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Observation of Deep Seafloor by Autonomous Underwater Vehicle

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The AUV (Autonomous Underwater Vehicle) is a dynamically stable platform for visual and acoustic observation of the deep sea floor. It can automatically take images of seafloor in high resolution. Two examples of observation carried out by the AUVs r2D4 and Tuna-Sand show significant advantage of the AUV and give us various ideas of AUV application. The first example is the dive to Kuroshima Koll by the hovering type AUV Tuna-Sand in June 2010 following the results of survey by the cruising type AUV r2D4 in January 2010. AUV Tuna-sand brought us photo images of the seafloor where unusual features in the side scanning sonar image captured by the AUV r2D4 were found. Second example is twelve dives over the gas-hydrate field in Toyama bay and took about 7,000 pictures from 2.2 meters above the floor in 1,000 meter depth. One of the mosaic shows that there are 3,500 snow crabs (Chionoecetes japonicas) in a 40 meters by 20 meters area.

Keywords: AUV, Sea Floor, Mosaic, Deep Sea, Snow Crab

Introduction

Observatory Platform

If a targeted region of the seafloor is precisely predetermined and its area is small (less than several thousand square meters), it is possible to conduct a close-range survey of the region by lowering a Remotely Operated Vehicle (ROV) to the bottom of the ocean. When the targeted region is wide, however, it is difficult to conduct a survey with an ROV, which moves at a speed of one knot or less, being restricted by its troublesome umbilical cable. Generally speaking, a sonar topographic survey (e.g., Fig. 1) from a surface vessel or a towed fish is required as the first stage of a seafloor survey. However, as the water depth increases, the horizontal resolution suffers in the former case, whereas the towing speed decreases and maneuvering becomes more difficult in the latter. At the second stage, therefore, a cruising-type autonomous underwater vehicle (AUV) such as *r2D4* (Fig. 2) is deployed. Because an AUV can close in on the seafloor, the horizontal resolution of sonar data will be improved. In addition, because it is not tethered by any cable, an AUV can move freely and stably. Furthermore, it can directly measure turbidity, *p*H, and other characteristics of the water. Based on the collected data, researchers can define their target area precisely and conduct a refined survey as the third stage.

Today it is even possible to conduct the third stage, not by utilizing an ROV, but by using a hovering-type AUV. Consequently, hovering-type AUVs, which operate close to the seafloor, are finding widespread use. This article presents examples of how a survey strategy that focuses on the sequential use of a surface vessel, a cruising-type AUV, and a hovering-type AUV can facilitate the observation of regions of the seafloor that have heretofore been unobservable.

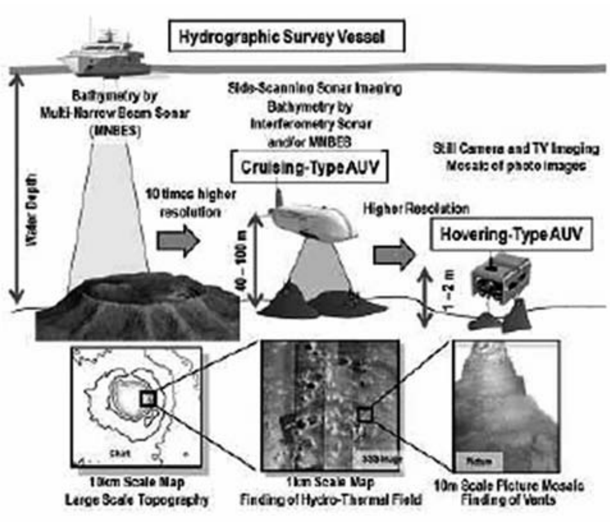

Fig. 1—Three-stage strategy for seafloor survey by use of a surface ship, cruising-type AUV, and *hovering-type AUV*

Materials and Methods

Kuroshima Knoll Survey

Side Scan Survey using AUV *r2D4* Fig. 3 shows a topographic map of Kuroshima Knoll measured during the YK03-05 cruise of the *Yokosuka* in 2003, a research ship owned by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC). According to the dive plan indicated by the solid lines on the map, a cruising-type AUV named *r2D4*[1] (weighing 1.6 tons in the air and having a maximum endurable depth of 4000 m) was deployed during the KR10-03 cruise of the research vessel *Kairei* in January 2010. During the dive, the topography of the seafloor was measured by using an interferometric side-scan sonar (IFS) with an operating frequency of 100 kHz. The AUV *r2D4* was programmed to maintain a cruising depth of 610 m so that it could cover the top of the knoll, where the seafloor depth was shallower than 660 m. To improve the quality of the side-scan sonar (SSS) data, efforts were made to minimize any pitching motion. Spacing of survey track-lines was set to approximately 400 m so that there would be sufficient overlap between the 600-m swaths of the SSS (300 m on each side). Total length of the survey lines was approximately 9 nautical miles, and the duration of the observational dive was 3 h.

Figure 4 shows the side-scan image of Kuroshima Knoll. The figure reveals a detailed, characteristic topography that is not visible in Fig. 3. The points of interest are pockmark groups that appear in the central area, as well as a group of scratch marks located in the lower region of the central area. Fig. 5 shows a close-up image of a pockmark group in Fig. 4, and Fig. 6 is a bathymetric map generated from the measurements made by the IFS installed in *r2D4*.

Fig. 2—Cruising type AUV r2D4

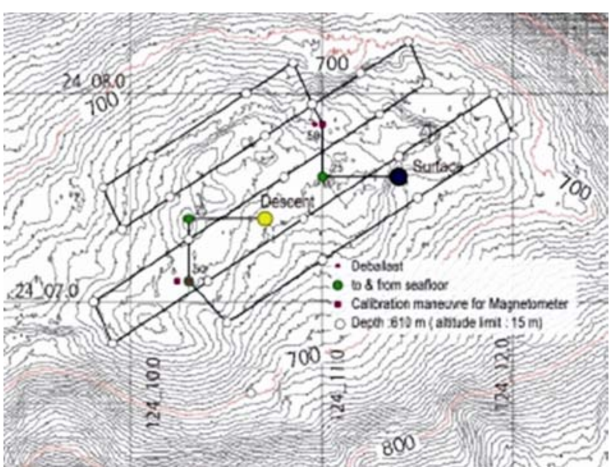

Fig. 3—Topography of the Kuroshima Knoll measured by equipment on board the R/V Yokosuka of JASMSTEC, and a dive plan of the AUV r2D4 executed in January 2010

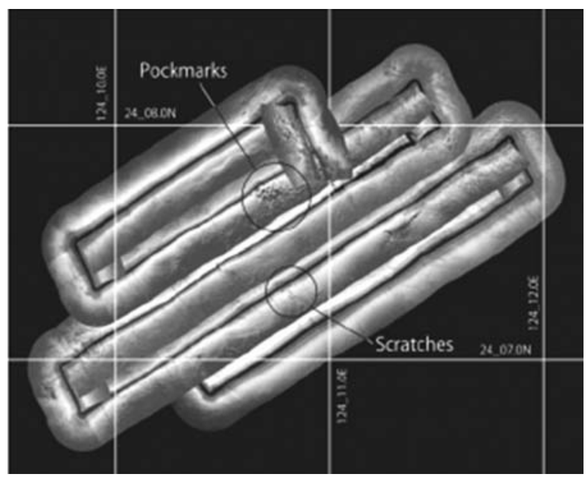

Fig. 4—Side-scan image of the Kuroshima Knoll captured by the AUV r2D4

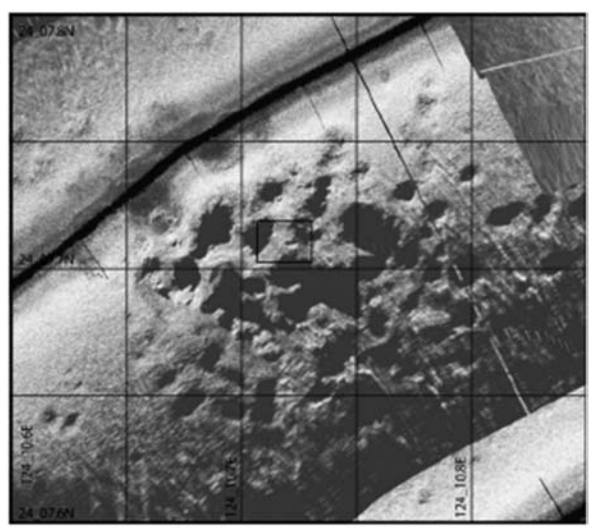

Fig. 5—Close-up of side-scan image of pock marks, and bathymetric data, at Kuroshima Knoll

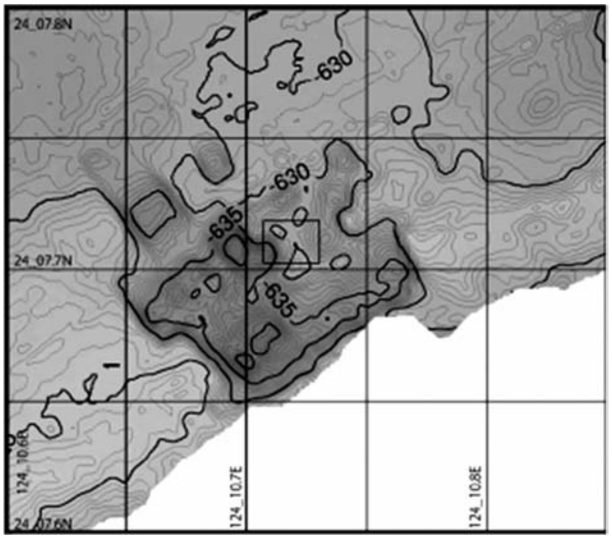

Fig. 6—Bathymetric map of the area in Fig. 5 measured by interferometric sonar on r2D4

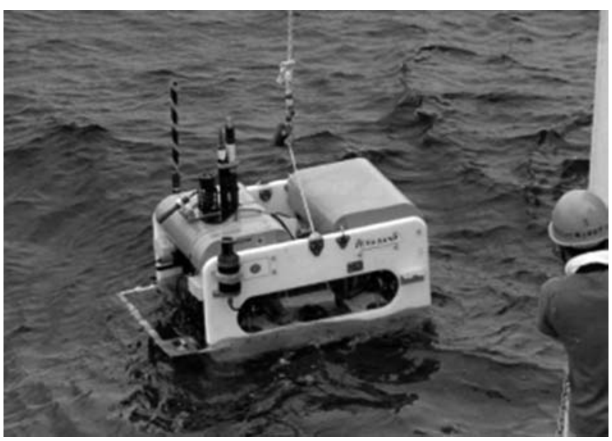

Fig. 7—Hovering-type AUV Tuna-Sand

Photographic and Bathymetric Survey by the AUV Tuna-Sand

Overview of AUV Tuna-S and To determine the nature of the pockmarks and scratch marks observed by AUV *r2D4*, a hovering-type AUV named *Tuna-Sand* was deployed from the survey vessel *Meiyo* of the Japan Coast Guard in June 2010.

Tuna-Sand, which is shown in Figs 7 and 8, weighs 240 kg and is small and light compared to *r2D4*. Unlike an ROV, it does not need to be tethered by a cable. For these reasons, *Tuna-Sand* can be deployed from a small fishing vessel[2]). Furthermore, because it is equipped with a sophisticated Inertial Navigation System (INS), it can go precisely to the target location.

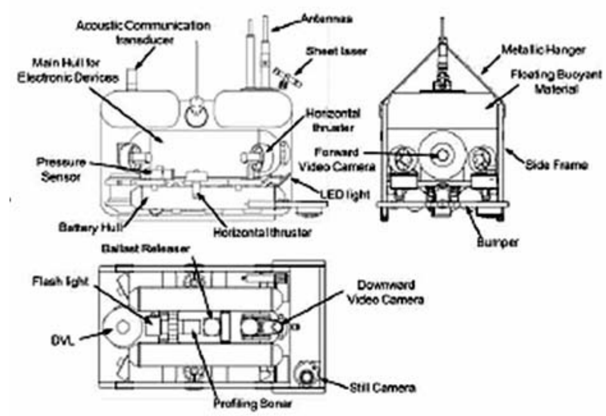

Fig. 8—General schematic showing the organization

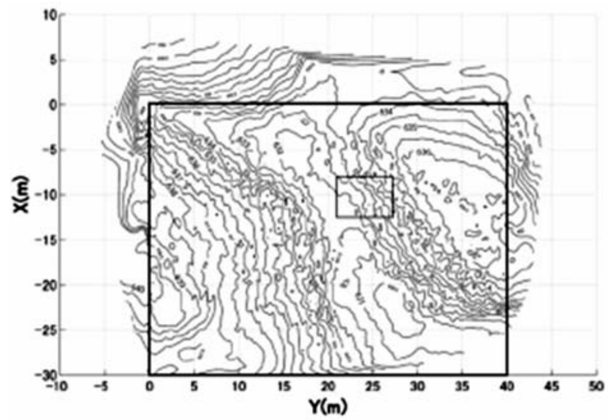

Fig. 9—Bathymetric data of pock marks measured by Tuna-Sand

Tuna-Sand adopts a navigational mode that allows it to cruise along a predefined survey line, maintain an altitude of about 2 m to facilitate photographing the seafloor, and avoid obstacles by checking the sheet laser reflection point through a TV camera.

Results and Discussion

Pockmarks

Tuna-Sand was deployed to survey the area marked by the rectangle in Fig. 6 while maintaining an altitude of approximately 2.2 m and a survey line spacing interval of 2 m. During the 90-minute dive, *Tuna-Sand* measured the topography of the seafloor by a mechanical-scanning sonar while taking approximately 600 photographs. The resultant bathymetric map of the surveyed area (Fig. 9) is consistent with the image shown in Fig. 6, although its resolution is greatly improved. Three depressions, each approximately 20 m in diameter, can be observed in the area. Fig. 10 shows an entire mosaic image of all the photographs (40 m × 20 m), and

Fig. 11 shows an enlarged image of a 6 m ´ 4 m area of its central portion (see Fig. 9). Because of a strong current near the cliff, the AUV did not go straight along the predetermined track line; and because of the steep wall of the pockmark, the AUV sometimes came so close to the seafloor that the area covered by the photograph is reduced and the sides of the image do not extend as far as expected. There are consequently some void spaces where the AUV did not take pictures. The image in Fig. 11 also shows a large number of carbonate chimneys scattered around the area.

Scratch marks

Tuna-Sand was also deployed along four 160-m survey lines running east-to-west on the scratch marks to generate a detailed topographic map and take photographs of the area. Fig. 12 shows a topographic map measured with scanning sonar. On the spots that correspond to scratch marks, mounds of approximately 70 cm in height can be detected. Fig. 13 shows a mosaic image of the surface of a mound, and Fig. 14 shows a mosaic image of the surface of the outer area of a mound. The differences between the two images are apparent.

Observation of a Gas Hydrate Field Joetsu Knoll

The central area of Joetsu Knoll is known as a gas hydrate field[3]. The area around 37°32.41'N, 137°56.27'E forms a collapsed, crater-like structure, which has been surveyed by the ROV *Hyper Dolphin* of JAMSTEC. Although the region of the seafloor has been videotaped, only researchers who have been able to mentally reconstruct a picture of the entire region from the recorded video images have an understanding of the area. The YK10-08 cruise of the *Yokosuka* was planned, therefore, to deploy *Tuna-Sand* to produce 12 detailed topographic maps of the area.

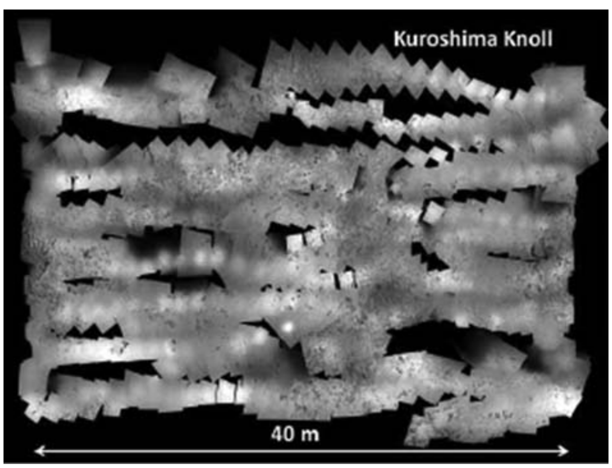

Fig. 10—Mosaic of the seafloor captured by Tuna-Sand

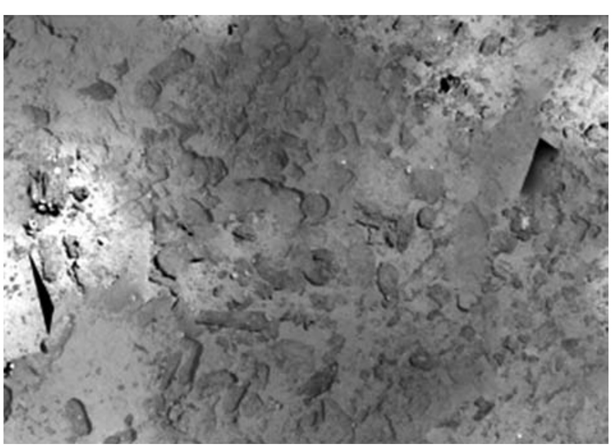

Fig. 11—Close-up of the area indicated by the small rectangular box in Fig. 6

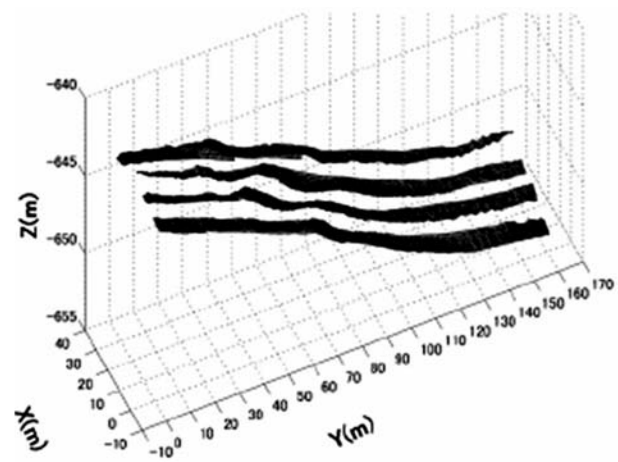

Fig. 12—Topography of seafloor in scratch-mark field at Kuroshima Knoll

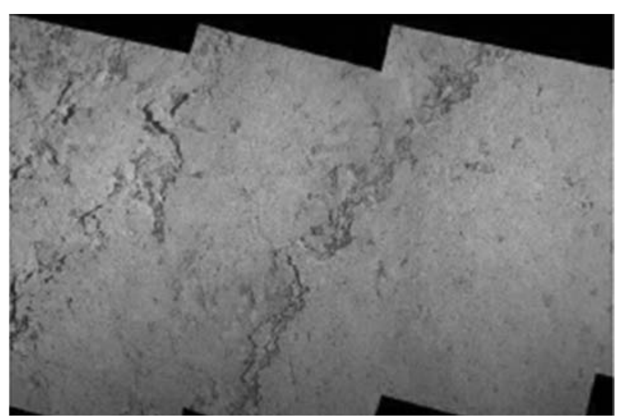

Fig. 13—Surface of a scratch mark

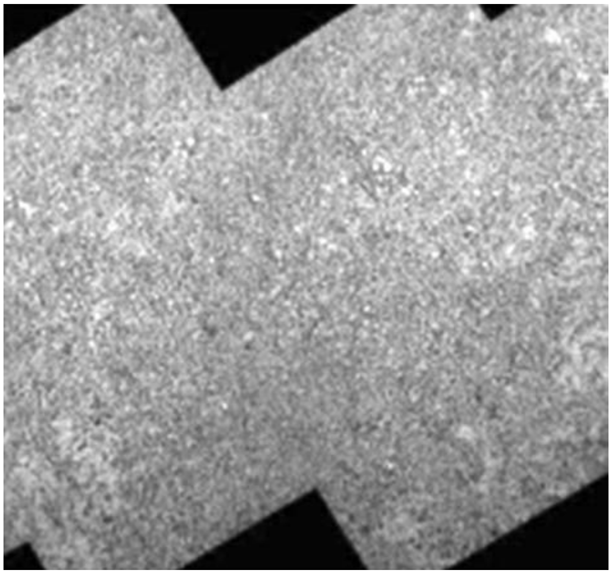

Fig. 14—Surface outside of the scratch mark

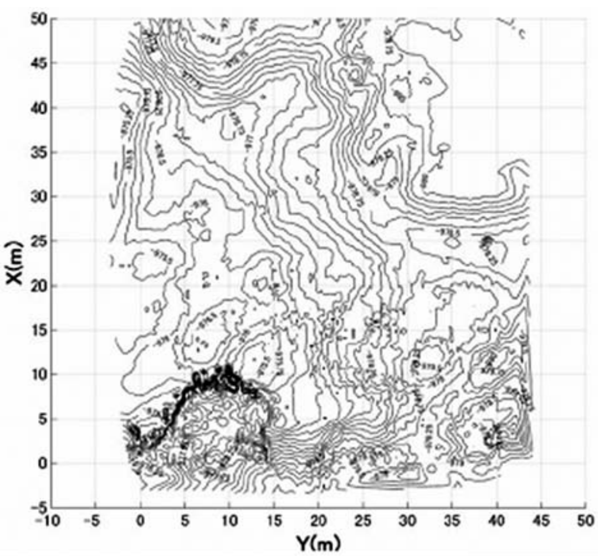

Fig. 15—Topography of gas hydrate field at Joetsu Knoll

Photographic and Topographic Survey by the AUV *Tuna-Sand*

Tuna-Sand took photographs of the seafloor by maintaining an altitude of approximately 2.2 m while using scanning sonar to carry out a bathymetric survey of the area. The size of the photographed area was approximately 40 m × 20 m; the size of the scanned area was 40 m × 40 m. Fig. 15 shows a bathometric diagram with 25-cm contour intervals. A collapsed, crater-like structure, approximately 5 m in depth and approximately 10 m in diameter, is observable in the southwestern part.

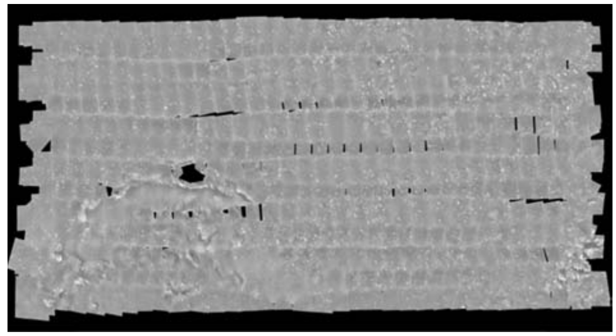

Fig. 16—Mosaic of gas hydrate field at Joetsu Knoll

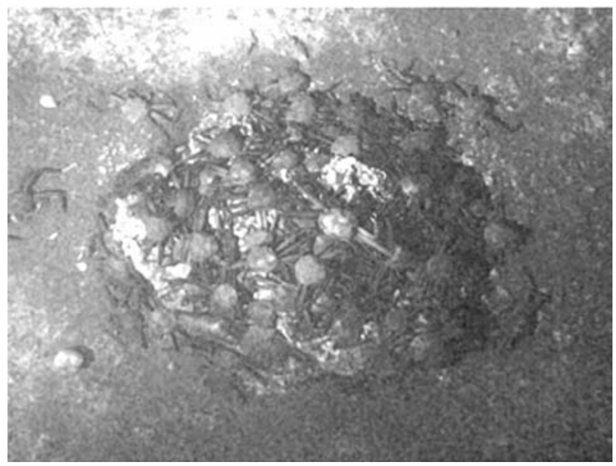

Fig. 17—Close-up of the sea floor in the gas hydrate field at Joetsu Knoll

Fig. 16 shows a mosaic image consisting of approximately 600 photographs. Because the absence of ocean currents allowed *Tuna-Sand* to consistently follow its assigned survey lines, the mosaic image covers the region of the seafloor almost in its entirety. Along the cliffs of the collapsed structure, however, a small number of images are missing because *Tuna-Sand* had to change its cruise altitude to avoid colliding with the cliffs.

Snow Crabs

Figure 16 shows that approximately 3,500 snow crabs inhabit the area. It also shows portions of the seafloor covered with bacterial mats or inhabited by sponge-like creatures. Fig. 17, an enlarged image of a part of the photographic mosaic, illustrates the characteristics of an ecosystem where methane bacteria are the primary producers. It is notable that many of its do not have sufficient number of legs due preying on each other when the primary products are not enough; this finding suggests a relationship between the spouting methane and the ecosystem.

The YK10-08 cruise included a total of 12 dives that collectively revealed various aspects of crab biomass within the gas hydrate field, which included areas without crabs as well as areas where numerous crabs congregated as shown in Fig. 16.

Conclusions

It is possible to obtain the kind of images collected by *Tuna-Sand* with an ROV equipped with an auto-cruise system that can follow its survey line, keeping a specified altitude and speed. In 1997, for example, *Jason*, an ROV designed by the Woods Hole Oceanographic Institution, produced a detailed photographic mosaic of the wreck of the ship *Derbyshire*, a very large bulk carrier that sank off Daito Jima to a depth of 2700 m[4]. Nevertheless, ROV operations in the deep sea are costly and technically difficult. If a well-defined survey area can be predetermined, a small hovering-type AUV such as *Tuna-Sand*, as discussed in this article, can easily accomplish the task and expand the range of AUV applications.

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4 Report on the sinking of the MS Derbyshire, by UK/EC assessors,ISBN1-85112-072-6