RESPONSIBLE SCIENCE AT HYDROTHERMAL VENTS

BY COLIN W. DEVEY, CHARLES R. FISHER, AND STEVEN SCOTT

Courtesy of R. Lutz, Rutgers University.

Hydrothermal systems of deep-sea spreading centers stand out as islands of life on a seafloor where the abundance of megafauna is otherwise very low. These hydrothermal systems support a dense biomass of microbes and animals in an ecosystem that relies on chemosynthesis for energy. Hydrothermal systems are relatively rare features of the vast, deep seafloor. Current data suggest that hydrothermal systems probably occur every 50–100 km and that around 1000 systems are active at any one time (Baker and German, 2004); however, only about 10 percent of the total 60,000 km of the global mid-ocean ridge has been surveyed in any detail for the presence of hydrothermal activity. Although some individual sites cover an area the size of a football stadium and are described as being "large," on the expanse of the seafloor they, too, represent a minute area.

Since their discovery 30 years ago, scientists and tourists have visited several dozen hydrothermal sites. In recent years, two marine mining companies, Nautilus Minerals and Neptune Minerals, acquired exploration rights to deep-sea hydrothermal deposits in the western Pacific and are actively prospecting and evaluating these deposits (see www.neptuneminerals.com and www.nautilusminerals.com). All of this activity prompts concerns about whether hydrothermal vents need protection from some types of anthropogenic exploration. Hydrothermal sites have also caught the attention of nongovernmental organizations, such as WWF, and international bodies, such as the Commission for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), the World Conservation Union (IUCN), and the International Seabed Authority (ISA), all of which have begun examining mechanisms to regulate activities there. With these new stakeholders on the scene, hydrothermal-vent research has recently been thrown into the policy spotlight, a relatively new situation for this branch of research. InterRidge, the international body representing ridge research, decided to address this situation proactively by assembling a "Statement of Responsible Research Practices at Hydrothermal Vents." Development of this statement—and the questions surrounding it—are discussed below.

Several questions arise in a discussion of the management of hydrothermal systems. First: What is the proper balance between impact and benefit? As the famous Austrian physicist Erwin Schrödinger pointed out, observing a system changes that system. This statement applies to much more than the subatomic physical systems that Schrödinger examined. For scientists studying the natural environment, this fact of life requires a permanent balancing act: collecting knowledge to better understand (and if necessary, better protect) the environment, but, in the process, changing that environment to some extent.

A second question is: Do hydrothermal systems need protection and, if so, from what and whom? The fact alone that hydrothermal systems and their unique fauna are relatively rare suggests that it is essential to prevent human activity from impacting them negatively. It is important at the outset, however, to deal with the "from whom?" part of this question. We are concerned in this article purely with any possible impacts of scientific research on hydrothermal vents. Questions about, for example, the impact of possible future seafloor mining, are being investigated by the International Seabed Authority, a United Nations body based in Jamaica, and are outside the scope of this article.

A third question is: If the goal is to protect a hydrothermal system, what is the best way to do it? On land we have national parks or national sanctuaries—sites protected for their aesthetic value, scientific interest, or rarity. Would a similar system, based on the definition of Marine Protected Areas (MPAs), work for active hydrothermal systems, making them akin to national parks under the waves? Some groups, such as WWF (see WWF, 2003), believe it would. Indeed, OSPAR has declared mid-ocean ridges with their hydrothermal vents to be priority habitats under the organization's convention aimed at establishing a network of MPAs by 2010, including hydrothermal vents in the Northeast Atlantic (see OSPAR recommendation 2003/33 at http://www.ospar.org/documents/dbase/decrecs/recommendations/or03-03e.doc). As we will see later in this article, some MPAs have been or are being set up at hydrothermal sites.

The "national" in "national park" highlights one of the major problems with this idea as it applies to the majority of hydrothermal systems: most of them are in international waters and therefore not under the jurisdiction of any particular nation. Also, access to the deep sea is limited and expensive—just who can and would play the role of "park rangers," even for systems in national waters?

The intrinsically ephemeral nature of hydrothermalism further complicates matters; although not impossible, it is nevertheless highly unlikely that the stand of redwoods in a national park will be wiped out from one day to the next by a natural event, so declaring them to be part of a national park is an effective way to protect them. Hydrothermal systems, on the other hand, are under constant threat of annihilation from the very natural processes to which they owe their existence. It is inevitable that hydrothermal features targeted for protection will at some point be wiped out by a lava flow or lose their hot water supply as a result of tectonic events. Although some systems may last for millennia (Cave et al., 2002), we know now that, for many ridge systems, these types of events occur on scales of years to decades. This fact was made abundantly clear to the international research community last year when one of the most actively studied sites in the world, the hydrothermal system at 9°50´N on the East Pacific Rise, was largely paved over as a result of a volcanic eruption (Tolstoy et al., 2006; Figure 1). Fortunately for the hydrothermal-vent fauna, current research suggests that the communities of animals from nearby vent sites are genetically connected, forming metapopulations that interbreed (see Ramirez-Llodra et al, this issue). This interbreeding provides a degree of resilience at the species level to events that affect individual vent sites.

The fascinating science of deep-sea hydrothermal vents is advancing hand in hand with the development of measures of effective and responsible scientific stewardship.

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RESPONSIBLE SCIENCE: NO PROTECTION WITHOUT RESEARCH

InterRidge is an international, nonprofit organization comprised of some 2000 researchers from more than 27 nations who have organized themselves to facilitate international research cooperation and build consensus on important policy issues. InterRidge scientists have wrestled with the problem of how best to study hydrothermal sites for many years. Members of the InterRidge Biology Working Group published a position paper in 1998 addressing the need for "sanctuaries" (no-sampling zones) within hydrothermal vent sites (Mullineaux et al., 1998). InterRidge sponsored two international workshops specifically addressing management and conservation of hydrothermal systems. The first, "The InterRidge Workshop on the Management and Conservation of Hydrothermal Vent Ecosystems," was held in Victoria, Canada, in September 2000 (see http://www.whoi.edu/science/GG/interridge/SCIENCE/Science_reports/ReportPDFs/ventrepMay01.pdf). The second, "The Azores Triple Junction Hydrothermal Vents Marine Protected Area Management Plan workshop," was held in Horta, Azores, Portugal, in June of 2002 (see http://www.horta.uac.pt/editions/suplementos/Supplement%204%20Management.pdf). Opinions were naturally often disparate—not on the question of the need for scientific research as an integral part of the conservation effort (Figure 2), but often on the question of how best to oversee this research.

Figure 1 (above). A community of the vent pioneer species, *Tevnia jericonana*, photographed in November 2006 near the former Tica site at 9°50´N on the East Pacific Rise. This animal community began to grow after the January 2006 eruption, on recently "renovated" seafloor. *Photo courtesy of K. Von Damm*

Figure 2 (left). Snails, mussels, and anemones clustered around a low-temperature vent in the Lau back-arc basin. Six new species of anemone sampled during cruises to this back-arc basin in 2005 and 2006 are currently under description, highlighting the importance of continued scientific exploration and sampling. *Photo courtesy of the Ridge 2000 Program*

These early discussions eventually led to the proposal, in 2002, to establish two MPAs at vent sites on the Mid-Atlantic Ridge south of the Azores in the Portuguese Economic Exclusive Zone (EEZ) and, in 2003, to the legal ratification of another MPA west of Vancouver in Canadian territorial waters (see section on Endeavour Marine Protected Area). The Mid-Atlantic Ridge MPAs (proposed for the vents Lucky Strike and Menez Gwen) were the subject of local management consultations (e.g., Santos et al., 2003); public consultation has recently been completed and these MPAs are expected to pass into law shortly. In October 2006, Portugal proposed sites farther south on the Mid-Atlantic Ridge, outside the Portuguese 200-nautical-mile limit but within an area claimed by Portugal under the UN Convention on Law of the Sea (UNCLOS, Article 76) and also within the area covered by OSPAR, for MPA status via OSPAR consultation mechanisms. For all of these MPAs, however, the underlying scientific questions and problems remain to be answered: Do these sites need protection and, if so, what are the main threats? Is an MPA an appropriate or effective mechanism to provide this protection? How will the effectiveness of an MPA be measured? How will the MPA respond to physical changes in the hydrothermal system or seafloor geology?

In 2001, as a result of InterRidge's international consultations, a first draft of guidelines for conducting scientific research at hydrothermal vents was circulated among InterRidge scientists. The draft was discussed and revised many times in the ensuing years. The essence of the guidelines was distilled to a compact set of statements reflecting an international consensus. In early 2006, the InterRidge Steering Committee and leaders of all InterRidge working groups unanimously accepted these statements, effectively speaking for the international ridge science community. The statements were presented to the media and the public at the American Association for the Advancement of Science (AAAS) meeting in St. Louis, MO, in February 2006 and at the EuroScience Open Forum (ESOF) Meeting in Munich, Germany, in July 2006. The text below is extracted from this statement.

The sustainable use and protection of the oceans is best served by a fundamental understanding of complex marine systems. This understanding is only attainable through scientific research. This means that detailed research on the oceans is an integral and necessary part of effective resource management and environmental protection. In the interest of environmental stewardship, it must be the goal of research scientists to minimize disturbances as much as possible, while still gathering the information necessary both to understand the systems and to form a basis for sustainable use strategies. Therefore, marine scientists should always evaluate their research plans from a conservative standpoint, and choose the most environmentally friendly research approach.

As marine research scientists we especially appreciate the uniqueness and complexity of the deep-sea hydrothermal vent fauna and environments, and are particularly interested in preserving vents for their scientific, aesthetic, ecological, and potential economic values. Because of the specialized nature of the equipment required to work at deep-sea hydrothermal vents, such as occupied and unoccupied research submersibles, scientists are the primary group of people who have the opportunity to visit these extraordinary environments. The potential for significant impact of scientific activities on a single vent site or a population of vent animals pales in comparison to the potential for disturbance by volcanic/tectonic events or industrial mining/harvesting activities. Nonetheless, we recognize that some scientific activities could adversely affect individual sites or impact communities more than is necessary, if research activities are not carefully planned and executed. In addition, because only a limited number of sites are currently known and scientists from a wide variety of disciplines frequently work at single locations, we recognize the potential for use conflicts among scientists, at sites where scientific activity is intense.

RESPONSIBLE RESEARCH PRACTICES

Six main recommendations define what InterRidge considers to be good scientific practice. These recommendations are presented as orientation guidelines for individuals when carrying out their scientific work.

1 Avoid, in the conduct of scientific research, activities that will have deleterious impacts on the sustainability of populations of hydrothermal vent organisms.

2 Avoid, in the conduct of scientific research, activities that lead to long-lasting and significant alteration and/or visual degradation of vent sites.

3 Avoid collections that are not essential to the conduct of scientific research.

4 Avoid, in the conduct of scientific research, transplanting biota or geological material between sites.

5 Familiarize yourself with the status of current and planned research in an area and avoid activities that will compromise experiments or observations of other researchers. Assure that your own research activities and plans are known to the rest of the international research community through InterRidge and other public domain databases.

6 Facilitate the fullest possible use of all biological, chemical and geological samples collected through collaborations and cooperation amongst the global community of scientists.

Let us now look at the rationale behind each of these six statements, paraphrasing the statement text a little to elicit the core message:

1 Avoid activities that will have deleterious impacts on the sustainability of vent animal populations.

Vent organisms, as described in Desbruyères et al. (2006), live life on the "edge." Individual vent creatures are constantly threatened by the variable and extreme environment they inhabit. This recommendation therefore focuses on protecting the populations rather than the individuals (see also Figure 3). An analogy from the garden can illustrate the point: digging up and dissecting a rose bush for research purposes will not, generally, impact the sustainability of this species of rose. If it comes to that, neither would digging up a whole row of roses, although that could have other effects, which leads to the next point.

2 Avoid activities that lead to long-lasting and significant alterations to and/or visual degradation of vent sites.

There are two issues here. The first deals with long-lasting alteration, preserving the site not only for future research but also for humankind in general. It is intimately connected to the quandary with which we opened this article: how to study a system without significantly changing it. The second issue covers the appearance of the site. Looking at the desks (or desktops!) of many scientists, it may not seem that they are concerned with appearance and beauty, but in fact this concern for the protection of the appearance of these awesome sites is something dear to all our hearts. Sticking with the rose-garden analogy, make sure the garden is around for study and enjoyment by future generations and make sure it still looks like a garden!

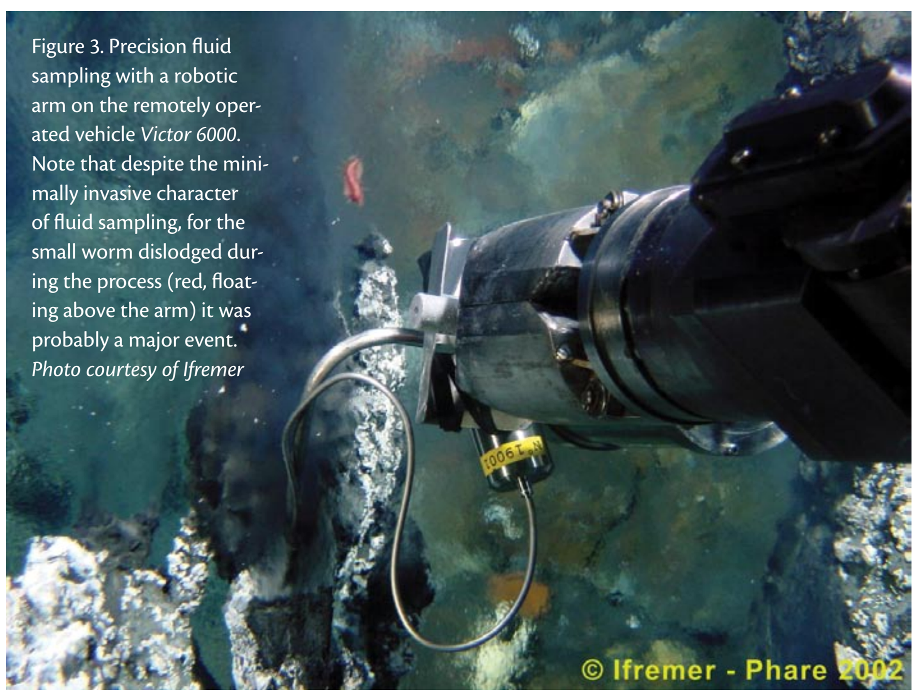

Figure 3. Precision fluid sampling with a robotic arm on the remotely operated vehicle *Victor 6000*. Note that despite the minimally invasive character of fluid sampling, for the small worm dislodged during the process (red, floating above the arm) it was probably a major event. *Photo courtesy of Ifremer*

3 Avoid collections that are not essential to the conduct of scientific research.

The main thrust of this statement is to make crystal clear the distinction between essential sampling for scientific research and commercial or souvenir sampling.

4 Avoid, in the conduct of scientific research, transplanting biota or geological material between sites.

Statement 1 addressed the need for scientists to avoid endangering the sustainability of populations. Statement 4 focuses on maintaining the genetic identity of these populations and protecting them from disease and negative impacts of potential invasive species (Raloff, 2006). The statement about not transplanting geological materials reflects the fact that knowing the location at which a seafloor sample was formed is important information. Scientists do not know of a natural process that moves rocks around at spreading centers in a significant way; when we collect them, we tacitly assume that the samples were formed where we found them, an assumption which would be confounded if people were to start transplanting samples. This leads directly into Statement 5.

5 Avoid activities that will compromise experiments or observations of other researchers, and communicate what you are doing.

When several different groups work in the same area, it is critical—in terms of efficiency and, therefore, the guiding principle of minimum impact—that experiments do not interfere with each other. Thus, it is necessary that scientists do three things: find out what others are doing in the area, make details of one's experiments available to others, and respect ongoing and planned experiments of others. InterRidge is an ideal vehicle for this communication, through its Web site, email updates, and the newsletter *InterRidge News*.

6 Facilitate the fullest possible use of all samples collected.

Not only is the maxim of "minimizing impact" a reason for Recommendation 6, but also the realization that samples that have been studied with the widest variety of methods are, scientifically, often the most informative and valuable. Facilitating the sharing of samples not only reduces the environmental impact of scientific sampling but also enhances scientific output.

IMPLICATIONS AND EFFECTS

In general, what does InterRidge hope to achieve with this statement of good research practice? Although it may sound prosaic, one of the major reasons for undertaking this challenging task is to state, in a proactive and unified voice, what the scientists, as the professionals of deep-sea, spreading-center research, consider to be appropriate ways of studying these fascinating ecosystems and why. The individual statements themselves embody ideas that ridge scientists have adhered to for decades; the statement as a whole firms them up and spells them out in order to make them more accessible to the scientific community and the general public at a time when many stakeholders are interested in this part of the deep sea. The statement has also stimulated discussion on best research practice not only at national and international levels, but also on research vessels, between scientists and crew.

A further hope is that this statement will provide a sound scientific foundation for possible future legal regulation of deep-sea research, if appropriate. As a first step in this direction, various national funding agencies are considering adopting the tenets of the statement as prerequisites for funding research cruises, effectively using national mechanisms to bolster the guidelines for application in international waters.

When the hydrothermal system lies within national waters, such indirect regulations via funding agencies are not necessary, and legislators can use national legal mechanisms to set up seafloor protected areas. An example, which from the point of view of MPAs is perhaps particularly interesting, is the Endeavour Field on the Juan de Fuca Ridge in the Northeast Pacific.

ENDEAVOUR MARINE PROTECTED AREA

On March 7, 2003, the Minister of Fisheries and Oceans announced the creation under Canada's Ocean Act of the "Endeavour Hydrothermal Vents Marine Protected Area," thus establishing one of the world's first deep-sea MPAs (see http://www.pac.dfo-mpo.gc.ca/oceans/mpa/Endeavour_e.htm). It had been a "Pilot Marine Protected Area" since 1998. The site is in the Canadian EEZ, 250 km southwest of Vancouver Island on the Juan de Fuca Ridge at a water depth of 2250 m (Figure 4). Marine scientists who worked in the area and appreciated its special splendor initiated the idea for a deep-sea MPA.

Why establish a "park" in such a re-

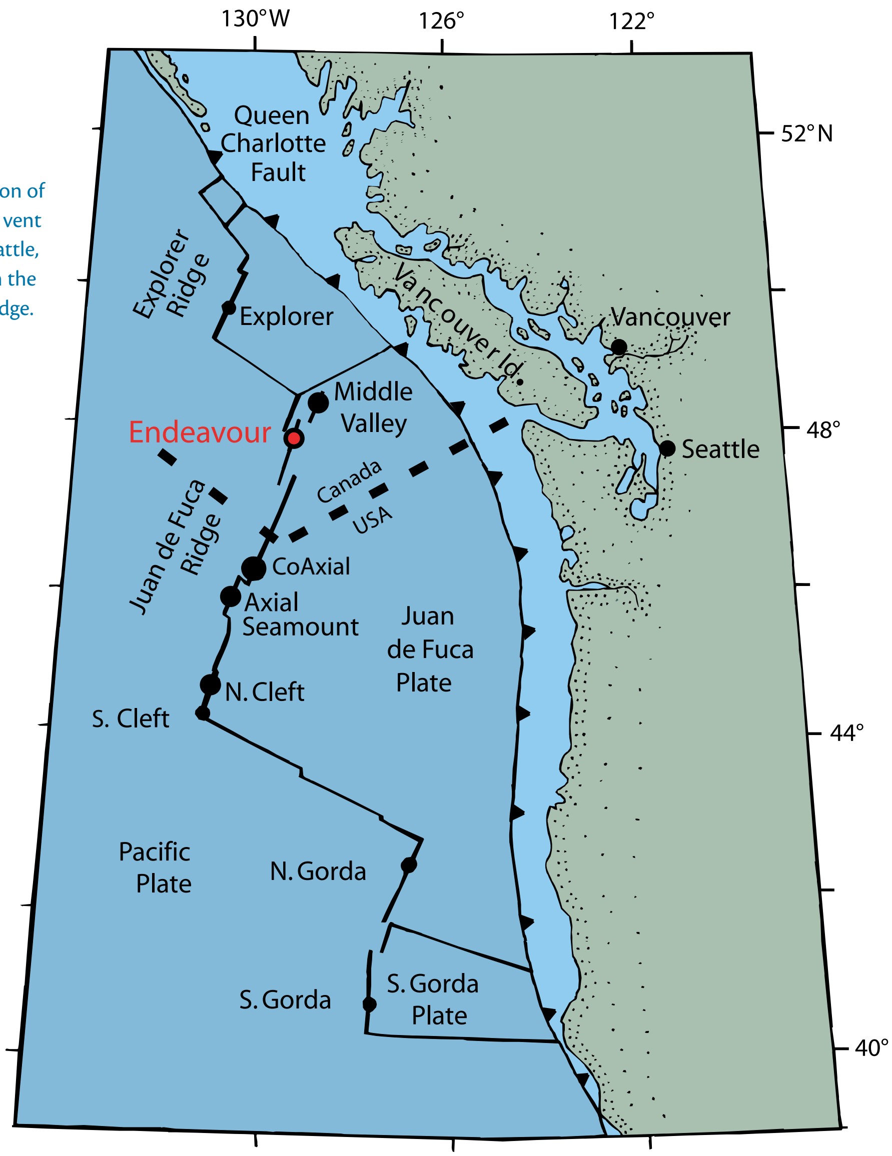

Figure 4. Location of the Endeavour vent fields, west of Seattle, Washington, on the Juan de Fuca Ridge.

mote location that is inaccessible to all but a few marine scientists? The simple answer is because it is a spectacular and well-studied example of seafloor hydrothermal activity that needs to be managed in a way that will protect it for continuing research and for the enjoyment of future generations of the public. Although it may seem far-fetched to imagine that the public will ever really be able to enjoy this site, it is instructive to compare it to Yellowstone National Park, with its superb scenery, wildlife, and geysers. When Yellowstone was established in the wilderness of the western United States in 1872, it was inaccessible to all but a few hardy adventurers who rode several days by horse from the nearest railhead to get there. Today, with improvements in transportation, about three million visitors see the wonders of the park every year. We can expect advances in submersible technology that will enable the general public to visit the seafloor, and the quest for new and unusual vacation destinations, to make the Endeavour MPA accessible to our descendants.

Hydrothermal vents were discovered on the Juan de Fuca Ridge in 1982 and at Endeavour in 1984. Since then, there have been numerous Canadian and American, commonly joint, marine

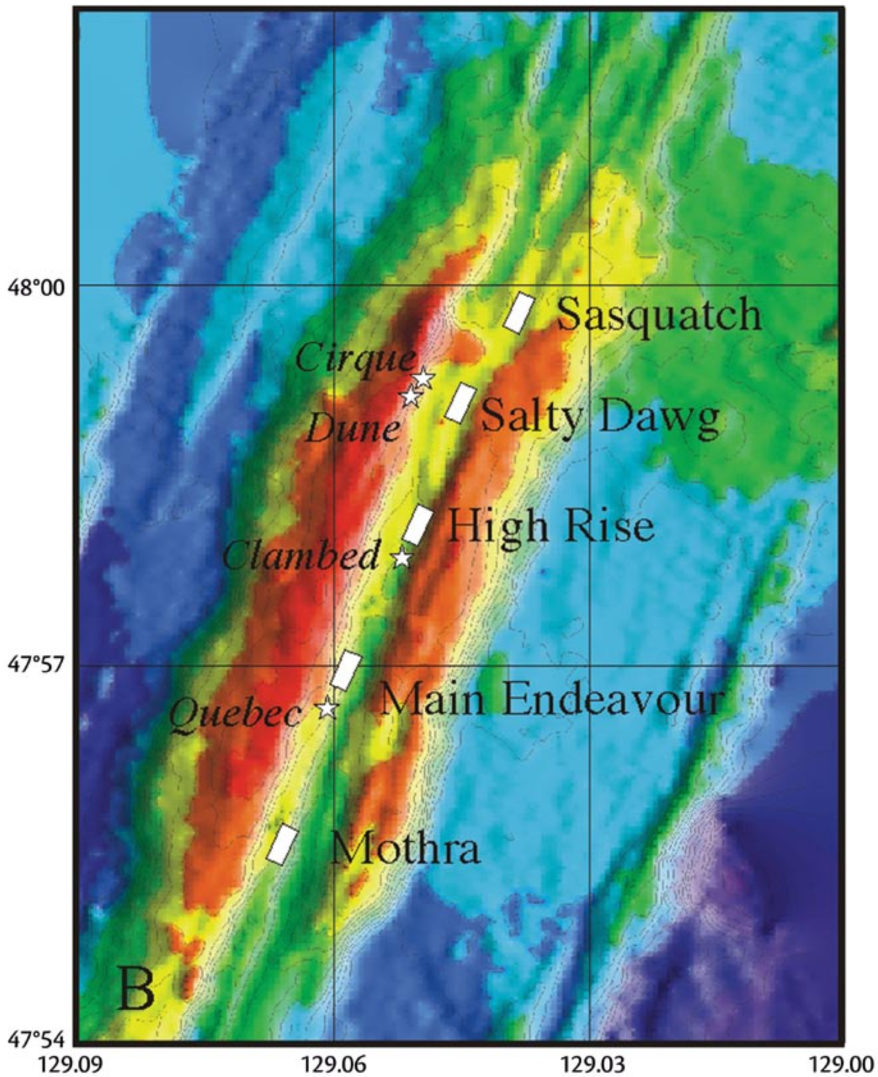

Figure 5. Individual vents (stars) and more extensive vent fields (boxes) in the Endeavour Marine Protected Area. *After Kristall et al. (2006)*

expeditions to Endeavour to study the geology, biology, and geophysics of the area's seabed and the biology, chemistry, and physics of its overlying water column. The Endeavour MPA has five main vent fields (Figure 5) with black-smoker chimneys and majestic spires, one of which, named Godzilla, was measured to be about 40-m tall before it collapsed (through natural causes) in 1994. In 1998, the upper sections of four spires were harvested for display at the American Museum of Natural History in New York and the Royal Ontario Museum in Toronto. Long-term experiments have been conducted using recording and sampling instruments left on the seabed for extended periods, and several seismometers are buried in the seafloor. One of the nodes of the NEPTUNE cabled observatory will be located within this MPA. This observatory will permit real-time experimentation and observation by scientists and provide the general public with a live window to the seafloor (see http://www.neptunecanada.ca and Juniper et al., this issue).

Before the Endeavour MPA was established, all potential stakeholders were consulted to determine their commercial or other interests in the area. The stakeholders included deep-sea fisheries, the military, various levels of government, nongovernmental organizations, academic scientists, granting agencies, tourism groups, and ocean miners. In response to a concern from the mining industry, an economic assessment was conducted. The assessment ascertained that the known sulfide edifices totaled only about 45,000 metric tons and the likelihood of finding substantially more was low, so there was insufficient economic potential to support industrial mining interests.

A Management Board made up of Canadian and US representatives from government, academia, and industry oversees activities in the MPA. The Board reviews all requests for access to the area and ascertains if they are consistent with the MPA's management plan. For planning purposes, the Endeavour MPA has been subdivided into four management areas. The Salty Dawg vent field is reserved as an observational research site with no intrusive activities allowed. The High Rise vent field is reserved for projects focused on education/outreach with more intrusive activities not allowed. The Mothra and Main Endeavour vent fields are reserved for research projects, including those involving moderate sampling. The full management plan and related documents are available on the Web at http://www.pac.dfo-mpo.gc.ca/oceans/mpa/Endeavour_e.htm.

Our aim is to develop a thorough understanding of these oases of life in the deep sea in order to advise the public and policy-makers on how best to preserve them and their outstanding beauty for future generations.

The Endeavour MPA was not defined by simply drawing boundaries on a map and declaring the area "off limits." The process for setting up the MPA was thorough and time consuming, but necessary to ensure all potential commercial, military, and research aspects were documented, carefully considered, and adjudicated fairly. The process is still evolving as the Management Board wrestles with numerous issues and details that will be applicable to other deep-sea ridge MPAs. For example, should dredging be permitted at Mothra and Main Endeavour, or must all sampling of rocks be done more surgically using a submersible or remotely operated vehicle? How does one manage an environment that nature will alter on short time scales? Can active seismic surveys using air guns be permitted and, if so, where? What actually does constitute an "intrusive activity"? For example, are lights on a submersible intrusive? When does biological or geological sampling "cross the line" and become intrusive? How does one balance infrastructure for observations with impact to the site? Answers to these and many more questions are slowly coming to light, and the expectation is that a comprehensive and sensible management plan will emerge that could be a model for others to use.

CONCLUSION

The fascinating science of deep-sea hydrothermal vents is advancing hand in hand with the development of measures of effective and responsible scientific stewardship. Our aim is to develop a thorough understanding of these oases of life in the deep sea in order to advise the public and policy-makers on how best to preserve them and their outstanding beauty for future generations. Continuing dialogue is an integral component to the process of defining limits among total avoidance, scientific activities, and commercial exploitation.

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