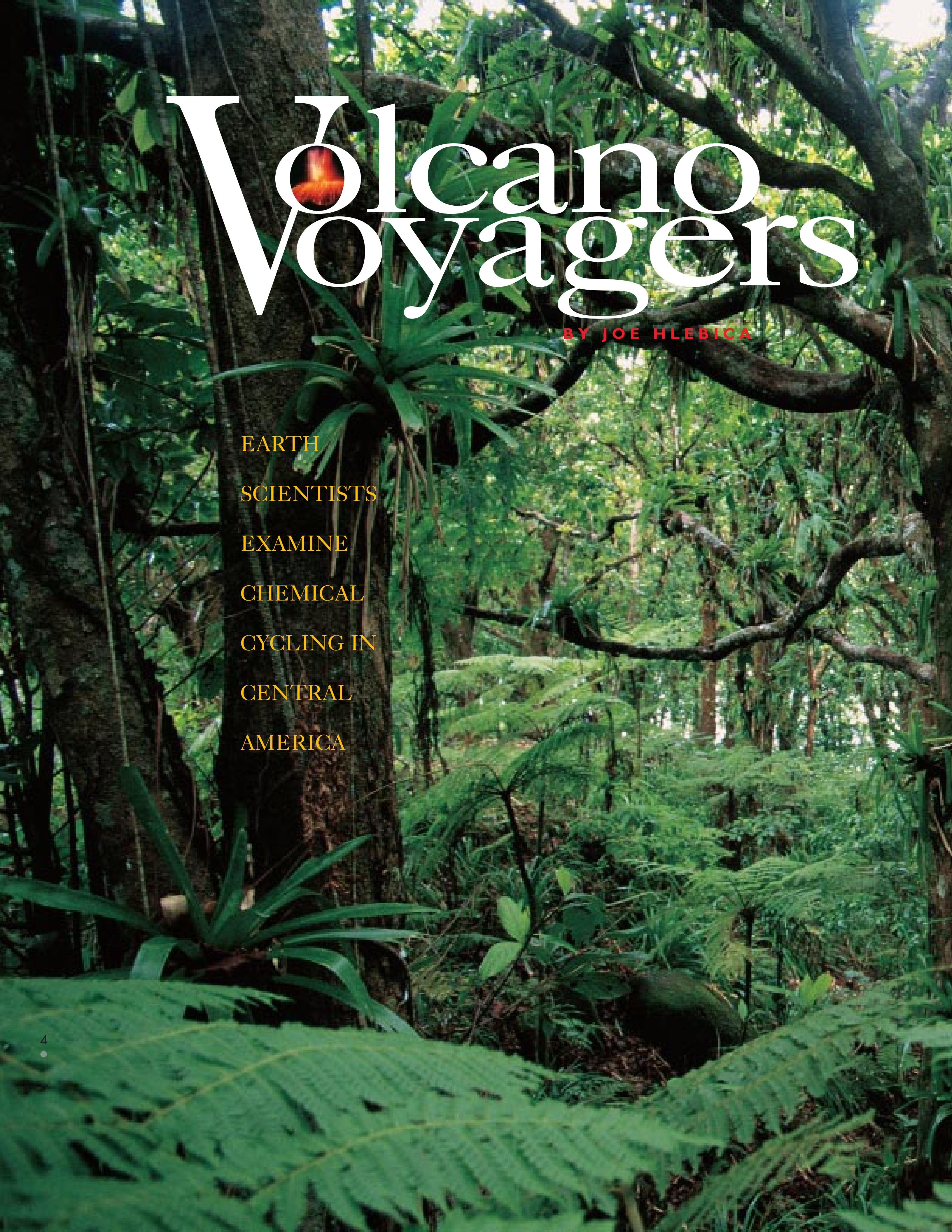


Volcano Voyagers

BY JOE HLEBICA

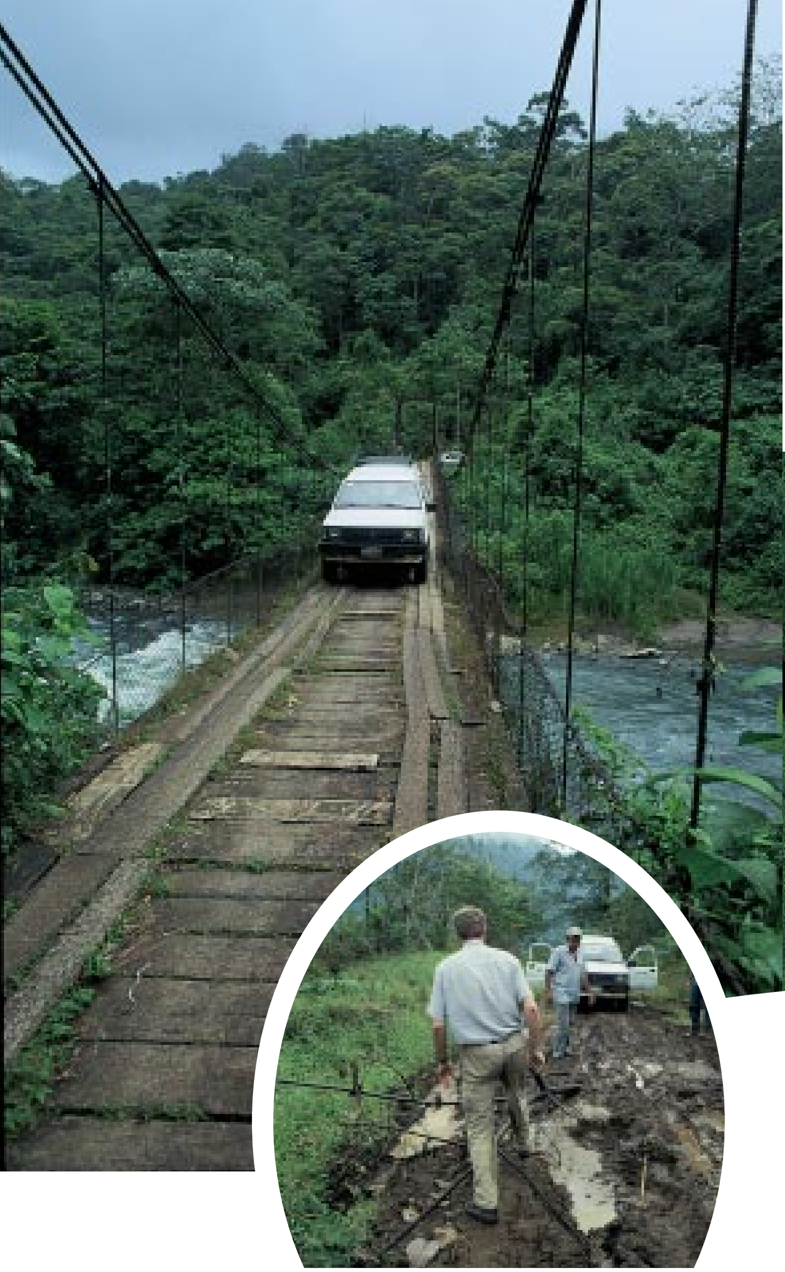
EARTH SCIENTISTS EXAMINE CHEMICAL CYCLING IN CENTRAL AMERICA

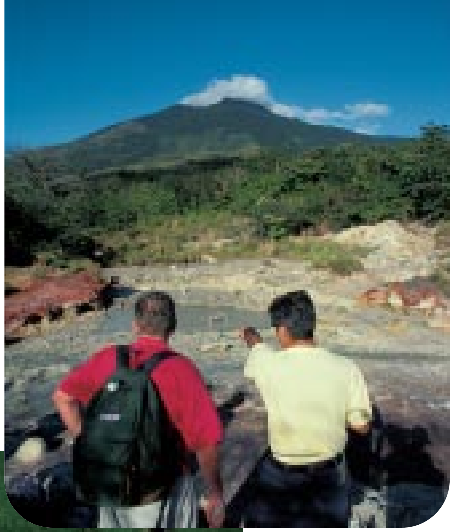
ON THE FLANK OF Rincon de la Vieja volcano, Scripps geochemist David Hilton and an expedition team from Scripps Institution of Oceanography, the University of New Mexico, and the University of Costa Rica experienced a tremor from the massive January 13 earthquake that rocked neighboring El Salvador. This disastrous event attained a magnitude of 7.6 on the Richter scale and took more than a thousand lives.

Rincon de la Vieja is one of several active volcanoes along the Central American arc, a continuous range of volcanoes running southeast from Mexico through Guatemala, El Salvador, Honduras, Nicaragua, and Costa Rica. Hilton and the team were in Costa Rica at the time of the earthquake collecting volcanic gases and lavas. The earthquake hit on their last day of sampling, and seemed to underline current efforts of the scientific community to focus on subduction zones, where irregular slabs of solid rock, known as tectonic plates, converge.

Hilton's interest lies in understanding how volatiles—gaseous chemicals under normal conditions of pressure and temperature—cycle through these seismically active zones. Volatiles, such as water and carbon dioxide, play a crucial role in determining the physical properties of magmas, or molten rock, and are part of the reason why regions such as Central America are so seismically and volcanically active.

Earth's solid surface is made up of tectonic plates that float on the upper mantle—the area that lies beneath the crust. The plates are continually pushing into one another, being pulled apart, or grinding against each other; all with tremendous geophysical power. This constant motion concentrates





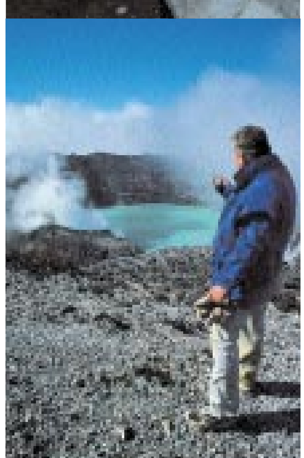
earthquakes and volcanic activity near the boundaries between tectonic plates. At converging plate boundaries—subduction zones—one plate passes underneath another and enters the fiery furnace of the mantle. The downgoing plate acts as a great conveyor belt to transfer elements into the mantle. The same elements may reemerge via volcanic activity along the arc.

In this way, subduction zones act to recycle elements between Earth's interior (mantle) and exterior (crust, oceans, and atmosphere). This recycling process involves both input to the mantle via the downgoing plate and output to the surface by magmatic activity.

"We are interested in finding out if a balance exists at subduction zones between the input and output of volatiles, such as carbon dioxide," explained Alison Shaw, a Scripps graduate student and expedition member. This mass balance can theoretically be calculated for a number of volatiles, leading to a

Today started with a trek across the so-called Ridge of Death. We scrambled down the back of Irazu volcano in search of fumarole sites. After two hours of climbing over slippery gullies and ridges, we discovered a large crack in the volcano's outer wall with gas pouring out. We managed to take several gas samples and one fluid sample.

Opposite page left, *Expedition members prepare a path for the team's truck through the Costa Rican rainforest.* **Opposite page right,** *University of Costa Rica geologist Guillermo Alvarado points out an approach to volcanic mud pots near Mount Miravalles.* **This page right,** *University of New Mexico volcanologist Tobias Fischer at the crater's rim atop active Mount Poás.*

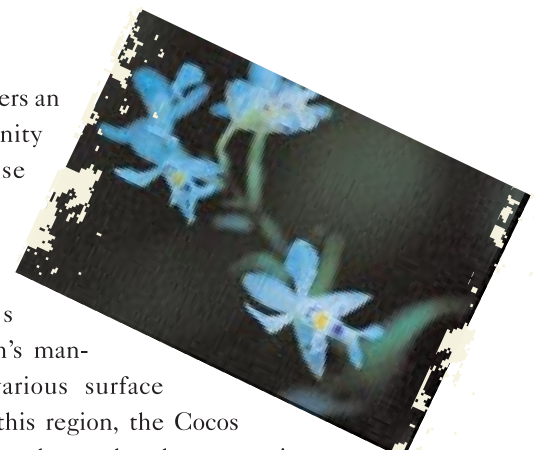


better understanding of global chemical cycling. These data can help researchers evaluate the origin and evolution of Earth's atmosphere and oceans.

VOLATILES AND VOLCANOES

The process of subducting a plate into the mantle results in a gradual heating of the plate edge. This induces a number of chemical reactions that lead to the breakdown of sediments on the edge of the plate. In turn, this acts to both produce and release volatiles to the mantle wedge—that portion of the mantle trapped between the subducting plate and overlying crust. The volatiles are then transferred to the volcanic arc by magmatic activity. The most common volatiles released by volcanoes along the arc are water, in the form of steam, and carbon dioxide.

The Central American arc offers researchers an ideal opportunity to collect these volatiles and to study the recycling of elements between Earth's mantle and its various surface reservoirs. In this region, the Cocos Plate plunges beneath the opposing Caribbean Plate and enters the mantle, subducting with it marine sediments that have been deposited on the seafloor for millions of years. These sediments are rich in calcium carbonate, a source of the carbon that, through magmatic activity, is released into the atmosphere as carbon dioxide.



Researchers debate whether the amounts of carbon dioxide, water, and other volatiles subducted annually are roughly equal to the amounts returned to Earth's surface. If not, throughout Earth's history, subduction would lead to huge changes in the volatile budget of the mantle and its ability to supply volatiles such as water to the atmosphere and oceans.

It has long been known that gases play a crucial

role in forcing magma to Earth's surface and generating explosive volcanic eruptions. As magma rises toward the surface, pressure decreases, causing the dissolved volatiles to come out of solution and form gas bubbles. The mixture of gas and magma undergoes rapid expansion as it nears the surface, which provides the driving force for volcanic eruptions. "Like champagne spouting from a bottle," as Hilton put it.

"All terrestrial magmas contain dissolved volatiles. The principal volatiles are water and carbon dioxide, but there are others including sulfur dioxide, hydrogen chloride, hydrogen sulfide, and the noble gases (a group of rare gases)," Hilton explained.

To assess the magma's total volatile content, Hilton and his team collected gases from volcanic vents and thermal springs. A volatile of particular interest was carbon dioxide, which is a widely known greenhouse gas contributing to global warming. The natural flow of carbon dioxide into the atmosphere, or flux, that is associated with subduction zone volcanism is not well understood.

"Knowing how much carbon dioxide is released by volcanoes not only allows us to establish a baseline for the continuous natural flux of carbon dioxide into the atmosphere, but also provides a basis for determining the inventory of carbon in Earth's largest reservoir, the mantle," Shaw added.

SCIENCE ON THE CRUMBLING EDGE

Poás volcano, close to San José, the capital of Costa Rica, is one of Costa Rica's most active volcanoes. "It is an ideal locality to sample," Hilton said, "because the magma is relatively close to the surface and the chance of contamination by crustal gases is low."

The team found a high proportion of carbon dioxide emanating from Poás. Although green plants consume carbon dioxide, high concentrations can be deadly. Evidence of this lies in the "dead zone," where one flank of the mountain is picketed with stark gray defoliated trees.

Another volatile in evidence on Poás is hydrogen chloride. "A higher ratio of hydrogen chloride to carbon dioxide would indicate a more direct pathway for the gases from the magma to the surface," said Tobias Fischer, a University of New Mexico volcanologist and Hilton co-investigator. "In contrast, if the ratio is relatively low, this may show that the gases interact significantly with a hydrothermal system, and that the magma is at a deeper level," Fischer explained.

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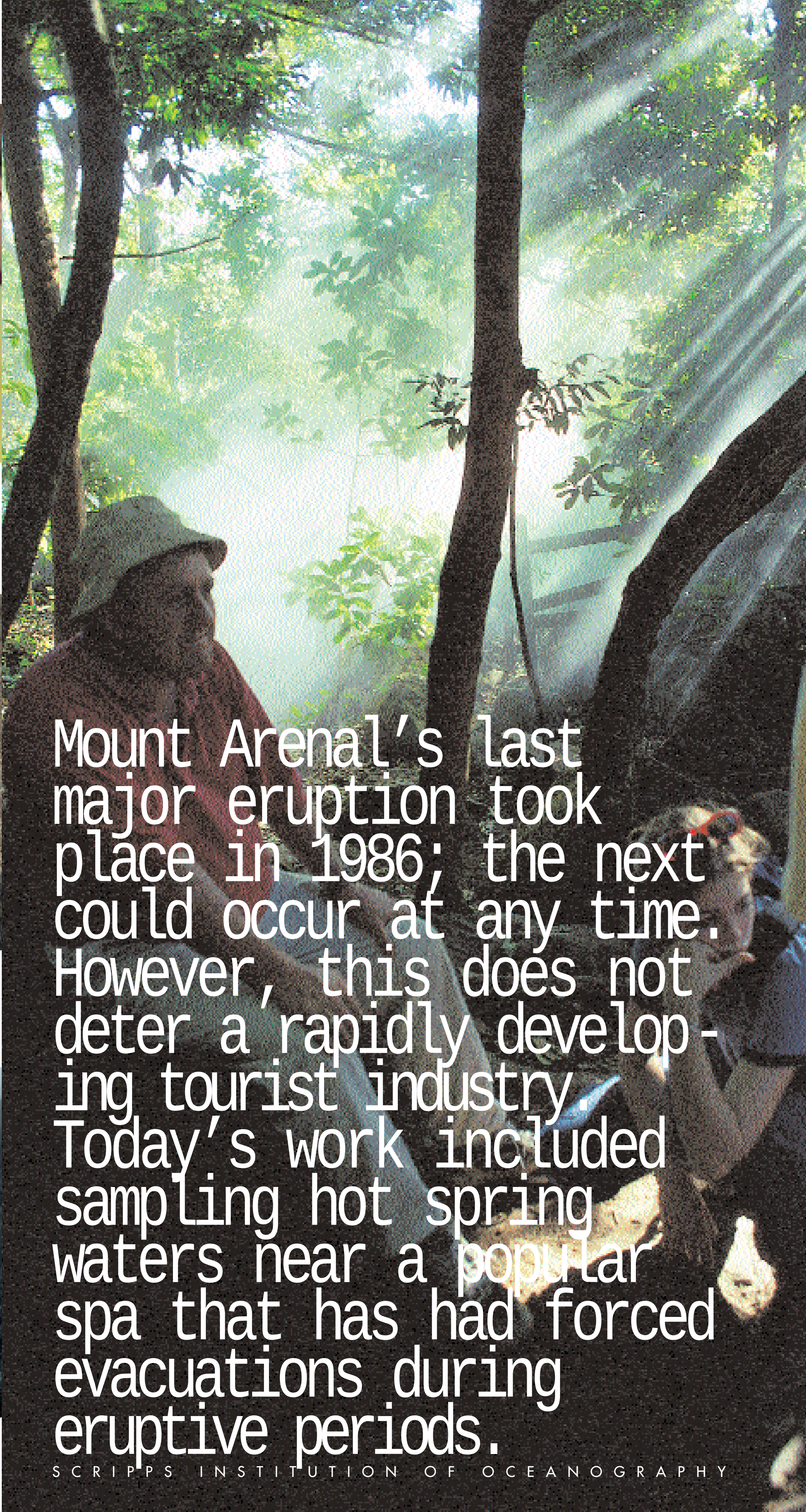
Top left, *David Hilton and Alison Shaw collecting volcanic gas samples in the crater of Mount Turrialba and near Mount Miravalles (opposite top).* **This page,** *Geological tools and volcanic rock samples.* **Opposite page center,** *Guillermo Alvarado assists Shaw with volcanic rock sampling.* **Opposite page bottom,** *An acidic lake lies within the crater of Mount Poás.*



Mount Arenal's last major eruption took place in 1986; the next could occur at any time. However, this does not deter a rapidly developing tourist industry. Today's work included sampling hot spring waters near a popular spa that has had forced evacuations during eruptive periods.

This ion gauge at the Fluids and Volatiles Laboratory at Scripps is used to measure gas pressure. Gas molecules are ionized by the filament visible within the vacuum tube, causing an electrical current flow to the ion collector. The magnitude of this current is a direct measure of the gas pressure.

Rincon de la Vieja, Poás, and Turrialba are but three of the many volcanoes the Hilton team sampled during expeditions to the region.

Rincon de la Vieja, at 6,300 feet (1,900 m), is the largest volcano in northwest Costa Rica. The last major eruption occurred approximately 3,500 years ago, but many minor eruptions have occurred subsequently, including some in recent history.

At 8,500 feet (2,600 m), Poás is not a particularly high mountain, but within its crater are an impressive central dome and an acidic lake, an eerie green in color. Scores of fumarole vents give the crater's interior the look of a mythical underworld.

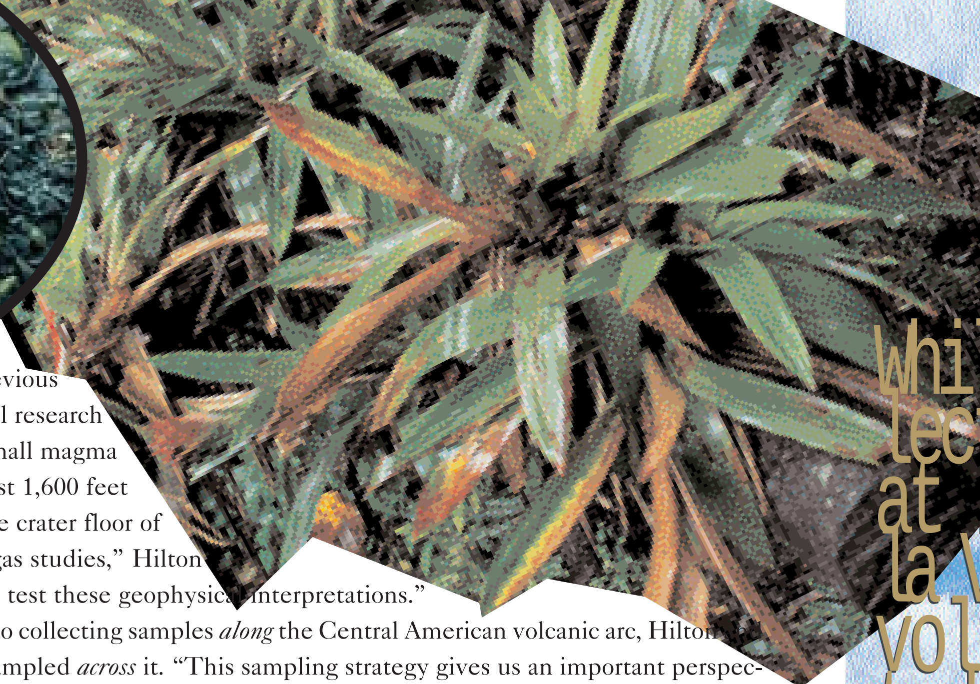
Turrialba, on the other hand, is one of the highest volcanoes in Costa Rica, at some 10,000 feet (more than 3,000 m). It last erupted 135 years ago, and is currently dormant, although there is a great deal of fumarole activity around its summit.

After a grueling hike up the mountain and into its yawning crater, Hilton's team spent the first day of the two-week-long expedition taking samples of Turrialba's gases.

"We were greeted by the acrid odor of sulfur dioxide, a gas characteristic of volcanoes, and a dangerous one if too much is inhaled," Hilton said. "It emanated from a number of fumaroles venting on the crater wall. We sampled these vents using our vacuum flasks."

While this procedure was under way, the expedition's guide, University of Costa Rica geology professor Guillermo Alvarado, examined volcanic bombs ejected from the crater during Turrialba's last eruption in the nineteenth century. They contained tiny green crystals of olivine, a mineral that traps volatiles within its structure when formed, acting as a natural time capsule for volcanic events.

The gases from this dormant volcano will help the researchers in their understanding of volcanic processes and element recycling, especially in comparison to the gases of the active volcano, Poás.



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Previous geophysical research suggests that a small magma chamber may exist 1,600 feet (500 m) below the crater floor of Poás. "With our gas studies," Hilton said, "we hope to test these geophysical interpretations."

In addition to collecting samples *along* the Central American volcanic arc, Hilton and the researchers sampled *across* it. "This sampling strategy gives us an important perspective on the source of volatiles from the crustal slab currently subducting beneath the region," Hilton explained. "In effect, by making these across-arc studies we can follow the subducting slab into the mantle and sample at different depths on the slab."

"One of the principal questions we can address is how far marine sediments make it into the mantle before they are broken down to form the carbon dioxide sampled at the surface," Shaw added.

VOLCANIC SAMPLING

There are a number of ways to sample volcanic gases, which is the first step in understanding the recycling of volatiles. Beneath the ocean, gases emanating from hydrothermal vents, and those contained in volcanic lavas erupting from the seafloor, are collected by either manned submersibles or dredging. In a manner just as challenging, and poten-

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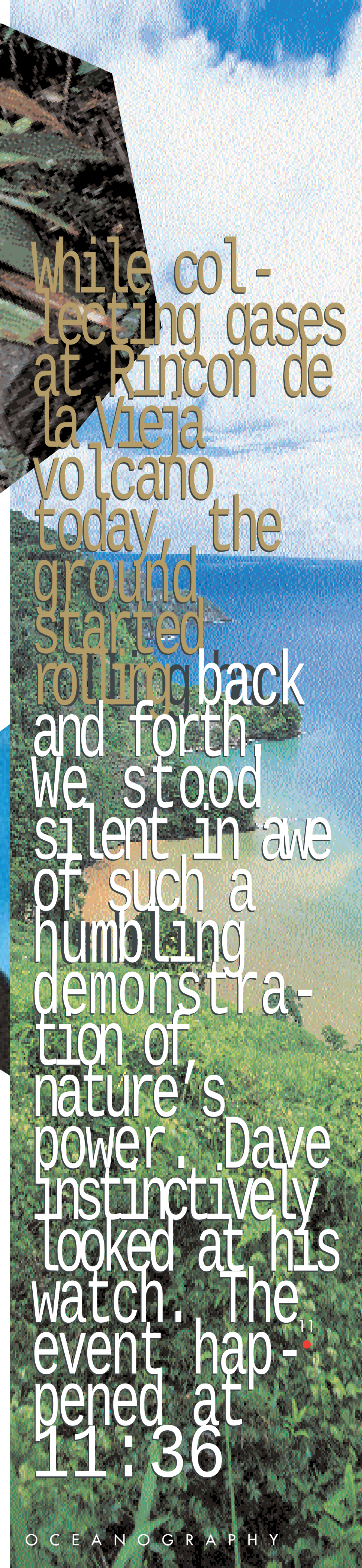
Left and inset, *Tobias Fischer and Alison Shaw sample volcanic gases from mountain streams.* **Above,** *Part of the Central American volcanic arc, Mexico's Mount Paricutin was a newly formed cinder cone when this photograph was taken in 1943.*



While collecting gases at Rincon de la Vieja volcano today, the ground started rolling back and forth. We stood silent in awe of such a humbling demonstration of nature's power. Dave instinctively looked at his watch. The event happened at 11:36

tially more dangerous, scientists venture into active volcanic craters to sample gases emanating from fumarole vents, or they capture scalding geothermal waters flowing from the ground.

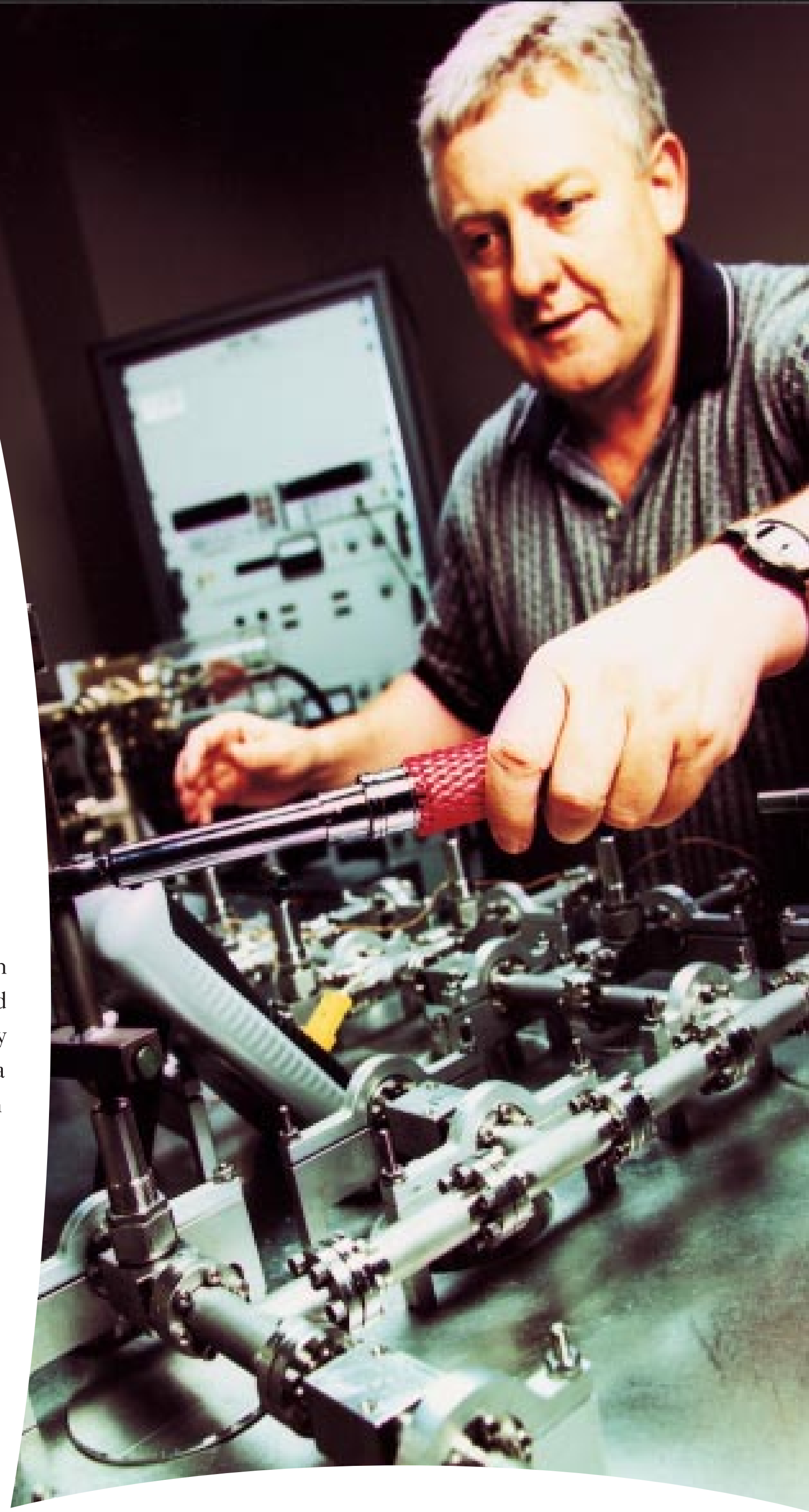
In Costa Rica, the Hilton team collected gas samples by using glass flasks. To capture the gas, a large plastic funnel is placed over the source of venting gas. A length of hose is attached to the funnel and another length to a hand pump. Both are connected to the leak-proof flask. As the volcanic gas flushes the air out of the line, the vacuum flask is opened to take-up the sample. It is then packed away in a shockproof case for transfer from the field to the laboratory.

AT HOME IN THE LAB

After completion of the two-week expedition, Hilton and Shaw analyzed the volcanic gases they collected for volatile content and isotopic compositions. They used state-of-the-art laboratory equipment such as a mass spectrometer to measure isotope ratios, which help indicate a volatile's origin.

The Costa Rica trip represented the first stage of this scientific study. In May, the Hilton team returned to the Central American arc to resume collection of gas samples, this time in Guatemala. In 2002, they will complete the sampling phase of the arc by visiting Nicaragua, El Salvador, and Honduras.

"The overall aim is to better understand mass and energy transfer at subduction zones by determining carbon dioxide, water, and other volatile balances throughout the Central American arc system," Hilton said.

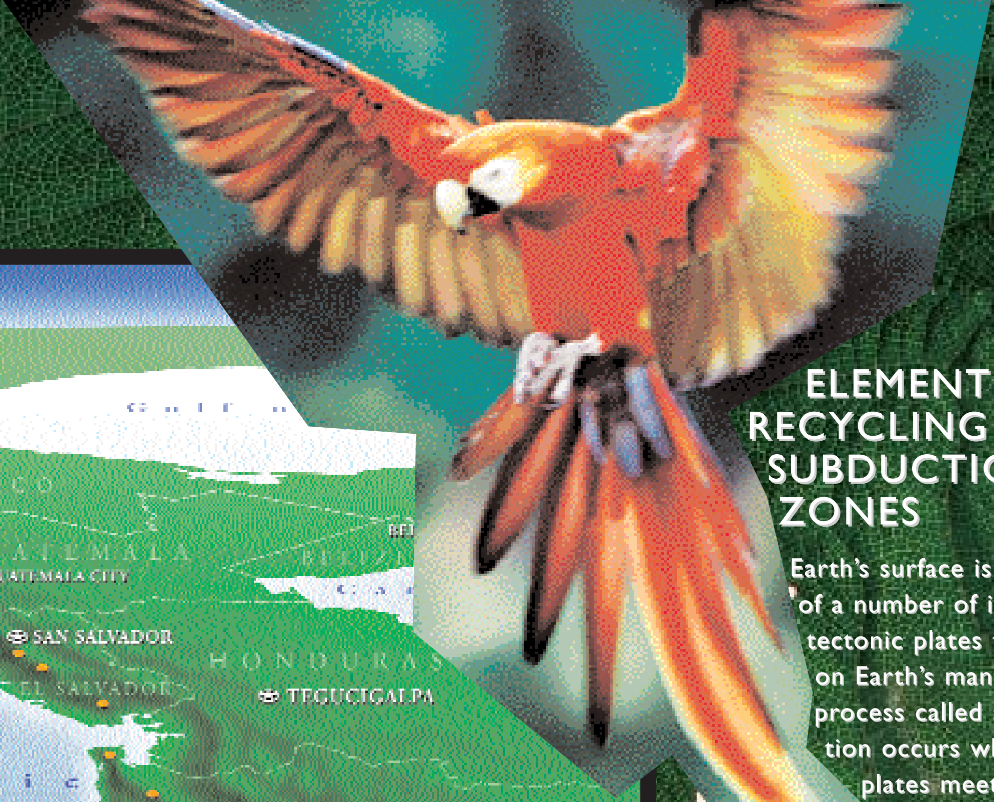


David Hilton processes a gas sample through the inlet line of the mass spectrometer in the Fluids and Volatiles Laboratory at Scripps.

VOLCANO LECTURE AT THE BIRCH AQUARIUM

As part of the Perspectives on Ocean Science series offered by the Birch Aquarium at Scripps, on Wednesday, November 14, at 7: 30 A.M. Dr. David Hilton will present a lecture on his travels to the volcanoes of Central America, as well as to Indonesia. RSVP: 858/534-7336. Price includes continental breakfast, parking validation, and aquarium admission for the day.

Check out scripps.ucsd.edu/volcano for more details of the Scripps Costa Rica expedition, or visit Dr. Hilton's homepage at everton.ucsd.edu.



ELEMENT RECYCLING VIA SUBDUCTION ZONES

Earth's surface is made up of a number of irregular tectonic plates that float on Earth's mantle. A process called subduction occurs when two plates meet and one passes beneath the other to enter the mantle. Along the Pacific margin of Central America, the Cocos Plate plunges beneath the Caribbean Plate to form the Central American subduction zone.

As the downgoing plate enters the mantle, it takes with it a veneer of sedimentary material that is derived from both the oceans (marine sediments) and the land (terrigenous sediments). The sediments contain volatiles such as water and carbon dioxide (in the form of calcium carbonate).. Volatiles taken down to mantle depths of up to 90 miles (144 km) induce melting in the mantle wedge, with the resulting magma (molten rock) creating a continuous range of volcanoes stretching from Mexico through Guatemala, El Salvador, Honduras, and Nicaragua to Costa Rica. The frequent volcanic activity along the Central American margin allows the volatiles to recycle back to the surface.