Earth and Planetary Science Letters 274 (2008) 34–39

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

journal homepage: www.elsevier.com/locate/epsl

Gas emissions and active tectonics within the submerged section of the North Anatolian Fault zone in the Sea of Marmara

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ARTICLE INFO

Article history:
Received 20 May 2008
Accepted 29 June 2008
Available online 8 July 2008

Keywords:
seismicity
fluids
gas emission
Marmara Sea
North Anatolian Fault

ABSTRACT

The submerged section of the North Anatolian fault within the Marmara Sea was investigated using acoustic techniques and submersible dives. Most gas emissions in the water column were found near the surface expression of known active faults. Gas emissions are unevenly distributed. The linear fault segment crossing the Central High and forming a seismic gap – as it has not ruptured since 1766, based on historical seismicity, exhibits relatively less gas emissions than the adjacent segments. In the eastern Sea of Marmara, active gas emissions are also found above a buried transtensional fault zone, which displayed micro-seismic activity after the 1999 events. Remarkably, this zone of gas emission extends westward all along the southern edge of Cinarcik basin, well beyond the zone where 1999 aftershocks were observed. The long term monitoring of gas seeps could hence be highly valuable for the understanding of the evolution of the fluid-fault coupling processes during the earthquake cycle within the Marmara Sea.

Associations between fluid expulsion sites on continental margins (generally called cold seeps) and active fault systems have been recognized for some time (Moore et al., 1990; Le Pichon et al., 1992). It is also known that earthquakes influence gas emissions at cold seeps, and precursor gas emissions have been observed (Hovland et al., 2002). In the Gulf of Izmit at the eastern end of the Sea of Marmara, expulsion of gas through seafloor fault ruptures was observed after the 1999 Kocaeli earthquake on the North Anatolian Fault (Alpar, 1999; Kuşçu et al., 2005). However, detailed studies often conclude that spatial relationships between cold seeps and presumably permeable faults are complex (Henry et al., 2002; Gay et al., 2007) or, worse, absent (Paull et al., 2005). Other authors (Tryon et al., 1999, 2002) have suggested that it is very difficult to get free gas to pass through sediment but relatively easy to get it to go through fractures, which leads to water seeps being found in lots of places, such as outcrops of sand layers, while gas seeps more often are found associated with fractures. We here present data from acoustic surveys and Nautile submersible dives over the whole Sea of Marmara showing that, at least in some settings, distribution of gas seeps may provide indications of fault activity and even help identify buried structures.

In September 2000, acoustic reflectivity images of the deeper parts of the Sea of Marmara were obtained (Rangin et al., 2001; Le Pichon et al., 2001) with a 180 kHz side scan sonar (hereafter called SAR, for “Sonar Acoustique Remorqué”) towed by R/V Le Suroit, ~75 m above seafloor (Fig. 1a). Echoes were observed before the first seafloor arrival; such echoes are known to be produced by gas plumes (Klaucke et al., 2006; Merewether et al., 1985; Paull et al., 1995). In May–June 2007, during the MarNaut cruise of R/V L'Atalante, a SIMRAD-EK60 echo sounder operating at 38 kHz and mounted on a fish towed at approximately 10 m depth was used for plume detection (Fig. 1b). Remarkably, all those sites where acoustic anomalies were detected in 2000, were still active when revisited seven years later (Fig. 2). The Sea of Marmara is also densely covered with chirp sediment sounder profiles. Fading patterns indicating the presence of gas in the sediment are systematically

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doi:10.1016/j.epsl.2008.06.047

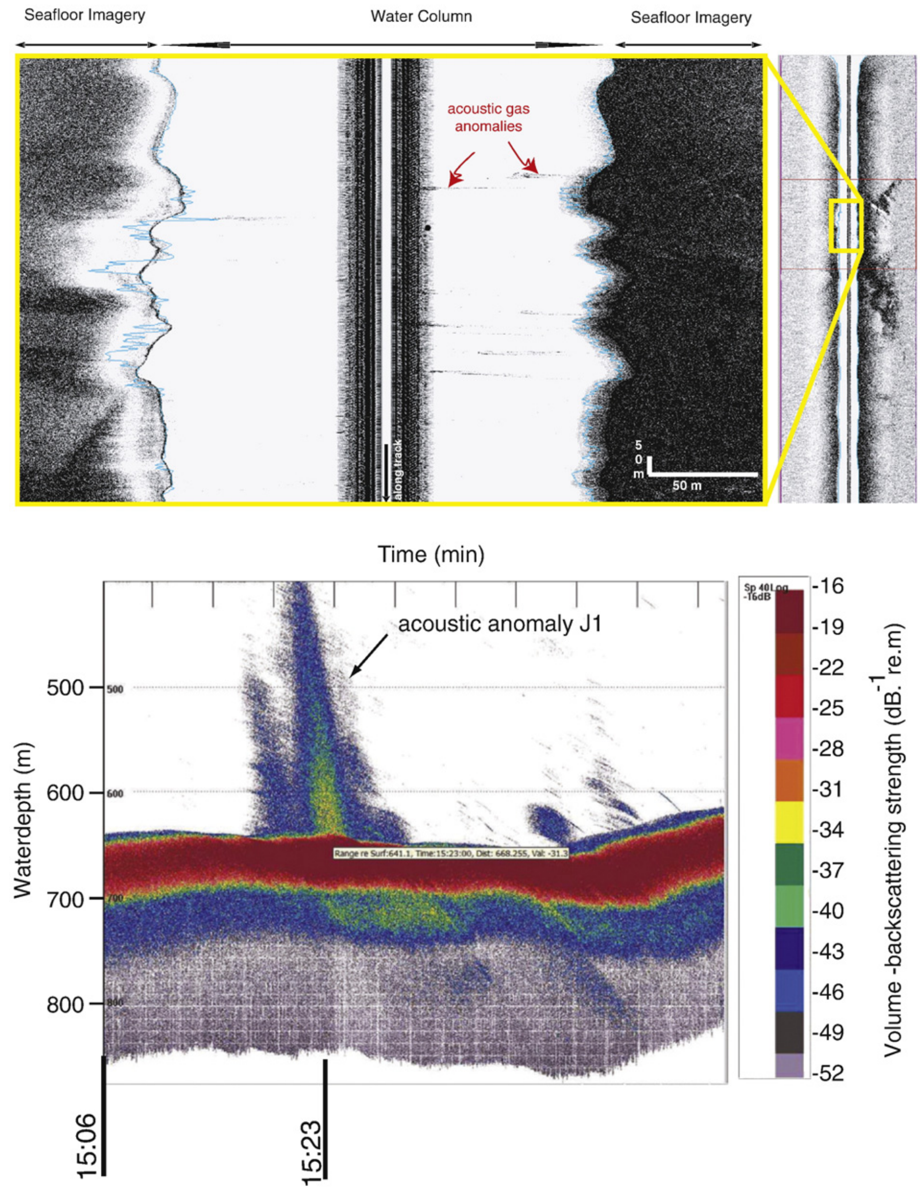

Fig. 1. (a): Example of side scan sonar (SAR) data collected in september 2000 with R/V Le Suroit, using a 180 kHz system towed ~70 to 80 m above seafloor. The presence of acoustic anomalies in the water column below the SAR was only recognized recently. In the usual data processing flow of side scan sonar data, the signal recorded before the first seafloor arrival is discarded and the later signal, corresponding to seafloor backscatter, is projected on a flat surface or on topography On the raw data, however, echoes may be observed before the first seafloor arrival within a 100–200 m swath, depending on the elevation of the SAR above the seafloor. Gas plumes have for long been known to produce such echoes (Klaucke et al., 2006; Merewether et al., 1985; Paull et al., 1995). The right image represents the reflectivity image that is traditionally used by marine geologists (see on the middle right a typical trace of landslide). The central white stripe below ship tracks is a (blind zone), indicating signal propagating in the water column. The left image is a blow up of the yellow box extracted from right image, showing details of the (white stripe). (b): Example of acoustic anomalies, detected near 40°49′N, 27°47′E in May–June 2007, during the MarNaut cruise of R/V L'Atalante, using a SIMRAD-EK60 echo sounder (operating at 38 kHz, a standard for fishery purposes). The transducer unit was mounted on a fish towed 5 m off the ship and at approximately 10 m depth, limiting ship speed to 3 knots. The opening angle of the acoustic lobe is 7.1°. Average water depth is about 666 m, corresponding to a 80-m diameter footprint on the seafloor. The horizontal scale can be inferred from the ship speed and the distance (equal to 1570 m) between the two vertical lines indicating the position of the vessel at 15h06 and 15h23. The source of this acoustic anomaly, ground truthed during Nautile dive 1662, is not located on the fault valley, but on top of the Western Ridge, less than 1 km north of the fault trace.

observed near where acoustic anomalies are found in the water column (Fig. 3). Nautile submersible dives performed at acoustic anomaly sites found manifestations of fluid outflow such as patches of reduced sediment, with 1–10 m size range (Fig. 4). In some of them, trains of bubbles flow out from ~1 cm in diameter carbonate-cemented conduits. In total, bubble emissions were found at 7 of the 11 sites with water column echoes that were explored with the submersible, but some could easily have been missed by visual observation because of the small bubble sizes (1–5 mm diameter).

Most anomalies (Fig. 2) were found in the Cinarcik Basin, in the Tekirdag Basin and on the Western High. They appear less common over the northeastern Central Basin, the Central High, and are absent in the Kumburgaz Basin. A statistical approach of cold seep distribution is shown in the supplementary material. The seafloor trace of active faults is known from previous morphotectonic studies (Rangin et al., 2004; Armijo et al., 2002; 2005; Imren et al., 2001). We analyze the relationships between gas seep distribution and active faults based on this framework, complemented on the local scale by Nautile observations.

In the Cinarcik Basin, although SAR coverage is evenly distributed over most of its surface, gas emissions are only identified along the edges of the basin. A series of acoustic anomalies were identified along the base of the northern escarpment but no bubble emission was seen