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SEETHING HISTORY

By Annie Reisewitz

A Scripps team captures gases emitted from Iceland's volcanoes to plumb the island's geologic roots and address hot scientific debates

FROM VIKINGS TO VOLCANOES, ICELAND IS RICH IN HISTORY.

As one of the most volcanically active places in the world, its landscape is dotted with bubbling mudpots, exploding geysers, and fresh lava flows that ooze alongside older lava stacks laced with moss and eroded by Ice Age glaciers. It is an unusual setting that has been compared to a lunar landscape.

The island's most misrepresented feature is its climate. It is home to mild year-round temperatures – nothing close to the extremely cold and icy conditions that its name conjures.

For David Hilton, a geochemist at Scripps Institution of Oceanography at UC San Diego, this rugged landscape provides an ideal vantage point to peer into Earth's interior. His research is helping to explain the formation of our home planet and the atmosphere that makes life here possible.

"Iceland is a fantastic place to visit and conduct research," said Hilton. His first trip to Iceland as a Ph.D. student at the University of Cambridge, U.K., in 1983 has inspired him to return more than a dozen times in the last 25 years to study the island's geochemistry. Armed with an array of analytical tools, he is creating what could be the most complete picture yet of this geological Valhalla through

Top, *A Viking long boat sculpture in Iceland's capital city Reykjavik.* **Below**, *Scripps geochemist David Hilton collects fluid samples as a steaming geyser erupts in the background.*

techniques that allow his team to map out the volcanic pathways to the underlying mantle hotspot that continue to contribute to Iceland's land mass.

During three National Science Foundation-funded field expeditions from 2006 to 2008, Hilton and Scripps graduate students collected samples of geothermal fluids, volcanic glasses formed under glaciers, and volcanic lava rocks.

The geochemical signatures locked inside the lavas erupting from the island's 30 active volcanoes and within the geothermal fluids seeping out from below the surface, offer the scientists unprecedented access to processes taking place deep in the earth's mantle.

Hilton's team is now back in Scripps' Fluids and Volatiles lab analyzing the tiny bubbles of primordial gases trapped within olive-colored crystals and other semi-precious minerals locked inside Iceland's lavas, helping them to gaze into the earth's mantle to study the early earth and the origin of hotspots.

The fiery island sits atop Earth's longest mountain range, the 10,000-kilometer (6,214-mile) underwater Mid-Atlantic Ridge. This extensive chain of volcanic mountains only surfaces here, at a point where the North American and European plates move away from one another.

The huge volume of volcanic rock that makes up Iceland is a result of the extensive melting taking place inside the earth's mantle, a process presently revealing itself as the geological hotspot known as Iceland.

Canadian geophysicist J. Tuzo Wilson first devised the hotspot theory in 1963 to explain the Hawaiian Island chain, where volcanic activity is occurring far from tectonic plate boundaries.

Although Iceland's volcanic fury is located at the juncture of two diverging tectonic plates, it doesn't explain why Iceland sits more than 3,000 meters (9,800 feet) above the adjacent parts of the Mid-Atlantic Ridge. Something else must be occurring in the mantle to produce enough melting to thrust Iceland out of the murky depths.

The popular theory is that fixed-location hotspots, such as those located in the Hawaiian Islands and Iceland, are regions where hot mantle-derived plumes

Top left, *Iceland is home to many natural wonders including the Gulfoss waterfall, located in the southern lowlands region.* **Below**, *Hilton surrounded by bubbling mudpots.*

Top, *Scripps graduate student Evelyn Füri collects pillow basalt rocks from a volcano.* **Middle right**, *A sample of olivine crystals extracted from Icelandic rocks will undergo nitrogen isotope analysis in Scripps' Fluids and Volatiles laboratory.* **Below**, *Scripps graduate student Peter Barry makes adjustments to a specialized instrument to analyze gas samples retrieved from Iceland.* **Below right**, *Hilton treks to the Kerlingarjoll fumarole to collect the steam and gas emitted through a crack in the earth's crust.*

Above left, *A view of the Mid-Atlantic Ridge as it surfaces at Iceland.*

are thought to rise from deep inside the earth's mantle to the surface like a lava lamp in full motion.

The plume theory has been used to explain the origin of Iceland and the opening of the North Atlantic Ocean, said Hilton. The Icelandic plume has funneled melts to the ridge for a long period leading to the formation of the island. Previously, the plume was located under Greenland and as the tectonic plates shifted over the last tens of millions of years, the stationary hotspot has left its mark in the geochemical traces in older lavas located on Greenland and Scotland.

The question, however, as to whether mantle plumes exist is still a continuing debate within the earth science community and is being intensively studied by many other researchers at Scripps. (See "Hotspot or Not Spot?" Fall 2006 *Explorations*).

"We are hoping to learn more about plumes, and, if they exist, are there plume heads and plume tails, how long do they last, and will Iceland's plume eventually die out?" said Hilton, who studies different forms of the same element—known as isotopes—which are present in rock samples and geothermal fluids from Iceland. From them, his team will learn more about plumes in hopes of offering a better explanation as to how Iceland's hotspot formed.

Using geochemical tracers extracted from the island's lava and geothermal fluids, the researchers can identify primordial material that has been trapped inside the earth since its formation and track vestiges of old crust that has recycled itself back to the surface from inside the earth.

Evidence obtained from gas samples reveals that some of the material may have originated from as deep as the core-mantle boundary before it reemerges at the Icelandic hotspot.

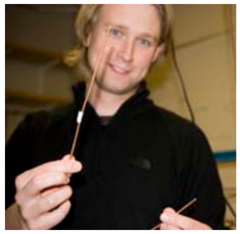
Hilton uses analyses of gases such as helium, nitrogen, and neon in combination to distinguish between the primordial and recycled material.

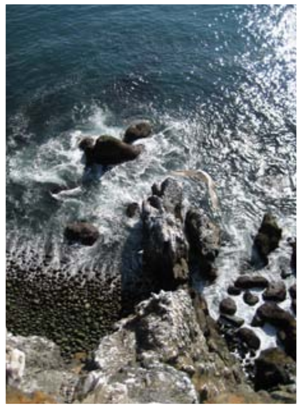
NITROGEN FIX

Analysis by Hilton has revealed that Iceland has the highest concentration of primordial helium-3 on Earth relative to its other isotope, helium-4, which has been produced throughout Earth's history by radioactive decay. This observation suggests that there is an abundant reservoir of helium-3, likely deep in the mantle, transferring material to the surface through a mantle plume.

Evelyn Füri, a Scripps graduate student, is analyzing mantle-derived gases trapped inside volcanic glasses, which are basalts that froze quickly below glaciers forming glass instead of rock, to trace the distribution of the primordial helium-3 signal in Iceland and how it is affected en route to the surface.

At the Hilton lab, the team is about to unleash another trapped





Clockwise from far left, *A geyser erupts under a portentous sky over Iceland; Scripps graduate student Sæmundur Halldórsson holds copper tubing used by scientists to collect fluid samples; Iceland's Gulfoss waterfall; The bridge at Skjalfanda Fljot crosses a glacial river in northern Iceland; A downward look at where the Mid-Atlantic Ridge meets the Icelandic coast.* **Bottom**, *Geothermal wells are used to generate electricity and heat for Icelandic homes.*

gas, nitrogen, which is abundant in the atmosphere yet only found in trace concentrations in Earth's mantle. This gas offers researchers a new opportunity to trace the crust as it re-emerges from inside the earth.

Scripps graduate student Peter Barry has begun early nitrogen isotope analysis on the young lava samples taken from across the island as well as from the Reykjanes Ridge, which is the transition between Iceland and the Mid-Atlantic Ridge.

Barry's initial analysis on concentrations of nitrogen-15 to nitrogen-14 suggests the presence of recycled material. Using the nitrogen information coupled with information obtained from helium, he is beginning to paint a more detailed picture of the chemical makeup of the Icelandic hotspot.

Requiring a new analytical technique for further analysis, Barry spent two months with colleagues at the University of Tokyo to learn how to design and build a new system to analyze the nitrogen. The Hilton lab at Scripps is now one of only a handful of labs in the world where researchers are able to conduct both helium and nitrogen isotope analysis. Native Icelander and Scripps graduate student Sæmundur (Saemi) Halldórsson will be analyzing some of the samples in the newly constructed nitrogen-dedicated instrument. Crushing the minerals will release the gases into the instrument's vacuum system where sophisticated platinum-based catalysts are used to selectively filter out other gases through chemical reactions while leaving the nitrogen behind.

In analyzing these gases in the lab, the researchers are looking for variations in an element's isotope ratio, which can change through time due to radioactive decay. Since the atmosphere was produced early, within the first tens of million of years of Earth's birth, certain isotope ratios represent the early atmosphere whereas others represent the effects of radioactive decay.

"If the plume theory is correct, the Iceland hotspot provides access to the deep mantle where the primordial gases are stored, offering insights into conditions of the early earth," said Halldórsson.

The Scripps team will continue to analyze the samples collected in Iceland using the new instrument in hopes of revealing a more comprehensive story on the planet's origins and to reveal what mechanism deep inside the earth is driving geological activity in what remains one of Hilton's favorite spots on Earth.

"We're really getting a clearer picture of what's making hotspots," he said. "It may help refine geophysical interpretations of how the mantle works."

View the complete multimedia presentation of this story at explorations.ucsd.edu.

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