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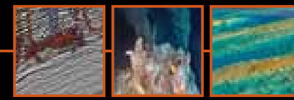

## Introduction to the Special Issue

# From RIDGE to Ridge 2000

BY DANIEL J. FORNARI, STACE E. BEAULIEU, JAMES F. HOLDEN, LAUREN S. MULLINEAUX, AND MAYA TOLSTOY

Articles in this special issue of *Oceanography* represent a compendium of research that spans the disciplinary and thematic breadth of the National Science Foundation's Ridge 2000 Program, as well as its geographic focal points. The mid-ocean ridge (MOR) crest is where much of Earth's volcanism is focused and where most submarine volcanic activity occurs. If we could look down from space at our planet with the ocean drained, the MOR's topography and shape, along with its intervening fracture zones, would resemble the seams on a baseball, with the ocean basins dominating our planetary panorama. The volcanic seafloor is hidden beneath the green-blue waters of the world's ocean, yet therein lie fundamental clues to how our planet works and has evolved over billions of years, something that was not clearly understood 65 years ago—witness the following quote from H.H. Hess (1962) in his essay on "geopoetry" and commentary on J.H.F. Umbgrove's (1947) comprehensive summary of Earth and ocean history:

*The birth of the oceans is a matter of conjecture, the subsequent history is obscure, and the present structure is just beginning to be understood. Fascinating speculation on these subjects has been plentiful, but not much of it predating the last decade* [the 1950s] *holds water.*

The discovery of deep-sea hydrothermal vents in the late 1970s, and the overwhelming evidence that seafloor spreading and volcanism exerted fundamental controls on myriad Earth processes spanning the geo- and biosciences, led to an Ocean Studies Board (1988) workshop that reported the following:

*Recent discoveries of the widespread nature of volcanically-driven submarine hot springs and their attendant chemosynthetically-based animal communities underscore the fact that the seafloor/ridge crest environment represents one of the current frontiers in the exploration and understanding of our planet. The global spreading center network may be viewed as a single system of focused energy flow from the earth's interior to the lithosphere, hydrosphere and biosphere. Viewed in this manner it becomes evident that the processes involved in generation of oceanic lithosphere are strongly interconnected and that an interdisciplinary approach will be necessary to achieve major strides in our understanding of the role lithosphere genesis plays in planetary evolution.*

This statement, derived from the expansive deliberations of over 80 ocean and Earth scientists immersed in the






early spring mists of Salishan Lodge along the Oregon coast, served as the overarching unifying objective of the Ridge Interdisciplinary Global Experiments (RIDGE) Initiative funded by the National Science Foundation's Ocean Sciences Division. That guiding principle focused research efforts through the 1990s to explore all facets of global MOR phenomena, yielding a profound expansion of our knowledge of oceanic spreading center processes.

The RIDGE geographic purview was global, with scientific imperatives ranging from understanding mantle dynamics using a variety of geophysical techniques and modeling, to along-strike characterization of MOR lava variability and correlation to mantle melting processes. A key RIDGE objective was to better resolve the nature and influence of MOR segmentation and spreading-rate variability on a host of processes associated with hydrothermal venting, including seafloor chimney distributions, sulfide mineral and fluid chemistry, relationships to local- and regional-scale volcanic and tectonic processes, and the physics and chemistry of hydrothermal plumes that carry the effluent into the global hydrosphere. Biological objectives included a focus on chemoautotrophy and how it fuels deep communities at vents; characterization of diversity, gene flow, and global distribution of vent species; investigation of metabolic and physiological capabilities of microbes and animals; and exploration of the role of larval dispersal in population dynamics and maintenance. The results of these decade-long multidisciplinary efforts on a wide range of field, laboratory, and modeling studies laid the essential groundwork for future MOR research.

The RIDGE Program capitalized on the use of new, innovative technologies, including both tethered and autonomous robotic vehicle systems, as well as traditional human-occupied submersibles, and also improvements in near-bottom sonar and imaging

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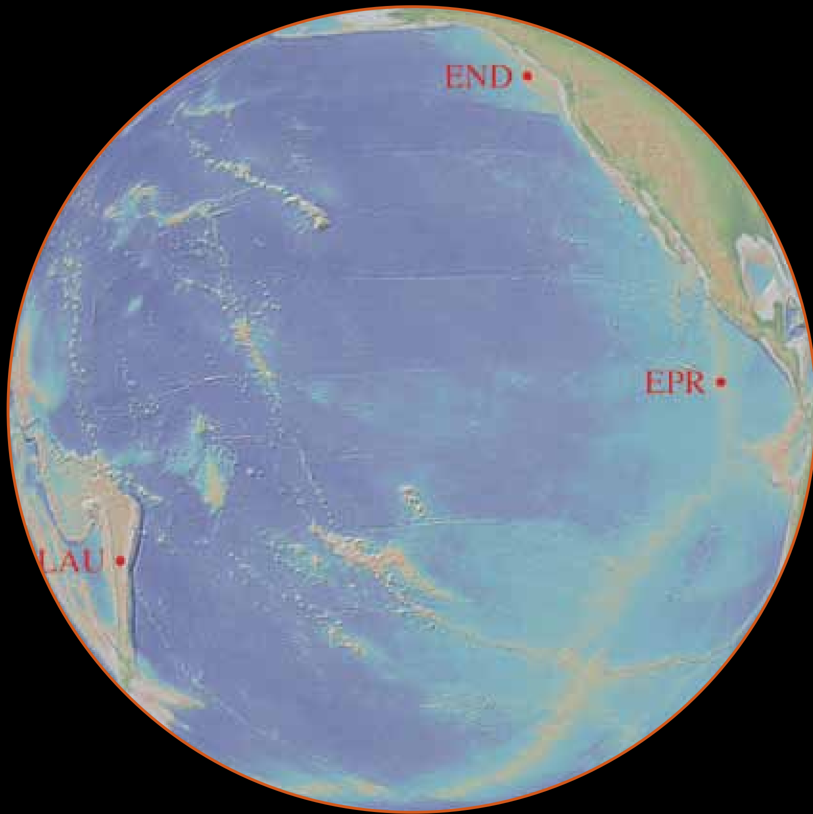


Figure 1. Locations of the three Ridge 2000 Integrated Study Sites plotted on the global bathymetric tile set available through *Virtual Ocean* (http://www.virtualocean.org; Ryan et al., 2009). EPR = East Pacific Rise. END = Endeavour Segment of the Juan de Fuca Ridge. LAU = Eastern Lau Spreading Center.

hardware and software that provided ever-increasing resolution of seafloor features and processes. During the Ridge 2000 Program, implementation and use of robotic and autonomous vehicles became routine, and a wide range of new, specialized sensors and sampling devices were developed to capture various physical and biogeochemical characteristics of hydrothermal fluids. Much of the new technology was designed to operate in situ, thereby making the measurements more accurate and relevant to interactions between vent macro- and microfauna and the chemistry of fluids that bathe them. A significant development during the past few decades of spreading-center research was the first recognition of the association between $H_2$, S, and Fe oxidizing microbes and seafloor volcanic eruptions, which led to an explosion in the recognition and importance of deep-sea microbial processes and the techniques to study them.

During 2000–2002, the US oceanographic community gathered to evaluate the RIDGE Program's previous decade of findings and to outline priorities for the next decade. The Ridge 2000 Program formally began in 2002 with new proposal solicitation guidelines for the types of research activities that would be the focus of the new program. The next steps required coordinated and focused studies that included exploring both temporal and spatial associations among diverse processes involved in the transfer of mantle-derived heat and chemical energy to the seafloor and into the biosphere through hydrothermal circulation. Part of this effort involved a dedicated approach toward data and metadata archiving and accessibility in order to facilitate and enhance scientific discovery (Carbotte et al., 2004; Ryan et al., 2009; http://www.marine-geo.org/portals/ridge2000). The MOR community chose three focus areas as Integrated Study Sites (ISSs) where coordinated experiments would be conducted—the East Pacific Rise (EPR) from 8°N to 11°N, the Endeavour Segment of the Juan de Fuca Ridge, and the Eastern Lau Spreading Center (see Figure 1).

The articles in this special issue of *Oceanography* highlight the wealth of interdisciplinary research on oceanic spreading centers accomplished over the past decade of Ridge 2000 field, laboratory, and modeling studies. Many of the articles were conceived during detailed discussions in various working groups at the Ridge 2000 meeting in Portland, Oregon, in 2010, and in follow-up efforts since then (see Rubin and Fornari, 2011). These research endeavors represent not an "end" but rather a beginning of a vibrant next phase of global research


on oceanic spreading centers that will continue to explore myriad links between causal processes in both spatial and temporal domains.

This issue is organized both thematically and topically, beginning with overarching presentations of integrated research accomplished at each of the ISSs (**Fornari et al., Kelley et al., and Tivey et al.**), and then focusing on various disciplinary research efforts, beginning at the base of the MOR system—the mantle—and moving upward into the water column. Throughout the issue, we provide complementary illustrations and captions that touch on key elements involved in Ridge 2000 research, and photographs that show some of the investigators and students who have worked on this exciting science over the past decade.

In keeping with the "mantle to microbe" concept of the Ridge 2000 Program, we chose to start the research review articles with the geophysics and petrology of the lithosphere. **Gregg et al.** focus on mantle processes and melting, which are key to delivering the heat that drives crustal processes beneath spreading centers. **Perfit et al.** report on the geochemical compositions of extruded lavas at the EPR based on the largest data set of MORB samples spanning several second- to fourth-order ridge segments, and relate them to crustal formation processes. **Smith et al.** provide an overview of slow to ultraslow spreading centers where core complexes and long-lived detachment faulting dominate the tectonic histories of those ridges, in contrast to the more normal accretionary processes associated with the Ridge 2000 ISSs. Geophysical measurements and experiments have been crucial to understanding the structure of oceanic spreading centers for the last 60 years. Two articles, by **Carbotte et al.** and **Canales et al.**, present some of the latest results from multichannel seismic studies at the EPR and Endeavour ISSs, and discuss the sophisticated technology used to acquire those geophysical data. **Dziak et al.** focus on innovative hydroacoustic methods that provide greatly expanded coverage of the global system of spreading centers. That work complements other regional geophysical studies, providing insights into MOR seismicity and volcanic/tectonic episodicity.

We then move into geological, geochemical, and microbial processes occurring within, on, and above the seafloor, starting with a discussion of hydrothermal discharges by **Baker et al.** and extrusive volcanism by **Rubin et al.** during submarine eruptions. **Lowell et al.** provide an integrated magma-hydrothermal model for the EPR ISS.

**Di Iorio et al.** detail measurements of heat flux from high-temperature vents, and **Thurnherr and St. Laurent** provide a snapshot of new measurements of turbulence in a buoyant plume. **Bemis et al.** further review the modeling of the partitioning of heat and chemical fluxes from diffuse-flow hydrothermal discharges relative to high-temperature discharges, and **Hautala et al.** describe measurements of these discharges into the bottom boundary layer. **Holden et al.** summarize the biogeochemical processes enabled by microbial use of the reduced hydrothermal fluids and mineral precipitates. **Toner et al.** highlight, in particular, microbial use of iron transported in hydrothermal plumes, and **Girguis and Holden** examine two potential biotechnological applications of microbial energy and primary production at vents. **Sievert and Vetriani** review the diversity of chemoautotrophic microbes discovered at vents, including a comprehensive list of species in culture, and molecular approaches for understanding their in situ function.

The special issue continues with articles related to vent fauna at the seafloor and in the water column and the physical oceanographic processes that are important in larval and chemical dispersal. **Luther et al.** describe a unique data set that compares in situ chemistry and controls on vent fauna at Lau and EPR sites. **Govenar's** article links the energy transfer from microbial chemosynthesis to higher trophic levels through symbiosis or grazing. **Adams et al.** discuss life-history processes of vent fauna, including larval dispersal, settlement, and recruitment. **Burd and Thomson** describe surveys of zooplankton in the proximity of the Endeavour ISS. **Lavelle et al.** summarize observational and modeling studies of physical oceanography at the EPR ISS, with new implications for the importance of ridge topography in structuring flows that transport larvae and hydrothermal plumes. **Speer and Thurnherr** discuss a seven-year time series of Lagrangian measurements of flow in the Lau Basin, with implications for the transport of larvae between vents on back-arc spreading centers. We conclude the issue with an article by **Goehring et al.** highlighting a variety of education and public outreach projects conducted during the Ridge 2000 Program.

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Compiling this type of synthesis requires dedication by the authors as well as the many named and anonymous reviewers who gave their time to improving the materials presented. We are indebted to them for their hard work and commitment to seeing the seminal results of Ridge 2000 presented in this compendium. We also are very grateful to Ellen Kappel, Vicky Cullen, Johanna Adams, and Jenny Ramarui of The Oceanography Society for their patience and dedication to producing the work represented in this special issue. This special issue was funded by a supplement to the Ridge 2000 Office grant at the Woods Hole Oceanographic Institution (NSF-OCE-0838923).

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