The Marmara Sea is an intra-continental marine basin between the Aegean and Black seas. It is in a tectonically very active region located on the North Anatolian Fault (NAF) zone (Şengör, 1979; Barka, 1992; Straub et al., 1997; Okay et al., 1999, 2000; Le Pichon et al., 2001; Şengör et al., 2004). The NAF is a major transform-plate boundary that has produced devastating historical earthquakes along its 1600 km length (Ambraseys and Finkel, 1995). The most active northern branch of the NAF cuts across the Marmara in an E-W direction and continues westward into the NE Aegean Sea (Fig. 19).

The Marmara Sea has three ~1250 m-deep strike-slip basins between 10-20 km-wide northern shelf and a 40 km-wide southern shelf. The deep basins are separated by -450 to -600 m deep, NE-trending transpressional ridges. The shelf break is at about -100 m water depth. The slopes leading to the deep basins are steep (>18°) and carry the scars of many paleo-landslides and submarine canyons (Fig.1). They also have some unstable areas near the shelf break and in the upper slope that may slide during future seismic events.

The earthquake events along the NAF have a westward progression with sixty year sequence of rupturing toward Istanbul, in which one event promoting the next. After the 1999 Izmit and Düzce earthquakes, the next large (Mw> 7) earthquake is expected in the Marmara Sea close to Istanbul, an important cultural centre and a mega-metropole with 15 million inhabitants (Parsons et al., 2000). There are also large faults with dip-slip component in the south, near the edge of the southern shelf and Imralı submarine platform which in the event of their rupture, would cause tsunamis in the Marmara Sea. The earthquake activity in the Marmara Sea has produced more than 30 tsunami events in the past two millennium, with heights up to about 6 m in the coastal areas (Yağcı et al., 2002). Most of these tsunamis have probably been caused by submarine land slides.

The coastal areas and freshwater reservoirs providing Istanbul with water are under tsunami risk. The Büyük Çekmece Lake on the northern coast of the Marmara Sea is in location particularly prone to tsunamis. This lake provides more than 15% of Istanbul’s drinking water.

ROV video surveys of the sea floor during the R/V Meteor Leg M44-1 (Halbach et al., 2000) and R/V Le Atalante (Armijo et al., 2005) have proven active venting of methane-rich fluids from the fault on the Western Ridge and the SE corner of the Tekirdağ Basin (Fig. 20). These sites are also characterized by black bacterial mats, chemosynthesis-dependent fauna consisting of mainly bivalves (abundant mytilids), echinids and crustacea and carbonate crusts (Fig. 20). The ROV video observations show that the deep basin floors are commonly marked with very densely distributed burrows, indicating a high benthic faunal activity.

The Marmara Sea is also interesting in terms of its oceanographic setting. It is connected to the low salinity (S=18‰) Black Sea via the İstanbul (Bosphorus) Strait and to the normal marine (S=38.5‰) Aegean Sea via the Canakkale (Dardanelles) Strait; the two straits have sill depths of -65 and -35 m, respectively. There is a permanent two-layer flow in the straits and the Marmara Sea with the halocline located at -25 m (Ünlüata et al., 1990; Besiktepe et al., 2004). The Black Sea waters enters the Marmara Sea as a jet through the İstanbul Strait and forms the upper layer (Besiktepe et al., 1994). The upper layer water circulates in the Marmara Sea as an anticyclonic gyre at velocities of 20-50 cm/s Marmara Sea as an anticyclonic gyre at velocities of 20-50 cm/s and flows out through the Marmara Sea as an anticyclonic gyre at velocities of 20-50 cm/s and flows out through the Çanakkale Strait as the surface current. The Mediterranean water enters the Marmara Sea as an undercurrent and dips into the Tekirdağ Basin and forms the lower water layer with a potential temperature of 14.5°C (Ünlüata et al., 1990; Besiktepe et al., 1993). Its eastward flow towards the
Istanbul Strait is somewhat hindered by the pressure ridges. The slow circulation, coupled with the microbial degradation of the organic matter, results in a gradual depletion of oxygen in the lower-layer to 2-3 mg O2/l in the Çınarcık Basin. The renewal time of surface and the deep waters is estimated to be 4-5 months and 6-7 years, respectively (Ünlüata et al., 1990, Beşiktepe et al., 1993). The Sea of Marmara region is densely populated and industrialized with more than Turkey’s 20% population and 50% industry located in its drainage basin. The municipal and industrial inputs from its drainage basin, together with nutrient and contaminant inputs from the Black Sea, have polluted the Marmara Sea in the last 40 years (Orhon et al., 1994; Polat and Turgut, 1995).

Its high tectonic activity with catastrophic earthquakes, submarine landslides and resulting tsunamis, as well as its special oceanographic setting as a gateway between the Mediterranean and Black Seas, makes the Marmara Sea a natural laboratory for multidisciplinary scientific research and training area for young scientists.

**The significance of the Marmara Sea seismic gap for earthquake risk assessment and mitigation**

The westward progression of major ruptures along the NAF (Barka, 1996), culminating with the 1999 destructive earthquake events, leaves a 170 km long seismic gap along the Sea of Marmara capable of generating large earthquakes (Reilinger et al., 2000; Hubert-Ferrari et al., 2000). The last destructive earthquakes occurred at the western and eastern edges of the Marmara basin (i.e., 1912 Ganos and 1999 İzmit and Düzce earthquakes). It is likely that fault ruptures will fill this gap in the next decades (Toksoz et al., 1999; Pinar et al., 2001; Öncel and Wyss, 2000; Parsons et al., 2000; Atakan et al., 2002).

The hazard facing Istanbul and adjacent areas varies widely depending on where and how the predicted Marmara seismic rupture will take place. This region of the North Anatolian Fault is thus critical to our understanding of fault interactions, stress build-up during seismic cycle and seismic hazard in the Istanbul area. Estimates of the slip rate, distribution of motion, microseismicity along the strands of the NAF, detection of fluid outflow and the analysis of how it relates to the seismic activity can help reach a realistic assessment of seismic hazards for this densely populated area of Turkey.

Seafloor observatories would offer earth scientists and oceanographers working in this region unique new opportunities:

. to study multiple, interrelated processes over time scales ranging from seconds to decades;
. to conduct comparative studies of regional processes and spatial characteristics;
. to map basin-scale structures using time-series measurements.

**Scientific objectives**

The overall objectives of the proposed activity in the Marmara region are mainly focused to conduct comparative studies of multiple, interrelated processes driven by fault movement. These studies should be carried out giving high priority to those areas which are more prone to seismic hazard.
Figure 1: Morphotectonic map of the Marmara Sea, showing the location of the proposed observatory sites.

Figure 2: Cold fluid venting, carbonate mound, black bacterial mats and benthic fauna (mainly bivalves) as white shells from the SE Tekirdag Basin, proposed observatory site 2 (R/V Le Atalante cruise, Marmarascarp project; Armijo et al., 2005). The fish is 10 cm long. See Fig. 1 for location of the site.

The lack of extensive, more-or-less continuous time-series measurements is probably one of the most serious limits to understanding of long-term trends and cyclic changes of fault behaviour, as well as episodic events such as major earthquakes or submarine landslides. The key point to address these issues will be obtaining time-series observations at different locations along the North
Anatolian fault system. The results of these observations could be integrated in theoretical models that will be used to predict fault behaviour and to guide new experiments.

The science topics and themes that can be tackled using ocean observatory capabilities, span a wide range of studies. The following outlines a set of scientific issues and a selection of questions for which ocean observatories could enable major breakthroughs by using new technology and innovative experimental approaches:

1) Earthquake processes: As fault blocks move, they can lock and accumulate stress that can be released quickly in the form of earthquakes (seismic deformation) or as creeping motion (aseismic deformation). Monitoring the seismic and aseismic deformation over an extended period of time will enable scientists to understand how and when strain is released along the NAF system. These data will be used to assess and mitigate the geological risk. Observatories can facilitate contemporaneous measurements of different parameters over long time scales, which is essential to their characterization and understanding.

2) Sedimentation and sediment transport: normal hemi-pelagic sedimentation, and sedimentation triggered by storm events, floods, and earthquakes;

3) Water column studies;

4) Fluids, chemistry, and ecological characterization;

5) How often, and in what pattern and quantity, is fluid delivered from the fault to the sea?

6) What are the primary heat transfers, chemical and biological consequences of fluid outflow along the fault system?

7) To what degree does fluid venting influence the physical, chemical and biological character of the overlying water column? What is the relative importance of episodic vs. steady state outputs?

Each question is an important research focus in its own right; taken together they encompass the major interactive processes operative along the global fault system.

Significant observatory sites

1) Eastern edge of the Çınarcık Basin: the 1999 earthquake rupture extends up to here. The next earthquake rupture is expected to involve the fault segment in this basin and its westward extension at least all the way to the Central Basin (Le Pichon et al., 2001). This basin is also prone to submarine landslides and tsunamies. It is also the location where the deep waters of Mediterranean origin move towards the Istanbul Strait on their way to the Black Sea, and where the pollutants and nutrients from the Istanbul Metropolitan area and the Black Sea begin affecting the deep basinal areas of the Marmara Sea.

2) Tekirdağ Basin: Tekirdağ Basin and the Western Ridge is intersected by the main Marmara fault with fresh scarps and a prominent deep furrow, where fluid escape, bacterial mats, mineral crusts and associated benthic life have been observed (Fig. 20) The western extension of the main Marmara fault in the Tekirdağ Basin connects with the onshore Ganos Fault, which ruptured during 1912 earthquake. The Tekirdağ Basin is also the first location where the waters of Mediterranean origin from the Çanakkale Strait (Dardanelles) descend into the deep Marmara basinal areas.
3) The Eastern Ridge: this ridge separates the Çınarcık and Central Basins and constitutes a part of the seismic gap in the Marmara Sea. Here, it is important to monitor micro-seismic activity, with a view to determine if the fault segment is locked or creeping.

The main objectives in these locations are to monitor:

1) micro-seismic activity,
2) fluid escape and its relation to seismic activity, benthic organic activity and ecology,
3) sedimentary processes related to seismic activity, submarine landslides, resulting tsunamis and turbidity currents, and
4) to obtain time-series oceanographic data (T, salinity, dip currents, turbidity, oxygen content), which are important for understanding the deep circulation dynamics and for monitoring ecological changes and effects of pollution in the deep Marmara Sea.

Existing national and international programs on the Marmara Sea

There are no sea-floor observatory programmes presently being carried out in the Marmara Sea. However, there are several ongoing collaborative international research projects, related to mainly the earthquake geology and geophysics.

6) MARNAUT (investigation of cold seeps and potential landslide areas with Nautil submersible) CNRS (CEREGE, PEPS), College de France, ITU, MAM, IFREMER, FUB, GEOMAR, 2007.
7) Sediment Geochemistry Atlas of the Marmara Sea, ITU supported by TUBITAK, Project no.103Y053.

Participants

ITU-EMCOL (Turkey)
ISMAR (Italy)
COLLEGE DE FRANCE
Financial support

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## Regional consortium of users

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Selected References for Node description and participants:


Reilinger R., N. Toksoz, S. McLKusky, A. Barka, 1999 Izmit , Turkey earthquake was no surprise, GSA Today, 10 (2000) 1-6.


