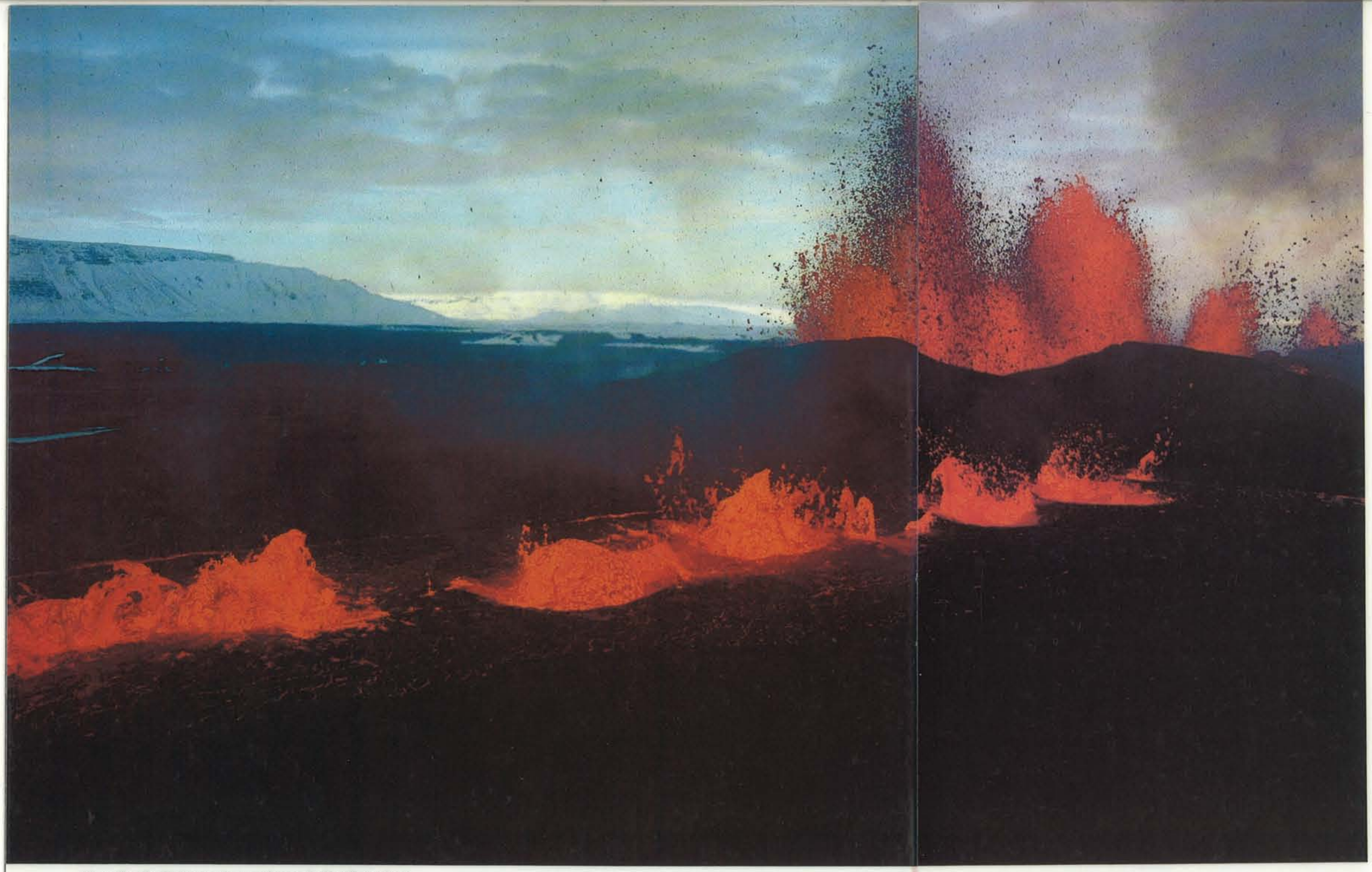


Near Krafla Volcano in northeast Iceland, molten lava spews into the air from two rows of fissures.

Article and photographs by Randall Hyman

An island trembles astride a rift where our planet's crust is forming

In Iceland, where the Mid-Atlantic Ridge comes ashore, recent volcanic eruptions create fiery illustration of continental drift

Billows of sulfuric steam cloak Hjörtur Tryggvason as he makes his way up the mucky slope of Leirhnjúkur (Clay-peak). Stopping beside a deep fissure at the top of the ridge, he turns and gazes down across the coal-black fields of steaming lava.

"Just before one of the eruptions in 1977, I came up here to watch the fireworks begin in those lava fields. Suddenly the ground beneath my feet started sinking and shaking apart. I got off this ridge as fast as my legs would carry me!"

In October 1980, I learn why Hjörtur must be so nimble. The earth bursts open near Leirhnjúkur once more and sends fountains of lava gushing skyward along miles of fissures. The eruption occurs right on schedule, as predicted by scientists months earlier. Brilliant orange rivers of lava rush in all directions, leaping down slopes as fiery waterfalls. I stand just a stone's throw from the thundering lava fountains, but the "stones" in this case are volcanic cinders that rain upon me in torrents.

The wind changes direction and I am caught in a cloud of smoke that smells of burnt gunpowder. The sulfuric gas burns my lungs; it is impossible to breathe until the wind once again blows in my favor. The scene is like some fantastic excerpt from Dante's *Inferno*: awesome, terrible and compelling. Unable to pull myself away, I receive unwelcome persuasion. A large chunk of lava hits me squarely in the back and a smaller piece smashes into my camera lens. Remembering Hjörtur's words, I make a quick retreat.

Hjörtur shrugs off this kind of danger; it's all part of his job as field recorder for Iceland's National Energy Authority. As he straddles the fissure on Leirhnjúkur to measure the ever-increasing gap, Hjörtur jokes that he has one foot in America and the other in Europe. He is referring to the North America and Eurasia "plates" which, according to continental drift theory, are spreading apart at an average rate of two centimeters (almost an inch) per year. It is Iceland's dubious honor to be caught in the middle, atop the Mid-Atlantic Ridge, one of the few growing countries in the world!

Until 1975, the Ridge had not spread in northeast Iceland since the last recorded volcanic activity some 100 years ago. Suddenly, in the autumn of 1975, the earth came to life. Over the past six years, this 80-kilometer (about 50-mile) portion of the Mid-Atlantic Ridge has rifted apart five meters (16 feet), erupted eight times, and shaken the earth with thousands of earthquakes. It is the supreme opportunity for scientists to study an active section of mid-ocean ridge.

The author, a free-lance writer and photographer living in St. Louis, studied at the University of Iceland and is fluent in the Icelandic language.

The Mid-Atlantic Ridge comes ashore

"Cheap oceanography" is what one scientist has called the land-based research being conducted here by the Nordic Volcanological and Sciences Institutes of the University of Iceland, and the National Energy Authority. Elsewhere in the world, spreading plate boundaries are found strictly on the ocean floor. Only in Iceland can geophysicists abandon their diving gear to hike along the Mid-Atlantic Ridge and measure the growing rift between Europe and America—or watch it spew lava 50 meters into the air.

The past six years have been a heyday for geophysicists, but a nightmare for many Icelanders; perched astride the region's tangled network of fissures are two geothermal industries and a village.

"They couldn't have built the Krafla Power Plant in a better place for measuring land tilt and predicting eruptions," says Hjörtur. "The main station house sits right above the Krafla magma chamber."

Three kilometers beneath Leirhnjúkur, just north of the Krafla Geothermal Power Plant, simmers a huge chamber of magma. This is the immediate source of the eruptions, christened the Krafla Fires, which have been growing steadily more frequent and massive since they began in 1975. In just the past year and a half, this hidden "volcano" has given birth to five lava eruptions, some lasting longer than a week.

Hjörtur is called the "midwife" of the Krafla Fires. Making his daily rounds to the riftmeters, tiltmeters and seismometers spread across this fault zone, Hjörtur records every contraction of the fiery womb below. Icelandic scientists have used these records to make accurate predictions of eruptions months in advance.

Field recorder Hjörtur Tryggvason explores a fissure; background steam is from hot springs flowing below.

The rise of the land above the Krafla magma chamber is the key to predicting eruptions. The chamber behaves like a balloon being inflated while buried in sand: as the chamber inflates with magma fed from unknown depths, the land above rises. When it becomes too bloated, it bursts. Unlike Mt. St. Helens, Krafla stifles her volcanic sneeze underground, pouring tons of magma into subterranean dikes. These dikes are the hidden roots of fissures that stretch north and south from Krafla. As the magma drains off through many kilometers of these dikes, the land above the chamber subsides. If the magma finds its way to the surface via open fissures, a spectacular eruption results.

As soon as the chamber stops releasing magma the land begins to rise anew. Once the land rises beyond the level attained before the last magma flood, another "breakout" is due. The balloon analogy fits well, for the chamber appears to "stretch" increasingly more with each inflation of magma.

A nightmare out of the past

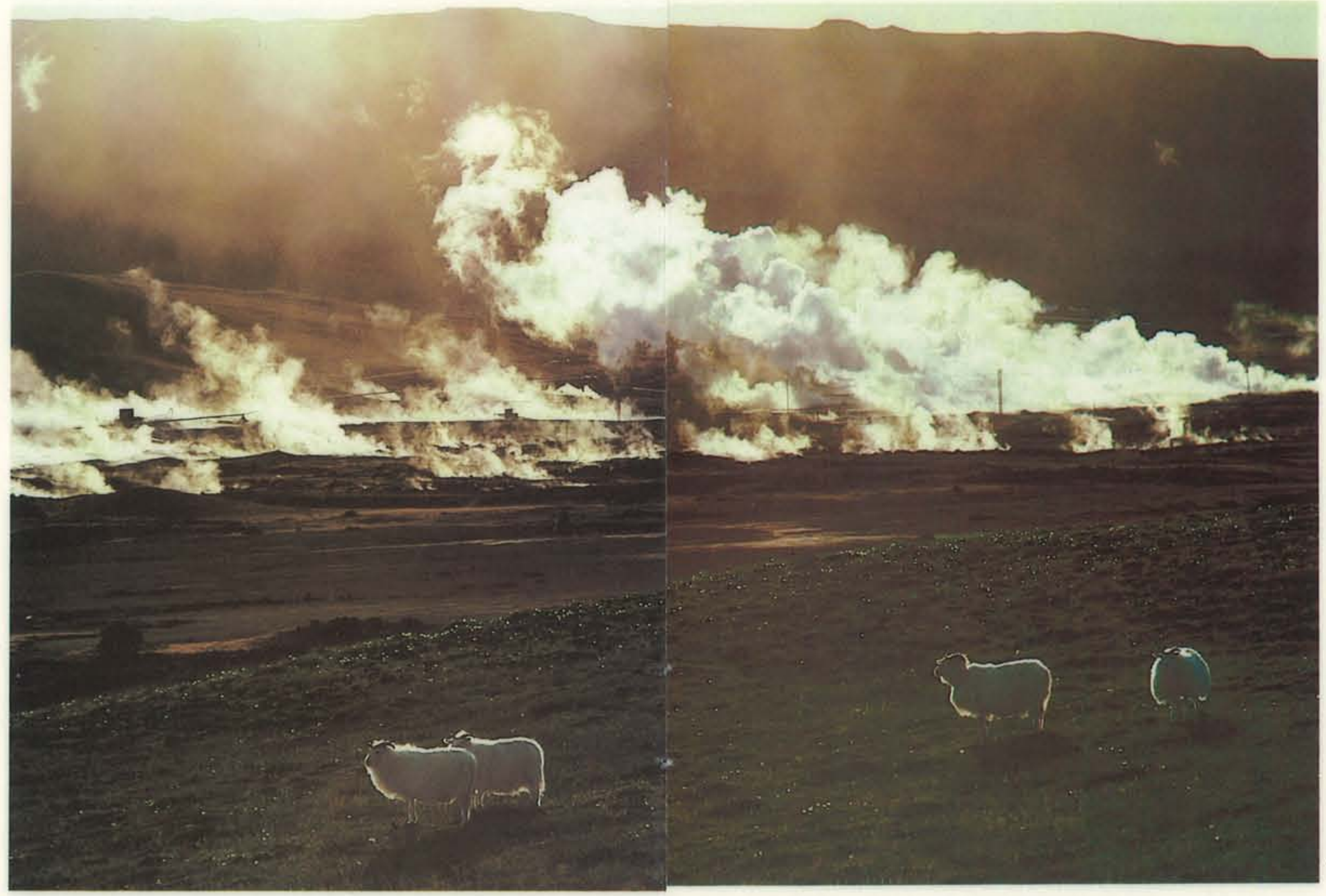
The Krafla Fires bear a chilling similarity to the catastrophic Mývatn Fires of 1724-29. The Mývatn Fires lasted five years and four months. The Krafla Fires have more than matched that record, erupting from the same fissures that spewed the Mývatn Fires some 250 years ago. So alike are the two periods of volcanism that scientists have been keeping a running chronology of Krafla's eruptions and earthquakes, and matching them against the history of Mývatn Fires. All that is lacking to perfect the resemblance is a final, immense eruption like that of 1729, as described in this account: "Then began the final tempest of fire from a crater near Leirhnjúkur. This eruption was one of the largest to date and lava poured over previous flows with such a fury that it appeared that this would tie the final knot on the total destruction of the county."

As it was, four farms were lost to the flood of lava. A hotel now stands on that same site. Will history repeat itself? Upon entering the hotel, one is greeted with this foreboding sign: "FROM CIVIL DEFENSE —If you hear a steady sound of sirens and see green rockets being fired at the same time, ask the hotel staff for information. If you hear alternately high and low tones from the sirens and see red rockets being fired, go to Skútustadir immediately."

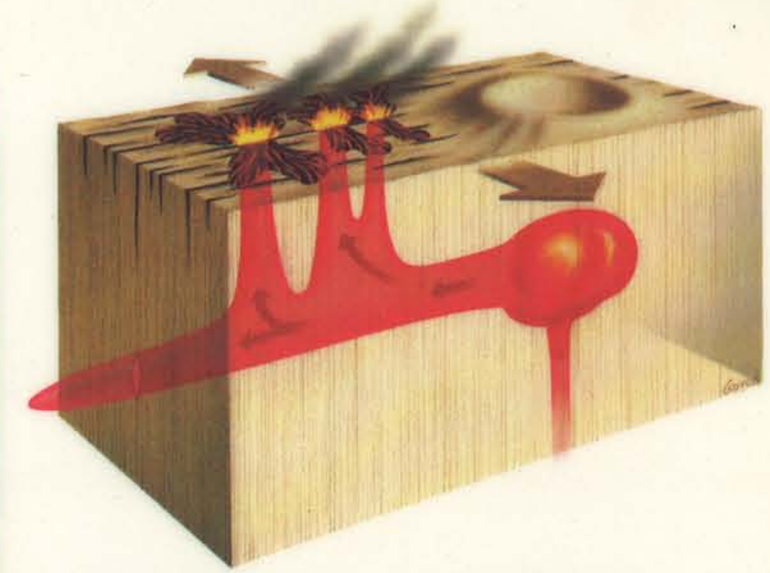
Whether or not the prospective hotel guest chooses to stay for the more-than-warm reception promised by this sign, the 500 people of Reykjahlíd have little choice. They have coped with the danger of eruptions and the violence of earthquakes for the past six years. Ironically, the same volcanic energy that threatens the

Thorarinsson

For a few hours in 1977, lava spewed forth along seven-tenths of a kilometer of this fissure; some eruptions last weeks. View is south toward Krafla.



Icelandic sheep wander on cotton grass; behind them is geothermal steam field used by diatomite plant.



In stylized diagram, inflated magma chamber bursts, allowing magma to travel underground in bladelike dike; eruptions along fissure are fed from dike below.

town with destruction also blesses it with prosperity—in the form of geothermal energy.

The cornerstone of life in Reykjahlíd is a unique factory that uses geothermal heat to convert seemingly useless sludge from nearby Lake Mývatn into valuable diatomaceous earth. The diatomite is sold in Europe as a filtering agent for swimming pools and wine distilleries. Normally, diatomite is mined only in its dry form; wet diatomite sources are impossibly expensive to dry and reclaim. The happy coincidence that there is plenty of cheap geothermal steam available here has made the impossible possible.

In 1977, the land's volcanic nature turned from boon to bane. The factory's office building was ripped in two by an underlying fissure. Reservoirs holding the winter supply of diatomaceous earth burst open and several geothermal steam wells were damaged.

"We've built a new reservoir and drilled two steam wells, all outside the danger zone, away from any of the fissures," says Hákon Björnsson, plant manager. "Only thing we can't move to safer ground is the factory—but we put a dike around it in case there's a lava eruption."

The diatomite plant sits right on the line of fissures that run south from the Krafla magma chamber. Although the Krafla Fires have always erupted north of the magma chamber, they could just as easily move to the south and bury the diatomite factory and village under lava.

"We'll just have to bite the sour apple if the lava flows the wrong way," reflects Rakel Gudlaugsdöttir, a Reykjahlíd housewife. "I think we're too careless now. This winter we were near hysteria, and now we're just the opposite. It seems like we can't live with this on a middle ground."

The cause of the hysteria was one of the Krafla Fires' largest eruptions, in October 1980. Lava jetted and roared from the earth for six days, erupting first from Leirhnjúkur (dangerously close to the Krafla Power Plant) and then migrating northward for seven kilometers. For the first time, the townspeople realized that they were well within the grasp of Krafla's molten tentacles.

"The whole county lit up that night," says Rakel. "It was like a sunrise with no sun. Everything glowed orange. The energy was incredible."

Authorities, too, were shaken by the October eruption. The Krafla Fires seemed to be growing more frequent and massive with each new eruption. The Icelandic winter was approaching, with its blizzards and endless nights; any emergency evacuation during the dark, icy months would be difficult.

The civil defense organization called a town meeting to organize and prepare the people for the worst. Geophysicists were the star speakers. Armed with graphs that showed the land at Krafla rising at an alarming rate, they said that a new eruption could occur as early as late November.

All winter, villagers kept packed suitcases ready at their front doors, and nervously counted each day as the land continued to rise. The eruption was long overdue.

Finally on January 30, 1981, the earth split open with volcanic fireworks far to the north of Leirhnjúkur. Though similar in size to the October eruption, this one was safely distant from the town. In a bizarre way, it was as much an anticlimax as a relief. Frustrated and frazzled by unfulfilled predictions of doom, the town shed its worn coat of worry and donned one of apathy.

"The public misses the point of what's happening at Krafla," claims Páll Einarsson, geophysicist with the University of Iceland's Science Institute. "Journalists always ask us to predict eruptions, and then complain if we're slightly off. They miss the real story. They should focus on the *science*—the research that's going on here. Eruptions in themselves are really nothing special."

Páll calls the Krafla Fires "a rifting incident," not a period of eruptions. The eruptions are simply "minor by-products" of plate spreading on the Mid-Atlantic Ridge. Research at Krafla has revealed important new information about the behavior of spreading plates.

Contrary to the old assumption that plate spreading is a constant, gradual process, the Krafla Fires have demonstrated that rifting can occur in violent surges separated by long periods of dormancy. The Krafla region had not spread for 250 years until 1975, but the five meters the Ridge has rifted over the past six years is precisely 250 years' worth of continental drift (two centimeters per year times 250 years = five meters).

Continental drift theory proposes that the Earth's crustal plates are driven by a global system of convection currents in the hot magma below that behave like giant conveyor belts. Where these currents well upward and push the plates apart, mid-ocean ridges form (SMITHSONIAN, January-February 1975). Iceland, situated astride the Mid-Atlantic Ridge, is the child of such an upheaval.

Prior to the Krafla Fires, eruptions along the Ridge were presumed to be fed from directly below. Dense concentrations of fissures and underground igneous dikes, found widely in Iceland, were thought to have been formed by vertical injections of magma. Now they are recognized to be remnants of Kraflalike rifting episodes. The dikes are frozen blades of magma that penetrated horizontally from a central magma chamber. Some of these dike and fissure swarms are segments of the Mid-Atlantic Ridge, biding their time until it is once again their turn to come to life like Krafla. Apparently, the Ridge spreads not only in pulses, but in sections too.

When Krafla first began to stir in July 1975, construction of the geothermal power plant was still in its early stages. Few people imagined that those earthquakes were the birth contractions of a hidden volcanic womb. The first of the Krafla Fires erupted in December of that year, followed by an intense period of earthquakes. For several weeks the land shivered with up to several thousand earthquakes per day, a few exceeding 5.0 on the Richter scale. Construction of the power plant was pushed through in spite of these omens.

Today, the 60-megawatt facility barely produces one-fourth of its designed capacity; the geothermal steam fields have been "overcooked" by the Krafla magma chamber. The steam wells must be drilled about two kilometers deep, two-thirds of the way down to the level of the magma chamber. Half of the 16 wells (drilled at a cost of one million dollars each) produce steam that is either too corrosive or too hot to use. One well created a house-size crater after exploding from steam pressure and continuing out of control for two months. Several other wells have been damaged, possibly due to the crustal movements.

In their early years, the Krafla Fires consisted more of earthquakes and crustal movements than of fires. During the winter of 1975-76, the land shook ceaselessly for several months as it rifted apart. Life was disrupted in two areas along an 80-kilometer portion of the Mid-Atlantic Ridge. Local citizens say that it was like "being on a ship in bad seas." They removed all breakables from shelves, never filled cups to the brim, and walked like ship stewards when serving meals. The analogy of living on a ship became all too accurate when coastal farmlands began subsiding below sea level: farmers had to row out to their homes.

In March 1980, the Krafla Fires began to earn their name. Numerous magma flows had occurred before that date, filling the huge subterranean cracks formed by rifting of the Mid-Atlantic Ridge, but only thrice had they surfaced and caused small lava eruptions. The March eruption was the first of respectable size in which a considerable percentage of flooding magma surfaced. As an underground dike became too full to handle more magma, the fiery blade of magma had nowhere to go but up.

The earth belched fire for more than a week

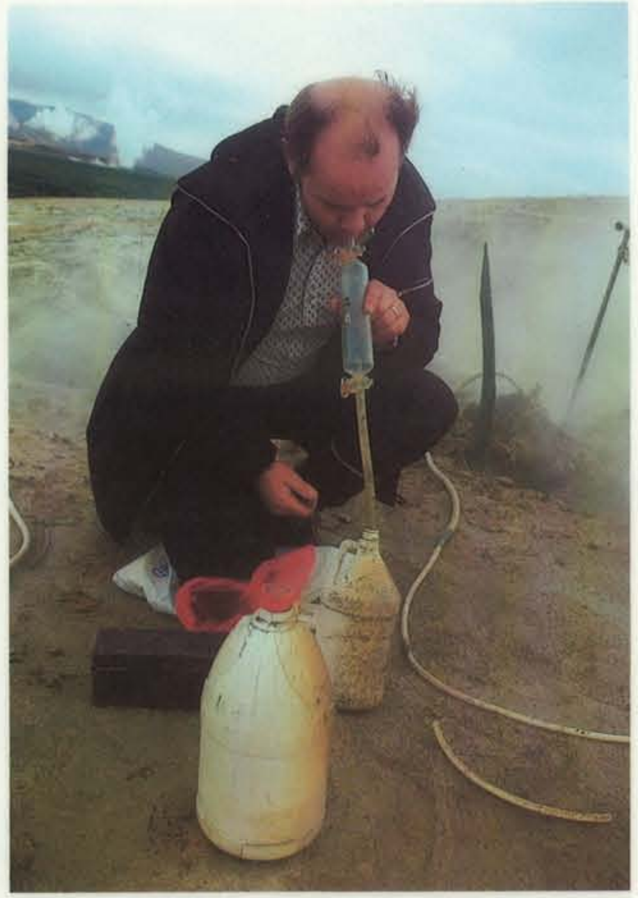
Four months later, on July 10, the land erupted like never before. The earth belched fire for more than a week, covering a vast area of the plains called Gjástykki (Fissured-place). It was particularly unusual that more than 30 percent of the lava flow went pouring back into the depths of the earth, swallowed by a large fissure that stood in its path.

Pausing for only three months, Krafla erupted once again in October, turning in its most impressive performance up to then. Thirty-five million cubic meters of lava buried nearly 12 square kilometers of Gjástykki under lava, spewing fire along seven kilometers of fissures. This was the largest and closest eruption that workers at the power plant had witnessed.

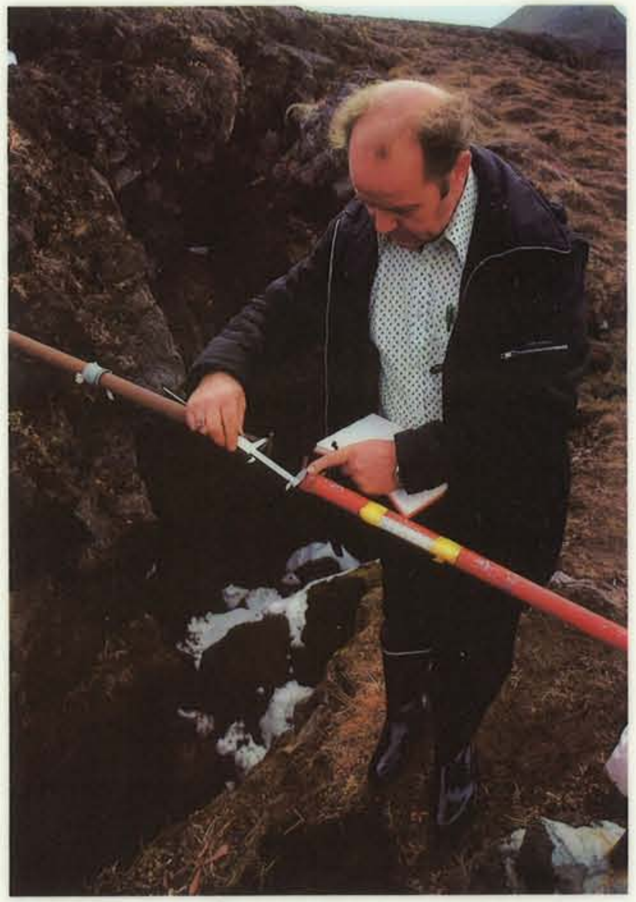
After another three months, in January 1981, Krafla erupted again for one week, producing nearly as much lava as in the October eruption. Finally, last November 18, alarm bells went off as the chamber started rapidly deflating; an hour and ten minutes later lava erupted from an eight-kilometer-long fissure that extended north from above the Krafla caldera. Reports said the area of lava flow was greater than any since the episode began in 1975.

Karl Gronvöld of the Nordic Volcanological Institute remarks, "We're surprised that the eruptions have continued for so long, so predictably. We never dreamed we'd be able to deal so effectively with predictions when this first started."

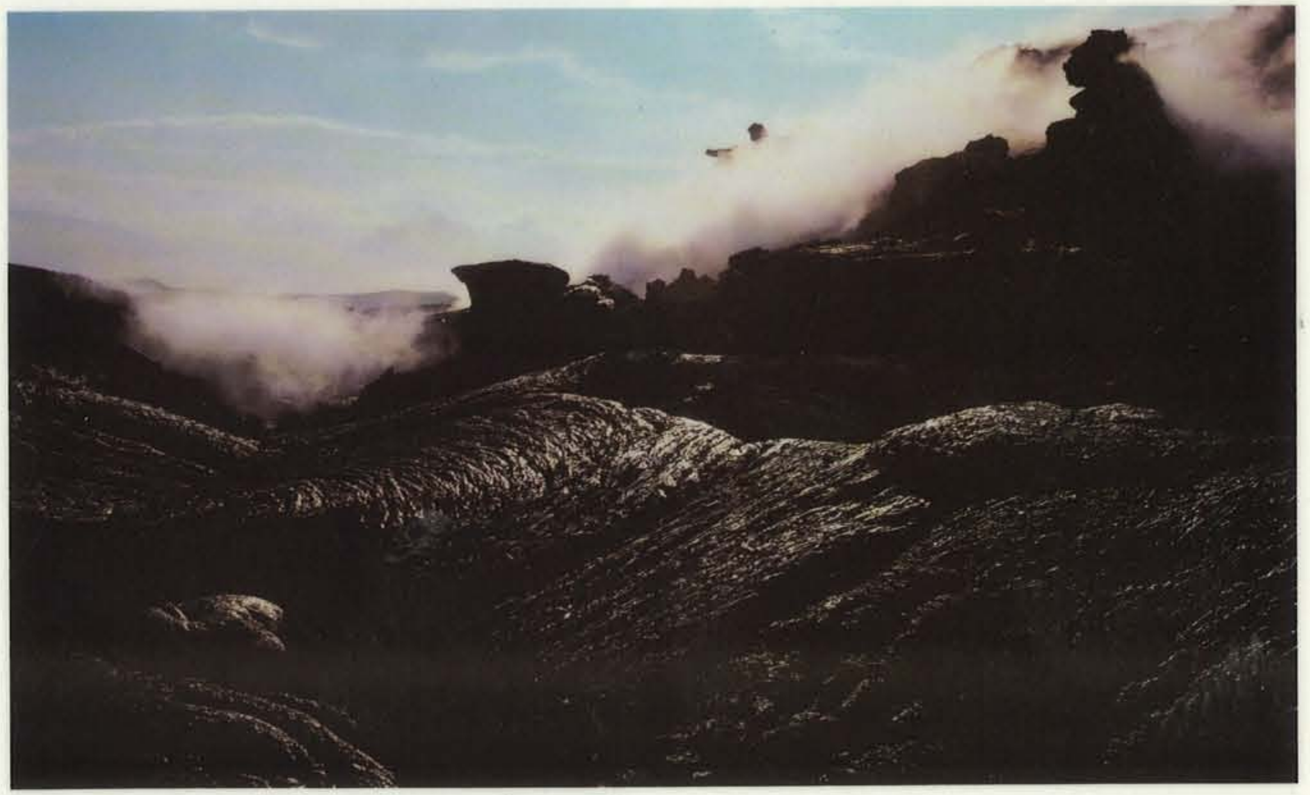
Like detectives hot on the trail of an unseen suspect, Icelandic geophysicists are using laser beams, tiltmeters, riftmeters and seismometers to pry the secrets of the hidden magma chamber and under-



On Leirhnjúkur, Hjörtur Tryggvason takes a gas sample—part of his research for predicting eruptions.



Tryggvason, standing in fault zone of Mid-Atlantic Ridge, measures amount of spread on riftmeter.



Ropy, shimmering *helluhraun*, lava recently erupted from a Krafla fissure, will turn dull in a few months.

ground dike system. Land surveys are made at three-month intervals with laser-beam equipment to ensure the utmost accuracy in measuring the lift of the land. Tiltmeters are used continuously for the same purpose. The most ingenious and reliable tiltmeter is a long water hose that stretches the length of the Krafla station house: the changing level in vessels at each end reflects tilt.

Another valuable tool is the "homemade riftmeter." Two opposing pipes are anchored on each side of a fissure, meeting halfway across the rift (p. 59). The growing gap between them tells scientists which areas are most active and prone to an eruption.

Finally, seismometers are used to determine the speed and direction of underground magma flows when they first burst from the Krafla magma chamber. By monitoring the successive earthquakes set up along the magma's path, geologists are able to track the advancing flood's progress. In recent months, data gathered from the tiltmeters have become more complex, and some scientists say it has become more difficult to analyze the data and to predict future eruptions.

"I haven't missed a single eruption in Iceland since 1934, but the Krafla Fires top them all," comments Sigurdur Thorarinsson, one of the world's veterans of volcanology. "I've seen Hekla erupt like your Mt. St. Helens, Surtsey explode from the ocean floor and become an island, and the fishing village of the Westmann Islands be buried under lava . . . to name just a few. But the Krafla Fires are the most important eruption of my career because of their relationship to ocean-floor spreading."

Standing above flowing magma, gases burning blue at their feet, scientists are lit by rifting hellfire.