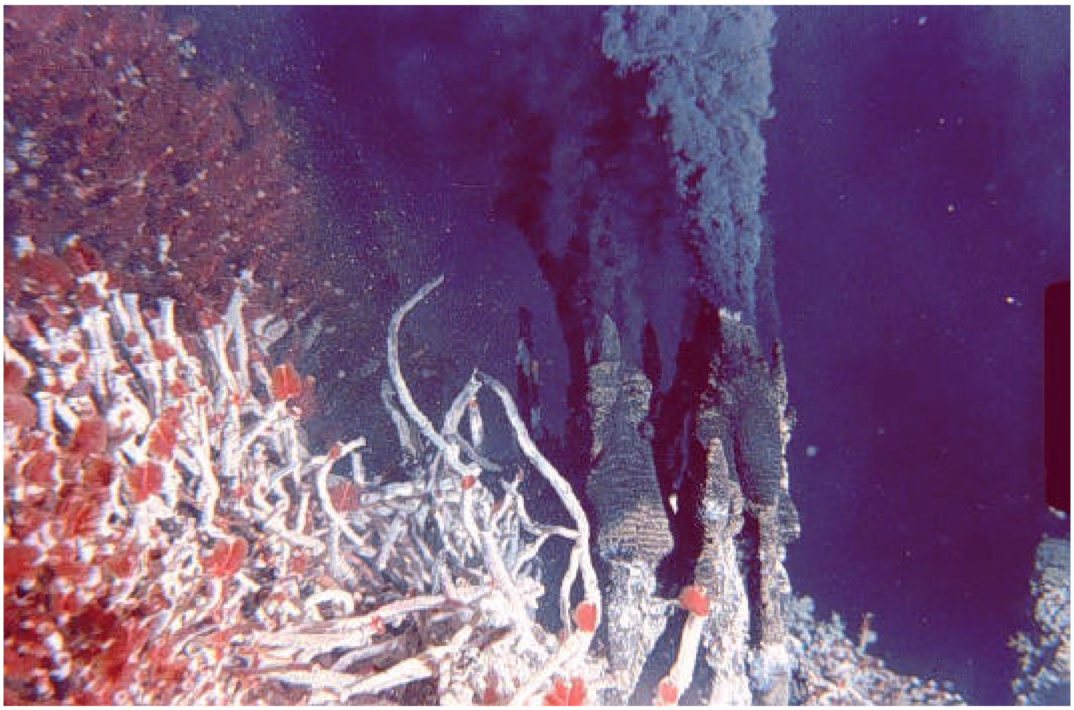
OCEANS BACKGROUND REPORT

THE ENDEAVOUR HOT VENTS AREA:

A Pilot Marine Protected Area In Canada's Pacific Ocean



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Prepared by:
Verena Tunnicliffe[1] and Richard Thomson[2]

[1] **Department of Biology/**
School of Earth and Ocean Sciences
University of Victoria,
Victoria, British Columbia V8V 3P6

[2] **Institute of Ocean Sciences**
Fisheries & Oceans Canada
Sidney, British Columbia
V8L 4B2

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1. Location of Pilot Marine Protected Area (MPA)

Regional Setting

The hydrothermal venting regions of the Endeavour Hot Vents Area lie in the offshore waters of the northeast Pacific. Located at 256 km southwest of Vancouver Island (Clayoquot Sound) and centred at 47°57'N and 129° 06'W, this seafloor spreading centre falls within Canadian jurisdiction (Figure 1).

The Endeavour Hot Vents Area is part of the Juan de Fuca Ridge. This ridge comprises seven segments. The ridge is a seafloor spreading zone where new rock is formed and spreads to each side of the ridgecrest. This process pushes the huge Pacific Plate westward toward Japan and the small Juan de Fuca Plate eastward toward British Columbia and the northwestern United States. Associated with seafloor spreading and upwelling magma is the process called hydrothermal circulation. Water under the crust is heated and eventually ejected as 'hot vents'. There are several major sites of hydrothermalism along Juan de Fuca Ridge of which Endeavour Hot Vents Area is the largest and most diverse.

Canadian Setting

In neither the Arctic nor Atlantic oceans do the spreading ridgecrests enter Canadian waters. At the latitude of Canada, the Mid-Atlantic Ridge bisects Iceland and runs east of Greenland. Only in the northeast Pacific does the Juan de Fuca/Explorer ridge system sponsor hydrothermal vents habitats. And here, there are only three known sites in Canadian waters.

Global Setting

Mid-ocean ridges and, therefore, hydrothermal sites are found in all oceans. Ridge crests run like a baseball seam around the globe (Figure 2). Not all parts of the ridge are actively heated or have hot water circulation. Global exploration is far from complete so we know of only about 25 distinct vent sites in the world. The northern end of the East Pacific Rise is presently subducted under North America and is extended by the San Andreas Fault. This ancient system re-emerges off the Oregon coast as Juan de Fuca Ridge. The northern extension, Explorer Ridge, is truncated by the Queen Charlotte Fault system. Compared to other systems in the world, this termination is most unusual because of the interference of a continental mass, that is, Canada.

2. Description of the Pilot Marine Protected Area

Hydrothermal Vents

Hot vents form on seafloor spreading ridges where tectonic plates diverge and new Earth's crust is created. Cold seawater trapped under the crust is heated by nearby magma and ejected into the overlying water column as superheated plumes. *Black smokers* with temperatures over 300°C precipitate dissolved minerals and metals on the seafloor as *polymetallic sulphide chimneys*. Cooler waters, below 115°C, support abundant microbial and animal life. This rich ecosystem is supported by microbes that use chemical reaction energy in the emerging fluids; the process is called *chemosynthesis*. Vents host one of the highest levels of *microbial diversity* on the planet.

The high production rates feed large numbers of animals but the hostile chemical conditions have required unusual adaptations. Thus, most of the animals found at vents are new to science and often highly localized. Over ninety percent of the animals found are *endemic* to vents. While spreading ridges form a continuous seam around the Earth, vents sites are small pockets of focussed flow separated by large distances. Thus, species differ from site to site.

The Endeavour Field

An exact terminology remains to be developed among vent workers; those presented below represent the most common parlance.

The known Endeavour Hot Vents site consists of four 'fields' of large black smoker structures surrounded by lower temperature venting. Vent fields are separated from one another along the seafloor by about 2 km. The proposed area (Figure 3) encompasses the four fields and the surrounding ridge axis rift zone. Depth in this region is around 2250 m. The ventfields are found within the axial valley where deep faults channel the hydrothermal circulation (Figure 4). The floor of the axial valley is not sedimented because it is too young geologically to accumulate planktonic sediments. The bare rock is glassy black basalt that forms a rugged, broken terrain.

A ventfield may have dozens of sulphide structures or edifices rising to tens of metres in height. A sulphide structure is built of coalescing chimneys and the chimneys are topped by spires often belching black smoke. A single ventfield may measure around 300 m by 200 m. Within that area, the high temperature fluids are responsible for building the sulphide rock structures. Diffuse venting through the valley floor basalts usually sponsors dense tubeworm bushes or clam beds.

The fields of Endeavour Hot Vents area are regularly spaced, probably reflecting subsurface geological structure. The Main Field was discovered in 1982 by a University of Washington expedition. The remaining fields are relatively recent discoveries so much less is known about them. Hot water characteristics, morphology of the sulphide structures, and animals abundances vary among the four fields; the fields appear to represent a wide range of hydrothermal characteristics.

On the 'normal' floor of the ridgecrest, animal life is very sparse. Creatures common to the deepsea eat organic material fallen from the surface, or they eat each other. An average density might be around twenty worms and brittlestars in a square metre. In the diffuse flows around the sulphide structures of Endeavours biomass is greatly augmented. Here, an estimate of abundances could range up to half a million animals in a square metre. Many are very small but represent a wide diversity of taxa.

The water column above the ventfields is strongly influenced by the hydrothermalism. Several hundred metres above the seafloor, buoyant plumes from the ventfields reach their level of neutral buoyancy and spread laterally in the water column. Because of increased concentrations of vent-derived material (including vent-derived chemosynthetic bacteria), the tops of the plumes are regions of enhanced macrozooplankton aggregation and abundance; the toxic inner plumes are regions of reduced zooplankton abundance. Plume macrozooplankton aggregations comprise both deep species as well as species normally found in the upper ocean. The increased zooplankton aggregations attract other types of animals including fish and jellyfish, and lead to enhanced productivity throughout the entire water column overlying the broad venting region.

The Pilot Marine Protected Area

The suggested boundaries encompass the known ventfields plus a cross-section of non-venting ridgecrest. The pilot MPA would include the overlying water column and the sub-seafloor. In all, about 45 square kilometres of ocean floor are included and 100 cubic kilometres of water.

All four fields are included because of the variability in venting characters that they exhibit. Hydrothermal production influences both the surrounding deepsea and the overlying water. In that sense, they form contiguous ecosystems. The area includes representation of ridge flank and valley floor.

The closest hydrothermal field in Canadian waters is that found in Middle Valley 62 kilometres north-northeast along the ridge axis.

3. Environmental and Socio-economic Significance of the Pilot Marine Protected Area

Although vents are found elsewhere in the world, the unusual nature of Endeavour Ridge was recognized in 1995 by the U. S. RIDGE research program in its selection of this site to develop an international observatory. There are several features about the Endeavour ventfields that are unique, not only in Canada but in the world.

* **Highly unusual natural phenomenon**: Endeavour Hot Vents Area hosts some of the largest complexes of seafloor hydrothermalism currently known in the world.
* **Specialized fauna:** the vent animals of the spreading ridge are found nowhere else in Canada. Many invertebrate species are endemic to the proposed MPA.
* **Diversity of habitats:** the fields span several venting types providing a broad range of biotic habitats.
* **Polymetallic sulphide deposits:** Endeavour is one of the larger deposits of modern ocean-floor sulphide mineral deposits in the world. It forms a vital seafloor laboratory to study ore-forming processes.
* **Hydrothermal output:** the sheer volume of venting fluid and the biological products it generates has a profound influence on the overlying water column.
* **Public interest:** the visual impact and the bizarre nature of hot vents has sparked a great interest in the general public to follow the exploration of this habitat and phenomena.

The Endeavour Vent Biota

The hydrothermal vent habitat is harsh and extreme. Where animals live, temperature gradients can be steep, from 2 to 60^{o}C over a few centimetres. Oxygen is depleted, supplied only from surrounding sea water. Hydrogen sulphide is abundant and is a metabolic toxin for all animals.

Heavy metals are present in all vent fluids as well as trace elements such as arsenic, cadmium, and radium, well-known as mutagens. The creatures that live here are extensively modified to deal with these adverse conditions. The reward is the food supply from the chemosynthetic bacteria.

World-wide, hot vents foster unique species. The northeast Pacific forms a distinct biogeographic province with at least sixty species endemic to the Juan de Fuca Ridge. These animals are not just unique at the species level. Many are new to science at the genus level and a few are new at the family level. These unique species are sequestered in very small areas of venting. Endeavour is the largest of the eight known vent sites on the Juan de Fuca Ridge.

At the Endeavour vents, we currently know of 12 species that have not been found elsewhere. An additional three species are known at only one other vent site on the Juan de Fuca Ridge. As greater exploration occurs, some of these species will be found elsewhere. However, there has been little systematic examination of Endeavour vent animals. In the past year, four new species alone have emerged from careful sorting of a single grab by a submersible. Little is known about the fauna from three of the four fields. Extrapolation of research from other areas leads to the prediction that Endeavour will hold the greatest diversity of vent species in the Juan de Fuca/Explorer system. This extrapolation is based on the greater area of venting and the greater diversity of venting habitats.

Hot vent animals are restricted to very small geographic areas. It can be tens to hundreds and even thousands of kilometres to the next vent site. How do they disperse? Nearly all these animals are invertebrates that have a larval stage in the water column. The slow deepsea currents can spread larvae from one site to the next. For some animals, the volume of larvae produced overwhelms the odds of complete loss between sites. However, high endemism is the result of poor dispersal over very long distances.

Thus, the Endeavour Hot Vents Area appears to be a critical source to sustain the regional vent species pool on Juan de Fuca Ridge. In addition to habitat size and diversity, predictability and stability are critical features. The extent of the Endeavour sulphide structures indicates that hydrothermalism has been active here for a long time, perhaps hundreds to thousands of years. This stability is in contrast to many other areas on the Juan de Fuca Ridge where volcanic eruptions and tectonic shifts have altered hot water conduits in very recent times.

The Hydrothermal Habitat

The animal species that provides the structural basis of this ecosystem is the vestimentiferan tubeworm, *Ridgeia*. Within the tubeworm bushes, about 40 species of invertebrates forage. The bushes on the valley floor are distributed in a patcy fashion, growing where warm water laden with hydrogen sulphide emerges. This mosaic pattern sponsors a patchwork of populations many of which operate in isolation while others are best described by metapopulation dynamics.

Animal types tend to be zoned because there are strong gradients in temperature and chemical concentrations (Figure 5). On the sulphide structures, biotic patterns are governed by hot water flows through the sulphide walls. Distinct assemblages dominated by different species develop in response to flow vigour.

These animals are highly localized at the vents. They are dependent upon a continual supply of enriched fluids. Any disruption, either natural or induced, kills most of the animals. The most common stress comes from the habitat that supports the communities: sulphide structures build and fall over the years, tectonic shifts re-route fluid conduits, and magma movement can change water temperatures drastically. It is tempting to believe these organisms are well adapted to disruption but studies on disturbed communities are equivocal about whether original communities re-establish.

The trophic pathways within the vent community are relatively predictable. Trophic steps are few and most animals appear to feed directly on microbial production. Of particular interest at Endeavour is the link to surrounding communities. Such interaction is poorly understood. The density of deep sea crabs, octopus and fish surrounding the fields suggests that substantial carnivore biomass outside the vents is dependent upon localized production.

Links into the overlying watermass are better known. It appears that chemosynthetic bacteria, resuspended detritus from the upper ocean, and other biological products carried upward by the buoyant plumes support a wide range of biological activity in the overlying water column. Deep acoustic sensing and towed plankton nets reveal that macrozooplankton in various stages of their life cycle aggregate in large numbers at the height of the spreading plumes, 100 to 200 m above the seafloor. Within a radius of about 50 km of the Endeavour Ridge venting region, zooplankton communities consist of both deep- and shallow-water species of zooplankton, suggesting that the animals migrate vertically over 2000 m to reach these food-rich zones. Away from the venting region, only deep species are captured in the net surveys. The presence of large numbers of zooplankton attracts their natural predators such as mictophids, jelly-fish and snipe eels, which are often found in significant abundance in the deep net tows.

Some Human Pressures and Other Change Agents

Since its discovery, the major uses of the hot vents area have been for research and public awareness, mostly through oceanographic researchers. The US submersibles *Alvin* and *Jason* have executed over a dozen dive missions here but joint work with Canadian universities has used the vehicle *ROPOS* on four expeditions. Research is limited to the summer months when weather conditions are amenable to diving. Several cruises using surface vessels have concentrated on water column characteristics. Canadian government research at Endeavour Ridge began in 1985 with the deployment of deep sediment traps and current meters in conjunction with Oregon State University. This work culminated in 1995 following a two-year study with the University of Hawaii and NOAA in Seattle that used deep sediment traps to measure both the upward and downward fluxes of biomass associated with the Endeavour Ridge vent fields.

The Endeavour vent fields are visited once or twice a year by Canadian and foreign scientists. Collection of animals and rocks is standard practise but most manipulations concentrate on measuring characteristics on the bottom, taking photographs, and deploying time-series observation equipment. Other activities include saturation coverage of the fields to retrieve acoustic data to produce geological and navigation maps. In July 1998, the American Museum of Natural History contracted with University of Washington to recover parts of the large sulphides as display and study specimens. The upper sections of four chimeys were removed in the Mothra Field.

Fundamentally, the pressures from research activity are very low. A few vents within two fields have been intensively studied and show signs of human activity. The natural variability within the vent system is so high that it is difficult to assess the human effects. Toppling and regrowth of sulphide structures occurs on a yearly basis. Death of assemblages due to fluid rerouting is very common.

Some Social and Cultural Values

All known values relate to the scientific discoveries that surround the Endeavour ventfields. As the hydrothermal phenomenon is only recently known, there are no historical issues to address.

The Endeavour ventfields are a showcase of scientific discoveries:

* the first vents discovered on Juan de Fuca Ridge (1982);
* the first extensive seafloor ore deposits explored (1984);
* the first discovery of "glowing" vents (1989);
* the highest natural water temperatures known on Earth (1990);
* the first extensive uses of robotic vehicles (1991, 1994);
* site from which the microbe with the highest temperature tolerance has been isolated (113^{o}C);
* the first direct measurement of currents within the main vent field;
* the first evidence that hydrothermal plumes were zones of greatly enhanced zooplankton aggregation;
* the first measurements of both upward and downward fluxes of biomass associated with hydrothermal plumes.

These deep sea discoveries have received extensive media attention in Canada and the United States. Public interest in the area is high. This ventfield embodies the concept of the "unimaginable still to be discovered on our Planet". The bizarre habitat and its inhabitants makes great material for magazine, TV, and newspaper reporting. NASA is considering funding research at this site under the umbrella concept of "Telescope to Inner Space".

Economic Value

Seafloor metallic sulfide deposits, such as those at Endeavour, have many features in common with so-called "volcanogenic massive sulfide ores" that are mined on land in Canada and formed in ancient oceans as much as 2700 million years ago. Canada is particularly well endowed with such deposits. From west to east examples include: Myra Falls on Vancouver Island, Flin Flon, Kidd Creek, Noranda, Bathurst, and Buchans. The Endeavour site offers a spectacular natural laboratory in which to study ore-forming processes.

A better understanding of the structural, petrological, and chemical processes responsible for the Endeavour deposits can lead to a refinement of exploraton models for ancient ores on land. The seafloor deposits may, themselves, be resources for the future both for their contained metals and perhaps also for their thermal energy -- a large black smoker has the same power output as a small nuclear reactor. Some seafloor deposits, although not Endeavour, are of sufficient size and apparent grade that, if they were on land, would attract the interest of the mining industry.

Ocean mining of metallic sulfides will inevitably follow oil production into the deep ocean. By establishing a pilot MPA at Endeavour and conducting appropriate long-term experiments, Canada, with its home-grown biological, geological, and environmental expertise, can take the lead in establishing guidelines for marine mining of polymetallic sulfides.

3. Other Marine Protected Areas of Pertinence to the Pilot Marine Protected Area

Regionally

The companion pilot MPA, Bowie Seamount, is relevant in terms of an offshore position and consideration of assessment mechanisms. The phenomena proposed for protection bear some similarity in terms of a highly localized feature that sponsors increased productivity in a relatively barren deep ocean. There are no geographic or circulation connections between the sites. There are few ecosystem similarities.

Remoteness requires innovative mechanisms of evaluation for both sites. Concurrent development of the pilot concepts is appropriate: management plans that address access, remote instrumentation, database assimilation, and environmental quality indicators may share some aspects.

Globally - Hydrothermal Sites

Most of the productive hydrothermal sites in the world do not fall within any nations territorial waters. Those that do, tend to be within the jurisdiction of nations without marine protected area policies (Mexico, Ecuador, Fiji, New Guinea). New Guinea is examining the potential for mineral exploitation of the known vent sites in its waters. In 1997, exploration licences were granted to an Australian company for trial mining in 1600 m of water. An environmental impact process for the exercise remains to be defined.

The international science community that works on the global ridgecrest system is informally organized through an overseer organization called *InterRidge*. Canada is an Associate Member of the InterRidge community. This program focuses on multidisciplinary studies of the ridgecrest throughout the world and designs specific studies to optimize international collaboration. Through workshops and Web-based News Groups, information and ideas are exchanged.

In 1995, the Biological Studies Ad Hoc Committee recommended the establishment of *Biological Reserves* at intensively studied vents. A 1998 Position Paper formally proposed the concept (http://www.lgs.jussieu.fr/~intridge/reserve.htm). The need was felt partly to disseminate information about on-going observations that require no interference. The community also wished to demonstrate its commitment to protection of a habitat vulnerable in its localized nature and dependency upon venting. A specific call was made to establish areas protected from the type of mining proposed in New Guinea.

Globally - Offshore Sites

There is some precedent for offshore protected areas. The Flower Garden Banks sanctuary in the Gulf of Mexico lies a hundred miles off the coast of Texas. Protection against destruction of coral banks by boat anchors was granted in 1992. An interesting feature of this site is the presence of brine seeps. These seeps harbour unusual species adapted specifically to unusual water conditions -their isolated nature resembles that of hydrothermal vents.

Recently, a CSIRO (Australia) report recommended protection of 15 seamounts 50 to 100 km off the south coast of Tasmainia. The target community for protection are coral beds at depths about 1500 m that foster numerous invertebrate and fish species. Current trawling activity in the area is destroying the coral cover.

5. Some Stakeholders Affected by the Pilot MPA

Governments

International perception is, perhaps, the key issue in the establishment of an MPA on Endeavour ventfields. One component to illustrate that Canada is fulfulling its obligation to the global Biodiversity Convention is by identifying an unusual habitat and fostering protection of endemic species and gene pools. A second component is establishment of an international precedent of conservation of the hydrothermal vent ecosystem where other countries are exploring exploitation.

Researchers

The greatest human use of the Endeavour ventfields is by scientific investigators. There are two ways that the scientific community will view declaration of an MPA at Endeavour: negatively, if impediments to access and activities are perceived, and positively, if legislation improves public support of research and better integration of research efforts. Which view prevails will depend upon the process undertaken in the pilot period. Early definition of goals and involvement of these stakeholders will make a big difference in the final reception of the product.

Interested groups include a large number of researchers in the international and national community. Within Canada, these research groups are found at Universities of Toronto, New Brunswick, Quebec à Montreal, Victoria, and British Columbia. These workers are funded by National Science and Engineering Research Council (NSERC) and form collaborations to maximize use of study resources and to develop interdisciplinary programs. Researchers from government labs within the Department of Fisheries and Oceans (DFO) work on water column characters while geologists at Natural Resources Canada study sulphide mineralogy.

Canada is a paying associate member of the InterRidge Program. This program focuses on multidisciplinary studies of the ridgecrest throughout the world and designs specific studies to optimize international collaboration. InterRidge would disseminate information on an Endeavour ventfields MPA along with information on restrictions, collaborations, and mechanisms for accessing the Canadian access process. If the process appeared reasonable, the InterRidge community is likely to receive an MPA designation favourably because of the perception of special status legislated by a member country to hydrothermal vents.

General Public

There is a potentially large interest in the general public to an MPA at the Endeavour site. Vents are well known among the public. It is less well known that Canada has jurisdiction over one of the largest and best known systems. Virtual tourism to the Endeavour site can be offered in a manner open to all with Internet access. A pilot project involving Canadians along this line was highly successful in 1997 (ABC website). Public awareness is relatively easy because of a natural interest in the deepsea. Exploitation of this interest to expose conservation issues would be very easy.

Educators

Photographs of Endeavour ventfields already appear in secondary and tertiary level textbooks. Articles are used extensively in teaching. Assembly of educational material would be a natural sequitor to the MPA process. Research cruises to this site have included a strong educational component: inclusion of high school teachers, assembly curriculum material, and web-based interaction with school children on shore. There may be no other precedent for working research cruises that could be so inclusive of shore-based participants.

Private Sector

Declaration of MPA status would focus attention on Endeavour and research activites at this site. Canada is a world leader in deep-sea technologies such as telemetry systems, automated instrumentation, and robotic vehicles. Exposure through various media has aided these industries in the past and surely would encourage greater attention as the public focusses on how the site will be monitored. The development of enterprises that exploit scientific work commercially should develop both directly (i.e. communications and public access products like documentaries or CD-ROMS) or indirectly (i.e. video camera interfaces that bring better imagery to the surface).

6. Preliminary Geographical Boundaries of the Pilot MPA

The suggested boundaries include the known ventfields of Endeavour. All four are included because of the variability in venting and communities conditions observed. There may be more venting outside these boundaries. Given lack of information and the likelihood that new vents will show the features of known ones, there is no compelling reason to extend the boundaries. The box shape allows easy identification for navigators on the surface. The area also includes representative non-vent ridge axis. The bare-rock axial valley and the sedimented ridge slopes are part of an extensive ecosystem beyond the hydrothermal vents.

7. Some Activities in the Endeavour Ventfields

Research

Since its discovery, the major uses of the Endeavour Hot Vents Area have been for research, mostly through American workers. The research has concentrated on study of the basic phenomenon of hydrothermalism and how fluid flow and chemistry are controlled by the geological setting. Much of the published work concentrates on vent water characters, regional setting, mapping techniques, and geophysical controls. Scattered biological studies are beginning to form an ecosystem description. The US submersibles *Alvin* and *Jason* have executed over a dozen dive missions here. In July 1998, the American Museum of Natural History contracted with University of Washington to recover parts of the large sulphides as display and study specimens.

For historical reasons, the amount of Canadian research at Endeavour is considerably less that other areas of Juan de Fuca Ridge. Researchers at University of Washington discovered the site in the early 1980s and rapidly developed an extensive research program involving many American workers. The one continuing Canadian collaboration is with R. E. Thomson (DFO) to study plume characters. However, two recent joint expeditions with Canadians used the vehicle ROPOS for biological studies here. S. K. Juniper (UQàM) and C.R. Fisher (Univ. Pennsylvania) established a biological observatory in Endeavour Main Field in 1994. In conjunction with V. Tunnicliffe (U. Victoria), the biologists are trying to assemble a community assessment of this part of Endeavour ventfields.

Public Awareness

There are a myriad of public media presentations on work at Endeavour vent fields, mostly in the American press. These include newpapers, radio interviews, television news, television science programs, and the Internet. William Broad, a lead scientific correspondent for the New York Times, has written several cover pieces for the science section. Nova is in the process of producing a video on the Endeavour vents. In Canada, Discovery Channel has featured Canadian work at Endeavour. With the recent involvement of the American Museum of Natural History and the Royal Ontario Museum in recovery of sulphides from Endeavour, further public exposure is planned.

Other groups that have expressed interest in interactive public programs include Vancouver Aquarium, Bamfield Marine Station, and Canadian Museum of Nature.

Commercial Developments

Commercial developments and technology applications will continue to develop from research at Endeavour. Even in just the mapping of this area, prototype developments (some are Canadian) can be applied. For example, Simrad Canada is working with the Underwater Engineering group at Univ. New Brunswick to attach an acoustic imaging system to a remote vehicle for high level flyover. A low-level sonar system has just been successfully tested using the Canadian vehicle, ROPOS. Work to define the pilot MPA boundaries and characters by this vehicle would allow opportunities for exposure and development of marine technologies through Canadian Scientific Submersible Facility (CSSF) and the Deep Ocean Telepresence Alliance (DOTA), a consortium of Canadian marine technology companies. In the summer of 1998, CSSF was contracted to develop several products to assist the American Museum sulphide recovery: a hydraulic saw and a multiple monitoring device are two examples.

The Canadian mineral exploration industry has shown interest in the results of seafloor sulfide research. A recent symposium in Toronto co-sponsored by Falconbridge Corporation explored how knowledge gained from seafloor research can aid exploration for ores on land. Sulphides from Endeavour have been examined for metal content but this site is not a candidate for mineral exploitation from the industry perspective.

Several strains of hyperthermophilic microbes have been isolated from Endeavour and some biotech applications from microbial products are currently under examination. However, the biotech industry takes a very arms-length approach to exploration research and tends not to enter the research until a product is nearly proven. At UBC, T. Beatty is examining characteristics of mesophilic microbes from Endeavour vents.

8. Some Information and Knowledge Gaps

A lot of information exists on the Endeavour Hot Vents Area in published and unpublished form. The work covers geophysical, geochemical, volcanology, and structural geology quite extensively. Water column characters, water physics, and plume dynamics are addressed but not in depth. Several papers address microbial phenomena at the vents but much work is still underway. There is a considerably smaller body of literature on the macrofauna and ecosystem structure.

Mapping

Reasonable geological maps of the site exist from the many submersible dives in the area. Much detailed information is available for the ventfields (mostly through University of Washington). The overall context of the ventfields and their setting in the axial valley is less well known. There has not been good evaluation of the ocean floor between the known fields. Fault-related and off-axis venting areas may exist.

Water Column

Plume dynamic modelling is underway but needs more attention. The role of hydrothermal production in open ocean ecosystems is not well known. It is clear that zooplankton communities are affected but spatial and trophic level extents are not known.

Sulphide Deposits

Systematic evaluation of the sulphides has not been undertaken although scattered information is available. A sampling program would not be difficult to arrange and Canada has the expertise to make the resource evaluation and to apply the information for land-based ore deposit interpretation.

Ecosystem Characters

There is less known about the Endeavour ecosystem than most of the vent sites of Juan de Fuca. Much can be extrapolated but the complexity and variety of the Endeavour ventfields complicates simple models. An assessment of basic biodiversity (i.e. taxa present) is underway in several labs but lack of systematic support is a serious detriment. Two fundamental biodiversity questions need to be addressed. One is whether Endeavour fosters a greater diversity of species and greater endemism as might be expected by its size. The second is whether any one of the Endeavour ventfields serves as a dominant source of genetic material for the site and for other ventfields. Links to physical circulation models suggest that dispersal of larvae along the ridgecrest is highly likely.

Figures

1. Location map of the Endeavour ventfields on Juan de Fuca Ridge in the northeast Pacific. Dotted line represents Canadian jurisdictional boundary.

2. Location of studied vent sites throughout the world. While several fall within the EEZ of various countries, none has been granted any protection status.

3. A multibeam seafloor topographic representation of the Endeavour Hot Vent area spreading centre. The spreading axis lies in the central valley. Boxed area is the proposed boundaries of the Endeavour ventfields site as presented in the following diagram. [Need to credit source.]

4. Proposed boundaries of the Endeavour ventfields pilot Marine Protected Area. The four boxes indicate the areas of concentrated hydrothermal venting where large sulphide rock structure have formed. A minute of latitude equals one nautical mile (= 1.86 km). Adapted from Sarazzin et al. 1997.

5. Geological map of the High Rise Ventfield illustrates the dispersion of sulphide structures and tubeworm fields. Distances around the box are in metres. Godzilla is illustrated in the following diagram. From Robigou et al. 1993.

6. Godzilla, in the High Rise Ventfield, is the largest sulphide structure recorded from a ventfield. It dwarfs the manned submersible *Alvin*. Black smokers were numerous on top of the structure and the sides supported abundant vent fauna. In 1994, the huge structure had toppled and begun to regrow.

7. Faulty Towers, in the Mothra Ventfield, displays a different venting chemistry and morphology from High Rise: tall, thin barite-rich structure with lower (less than 350^{o}C) temperatures. Three of the side spires were recovered in 1998 for study and display in the American Museum of Natural History. Note the scale.

8. These images were made during the BIOROPOS Expedition of 1995 to establish a biological observatory at Endeavour Mainfield. S. K. Juniper Chief Scientist in collaboration with V. Tunnicliffe and C. Fisher.

A. *ROPOS* is a DFO remote vehicle operated by the Canadian Scientific Submersible Facility. Its cameras took these images.
B. Black smokers atop Smoke & Mirrors surrounded by the vestimentiferan tubeworm *Ridgeia piscesae*. Image about 1.5 m across.
C. The deep-sea crab *Macroregonia macrocheira* is a frequent visitor to vent where it preys on tubeworms and molluscs. Image about 70 cm across.
D. A time-lapse camera and temperature probes are deployed on basalt pillow lavas where diffuse hydrothermal flows sponsor extensive tubeworm colonies. Camera frame is 75 cm long.
E. *Benthoctopus* often occupies a position around the Endeavour vents where clams are the favourite prey.
F. Close-up on the tips of *Ridgeia piscesae*. The red branchiae take up oxygen and hydrogen

sulphide to fuel the chemosynthetic bacteria within the body. The grey lumps are the common vent limpet *Lepetodrilus fucensis* that also harbours bacteria in its gills. Image about 20 cm across.

G. A breeding mass of the vent 'spider' *Ammothea verenae* along with a second species *Sericosura venticola* that is endemic to Endeavour. These pycnogonids are about 2 cm in diameter; they frequent the cooler areas of vents and graze on microbial filaments.

H. *Paralvinella palmiformis* belongs to a polychaete family (Alvinellidae) known only from hot vents. This species feeds on suspended particles. The white mat is mucus and bacteria surrounded by limpets. A red predatory scaleworm (*Branchinotogluma* sp.) can be seen in the upper left. Image about 25 cm across.

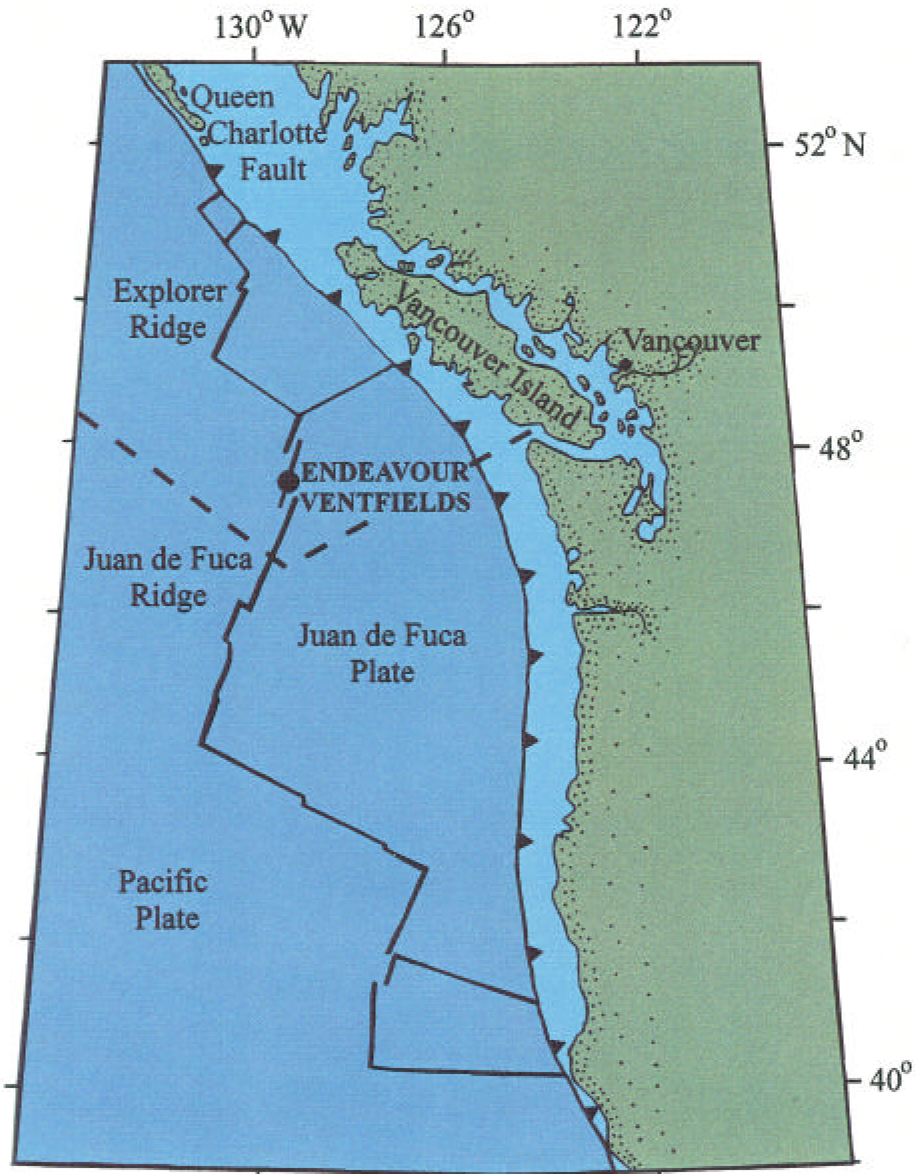
130° W
126°
122°
52° N
48°
44°
40°
Queen Charlotte Fault
Explorer Ridge
Vancouver Island
Vancouver
ENDEAVOUR VENTFIELDS
Juan de Fuca Ridge
Juan de Fuca Plate
Pacific Plate

Figure 1

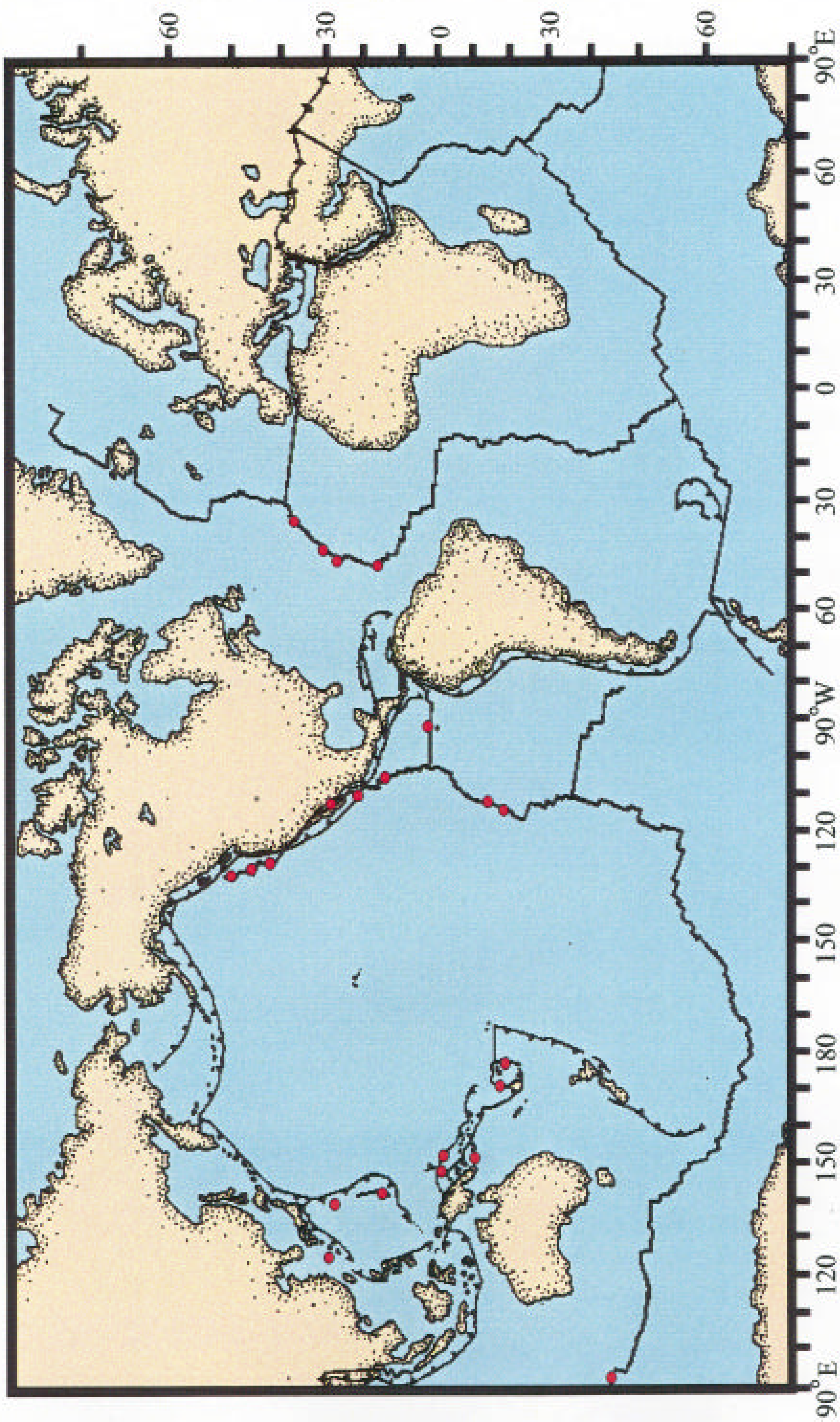

Figure 2

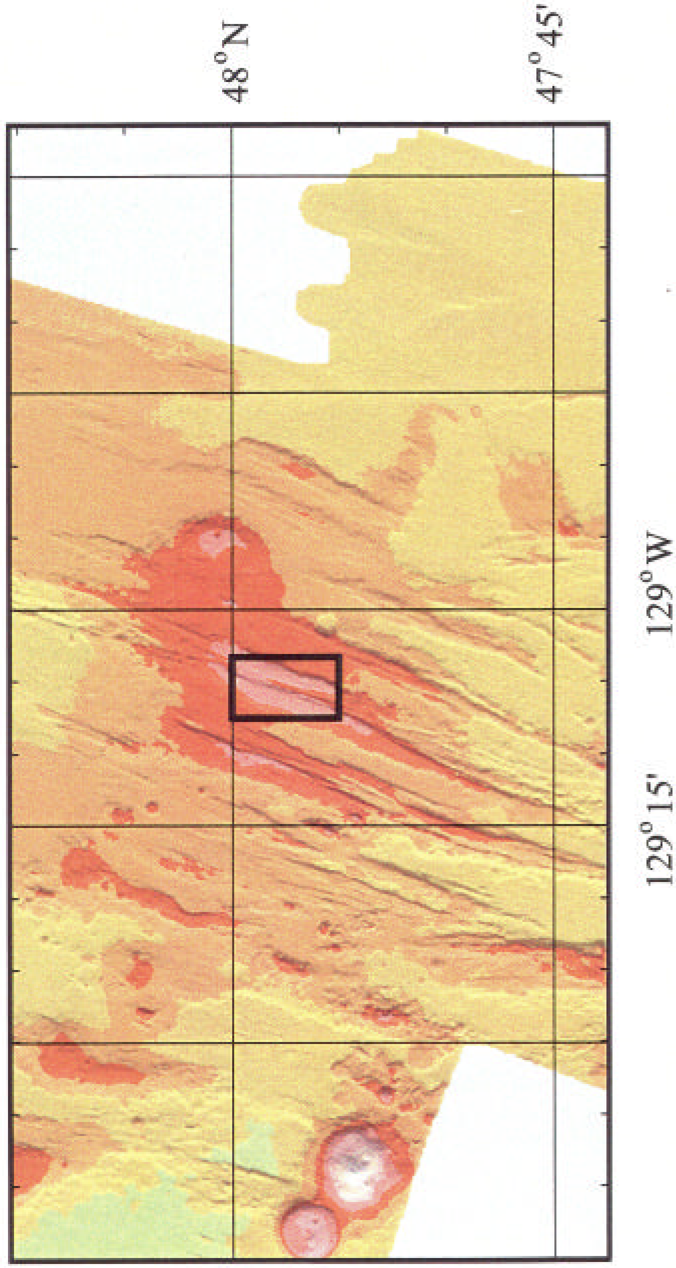

Figure 3

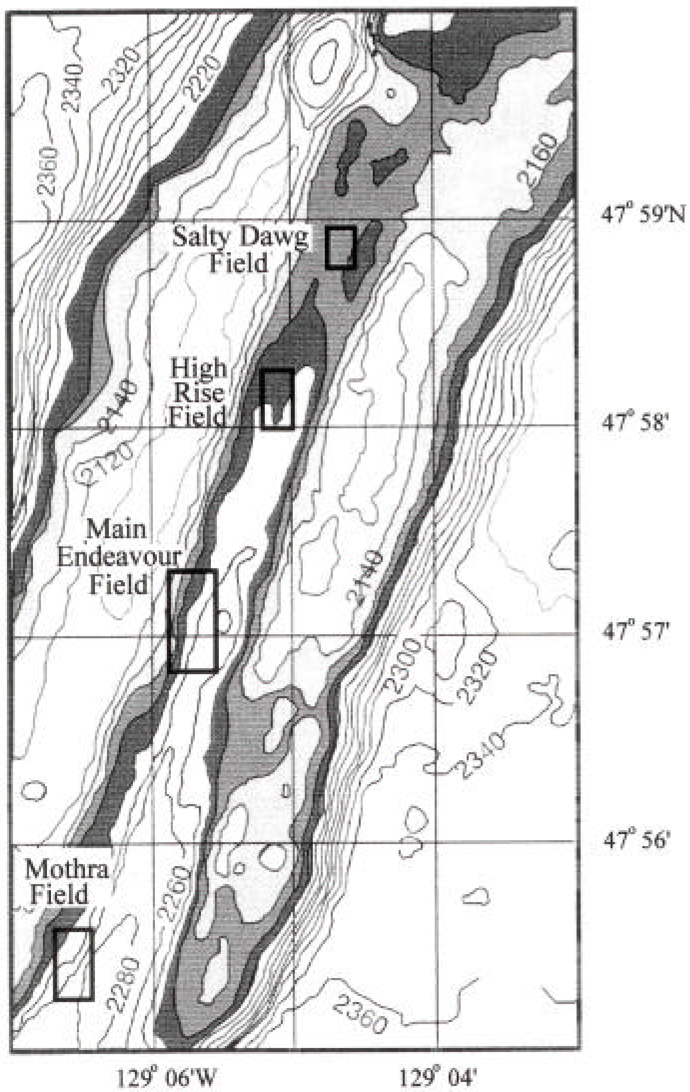
2360
2340
2320
2220
2160
47° 59'N
Salty Dawg
Field
High
Rise
Field
2140
2120
47° 58'
Main
Endeavour
Field
2140
47° 57'
2300
2320
2340
47° 56'
Mothra
Field
2260
2280
2360
129° 06'W
129° 04'

Figure 4

Robigou et al.: The High-Rise Vent Field

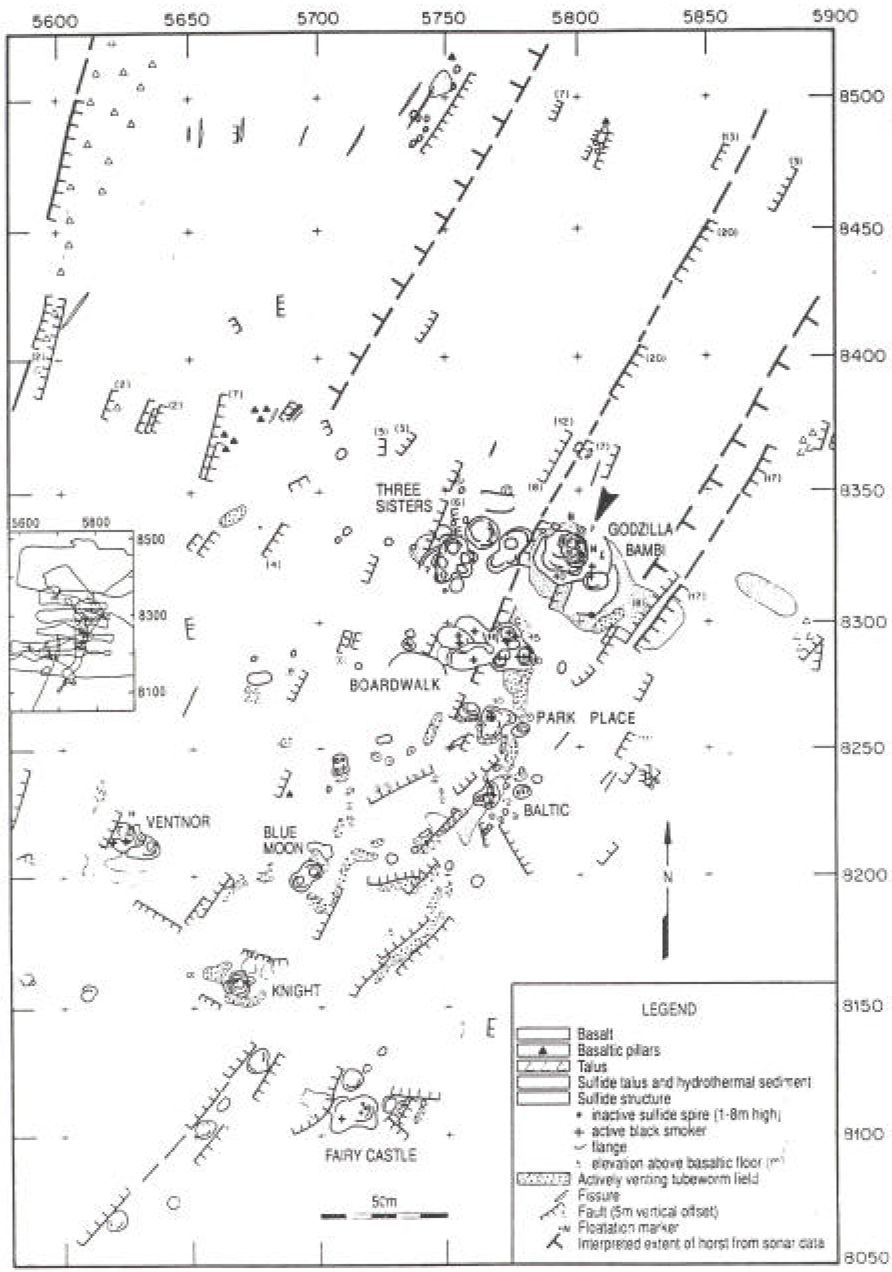

Figure 5

The Alvin submersible investigating an actively-venting sulfide structure about the height of a 15-story building. This sulfide edifice on the Endeavour Segment, was named Godzilla.

"Courtesy of V. Robigou, University of Washington."

Figure 6

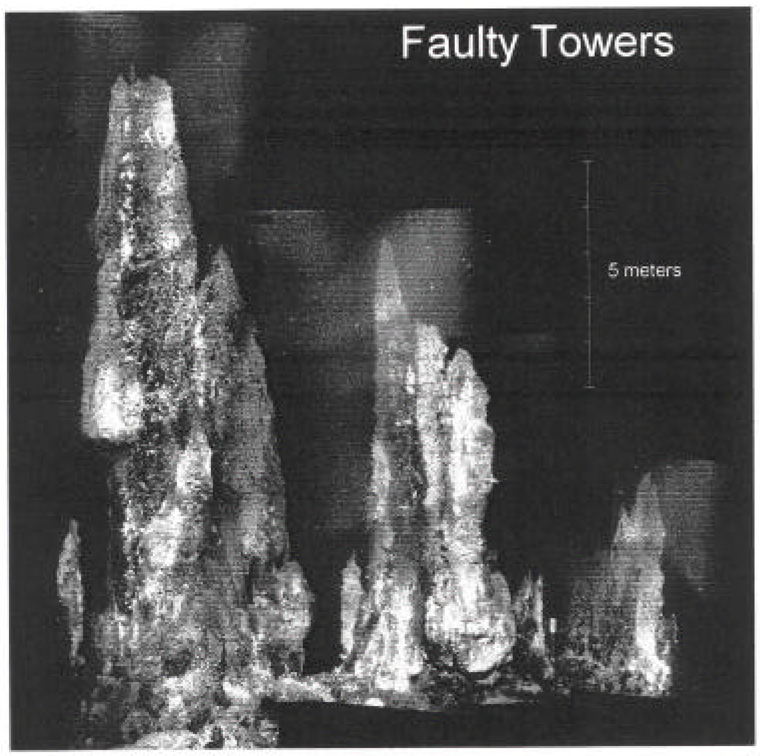

Figure 7

Image courtesy J. Delaney

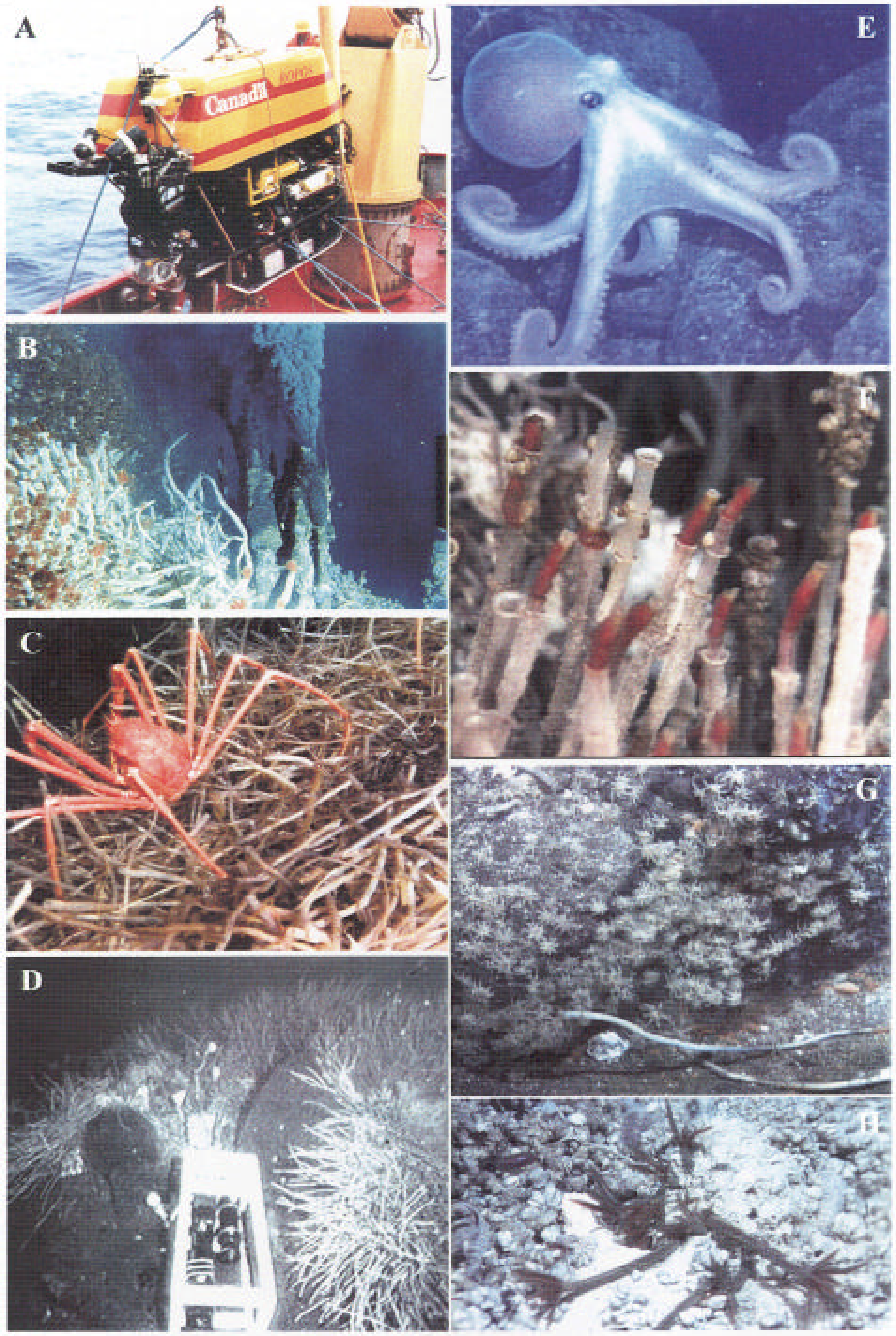

Figure 8

Images courtesy S.K. Juniper and V. Tunnicliffe