraphic horizons and the acoustic basement for the larger fault zones, as well as for some of the other faults. Although lack of an age model before late Quaternary makes ages uncertain, we cannot rule out that deformation has been relatively steady on the Southern Shelf for the last couple of million years. Similarly, we suggest that significant slip has been ongoing for more than a half million years and probably for millions of years on the Northern Branch.

The long major faults we image merge eastward into the Central Branch of the North Anatolian fault in Gemlik Bay. Farther west they form a broad network of faults. While part of the Kapidag fault is buried and may be inactive, elsewhere it offsets the LGM unconformity and produces sea floor scarps. It locally has a couple of kilometers of vertical separation of acoustic basement. We interpret it to be a right-lateral strike-slip fault. The Imrali Ridge fault is not nearly as straight as the Kapidag fault, going through large bends. It exhibits transtension in segments striking ESE and transpression in segments striking ENE. This is part of the evidence that it is also a right-lateral strike-slip fault. It also locally has a couple of kilometers of vertical separation of acoustic basement across it.

Keywords: multi channel sesimic, Southern Marmara shelf, active faults, late Quaternary, LGM

The Quaternary evolution of the Mudurnu River Valley (NW Turkey): Insights from tectonic uplift, mass movements and the horizontal slip rate of the North Anatolian Fault

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In the eastern Marmara Region, the North Anatolian Fault (NAF) bifurcates into multiple branches, where the total strain is distributed among parallel/sub-parallel fault strands. The Almacık Block diverts two of these structures, of which the northern one was ruptured during 12 November 1999 Düzce (Mw 7.1) and the southern ones created 26 May 1957 Abant (Mw 7.1) and 22 July 1967 Mudurnu Valley (Mw 7.1) earthquakes. The southern part of the Almacık Block, the Mudurnu Valley, hosts complex geological and geomorphological features such as landslide debris, lacustrine deposits and depositional fluvial terrace staircases, which are all directly linked with the activity of the NAF. We conducted a high-resolution detailed mapping accompanied by radiocarbon and luminescence dating to build-up the chronology of the events and to determine the rate of internal and external processes, especially for the Holocene.

The complex geomorphology of the Mudurnu Valley is controlled by the joint-processing of the North Anatolian Fault and fluvial system. The fast incision of the river is reflected in three-step high depositional terraces, which two of them are dated with pulsed IRSL to 180±18 and 128±13 ka. These terraces reveal a constant and high incision/ tectonic uplift rate (0.62±0.11 mm/year) for the Almacık Block and the Samanlı Mountain Range. This incision rate forms steep slopes at the northern and southern sides of the valley, causing instability especially at the highly sheared Cretaceous limestones expose to the southern side of the valley. During the middle Holocene, a remarkable mass movement at this unit blocked the Mudurnu Valley and formed an extensive landslide lake. Radiocarbon and luminescence dating of the lacustrine sediments indicate that the lake lasted more than a thousand-year and reigned in between ~7 to 5.8 ka.

When the headward incision of the river finally captured the lake, the unconsolidated lacustrine sediments were rapidly eroded by forming a six-step depositional terrace staircase formations observed at around Taşkesti Town. Two of these terrace steps are dated as 5.36±0.19 and 4.33±0.34 ka using OSL dating method. Our geological mapping aided with Rtk-GPS surveys and high-resolution UAV based DEM's reveal that these terraces are cut and displaced by the Mudurnu Valley Segment of the NAF. We were able to isolate one of these terraces, having a dextral offset of 52-62 meters where its age is constrained to 5.79±0.13 ka (radiocarbon) as an upper boundary and 5.36±0.19 ka (OSL) as a lower boundary. By using a boxcar uncertainty model, we calculate 10.3 +2.4/-2.3 mm/yr as the Holocene slip-rate of the Mudurnu Valley Segment. These results strongly advocate strain partitioning between parallel/sub-parallel elements of the North Anatolian Shear Zone, namely the Düzce and the Mudurnu Valley segments, but favour a higher strain accumulation than previous assumptions.

Keywords: NAF, Mudurnu Valley, Fluvial Terraces, Landslide, Luminescence Dating

Bi-Modal behavior of the North Anatolian fault

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The North Anatolian fault is one of the best studied dextral strike slip faults in the world. Combination of multiple investigation methods; such as traditional paleoseismic excavations, archeoseismology, dendroseismology, mapping and dating of offset geomorphic features, and geodetic observations performed along the 1200km-long fault over the past two decades yield new insights into the spatio-temporal behavior of the North Anatolian fault. Integration of such complementary methods helped us reduce the uncertainties on interpretations, revise our early measurements, and enhance our understanding of the fault behavior. Paleoseismic data suggest that the majority of the North Anatolian fault may rupture in short (about a century long) sequences with less than approximately 300-year recurrence intervals as well as occasional 600 year or longer interseismic periods followed by long, single co-seismic ruptures involving multiple segments. The generally accepted maximum co-seismic displacement per event for the North Anatolian fault is approximately 5 meters. However, integration of geologic slip rate sites and nearby paleoseismic trench sites suggest that the 20th-century rupture displacements (approximately 4-5 meters) may not be "typical" and the approximately 8-10-meter 1939 Erzincan earthquake coseismic may not be that extraordinary. These observations will likely have implications on both our scientific understanding on fault behavior from a strain accumulation and stress release cycle perspective and also on seismic hazard assessment studies.

Keywords: North Anatolian Fault, Bi-modal behavior, Paleoseismology, Coseismic displacement, Surface rupture hazard

The western transformation of the North Anatolian Fault in the North Aegean Basins

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The North Anatolian Fault extends westwards in the North Aegean Sea in two major strands; the predominant strand along the North Aegean Basin and the secondary strand along the subparallel Skyros Basin to the south. High spatial resolution swath bathymetric data supported by air-gun seismic profiles and coring have been obtained by our research group during the last 20 years in the North Aegean Basins, using the R/V AEGAEON of the Hellenic Centre for Marine Research. Our results have been published separately for the North Aegean Basin (NAB) and the Skyros Basin (SKB). Here, we present a synthetic review of the overall North Aegean Sea and its relation to the North Anatolian Fault. Both basins are gradually expanding and deepening from east to west. This is reflected on: 1) Their seafloor morphology, with the maximum depths ranging from 700m to 1650m (in NAB) and from 500m to 1200m (SKB) respectively; 2) Their length (350km (NAB) versus 200km (SKB) and width (from 25km to 50km and from 10km to 40km); 3) Their maximum throws (from >800m to >1700m versus >1100m to >1200m). It is remarkable that the two basins are similar, both regarding their geometry and their geodynamic characteristics with an approximate 2/1 (NAB/SKB) ratio. This is shown by: a) Their maximum submarine escarpments (1400m versus 800m); b) Their subsidence, as indicated by the depth of the Alpine basement beneath the syntectonic sedimentary sequences (>2500m versus >1900m); c) Their seismicity, with much higher activity in the northern basin; d) Their GPS ratios, showing oblique extension to the SSW, with ~16 mm/year versus ~8mm/year. The overall geometry of the two basins can be distinguished in three segments: I) The eastern segment, where the dominant tectonic trend is ENE-WSW, with relatively shallow depths, forming narrow basins with dextral strike slip dominant deformation; II) The central segment, where the tectonic trend becomes NE-SW with an oblique faulting dominant deformation; III) The western segment, where the tectonic trend remains NE-SW, but the width becomes larger, the basin depth reaches a maximum and the normal faulting, becomes dominant. The overall process indicates a gradual change from strike slip to normal faulting, with well-established knick points/zones separating all three segments. The widening and deepening towards the west is also supported by NW-SE trending active faults. The development of NW-SE basins/structures towards the western–southwestern area in continental Greece corresponds to the Hellenic arc parallel structures in its back arc area, above the subduction zone, disrupted by the en echelon E-W structures within the Central Hellenic Shear Zone. Towards the eastern Aegean Sea, the effect of the Hellenic subduction zone diminishes and the main process is related to the westward escape of Anatolia, away from the continental collision of Eurasia/Arabia.

Keywords: North Aegean Tectonics, tectonic segmentation, sea floor morphology, strike slip and normal faults, oblique opening

Back-arc deformation, kinematics and basin evolution/inversion in the Aegean: Implications for the westward propagation of the North Anatolian Fault

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Deformation in back-arc settings varies between extensional (eg. Mariana Arc), compressional (eg. Chilean Arc) and transtensional/transpressional (e.g. Alboran, Caribean). Understanding of the deformation and present-day kinematics in the Aegean back-arc area requires understanding of the interaction between the Hellenic Subduction and the westward propagation of the North Anatolian Fault. The recently compiled EMODnet bathymetry enables a comprehensive analysis of the submarine geomorphology of the Aegean. Recent and older seismic profiles enable mapping of the offshore fault network and the distribution and structure of sedimentary basins in unprecedented detail and extent. Integrated analysis of geomorphological, seismic profiling, seismological and geodetic data provides insights into the evolution of the deformation and kinematics in the Aegean back-arc area during Plio-Quaternary.

The Aegean crust "flows" toward SW to SSW between two boundaries: the northern one is a composite dextral boundary that includes the Kephallinia and North Anatolian Faults with the Central Hellenic Relay Zone between them; the southern one is delineated by the sinistral Pliny and Strabo Trenches. The SW- to SSW-ward extension of the Aegean crust is accommodated by dextral NE-SW to ENE-WSW oriented shear zones and conjugate, NW-SE sinistral strike-slip, oblique and E-W to ESE-WNW normal faults. Sinistral shear dominates in the eastern South Aegean, including eastern Crete and the area south of Astypalea and Kos islands. The change from the dextral to the sinistral sense of shear coincides with the most advanced, southern part of the Arc.

The unconformity between the Messinian evaporites and/or exposed basement and the Pliocene sedimentary basins has been followed by a second, major unconformity in Late Pliocene / Early Quaternary. The latter has been observed in DSDP Hole 378 in the Cretan Basin and on seismic profiles from many. It marks the onset of the kinematic pattern described earlier, the deformation or inversion of older basins and the initiation of new ones. Since Late Pliocene / Early Quaternary the sedimentary basins evolve either as transtensional basins or oblique rifting (Amorgos), pull apart basins (Karpathos, Kamilonisi), at the junction between the NE-SW dextral strike-slip and the NW-SE sinistral strike-slip to oblique faults (Mirtoon) and in horsetail structures (North Aegean, North Skyros).

The establishment of the new kinematic regime in Late Pliocene / Early Quaternary in the Aegean coincides with the initiation of rifting in Central Greece (Corinth, North Evia Gulfs). It is proposed here that it marks the "arrival" of the North Anatolian Fault and its southern branches in the Aegean Sea and the onset of the interaction with the Hellenic Subduction.

Keywords: North Anatolian Fault, Aegea, Hellenic Arc, Corinth

On the interaction between Nubia-Anatolia plates: Segmentation, geometry and kinematics of an isolated slab

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Converging plate boundaries containing heterogeneous lithospheric fragments and irregular boundaries led to development of narrow subduction zones with segmentation through slab tears. We investigate the segmentation of the subducting Nubian Plate along the Cyprus Arc in the easternmost Mediterranean, and its relationship to deformation of the overriding Anatolian plate. Towards this end, we develop a new focal mechanism catalog with M>4.2 earthquakes using regional waveforms and utilize this catalog along with high resolution tomographic images, topography, Bouguer gravity, seismicity, and horizontal GPS velocities to reveal the geometry of the subducting slab (here designated as the Antalya Slab) and to determine how convergence is accommodated along this segment of the Nubia-Anatolia plate boundary. Our results indicate that the Antalya Slab is discernable beneath Antalya Basin, but is isolated from the Hellenic Slab by a slab tear that allows it to subduct towards the NE. This slab tear also marks the eastern boundary of N-S extension in the Aegean extensional province of SW Turkey. We suggest that the Antalya Slab deforms as an isolated block, responding in part to adjacent plates, including the Anatolian Plate that moves toward the west overriding the remnant Antalya slab. Our results show that the internal deformation and tearing of the subducting Nubian Plate have a major effect on deformation of the overriding plate

Keywords: Slab Segmentation, Subduction, Mediterranean, Seismotectonics

Interdisciplinary earthquake hazard research in Gulf of Aqaba

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The southern end of the Dead Sea transform fault system, within and south of Gulf of Aqaba, poses the highest earthquake hazard in Egypt and Saudi Arabia. Here the fault system is trans-tensional and consists of a series of en-echelon fault segments and several major basins, both within the gulf and to the south of it. Little is known about past major earthquakes in this area, apart from the 1995 (Mw=7.2) earthquake, which occurred in the central part of the gulf, causing several fatalities and considerable damage. The earthquake ruptured only a part of fault system within the gulf while other segments have remained unruptured for several centuries. The need of better understanding of the seismic hazard in the area has significantly increased with the decision of building the new high-tech city of NEOM and a bridge between Saudi Arabia and Egypt. Therefore, we are conducting an international and interdisciplinary project aimed at locating active faults in the gulf and constraining better the overall tectonics, as well as obtaining new information about how frequent and how large major earthquakes in the area likely are. The project title is "Interdisciplinary earthquake hazard research in Gulf of Aqaba and Strait of Tiran (GAST)". Within the project, we have mapped the bathymetry of large parts of the gulf with a high-resolution multibeam sounder and the results show well the locations of the active fault strands leading to a new fault map of the gulf. In addition, we collected 23 sediment cores that show clear evidence of the 1995 earthquake and two older earthquakes, of which one is likely the 1588 earthquake. Furthermore, to learn more about the structure and activity of normal faults bounding the basins in the gulf, we carried out a seismic survey along a 7 km long profile, crossing one of the onshore faults, as well as collected and dated samples from uplifted coral terraces along the gulf's coastline. Furthermore, we installed a new GPS network in the area and the results show both the interseismic deformation near the gulf and the relative motion across it, which helps to constrain better the moment accumulation rate in the area. Finally, using earthquake scenario calculations, we are estimating expected shaking levels of possible future major earthquakes at the bridge location and within NEOM. Together the results are providing new knowledge of the active tectonics and earthquake activity in the Gulf of Aqaba area that will improve future seismic hazard assessments.

Keywords: Earthquakes, Tectonics, Seismic Hazard

The 2011 (Mw 7.1) Van (Turkey) Earthquake: Geodetic evidence for complex faulting in the Turkish-Iranian Plateau

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The October 23rd, 2011, Mw 7.1, Van (Turkey) earthquake that took place 8 years ago is a key event that provides an opportunity to refine our understanding of the active continental deformation in the Turkish Iranian Plateau. Several scientific studies were published in this period with the introduction of newly available seismological, geodetical and geological datasets. These studies generally agreed upon a deeply buried coseismic slip (10-22 km) on a north-dipping blind thrust fault and a lack of slip at shallower depths (< 8 km). That being said the researchers are divided into two camps: while one group of studies is proposing a two-fault model with subparallel segments others suggest a single segment. Our coseismic study shows that these two fault models fail to explain fully the surface deformation that were recorded by the radar satellites, the field observations that were reported along the west coast of Lake Erçek as well as the relocated aftershocks. In this presentation, after a concise review of the earlier studies, we will be presenting our two-fault coseismic model which is comprised of a tear fault running parallel to the west coast of Lake Erçek in addition to the main Van fault itself.

Here we will also be presenting an up-to-date analysis of the postseismic deformation by complementing the data from eight near-field GPS campaigns with up to 5 years of InSAR measurements from the Sentinel-1 satellites between 2014 and 2019. The geodetic data clearly indicate that the postseismic ground motion following the earthquake has not ceased yet, making it one of the longest lasting postseismic deformation following a thrust faulting event in the world. One of the key features observed in the InSAR velocity maps is the presence of shallow afterslip along a NE-SW extending sharp discontinuity that is different than the up-dip trace of the causative coseismic fault that lies between Lake Van to the west and Lake Erçek to the east. While the westernmost part of the discontinuity coincides with the earlier recognized aseismic slip on the Bostaniçi (Beyüzümü) Fault to the south that crosses the Van city center, the remaining part of the discontinuity veers towards northeast and reaches the Kozluca Fault on the western coast of Lake Erçek, confirming our coseismic model where that fault is proposed as being part of the main coseismic rupture bounding it to the east.

Keywords: 2011 Van (Turkey) Earthquake, coseismic model, InSAR, postseismic motion, blind thrust, tear fault

Remote Sensing Application to an active fault segment on the East Anatolian Fault Zone

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The remote sensing applications comprise processing and interpretation of satellite images. The application techniques are very important for understanding nature of active fault segment on strike-slip fault zones. Especially this application provides great benefits for the field studies and kinematic analysis of the faults in metamorphic massifs related to activity of the segment. In this scope, remote sensing techniques are carried out center part of East Anatolian Fault Zone (EAFZ).

Advanced Space-borne Thermal Emission Radiometer (ASTER) images are used for visual interpretations of active fault segment. The enhancement techniques including contrast enhancement, color composites, histogram equalization, Principal Component Analysis (PCA) and Decorrelation Stretching (DS) are applied on ASTER images in order to maximize image visualization. The enhanced ASTER images belong to the study area show us prominent kinematic indicators and morphological structures such as linear valleys, pressure ridges, stream offsets are controlled by initial fault geometry.

The orientation of the pressure ridges observed between Pütürge and Sincik defines the strike of the segment on EAFZ. Stream offsets along the segment clearly show sinistral motion of fault zone. Besides the 13 km large displacement of the Euphrates, there are prominent stream offsets arrives up to 1 km along the Şiro linear valley and in the southern part of Çelikhan. Also these images ensure the lithological discrimination based on processing and enhancement of spectral data. Heterogeneity of units in the study area is the significative measure for determination of fault traces and their offset.

Keywords: Remote Sensing Application, East Anatolian Fault Zone, ASTER Image, Enhancement Techniques

The 2017 two strong earthquakes of eastern Aegean: Lesvos and Kos-Bodrum

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The broader Aegean geodynamic interpretation and its models based mainly on the geometry of the main structures, as well as on the fault kinematics, that is a result of the upper crust processes. It is a partial picture, while new deep seismotectonics and geophysical data of the upper mantle and lower crust will complete or change drastically them. The updated models are based on the well-known subduction, Anatolia westward escape and the influence of the North Anatolia Fault and consequently the stripe slip regime on the Aegean. Many active multi segmented faults from western Anatolia to Greek Island and the Aegean Sea, were developed in a complex pattern. Normal faulting is the most prominent extensional tectonic feature, although significant strike-slip faulting of NE-SW direction is very common at the eastern Aegean. Two complex such fault segments activated during 2017.

A strong and destructive seismic event occurred on June 12, 2017 offshore of Lesvos Island, NE Aegean, Greece (38.85° N; 26.31 E), M_w 6.3 (National Observatory of Athens – NOA) and maximum Intensity IX at Vrissa village. The hypocentre is located at a depth of 7 km. The mainshock ruptured an offshore WNW-ESE striking, SW dipping, normal fault, projecting offshore and bounding the Lesvos Basin. It was modelled simply, while the onshore faults are questioning. Crustal stretching and its consequent tectonic and seismic activity also affect local geomorphology both onshore and offshore. The fault modelling estimates a series of parameters (stress transfer, GPS displacement and surface deformation). On July 20, 2017 a strong (M_W 6.6) and destructive earthquake occurred in the SE Aegean Sea, near the border region of Greece and Turkey. The epicentre is located offshore, within the Gökova (Keramikos) Gulf, between Kos Island and Bodrum City. Mainshock's relocated hypocentral depth is 9.3 km. The depth distribution of the sequence suggests that the maximum number of events occurred at the depths of 8-9 km (28.7% of total aftershocks). Besides sub-cluster, all other clusters reach maximum depths of approximately 15 km. The spatio-temporal evolution of the 2017 sequence showed an asymmetrical development of seismicity, as well as fault geometry. This evolution of the aftershock sequence shows that 1st day after the main shock, a sub-cluster developed, whilst a second one, is much poorer in aftershocks. This contrast continues for almost one week, after of which a new sub-cluster closes to the 1st one developed and the second cluster became richer. Approximately one month after, all clusters and sub-clusters had been adequately developed. The spatio-temporal evolution indicates different behaviour in the clusters development which is probably due to stress loading and successive reactivation of different tectonic structures. Our preferred model suggests a N-dipping fault plane based mainly on seismological and secondary on morphotectonic data. The NOA's focal mechanism, their aftershock relocation and the morphotectonic evidences at the eastern part of Kos Island, suggesting that the ENE-WSW striking normal faulting at the slopes of Kos is the upward prolongation of the 2017 offshore rupture.

Keywords: fault model, aftershock, geodynamics

Coseismic (21 July 2017 Bodrum-Kos) coastal deformations along the Gulf of Gökova, SW Turkey

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Gökova Gulf is located between Datça and Bodrum peninsulas at the SW part of Turkey. It is one of the most seismically active domain of the Agean Sea. The northern coast of the gulf is delimited by normal fault segments of the Gökova Fault Zone. The sea bottom topography of the gulf is delimited by the low-angle offshore Datça Fault in the south and its high-angle antitethics. The Quaternary and especially Holocene activities of these faults are poorly understood. In this kind of settings, investigation of uplifted abrasion platforms and tidal-notches are useful geomorphic markers to quantify modern and paleo-earthquake activities. This contribution provides preliminary results of our geomorphic observations and measurements subsequent to 21 July 2017 Bodrum (Mw:6.6) Earthquake around the Bodrum and later on all along Gökova Gulf shores. Our measurements reveal 20-25 cm of coseismic uplift of the shoreline during the 21 July 2017 Bodrum Earthquake along the Karaada coasts locating 1 km South of the Bodrum town. We found at least 3 tidal notches which are 20 cm to 120 cm higher than modern sea level along the southern coasts and at least 5 tidal notches which are 20 cm to 170 cm higher than modern sea level along the northern coasts. Unfortunately, these notches are very poor in terms of samples for 14C dating, therefore, it is impossible to provide dates of those paleoearthquakes responsible for coastal uplift. Nevertheless, we provide evidence of the presence of coseismically uplifted shorelines along the Turkish coasts of the Aegean Sea for the first time and presence of active faults very close to the shoreline and capable to produce large earthquakes and might be important for the regional seismic hazard. This project is supported by TUBITAK 1002 Program (Project No: 118Y116) and Istanbul Technical University Research Fund (Project No. TGA-2018-411184)

Keywords: Göokova Gulf, cosesimic coastal deformations, Kos Earthquake

Anatolia-Aegean at the junction of ocean subduction and continental collision: Geodetic implications for the dynamics of E Mediterranean tectonics

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We present a broad view of present-day motions and deformations derived from 336 GNSS survey sites and 226 continuous GNSS stations across the Nubia-Arabia-Eurasia zone of plate interaction to investigate the role of subduction along the Hellenic and Cyprus arcs, and continental collision between Arabia and Eurasia in deforming the interplate, Anatolia-Aegean region. We show that internal deformation of the region occurs in large part on mapped, seismically active fault systems, indicating elastic behavior of the seismogenic crust (above ~15 km). Model fault slip rates are comparable to geologic rates, suggesting that major faults have controlled the recent geologic evolution of the region. The pattern of present-day deformation, including accelerating motions towards the Hellenic trench, and the roughly simultaneous opening of all the major Mediterranean basins in the early Miocene with the slowing of Nubia-Eurasia convergence, suggests that foundering and rollback of the subducted Nubian slab beneath the Aegean is the primary mechanism responsible for present-day motion and internal deformation of the Anatolian-Aegean region.

Keywords: Anatolia, Aegean, GNSS deformation, subduction, Mediterranean

Intermediate-Depth earthquakes and the lithospheric removal beneath the Southeast Carpathians

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The intermediate-depth earthquakes (0-200 km) at the southeastern corner of the Carpathian mountains (Vrancea region) in relatively localized region (30 x 80 km) has been reported but the cause of such seismicity is not well understood. The distribution of seismicity spatially correlates well with the high speed seismic waves which suggest vertically sinking (lithospheric) material into the mantle. In this work, geodynamical models are used to investigate the lithospheric evolution in the Southeast Carpathians while reconciling results with the available geological, petrological (volcanism) and geophysical data to reveal the origin of such high speed/seismically active lithosphere (e.g. whether it is continental or oceanic lithosphere). Furthermore, experimental results are also used to compare against the strain rate calculations based on the seismic moments of earthquakes (collected in 40 year time interval) where vertical stretching at depths 50-100 km (35% myr^{-1}/18 km myr^{-1}) has been inferred. On the basis of these calculations, the lithosphere under the Southeast Carpathians extends nearly twice in only 3 myrs timescale and such extension is entirely controlled by the vertical tectonics since the net convergence between the East European platform (foreland) and the Carpathian hinterland is approximately 0. Model predictions in accordance with the Alpine orogenesis and the plate reconstructions suggest that the lithospheric gravitational instability or the roll-back and the necking of the European lithosphere subducting under Adria are potential causes of intermediate depth seismicity under Romanian Carpathians.

Keywords: Intermediate-depth earthquakes, Southeast Carpathians, Lithospheric removal, Geodynamics

Active geodynamics and seismic hazard in the Caucasus Region

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We present GPS observations of crustal deformation in the Africa-Arabia-Eurasia zone of plate interaction, and use these observations to constrain broad-scale tectonic processes within the collision zone of the Arabian and Eurasian plates. Within this plate tectonics context, we examine deformation of the Caucasus system (Lesser and Greater Caucasus and intervening Caucasian Isthmus) and show that most crustal shortening in the collision zone is accommodated by the Greater Caucasus Fold-and-Thrust Belt (GCFTB) along the southern edge of the Greater Caucasus Mountains. The eastern GCFTB appears to bifurcate west of Baku, with one branch following the accurate geometry of the Greater Caucasus, turning towards the south and traversing the Neftchala Peninsula. A second branch (or branches) may extend directly into the Caspian Sea south of Baku, likely connecting to the Central Caspian Seismic Zone (CCSZ). We model deformation in terms of a locked thrust fault that coincides in general with the main surface trace of the GCFTB. We consider two end-member models, each of which tests the likelihood of one or other of the branches being the dominant cause of observed deformation. Our models indicate that strain is actively accumulating on the fault along the ~200 km segment of the fault west of Baku (approximately between longitudes 47-49°E). Parts of this segment of the fault broke in major earthquakes historically (1191, 1859, 1902) suggesting that significant future earthquakes (M~6-7) are likely on the central and western segment of the fault. We observe a similar deformation pattern across the eastern end of the GCFTB along a profile crossing the Kur Depression and Greater Caucasus Mountains in the vicinity of Baku. Along this eastern segment, a branch of the fault changes from a NW-SE striking thrust to an ~ N-S oriented strike-slip fault (or in multiple splays). The similar deformation pattern along the eastern and central GCFTB segments raises the possibility that major earthquakes may also occur in eastern Azerbaijan. However, the eastern segment of the GCFTB has no record of large historic earthquakes, and is characterized by thick, highly saturated and over-pressured sediments within the Kur Depression and adjacent Caspian Basin that may inhibit elastic strain accumulation in favour of fault creep, and/or distributed faulting and folding. Thus, while our analyses suggest that large earthquakes are likely in central and western Azerbaijan, it is still uncertain whether significant earthquakes are also likely along the eastern segment, and on which structure. Ongoing and future focused studies of active deformation promise to shed further light on the tectonics and earthquake hazards in this highly populated and developed part of Azerbaijan.

Keywords: Seismicity, GPS monitoring, crustal deformation, dilatation, contraction

Contribution of GNSS measurements in monitoring 1999 Izmit Rupture Zone after 20 years

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The North Anatolian Fault (NAF), which is a 1200 km dextral fault extending from the Karlıova triple joint in the east to the North Aegean Sea in the west, has experienced M> 7 earthquakes in the last century. Except for 1912 Mürefte and 1999 Düzce, these earthquakes started from Erzincan in 1939 as dominoes and progressed to the west by breaking the fault (Barka, 1992; Stein et al., 1997). The last earthquake of this series occurred in Izmit in 1999 and the fracture of this series crossed the Gulf of Izmit and reached the shores of Yalova in the Sea of Marmara. Therefore, it is accepted by all earth sciences researchers that this western chain will continue and that a major earthquake like Izmit will occur in the Marmara Sea in the near future (Parsons et al., 2000; Parsons et al., 2004; Bulut et al., 2012; Ergintav et al., 2014).

The 1999 Izmit earthquake is still known as the best observed strike-slip earthquake in the world. This earthquake formed in the center of the GNSS network (Reilinger et al., 2000; Ergintav et al., 2009; Ergintav et al., 2014) in the geometry surrounding the west of the NAF and having the most intensive station distribution for that period (Reilienger et al., 2000; Çakır et al., 2003; Ergintav et al., 2014). Ergintav et al. (2014), has produced a unique data set in the near-fault region 1999 Izmit (Mw7.6) and Düzce (Mw7.4) earthquakes before and after (~ 20 years) data collected from GNSS campaigns and continuous GNSS stations, systematically.

In this study, time series and the current velocity field that has been produced from the data of survey and continuous GNSS measurements around the Izmit earthquake region will be questioned in detail. The hypocentre of the 1999 Izmit earthquake, which is the richest observation point distribution of the region, formed within the scope of our different collaborations and projects in Marmara Region, will be questioned in detail. Spatial and temporal variations of creep on fault rupture will be questioned. Findings will be interpreted with creepmeter and seismology data.

Keywords: NAF, 1999 Izmit Rupture Zone, Marmara Region, GNSS

Determination of surface creep rates by GNSS measurements along the İsmetpaşa Section of the North Anatolian Fault Zone

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Although 50 years ago it was determined that the Ismetpasa segment of the North Anatolian Fault constantly creeping without producing earthquakes, to date, no detailed and reliable information about the temporal and spatial nature of this movement is available. Since the discovery of the deformation caused by the fault at the intersection of the garden wall of the Ismetpasa road maintenance facility in 1969 by Ambraseys (1970), a 6-point geodesic network established only in a small area could be traced by terrestiral surveying and GNSS measurement methods (Aytun, 1982; Altay and Sav, 1991; Deniz et al., 1993; Kutoğlu et al., 2006; Kutoğlu et al., 2008; Özener et al., 2013). In addition, Karabacak et al. (2010) conducted terrestrial Lidar measurements between 2007 and 2009 and Bilham et al. (2016) monitored creep movement with the creepmeter they established. InSAR studies (Cakir et al., 2005; Kaneko et al., 2013; Cetin et al., 2014) show that the creeping segment is approximately 100 km long and the creep velocity varies spatially, reaching its highest values approximately 15-24 km east of Ismetpasa. According to Bilham et al. (2016), as shown by the compilation of old data, the creep movement observed in creepmeters does not show continuity, stops from time to time and/or accelerates. Therefore, there are question marks about the creeping depth and how much and how fast the slip continues along the fault. In addition, despite all these studies, the characteristics of the change in the velocity of creep movement and the cause of the beginning (probably 1944 earthquake) are not known. Although it has been reported that a significant part of the cause of sudden changes in creep movement is reported to be related to meteorology, the causes and the depth dimension of all transient creep accelerations are not understood from the available data sets. InSAR-PsInSAR (Permanent Scatterers InSAR) and GNSS measurement methods are the most effective methods to find answers to these questions. Naturally, by examining the presence of seismic mobility, it will be possible to determine the characteristics behaviour of creep observed on the surface and at the depth.

In order to find answers to all these questions, we established ISMENET (Ismetpasa Network). In this presentation, we will give information about ISMENET stations, velocity field of the area and current creep rates along the Ismetpasa section.

Keywords: NAFZ, Ismetpasa, Creep, ISMENET, GNSS

Interseismic strain build-up on the submarine North Anatolian Fault Offshore Istanbul

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Little is known about the movement of offshore faults because of the absence of direct, underwater geodetic measurements. Furthermore, satellite geodesy techniques such as GPS cannot be applied underwater due to the strong attenuation of electromagnetic signals. However, capturing fault movement is crucial to determine the state of locking which reveals whether a fault is creeping or accumulating elastic energy. Here we show that horizontal crustal strain on the seafloor can be continuously measured with mm-precision over periods of years and dozens of baselines allowing to resolve tectonic deformation quasi-in-situ on the seafloor. To this effect, we installed an acoustic ranging network across the central segment of the North Anatolian Fault in the Marmara Sea offshore metropolitan Istanbul. The seafloor observation shows that the fault is locked with an upper bound of the local creep rate of 2 mm/a. The absence of any significant fault displacement on the seafloor for 2.5 years together with sparse local seismicity from OBS observation reveal that the fault is currently locked and therefore is accumulating strain. The slip-deficit since the last known rupture in 1766 of at least 4 m is sufficient to trigger an earthquake up to magnitude 7.4. The rate of strain accumulation on the central segment of the North Anatolian Fault in the Marmara Sea had previously been extrapolated from onshore observations or inferred from the absence of seismicity, but results remained inconsistent. Our study (Lange et al., 2019, Nature Communications) for the first time fills part of this data gap through in-situ seafloor geodetic measurements and demonstrates the urgent need to conduct similar studies in regions with a high-hazard potential from active faults offshore.

Keywords: Strain buildup, Marmara Sea, Seismic Gap, Earthquake

Small scale fault interactions in Southwestern Anatolia as revealed from seismology & InSAR

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Southwestern Anatolia is part of N-S extensional regime mainly driven by rollback along the Hellenic subduction zone beneath the Aegean Sea. This seismically active area is controlled primarily by normal fault systems and some of them have small strike slip component because of counter clockwise rotation of Anatolia. The fault structures in the region are segmented and in many cases seismic interaction between these segments can be observed.

Here we focus on 2017 seismic activity of Eastern and Western edges of Gökova Bay. Significant seismic activity occurred in SW Turkey following the July 21,2017 Mw 6.6 Bodrum- Kos earthquake. Within the same year, three separate moderate sized (Mw~5) events took place near the town of Ula (Muğla) on the eastern edge of Gökova Bay. One of these earthquakes occurred in April before the Bodrum-Kos earthquake while the other pair occurred in November within two days. We relocated all the events that occurred in Ula region in 2017 and remodeled the source mechanisms by using regional waveforms. In addition, we modeled the first event and the sequence in November using InSAR data. For the November sequence, we determined the contribution of each events to the displacements observed in InSAR using the source models from seismic waveforms. The locations and the source mechanisms imply that these earthquakes occurred on a previously unknown normal fault rather than the southeastern branches of the nearby Muğla Fault as proposed earlier. The results are consistent with the recently mapped fault structure by Akyüz et al. (2018).

Co-seismic and post-seismic InSAR analysis shows that the seismic activity following the 2017 Bodrum-Kos propagated from western Gökova Bay where rupture occurred toward east including the Ula region. Comparison of seismicity beneath Gökova Bay and Ula region shows that the seismicity in these two regions are temporally correlated. Hence, while the aforementioned moderate sized earthquakes are not directly triggered by the Bodrum-Kos earthquake, increased seismic activity following Bodrum-Kos earthquake shows that the stress changes in these two regions affect each other.

Keywords : Seismology, InSAR, SW Turkey, fault interaction

Active tectonics of the western part of the Turkish Iranian Plateau

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The Turkish-Iranian Plateau is the most interesting areas of the Arabian-Eurasian collision zone and the plateau include the eastern Turkey, the Caucasus and the NW of Iran. The active slip rates and kinematics of the faults in the plateau are still under debate and constitute one of the primary data for models that aim to describe the overall deformation characteristics of this large deformation zone such as; beginning of the collision and convergence velocity.

Since the spatial distribution of horizontal slip and rock uplift rates in the mountain range that aligned to the Bitlis-Zağros Suture Zone are not yet fully resolved, our understandings about active deformation of Turkish-Iranian Plateau is limited. The NW part of this mountain range is known as Mt. Muşgüneyi and presents one of the prominent morphological elevations in the Turkish-Iranian Plateau. The northern and southern margins of this active convergent mountain belt are delimited by active fault zones furthermore number of active structures accommodates the ongoing deformation within this mountain belts.

In this study, my primary aim is to isolate the tectonic activity in the Mt. Muşgüneyi, which shows well-developed morphologic structures associated with recent deformation (e.g., offset streams, deep and narrow valleys), by drawing on spatial distribution of horizontal slip along the faults, geomorphic indexes (mountain-front sinuosity, valley floor width to valley height ratio, transverse topographic symmetry factor, asymmetry factor, hypsometric curve and integral) and drainage pattern analysis (channel concavity, integral analyses and knick point analyses). I also applied these methods to investigate effect of tectonic activity on the southern front of the Mt. Şerafettin that located to the north of the Mt. Muşgüneyi therefore relatively middle part of the Turkish-Iranian Plateau. The results of this study reveal that cumulative horizontal offset within the Mt. Muşgüneyi is three times larger than previous estimates and c.a. 12 Ma needed to account for the offset. Morphometric studies point out sustaining significant uplift within western part of the Turkish-Iranian Plateau and signify the uplift rate is larger than horizontal slip rate. Considering similarities between the, strike-slip fault within the Mt. Muşgüneyi and the strike-slip fault in the Anatolia that and located at c.a. 70 km south of the North Anatolian Fault Zone, in terms of their ages, orientations, slip senses and cumulative offset, I suggest that they belonged to the earlier dextral deformation zone along the southern margin of collision that sinistrally offset by the East Anatolian Fault Zone about 33±3 km c.a. 6 Ma ago.

Keywords: Turkish-Iranian Plateau, East Anatolian Fault Zone, Morphometric Indices

No gradual decrease of cumulative offset along the NAFZ from eastern to western Turkey

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The North Anatolian Fault Zone (NAFZ) is a ~1400 km long active strike-slip fault zone connecting the Eastern Anatolian convergence and the Aegean subduction zone, currently accommodating 23-24 mm/yr of dextral motion between the Anatolian and the Eurasian plates. In eastern Turkey, where the NAFZ forms a relatively narrow deformation zone, its cumulative offset is generally accepted as ~90 km. However, in northwestern Turkey, the NAFZ becomes a broad, complex shear zone where there is no systematical study reporting the cumulative offset of the NAFZ. This caused two main opposing views on the cumulative offset along the NAFZ: (1) the total offset of the NAFZ decreases gradually from Eastern Turkey towards the Aegean Sea; from ~90 km in the east to 30–75 km in the central and to 25–40 km in the western part of the NAFZ and (2) the cumulative offset of the NAFZ is ~90 km both in the eastern, central and western Turkey, between 30° and 42° E longitudes, hence, there is no gradual decrease of offsets along the fault zone. In this study, I have reviewed all the available offshore and onshore structural data showing that the NAFZ is made up of 14, more or less parallel faults together forming a ~140 km wide shear zone between 28°E and 27°E longitudes in the Western Marmara Region. The offset of the rivers and older geological structures observed along these 14 faults suggests that a total of ~80 km cumulative offset partitioned by these faults. This cumulative offset value is in good correlation with the recently reported total 88±5 km offset in the Eastern Marmara region, near 31°E longitude. The age of the drainage system in the Marmara Region is reported as Pliocene. Hence, the ~80 km offset measured in the Western Marmara Region represents post-Pliocene displacement. Previously, the initiation of the transform displacement in the Eastern Marmara Region also reported as post-Pliocene (~3.9 Ma). All these data suggest the Pliocene inception of the NAFZ in the Marmara Region and no significant gradual decrease of offsets, from east to west, along the NAFZ.

Keywords: Cumulative offset and age, North Anatolian Fault Zone (NAFZ), offset partitioning, Western Marmara Region

Kinematics of the Bursa Fault; the Southern Strand of the North Anatolian Fault Zone

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Along the deformation zone of North Anatolian Fault Zone (NAFZ), the Bursa Fault is described as Holocene Fault on active fault map of the region. There has been still an active debate in the literature about whether it belongs to deformation zone of the NAFZ or the Eskişehir Fault Zone. To shed a light on this controversy, we mapped active fault segments along the southern boundary fault of Bursa basin, documented its kinematic properties, and manifested its relationship between older structures.

According to field studies, stratigraphy of the Bursa region includes two main rock packages. From older to younger; (i) Basement rocks consisting of Paleozoic-Mesozoic metamorphic rocks and Miocene volcano-sedimentary rocks, (ii) Quaternary infill of Bursa basin composed of alluvial fan, alluvial plain and colluvial deposits. Faults around the Bursa region separated into three groups in terms of their activities. These are, older to younger; (i) Pre-Quaternary faults, (ii) Quaternary faults and (iii) Holocene faults. Based on fault kinematics, the NE-SW trending Pre-Quaternary faults are mainly dextral strike slip faults, while the E-W trending Quaternary-Holocene faults are normal in character.

Kinematic data yielded from faults along the Bursa basin shows that region has experienced two different paleostress states since Miocene. The first one is related with Pre-Quaternary faults and is calculated as NE-SW trending contraction and associated NW-SE trending extension. The second one is associated with Quaternary and Holocene faults and is calculated as NE-SW trending extension. Bursa Fault and Bursa basin have formed during the still ongoing second stress phase and belong to North Anatolian Fault (deformation) Zone. This study is supported by TUBITAK (Project Number: 117R011).

Keywords: Bursa Fault; stratigraphy; fault kinematics; paleostress; North Anatolian Faut Zone

Earthquake history and relative tectonic activity of the Yatağan Fault, Muğla, SW Turkey: Implications and contributions for quantifying the tectonic activity along normal faults

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Convergence between Arabian, African, and Eurasian plates lead to westward escape of the Anatolian microplate. The extension in western Anatolia is mostly characterized by E-W trending horst-graben systems, which are formed within a N-S extensional system. Moreover, the NE-SW and NW-SE trending fault systems are the other important neotectonic features in this system. The Yatağan Fault is one of these NW- striking structures, which prolongs of about 30 km to the west-northwest of the Muğla City Centre.

We excavated two trenches to study the earthquake history and the earthquake potential of the Yatağan Fault. The tectono-stratigraphic relations of trench walls point out one (most probably last) event horizon of a paleoearthquake, which caused a surface rupture. In order to date this event, 6 OSL (Optical Stimulated Luminescence) and 6 radiocarbon samples were collected in trenches. The combined interpretation of the ages obtained from the samples indicates a historical earthquake between 265 ± 95 BCE and 342 ± 131 CE.

In addition, we used geomorphic indices and field observations to quantify the deformation style and characteristics along the Yatağan Fault. In terms of geomorphic analyses, we first classified the Yatağan Fault into two geometric segments; fs1 and fs2. Then, we applied hypsometric curve and integral (HI) to discuss the stage of the landscape along the Yatağan Fault. Longitudinal channel profiles, normalized channel steepness, and concavity (k_{sn}, θ) indices were studied in order to infer the stage of topography and anomalies that are formed by tectonic processes along the Yatağan Fault. The indices of mountain front sinuosity (S_{mf}) and valley height–width ratio (V_f) was helpful to quantify the relative uplift rate along the mountain-fronts. All these indices extract information about the effects of tectonics and lithological factors on the regional morphology. A joint interpretation of the tectonic geomorphological studies reveals that the Yatağan Fault is active. In general, results of all analysis are consistent with each other. Combined results also illustrate a gradual increase in tectonic activity toward the southern part of the Yatağan Fault. Furthermore, we calculated morphology-based slip rates from the relationship of triangular facet slopes and heights methods respectively. Utilizing triangular facet slope based method; we calculated vertical slip rates of 0.16 ± 0.05 mm/yr (fs-1) and 0.3 ± 0.05 mm/yr (fs-2). Moreover, we calculated similar rates, 0.24 (fs-1) and 0.36 (fs-2) mm/yr according to the relationship between the vertical slip rate and the basal facet height. These estimates are also supported by the mountain front-based tectonic activity classes proposed by Rockwell et al. (1985), which provide high activity (>0.5 mm/yr) for the fs-1 and fs-2. As a result, morphometric analysis of the Yatağan Fault

supports the tectonic control of the Yatağan Fault on the geomorphologic evolution of the region.

Comprehensive interpretation of the obtained results from paleoseismology, tectonic geomorphology and geological studies reveal that the Yatağan Fault has the potential to produce large earthquakes at relatively long intervals. However, considering the urbanization rate in the region and the population density around and along the fault, the risk of a possible future earthquake on the Yatağan Fault is an important issue that should not be ignored.

This study is supported by TÜBİTAK (Project no. 116Y179).

Keywords: Paleoseismology, Tectonic Geomorphology, Slip rate, Yatağan Fault, SW Turkey

Late Pleistocene slip-rate of the Aydın Fault, Southern Menderes Massif

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Western Anatolia is one of the rapidly extending areas on the earth. The Menderes Massif has an actively deforming horst-graben structure in the Western Anatolian Extentional Province. The high-angle normal faults are the principal active tectonic structures of the Menderes Massif. Especially, the southern margin of the Aydın Block is characterized by actively growing normal faults. The study of the geometry and slip rate of the faults holds crucial value for better understanding the regional deformation pattern. Additionally, to determine the vertical slip rate of a normal fault is one of the most important parameters for evaluating its level of activity. However, quantitative dating studies on determine the slip rate of normal faults in Aydın Block has not yet been perform.

The main purpose of this study is mapping and dating of faulted or uplifted fluvial terraces and strive to extract information about timing and rate during the late Pleistocene deformation. We focus on Quaternary fluvial deposits that surround southern flank of the Aydın Block. Here, we used high resolution UAV based DEM (20 cm) together with 12.5 m resolution TanDEMX data to extract the river terraces. River terraces and their offsets were mapped using high-resolution DEMs combined with field observations of terrace morphology and the characteristics of the soils developed in each terrace remnant. We determined at least five terraces staircase above the Tabakhane River controlling by the Aydın Fault Segment. We calculate the displacement of the fault by measuring the heights of river terraces on the footwall according to the Büyük Menderes Graben. Optically Stimulated Luminescence dating method was performed to date depositional ages of the fluvial terraces as a proxy of vertical slip rate. We then calculate the vertical slip rate of the fault based on the displacements and ages of the river terraces. OSL ages range between 52.134 ± 4.817 ka and 3.914 ± 0.513 ka. Incision rates derived from river terraces range between 3.8 mm yr-1 and 0.62 mm yr-1. Based on Optically Stimulated Luminescence dating of offset-related river terraces, we obtain late Pleistocene slip rate of ~1.72 mm/a along the Aydın Fault Segment. We consider that the slip rate is the highest along the eastern part and is lower to the west and middle part of the Aydın Block. In the same way, river incision rates and morphometric features show that tectonic activity is much higher for eastern part of Aydın Block.

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Surface faulting history of the Knidos Fault, inferences from surface exposure dating (36Cl) and paleoseismic trenching

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In this study, we focused on a normal fault scarp exhumed within an ancient harbor city, Knidos, located Aegean coast of SW Turkey. This part of Aegean Sea is an extensional region at the back-arc region of the Hellenic Trench. We have made the inversion of the 36Cl profile to determine the age and the slip of the events that have exhumed the fault-scarp. The number of events that exhumed the fault-scarp during this period is not well constrained, but it appears that at least 2 events can be distinguished by the 36Cl approach, and that most slip is exhumed during two events at 500-1000 yr BP and 1500-2100 yr BP. Our trench wall logging and radiocarbon 14C dating efforts together with archeological evaluation of artifacts provide the information about activity of the fault zone in the last 2 kyr. We identified traces of 3 and possibly 4 earthquakes that deformed the walls of the trench within the colluvium of the fault. When we consider the ages and slip-per events, the best scenario implies that the 11 m height of the scarp exhumed in the last 2731 yr (-1020, +2450) BP with six events (between Events 4 and 9) with 2,83±0,96 m average displacement per event.

Keywords: Knidos Fault, cosmogenic dating, paleoseismology, trenching

Uplifted Holocene and Pleistocene shorelines along the Northern Cyprus coasts, evidence of coseismic and long-term deformation

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Cyprus is uplifted between African and Anatolian plates. The coastal geomorphology of the island formed by several landforms associated with large magnitude earthquakes occured along this plate boundary. Plate boundaries are the most seismically active regions on the earth. Therefore it is significant to employ paleoseismic methods to estimate seismic hazard of the island. In this study we focus on the northern coasts stretch between Koruçam Peninsula in the west and Karpaz Peninsula in the east. We mapped marine terraces, wave-cut notches and platforms by using UAV and DGPS with cm resolution. Tsunami boulders weighing tons of kilograms were discovered and surface rupture of an eartquake strechting from offshore to onshore was mapped for the first time with this study. We collected marine fossils from marine terraces for U-Th dating and coral fossils from tsunami boulders and from uplifted marine platforms associated with the surface rupture. Our 14C dating results indicate coseismic uplift of the abrasion platforms between 1655±30 BP and 4725±35 BP and our U-Th dating results yield 144±22 ka and indicate presence of MIS5e marine terrace level on the island. Here we will present tectonic implicatios from spatial distribution of marine terraces and wave-cut notches and surface rupture. This study is supported by the Istanbul Technical University Research Found (Project no: 37548).

Keywords: Northern Cyprus, uplift, terraces

Factors controlling long wavelength progressive plateau uplift in Eastern Anatolia: Limited role for slab break off

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Stratigraphic evidence are used to interpret that the East Anatolian Plateau with 2 km average elevation today- was below sea level ~20 Ma and uplift began in the northern part. The presence of voluminous volcanic rocks/melt production across the plateau – younging to the south - corroborates geophysical interpretations (e.g. high heat flow, lower seismic velocities) that suggest progressive lithospheric removal (southward trending) from beneath the plateau. Here, we conduct numerical experiments that investigate the change in the surface uplift as a response to subducting slab peel back and potential break off processes under subduction-accretionary complexes and continental lithosphere. Model results show similar types of tectonic behavior and magnitudes of uplift-subsidence in both oceanic and continental removal processes, and they satisfactorily explain >1.5 km of plateau rise along a ~280 km wide asthenospheric upwelling zone beneath Eastern Anatolia over a 18 Myr timescale. Parametric investigation for varying plate strength and convergence velocities show that such model parameters control the amount of surface uplift (1 to 3 km), the width of the asthenospheric upwelling zone, and the potential timing/depth of break-off of the steepening/peeling slab. Experiments show that slab break off develops during the terminal phase, which may correspond to only a few million years ago for Eastern Anatolia. Therefore, the long wavelength plateau uplift and magmatism over the Eastern Anatolian-Lesser Caucasus region since at least 20 Ma is controlled by progressive slab removal, asthenospheric mantle upwelling, as the break off process has only a minor role.

Keywords: Slab peel back, Plateau uplift, East Anatolia, Slab break off

TH-3

PALEOSEISMOLOGY

Paleoseismology of the North Anatolian fault

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The geologic studies on the past large earthquakes from the North Anatolian fault advanced greatly in the decade following the 1999 Kocaeli earthquake. There was a serious concern about the seismic risks of the Istanbul metropolitan area and of large cities along the fault. Intensive investigations brought a lot of precious information on the past devastating earthquakes from the North Anatolian fault, and our understanding of the risks as well as the fault behavior progressed much. However, the progress seems to have been slowed down during the second decade until now and there still remains a number of unanswered questions on the future activity of the fault. On the other hand, the nation-wide efforts let us learn about many more active structures and their earthquake potentials have been partially revealed. Anatolia seems to be much more unstable than we had known before. This paper aims to summarize what we have learned and what we need to learn about the future large earthquakes from the North Anatolian fault and in Anatolia. Some important topics are as follows.

The completeness of historic catalogs are seldom questioned by paleoseismology though it is the only way to supplement incomplete historic records. Many paleosseismological works just confirm catalogs based on historic records. However, the author's studies on 1944 and 1939 segment eventually excavated earthquakes without any historic reference. On the 1944 segment an event in 12 to 13 century with no records have been very unequivocally confirmed. Historic records must be unreliable during warfare and disruption. Further excavations of events without historic records are necessary.

Judging from the rupture history in and around the 1944 segment, the extent of seismic ruptures differs from one event to another. Kondo et al. (2005) hypothesized characteristic slip in each behavioral segment and combination of the behavioral segment as a segment of an earthquake. Okumura (2007) recognized stationary and variable segment boundaries based on structural significance or size of discontinuity affecting rupture propagation. Have the segmentation and the westward migration in 20th century been repeated? The answer so far is negative, but further investigations are needed.

The cumulative offset and slip-rate in thousands of years has been very poorly studied until now. Only Kozaci et al. (2007) examined 2000 to 3000-year long-term slip-rate on the 1943 segment. Otherwise, long-term slip-rate has been discussed on very low resolution data for uncertain time periods only. We really need more intensive studies on high-resolution long-term slip-rate of the North Anatolian fault.

As mapping and detailed studies on the intra-plate faults advance, many more sources of hazardous earthquakes have been recognized. We need more studies on the hazards and risks.

Keywords: paleoseismology, segmentation, recurrence time, characteristic earthquake

The 2016 earthquake sequence in central Italy, new insights for paleoseismology

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The 2016 earthquake sequence in Central Italy started with a Mw6.0 earthquake on August 24 that was followed, within two months, by a Mw5.9 on October 26 and a Mw6.5 on October 30. The three earthquake ruptures are juxtaposed and partially overlap forming a main NW-striking, SW-dipping structure, accommodating NE-SW extension across this portion of the Apennines.

All the three mainshocks produced clear surface faulting: (1) Mw6.0, 5.2km-long continuous rupture with average throw of 13cm; (2) Mw5.9, ~7-10 km-long discontinuous rupture with average throw 11cm; (3) Mw6.5 a 22 km long rupture with average 45cm throw and a well-defined >5km-long antithetic rupture.

During this sequence, we had the rare opportunity to observe, analyse and compare the coseismic surface geological effects of shocks occurring within a few months in the same crustal and tectonic region, displaying different magnitudes, and being recorded by high-quality multidisciplinary geophysical monitoring systems. This provides a unique occasion to reason on the meaning of surface faulting we observe in trenches, on the uncertainties of paleoseismological interpretations, on the active fault mapping and development of fault segmentation models.

Several key understandings provided by the 2016 earthquake sequence have an impact for paleoseismology. Relevant insights are: validation of earthquake empirical relations rupture length and avg slip vs M; increase of complexity and width of the deformation zone with M (at least for normal faults) and consequent difficulty in catching small distributed throws but existence of more potential trenching sites, direct influence of subsurface setting on the efficiency of surface faulting; limited size of sympathetic ruptures of nearby faults. A further critical insight is that surface ruptures can repeat along the same fault segment(s) with only a few days/months delay. In trenches, we can hardly separate the ruptures of discrete paleoearthquakes too close in time because they are easily subject to overprinting by later events. Thus, these ruptures could be paleoseismologically interpreted as due to one single larger slip event instead the cumulative effect of multiple events very close in time; this has a dramatic impact on the reconstruction of the earthquake history of a fault and on the definition of recurrence models and rupture scenarios.

In summary, the observations from the 2016 earthquake sequence stresses (1) the importance of framing paleoseismological results within the broader setting of seismogenic structures, and (2) the fact that the acquisition of a large amount of paleoseismological data is a unique chance to define the variability of the rupture parameters and possible different rupture arrangements and link faults to historical earthquakes. At the same time, we need to revise the common use of the estimates of elapsed time and average recurrence interval to infer how close we are to the next earthquake.

Keywords: Paleoseismological trench data and interpretation, Individual surface faulting event recognition; Earthquake recurrence and seismic hazard, Central Apennines normal faulting earthquake

Paleoseismic history of the Dinar Fault, Southwestern Anatolia, Turkey

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Due to the slab pull of the African Oceanic lithosphere, which dived northward along the Aegean-Cyprus Arc, NW-SE trending and SW dipping normal faults were developed in SW Anatolia. The southwestern blocks of these faults move faster than the northeastern blocks, towards to the southwest. This relative velocity difference in the hanging and foot blocks led to the development of the main breakaway faults in SW Anatolia. Most of researchers agree with the explanation of the Dinar fault as a breakaway fault in the neotectonic framework of SW Turkey.

Dinar fault is well known active normal fault in southwest Turkey. The Dinar fault has 60 km length, with N35°W general strike and dip 45°-65° SW and is a normal fault with minor sinistral component. The seismic activity of the Dinar fault was proven by the October 1, 1995 Dinar Earthquake (Mw: 6.2). The earthquake caused very severe damage. Nearly 30% of all structures in Dinar and its vicinity were destroyed with 92 people killed and 25 000 people left homeless. Due to the foreshock activity, Dinar earthquake is a unique example for Turkey. Dinar earthquake activity started on 25 September 1995, one week before the main shock and ended on 24 October 1995. Dinar Fault consists of three geometric sub segments, namely Gümüşsu, Kızıllı and Dikici, from northwest to southeast. The October 1, 1995 Dinar Earthquake occurred in Kızıllı sub-segment, which is 10 km long. During the Dinar earthquake, approximately 10 km-length of surface rupture occurred between the town of Dinar and Yapağılı village. The surface rupture of Dinar earthquake is characterized by a main body with tail sections near the northern and southern tips of rupture. The maximum vertical displacement on the surface rupture was reported as 25 cm at 3.1 km east of Yakaköy.

This study presents paleoseismic history of the Dinar fault with detail trench analysis. Based on the air photo interpretation in scale of 1:35 000, surface rupture mapping in scale of 1:25 000 and field observations, optimum trench sites were selected. In this study, five trenches were excavated along the 1995 earthquake surface rupture, at three-difference site. A total of 13 charcoal, organic sediment, bone or shell samples, collected from trenches, were analysed by radiocarbon dating method (^{14}C) in the Scientific and Technological Research Council of Turkey - Marmara Research Center (TUBİTAK-MAM). Additionally, 3 samples were dated by Optical Stimulated Luminescence (OSL) method in Ankara University, Institute of Nuclear Sciences Laboratory. Based on the trench studies and dating results, at least five earthquakes resulting in a surface rupture within the last 6000 years, including the 1995 earthquake have been identified and dated. Ancient city of Kelainai / Apameia Kibotos (ancient Dinar) destroyed by at least two severe earthquake. According to the paleoseismic results, earthquake recurrence period of Dinar fault is non-characteristic.

Keywords: Dinar fault, Paleoseismology, Dinar Earthquake, Kelainai / Apameia Kibotos, ^{14}C and OSL

Spatio-temporal behaviour of continental transform faults: Implications from the late Quaternary slip history of the North Anatolian Fault, Turkey

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The study of the spatial and temporal behaviour of continental transform faults by estimating their geological and geodetic slip rates is critical considering their complex structures. Geodetic data can provide detailed spatial coverage but represent a short time interval of a single earthquake cycle, while geologic rates are derived as average values for multiple events at spatially limited sites. In the complex tectonic setting of the eastern Mediterranean, the westward extrusion of the Anatolian Scholle is mainly accommodated along two major tectonic structures, the North Anatolian (NASZ) and the East Anatolian (EASZ) shear zones, respectively forming the northern and eastern boundaries. The rate of deformation all along the North Anatolian Fault (NAF) has been spatially well documented mainly by GPS and InSAR based geodetic studies for the last two decades. Furthermore, the number of the morphochronology-based geologic slip rate studies significantly increased, covering the different sections of this large strike slip fault for various time intervals.

In this study, the slip history of the North Anatolian Fault (NAF) is constrained by displacement and age data for the last 550 ka. First, I classified all available geological estimates, being member of three groups: Model I for the eastern, Model II for the central and Model III for the western segments where the NASZ gradually widens from east to west. The short-term uniform slip solutions yield similar results, 17.5 +4/-3.5 mm/a, 18.9 +3.7/-3.3 mm/a and 16.9 +1.2/-1.1 mm/a for the main displacement zone of the NASZ from east to the west. Although these model rates do not show any significant spatial variations among themselves, the correlation with geodetic estimates, ranging between 15 mm/a and 28 mm/a for different sections of the NAF, displays significant discrepancies especially for the central and western segments of the fault. Discrepancies suggest that the majority of strain is accumulated along the NAF, but some portion of it is distributed along secondary structures of the North Anatolian Shear Zone. The deformation rate is constant at least for the last 195 ka, whereas the limited number of data show strain transfer from northern to the southern strand between 195 and 320 ka BP in the Marmara Region when the incremental slip rate decreases to 13.2 +3.1/-2.9 mm/a for the northern strand of the NAF. Considering the possible uncertainties of incremental displacements and their timings, it is clear that more studies on slip rate are needed at different sites, including major structural elements of the North Anatolian Shear Zone. Although most of the strain is localized along the main displacement zone, the NAF, secondary structures are still capable of generating earthquakes that can hardly reach M_w 7.

Keywords: Continental transform faults, North Anatolian Fault, slip-rate, Turkey

Sandıklı (Afyonkarahisar) ve yakın çevresini kontrol eden aktif yapıların paleosismolojisi, GB Anadolu

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Maden Tetkik ve Arama Genel Müdürlüğü (MTA) tarafından yürütülmekte olan Türkiye Paleosismoloji Araştırmaları Projesi'nin (TÜRKPAP) 2018 yılı çalışmaları kapsamında, Sandıklı (Afyonkarahisar) yöresinde yer alan aktif fayların paleosimolojik özellikleri araştırılmıştır. Yenilenmiş Türkiye Diri Fay Haritası'na göre bölgede yeralan aktif yapılar Kuvaterner fayı olarak sınıflandırılmıştır. Bu kapsamda, Kızılören (16 km), Düzbel (13 km), Örenkaya (30 km), Sandıklı (12 km) ve Akharım (14 km) fayları üzerinde hendekli paleosismolojik çalışmalar gerçekleştirilmiştir. Sandıklı (Afyonkarahisar) yöresinde yeralan aktif yapılar, GB'da Dinar fayı, KD'de ise Simav-Afyon-Akşehir Fay Sistemleri tarafından sınırlandırılmaktadır. Çalışma alanı hem GB'de hem KD'de yeralan genişlemeli iki tektonik rejim arasında kalan makaslamalı bir zonda yeralır. Bölgede bulunan aktif faylar, çeşitli kayaç gruplarını kesmekte ve ötelemektedir. Arazi gözlemleri ve uzaktan algılama yöntemleri ile bölgede yeralan fayların sol yanal bileşeni olan faylar olduğu ve morfolojide çok belirgin izler bıraktığı gözlemlenmiştir. Gerçekleştirilmiş olan detaylı çalışmalar sonucunda bölgede yeralan fayların geometrik özelliklerinin ve yapısal unsurlarının farklılıklar gösterdiği belirlenmiştir. Elde edilen en önemli bulgu ise bu fayların Holosen fayı olarak güncellenmesi ve sınıflandırılması olmuştur. Tarihsel ve aletsel dönem deprem kayıtları incelendiğinde bu faylardan kaynaklanan herhengi bir yıkıcı depreme raslanılmamakta, ancak aletsel dönemde Mw:5.5 büyüklüklerini geçmeyen depremlerin varlığı da bilinmektedir.

Bu çalışmada, bölgede yeralan beş adet aktif fay üzerinde gerçekleştirilmiş olan hendek çalışmalarından elde edilen sonuçlar anlatılacaktır. Paleosimolojik hendek çalışmaları detay Kuvaterner jeolojisi haritalamalarını takiben belirlenen Holosen yaşlı birimler içerisinde belirlenmiş olan lokasyonlarda gerçekleştirilmiştir. Açılmış olan hendek duvarlarından çalışılan fayların yakın jeolojik dönemdeki aktivitesi ve faylanma kinematiği hakkında bilgiler elde edilmiştir. Holosen döneminde yüzey yırtılmasıyla sonuçlanmış depremlerin varlığı sedimantolojik ve yapısal unsurlar birlikte değerlendirilerek belirlenmiştir. Ayrıca deprem sevilerinden derlenen radyokarbon örneklerinden elde edilen yaş verileri ile de bu sonuçlar desteklenmiştir.

Anahtar Kelimeler : Afyonkarahisar, Sandıklı, aktif tektonik, paleosismoloji, GB Anadolu

KAFZ üzerinde 8 bin yıl önceki bir mega-deprem (Mw>8.4): Sünnet paleo-heyelanından (KB Anadolu) kanıtlar

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KAFZ'nin güney kolunun katetdiği Dokurcun Vadisi güneyinde Jura-Kretase karbonatları üzerinde heyelanların yoğunlaştığı 40x20 km büyüklüğünde bir zon bulunur. Bu zonun en güneyinde, faydan 18 km kuş uçuşu mesafede, kuzeye akan Değirmendere'nin her iki sarp yamacında tıkız Kretase karbonatları içinde iki büyük (100'lerce m) heyelan gelişmiştir. Vadi membasında oluşan heyelan set gölünün ilk gölsel sedimanlarının radyokarbon tarihlemesi, heyelanların GÖ 7941±35 yılında geliştiğini göstermektedir.

Değirmendere Vadisi'nin güneyindeki Sünnet-1 heyelanı üzerinde geriye dönük duraylılık analizleri yapılmıştır. Bu amaçla öncelikle mevcut topoğrafyadan hareketle heyelan öncesi topoğrafya ve kaşık şekilli heyelanın kayma dairesi belirlenmiştir. Ek olarak, heyelanın üstünde geliştiği karbonat kayaçların ve kaya kütlesinin jeomekanik özellikleri bir dizi hat etüdünün değerlendirilmesi ve alınan örneklerin laboratuvar testleri vasıtasıyla belirlenmiştir. Buna göre, Sünnet-1 heyelanının geliştiği kaya kütlesi için sağlam kaya malzemesi tek eksenli sıkışma dayanımı 94.5 Mpa, Hoek-Browm m_i parametresi 9, GSI puanı ise 45 ile 55 arasında değişmektedir. Bu parametreler ve Hoek-Brown yenilme ölçütünden yararlanılarak ve pseudo-statik iki boyutlu limit denge analiz yöntemi kullanılarak yapılan geriye dönük analizlerden heyelana yol açacak minimum PGA değerinin kuru koşullar için 0.97, doygun koşullar için 0.48 PGA olabileceği tespit edilmiştir. Heyelanların içinde geliştiği ortamın morfolojik ve litolojik özellikleri tartışmaya kısmen açık olmakla birlikte heyelanların, kayma yüzeyinin kuruya yakın koşullardayken gelişmiş olabileceğini göstermektedir. Yaygın kabul gören ivme azalım eşitlikleri, Sünnet-1 heyelanından elde edilen minimum PGA değerinin KAFZ'nin Dokurcun Segmenti üzerinde çok büyük (Mw>8.4) bir depremle gelişmiş olabileceğini kanıtlamaktadır.

Mevcut çalışma, paleo-heyelanların eski mega-depremlerin konum ve büyüklüklerinin belirlenmesindeki potansiyelini ve KAFZ'nin aletsel ve tarihsel dönemler öncesinde muhtemelen çok geniş tekrarlanma aralığına sahip mega-depremler üretmiş olabileceğini kanıtlamaktadır.

Keywords: Dokurcun segmenti, geriye dönük analiz, jeomekanik, paleo-heyelan, mega-deprem

A case study for re-evaluation of historical earthquakes: 1789 Palu (Elazığ) Earthquake, East Anatolia, Turkey

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The East Anatolian Fault (EAF) is a left lateral active strike-slip fault, extending from Karlıova (Bingöl) at the northeast through İskenderun Gulf at the southwest. Palu (Elazığ), which is the subject of the study area, is located on the EAF. The Palu Fault is about 70 km long and it reaches the Hazar Lake over the Baltaş Plain.

During the instrumental period, the biggest earthquake occurred on March 26, 1977 with magnitude of 5.2 and 9 people lost their lives. According to the historical period records, the largest earthquake affecting Palu occurred in 1789 and is estimated to be magnitude of 7, which caused 51000 casualties. Taylesanizade Hafiz Abdullah Efendi's book with the title of 'Long Four Year Istanbul (1785-1789)' suggests the number of dead is about "8.000-10.000''.

In this study, the Ottoman Archives in Prime Ministry, the Ottoman Law Records and related books are studied in order to reveal the effects of the Palu Earthquake. Although there is an earthquake occurred in Palu in the light of the data, we suggest that the size of the earthquake and the numbers about loss of life are exaggerated in previous studies.

Keywords: East Anatolian Fault, 1789 Palu Earthquake, historical records

Palaeoseismic behaviour of the Malatya – Ovacık Fault Zone: Implications for the internal deformation of the Anatolian Block

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The post-collisional convergence (Eurasian and the Arabian plates) and subduction along the Hellenic trench (Eurasian and African plates) are the main driving mechanisms for the deformation of the Anatolian Block, which is mainly accommodated along the dextral North (NASZ) and sinistral East (EASZ) Anatolian Faults. The westward extrusion of the Anatolian Block with respect to Eurasia is accommodated along its boundary faults, whereas the interior of the block also reveals intense deformation of variable kinematic types. The Malatya- Ovacık Fault (MOFZ), which is 240-km long NE-striking sinistral fault, is one of the poorly known interior structure of the Anatolian Block. Although the earlier hypothesis claims that the seismic activity of the MOFZ is ceased around 3 Ma, recent geologic and geodetic studies and microseismic activity strongly suggest the opposite. Nevertheless, there is very limited knowledge on the seismic and kinematic behaviour of the MOFZ.

In the frame of this study, we tried to understand the character of deformation and earthquake behaviour along the MOFZ and contribution the internal deformation of the Anatolian Plate. The almost N - S striking sinistral Malatya (MF) and NE-SW striking sinistral Ovacık Faults (OF) are two components of the MOFZ and show very clear fault morphology and excellent sinistral deflections of the rivers. We excavated three different trenches along the MF and a single trench on the OF. The radiocarbon dating of faulted stratigraphic layers yields an average recurrence interval of 2275 ± 605 years for the MF and 2400 ± 765 years for the OF, which suggests the MOFZ shows the highest seismic potential among other interior structures of the Anatolian Block. Moreover, the decreasing deformation rates of active faults from east to west (~2.5 mm/yr for the MOFZ, ~1 mm/yr for the Central Anatolian Fault Zone and < 1mm/yr for the TuzGölü Fault), support the effect of post-collisional conditions for the deformation pattern in the eastern central Anatolia. Therefore, these correlation helps to understand the interior crustal deformation of the Anatolian Block and is also important to develop a better understanding of the diffused deformation zones of collisional systems.

Keywords: Anatolia, paleoseismology, Malatya- Ovacık Fault Zone, internal deformation

Paleoseismologic data to build earthquake recurrence and rupture patterns in Central Apennines (Italy)

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Earthquake-hazard assessment can greatly benefit from paleoseismic data as they provide useful information for the understanding of fault behaviour over multiple earthquake cycles. This is relevant for understanding the earthquake cycle and its variability within a region and time frame and thus, to build informed earthquake rupture models.

Paleoseismology provides long histories of recurrent earthquakes or of recurrent series of earthquakes on individual faults; a synthesis of these data may include different scenarios that may propagate into different rupture patterns from a local to regional scale. Analytic approaches may help reduce the uncertainties affecting the paleoevents ages and help avoiding biased interpretations; thus, to obtain the best possible scenarios. Specifically, we develop a probabilistic framework to explore the distribution and possible variability of earthquake recurrence intervals (e.g. Schwartz et al., 2014). We applied this approach from the scale of a single fault section to the fault system and to several fault systems. Our goal is to use the obtained results to define the most reliable potential rupture scenarios (e.g., clustered vs. random, interacting faults vs. isolated faults etc.).

The Central Apennines are characterized by a dense array of prevalently NW-SE striking normal faults and by an old and recent history of frequent damaging and deadly earthquakes that show how earthquake ruptures often occur in temporal and spatial clusters. The collection of paleoseismic data in this area was started about three decades ago; although still far to be considered complete these data represent a unique set of paleoseismic records of surface-rupturing earthquakes during the Late Pleistocene-Holocene.

We show some initial examples of the analysis of recurrences of paleo-surface faulting earthquakes along some of the fault sections and fault systems of the central Apennines. A total of 90 trenches are available for this investigation. Our final aim is to estimate on the basis of the paleoseismic evidence, rupture scenarios in time and space, also for anticipating the location of future surface ruptures.

The development of earthquake recurrence models in central Apennines has also implication to the assessment of the earthquake hazard of the city of Rome. In fact, as it is historically documented, the city is particularly vulnerable to the earthquakes that originated in the Central Apennines.

Keywords: Earthquake recurrence models, paleoseismic data, normal faults, seismogenic faults behaviour, seismic hazard

New trenching results along the Iznik section of the MNAF: integration with preexisting data

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The integration of historical and paleoseismological data on earthquakes of the past has the benefit to extend back in time the seismic history of a region and figure out typical earthquake ruptures in time and space that can be used to build future earthquake scenarios for seismic hazard assessment. How frequent earthquakes may be on individual fault segments or what is the probability of a cascade of earthquakes in a short interval of time on adjacent fault segments are basic questions for seismic hazard. Answers may come from long historical series that are a key for future fault behaviour. However, an important amount of data is needed to complete this mosaic and provide the most likely answers; paleoseimology may help in this.

We provide a new mosaic tile on the recent Late Holocene history of surface ruptures on the Iznik segment of the Middle strand of the North Anatolian Fault (MNAF). The MNAF clearly displays lower slip-rates (~4-5 mm/yr) with respect to the northern stand. However, large damaging earthquakes (M>7) occurred in the past along the MNAF and left clear signatures in the built and natural environment. Historical catalogues report several damaging and felt earthquakes in the town of Iznik (former Nicaea) in the past 2 millennia (eg., CE 32, 121, 1065, 1419, 1855, 1863, ecc). However, in most of the cases, association of the related earthquake source (e.g., Gemlik, Iznik, or Geyve fault segments) remains matter of debate. Conversely, paleoseismological data are tied to the fault segment itself and, although with broad chronological constraints, their integration to historical data can help solving earthquake source attribution.

Paleoseismological studies along the Iznik fault segment were able to set the age of the most recent surface faulting earthquake between 1400 and 1850 CE. Evidence for multiple events was found only at a site but with no chronological constraints. Paleoseismological sites from the nearby Gemlik and Geyve segments show evidence for at least one event during the past millennium.

We excavated two trenches across the long-term scarp of the Iznik fault segment near Mustafali, (WSW of Iznik): one excavation was on a flat alluvial surface and the other was at the base of a slope with colluvial, alluvial and lacustrine deposits. At both sites, the fault trace was visible although locally modified by agricultural activities. Preliminary radiocarbon and TL dating on samples collected from the trench show that the displaced deposits are very recent and span maximum the past 2 millennia. Evidence for at least 4 surface faulting events was found, with the most recent one occurring largely after 640 CE, likely close to 1650-1950 CE. This latter could be one of the shocks that hit Iznik in the 1800s (e.g. 1863? or 1855). The two previous surface faulting earthquakes occurred at this site at about 600 and

2-400 CE suggesting variable recurrence intervals and possible interaction with adjacent fault segments.

Keywords: Paleoseismology, earthquake recurrence, Middle strand of NAF, Surface rupturing Earthquakes, Ancient Nicaea

Tectonic and paleoseismological analysis of active deformation along the Milas Fault (Muğla, SW Turkey): Earthquake history and seismicity.

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Western Anatolia is subject to the extension and associated impacts of deformation resulting from the westward extrusion of the Anatolian Block along the North Anatolian Fault (NAF) and East Anatolian Fault (EAF). E-W trending horst and graben systems and NE-NW-trending cross faults are formed as a result of this N-S extension in the Western Anatolia. The main tectonic structures of the region are revealed by the Gediz, Simav, Bakırçay-Soma, Edremit, Büyük Menderes and Gökova Fault Zones. Milas Fault is one of the important tectonic structures in SW Anatolia, which is characterized by a dominant right-lateral strike-slip movement, 50 km-length and N50°W orientation. The Karakuyu Segment starts from the south of the Lake Bafa and extends up to Milas Town throughout the southern parts of Danişment, Eğridere, Çandır, Hisarcık, Karakuyu and Sırtlan villages. The fault jumps around 3 km to the right after Milas Town. This segment starts around Beçin town and continues southeastward up to Çamlıca village.

In spite of the active seismic regime of SW Anatolia, the Milas Fault displays a weaker seismicity during the instrumental period (between 1900-2019 CE). A total of Mw ≥3 earthquakes are recorded around Milas Fault. One earthquake larger than M=5 effected the Milas region at 23.05.1941 and another one of Mw= 5.6 magnitude were located 18 km southeast of Beçin. In order to investigate the palaeoseismicity of the Milas Fault, we excavated three trenches at two different sites on the Karakuyu Segment: Ağılyanı-1, Ağılyanı-2 (UTM 35 S 566573E, 4131493N) and Zeytinlik (UTM 35 S 567394E, 4130915N) trenches. Total of 10 OSL (Optically Stimulated Luminescence), 8 bulk and 2 charcoal samples were collected from 3 trenches to reconstruct the earthquake history of the Milas Fault. C-14 and OSL ages reveal information on two historical earthquakes in the Ağılyanı-1 trench: an older one before 7722 ± 1510 BC and younger (probably the last) earthquake between 4322 ± 380 BC and 232 ± 260 BC. With similar stratigraphy-structure relations, an earthquake event between 2963 ± 67 BC and 1702 ± 260 BC was determined on the wall of Ağılyanı-2 trench. This earthquake is in conformity with the last earthquake determined in the Ağılyanı-1 Trench and further narrows down the earthquake interval . The date of 1610 ± 84 BC coming from above the event horizon in the Zeytinlik trench may confirm the last earthquake. These dataset obtained from three trenches were evaluated together and assumed that two large earthquakes occurred on Karakuyu Segment during Holocene; one before 7722 ± 1510 BC and other one between 1702 ± 260 BC and 2963 ± 67 BC.

Considering the last surface rupture might have happened about 4000 BP on the Milas Fault, we suggest a higher seismic risk than previous assumptions for Milas Region in near future. This study is supported by TÜBİTAK (Project No: 116Y179).

Keywords: Paleoseismology, active tectonics, Milas Fault, SW Turkey

Correlation of sedimentary records with historical earthquakes in Lake Sapanca (NW Anatolia)

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Lake Sapanca (40°43'N 30°16'E) has a maximum depth of 55 m and a surface area of 46.8 km^2, measuring 16 km in E-W and 5 km in N-S directions. The lake is important to the Marmara region because of its freshwater character and has been used as a source of drinking water by this most populated region of Turkey.

We determined earthquake records in sediment cores from Sapanca Lake which is a pull-apart basin located along the North Anatolian Fault zone in NW Anatolia. A systematic study of the sedimentological, physical and geochemical properties of three water-sediment interface cores, up to 75.7 cm long, located along depth transects ranging from 43 to 51.5 m water depths. The cores were analyzed using Geotek Multi Sensor Core Logger (MSCL) for physical properties, laser particle size analyzer for granulometry, TOC Analyzer for total organic carbon (TOC) and total inorganic carbon (TIC) contents, µXRF Core Scanner for elemental analysis and high resolution digital X-RAY Radiography. The geochronology was established using radionuclide (^{210}Pb, ^{137}Cs) methods and accelerator mass spectrometry (AMS) radiocarbon analyses.

The Sapanca Lake earthquake records are characterized by mass flow units consisting of grey or dark grey coarse to fine sand and silty mud with sharp basal and transitional upper boundaries. The units commonly show normal size grading with their basal parts showing high density, and high magnetic susceptibility and enrichment in one or more elements, such as Si, Ca, Ti, K, Rb, Zr and Fe, indicative of coarse detrital input. Based on radionuclide and radiocarbon analyses the mass flow units are correlated with 1999 Izmit and Düzce earthquakes (Mw=7.4 and 7.2, respectively), 1967 Mudurnu earthquake (Mw= 6,8), 1957 Abant (Mw= 7.1) earthquake, 1943 Hendek earthquake, 1894 East Marmara earthquake, 1878 Eşme earthquake and 1754 Izmit earthquake. Also, we focused on thickness of mass flow units. The relations between earthquake parameters (magnitude, distance from epicenter, focal depth) and mass-flow parameters (thickness, sedimentary structure, grain size, composition) are discussed.

Keywords: Lake Sapanca, Earthquake, Mass Flow Unit, North Anatolian Fault

Seismoturbidites in highly bioturbated marine sediments: Example from the Gulf of Aqaba

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The GAST Project (i.e. Interdisciplinary earthquake hazard research in Gulf of Aqaba and Strait of Tiran) was initiated in April 2017 to improve our knowledge on the location and geometry of active faults in the region, its overall tectonics and its paleoseismic behavior. As a part of the project, we collected 23 short sediment cores, with lengths between 35 and 107 cm, distributed almost evenly along the Gulf's length (approx. 180 km). The cores were scanned by ITRAX micro-XRF scanner at Marine Research Laboratory of the General Directorate of Mineral Research and Exploration (MTA, Ankara). Instead of doing radiographic imaging on half-cores, we obtained radiographic images on 4 cm-wide and 0.5 cm-thick u-channels extracted from the cores, which allows better evaluation of sedimentary structures. High-resolution radiographic images reveal that the sediments in the gulf are highly bioturbated. Turbidites appear in the radiographic images as well-laminated basal levels and almost homogeneous middle and upper levels, which is a proof of sudden deposition not allowing bioturbation. Sudden deposition of detrital clastics is also confirmed by distinct anomalies along [Ti,Zr] / [Ca,Sr] profiles, where detrital clastics are represented by [Ti,Zr] and biogenic carbonates from the water column are represented by [Ca,Sr]. Sudden deposition does not allow deposition of biogenic carbonates that results in high [Ti,Zr] / [Ca,Sr] values. The chronology of the cores was constructed by 22 radiocarbon dates on planktonic foraminifera content of the sediments, which yields sedimentation rates around 0.15 mm/yr in Dakar basin, and around 0.32 mm/yr in Tiran and Eilat basins. The cores collected from Aragonese Deep are almost totally composed of turbidites, which does not allow distinguishing background sediments and turbidites. Constructed sediment chronologies confirm temporal correlation between the turbidites and the historical earthquakes in the Gulf of Aqaba region.

Keywords: Marine paleoseismology, ITRAX micro-XRF scanning, U-channel radiography, Bioturbation

Preliminary results on the paleoseismology of the Muğla Fault (SW Turkey)

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South Western Anatolia and its surrounding is seismically an active region due to the extension tectonics caused by the Hellenic arc and the westwards escape of the Anatolian plate. Several normal faults control the morphology by forming horst and grabens in the region. The Muğla-Yatağan fault is a NW-SE trending ~50 km long normal fault located between the E-W trending Büyük Menderes and Gökova grabens. The fault runs through populated and in-dustrialized settlements, however its seismic hazard is poorly known. The most recent destructive earthquakes in the vicinity are the 1941 (M5.8), 1944 (M6.3) and 2017 sequence (M 4,9-5,3) that caused damages to villages nearby. However, empirical relations suggest that the fault may cause an earthquake reaching Mw7.0 magnitude.

Field mapping, quantitative geomorphology and paleoseismic trenching reveal the recent tectonic activity of the fault. The Quaternary deformation of the fault is expressed in both, morphology and geology; steep slopes, hanging valleys, iron-flats, fault surfaces and offset Quaternary deposits are observed as clear markers of the ongoing tectonic activity.

We applied paleoseismic trenching at two sites on the hanging wall block of the eastern section of the Muğla fault. The Yaraş 1 trench (length: 18 m, 3.5 depth) exposed several fault strands within a 1-4 m wide fault zone, overlain by coarse colluvium packages, a fluvial deposit and an uppermost soil unit. The fluvial deposit is a reddish-brown silt-clay layer with an erosional bottom and is visible along the trench. The unit corresponds to the flood plain deposits of the nearby Kurudere stream but is tilted southward by 10°-30°. The reddish deposit is truncated by two fault strands and offset by 10 to 40 cm and likely marks the last surface rupturing event along the fault. The other fault branches are overlain by this unit with an erosional contact.

The other site Yaraş 2, was opened within the colluvial deposits of a limestone fault scarp. The 3.5 m long and 2 m deep trench walls exposed two sequences of colluvium packages (b&c) overlain unconformably by a brownish medium to fine grained colluvium (a). The upper colluvium sequence (b) consist of 4 distinct, cemented colluvial layers that are tilted southward by 5° to 23° (towards the fault). The layers are partly fractured with offset of 2-5 cm. The lower sequence (c) is made coarse grained colluviums that are cut and displaced by antithetic and synthetic faults. The total offset was measured as 15 cm and affects the uppermost colluvium (a) at its bottom. A second fault strand that is overlain by colluvium (a) suggests the existence of at least two faulting events.

Preliminary results at two paleoseismic trench sites suggest that both sites experienced at least two surface faulting events with 10-40 cm slip during the Quaternary-Holocene period. Radiometric dating of trench deposits will allow constraining the timing of the events. Our earliest findings show that the Muğla-Yatağan fault is potentially a source for a destructive earthquake in the region and requires further paleoseismic analysis to evaluate quantitatively its seismic hazard. This work has been funded by the MSKU Research Fund project 17-288.

Keywords: extension tectonics, normal faulting, active tectonics, paleoseismology, trenching, Aegean, South West Anatolia

Morphotectonic features and paleoseismic events between Geyve and İznik: The Southern Strand of the North Anatolian Fault Zone (NAFZ) in the Marmara Region, NW Turkey

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The North Anatolian Fault Zone (NAFZ) splays into two main strands to the west of Bolu in the Marmara Region. The Southern Strand is mainly characterized by discrete structures of a wide deformation zone, whereas the Geyve and İznik-Mekece segments are the most continues members between the Gemlik Bay in the west and Dokurcun in the east. The Geyve Segment prolongs with N70-80E strike and has significant morphological indicators along its course. This 60 km-long segment is separated with its western neighbour (the İznik-Mekece Segment) with a 1.5 km-wide releasing step-over at Mekece Town.

Many morphological features related to faulting can be observed along these fault segments such as offset channels, elongated ridges, shutter ridges, topographic saddles, and triangular facets. Morphological structures, which are displaced between 40 m to 20 km, were determined and measured along the fault line. In order to understand the palaeoseismic activity, we excavated trenches at two sites, one on Geyve and another on the İznik-Mekece fault. The results of Geyve trench suggest two events, which were dated to be around 8000 and 6000 BCE. Mekece site includes 5 trenches, which reveals evidence of three palaeoevents occurred after 1500 BCE, around 500 BCE and between 20 BCE and 660 CE. The youngest event is correlated with the 368 CE historical earthquake.

Keywords: North Anatolian Fault Zone, Paleoseismology, Morphotectonic, Geyve Fault, İznik-Mekece Fault

TH-4

SEISMOLOGY - SEISMOTECTONICS

Complex earthquake source characteristics and numerical simulations of associated tsunamis: Case studies from global events

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On a global scale, many destructive and tsunami-generating earthquakes ($M_w \geq 7.5$) cause widespread devastation, economic and human life loss due to the active plate interactions along the major subduction zones. To accurately model the rupture properties of earthquake source, which is one of the main subjects of seismology, also postulates important clues for the relevant research fields. Seismological observations and analysis are essential to better constrain and to elucidate tectonically dynamic forces and deformation styles that lead to the secondary effects of earthquakes, i.e. tsunamis. Understanding the complex behaviour of earthquake source evolution provides principal knowledge in terms of estimating input parameters of tsunami studies (e.g., faulting geometry, focal depth and seismic moment release). It is also known that mathematical tsunami simulations based on heterogonous slip distribution models of earthquakes give more detailed and precise estimations of synthetic tsunami waves, which are quite compatible with the real-time DART and tide-gauge records. Here, we present a brief summary of the source mechanisms and slip distribution models of complex large earthquakes happened at diverse parts of the Earth by providing case studies from global events. Source mechanisms and finite-fault slip distribution models of earthquakes were revealed by teleseismic P- and SH- waveform inversion methods. Furthermore, general characteristics of earthquake-induced tsunamis observed at the Aegean-Mediterranean Seas, Pacific and Indian Oceans were investigated by using mathematical simulations. For example, numerical simulation results of the historical Eastern Mediterranean earthquakes and associated tsunamis (e.g., 365, 1222, 1303, 1481, 1494, 1822 and 1948) occurred along the Hellenic and Cyprus subduction zones clearly demonstrated tsunami wave characteristics and potential tsunami risk particularly at the coastal plains of Crete and Rhodes Islands, Turkey, Cyprus-Levantine, and Nile Delta regions. Likewise, a latest large strike-slip earthquake (M_w 7.5) hit the eastern part of Indonesia on the September 28, 2018 by producing astonishing tsunami waves along the coasts of Sulawesi Island. It is correlated with the NW–SE trending left-lateral Palu-Koro strike-slip fault in central Sulawesi. Inversion results indicate a strike-slip faulting mechanism with small amount of dip-slip component at a shallow focal depth succeeding a super-shear rupture velocity of V_r: 4.1 km/sec. This oblique shear that also revealed from the slip inversion could be partially responsible for the unexpected tsunami generation along the left-lateral Palu-Koro Fault. Overall, the importance and necessity of seismological parameters and a high-resolution bathymetry data in tsunami simulations, and the major effects of tectonic structures developed under the complex tectonic evolution on earthquake source parameters and tsunami wave characteristics are evidently emphasised.

Keywords: Aegean-Anatolia, Earthquake source mechanisms, Finite-fault slip distribution, Palu-Sulawesi, Subduction zones, Tsunami modelling and simulation

Investigating Gutenberg-Richter b-value and seismic hazard in Caucasus (Azerbaijan)

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Azerbaijan represents the mountainous section of the Greater Caucasus, the Lesser Caucasus, Kur depression zone, and the South Caspian Basin. Mountains of the Greater and Lesser Caucasus extend between the Black and Caspian seas and creates a part of the continuous Alpine-Himalayan orogenic belt. Seismically, Azerbaijan is representing from moderate to strong earthquake-prone area depending on the seismic provinces. The Gutenberg–Richter relation is a well-known empirical relation in seismology, representing the frequency magnitude distribution (FMD), generally expressed as log10(N) = a-bM, where N represents the number of events whose magnitude is above the threshold M, a represents the earthquake productivity, and b is a critical parameter informing about the size distribution of earthquakes. We analysed the seismicity of Azerbaijan from 2003 to 2016 (seismic data extracted from the RCSS) and found that the non-cumulative FMD shows a bimodal shape indicating a certain spatial heterogeneity of the completeness magnitude. By using several methods to estimate the completeness magnitude (Wiemer and Wyss, 2000) we found that the more conservative choice is a completeness magnitude equal to 2.9, which leads to b-value around 0.76. We investigated the time variation of the completeness magnitude and b-value and found that, in particular, the variation of the b-value seems to be correlated with the occurrence frequency of relatively strong earthquakes. In this study, we also attempted to estimate seismic hazard in terms of b-value distribution for Azerbaijan.

Keywords: Gutenberg-Richter law, b-value, seismic hazard, Caucasus, Azerbaijan

Investigation upper mantle structure of Marmara and its surrounding region using teleseismic tomography

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The main scope of this research is the investigation of the lithosphere and deeper mantle structure of the Marmara and its surrounding regions. We present high-resolution tele-seismic tomographic results using the travel time of far-field earthquakes. Investigation of the heterogeneous mantle structure, the delineation of fast seismic velocity anomalies in the mantle, delineation of possible subducted oceanic lithospheric slabs, the identification of mantle upwelling zones can be achieved using seismic tomography.

In this study, we used 15,624 direct P-phase arrival times from 126 earthquakes recorded at a variety of permanent seismic networks (Boğazici University, Kandilli Observatory and Earthquake Research Institute and Disaster and Emergency Management Authority). In order to increase the station coverage and increase the resolution, we selected arrivals from earthquakes with moment magnitude 5.5 and greater (Mw>5.5) at distances between 28° and 90° from the stations for direct P phases (126 earthquakes). After combining data sets, relative arrival time residuals and errors were determined with respect to the ak135 one dimensional global velocity model using the Adaptive Stacking Method. These results were used in the fast marching tele-seismic tomography inversion and we have obtained new three-dimensional (3-D) P-wave velocity perturbations of the mantle beneath Western Anatolia down to about 700 km depth.

The tomographic results show the existence of two distinct high velocity anomalies in the mantle. Seismic tomographic cross-sections clearly show the northward subducting African slab as well as the low-velocity subduction wedge located between this slab and the Aegean continental lithosphere. This low-velocity wedge can be interpreted as the mantle source region of the active Aegean arc volcanism. The obtained tomographic results also indicate the presence of a distinct, southward subduction, high-velocity zone in the north. This high-velocity zone, which is located beneath the Marmara Sea, extends down to 350 km and it consists of two oceanic lithospheric pieces that are detached at about 200 km depth. This high-velocity zone can be interpreted as the remnant of the southward subduction Black Sea oceanic lithosphere. A high velocity zone that would be expected from the İzmir Ankara-Erzincan suture zone was not observed in this study.

Keywords: Marmara and Surrounding Region, Teleseismic tomography, Upper mantle structure

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24 ve 26 Eylül 2019 tarihlerinde Silivri açıklarında meydana gelen depremler TÜBİTAK MAM Yer ve Deniz Bilimleri Enstitüsü'nün 2006 yılından bugüne Marmara Bölgesi'nde işlettiği sayısal gözlem ağı tarafından kayıt edilmiş olup bu depremlerin öncesi ve sonrası izleme ve değerlendirme çalışmalarına devam edilmektedir. 26 Eylül depremi tüm YDBE istasyonları ve diğer bölgesel ağların (KOERİ ve AFAD) verileri de kullanılarak 40.868°K ve 28.213°D koordinatlarında ve derinliği 11 km olarak saptanmıştır. İzleme süresince daha önceki yıllarda da bu bölgede deprem etkinliği gözlenmektedir. Bu depremlerden sonra bölgede oluşan artçı depremlerin dağılımı anaşokun güney doğusuna doğru 15 km aralığında 2-18 km derinlikleri boyunca devam etmektedir. 26 Eylül tarihli Silivri depremi odak mekanizma çözümü P dalgası ilk hareket ve moment tensörü yöntemleriyle çözülmüş olup birbirleriyle uyumlu olarak ortalama ~70° dalım ve ~158° kayma ~270 doğrultulu yanal atımlı fay karakteri taşımaktadır. Elde edilen verilerle yüksek doğruluğa sahip deprem dağılımı ve odak mekanizmaları ile fay zonunun yapısı analiz edilerek bölgenin tektonik unsurları ile ilişkilendirilerek toplantıda sunulacaktır.

Keywords: Silivri Depremleri, artçı dağılımı, odak çözümü

Can supershear transition be seen in damage and aftershock pattern? Part one: Theory

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Supershear earthquakes remain powerful events with devastating consequences, as the variability in rupture speed affects the generation of high-frequency waves and the spatial extent of coseismic off-fault damage. However, only a handful of events have so far provided the opportunity to study their physical characteristics. In particular, the transition from sub-Rayleigh to supershear rupture speed is often left aside to focus solely on the rupture segment that sustained a supershear rupture. Why, when and how fast does a rupture transition from sub-Rayleigh rupture speed to supershear in real, natural earthquakes? Some efforts have been made in order to understand the behavior and characteristics of this transition zone (from a numerical perspective), but the evidence and mechanisms in nature are still poorly understood.

Here, we combine theoretical and numerical models to locate and characterize the physical behavior of the transition of a seismic rupture to supershear speed. First, we use classical modeling of linear elastic fracture mechanics (LEFM) to demonstrate that, before transitioning to supershear, when a sub-Rayleigh rupture approaches Rayleigh wave speed, the stress concentration at its tip shrinks, limiting the spatial extent of possible off-fault damage. Then, employing two different dynamic rupture approaches that include damage zone modeling, we confirm such reduction in the stress perturbation, and consequent off-fault damage in the transition region. Identifying observational evidences of the stress reduction will allow to pinpoint the transition from sub-Rayleigh to supershear, hence providing an opportunity to explore the morphological and dynamic characteristics of faults sustaining supershear transition. Examples of those observations will be given in the second part of this talk.

Keywords: Supershear ruptures, dynamic modeling, damage and aftershocks

Can supershear transition be seen in damage and aftershock pattern? Part two: Observational evidence

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Numerical and theoretical results shown in the previous part, are contrasted with high-resolution aftershock catalogs for 3 earthquakes well known as supershear ruptures: 1999 Izmit Mw7.2, 2002 Denali Mw7.9 and 2013 Craig Mw7.5. For each of these examples, we identify a small region, ranging from 5 to 10 kilometers, with a drastically low density of aftershocks just next to the transition to supershear. Finally, we use optical correlation images to show that, for the 2001 Kunlun Mw7.8 earthquake, the transition zone is characterized by a diminution in the width of the damage zone. Identifying an absence of aftershocks and decrease in off-fault damage allows to pinpoint the transition from sub-Rayleigh to supershear, hence providing an opportunity to explore the morphological and dynamic characteristics of faults sustaining supershear transition.

Keywords: Supershear ruptures, dynamic modeling, damage and aftershocks

Seismological and numerical constraints on the mantle dynamics beneath the Eastern Mediterranean and Anatolia

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Proper knowledge of seismic anisotropy provides a key tool in constraining the deformation styles beneath subduction systems and its adjacent regions. This work examines the eastern Mediterranean Sea region and Anatolia that are mainly under influence of two northward convergent regimes, subducting African lithosphere to the west and collisional tectonics between Arabian and Anatolian plates to the east. Passive seismic imaging efforts have well elucidated the complex structure of subducting African lithosphere underneath relatively thin Anatolian lithosphere. This implies that mantle kinematics is presumably controlled by mantle flow patterns resulting from the dynamic interactions between a relatively dense subducting oceanic plate and the surrounding mantle. To understand the contribution of complicated dynamic setting to the seismic anisotropy, we benefit from seismological observations (e.g., shear wave splitting parameters, receiver functions) and 3-D geodynamic modelling of the anisotropic source. Numerical model setting is adjusted to be a first order representation of the present-day tectonic regime of the study area. Overall consistent regional pattern of both calculated and observed anisotropy parameters confirms the flow induced lattice-preferred orientation of olivine (LPO) in the sub-lithospheric mantle and the underlying the roll-back effect. A comparison between synthetically calculated fast polarization directions (FPDs) and early SKS splitting measurement regions of FPD similarities where N–S to NE–SW anisotropic orientations are parallel to the extension in the back-arc region and in general perpendicular to the trench. The pattern of FPDs appears to be more complex nearby the trench. Both seismological and numerical constraints suggest that the development of a tear in the African slab and the detachment occurring within the Arabian plate (break-off) appear to have a significant influence on the FPDs due to stronger mantle flow through the slab windows. Observed discrepancies from the regional NE-SW directed FPDs that can be attributed to the effect of flow through the tear in the southwest is well explained in numerical models.

Keywords: Seismic anisotropy, Subduction zones, Numerical modeling of mantle flow, Shear wave splitting measurements, Eastern Mediterranean, Anatolia

Spatial variations of seismic attenuation and heterogeneity in western Anatolia (Turkey) lithosphere from analysis of coda waves

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Seismic attenuation describes decrease in amplitudes of the seismic waves, as they propagate through inelastic and heterogeneous media. The quality factor Q, which is inversely related to seismic attenuation is widely utilized to image the interior Earth, since it is directly related with the physical/chemical state of rocks such as the distribution of fractures, fluid saturation of cracks and differences of temperature and pressure. Measuring the quality factor of coda waves (Qc), the wave train following the direct S-waves in local earthquake, has been widely utilized for this purpose and provides valuable information for understanding regional tectonics, playing a vital role in seismic risk analysis and engineering seismology.

The goal of this study is to regionalize of attenuation parameters from the analysis of the local earthquake coda waves recorded by WASRE (Western Anatolia Seismic Recording Experiment, 2002-2003) network. Seismic Quality factor (Q0) and its frequency dependence (n) were obtained from Qc(f) = Q0 f n relationships. To better understand the relation between spatial variation of seismic attenuation and tectonic setting of the region, not only the Q0 and n values but also the attenuation coefficients (δ), which is depending upon both the Qc values and velocity distributions of the region, were mapped for different depth levels. In general, increase in the Q0 and decrease in the n and δ values with lapse time (and accordingly depth) show that upper part of the lithosphere is more heterogeneous compared to its lower layers. The results are well correlated with thermo-mechanical weakening of the Anatolian plateau due to Eocene-Miocene Africa-Eurasia convergence, resulting in the buckling of the Menderes Metamorphic Core Complex along with the Izmir-Ankara-Erzincan suture zone and also the mantle flow due to uprising leak through a vertical tear in the subducted African slab. Variations of the δ coefficients and n parameters with depth imply the anomalous nature of melt migration and segregation at high pressure and temperatures, corresponding to depth of the lithosphere-asthenosphere boundary.

Keywords: Anatolia, seismic attenuation, coda waves

Monitoring Ganos Fault with a dense local seismic network (MONGAN project)

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The last large earthquake occurred on the Ganos Fault segment of the North Anatolian Fault Zone (NAFZ) was August 9, 1912, Mürefte earthquake (M7.4). The earthquake caused a rupture ~120-140km long extending from the Central Basin in the Sea of Marmara to the Saros Gulf. If the average annual slip rate along the NAFZ in the Marmara Region is assumed to be 20 mm, during a period of 100-year from 1912 Mürefte earthquake to the present day cumulative stress of about 2 m can be reached along the Ganos Fault. Recent discussions on the Ganos Fault is about how much of the ongoing plate movements have transferred into the accumulation of tension along the fault, how much creep it shows and how this sharing is distributed over the fault plane. The seismicity studies conducted with national seismic networks (KOERI and AFAD) exhibit very rare activity on the inland segment of the Ganos Fault when compared with those in the Marmara Sea and Saros Gulf. Cumulative stress and the resulting micro-seismicity are closely related to the physical and mechanical properties of the fault zone. This project aims to monitor seismicity of the Ganos Fault with dense local seismic networks crossing the fault and reveal current micro-earthquakes presumably occurred on the fault. Moreover, it is aimed to determine the physical properties of the fault zone and the current state of stress. For this purpose, at the first stage, a network consisting of 40 short-period seismometers was installed in the Güzelköy area located at the eastern end of the fault and operated during approximately two years. At the ongoing second stage, the network has been moved on the western part of the fault between Gölcük and Kavakköy. According to preliminary examinations, the network has captured hundreds of event differently from the national network. Analyses of the source parameters of the events are continuing. By using the obtained high-resolution source parameters, the present stress state along the fault plane can be determined. At the same time, the seismic networks are capable of collecting data that can be analyzed to reveal physical properties of the rupture zone by using Fault Zone Head Waves (FZHW) and Fault Zone Trapped Waves (FZTW). The first examples of these waves were found in the records. High-resolution seismicity information, the current state of stress and physical properties of the fault zone are crucial in determining the seismic hazard and understanding the rupture dynamics of the NAFZ in the Marmara Region.

Keywords: Ganos Fault, seismicity, seismic hazard, Marmara

Applications of post-stack migration types in seismic data

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In this study, various migration techniques were applied to the data obtained after routine data processing steps were applied to multichannel seismic reflection data and the positive and negative aspects of these techniques were analyzed after comparison of these migration types within and between each other. The applied migration types are Kirchhoff migration, Finite Difference Migration, Wave Equation Migration and Time Migration After Stack.

Data processing steps were carried out in the seismic data processing laboratory of Istanbul University - Cerrahpaşa Geophysical Engineering using Paradigm ECHOS program.

The seismic migration process is a data-processing stage with a wave equation that carries the sloping reflections in the seismic section and eliminates the energies of scattering at fault boundaries. The aim of this process is to make the seismic stack section similar to the geological section. It is tried to simulate the geological cross-section in the mound section. The reason that the geological section is not similar to each other is that the underground environment is inclined. In operations up to migration, the underground environment is considered to be flat, and reflection points are treated as if they were reflected from the center of the shot-receiver. Migration carries these inclined events to their real places and discards some of the effects caused by the slope. These are the effects of bow tie-tie, anticline and synclinals, and the location and size of inclined events. After the migration process, it is tried to eliminate the effects of bow tie ties that occur due to synclinals, while events such as anticline are narrowed and events such as syncline are widening and the slope of the structures located in the mound section increases after migration process. The success of removing these effects depends on the parameters used during the migration process.

After the stack process, migration process was started and four types of migration were applied. Firstly, the effect of migration on the cross-section was investigated by making parameter changes within these migration types. Then, using the most successful parameter for each type of migration, the cross-sections were compared with each other, and the success in the mound was compared to the geological environment.

Keywords: Seismic data processing, Kirchhoff, finite difference, wave equation, time migration after stack

Structural and stratigraphic research on the North Anatolian Fault based on multi-channel seismic reflection data in Adapazarı Basin, Eastern Marmara

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The North Anatolian Fault (NAF) zone splits into branches as north and south around the Mudurnu Valley. The northern branch of the NAF reaches to the Sea of Marmara through Lake Sapanca and Gulf of Izmit. About 145 km surface rupture occurred between the Sea of Marmara and Duzce as a consequence of the 17 August 1999 Izmit Earthquake. The NAF was investigated in great detail especially after the M_w>7 1999 earthquakes in the Sea of Marmara through the utilization of seismic reflection method by using wide range of penetration depths. However, investigations in the land to the east of the Gulf of Izmit were mainly carried out by using geological and geodetic data. Therefore, multi-channel seismic reflection data were collected along five different lines crossing the NAF perpendicularly in the NE-SW direction in the frame of TÜBİTAK-1001 Scientific Research Project (No: 117Y130) in order to determine the geometry of the NAF at depth. , Among these lines, three were processed whose total length is approximately 2.3 km. Collected multi-channel seismic reflection data was processed in ITU Geophysical Engineering Department, Nezihi Canıtez Data Processing Laboratory using the Paradigm® ECHOS® (v15.5) seismic data processing software package. Processing steps can be listed mainly as defining the shot-receiver geometry, editing, filtering, gain application, CMP sorting, velocity analysis, stacking and migration. In order to strengthen the results related to the near-surface structures, seismic refraction tomography method was carried out by using SeisImager/2D™ program, through the utilization of first arrivals that are present in the collected multi-channel seismic reflection data. In the obtained final multi-channel seismic reflection sections, the NAF is located precisely and it was observed that the NAF has an approximately vertical geometry. In the final seismic reflection section of the easternmost line, three different stratigraphic units were observed, which were interpreted as Pliocene age Örencik Formation, Pleistocene age river terrace deposits and Holocene age alluvium and alluvial fan units upwards. s Additionally, it is observed from this seismic reflection section that a negative flower structure deformed these stratigraphic units. On the other hand, velocity gradient sections obtained through the seismic refraction tomographic approach show that the undulating structures in the interfaces at shallower depths are compatible with the observed faults in the seismic reflection sections which are present at greater depths.

Keywords: North Anatolian Fault; Adapazarı Basin; multi-channel seismic reflection

Revising earthquake source parameters of the 26.12.1939 Erzincan Earthquake from historical seismograms

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The re-analysis of historical seismograms for earthquakes prior to the 1960's improves our knowledge on the source parameters of earthquakes and enables a better constrain on the associated seismic hazard. The 1939 Erzincan earthquake is the first of a sequence of thirteen shocks (M>6.8) along the North Anatolian Fault (NAF). The earthquake occurred on 26 November 1939 at 23:57 (GMT) with an epicentre near Erzincan-Turkey. The quake caused significant damage and death to nearly 33,000 people. Earlier studies suggest different type of earthquake magnitudes that range from 7.1 to 8.0 for the main shock. Similarly location estimations for the event show epicentre differences reaching up to 30 km in distance. In order to improve our knowledge on this event we are collecting historical newspapers, documents, reports, photographs, seismograms and bulletins. Currently, we retrieved several contemporary documents that provide inside on the social and economic consequences of this disastrous event. The 1939 event was recorded at 159 seismic stations around the world. The available bulletins provide 433 phase readings that will be used to constrain the epicentre and the timing of the event. Besides we retrieved 21 seismograms from 12 different stations that will allow to re-evaluate the magnitude and source characteristics of the earthquake. Our preliminary findings show that seismological parameters (location, magnitude, timing) for the 1939 Erzincan earthquake vary among different catalogues and earlier studies. Significant amount of historical and seismological data is available in order re-assess the source characteristics and socio-economic impacts of the large earthquake.

Keywords: Seismology, historical earthquake, historical seismogram, North Anatolian Fault, Erzincan earthquake

20 Mart 2019 Acıpayam (Denizli) Depremi (Mw=5.5) ana şok ve artçı şoklarının sismotektonik analizleri

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20 Mart 2019 tarihinde ulusal deprem izleme merkezlerinin verdiği bigilere göre Yeniköy-Acıpayam-Denizli merkez üstünde Türkiye yerel saati ile 09:34'de 37.4313º N enlem ve 29.4385º E boylamlarında, aletsel büyüklüğü Ml=5.6 (Mw=5.6) olan bir deprem meydana gelmiştir. Depremin odak derinliğini çeşitli ulusal sismoloji merkezleri 7 ile 16 km olarak vermişlerdir. AFAD verilerine göre ana şoktan, 20.03.2019 14:00'a kadar geçen zamanda, büyüklükleri 1.4 ile 4.8 arasında değişen 123 artçı deprem kaydedilmiş ve anaşoku takip eden Mw 4.8, Mw 4.5 ve Mw 4.2 büyüklüğünde üç artçı deprem sol yanal doğrultu atımlı Fethiye-Burdur Fay Zonun'un Acıpayam parçasında olmuştur. 20 Mart 2019 Acıpayam depremi, Isparta Isparta Açısı'nın Kuzeybatı kenarından başlayıp, Fethiye Körfezi'ne kadar uzanan, KD-GB uzanımlı geniş bir deformasyon zonu içinde meydana gelmiştir. Bu deformasyon zonu içinde KD-GB uzanımlı minör sol yanal doğrultu atım bileşenli normal fayların yanısıra bu faylara eşlenik konumda gelişmiş KB-GD doğrultulu normal faylar da bulunmaktadır .

Bu çalışmada, 20 Mart 2019 Acıpayam depremi ve devamında meydana gelen artçı şoklardan oluşan Mw>3.5 olan toplam 20 adet depremin moment tensör çözümleri yapılmıştır. Ana Şok ve artçı şoklarının odak mekanizma çözümleri, ana şokun derinliğe göre odak mekanizma değişimi ve deprem dağılımları incelenmiştir. Ana Şokun ve artçı şokların ters çözümü Sokos & Zahradnik, 2006 tarafından geliştirilmiş olan ters çözüm algoritması kullanılarak modellenmiş ve odak mekanizma çözümleri yapılmıştır. Ters çözümlerde 8 adet deprem istasyonu ve deprem kayıtlarına sırasıyla 0.05-0.06-0.08-0.09 hz filtre uygulanmış ve ana şokun derinliği 8 km olarak elde edilmiştir. Elde edilen sonuçlara göre; deprem K28°B doğrultulu ve odakta 37° KD'ya eğimli bir faydan kaynaklanmaktadır. Bölgede, depremin Acıpayam ile Serinhisar arasında yaklaşık KKB-GGD doğrultusunda ve KKD'ya eğimli uzanan normal bir faydan kaynaklandığı sonucuna varılmıştır. Fay düzlemi çözümü bölgenin genel tektoniği ile uyumlu olup, Batı Anadolu'nun açılma rejimi içerisinde olağan bir deprem silsilesi olarak yorumlanmıştır. M ≥ 3.5 olan artçı depremlerin dağılımları da incelendiğinde depreme neden olan fayın doğrultusunun KKB-GGD gidişli olduğu netlik kazanmıştır.

Anahtar Kelimeler: Acıpayam Depremi, Moment Tensör Çözümü, Sismotektonik

Damage and environmental impact zone of the 2018 Eastern Taiwan earthquake following an active fault trace in Hualien City

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On February 6, 2018, an Mw 6.4 earthquake hit eastern Taiwan with epicenter close to the coastal area north of Hualien city and focal depth around 10 km. The main shock caused 17 casualties and 285 injured in the Hualien city. The most affected area was Hualien city. This area is composed of metamorphic rocks of the Central Range overlain by sediments of the Longitudinal Valley, which are in turn overlain by alluvial deposits. Hualien city occupies an area founded on sediments of the Longitudinal Valley overlain by recent alluvial deposits. One of the major active faults of Taiwan, the Meilun fault, runs right underneath Hualien city and disrupts these recent formations. Moreover, it ruptured in the October 1951 earthquake and produced up to ~1.2 m of coseismic vertical offsets and up to ~2 m of sinistral offsets. The onshore length of the fault is less than 10 km, while it may extend further offshore to the north.

The scientific team visited the 2018 earthquake-affected area in Eastern Taiwan and conducted a field macroseismic survey and a geological reconnaissance in order to assess the earthquake impact on the natural environment and the building stock in Hualien County and to study the factors controlling the distribution of the observed damage and earthquake environmental effects (EEE).

As regards building damage, the earthquake caused almost identical heavy structural damage, comprising collapse of the ground floors and tilting, to 6 multistory buildings in Hualien city, while the rest of the building stock suffered light non-structural damage or no damage at all. The common damage characteristic of the inspected buildings was the decomposition of the concrete in the columns of the ground floor due to crashing, resulting in failure of columns and the subsequent tilting, while the upper floors of the structures were left intact. The earthquake also caused damage to infrastructures of Hualien. Cracks indicating left lateral displacement were observed in the superstructure of a bridge.

Taking into account the distribution of building damage and the tectonic setting of Hualien city, it is concluded that all damage was arranged along or close to the Meilun fault trace that runs right underneath Hualien city.

As regards the EEE, secondary EEE comprising ground cracks and liquefaction phenomena were generated in the city. Ground cracks were observed in several sites in Hualien city characterized by different direction and offsets. It is significant to note that they were observed close to the damaged buildings. Liquefaction phenomena included ground cracks accompanied by ejection of sand-water mixture that covered parts of the asphalt pavement in the area east of Hualien airport and outside of the perimeter wall of the military base.

Based on the distribution of the EEE in Hualien city, it is concluded that ground cracks and liquefaction phenomena were also observed close to or along the Meilun fault trace.

Keywords: active faults, Taiwan, Hualien, building damage, earthquake environmental effects

The study of environmental effects induced by historical and recent earthquakes and its contribution to the seismic hazard assessment and seismic risk reduction: application to the Central Ionian Islands (Greece)

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The complete and detailed knowledge of the historical earthquakes, the past earthquake environmental effects (EEE) and the respective seismic intensities has become significant in recent years due to the fact that among others it serves as a valuable tool for revealing and highlighting sites of significant earthquake-related hazards. Many efforts have been made to record the EEE of individual recent earthquakes and evaluate their seismic intensity based on the Environmental Seismic Intensity 2007 scale (ESI-07) in Greece and around the world. But fewer studies have focused on the complete seismic history including all known historical and recent earthquakes of an area and the respective intensities based on the induced EEE. The Central Ionian Islands (Western Greece) comprising Lefkada, Cephalonia and Zakynthos Islands are considered appropriate for the development of this approach. They present the highest seismicity in Greece characterized by shallow destructive earthquakes with magnitudes up to 7.4 and significant impact on public health, the built and the natural environment of the islands.

The applied methodology included the revision of all available data and information on historical and recent earthquakes generated in the Central Ionian Sea and the offshore western Peloponnese with impact on the aforementioned island. The presented list comprises the full record of earthquakes with significant impact on the natural environment of: (a) Lefkada Island from 1612 to 2015 with magnitudes varying from 5.0 to 6.7, (b) Cephalonia Island from 1636 to 2014 with magnitudes varying from 6.0 to 7.4 and (c) 1513 to 2018 with magnitudes varying from 6.1 to 7.2.

Emphasis was given on the induced EEE. Qualitative and quantitative information on EEE were collected and entered in a database specially designed and developed for the purpose of this study in GIS environment. The database includes coordinates of the EEE site, type and main category of the EEE and quantitative information such as surface rupture length for primary effects, length, width and areal density for ground cracks, volume and mobilized material for slope movements as well as tsunami height among others. Then, the ESI-07 scale is applied to the earthquakes of the catalogue and the respective environmental seismic intensities are assigned.

This approach highlights zones most prone to the occurrence of earthquake-related hazards. It could constitute a basic guide for the future urban design and planning and the sustainable local development since all scientists and agencies competent to the prevention and management of natural disasters can informed and guided. For developing modern and novel risk mitigation strategies, it is fundamental to consider, study and evaluate the effect of active faults and seismic zones to the formation and evolution of the seismic active areas and to emphasize the role and the

contribution of the EEE on the assessment of the national and regional seismic hazard.

Keywords: ESI 2007, earthquake environmental effects, Ionian Islands, Greece, historical earthquakes

Neotectonic Investigation in vicinity epicentral zone of Constantine Earthquake [October 1985], Northeastern Algeria

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The purpose of this present work is to discuss the neotectonic indications around the epicentral zone of 27 October 1985 earthquake that had shaken Constantine region.

The region belongs to Eastern Algerian Maghrebides, is an authentic case which deserve neotectonic investigations, around a fault zone oriented ENE-WSW. The zone reveals geomorphological indications as a very remarkable scarps in Neritic domain, and tectonic indications as, compressive strain affecting Pliocene lacustre limestones.

For seismic hazard assessment, two distinct seismotectonic zones can be proposed:(i) the Northern zone corresponding to Neritic domain characterized by moderate seismicity that could be associated to Ain Smara fault, (ii) the South zone corresponding to the High plains with low seismicity which is not related to cartographical faults.

Keywords: seismicity, neotectonics, slow deformation, Eastern Algeria

Measuring finite-frequency travel time residuals for a future body-wave tomography in Scandinavia

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The ScanArray experiment is an extensive collaboration between the universities of Aarhus, Bergen, Copenhagen, Karlsruhe, Leicester, Oslo, Uppsala, Istanbul Technical University together with GFZ Potsdam and NORSAR, that focuses on structure of the lithosphere and upper mantle processes below Scandinavia using dense temporary broadband seismometers through applications of geophysical methods.

In this PhD study, finite-frequency body-wave tomography will be performed to determine the velocity structure and understand the mechanism responsible for the topography of the Scandinavian region and thus help to determine whether the crust and lithosphere are in isostatic equilibrium or dynamic forces still actively affect the high topography in the region. Crustal and upper mantle structure will be determined by using finite-frequency residuals of P and S waves from teleseismic earthquakes at epicentral distances between 30° to 104° and with the magnitudes of 5.5 or greater, gathered from 200 broadband seismic stations installed through Norway, Sweden and Finland, operated between 2012-2017.

Since the quality of the tomography models directly depends on the precision of the travel time residuals, it is crucial to measure accurate relative travel times. Therefore, in the first part of the study, we pay particular attention to appropriate crustal corrections and procedure for measurement of finite-frequency travel time residuals. Crustal correction based on reflectivity method will be applied at each station, ensuring that the proper frequency dependence of the corrections is well taken into account. Corrections will be applied on low- and high- frequency bands separately. This new crustal correction procedure will be implemented in the data processing routine suggested by Kolstrup etal. (2015), which will be used to estimate finite-frequency travel time residuals using the combination of the Iterative Cross-Correlation and Stack (ICCS) algorithm and the Multi-Channel Cross-Correlation (MCCC) method. Here, results of this first part will be discussed. At a later stage, as a second part of the study, finite-frequency body-wave tomography method will be applied and the final results will be discussed in coordination with other Scandinavia-based studies.

Keywords: Seismic tomography, crustal correction, travel time residuals, dynamic topography

The structure of the crust in the Anatolia using magnetic data

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The Anatolian plateau accommodates the Arabia-Eurasia collision and is a complex puzzle of continental and oceanic fragments that were amalgamated during the closure of the PaleoTethys and NeoTethys oceans. The opening and continuous subduction along the northern margin of the Paleotethyan from Paleozoic to late Triassic and later Neotethyan ocean from Mesozoic to Cenozoic time emplaced several discontinuous ophiolite belts, long magmatic arcs and created intracontinental basins. Ophiolites are normally emplaced along today's major faults between the different blocks and they are generally interpreted as marks of sutures.

We present a new approach for understanding the tectonic structure of the Anatolian region. We have created depth to magnetic basement and averaged crustal susceptibility map for the region based on the radially average power spectrum of magnetic data. The depth to the magnetic basement is assumed to serve as proxies for the shape of sedimentary basins provided that igneous basement is strongly magnetized relative to the overlying sediments and there is no interbedding magnetic layer in the sediments.

The depth to magnetic basement and averaged susceptibility map both correlate well with the major tectonic units in the region. The average susceptibility map shows high values at known Magmatic-Ophiolite belts and low values at known sedimentary basins. Based on the averaged susceptibility map, we introduce hitherto unknown sedimentary basins and hidden magmatic-ophiolite belt.

Our results have implications for elongated magmatic arc from south of Iran to south of Turkey in the arch shape, suggesting that subduction of the Neotethys have a significant effect on tectonic evolution of the region.

Keywords: Anatolia, crustal structure, magnetic susceptibility

Analysis of the relationship between water level temporal changes and seismicity in the Mingechevir Reservoir (Azerbaijan)

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The time dynamics of the instrumental seismicity ($0.5 \leq M_L \leq 3.5$) occurred from January 2010 to April 2018 in Mingechevir area (Azerbaijan) and its relationship with the water level variation of the water reservoir was analysed in this study. Due to the relative high completeness magnitude (M_C = 1.6) of the seismic catalogue of the area, only 136 events were selected over a period of a bit more than 8 years. Thus, the monthly number of events was analysed by using the correlogram-based periodogram, the singular spectrum analysis (SSA) and the empirical mode decomposition (EMD), which are robust against the short size of the time series. Our results point out to the following findings: 1) annual periodicity was found in one SSA reconstructed component of the monthly number of events; 2) quasi-annual periodicity was found in one EMD intrinsic mode function of the monthly number of earthquakes. These obtained results could support in a rigorously statistical manner that the seismicity occurring in Mingechevir area could be of triggered by the yearly cycle of the water level of the reservoir.

Keywords: reservoir-triggered seismicity, Azerbaijan, time series analysis

Comparison of methods used for suppression of multiple reflections in multichannel seismic data

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The multiple reflections are created by the seismic signal traveling to same way more than one can create difficulties in marine geophysics studies in shallow water. Since the sea floor is so powerful reflector, it reflects great part of the coming signal. This reflected signal reflecting back from the surface of sea-air reaches again to the seafloor. This condition depending on water depth, power of source and record length can repeat itself several times. Multiple reflections may cause difficulties in data processing and misinterpretation of data. Interference of multiples with the primary reflections can cause inaccuracy in data processing and interpreting. Constructive interference can cause that amplitude of the primary reflections to be seen higher than it is, but distractive interference can cause that amplitude of primary reflections to be seen lower than it is. Knowing the differences between multiples and primary reflections is very important to remove multiples. Removing multiples during data acquisition is not possible. For this reason, many methods have been developed in data processing to remove multiples from data. In this study, besides routine data processing, predictive deconvolution and f-k filter were applied to data. This multichannel seismic data was processed using Paradigm® Echos® software in "Seismic Data Processing Laboratory" at the Department of Geophysical Engineering Istanbul University-Cerrahpasa. Routine data processing steps are; data loading, geometry definition, editing, muting, gain recovery, band pass filtering, CDP sorting, velocity analysis, NMO correction, stack and migration. In this study, the methods used in removing multiples from seismic data are discussed. First of all, predictive deconvolution was applied to data using DECONA module in Echos software. The parameters using in predictive deconvolution were compared with each other and then the parameter that gives the best result was selected. Also, the f-k filter was applied to multichannel seismic data as two separate techniques by using FKFILT and ZMULT module in Echos software. The aim of this study is to compare these methods used for removing multiples with each other and determine the method that gives the best result according to stack sections.

Keywords: Multichannel seismic data, multiple reflections, f-k fitler, predictive deconvolution

Resolving source characteristics of 26 September 2019 Kumburgaz Basin Earthquake (M_w 5.8) at the North Anatolian Fault Zone (Central Marmara Sea)

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Recently, there is an intense earthquake activity ($M_w \geq 3.5$) with several small-to-moderate size earthquakes particularly observed along the North Anatolian Fault Zone (NAF) in the central part of the Marmara Sea. The largest earthquake occurred on 26 September 2019 (M_w 5.8) in the Kumburgaz Basin (Central Marmara Sea), where there is a distinct seismic gap with relatively little seismicity along the NAF. Two days before this earthquake, another earthquake (M_w 4.7) occurred in the same area. Those earthquakes attracted great interest as they provided essential information about the latest deformation types and the major source orientations in the region. Furthermore, previous studies suggested that this part of the NAF would be locked at shallow depths by taking into account the lack of earthquakes together with the observed seismicity on either side of the fault beneath the Kumburgaz Basin. Therefore, the detailed analysis of recent earthquake data along with the other seismological observations are necessary for a better understanding of the earthquake source characteristics and the structural complexities of the main fault in the central Marmara Sea. Here, we present source mechanism parameters and non-uniform finite-fault slip distribution model of the 26 September 2019 (M_w 5.8) earthquake by inverting P- and SH- body waveforms recorded at teleseismic stations of the Federation of Digital Seismograph Networks (FDSN) and the Global Digital Seismograph Network (GDSN) in the distance range of 30˚- 90˚. The distributions of P- wave first motions recorded by near-field stations on the focal sphere are also checked in order to confirm the source mechanism solution of this earthquake. Overall results indicate an oblique faulting mechanism with a large amount of thrust component at a shallow focal depth. The source time function also revealed a rather simple rupture at focus. In addition, kinematic and dynamic source parameters of this event (i.e., fault length, fault width, maximum and average displacement values on the fault plane, stress drop etc.) are estimated from the non-uniform slip distribution model of the earthquake.

Keywords: Earthquake source mechanism, Finite-fault slip distribution, Kumburgaz Basin, Marmara Sea, North Anatolian Fault

TH-5
TECTONIC GEODESY AND CRUSTAL DEFORMATION

Seismotectonic evaluation of August 08, 2019 Bozkurt (Denizli) Earthquake (Mw 6.0), Western Anatolia

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An earthquake with magnitude Mw=6.0 occurred at UTC 11:25 on August 08, 2019 in Bozkurt (Denizli) in the western part of the Acıgöl Basin within the Aegean Graben System (AGS). A foreshock Mw 4.2 took place about 6 minutes before the main shock at the same location. Focal mechanism solution performed by considering the moment tensor method of Mw=6.0 earthquake indicates WNW-ESE direction normal faulting consistent with the tectonic structure of the Acıgöl basin bounded by normal faults from north (south-dipping faults) and south (north-dipping faults). On the other hand, 484 aftershocks with magnitude varying between 0.4 to 3.9 were recorded until August 26, and it is noteworthy that no earthquake larger than 4.0 have occurred.

The depth cross section of aftershocks indicates that the northeast dipping structures bounding the basin from the south control the southwest dipping structures that bounded from the north.

After the Mw=6.0 main shock, to observe potential co-seismic deformation, it is used from C-band (~6 cm wavelength) Sentinel 1 A/B data. Including pre and post-event, 2 images were evaluated on descending Track 138 (02.08.2019 ve 14.08.2019) by the help of the GmtSAR Parallel Software. According to obtained results, it was determined that there may be subsidence of approximately varying between 1.5 cm to 6.5 cm in the east part of Bozkurt District after the unwrapping process.

According to all geological, seismological and geodetic data, it was concluded that the main shock was caused by the N60W direction and 47NE dipping fault which bounded the basin from the south and this fault activated the south-dipping faults that bounded the basin from the north (Maymundağı Fault). After the main shock, the absence of an earthquake that is magnitude greater 4.0 indicates that there may be an accumulation of energy on south-dipping faults. As a result of this earthquake, it can be said that the Acıgöl Fault, which bounds the Acıgöl Graben from the south and tectonically controls the basin, disrupts the seismic balance in the region and consequently, the faults bounding the basin from the north are more affected by this seismic imbalance.

Keyword: Aegean Graben System, Acıgöl Basin, Fault Plane Solution, InSAR

An approach to the tectonic structure of the Acıpayam Basin: Analysis of the 20.03.2019 (Mw 5.5) earthquake and its aftershocks

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After the Acıpayam (Denizli) earthquake of Mw 5.5 that occurred on 20 March 2019, more than 2200 aftershocks were recorded by the Disaster and Emergency Management Authority (AFAD), and more than 1600 aftershocks were recorded by the Kandilli Observatory and Earthquake Research Institute (KOERI). Thirteen earthquakes with M≥4.0 occurred during the period of aftershocks, which lasted for about three months. The aim of this study is to determine the characteristics of the fault system that controls the basin as well as to identify the deep seismic velocity structure of the basin. Three different analyzes have been planned in this context: aftershock relocation, focal mechanism solution and local earthquake tomography. For relocation, the phase readings of AFAD and KOERI were merged. Earthquakes with origin time difference smaller or equal to 5 seconds were considered as the same event. In such cases, the mean value of the focal parameters (latitude, longitude, depth, magnitude) reported by KOERI and AFAD were used. After merging the two data sets, the final data set comprises of 2611 earthquakes, 1324 of which are common. Once the data sets were merged we have relocated the earthquakes using only one crustal velocity model (already published 1-D crustal velocity model) in order to minimize the differences caused by the different velocity models of KOERI and AFAD. This procedure reduced the number of earthquakes to 2447. Then, the relocation was repeated by using double-difference algorithm, which produces more reliable solutions in cases of clusters like aftershocks. Focal mechanisms were calculated by moment tensor inversion. Local earthquake tomography calculations have not been completed yet. Data recorded by KOERI and AFAD were used in this study. While recordings of the weak-motion seismometers deployed in and out of the region are used for relocation and focal mechanism solutions, it is planned to use the data from 12 strong-motion and 8 weak-motion seismometers for tomographic analyzes. As a result of the analysis, the depth plane and lateral extension of the fault system within the basin were determined by using the new locations of the aftershocks. Another information about the fault plane was obtained from the focal mechanism solutions of the main shock and aftershocks with magnitudes M≥4.0. According to these solutions, the strike, dip and dip direction of the fault system passing through the basin were determined in 3-D.

Keywords: Acıpayam, earthquake, seismology, aftershocks

Interpretation of the 2019, March, 20 Acıpayam (Denizli) Earthquake (Mw=5.5) with Seismological-Geodetic Data and Field Observations: Western Anatolia

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A destructive earthquake with magnitude Mw=5.5 occurred in Western Anatolia on March, 20, 2019. In this study, we tried to interpret rupture mechanism of the earthquake with seismological and geodetic data and field observations. The epicentre located between Ucarı and Yenikoy villages which is ~6 km far away from the Acıpayam city center.

The earthquake that is effective on 21 villages in the region caused heavy damage to the Ucarı, Kırca, Karahüyük and Apa villages. It is not observed any damage in Acıpayam city center. Totally 572 rural houses are damaged by the earthquake. According to their damage ratio distribution is 44 ruined, 303 heavy damage and 225 less damaged. Cause of mostly damage buildings is that they are more than 50 years old, non-engineered buildings and they are mud brick and rubble stone masonry structures.

Before the main shock, the activity began in the region on March, 18. 31 earthquakes occurred with the magnitude varying between 0.9 and 3.7 in the period 18 and 20 March. On the other hand, 2330 aftershocks have occurred magnitude ranging between 0.6 and 4.9 since the earthquake occurred. 13 of them are greater than 4.0. Aftershocks distribution is NW-SE trending perpendicular to the northern end of the Acıpayam Segment which is left-lateral strike slip fault with NE-SW trending in the Fethiye-Burdur Fault Zone. This region, also called Acıpayam-Serinhisar basin, is a graben system which is bounded by normal faults with NW-SE trending approximately 5-15 km width and 30 km length. The focal mechanism solution of the main shock indicates that the earthquake is caused by normal faulting with N43W/43NE. Similarly, the fault plane solutions for earthquakes with M> = 4.0 are compatible with the focal mechanism of the main shock. N10E trending right step shear cracks ranging from 1.0 m to 10 m in length, 2-5 cm in width were observed 7 km east of Acıpayam, approximately 700 m south of Yeniköy in the field observations. On the other hand, in connection with these cracks, N30-40W trending left lateral discontinuous shear cracks that are approximately 100-150 m length were followed. 1-2 cm vertical displacement was measured in the SSE blocks of these structures.

After the Mw=5.5 main shock, to observe potential co-seismic deformation, it is benefited from C-band (~6 cm wavelength) Sentinel 1 A/B data. Including pre and post-event, 2 images were evaluated on ascending Track 58 (17/03/2019-23/03/2019) by the help of the GmtSAR Parallel Software. According to obtained interferogram, approximately 3-4 cm subsidence has been detected on the east part of the Acıpayam. According to the updated interferometry results after the earthquake of Mw = 4.9 on March, 31, it is determined the deformation increased to 4.5 cm in some regions.

Keywords: Western Anatolia, Acıpayam Basin, Aftershock Activity, Focal Mechanism, InSAR

Analysis of two recent moderate-size events in Denizli with InSAR: The 20 March (Mw 5.7) Acıpayam and 8 August (Mw 6.0) Bozkurt Earthquakes

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On 20 March 2019 and 8 August 2019, two moderate-size earthquakes, Mw 5.7 and Mw 6.0 respectively, struck the Acıpayam and Bozkurt towns of Denizli in Western Turkey. While focal mechanism solutions clearly indicate that both occurred due to normal faulting, the estimated dip angles, the epicenters and also the distribution of the aftershocks did not quite well match with the mapped faults in the region.

Thanks to the 6-day revisit time of the European Space Agency's Sentinel-1 satellites first set of coseismic synthetic aperture radar (InSAR) data were captured in 3 days for the Acıpayam event and <5 hours for the Bozkurt event. While the interferograms were quite coherent and a single set of concentric fringes due to the earthquakes are easily detected, both interferograms contain significant amount of atmospheric noise that obscure parts of the coseismic signal. Subsequent modeling of the unwrapped data also proved that it's not possible to constrain some of the important parameters of the faulting like the dip direction by using single interferograms alone.

Here in this study, we will be presenting how time-series analysis of SAR data instead of two-pass differential InSAR helps to recover the coseismic signal when there is spatially-correlated atmospheric noise and/or the observed surface deformation is too small.

Keywords: InSAR, coseismic, normal faulting, Acıpayam, Bozkurt, Denizli, Western Turkey

Shallow creep along the 1999 İzmit Earthquake Rupture (Turkey) from GPS and high temporal resolution Interferometric Synthetic Aperture Radar Data (2011–2017)

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Characterizing the spatiotemporal evolution of creep is essential to constrain fault slip budget and understand creep mechanism. Studies based on interferometric synthetic aperture radar and Global Positioning System (GPS) satellite observations until 2012 have shown that the central segment of the 17 August 1999 Mw 7.4 Izmit earthquake on the North Anatolian Fault began slipping aseismically following the event. In the present study, we combine new interferometric synthetic aperture radar time series, based on TerraSAR-X and Sentinel 1A/B radar images acquired over the period 2011–2017, with near-field GPS measurement campaigns performed every 6 months from 2014 to 2016. The mean velocity fields reveal that creep on the central segment of the 1999 Izmit fault rupture continues to decay, more than 19 years after the earthquake, in overall agreement with models of postseismic afterslip decaying logarithmically with time for a long period of time. Along the fault section that experienced supershear velocity rupture during the Izmit earthquake creep continues with a rate up to ~ 8 mm/year. A significant transient accelerating creep is detected in December 2016 on the Sentinel-1 time series, near the maximum creep rate location, associated with a total surface slip of 10 mm released in 1 month only. Additional analyses of the vertical velocity fields show a persistent subsidence on the hanging wall block of the Golcuk normal fault that also ruptured during the Izmit earthquake. Our results demonstrate that afterslip processes along the North Anatolian Fault east-southeast of Istanbul are more complex than previously proposed as they vary spatiotemporally along the fault.

Keywords: Izmit, InSAR, time-series

Geostatistical approach of active deformation in Peloponnese Greece, using primary geodetic data.

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Peloponnese region is a tectonically active region, located at southern Greece. During the neotectonic extensional period three major NNW–SSE trending normal fault zones are observed, controlling Messiniakos, Lakonikos and Argolikos Gulfs, while the NW – SE and E–W trending normal fault zones at the northern part are related to the Corinth Gulf tectonic activity. In addition, numerous seismic events are documented within the Peloponnese region.

Regarding the GPS data analysis, 59 permanently installed GPS stations monitor the study area, collecting geodetic raw data for a 7-year time period, while Eurasia is used as fixed reference frame. The primary geodetic data process includes the GPS stations triangulation, combining the data of three different GPS stations each time. The triangulation process leads to the formation of different triangles, while for the triangle centroid the following parameters are calculated: maximum horizontal extension, total velocity, maximum shear strain, area strain and rotation. In total, 932 triangle centroids were determined and the aforementioned parameters were calculated for each of them. The interpolation methodology was applied on the extracted parameters results, in order to estimate their distribution throughout the study area.

Regarding the extracted results, the maximum horizontal extension is a tectonically active structures indicator, while the values range between -100 and 1800 nano-strain. The highest values are concentrated in the Corinth Gulf area. The total velocity parameter is a geodynamic evolution indicator, including values ranging between 0,006 and 0,038 m/yr. The lowest and the highest values are observed at the NNE and the SSW part of the study area, respectively. Maximum shear strain is a seismic occurrences indicator, presenting values ranging between -100 and 2000 nano-strain. The highest values concentration is identical with the maximum horizontal extension values concentration. Area strain is dilatation and compaction area indicator, related to extension and compression, respectively. The values range between -1000 and 2000 nano-strain, while a general extensional regime dominates in the study area. The compressional regime is limited at the western part of the study area. Rotation is a geotectonic and geodynamic evolution indicator. The values range between -35 and 45 degrees for 1 Myr model, -180 and 240 degrees for 5 Myr model and -350 and 450 degrees for 10 Myr model, while a dominant clockwise and a local counter-clockwise rotation of the study area is recorded.

Therefore, the triangulation and interpolation methodologies are reliable tools in order to extract several parameters and apply the geostatistical process. The northern part (Corinth Gulf) is the most tectonically active region of the study area, while it should be mentioned that the effect of the M_w6.4 2008 earthquake, recorded by the permanently installed GPS stations, show the activation of a strike-slip seismic fault.

Keywords: crustal deformation, active tectonics, Corinth gulf, GPS/GNSS stations, Southern Greece

Surface creep and interseismic strain accumulation along the Chaman Fault System (Pakistan, Afghanistan) from time series analysis of Sentinel 1 TOPS data

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The ~1000-km-long Chaman fault system consists of a series of subparalel left-lateral strike-slip faults and thrusts that form the transform to transpressive plate boundary between the Indian Plate and the Eurasian Plate. Studies based on geological and plate closure estimates show that the northward plate motion of India with respect to Eurasia is on the order of 35 mm/yr. Previous InSAR studies (Barnhart, 2016 ; Fattahi & Amelung, 2016) along the Chaman fault system based on Envisat and ALOS data have shown that the northeast-southwest trending Chaman fault itself only account for ~30% of this relative motion. How the remaining 70% are distributed or localized on adjacent structures remain to be determined. Such studies also revealed the existence of shallow creep along more than 300 km of the Chaman fault. The large spatial coverage of the recent Sentinel-1 data allow to tackle both the large-scale strain partitioning issue and the fault-scale creep behavior characterization.

In order to estimate strain accumulation rates along and across the Chaman fault system, we map the present-day interseismic velocity fields using long-swath (> 1250 km) Sentinel-1 (S1) TOPS radar images acquired on both ascending (T42, T71, T144) and descending (T151, T78) orbits, along the western boundary of the Indian subcontinent. Using an automatized processing workflow, we have processed time series of ~150 S1 images acquired between 2014 and 2018. Preliminary results show left-lateral shear velocities of ~20 mm/yr across the distributed plate boundary, with a complex partitionning between the main Chaman left-lateral fault, other adjacent left-lateral faults or secondary structures within the thrust belt. While ascending data are mostly sensitive to the left-lateral component of slip and vertical motion along the Chaman fault, descending data highlight horizontal and vertical motion across secondary structures branching on the main Chaman fault. Surface aseismic creep rate along the Chaman fault seems to reach up to ~10 mm/year and may extend along a ~600 km-long segment, between 28.5 ^{o}N and 32.5^{o}N, which appears significantly (50%) longer than that reported in previous studies. Surface creep thus accommodates ~30% of the tectonic loading along a significant portion of this plate boundary. Further data analysis and modelling will provide a better quantification of the creep rate amplitude and depth along fault strike, deep tectonic loading, and strain partitioning on secondary structures.

Keywords: Aseismic Slip, Chaman Fault, Sentinel, InSAR, creep, time-series

Rapid subsidence in Konya City from Sentinel-1 InSAR Time-series

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We studied surface deformation in the city of Konya and its vicinity using Synthetic Aperture Radar Interferometry technique with Sentinel 1A/B images (2014-2018). The vertical velocity field reveals a pattern of two lobes of rapid subsidence to the west and south of the Konya city centre. The most prominent subsidence signal is taking place in the western lobe centred near the Konya train station with rates up to 9 cm/yr. Another localized subsidence signal up to 6 cm/y is centred around Akabe Park about 3.5 km east of the city. Modelling results suggest that subsidence is unlikely related with the Konya fault. There is no correlation between the different geological units in the flat plain. Therefore, the heterogeneous pattern of subsidence is most likely caused by lithological heterogeneities such as lenses of course material in the Quaternary alluvium and excessive extraction of groundwater at different locations. The InSAR time series are well correlated with changes in the ground water level which is dropping about 3 m/y. The drop of the ground water is probably due to excessive ground water pumping to water parks, trees and flower along the roads in the city.

Keywords: Konya, Subsidence, InSAR, Sentinel

InSAR velocity fields around the Sea of Marmara from Sentinel-1 InSAR time series

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Recent GPS suggest that central section of the North Anatolian Fault (NAF) in Marmara Sea is creeping. It is known that creep on some segments of the NAF on land occurs as long-term post-seismic motion, affecting shallow parts of fault segments that slipped co-seismically, with the best observations coming from the 1999 M7.6 Izmit Earthquake. The low, or absence of, interseismic loading, along central segment of the NAF in Marmara is puzzling. Possible explanations involve asymmetry in crustal elastic properties north and south of the fault, the southward dipping fault skewing the locus of surface shear strain to the south, creep at near plate velocity, or a very shallow locked zone (< 5 km). However, the depth distribution of microseismicity supports the notion that some shallow creep occurs in the western Marmara Sea from Ganos to the Central Basin, arguing against shallow locking.

Revealing which section of the NAF in the Marmara is creeping can be confirmed by increasing the density of the GPS network and using large scale InSAR images along the shores of the Marmara Sea, which has direct implications for assessing the earthquake potential of the offshore fault systems in the Marmara Sea. Therefore, we started mapping the interseismic InSAR velocity field along both the southern and northern shores of the Sea of Marmara using Sentinel-1 A/B TOPS SAR data between 2014 and 2019. Three tracks have been used to map the velocity field; T36, T58 and T131 using GMTSAR and StaMPS permanent scatter InSAR time series technique. Preliminary results indicate accumulation of elastic strain particularly along the Princes' Islands fault. This study shows that large-scale velocity mapping can be done using Sentinel TOPS images (250x500 km) with StaMPS. Refining the results by filtering the atmospheric phases will reveal the variation of strain along the northern Marmara coastline.

Keywords: InSAR, Marmara, NAF, creep, Sentinel

The Mw 5.7 2007 Sivrice earthquake: reactivation of the Adıyaman fault inferred from InSAR data and seismicity

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On February 21, 2007, an earthquake of moderate size (Mw 5.7) struck Sivrice (Elazig, Turkey) situated within the East Anatolian Fault (EAF) region. We combined remotely sensed Synthetic Aperture Radar data obtained from ESA (European Space Agency) ENVISAT ASAR images with relocated seismicity to map the coseismic surface displacement field. In order to solve the earthquake source parameters, we calculated coseismic interferograms from both ascending T400 and descending T264 orbits. The coseismic interferograms associated with two different look angles carry the same signal. Moreover, in each of the interferograms the lobe of fringes is noticeably asymmetrical with direction of its longer axis matching the Adıyaman Fault (AF) surface trace. The AF is a major southern splay of the EAF. The computed lobe is confined in a region between the AF and the EAF. Jointly the InSAR data and the seismicity analyses support that the earthquake took place on the AF via normal faulting with left-lateral strike-slip component motion on a fault plane with listric geometry. Even though the EAF zone is a region of active shortening the nearby triangular mountain facets in the NE, and the presence of an immediate concave bow shaped fault trace, characteristic to listric faults, imply that there is an extensional system on a micro scale. We modeled the interferograms through applying elastic dislocations on rectangular fault surfaces using a downhill simplex simulated annealing algorithm developed by Donnellan and Lyzenga, 1998. The inversion results give that the ruptured part of the reactivated AF is with coseismic slip of 64±18cm on a fault plane with a high gradient near the surface and mildly dipping geometry further at a depth between 3.6 and 8.5km (dip 63° ± 4°), rake of -73°± 21°, and a strike of N42°E. The calculated moment magnitude is Mw5.9. As the temporal baseline "△Date" extends to 6 months after the shock the difference in moment magnitudes between the catalogued and the one which we calculated could be inferred as the effects of viscoelastic relaxation in the postseismic period. Likewise, the kinematics of the faulting is supported by the observed transtensional left-lateral strike-slip regime in the region of tectonic depression of Hazar Lake.

Keywords: InSAR, Envisat ASAR, earthquakes, Sivrice, East Anatolian Fault, Adiyaman Fault, listric fault

TH-6
MONITORING AND MODELLING CRUSTAL DEFORMATION

Determining surface deformation in the Bursa (NW Turkey) Plain using Sentinel-1 InSAR time series

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In this study, we studied the surface deformation (subsidence) of the Bursa Plain (southern Marmara region of Turkey), which has been previously proposed to result from tectonic motions in the region [Kutoglu et al., 2014] and antropogneic and lithological control of the subsidence. We have detected the subsidence signal based on Sentinel 1 A-B radar images acquired over the period 2014 – 2017 on both ascending and descending tracks using the Stanford Method for Persistent Scatterers InSAR package (StaMPS) is employed to process series of Sentinel 1 A-B radar images regularly acquired between 2014 and 2017 on both ascending and descending tracks. The vertical velocity field obtained after decomposition of line-of-sight velocity fields on the two tracks reveals that the Bursa plain is subsiding at rates up to 25 mm/yr. The most distinctive subsidence signal in the basin forms an east-west elongated ellipse of deformation in the east and overlapping well with the Quaternary alluvial plain undergoing average vertical subsidence at ~10 mm/yr. Another localized subsidence signal is located 5 km north of the city, follows the Bursa alluvial fan, and is subsiding at velocities up to 25 mm/yr. Temporal comparison of the subsiding surface deformation and variations of pressure head of water in the aquifer allowed estimating that the compressibility of the aquifer, α, falls in the range $0.5 \times 10^{-6} < \alpha < 2 \times 10^{-6}$ Pa-1, which is a range of values typical for clay and sand sediments. We found strong correlation between subsidence signal and the lithology, suggesting a strong lithological control in subsidence process within the Bursa Basin. In addition, the maximum rate of vertical motion occurs where agricultural activity relies on groundwater exploitation. The InSAR time series within the observation period are in agreement with the ground water decline. These observations show that recent acceleration of subsidence is mainly driven by the anthropogenic activities like water pumping for agricultural purposes rather than tectonic motion.

Keywords: Subsidence, InSAR, Sentinel, Bursa

Land subsidence monitoring in megacity of Istanbul using InSAR time-series (1992-2017)

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Observation of ground deformations in residential areas is of vital importance for sustainable urban development and hazard mitigation. Interferometric synthetic aperture radar (InSAR) time series analysis is a remote sensing tool capable of measuring small ground deformation driven by subsidence and landslide phenomena. In this study, we compute InSAR time-series (1992-2017) of multi-sensor data (ERS, Envisat, Sentinel-1A and its twin sensor Sentinel-1B) to investigate the spatiotemporal behaviour and rate of land deformation in the mega-city of Istanbul. We combined the various multi-track InSAR datasets (291 images in total) and analyzing persistent scatterers (PS-InSAR), we present mean velocity maps of ground surface displacement for selected areas of Istanbul. We analyzed the vertical deformation for several sites along the terrestrial and coastal regions of Istanbul that undergoes land subsidence at varying rate from 5 ± 1.2 mm/yr to 15 ± 2.1 mm/yr. The results show that the most distinctive subsidence signals are associated with relatively weak lithologies, along the Haramirede valley in particular where the observed subsidence is up to 10 ± 2 mm/yr, and anthropogenic factors. We show that land subsidence is occurring along the Ayamama river stream at a rate of up to 10 ± 1.8 mm/yr since 1992, slowing down over time following the restoration of the river and stream system. We also identify subsidence at a rate of 8 ± 1.2 mm/yr along the coastal region of Istanbul, associated with land reclamation (Yenikapı and Maltepe reclamation area), and a very localized subsidence at a rate of 15 ± 2.3 mm/yr starting in 2016 around one of the highest skyscraper of Istanbul built in 2010.

Keywords: Time series analysis; InSAR; PS; subsidence; land reclamation; risk; Istanbul; Turkey

"The investigations of crustal features and geodynamics of Turkey" project: İnebolu (Kastamonu) – Karkamış (Gaziantep) geotravers

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The Investigations of crustal features and geodynamics of Turkey" project is implemented by the General Directorate of Mineral Research and Exploration (MTA). The main target of the project, in the light of geological and geophysical studies, investigation of the crustal features and geodynamics of Turkey. Furthermore, it is aimed to control the proposed geodynamic models in depth dimension.

Anatolia is a plate mosaic, consisting of numerous tectonic units with different geological origins between the Gondwana and Lavrasian plates. The distribution of these units is controlled by Alpine Orogeny, which is formed by the diacronic closure of the branches of the Neotethys Ocean at the end of the Mesozoic. The effects of mantle dynamics of the Eastern Mediterranean were reflected in surface geology and geomorphology. Thus, Turkey and the surrounding area has developed into one of the most complex areas within the Alpine-Himalayan Orogenic Belt. Exploration of such complex areas is possible with integrated geological and geophysical studies. Within the scope of this project, geological and multidisciplinary geophysical surveys are carried out along the geotraverses. Geotraverses are designed to cut in vertical or diagonal direction of main tectonic units of Turkey (Pontide, Anatolide, and SE Anatolian Fold and Thrust Belt), suture zones, intrusive bodies, neotectonics basins and active faults. Within the framework of geological studies, geological cross sections are prepared in scale of 1.100 000 along the geotravers. Magnetotelluric and gravity measurements are conducted along the geotraverses within the scope of geophysical studies in the project. For the magnetotelluric measurements, the average distance between the MT stations is 3 km and time series were recorded 45-48 hours on mentioned MT stations.

İnebolu – Karkamış Geotravers (IKG), which is 670 km long, was completed in 3 years between 2015-2017. IKG cuts different geologic and tectonic elements such as central Pontides, North Anatolian Fault Zone, İzmir-Ankara-Erzincan Suture Zone, Çankırı-Çorum Basin, Akdağmadeni Massif, Sivas Basin, Inner Tauride Suture Zone, Central Anatolian Fault Zone, Taurides, East Anatolian Fault Zone, Southeast Anatolian Fold - Thrust Belt and Arabian Plate. MT time-series were recorded at 224 MT stations along the IKG. 1:100.000 ions were derived down to 50 km from 2B modelling and inversion of the MT data. Within the scope of gravity studies 4675 measurements were made within a zone with 100 km and the collected data was included in the 4741 regional gravity measurements. Bouguer anomaly map and crustal thickness section were prepared from this combined data set.

As a result of the combined geological and geophysical data interpretation was obtained considerable results about the crustal features and geodynamics of Turkey.

Keywords: Earth's Crust, Magnetotelluric, Gravity, Geodynamics, Geotravers

How deformation localizes in the western part of the NAF and its effects on topography: an analogue modelling approach

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The northernmost-branch of the North Anatolian Fault (NAF) is the most seismically active in historic time and accumulated the highest amount of strain. In general, the NAF is a great seismic hazard throughout Turkey. A specific major hazard is associated with a well-documented, 250 years seismic gap south of Istanbul and across the Marmara Sea segment of the northern fault system. This gap is adjacent to the region that was activated by the 1999 M 7.4 Izmit earthquake. Regardless of the multitude of specific studies focusing on this portion of the NAF, its deformation and strain accumulation pattern is still hard to follow, because of complexity of the geometry -strike slip system combining releasing bend and restraining bend producing deep basins separated by highs. In this contribution, we present the results of sandbox analogue experiments at the crustal scale, designed to covering the whole segments of northern branch of the NAF, to get further insights on understanding of the relation between the tectonic evolution and present activity. Analogue results reveal that the northern branch of the NAF developed from a single to a multi-branch fault system, with different branches active and dominant at different times. Comparison with the tectonic setting of the Sea of Marmara propose that the western portion of the basin might be indicated by a fault shortcut associated with both a compressional regime and uplift of the Ganos Mountain.

Keywords: Marmara Sea, North Anatolian Fault, analogue modelling

Quantifying observed surface topography anomalies with the mantle flow in the Southeast Carpathians

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The Southeast Carpathians with unique morphological features in Europe is one of the examples of the rapid surface displacements controlling by mantle flow-induced dynamic forces in the Mediterranean. The deep basins (e.g., Transylvania and Focsani) and the southeast mountain belt (SE Carpathians mountain chain with ~1.5 km elevation) are the characteristic structures in the region. The geological observations indicate that the subsidence of the Focsani foredeep basin and uplift of the adjacent Carpathian fold-thrust belt occurred contemporarily in the aftermath of Alpine collision. The highly-variable upper mantle bodies (e.g., vertically sinking Vrancea slab) related to post-collisional tectonics are imaged by geophysical studies (e.g., seismic tomography models). Based on the focal depths and mechanisms of earthquakes, it is proposed that the Vrancea seismogenic zone is linked with active geodynamic processes developing in the east part of the region. In this study, we investigate the mantle flow-induced topographic subsidence and uplift in the Southeast Carpathians by using multi-dimensional (2 and 3D) numerical experiments. Thermo-mechanical modeling studies are performed with varying temperature models and crustal configurations. Non-isostatic compensation of the elevation is analyzed based on admittance functions between free-air gravity and topography in addition to residual topography calculations (Airy-type isostasy). According to our results, mantle processes dynamically modify the elevation with positive amplitudes over the Transylvania Basin (0.8-1 km) and the high SE Carpathian Mountains (~ 1 km) and subsidence of the Focsani Basin (0.5-1 km).

Keywords : Numerical modelling, Southeast Carpathians, Dynamic topography

Eclogite induced deformation of the Siberian Craton

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The deformation of the cratons, whose roots are approximately 250 km deep is very difficult. The removal of the mantle lithosphere, which is one of the proposed mechanisms for the deformation of the craton that is stable for long periods, is carried out by many different processes. Deformation of the craton as a result of a gravitational instability is one of the most likely mechanisms. According to isopycnic hypothesis, lithospheric mantle of cratons thought to be buoyant due to their depleted composition, even though most of them Archean in age and cold. Since the mantle lithosphere of the craton is lighter in density than asthenosphere, an additional force is required for a gravitational instability to occur. This thermo - mechanical force causes deformation of the roots of the craton by creating an instability between the mantle lithosphere and the asthenosphere.

The Siberian craton is one of the world's largest Archean - Proterozoic cratons. The Siberian craton has approximately 100 - 1300 m surface topography, 35 - 53 km MOHO thickness, and a maximum depth of 350 km LAB which are acquired from petrological studies, seismic tomography and gravity anomalies. Specifically, the LAB varies among 170-350 km and such depth change is not well understood. Until the formation of the Siberian craton is completed, it hosts many tectonic and magmatic events. These include active margin zones, continent collisions, and rift zones. As a result of pressure change in the active boundary regions, the transformation of basalt to eclogite takes place. Therefore, it creates a gravitational instability in the environment. Gravity anomalies observed near kimberlite fields, reflect the possibility of denser eclogitic bodies under the crust of Siberian craton. Our study focuses on testing potential deformation of the Siberian continental lithosphere with the presence of these eclogitic bodies. We performed 2D numerical experiments to investigate the effects of eclogite blocks that are varying in size and density. Crust rheology was prepared in accordance with Siberian craton. The density of the mantle lithosphere (3330 kg / m^3 - 3410 kg / m^3 +20 kg / m^3) is changed to observe its effect on the system, and eclogite blocks of different size (5 km x 500 km, 10 km x 250 km, 25 km x 100 km) are added to the lower crust base to start a gravitational instability.

According to model results, depending on the deformation of the mantle lithosphere, eclogite block can either stay attached to the lower crust, or it can be detached from it. In the case where the eclogite block attached to the lower crust, two different conditions: localized deformation (do not occur the drip mechanism) and non-localized deformation occurs due to the small-scale convection movement. Also, two different removal mechanism for the case where eclogite becomes detached are also observed: high degree deformation of mantle lithosphere, and the eclogite block pierce through the mantle lithosphere. Comparison of experimental results with geophysical data for MOHO and LAB depths showed that, the most convenient models for Siberian craton are the models where the dripping were not observed. Mantle lithosphere densities of 3350 kg / m^3 or less yields the most consistent results. While the width of the eclogite block causes high-degree deformation, it is observed

that with increasing thickness it leads to formation of viscous drips. Taking MOHO and LAB depths into account obtained from the model results, it has been observed that the model #A1, #A2 and #A3 agrees well with the BB' cross-section at 20.92 Ma, 25.36 Ma and 20.92 Ma, respectively. Experimental results indicate that, eclogite block(s) under the Siberian craton may still be there and craton itself does not undergo any significant deformation.

Keywords: Siberian Craton, gravitational instability, eclogite, craton deformations, numerical modelling

Rift system evolution of the Eastern Black Sea back-arc basin: Inferences from geodynamical models

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The Black Sea back-arc basin is formed by the southward retreat of the Neotethyan oceanic slab during the Cretaceous time. Divided by NW-SE oriented ridge system, both western and eastern Black Sea domains represent the characteristics of typical rift basin. Specifically, seismic reflection studies are used to interpret the presence of numerous well-developed normal faults, tilted fault blocks, exhumed oceanic crust (at depth of 8-9 km in the centre of the Eastern Black Sea). Seismic cross-sections approximately perpendicular to the rift axes of the basins reveal that the architecture of the rift system varies at the eastern and western portion of the Black Sea, for instance, symmetric vs asymmetric, narrow vs wide rift. Furthermore, there are changes in the sediment thickness and Moho depths but the cause of these distinct tectonic features is not well understood. Here, we use numerical experiments to investigate how the rift system developed within the Eastern Black Sea since Cretaceous. The numerical models are designed to approximate the geological characteristics of the region in which varying crustal/lithospheric thicknesses, extension rates, rheological characteristics are considered in an evolving rift domain (17-63 Myr timeframe inferred from plate reconstructions). Model results suggest that the rate of extension imposed on the margin of the lithospheric domain should exceed 3 cm /year to reconcile with the observations inferred from the seismic cross-sections.

Keywords : Eastern Black Sea, rifting, numerical modelling, geodynamics

Mobile cratons and subcretion tectonics

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The formation of Archean cratonic lithosphere and TTG (Tonalite-Trondjemite-Granodiorite) suites is not well understood, in part because the style of global tectonics active at that time is uncertain. The non-plate tectonic hypothesis for formation and evolution of continents we test in this study involves: intense magmatism above mantle upwellings in an unstable single plate regime to form cratonic nucleii; imbrication and anatexis of crust-dominated oceanic lithosphere at convergent margins driven by mantle flow, with build-up and thickening of cratonic keels by collisions. We use 2D numerical geodynamic models to investigate whether differential motion between the convecting mantle and cratonic keels can induce horizontal motion of a craton to form an accretionary orogen. Using the convection code StagYY, we attempt to model a self-consistent subcretion of oceanic lithosphere pushed by a pre-imposed craton. We propose that cratonic keels can be become mobile by sub-lithospheric mantle flows and what happens afterwards strongly dependent on the viscosity of the mantle rocks. Our experimental results show that, initiation of subduction can only be achieved with an efficiently high mantle viscosity.

Keywords: plate tectonics, subduction initiation, archean, stagnant-lid.

Subduction roll back and the generation of wet and decompression melting in NE Japan Arc

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Subduction zones are characterized by the sinking of relatively colder and denser oceanic lithospheres into the underlying asthenospheric mantle and they are associated with formation of volcanic arc systems. These volcanic provinces show varying chemical compositions based on the thermal, mechanical and chemical conditions of sinking oceanic lithospheres (pressure and temperature conditions, volatile content etc.). Specifically, in NE Japan, synthesis of geochemical, geophysical and geological findings has led to interpretation that volcanic arc displays a broad range of chemical composition (e.g depleted and enriched source, Mg rich Ryozen basalts) where Pacific slab subducts under the Eurasian slabs. Specifically, the opening of the Japan Sea and Yamato basin formations may be controlled by asthenospheric injection. Here, we conducted a series of 2D geodynamic models (I2ELVIS) to investigate: (1) the geodynamic evolution of NE Japan arc in the context of slab roll back under the accretionary prism; (2) the petrological characteristics of melt production, such as hydrous vs dry melting and (3) the volume of generated melt under Japan arc/mantle wedge. In our numerical experiments, we systematically explored the variation of the ocean lithosphere ages (50 to 120 Myrs) and the plate convergence velocities (4 to 8 cm.yr-1) to relate how such parameters affect the magmatism in NE Japan since last 30 Myrs. Our model results suggest that older oceanic lithospheres generate volcanics in higher volume comparing to the younger oceanic lithosphere age. On the other hand, the volume of generated melt increases with respect to the angle of the subducting slab. Also melt generation rate shows similarity with Japan arc system and is maximized in 15 Ma. Furthermore, the distribution of the chemical compositions of the generated melt in the models is in a good agreement with the volcanics in Japan arc under the forearc where a slab roll back drives such asthenospheric injection and the collapse of the megalith at 660 km boundary may not be necessary.

Keywords : Subduction, Geodynamic modelling, Alkaline volcanism, Calc-alkaline volcanism

Modeling the structural evolution of the low-angle detachment faults in Western Anatolia Back Arc System

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Extensional tectonics in the western Anatolia-Aegean region feature exhumation of the metamorphic core complexes that is accommodated by low angle normal (detachment) fault systems. Specifically, the central Menderes massif contains two symmetrically developed outward facing (Gediz and Büyük Menderes) detachment faults, which accommodated large scale displacements. Additionally, there are many younger high-angle normal faults in conjunction with the initiation of extension and synextensional magmatism since the Early Miocene. The standard fault mechanical theory does not allow such orientations, the occurrence of these faults at low angle and the seismicity on them are still not well-understood. Here, we investigate the evolution of the normal fault systems on lithospheric scale using thermomechanical forward models. We employ the numerical finite element code ASPECT to compute the visco-plastic deformation within a model domain that is 500 km wide and 165 km deep. The initial condition of our model is designed to reproduce the first-order lithospheric structure at the onset of Western Anatolia extension approximately 20 million years ago and consists of an upper crust (25 km thick) with wet quartzite rheology, a lower crust (25 km thick) with wet anorthite rheology, and a mantle lithosphere (30 km thick) with dry olivine rheology. We conduct two model suits where we investigate the impact of key parameters within a plausible range: (1) we vary the extension velocities imposed on the margins of the model boundary from V_{ext} = 1- 4 cm/year full rate. (2) we vary the friction strain weakening factor of the upper crust (f_C = 0.1 to 0.5). Our models show that these two parameters directly control the initial dip angle and development of the normal faults. We find that major faults are formed initially at 50-52° dip but evolve towards shallower dipping angles, 10-15°, because of the isostatic adjustment due to thinning/exhumation of the crust. The sequentially tilted faults on where slip can no longer be accommodated are abandoned and left behind as inactive low angle fault surfaces. Basin ward migration of newer fault is formed in the hanging wall to accommodate strain. The tectonic evolution of the central Menderes region is best reproduced in our reference model with a friction strain weakening factor of 0.2 and an extension rate of V_{ext} = 3 cm/yr. Namely, this model agrees well with the detachment faults shallowing dip angles, outward facing faults and symmetry with respect to the central Menderes massif. In addition, the exhumed massif has a dome shaped structure and the distance to one another (80 km) is comparable to those of Western Anatolia. Also, high angle normal faults are formed above the detachment faults, typical for Gediz and Büyük Menderes grabens. When the friction strain weakening factor of the upper crust and extension rates are changed, differences in these structural elements are observed. We conclude that our reference model supports the two rolling-hinge detachment system separated by elongated metamorphic domes with fold axes perpendicular to the direction of extension.

Keywords: Detachment Faults, Geodynamical Modelling, Western Anatolia

TH-7
TUSUNAMIS

2D versus 3D models of tsunamis in the Sea of Marmara

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In this work we present a comparative look on the modelling aspects of the Tsunamis in the Sea of Marmara with realistic initial conditions that are based on stress recovery calculations using a finite element algorithm. Both 2D and 3D Tsunami models are based on the numerical routines, the 2D model being a finite element algorithm and 3D model being a dedicated model used in physical oceanography. Our aim in this study is to understand limits of representativeness of the shallow water model to capture important aspects of the Tsunamis in an enclosed sea featuring very rapid bathymetric gradients.

Keywords: Tsunamis, Numerical Modeling, 3D Hydrodynamics

The impact of the 2018 Central-Western Sulawesi (Indonesia) tsunami on the Palu Bay and application of the Integrated Tsunami Intensity Scale (ITIS 2012)

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On September 28, 2018, at 10:21 UTC (18:02:44, WITA), an earthquake occurred in the western part of Sulawesi Island (Indonesia) and more specifically on the coastal Lende area. It was assessed as M 7.5 (USGS) or M 7.7 (BMKG). The main shock was located onshore at a distance of 61 km north of Palu city and at depths of about 10 km. The fault plane solutions of the main shock demonstrated the activation of an almost N-S striking left lateral strike slip fault (USGS, GCMT, CPPT, IPGP, GFZ).

The earthquake-affected area was the Palu depression, along the boundary between the Makassar and the North Sula blocks. The most affected parts of Palu depression included the coastal areas of the Palu Bay and more specifically the onshore Palu valley, in the east of the Palu-Koro fault, which is considered as the causative fault based on the primary earthquake environmental effects observed in the field.

Among the most significant secondary earthquake environmental effects, the 2018 Palu earthquake triggered a tsunami that struck the western coastal part of the Central Sulawesi Province. It is mainly attributed to the synergy of coseismic seabed displacement, submarine landslides and liquefied gravity flow within the Palu bay. The Central Sulawesi is a tsunami-prone area according to historical and recent data. Since 1927, it sustained the destructive effects of seven tsunamis attributed to earthquakes involving main tsunamigenic tectonic structures comprising the Palu-Koro fault.

The most tsunami-affected area extended from Magapa area to Palu Bay located north and south of the earthquake epicenter respectively. The tsunami struck several settlements with the Palu Bay. The coastal part of Palu City was devastated. The destructive waves arrived up to 10 minutes after the generation of the earthquake allowing little to no time for early warning and leaving no time for evacuation.

Based on our field survey on the tsunami affected area shortly after the earthquake and on all already published reports, satellite imagery and related information on the tsunami impact, the Integrated Tsunami Intensity Scale (ITIS 2012) is applied. Tsunami quantities and impact on humans, mobile objects, coastal infrastructure, the natural environment and buildings were taken into account. The lowest assigned intensity is $V_{ITIS\ 2012}$, while the highest is $XII_{ITIS\ 2012}$.

With run up ranging from 0.36 ($V_{ITIS\ 2012}$) to 9.34 ($IX_{ITIS\ 2012}$) meters, inundation height from 1.42 ($VII_{ITIS\ 2012}$) to 8.91 ($XI_{ITIS-2012}$) and inundation distance of hundreds of meters, the waves devastated the Talise beach in Palu City, the Dongala village at the western tip of the Palu bay as well as all many villages along the coast of Palu bay. It claimed the life of thousands ($VII_{ITIS-2012}$ to $XII_{ITIS-2012}$) and resulted in heavy impact on buildings ($VIII_{ITIS\text{-}2012}$ to $XII_{ITIS\text{-}2012}$), infrastructures ($IX_{ITIS\text{-}2012}$ to $XII_{ITIS\text{-}2012}$), mobile objects ($VII_{ITIS\text{-}2012}$ to $XI_{ITIS\text{-}2012}$) and the environment ($VIII_{ITIS\text{-}2012}$ to $XII_{ITIS\text{-}2012}$).

Keywords: Indonesia, Tsunami, tsunami intensity, Intensity scale, ITIS 20