CONTINUUM

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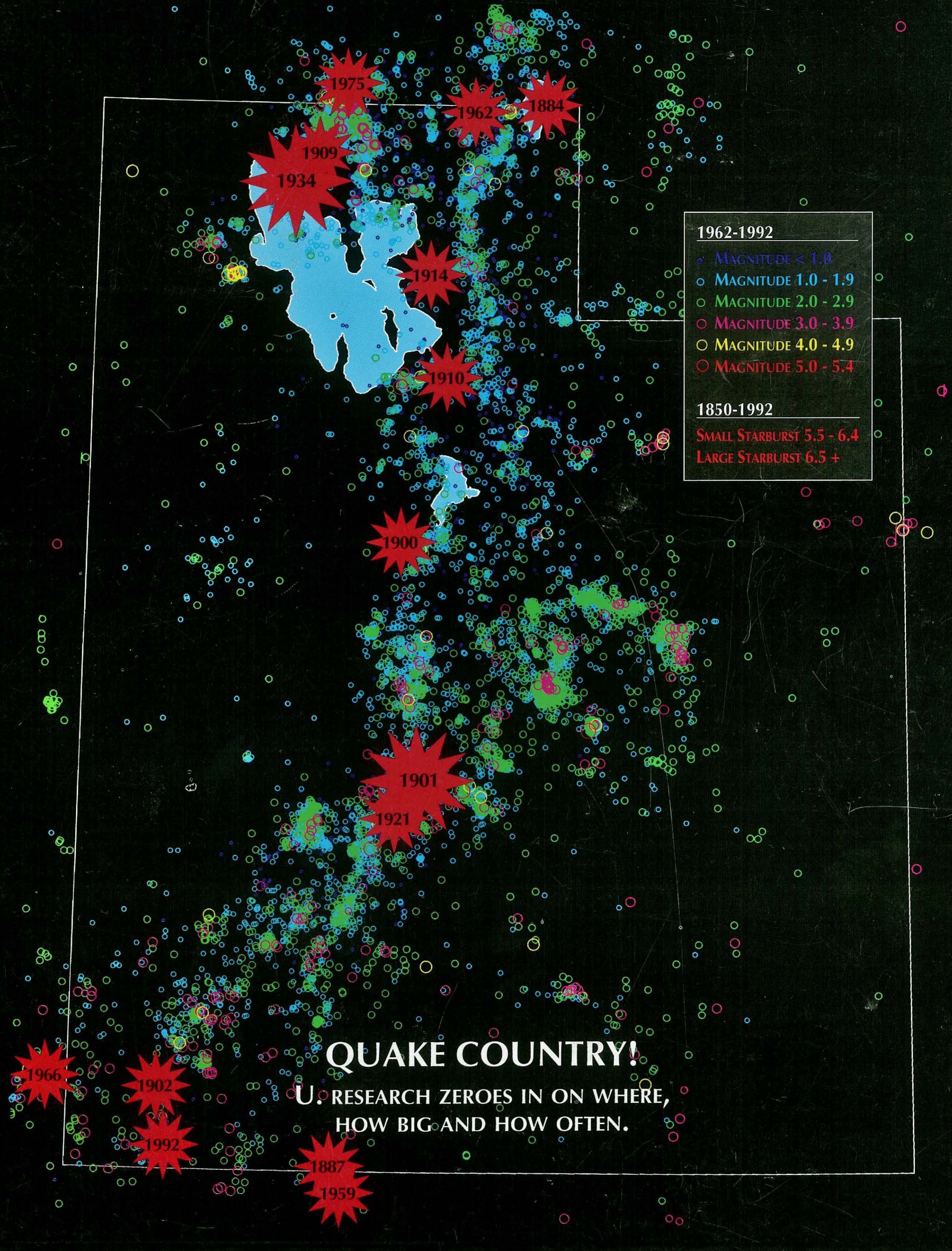
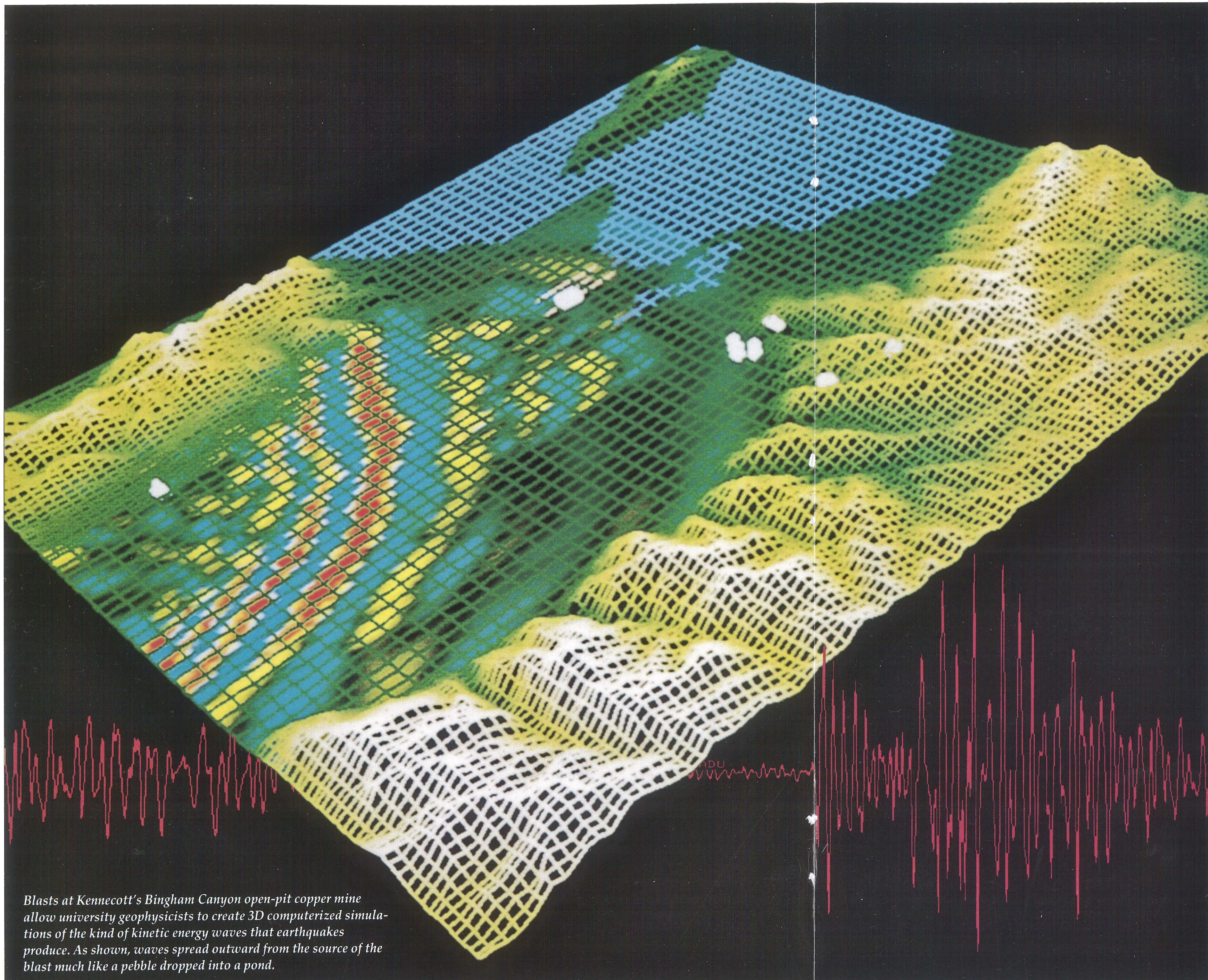


QUAKE COUNTRY!

U. RESEARCH ZEROES IN ON WHERE, HOW BIG AND HOW OFTEN.



Blasts at Kennecott's Bingham Canyon open-pit copper mine allow university geophysicists to create 3D computerized simulations of the kind of kinetic energy waves that earthquakes produce. As shown, waves spread outward from the source of the blast much like a pebble dropped into a pond.

QUAKE COUNTRY!

EARTHQUAKE RESEARCH DOESN'T JUST DWELL ON WHAT HAS ALREADY TAKEN PLACE. THROUGH EXTRAORDINARY SCIENTIFIC INITIATIVES AT THE U OF U, IT ZEROES IN ON THE COMPELLING QUESTIONS OF WHERE, HOW BIG AND HOW OFTEN.

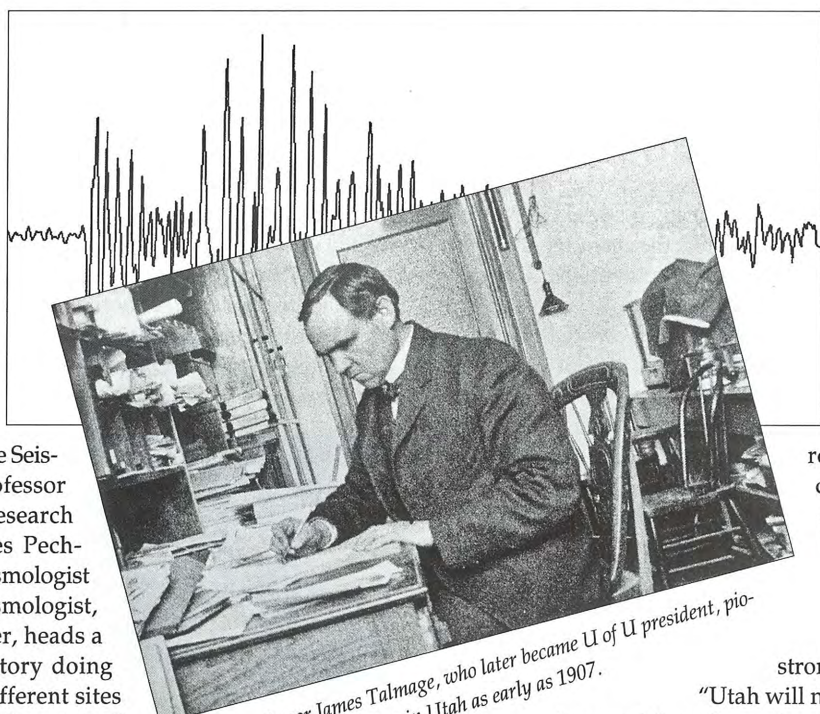
BY JAMES C. BAPIS

IN THE LATE 1800s, A SEISMOLOGIST appeared before New Zealand's parliament to request funds to buy a seismograph. "What do you want the money for, just to tell us there's been an earthquake?" asked a farmer serving in the legislative body. "We'll already know that when it happens."

Prevalent in the public mind today is the image of scientists such as Utah's Walter Arabasz whiling away their time watching recording instruments, waiting for the next big earthquake to strike. "The media tend to reinforce the perception of a seismologist standing in front of a cylindrical drum recorder, watching the instrument make wiggly lines," says Arabasz, "because that's what the public expects to see." But the image belies the high-tech nature of modern seismology—and it wrongly conveys the impression that seismologists just relay information about earthquakes after the fact.

Arabasz says the New Zealand episode flashed through his mind in 1987 when then-U of U president Chase Peterson toured the Seismograph Stations' recording and research lab in the Browning Building on campus. "I think one of your problems is that you're perceived as just historians," Peterson offered. Seismologists are trying to dispel that "just historians" image in order to give the public a true understanding of the predictive and real-time aspects of what earthquake scientists now do.

Several researchers in the Department of Geology and Geophysics are doing complementary studies that relate squarely to Utah's ever-present earthquake threat. This includes work by Arabasz's colleagues in the Seismograph Stations—professor Robert Smith PhD'67, research associate professor James Pechmann, and senior staff seismologist Susan Nava. Another seismologist, professor Gerard Schuster, heads a seismic modeling laboratory doing studies to predict how different sites along Utah's Wasatch Front will respond to the shaking of future earthquakes. On the geology side, professors Ronald Bruhn and William Parry BS'57 PhD'61 are trying to develop better physical models of earthquake faulting that can enhance the basis for predictions.



Geology professor James Talmage, who later became U of U president, pioneered earthquake recording in Utah as early as 1907.

Photo: Utah State Historical Society

The original U of U Seismograph Stations were a skeletal statewide network of six installations developed by Kenneth Cook during the 1960s. Earthquake recording in Utah dates back to 1907, when geologist James Talmage (who served as U of U president from 1894 to 1897) installed on campus two pendulum seismographs, which recorded with a sharp stylus on smoked paper. The university's modern regional network consists of 90 remote stations that stretch from Yellowstone National Park to southern Utah, and transmit seismic data continuously to a central recording lab on campus.

Today UUSS is the primary center for seismological research and earthquake monitoring in the Intermountain West. Some 2,200 seismic events are digitally recorded and analyzed every year. The data and facilities are used routinely for research training and for graduate and undergraduate course instruction.

"Many people have the idea that regional seismic networks are just for earthquake monitoring," says Arabasz. "But they are also a multipurpose tool for gathering important information for science, earthquake engineering, and crisis management." Recordings are routinely used to probe the subsurface structure and material properties of the earth and to study the mechanics of earthquake behavior in the region. The data is fundamental for quantifying in advance where, how big and how often future earthquakes can be expected, and what effects should be anticipated for seismic risk management and defensive engineering.

A UUSS goal is to equip Utah's seismic network with the kind of new technology that will improve data for research and lead to rapid post-earthquake processing and communication of information to crisis managers. Such an arrangement could help reduce losses from future disasters. California is experimenting with systems aimed at providing "real-time" warnings of up to tens of seconds before the onset of strong earthquakes.

"Utah will need more serious support from public policymakers if it ever hopes to achieve similar capabilities," says Arabasz. Instead of moving ahead though, Utah's network may soon take a giant step backwards. Without adequate supplemental funding from the state legislature, UUSS will be forced to terminate the monitoring of seismically active parts of southwest and eastern Utah and large parts of central Utah after July 1, 1993. Valuable information for science and for safely designing large engineering projects in those parts of the state would be lost.

The prospect of having to cut back the statewide infrastructure of their regional network seriously worries U of U seismologists. The ability to relay information quickly to public safety officials about strong shaking associated with a large earthquake would be valuable in saving lives and property, says Arabasz. As badly as San Francisco was damaged in the 1989 so-called "World Series" earthquake, the tremor's epicenter was some 50 to 60 miles south in the Santa Cruz-Los Gatos area. Because of disrupted communications, the full extent of damage and emergency needs in Santa Cruz went unknown for a full day.

A similar scenario is possible in Utah. "It's conceivable that if an earthquake were to occur in Utah at night in the dead of winter and interrupt communications, public officials couldn't rely on aerial reconnaissance to show where the disruption and damage had occurred," says Arabasz. The absence of communications might produce a long and possibly costly delay in getting emergency relief to people requiring major assistance.

The valley-mountain relationship on the Wasatch Front represents a unique geological symbiosis.

The work of Schuster and graduate student Kim Olsen picks up where that of the Seismograph Stations leaves off in terms of Utah's earthquake dangers. Schuster and Olsen simulate the response of the Salt Lake Valley to future large earthquakes. With powerful IBM and Cray supercomputers, they mimic the likely shaking behavior of subsurface soils and basin sediments during quakes. Their studies will eventually enable scientists to predict the character and severity of earthquake ground motions so that potentially damaging effects can be mitigated.

The valley-mountain relationship on the Wasatch Front represents a unique geological symbiosis. The crustal uplift that produced the Wasatch Range also filled valleys to the west with soft material on which Salt Lake City now sits. Moreover, the city itself is located on one of the deepest parts of the basin, as are parts of south Salt Lake County.

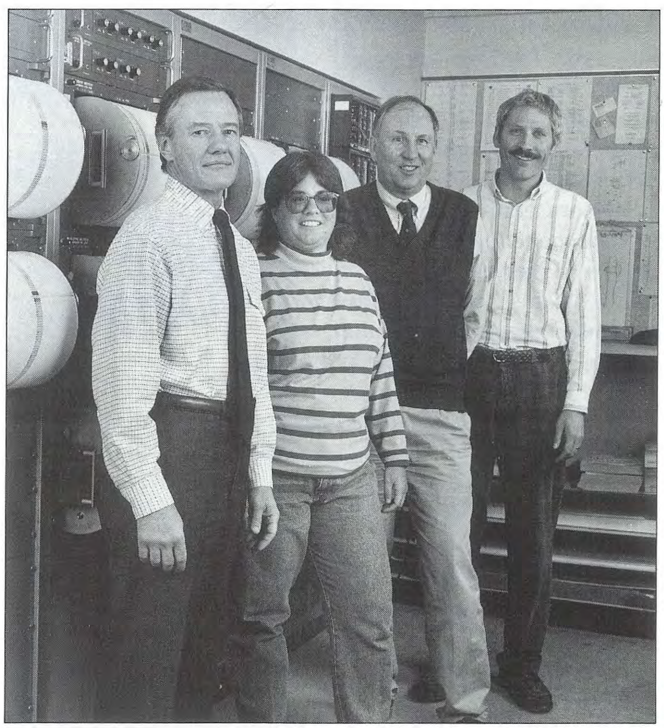
Through supercomputer calculations, Schuster and Olsen generate the kind of seismic (shock) waves that earthquakes produce. These waves are propagated into their computer models of the Salt Lake Basin. "When an earthquake strikes, seismic waves spread outward in all directions from the point of the fracture within the earth, much as sound waves do when a gun is fired," explains Schuster. Put another way, he says, "If we have a large earthquake in our valley, particularly along the Wasatch Fault, the basin will ring like a bell. Certain parts of the bell will ring louder than others. First, we've got to find out what the bell looks like, which requires learning a lot more about the subsurface structure of the basin. That takes time, as does the job of monitoring the reflection and refraction of acoustic waves from the valley's subsurface."

The pioneering 3D modeling work, now in its sixth year, will have important practical value, says Schuster, as soon as the two researchers are able to accurately predict the course and intensity of seismic wave amplification in the valley. Such advance information would be invaluable to government officials for siting schools, dams and hospitals, and retrofitting public buildings to reduce their vulnerability to tremors. Olsen mathematically creates and analyzes the waves. He "shakes" the basin on a high-resolution computer screen and studies the erratic movement to learn which parts of the basin are most responsible to major ground motion. A sophisticated software package he wrote visualizes images in three dimensions. On a monitor, he calls up a simulation of the valley's subsurface makeup—a kind of inverted mountain range, indicating the presence of soil basin fill. Parts of the basin are as deep as the Wasatch Range is high.

Olsen recently explained his research to officials in Mexico City, the site of a devastating 7.5 earthquake in 1985 that killed more than 7,000 people. Since then, officials at University Autonomous of Mexico, the world's largest university, purchased a supercomputer to prepare simulations based on the Utah work. Salt Lake City and Mexico City are alike in that they were both built on sedimentary basins (ancient lake beds), are surrounded by mountains, are close to seismically active zones, and historically have had comparatively lax building codes. Olsen's work has also drawn the attention of seismologists in France and Denmark. And, taking a cue from the Utah work, California scientists have begun 3D modeling of small basins in their state as a prelude to studying the Los Angeles Basin.

Simulating the complex physics of earthquake ground motion required writing a Fortran computer code more than 5,000 lines long, a code Schuster recently gave to Mexican officials. Calculations can now be made that were impossible a short time ago. Each simulation solves more than 100 billion equations and requires up to two weeks of supercomputer time. The processing of such a massive number of equations produces a striking, multicolored simulation of a single earthquake in progress, a detailed graphical creation that seismologists can replay as often as they want.

A preliminary conclusion is that the direction from which an earthquake strikes is crucial to identifying the basin areas most

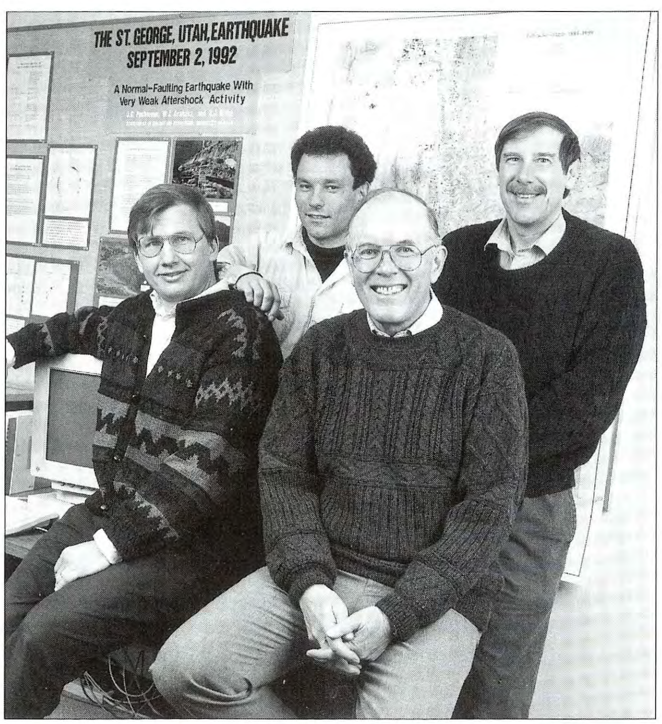


Walter Arabasz, Susan Nava, Robert Smith and James Pechmann are principal figures in the research and public service-oriented University of Utah Seismograph Stations.

likely to experience the strongest ground motion. Most prone to shaking appear to be the deepest parts of the basin whose depth ranges from two kilometers to just a few feet. Bedrock similar to the solid face of Mt. Olympus, a prominent feature of the Wasatch Range, underlies the sediment.

As seismic waves enter the simulated basin, they are replicated as complex patterns displayed in different colors. Through pattern and color differences, Schuster and Olsen analyze the various features of wave propagation. After a certain amount of simulation time, a pattern develops on the screen that shows the strongest energy accumulation above the deepest parts of the basin. Colors correspond to ground motion intensity, with blues representing the weakest motion and the reds and yellows the strongest. When additional computing speed and memory become available, mountains will be added to the model to build an even more accurate simulation of seismic wave effects on structures on the valley floor. In these simulations, as in the basin itself during an actual earthquake, seismic waves are bounced back and forth off the basin walls. The work of Schuster and Olsen benefits from computer visualization technology developed in the Department of Computer Science, and the assistance of graduate student Elena Driskill and Robert McDermott PhD'80, staff scientist with the Utah Supercomputing Institute.

The Wasatch Fault's earthquake history is a key area of interest for geologist Parry, who's done much of his field work at what he termed the geological "groin" known as Corner Creek in south Salt Lake County. It's hallowed ground, says Parry, because several of America's most famous geologists have worked there. Clarence King and Grove Karl Gilbert explored the area a century ago in some of the first studies of Utah's geology. Corner Creek sits east of Draper, in the foothills far beneath the twisted spiral of Lone Peak mountain, or at the convergence of the Wasatch and Traverse mountains. The site is tailormade for Parry's studies of the tiny fluid remnants of ancient earthquakes and possible foretellers of earthquakes.



Gerard Schuster, who operates a seismic modeling laboratory, and his assistant, Kim Olsen; and William Parry and Ronald Bruhn, modelers of earthquake faulting, are part of the U.'s diverse research program.

Each simulation solves more than 100 billion equations and requires up to two weeks of supercomputer time.

"You can't help but feel a sense of reverence about Corner Creek's historical importance," says Parry. "Many of the relationships relating faults to earthquakes were worked out there. Geologists have been studying earthquake behavior in that area for the past 130 years." King was the first head of the U.S. Geological Survey and discoverer of Mt. Whitney. Gilbert was a founder of modern geomorphology and companion to explorer John Wesley Powell from 1874 to 1879.

In an article published Sept. 16, 1883 in *The Salt Lake Tribune*, Gilbert wrote ominously of the earthquake threat to Salt Lake City. "It is useless to ask when this disaster will occur," he penned. "Our occupation of the country has been too brief for us to learn how fast the Wasatch grows; and indeed, it is only by such disasters (earthquakes) can we learn. By the time experience has taught us this, Salt Lake City will have been shaken down."

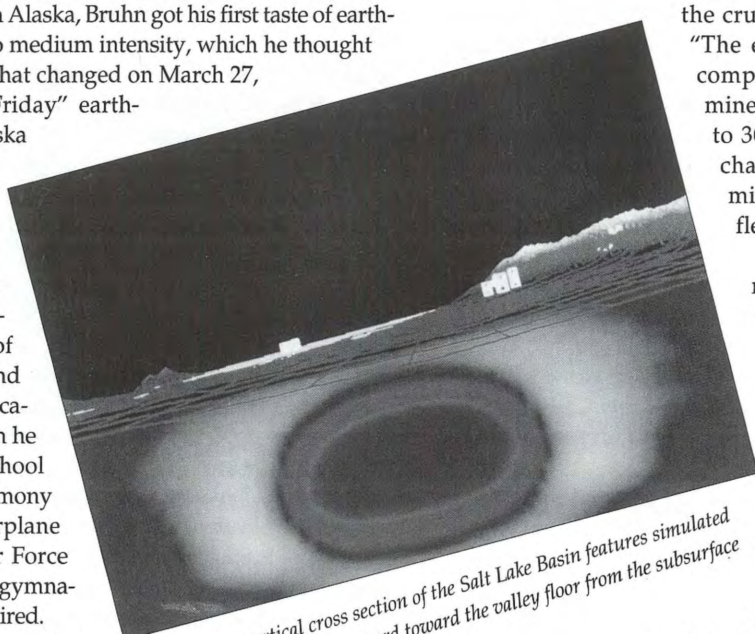
Parry and Bruhn are convinced that a key to the mystery of how faults work is the behavior and characteristics of water, evidenced by samples once buried deep inside the fault but pushed to the surface by the slow, uplifting geological processes that created the Wasatch.

"Outside of Tibet, Corner Creek right here in our own backyard is the best place for this kind of experimentation," says Parry. Surface rocks at the Draper site hold a bounty of small water samples trapped in rocks by earthquakes as long as 18 million years ago. These tiny samples are called aliquots, or fluid inclusions. Heating these inclusions and examining them under a microscope shows the fault temperature and pressure as well as the ground displacement that occurred in ancient earthquakes. The specimens are first cooled with liquid nitrogen until frozen at a temperature of about 100o Celsius. Then they are heated with dry nitrogen until they melt. The temperature at which the various sample constituents liquify reveals their chemical components. Even though each specimen is only about 100 micrometers thick, it tells part of the story, fills part of the puzzle of the region's geological evolution and upheaval.

Based on years of innovative examinations of such inclusions, Parry estimates the Wasatch Fault uplifted the Wasatch Range about 11 kilometers over the past 18 million years. If it weren't for the natural forces of wind and water erosion, the escarpment would stand some 36,000 feet high today. (Presently, some peaks are over 10,000 feet high.) The aggregate fault has moved about seven miles in relation to the Salt Lake Valley floor. The displacement that created the Wasatch Range resulted from an estimated 11,000 earthquakes along the fault, or one significant earthquake about every 1,500 years.

"The interaction of water with rocks during faulting alters the content of the minerals in the fault as well as the texture of the fault itself," explains Parry. This information, along with analyses of the chemistry of water and other liquids trapped in the ancient minerals, reveals total fault movement. "If I wanted to know what the water was like that helped produce the copper deposits at Bingham Canyon, I would study the ancient water trapped for millions of years in the minerals at the open pit mine," Parry says.

As a boy growing up in Alaska, Bruhn got his first taste of earthquakes, mostly of small to medium intensity, which he thought of only as novelties. But that changed on March 27, 1964 when the "Good Friday" earthquake rolled through Alaska with dramatic force, a magnitude 9.2 event and the second most powerful earthquake in the 20th century. "I spent most of that evening helping people get out of wrecked buildings and directing them to a safe location," recalls Bruhn. When he graduated from high school two months later the ceremony had to be held in an airplane hangar at Elmendorf Air Force Base because the school's gymnasium still hadn't been repaired.



An east-west vertical cross section of the Salt Lake Basin features simulated elastic waves expanding upward toward the valley floor from the subsurface hypocenter of an earthquake.

New models for forecasting earthquakes should include substantially more data on the chemical interactions that occur between fluids and rocks in fault zones, says Bruhn. "We have known that geochemical processes are important in faulting, but only recently did we grasp the reality that these processes may act as fast or even faster than the rates at which forces build up to trigger earthquakes," he says. Chemical reactions between the water and the rock reduce resistance to sliding as rocks on either side of a fault rub together. In effect, the fluids act as a lubricant to overcome the great pressure holding rocks together. "As of today," Bruhn says, "we still don't understand the failure process of faults, especially what happens in the pre-critical stage. I think we're due for a paradigm change. We keep trying to force old models (to work), but the data won't fit."

Because earthquakes are the most convincing evidence of crustal movement, the ability to measure these mostly subtle changes is crucial to achieving a higher level of credibility in prediction. To that end, Smith, a primary figure in several recent national seismological research initiatives, has pioneered the use of the military Global Positioning System satellites in the study of seismology and plate tectonics. Because of the new navigational system's precision (they operate on atomic clocks), scientists no longer need unobstructed line-of-sight views to accurately measure the distance between two pre-selected points, whether within a few feet of each other or continents apart.

Crustal deformation is most intense in the great mountain belts of the world where sedimentary rocks, originally horizontal, fold, contort, fracture and overturn. GPS portable receivers deployed along a fault collect radio signals from the satellites and help scientists confirm how much the crust has expanded or contracted. "The equipment enables us to make comparisons with previously determined positions, some as many as 25 to 30 years old," says Smith. Small changes in steady deformation might serve as precursors to full-fledged earthquakes.

The GPS high-frequency ground receivers Smith's research team deploys collect and analyze position-reference data from overhead satellites. As the satellites circle the earth at an altitude of about 20,000 kilometers, they send back positioning signals to the cone-shaped, tripod-mounted receivers, which record ground positions with great accuracy. In the long run, the researchers hope to predict when earth deformations might accelerate and reach a late-stage of preparation for earthquake failure.

"Perhaps the seismically inactive parts of the Wasatch Fault are locked and storing energy, which could eventually produce measurable deformation prior to a large quake," says Smith. He and Charles Meertens, research assistant professor of geophysics at the U., pioneered use of the geostationary satellites in crustal deformation studies several years ago at Yellowstone National Park, one of the world's most volcanically and seismically active areas. The Yellowstone research is important to Utah because the two areas have many seismological similarities.

As new technologies continue to emerge, scientists expect to uncover even more startling details about the earth's turbulent interior, characterized by some as a kind of gigantic geological ballet. The more scientists learn about how earthquakes work, the more they learn about the workings of the earth itself.

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