EVALUATION OF EARTHQUAKE RISK IN THE SEA OF MARMARA

SUMMARY

Within the scope of the "Evaluation of Earthquake Risk in the Sea of Marmara" project, marine field studies were carried out in the northern shelf of the Sea of Marmara and in the Gulf of Izmit, Gemlik and Saros between September 10 and October 1, 2005, using the Italian research ship R/V Urania. In these studies, 24 core and 7 bucket samples were collected with multi-beam bathymetry (Multi Beam Echosounder System: MBES) and high-resolution shallow seismic (Chirp-Subbottom Profiler: Chirp - SBP) data. In addition, multi-channel seismic reflection (Multi-Channel Seismic: MCS) data were obtained in the Gulf of Gemlik. As a result of the initial evaluation of the field data, WNW-ESE direction, transtantional seconder active faults were found in the Çekmece and the shelf areas around the Adalar to the north of the main fault. It is aimed to date and calculate the deformation rates of sediment cores from the old coastlines, in the Izmit Bay. In addition, it is aimed to determine and date the records of 1999 and previous earthquakes by taking cores from the Karamürsel (Middle Izmit) Basin. In the Gulf of Gemlik, where the middle branch of the North Anatolian Fault (NAF), E-W directional right-lateral strike-slip main fault and NW-SE stretched active faults are mapped by bathymetry, Chirp-SBP and MSC seismic reflection data.

In the second development report, MBES bathymetry map around Adalar and Gemlik Bay and 2nd derivative maps of bathymetry data of the Holocene floor, some processed MCS lines in Gemlik Bay, core definitions and analysis, core definitions in Izmit Bay, Hersek Delta and Tuzla on land In the with this studies, earthquake geology and apatite fission-track analysis results that made around the Ganos Fault are given.

In the third development report period, multi-channel seismic and ground radar (GPR: Ground Penetrating Radar) studies were carried out in Hersek Delta and GPR studies were carried out in Tuzla. In addition, the MARM05-110 core was drilled from the Adalar shelf, and the sediments at and below the 65 m coastline were dated by AMS 14C in this core. The vertical tectonic velocity was calculated by aging the shoreline, which stands at -125 m today, on the MARM05-118 core taken from the Gulf of Izmit. The sedimentological, physical (color, density) and geochemical properties of the seismoturbidite units formed by earthquakes were defined by analyzing the MARM05-115 and MARM05-119 cores with an X-ray core scanner in the Gulf of Izmit. Samples were taken from these units and sent for AMS 14C dating. Magnetic susceptibility logs of all examined cores within the scope of MSCL logs are presented in this report. Data-processing of multi-channel seismic lines taken from Gemlik Bay continued and 5 new lines were processed and interpreted. A fault map of the western part of the bay was drawn by using these lines and the bathymetry map. It is planned to further develop this fault map in the next project phases. The apatite fission-trace analysis results, which should be given during this study period, were presented in the previous reporting period and are therefore included in this report.

In the fourth reporting period (December 2006 – December 2007), MARM05-110 on the Islands shelf, MARM05-113 on the Gulf of Izmit, MARM05-113, MARM05-115; and GE-124 and GE-125 cores taken from Gemlik Bay were analyzed by the Sensor Core Logger (MSCL: Multi Sensor Core Logger). For these analyses, gamma density, magnetic susceptibility, P-wave velocity and electrical resistance sensors were used in the device. These features gave important information about the physical properties of the sediments and especially the seismoturbidites deposited on the sea floor in the last 10-15 thousand years. In the fourth reporting period, 210Pb and 137Cs were dated to confirm whether the 32.5 cm thick mass flow at the top of the sediment/water core no. MARM05-112 taken from the deepest part of the Izmit Bay (Karamürsel Basin) belongs to the 1999 earthquake. Seismoturbidites (mass flows)

were detected by XRF core scanner analyzes in the 2.35 m long MARM05-115 gravity core taken from the same location as MARM05-112 and MARM05-113, and dating studies of 4 of these levels were carried out using the AMS 14C method. The average recurrence interval of earthquakes was calculated by taking into account the number of seismoturbidite levels determined according to XRF core scanner studies and the age of the last one of 2400 years. Relief and contour bathymetry maps of the Gulf of Izmit were prepared by combining the multibeam bathymetry data collected by the voyages of Odin Finder, Urania and SHOD Çubuklu in the Gulf of Izmit between 2000-2005. The relief map shows the trace of the NAF on the seafloor in the Gulf of Izmit well. Again in the 4th reporting period, data-processing and interpretation of 8 Multi-Channel Seismic (MCS) sections in the Gulf of Gemlik were carried out. Thus, the total number of processed and interpreted sections reached 18. As a result of these studies, some additions were made to the fault map of the Gemlik Bay, especially for the western part of the Gulf.

In the fifth and last reporting period, age determination analyzes of 3 seismoturbidites determined according to XRF core scanner analyzes in the MARM05-115 gravity core taken from the Gulf of Izmit were carried out using the AMS 14C method. With these analyses, age determination analyzes with the AMS 14C method in the Gulf of Izmit were completed. Data processing and interpretation of 27 MCS lines in total in the Gulf of Gemlik have been completed and based on these, the fault map of the Gulf of Gemlik has been prepared in its final form. Considering all the data obtained in this project and the results of previous marine research and modeling, the earthquake risk in the Marmara Sea has been evaluated and presented in the final section of the report.

The main results from the studies to date are summarized below.

Bathymetry map of the Holocene baement in the east of Adalar, together with the Chirp - SBP data, shows the WNW-ESE trending secondary transtensional faults, some of which cut the Holocene unit and are active faults, the elevations of the E-W directional Paleozoic basement and the old coastline at -85 m. The age of this shoreline is known from previous studies to be approximately BP 12 14C years (BP 14 calendar years). WNW-ESE trending faults are structures formed by the remobilization of Hercynian structures to the Paleozoic basement. These structures control the slope and shelf of morphotectonics of today's Çınarcık Basin. Similar faults were also found off the shelf of Çekmece. "Physical property" analyzes of the MARM05-110 core on the Islands shelf were made with the Core Logger (MSCL: Multi Sensor Core Logger) and interpreted. For these analyses, gamma density, magnetic susceptibility, P-wave velocity and electrical resistance sensors were used in the device. The shoreline at -64 m in core MARM05-110 was dated for the first time in this study by AMS 14C analysis and was found to be BP 10100 14C years. This indicates that the shoreline was formed during the sea level stagnation of the Younger Dryas period (approximately 11,000-10,000 14C years BP).

In Tuzla, there are the shales of the Devonian aged Kartal Formation of the Istanbul Zone and the nodular limestones of the Tuzla Formation, and the Quaternary aged coastal plain and lagoonal sedimentary cover unconformably overlying them. The GPR studies we conducted in Tuzla did not give good results due to sea water intrusion and silt-clay cover. However, the density of microseismicity here indicates live fault activity. The most important reason for this activity is the NW-SE trending İçmeler Fault separating the Paleozoic and Quaternary units. This fault is similar to the faults we see on the shelf, which were formed by the re-activation of the Hercynian aged structures. It may take action in the Great Marmara Earthquake and cause loss of property and life in the Tuzla region.

Faults and soil properties determined during the studies on both Tuzla and the islands shelf bring to the agenda the submarine landslides, which are another important geological risk, and the tsunamis they may cause in the Çınarcık Basin. There is a risk of mass movements due to earthquake activity on

the slopes due to the presence of WNW-ESE direction transtensional faults detected on the shelf and shelf edge in the south and east of the Islands and the presence of Devon aged shale ground belonging to the Istanbul Zone. Indeed, past examples of submarine landslides are observed on bathymetric maps along the slopes.

Relief and contour bathymetry maps of the Gulf of Izmit were prepared by combining the multibeam bathymetry data collected with the expeditions of the Odin Finder, Urania and SHOD Çubuklu ships in the Gulf of Izmit between 2000-2005. The relief map shows the trace of the NAF on the seafloor in the Gulf of Izmit well. The branch of the NAF crossing the Herzegovina Delta was defined in the land seismic study. The geometry of the NAF on the delta was determined as a result of the interpretation of the land data together with the sea seismic lines. Accordingly, the NAF formed the 28 m high Dedeler Tepe pressure ridge with a leftward jump in the north of Hersek Lake. GPR studies in Herzegovina gave very shallow penetration. The main reasons for this are salt water intrusion and clay and silt cover on the surface as these areas are close to the sea. When the data obtained from this project and previous studies on land (sea seismic, radar interferometry and aftershock data (InSAR)) are evaluated together, it is seen that the 1999 Izmit earthquake rupture continues until 30 km west of the delta after fading.

Sensored Core Logger (MSCL: Multi Sensor Core Logger) and XRF core scanner analyzes of MARM05-113, MARM05-113 and MARM05-115 cores in the Gulf of Izmit were performed and interpreted. These physical and geochemical analyzes gave important information about the physical and geochemical properties of the sediments deposited on the seabed, and especially of the seismoturbidites. It was also found at -125 m in the MARM05-118 core at -64 m southeast of the coastline on the northern slope of the Izmit Bay Karamürsel Pithole, and was determined by the AMS 14C method. Aged at 10,700 14C years (11,900 caliber years). As a result, the vertical tectonic velocity (subduction) for this region has been calculated as approximately 5 m/1,000 years.

In the Karamürsel basin of the Izmit Bay, the cores contain many turbidite units whose precipitation was triggered by earthquakes. The lower contact of these units is sharp and sometimes eroded, consisting of sand-silt at the base of a few cm and a few 10 cm thick mud units with a banded and laminated structure on the upper part. In the coarse-grained base parts, it generally shows upward grain-size gradation and a repetition of sand-silt layers or laminae, the thickness of which decreases upwards. These units, which present a reflected seismo-turbidite characteristic with these features, were deposited by turbidite currents reflecting from the opposite slope and gradually losing their flow velocity. Physical properties with MSCL and geochemical analyzes with XRF-core scanner gave detailed and important information about the physical and geochemical properties of seismoturbidites in the Karamürsel Basin. The results show that seismoturbidite units are generally of high density, low electrical resistivity and low porosity. In addition, magnetic susceptibility values are variable depending on the source region. Within the seismoturbidite units, geochemical anomalies such as Mn depletion and Ca depletion at the base have been detected. The sand member at the bottom of the top turbidite unit, which was proven by the 210Pb, 137Cs and AMS 14C methods to have formed in the last earthquake, is rich in Ca and depleted by other elements. It indicates that Ca enrichment may occur as a result of partially shell and partially reduction of methane with sulfate under anaerobic conditions and carbonate precipitation. Mn enrichment below the unit; on the other hand, Mn depletion in and above it, before the earthquake, the bottom water was oxygenated; shows that after the earthquake, it became anoxic. Using these physical, sedimentological and geochemical features determined in the 1999 earthquake record, seven other seismoturbidite units were determined in the gravity core no. MARM05-115 and age determinations were made using the AMS 14C method. In this way, 8 earthquakes that have occurred on the Izmit Bay segment in the last 2400 years have been detected,

and based on this, an average of 300-year earthquake recurrence interval has been found. However, this interval is not regular and varies considerably.^

In the Gulf of Gemlik, NW-SE trending active faults are clearly visible on the MCS and Chirp - SBP lines and on the MBES bathymetry map. The structures in the Gemlik Bay are generally tensional (transtensional) faults. Compression structures are not seen. To the east of the bay, the submarine part of the Büyükdere delta is very well observed on the MBES bathymetry map, MCS and Chirp - SBP lines. According to the MSCL, XRF core scanner, organic and inorganic carbon, and AMS 14C age determination analyzes obtained from GE-124 and GE-125 gravity cores, the divergent part of the delta, which is under the sea today, has developed with the rising sea level from today to 11,500-12,000 14C years (~13,000 caliber years) ago. According to the high resolution bathymetry map, the delta deposits show an offset of roughly 70 m by the fault. Since this translation occurred in the last 13 thousand years after delta deposition, the average slip rate along the Middle Arm was calculated as 5.4 mm/year. This speed is compatible with the slip rate obtained by block modeling from GPS data. The slip velocity on the Gemlik Fault is slower than the movement on the northern branch of the NAF. However, when the calculated slip rate of 5.4 mm/year is evaluated together with the fact that the last major earthquake (M=7.2) according to historical records was in 1419, it can be said that the risk of producing an earthquake for this fault is higher than expected. However, more detailed bathymetry studies are needed to accurately determine this amount of drift. Apatite fission-track analyzes show that the Ganos Fault uses an old weak zone (Intra-pontide suture zone), that the Ganos Mountain has existed since the end of the Oligocene, the rocks in the south of the fault uplifted 30-25 Mya, and the rocks in the north 11 Mya.

In the continuation of the most active northern branch of the NAF, dextral strike-slip main branch and E-W directional stretched secondary faults were also detected in Saros Bay, which is located in the Aegean Sea. Here, the offset amount of a valley offset by the main fault and descending from the slope to a deep depression was found to be approximately 150 m from the bathymetry data. Considering that this valley lost its activity as a result of sea level rise about 15 thousand years ago, it has been calculated that the average slip-rate on this fault in the last 15 thousand years is approximately 1 cm/year.

When the data obtained in this project is interpreted by combining with other known data, it is clear that the expected Marmara Earthquake will be on the northern branch of the NAF zone, which is the most active branch. The part (segment) with the least seismicity and fluid outflow activity along this branch is the part called the Middle Ridge Fault on the Middle Ridge (South of Çekmece-Silivri). This fault has not produced earthquakes since 1766. The current microseismic activity on this segment is very low. On the other hand, after the 1999 earthquake, a significant microseismicity is observed on the Adalar Fault in the east, the Gulf of Izmit, and the West Ridge and the Tekirdağ Trough in the west. All these data indicate that the North Branch is most likely locked along the Middle Ridge Fault and that this segment is likely to break in the expected Marmara Earthquake. The faults observed in the south of the Çınarcık Trough are non-continuous, vertical (normal) component faults. They can produce earthquakes of around magnitude 6 and cause a tsunami of 4-6 m high due to its normal component.