Skylab 4 photo with view north up the Rio Grande rift from altitude of 432 km over central New Mexico. The rift crosses a wide zone with a strong northeast trending grain. It passes through the Jemez lineament, one of the most active volcanic zones in the U.S. for the past 10 million years. Note the Jemez caldera top left.

Plate Tectonics-Where the Action Is

by Bob Riecker

During your lifetime, North America and Europe will separate by the average height of a person; the Pacific Ocean will shrink by the average width of a single-family home. Next year, Los Angeles will move closer to San Francisco by the length of your little finger. Last year, some 100 cubic kilometers of new earth crust were born at crests of ocean ridges. In the last 76 million years, the north magnetic pole has reversed its polarity at least 171 times, and in the last 100 million years, an area equal to the size of the Pacific Ocean basin has disappeared beneath surrounding continents.

Plate tectonics is the unifying concept in geosciences. The Earth's surface is divided into a mosaic of possibly 10 to 12 large (and many smaller) rigid, moving plates, varying from 10 to 100 kilometers thick and often many thousands of kilometers wide. The plates that move apart on our globe must collide somewhere, and when they do, earthquakes and volcanism remind us of turmoil. In an ocean chain over 30,000 kilometers long, new earth crust forms to add rock to continents. At other places, mountains rise because of plate collisions.

We ride northwestward on our namesake, the North American plate, which extends from the Pacific coast to the middle Atlantic Ocean. We grind against the Pacific plate along the San Andreas Fault in California. Plate motion insures that, in 50 million years, Los Angeles will become a western suburb of San Francisco. That trip is not easy geologically, as major earthquakes attest periodically.

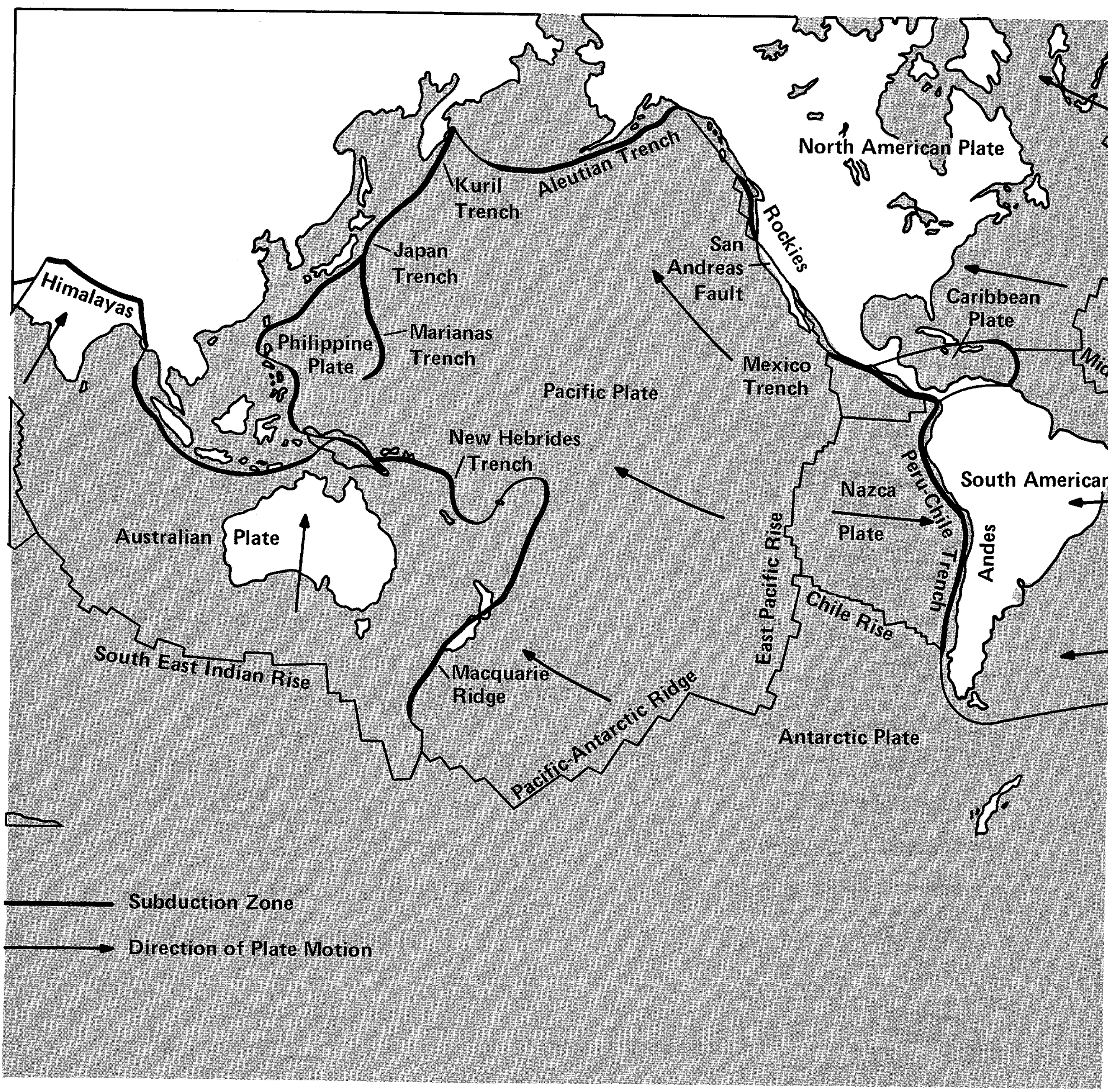
The gurus of plate tectonics predicted at the paradigm's inception, about 15 years ago, that the new theory would require rewriting of geology textbooks. In fact, that's happened. But we are just now beginning to understand how dynamic and changing the Earth's surface really is.

Problems remain. The simple model of 100-kilometer-thick, rigid plates, or rafts, floating about on "greasy skids" of the Earth's upper mantle looks naive. Seismic research based on study of propagation of elastic waves through the Earth suggests that continents have much deeper roots. Also, we don't really know yet what makes the plates go! Certainly the Earth's natural heat engine drives the rafts, but how, and over what vertical dimensions? The Earth loses heat, generated mainly by radioactive decay, at a rate about five times more than the rate at which man uses energy (2×10^{12} calories/second). How long have plates moved over the Earth's surface since the planet's birth? As the Earth's heat engine cools, are plate motions slowing, and is mountain building ceasing? Often earthquakes and sometimes volcanism appear in the interior of plates, not only along their edges as predicted by the theory.

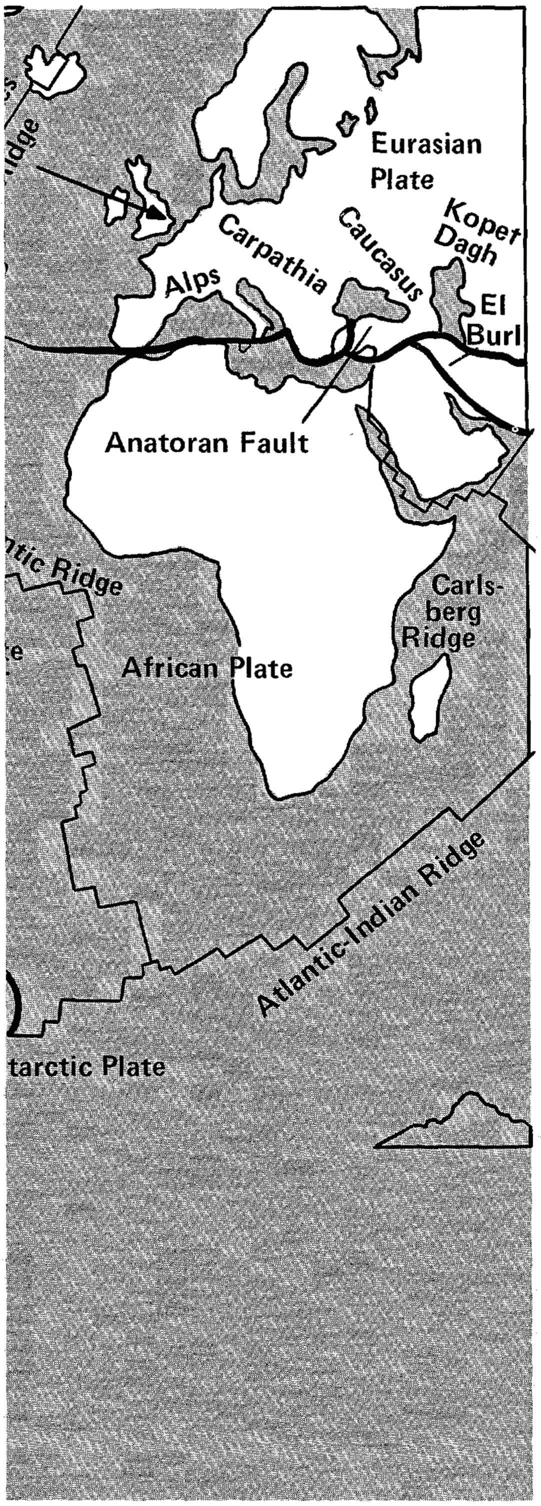
Normally the hottest spots are where the action is. That's where plates originate or where they collide or are consumed. At ocean spreading centers, new crust forms and enlarges the plates.

One such hot zone centers along the Rio Grande rift. A rift is a long, narrow, usually down-faulted valley in the Earth's crust. The Rio Grande rift extends from Leadville, Colorado, through New Mexico, and across the border into northern Mexico. Along this 800-kilometer rift, significant volcanism, earthquake activity, uplift, and separation have occurred during the last 30 million years.

For the preceding hundreds of millions of years, the entire zone along which the Rocky Mountains stand had been an active mountain-building region. Then 30 million years ago, regional separation initiated rifting. The rift opened along a series of northward and northeastward flaws or lineaments, which reach down through the overlying



North American Plate
Aleutian Trench
Kuril Trench
Japan Trench
Himalayas
Rockies
San Andreas Fault
Caribbean Plate
Philippine Plate
Marianas Trench
Mexico Trench
Pacific Plate
Mid
New Hebrides Trench
South American
Nazca Plate
Peru-Chile Trench
Andes
Australian Plate
East Pacific Rise
Chile Rise
South East Indian Rise
Macquarie Ridge
Pacific-Antarctic Ridge
Antarctic Plate
Subduction Zone
Direction of Plate Motion



Major plates of the Earth's surface.

sedimentary cover. The series of deep basins that eventually formed in the rift now contain thousands of meters of sediment and volcanic fill.

The deeply cutting flaws that cross the rift are zones of weakness that probably extend deep into the Earth's mantle. They leak vast quantities of molten rock into and through the crust. The Jemez lineament, which extends across the Jemez caldera northeast, was especially active volcanically during the last 10 million years as indicated by large volumes of young volcanic rocks blanketing the surface. Many of these volcanics, silicic in composition, erupted during violent explosions much larger than modern man has seen. Layers of fine ash from some of the eruptions reached as far east as Iowa and Illinois before falling from the atmosphere. The giant scale of these events can be imagined as one rides past the Jemez caldera in the center of the Jemez mountains. This grassy pastureland, more than 15 kilometers in diameter, is the remnant of a large volcano.

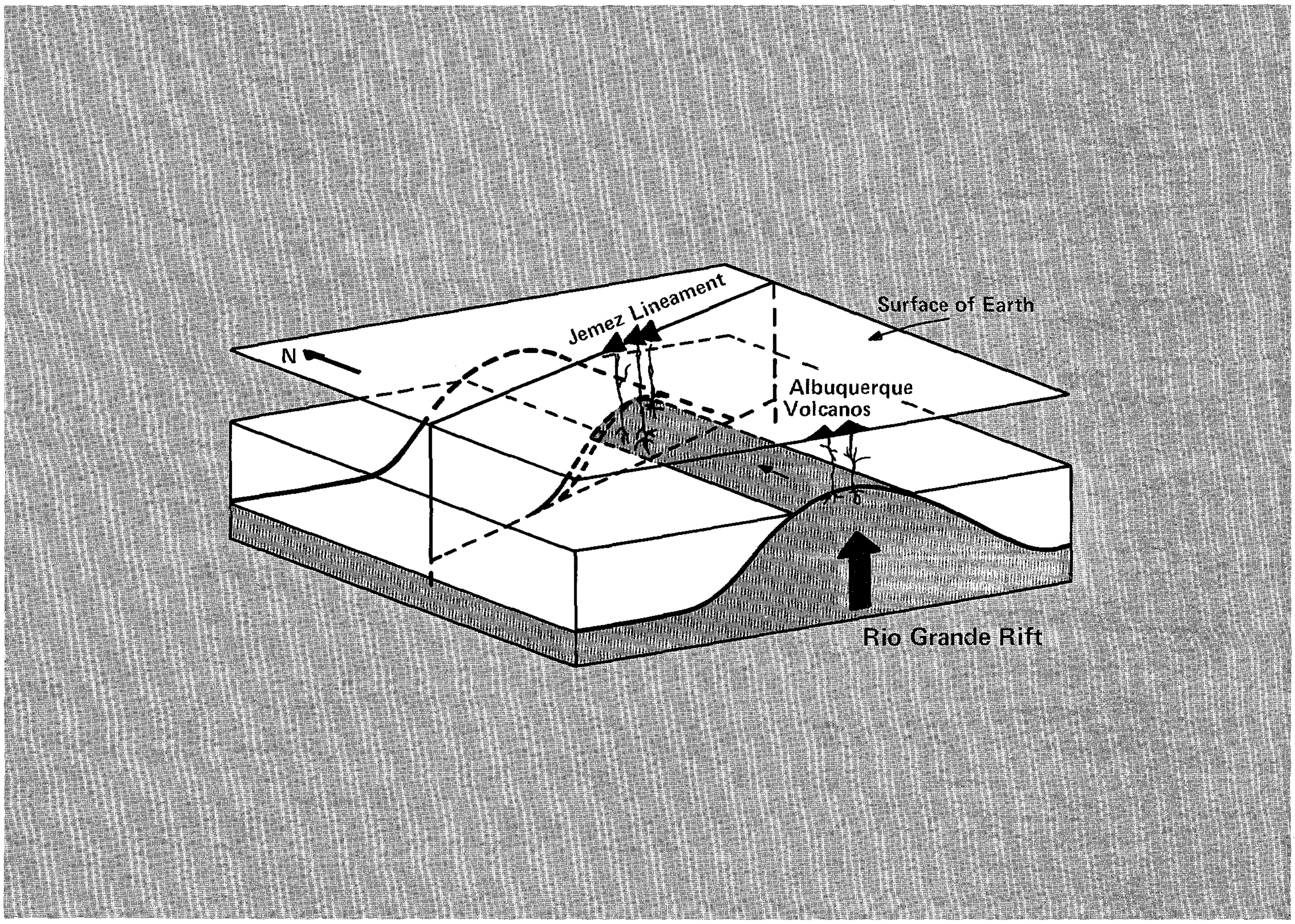
The scale of the Rio Grande rift is also quite large. Separation across the rift is as wide as 10 kilometers and uplift exceeds many thousand meters. Does this mean that the North American plate is being torn asunder in the southwestern United States? Some geoscientists believe so, and in their jargon, the rift represents an incipient spreading center where new earth crust forms and shoves aside older rock.

Major crustal stretching occurred not only along the Rio Grande rift but over the entire southwestern portion of the United States. We see evidence of the stretching in the patterns of faulting and the appearance of volcanic rocks in the Basin and Range provinces in Arizona and Nevada to the west and in the High Lava Plains of Oregon and California to the north. The exact cause of the stretching remains obscure and controversial. It must involve interactions during the last fraction of geologic time among the North American and Pacific plates and the Farallon plate, which lay between them, but since has been consumed as the southwestern part of our raft overrode it. These interactions also produced and now drive the San Andreas fault splitting California.

There is no question that episodic rifting continues today in New Mexico, as evidenced by the abundant fault scarps, earthquakes, high heat flow, modern elevation changes, recent volcanism, and the geophysical evidence of an anomalous thin crust beneath the rift.

The earliest written record of earthquake activity in New Mexico is of an earthquake swarm described by an army surgeon camping near Socorro in late 1849. Most of the recent earthquakes have occurred in a 150-kilometer section between Belen and Socorro, New Mexico. During the last 20 years, seismic recording suggests a very low level of activity. The level is surprising in view of major crustal movements in the past and the presence of modern fault scarps along the edges of the rift. The rift now appears quiet, but seismically pregnant.

Detailed seismic studies continue in New Mexico with measurements performed by LASL, the New Mexico Institute of Mining and Technology, and the Albuquerque Seismological Laboratory of the U.S. Geological Survey. Each group installed seismometers for different reasons, but all cooperate closely in trying to learn more about seismic activity in New Mexico. One motivation for LASL's seismic research has been to study natural earthquake activity near the hot dry rock geothermal energy experiment at Fenton Hill, so that man-made and natural events can be distinguished. Also construction of new



The central Rio Grande rift. The partly molten rock (dark grey) reaches within 35 km of the Earth's surface below the Albuquerque volcanoes.

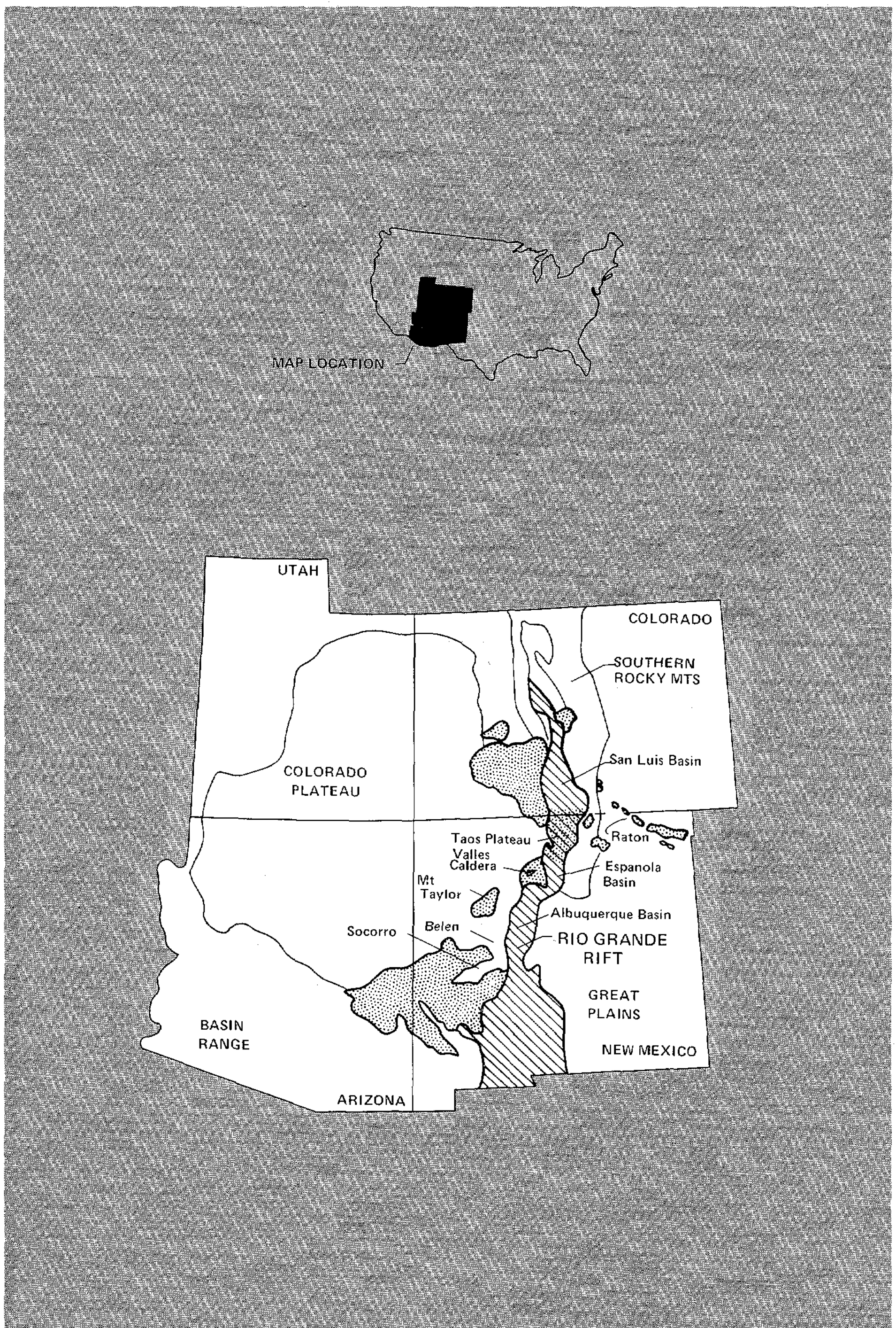
facilities in Los Alamos, such as the half-mile-long accelerator, required knowledge of seismic risk. New Mexico is still earthquake country even though current activity is low.

Joint research shows that microseismic activity is concentrated in two areas, one between Belen and Socorro and another 15 kilometers west of Espanola. Near Socorro, seismic analysis suggests the presence of a large, complicated-shaped magma body (molten rock) at a crustal depth of about 19 kilometers, leaking into shallower bodies. Most of the Socorro activity consists of small-magnitude earthquake swarms apparently related to movement of molten rock at depth. The swarms suggest an extension of the upper crust produced by the intrusion of a layer of magma at mid-crustal depths. Unusually high heat flows occur over the inferred magmas. Recent seismic reflection research by the Consortium for Continental Reflection Profiling penetrated to depths of at least 35 kilometers. Results confirm the existence and shape of the molten rock mass.

West of Espanola, seismic activity also suggests a possible underlying magma body. Activity consists of small-magnitude earthquakes that recur at intervals of several months. Seismometers record a few swarm-like sequences. Interestingly, LASL researchers recently noted a major relative subsidence northwest of Espanola associated spatially with the earthquake belt. Geodetic releveling analysis reveals a maximum subsidence of about 5 centimeters between surveys performed in 1934 and 1939. Researchers suggest that the sinking and the associated earthquakes originate in deflation of a shallow magma body. Continued studies will help to identify the processes responsible for regional extension in the Southwest.

Plate movements not only create earthquakes and produce volcanism; they also determine where mineral deposits form. In addition, most geothermal energy resources originate as a result of plate interaction. The LASL hot dry rock experiment on Fenton Hill is successful partly because of its location on the edge of the Rio Grande rift. Plate travels determine whether diamonds form in Arkansas or gold appears in California. Many ore bodies, for example, occur at present or past boundaries of crustal plates.

Geology is a young discipline with a rapidly increasing pace of surprising discoveries. Only astronomy shares with it the complexities of scale and time. In 20 A.D. Seneca wrote, "It is useful to be assured that the heavings of the Earth are not the work of angry deities. These phenomena have causes all their own." Two millennia later we are just beginning to understand what those causes are. Moreover, we are just beginning to exploit our understanding through improved exploration for mineral and energy resources. Few theories have made such an impact on their disciplines, and few disciplines, stimulated by new theories, have had such an impact on energy technologies as has plate tectonics on the geosciences.



The Rio Grande Rift. The crosshatched areas indicate the Rift itself and the stippled areas indicate surface volcanics.