CRUISE REPORT ECO2-5
(Panarea Island, Italy)
August 21-23, 2012

ECO$_2$

Sub-seabed CO_2 Storage:
Impact on Marine Ecosystems

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Università di Roma "La Sapienza" - Centro di Ricerca "Previsione, Prevenzione e controllo dei Rischi Geologici"

ISTITUTO NAZIONALE DI OCEANOGRAFIA E DI GEOFISICA SPERIMENTALE

1 INTRODUCTION

Carbon capture and storage (CCS) is expected to provide an important, short-term approach for mitigating potential global climate change due to anthropogenic emissions of carbon dioxide (CO_2). This technology involves the capture of CO_2 emitted from large point sources and its injection into deep geological reservoirs, such as depleted hydrocarbon reservoirs and deep saline aquifers, both on land and off-shore. Offshore reservoirs are particularly favourable due to potentially high storage capacities, the extra barrier provided by the overlying water, and the physical separation between injection sites and populated centres. The 14-year old Sleipner project, in the North Sea, is the world's first and largest pilot-scale CCS project; here about 1 million tonnes of CO_2 are injected per year into a deep saline aquifer

Despite the safe track record at Sleipner, several concerns exist amongst various stakeholders regarding the long term safety of sub-seabed CO_2 storage. In addition, due to greater logistical problems, marine sites have been studied much less than terrestrial systems regarding site characterisation, monitoring, leakage detection and quantification, ecosystem impact, and human health and safety.

Although laboratory experiments and modelling can be performed, for a more complete (and realistic) understanding of a possible seabed leak of CO_2, it is preferable to study natural, analogous systems. This is particularly important because CO_2 leakage presents some unique challenges. First, it is highly soluble and thus CO_2 bubbles will dissolve extremely rapidly; this makes bubble detection more challenging using hydroacoustic techniques. Second, dissolved CO_2 increases the density of seawater, and thus high CO_2 concentration seepage will likely remain closer to the seafloor.

Because of these complications, the Università di Roma "La Sapienza" and OGS first proposed the inclusion (within the ECO2 project) of the natural, shallow analogue site near the island of Panarea (Aeolian Islands, Italy; Figure 1), where natural, thermo-magmatic CO_2 is leaking at substantial rates from the seafloor at water depths ranging from 5 to 30 m. This CO_2 is released most strongly in the area surrounding two of islets located 3 km to the east of Panarea (Lisca Bianca and Bottaro). This natural CO_2-release field (c. 3 km^2) has been active for centuries, with gas emanating from a series of NW-SE and NE-SW trending fractures

(Esposito et al., 2006). In the early 1980's researchers began to conduct gas geochemistry surveys of the area (Caliro et al., 2004), showing that the system was relatively stable in both gas chemistry (e.g. 98% CO_2, 1.7% H_2S plus other trace gases) and flux rates (7-9 x 10^6 l/d). Most release points are gas only, although various points also release water of different origin, ranging from geothermal to seawater end-members that are mixed to variable degrees (Tassi et al., 2009).

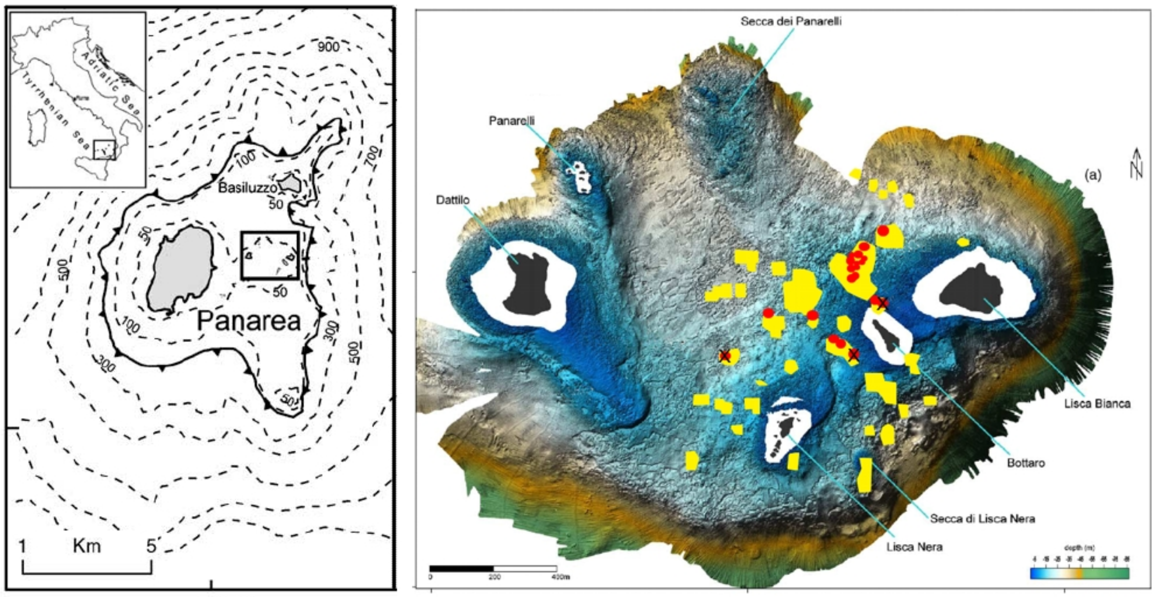


Figure 1. Map (left) showing Panarea Island and associated islets to the east (boxed area). Bathymetric map (right) showing the location of the gas leaks in December 2002 (yellow) soon after the outburst, the three strongest gas release points during the outburst (x), and the gas leak locations one year later (red circles). Modified after Esposito et al. (2006).

Based on the range of depths and relatively high and persistent gas flow rates, the occurrence of both gas only and gas-water seepage, and its close proximity to shore (Figure 1b), Panarea represents an exceptional location to study natural processes and impacts related to shallow seabed CO_2 leakage.

The present report details work conducted at the Panarea site by UniRoma1 and OGS within the ECO2 project from August 21-23, 2012. This work involved video filming of gas bubbles rising in the water column to better understand the processes controlling mass transfer from the gas to the dissolved phase. This information is needed for modelling efforts aimed at understanding the fate of CO_2 in the water column as well as its potential transfer to the atmosphere.

2 OBJECTIVES

Research conducted at the Panarea site by UniRoma1 and OGS within the ECO2 project is within the framework of three separate work packages, however only work for WP3 was conducted during this campaign.

WP3, entitled "Fate of CO_2 and other Gases emitted at the Seabed", focusses on the chemical, biological, and physical mechanisms that control CO_2 within the water column. In this regard, UniRoma1 and OGS are conducting a series of experiments at Panarea which involves studying the evolution of gas bubbles released from the sediments as they rise through the water column. Overall the plan is to collect data on bubble rise velocity, bubble size, bubble chemistry, and water column chemistry, however such a logistically challenging study will require various campaigns to develop the best possible experimental setup and approach.

As a result, this short field campaign had one objective only:

- To conduct preliminary testing of the structure built for video filming of gas bubbles as they rise through the water column.

3 DESCRIPTION OF WORK

Work was conducted over a total of 3 days, whereby the video structure was mounted on land, transported to the site on a large Zodiac boat, and then lowered and deployed by divers. All work was conducted at one site, but a different gas bubbling point was filmed each day. During this campaign, testing of the structure and of the support mechanism / guide was performed, and the divers worked on perfecting their technique. Considering the need to rapidly rise through the water column at the speed of the bubbles, this work required highly trained divers both to complete the work and to understand their own physical limits.

3.1 Site

The site, located between Bottaro and Lisca Nera Islands (Figure 1; 38° 38.253' N 15° 06.157' E) is known as the "crater", a blow-out structure left after a particularly violent gas eruption event in November of 2002. A wide range of gas flux rates and gas bubble sizes occur at this site, as shown by the diffuse and point leakage in Figure 2.

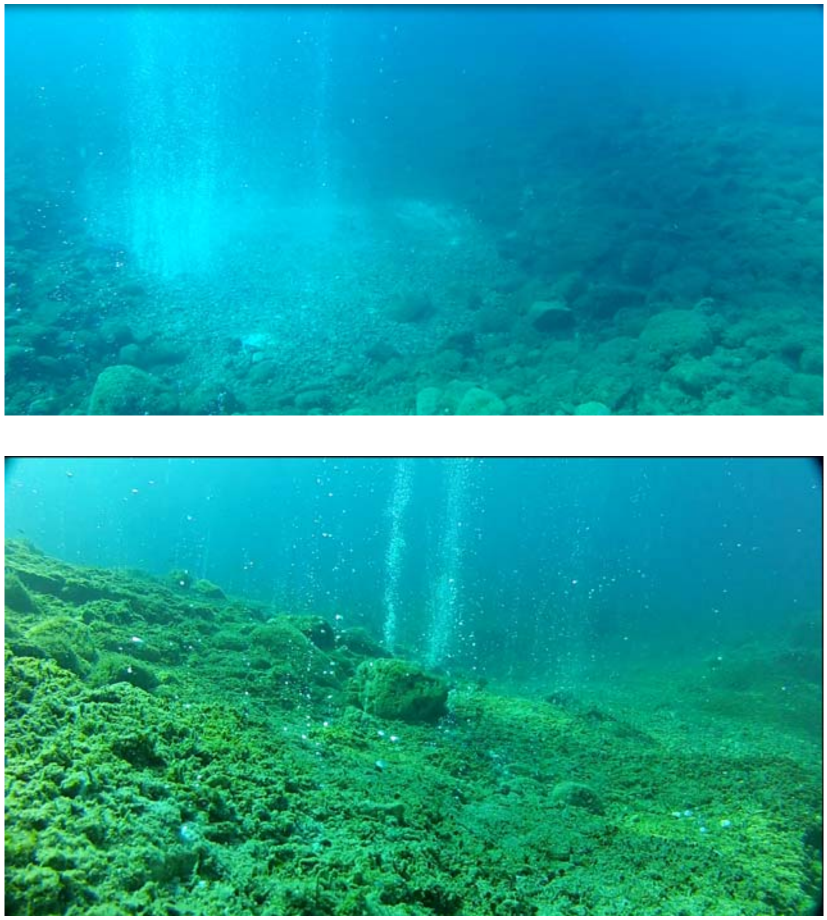


Figure 2. Overview photographs showing the variable gas leakage rates within the study area known as the "crater". Top: Depressed area of the crater, and the diffuse but high volume flux coming from the area to the left; Bottom: More localized high flux points along the border of the crater.

These photos clearly show the rocky nature of the seafloor in this area, which at times made deployment of the structure challenging (see below)

Despite the large volume of CO_2 gas leaking into the overlying water column, this area is actually quite rich in terms of sea life. Fish in particular were common, and did not appear to be particularly bothered with swimming directly within the bubble streams (Figure 3, top) while squid were found in the immediate vicinity on the edge of the crater (Figure 3, bottom).

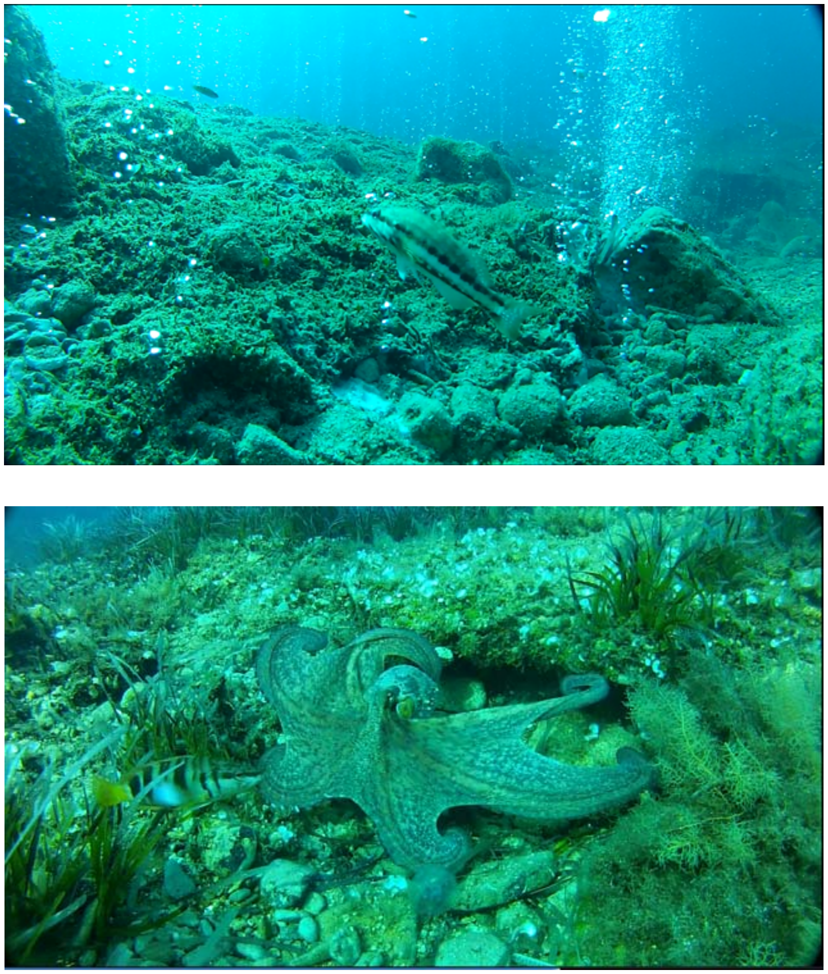


Figure 3. Fish (top) and squid (bottom) living in the CO2 leakage area.

3.2 Structure and structure deployment

The structure itself is 3 m tall and 1 x 1 m square on its base. It is made of tubular iron rods and angle joins that are actually sold for shelving units. Its robustness and light weight, however, made it particularly well adapted for the purposes of these experiments. A 1 x 3 m, dark blue cloth was mounted along the back of the structure to give background contrast for the filming of the bubbles, while white horizontal lines every 20 cm were marked on the cloth to give reference points for calculating bubble rise velocity. The structure can be seen in the photos of Figure 4, where the divers are carrying it down to the sea floor (top) and then raising it into working position (bottom).

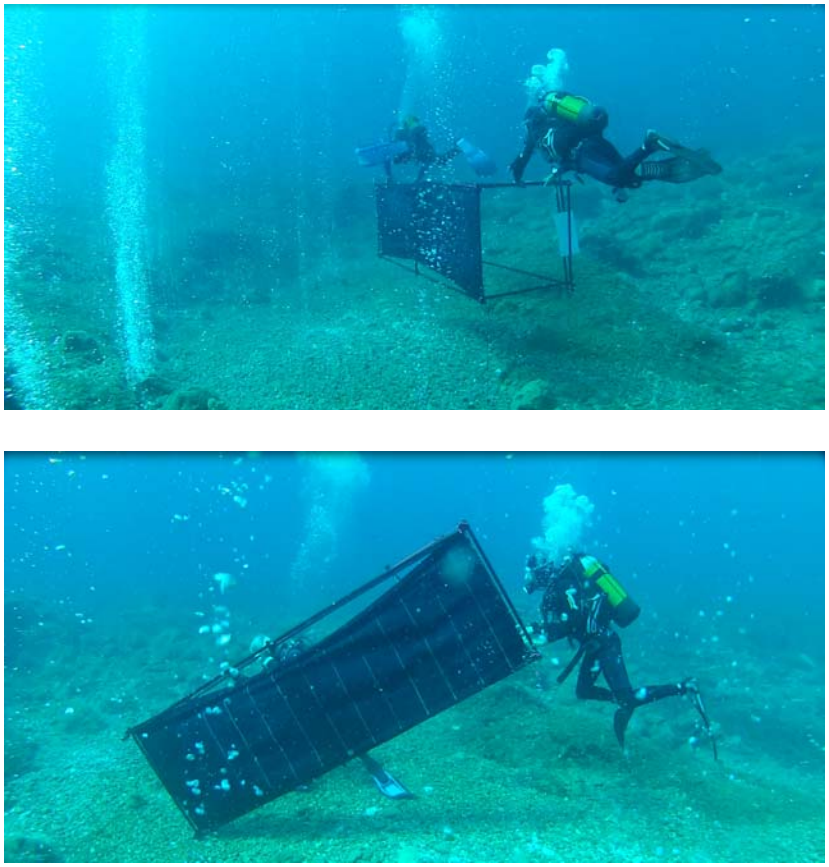
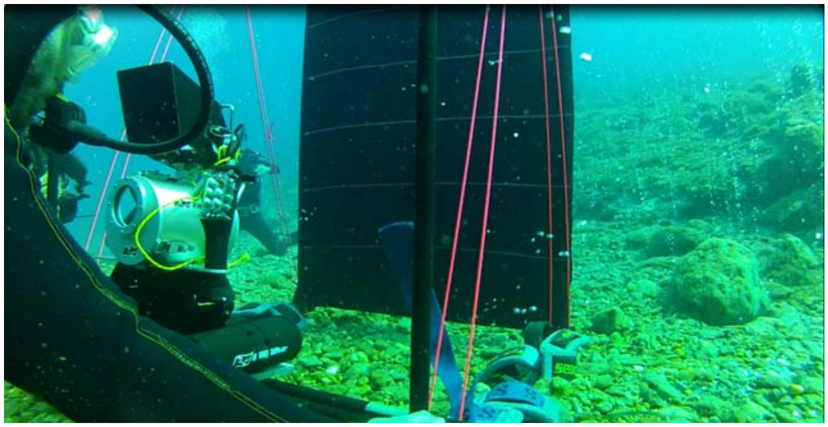


Figure 4. Deployment of the video structure by divers.

A high definition underwater camera was used for the filming of the bubbles, with the unit mounted on the structure using horizontal rods on which was bolted a thick Plexiglas plate (Figure 5). This guide maintained the video camera at a constant distance from the cloth background and helped maintain the camera horizontal. Although it functioned, it was found that with the size of the camera and the design choice of the guide, the system in its present form is not appropriate due to the fact that the guide often jammed and blocked on the vertical bars of the structure during ascent. Based on this crucial observation plans are underway to modify this system for the next field campaign.



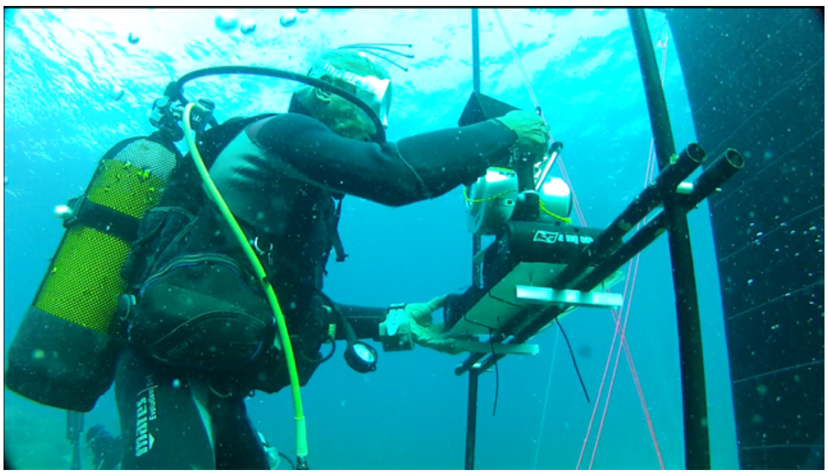


Figure 5. Photographs showing the high definition video camera and the mounting system / guide used to slide it up the structure. Note the dark blue cloth background used, with horizontal lines every 20 cm for reference.

The structure was deployed at three different locations within the crater, taking advantage of the fact that there is a wide range of gas flux rates within a relatively small area. Figure 6 shows some photographs of the structure from further away, giving a clear idea of the distribution of gas leakage points near the structure (top, middle) and the uneven nature of the sediments (middle) that made deployment at some stations challenging (bottom). Note that the deployment of the structure in an area with such a high CO_2 flux will clearly have an influence on the behaviour of the bubble as it rises. This is because the dissolved CO_2 concentration will be higher here than in an area with no leakage, thus influencing the gradient between the bubble and the surrounding water that will control dissolution kinetics and thus the distance over which the bubble will travel before it dissolves completely.

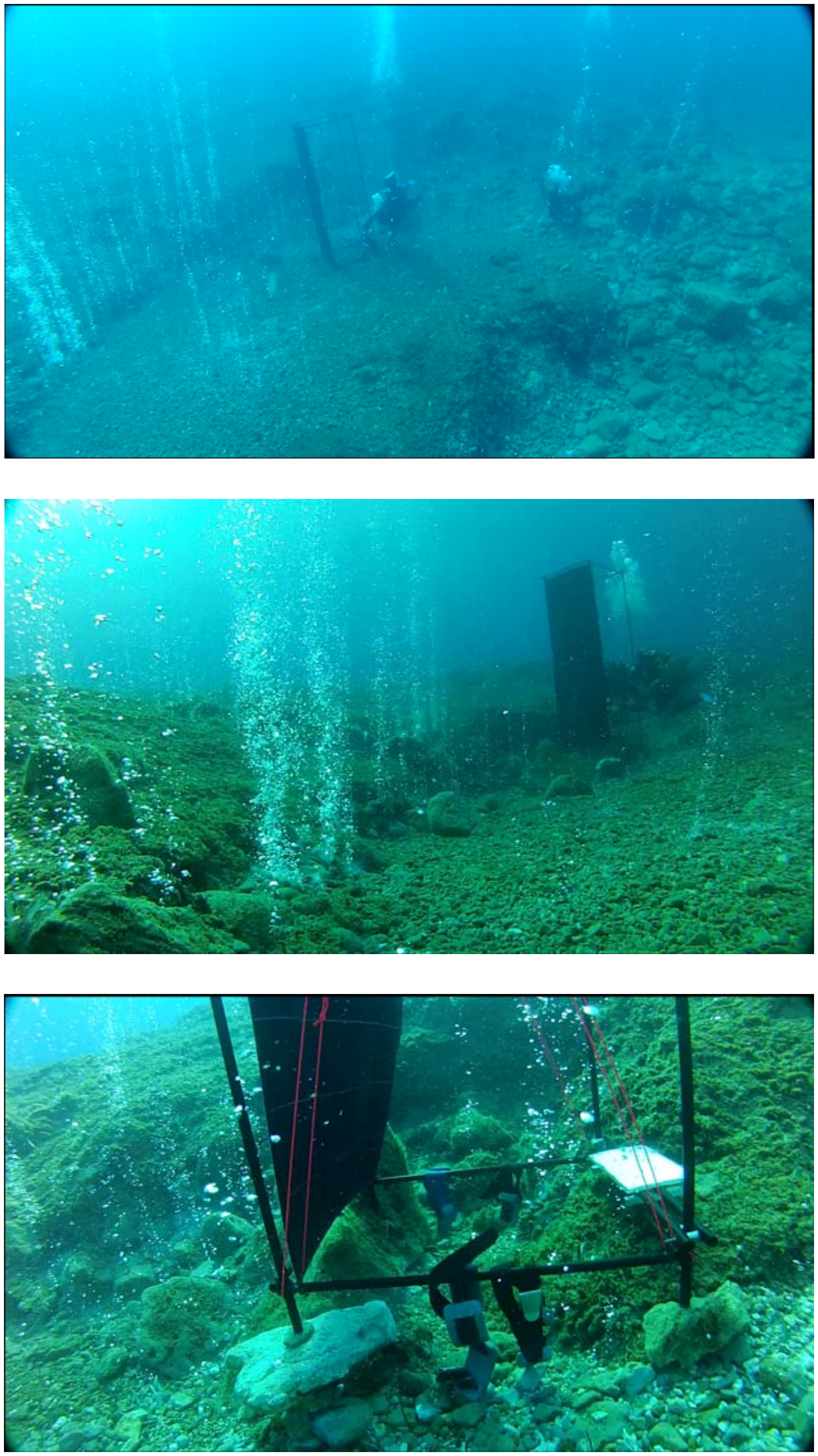


Figure 6. Photographs showing the structure after deployment. Note the large number of gas release points in the vicinity of the structure (top and middle), and the irregular surface on which it had to be placed at some sites (bottom).

3.3 Filming

Filming of the rising bubbles was difficult for two main reasons, the first because the divers had to match well the rise velocity of the bubbles and second because constant rising and descending in the water column, with the resultant pressure changes, is physically demanding on the diver. We were fortunate to be working with highly trained and capable divers, thus this work proceeded well.

As can be seen in the series of photographs in Figure 7 and Figure 8, the divers started from the sediments and then moved upwards once a suitable bubble was released. Upon reaching the end of the 3m high structure the diver returned to the bottom to repeat the procedure. At least 30 ascents were conducted for each station.

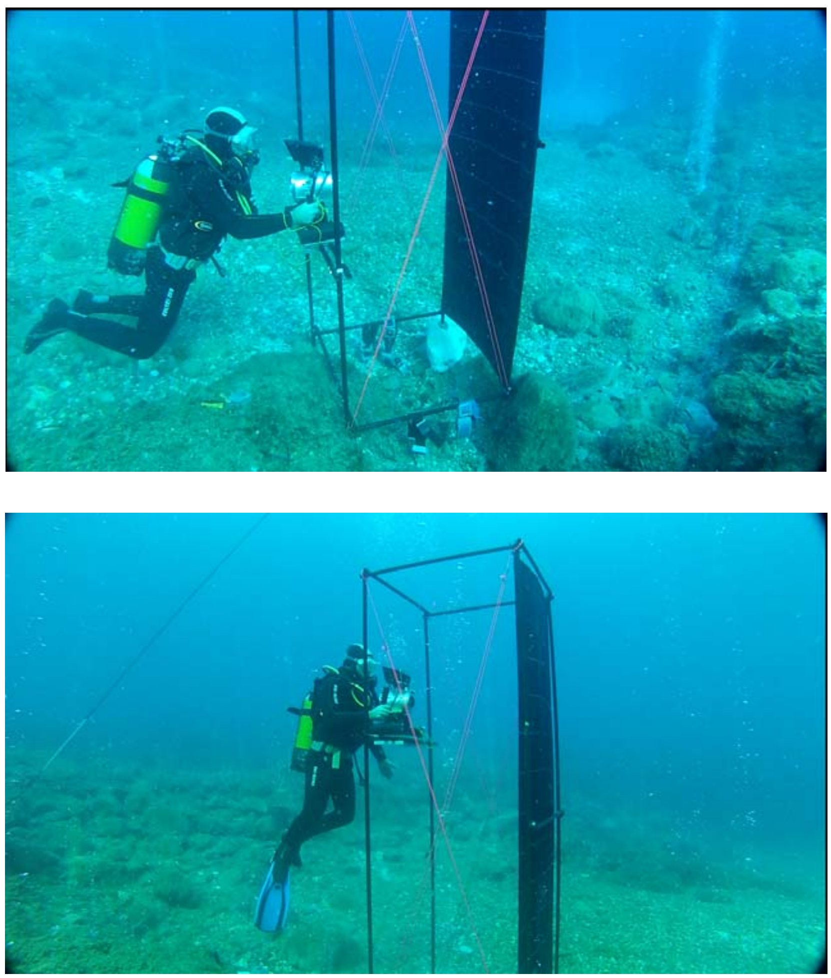


Figure 7. Series of photos showing the diver filming a bubble along the 3m height of the structure.

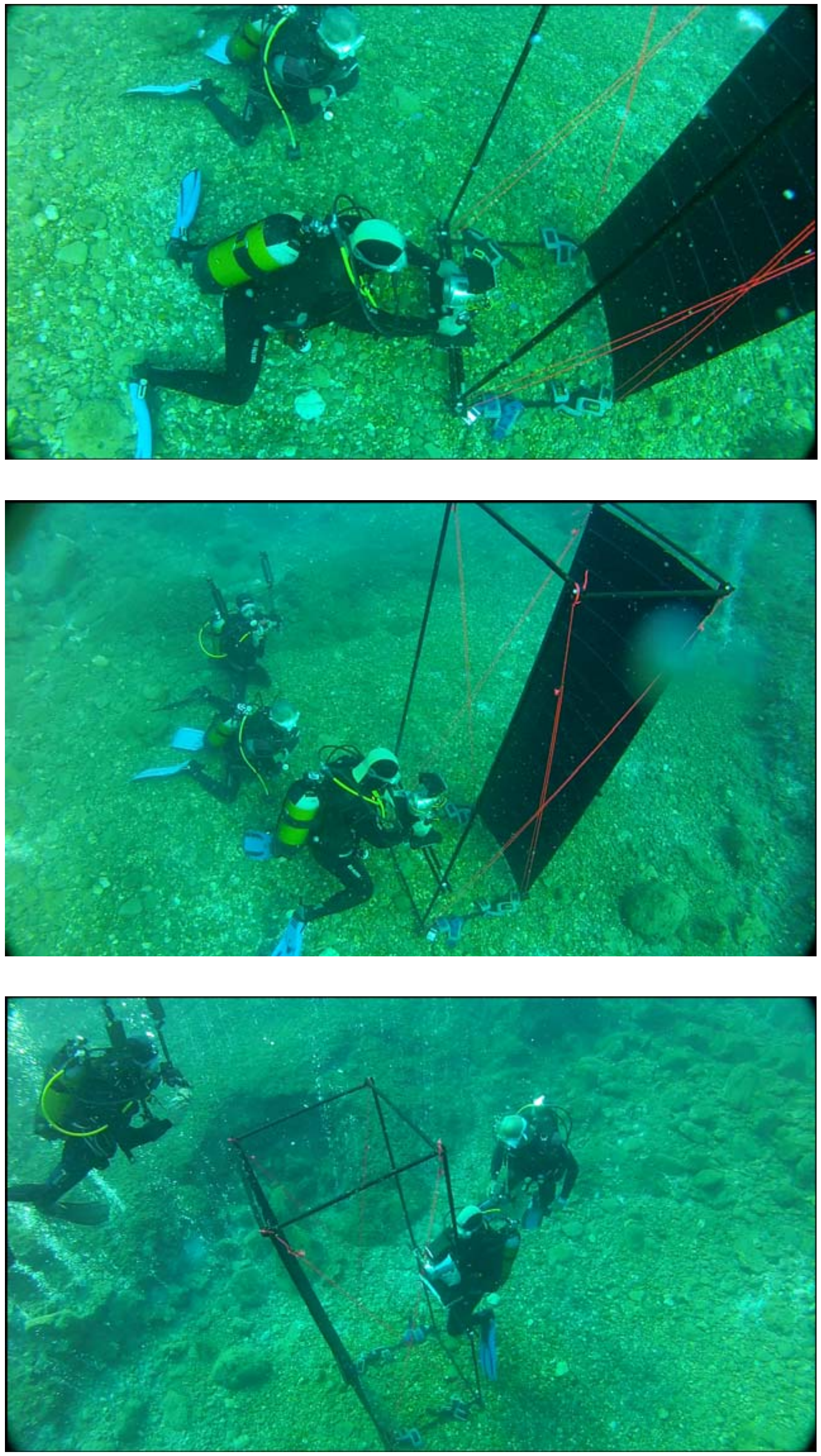


Figure 8. Series of photographs from above showing the diver filming a bubble along the 3m height of the structure.

3.4 Experiments

As stated, measurements were conducted at three stations within the crater, one with small bubbles, one with medium sized bubbles, and one with a continuous bubble train or stream. In addition, the decision was taken to attempt to follow large bubbles higher up in the water column by not using at all the structure.

3.4.1 Small bubbles

An example of the type of bubble size and distribution measured at the first station is given in Figure 9. In this case these bubbles, which ranged in size between about 1 to 10 mm, were observed to shrink over the 3m height of the structure. Interestingly some of the smaller ones were observed to change abruptly their rise velocity and rise "style", going from rapidly rising oscillating bubbles to bubbles that rose more slowly in a straight manner.

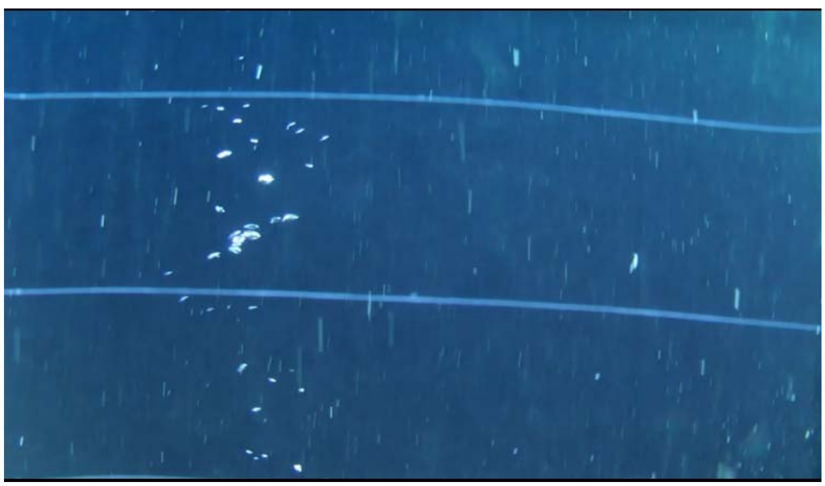


Figure 9. Screen capture of the video film of the small bubbles.

3.4.2 Medium bubbles

An example of a medium sized bubble in given in Figure 10, where one individual bubble is highlighted with a black arrow. For this type of bubble very little change could be observed in terms of size or behaviour over the measurement distance.

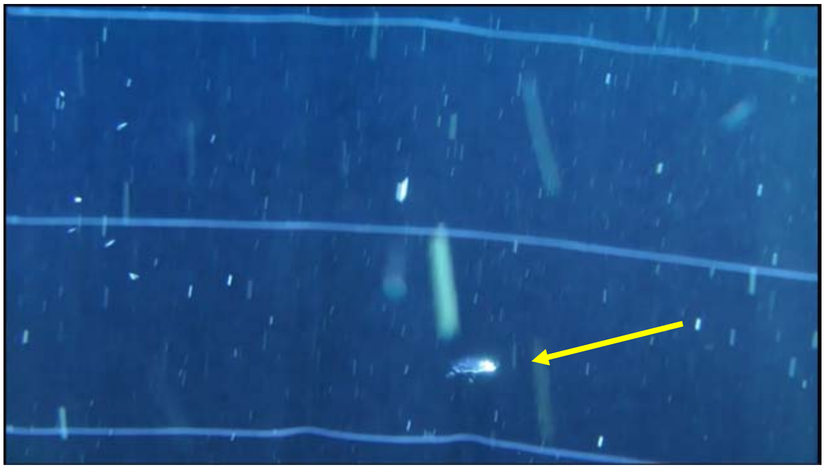


Figure 10. Screen capture of the video film of the medium sized bubbles, with one bubble marked with the black arrow.

3.4.3 Bubble train

A large flux point was measured on the edge of the crater for this experiment, as shown in Figure 11. Here it was difficult for the divers to follow an individual bubble, due obviously to the general chaos of the bubble flow as well as the much higher rise velocity (Figure 12).

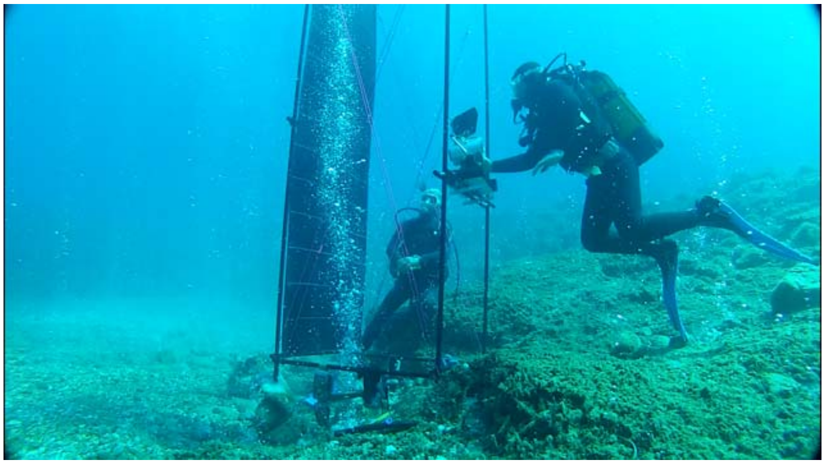


Figure 11. Experimental setup at the station with a continual bubble train.

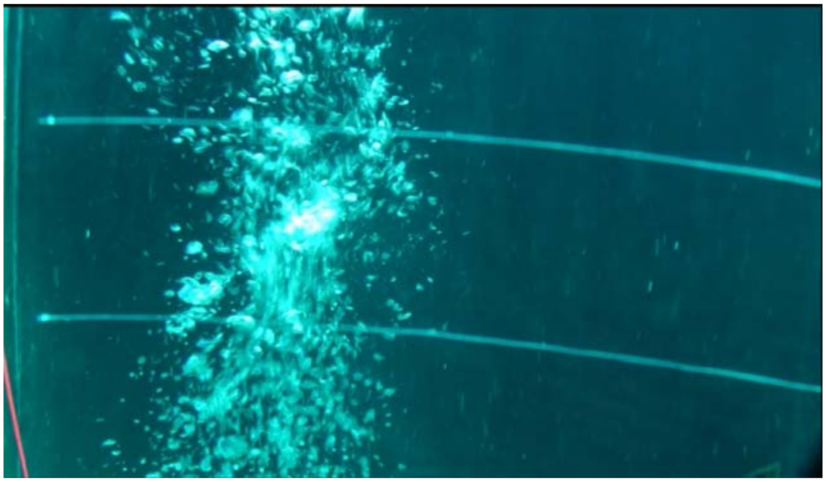


Figure 12. Screen capture of the video film from the bubble train station.

3.4.4 Large bubble without structure

In an effort to monitor bubble behaviour beyond the 3m limitation imposed by the structure, it was decided to make an attempt at following a bubble directly with the camera (Figure 13). For this work the diver's computer was mounted within the camera's field of view so that water depth could be monitored (and thus rise velocity of the bubble could be calculated). Although this experiment gave interesting results, it is limited in its use due to the size of the bubble needed (large enough to see) and the maintain a constant distance so that bubble size can be estimated.

Figure 13. Photographs showing the divers rising in the water column filming a single large bubble without the use of the structure. Note the diver's computer mounted in front of the camera to record water depth during ascent.

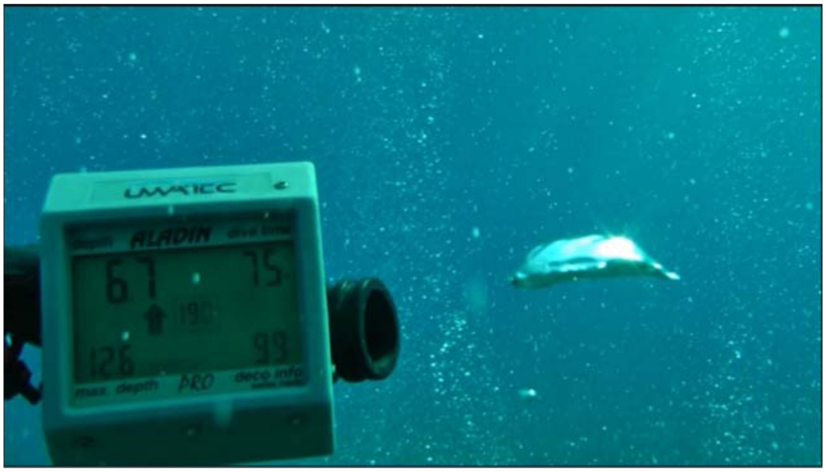


Figure 14. Screen capture of a single large bubble followed by the divers without the use of the structure. Depth is given in the top left of the diver's computer.

An example of the type of data given with this experiment is given in Figure 14, where a single, cap-shaped bubble was followed for about 7 m in the water column. Dynamics of the bubble shape and form were observed, with (in some cases) the bubble breaking into smaller bubbles that then subsequently re-merged.

4 SUMMARY AND CONCLUSIONS

The work conducted during the present field campaign was not designed so much for the collection of actual data, but rather for the testing of an experimental setup designed to study bubble evolution during its ascent through the water column. Based on this work it has been decided to modify the experiment for the upcoming campaign in October of 2012 in the following ways:

- Extend the structure to approximately 9m to allow following the bubbles over a greater distance
- Change the guide for the camera, to allow for a more smooth rise
- Change the camera type to a unit which is smaller and more manageable
- Design a system for creating bubbles of a known volume and diameter. In addition to giving more experimental control, it will also allow us to choose a deployment site based ground characteristics and not the occurrence of a leak

In addition, it is planned to expand the scope of the work to take into account the other aspects of the experiment, including:

- Test a system for measuring the size of the bubbles at different heights
- Capture bubbles at different heights for gas chemistry analysis
- Collect water samples at different heights to measure various parameters in the carbonate system, as well as parameters that can influence gas solubility. CTD measurements will also be performed along the water column to measure such important parameters as salinity and temperature
- Deploy pCO_2 probes at the site to observe how dissolved CO_2 values are changing during the experiment.

Based on the experience gained during this field campaign we are confident that it lays the groundwork for successful measurements during the October campaign.

5 ACKNOWLEDGEMENTS

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