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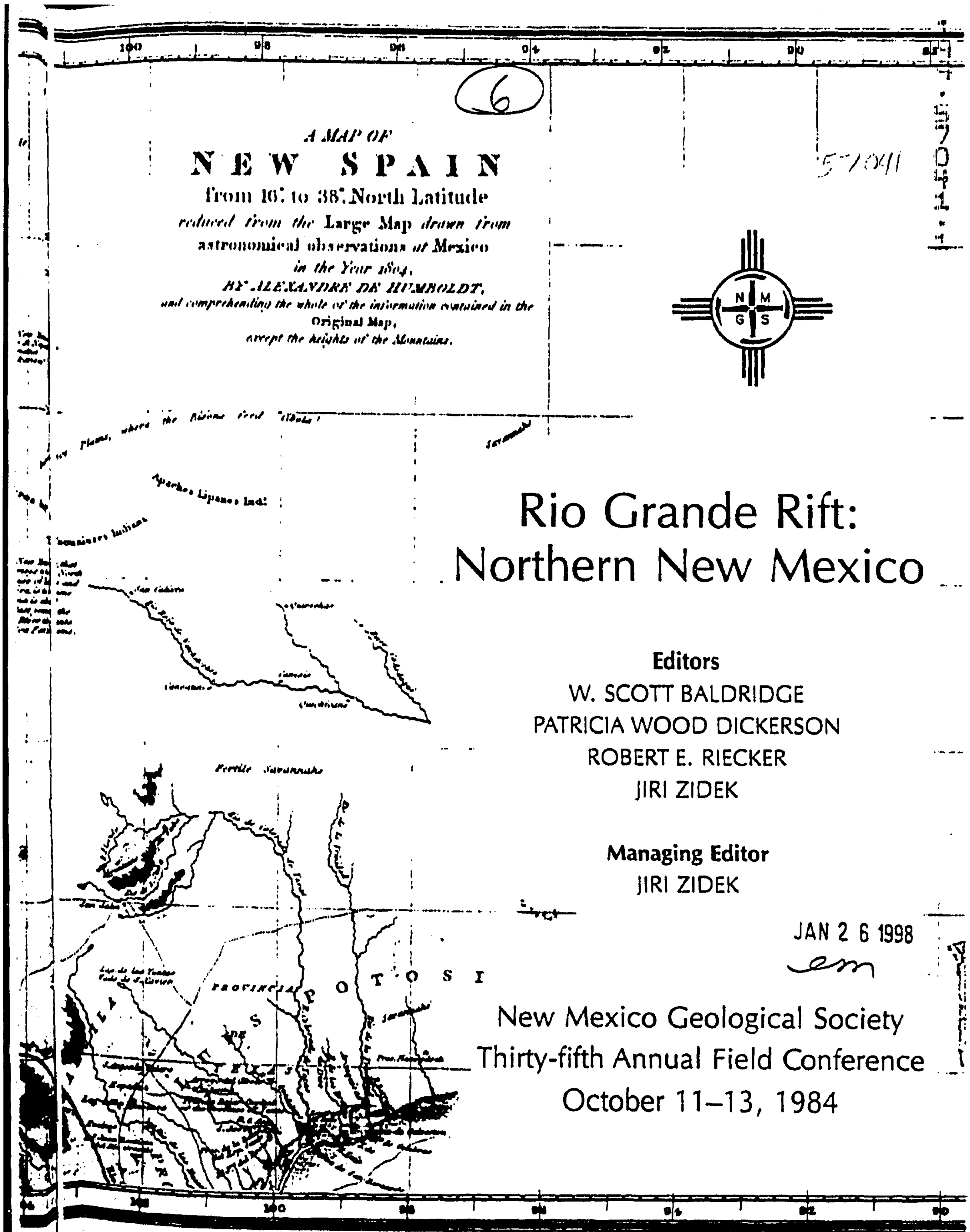

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Rio Grande Rift: Northern New Mexico

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SEISMICITY OF THE RIO GRANDE RIFT IN NORTHERN NEW MEXICO, 1973–1983

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INTRODUCTION

In the years before adequate seismograph coverage, reports of felt and damaging earthquakes in New Mexico came mostly from along the Rio Grande rift because most of the state's population was concentrated along the Rio Grande River, which lies within the rift. Even though the seismograph coverage is now fairly substantial and the population more widely spread, the picture is little changed. The Rio Grande rift and related structures continue to be the sites of most earthquakes, although earthquakes are occasionally felt in almost all areas of New Mexico.

The Los Alamos Seismograph Network (LASN) was begun in late 1973. Current LASN station locations are shown in Figure 1. Tectonic research on the Rio Grande rift was the principal reason for establishing the network. Continuous data of good quality have been acquired for about a decade; close to 2,000 earthquakes and microearthquakes have been recorded, analyzed, and cataloged. The largest event occurred in 1976, 60 km east–northeast of Gallup, and had a magnitude $M_L = 4.6$ ($m_b = 5.2$).

SEISMICITY–STRUCTURE RELATIONS

The seismicity of northern New Mexico based on LASN data (Fig. 2), although concentrated near the Rio Grande rift, is not entirely correlated with rift structures. Some epicenter patterns cut obliquely across the rift, some are associated with volcanism, and some outline pre-rift structure. Several noteworthy correlations between recorded seismic activity and geologic features are discussed below.

Calderas of the Jemez Mountains

Very few events have occurred within the calderas, despite the presence of numerous faults associated with ring fractures and resurgent doming (Cerro Redondo) that followed the formation of the calderas about 1 m.y. ago. This aseismicity may be attributed to high crustal temperatures or to the relief of stress on the surrounding active fault zones. The high heat flow of the caldera region is well known (Edwards et al., 1976). Both Los Alamos National Laboratory and Union Geothermal Company have major geothermal projects on the west side. In areas such as the Rio Grande rift, where basin geology and normal

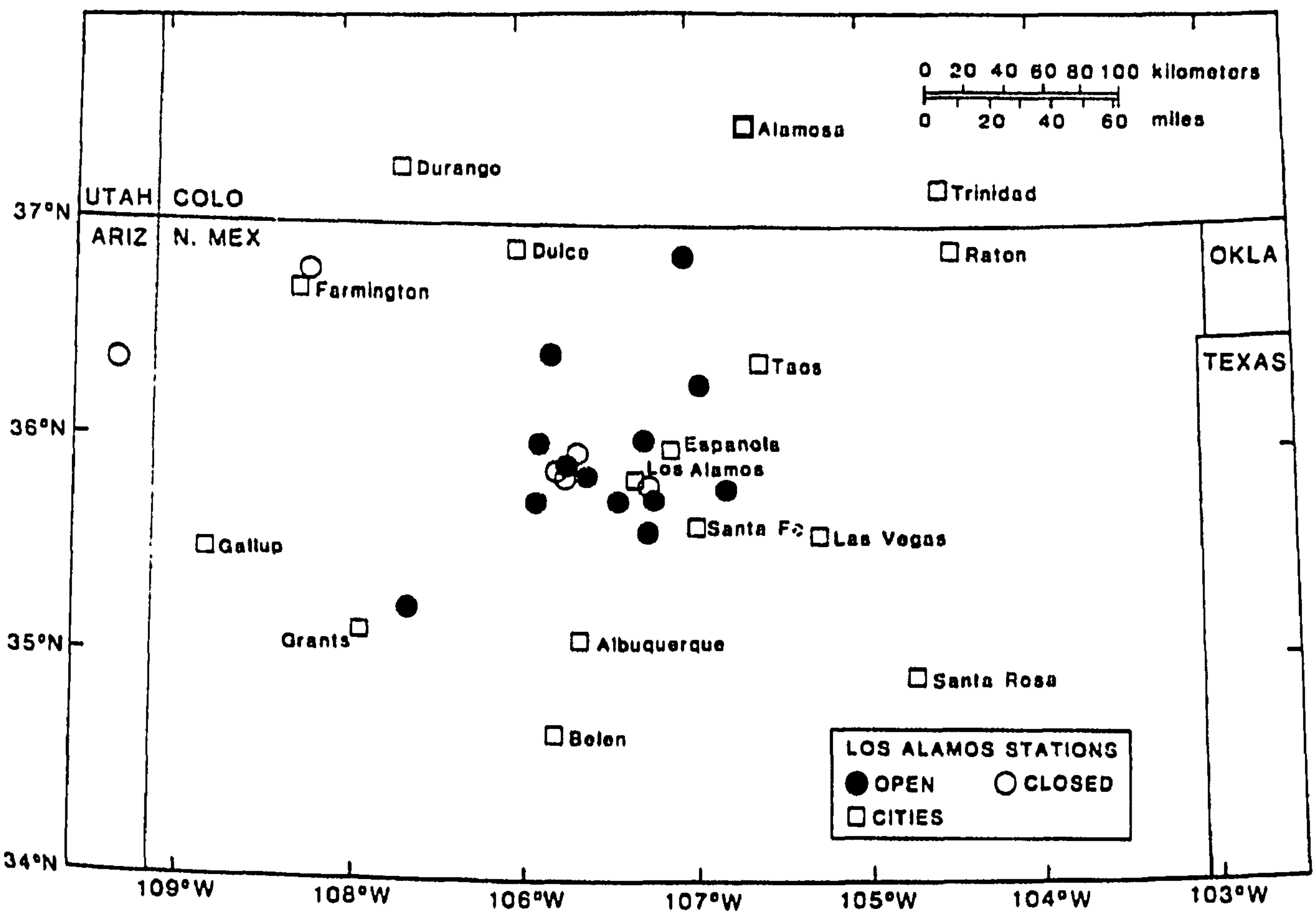

FIGURE 1. Map of stations of the Los Alamos Seismograph Network.

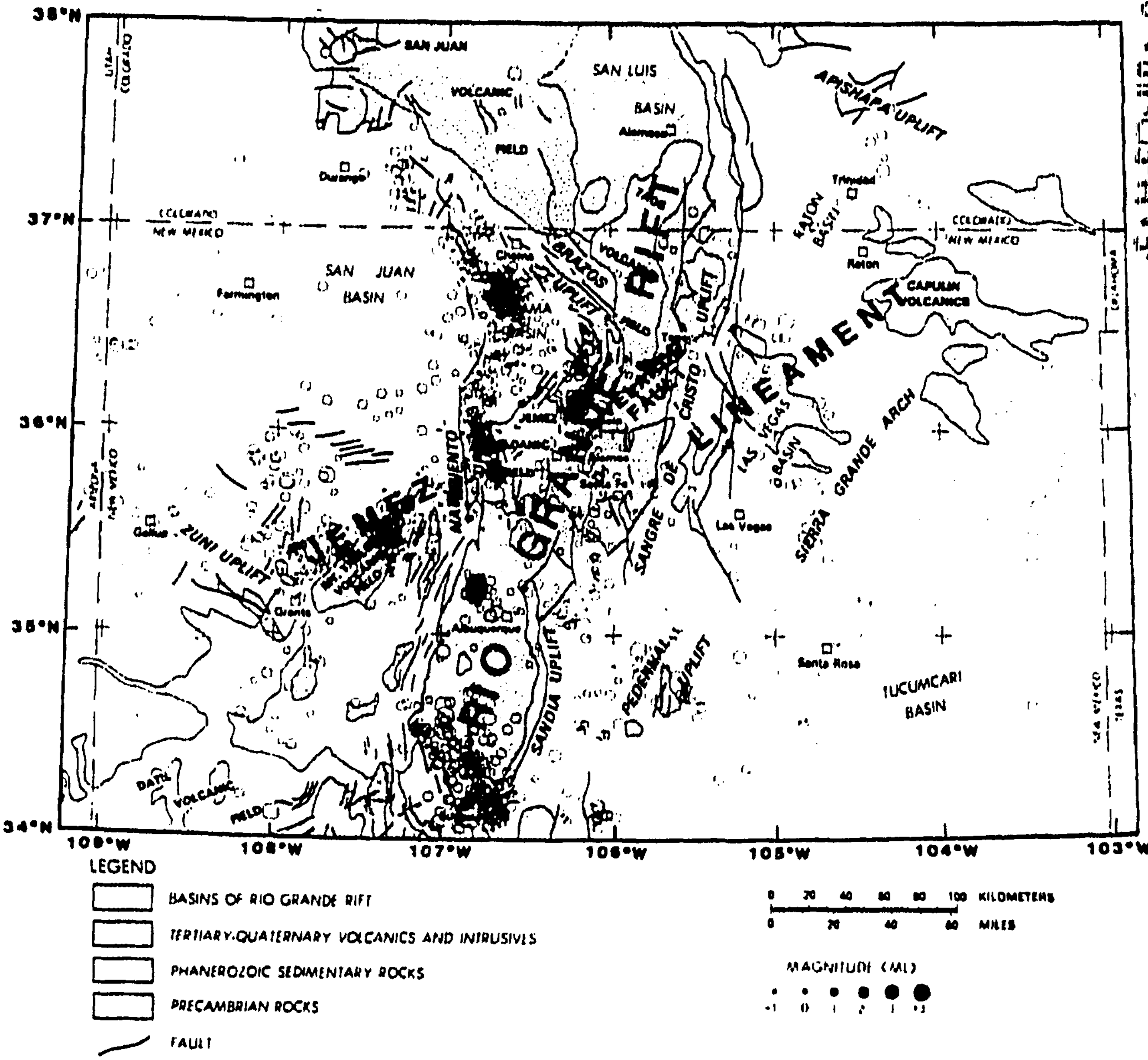

FIGURE 2. Map of earthquake epicenters for northern New Mexico, September 1973–December 1983.

faulting predominate, seismicity tends to be shallow. Where temperatures are high, the brittle nature of the crust at even shallow depths is replaced by a degree of ductility, making the process of brittle fracture or faulting much less probable. Stress that would increase to the breaking point in brittle rock is relieved through creep in the more ductile material. The absence of seismicity may also be attributed to stress being relieved on active fault zones immediately outside the calderas, most notably the north-south zones of activity along the Nacimiento uplift on the west and near the Rio Grande on the east.

San Felipe Fault Zone

Immediately to the south of the Jemez Mountains lies an area that appears seismically similar to the Jemez calderas. The region is nearly aseismic, surrounded by zones of marked seismicity, and contains a high density of normal faults no older than Pleistocene. These faults are particularly visible in the surficial Quaternary–Tertiary basalts of Santa Ana Mesa near the center of the aseismic area (Smith et al., 1970). Little is known about heat flow in this region, so speculation about the cause of aseismicity has little foundation at present.

Nacimiento Uplift

The zone of concentrated epicenters on the west side of the Jemez Mountains lies on the Nacimiento uplift. The uplift was formed in Laramide time by reverse or high-angle thrust faulting upward toward the west; thus the Nacimiento fault dips to the east under the uplift and is the probable source of the seismicity. The tectonic stresses are much different now than during the Laramide time. The Nacimiento fault was originally a result of east–west compressional tectonics. In contrast, the present-day rift structures are more consistent with east–west extensional tectonics. Apparently, the Nacimiento fault is a zone of crustal weakness that has been reactivated by the tectonic processes of rift formation. Fault-plane solutions for Nacimiento events would contribute to answering questions about contemporary tectonics in the Nacimientos, but results of fault-plane analyses have so far produced ambiguous results.

Induced seismicity occurs during hydraulic-fracturing experiments at Los Alamos' Hot Dry Rock (HDR) geothermal project on the west side of the Jemez Mountains. The HDR-project site lies along the east edge of the seismically active region of the Nacimiento uplift. The several hundred microearthquakes that have been induced are not shown in Figure 2 because they are too small to be located by the permanent network, and are too numerous to be shown. A temporary network of nearby seismographs is used to record and research the HDR microquake activity.

Gallina–Archuleta Arch

North of the Nacimiento uplift, the seismic activity closely follows the Gallina–Archuleta arch to the Colorado border. The epicenter of the Dulce earthquake of 1966 lies in this zone. The earthquake had a magnitude $m_b = 5.5$ (Herrmann et al., 1980), a maximum intensity of MM VII on the Modified Mercalli scale, and caused moderate damage.

The concentration of approximately 150 events 30–40 km south-southwest of Chama is the site of El Vado and Heron reservoirs. Nearly two-thirds of the events occurred in 1982, although some seismic activity has occurred there every year. The largest magnitude recorded was $M_L = 2.7$ ($m_b = 3.8$). This may be a case of reservoir-induced seismicity (RIS) in which tectonic stress is being released prematurely by either the weight of the reservoir or the production of abnormally high pore-fluid pressure. In contrast, the nearby Abiquiu reservoir on the north side of the Jemez Mountains does not manifest an abnormal level of seismicity, perhaps because less tectonic stress exists there as evidenced by lower seismic activity in general north of the Jemez Mountains.

Jemez Volcanic Lineament

At the south end of the Nacimiento seismic zone the trend of epicenters turns to the southwest and is coincident with (at least as far as Grants) the Jemez volcanic lineament (Mayo, 1958), a line of extrusive volcanics. Near Grants, basalts as young as 1,000 years (Nichols, 1946) are visible along Interstate 40. The lineament intersects the west side of the Rio Grande rift at the Jemez Mountains. On the east side of the rift, the lineament continues northeastward, but is offset to the south as though some north–south right-lateral displacement has occurred along the rift. Where the lineament meets the southwest edge of the Jemez Mountains, the seismicity lies on the San Diego fault near Jemez Springs. The San Diego fault is colinear with the southwest portion of the lineament, which suggests a correlation between volcanism, faulting, and seismicity.

Velarde Fault

Northeast of the Jemez Mountains seismicity continues northeastward, colinear with the seismic zone to the southwest. Here it follows the trace of the Velarde fault, extending through and to the northeast of Taos. This activity is somewhat to the north of the Jemez volcanic lineament on this side of the rift. There is a concentration of events northwest of Española where the Velarde fault projects to the Pajarito fault zone, and the northeast trend of epicenters crosses another trend oriented north–south. This area of seismicity, which lies about 25 km north of Los Alamos, has been the site of earthquakes felt generally throughout the Los Alamos–Española region, four of them since the town of Los Alamos was established in the early 1940's. One occurred in 1952, two in 1971, and one in 1973. All of these occurred before the establishment of the LASN, and, therefore, the epicenters are not precisely known. The first two may have been very near Los Alamos, while the last two are estimated to have occurred about 25 km north of there. The seismicity along the Velarde fault and that along the San Diego fault are separated by the aseismic region of the Jemez calderas.

Pajarito Fault Zone and the Española Basin

The Pajarito fault, a major vertical offset downthrown to the east, occurs on the east side of the Jemez Mountains just west of Los Alamos. The fault offsets the Bandelier Tuff 100–150 m at Los Alamos (Bailey and Smith, 1978). Despite its relatively recent age and significant displacement, the Pajarito fault was not very active near and south of Los Alamos in the 10-year period of coverage in Figure 2. This observation must be accompanied by caution, because 10 years is an extremely short interval for drawing conclusions about absolute levels of seismicity. North of Los Alamos the Pajarito fault zone becomes quite active. This activity is part of a band of epicenters that runs from an area northeast of Abiquiu almost due southward along the center of the Velarde graben in the Española Basin (Manley, 1979) and on to the Tijeras Canyon east of Albuquerque. From there the seismic trend turns westward through Albuquerque to the volcanoes on the city's West Mesa.

Albuquerque Volcanoes

In 1978–1979, a swarm of approximately 160 small earthquakes occurred near the volcanoes on Albuquerque's West Mesa. A few events still occur there, but 95% occurred within a period of 15 months. The largest recorded magnitude was $M_L = 2.4$ ($m_b = 3.6$). This activity and that along the Jemez volcanic lineament suggest that volcanism-induced stresses are still occurring in these regions. A detailed investigation of the swarm is reported by Jaksha et al. (1978).

GENERAL DISCUSSION

Information about earthquakes that occurred in New Mexico before 1962 is quite sketchy. The first high-magnification seismograph in the state was installed at Albuquerque in 1959. The World-wide Seismograph Station Network (WWSSN) was begun in the early 1960's and included a station in Albuquerque installed in 1961. New Mexico Institute of Mining and Technology installed another one at Socorro in 1962. Before then, the only reports of New Mexico earthquakes were from people who experienced the effects. Such reports are subject to the imagination of the reporter and tend toward exaggeration and misinterpretation of observations. Often earthquakes large enough to be felt go completely unnoticed, or at least unreported, if they occur in an area where the population density is low. Even when reported from low-population regions, estimates of the epicenter locations can be in error by many kilometers.

The seismic history of New Mexico includes several earthquakes that caused moderate damage and frequent events that were felt locally. Earthquakes that have caused moderate damage include those at Socorro in 1906 (Reid, 1911; Sanford, 1963), Cerrillos in 1918 (Olsen, 1979), and Dulce in 1966 (Cash, 1971; Hermance et al., 1980). Earthquakes have been felt in almost all parts of the state, but most often along the Rio Grande River, in part due to the higher population density there (Northrop, 1976, 1982). That no tremor has been severe is not surprising. Very strong shocks usually occur in subduction zones, as in Japan, Alaska, and South America, or on long transform (strike–slip) faults such as found along the San Andreas fault system in California. Severe shocks are much less common in areas of extensional tectonics, where normal dip–slip and short transform faulting predominate. The Rio Grande rift is an example of extensional tectonics in a generally east–west direction, although some structural evidence exists for strike–slip displacement parallel to the rift, i.e., approximately north–south.

Although New Mexico's level of observed seismicity is only about 5–10% that of highly active areas of California, the potential for seismic disaster exists. The LASN was established by the Los Alamos National Laboratory in 1973 to address the seismic-hazard question and to pursue research on the local structure and tectonics. There are currently 15 stations in the network. About the same time, the U.S. Geological Survey (Albuquerque Seismological Laboratory) installed a network of seismographs to the south of the Los Alamos network. These two networks and the New Mexico Institute of Mining and Technology seismographs provide excellent coverage of the Rio Grande rift region of New Mexico from south of Socorro to the Colorado border. The three institutions continue frequent exchange of pertinent seismic data.

REMARKS ON THE DATA

Los Alamos publishes a quarterly catalog containing a list of earthquakes and a seismicity map (see, for example, Cash et al., 1983).

Figure 2 is a plot of all events listed in the catalogs for the period September 1973 through December 1983. We believe that very few non-earthquake events are included. Careful effort has been devoted to locating the sources that are explosions produced by mining and construction activities. Other man-made events, such as sonic booms from supersonic aircraft, are readily identifiable by the character of their seismic signal or by their relative time of arrival across the network.

The accuracy of epicenter locations varies widely, dependent on the number and proximity of seismograph stations. We believe that epicenters of events large enough to be recorded at five or more stations and located within the network are determined correctly within 3 km. Because of this uncertainty, attempts are usually not made to associate a specific event with a specific fault. But where trends of events can be seen to lie on or near a fault or fault zone, the correlation becomes credible and is included in the discussion in this paper. Because of low station density and complex velocity structure, few depths are well determined. Depth calculations are much more susceptible to poor velocity control than epicenters. Events whose depths are reliably determined are usually shallow, i.e., less than 10 km and often between 0.5 and 5.0 km.

Magnitude is determined from the measured duration of each event, defined as the time interval from the arrival of the first P wave until the signal level drops to the level of the background noise. The formula we derived for this purpose is

$$M_L = 2.79 \log T - 3.63$$

where T is the event duration in seconds and log is the common logarithm (base 10). The formula was obtained by correlating the duration of local events with the value of M_L calculated from records of the standard Wood–Anderson torsion seismometers at the WWSSN station, ALQ, in Albuquerque. It is therefore nominally the same magnitude scale as the local magnitude scale derived by C. R. Richter for use in California. Our values of M_L compare very well with those published by the U.S. Geological Survey for earthquakes occurring in New Mexico and Arizona.

REFERENCES

Bailey, R. A., and Smith, R. L., 1978, Volcanic geology of the J tains, New Mexico; *in* Hawley, J. W. (compiler), Guidebook t rift in New Mexico and Colorado: New Mexico Bureau o Mineral Resources, Circular 163.

Cash, D. J., 1971, The Dulce, New Mexico, earthquake of Janu location, focal mechanism, magnitude, and source paramete sentation, *New Mexico Institute of Mining and Technology,*

———, Olsen, K. H., Stewart, J. N., and Wolff, J. J., 1983, Earth for northern New Mexico, October–December 1982. Los Ala Laboratory, LA-9782-PR.

Edwards, C. L., Reiter, M., Shearer, C., and Young, W., 1978, T flow and crustal radioactivity in northeastern New Mexico Colorado. Geological Society of America, Bulletin, v. 89, pp

Herrmann, R. B., Dewey, J. W., and Park, S., 1980, The Dulce, earthquake of 23 January 1966. Seismological Society of Ame v. 70, no. 6, p. 2171.

Jaksha, L. H., Locke, J., and Gebhart, J. H., 1981, Microearthq Albuquerque volcanoes, New Mexico. Geological Society Bulletin, v. 92, pp. 31–36.

Manley, K., 1979, Stratigraphy and structures of the Española Basi rift, New Mexico; *in* Riecker, R. E. (ed.), Rio Grande rift: magmatism: American Geophysical Union.

Mayo, E. B., 1958, Lineament tectonics and some ore districts of t AIME, Transactions, pp. 1169–1175.

Nichols, R. L., 1946, McCartys basalt flow, Valencia County, Geological Society of America, Bulletin, v. 57, pp. 1049–1

Northrop, S. A., 1976, New Mexico's earthquake history, 1849- tonics and mineral resources of southwestern North America: Geological Society, Special Publication 6, pp. 77–87.

———, 1982, Earthquakes of Albuquerque country: New Mexi Society, Guidebook 33, pp. 171–178.

Olsen, K. H., 1979, The seismicity of north-central New Mexico reference to the Cerrillos earthquake of May 28, 1918: New logical Society, Guidebook 30, pp. 65–75.

Reid, H. F., 1911, Remarkable earthquakes in central New Mexic 1907. Seismological Society of America, Bulletin, v. 1, pp.

Sanford, A. R., 1963, Seismic activity near Socorro: New Mexi Society, Guidebook 14, pp. 146–151.

Smith, R. L., Bailey, R. A., and Ross, C. S., 1970, Geologic ma Mountains, New Mexico: U.S. Geological Survey, Miscellan Investigations Map I-571.