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# Establishing a new era of submarine volcanic observatories: Cabling Axial Seamount and the Endeavour Segment of the Juan de Fuca Ridge

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ABSTRACT

At least 70% of the volcanism on Earth occurs along the 65,000 km network of mid-ocean ridge (MOR) spreading centers. Within these dynamic environments, the highest fluxes of heat, chemicals, and biological material from the lithosphere to the hydrosphere occur during volcanic eruptions. However, because underwater volcanoes are difficult and expensive to access, researchers are rarely, if ever, in the right place at the right time to characterize these events. Therefore, our knowledge is limited about the linkages among hydrothermal, chemical and biological processes during seafloor formation and crustal evolution. To make significant advancements in understanding the evolution of MOR environments, the United States and Canada have invested in the first plate-scale submarine cabled observatory linked through the global Internet. Spanning the Juan de Fuca tectonic plate, these two networks include >1700 km of cable and 14 subsea terminals that provide 8–10 kW power and 10 Gbs communications to hundreds of instruments on the seafloor and throughout the overlying water column — resulting in a 24/7/365 presence in the oceans. Data and imagery are available in real- to near-real time.

The initial experimental sites for monitoring volcanic processes include the MOR volcanoes called Axial Seamount and the Endeavour Segment that are located on the Juan de Fuca Ridge. Axial, a hot-spot influenced seamount, is the most robust volcano along the ridge rising nearly 1400 m above the surrounding seafloor and it has erupted twice in the last 15 years. In contrast, the Endeavour Segment is characterized by more subdued topography with a well defined axial rift and it hosts one of the most intensely venting hydrothermal systems known. A non-eruptive spreading event lasting 6 years was documented at Endeavour between 1999 and 2005. Hydrothermal venting intensity, chemistry, and temperature, as well as associated biological communities at both sites were significantly perturbed by the magmatic and intrusive events. This paper presents the similarities and differences between the Axial and Endeavour volcanic systems and identifies reasons why they are ideal candidates for comparative studies. The U.S. has made a 25-year commitment for sustained observations using the cabled infrastructure. The highly expandable nature of submarine optical networking will allow for the future addition of novel experiments that utilize ever evolving advancements in computer sciences, robotics, genomics and sensor miniaturization. Comprehensive modeling of the myriad processes involved will continue to assimilate and integrate growing databases yielding a new understanding of integrated processes that create the seafloor in the global ocean basins.

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## 1. Transforming studies of volcanoes, hot springs, and life

For four billion years submarine volcanism has impacted the global oceans, driving hot spring systems that not only influence the chemistry of the ocean, but which also support some of the most novel organisms on Earth (Davis and Elderfield, 2004; Wilcock et al., 2004). Approximately 70% of the volcanism on the planet occurs beneath the ocean's surface, with much of the activity focused along the 65,000 km-long mid-ocean ridge (MOR) spreading system. Although, the associated hydrothermal vent ecosystems were initially viewed as isolated, widely-spaced oases on an otherwise barren seafloor, in the past three decades the discovery rate of vent sites has dramatically increased in response to maturation of search strategies and improved detection techniques: more than 300 vent sites have now been documented with evidence of many more in the global oceans (Fig. 1).

On-going discoveries about these remarkable environments continue to astound us, from the chemical and physical nature of black smokers and hydrothermally active fissure systems, to the multitude of highly-adapted life forms thriving within these extreme environments. Striking examples include the discovery of the 350 °C black smoker 'Godzilla' on the Endeavour Segment of the Juan de Fuca Ridge, which in 1995 stood as high as a 15-story building, towering

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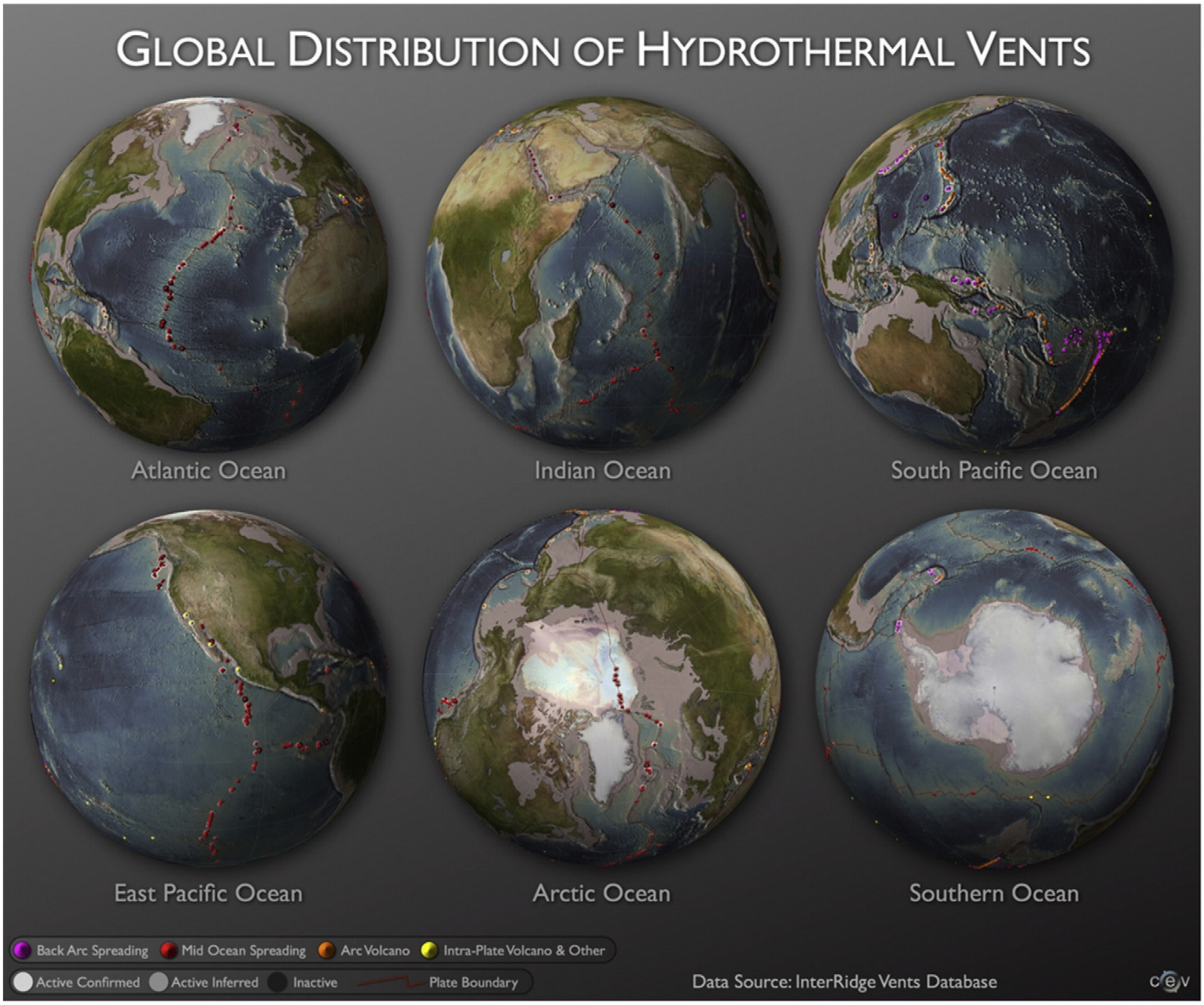


**Fig. 1.** Global distribution of hydrothermal vents based on the InterRidge vent database (http://www.interridge.org/Irvents). Image produced by the Center for Environmental Visualization, University of Washington.

over the surrounding volcanic terrain (Robigou et al., 1993). In 1999, one of the highest temperature organisms on Earth, capable of surviving at temperatures 121 °C, was cultured from 1-year old black smoker material recovered from the Endeavour (Kashefi and Lovley, 2003). In 2000, a completely different type of hydrothermal system was serendipitously discovered on the Mid-Atlantic Ridge called the Lost City Hydrothermal Field, hosting actively venting limestone chimneys that rise 60 m above the seafloor (Kelley et al., 2001a, 2005). Equally surprising, in 2004 and 2010, shallow volcanic calderas in the Mariana arc and volcanoes in Lau Basin were discovered hosting pools of molten sulfur (Embley et al., 2006; Lupton et al., 2006) and explosive lava bubbles (Resing et al., 2011). Perhaps the most far-reaching of these discoveries, however, is that life itself may have originated within these dynamic systems in which geological, chemical, and biological processes are intimately linked (Baross and Hoffman, 1985; Martin et al., 2008; Langmuir and Broecker, 2012).

Although significant progress has been made in understanding process linkages in these dynamic environments, further scientific advances are increasingly dependent on our ability to collect long-term, high-frequency observations using diverse networks of platforms, sensors, and samplers that are in the right place at the right time to capture the events/processes of interest. Distributed sensor networks in terrestrial environments, which provide real-time documentation about the environment and human activities are now widespread and accessible to a global audience via the Internet. However, similar capabilities in the oceans are extremely rare, leaving many of the significant seafloor processes poorly characterized, particularly in both the time domain and at the required spatial scales.

The major volcanic and tectonic processes that create the oceanic crust and modulate heat, chemical, and biological fluxes through the seafloor are inherently episodic on decadal timescales, but they are also punctuated by short-lived and frequent events. For example, water column analyses above recently erupted submarine volcanoes show that significant heat, chemicals, and biological material are ejected into the overlying ocean during the formation of megaplumes and following eruptive events (Embley et al., 1991; Haymon et al., 1991; Baker et al., 1995; Lupton, 1995; Delaney et al., 1998; Kelley et al., 1998; Lupton et al., 1999; Lilley et al., 2003; Baker et al., 2004; Meyer et al., 2013). The megaplumes are characterized by anomalous heat-helium content and are enriched in hydrogen and methane (Kelley et

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