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Recent advances in imaging deep-sea hydrothermal vents

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Introduction

Over the past decade, we have used a spectrum of innovative new imaging technologies on the deep submergence vehicle (*DSV*) *Alvin* to document biological and geological features at deep-sea hydrothermal vents located at 9°50' N along the East Pacific Rise (EPR). In addition, during August 2001, we utilized two of the most advanced of these imaging systems [Digital High Definition Television (HDTV) and IMAX 15/70 mm format], coupled with extensive HMI lighting arrays, to document biological and geological features at several sites of hydrothermal activity (*e.g.*, Lost City and TAG) on, or adjacent to, the Mid-Atlantic Ridge. The present paper reviews results obtained with these systems.

Materials and methods

During a DSV *Alvin* cruise in November, 1999, a prototype SONY high-definition television (HDTV) camera, with the signal recorded to a digital HDVS media, was mounted on a pan and tilt assembly beneath the pilot's viewport. During this same expedition, an IMAX camera was utilized for the first time inside *Alvin*'s titanium sphere during 5 separate dives to generate images of vent ecosystems on a 15/70 mm format. In August 2001, the HDTV and IMAX systems were utilized on 15 *Alvin* dives to the Lost City, TAG and Snake Pit hydrothermal fields along the Mid-Atlantic Ridge system. Images generated using the IMAX camera system were printed directly from the associated 15/70 mm negatives, while HDTV images were frame-grabbed utilizing HDStation Pro VGUI software with a DVS High-Definition RAM recorder (DVS Digital Video Inc., Glendale, California). Figure 1 depicts externally-mounted lighting arrays on specially-designed, extendible booms and a modified starboard arm, which equipped *Alvin* with seven 400 watt fixtures and one 1200 watt assembly. These lighting systems provided *Alvin* with an unprecedented capability of delivering to the seafloor 4000 watts of light and were key to the acquisition of high quality images. The combined lighting arrays were capable of illuminating an area of the ocean floor approximately 50 meters in extent.

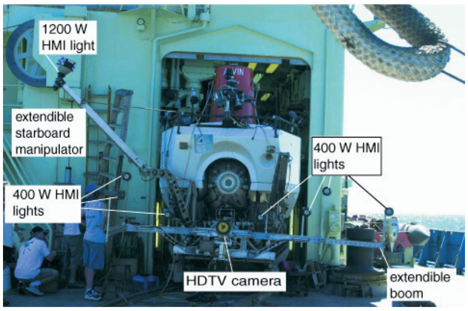

Figure 1. *DSV Alvin* configured with front-mounted, extendible booms equipped with seven 400 watt HMI fixtures and a 1200 watt HMI light assembly mounted on an extended starboard arm. The combined lighting arrays provided an unprecedented 4000 watts of light on the seafloor.

The mounting of HMI fixtures on long, extendible booms provided a means of maximizing the separation between the camera lens and the light sources, as well as minimizing the scattering effect of suspended particles. The fact that the HMI light fixtures themselves were mounted relatively far forward on the submersible allowed the camera systems to "shoot" through a zone of darkness into the lit regions, which also resulted in a reduction of "back-scattering" effects.

Results and Discussion

The manner in which detail is perceived within an image is directly related to its resolution. Hence, one's ability to see detail is limited by traditional CCD cameras and by the standard video formats of NTSC (350,000 pixels) and PAL (440,000 pixels). HDTV camera and recording systems (2 M pixels) and IMAX camera systems (15/70 mm film) dramatically increase the resolution of detail in the recorded image. A print prepared from a 15/70 mm negative generated from the IMAX camera system is depicted in Figure 2. The vertical extent of this image of a tubeworm-covered sulphide edifice is presented to illustrate not only the high resolution of the print, but also the extensive area that has been illuminated by Alvin's lighting system. Figures 3 and 4 represent frame-grabbed images generated from HDTV video footage taken at 9°50'N on the EPR and at the TAG hydrothermal field on the Mid-Atlantic Ridge, respectively. The resolution of these HDTV images is approximately equivalent to that of 35 mm film. In contrast to the handful of scientifically-useful 35 mm images that are traditionally generated during an *Alvin* dive, HDTV footage typically provides easily thousands of images from which to choose when attempting to illustrate scientific observations made during the course of a single dive. In addition, from a biological perspective, the increased resolution offered by the IMAX and HDTV systems permits documentation of smaller (< 1 cm) faunal constituents of the hydrothermal vent community than have heretofore been documented using traditional CCD camera systems. Further illustrations of the quality and utility of IMAX- and HDTV-generated images of biological and geological features associated with deep-sea hydrothermal vents may be found in Lutz (2000, 2001) and Lutz et al. (2001). Figure 5 is a frame-grabbed image from video footage generated utilizing a single-chip CCD camera system to illustrate the contrast in resolution relative to that associated with the images generated from the IMAX and HDTV footage taken during the course of our *Alvin* dives. The image, taken using a camera mounted directly above the IMAX camera lens, is that of hydrothermal chimneys at an off-axis hydrothermal field (Lost City) near the Mid-Atlantic Ridge at 30°N (Kelley et al., 2001). The vertical extent of the image (about 4 meters) and lighting conditions are approximately the same as those associated with the IMAX image presented in Figure 2. While the IMAX format offers a higher quality image than HDTV, routine use of the awkward IMAX camera system on deep-diving submersibles is unlikely. HDTV cameras and associated recording devices are more likely to be the systems of choice for improved resolution because their smaller size permits mounting inside external pressure housings and because the image format is accessible to a broader community of scientists than would be possible with IMAX film.

The adaptation of increasingly high resolution imaging systems for use on DSV *Alvin* has facilitated in recent years the unprecedented documentation of biological and geological features associated with deep-sea hydrothermal systems. The ability to acquire, almost instantaneously, still images from HDTV video represents a powerful new tool for documenting vent ecosystems. This technology

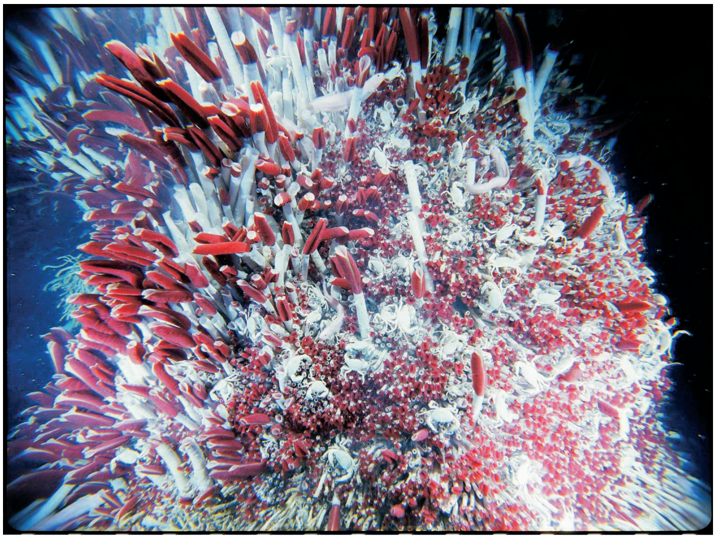

Figure 2. Image taken with an IMAX camera (15/70 mm format) of a polymetallic sulphide edifice covered with vestimentiferan tubeworms (*Riftia pachyptila* Jones, 1981 and *Tevnia jerichonana* Jones, 1985) at 9°50'N along the East Pacific Rise. The vertical extent of the image is approximately 4 metres. Image courtesy of Stephen Low Productions and Woods Hole Oceanographic Institution.

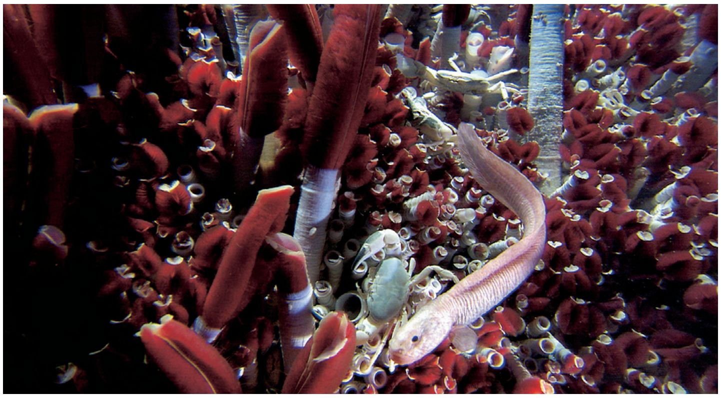

Figure 3. A frame-grabbed image from a digital HDTV video system mounted on *DSV Alvin*. The image depicts vestimentiferan tubeworms (*Riftia pachyptila* and *Tevnia jerichonana*) and a zoarcid fish (*Thermarces cerberus* Rosenblatt & Cohen, 1986) at a vent field located at 9°50'N on the East Pacific Rise. Image courtesy of Woods Hole Oceanographic Institution.

Figure 4. A frame-grabbed image from a digital HDTV video system mounted on *DSV Alvin*. The image depicts a sea anemone located at the periphery of the TAG hydrothermal field on the Mid-Atlantic Ridge.

Figure 5. A frame-grabbed image from video footage generated utilizing a single-chip CCD camera system to illustrate the contrast in resolution relative to that associated with images captured from the HDTV footage. The image depicts calcium carbonate hydrothermal chimneys at an off-axis hydrothermal vent field (Lost City) near the Mid-Atlantic Ridge at 30°N. The vertical extent of the image is approximately 4 metres.

facilitates analysis of images while at sea or immediately following a cruise, greatly accelerating the communication of research results in publications and on the Internet. In addition, the video and film media provide new and exciting possibilities for both scientific and educational outreach initiatives. To this end, a giant screen film production focusing on hydrothermal systems of the eastern Pacific and the mid-Atlantic is in the process of being assembled from the HDTV and IMAX vent footage shot to date. The footage is already providing researchers with unprecedented images to enhance their studies of vent ecosystems. In addition, the film will provide a vehicle for educating and exposing a huge, world-wide scientific and lay audience to the wonders associated with what we know and what we have yet to learn about these fascinating deep-sea hydrothermal ecosystems.

Acknowledgements

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