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EARTH BRIEFS

How can earthquakes be useful?

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Earthquakes are one of nature's most destructive forces. However, small earthquakes associated with volcanic eruptions can be very useful as a predictor of eruptive activity, and can warn scientists, emergency managers, and the public that a big eruption may be about to begin. For instance, the recent large eruption of Mount Etna, Italy's highest and most voluminous volcano, was preceded by the largest swarm of earthquakes seen at this volcano in the last 20 years. Increased earthquake, or seismic, activity was observed on Mt. Etna starting on July 13, 2001. Over a two-day period, more than 2,500 earthquakes were recorded, many of which were felt in nearby towns. Warnings were issued. On July 17, a major flank eruption began, generating explosive activity and lava flows from five separate fissure vents on the volcano's flank. The lava flows destroyed roads and structures, and ash from explosive activity fell in towns up to 25 kilometers away. A nearby international airport had to be closed because ash was covering runways and obscuring visibility. Ash is also dangerous to aircraft engines.

Camera recording volcanic eruptions on the outer rim of Mt. Erebus, Antarctica. Images of eruptions are used to help interpret seismic activity in the volcano.

Why are earthquakes associated with volcanic activity? Magma movement within the upper 10 kilometers of the earth stresses the crust, generating movement that radiates elastic waves to the

In This Issue....

NEW MEXICO BUREAU OF GEOLOGY & MINERAL RESOURCES A DIVISION OF NEW MEXICO TECH

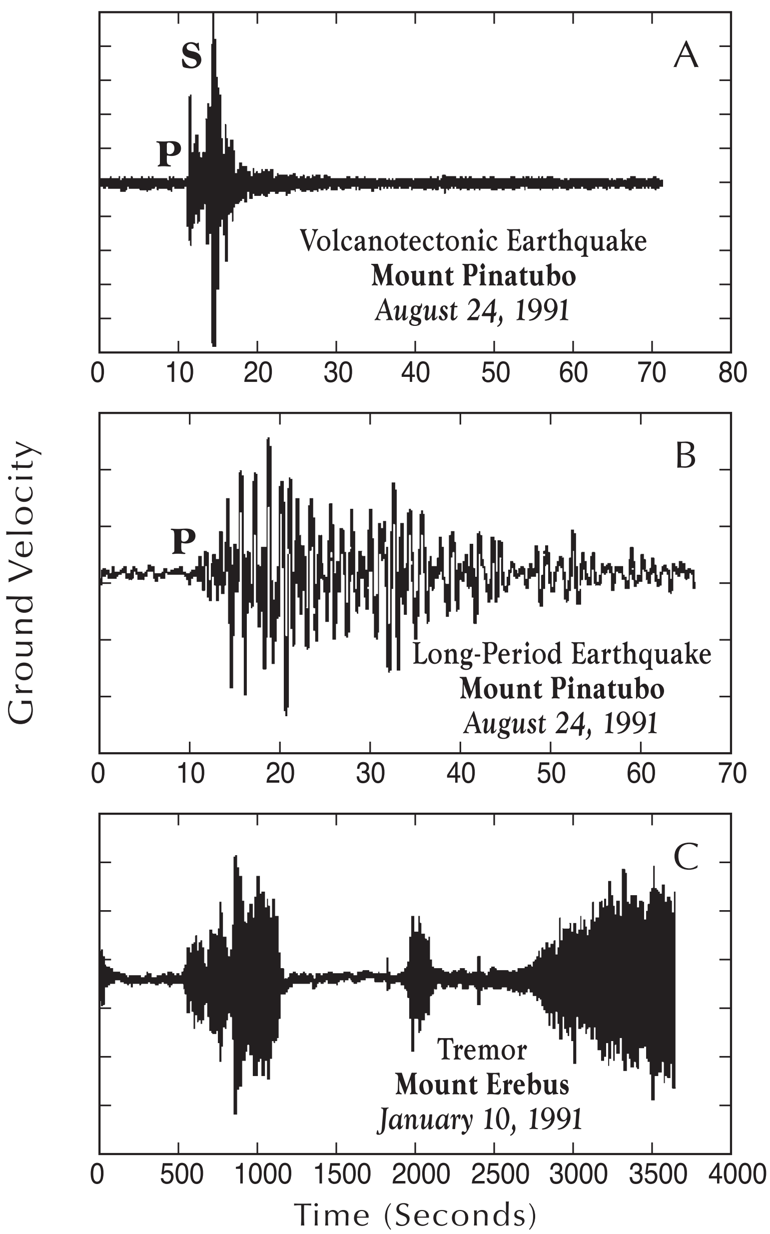

FIGURE 1—Seismograms, graphical displays of seismic motion, showing types of earthquakes commonly observed on active volcanoes (see text). Two types of seismic waves can be clearly detected from volcanotectonic earthquakes (a), called "P" (primary) and "S" (secondary) waves. S waves travel more slowly through the Earth and thus arrive later than P waves. The arrival times of P and/or S waves at several observing points can be used to estimate the location of the earthquake source. Volcanotectonic earthquakes are caused by slip on faults and are indistinguishable from earthquakes in nonvolcanic areas. Long-period earthquakes (b) are unique to volcanic and hydrothermal areas, are linked to resonant crack behavior, and generate weak or no S waves. Tremor (c) is caused by the unsteady movement of magma within volcanoes.

surface, which are recorded as small earthquakes. These earthquakes are typically of low magnitude (typically less than 2 to 3 on the Richter scale), but can be very numerous. Many active, or potentially active, volcanoes in the world are thus instrumented with networks of seismometers, which measure earthquake size, location, and other characteristics. Earthquakes detected by these networks are continuously monitored to look for the type of magma movement that may lead to a volcanic eruption.

One can infer important information about the physical processes involved as magma struggles towards the surface by looking at the characteristics of volcanic earthquakes. Some earthquakes in volcanic regions (called volcanotectonic, *Figure 1a*) are clearly caused by sideways slip along faults, just as in nonvolcanic regions. However, the origin of volcanotectonic earthquakes can be ambiguous, because they have no seismic characteristics that allow them to be directly linked to the movement of magma, or other volcanically-related fluids. Other earthquakes (called long-period, *Figure 1b*) are only seen in volcanic regions and can be attributed to the injection of magma or aqueous fluids, thus showing that fluids are migrating.

Finally, most active volcanoes exhibit volcanic tremor *(Figure 1c)*, where the volcano goes into a continuous vibration from the sustained movement of magma through its conduit system. The occurrence of sustained tremor is almost always associated with eruptions or imminent eruptions.

Within New Mexico, the Valles caldera, in the Jemez Mountains, and the area around Socorro, where a magma body is thought to be present in the earth's crust at a depth of about 19 km (Balch et al., 1997), are both instrumented with seismometers. Scientists at New Mexico Tech and Los Alamos National Laboratory monitor earthquake activity at both of these potentially active volcanic areas. Information about these monitoring programs can be found at http://www.ees.nmt.edu/Geop/NM_Seismology.html, and at http://www.ees4.lanl.gov/lasn.

Although seismic monitoring has proven to be a successful method for predicting volcanic activity, much remains to be learned about the relationship between seismic and volcanic activity. For example, a major volcanic seismic swarm occurred in the Mammoth Mountain area of California in 1989 as part of ongoing unrest that began in 1980. Although long-period earthquakes showed that the seismic activity was the result of magma movement within the earth's crust (Hill et al., 1990), and geophysicists felt that eruptive activity was likely, no eruption occurred. In this case a body of magma intruded to within several kilometers of the surface but was not energetic enough to reach the surface and erupt.

References:

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Hill, D.P., Ellsworth, W.L., Johnston, M.J.S., Langbein, J.O., Oppenheimer, D.H., Pitt, A.M., Reasenberg, P.A., Sorey, M.L., and McNutt, S.R., 1990, **The 1989 Earthquake Swarm Beneath Mammoth Mountain, California : an Initial Look At the 4 May Through 30 September Activity: Bulletin of the Seismological Society of America;, v. 80**, p. 325-339.

Much of the information presented about activity on Mt. Etna and volcanically-related seismology was compiled from the Italy Volcanoes web site, http://stromboli.net/boris.

Discussion Ideas for Teachers and Students

Contributed by Dave Love

1. Interpretation of earthquakes preceding volcanic eruptions is a young science. What should researchers tell the public and the media about possible eruptions following earthquakes?

2. Should scientists be legally liable for economic losses if they predict eruptions that don't occur and the public stays away from the predicted area?

3. Should scientists be liable for loss of life and property if they fail to adequately predict the size of eruptions, such as if an eruption covers a larger area than originally predicted?

4. Are there circumstances under which the public is better off not knowing about an impending eruption?

Minerals of New Mexico

NEW MEXICO EARTHQUAKES: MID-1800S THROUGH 1998

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About thirty earthquakes have caused slight to moderate damage in New Mexico during the past 150 years, which raises several questions. Can we expect similar or even larger quakes in the future? What are the strengths and numbers of earthquakes in the 150-year record and how were they measured? What is the geographic distribution of earthquakes in New Mexico? What is the average annual number of earthquakes in the state, and how does New Mexico's level of seismicity compare with the state of California? To answer these questions, we present a summary of earthquakes for the 150-year period that emphasizes earthquakes of magnitude 4.5 or greater for the period 1850 through 1961 (pre-instrumental quakes) and magnitude 2.0 or greater for the period 1962 through 1998 (measured by instruments). A more comprehensive tabulation of earthquakes in New Mexico may be found in new catalogs by Sanford and others (in press).

Pre-Instrumental Record of Earthquakes in New Mexico

Historical documents record earthquakes in New Mexico as far back as the mid-nineteenth century. Although settlement by the Spanish began in 1598, little is known of earthquake activity in the state prior to its becoming a territory of the United States in 1848. Reports of earthquakes probably exist in Spanish and Mexican archives, but to our knowledge no attempt has been made to extract the information. The earliest known earthquake report after U.S. occupation is the description by an Army surgeon of a small 1849–1851 swarm of 28 small shocks in the Rio Grande valley at Socorro. Another nineteenth-century report describes a swarm of earthquakes in the Rio Grande valley that occurred near Los Lunas in 1893. Damaging quakes in Socorro were reported in 1869 and 1897. In the twentieth century, 237 earthquakes were reported in New Mexico before instrumental records began in 1962: 53 during 1904 and 1906-1907 swarms in Socorro, 38 during a swarm near Belen, and 85 during a swarm in the Gila Wilderness (Stover and others, 1988). The rest of the earthquakes were scattered around the state.

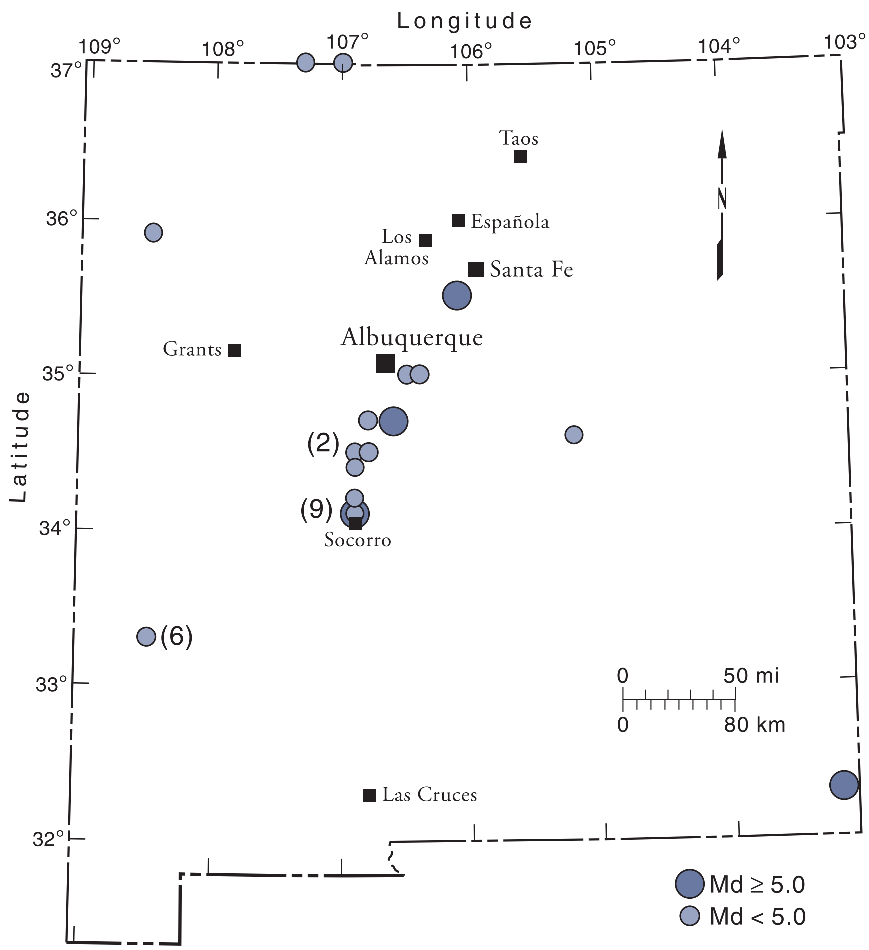

FIGURE 1—Strongest New Mexico earthquakes from 1869 through 1998 with moment magnitudes of 4.5 or larger. Number in parenthesis indicates multiple events at that location.

Strengths of Pre-Instrumental Earthquakes

Many of the New Mexican earthquakes occurred before instruments were available to measure the magnitudes of the earthquakes. The strengths of earthquakes from these mid-nineteenth century events until 1962 are based on earthquake **Intensity**, which is estimated from what people observed during earthquakes and the damage to structures. The **Intensity Scale** is expressed in Roman numerals and ranges from barely perceptible tremors at **Intensity I** to total damage at **Intensity XII** *(See sidebar on this page).* The difficulty with this procedure is that to reflect the strength of an earthquake accurately, people and/or structures need to exist in the vicinity of the shock. Therefore, the reliability of the procedure is dependent on population density, which was very low for nearly all of New Mexico prior to 1962, particularly outside the Rio Grande valley. In contrast, **magnitude** scales for earthquakes are based on recordings from instruments called seismographs that can detect ground shaking, from imperceptible vibrations to large ground-rolling waves. An earthquake's magnitude is reported as a single number such as 5.4 or 6.2 *(See sidebar on pages 8 and 9).* To calibrate the **Intensity Scale,** the senior author (Sanford, 1998) compared twenty-four instrumentally measured earthquake magnitudes and documented intensities of New Mexican earthquakes between 1962 and 1987, and formulated a relationship between reported intensity and magnitude. To compensate for the sporadic distribution of population and structures in New Mexico, we restricted the list of strongest earthquakes for the period prior to 1962 to shocks with maximum reported intensities that yield magnitudes of 4.5 or greater. Data on the 30 earthquakes equaling or exceeding magnitude 4.5 from 1869 through 1998 are given in *Table 1* and a map of their locations is presented in *Figure 1.*

The strongest earthquakes in this 130–year period occurred during a world-class swarm at Socorro that began in July 1906 and continued into 1907. Two shocks in this swarm reached magnitudes of 5.8 and were felt at distances beyond Santa Fe and El Paso. The distribution of epicenters in Figure 1 suggests that the majority of future seismicity is likely to occur in or near the Rio Grande valley, particularly from Santa Fe to Socorro. However, more than 80% of the events on this figure occurred before instrumental recording of earthquakes began in New Mexico.

MODIFIED-MERCALLI INTENSITY SCALE

I—Not felt except by a very few under especially favorable conditions.

II—Felt only by a few persons at rest, especially on upper floors of buildings.

III—Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.

IV—Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.

V—Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.

VI—Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.

VII—Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.

VIII—Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.

IX—Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.

X—Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

XI—Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.

XII—Damage total. Lines of sight and level are distorted. Objects thrown into the air.

Abridged from The Severity of an Earthquake, a U. S. Geological Survey General Interest Publication and http://neic.usgs.gov/neis/general/handouts/mercalli.html

	Date			Origin Time			Approx. Loc.		Max. Intensity (Modified Mercalli)	Est. Md	Nearby City
No.	Month	Day	Year	Hr	Min	Sec	Lat (N)	Long (W)			
1.			1869				34.1	106.9	VII	5.2	Socorro
2.	Sept	7	1893				34.7	106.6	VII	5.2	Belen
3.	Oct	31	1895	12			34.1	106.9	VI	4.5	Socorro
4.			1897				34.1	106.9	VI	4.5	Socorro
5.	Sept	10	1904				34.1	106.9	VI	4.5	Socorro
6.	July	2	1906	10	15		34.1	106.9	VI	4.5	Socorro
7.	July	12	1906	12	15		34.1	106.9	VII to VIII	5.5	Socorro
8.	July	16	1906	19			34.1	106.9	VIII	5.8	Socorro
9.	Nov	15	1906	12	15		34.1	106.9	VIII	5.8	Socorro
10.	Dec	19	1906	12			34.1	106.9	VI	4.5	Socorro
11.	May	28	1918	11	30		35.5	106.1	VII to VIII	5.5	Cerrillos
12.	Feb	5	1931	4	48		35.0	106.5	VI	4.5	Albuquerque
13.	Feb	21	1935	1	25		34.5	106.8	VI	4.5	Bernardo
14.	Dec	22	1935	1	56		34.7	106.8	VI	4.5	Belen
15.	Sept	17	1938	17	20		33.3	108.5	VI	4.5	Glenwood
16.	Sept	20	1938	5	39		33.3	108.5	VI	4.5	Glenwood
17.	Sept	29	1938	23	35		33.3	108.5	VI	4.5	Glenwood
18.	Nov	2	1938	16	0		33.3	108.5	VI	4.5	Glenwood
19.	Jan	20	1939	12	17		33.3	108.5	VI	4.5	Glenwood
20.	June	4	1939	1	19		33.3	108.5	VI	4.5	Glenwood
21.	Nov	6	1947	16	50		35.0	106.4	VI	4.5	Albuquerque
22.	May	23	1949	7	22		34.6	105.2	VI	4.5	Vaughn
23.	Aug	3	1955	6	39	42	37.0	107.3	VI	4.5	Dulce
24.	July	23	1960	14	16		34.4	106.9	VI	4.5	Bernardo
25.	July	3	1961	7	6		34.2	106.9	VI	4.5	Socorro
26.	Jan	23	1966	1	56	39	37.0	107.0		4.8	Dulce
27.	Jan	5	1976	6	23	29	35.9	108.5		4.7	Gallup
28.	Nov	29	1989	6	54	39	34.5	106.9		4.7	Bernardo
29.	Jan	29	1990	13	16	11	34.5	106.9		4.6	Bernardo
30.	Jan	2	1992	11	45	35	32.3	103.2		5.0	Eunice

TABLE 1—Strongest earthquakes in New Mexico, 1869 through 1998

In contrast, what we learned from studying instrumental records of earthquakes, which are not dependent on the presence of structures or an observant population, is that earthquakes occur throughout the state.

History of Instrumental Studies and Earthquake Catalogs

New Mexico Tech (NMT) was the first organization to undertake instrumental studies of New Mexico earthquakes. The research began in 1958 after the senior author had learned from publications, notably by Stuart Northrop at UNM, that earthquakes had been felt in New Mexico, most strongly and often in the Socorro area. In a short 3–day period of instrumental recording in the fall of 1959, 49 microearthquakes were detected, 40 within 20 km of Socorro. This was a strong indication that research based on seismograph recordings would be productive. At the end of 1960 we had a suite of instruments operating in abandoned mines at the foot of Socorro Mountain. Through the years, permanent NMT seismograph stations have increased to 16:9 in a network surrounding Socorro, and 7 in a network in southeastern New Mexico surrounding WIPP, a repository for nuclear waste. The forthcoming publication that catalogs the results would not have been possible without the contributions of talented New Mexico Tech undergraduate and graduate students from the inception of the research program to the present. They maintained instruments, interpreted seismograms, and conducted special studies as well as doing routine determinations of strengths and locations of earthquakes.

Although our research program has emphasized earthquake activity within the Socorro area, beginning in 1962 we were able to locate earthquakes throughout New Mexico and bordering areas using data from New

Mexico Tech instruments in conjunction with seismograms or readings from stations throughout the region. These regional stations were supported by the federal government (U.S. Air Force Office of Scientific Research, U.S. Geological Survey, Los Alamos National Laboratory, Sandia National Laboratory) and by universities (University of Texas at El Paso, University of Texas at Austin, and Texas Tech University). The periods of operation, number and sensitivity of instruments, and procedures for locating and assigning magnitudes were highly variable among these organizations during the 37 years since 1962. For this reason, we undertook the project of collating data from all organizations into a comprehensive and consistent catalog for New Mexico and nearby bordering areas. A major effort was made to have all magnitudes based on or tied to a New Mexico duration-magnitude scale *(See sidebar on pages 8 and 9).*

The NMT catalog contains epicenters and magnitudes for more than 2000 earthquakes with moment magnitudes of 1.3 or greater. Because of the geographic distribution of seismograph stations, earthquakes with magnitudes less than 2.0 could not always be located, particularly before 1982 near the outer borders of New Mexico and beyond. To limit any distortion in the geographic distribution of earthquakes, Figure 2 plots only epicenters for events of magnitude 2 or greater. Within the borders of New Mexico, there are 581 earthquakes with magnitudes of 2.0 or greater, 117 with magnitudes of 3.0 or greater, and 18 with magnitudes of 4.0 or greater.

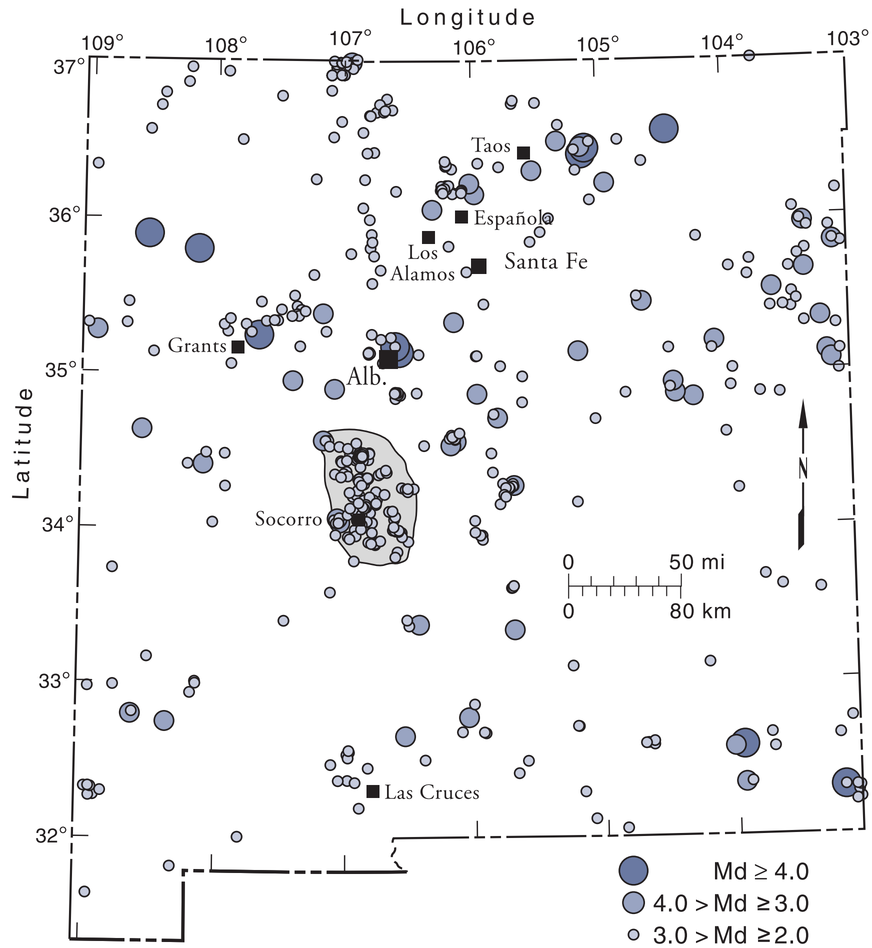

FIGURE 2—Seismicity of New Mexico from 1962 through 1998, moment magnitudes 2.0 or greater. A total of 581 earthquakes are plotted on this map, with 215 in the Socorro Seismic Anomaly (SSA; gray area above and in Figure 3). Symbols for epicenters of the smaller earthquakes (Md<3.0) in the Socorro Seismic Anomaly hide the locations of the larger earthquakes in that area.

Geographic Distribution of New Mexico Earthquakes

The most striking feature of the seismicity in *Figure 2* is the tight cluster of earthquakes in the Rio Grande valley near Socorro, a feature we call the Socorro Seismic Anomaly (SSA). The area within the SSA occupies 1.6% of the total area of the state but accounts for 37% of the earthquakes of magnitude 2.0 or greater, or 47% of the earthquakes of magnitude 4.5 or greater *(Table 1).* The SSA is believed to be the result of crustal extension over an inflating mid-crustal magma body. Researchers at NMT have determined that the magma body is ~150 meters thick, ~19 kilometers deep and has a lateral extent of 3400 square kilometers. Surveys of benchmarks indicate that the surface above the magma body is rising at a maximum rate of ~2 millimeters/year (Larsen and others, 1986; Fialko and Simons, 2001), presumably because of injection of new magma into the thin, extensive mid-crustal chamber.

In *Figure 2*, the pattern of seismicity outside the SSA is diffuse, and well-defined trends are not apparent. However, on a map of magnitude 3.0 or greater shocks *(Figure 3),* an interesting alignment of epicenters does appear. Extending east-northeast from the SSA into the Great Plains of eastern New Mexico is a band of epicenters that straddles the eastern end of a prominent topographic lineation that runs from southwestern Arizona through New Mexico to the

MEASUREMENTS OF EARTHQUAKE MAGNITUDE

(modified from "How Earthquakes are Measured" by Richard Aster, Lite Geology, Summer 1994)

The most commonly quoted measure of earthquake size is its **magnitude**. An earthquake's magnitude is intended to be reported as one number, but because there are several ways of measuring magnitude, the media may report earthquakes as having more than one or changing magnitudes that differ by one or two decimal points (6.5-6.7). The original earthquake magnitude scale was developed by Charles Richter in 1935 for California. If you want to impress your friends, here is a strict definition of the **Richter Magnitude**:

The base 10 logarithm of the maximum seismic-wave amplitude (in microns, or one one-millionth of a meter) recorded on a standard Wood-Anderson seismograph at a distance of 100 km from the epicenter, where the standard seismograph consists of a 5-gram mass suspended on a torsion wire with optical recording and electromagnetic damping. It has a period of 0.8 seconds and magnifies ground motion by a factor of 3000.

Mathematically, then, the Richter, or **local magnitude** is

$$M_l = \log_{10} (3000\ u_{max})$$

where u_{max} is the maximum ground displacement in microns. The specified seismometers magnify the ground motion 3000 times and record it as a series of **seismograms** that can be analyzed. Because of the base 10 logarithm in the definition, each unit increase in magnitude reflects a ten-fold increase in ground motion. An increase of two magnitude units corresponds to a ground motion increase of 10^2 or 100. The instrument calibration is such that the maximum seismogram amplitude expected from a Richter magnitude 5 earthquake 100 km away is about 100 mm. This corresponds to a maximum ground motion of about 33 microns, which is about 1/1000 of an inch. The expected ground motion for a magnitude 7 is 100 times greater (3300 microns or about 1/10 of an inch) which can easily be felt even 100 km away.

Another scale that is used to measure earthquakes at local distances (typically less than 100 km) is the **duration magnitude**, which assesses how long the seismic waves rattle around in the earth's crust before they become indistinguishable from the background noise. Its formula is

$$M_d = c_1 \log_{10} (d) + c_2$$

where d is the duration in seconds, c_1 is a constant, and c_2 is a factor used to make M_d approximately equal to M_l. A duration magnitude scale was developed for New Mexico at LANL by Dan Cash (a PhD graduate of NMT) and later confirmed at NMT by Jon Ake, Allan Sanford, and others. This duration magnitude scale is the standard used in monitoring New Mexico earthquakes today.

Many earthquakes around the world occur in remote regions (such as under the oceans) and are recorded only at **teleseismic** distances of 1000s of km away. Distant earthquakes produce two basic types of seismic waves that can be seen on seismograms recorded virtually anywhere on Earth. Each of these waves has its own associated magnitude scale. **Body waves** travel deep into the earth's mantle and core before reaching a particular station, while **surface waves** travel near the earth's surface. At teleseismic distances these two types of waves are quite distinct on seismograms (in contrast with seismograms recorded close to the source, which are characteristically a more complicated superposition of body waves and surface waves). Surface and body wave magnitudes may differ by several tenths of a magnitude unit, because shallower earthquakes release more energy near the Earth's surface and generate proportionately larger surface waves than deep earthquakes.

The formula for **body wave magnitude** is:

$$m_b = \log_{10} (A/T) + Q$$

where the standard practice in the United States is to measure the maximum amplitude, A, in microns of the initial arrival of body wave, T is its period in seconds, and Q is a term that depends on source distance and depth and minimizes the difference between m_b and other magnitude scales.

The formula for **surface wave magnitude** is:

$$M_s = \log_{10} (A/T) + 1.66 \log \Delta + 3.3$$

where A is the maximum surface wave amplitude, T is its period in seconds, and Δ is the source-to receiver distance in degrees (e.g., a quarter of the way around the earth would be $\Delta = 90^o$).

Note that all of these magnitude scales are empirical and relative. Some do not reflect the real sizes of very large earthquakes very well. What is needed is a way of estimating the physical processes that release energy during earthquakes. This may be done by considering the physics of fault slip. When a fault slips, the mechanical process is equivalent to a force operating on a lever arm or a mechanical **moment** (the units are torque, or Newton-meters). The **seismic scalar moment** of an earthquake is just the size of this torque, and is defined by

$$M_o = \bar{\mu} S \mu$$

where $\bar{\mu}$ is the average amount of slip on the fault, S is the area of the fault, and μ is a scale factor with units of force per unit area, or pressure, called the rigidity. The rigidity describes how hard it is to bend the rocks in the earthquake source region with a shearing motion. Both $\bar{\mu}$ and S can be estimated from modern seismograms and/or from ground rupture or aftershock patterns, while μ is estimated from laboratory rock squeezing experiments. The scalar moment helps define the **moment magnitude scale**:

$$M_w = 2/3 \log_{10} M_o - 6.0$$

This scale is preferred by earthquake experts because it can be measured and applied in several consistent ways and can be related directly to the physical fault processes.

The total amount of energy an earthquake released in the slipping of the fault is expressible in terms of the seismic moment:

$$E = M_o \; (\bar{\sigma}/\mu) = \bar{\sigma} S \bar{\mu}$$

where $\bar{\sigma}$ is the average shear stress (the force per unit area pushing the fault) along the fault surface during the earthquake. Typically, $\bar{\sigma}$ is on the order of 100 times the pressure of the atmosphere at the earth's surface or about 10^5 Newtons per square meter. This is a surprisingly low rate that reflects the fact that faults are quite weak relative to surrounding rocks.

Texas Panhandle–Oklahoma border *(Figure 3)*. The lineation, a possible Precambrian fracture zone we call the Socorro fracture zone, is defined by the line-up of many features such as rivers, elongate depressions, and faults (Thelin and Pike, 1991). We have determined that the alignment of epicenters coincident with the eastern end of this lineation is not accidental.

A large number of the earthquakes in northern New Mexico appear to be related to another northeast-trending lineation, the Jemez lineament (Aldrich and Laughlin, 1984). This geologic feature extends from southwest of Grants to Los Alamos and Española in the Rio Grande valley, and then on along an east-northeast track to beyond the northeast corner of the state *(Figure 3)*. The Jemez lineament is a leaky fracture zone defined by hundreds of magmatic eruptive centers, including the very large, but seismically quiet, Jemez volcanic complex just west of Los Alamos.

Perhaps the most unusual feature of the earthquake activity from

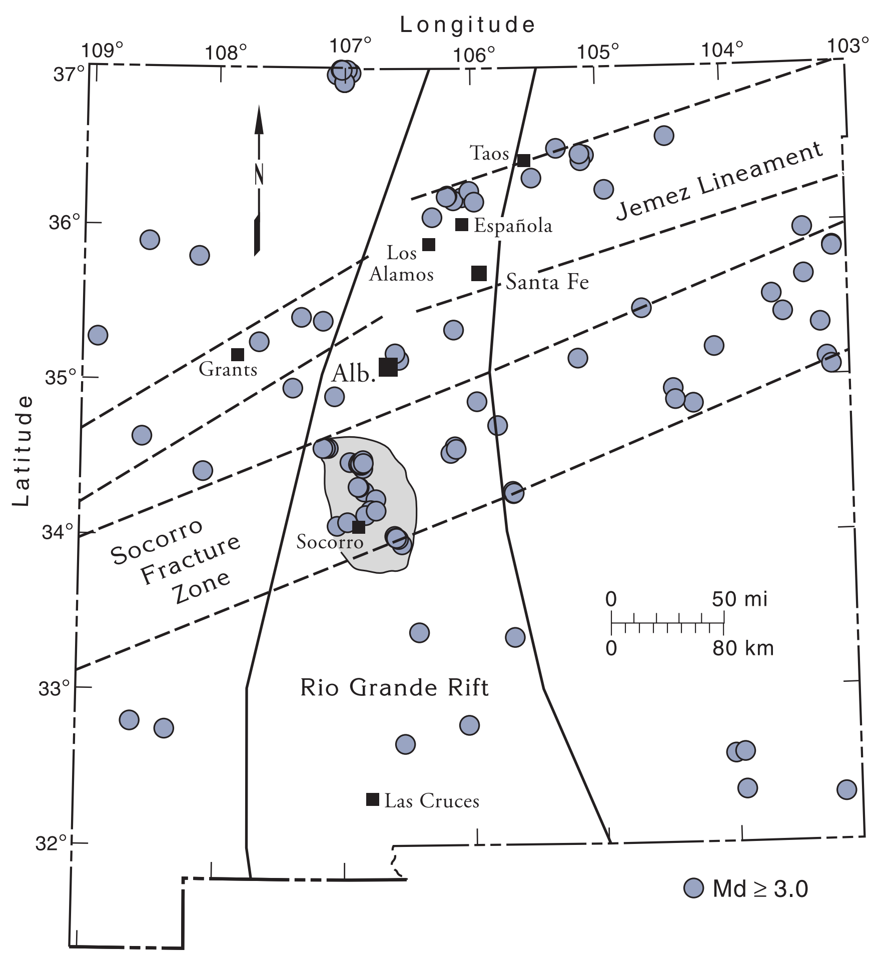

FIGURE 3—Seismicity of New Mexico from 1962 through 1998, with moment magnitudes 3.0 or larger. A total of 117 earthquakes are plotted on this map, with 36 in the Socorro Seismic Anomaly (SSA). Eighteen of the 81 events outside the SSA fall within the Socorro Fracture Zone. Also shown are the approximate boundaries of the Rio Grande rift and the Jemez lineament.

1962–1998 is its failure to define the Rio Grande rift *(Figure 3),* a major continental rift extending north-south through the state from north of Taos to south of Las Cruces (Chapin, 1971; 1979). The overwhelming majority of faults in New Mexico with Quaternary movements are associated with the Rio Grande rift (Machette and others, 1998), and yet earthquakes are absent or nearly so over much of its extent—for example, just south of Socorro to just north of Las Cruces *(Figure 2).*

The Bottom Line

The earthquake data we have accumulated over the past 40 years of research provides an estimate of the probable earthquake activity in New Mexico during the next 50 to 100 years. On the basis of 37 years of instrumental studies, the expected number of magnitude 2.0 or greater earthquakes each year is 16, and the expected number of magnitude 3.0 or greater shocks each year is about 3. Between 30% and 40% of these quakes will occur within a 5000-square-kilometer region near Socorro. On the basis of the 130-year history of felt and instrumentally recorded earthquakes *(Table 1),* a magnitude 4.5 or greater earthquake will occur on average once every 4.3 years. From this same history we know that a magnitude 6 or greater earthquake has not occurred in New Mexico since 1869. By contrast, the number of shocks of this strength in California over the same time period was about 150 (Toppozada and others, 2000).

The earthquake statistics indicate a low level of seismicity for New Mexico; for example, the 30 earthquakes of magnitude 4.5 or greater in the 130 years from 1869 through 1998 would be observed within about three years in California. However, we cannot be absolutely certain that the level of seismic activity in New Mexico in the future will be the same as in the past. A possibility exists that it could increase, and if so, the increase is most likely to occur in the Rio Grande rift where nearly all faults with known movement in the past 15,000 years are located (Machette and others, 1998) and where the majority of New Mexico's population resides.

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For more information on New Mexico earthquakes we recommend these two upcoming New Mexico Bureau of Geology and Mineral Resources publications:

Sanford, A. R., Lin, K., Tsai, I., and Jaksha, L. H.
Earthquake Catalogs for New Mexico and bordering areas:
NM Bureau of Geology & Mineral Resources, Circular 210

Machette, M. N., Personius, S. F., Kelson, K., Sanford, A. R., Lin, K., Dart, R. L., Bradley, L. A., and Jones, G.
New Mexico's young faults and historic earthquakes:
NM Bureau of Geology & Mineral Resources, Resource Map 24

Information can also be obtained from New Mexico Tech Geophysics Open-File Reports available at the following addresses:

http://dutchman.nmt.edu/~nmquakes
http://www.ees.nmt.edu/Geop/homepage

EARTHQUAKE EXERCISE AT ALAMOGORDO, NEW MEXICO

Evonne Gantz

New Mexico Office of Emergency Services and Security, New Mexico Department of Public Safety

More than two hundred people participated in a full-scale earthquake exercise in Alamogordo on August 4, 2001. The exercise, which simulated a magnitude 7 earthquake in the city, was designed to test the abilities of various agencies to respond to multiple incidents in a short period of time. The City of Alamogordo brought in participants from Otero County, the New Mexico National Guard, Holloman Air Force Base, the American Red Cross, the Salvation Army, Civil Air Patrol, Gerald Champion Regional Medical Center, American Medical Response, an amateur radio group, a confined space rescue team, emergency medical services, and several volunteer fire departments.

Alamogordo and the other participating agencies had extensive preparation leading up to the full-scale exercise. A tabletop exercise and a functional exercise in the winter and spring of 2001 preceded the event on August 4th. The tabletop and functional exercises, low to moderate stress events, respectively, were opportunities to discuss response options as well as work on interagency communication.

The full-scale exercise, a high stress event, involved mock victims and actual response efforts. Exercise participants responded to a simulated building collapse (the Space Hall of Fame), a propane fire at Cortez Gas, and a vehicular accident involving a military tanker leaking an unknown liquid. Search and Rescue personnel extracted a volunteer from a street drainage pipe (simulating conditions in a collapsed building) while several fire departments battled the propane fire at Cortez Gas. A hazardous materials team suited up to contain the unknown liquid that was leaking from the military tanker as emergency response teams went door to door in order to evacuate a neighborhood at risk from the spill.

Monitoring events in the field, Emergency Operations Center (EOC) participants procured and tracked resources for the on-scene responders, viewed images provided by the Civil Air Patrol (CAP) of the emergency sites, and gathered and disseminated vital information via radios and cell phones. In addition to the images provided by the CAP, Dr. David Love, Senior Environmental Geologist with the New Mexico Bureau of Geology and Mineral Resources, gave a slideshow presentation in the EOC during the exercise. Dr. Love's presentation illustrated the geologic results and damage to buildings by earthquakes, thus giving responders an idea of what type of damage to expect during a real event. EOC participants saw slides of damaged roads, broken pipes, collapsed buildings, liquefaction, and mudslides. They saw how a soft (relatively unsupported) first story of a building could collapse onto cars or ambulances, rendering the vehicles unusable. Slides of non-structural damage, such as a library in which all the books were haphazardly flung to the floor and a grocery store with its cans of food tossed off the shelves, demonstrated how preparedness and recovery efforts involve more than merely ensuring a building is secured to its foundation. Also included were pictures of a tent city, erected to shelter hundreds of displaced people after an earthquake in California. Dr. Love's presentation gave the participants an example of how devastating earthquakes can be as well as of the amount of clean up involved.

The lessons learned in the field, EOC, and Dr. Love's presentation made the exercise beneficial to all involved. Realizing that an earthquake would not single out the City of Alamogordo, but would affect the surrounding region as well, Alamogordo Emergency Management personnel choose to involve other jurisdictions, such as Holloman Air Force Base and Otero County, in the exercise.

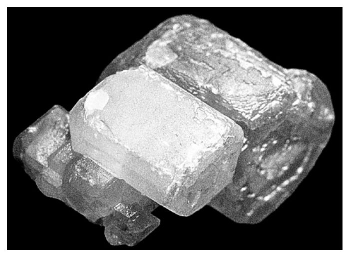
Although the exercise demonstrated that communication capabilities need to improve, participants nevertheless felt comfortable working with multiple agencies. Another important issue raised was that of sustainability. Alamogordo Emergency Management personnel, aware of how easily and quickly staff can be overextended, are looking into how to supplement staff during a long-term response and recovery event. While the participants acknowledge the need for further training, they feel more confident about handling potential future emergencies, no matter what type of disaster should occur.

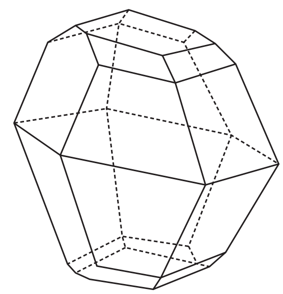
For more information on this exercise, or about conducting a similar exercise in your community, contact Evonne Gantz, Office of Emergency Services and Security, New Mexico Department of Public Safety, P.O. Box 1628, Santa Fe, NM 87504-1628; 505-476-9684

NEW MEXICO'S MOST WANTED MINERALS

Dr. V. W. Lueth, *NM Bureau of Geology & Mineral Resources Mineralogist*

SULFUR





DESCRIPTION: Most commonly bright "sulfur" yellow, sulfur can vary in color as green, red to yellow gray. It is an orthorhombic mineral so it tends to form blocky pyramid shapes but can also be needle-like to tabular (see crystal drawings). It is very soft with a hardness of 1.5 to 2.5 on the Mohs scale. It has three very poor cleavages so it tends to break with a conchoidal to uneven fracture. A very poor conductor of heat, it tends to feel warm in your hand. Very fine, transparent crystals can sometimes break from the heat of holding the crystals. When not in crystals, sulfur can be massive, reniform (kidney shaped), incrusting, stalactitic, stalagmitic, or powdery (pulvurulent).

WANTED FOR: The most common uses for sulfur are in the chemical industry, where almost half of the world's production is used. Fertilizers and insecticides are the next most abundant uses. Pulp and paper production also uses significant amounts of raw sulfur. Of course, it is also used to make gunpowder and explosives. Some sulfur is also used in the food products industry.

HIDEOUT: Sulfur is a bright yellow native element commonly associated with volcanic activity. It is also found with gypsum where it is formed as a byproduct of microbial activity. Look for little yellow grains in gypsum deposits. Sulfur is occasionally found in the weathering zone of ore deposits.

LAST SEEN AT LARGE: New Mexico is not known for large amounts of sulfur production, but some deposits have been mined in the past. Sulfur associated with volcanic activity has been mined in the Jemez area at Sulfur Springs and small deposits in a volcanic cone north of Tres Piedras. The sulfur occurs as beautiful acicular (needle-like) crystals lining the walls of vents. Large deposits of sulfur are found in Lechuguilla Cave near Carlsbad. In fact, Lechuguilla Cave contains more sulfur than any other cave in the world. Sulfur associated with weathering ore deposits has been reported from White Oaks (Lincoln Co.), La Bajada (Santa Fe Co.), Hansonburg (Socorro Co.), and Red Hill (Hidalgo Co.).

ALIASES: Also known as sulphur or brimstone.

Afield, Horseback

Steve Cather

Steve Cather is a Senior Field Geologist with the New Mexico Bureau of Geology and Mineral Resources. The following was written while he was mapping the geology of the San Felipe Pueblo NE 7.5' quadrangle during Spring 2000.

The wake-up call comes much too early. As I gather my field gear in the motel room, the Weather Channel confirms what is already quite obvious: today will not be the best day for field work. I throw my saddle into the truck and head up the hill to Placitas, where Sasquatch is stabled. The leaden clouds of an April storm obscure all but the base of the Sandia and Ortiz Mountains ahead.

Sasquatch, my sorrel gelding with his namesake oversize feet, is standing quietly in his stable when I arrive. He reluctantly accepts my bribe of grain as I halter him and lead him out to the horse trailer. He has carried me and my gear for several thousand miles of geological mapping during the past seven years; he has learned to anticipate the difference between short pleasure jaunts and real fieldwork.

As we head north on the interstate, blasts of wind buffet the truck and trailer. We exit at Santo Domingo and turn east into the 65-square-mile quadrangle of mixed tribal, federal, and private lands that I am currently mapping. I saddle Sasquatch as the first few drops of rain arrive on a cold wind. I lead him through a narrow horse gate in the barbed-wire fence and onto a broad tract of nearly roadless land, beyond which is one of the last blank areas on my quadrangle map. Being easily accessed by roads, most of the quadrangle I have mapped from the truck or afoot. But the few large roadless areas are most efficiently mapped on horseback, and this is my favorite part. Or at least it would be if the weather would cooperate.

I swing into the saddle and point Sasquatch southward down through some broken hills and into the broad valley below that is my mapping objective today. It is raining harder now, and my oilskin slicker is proving its worth. We ride up and down the various small arroyos that flank the valley, searching in their cutbacks for exposures of the sands and gravels that compose the fill of the Santo Domingo Basin. These exposures provide clues about the nature of the sedimentary fill of the basin, which in turn allow hydrologists to better understand the distribution of ground water in the basin.

It is pouring now, so I dismount and crouch beneath a juniper, trying to keep my map dry. Sasquatch stands hobbled nearby, dozing and steaming, with his tail to the wind. He likes this kind of weather better than I. Just when I am thinking of giving up for the day, the wind moderates and the sky begins to clear.

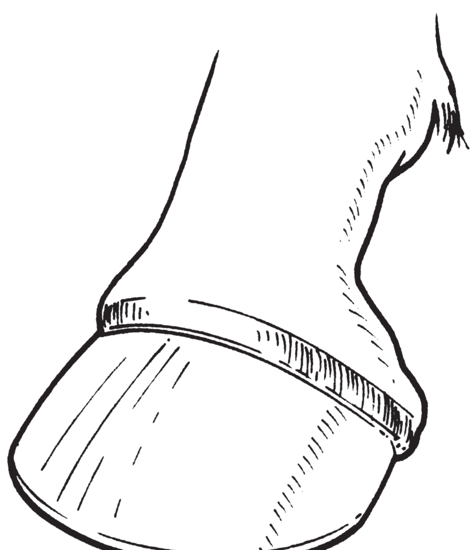
This is more like it, riding along and mapping in the bright sunlight. We haven't seen a soul all day. The country here is a gentle grassy borderland of the Rio Grande valley, cut by broad arroyo valleys that head in rolling, juniper-dotted hills to the east. We are mapping more quickly now, and I eat lunch in the saddle to save time.

There are four main tasks that I perform when mapping in basin areas. The first is to map lithologic contacts, which are the boundaries between the differing geological formations of the basin, as well as the boundaries of the more modern arroyo deposits and windblown sand that overlie and tend to obscure these formations. Second, I map faults, which are planes of slippage where rocks have been broken by movement of the earth's crust. I also measure the strike and dip of beds with a geologist's compass. This is a way to determine how much, and in what direction, the sedimentary strata of the basin have been tilted. Finally, I determine paleocurrent directions by measuring the orientation of pebbles and other features. With this information, geologists can tell the direction of flow of the ancient rivers that filled the basin over millions of years.

As we near our turnaround point about six miles from the truck, we unexpectedly come across a white bed of volcanic ash interbedded in the basin-fill sands and gravels along an arroyo. I sample the ash in hopes that later analysis of the naturally radioactive minerals in it will reveal its age, and thereby the age of the enclosing sediments. By knowing the age of the sediments that fill the basin, the evolution of the basin can be analyzed more precisely. As I collect the sample, I notice that the wind has shifted around to the north, and with it are more dark clouds.

It is time to head back to the truck, and good thing, too, as it is raining again, and the wind has turned colder yet. Realizing we're headed home, Sasquatch finds new inspiration as we head back through the country we mapped earlier in the day. I hunker beneath the sagging brim of my soaked hat and try to keep the rain off my glasses as we trot and lope up the valley toward the truck. Sasquatch mistakes our route and tries to veer up out of the valley to the north. But, having seen the broken hills of our earlier descent farther up the valley, I rein him back on course. As we approach the hills, even through my rain-spattered glasses it is quickly apparent something is wrong: I've never been here before. It is not until we rim out of the valley and spot the truck that I realize I should have listened to Sasquatch. We have ridden well past our goal.

The rain has turned to sleet and the sun has nearly set when we reach the truck. Sasquatch stands impassively as I unsaddle him. I wonder if he's gloating. I load him into the trailer, and we're on our way. As we merge with the interstate traffic streaming southbound from Santa Fe, I'm thinking this may not have been my best field day, but it was a memorable one.



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Sources for Earth Science Information

Make plans to celebrate Earth Science Week...

October 13–19, 2002

Increasing public understanding and appreciation of the earth sciences is of critical importance to our nation and to the geoscience profession. Since its inception in October 1998, Earth Science Week has been celebrated annually in every state and several countries. Through these activities, thousands of scientists, educators, and youth leaders have reached millions of students and individuals. This year, the theme for Earth Science Week is "**Water is All Around You.**" As in the past, Governor Gary Johnson has issued a proclamation declaring ***October 13-19, 2002*** as ***Earth Science Week in New Mexico.***

Interested teachers, students, parents, and citizens can visit the Web site at http://www.earthscienceworld.org/week/ for the latest news and information about Earth Science Week. Check out the activities page for adventures in modeling the interior of the earth, tracking earthquakes on your computer screen, cupcake coring, mineral identification, and geologic time. There is also a helpful checklist for those who want to organize an Earth Science Week in their own community. For more information on what to do in your area to celebrate Earth Science Week, contact **Michael J. Smith** at the **American Geological Institute** (AGI) by phone at (207) **230-0046;** or e-mail: **msmith@agiweb.org.**

The **American Geological Institute** is a non-profit federation of 40 scientific and professional associations that represent more than 120,000 geologists, geophysicists, and other earth scientists. AGI plays a major role in strengthening geoscience education, and strives to increase public awareness of the vital role the geosciences play in mankind's use of resources and interaction with the environment. More information about AGI can be found at http://www.agiweb.org. The Institute also provides a public-outreach web site, http://www.earthscienceworld.org.

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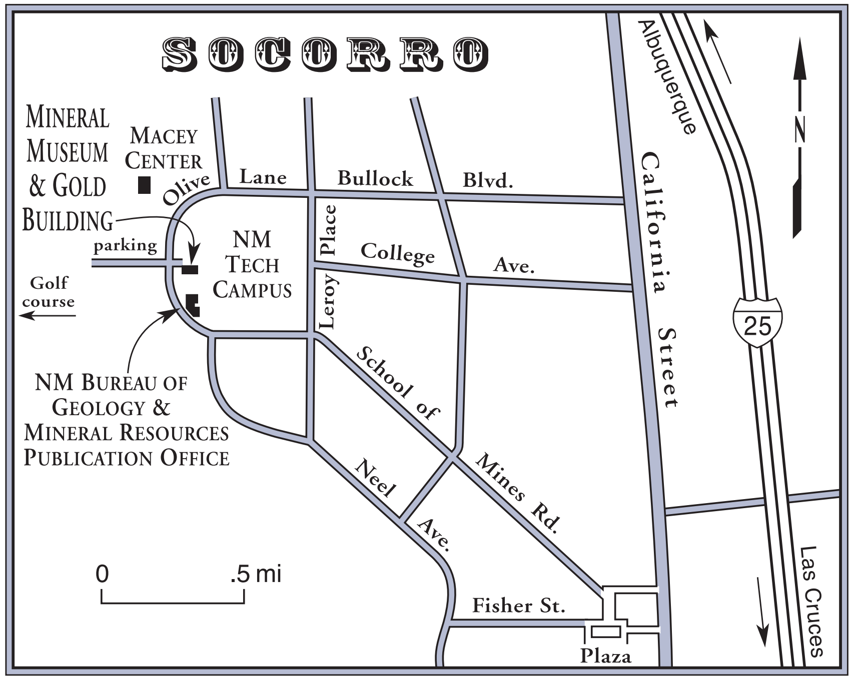
Visit the Mineral Museum

The Mineral Museum is located in the Gold Building on the campus of New Mexico Tech in Socorro. The bureau's mineralogical collection contains more than 13,000 specimens of minerals and rocks, along with mining artifacts and fossils.



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Museum Hours:

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