15th International Congress of the Geological Society of Greece
Athens, 22-24 May, 2019 | Harokopio University of Athens, Greece
Bulletin of the Geological Society of Greece, Sp. Pub. **7** Ext. Abs. GSG2019-379

Monitoring of Seabed Fluid Flow through Underwater Benthic Observatories. Environmental and Geohazard Assessment. Case studies from Patras and Katakolo Harbours

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Introduction

Hydrocarbon seeps, mainly methane (CH_4) of microbial and thermogenic origin, formed during sediment burial. Seabed fluid determines a wide range of fluids (gases and liquids) passing from seabed sediments to seawater. The significance of seabed fluid flow goes beyond the geosciences, since they have a major impact to marine ecology and chemistry, representing also an important greenhouse gas source for the atmosphere (e.g., Etiope, 2004; Papatheodorou et al., 2007; Etiope and Ciccioli, 2009). Moreover gas seeps could be a geo-hazard for the social community, the constructions and the industry.

The link between gas emission and seismicity has been the subject of a wide number of multidisciplinary studies. Mellors et al. (2007) found significant statistical correlations between large earthquakes ($M > 5.5$) and the eruption of mud volcanoes. Signals recorded by Ocean Bottom Seismometers (OBSs) were explained as due to bubbles coming from gas seepage at the seafloor (Tary et al., 2012). Embriaco et al. (2013), suggested a link between seismic energy release and methane seepage using data from a multiparametric benthic observatory along the North Anatolian Fault in the Sea of Marmara.

Two major harbour in Western Greece, have been established over active, intense gas seepage areas, Patras Harbour (Christodoulou et al., 2003) and Katakolo Harbour (Etiope et al., 2006). Laboratory of Marine Geology & Physical Oceanography, participating among others, in three EU projects, has been used underwater benthic observatories for seepages activity monitoring.

Geological Setting

In Patras Gulf, a pockmark field has been developed in soft, layered Holocene silts, showing episodes of gas venting from the Pleistocene/Holocene interface which forms a gas accumulative horizon (Christodoulou et al., 2003; Papatheodorou et al. 1993). It is one of the most well documented pockmark field regarding its activity and the relationship with seismicity. On July 14th, 1993 an earthquake of magnitude M=5.4 on Richter scale was recorded in the active Patras graben. In a temperature recording station in the pockmark field, the temperature increased anomalously on three occasions prior to the earthquake and the earthquake occurred just after the last peak of increased temperature. Furthermore, it was noted that some pockmarks few days after the earthquake were still venting gas bubbles as is indicated by the extremely high reflectivity plumes shown on the sonographs (Hasiotis et al., 1996). On June 2008, after a major earthquake of MW=6.4R, which occurred on the Northwestern Peloponnese and for a period of fifteen days, gas plumes were recorded in the water column above pockmarks and methane measurements showed high concentrations of dissolved methane in the water column all over the pockmark field (Christodoulou et al., 2009).

Katakolo is one of the most productive thermogenic gas seepage zones in Europe and the biggest methane seep ever reported in Greece. The gas seepage takes place over an extended area in the Katakolo harbour and along two main normal faults off the harbor. Based on side scan sonar sonorgraphs at least 823 gas bubble (10-20 cm in diameter) plumes escaping over an area of 94,200 m^2 were recorded, at depths ranging from 5.5 to 16 m. The gas consists mainly of methane and has H_2S levels of hundreds to thousands ppmv, and shows significant amounts of other light hydrocarbons like ethane, propane, iso-butane and C_6 alkanes. Due to the shallow depth, more than 90 % of CH_4 released at the seabed enters the atmosphere and the gas seeps may produce severe geohazards for people, buildings and construction facilities due to the explosive and toxicological properties of methane and hydrogen sulfide, respectively (Etiope et al., 2005; 2006; 2013; Christodoulou, 2010).

Methodology and Results

In Patras Gulf gas monitoring module (GMM) has been developed for continuous and long-term measurements of seabed gas seepage integrated with seawater physical parameters data. GMM equipped by three semiconductor methane sensors, an H_2S electrode microsensor and a CTD SBE-37-SI Microcat (Sea Bird) for measurements of temperature, conductivity (C), temperature (T), and depth (D, or pressure, P) sampled every 10 minutes (Marinaro et al., 2006). GMM was deployed at the base of a large pockmark, at a water depth of 42 m.

Recordings were carried out in two consecutive campaigns over a period of about 6.5 months. This was the first long-term monitoring ever done on gas leakage from pockmarks by means of CH_4+H_2S+T+P sensors. The results showed frequent T and P drops associated with gas peaks, more than 60 events in 6.5 months, likely due to intermittent, like pulsation, seepage. Decreases in temperature below an ambient T, were associated with short-lived pulses (10-60 min) of increased CH_4+H_2S concentrations. This seepage "pulsation" can either be an active process driven by pressure build-up in the pockmark sediments, or a passive fluid release due to hydrostatic pressure drops induced by atmospheric wind.

A newer version of GMM, equipped among others sensors, with a current meter, deployed at the eastern part of the Katakolo harbor at water depth of -7m, where intense gas seepage and oxygen concentration reductions have been identified during preparatory surveys. GMM monitoring lasted 3.4 months (101 days).

From detailed observation of the GMM parameters (CH_4, O_2, temperature, turbidity, current speed and direction) and wind speed obtained from the local meteorological station, 8 main periods were observed when dissolved oxygen concentration decreases and reaches hypoxic up to quasi-anoxic levels. Within these 8 periods, 54 short term (scale of hours) hypoxia events and 43 short term CH_4 peaks were observed, which in more than 95% of cases were followed by O_2 decrease. Current speed in combination to elevated CH_4 concentrations appeared to be the key factor responsible for the hypoxia and quasi-hypoxia events. When current speed is relatively steady and low (<4 cm/s) for a considerable amount of time (>4 h) and at the same time CH_4 concentration rises, dissolved oxygen concentration lingers at hypoxic levels and may even reach quasi-anoxic levels. The longest event of continuous hypoxia was almost 2 days, which was coupled with low current speed and elevated CH_4 concentrations.

At the same place a prototype fiber-optics-based monitoring system implemented both a distributed temperature sensor (DTS) and an intelligent distributed acoustic sensor (iDAS) of Silixa, Ltd. As far as we know, this was the first time that DTS and iDAS were used in marine environment. The iDAS system makes it possible to observe the acoustical signal along the entire length of an unmodified optical cable, detecting bubble plumes and allowing seepage detection and quantification. The DTS system can measure temporal variations of the gas plumes. A large metal pyramid frame was constructed, where fiber optic cable wrapped, and deployed on the seabed.

The preliminary analysis and interpretation of the collected data showed that the lower temperature values indicate gas leakage points. The cooler monitoring points are, at the same time, the points with the smallest typical daytime temperature deviations. Furthermore, a certain spatial pattern and a systematicity has been observed regarding the location of the colder monitoring points. This indicates possible permanent leakage points. iDAS data (acoustic footprint of the bubbles upon escape) is in agreement with the spatial temperature distribution of the DTS. Confirmation of these possible gas escapes also results from submarine optical reception of the fiber-optics-based monitoring system. Small local earthquakes of 1.3 to 2.8R, during the experiment, do not appear to affect the leaks.

Acknowledgements

The surveys presented in this chapter were carried out within the framework of three European Union funded projects (ASSEM, contr. EVK3-CT2001-00051, PYTHAGORAS II. Social Funds, HYPOX project EC Grant 226126, ENV.2008.4.1.2.1, FP7).

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