GEOTHERMAL ENERGY

The Power of Letting Off Steam

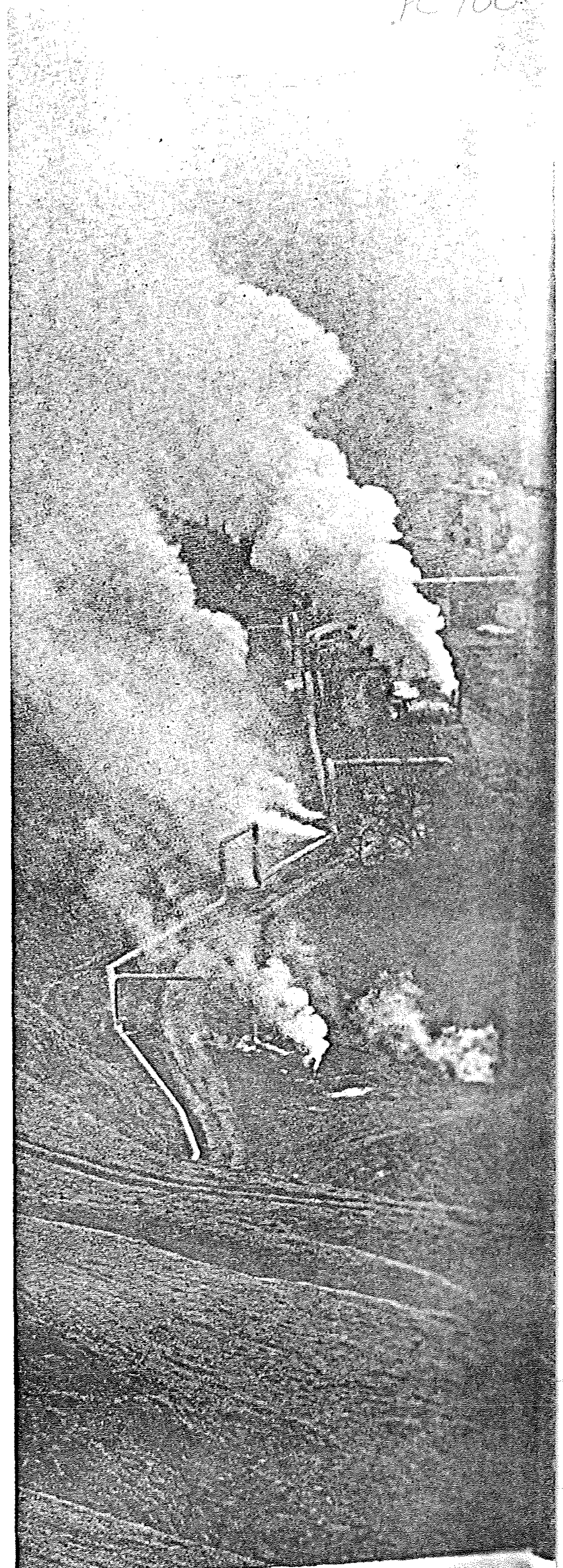
By KENNETH F. WEAVER
ASSISTANT EDITOR

THE SMELL OF BRIMSTONE hung on the air. Steam vents hissed at me like snakes. Craters of boiling mud seethed and burped; black bubbles formed, swelled, and collapsed with rude plops.

Heat had created a scabrous landscape almost devoid of vegetation and stained with yellow streaks of sulfur and the white crusts of mineral salts. It suggested an outpost of Dante's Inferno—although it bore the more earthly name Laguna Volcano.

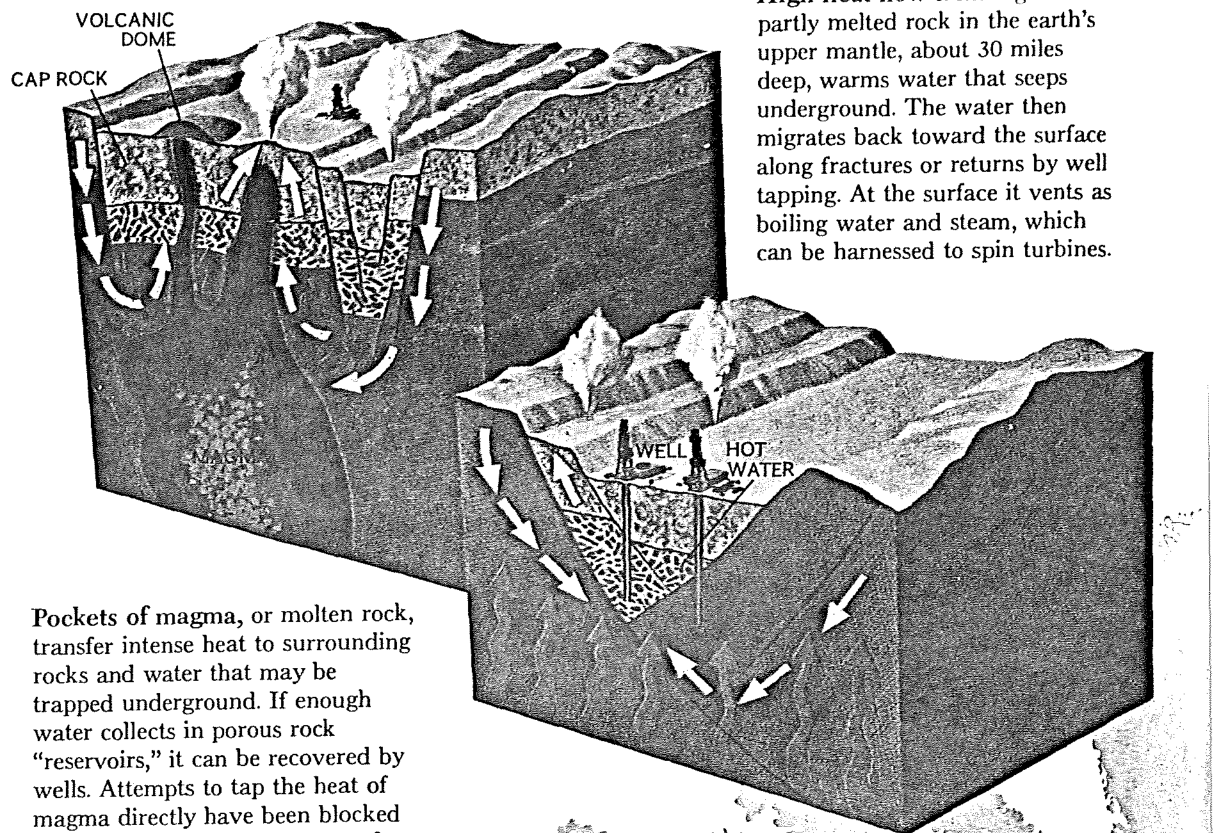
Only a short distance away, towering plumes of steam sent a muffled roar to my ears. These plumes marked the location of the new Cerro Prieto power plant in northern Mexico. The heat that drove the electric generators of Cerro Prieto was the same heat that had created the wasteland at my feet. It was the terrible heat from inside the earth.

The cold, hard crust of our planet gives



Plumes of hope in the search for energy, steam tapped from underground reservoirs roars through pressure-release vents at The Geysers steam field, where the Pacific Gas and Electric Company operates a generating plant. Steam-driven turbines produce enough power for a city of half a million. The California facility is the only one in the U. S. now turning earth heat into electricity.

High heat flow from regions of partly melted rock in the earth's upper mantle, about 30 miles deep, warms water that seeps underground. The water then migrates back toward the surface along fractures or returns by well tapping. At the surface it vents as boiling water and steam, which can be harnessed to spin turbines.

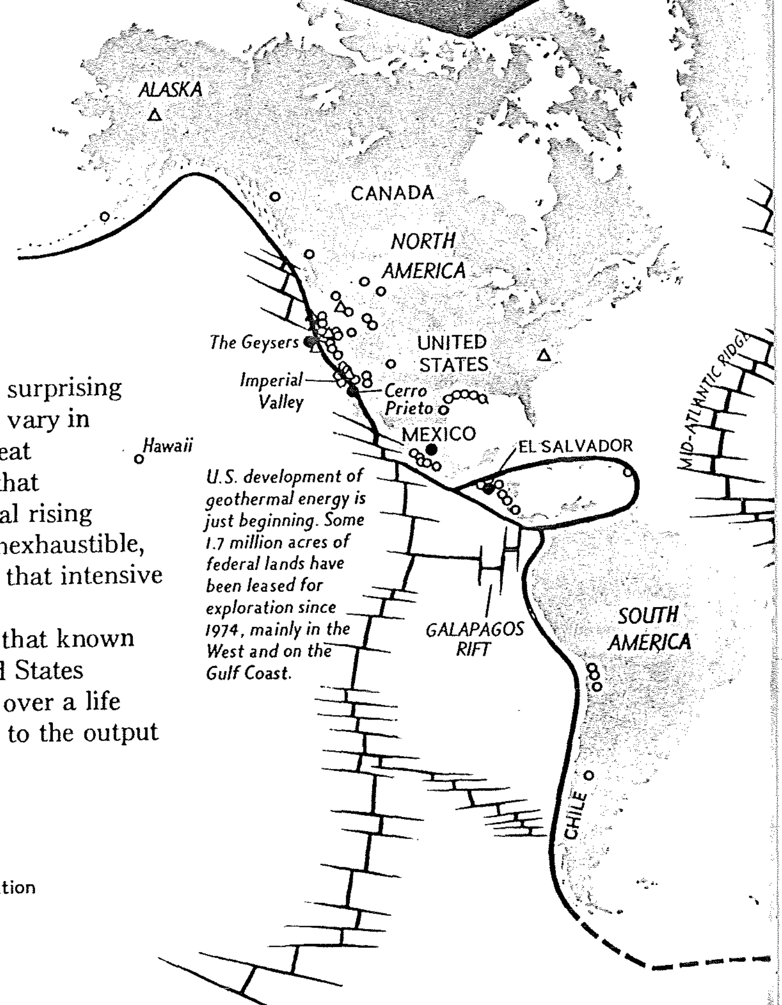


Pockets of magma, or molten rock, transfer intense heat to surrounding rocks and water that may be trapped underground. If enough water collects in porous rock "reservoirs," it can be recovered by wells. Attempts to tap the heat of magma directly have been blocked by temperatures as high as 2200° Fahrenheit (1200° Celsius).

Tapping heat from earth's depths

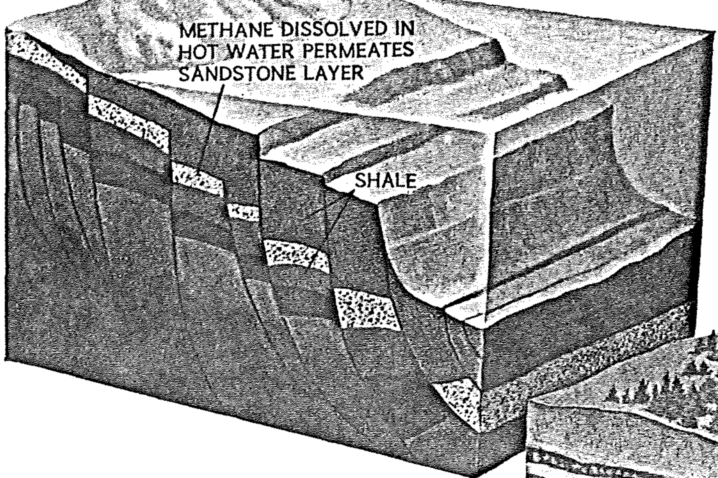
FOUND throughout the world in surprising abundance, geothermal systems vary in makeup but share a common heat source—the natural radioactivity that exists in all rocks. With oil and coal rising in cost and no longer considered inexhaustible, earth's heat offers potential power that intensive development may harness.

A government survey estimates that known geothermal resources in the United States could produce 140,000 megawatts over a life expectancy of 30 years, equivalent to the output of 140 nuclear plants.

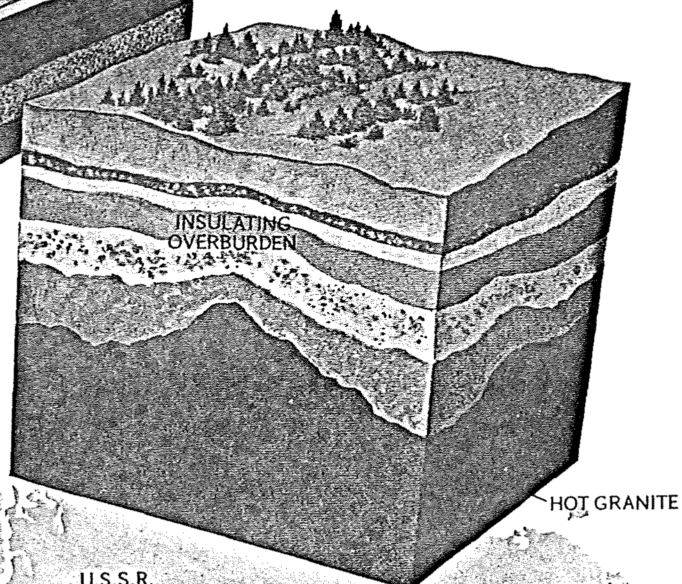


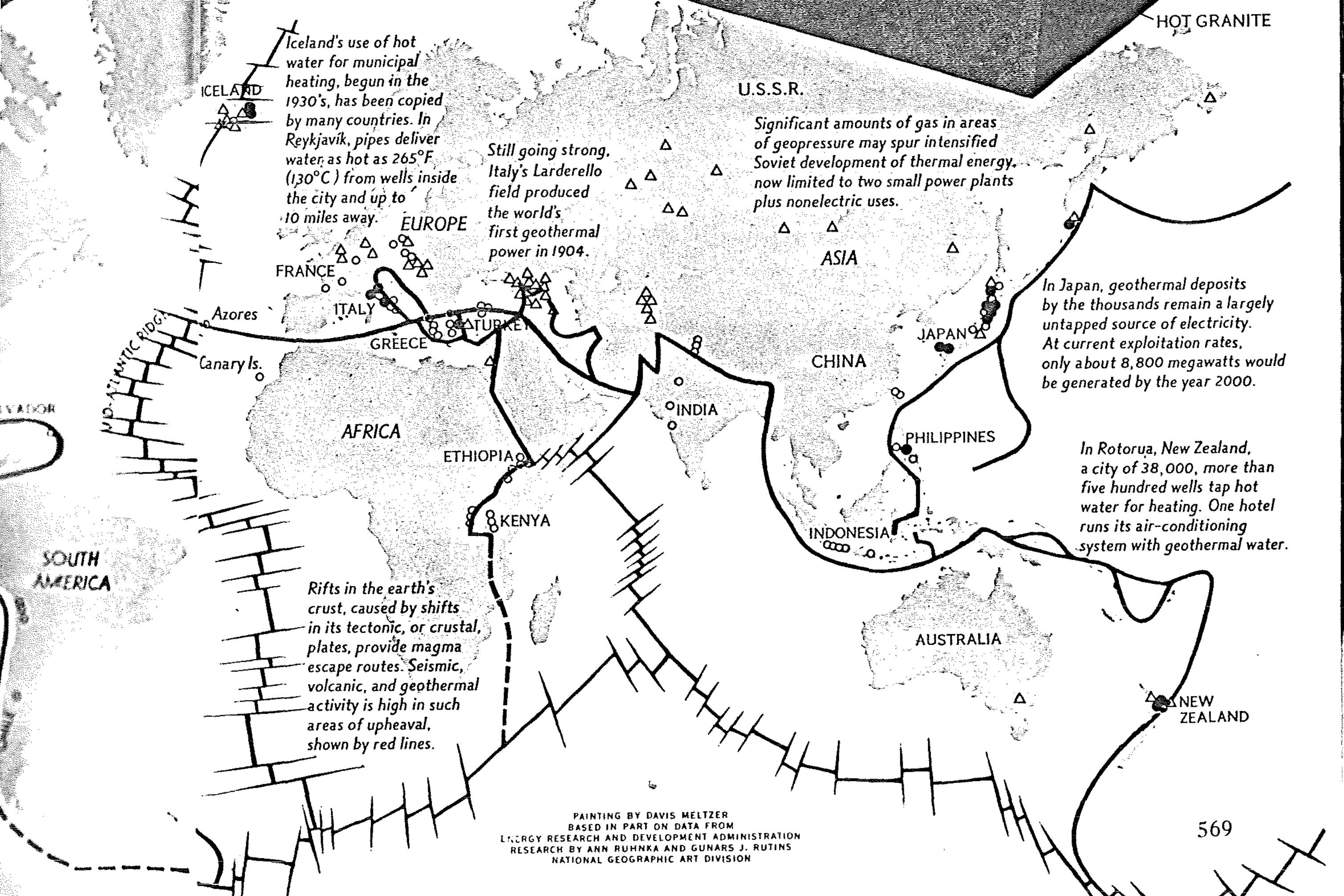
- ● Geothermal power plants
- o Geothermal power sites under exploration
- △ Major nonelectric geothermal sites
- ┼ Plate boundaries and fracture zones

Hot, dry rocks near the earth's surface offer perhaps the richest potential source of geothermal energy, if recovery technology can be developed. Scientists hope to fracture the rocks by forcing cold water underground via a well. After the water circulates through the fractures, picking up heat, it would be recovered by a second well.



Sandwich of heat and pressure results when hot shale traps water containing methane. But the depths of two miles or more of such "geopressured zones" complicate economical recovery of the triple energy punch—gas, heat, and water under great pressure. Vast formations lie beneath the Texas-Louisiana coastal region.





PAINTING BY DAVIS MELTZER
BASED IN PART ON DATA FROM
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
RESEARCH BY ANN RUHNKA AND GUNARS J. RUTINS
NATIONAL GEOGRAPHIC ART DIVISION

little hint of that awesome heat, chiefly the result of decay of radioactive elements. Only where the heat leaks through rifts in the crust —in the molten lava of volcanoes, the hot water of geysers and hot springs, or the steam of fumaroles—does man begin to suspect the titanic forces beneath his feet.

Yet most of earth's 260 billion cubic miles of rock are at or above the melting point—about 2200° Fahrenheit (1200° Celsius). Donald E. White of the United States Geological Survey estimates that just the top 6.2 miles (10 kilometers) of the crust hold 3×10^{26} (300 million billion billion) calories of heat.

"We would have to burn 2,000 times the world's entire supply of coal to generate that much heat," says White.

AT A TIME when fossil fuels—especially oil and gas—are becoming increasingly scarce and expensive, and when nuclear power faces an uncertain future, such a prodigious energy source cannot be ignored, even if much of it can never be used. And, indeed, geothermal ("earth heat") energy has become a warm new prospect. At present nine nations have begun tapping that resource to generate electricity. Several, such as Iceland, France, Hungary, and New Zealand, heat homes with the earth's hot water and use the heat for industrial purposes as well.

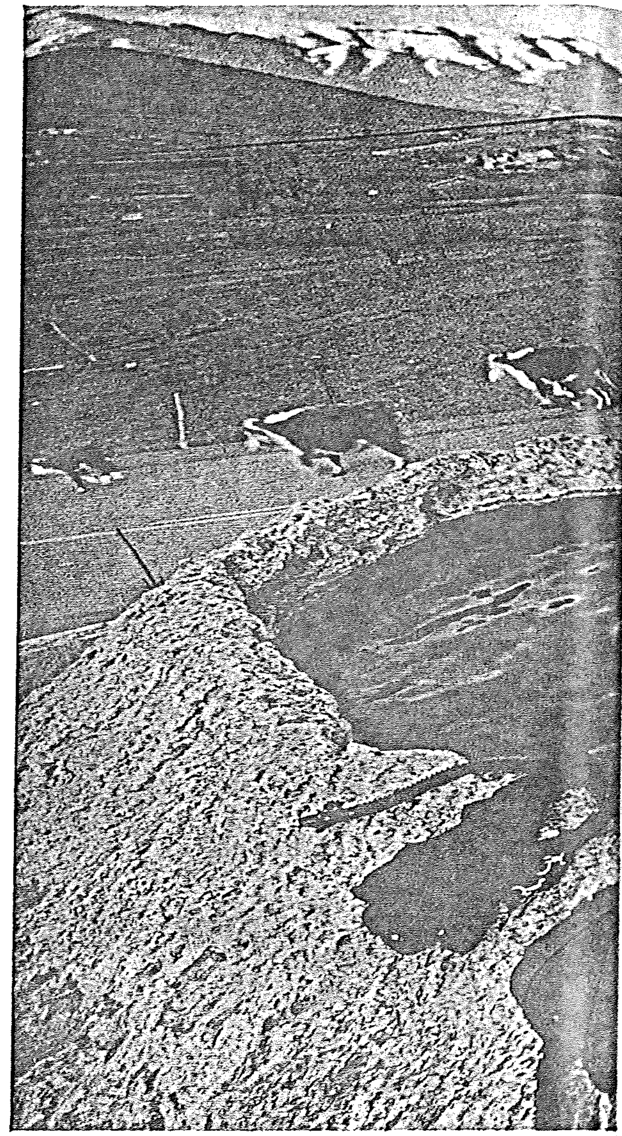
Of course, no one expects geothermal energy to solve the energy shortage; no single source can do that. Despite the magnitude of the earth's heat, capturing it on a large scale for man's use still presents a number of technological and economic problems.

But a few years from now we may well be scrambling for every kilowatt of power we can get. Geothermal energy may then be more available and very welcome. Already it provides more electricity than the world extracts from the sun's heat or from wind power—two other promising sources.*

The Federal Government's Energy Research and Development Administration (ERDA)† thinks geothermal energy is so important that the agency has included 101 million dollars in its fiscal 1978 budget to

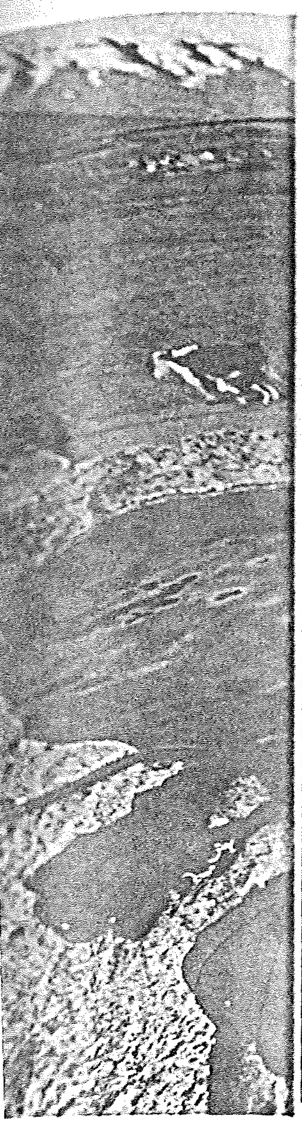
*See "Solar Energy, the Ultimate Powerhouse," by John L. Wilhelm, NATIONAL GEOGRAPHIC, March 1976, and "Can We Harness the Wind?" by Roger Hamilton, in the December 1975 issue.

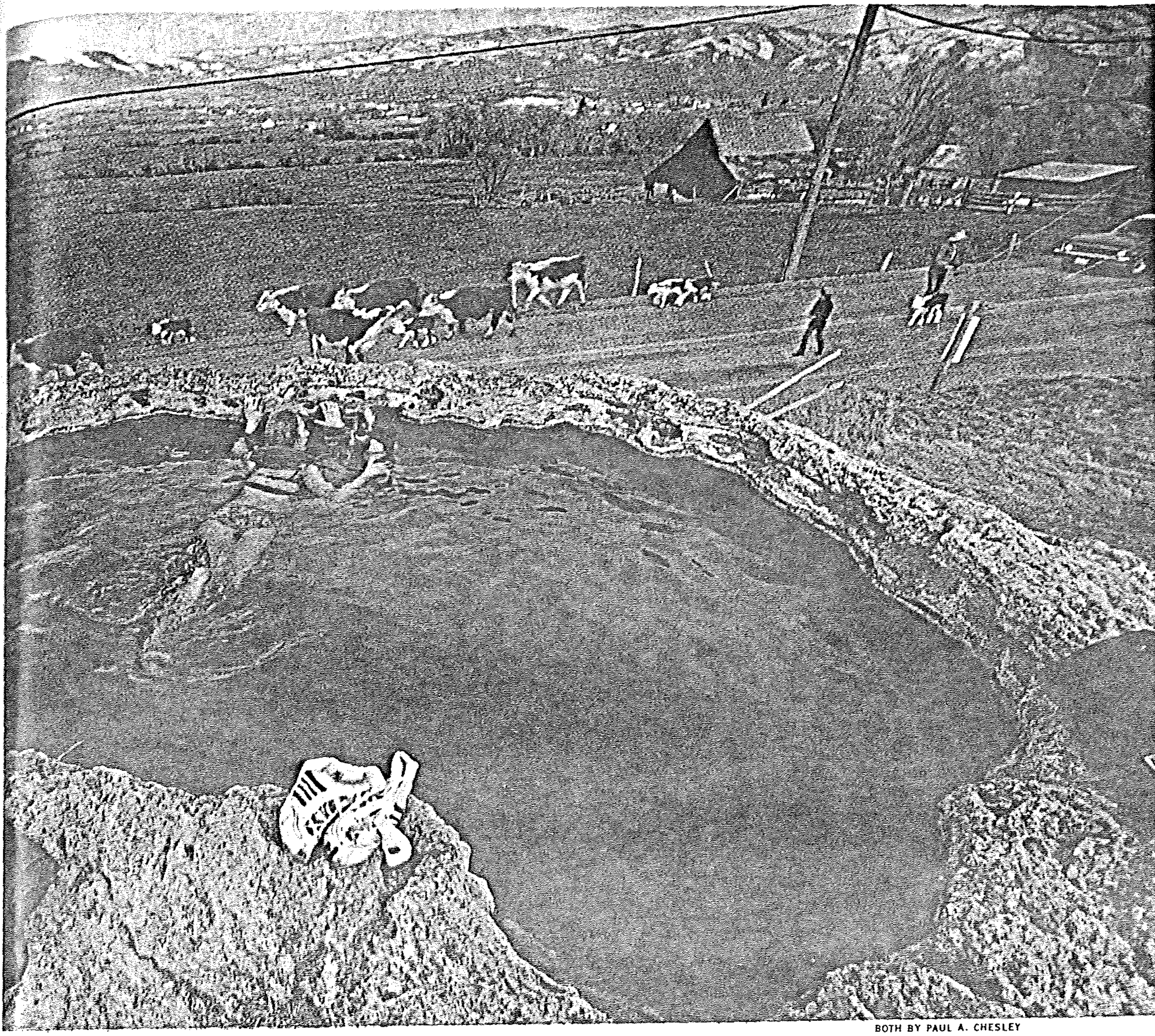
†By the time you read this article, ERDA may have become part of the new Department of Energy.



"It's like a warm bath—you tend to stay in too long and risk having a heat stroke," one diver warned after exploring a thermal spring (above) in Utah's Wasatch Range. Dissolved minerals deposited this "hot pot's" volcanolike cone. Temperatures in the region's pools, some 100 feet deep, range from 86°F to an uncomfortable 113°F. Subsurface waters under pressure may exceed 500°F (260°C).

Mineral-rich water throughout the world, such as that piped into Colorado's Glenwood Springs pool (right), has been considered healthful since Roman times.





BOTH BY PAUL A. CHESLEY

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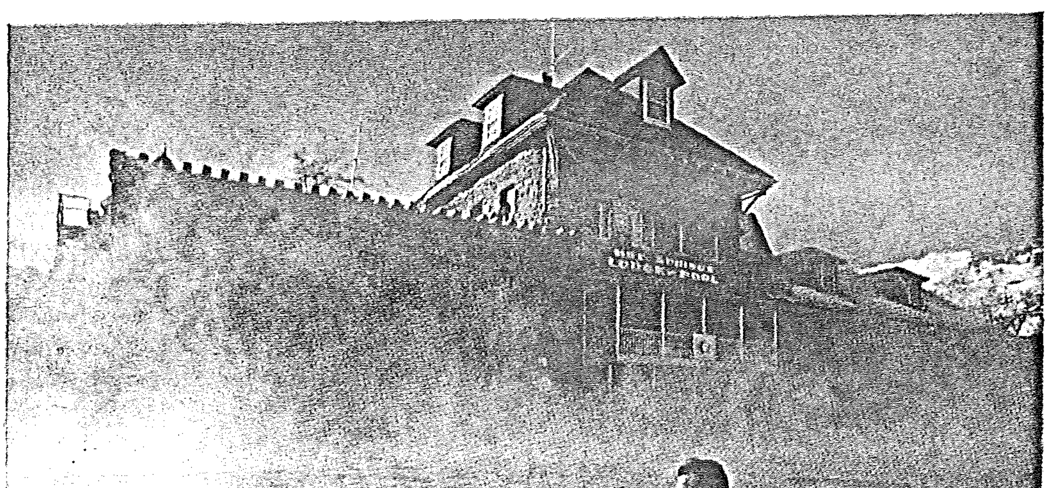


encourage development. That's 84 percent more than in fiscal 1977.

And industry is more than mildly interested. In January 1974 the Bureau of Land Management opened up large areas of public lands in the West for geothermal exploration. The demand for leases recalled the frenzy of the Oklahoma land rush. In the first month, nearly 2,500 applications were filed for leases covering 5,280,000 acres in 11 states. Both wildcatters and giant oil companies are beginning to drill on these lands, looking not for oil or gas but for heat.

O. LOUIS MAZZATENTA, NATIONAL GEOGRAPHIC STAFF

Hole-in-the-ground oven will cook pork, kale, and cabbage in three hours for these Azoreans on São Miguel. Metal containers in the bags keep out sulfur—an unpleasant by-product of some geothermal systems.

How much contribution can geothermal energy make? Estimates of its potential in the United States vary widely. Some enthusiasts have suggested that the Southwest could in time get all its energy from geothermal. Some very conservative observers doubt that geothermal could ever provide more than one percent of U. S. power needs.

The truth probably lies between these extremes. A 1975 study by the U. S. Geological Survey foresees 12,000 megawatts (12,000,000 kilowatts) of electricity from hydrothermal reserves, lasting for at least 30 years, at present prices and with current technology. (A thousand megawatts is about the energy needed for a city of a million persons.)

The USGS further estimates that perhaps 12 times this much hot-water energy remains to be discovered in the United States, or awaits higher prices or improved technology before it will be economical to develop.

BY FAR THE SIMPLEST, cheapest, and best form of geothermal energy comes from the ground in the form of dry steam. It can be used directly to drive turbine generators with a minimum of problems.

Unfortunately, dry steam occurs in only a few places. As Morton Smith of the Los Alamos Scientific Laboratory puts it, "Dry steam is a geological freak." But this highly desirable freak is found in Japan and Italy, and in the United States at The Geysers, in California's Sonoma County about 90 miles north of San Francisco.

I found The Geysers after following the tortuous windings of an old stagecoach road deep into the Mayacmas Mountains. Miles of pipelines streaking along the sides of Big Sulphur Canyon, vapor billowing from rows of generating-plant cooling towers, and roaring jets of steam from vent valves gave the valley an awesome appearance (pages 566-7).

The Geysers must have been a frightening place to William Bell Elliott when he discovered its fumaroles in 1847 while hunting a grizzly bear. The explorer-surveyor was overwhelmed by the sight of steam pouring from fissures along the steep canyon.

"I thought I had come upon the gates of hell itself," he told friends.

Today at The Geysers, the Pacific Gas and Electric Company, drawing on a hundred wells operated by Union Oil, produces 500 megawatts of electricity, about half of San Francisco's needs. More wells and new generator units should increase output to about 900 megawatts by mid-1979.

By the 1990's PG and E hopes to develop The Geysers to a level of 2,000 megawatts—almost the capacity of two Hoover Dams or two large fossil-fuel or nuclear power plants.

THE EARTH is stingy with its natural steam. Aside from The Geysers, dry steam has been found in the United States only in Yellowstone National Park, where law forbids development.

But earth's heat is much more readily available in the form of very hot water under pressure. All along the world's earthquake and volcano belts, pockets of magma, or molten rock, have worked their way close to the surface. Water filtering into permeable rock layers above these pockets is heated—often far above the normal boiling point.

Sometimes the superheated water forces its way out as hot springs or geysers. More often, trapped by an impermeable cap rock above it, the water becomes a subterranean caldron under extremely high pressure, waiting to be tapped by wells (diagrams, pages 568-9).

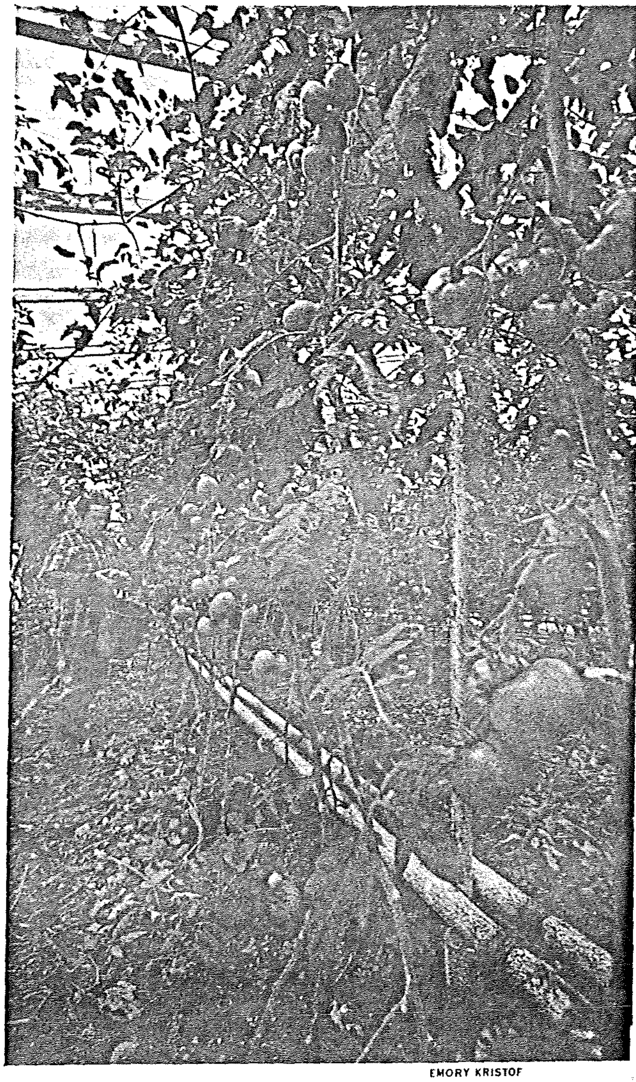
Mexico's Cerro Prieto, not far south of the border city of Mexicali, is a prime example of tapping such a reservoir. As the 570°F water rises to the wellhead, the pressure drops and the water flashes, or boils. About 20 percent turns to steam, which is separated out and piped to the generator turbines. The remaining hot water roars through discharge pipes into large ponds, but it could be used for industrial or household purposes.

Just to the north of Cerro Prieto, in the Imperial Valley of California, I found intensive interest in geothermal water. Signs at the airport predict that this rich agricultural region might become the nation's teakettle as well as its salad bowl.

Oddly enough, were it not for the higher country around it, the Imperial Valley would be an inland sea and therefore worthless for either agriculture or geothermal energy. A flagpole in Calipatria, which advertises itself as the lowest city in the Western Hemisphere, raises its tip 184 feet, to the level the sea would reach if it could get into the valley.

And, strangely, this extremely flat valley, resting upon vast reservoirs of subterranean waters, would be desert were it not for irrigation water brought in from the Colorado River. "Rain for rent" reads the sign of one firm that provides sprinkler systems.

Amid the interminable checkerboard fields of lettuce, cantaloupes, and cotton, the endless rows of baled alfalfa, and the occasional palm trees, evidences of a fledgling geothermal industry are becoming steadily more apparent. At places like Heber and Brawley, Niland and East Mesa, drilling rigs grind day and night searching for hot water. Dozens of completed wells tell of successful searches.



EMORY KRISTOF

Not bad for winter in Iceland! Hothouse tomatoes and other vegetables thrive year round in Reykjavík, where geothermal water has heated homes and buildings for some forty years.

And at Niland, near the Salton Sea, a test facility takes boiling brine from the earth and simulates the conditions of a power plant. This facility, a venture of ERDA and San Diego Gas & Electric in cooperation with the Magma Power Company, tests materials, methods of handling hot brine, and techniques for extracting heat.

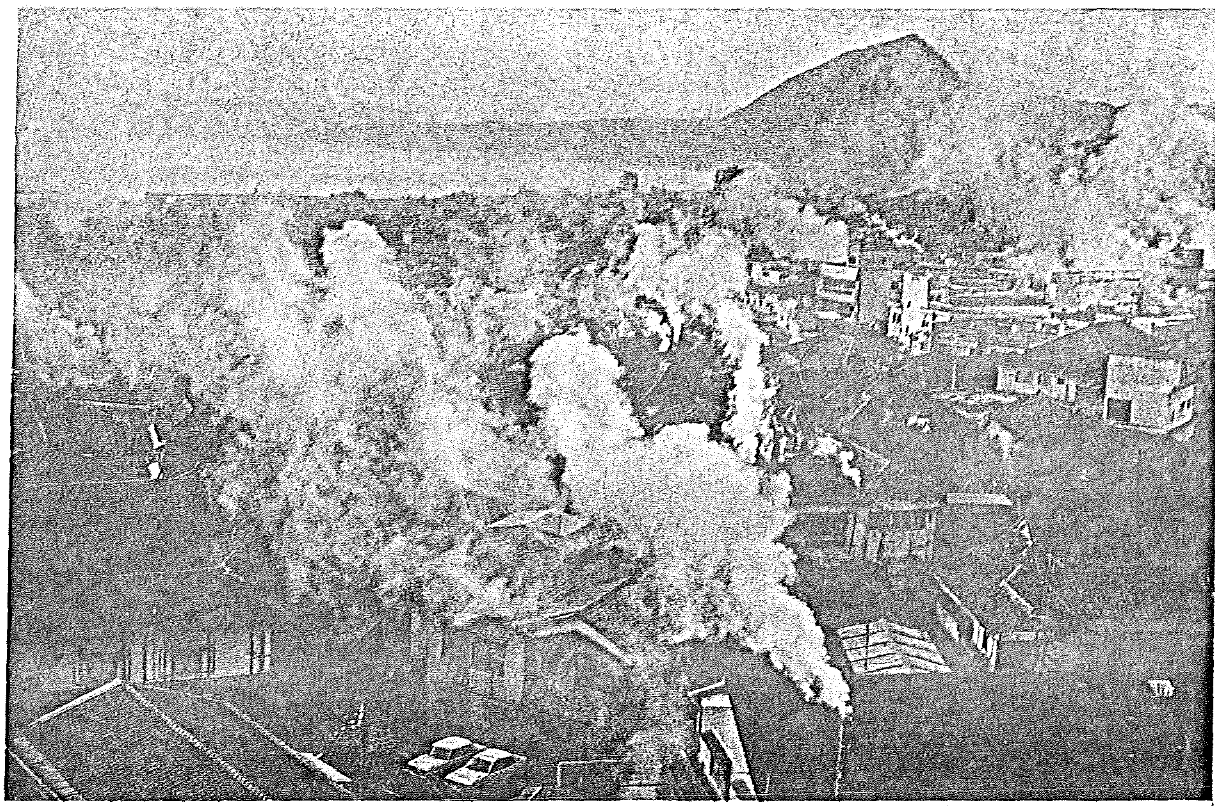
I USE THE WORD "BRINE" advisedly, for geothermal waters are sometimes highly saline. Hot water under pressure can dissolve and carry astonishing amounts of salts and minerals from the rocks.

In most places, to be sure, the concentration of such materials is quite low—even much less than seawater's 3.5 percent. But in the Imperial Valley, which holds some of the nation's most important high-temperature geothermal resources, salinity can run high. At Niland it reaches the incredible level of 20 to 30 percent dissolved solids. Such concentrated brine creates major problems. It can be violently corrosive and erosive, swiftly eating away turbine blades and nozzles. Even worse, the minerals precipitate rapidly as temperature and pressure are reduced. I have seen pipes choked by an inch-thick layer of hard rusty scale that deposited in only a few hundred hours of operation.

"The total energy in the Niland area is about equal to the recoverable energy in Alaska's North Slope," an ERDA official, Eric H. Willis, once told me. "But how do you stop it from having arteriosclerosis?"

Until recently these problems seemed likely to block geothermal development in parts of the valley. But new developments alter the prospects.

At the Niland test facility, a four-stage heat exchanger offers one solution. When heat is drawn from the hot brine in several stages



PAUL A. CHESLEY (LEFT) AND NATIONAL GEOGRAPHIC PHOTOGRAPHER GEORGE F. MOBLEY

Land of rising steam, Japan first used geothermal heat for generating electricity at Beppu in 1924. Today the city also taps its extensive fields for heating (**above**), for health spas, and even for restaurant cooking (**left**). Elsewhere in Japan many towns that operate profitable spas oppose geothermal-power development, fearing loss of their springs. Japan also harnesses natural heat for a variety of industrial and agricultural uses, ranging from sulfur-extraction plants to eel and alligator farms.

instead of all at once, and when the pressure is lowered gradually, scaling is sharply cut.

At ERDA's Lawrence Livermore Laboratory near San Francisco, engineers have developed a new process known as "total flow," which uses a well's entire output, liquid and vapor, to drive specially designed turbines. As part of this work, they believe they have solved the scaling problem by treating the brine with hydrochloric acid.

"Under the worst conditions we add only about 200 parts per million to the brine," Roy Austin told me. "This will probably cost less than two-tenths of a cent a kilowatt-hour. And we get absolutely no scaling in the nozzles. They come out so clean we can still see the machine marks. We have also tested materials that appear promisingly resistant under these conditions."

SO FAR THE IMPERIAL VALLEY seems to offer the nation's richest prospects for geothermal hot-water development. Pilot power plants are already on engineers' drawing boards. By the 1980's the industry expects that Imperial Valley electricity will be flowing into the grid, just as it already does at The Geysers.

But the Imperial Valley holds only a few of the 106 geothermal systems in the Western States that have been identified by the Geological Survey as KGRA's (Known Geothermal Resource Areas). Thirty-seven of these yield water at temperatures above 300°F—hot enough for electric-power generation.

For example, near Los Alamos, New Mexico, the Union Oil Company has brought in a number of productive wells inside the Valles Caldera, an enormous volcanic basin some 13 miles across. Union is now negotiating with potential purchasers of the steam.

Around Roosevelt Hot Springs in southwestern Utah, five major companies and several smaller ones are probing a very important new reservoir. On the slopes above an ancient lake bed, amid sagebrush, yellow-flowered rabbit bush, and juniper, drill rigs are sprouting and geologists are measuring heat flow and electrical properties to find likely spots for wells.

At places on this Utah site, one does not have to go far below the surface to find evidence of heat. On one claim I found a prospector's trench scooped into the bank of a wash. Idly curious, I stooped over to scratch at the bottom of the trench. I had flicked away no more than half an inch of soil when I jerked my hand back. I had burned my fingers as surely as if they had touched a hot kettle.

Temperatures of the water from some of the Utah wells exceed 500°F (260°C). But geothermal water in many other places is nowhere near as hot—not even up to the 300°F regarded as minimum for efficient production of electricity. Can these cooler waters be used?

I FOUND abundant answers in Iceland, whose volcanic hills and rifts lie directly on the Mid-Atlantic Ridge (map, pages 568-9). There, where upwelling magma is steadily forcing apart the crustal plates, the inner fires of earth are always close at hand.*

When the Vikings first approached Iceland, they saw geothermal steam rising from the area now occupied by Reykjavík. They thought it was smoke; hence the name Reykjavík (Smoking Bay).

As recently as three decades ago, Reykjavík was indeed smoky. Early photographs show it as a filthy, black-stained town shrouded by smoke from coal fires.

Then geothermal energy came to the rescue. Today virtually all the buildings in the Reykjavík area are heated by geothermal water. Some 115,000 persons enjoy one of the cleanest cities in the world.

Simple sheds covering the wellheads, a few low storage tanks, and raised concrete conduits carrying the major pipelines are the only outward evidence of this splendid heating system. The cost? The average householder pays from 130 to 160 dollars a year for heating and hot water—on an island that touches the Arctic Circle!

With two scientists from Iceland's National Energy Authority—Dr. Stefán Arnórsson, a geochemist, and Dr. Kristján Saemundsson, a geologist—I visited other communities in Iceland whose very existence depends on geothermal springs and wells.

Our road traversed a huge lava flow and we passed between volcanic hills that had pushed up under the ice sheet some 20,000 years ago. We saw fumaroles steaming in the snow and little Icelandic ponies standing with their tails to the wind.

*See "This Changing Earth," by Samuel W. Matthews. NATIONAL GEOGRAPHIC, January 1973.

Dropping below an escarpment, we came into the valley town of Hveragerdi (Garden of Hot Springs). A thousand souls have settled here since the first house was built in 1928. As in most geothermal towns, escaping steam is ever present. At the center of town, a violently boiling hot spring and an abandoned borehole that erupts at intervals are fenced off for safety.

Large greenhouse complexes make efficient use of Hveragerdi's geothermal water. I visited one owned by Ingimar Sigurdsson. Outside, the sharp winds of February had slashed through my coat; inside, I found springlike temperatures.

The gardener picked a rosebud from one of 50,000 plants. "I'll have blooms," he said, "from now till mid-December."

The borehole for the greenhouse goes down only 2,000 feet, he told us. Water and steam come up without aid of pumps or electricity. The rejected water goes into the river after heating a swimming pool.

DR. ARNÓRSSON told me that Iceland is turning its natural heat more and more to purposes other than space heating. One farmer we visited, for example, uses hot water to heat air to dry his hay.

In the northern part of the island, an industrial plant takes diatomaceous material from a lake bed, dries it with geothermal steam, and produces diatomite for use in filters, insulation, and other industrial purposes.

In addition, Iceland is beginning to develop hot water for electric power. Since much of the water is below 300°F (150°C), and thus will not produce efficient amounts of steam, the Icelanders have considered using the vapor-turbine cycle technique: The water would heat low-boiling-point liquids such as Freon and isobutane, and the resulting vapor would drive the turbine generators.

This technique is being used successfully on the Soviet peninsula of Kamchatka in the northwest Pacific Ocean to supply power to the Paratunka State Farms.

Geothermal heating in the United States goes back even further than in Iceland. Some 350 households in Klamath Falls, Oregon, have long had individual hot-water wells. In Boise, Idaho, homes along Warm Springs Avenue have drawn hot water from a central well for nearly a century. And today, in Boise, the Idaho state government is considering the investment of more than three million dollars to bring geothermal hot water to heat the state university, the capitol, and a number of other state buildings.

TWO ESPECIALLY RICH SOURCES of geothermal energy glimmer in the future, if they can be developed economically.

One, known as "geopressured zones," involves large hot-water reservoirs in the Texas-Louisiana area, both onshore and off. These hot waters, at depths of two to three miles, are trapped below thick sedimentary deposits under abnormally high pressures.

Drilling in such areas is difficult and costly. But dissolved in the waters are vast amounts of methane—the chief ingredient of the natural gas we sought so avidly during the deep freeze of last winter. It is estimated that the potential of the geopressured resource is as much as 115,000 megawatts for 30 years, with the methane of equal value for power. (Total U. S. power capacity last year was about 550,000 megawatts.)

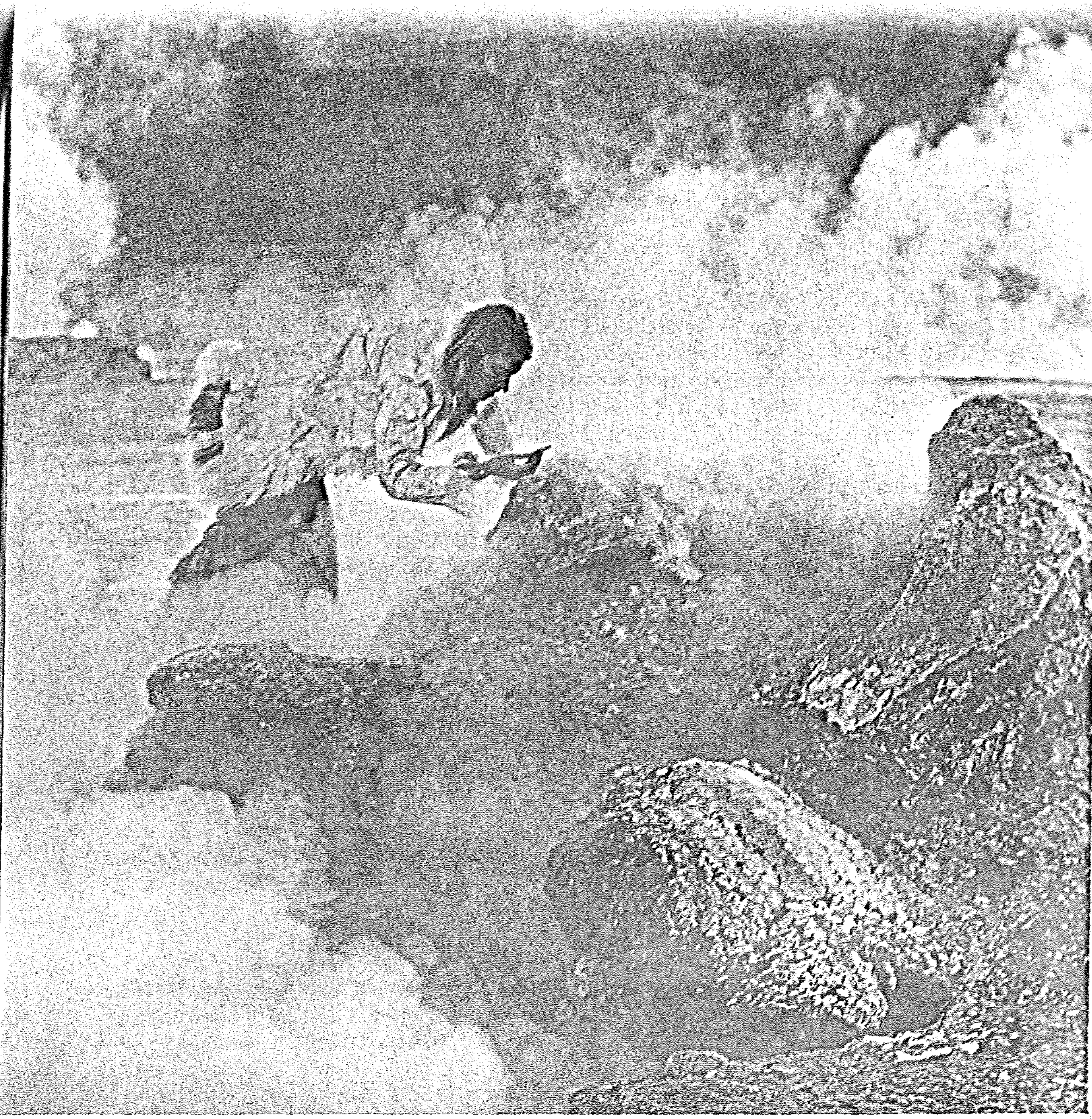
As prices for other forms of energy rise, it may become economically profitable to extract geopressured water and gas.

The other far-out possibility is called "hot dry rock." It refers to many regions of heated rock near the surface that lack reservoirs of water to carry away the heat. Such deposits, much more common than the hot-water reservoirs already being exploited, are found even in the eastern U. S.

Scientists at the Los Alamos Scientific Laboratory in New Mexico believe that this heat can be tapped with water from the surface. Their technique is to force cold water down a well to cause the heated rocks to fracture, circulate the water through the network of fractures, then bring it back to the surface through a second well.

To test this idea, the Los Alamos scientists have been making test drills on the Jemez Plateau near the Valles Caldera. Two holes 250 feet apart, reaching depths of approximately 10,000 feet, have been successfully connected. Fracturing experiments to increase the hot-rock area exposed to the water flow seem promising.

Like all other energy sources, geothermal offers both advantages and disadvantages. On the plus side, it is relatively clean, there is



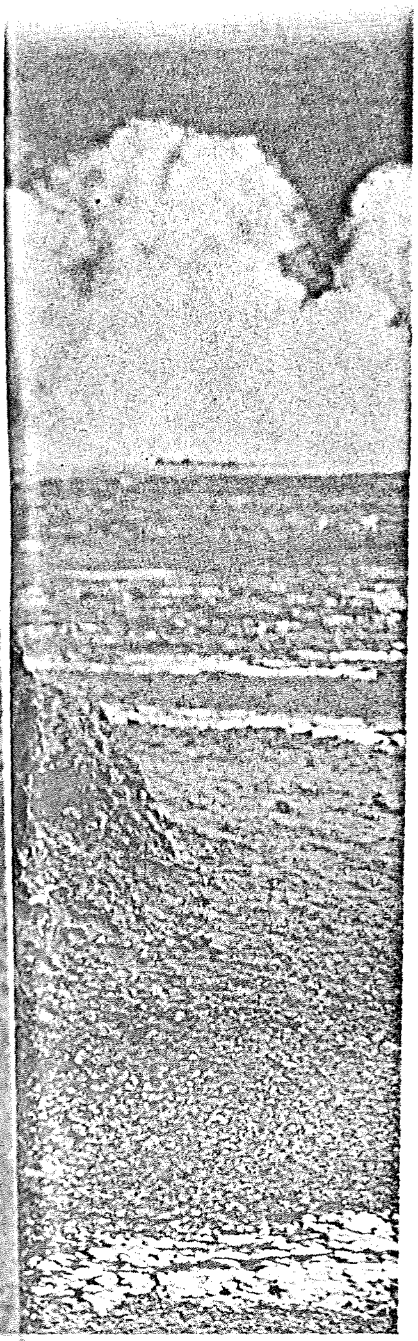
no fuel to buy, and the reserves (of hot water, if not of steam) are thought to be long lasting.

On the negative side, critics note that the best geothermal deposits seem to be localized in the West. However, recent discoveries point to rich potential in the eastern United States as well.

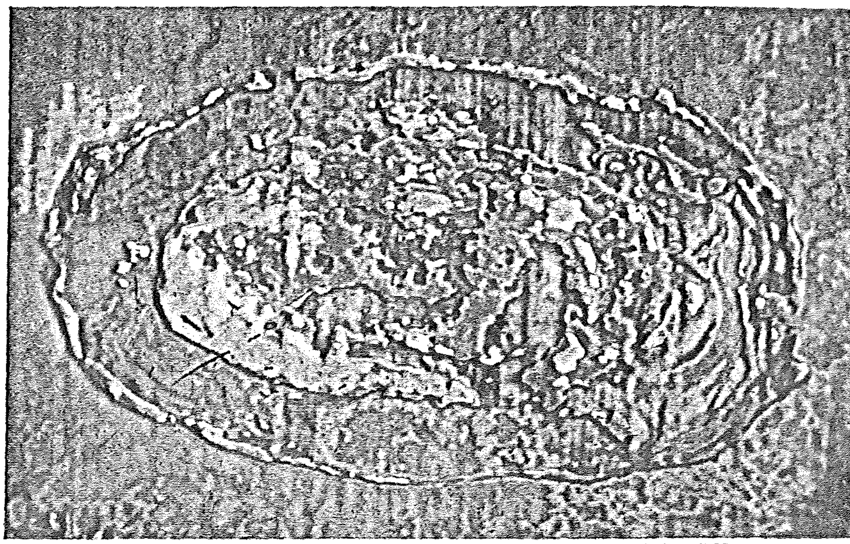
Further, the capital investment for developing geothermal energy is high, and, under present taxes and regulations, prospecting is somewhat limited. The Federal Government is meeting this problem in part by providing for government-guaranteed loans and tax credits.

Then there is the problem of subsidence. If large amounts of water are drawn out of the earth, will the earth sink in that area? The answers are uncertain, and some geothermal plants avoid the problem by injecting the water into wells after extracting its heat.

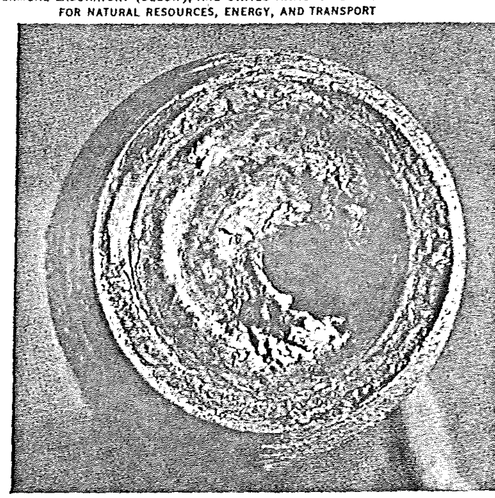
Finally, there is the problem of pollution. The odor of rotten eggs hangs over some geothermal sites because of hydrogen sulfide gas. More serious is the presence of poisonous



Wildcatter's dream: Steam from Chile's El Tatio field (**left**) eventually may produce electricity and two valuable by-products: the metal lithium, used in nuclear reactors and metallurgy, and water that can be desalinated.



GEORGE F. MOBLEY (LEFT); LAWRENCE LIVERMORE LABORATORY (BELOW); AND UNITED NATIONS CENTRE FOR NATURAL RESOURCES, ENERGY, AND TRANSPORT



Energy treasure map, an enhanced infrared image (**above**) helped U. N. experts assess the geothermal potential of Ethiopia's Great Rift Valley. Hottest areas within the 2.3-mile-wide ring are orange, coolest are blue.

Briny flow from a geothermal well quickly clogs a 9/10-inch pipe (**right**); scientists at Lawrence Livermore Laboratory in California fight it by adding hydrochloric acid. Such techniques may open new areas to development, including parts of California's Imperial Valley.

arsenic and boron in geothermal waters. But this problem is usually avoided if waste waters are re-injected into wells.

All things considered, then, mining the earth for heat may offer a highly desirable substitute for gas and oil in the not too distant future.

WHEN EXPERTS TALK about enormous amounts of energy, they often use the term "quads." One quad is a quadrillion (10^{15}) British thermal units, or BTU's. The United States last year used on the order of 74 quads of energy.

I asked Dr. Robert C. Seamans, Jr., then head of ERDA, how he evaluated the contribution of geothermal energy in quads.

"By the year 2000," he said, "geothermal energy might well amount to as much as four quads, and by 2020 as much as fourteen quads. That may not sound like much, but if you think of it in terms of oil, every two quads a year represents a million barrels a day."

And that's not peanuts! □