The Recycling Earth

Volcanic Activity Yields Clues about Planetary Evolution

"What goes down must eventually come up" is how David Hilton sees the earth taking shape. Hilton is one of a group of earth scientists at Scripps Institution of Oceanography probing deep into the ground and beneath the sea to extract volcanic materials—gases, fluids, rocks, and sediments—to reveal the workings of global processes and recount the history of our present-day planet.

The earth is viewed by scientists as a dynamically changing planet with materials that cycle up as lava, hot water, and steam from the interior and circulate on the surface, only to descend into deep-ocean trenches and beneath the crust to become molten magma again.

The principal clues for examining this complex mixing are trace chemicals, substances that give volcanic material a certain signature or set of characteristic qualities. These geochemical markers include isotopes of common elements, like hydrogen and carbon, and more exotic elements, such as strontium and rubidium. The ratio of each isotope in a sample serves as a diagnostic indicator.

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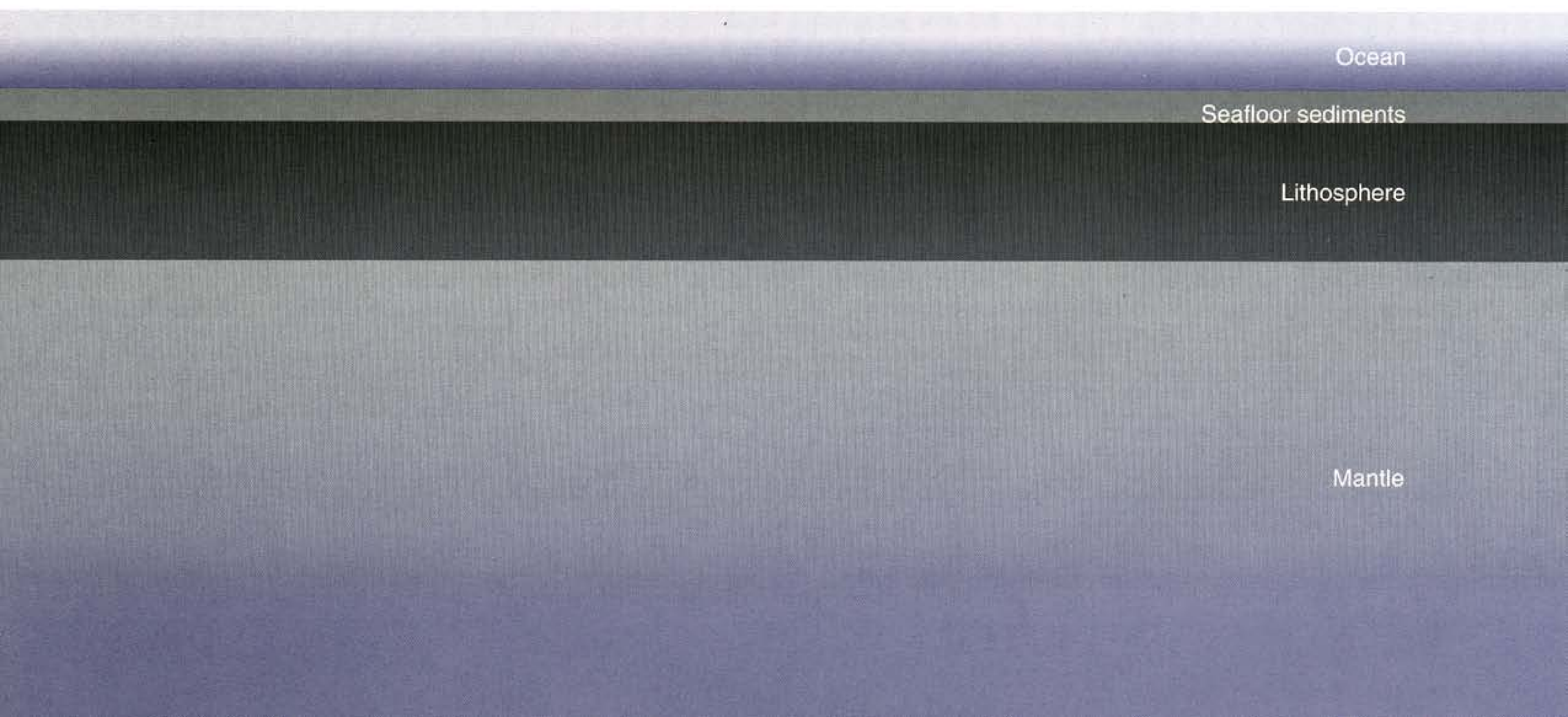
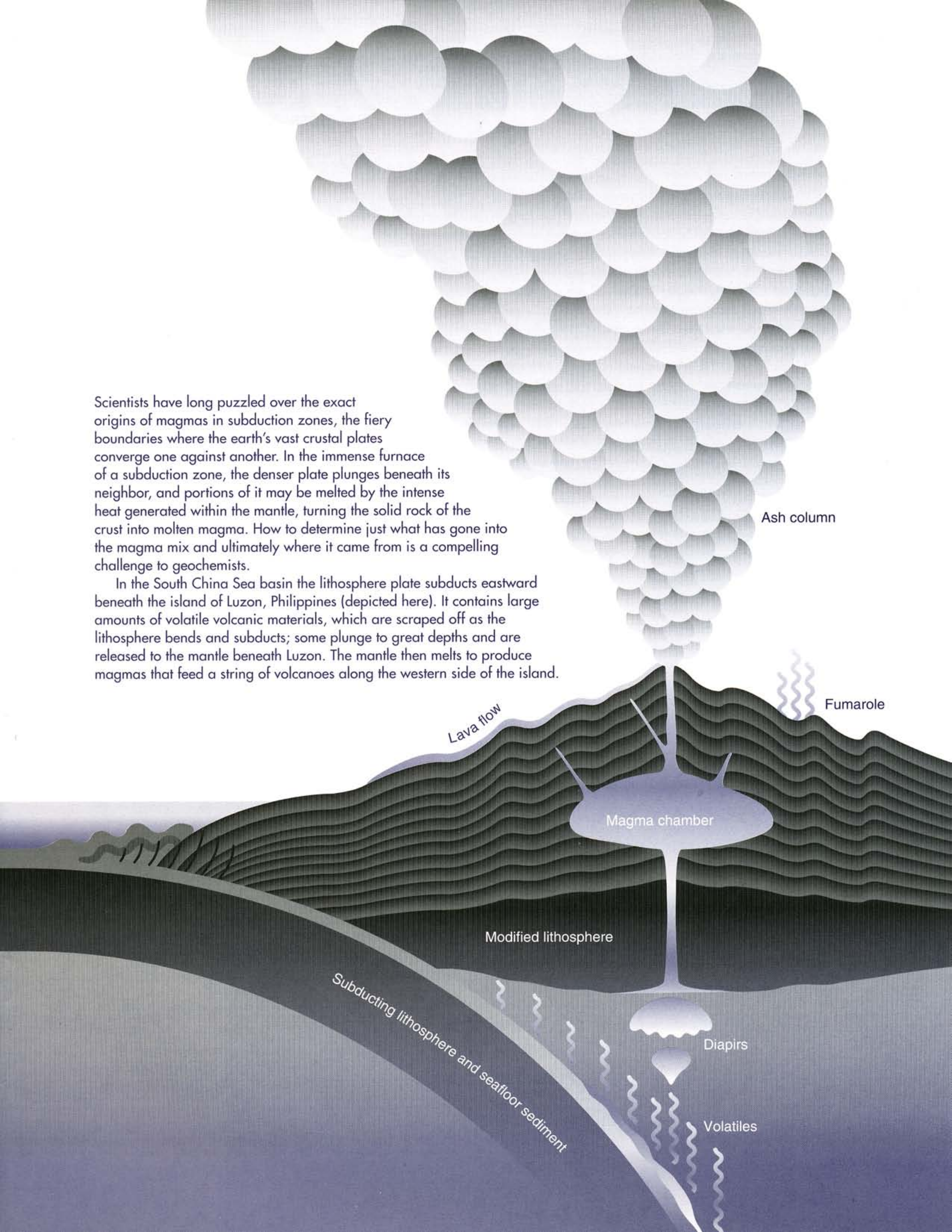
BY JOE HLEBICA



Scientists have long puzzled over the exact origins of magmas in subduction zones, the fiery boundaries where the earth's vast crustal plates converge one against another. In the immense furnace of a subduction zone, the denser plate plunges beneath its neighbor, and portions of it may be melted by the intense heat generated within the mantle, turning the solid rock of the crust into molten magma. How to determine just what has gone into the magma mix and ultimately where it came from is a compelling challenge to geochemists.

In the South China Sea basin the lithosphere plate subducts eastward beneath the island of Luzon, Philippines (depicted here). It contains large amounts of volatile volcanic materials, which are scraped off as the lithosphere bends and subducts; some plunge to great depths and are released to the mantle beneath Luzon. The mantle then melts to produce magmas that feed a string of volcanoes along the western side of the island.



"Any process that generates such a large volume of volcanic rock is bound to have a significant impact on climate and the global environment."

"Such isotope ratios comprise a fingerprint, leaving little doubt as to the origins of samples containing them," explains Hilton, an assistant professor in Scripps's Geosciences Research Division (GRD). "What we're looking for is the mass balance between what goes down and what comes up."

Hilton's research centers on subduction zones where the motion of Earth's massive tectonic plates causes one section of the crust to descend beneath another, a sort of geophysical recycling center. By examining materials from these areas, Hilton is trying to determine the contributions of seafloor sediments and subducted oceanic crusts to the upward moving magma.

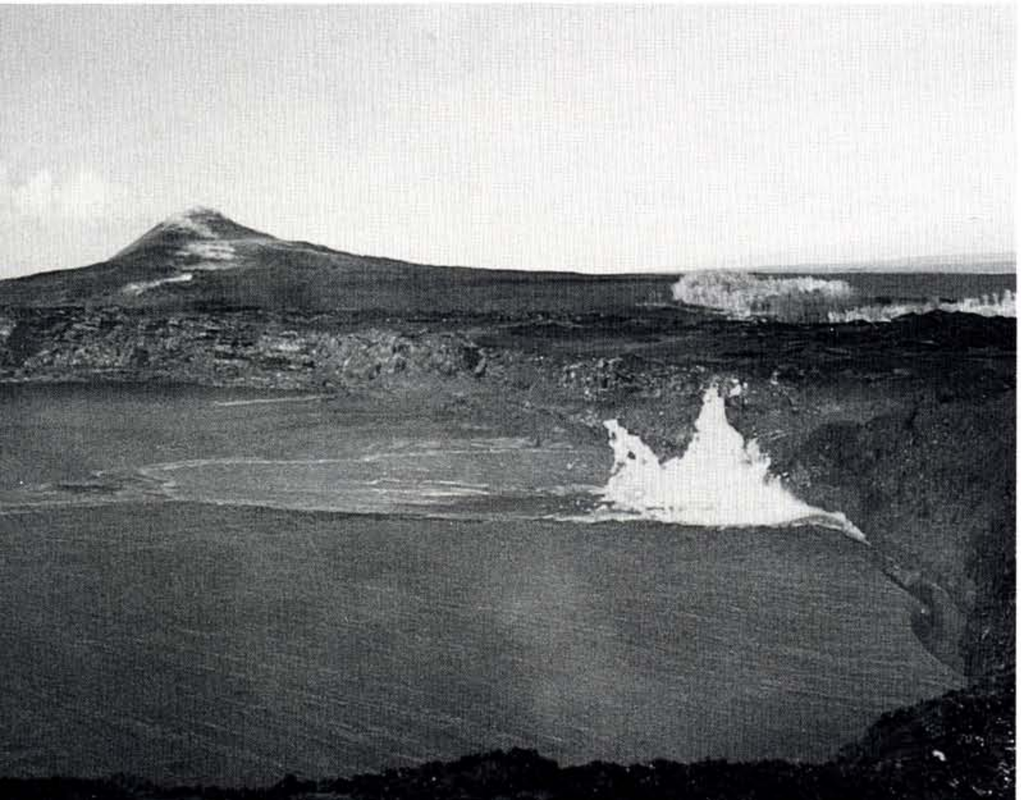
After receiving his doctorate from Cambridge University, Hilton became a postdoctoral researcher at Scripps under Professor Harmon Craig, one of the world's most respected geochemists, who pioneered isotope studies of volcanic gases and fluids. While on an expedition to collect samples from the Loihi Seamount, an underwater volcano near the island of Hawaii, Hilton received his baptism by fire.

"During the expedition, we investigated the Kupaianaha lava lake on the island," Hilton recalls. "We were standing very close to the edge, and as lava came spattering out at us, we turned to run away. A drop hit the back of my head. When I smelled burning hair, I yelled 'I'm burning! I'm burning!' At that point, Dr. Craig looked at me and announced, 'NOW you're a volcanologist.' "

Millions of years ago Earth sustained massive volcanic activity, as shown today by what geophysicists call Large Igneous Provinces, or LIPs—areas on the crust where vast outpourings of lava created rocky plateaus, sometimes covering whole regions. Many of them lie submerged under the oceans, though a few of the larger ones cover areas of the continental surfaces, where they are commonly referred to as flood basalts.

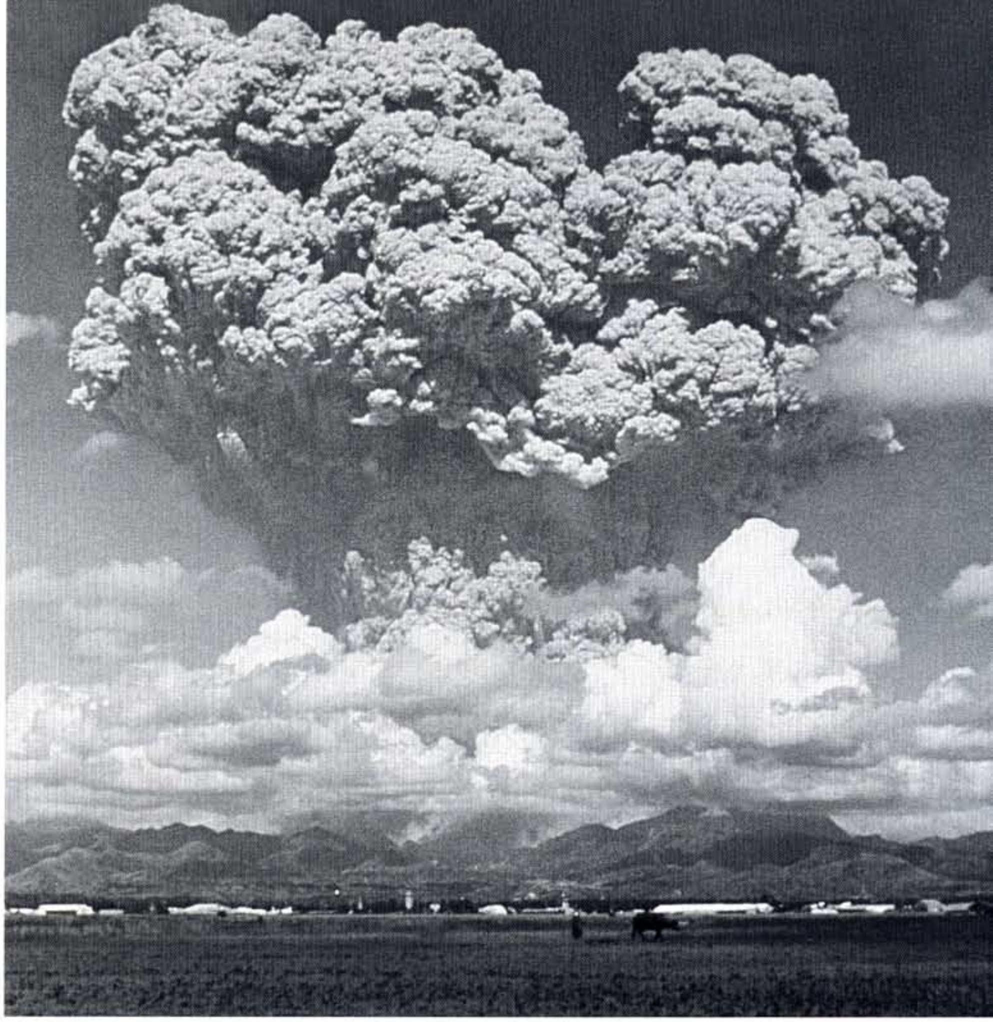
The Ontong-Java Plateau in the southwest Pacific is an area where magma penetrated the oceanic crust roughly 100 million years ago. Volcanic rock covered more than one million square miles of seafloor, and a chain of submarine volcanoes was produced. Such major volcanic activity must have had a tremendous impact on the global environment of the time.

"Any process that generates such a large volume of volcanic rock is bound to have a significant impact on climate and the global environment," claims Paterno Castillo,



Molten lava boils to the surface of Kupaianaha lava lake in this 1987 photograph taken in the East Rift Zone of Mount Kilauea on the island of Hawaii. In the background, the Pu'u O'o vent spews steam and sulfur.

Mount Pinatubo during the 1991 eruption (right) and just prior to the eruption (below). Note steaming fumarole on the mountain's flank (below), which warns of the impending blast. The initial ash cloud (right) climbed tens of thousands of feet.



a GRD assistant professor and a native of the Philippines. "Basically, the more volcanoes you have, the more transference of heat and volatile substances into the atmosphere."

As part of a broader study of tectonic activity throughout the southwestern Pacific region, Castillo has looked closely at the effects of the 1991 eruption of Mount Pinatubo, a prominent volcano located in his home country.

"Pinatubo is a classic example of an oceanic island arc volcano, and the Philippines is an excellent case study for magma origins because the island chain is sandwiched between two subduction zones," Castillo points out.

Castillo's efforts may well have implications for those who live in volcanically active regions. The eruptions of Mount Pinatubo and other volcanoes have been catastrophic in terms of the effect on human life and the environment, though the geologic record shows that much more devastating events have taken place in the distant past.

"More and more people engaged in this research are agreeing that major tectonic events such as those that produce LIPs are a regular occurrence in Earth's history. The major flood basalts appeared long before the advent of humans, but if such an event were to take place in our future, it would have a major impact on our species."

And what are the chances of humans witnessing such a major catastrophe? Slim, considering the vastness of geologic time.

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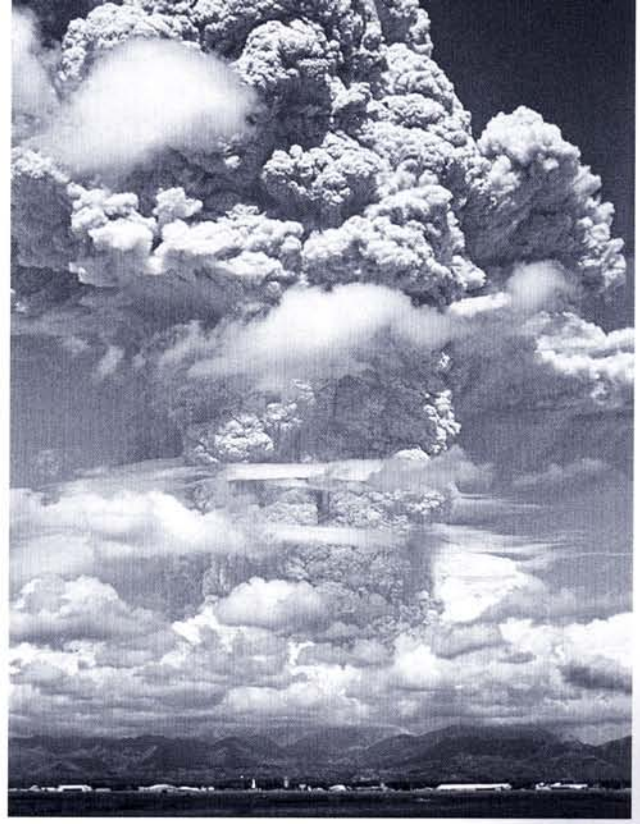
Volcano Rocks World

EXPLORATIONS
FALL 1996

Mount Pinatubo in the Philippines erupted on June 15, 1991, after more than 400 years of dormancy. The third largest eruption this century spewed a cloud of gas and dust into the atmosphere that eventually circled the globe and altered weather patterns in dramatic ways.

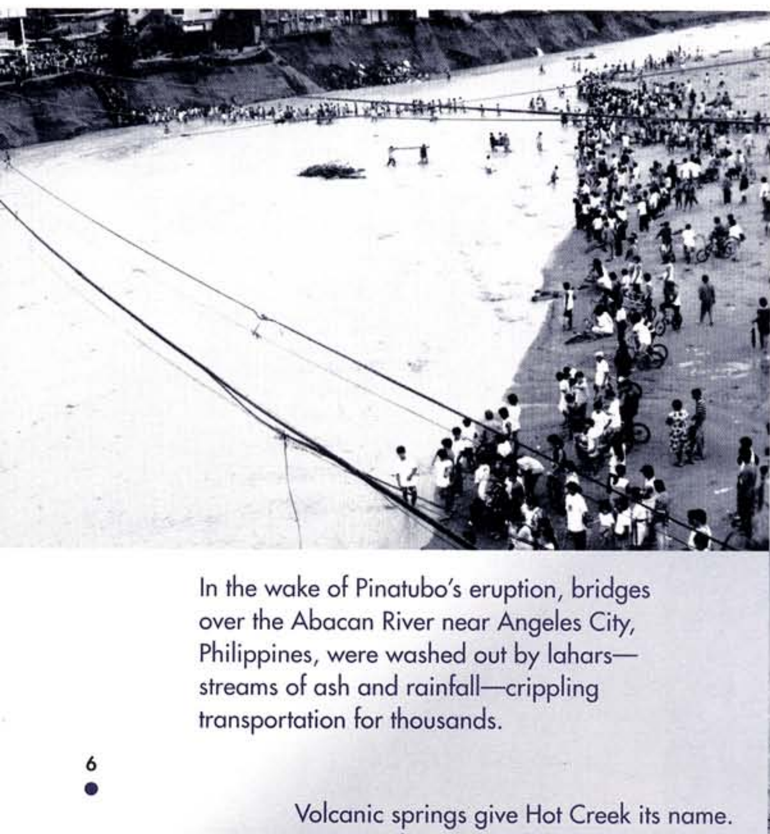
One of the more immediate effects was atmospheric cooling resulting from the highly reflective nature of volcanic emissions. Sulfur dioxide, a gas with a relatively high albedo (reflective power), was emitted from Pinatubo in record quantities, enough to deflect a considerable amount of the sun's energy back into space. National Oceanic and Atmospheric Administration scientists have estimated that average global temperatures may have dropped by about one degree Fahrenheit for a period of two to four years following the eruption.



Ash cloud looms over Clark Air Force Base in this USGS photograph of the 1991 Mount Pinatubo eruption.

Professor James Hawkins of Scripps's Geosciences Research Division still jokes about the "Pinatubo tax" he paid during June of 1992, one year following the eruption. Hawkins and his wife, both avid mountain climbers, were attempting to reach the top of Alaska's 20,320-foot Mount McKinley, the highest peak in North America.

"It was already June but the temperature was still down around forty below zero, with hundred-mile-an-hour winds at the summit that threatened to blow us off the mountain. There were seven fatalities there that summer, most resulting from extreme weather conditions attributed to Pinatubo's eruption the year before. We survived, and subsequently reached the summit the following year, but I still say I paid my Pinatubo tax on Mount McKinley."



In the wake of Pinatubo's eruption, bridges over the Abacan River near Angeles City, Philippines, were washed out by lahars—streams of ash and rainfall—crippling transportation for thousands.

Volcanic springs give Hot Creek its name. Located in Long Valley Caldera, on the eastern flank of the Sierra Nevadas, this and other features of the region are evidence of volcanic activity beneath the surface.

Donna Hawkins climbs to the "End of the World" at 15,000 ft. on the West Buttress of Mount McKinley (right). McKinley's summit as seen from Camp II at 7,500 ft. on Kahiltna Glacier (below). The summit is about eight miles away, visible in the center of the photo. The granites of McKinley are the exposed roots of former volcanoes, which would have looked and acted like Mount Pinatubo when they formed about 56 million years ago.

Others paid dearly as well. More than 300 Filipinos lost their lives in Pinatubo's eruption and a coincidental typhoon as rooftops collapsed under the weight of rain-soaked ash. The toll might have been much higher, though, were it not for a well-organized government evacuation of some 58,000 people prior to the disaster. In this case, early warnings issued by a joint team of Filipino and American observers averted what could have been a much more costly disaster.

Such warnings are not always heeded, however. According to Professor Hawkins, "People died on Mount St. Helens [the 1980 eruption in the state of Washington] because they went back into the area in spite of the warnings. But you have to be careful about making predictions, because if you tell people a mountain is going to erupt, and it doesn't, you're in bigger trouble. It's a matter of public credibility."

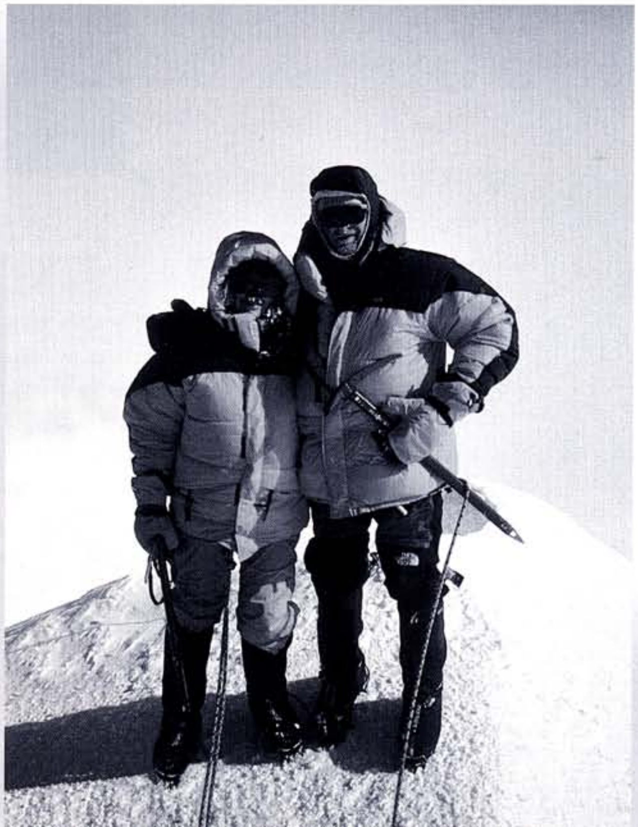
Primarily a marine geologist, Hawkins has dived aboard submersibles to ocean depths as extreme as some of the altitudes he has climbed. He describes the seafloor volcanic activity he has seen as mild in comparison to what is witnessed on land.

"Land volcanoes contain more water. Their chemistry features a higher silica content, making for more viscous lava. The combination of higher vapor pressure and greater viscosity make land eruptions more explosive, whereas in submarine volcanoes, lava tends to just ooze out of the vents onto the seafloor."

With potentially eruptive volcanoes in many parts of the world—including Mammoth Mountain in California—how can scientists determine whether an eruption is likely or not? A reliable method is monitoring of volcanic gas chemistry, a technique to which Scripps geochemists have made and continue to make major contributions.

"Once a volcano starts erupting, that's it," he says, throwing his hands open in a gesture of resignation, "but gas emissions can lead to a prediction."

This is what probably saved thousands of lives in the Philippines, and could help avert future catastrophes. The veteran geologist observes, "It's a more modern approach, a view you can't get by just looking at rocks."



Scripps professor James Hawkins and his wife, Donna, in Denali National Park, on summit of Mount McKinley, highest peak in North America, June 21, 1993.

"They [flood basalts] are sometimes two or more miles thick, lying in layers, flow upon flow, covering vast areas of the earth's crust."

A joint USGS-Philippine government survey team arrives by helicopter at a remote location in the wake of Pinatubo's eruption (left). Secondary explosions followed the initial eruption (below). Later, trapped rainwater mixed with volatile substances to form a lake in the mountain's caldera (bottom).

"Flood basalts are notable because they are rare, massive, and have occurred infrequently in geologic history," observes Professor Douglas Macdougall of GRD. "They are sometimes two or more miles thick, lying in layers, flow upon flow, covering vast areas of Earth's crust."

The largest of the world's half dozen or so major continental flood basalts, located in Siberia, is the product of a sequence of sudden events that took place some 250 million years ago. These flows produced enough lava to have covered the planet's surface with a layer of molten rock 30 feet deep. The expansive Deccan traps of India, where Macdougall has conducted field research, are flood basalts dating from 65 million years ago that cover an area larger than the state of Texas.

According to Macdougall, "The events that formed these two basalt provinces are significant because they took place at boundaries between major geologic eras. Both resulted from massive eruptions of lava during very brief instances, geologically speaking—perhaps less than a million years each."

The boundaries cited by Macdougall were as cataclysmic as they were brief. The birth of the Siberian flood basalts coincided with the end of the Permian, a geologic threshold entailing mass extinctions, when life on Earth declined measurably. During the time that the Deccan traps formed at the boundary of the Cretaceous and Tertiary periods, the dinosaurs, among other living groups, vanished.

"That two of history's largest volcanic events should coincide exactly with history's two greatest extinctions is just too much to be coincidental."

The Deccan traps of western India cover roughly 350 thousand square miles of the earth's surface with layer upon layer of ancient volcanic deposits.

Macdougall, whose geochemical research focuses on the evidence arising from these events, comments on their environmental significance:

"Some studies of these boundary events have concentrated on the global environmental impact of flood basalts and accompanying volcanic activity. An enormous burden of sulfur dioxide and carbon dioxide was released into the atmosphere during these two very brief periods."

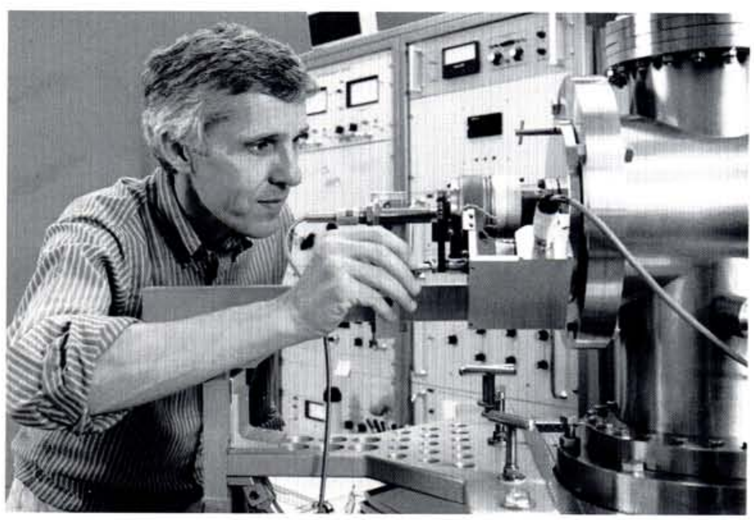
Sulfur dioxide gas in the atmosphere may have blocked sunlight, cooling the earth and making it uninhabitable for many species. Carbon dioxide, on the other hand, is believed to have warmed the atmosphere, causing other species to decline. Though there is debate over which process might have actually taken place, if indeed either did, there is little doubt as to the cause-and-effect relationship between massive volcanic activity and mass extinctions, according to Macdougall.

"That two of history's largest volcanic events should coincide exactly with history's two greatest extinctions is just too much to be coincidental."

Macdougall and his colleagues travel on expeditions far afield to gather basalt samples, and then return to their laboratories at Scripps, where the chemical composition is determined with mass spectrometers. What most interests Macdougall is the search for the origins and composition of the basalts themselves.

"It's important to get detailed views in order to distinguish separate flows that happen to be lying one over another," he said. "We sometimes must cross great distances where the formations have been broken by other features of the landscape. So we do comprehensive stratigraphic sampling of entire flood basalts, top to bottom, through all the layers."

Through meticulous sleuthing such as this, Macdougall, Castillo, Hilton, and others are tracing the current hard evidence of volcanic activity back in time to primordial sources within the earth in an effort to understand how our world has taken shape.



Geochemist Douglas Macdougall adjusts the position of a sample for analysis. The thermal ionization mass spectrometer is used to measure the ratios of isotopes in geological samples. Macdougall will speak at the Aquarium this fall; see details in "Around the Pier" on page 31.