A 3000 yr history of earthquakes recorded in Hazar Lake potentially related to ruptures along the East Anatolian Fault (Turkey).

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Abstract:

In this study, we focus on the paleoseismicity of the East Anatolian Fault (EAF). We investigated Hazar Lake, a pull-apart basin located on the EAF. During the campaign of 2007, short and long cores were taken from the bottom of the lake. Several thin earthquake-triggered sedimentary events (less than 2 cm) were detected in the cores. Radiometric dating (^{14}C, ^{210}Pb, ^{137}Cs) revealed the correlation between the youngest four events and historical earthquakes in 1874-75, 1779-1789, 1513-1514 and 1285. Thin sections showed that the sedimentary events are composed of several thin turbidites, characterized by bioturbated coarse basal sand layers. The bioturbation indicates the time elapsed between two sub-events. We inferred that Hazar Lake is extremely sensitive to earthquake shaking, and its sedimentary sequence may contain a complete record of large M>6.5 paleoearthquakes along the EAF.

Key words: *Hazar Lake, Paleoseismology, East Anatolian Fault, Thin turbidites*

INTRODUCTION

The East Anatolian Fault (EAF) is a major left-lateral strike-slip fault accommodating, with the conjugate North Anatolian Fault, the westward extrusion of the Anatolian Plate away from the Arabia-Eurasia collision zone. The East Anatolian Fault ruptured over most of its length during the 19th century in a series of magnitude ~7 earthquakes. During the 20th century this fault was less active with only two events of magnitude greater than 6. This absence of large earthquakes has resulted in relatively little attention being paid to the East Anatolian Fault compared to the North Anatolian Fault, which has ruptured during the last century in several earthquakes of Ms~7. To constrain the seismic history of the East Anatolian Fault at its central part, we focus on the sedimentary sequence of Hazar Lake, which occupies a 20 km long pull-apart basin. Historical earthquakes in this region are well documented (Ambraseys, 1989; 2009; Guidoboni et al., 1994; Cetin et al., 2003). We inferred that Hazar Lake is an ideal location to study the paleoseismicity of the EAF, specially the linkage between earthquakes and turbidites.

GEOLOGICAL AND TECTONIC SETTINGS

Hazar Lake (1248 m above sea level) is located in the Taurus Mountains, in the Eastern Anatolia (Turkey). It is a depression 25 km long, 7 km wide and up to 216 m deep. It is a hardwater lake characterized by a pH around 9.3 (Sen et al., 2012). The basin has been interpreted as an active pull-apart (Arpat & Saroglu, 1972; Hempton & Dunne, 1984; Sengör et al., 1985; Çetin et al., 2003). However, based on a dense grid of reflection-seismic profiles, Garcia Moreno et al. (2010) showed that a continuous left-lateral strike-slip fault runs in fact across Hazar Lake from its northeastern to its southwestern corner. Secondary oblique faults were also mapped (Garcia Moreno et al., 2010) which comprise in particular the Northwestern Sivrice Fault at the WSW extremity of the Lake and the Southern Gezin Fault bounding the steep slopes of the southern margin of the basin.

The Kurk River discharges into the southwestern part of Hazar Basin forming a wide delta. Its large catchment area is composed of the Senomamian Yüksekova Melange (andesites, basalts, gabbros, dacites dykes) and of the Middle Eocene Maden Melange (sedimentary and volcanic formations) (Sengor and Yilmaz, 1981).

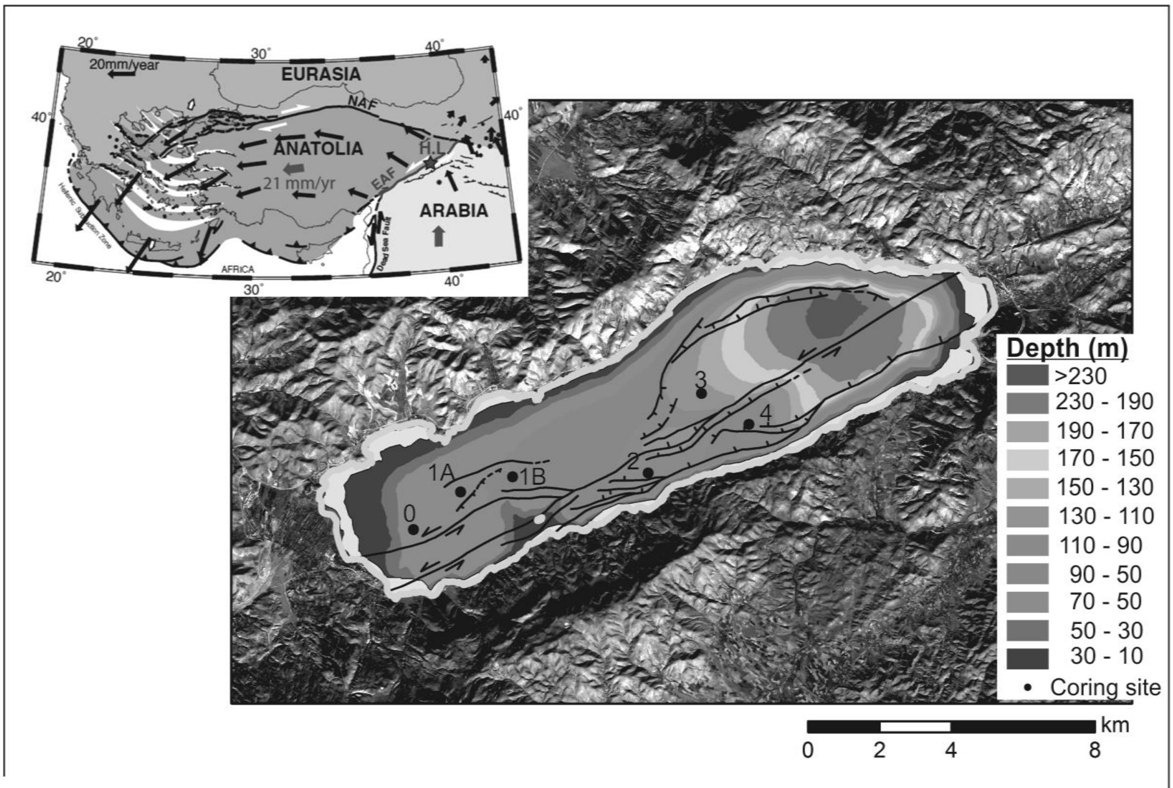

Figure 1- Hazar Lake is located on the East Anatolian fault (blue star). The six coring sites are indicated on the bathymetric map. Coring site 0 is situated in the shallowest part of the basin whereas coring site 3 and 4 were taken in the deep basin.

The bedrock of the southern margin is mainly made of Late Jurassic magmatic rocks and Middle Eocene limestones, whereas the northern margin is composed of Late Cretaceous sedimentary rocks and ophiolite.

MATERIALS AND METHODS

Short and long sedimentary cores were collected during the 2007 field campaign in order to retrieve a paleoseismic record. Using a platform, the short cores were taken by a UWITEC gravity corer, whereas the long cores were collected using a piston hammering system of ITU-EMCOL. We obtained short cores of 1 to 1.3m in length at six sites, and 5 m long cores at two sites (Fig. 1). The cores were split and studied at the University of Liège. The sedimentary records were analyzed by combining X-ray imagery, magnetic susceptibility, grain-size distribution, loss-on-ignition and XRF measurements. We investigated the nature and microstructure of the sedimentary events with thin sections analysis. The sources of event deposits were estimated by heavy minerals provenance analysis. Identified sedimentary events were dated by radiometric dating (^{14}C, ^{137}Cs and ^{210}Pb) and compared to the historical earthquake record (Ambraseys, 1989; Ambraseys and Finkel, 1995; Ambraseys, 2009). We computed shake maps for the individual historical earthquakes in order to decipher the ones that potentially have triggered turbidites in Hazar Lake and be recorded there.

RESULTS AND DISCUSSION

All cores were correlated based on obvious along-core anomalies in the magnetic susceptibility (MS) and Ti or Ca-content profiles. These variations were related to lake level changes.

At least 4 sedimentary events characterized by MS peaks were identified in the short cores, and more in the long cores. The events are inferred to be earthquake-triggered based on (1) their occurrence at different sites, which is an indication of multiple coeval turbiditic flows; (2) their large-scale basin-wide impact on the lake sediments even at sites where no turbiditic deposit occurred. According to the radionuclide dating, the youngest four events would correspond to the historical earthquakes occurred in 1874-75, 1779-1789, 1513-1514 and 1285.

The individual events showed distinct signatures at the different sites. In particular, the magnitude of the terrigenous signal varies significantly. We thus conclude that each site has a specific sensitivity to earthquake shaking, with site 2 revealed as the most sensitive. It is located in a flat area near the base of the steep subaqueous slopes overhung by the steep subaerial southern slopes of the Hazar Mountains. The rivers draining the Hazar Mountains are ephemeral and provide restricted sedimentary supply; hence the subaqueous slopes do not accumulate significant sedimentary load. However, these steep slopes are extremely sensitive to earthquake shaking and an earthquake with an intensity of 6 or potentially less would trigger a turbiditic flow. Sites1a and 1b, located in the flat basin east of the Kürk Delta, are slightly less sensitive. Sites 0, 3 and 4, located in different dipping parts of the basin, do not record any terrigenous events. Nevertheless, Ca enrichments after these events are recorded at all sites. This means that the terrigenous events recorded at sites 1 and 2 affected the chemistry of the entire water column. We attributed Ca enrichments to indirect effects of strong earthquake shaking, which supplied nutrients in Hazar Basin by water-column mixing and triggered a benthic bloom. In these particular conditions, calcite is precipitated by phytoplankton, creating peaks of Ca. This was confirmed by SEM investigations that revealed the presence of calcite biomineralization.

Thin section analyses provided further information regarding the sedimentary arrangement of individual event deposits. In fact, it is seen that event deposits are composed of series of individual thin turbidites characterized by a basal coarse grained sand, grading upward to a clayey layer. The thicknesses of the sub-events are less than 0.4 mm on average. We observed the presence of bioturbation caused by oligochaetes and chironomids in each sub-event. Each layer with a coarse-grained base is thus a separated turbiditic flow. The thin section study allows us to conclude that an individual event can be composed of several coarse-grained sub-events of different magnitude, with a time lapse in between longer than a week.

Individual thin turbidites are inferred to have a seismic trigger because the largest ones are recorded simultaneously at sites 1 and 2, which cannot be formed by a unique turbiditic flow. The different earthquake triggered turbiditic sub-events contained in a given sedimentary event can be interpreted in two different ways. They may be the expression of a complete earthquake sequence (i.e main-shock, foreshocks and aftershocks) or of a burst of earthquakes of M>6.5 rupturing the East Anatolian Fault in a pattern similar to the 20th century sequence of the North Anatolian Fault (Stein et al., 1997). A comparison between the computed shake maps based on historical data and the dated turbiditic record will be used to decipher between the two options.

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