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International Workshop on Comparative studies of the North Anatolian Fault (Northwest Turkey) and the San Andreas Fault (Southern California)

İstanbul/2006

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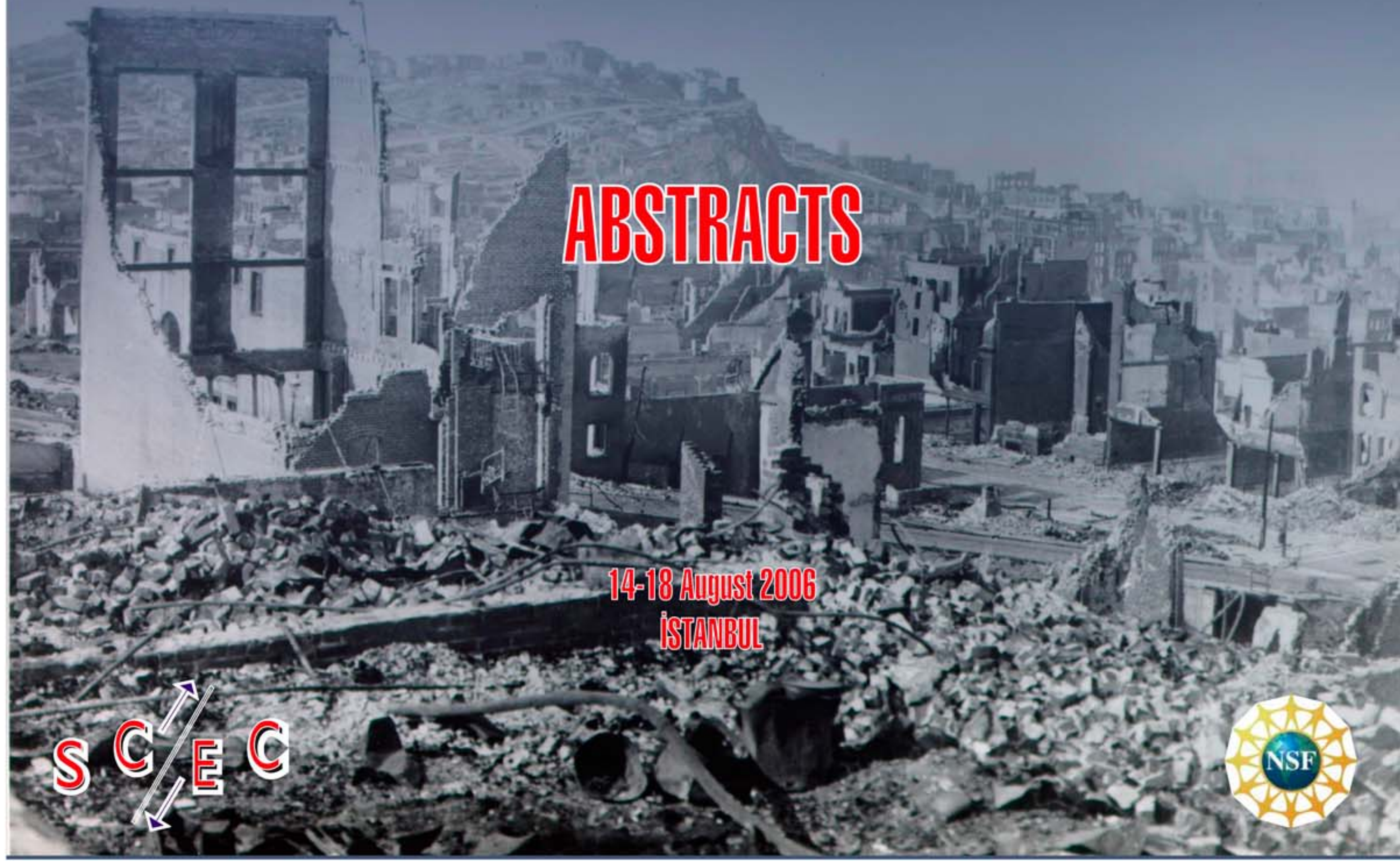

ABSTRACTS

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INTERNATIONAL WORKSHOP ON COMPARATIVE STUDIES OF THE NORTH ANATOLIAN FAULT (NORTHWEST TURKEY) AND THE SAN ANDREAS FAULT (SOUTHERN CALIFORNIA)

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PREFACE

The North Anatolian Fault (NAF) is a 1200-km-long dextral transform fault in northern Turkey with a very distinct morphological expression on land. Its westernmost portion is mainly concealed beneath the Sea of Marmara. This fault zone formed approximately 13 to 11 Ma ago and has been active since than. Recently, it ruptured catastrophically in two large earthquakes on the 17th August and 12th November 1999, causing great human casualties and economic damage. These earthquakes have alerted the earthscientists, because historical earthquake data indicate that earthquakes on this fault concentrate the shear stress at the western tips of the broken segments, thus leading to westward migration of large earthquakes. It is now a common belief among Turkish scientists that the last two earthquakes, which took place in close proximity to the eastern end of the Sea of Marmara, have loaded the earth crust under this sea and have made it a target for a future large earthquake. M=7.6 event is expected within 30 years with an approximately 62 % probability on the submarine segment (Marmara Fault) of the NAF.

Marmara Fault lies beneath the Sea of Marmara just offshore Istanbul. Approximately 13 million people live in the large metropolitan areas of this city. Their lives and homes are under a serious threat. Despite this great danger, little has been made up to now in preparing the city for the large earthquake expected. However, earthquake studies on the Sea of Marmara have made spectacular progress in understanding the geological and geophysical features of the Marmara Fault. Unfortunately, implementation of this knowledge in earthquake loss reduction is insufficient. This may be due to poor communication in this country between scientists and the governmental authorities.

This workshop is aimed to initiate comparative studies on the North Anatolian and the San Andreas Faults. It will probably lead to reciprocal collaborative projects. It is my sincere hope that such projects will lead to better earthquake forecast and better technology for early warning. All these have the potential to substantially reduce earthquake losses. Considering that south California and Istanbul are so densely populated and the centre of economic activity, these contributions will be invaluable.

Prof. Dr. Naci GÖRÜR

Acknowledgements
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A Breif history of earthquake research in the Sea of Marmara since the 1999 Earthquakes

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Two devastating 1999 Gölcük (Mw 7.4) and Düzce (Mw 7.2) earthquakes struck the Marmara region and caused over 18000 deaths and an economic damage of 20 billion USD. After the earthquakes, earth scientists in Turkey announced that these earthquakes have loaded the earth crust under the Sea of Marmara and therefore have made this sea a potential target for a future large earthquake. Their thoughts are based mainly on historical earthquake data. Analysis of these data shows that the earthquakes on the North Anatolian Fault (NAF) mostly migrate from east to west. The 1999 earthquakes advanced the rupture front of this fault to the Gulf of Izmit and therefore the next large earthquake is expected to occur offshore in Istanbul. According to stress transfer analyses, such an event will likely take place within 30 years or so. When this happens, it will cause a significant damage in Istanbul and other coastal urban areas. Naturally, this alarming situation was of great concern to the public and the civil authorities. They wanted to know the source, magnitude, and time of the expected earthquake. Soon after the 1999 earthquakes, our knowledge on the Sea of Marmara was not sufficient to give reliable answers to such questions. Studying of the marine portion of the NAF was a critical issue, but unfortunately earthscientists in Turkey hardly interested in marine geology. Besides this, there were only few marine research vessels in Turkey with limited technological capacity. For a better understanding of the seismotectonic activity in the Sea of Marmara, multinational research projects were urgently needed.

In order to develop multinational research projects with a view to mitigating the impact of future disasters, a NATO Advanced research Seminar was held in Istanbul in May 2000. Following this seminar, scientists from France, Italy, US, Japan, and Germany initiated several multidisciplinary projects on the Sea of Marmara in collaboration with Turkish scientists. These projects were supported by CNRS in France, IGM in Italy, LAMONT in US, Tokyo University in Japan and the NATO itself.

Many foreign research ships came to Turkey and worked on various aspects of the Sea of Marmara. R/V Le Suroit collected bathymetric data and mapped the NAF throughout the Northern Marmara trough. Owing to these studies, trend and geometry of this fault system were better understood and an atlas of the northern trough was produced.

In the R/Vs Odin Finder and Urania expeditions, multibeam bathymetric coverage of the Izmit Gulf was collected and high-resolution seismic (chirp) profiles of the northern shelf were acquired. By the R/V Le Nadir expedition, deep seismic reflection and refraction data were collected along the northern trough. During these works, 37 OBS were also deployed on the sea-floor along the NAF for micro-seismic studies. R/V Marion Dufrasne took many cores up to 50 m long from the Çınarcık, Central Marmara and the Tekirdağ depressions. Studies of these core samples provided a better understanding of the sedimentological and stratigraphical evolution of the Marmara basin. R/V Le Atalante did extensive video survey of the well-preserved open fault fractures on the sea-floor between the Tekirdağ and the Central Marmara depressions and collected a number of samples from the scarps associated with these fractures. This expedition yielded invaluable data for palaeoseismological works in the Sea of Marmara.

Scientific results from all these studies have been presented at special sessions of many national and international meetings, as well as published in various well-known international journals. Before the 1999 earthquakes, the Sea of Marmara was poorly-known, but now it has become one of the best known inland basins in the world.

After the devastating 1999 Gölcük (Mw 7.4) and Düzce (Mw 7.2) earthquakes on the NAF, just to the east of the Sea of Marmara, this sea has become very risky. This was due to two main reasons. The first reason is that the earth crust under this marine realm has been loaded with stress following the earthquakes. The second reason is related to the fact that earthquakes on the NAF commonly migrate westward and therefore the Sea of Marmara has become a target for the next big earthquake.

On the basis of these reasons, the people of this region have been alerted and now everyone here knows that in the near future a big earthquake will take place in the Sea of Marmara. Soon after the 1999 earthquakes, it was not possible to make a reliable risk assessment, because our knowledge on this sea was rather limited. Before the earthquakes, few marine researches had been conducted in the Sea of Marmara and therefore published marine data were hardly available. However, the public was so concerned with the new future threat and authorities urgently needed to know the source, magnitude, time and possible damage of this expected earthquake.

In order to find answers to such questions, a NATO Advanced Research Seminar was organized in Istanbul in 2000. 83 scientists from different countries, including Europe, America, Germany, and Japan attended to the meeting. In the meeting, expected Marmara earthquake was discussed in certain detail and strategies for future investigations were decided.

Following the NATO seminar, marine national and international studies were initiated in the Sea of Marmara. In the national marine investigations, two Turkish research ships, Sismil-1 and Çubuklu, are used. These research vessels collected great amount of seismic and bathymetric data in both the Gulf of İzmit and the Sea of Marmara. Planning of later international studies is based on these data.

The international marine studies started in collaboration with CNRS in France, LAMONT in USA, IGM in Italy and Tokyo University in Japan. Many foreign research ships came to Turkey and collected geological and geophysical data along the active marine branches of the NAF. R/V Le Suroit collected bathymetric data and mapped the NAF along the northern depression of the Sea of Marmara. Owing to these studies, trend and geometry of this fault system were understood and a marine atlas was produced. In the expeditions of the R/Vs Odin Finder and Urania, multibeam bathymetric coverage of the Izmit Gulf was collected. High- resolution seismic (chirp) profiles of the northern shelf of the Sea of Marmara were also acquired. With the R/V Le Nadir, the Seismarmara Project was conducted. In this project deep seismic reflection and refraction data were collected. During this expedition, 37 OBS were also deployed along the fault for micro-seismic studies. R/V Marion Dufrasne realized Marmara Core Project. Many cores up to 50 m were taken during this project from Çınarcık, Central and Tekirdağ depressions of the Sea of Marmara to study sedimentological and stratigraphical evolution of this marine basin. R/V Le Atalante is used for the Marmara Scarps Project. In this project, active fault fractures on the sea-floor were filmed and sampled for palaeo-seismological studies.

Scientific results from all these studies have been presented at special sessions of many national and international meetings, as well as published in various well-known international journals. Before the 1999 earthquakes, the Sea of Marmara was poorly-known, but now it is one of the best known inland seas in the world.

SCEC's Program of Earthquake System Science in Southern California

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The Southern California Earthquake Center (SCEC) coordinates an extensive research program in earthquake system science involving more than 500 scientists at 55 research institutions. The Center strives to attain a physics-based, predictive understanding of earthquake phenomena through interdisciplinary studies of fault system dynamics, earthquake forecasting and predictability, earthquake source physics, and ground motions; and it seeks to apply this understanding to improving seismic hazard analysis and reducing earthquake risk. The major research issues of earthquake science are true system-level problems: they require an interdisciplinary, multi-institutional approach that attempts to model the nonlinear interactions among many fault-system components, which themselves are often complex subsystems. SCEC attempts to advance earthquake system science through a comprehensive program of system-specific studies in Southern California. It thus operates on the premise that detailed studies of fault systems in different regions, such as Southern California and Turkey, can be synthesized into a generic understanding of earthquake phenomena. International partnerships are clearly necessary to achieve this synthesis. This presentation will review the current 5-year research program (SCEC2, 2002-2007) and outline the mechanisms the Center has employed to transform research into practical knowledge. It will also describe the science plan approved by the National Science Foundation and U. S. Geological Survey for the next 5-year phase of the Center (SCEC3, 2007-2012). The plan includes the establishment of a new infrastructure for conducting and evaluating scientific earthquake prediction experiments, the development of a uniform time-dependent earthquake rupture forecast for California, a major study of the Southern San Andreas Fault, and end-to-end ("rupture-to-rafters") earthquake simulations that incorporate built structures into the geologic environment. The plan also calls for expanded international partnerships with Turkey and other countries seeking to reduce seismic risk.

The North Anatolian Fault

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The North Anatolian Fault (NAF) is a 1200-km-long dextral strike-slip fault zone that formed by progressive strain localization in a generally westerly widening right-lateral keirogen in northern Turkey mostly along an interface juxtaposing subduction-accretion material to its south and older and stiffer continental basements to its north. The NAF formed approximately 13 to 11 Ma ago in the east and propagated westward. It reached the Sea of Marmara no earlier than 200 ka ago, although shear-related deformation in a broad zone there had already commenced in the late Miocene. The fault zone has a very distinct morphological expression and is seismically active. Since the seventeenth century, it has shown cyclical seismic behavior, with century-long cycles beginning in the east and progressing westward. For earlier times, the record is less clear but does indicate a lively seismicity. The twentieth century record has been successfully interpreted in terms of a Coulomb failure model, whereby every earthquake concentrates the shear stress at the western tips of the broken segments leading to westward migration of large earthquakes. The August 17 and November 12, 1999, events have loaded the Marmara segment of the fault, mapped since the 1999 earthquakes, and a major, $M \leq 7.6$ event is expected in the next half century with an approximately 50% probability on this segment. Currently, the strain in the Sea of Marmara region is highly asymmetric, with greater strain to the south of the Northern Strand. This is conditioned by the geology, and it is believed that this is generally the case for the entire North Anatolian Fault Zone. What is now needed is a more detailed geological mapping base with detailed paleontology and magnetic stratigraphy in the shear-related basins and more paleomagnetic observations to establish shear-related rotations

Comparison of Paleoseismologic Evidence for Patterns of Earthquake Occurrence on the North Anatolian and San Andreas faults: The Importance of Structural Context

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Analysis of paleoseismological and historical data from the North Anatolian fault in Turkey and the central-southern SAF in California suggests that the occurrence of large earthquakes is controlled, to a large degree, by the structural setting of the master fault. Where the main fault extends through structurally complicated regions characterized by multiple nearby, moderatehigh slip-rate faults (as in southern California), earthquakes occur more frequently and less regularly (relative to the same fault loading rate). Along structurally simple parts of the fault in areas with relatively few nearby faults (as along much of the central and eastern NAF), however, earthquakes are generally larger, less frequent, and occur more regularly. Although numerous factors exert important controls on the occurrence of large earthquakes (e. g., quasi-permanent structural complexities such as releasing or restraining steps, stress changes from other earthquakes on the same fault?), we suggest that these observations may best be explained by the more complicated stress evolution of the master fault related to: (1) the occurrence of nearby large earthquakes that generate ephemeral zones of stress enhancement and stress shadows; and (2) changes in loading rate over multiple earthquake cycles, as appears to be occurring in southern California.

Evolution of transform ridges and basins with special reference to the Marmara region

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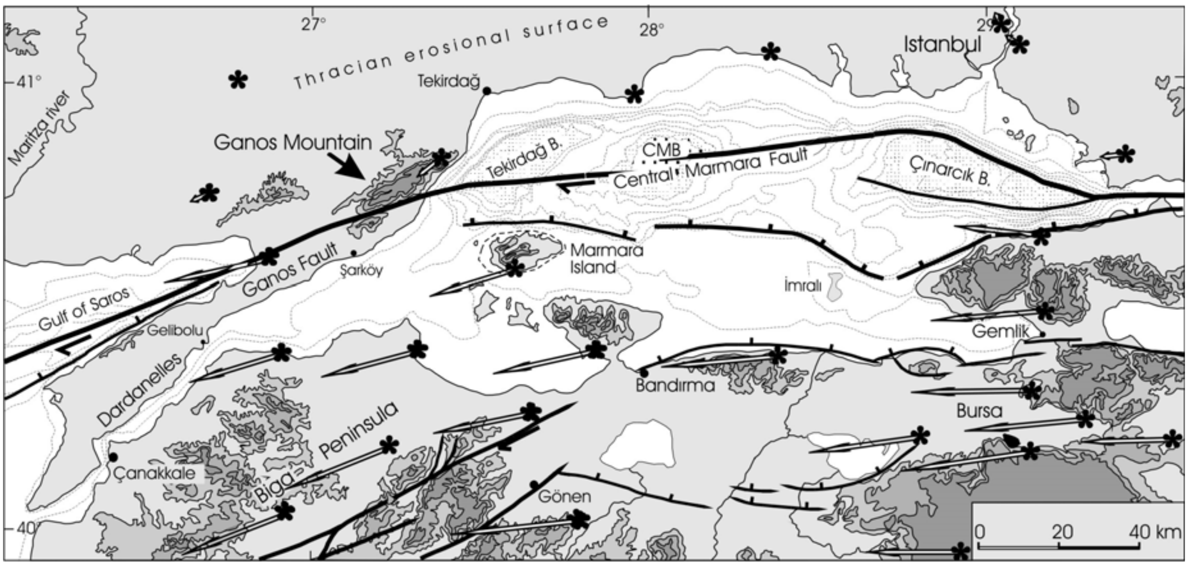
The obliquity between the orientation of the strike-slip faults and that of the relative plate motion leads to the formation of the transform ridges and basins, which are ubiquitous along major strike-slip fault zones. To conserve energy, however, strike-slip faults should be parallel to the relative plate motion. There are probably two main reasons as why most major strike-slip faults deviate from this condition. The first is the influence of the pre-existing faults on the location of the active fault, and the second is temporal and spatial changes in the relative plate motion. These two factors counteracted by the tendency of the strike-slip fault to follow the relative plate motion results in a complex evolution of the transform ridges and basins.

The Marmara Sea region provides a good example of the influence of the former fault geometry on the formation and evolution of the transform ridges and basins. In the Marmara Sea the North Anatolian Fault (NAF) is strongly segmented forming the İzmit, North Boundary (45 km long), Central Marmara (105 km) and Ganos faults. The almost pure strike-slip İzmit fault bends 26° in the west to form the strongly transtensional North Boundary Fault. An active transform basin with syntransform sediments, over 3-km in thickness, is forming southwest of the North Boundary Fault. The major bend and the associated transform basin most probably owe its origin to a Miocene strike-slip fault zone, which was followed by the NAF. Despite claims to the contrary the NAF has not yet cut a new fault through the basin, although this would energetically be favorable. In the central Marmara region the plate motion vectors between the Anatolian and Eurasian plates show an anti-clockwise rotation induced by the increasing pull of the Hellenic subduction zone. This creates transtension in the western section of the Central Marmara Fault opening the Tekirdağ basin, and transpression in the eastern part, forming the anticline of the Central Marmara ridge. The 17° contractional bend between the Central Marmara and Ganos faults is resulting in the uplift of the Ganos Mountain. Recent apatite fission track studies have shown that the Ganos Fault and Ganos Mountain have a history going back to the Oligocene; the Ganos fault bend and the associated structures are also apparently imposed on the NAF.



North Anatolian fault and other active faults in the Marmara region in northwest Turkey (Okay et al., 2004).

Stepover Geometry in the Gemlik Bay on the Southern Strand of the NAF

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The southern branch of the North Anatolian Fault emerges west of Mudurnu town and extends almost in east-west direction along the Geyve-Pamukova basin, the Lake İznik basin and the Gemlik Bay where it enters the Sea of Marmara. It is then again observed on land on the southern shores of the Sea of Marmara between Sigiköy and Mudanya and extends westward bounding the Karadağ in the north and the alluvial plain surrounding the Lake Dalyan (MTA, 2001). GPS measurements, paleoseismic data and historical records indicate that most of the westward motion of the Anatolian Plate occurs and probably has occurred along the northern strand of the North Anatolian Fault rather than that along the southern strand and consequently the seismic activity is at lower levels.

High-resolution shallow seismic data were collected along 61 lines by *Ustalar*, a 10-m-long boat, in August - September 2002. The aim of the study was to trace the active faults and collect piston cores in the Gemlik Bay. The seismic profiles were taken generally with a N-S direction and with an interval of 500 m. A bathymetric chart of which contour intervals are at every 2 m of the study area was prepared based on the sounding data obtained during the cruise.

The Gemlik Bay which is an approximately 35-km-long and 15-km-wide basin lying in east-west direction is located in the southeastern corner of the southern shelf of the Sea of Marmara and to the south of the Armutlu peninsula. The maximum depth in the bay is approximately 110m. Two morphological features at the bottom of the study area are much striking: (i) the northwest-southeast trending elliptic depression in the centre of the bay, situated roughly between Kapaklı and Burgaz *(Burgaz Trough)*, and (ii) the adjacent E-W oriented submarine rise between Karacaali and Kurşunlu *(Gemlik High)*.

Detailed examination of the seismic profiles has shown that there are three sets of faults in the Gemlik Bay: 1) prominent (with south-dipping normal fault component) faults along the southern coast of the Armutlu Peninsula 2) several continuous (with north-dipping normal fault component) along the southern coast of Gemlik Bay, 3) normal faults bounding the small central basin. Geometrically, the faults in the first two sets bound the Burgaz Trough and their right stepping pattern explains the opening of the basin by pull apart mechanism. Conversely, to the east, the left stepping faults on both side of the Gemlik High, the Gemlik Fault (running in the easternmost Gemlik Bay) and the Gençali Fault (running along the Kocadere stream) have led the formation a push-up structure mainly offshore, the Gemlik High, adjacent to the Burgaz Trough in the east. The bathymetry of the study area supports this idea.

Paleoseismology of the 1912, 1944 and 1999 ruptures on the North Anatolian fault: Implications for late Holocene patterns of strain release

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We excavated over fifty trenches at five sites along the 1912, 1944 and 1999 surface ruptures to study the late Holocene rupture history along the North Anatolian fault east and west of the Marmara Sea. Two of these studies also bear on the late Holocene slip rate and can be compared with rates of strain accumulation determined from GPS. Along the 1912 rupture on the Galipoli peninsula, we excavated nearly 30 trenches near Kavakkoy to resolve cumulative slip of 9 m from the 1912 and 1766 earthquakes. We also found evidence for two additional surface ruptures after about AD 900, which probably correspond to the large regional earthquakes of 1063, and 1344. These observations suggest fairly periodic occurrence (RI =~250+75 yrs for the past millennium and a rate of about 18 mm/yr if all events experienced similar slip.

Along the 1999 rupture, we excavated two sites near Kosekoy to resolve the occurrence of three events after AD 1650. In addition to 1999, one is almost certainly the large 1719 earthquake that had very similar damage distribution to 1999. The other event may be the poorly studied 1878 earthquake or one of several other moderately large events (such as 1754 or 1894) that are poorly located in the region. Radar surveys show a buried channel that is offset by all three events, with about three times the 1999 displacement at this site. These observations suggest that the Izmit-Sapanca segment fails more frequently, and with smaller displacements, than segments to the west and east.

Near Gerede along the 1944 rupture, we excavated about a dozen trenches to resolve six surface ruptures in the past two millennia, with events ca AD 480, 710, 1035, 1235, 1668 and 1944. The 1944 rupture expressed 5 m of slip at the trench site. The penultimate event also experienced a similar amount of slip, based on offset stream channels. Cumulative slip for all five events is about 21-26 m based on 3D trenching of a channel margin dated to AD 550, suggesting a slip rate of 14-18 mm/yr for the past 1500 years.

Using the intervals between events for the past 6-7 surface ruptures (290+83 years back to about AD 0) suggests a slightly higher average rate of about 19 mm/yr.

These paleoseismic results have implications in four main areas. First, individual segments appear to have quasi-periodic behavior, at least for the intervals tested. Second, 9-10 m of slip has occurred on fault segments both to the east and west of the Marmara Sea, whereas the last major earthquake in the central Marmara was in 1766, supporting the contention that the segment closest to Istanbul may be ripe for rupture. Third, the Izmit-Sapanca section of the 1999 rupture sustained less slip than at Gulcuk or east of Sapanca, consistent with the more frequent occurrence of events at Kosekoy, suggesting that 1999 was a multi-segment or cascade event. Finally, all of the dated geologic offsets from our work suggest a late Holocene rate in the range of 14-19 mm/yr. These rates are lower than the ~23-25 mm/yr inferred from GPS measurements, suggesting that either there are periods when the fault "catches up" with more frequent events or that the GPS rate carries a transient signal, possibly related to rupture of most of the 1000 km of fault this past century.

Space geodetic constraints on the earthquake deformation cycle along the North Anatolian Fault

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Global Positioning System observations for geodynamic studies were initiated in Turkey in 1988 with the establishment of a very broad and sparse network of GPS survey points.

Densification and repeat observations of this initial network have progressed at a rapid rate since that time. A focused survey network in the Marmara region of the NAF was installed by ETH-Zurich and Istanbul Technical University in the early 1990s (e.g., Straub and Kahle, 1995) and a network of continuous GPS (CGPS) stations (MAGNET) was installed by TUBITAK MRC along the Marmara NAF segment in the late 1990s (Yalcin et al., 1999). In addition, the Turkish General Command of Mapping has developed a major GPS program to maintain geodetic control and monitor crustal deformation in Turkey and is cooperating with the Turkish Earth Science research community (e.g., Ayhan et al., 2002). These data, which we continue to develop, are providing estimates of the rate and spatial distribution of strain accumulation along the entire 1000 km length of the NAF. These new constraints are in turn providing information on variations in fault properties along the fault and with the stage in the earthquake cycle, particularly around the Marmara segment believed to still be a seismic gap with the potential for a significant future earthquake. For the 1999 Izmit earthquake segment, the well constrained pre-earthquake velocity field and the location of a number of MAGNET stations within the co-seismic deformation zone at the time of the earthquake provide a wealth of information about co- and post-seismic processes and hence fault mechanics and crustal/upper mantle rheology. In this presentation, we review the current status of GPS control along the NAF and our present understanding of earthquake processes and crustal rheology revealed by these data.

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The Parkfield Section of the San Andreas Fault, California: Characteristic or Complementary Earthquake Ruptures?

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The San Andreas Fault is the major fault in California; it accommodates rightlateral strike-slip motion between the Pacific Plate and the North American plate. Individual sections of the San Andreas Fault behave in seismically different ways – some sections of the fault are locked (they slip only co-seismically in large ~M8 earthquakes; e.g.: the 1857 M7.9 Fort Tejon earthquake, the 1906 M7.8 San Francisco earthquake), while others parts of the fault creep (they accommodate all the relative plate motion by slow steady-state slip; this is the case of the San Juan Bautista – Cholame segment). The North Anatolian Fault has no creeping section and exhibits an earthquake cascade pattern (consecutive earthquakes rupture neighboring sections of the fault). Despite the different patterns of occurrence of large mainshocks, a key aspect to understanding both the San Andreas and the North Anatolian fault systems is earthquake interaction. We approach this subject by looking at the Parkfield fault section of the San Andreas Fault. The Parkfield dataset allows us to study two consecutive earthquakes that ruptured the same fault section. Parkfield marks the transition between a creeping and a locked part of the San Andreas Fault. In the historical period (post 1850's) it has generated at least five ~MW6 earthquakes. Based on similarity of waveforms from the 1922, 1934 and 1966 Parkfield earthquakes, Bakun and McEvilly (BSSA 1984) proposed the idea of characteristic earthquakes: a given fault segment would rupture repeatedly in earthquakes that would nucleate in the same hypocenter and generate slip on the same areas of the fault. Unlike previous Parkfield earthquakes, the 2004 Parkfield earthquake did not nucleate near Middle Mountain and rupture to the SE, but rather nucleated near Gold Hill and ruptured NW. Despite these differences, do the 1966 and 2004 slip distributions look similar? We compute a kinematic rupture model for the 1966 event by inverting the scarce co-seismic dataset (Figure 1). Only five strong motion instruments were nearby at the time of the 1966 mainshock; all were located perpendicular to the fault, near its SE end. Because the data coverage of the fault is poor, the resolution of the rupture model becomes an important question. To estimate the resolution of the 1966 rupture model, we use 3 different approaches: 1) we use synthetic slip distributions to generate waveforms at the 5 stations, and then invert the synthetic waveforms to see how well the initial slip distributions can be recovered; 2) we invert seismograms of the 2004 earthquake recorded at 5 stations coincident or close to the stations that were in place in 1966; we then compare the obtained rupture model with one obtained by inversion of a more complete dataset; 3) we invert the 1966 dataset applying the constrain that the slip amplitude distribution must be similar to the 2004 earthquake. The resolution tests indicate that the 1966 rupture model is poorly resolved; however, we can eliminate the hypothesis that the 1966 and 2004 Parkfield earthquakes slip distributions were identical.

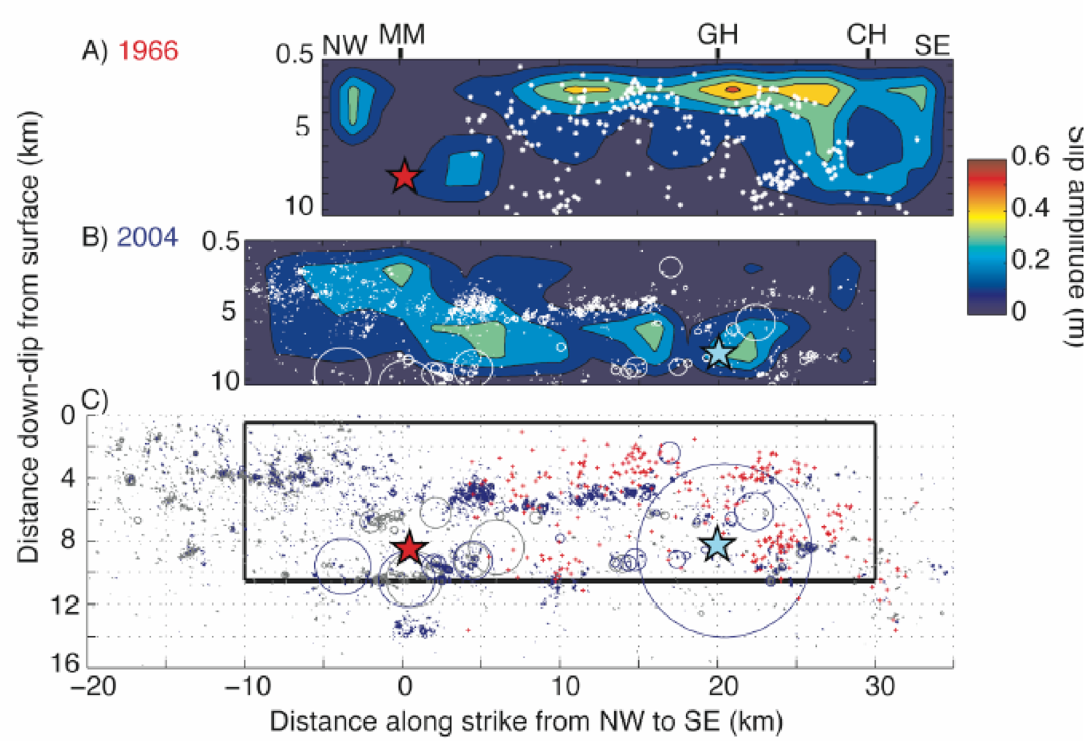

Figure 1 - Comparison between the rupture models for the 1966 and 2004 Parkfield earthquakes and microseismicity. According to our modeling of strong-motion seismic data, the two most recent Parkfield earthquakes (1966 and 2004) ruptured complementary parts of the fault plane. A) Slip amplitude and aftershocks of the 1966 earthquake. B) Slip amplitude and aftershocks of the 2004 earthquake. C) Aftershocks of the 1966 earthquake (red crosses), aftershocks of the 2004 earthquake (blue circles) and background seismicity from 1984 to the 2004 earthquake (gray circles) (Thurber et al., in press}. The size of the aftershocks (circles) is computed assuming a 3~MPa stress drop in a circular region. In the absence of information on the magnitudes of the 1966 aftershocks, we cannot compute their size; these aftershocks are represented by crosses. The rectangle indicates the position of the fault plane modeled for the 2004 earthquake. The red and blue stars mark the 1966 and 2004 hypocenters, respectively. MM - Middle Mountain; GH - Gold Hill; CH - Cholame.

Late Quaternary stratigraphy and sedimentology of the Marmara Sea: Implications for tectonic studies

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High resolution sub-bottom profiles on the shelf edge in various parts of the Marmara Sea generally includes a sediment wedge that within the seismic penetration depth of the subbottom profiles, appears to extend back to at least marine isotope stage (MIS) 11 (~360 kyr). The seismic units in the sediment wedge are separated by shelf crossing unconformities that can be clearly correlated with sea-level lowstands in the global sea-level curves based on the oxygen isotope data. The most conspicuous unconformities occur at the base of Units 1 and 5 deposited broadly during the Marine Isotope Stage 5 (MIS-5, ~80-127 kyr BP) and MIS-1 (mainly Holocene), respectively. These units are represented by mainly seismically transparent transgressive muds (high stand systems tract, HST) that have a maximum thickness of about 2.5 and 12 m, respectively on most parts of the northern shelf. The intervening Units 2, 3, and 4 were deposited during MIS-2, MIS-3, and MIS-4, respectively and represent relatively low stands in the Marmara basin. Unit 2 has been largely eroded in most parts of the shelf. They are generally represented by parallel to prograding reflections, having internal reflection characteristics indicative of relatively coarse-grained sediments.

The cores recovered from the shelf edge and pressure ridges reach up to MIS-5 and, together with seismic and bathymetric data, give important information on the late Quaternary evolution of the Marmara Sea. According to the core data, the Marmara Basin was marine during MIS-5 and 4, but mainly fresh to brackish, disconnected from the Mediterranean during the deposition of MIS 3 and 2. The basin was last inundated by Mediterranean waters at ~12 kyr BP ($^{14}C_{uncalib.}$). The shoreline of the Marmara "lake" prior to the transgression was at –85 m, controlled by the bedrock sill depth of the Çanakkale (Dardanelles) Strait. Another shoreline is located at -64 m, probably formed during Younger Dryas still stand. These shorelines, together with a sapropel unit dated 10.6 - 6.4 kyr BP and two ash layers originated from the Santorini Cape Riva and Campanian eruptions (dated 22 ka BP and 39.3 ka BP cal. year respectively) provide important time lines for studying tectonic events and rates.

The geometry of sediment fill in the ~1250 m-deep basins with steep slopes (>15-28º) shows the changing rates or styles of tectonic activity and sedimentation rates in the basin. The rates of thickening and the dipping of the strata in the basins have been determined by the interplay of the rates of subsidence, sedimentation and sea-level change. The basinal sediments are characterized by alternation of normal hemipelagic sedimentation and turbidite-homogenite (T-H) units that are mostly deposited during seismic events. As such, they are important archives of past earthquakes. The T-H units commonly consists of a thin (<5 cm) sand layer with erosional lower contact at the base and a relatively thick, homogeneous mud layer at the top. They thicken towards the deepest, subsiding part of the basins close to the active Main Marmara Fault. The relatively coarse turbiditic units correspond to different units in a discontinuous Bauma sequence. Some demonstrate "amalgamated" features, typical of deposition from reflected or deflected single turbidity currents. As a result of mass flow sedimentation, the deep basins are characterized by very high (>1 m/kyr), but variable sedimentation rates that are controlled by the morphotectonics and glacio-eustatic water-level changes (i.e., lacustrine vs. marine periods). The rates are the highest in the deepest, tectonically subsiding parts of the basins, and 2-3 times higher for the latest low-stand lacustrine period than those for the latest high-stand marine period.

The Transitional zone between the Extensional and Strike-slip neotectonic regimes in southern Marmara region: Bursa Graben

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Bursa Graben is a 2-36 km wide, 150 km long and approximately E-W-trending major depression subdivided into a series of sub-grabens and horsts. Its evolutionary history is episodic as indicated by two graben infills separated from each other by an intervening angular unconformity. These are the underlying and deformed (folded) infill of Miocene-Lower Pliocene age and the overlying and undeformed Plio-Quaternary neotectonic infill. The Bursa graben is also asymmetrical in nature. This is indicated by: (a) a big relief differences between the graben floor and the surrounding fault-controlled mountain fronts; these are the ~2.4 km (2542 m- 100 m) for southern margin, and ~1 km (1108 m-100 m) for northern margin; (b) a big difference in slip amounts along its northen and southern margin-boundary faults, and (c) the occurrence of two large lakes (Lake Manyas and Lake Ulubat) leant their one margins against the southern fault–controlled margin of the graben.

The southern margin of the Bursa major graben is bounded by the northerly-dipping Bursa fault zone. It is about 30 km wide, 150 km long and approximately E-W-trending oblique-slip normal fault zone located Kınık (Inegöl) in the east and Gönen in the west. The Bursa fault zone consists of a series of parallel to sub-parallel, closely-spaced and diverse-sized normal fault segments. In general, the Bursa fault zone displays a curvilinear and northerly-facing step-like normal faulting pattern characterized by steep fault scarps and well-preserved slickensides. The northern margin of the Bursa graben is bounded by the southerly-dipping Karacabey-Demirtaş fault zone. This is a 1-10 km wide, 140 km long, discontinuous and E-W-trending oblique-slip normal fault zone located between Gölbaşı (Gürsu) in the east and Buğdaylı in the west. It also consists of a number of parallel to sub-parallel, diverse-sized and discontinuous normal fault segments. It displays a relatively gentle fault scarp but well-preserved slickensides in places.

In the previous literatures, both of these two fault zones were informally named and misinterpreted to be the southern Marmara sub-strands of the North Anatolian right-lateral strike-slip fault system (NAFS). In contrast to this previous informal naming and misinterpretation, the recent detailed field geological mapping, palaeo-stress analyses of slip-planes of fault segments and the focal mechanism solution of surface rupture-forming devastative earthquakes, such as the 1964.10.06 Ms = 7.2, and also the historical earthquakes clearly indicated that both the Bursa and the Karacebey-Demirtaş fault zones are oblique-slip normal faults in nature, and they determine northernmost limit of the southerly operating extensional neotectonic regime. In this frame, southern sub-strand of the NAFS, which is here termed as the Geyve-İznik right lateral strike-slip fault zone, is approximately confined to the southern margin of Sea of Marmara, and it is dominated by a number of parallel to sub-parallel, closely-spaced, diverse-sized strike-slip fault segments, compressional to extensional double bendings, extensional step-overs, pull-apart basins of Quaternary age, well-preserved slickensides and deflected to offset drainage systems.

Morphotectonic features along the Tosya-Havza segment of the North Anatolian Fault

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North Anatolian Fault is an active right-lateral strike slip system emplaced into a broad shear zone, North Anatolian Shear Zone (NASZ), reaching up to 100 km width. The morphology of the NASZ is mainly controlled by the faults within the NASZ. Different morphological entities such as river offsets, sag ponds, releasing and restraining bends, shutter ridges, terraces, push-up structures etc have been mapped along the shear zone. In this study, morphology of an area in the central part of the NASZ between Tosya (Kastamonu) and Köprübaşı (Havza, Samsun) have been studied. In this area there are two sedimentary basins, Tosya Basin filled by Upper Miocene deposits and the Kargı Basin filled by Quaternary sediments. Both basins developed as pull apart basins along the central part of the North Anatolian Fault Shear Zone.

To the east of the Kargı Basin the main branch of the North Anatolian Fault extends along a narrow and deep valley. In the north and south of the fault there are mountainous areas elevated as positive flower structures. Close to the Köprübaşı in the east, the shear zone widens again. The fault zone widens close to the Neogene and Quaternary basins while it is represented by a single fault branch lying in a very narrow depression in the other areas. This widening and narrowing structure of the shear zone indicate that the geometry of the fault is controlled by the structure of the crust. On the other hand, morphological features along the main active North Anatolian Fault between Köprübaşı and Tosya indicate 11km of right lateral offset for this region.

Combining High-Resolution Climate Studies and Tectonics: Imaging Complex Folding in 4-Dimensions Above Active Blind Faults

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Understanding the regional geometry and slip of active faults and folds is crucial to proper seismic hazard evaluation. This knowledge is used to model earthquake sources, recurrence and effects, as well as to understand the distribution of plate boundary motion. Folding is important as it is critically linked to the slip on blind faults, as well as to bends and terminations of strikeslip faults, and absorbs finite strain that is not otherwise observable as near-surface fault offset. A quantitative measure of the finite strain absorbed by folding and fault slip is the cumulative deformation defined by mapped stratigraphic reference horizons and paleo-sealevel markers.

As part of a detailed global climate study in Santa Barbara Basin, grids of high-resolution single-channel and multichannel seismic (MCS) reflection data were used to correlate and map arious stratigraphic reference horizons from ODP Site 893 (and other wells) across the basin to the Mid-Channel Trend. This trend is a complex fold structure growing above (and between) the high-angle oblique-reverse Oak Ridge fault and an associated back thrust. Fold growth has caused sediments deposited in the deep paleo-bathymetric basin to be uplifted and partially eroded so that strata as old as ~700 ka are exposed at the seafloor where they are now accessible to piston coring. In August 2005, over 30 piston cores—together with deep-towed chirp data— were taken using the *R/V Melville* to sample and survey these horizons and their intervening stratigraphic sequences (**Figure 1**). Preliminary core analyses confirm that most glacial and interglacial intervals between about 150 ka and 500 ka were sampled. The core results, together with the chirp data and interpreted grids of high-quality industry MCS data thus provide a dated high-resolution seismic stratigraphy to image and document the nature, geometry and evolution of the Mid-Channel anticline and the Oak Ridge fault system in 3D.

Our sequence of multiple mapped reference horizons documents a fairly complicated process of how slip on the deep fault system is transformed at shallow levels into fold growth as different strands, splays and back thrusts became active. The result is that much of the active offshore Oak Ridge fault is blind, despite the fault locally offsetting the unconformity created during the Last Glacial Maximum in the eastern Santa Barbara Channel. In addition, stratal thinning across faults and on to folds indicates the onset of fold growth and an alternation in fault activity between the north-verging Oak Ridge fault and the south-verging back thrust. Modeling the fold structure and stratigraphy in 3D also confirms propagation of the Mid-Channel Trend from east to west as previously proposed. South of Santa Barbara harbor, folding on the anticline began about 1 Ma, while 10 km farther west, folding began after ~500 ka.

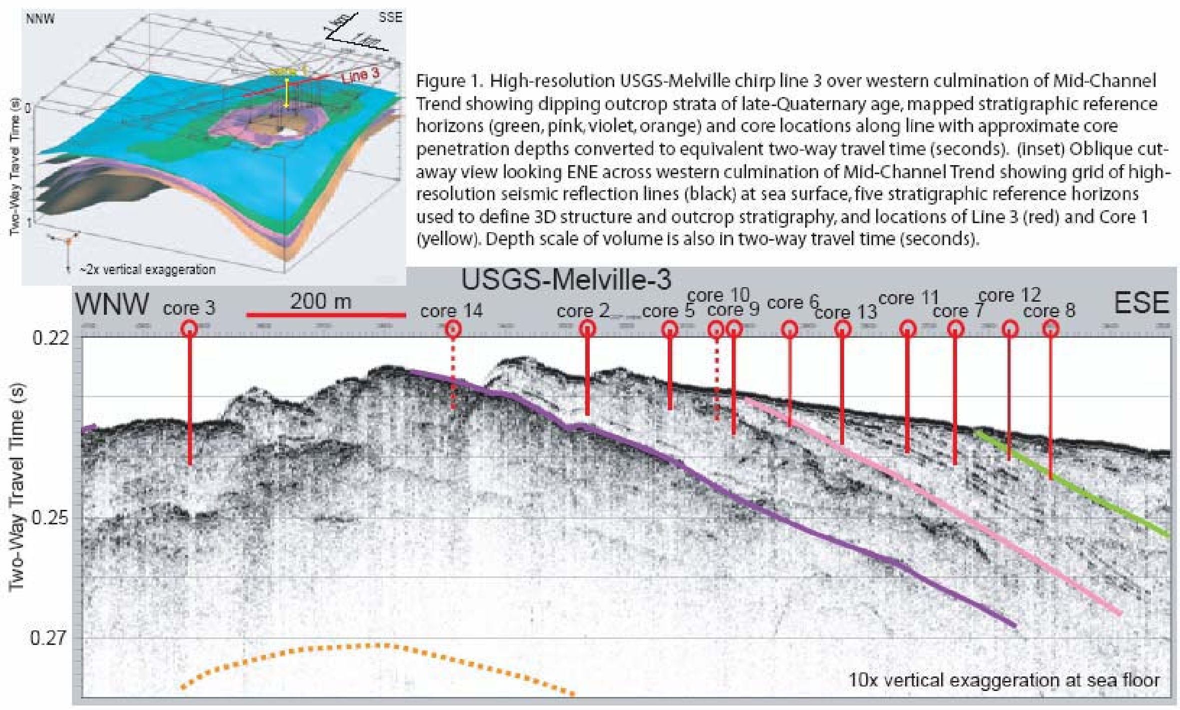

Figure 1. High-resolution USGS-Melville chirp line 3 over western culmination of Mid-Channel Trend showing dipping outcrop strata of late-Quaternary age, mapped stratigraphic reference horizons (green, pink, violet, orange) and core locations along line with approximate core penetration depths converted to equivalent two-way travel time (seconds). (inset) Oblique cut-away view looking ENE across western culmination of Mid-Channel Trend showing grid of high-resolution seismic reflection lines (black) at sea surface, five stratigraphic reference horizons used to define 3D structure and outcrop stratigraphy, and locations of Line 3 (red) and Core 1 (yellow). Depth scale of volume is also in two-way travel time (seconds).

Assessment of earthquake hazard in Marmara Region, Turkey

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After 1999 Mw7.4 Kocaeli earthquake the probabilities of having a Mw7+ earthquake in the Marmara Sea to the immediate south of Istanbul have increased due to stress transfer on the existing seismic gap. Earthquake hazard in the Marmara region has been investigated using Deterministic (scenario earthquake based) and Time-dependent probabilistic (renewal) models. A fault segmentation model was developed for main Marmara Fault, damage distribution of the historical earthquakes was carefully correlated and the inter-event time periods between characteristic earthquakes were estimated. . For the probabilistic studies characteristic earthquake based recurrence relationships are used. Assuming normal distribution of interarrival times of characteristic earthquakes, the Mean Recurrence Time, Covariance and Time Since Last Earthquake parameters are developed for each segment. The characteristic earthquake recurrence rates are determined by assigning characteristic magnitude and recurrence intervals to each fault segment in the region. For the renewal model, the conditional probability for each fault segment is calculated from the mean recurrence interval of the characteristic earthquake. The probabilities are conditional since they change as a function of the time elapsed since the last earthquake. For the background earthquake activity, a spatially smoothed seismicity is determined for each cell of a grid composed of cells of size 0.005° x 0.005°. Seismic activity in each cell is determined for earthquakes of magnitude between 5.0 and 7.0 assuming that a Gutenberg-Richter type recurrence relationship governs the earthquake recurrence in the background for magnitudes between 5.0 and 6.0. For background earthquakes with magnitude 6.0 to 7.0 finite faults are used. Earthquake hazard is quantified in terms of peak ground acceleration (PGA) and the spectral accelerations (SA) for natural periods of 0.2 and 1.0 seconds. The ground motions are determined for soft rock (NEHRP B/C boundary) conditions. Locally developed and Western US–based attenuation relationships with appropriate weights were utilized. Earthquake hazard results obtained for 10% and 2% probabilities of exceedence in 50 years for PGA and SA for the Deterministic and Renewal models are presented in terms of contour maps with comparisons and suggestions for use in performance based design of engineering structures.

Current “official” earthquake hazard zonation map, other deterministic, probabilistic and time–dependent hazard maps that resulted from several projects (e.g. GSAHP, SESAME, TEFER) are compared with appropriate suggestions for use in performance based design of engineering structures.

Current earthquake hazard models are mostly static; they do not change with time unless exchanged every few years for a new generation of maps. However, in order to respond to changing societal needs and emerging capabilities, a new physics-based and time-dependent “forecasting” approach to hazard assessment is needed. This approach will accommodate recomputation of hazard automatically when new significant data becomes available or when detectable changes in the seismicity distribution have occurred. A newly started EU-FW6 project (NERIES, http://www.orfeus-eu.org/neries/neries.htm) incorporates a sub-project that will develop, implement and test such reference time-dependent earthquake models that reflects clustering of earthquakes in space and time. In this connection a statistical timedependent earthquake hazard model that takes into account the contribution of aftershocks, potential foreshocks and earthquake swarms into hazard computations will be created. The model will provide an important resource for emergency response workers and decision 2 makers after a mainshock, a comprehensive platform to communicate time-dependent hazard to the public and a benchmark for seismologist for the development of more sophisticated models.

TeraShake: Large-scale Simulation of Ground Motion in Los Angeles for a M 7.7 Earthquake on the Southern San Andreas Fault

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We have carried out some of the laregest and most detailed earthquake simulations completed to date (TeraShake), in which we model ground motions expected from a large earthquake on the southern San Andreas fault on a parallel supercomputer at the San Diego Supercomputer Center. The TeraShake calculations simulate 4 minutes of 0-0.5 Hz ground motion in a 180.000 Km^2 area of southern California, for a M 7.7 earthquake along the 199 km section of the San Andreas fault between Cajon Creek North of Los Angeles, and Bombay Beach on the shore of the Salton Sea. The San Andreas fault South of the 1857 rupture, with average recurrence intervals of 146-220 years, has not seen a major event since 1690. The simulations include ruptures propagating both northwest-ward and southeast-ward on the fault. The TeraShake simulations use both kinematic (based on the 2002 Denali Earthquake) and dynamic (based on the 1992 Landers Earthquake) source models. We used the SCEC 3D Community Velocity Model Version 3.0 discretized into 200 m3 cubes. The result show that the chain of sedimantary basins between San Bernardino and downtown Los Angeles from an effective waveguide that channels love waves along the southern edge of the San Bernardino and San Gabriel Mountains. Earthquake scenarios in which the guided wave is efficiently exited (northward rupture) produce unusually high long-period ground motions over much of greater Los Angeles region. Intense, localized amplitude modulations arising from variations in waveguide cross-section can be explained to a remarkable level of accuracy in terms of energy conservation fort he guided mode. While the kinematic amd dynamic model are generally somewhat smaller than those for the kinematic source. The main reason fort the latter finding is primarily less coherent wave fronts generated by the more complex dynamic rupture history. Adding to the uncertainty is nonlinearity induced by the higher-than-anticipated waveguide amplifications we have identified here, likely causing significant reduction of both shear modulus and Q factor in the near-surface layers.

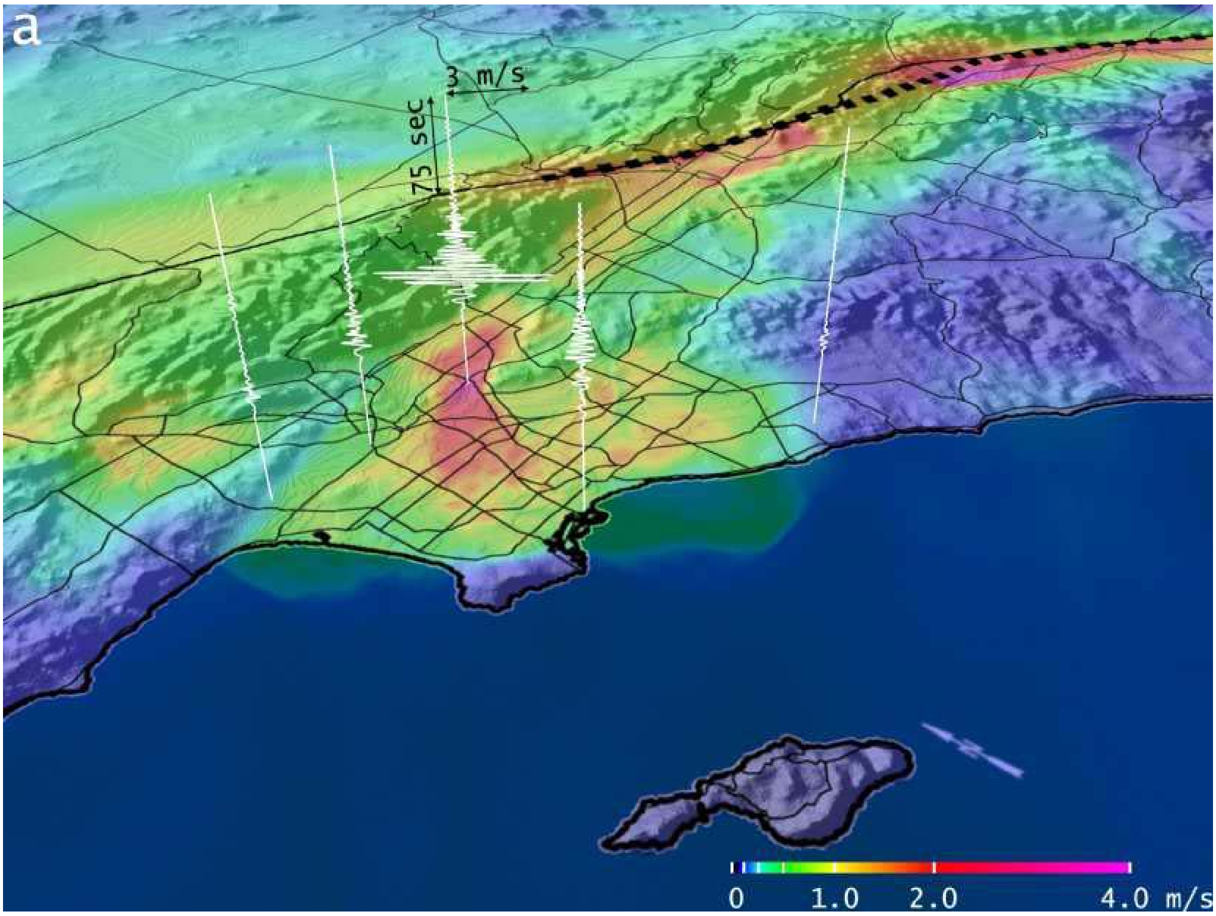

Figure 1: Maximum RMS PGV fort he Terashake SE-NW rupture. N50W seismograms are supreimposed at locations (from left to right) westwood, downtown Los Angeles, Montebello, Long Beach, and Irvine.

A Semi-Sepectral Approach for the Mathematical Modelling for the Underwater Landslide Scenarios in the Sea of Marmara

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The landslide tsumamis have been an active area of research during the last decade. Alongside the purely numerical models and the laboratory experiments, there have been efforts with analytical techniques to better understand the nature of the gravity waves created by sumbarine mass failures. In this work, we present the results obtained using a new semi-spectral technique that we developed at Istanbul Technical University. The Sea of Marmara presents an intersting setting for the landslide tsunami problem. There have been large-scale submarine mass failures in the past and given the present tectonic setting, the risk of submarine landslides on the flanks of the deep basins where the slope reaches , at places, to 29 degrees can not be ruled out. The best documented sumbarine mass failure is a slump-like event that occured around 17000 years ago on the northern slope that bounds the Cinarcik Basin. The scar area that corresponds to this event is around 32.5 km^2. We do our simulations without making a shallow-water assumption and we find that on a characteristic slope bounding the Cinarcik Basin when the width of the sliding mass reaches around 5 km, the maximum wave height reaches 0.65 times the thickness of the sliding mass.

Collaboratory for the Study of Earthquake Predictability

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Earthquake prediction is one of the most difficult problems in physical science and, owing to its societal implications, one of the most controversial. This presentation will be organized around three related questions: (1) How should scientific earthquake predictions be conducted and evaluated? (2) What is the intrinsic predictability of the earthquake rupture process? (3) Can knowledge of large-earthquake predictability be deployed as useful predictions; i.e., reliable advance warning of potentially destructive events? In response to public expectations, scientists have long sought a heroic answer to Question (3): the discovery of a precursory phenomenon or pattern that can reliably signal when a fault is approaching a large earthquake. While it is premature to say such deterministic predictions are impossible, this "silver bullet approach" has not been successful so far. An alternative is a "brick-by-brick approach" to Question (2): building an understanding of earthquake predictability through interdisciplinary, physics-based investigations of active fault systems across a wide range of spatial and temporal scales. However, the study of earthquake predictability has been impeded by the lack of an adequate experimental infrastructure—the capability to conduct scientific prediction experiments under rigorous, controlled conditions and evaluate them using accepted criteria specified in advance (Question 1). To remedy this deficiency, SCEC is working with its international partners to develop a virtual, distributed laboratory with a cyberinfrastructure adequate to support a global program of research on earthquake predictability. This Collaboratory for the Study of Earthquake Predictability (CSEP) will have rigorous procedures for registering prediction experiments, community-endorsed standards for assessing probabilistic predictions, access to authorized data sets and monitoring products, and software support to allow researchers to participate in prediction experiments and update their procedures as results become available.

Strategies for future investigations of the North Anatolian Fault

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Large numbers of studies have been conducted on the North Anatolian Fault (NAF). Most of them are conventional field studies, dealing with various geological and geophysical aspects of this fault system. Despite the tremendous amount of data collected, they are hardly integrated into the earthquake risk mitigation works. A community unified digital fault model, similar to that of SCEC, is needed. Such model will facilitate objective and quantitative earth science studies on the NAF. It will also help the compilation of high quality data that may lead to the establishment of an open digital database. Furthermore, the digital representation of the NAF may help the production of realistic scenarios for earthquakes and modelling 3D ground motion to evaluate hazard or risk at various locations. For a comprehensive study of the submarine portion of the NAF, a high-tech seafloor observatory must also be deployed beneath the Sea of Marmara.

In order to understand the physics and the earthquake behaviour of the NAF, the projects mentioned above must be realized. However, without strong international collaboration, this may not be possible, because they are long-term and costly projects. The best strategy for their realization is to make the SCEC-Turkey working effectively. This institution may organize all the international affords and manage the Turkish community fault and the Marmara seafloor observatory programs. It may also form a repository for all kind of data on the NAF. SCEC-Turkey may consist of the Istanbul Technical University (ITU), Kandilli Observatory and Earthquake Research Institute (KOERI), Istanbul University (IU), TUBITAK Marmara Research Centre (MAM), Middle Eastern Technical University (METU), and General Directorate of Mineral Research and Exploration (MTA). SCEC-Turkey may be jointly funded by these institutions, as well as may get financial support from other sources. It is hoped that this workshop will foster its establishment.

The EarthScope Plate Boundary Observatory

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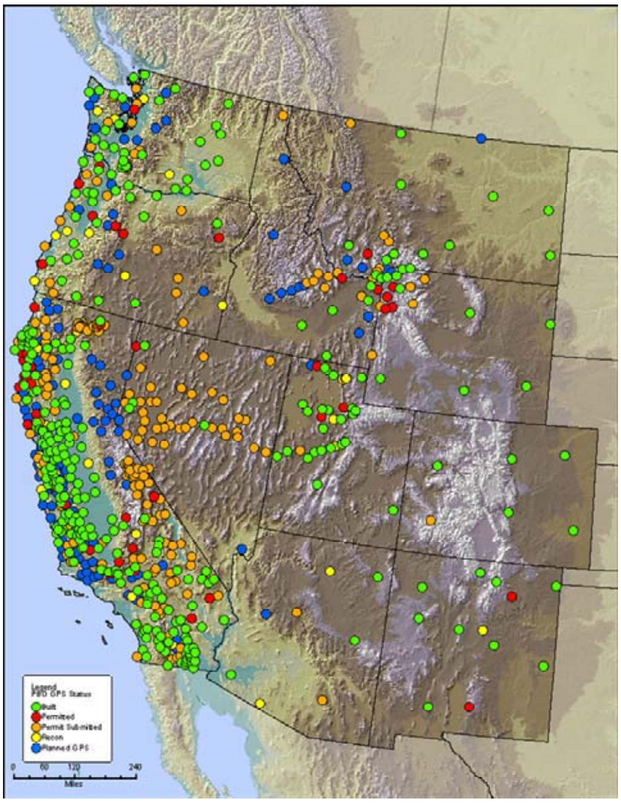
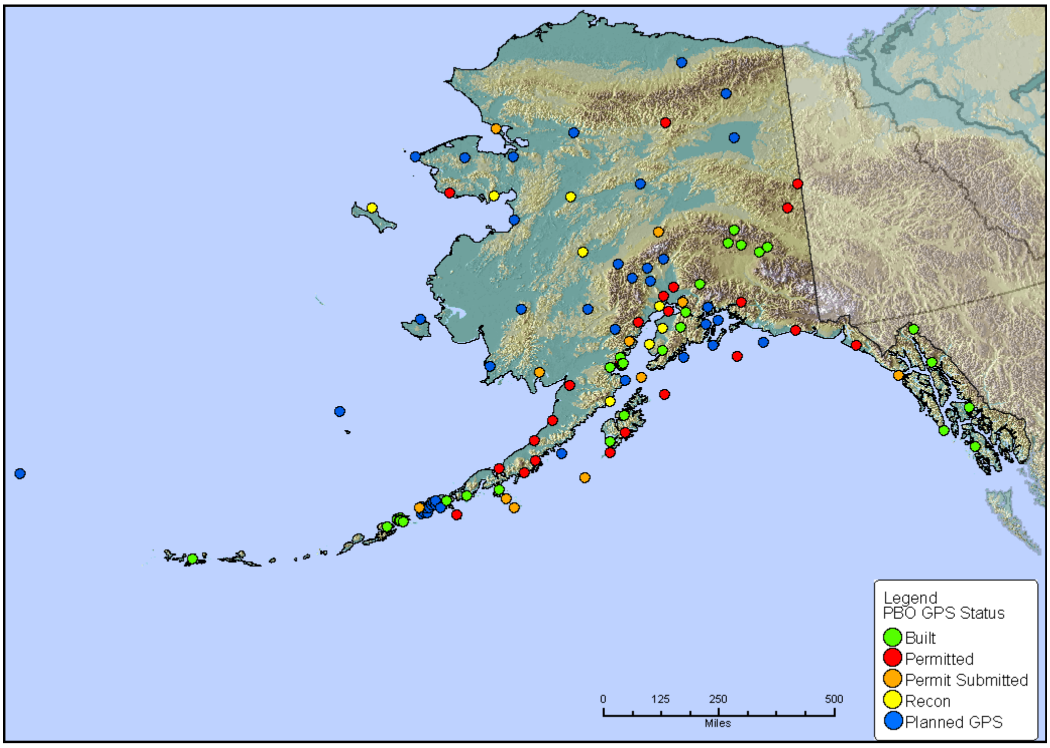
UNAVCO, 6350 Nautilus Dr., Boulder CO

EarthScope is a bold undertaking to apply modern observational, analytical and telecommunications technologies to investigate the structure and evolution of the North American continent and the physical processes controlling earthquakes and volcanic eruptions. EarthScope is funded through the National Science Foundation and consists of three main elements: USArray, a modern digital seismic array to produce three-dimensional images of the continental crust,; The Plate Boundary Observatory (PBO), a geographically dispersed geodetic array consisting of 852 GPS stations, 103 borehole strainmeters and 5 laser strainmeters to measure the active deformation in the entire western US; and the San Andreas Observatory at Depth, a deep borehole observatory which will provide measurements of the physical state and mechanical behavior of the San Andreas Fault at Parkfield. One of the major scientific rationales of Earthscope in pushing the frontiers of modern deformation analysis is the combination of all of these geophysical measurements across the entire observational spectrum and the combination of Earthscope data with observations from other disciplines of Earth Science. This will provide for enhanced analysis and improved understanding of the structures and processes that affect our environment.

The Plate Boundary Observatory is being constructed by UNAVCO, a community based facility dedicated to advancing high-precision techniques for the measurement of crustal deformation. PBO is ahead of schedule and on budget as it enters the third year of the five-year construction phase. By August of 2006 we anticipate the completion of over 400 GPS stations, 23 borehole strainmeter/borehole seismometer installations, and one laser strainmeter. PBO produced over 170 GB of raw GPS and strain data in over 300,000 data files, and over 60 GB of seismic data, all of which are freely available to research community from the UNAVCO website. PBO produces many levels of GPS data products including GPS station position estimates from two separate processing facilities and combined GPS station position estimates, position time, periodic estimates of long-term GPS station velocity, velocity fields, time series noise properties, and periodic time series components. Borehole and laser strainmeter data products include station strain scaled to natural strain units, conversion to areal, shear, and linear strain, fully corrected and scaled tensor and linear strain time series. UNAVCO is committed to making freely available all data products from PBO instruments, any software developed as part of EarthScope, and the transfer of technology, successes, and failures in building a state-of-the-art, geographically distributed observational network.





ESONET: The European Seafloor Observatory Network

Roland PERSON
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The aim of the ESONET Network of Excellence is to create an organisation capable of implementing, operating and maintaining a network of multidisciplinary ocean observatories in deep waters around Europe from the Arctic Ocean to the Black Sea. The NoE will structure the resources of the participating institutes to create the necessary critical mass, remove barriers and through a joint programme of activities arrive at durable solutions for this future organisation.

Long-term observatories are crucial for European scientist to maintain world leadership that was developed through past and present framework programs. Only long-term observatories allow continuous observation of large numbers of parameters collected through power intensive sensors. This capability is crucial for observing natural processes that are either very episodic or statistically require long time series to detect because they are hidden by noise of higher frequency. The ESONET predecessors have identified such processes in all fields of marine sciences. The most important ones are: (1) the episodic release of methane from the seabed affecting climate change, (2) the relationship between earthquakes and submarine slope failures, and (3) the short term biogeochemical processes affecting the marine ecosystem. These processes are of fundamental importance for European society, because we need to devise sensible climate change policies, protect our coastal population and infrastructure, and manage our marine resources. The establishment of long-term marine observatories can be justified because they are the only means of acquiring continuously large amounts of different data, and be able to respond to them through interpretation task forces. The ESONET project has identified several of crucial scientific objectives. Until funding for installing the observatories becomes available it is tantamount to continuously update these objectives as new scientific results become available, to sharpen the objectives, and to adapt the technological requirements to the refined scientific objectives.

The ESONET observatories will provide information on global change, warnings of natural hazards and a basis for sustainable management of the European Seas. They will be a sub-sea segment of the GMES initiative and linked to the EU INSPIRE initiative.

A network of observatories around Europe will lead to unprecedented scientific advances in knowledge of submarine geology, the ecosystem of the seas and the environment around Europe. Very rapid advances in technical knowledge are anticipated. This will place European SMEs in an excellent competitive position for installation of such systems around the world. Our efforts will be part of a system extending around the world in co-operation with Japan, USA and Canada.

The NoE will work towards establishing sea floor and water column infrastructure which will provide power for instruments and real-time two-way data communications. Key areas around Europe have been identified from which specific targets are selected for relevant science programmes of potential hazards, geo hot spots and ecosystem processes. Sea floor infrastructure will provide platforms for instrumentation deployed throughout the water column and the geosphere below.

These ambitions are to be realized with new, advanced organisational structures linking scientific institutes, industries, governments and agencies throughout Europe and by initiating integration processes. The NoE will construct that framework.

The integration process of ESONET NoE, a permanent effort during the project, will be based on:

- building up active groups sharing their knowledge, methods and resources.
- acting as one body towards funding institutions (including EC), stakeholders, potential users and similar international projects,
- jointly acting for a strong cooperation with other networking efforts in ocean sciences, ocean technology, ocean data management (GEOSS, MERSEA, GMES, EUROCEANS), and infrastructure (SEADATANET).
- Establishing functional relationships with the above (knowledge or data provider, cooperation, complementary scientific goals, complementary sea or subsea intervention means,…),
- Advancing the infrastructure policy of subsea observatories in Europe.
- On line monitoring to make the investment safer including quality control. This should not be underestimated (see COSTA project)

- Combination of oceanographic, geological, and biological themes at one station to enhance cost effectiveness compared to short term deployments

Networking quality and standardization will be driving the integration. From the beginning of the project, the aim of lasting integration on a set of ESONET CORE SERVICES and ESONET REGIONAL NETWORKS linked for their implementation scheme as well as for a scientific and technical improvement process.

Cold seeps along the Main Marmara Fault: context and perspectives for monitoring.

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Seafloor manifestations of fluid expulsion are common on sedimented margins worldwide and are designated as cold seeps. Observations at cold seeps sites typically include dark patches of reduced sediment, mats of sulfide oxidizing bacteria, chemosynthetic benthic communities and authigenic carbonates. These manifestations result from combined methane oxidation and sulfide reduction at a shallow depth (0-50 cm) in the sediment. Cold seeps are primarily the consequence of a locally increased methane flux, which may either be dissolved in the pore fluid or migrate as a separate phase.

In the Sea of Marmara, cold seeps were observed with towed cameras (Halbach et al., 2004) and ROV (Armijo et al., 2005) along the seafloor trace of active faults. We compiled video observations from MARMARASCARPS cruise and show that many fault segments have no or very limited cold seep activity. Most cold seep observations were done at few sites, suggesting very focused flow in the fault zone. Among the main active sites, a distinction is made between gas seeps and water seeps. At gas seeps, bubble emissions at the seafloor or disturbed echofacies on echosounder profiles (3.5 kHz band) demonstrate the presence of free methane gas at a shallow depth within the sediment. On the other hand, authigenic carbonate chimneys characterize the water seeps and visible water outflow was observed at two sites (in the Tekirdag and Central basins). This observation is rare at deep-water cold seep sites and may relate with the paleoceanography of the Sea of Marmara. The transition from lacustrine (or brackish) to marine conditions near the end of the last glaciation causes a salinity gradient in the sediment (between 5 and 40 m deep), which may trigger buoyancy driven convection if high permeability conduits are present. The chimney site in the Tekirdag basin is located at the outlet of a canyon feeding a buried fan with coarse sandy turbidites in the lacustrine sequence. Pore fluid composition profiles indicate that the sand layers channel brackish pore fluid laterally from the basin into the fault zone at less than 20 m deep. This suggests water seeps correspond to local flow cells. While a contribution from a deeper fluid source cannot be excluded, and still needs to be examined for gas seeps, the distribution of venting activity appears controlled by shallow, rather than deep, structures.

One motivation for monitoring cold seeps in the Marmara Sea is a possible relationship between seepage activity and processes occurring in the seismogenic zone. Because of the complexity of near seafloor processes, there may not be a simple relationship between fluid pressure in the seismogenic zone and cold seep flow rates. However, experiments performed above subduction zones (Brown et al., 2005; Davis et al., 2006) indicate that shallow flow cells are affected by silent slip events originating at depth. The mechanism proposed is the propagation of a silent slip wave from the seismogenic zone to the seafloor where it affects local stress and permeability conditions. We propose to perform an experiment in the Marmara Sea, combining shallow pore fluid and flow rate measurements with seismological monitoring.

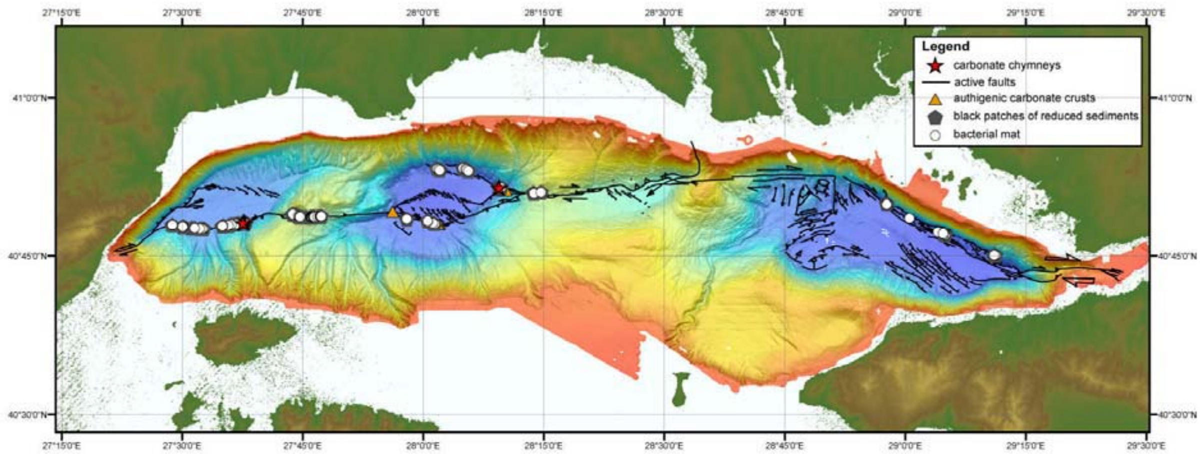

Figure1: Observations of cold seeps in the Sea of Marmara from Ifremer ROV cruise Marmarascarps. Active sites are systematically found in association with active fault scarps but their distribution along the faults is very heterogeneous. Note, however, that several segments of the Main Marmara fault have not been systematically explored.

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Crustal Structure in the Marmara Region and the Seismicity along the North Anatolia Fault Zone

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We present the results of the recent seismic/seismological investigations in the Marmara Region. Both active and passive sources are used to determine the crustal structure in the region using travel time tomography. We present 2-D images along profiles crossing the basins in the Sea of Marmara. The velocity structure is constrained for the upper crust only (<10 km) and indicates strong lateral heterogeneties. We also present the ongoing seismological projects in the Marmara Sea.

The improvements on the seismological network in Turkey following August 17, 1999 earthquake has provided more accurate seismicity catalogs along the North Anatolia Fault Zone. We present the current state of the seismological network with time and spatial distribution of the seismicity along (NAF) following August 17 1999 earthquake.

Community-driven 3D models of faults, strata, and seismic velocity for southern California and northwest Turkey

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Faults used in earthquake hazard models are commonly shown as traces in map view, with ramps of blind faults projected as polygons. This representation can be misleading for non-vertical faults, where much of the potential earthquake rupture area is located several or even many kilometers horizontally as well as vertically away from the surface trace. The Southern California Earthquake Center (SCEC) Community Fault Model (CFM) is composed of digital 3D representations of over 140 faults, which are publicly available (http://structure.harvard.edu/cfm/). Deciding which 3D geometry of intersecting faults to include in preferred models is an exercise in consensus building. These faults are defined from a variety of data, including outcrop, seismic reflection data, seismicity, wells, cross sections, and models. In southern California, many faults are blind or partially blind, with all or part of the dip-slip component absorbed by folding. Strike-slip motion can also be absorbed or transferred by folding. Therefore, it is important to include digital representations of deformed strata in the same models with the faults. Indeed, dated stratigraphy is required if one is to understand the evolution of a fault system through time.

Faults interpreted from seismic reflection data can be included in a model in two-way travel time (TWTT) and linked to a velocity model. Precise earthquake locations are dependent on accurate P-wave velocity models. Perhaps the most societally-relevant reasons to construct community fault and velocity models is to produce 3D ground motion models. Fault representations and kinematics from focal mechanisms, GPS data, and structural modeling allow realistic scenario earthquakes to be modeled. The fault and basin geometries can result in surprising amplifications of ground motion and their durations. Fault geometry and kinematics are also needed to realistically model stress transfer.

Once 3D representations are in place, structural modeling can be done to determine fault slip through time. For example, a left-lateral fault that extends offshore from Los Angeles, the Santa Monica-Dume fault, accumulates structural relief through a restraining double bend (Fig. 1). Modeling shows that left-lateral slip on this fault is associated with clockwise vertical axis rotation of the hanging-wall of this moderately-dipping fault.

Published modeling of GPS data show continuing clockwise rotation of the hanging-wall, suggesting that post-Miocene slip rates are similar to present rates.

The North Anatolia fault in Marmara Sea is characterized by various branches and bends. Abundant seafloor and subsurface imaging has been done since the devastating 1999 earthquakes. Much work is being done with the deep crustal and higher resolution seismic reflection and refraction data, as well as seismicity. These abundant data offer an opportunity to develop structural and stratigraphic models that represent 3D geometry provided that a framework for consensus building and constructing the models becomes available. Construction of SCEC-like representations requires cooperation of many people and institutions.

Finally, much of earthquake science is funded by the public, and it ultimately seeks to protect the public. Public outreach has been one of the major goals and successes of SCEC. Animations of southern California faults and seismicity have been completed that have proven to be an effective educational and communication tool used in the class room and for television coverage (http://structure.harvard.edu/cfm/modelaccess.html. -- "flythrough"). Similar animations can be done from existing data for northwest Turkey. There is an opportunity here to combine creativity and science to educate the public to the structure and behavior of the earth beneath them.

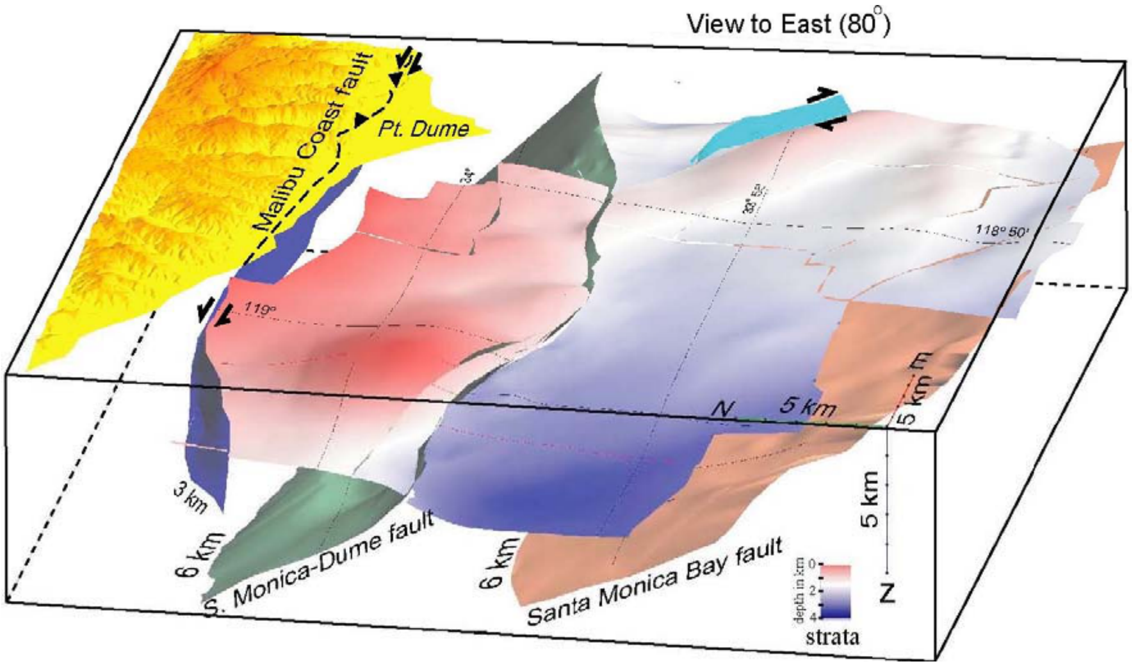

Figure 1: Oblique view eastward (toward 80º azimuth), from 20º above horizontal, of a ~4 Ma horizon, faults (labeled), and the 30 m DEM. Figure modified from Sorlien, Kamerling, Seeber, and Broderick., accepted by Journal of Geophysical Research. Folding is due to oblique-reverse left-lateral displacement in the foreground linked to left-lateral displacement in the background. The farther rocks in the hanging-wall (north) are transported through the restraining segment, the greater the structural relief.

Fault characteristics, segmentation and paleoseismology along the 9 August 1912 Ganos earthquake-rupture (North Anatolian Fault, Turkey)

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The Ganos fault is the most western segment of the North Anatolian fault that experienced the Ms = 7.4 / 7.3 earthquake of 9 August 1912. The earthquake revealed 45-km-long surface ruptures inland, trending N70°E, and 5.5 m of maximum right lateral offset near Gaziköy. The earthquake size requires about 100 / 80 -km-long faulting but the offshore extension of the fault is problematic. We measured co-seismic displacements of roads, paths, streams, man-made buildings and field limits using Differential GPS surveys and total station at 39 sites. Dextral displacements range from 2.5 to 5.5 m from Gaziköy to Yeniköy. In addition, we used 1/10 000 and 1/ 35 000 scaled aerial photographs, Landsat TM images, SPOT 5 images and digital elevation models (SRTM) to analyze the geomorphology of the region. Offset distribution, fault geometry and geomorphology have been used to identify 3 sub-segments with variable orientations (N72°E to N66°E).The Gölcük and Kavak basins are major step-overs along the fault and limit the sub-segments. The long term deformation of the fault is clearly expressed by several pull-aparts and sag ponds, pressure and shutter ridges and offset streams. Selected sites are studied with microtopographic surveys and paleoseismic trenches to characterize 3 faulting events since the 11th century and 8.3 ± 0.5 m and 19.4 ± 1 m cumulative and successive lateral offsets on present-day streams at Güzelköy. Parallel trenches expose paleo-channels and show a cumulative right-lateral offset of 11 ± 1 m, and a total stream deflection of 21 ± 1.5. Radiocarbon dating of older channel units imply a minimum 17.5 - 20 mm/year slip rate along this section of the North Anatolian Fault.

GPS Measurements on the western Marmara segment of North Anatolian Fault

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The one of the most important faults of world is the North Anatolian Fault (NAF) which range from Bingöl in the east to The Aegean Sea in the west. There have been a lot of destructive earthquakes occurred in the last century along the NAF (9 August, 1912 Saros-Marmara: Ms=7.4, 4 January, 1935 Marmara: Ms=6.4, 18 March, 1953 Yenice-Gönen: Ms=7.2, 18 June 1953 Edirne: Ms=5.2, 18 September, 1963 Yalova-Çınarcık: Ms=6.4, 6 October 1964 Manyas: Ms=6.9, 23 August 1965 Saros: Ms=5.9, 22 July 1967 Mudurnu-Adapazarı: Ms=7.1, 27 March 1975 Saros: Ms=6.6). Therefore, several seismic, geological, geophysical and geodetic researches have been done by international and national earth scientists during the last six years.

The project "The Determination of Deformations Along The Western Marmara of North Anatolian Fault and Characterization of Earthquake Hazard", founded by The Scientific and Technical Research Council of Turkey (TUBITAK) and Istanbul Technical University (ITU) Research Fund covers western part of the NAF from Balıkesir (in eastern Marmara) to Gökçeada (in western Marmara). The aim of the project is to obtain the information of the strain accumulation along fault zone and to determine the earthquake potential. Having information about the strain accumulation along the fault zone may allow to evaluate future probabilities of regional earthquake hazards and to develop earthquake scenarios for specific faults.

Three years of measurements from 2003 to 2005 have been carried out with 15 sites in 3 days period. The data processed by using GAMIT/GLOBK software. Daily solutions, combination of daily solutions, repeatabilities and annual combinations have been obtained and will be presented in this study with geological interpretations of study area obtained from GPS velocity vectors and local field studies.

Slip Partitioning and Regional Stress Fields from Geometrically Irregular Faults

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Oblique motion along bends in strike-slip faults typically results in a complex partitioning of slip onto a variety of faults with different senses of motion. Partitioning can be explained by the upward elastoplastic propagation of oblique slip from a fault or shear zone at depth. The strain field ahead of the propagating fault separates into zones of predominantly normal, reverse, and strike-slip faulting. We use an elastic approximation to plastic behavior to explain the distribution of faults observed along the San Andreas fault in California. This process has important implications for regional stress fields in areas where the strain is partitioned onto structures with different senses of motion. In particular, the notion of a partitioned stress field driven by slip at depth can be used to generate a realistic background stress field for models of Coulomb stress interactions.

Slip partitioning has also been observed in individual earthquake ruptures, most notably in the 2001 M=7.8 Kokoxili, China earthquake. The surface faulting in this event has been modeled using the static stress field from motion on a buried oblique slip fault. The static model successfully predicts the observed orientation of partitioned coseismic dip-slip and strike-slip faulting. The model also predicts the observed regions of surface fracturing where there are no coherent, colinear structures.

To further test the development of coseismic slip partitioning we use a dynamic 3-D finite element analysis to investigate rupture propagation on a branched fault system. The fault geometry is that of an oblique fault at depth that branches into vertical and dipping segments near the surface. We find that oblique slip on the basal fault results in partitioned slip on the near-surface faults, with more strike-slip motion at the surface trace of the vertical fault, and more dip-slip motion at the surface trace of the dipping fault. This result is in qualitative agreement with the static models. When slip on the basal fault includes a normal component, the preferred rupture propagation is upward to the vertical surface fault. Conversely, a thrust component of slip on the base fault results in preferred propagation upward to the dipping surface fault. Stress interactions within geometrically complex fault systems can lead to complexity in rupture propagation, including a crucial dependence on the direction of slip.

Creeping along the North Anatolian Fault at Ismetpasa (Western Turkey): Rate and extent from InSAR

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We study the surface creep along the North Anatolian Fault (NAF) at Ismetpasa (NW Turkey) using Synthetic Aperture Radar Interferometry (InSAR) and elastic dislocation models. Interferograms with temporal baselines ranging between 1.25 and 5 years show that creeping section starts at the western termination of the 1943 (M=7.6) earthquake rupture. It continues about 70-km to the west, overlapping with the eastern part of the 1944 (M=7.3) earthquake rupture. Line of sight measurements along the fault indicate a maximum creep rate of 11±3 mm/year near the mid point of the creeping section decreasing gradually towards the edges. Near Ismetpasa, InSAR data yield 7.7±3 mm/year of creep rate, consistent with the recent instrumental (triangulation and creepmeter) measurements. Modeling of the InSAR and GPS data suggests that the fault-creep occurs most probably at a shallow depth (0-7 km). Our analysis combined with the previous studies suggests that creeping might have commenced following a large earthquake, and thus may be a long-lasting transient deformation.

Subsurface Structure of the San Andreas Fault: Probable Analog to the North Anatolian Fault

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The San Andreas fault (SAF) is a right-lateral, strike-slip fault that extends approximately 1200 km from southernmost California to the Mendicino triple junction. Like the rightlateral, ~1200-km-long North Anatolian fault (NAF), the SAF is capable of generating large-magnitude earthquakes along most of its length. To better understand the subsurface geometry and the velocity structure of the SAF, we acquired a series of P wave seismic reflection and refraction profiles at multiple locations across the nearsurface traces of the SAF. The reflection images show that the SAF is characterized by multiple fault strands near the surface, with many of the faults merging into a more narrow fault zone at a depth of several kilometers. In general, the SAF is characterized by steeply dipping P-wave low-velocity zones (approximately 10 to 40%) in the upper few kilometers. The low-velocity zones occur at multiple scales, ranging in width from a few meters to more than a kilometer. At the San Andreas Fault Observatory at Depth (SAFOD) in central California, the upper few kilometers of the SAF is characterized by an approximately 1.5-km-wide, southwest-dipping low-velocity zone (about 35%) at the surface that tapers to a 0.5-km-wide zone at depth of about 1 km. Seismic reflection images and surface geologic mapping show that the low-velocity zones are composed of a complex array of faults within a wedge of tectonically transported sedimentary rocks. At the epicenter of the 1989 M 6.9 Loma Prieta epicenter, our data show that the SAF is characterized by a 3-km-wide, northeast-dipping low-velocity zone (10 to 25%) in the upper 4 km. Near San Francisco, the surface trace of the SAF that ruptured during the 1906 M 7.9 San Francisco earthquake is characterized by a 75-m-wide, northeast-dipping low-velocity zone (about 40%) in the upper 50 m. All these low-velocity zones represent decreases in P-wave velocities across the SAF at scales varying from meters to kilometers. Explosive-generated seismic waves recorded along the fault zone show that high-amplitude trapped or guided waves travel within the low-velocity zones. During large-magnitude earthquakes, the SAF low-velocity zones may act as guides for highamplitude seismic energy. These observations suggest that the SAF may generate particularly strong shaking within 1 to 3 km of its surface trace. Because the SAF and NAF have similar characteristics including length, slip rate, and 3-D geometries, comparison would be useful. We recommend high-resolution, active-source seismic profiling both across and along the NAF in order to make this comparison.

Comparison of Strong-Motion Networks along North-Anatolian (NAF-Turkey) and San Andreas (SAF-California) Faults – Need to Enhance

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On-scale recordings of ground shaking during earthquakes are important for understanding the physics of fault rupture and causes of earthquake damage, and for improving design codes. Two major right-lateral strike-slip fault systems, the North Anatolian Fault (NAF) in Turkey and the San Andreas Fault (SAF) in California, each approximately 1500 km long, have generated earthquakes that caused loss of life and property. The two most recent NAF earthquakes [August 17, 1999 Izmit (M_w=7.4) and November 12, 1999 Duzce (M_w=7.1)] resulted in more than 17,000 fatalities and damaged more than 250,000 residential and business units (U.S. Geological Survey Circular 1193). Strong-motion data recorded during and after this earthquake provided additional insight into long-duration pulses with significant engineering implications (Çelebi, 2001, Çelebi and others, 2001). One of the significant California earthquakes on the SAF [1989 Loma Prieta (M_w=6.9)] caused extensive loss of property (~$10B) and 62 fatalities (Page and others, 1999).

Table 1 provides a numerical comparison of the operating strong motion instruments in Turkey and California. Figure 1 shows equiscaled maps depicting the distribution of strong-motion stations in Turkey and California. The strong-motion network along the NAF when compared to the network along SAF is very sparse – particularly when compared with the networks in Japan where the distance between stations is generally about 20-25 km (about 2 km in some urban areas [Kashima, 2000]). With the recent addition of ANSS (USGS Circular 1188) strong-motion stations, California is far ahead in numbers (Table 1) compared to Turkey, particularly when comparison is made along SAF and NAF. Still, the density desired by seismologists and engineers have not yet been accomplished in either California or Turkey.

Future disastrous events are forecast on both faults. Significant enhancements in strong-motion networks to record these events are needed to improve response capabilities and build more earthquake resistant societies in the future. There are many gaps in the strong-motion network along the NAF to be filled. Recent addition of BYT Network (between Bursa and Yalova) is a good example of regional denser arrays (Gulkan and others, 2004) that can be added to the network in Turkey to fill gaps, particularly in urban areas. An example of a guideline for urban areas is that a network should produce necessary data to facilitate construction of shake-maps

(http://earthquake.usgs.gov/eqcenter/shakemap/).

Table 1. Comparison of Strong-Motion Networks in Turkey and California (Note 1: N100 means number of stations within 100 km offset on both sides of surface fault – SAF in California and NAF in Turkey, Note 2: IRREW – KOERI-Istanbul Rapid Response and Early Warning Network)

Ground Stations		Structures (total)		Sources/Comments
Total			N100	
California (424,001 sq. km.)	~1600	~1200	708	http://www.cisn.org (includes CGS and USGS, CalTech)
Turkey (814,578 sq. km) 779,452 sq. km. land only	~158	~40 (~100 if IRREW included)	<20	http://angora.deprem.gov.tr/ http://www.koeri.boun.edu.tr/

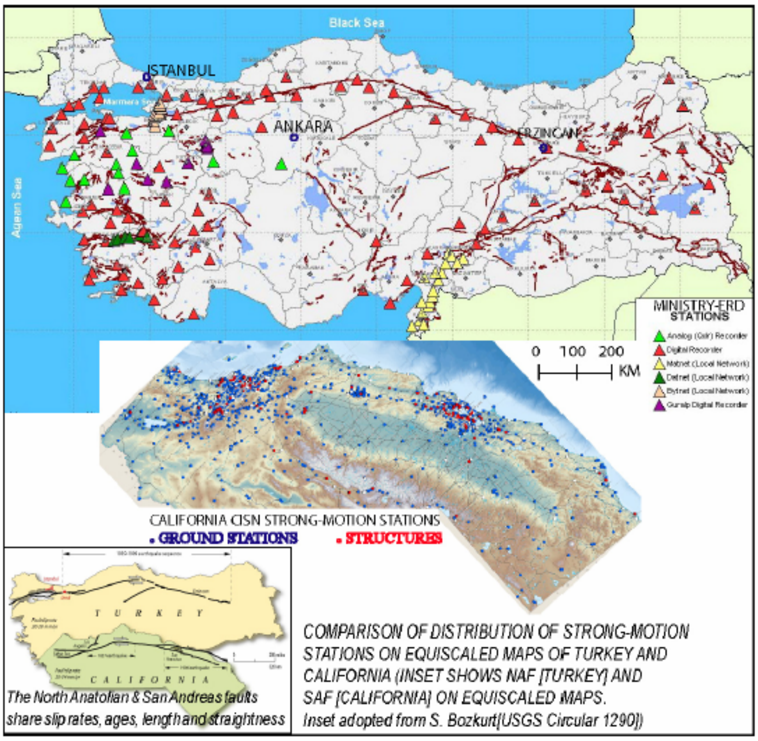

Figure 1. Equiscaled maps of Turkey and California. Maps depict general distribution of Strong-Motion Stations (Sources: Turkey Map- Mr. Akif Alkan, Earthquake Research Department, Ministry of Public Works, Ankara, Turkey, California Map: www.cisn.org , inset- courtesy S. Bozkurt, 2006)

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USGS Circulars 1290 and 1188

Constructing a 3D block diagram of the tectonic features in the Central Basin, the Marmara Sea, by means of bathymetric and seismic reflection data

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In this study, we made a comparative interpretation of the multi-beam bathymetric and seismic reflection data collected in the last decade along the North Anatolian Fault (NAF) zone in the Central Basin, the Marmara Sea. The main objectives are (i) to investigate and compare the active deformation observed on the sea bottom and within the uppermost sedimentary layers to that of the mid to deep seated ones within the limits of resolution and penetration of the available data and (ii) to build a three dimensional (3D) block diagram of the active faults of the Central Basin by means of sliced mapping technique. In this technique, we produce slice maps of the active faults at feature sampling depths and then combine them to form a 3D block diagram.. The motivation for such an approach is to construct a 3D structural diagram where there is no available 3D seismic data. We think that a 3D block diagram may provide better insight to evaluate the structural features and seismic risk assessment.

To form the 3D block diagram, we produced slice maps of the structures at feature sampling depths from the bathymetric image map and seismic sections and then combined them. We selected three levels of the feature sampling depths as follows: sea bottom is the first level sampling the scarps of the active faults; then, the second and third levels are at 2.0 and 3.0 s two-way-travel time depths in the seismic data, respectively. This approximation allowed us to check the continuation of the fault scarps observed at the sea bottom to deeper part of the sedimentary layers by which we have had a chance to see if some of these scarps were only surface features or if they were connected to the faults at greater depths in the basin.

We preferred to include only those features which we are sure about their continuation in the seismic sections. The surface response of the active tectonism is well marked on the bathymetry and they are correlated with the near surface response obtained from the pasisar seismic data. *R/V Le Suroît* data provided the *en échelon* pattern and *horse tail* splay of the active faults on the bathymetry as well as in shallow depths. *R/V MTA Sismik-1* data provided a good control on if the surface features were indeed faults or they were only surface features with no extension to the deeper parts. Extending the faults to the greater depths were accomplished by use of *R/V Le Nadir* data.

Paleoseismological investigations on 1999 İzmit earthquake surface rupture

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17 August 1999 Izmit earthquake ruptured 5 segments on the eastern Marmara region. Sapanca-Akyazı segment is one of the ruptured segments, trending between Sapanca Lake and Akyazı town. Two trench sites on the eastern and western banks of Sakarya River were chosen for 2D and 3D trenching. Both trench sites have good and identifiable stratigraphic units covering river, flood plain and pond deposits. Eastern trench evidenced penultimate and pre-penultimate events while western trenches marked 3 past earthquakes before 1999 event. Western bank of Sakarya river covers different terrace levels and edges. This site is 2 km far from maximum offset site of 5.2 m. On the trench site, 3.8 m and 3.6 m offsets were measured on an asphalt road and a wooden garden fence after 1999 İzmit earthquake respectively. 5 trenches were opened in the western site, three perpendicular and two parallel to the surface rupture. Three previous earthquakes before 1999 event were identified in perpendicular trenches. Western Sakarya river bank has also good evidence for 3D trenching. A terrace edge line is cut by 1999 earthquake surface rupture. This scarp is visible on the southern block of the recent rupture but it was buried on the northern block because of vertical movement on it. Buried terrace scarp is firstly investigated by Ground Penetrating Radar. It was also determined with an excavation, parallel to the surface rupture on the northern part and nearly perpendicular to the terrace scarp. The cumulative lateral displacement was measured by teodolite as 18.5 ± 0.5 m. Comparing dates of previous earthquakes and terrace age with cumulative offset will give slip history of probable past 5 events considering that there was 3.6-3.8 m lateral offset in 1999 earthquake. Dating process of collected charcoal samples are underway.

Earthquake ground motion simulation for İstanbul

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After the 1999 Kocaeli and Düzce earthquakes a significant amount of research and application oriented activities focusing on the characteristics of expected ground motion in the Marmara Sea region in general and in Istanbul in particular have taken place. In this talk we will try to present a summary of these efforts.

Essentially the results of any strong motion simulation technique are very sensitive to the input parameters used. A realistic simulation should not only provide peak values in accordance with empirical ground motion prediction relationships, but also produce good waveforms with satisfactory resolution in time and frequency domain, so that they can be employed in time-domain structural analysis. In that sense, from the engineering point of view, the simulation has a very clear target and it is not done for the sake of simulating ground motions. The simulation of strong ground motion in Istanbul is emerging as a new focal point of interest. Two studies have been carried out to this date within the EU-FP5 project RELIEF (Atakan et al, 2004) and EU FP6 project Less-Loss (Cultrera et al, 2006). Both of them involved hybrid simulation techniques using a 1-D velocity model and tried to come up with distribution of peak ground accelerations and velocities in and around Istanbul. Benchmark studies carried out to compare the and to investigate the effectiveness of several methodologies employed in simulation (Durukal et al, 2006) and well as studies on the efficiency of the methodology employed (Sanli et al, 2005) before setting out for a large-scale region-specific simulation are important. The development and verification of a regional 3-D velocity model is important. There exist a preliminary velocity model of the Marmara basin (Durukal et al 2003), currently used in on-going simulation studies by several groups (Durukal et al, 2006, Richwalski et al, 2006, Wenzel et al. 2006))

The urban strong motion network in Istanbul consists of 100 stations and serves to near-real time generation of post-earthquake damage distribution maps in Istanbul to assist local administrative bodies in emergency planning. In addition there are 10 stations dedicated to earthquake early warning. Using several small magnitude events recorded by the larger number of stations by the so-called IEEWRR interesting results have been obtained regarding the effect of local site conditions on the distribution of ground motion in Istanbul (Birgoren et al, 2004, 2006) and about spatial variation of strong ground motion within the city (Harmandar et al, 2006) . Grid-based high-frequency simulation of strong ground motion due to the rupture of fault segments in the Marmara Sea have been carried out using FINSIM, for employing in the development of an early warning algorithm (Böse, 2005). The data obtained from small magnitude earthquakes will be archived to serve as empirical Green's functions for site-specific simulations.

Today there are several large-scale engineering projects in Istanbul either in design or construction stage. Performance-based design criteria of these projects necessitate simulation of site-specific strong ground motion. The most important among such projects and efforts can be cited as Marmaray submerged tube tunnel, seismic retrofit of two suspension bridges over Bosphorus, base isolated Tarabya Hotel, Halic metro bridge and AnadoluRay lightrail transportation system. A state-of-the art hybrid simulation approach has been employed in characterisation and simulation of expected, site-specific strong ground motion at these project sites due to a series rupture scenarios along several segments of the North Anatolian Fault in the Marmara Sea (Erdik et al, 2003, 2004, 2005, 2006).

Several EU-FP6 projects, which are concerned with several aspects of strong ground motion, are either in execution or about to start. In project NERIES simulation methodologies for higher level shake-map generation will be developed and tested for the case of Istanbul. In SAFER ground motion will be simulated for on-line post earthquake shake-map generation for Istanbul and also for Naples and Thessaloniki. In TRANSFER generation and propagation of tectonic-origin tsunamis, as well as tsunamis due to submarine landslides will be investigated for the Marmara Sea region selected as one of the test-beds. Project 'MegaCity Istanbul' is a collaborative effort between CEDIM in Germany and KOERI and IMM in Turkey. One of the subprojects of this large-scale effort is concerned with the characterization of site conditions in Istanbul (Parolai et al, 2006), particularly at the IEWRR stations with the ultimate aim of simulating strong ground motion at these sites due to a large rupture along the Main Marmara fault.

The current level of existing knowledge regarding the characterization of source parameters associated with the segments of the North Anatolian Fault in the Marmara Sea is satisfactory except for simulation using the Empirical Green's function technique. The IEEWRR has the potential of providing a very good data set for simulation of ground motion in Istanbul using EGF. However the occurrence and thus the number of records of small earthquakes has been very limited so far. This obviously imposes a certain limitation on characterization of source parameters associated with Northern Boundary and Central Marmara segments if and when other simulation methodologies are employed. However existing historical and instrumental data are sufficient to pursue simulation studies using methods other than EGF. The main difficulty lies with the lack of a verified and tested 3-D crustal velocity model of the larger Marmara Region. Such a model will be extremely helpful not only for regional simulation of strong ground motion, but also for locating earthquakes. As stated above the ultimate aim of simulation from the earthquake engineering point of view is to provide design engineers with realistic broad-band time histories. As such the provision of 3-D ground motion is important. So far the efforts in general have been focusing on getting the horizontal components; however recent developments in our understanding of structural design, as well as capabilities of modern structural analysis tools require successfully simulated vertical components as well.

Revised Active Fault Map of Northwest Anatolia: Fault geometry and kinematics surrounding Sea of Marmara

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This paper present results of a project that carried out in Northwest Anatolia by General Directorate of MTA to revise of the Active Fault Map of Turkey published in 1992. The active faults are divided into four classes as earthquake rupture, active fault, potentially active fault and neotectonic fault or lineament. Original scale of mapping is in 1:25 000 however, regional Active Fault Map of the Northwest Anatolia would be published in scale of 1:250 000 sheets. New data indicate that NW Anatolia is formed a transition region between North Anatolian Transform Fault System (NAF), and Aegean extensional tectonic regime. The transition zone is bounded NAFS from the north and Sındırgı-Sincanlı fault zone from the south. In the NW Anatolia, the NAFS turns into a broad deformation zone and bifurcates into two main strand, northern and southern. The northern strand that is master zone of NAFS is extends in the sea of Marmara. Lateral motion along the NAFS is essentially accommodated by it. As for the southern strand, it extends between Dokurcun valley and Bandırma bay and it is connected to Gönen bend at the westernmost end. Active faults in NW Anatolia form three major bend systems concave to the south trending in E-W named Bursa, Gönen and Balıkesir. Both flanks of the bends are formed right lateral strike slip fault and at the apex of the bends in the west NE-SW trending faults have reverse or thrust component whereas in the east NW-SE trending faults have normal or normal dip slip component. Bursa and Gönen bends morphologically bound Southern Marmara Depression south of Marmara Sea. Bursa bend is formed Uluabat and Bursa faults. Uluabat fault is transpressional strike slip, however, Bursa fault is normal dip slip. The bend is connected to the Eskişehir fault zone trending of NW that is eastern boundary of Aegean extensional tectonic regime within the Central Anatolia together with Tuzgölü fault. Gönen bend system includes three parallel fault sets. Southernmost fault zone is constituted Yenice-Gönen, Mustafakemalpaşa, Manyas and Orhaneli faults. Second one is Sarıköy fault and third one is formed by Biga-Çifteçeşmeler fault zone and Edincik faults. Geometry of this bend parallel to the Ganos bend on the northern strand of NAF. Balıkesir bend forms Havran, Balıkesir and Kepsut faults.

The data indicate that active faults in the southern Marmara and Biga Peninsula can not be directly evaluate within the NAF system. Those fault systems form complex bend structure in the transitional area between NAF and Aegean extensional tectonic regime. Eastern margins of the southward concave bends join right lateral strike slip fault zones that reach within the Anatolian Block. We interprated that bend geometry in the region is controlled by the paleotectonic structures. We also speculate origin of the Marmara bend on the northern strand of the NAF between Ganos and Gulf of İzmit was formed due to the similar kinematic.

Characteristics of the Major Splays of the Central North Anatolian Fault.

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The North Anatolian Fault bifurcates into several branches upon its major course bending ~20 degrees from Niksar to Kargi and changing orientation from N110˚E to E-W. These splays strikes parallel to the main strand and extends trough inner Anatolia creating a wide wedge shaped deformation zone. Strike-slip deformation inside this zone is remarkable with morphology and seismicity that reduces in terms of activity from east to west.

Geodetical measurements indicate maximum 8 mm/year slip rate inside the deformation zone mostly concentrated on the southern border fault which has ruptured partly at 1939 Erzincan earthquake (Mw: 7.9) named Ezinepazar-Sungurlu Fault. The Upper Miocene-Holocene rhomboidal shaped Suluova basin is the major morphological element of the zone which has a complex evolution with basin fill more than 400 meters formed along the central splay Taşova-Laçin fault zone and cut recently by the Suluova fault.

In this study the geometry and kinematics of these splay faults will be introduced and the evolution of the deformation zone inside the North Anatolian Fault system will be discussed.

Analysis of micro-seismicity of İstanbul greater city area and active faults

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Several active or unidentified faults in Istanbul Greater City area have been proposed in some studies on geology and seismo-tectonics of Marmara region. The micro-seismic activity patterns have been evaluated to understand the relation of these faults to recent seismicity. The three earthquake catalogues of KOERI, USGS and ISC were processed and the space and time distribution of the seismic activity in the study area were examined. The micro-seismic activity reported at these catalogues apparently increased after 1970s when the earthquake detection capability has been greatly improved with the installation of the permanent stations in Marmara Sea region. The KOERI and Istanbul Municipality seismic networks were able to record the micro-seismicity down to magnitude M = 2.0 after 1970s. Four seismic clusterings have been distinguished in the greater city area, namely Catalca, Cebeci, Sariyer and Tuzla-Omerli clusterings. Graphical analyses of frequency of occurrence- magnitudes – time of occurrence diagrams and spatial patterns of epicenters proved that the earthquake clusterings with magnitude smaller than 3.0 are mainly associated to quarry blasts and mining activities.

Submarine earthquake geology in the Marmara Sea: a multiscale approach for seismic risk assessment.

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The 1999 earthquakes of Izmit and Duzce (Duzce, Mw 7.1; Izmit Mw 7.4) gave impulse to multidisciplinary geotectonic studies in north-western Turkey. This allowed to address some important scientific problems concerning the North Anatolian Fault (NAF). However, major uncertainties regarding nature, geometry and slip-rates of major fault branches still persist, affecting the accuracy of seismic risk assessment in this highly populated region, including Istanbul with its 15 million inhabitants. These uncertainties are mainly related to the submerged portion of the NAF in the Sea of Marmara, where high resolution seismo-acoustic images have only recently become available. The key to overcome these problems is a multiscale approach to the study of fault kinematics, spanning from the effect of the last event to the analysis of the earliest stage of basin formation in the Marmara pull-apart system.

We carried out three marine geological/geophysical cruises in coastal areas of the Sea of Marmara (Gulf of Izmit, northern shelf, Imrali region and Gemlik bay, Ganos and Gulf of Saros), that we considered important for studying the nature and geometry of major fault strands, and for reconstructing their activity in time through an integrated geological/geophysical approach, that involved the analysis of high resolution geophysical data (multibeam, chirp, side scan sonar, multichannel seismic reflection) in conjunction with sediment cores. The main purpose of our study was to apply the methods of paleoseismology to the submarine environment, and possibly gather new insights on the behavior of active faults that could be used in seismic risk assessment. Technological advances in the field of Marine Geology, such as accuracy of positioning and sonar systems led to carry out earthquake geological studies in submerged areas at a resolution comparable to those on land. The integrated analysis of the geological/geophysical data, has allowed us to obtain very high-resolution images of the seafloor and 3D or pseudo-3D reconstruction of key stratigraphic levels in the recent sediment column with a vertical resolution of a few cm. Recognition of piercing points (submerged paleoshorelines, river channels, submarine canyons) displaced along the fault strands represented an important tool to estimate deformation rates along single fault strands. These data are important to infer the fault behavior over geological time scales (10,000 years). Long term slip rate estimates from geological reconstructions can be used to test the significance of geodetic, short-term measurements, and analyze permanent deformation (co-seismic + post-seismic) along single fault segments. The effect of past earthquakes in the sedimentary record was studied through the analysis "high energy events" such as slumps, debris flows and turbidites. Stratigraphic correlations between key horizons observed in both sedimentary record and high resolution seismic profiles were carried out using synthetic seismograms, reconstructed from density and P-wave logs of sediment cores. Multichannel seismic profiles imaged the sedimentary sequence down to 2 km depths, i.e., the acoustic basement and the earliest deposits of the basin. They constitute the main data for a broad scale analysis of the structure of the margin and its evolution since the earliest stage of opening of the Marmara basin.

Our findings implies that submarine earthquake geology is a feasible technique since we were able to: 1) map the fault pattern, discriminating between active and inactive faults; 2) address their nature and geometry; 3) estimate slip-rates over geological time along single fault strands; 4) describe and date the past earthquakes in the sedimentary sequence; 5) recognize the submarine extent of the 1999 (last) rupture.

We further stress the importance of a multidisciplinary/multiscale approach that involves the fine scale reconstruction of single fault strand dynamics with the study of regional tectonics, paleoceanography, stratigraphy and ultimately basin evolution.

Ground Motion Prediction for Turkish Earthquakes

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The main result of this study is the development of a consistent set of empirical attenuation expressions for predicting free-field horizontal components of peak ground acceleration (PGA) and 5 percent damped pseudo acceleration response spectra (PSA) from 57 events that produced 112 strong ground motion records in Turkey. Precisely one-half of these records (56) have been recorded during earthquakes on various segments of the North Anatolian Fault, and more than a half of those have come from two major events in 1999.

The relationships for Turkey were derived in similar form to those previously developed by Boore et al. (1997) for shallow earthquakes in western North America. The used database was compiled for earthquakes in Turkey with moment magnitudes (Mw) ≥ 5 that occurred between 1976-2003, and consisted of horizontal peak ground acceleration and 5 percent damped response spectra of accelerograms recorded on three different site conditions classified as rock, soil and soft soil. The empirical equations for predicting strong ground motion were typically fit to the strong motion data set by applying nonlinear regression analysis according to both random horizontal components and maximum horizontal components. Comparisons of the results shows that ground motion relations for earthquakes in one region cannot be simply modified for use in engineering analyses in another region. Our results, patterned after the Boore et al. expressions and are further dominated by the Kocaeli and Düzce events in 1999, appear to underestimate predictions based on their curves for up to about 15 km. For larger distances the reverse holds.

Reconciling geodetic observations of timedependent deformation around faults with their geologic slip rates: Dynamic models of the North Anatolian and San Andreas Faults

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We often explain rapid postseismic deformation following large earthquakes in terms of rapid afterslip on and below the rupture, followed by relaxation of viscoelastic mantle and/or lower crust with a modest effective viscosity. In the case of the North Anatolian Fault Zone (NAFZ), however, the lithosphere that yields such deformation must also produce interseismic deformation that is highly localized around the fault, insensitive to time in the earthquake cycle, and (somewhat) consistent with the geologic slip rate. This is made clear by the kinematic block model of Reilinger et al. (2006), in which active faults must slip at close to their geologic rates, with shallow (16 to 20 km) locking depths, to fit the current GPS velocity field in the eastern Mediterranean region. Since modest mantle or lower crust viscosities are inconsistent with highly localized strain around the NAFZ (e.g., Savage and Prescott, 1978), the effective viscosity must increase interseismically. This could be acheived either by a nonlinear or transient viscoelastic rheology. We investigate both possibilities using numerical models of both the NAFZ earthquake cycle and (in more detail) postseismic deformation following the Izmit earthquake. Our new postseismic deformation models are calibrated to a GPS dataset spanning the first five years after the Izmit earthquake (Ergintav et al., 2006).

We confirm that immediately after the 1999 Izmit, Turkey earthquake, stable frictional slip with a very small velocity-strengthening parameter (A-B = 0.5 MPa) likely occured along the NAFZ in the middle to upper crust (Hearn et al., 2002). Within months, relaxation of transient upper mantle and/or lower crust with an initial, effective viscosity of 2 to 5 times 10^19 Pa s took over as the principal cause of the accelerated postseismic deformation. Earthquake cycle models show that the effective viscosity must increase by a factor of ten or more over the next few decades to explain the observed interseismic deformation (similar to the analytical results of Hetland, 2005). Using the earthquake cycle model, we investigate whether clustering of large earthquakes along the NAFZ might account for the fact that the NAFZ's GPS slip rate is somewhat higher than its geologic slip rate (e.g., Reilinger et al., 2006), and whether results of the latest paleoseismic studies are consistent with this idea.

A similar model could be applied to the southern California lithosphere around the creeping section of the San Andreas Fault Zone (SAFZ) and the Carrizo Plain (where the SAFZ geometry is fairly simple). Dynamic models of this part of the SAFZ already incorporate both aseismic fault zone creep and viscoelastic relaxation (e.g., Li and Rice, 1986; Johnson and Segall, 2004). I will present new dynamic models of deformation around the creeping section of the SAFZ, and (attempt to) stimulate discussion as to whether transient rheology, earthquake clustering, or other effects are required to reconcile geodetic deformation data with geologic estimates of the SAFZ slip rate.

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Numerical stress field model for the Marmara Sea region

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During the last decades the westward propagation of large earthquakes along the North Anatolian Fault has reached the Sea of Marmara. Thus, the seismic gap along the fault crossing the Marmara Sea has the potential to generate a strong earthquake in the near future. However, the size of the gap as well as the question whether the fault will rupture in a single event or in several smaller ones due to the structural complexities is an open issue. Both information's are essential input information's for the wave propagation codes which calculate peak ground acceleration distribution and site effects in the City of Istanbul.

In order to investigate the contemporary stress state of the Marmara Sea region and its evolution during the last earthquake cycle we constructed a 3D mechanical model which incorporates the 3D structural information as well as the lithological and rheological inhomogeneities. In contrast to other work which quantify stress field changes due to instantaneous co-seismic and transient postseismic stress transfer processes, our aim is to quantify the total stress field and its evolution in time and space. Even though a wide range of numerical models have been published in the last decade, additional improvements are necessary to meet our objective: The 3D model geometry will incorporate topography and bathymetry data, Moho variations, upper/lower crust boundary, and the complex geometry of the active fault system using contact surfaces with Coulomb friction. The constitutive law of the model is a non-linear visco-elastic rheology and boundary conditions are gravity as well as tectonic forces imposed from the indentation of the Arabian plate and the retreat of the Hellenic arc subduction zone. The numercial problem is solved with the finite element method using the commercial code ABAQUS. The resolution of the model is several hundred meters near and on the fault and has in total approximately two million linear elements.

In order to control the quality of the model results we compare the model results with independent data from GPS observations (permanent stations and results from campaign measurements) and information on the tectonic regime and principal stress orienations. We present first results from different geometrical model approaches.

Seismic and Geodetic Study of the 1999 Izmit and Duzce Earthquake Sequence

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While 1999 Mw7.4 Izmit Earthquake has been studied in detail using a variety of geologic, geodetic and seismic methods and datasets by many groups, their results prove incompatible caused by varying assumptions about crustal structure and methodology (Celvede *et al.*, 2004). We model Izmit earthquake along with Mw7.1 Duzce Earthquake using all available geodetic (InSAR, GPS, SPOT image) and seismic (strong-motions and teleseismic) data with multiple fault segments and 1-D layered structure using the method by Ji *et al.*, 2002. Models using various combinations of datasets show the sensitivity of each of these datasets to numerous features of the Izmit rupture including the issue of supershear rupture velocity and near-field ground motions. Our results show that the dip angle is shallower towards to the east of the Izmit rupture, consistent with reported dip angle from Duzce event. The slip model obtained is similar to the joint inversion of Delouis *et al.*, 2002, with three asperities, with the largest asperity to the east of the hypocenter. One difficulty in using the seismic datasets is caused by the timing issues. A comparison of broadband regional records of the event sequence displays a very weak onset (magnitude 4 or less) for the Izmit event. Thus, the trigger times at the various strong motion stations become a serious issue, which is addressed by using calibrated paths relative to Duzce earthquake, which has a strong and sharp onset. We can use these calibrations to reexamine historical events of the 20th century using existing teleseismic recordings by methods similar to previous studies of the 1906 San Francisco earthquake (Wald *et al.*, 1993) and 1927 Lompoc, California (Helmberger et al., 1992).

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Towards an understanding of the constancy (or non-constancy) of slip-rates on the North Anatolian fault

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Understanding the temporal and spatial distribution of strain storage and release on major faults is a key aspect of modern geodynamics. Over the past 15 years GPS measurements have provided increasingly detailed velocity fields along numerous plate boundaries. In contrast, in many locations too few intermediate- and long-term geologic fault slip rates exist to allow for meaningful comparisons between long- and short-term rates. We are using cosmogenic radionuclide dating of offset geomorphic features to generate slip rates for the North Anatolian fault (NAF) in Turkey at a range of time scales ranging from <2,000 to >10,000 years. One of our primary study sites is located along the central part of the fault near the village of Eksik. At the site several major south-flowing drainages have incised >25 m into a well-developed fluvial terrace. These terraces have been offset right-laterally by the east-west fault, which is manifested as a very simple, narrow zone across the study site. The terrace deposits consist almost entirely of distinctive, white limestone cobbles that contrast markedly with the underlying dark grayish-green bedrock. The inner edge of the fluvial terrace is geomorphically well-defined over most of the site, facilitating mapping of the fault offset. In addition, the inner edge of the distinctive terrace gravels is exposed in 3D in several natural side drainages. We also excavated three trenches to expose the terrace inner edge adjacent to the narrow fault zone. These exposures and our geomorphic mapping demonstrate that the inner edge of the fluvial terrace is offset by ~48.5 m across the NAF. The age of the terrace is constrained by ten ^{36}Cl cosmogenic radionuclide dates, which yield an age of ~2ka. In addition to these surface exposure dates, we dated charcoal samples from beneath the terrace deposits. These radiocarbon ages indicate a maximum, limiting age for terrace gravels of ≤2.9 ka. This provides an independent geologic minimum slip-rate of >14 mm/yr. Radiocarbon dates and surface exposure date results are in good agreement within the stratigraphic sequence. These data indicate a slip rate for the NAF over the past 2,000 years of 23.5+8.5/-6.5 mm/yr. This rate is indistinguishable from geodetic (GPS) rates of elastic strain storage across the fault, suggesting that strain storage and release have been relatively constant across the NAF, at least over the past 2 ka. Our ongoing studies of the NAF include sites with larger offsets, which should provide longer-term records of slip rate along the NAF. These longer-term rates will, in turn, allow us to assess the degree to which strain storage and release have been constant (or non-constant) throughout the Holocene. These data will provide an important point of comparison with similar continental strike-slip fault systems, such as the San Andreas fault in California.

Structural interpretation of multi-channel seismic reflection data in the Gulf of İzmit, Marmara Sea

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Active submarine tectonics in the Gulf of İzmit, eastern Marmara Sea, was investigated by high resolution multi-channel seismic reflection data. The data were collected along 63 lines by R/V MTA Seismic-1 in September 1999 (total of 348 km). Seismic profiles are mainly in N-S direction with 1 and 0.5 km intervals. Data collection parameters are as follows: 1 or 2 generator-injector (GI) airgun (each with 45 cubic inch volume) energy source, 24-channel streamer (18 live channels) with 6.25 receiver group interval, 6.25 or 12.5 m shot interval, 12.5 m near offset, 1 ms sampling interval, 1.5 s record length. These parameters provided 9 fold common-depth-point (CDP) data for stacking. The data were processed in the Department of Geophysics, İstanbul Technical University (ITU). A conventional data processing stream was applied as follows: data transcribing, in-line geometry definition, editing, CDP sorting, gain correction, band-pass filtering, velocity analysis, normal-move-out (NMO) correction, muting, stacking, band-pass filtering, automatic gain control, and post-stack finite-difference time migration. Finally, we obtained the first stacked and migrated seismic sections in the Gulf of Izmit for interpretation. These new sections have much better reflection continuity, signal to noise ratio and reflector geometry due to sorting, stacking and migration when compared to the single-channel sections.

The northern branch of the right-lateral North Anatolian Fault (NAF) controls the structure of the Gulf of İzmit. It enters the gulf from the easternmost tip and follows the central axis mainly in E-W direction. The fault is traced in the stacked and migrated sections as a vertical discontinuity from the sea bottom to the 0.5 seconds. Below 0.5 seconds the trace of the fault is hardly followed under the strong sea bottom multiples. Bathymetric image map shows 3 basins in the gulf from east to west: Eastern, Central (Karamürsel) and Western basins. General seismic character in the Karamürsel Basin displays that the dextral fault has a dip slip in places which is correlated to the bathymetry and around parallel to sub-parallel sediments to the south and folded strata to the north. To the north coast of the gulf, a south dipping, reflector is clearly observed on the seismic sections. This structure is traced from the sea bottom to the 1 s. Maximum slope of this structure is about to 21° and between the 0.3-0.5 seconds it has a hill shaped. On the map view, this structure is followed just front of the northern shoreline of the gulf.

An outline of the Turkish – Japanese post-1999 İzmit earthquake research in the Gulf of İzmit: Offshore faults, submarine mass movements, seafloor gas seeps and offshore paleoseismology

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High resolution shallow seismic data (along 133 lines, approximately 1200 km) collected during the post-August 17, 1999 earthquake cruise were interpreted to locate and map the active faults in the Gulf of İzmit in light of bottom topography provided by the bathymetry chart obtained from the cruise data. Considering the neotectonic features around the gulf in general, two sets of faults were recognized: an earlier and mostly now-inactive set of faults responsible for the formation of a large depressional area by the pull-apart mechanism in which the Gulf of İzmit is located; and a younger, second set of throughgoing active strike-slip faults in the gulf cutting the former set. The active faults in the gulf were further divided into two groups, the main fault and the secondary faults. The main fault is made up of longer and mostly continuous, roughly E-W striking segments. The secondary faults are shorter, lying in left-stepping or in en echelon pattern on both sides of the main fault especially in the Central Basin. Along the profiles in the Eastern and Central Basins there are evidence of recent rupturing during the August 17, 1999 earthquake which are supported also by on-land data.

High-resolution shallow seismic profiles were taken across the Gulf of İzmit, in the eastern Sea of Marmara, both before and after the İzmit earthquake on August 17, 1999. The seismic profiles were collected in July 1995 and March 2000 and revealed gas-charged sediments, gas seepage into the water column. In addition to gas seeping, a large number of sediment failures occurred in the offshore and coastal zones of the study area as a result of the İzmit earthquake.

Examination of the high-resolution shallow seismic data acquired during the March 2000 cruise revealed that a large offshore area had failed on the southern margin of the Eastern Basin due to seafloor instability from the earthquake. Five major zones of slumping are present in the area of this study. These areas are: north of Başiskele, east of Batak Point, north of Batak Point, Gölcük area, and Değirmendere. The large slump zones in the former areas are composed of a continuous series of translated sediment units. The slump zone Değirmendere area is rather small. The slumps in all areas generally start from the coastline and extend out onto the deeper parts of the basin.

Anomalous acoustic signatures on the March 2000 seismic profiles provide evidence for widespread gas-charged sediments and gas seeps. Seismic profiles from 1995 also show the presence of gas in the area before the earthquake. Comparing the pre- and post-earthquake data we found that the apparent amount of the gas in the sediment and water columns increased after the earthquake. We conclude that it is this change in apparent gas level, rather than simply the presence of gas, that indicates a causative relationship between the increase and the 1999 earthquake. The presence of gas in sediments and gas seeps in and around failed sediments, in fact, has often been observed in relation with seismic activity elsewhere.

Besides the offshore mass failure, excessive sea floor gas seeps the earthquake generated tsunami waves and caused subsequent damage and subsidence mainly along the southern shores of the gulf. We retrieved three piston corer samples in the area in order to detect signs of historical earthquakes recorded in the sediments of the Central Basin of the Gulf of İzmit. Based on the visual and laboratory investigations, magnetic susceptibility measurements, grain fraction and water contents, five turbidite layers were identified in the study area. We suggest that these turbidites were generated by submarine slides and slumps triggered by the August 17, 1999 İzmit earthquake and by major historical earthquakes previously occurred in the region. These turbidites are characterized by amalgamated beds, irregular or incomplete structure sequences, grain-size breaks/fluctuations, abrupt changes in composition within bed and variable composition among beds. These characteristic features of the seismoturbidites contrast with “normal” turbidite characteristics for identifying turbidites and seismoturbidites. With a precise dating of shell fragments in the cores it is expected to correlate the major on land and offshore earthquakes in the region.

Extinction of Pull-apart Basins in the Sea of Marmara: Transition from Pull-apart Mechanism to a Single, Through-going Fault

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Like most other structures in the earth's crust, pull-apart basins do not suddenly come into existence but evolve through a sequence of closely related stages. A single pull-apart, as it is exposed today, represents only one time frame in its development. The evolution of pull-apart basins can be separated into three stages of development: incipient, early, and mature (Rahe et al., 1998). Incipient pull-apart basins are characterized by closely spaced boundary faults that form parallel to the step angle between the main strike-slip zones. The beginning of the early stage in the evolution of pull-apart basins is marked by the formation of the cross-basin strike-slip faults which begin to transect the interior of the developing pull-apart basin. Progressive widening of pull-apart basins is accommodated by formation of additional normal faults. During the early stage, main displacement strike-slip faults are not linked with the normal faults that bound the edges of the pull-apart basin. Pull-apart basins attain their mature stage of development once cross-basin faults link the main strike-slip displacement zones. Commonly, normal faults bounding pull-apart basins become extinct in the late mature stage of growth.

Strike-slip faults with releasing bend geometries show tendencies toward straightening by constructing cross-basin faults (Zhang et al., 1989; Dooley and McClay, 1997). A cross-basin fault, therefore, can be considered as a contributing factor to the extinction of a pull-apart basin. At early stage of development, cross-basin faults form as separate, small faults having orientations and sense of slip similar to those of Riedel shear fractures in strike-slip settings. With further displacement, strike-slip displacement is concentrated toward the center of the basin developing a linkage between the main strike-slip zones at the tips of the basin. During this process, normal faults bounding the pull-apart basin on the side experiencing less absolute displacement (with respect to the basement) typically become inactive and do not cut late synkinematic fill. In the extinction model of Zhang et al. (1989), development of a single cross-basin fault is coupled with the extinction, or inactivity, of extensional faults bounding the basin. The observations from analog models (Dooley and McClay, 1997; Rahe et al., 1998) are consistent with natural examples. The analog models indicate the extinction of bounding normal faults occurs during the mature stages of pull-apart basin development.

Because the creation of this northern Sea of Marmara appears to be related to the passage of the northern branch of the North Anatolian fault, it was generally assumed that this part of the sea is a pull-apart basin created by the distension between the Izmit and Ganos offset portions of the fault (Armijo et al., 1999, 2002) as previously has been anticipated by Barka and Kadinsky-Cade (1988). Briefly, in this model, the Sea of Marmara has opened in a uniform manner as a pull-apart during the last 5 Myr and the present pattern of deformation is similarly governed by the pull-apart logic.

Le Pichon et al. (1999, 2001) made a proposition based on a completely different approach and suggested that it is possible to join the İzmit segment to the Ganos segment through the Sea of Marmara along a single fault and besides, the pull-apart structure is not active any more. Rather, the basin was cut by a single continuous strike-slip fault that may have been broken in its entirety during earlier earthquakes in 1509 and 1766.

These two ideas seemingly opposing, in fact, are not so much conflicting with each other, instead, they define successive events. What has happened in the Sea of Marmara regarding the fault geometry is simply a transition from complex pull-apart basins into single, through-going strike-slip faults. All of the pull-apart basins, regardless of offset geometry, evolve progressively from narrow grabens bounded by the oblique-slip link faults to wider rhombic basins flanked by terraced basin sidewall fault systems. The analog models (Dooley and McClay, 1997) reveal that in the later stages of this widening, the cross-basin faults cut the floor of the pull-apart basins and link the offset principal displacement zones. The jogs and therefore pull-apart basins extinct and strike-slip faults become straight as time passes. This development history of the faults and accompanying basins along is valid for the entire North Anatolian fault as well as the basins in the northern Sea of Marmara, where one can observe two sets of faults, the older being inactive – now.

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Tectonic map of the Western Portion, North Anatolian Fault System

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Tectonic maps are regional compilation showing locations, geometries, and types of faults, folds and unconformities, the distribution of lithotectonic packages formed in varying depositional/tectonic regimes, and the thicknesses of strata formed in depositional basins. Ages of such features may be shown through the use of patterns or colors: In the region of the North Anatolian fault system (NAFS) earthquake epicenters will be included as well. From approximately Bolu westward to the Aegean Sea and southward from the Black Sea to approximately the latitude of Eskisehir the NAFS is distributed across a broad zone, although the strongest deformation is centered upon the Sea of Marmara. A tectonic map of this region will define this great fault system at its uppermost crustal level showing the locations and patterns of currently active faults, which possibly link to earthquake foci at depth, as well as the locations of older, currently inactive faults and help to outline the structural evolution through time. It will show map patterns revealing the interaction of fault strands and the locations of confining and releasing bends, basins and uplifted blocks, etc. In addition, such a compilation would likely identify areas of probable structural significance meriting further field definition. The examination would commence with a pilot study of the region westward from Bursa and south of the Sea of Marmara.

The proposed tectonic map would be compiled from existing data sources at map scales of approximately 1:200,000 and synthesized to scales of 1:500,000 to 1:1,000,000. Such sources would include: 1) literature in journals and from Turkish entities such as the Mining Technology and Research Institute (MTA); 2) M.Sc. and Ph.D. theses from Turkish and international universities; 3) non-published maps and reports from Turkish entities e.g., the Turkish National Petroleum Corp. (TPAO), the National Water Works (DSI), the Disaster Defense Agency (DDA), etc.; 4) examination of remotely sensed data and: 5) field examination of selected areas. It is hoped that preliminary stages of the map could be reviewed by colleagues at Turkish institutions who are active researchers in the region.

Three-Dimensional Fault Topology in the Ventura Basin, California, and a new technique for Creating Three-Dimensional Interseismic Mechanical Models in Complex Regions.

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Geodetic data from the Southern California Integrated Geodetic Network (SCIGN) provides information on interseismic deformation patterns in the Ventura Basin, which can be compared to results from three-dimensional mechanical models. This comparison may determine the most realistic among differing three-dimensional active fault configurations and predict slip rates for unconstrained faults. Although the Ventura basin is one of the fastest converging areas within southern California, geodetic signals are complicated by seasonal fluid injection/withdrawal. We use geodetic data that has been corrected for seasonal and anthropomorphic effects for comparison to a set of threedimensional mechanical models. For our models, we use three-dimensional triangulated fault surfaces defined by the Community Fault Model (CFM) for the Ventura Basin. Fault surfaces from the CFM have been modified to extend below the seismogenic portion of the crust (depth < 18 km) to a 27 km deep freely-slipping horizontal crack representing the Mohorovic Discontinuity. We establish a set of Boundary Element Method (BEM) models with 171° remote contraction determined from relative displacement of distal SCIGN stations. For each set of tectonic boundary conditions, we calculate fault slip rates over a simulated period of 5000 years, which should exceed the recurrence intervals for all faults. For validation of the three-dimensional model and tectonic boundary conditions, fault slip rates and rakes are calculated and are compared to available paleoseismic rates. Our results suggest that model-calculated dip-slip rates are generally within the range of published paleoseismic rates for the tectonic boundary conditions tested. We simulate interseismic deformation by locking all fault surfaces above 5 km depth and prescribing the slip rates from the best-fitting geologic slip model to the portions of fault surfaces that fall below the 5 km seismogenic locking depth. Model surface velocities are then compared to geodetic data. We observe that the modeled interseismic deformation patterns resemble that of the geodetic data. Furthermore, we assess the sensitivity of fault slip rates and surface velocities to amplitude of fault surface topology by comparison to a model with simple planar faults. Analysis of these two models indicates that average slip rates and rakes do not significantly change in a planar model; however, many localized aspects of slip rates and sense are much better explained by a model with more realistic fault topology. We observe that in our topology model, numerous individual faults have both left- and right-lateral slip at different along-strike locations. This indicates that paleoseismic trench sites and structural cross sections could possibly occur in non-representative locations. Our models can therefore be used to help correct for non-ideal location selection along a given fault trace as well as help guide in the location of future sites.

Submarine earthquake geology along the North Anatolia Fault in the Marmara Sea, Turkey: What we learnt about transform basins, earthquakes, and sedimentation

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The submerged portions of the North Anatolia Fault system beneath the Marmara Sea were studied with high-resolution multibeam bathymetry, subbottom profiling, and sediment cores. The major objectives were to learn about the seismic and tectonic history of the fault from the stratigraphic record at a scale similar to paleoseismic studies on land, and to develop tools for submarine earthquake geology that can be applied to fault-controlled basins in general. We focused on Holocene sediment in several Marmara Sea basins of different sizes. The approach was to test whether: 1) the depocenters of the larger basins contain a record of all historic Ms >7 earthquakes within the Marmara Sea region; 2) the small transform basins record earthquakes that rupture through them; 3) vertical and strike-slip Holocene deformation can be quantified; and 4) the effects of an earthquake generally includes both primary structural features due to rupture of the sea floor, such as strata offset, scarps, and tilting, as well as secondary effects due to shaking, such as mass-wasting and gravitational flows (McHugh et al., in press)

We found geologic evidence of earthquakes that we correlate with historic events in 181AD, 740AD, 1063AD, 1343AD, 1509AD, 1766AD, 1894AD, and 1912AD (Fig. 1). This evidence is primarily from those basins adjacent to the ruptures as inferred from historic data (Ambraseys, 2002). This suggests that coseismic deformation of the sea floor in the vicinity the ruptures is a critical factor in the sedimentary record.

We propose a qualitative sedimentation model that relates this coseismic deformation to mass-wasting of the slope, scour of the basin floor, seiche motions and homogenite deposition. Frequent earthquake activity sheds sediments from the flanks, contributes sediment on the basin floor, and smoothes the sea floor while the basin infill typically tilts down towards the fault (Figs. 2 and 3). The surveying techniques and approaches used have therefore the potential of documenting earthquake ruptures of fault segments and to extend the earthquake record far before the known history, thus improving hazard evaluations and the fundamental understanding of earthquake process.

Results of this study indicate that submarine earthquake geology can be applied to transform basins of the San Andreas fault through a multi-step integrated approach: 1) It is critical to target the basin depocenter for maximum thickness of earthquake-related sediments, to avoid erosional discontinuities, and evaluate the extent to which pelagic sediments are reworked into the seismite. Long continuous sediment records can be obtained by using a drilling vessel such as the Joides Resolution of the Integrated Ocean Drilling Program. 2) High-resolution geophysics and understanding fault kinematics areprerequisites because the depocenters are generally much smaller than the basin's floor and typically shift along strike in these transform basins. 3) Closely spaced transects of precisely positioned cores are needed to ensure section completeness and to investigate lateral variations in the internal structure of each erosional-depositional event. Such '3D sampling' is also necessary to evaluate progressive vertical offset and tilting across a fault. Whether a basin preserves the record of every large rupture remains to be shown, but preliminary results suggest a close correspondence between geologic and historic record of large submarine ruptures. Our study also suggests that coseismic deformation of the seafloor plays an important role in generating seismites.

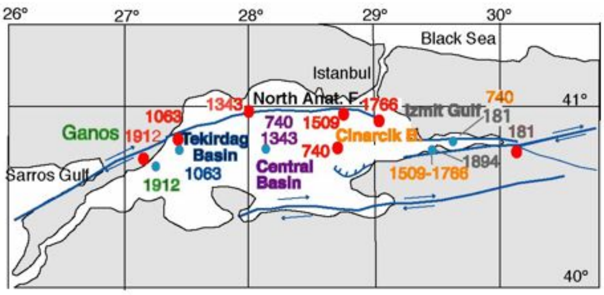
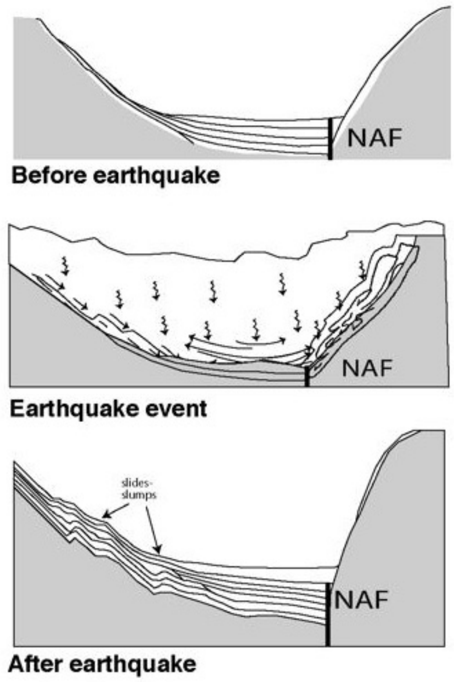


Fig. 1. Red dots are estimated locations of earthquake epicenters (Ambraseys 2002). Blue dots are our core locations (McHugh et al. in press).



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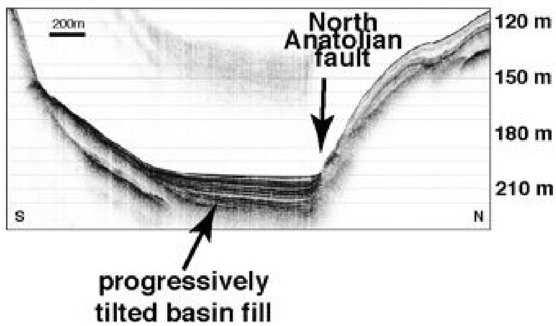

Fig. 2. Cormier et al. (2006)

Fig. 3. Sedimentation model for transform basins (McHugh et al. in press).

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Macroseismic, Paleoseismic, and Archaeoseismic Data: Independent Records of Earthquake Recurrence

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A fundamental question in understanding earthquake recurrence is whether seismic rupture patterns observed in the 20th Century repeat or whether other rupture models are likely. Large earthquakes appear to occur infrequently (possibly periodically) and are generated by rupture of multiple segments along a fault length. Testing models of earthquake behavior requires records longer than the instrumental period–data that can only be provided from historical text (macroseismic data), stratigraphic sequences at archaeological sites (archaeoseismic data), and from geologic investigations (paleoseismic data). Comparison and correlation of faulting events or paleoearthquake intensity maps along similar and adjacent fault segments provide the necessary data for developing earthquake rupture scenarios and quantifying variables for probabilistic earthquake hazard assessments.

The California historical record is very short, with extensive written material covering only the past 200 years, and limited accounts covering the past four centuries. Data on past earthquake rupture of the San Andreas fault system are determined largely through paleoseismic studies at numerous research sites on the various fault segments. For example, our paleoseismic investigations at the Vedanta site located along a segment of San Andreas fault in Northern California that ruptured in the 1906 San Francisco earthquake yielded evidence for twelve earthquakes over the past 3000 years. Recurrence intervals between faulting events range from 50 to 600 years. A smaller (3m) coseismic slip in the penultimate event compared to slip in the 1906 earthquake suggests this segment has also ruptured in M~7 events. These data do not support the model that the northern San Andreas fault fails repeatedly in characteristic or 1906-like earthquakes. Paleoseismic data from the southern San Andreas fault have also failed to adequately constraint different earthquake rupture scenarios (Weldon *et al*. 2004).

Because of the longer cultural history recorded both in historical texts extending over 2000 years and in the archaeological record into the Neolithic period, the North Anatolian fault in Turkey provides a unique opportunity to document earthquake data over multiple cycles. Historical text collected in earthquake catalogues and archaeological and geological data are three independent sources that can all provide crucially needed data about the location, date, and intensity of ancient earthquakes. Whereas macro- and paleoseismic studies are well underway on the North Anatolian fault, the archaeological records have largely been under-utilized by the seismic hazard community. Archaeoseismology can constrain the date of past earthquakes by providing the age of fault rupture or of collapsed and seismically damaged features. The distribution area of archaeologically-stratified, earthquake damage from several sites can be used to develop an isosesimal map, define the epicentral location, and possibly the magnitude of past earthquakes. This type of data should be systematically explored for the Northern Anatolia fault.

Dynamic Versus Static Cloumb Stres Trigerring of Earthquakes on the North Anatolian, Turkey

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The Coulomb Failure Stress Changes dCFS(t) from earthquake can be separated into static or permanent (dCFS) and dynamic, time-varying fields. dCFS is controlled only by fault area, orientation, and slip distribution, while the dynamic portion do dCFS(t) additionally depends on the complexity of the rupture propagation and the resulting radiated waves(Haris et al, 1991; Haris and Day 1993). Numerous studies have shown correlation of areas of positive dCFS from an earthquake with increased seismic activity (e.g., Das and Scholz, 1981; Stein, 1999). Recent studies of dCFS(t) have pointed out the importance of using dynamic rather than static Coulomb Failure Stres changes for explaining seismic triggering. For example, dCFS(t) with the time varying shear and normal stress to illustrate the origin of resulting patterns. The variation of dCFS(t) is illustrated for a series of seven large earthquakes from 1939 to 1999 on the North Anatolian Fault, Turkey.

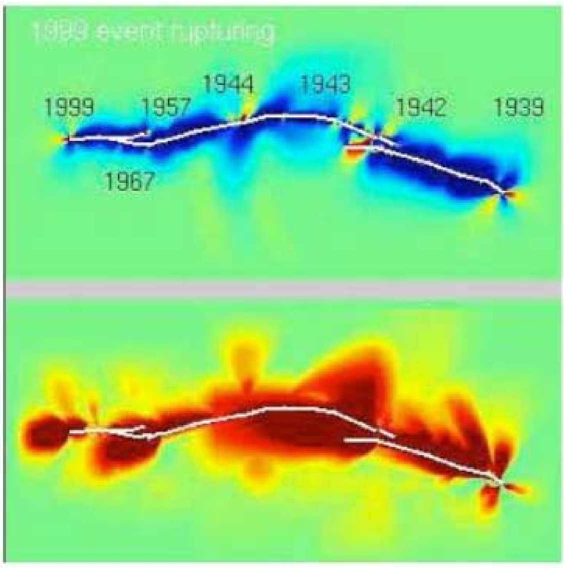

Figure 1: (top) Static and (bottom) peak dynamic Coulomb Failure Stress fort he North Anatolian earthquake series. Hot (cool) colors depict stress increase (decrease). Numbers indicate the years of the 1939-1999 westward propagating series of earthquakes. White lines depict fault traces.

Late Holocene uplift of the Hersek Ridge on the restraining bend of NAFS

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The Hersek promontory separates Karamursel and Darica submarine basins in the Gulf of Izmit. The peninsula consists of Hersek ridge characterized by Pleistocene and Late Holocene marine deposits in the north and recent deltaic sediments in the south. Hersek ridge formed in a restraining bend of Yalova and Gölcük segments in the North Anatolian Fault System (NAFS). The southern flank of the ridge is bounded by thrust faults. Therefore, it has an asymmetric topography in NS direction. We identified four uplifted Holocene coastal terraces and paleo-shorelines on the northern flank of the ridge. The oldest terrace surface (MT1) is about +7-8 m above the current sea level while the youngest one (MT4) is at an elevation of +2,04 m. The six trenches were excavated on the coastal terraces. The oldest unit in the trenches consists of bluish-gray mud with turbiditic sand intercalations. The soft sedimentation related deformational structures are commonly seen within this unit. It is overlain by the fossiliferous, gently seaward dipping, shoreface and fosilliferous beach sand deposits respectively.

Each coastal terrace formed due to large earthquakes and elevated up to 8 m. The C^{14} dating results of the terraces correspond with the some historical events occurred in eastern Marmara region. We suggest that the youngest terrace (MT4) uplifted by the great 1509 event. Possible tsunami deposits related to distant earthquakes were also identified in the trenches.

Segment Structure of the Southern Strand of the North Anatolian Fault System and Paleoseismic Behaviour of the Gemlik Fault, NW Anatolia

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The North Anatolian Fault System (NAFS) is a transform fault that accommodates relative motion between Anatolian and Black Sea microplates. The NAFS bifurcates two strands as the Northern and the Southern in the Marmara region. Recent lateral motion is about 24 mm/yr along the NAFS. According to the recent GPS data, there is a slip partitioning between both strands and the northern strand carries approximately 3 times as much right-lateral motion as does the southern strand. Therefore we interpret that the northern strand is the master zone which accommodate majority of the recent lateral motion. In this study, the southern strand is extending between Dokurcun valley and Bandırma bay is evaluated as a splay instead of a main strand diverging from the NAFS as described in previous studies. This splay is included in NW Anatolia transition zone which characterizes bend structures.

Length of the southern strand is about 140 km between Dokurcun valley and Gemlik bay along Pamukova basin, Lake İznik and Gemlik Bay depressions. The strand can be divided into three main geometric segments in right steeping pattern. Those are Geyve, İznik and Gemlik, from east to west. Length of the Geyve Fault is about 57 km and general trend is N70°E. The İznik Fault is about 56 km-long trending of N75°E. Western section of this segment is under the Lake İznik. General trend of the Gemlik fault is E-W, total length is 27 km and 12 km of it observed on the land. The fault segments separated from the each other by releasing step overs. The stepover between Geyve and İznik faults is located west of Pamukova basin. Another stepover which controls the Lake İznik basin is located between İznik and Gemlik faults. The Gemlik Fault controls the southern boundary of the Armutlu Block which is western half of the Samanlıdağları uplift. Western margin and eastern margin of the fault is delimited by Gemlik bay pull-apart basin and by Lake İznik pull-apart basin, repectively.

According to the historical records, many destructive earthquakes have occurred in the last two millennia along the southern strand. It is known that the recurrence intervals of the large earthquakes are 150-250 years on the western part of the 1999 İzmit rupture on the northern strand based on the recent paleoseismological data. However, there is not sufficient data to evaluate of the paleoseismic behavior of the southern strand. We performed paleoseismological survey along the Gemlik fault and two surface faulting events were identified. The last and penultimate events can be correlated with the 1857 and 1419 earthquakes, respectively, which indicate 438 years for recurrence interval. According to previous studies there is a different surface faulting history on the İznik and Geyve faults. Despite we identified 1857 event on the Gemlik fault that event was not identified on the İznik and Geyve faults. Therefore we can say that the 1857 earthquake should be triggered event on the southern strand by the 1855 Bursa earthquakes. We also suggest that 3.5 m of slip accumulated in the elapsed time of 587 years on the southern strand between İznik Lake and Dokurcun valley based on the 6 mm/yr slip rate.

Seismicity Parameters and Scaling Properties of Earthquakes in Marmara, western NAF

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The 17 August 1999, Gölcük and 11 November 1999, Düzce earthquakes have conspicuously reminded us of how seismic hazard assessment is necessary in terms of loss of life, casualties and finance. Moreover, a possible drastic earthquake in Marmara, western North Anatolian Fault (NAF) has exceptional importance concerning to its economical and social impacts, for whole Turkiye. Herein, statistical investigations on earthquakes and evaluation of results according to physical conditions which cause earthquake phenomenon are outstanding tasks. On this purpose, statistical properties of earthquakes in the area are analyzed by means of fractal analysis and seismic parameters.

Objects which are self-similar and show scale invariance are called as fractals. If a system does not have a characteristic length or scale, it is a good approximation to understand its behaviour using fractal analysis. Every fractal is characterized by a fractal dimension. Having fractal distribution requires that number of objects larger than a specified size has a power-law dependence on the size. The exponent of the power-law stands for the fractal dimension and characterizes the chaotic behaviour of system. Most of the phenomena or objects in geophysics and geology such as frequency-size distribution of earthquakes, faults, and fractures are scale invariant and show multifractal properties.

Using power-law relations for statistics of seismicity is not a new subject in geophysics. The b-value of Gutenberg and Richter, which is a good example, defines a relationship between occurrence rates and magnitudes of earthquakes and has been used as the indicator of seismic activity. Additionally, p-value of Omori is also a power-law relation and defines the decay rate of events' frequencies with time.

The present work aims to contribute to a better understanding of the occurrence systems of earthquakes in the area, by means of multifractals, b-value and p-value, using the data obtained from the web site of the Bogazici University Kandilli Observatory and Earthquake Research Institute. Earthquakes in the investigation area are examined by depth and contour maps of capacity dimension of active faults, information and correlation dimensions of epicentral distribution, b-value and p-value are prepared for time intervals of 0.5 days. Then correlations between these seismicity and scaling parameters are evaluated according to earthquake mechanisms and tectonic characteristics of the region.

Source Inversion Resolution Analysis of the 2004 Mw6.0 Parkfield Earthquake

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The Parkfield earthquake sequence is extremely important for testing ideas of earthquake recurrence and predictability. Historically the Parkfield earthquake series was the impetus for formulating the "characteristic earthquake" hypothesis which still today has great impact on ideas used in seismic hazard analysis. By comparing kinematic inversions of past earthquakes at Parkfield we can determine to what extent these earthquakes are truly "characteristic", and thus, to what extent ideas developed in this region can be extrapolated to future seismicity on the San Andreas Fault and in similar tectonic regimes such as the North Anatolian Fault. In order to compare the source processes of different earthquakes, a quantitative measure of the uncertainty between different inversions is needed.

The long-awaited 2004 Mw6.0 Parkfield Earthquake provides a unique opportunity to probe the resolution limits of source inversions due to the large amount of near-field seismic stations. This earthquake was well recorded by a dense network of strong-motion seismographs and GPS 1-Hz receivers. We investigate the resolution of the nonlinear source inversion performed by Custódio, Liu, and Archuleta [2005]. We compare the resolution bounds given by a singular-value analysis to a bootstrapping analysis already performed by Custódio et al. in which inversions of station subsets were compared. Joint inversions of GPS and strong-motion data can be problematic because the two data sets are in different frequency bands, have different sampling rates, and contain different error terms. Custódio et al. avoid mixing the data by inverting the GPS data independently, and then use the slip distribution obtained as a constraint in the inversion of strongmotion data. The drawback of this approach is that the GPS data is much denser around the northwest portion of the fault, as shown in Figure 1. The GPS data cannot resolve slip on the southwest portion of the fault, and thus using the GPS data to constrain the strong-motion data leads to little total slip in this area.

We calculate the spatial resolution of the GPS data to provide a natural way to weight the static field constraint spatially. In this way, the GPS data can better constrain the northwest portion of the fault while at the same time not prevent the inversion from placing slip on the southeast portion of the fault in areas allowed by the strong-motion data. This avoids the ad-hoc determination of weights that is often used to combine disparate data sets.

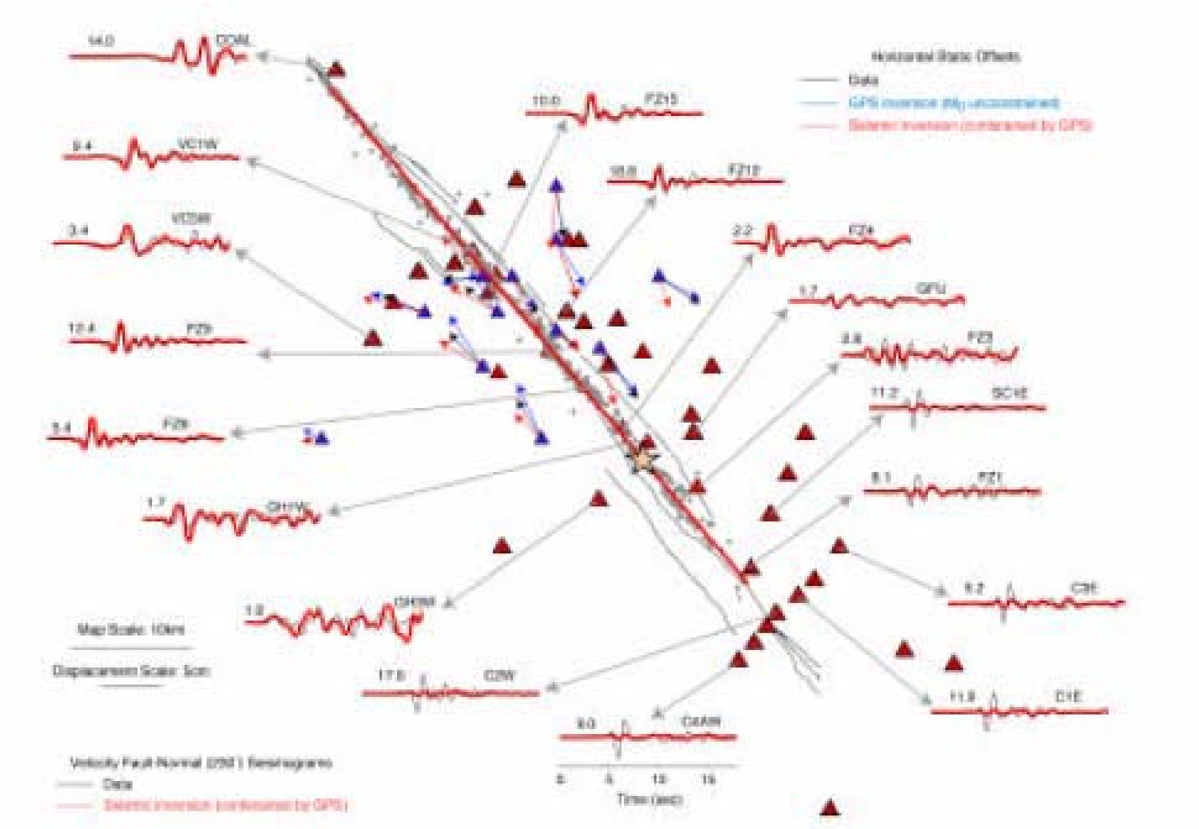

Figure 1. Map of the Parkfield section of the San Andreas Fault, showing the fit to data offered by the rupture model inferred from the inversion of seismic data constrained by GPS data. Small gray dots - aftershocks [*Thurber et al.*, in press]; star - epicenter; red line - modeled fault plane; blue triangles - 1-Hz GPS stations; red triangles – strongmotion seismic stations.

Analysis of stress and failure around step-overs and slip-gaps for strike-slip fault systems

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Designing for surface rupture and displacement in the immediate vicinity of active faults is essential for reduction of loss of life and property during earthquakes. The primary rupture zones in the 17 August 1999 Izmit and 12 November 1999 Duzce earthquakes were relatively simple and narrow along most of their lengths. The majority of buildings along the paths of rupture either collapsed or heavily damaged (Aydin and Kalafat, 2002). Losses of life and property in the above earthquakes could have been significantly reduced by simply avoiding construction within a narrow zone around the fault. Understanding the extent of failure zones and the distributions and orientations of secondary ruptures around faults are detrimental for analysis of fault displacement hazard. Existence of discontinuities in fault geometry, such as bends, step-overs, and slip-gaps, affects the extent and the direction of primary and secondary ruptures and failure zones. These earthquakes provide some very useful information on the impact of geometric discontinuities on rupture distribution, which can be built into fault displacement/rupture hazard analysis models (e.g., Petersen, et al. 2005). For example, reports from these earthquakes indicate that surface ruptures of the order of 5 meters were arrested by step-overs of 4-5 km wide, ruptures of 1-1.5 meters were arrested at 2-4 km wide stepovers, and a rupture of 3 meters propagated through a step-over of width 1-2 km (Lettis, et al., 2002). Barka and Kadinsky-Cade (1988) had proposed 5 km as the widest step-over and 30 o as the largest bend angle that can be generally jumped by an earthquake.

In this study, quantitative investigations of the extent and the distribution of primary and secondary ruptures and zones of failure around strike-slip faults with different geometric discontinuities are made. The distribution of stress is obtained by a simple two-dimensional linear elastic analysis of crustal rocks surrounding slipping faults of various geometries, using boundary element method. Various failure criteria applicable to intact and fractured rocks are then employed to estimate the extents and the patterns of failure zones. Preliminary results suggest that, depending on the failure criterion, fault geometry, and rock strength parameters used, rupture jump across/along step-overs and gaps up to several kilometers is possible. Using the extent of failure zones, probability density functions for the distribution of secondary ruptures around primary faults, for probabilistic fault displacement hazard analysis are developed. Results also imply that detailed characterization of the rocks in the step-over and gap areas would improve estimates of the critical size of step-overs and slip-gaps, and lead to more reliable density functions for the distribution of secondary ruptures for input into probabilistic fault displacement hazard analysis models.

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Behavior of the San Andreas fault over the last 5000 years: Wrightwood's clues and questions

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In a recent editorial, Seth Stein wrote: "[W]e still don't know the most basic question about earthquake recurrence: whether it's time-dependent or time-independent." (Seismological Research Letters v. 77, no. 3, 2006) Recent paleoseismic studies of the southern San Andreas fault are improving our ability to answer this basic question. At the Wrightwood paleoseismic site on the southern San Andreas fault, we* have excavated over 40 trenches into a small (200 x 400 m) marsh that is periodically covered by debris flow deposits. The depositional and structural setting of the site preserved a high-resolution record of ground-deforming earthquakes on the San Andreas fault for the last 5,000 years. Within this period, we have documented approximately 40 paleoearthquakes, but most of our effort has focused on two periods: the "young section" from present to 500 CE and the "old section" from 1500 to 3000 BCE. Additional work is required to unravel the stratigraphy and date the sediments of the intervening "middle section" before an earthquake series can be evaluated. However, concerning the two well-studied sections, we have shown that both sections contain about the same number of earthquakes (14) in the same amount of time (1500 years), indicating there is no material change in the average recurrence rate over a time span that is significantly longer (>25 times) the average recurrence interval. Using nonparametric statistical tests, we have begun to evaluate rate changes in the earthquake series that explore the time-dependence or independence of the fault. We examined the chronologies separately and in combination and explored the robustness of the results by including or excluding earthquakes that have less compelling expression in the trenches. Importantly, we found that due to the length of the series, stable estimates of recurrence parameters can be obtained even when the exact membership of the earthquake series is unknown. One test compares the periodicity of the earthquake series to the null pattern, a random (Poisson) series. This test showed that the old record is more regular than the younger. When the two periods are combined, 88 to 99% of the tests are too regular to result from a random distribution at the 80% confidence limit. The results imply an underlying regularity to the recurrence pattern that is consistent with the calculated lognormal variance of ~0.62 (0.49-0.92). This work directly answers the "basic question" - at least for one location on one long fault. Paleoseismic slip-per-event data and additional long series – on the San Andreas and elsewhere – are necessary to explore wider questions about fault behavior. *Ray Weldon, Tom Fumal, Glenn Biasi, and the author are principal authors of various published papers about the site.

Imaging and Mapping Active 3D Fault Geometry in the California Continental Borderland

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The Continental Borderland offshore southern California has had a complex tectonic history. This area experienced late Cenozoic subduction and Miocene oblique extension, as well as components of large-scale tectonic rotation that continue to the present. The northern part of the Continental Borderland was the locus of Pacific-North American plate motion for more than 70% of its displacement history, and recent GPS data suggest that as much as 20% of current plate motion is still located offshore. Much of this plate motion in the Continental Borderland appears to occur on NW-striking right-transpressive faults and folds that terminate against the predominantly E-W-striking left-transpressive structures of the rotating Western Transverse Ranges province. How this crustal deformation is accommodated in 3D, and the interaction between rotated and non-rotated domains is little understood. These active offshore structures also represent a largely as yet unknown seismic and tsunami hazard to many California coastal communities, and provide important analogs to active buried (less-accessible) onshore California structures that are likely to produce large, damaging earthquakes in the adjacent Los Angeles basin.

As part of a collaborative, multidisciplinary approach, extensive grids of existing highquality industry multichannel seismic (MCS) and high-resolution multibeam data are being used to image and map active 3D fault surfaces, stratigraphic reference horizons, and seafloor morphology in this offshore area. These digital surfaces help to define the geometry and evolution of active subsurface faults and folds, and to better quantify the finite strain field with time. Initial results suggest a complex pattern of faults and folds that interact to partition oblique strain on systems of intersecting high- and low-angle structures. For example, the near-vertical Malibu Coast fault accommodates predominantly left-slip above a set of stacked north-dipping low-angle thrust faults. At greater depth, these high- and low-angle faults may merge to form oblique-reverse faults that reactivate inherited Miocene normal-separation faults associated with the initial rifting and rotation of the Western Transverse Ranges province, and which now drive the uplift and folding of the Santa Monica Mountains and northern Channel Islands. This system of interacting faults, folds and crustal block rotations is comparable to similar fault systems around the world, including the North Anatolia fault system in the Marmara Sea, where combinations of low-angle faults beneath long-wavelength folds and adjacent high-angle faults also appear to accommodate distributed continental plate motion and inferred block rotation.

Simulation of Strong Ground Motion from the 2004 Parkfield Earthquake

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Two different studies have been conducted to simulate the near-field strong ground motion generated by the 2004, Mw=6.0 Parkfield earthquake. This earthquake took place in a very well instrumented area producing a substantial amount of high-quality near-field recordings. The first study is based on the hybrid Green's function method (HGF). HGF method starts with calculating the synthetic Green's function which is a combination of deterministically calculated, low frequency motion and stochastically simulated, high frequency motion. Summation of Green's functions using the numerical framework of the Empirical Green's Function method gives the large earthquake synthetics. Simulations with this method were carried out for the frequency range 0.1-25 Hz at eight rock and four soil site stations. The results compare favorably with the empirical data. Frequency dependent site amplification values are calculated using empirical data, and considered for the soil site simulations. The comparisons of simulated motion in time and frequency domain proved the efficiency of the HGF method in such broadband simulations. The second study is based on an explicit finite-difference algorithm developed by Frisenda and Madariaga for the computation of radiation from complex ruptures on extended faults. Taking advantage of the rare luxury of having a large number of near field ground motion recordings distributed around the fault zone, we used recordings from 40 stations covering a rectangular area of about 55 km by 33 km in fault parallel and fault normal directions, respectively. Using a grid spacing of 100 m in our 4th order explicit finite difference code, we could properly resolve frequencies of up to 1 Hz at a minimum of 8 grids per wavelength. A one dimensional averaged velocity structure was used in the simulations of wave propagation. The effect of the strong velocity contrast between the NE and SW sides of the San Andreas fault in Parkfield region at 5-12 km's depth has been investigated by using different velocity models for the two sides. The effects of different slip distributions and source-time functions have also been studied. We first used a simplified version of the preliminary source model by Ji (2004). A more recent slip distribution model by Ji et al. (2005) obtained by the inversion of waveforms from both strong motion and GPS stations has also been considered. The latest slip model that was implemented was the one obtained by Liu et al. (2006) using kinematic inversion. Several different kinematic rupture scenarios were considered with variable rupture speeds and several source-time functions of different shapes (decreasing exponential and trapezoidal) and durations.

Fault Segmentation Effects on Sequences of Dynamic Events

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One of the biggest assumptions, and a source of some of the biggest uncertainties in earthquake hazard estimation is the role of fault segmentation in controlling large earthquake ruptures. We have developed a model which spontaneously produces complex segmented fault geometries, and on this complex fault network generates long sequences of dynamic rupture events. Using this model, we have studied a number of aspects of ruptures relevant to hazard questions. We have examined the cascading of large events across segments, finding support for a modified segmentation hypothesis whereby segments both break in power law small events and occasionally participate in cascading multisegment larger ruptures, but also predominantly break as a unit. We have examined the probability of jumping segment stepovers, finding a systematic dependence on stepover distance. We have looked at the variation of ruptures, finding an increase in variation at the ends of segments and a decrease in variation for the longest segments. We have examined the initiation, propagation, and termination of ruptures, and their relationship to fault geometry and shaking hazard. We find concentrations of epicenters near fault stepovers and ends; concentrations of terminations near fault ends; and persistent propagation directivity effects. Taking advantage of long sequences of dynamic events, we directly measure shaking hazards, such as peak ground acceleration exceedance probabilities, without need for additional assumptions. This provides a new tool for exploring shaking hazard from a physics-based perspective.

Kinematics of the faults cutting the Pliocene deposits in the Gulf of Izmit and surroundings

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The North Anatolian Fault splays into two main branches in the Northwestern Anatolia. According to GPS measurements, the northern branch is the most active with a movement of ~20 mm per year. The Sea of Marmara and the Gulf of Izmit forming its eastern tip, were developed as pull-apart basins on this branch from Late Pliocene onward.

The study area is located along the western part of the North Anatolian Fault Zone between Gulf of Izmit and Adapazari is represented by an east-west trending narrow depression, filled by Late Pliocene and younger alluvial fan deposits. The depression started to form under the control of NE-SW and NW-SE trending faults having dominantly normal component during the Late Pliocene. This period is characterized by the development of series of pull-apart basins. In the mature stages of these pull-apart basins younger active faults cut the older basin sediments. Recent Izmit-Adapazari depression is formed by joining of these small pull-apart basins. Recent sediments are still depositing the Izmit-Adapazari depression and were cut by E-W trending active northern branch of the North Anatolian Fault.

The faults cutting the Pliocene deposits follow many small scale NE-SW and NW-SE trending faults having dominantly oblique-normal component, as is well displayed in the study area. The goal of this study is to describe the nature of this fault pattern in the light of the structural measurements of kinematic indicators. Basically, the faults cutting the Pliocene deposits shed light onto the kinematics evolution of North Anatolian Fault in the region.

Paleostress orientations and relative stress ratios determined by using different methods are used to improve the understanding of the kinematic characteristics of the study area. Two different dominant extension directions were determined using fault-slip data, NE-SW extension direction in the east and NNE-SSW extension direction in the west of the study area.

The Eastern Marmara pull-apart junction (North Anatolian Fault) and its relation to the submarine end of the 1999 Izmit earthquake rupture

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The North Anatolian Fault makes a major transtensional stepover in the west which forms the lithospheric scale Sea of Marmara pull-apart and smaller pull-apart basins at a range of scales. The easternmost pull-apart basin (Çinarcik Basin) is located at the junction where the strike-slip tectonic regime of the NAF dramatically changes into the oblique extension. Faults with large normal component bound the Çinarcik basin. They are clearly identified in the submarine morphology as well as in the deep seismic reflection profiles (down to 6 km) and shallow 3.5 kHz profiles (down to 50 m). The sediment fill in the basin records the evolution of the activity of these normal faults. Sedimentation rates and vertical components of slip are estimated and discussed from these profiles. The historical and instrumental seismicity indicates that the rupture of these oblique faults are probably associated with significant normal faulting earthquakes (e.g., 1963 and 1894). The 1963 Ms 6.4 Çinarcik earthquake has clear normal faulting mechanism.

The 1999 Mw 7.4 Izmit earthquake ruptured with purely right-lateral strike-slip motion. Modelling of InSAR and GPS data suggests that the Izmit rupture extended offshore to the eastern entrance of Çinarcik Basin. We performed an ultra-high resolution bathymetric survey with the ROV Victor 6000 to explore the geometry of fault breaks. The micro-bathymetry data allows us to identify with confidence the submarine extension of the Mw 7.4 1999 Izmit earthquake rupture. It is clearly expressed as a series of fresh fault breaks across the bottom of a submarine canyon at 180 m depth, 10 km west of the Hersek peninsula. The flat floor of the canyon appears to result from leveling by significant sediment transport. So, on the average the sedimentation rate must be low. Under such conditions, only the last earthquake break can be preserved across the canyon floor. Microbathymetry suggests the 1999 fault scarp is there 0.5 m high. The break continues for some kilometers to the west and appears to end at the junction with Çinarcik basin normal faulting, suggesting that the fault complexity at the junction acts as a barrier to rupture propagation of large earthquakes. Our findings are consistent with the 1999 rupture deduced from SAR interferometry. The evolution of the sedimentation and faulting in Çinarcik basin appears critical for a better understanding of mechanical fault interactions at the junction.

Neotectonic Evolution of the Uludağ Uplift and its connection with of the North Anatolian Fault Zone (Bursa-Turkey)

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At the southeast of Marmara, there exist basins and uplifts formed due to the right lateral movements of the southern branch of the North Anatolia Fault (NAF). One of these is the Uludağ uplift, which is one of the most attractive structures that was affected by the active tectonic developed around the Marmara Sea. Uludağ uplift is a mountain that is 40 km long in NW-SE direction, 20 km wide and 2543 m high. The mechanism that supplied the development of Uludağ uplift is the stress related with the deviations in local movement vectors that were formed by the movement of the Anatolian block eastward in the southern Marmara Region. NE, SW and southern sides of the Uludağ uplift were bordered with these faults. By combining the satellite images and the digitized counter lines from topographic maps, these structures that are difficult to be traced because of plant cover and morphological obstacles are exactly clarified. The prepared maps are verified with field observations and the characteristics of these faults are described. At Plio-Quaternary, Uludağ uplift was elevated about 500 m and 1000 m according to the NE-SE zone and Bursa plain respectively. Related with Thrace-Eskişehir Fault (TEF) the first elevation of Uludağ belongs to Early Miocene and the later.

Goemorphic manifestations of the damage assymetry induced by rupture propagation direction along the 1943 and 1944 rupture zones of the NAFZ

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The North Anatolian Fault (NAF) ruptured in a sequence of large earthquakes between 1939 and 1999, generally progressing from east to west. The 1943 rupture did not nucleate in the region of largest stress increase but rather at the opposite end of the final rupture. It propagated unilateraly eastward, opposite the propagation direction of the 1944 rupture. This anomaluos behavior may reflect the long term preferred propagation direction of ruptures on these fault sections. Here we analyze geomorphic properties that may express the damage structure of the fault along the 1943 and 1944 ruptures, testing whether correlative rock bodies across the fault have similar or distinct geomorphic expression. The study involved three scales of observations: 1) Large scale; thalveg adjustments of the rivers along the faults 2) Medium Scale; terrain analysis of topography and standart morphometric analysis on drainage basins with similar lithology 3) Small scale damage zone (<100m), generally expressed as fine textured badlands due to extremely high drainage density. The NAF perturbates drainage systems and forms fault valleys along its strike. Several valleys of various size follow the 1943 and 1944 ruptures. We found that along the 1943 rupture most of the river thalvegs are located south of the rupture, whereas along the 1944 rupture the locations are flipped and most of the river thalvegs are north of the rupture. On the medium scale we performed comparative morphometric analysis at two sites near Ismetpaşa with one north (N) and one south (S) of the fault. The two sites have the same lithology and similar morphometric controls. Morphometrical analysis were carried out to obtain information on the response of the erosional dynamics to the damage structure of the fault. Terrain analysis of the topography shows a clear difference especially of skewness of elevation on moment statistics. Morphometric analysis of the drainage basins shows closer bifurcations ratios revealing drainage basins with drainage patterns not heavily distorted by geology. Drainage density, stream frequency and ruggednes number values are higher at N side than S side of the fault. We also plot longitudinal profiles of the

streams to show differences between the N and S sides of the fault. The analysis is consistent with more intense geomorphic work on the N side of the fault. At two locations along the 1943 rupture, highly eroded badlands south of the rupture have a higher gully density and frequency compared to the north. The drainage density gradually decreases as a function of distance from fault. Our observations include various expressions for more erosion on the S side of the 1943 rupture, and on the N side of the 1944 rupture, presumabely due to higher levels of rock damage. These results are consistent with a preferred direction of rupture of west to east for the 1943 segment, and east to west for the 1944 segment, as occurred in these historical earthquakes. The observations from the 1943 rupture are compatible with smaller scale data of damage asymmetry obtained in several cross-fault trenches (Dor et al., 2006).

Slope instability in the Sea of Marmara and relationship with active faulting

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The assessment of earthquake hazards in the vicinity of Istanbul requires a characterization of active faults, but also an evaluation of the effect of the earthquakes on slope stability and associated tsunamis. In the Sea of Marmara, known historical tsunamis have been triggered either by coseismic displacement or by landsliding (Altinok et al. 2001; Hébert et al. 2005). Indeed, tsunamis generated by strike slip faulting are generally small because of low vertical motion of the seafloor, but submarine landslides following earthquakes may also contribute to tsunamis generation. Significant tectonic subsidence and offshore mass movements have actually been observed related to the 1999 Izmit-Kocaeli earthquake (Kuşçu et al. 2005).

The zones of instabilities along the slopes of the Sea of Marmara are mapped from high resolution multibeam bathymetric data. A distinction is made between large creeping slopes with a possible catastrophic evolution into debris flow, and instabilities related to steep canyons slopes. Numerous slope failures and scars incise the upper slope, particularly near the head of the canyons and within their flanks. These submarine mass movements consist of small volumes but may participate to tsunami source, because they occur at relatively shallow water depths. On the other hand, wider areas (20 to 80 km2) of the entire slope are affected by active gravity sliding processes. These features show complex seafloor morphology, with evidence for multiple slope failures (imbricated scars), retrogressive evolution (extensional scarps above recent failures) and creeping motion (rough and hummocky seafloor). Catastrophic events occur occasionally since related debris flows can be found downslope in the basin. Evidences are debris layers in cores and transparent lenses interbedded with the sedimentation visible on the 3,5kHz echosounder profiles. The most known catastrophic submarine mass failure occurred around 17 kyr BP to the northeast of the Çınarcık Basin (Özeren *et al*. 2006). The scar area of around 32.5 km2 consists of two parts: a creep-like movement on the east and a slump in which the vertical displacement reaches around 1000 metres on the west. Slope instabilities can also be observed in the southwestern part of the Tekirdağ basin, over an elliptical area of about 76 km 2.

So we remark that the largest two active creeping masses are located at active fault bends at both extremities of the Sea of Marmara and may relate to different sedimentary input or to the termination of recent seismic ruptures (i.e., the Ganos rupture to the west, and Izmit rupture to the east).

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PBO Borehole Strainmeters

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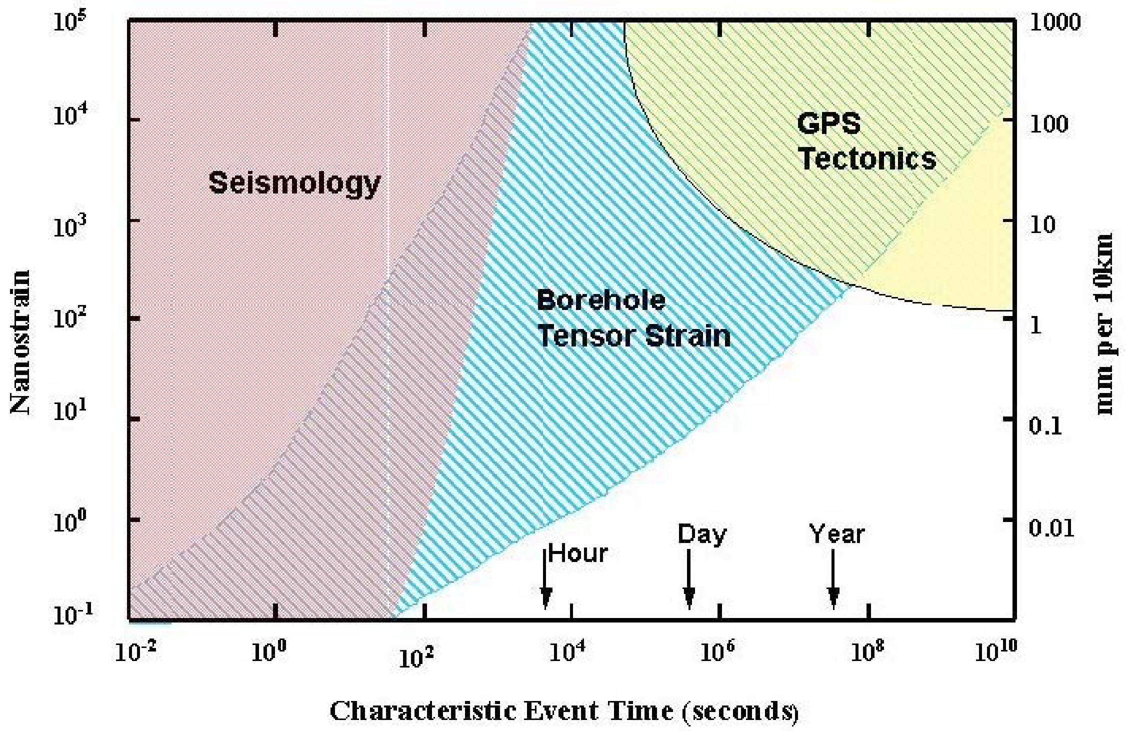
As part of the National Science Foundation's Earthscope project, the Plate Boundary Observatory (PBO) is installing 103 borehole tensor strainmeters in the Western conterminous US. This represents almost a tripling of all installed borehole strainmeters in North America. Since the initial deployment of strainmeters in the early 1980's, borehole strainmeters have contributed valuable data at periods ranging from minutes hour to weeks giving sensitivities two to three orders of magnitude better than continuous GPS at periods of days to weeks. Borehole strainmeters have been used to image earthquakes, slow earthquakes, creep events and volcanic eruptions primarily in the US, Iceland and Japan.



Initial deployments of the PBO have shown promising results but there are still major hurdles to overcome in production, installations processes, data quality control and the near real time delivery of calibrated strain data. PBO has made significant steps forward with the installation of over 20% of the array and raw data available within 24 hours.

The PBO Borehole Strainmeter Network represents the first large scale observations in the this regime in the US and the first dense measurements in this regime along a major strike-slip fault like the San Andreas that offer exciting possibilities for integrated data sets across the time span ranging from hundreds of Hz to years.

As PBO overcomes the complex engineering issues related to construction, installation and data processing of borehole strainmeters and strainmeter data we hope to transfer and apply this knowledge to other geophysical regimes such as the North Anatolian Fault.

Strategies for characterizing seafloor deformation along the submarine extensions of continental tresforms

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Recent near-bottom multibeam bathymetric and high-resolution subbottom profiling surveys in the Marmara Sea have documented the geometry of the North Anatolian Fault in great detail. An integrated approach that combines such high-resolution, near-bottom geophysical surveys with transects of shallow cores can also characterize the series of earthquakes that ruptured through a transform basin. Such high-resolution geophysical and sampling programs along fault segments that are expected to rupture in this century should allow for a reliable assessment of the seismic hazard facing the adjacent coastal areas. In addition, should the fault rupture, a series of repeat surveys would not only document the processes associated with underwater ruptures (homogenites, mass wasting, liquefaction, mud volcanoes, fluid seepages), but it could also be applied to precisely quantify the coseismic and postseismic deformations, in a fashion similar to InSAR interferometric studies on land.

Newly developed AUVs (=autonomous underwater vehicles) equipped with multibeam bathymetric sonars, subbottom profilers, and camera, can efficiently map seafloor ruptures at the sub-meter resolution over distances of several kilometers, a resolution higher than that of SAR data. Some AUVs are very portable and can be efficiently airfreighted anywhere in the world and deployed from small ships of opportunity, making them ideal tools for rapidly and accurately surveying fresh seafloor ruptures.

Novel but proven techniques for submarine geodesy that consist in deploying an acoustic arrays across a fault trace can directly quantify its slip rate. Long-term deployment of ocean bottom seismometers can also precisely monitor the fault background activity and illuminate its subsurface geometry. A program combining all these different approaches would provide unprecedented information on interseismic, coseismic, and postseismic seafloor deformation. The San Andreas Fault offshore California, and the North Anatolian fault beneath the Marmara Sea are prime candidates for such projects, considering the high population in these coastal areas. Because such projects would make use of emerging and costly technologies, they should realistically be planned and carried out as multinational collaborations.

Bends on Continental Transforms and the North Anatolian Fault in the Marmara Sea

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Several of the larger basins along the North Anatolian fault (NAF) in northwest Turkey share striking features. They are narrow triangular half grabens bordered along one of the long flanks by one of the segments of the NAF. Subsidence is asymmetric both across and along the basins so that tilting is oblique, toward the border faults and toward the apexes of the triangles where subsidence is fastest. The border faults dip toward the basins and accommodate oblique slip with a maximum dip to strike ratio at the apex. All these apexes are situated at prominent bends of the transform, with the basins developed on the extensional side of the bends. Prominent examples are the Tekirdag, Cinarcik, and Duzce basins. The horizontal to vertical motion ratios at the apexes of these basins are 0.1-0.2 (long term) based on the overall geometry of the Tekirdag Basin; 0.3-0.4 based on Holocene subsidence and current geodetic dextral motion at the Cinarcik Basin; and 0.8-1,0 for the 1999 rupture of the Duzce segment. In all 3 border faults the vertical components seem to vanish before the topographic end of the basins. Another important asymmetry in the system is the behavior of the opposite walls across the fault at the bends. In general, a change in strike along a transcurrent fault requires off-fault deformation, but not necessarily on both sides of the fault. In the three examples along the NAF, vertical deformation is largely confined to the hangingwall side of the faults. The behavior of these non-vertical transcurrent faults is thus similar to dip-slip faults where slip over vertical bumps and fault growth result in deformation only above the fault. Having no deformation in the footwall implies that the shape of the fault is fixed to that side. This behavior is manifested by the pattern of growth of the triangular transform basins. The basins develop on the hangingwall side, but are growing in response to the bends, which are fixed to the opposite sides. Thus the pattern of vertical motion that creates the basins is fixed to the inactive opposite sides of the fault and moves upstream at the dextral speed of the fault on the side where it is active. This accounts for the subsidence being fastest not only at the narrowest, but also the youngest end of the basins. Away from the bend, more subsidence has had time to accumulate and basement depth increases while subsidence rate decreases as the effect of the bend wanes. The Tekirdag basin is on the north side of the Ganos bend of the NAF while the Cinarcik basin is on the south side of the Tuzla bend. These bends are fixed on the Anatolian and Asian sides of the fault, respectively, thus they are moving apart at the plate speed lengthening the Marmara Sea. We present a simple Marmara Basins evolution model based on our concepts of how basins develop downstream of bends on the master transform fault and on published bathymetry and subsurface data (Rangin et al., 2002; Okay et al., 2000; Polonia et al., 2002). This model lets the Anatolia rigid block south of the northern branch translate (28km) and rotate CCW (2.4°). The deformation zone broadens in the Marmara sea area to include three separate domains decoupled from both plates: The Cinarcik-Imrali pair of extensional basins, the Central Marmara High zone of compression and left shear to account for the Istanbul bend on the NAF, and a zone of clochwise rotating blocks between Tekirdag and Central basins. These internal domains involve multiple faults and/or rotations that absorb some of the dextral strain from the Northern branch of the NAF and segment the fault.

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New paleosiesmological constraints on the behaviour of the San Andreas Fault in the Carrizo Plain.

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Paleoseismological investigations of the San Andreas Fault in the Carrizo Plain have greatly influenced models of fault behavior and seismic hazard. Early geomorphic analysis of channel offsets near Wallace Creek led to development of a hypothesis that the Carrizo Plain segment is unusually strong and produces only large earthquakes (>7.8 M) every 240 to 450 years (Sieh and Jahns, 1984) unlike the segments that bound it to the north and south. ^{14}C dates of mainly detrital charcoal samples from the Bidart Fan site, approximately 5 km southeast of Wallace Creek in the Carrizo Plain, have provided some of the best timing constraints on these large surface rupturing events (Grant and Sieh, 1994; and our work in progress). The Bidart site has good, reliably datable stratigraphy for discriminating individual earthquakes. Earlier results based on 14 ^{14}C analyses have suggested that five large earthquakes have occurred since 1218 AD, indicating that large earthquakes in the Carrizo Plain are more frequent than previously thought. Paleoseismological evidence for four surface rupturing earthquakes from three new fault perpendicular trenches excavated in 2005 and 2006 include a well-preserved sag pond, buried mole tracks, fissure infills, and upward terminating fractures. Analyses of new ^{14}C data from these new trenches, in addition to the incorporation of new ^{14}C analyses on charcoal samples collected from three earlier trenches reveal that the last four of these earthquakes occurred since 1475 +or- 50 AD, confirming the possibility of a much shorter recurrence interval, at least during the time period between circa 1400 AD and 1857 AD. Whether all of these events were similar in magnitude to the M7.9 1857 Fort Tejon earthquake or were smaller remains to be determined. We currently do not have slip per event data from the Bidart Fan site to address this problem. Our future work will focus on replicating these short recurrence interval data as well as trying to get slip measurements associated with each of these events. Our continuing efforts of extending the paleoseismological record to 10+ events will also enable us to determine how "characteristic" these shorter recurrence intervals are in the late Holocene history of the San Andreas Fault in the Carrizo Plain as these preliminary results have major implications for the San Andreas and general fault behavior.

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How did the North Anatolian and San Andreas Fault Zones Effect Developments of the Western Anatolia Extended Terrane in Turkey and the Southern Basins and Ranges in the USA, Respectively?

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Both the San Andreas and North Anatolian Faults are in close geographic proximity to two major extended terranes of the world. The San Andreas is located to the west of the southern Basins and Ranges in the USA. The North Anatolian Fault is located to the north of the Western Anatolia Extended Terrane in Turkey. The two fault zones have played major roles in the development of these two extended terranes. In the USA, the northwesterly movement of the Pacific Plate along the San Andreas fault has caused the northwest movement of the Sierra Nevada Block and the development of continental extension associated with the southern Basins and Ranges. In Turkey, westerly lateral extrusion of the Turkish plate along the North Anatolian fault zone has effected continental extension in the Western Anatolia Extended Terrane.

Field data, available radiometric age determinations and seismic reflection profiles suggest that the N-directed Cenozoic extension in western Anatolia is the product of three consecutive extensional stages and is still continuing today. The first stage was initiated in the late Oligocene along a north-dipping extensional simple-shear zone with a listric geometry at depth. The second stage of extension started in early Miocene and produced the Alaşehir Detachment surface as a secondary breakaway. The detachment controlled the Miocene sedimentation in the Alaşehir Graben. The third stage of extension started about 5 Ma ago when the North Anatolian fault was initiated. This extensional phase produced the second-and-third order faults in the Alasehir and Büyük Menderes Grabens. It also caused strike-slip movement along the third order faults and the north-south trending faults of the northern Menderes Massif. The first stage of extension could be attributed to orogenic collapse, the second stage to subduction roll-back, and the third stage to the combined effects of subduction roll-back and lateral extrusion of the Turkish plate.

In the USA, the southern Basins and Ranges extension is accomplished in two continuous stages. The first stage was initiated by the formation of the San Andreas Fault zone in early Miocene which caused the subduction of the Mid-Oceanic Ridge between the Farallon and Pacific plates. During this stage, partial melting of the lower crust produced granitic melts as ductile extension continued. The isostatic rise of metamorphic core complexes started when ductile extension began to subside about 20 Ma ago. Brittle normal faulting in the southern Basins and Ranges initiated at about 16 Ma ago when the North American Plate cooled sufficiently to allow widespread brittle extension.