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Allan R. Sanford, Lawrence Jaksha, and Daniel Wieder

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SEISMICITY OF THE SOCORRO AREA OF THE RIO GRANDE RIFT

ALLAN SANFORD
Geoscience Department and Geophysical Research Center
New Mexico Institute of Mining and Technology
Socorro, New Mexico 87801

LAWRENCE JAKSHA
United States Geological Survey
Socorro, New Mexico 87801

and

DANIEL WIEDER*
Geoscience Department and Geophysical Research Center
New Mexico Institue of Mining and Technology
Socorro, New Mexico 87801

INTRODUCTION

The Socorro area has long been recognized as a region of unusual seismic activity; the mode of occurrence is primarily in swarms and the intensity of earthquake activity, both in numbers and strengths, is the highest of any area along the Rio Grande rift (Bagg, 1904; Reid, 1911; Northrop, 1945 and 1947). Considerable effort has been devoted to documenting and understanding the seismicity of this region. Studies based primarily on reports of felt earthquakes, the only data available prior to 1960, have been published by Sanford (1963) and Northrop (1976). Papers emphasizing the results of instrumental studies are numerous, but those which best summarize the seismicity of the Socorro area and its relation to activity elsewhere along the rift are Sanford and others (1972) and Sanford and others (1979). The purpose of this paper is to review results of recent instrumental studies and to suggest a possible mechanism for the unusual seismicity of the Socorro area.

RECENT SEISMIC ACTIVITY

In early 1982, the United States Geological Survey (USGS) and New Mexico Tech (NMT) began a cooperative program of monitoring seismic activity in the Socorro area. By June 13, 1982, signals from five local stations and a station at Albuquerque were being telemetered into the NMT campus. Three additional local stations were added on September 1, September 16, and December 1, 1982, and a station approximately 40 km north of the local network began operation September 16, 1982. Transmission from the Albuquerque station ceased December 29, 1982. Therefore, since June 13, 1982, readings from six to ten stations have been available for determination of strengths and locations of earthquakes in the Socorro area.

Shown in Figure 1 is a map of epicenters for the period of June 13, 1982, through May 15, 1983. Plotted are epicenters for 275 earthquakes ranging in strength from magnitude — 0.5 to 4.0. The epicenters were calculated using the algorithm HYPO 71 Revised (Lee and Lahr, 1975) with a half-space crustal velocity of 5.85 km/sec and a Poisson's ratio of 0.25 (Ward and others, 1981). Errors in epicentral location (ERH in HYPO 71) average 1.3 km with a standard deviation of 1.0 km. As expected, errors in focal depth (ERZ in HYPO 71) are greater, averaging 3.2 km with a standard deviation of 2.0 km. These errors are influenced in part by the crustal structure used in the location program. Because the half-space model is only an average of crustal structure over the area, the true errors in hypocenter coordinates will be greater than those calculated.

Magnitudes of the earthquakes were calculated from durations of ground motions on the seismograms using an empirical equation derived by seismologists at Los Alamos National Laboratory for northern New Mexico earthquakes (Newton and others, 1976). Our own study indicates that the equation is applicable to earthquakes in the Socorro area in the magnitude range of 1 to 4 but it appears to progressively underestimate magnitudes for shocks weaker than magnitude 1.

The total number of locatable earthquakes from June 13, 1982 to May 15, 1983, was considerably greater than the 275 events shown on Figure 1. A significant part of the total activity occurred in two major earthquake swarms and numerous smaller ones. Generally only the stronger events within a swarm were located.

The first major swarm occurred from February 25 to March 12, 1983, and was centered at 34.32°N and 106.88°W. Approximately 330 shocks in the swarm had magnitudes ranging from —0.5 to a maximum of 4.0. The second swarm occurred from May 10 to May 14, 1983, and was centered at 34.06°N and 106.96°W. Approximately 20 shocks in this swarm had magnitudes ranging from — 0.5 to a maximum of 1.9.

A few months prior to full operation of the Socorro seismic network, two other major swarms were recorded in the area. From April 4 to April 20, 1982, a swarm centered at 34.16°N and 106.79°W generated about 65 earthquakes in the magnitude range from —0.5 to a maximum of 2.1. Eight days later, from May 8 to June 3, 1982, a swarm centered at 34.07°N and 106.86°W generated approximately 115 earthquakes above magnitude — 0.5. The three largest quakes of this swarm had magnitudes of 2.8, 2.8, and 3.3.

The seismic activity in the interval April 4, 1982, to May 15, 1983, was above normal both in number of major swarms and number of "felt" or perceptible shocks. Felt earthquakes generally have magnitudes greater than or equal to 2.8 in the Socorro area. Earthquakes exceeding this magnitude occurred five times during the major swarms and once in a minor swarm centered at 33.95°N and 107.06°W. The magnitude 4.0 earthquake during the 15-day February—March, 1983, swarm was the strongest earthquake in the Socorro area since an event during a swarm in July, 1960 (Sanford and Holmes, 1961). The 1960 swarm was initially located at 34.36°N and 107.04°W but a later calculation placed it 25 km to the east at 34.36°N and 106.77°W. This location, which has an uncertainty of approximately ± 5 km, is very close to or within the region of highest activity in Figure 1.

The pattern of activity in Figure 1 is similar to that obtained in all earlier studies (Sanford and others, 1972; Sanford and others, 1979) although the regions of most intense activity appear to shift with time. In general, the pattern has included an —10-km wide central zone of activity along longitude 106.9°W from —34.1°N to —34.4°N. Radiating outward from the central zone to the northwest, southwest, southeast,

*Now with Phillips Petroleum, Bartlesville, Oklahoma.

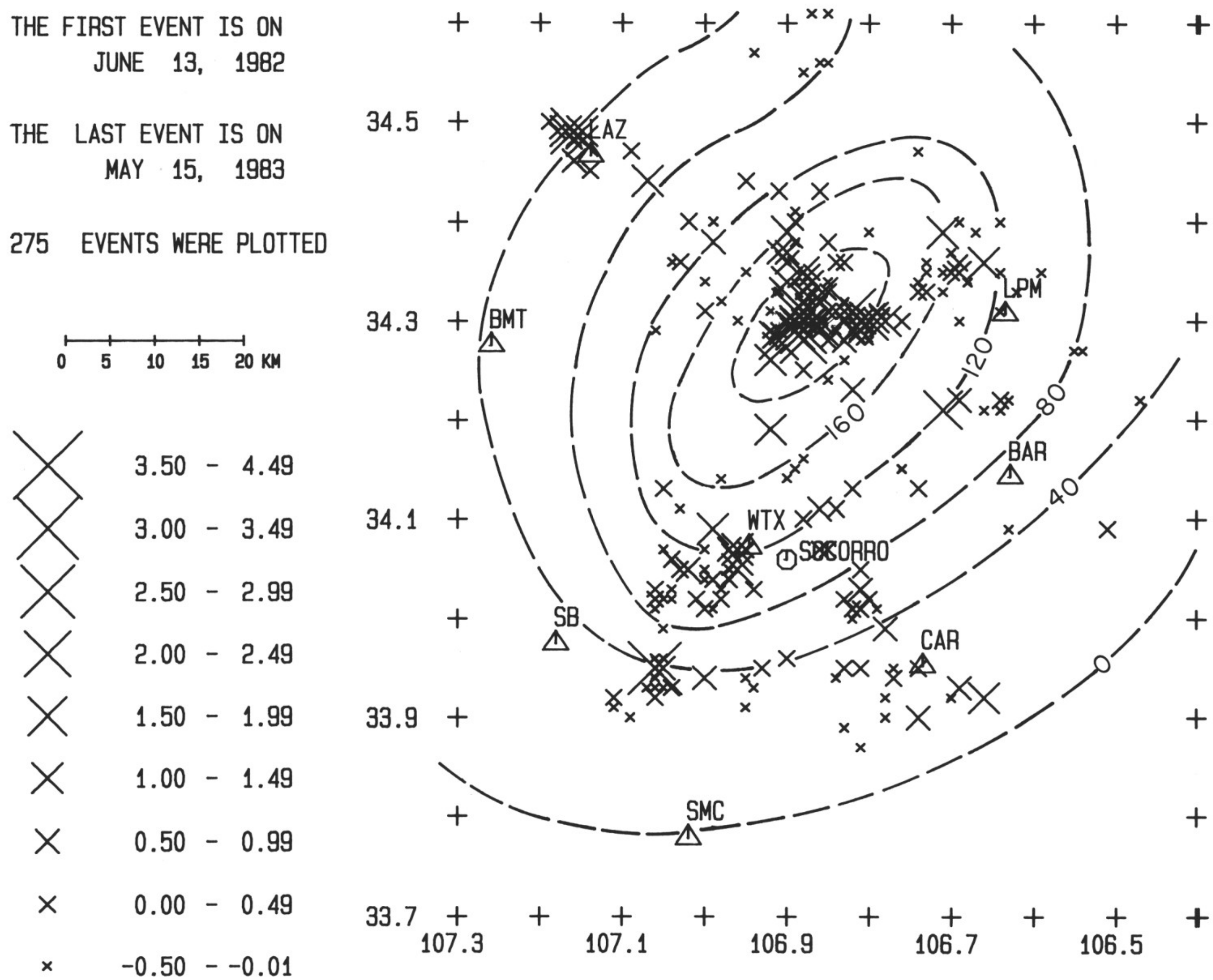

Figure 1. Seismicity of the Socorro area for the period June 13, 1982, to May 15, 1983. The contours are surface uplift in millimeters for a 40-year period (Reilinger and others, 1980). The triangles mark the location of stations in the present permanent seismic network.

and northeast are diffuse zones of activity with those to the northwest and southwest better defined than those in the other quadrants.

Some indication of temporal variations in the location of the most intense seismic activity can be seen by comparing Figures 2 and 3. Figure 2 is a plot of the epicenters in Figure 1 using the same size symbol for all earthquakes regardless of magnitude. Figure 3 is a similar plot of epicenters for the period May 20, 1975 through January 20, 1978 (Wieder, 1981). Recording for the latter period was with a movable array of four to seven stations which was deployed for 316 days during the 32-month interval. The distribution of stations for the recording period favored location of earthquakes south of 34.3°N (Wieder, 1981). However, the concentration of seismic activity to the southwest of station WTX in Figure 3 also appears on a seismicity map developed by the USGS—Albuquerque Seismological Laboratory (see fig. 5 of Sanford and others, 1979). The USGS map covered the two-year period 1976-1977 and was based on data from a fixed array of stations that favored location of earthquakes to the north of 34.3°N.

DEPTHS OF FOCUS

The present network is the best ever deployed for defining the geographic distribution of epicenters throughout the Socorro area (from 33.7°N to 34.6°N and from 106.4°W to 107.2°W). However, the stations are rather widely separated and tightly constrained focal depths are not commonly obtained.

The data shown in Figure 3 were obtained with movable networks whose station spacing was substantially less than the present network. From the total data set shown in Figure 3, it was possible to extract 336 hypocenters whose depth and epicentral errors were less than 1.1 km (Wieder, 1981). Focal depths for this data set range from 4 to 14 km with only 4 percent at depths less than 6.5 km and only 8 percent at depths greater than 11.5 km. The sharp cutoff in number of hypocenters in the depth interval between 11.5 and 14 km indicates a rapid decrease in the rigidity of crust. Other evidence for a ductile zone in the lower half of the upper crust is presented in Rinehart and others (1979).

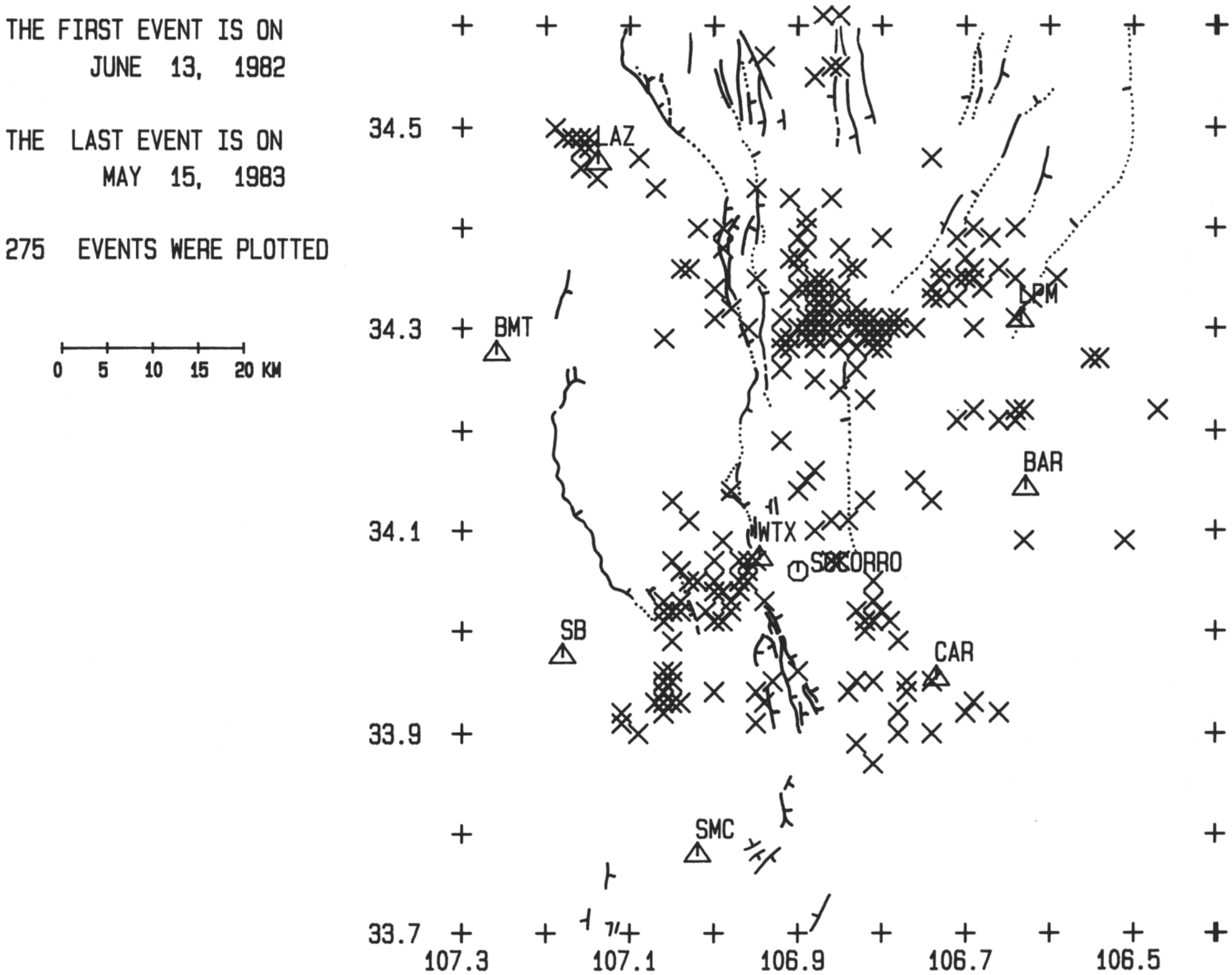

Figure 2. Seismicity of the Socorro area for the period June 13, 1982, to May 15, 1983. Faults shown are Pliocene or younger in age (Machette and McGimsey, 1982; Machette, unpublished data). The triangles mark the location of stations in the present permanent seismic network.

FAULT PLANE SOLUTIONS

From the data set shown in Figure 3, constrained composite fault-plane solutions were obtained for seven regions south of 34.35°N (Wieder, 1981). Six of the seven solutions have nearly pure normal dip-slip movement, with their T axes close to the same orientation, azimuth N75E (± 10° s.d.) and plunge 7.7° (2.8° s.d.).

The dips of the nodal planes for these six solutions range from 36° to 60° and average 46°. The average focal depth for earthquakes used in the solutions is 9 km. If faulting at this depth is assumed to be listric on fault planes whose dips are the average of the observed nodal-plane dips (46°), then the average minimum depth at which the listric faults can become flat is 13 km.

The seventh composite fault-plane solution is for events near 34.3°N and 106.9°W. This solution has significant strike-slip motion as well as normal dip-slip motion; one nodal plane strikes N8W with an unusually low dip of 30° and the other strikes N68W with an unusually high dip of 74°. The T axis for this solution has a N42E azimuth and a 26° plunge. Preliminary analysis of the first-motion data for the main shock in the February 25—March 12, 1983 swarm, which is located in the same area, indicates a mechanism more in agreement with the other solutions, that is, dominantly normal dip-slip motion on a north-south striking fault plane. However, first motions for some of the other earthquakes in the swarm indicate that faults with other orientations also were active. Three fault-plane solutions obtained by the USGS—Albuquerque Seismological Laboratory (see fig. 6 in Sanford and others, 1979) in the region 34.3°N to 34.5°N show considerable variation in type and orientation of fault motion. Collectively, the first motion data suggest great structural complexity over the topographic and structural constriction separating the Albuquerque and Socorro basins.

RELATION OF SEISMICITY TO PLIOCENE AND YOUNGER FAULTS

Shown in Figures 2 and 3 are Pliocene and younger faults (Machette and McGimsey, 1982; Machette, unpublished data, 1983) as well as

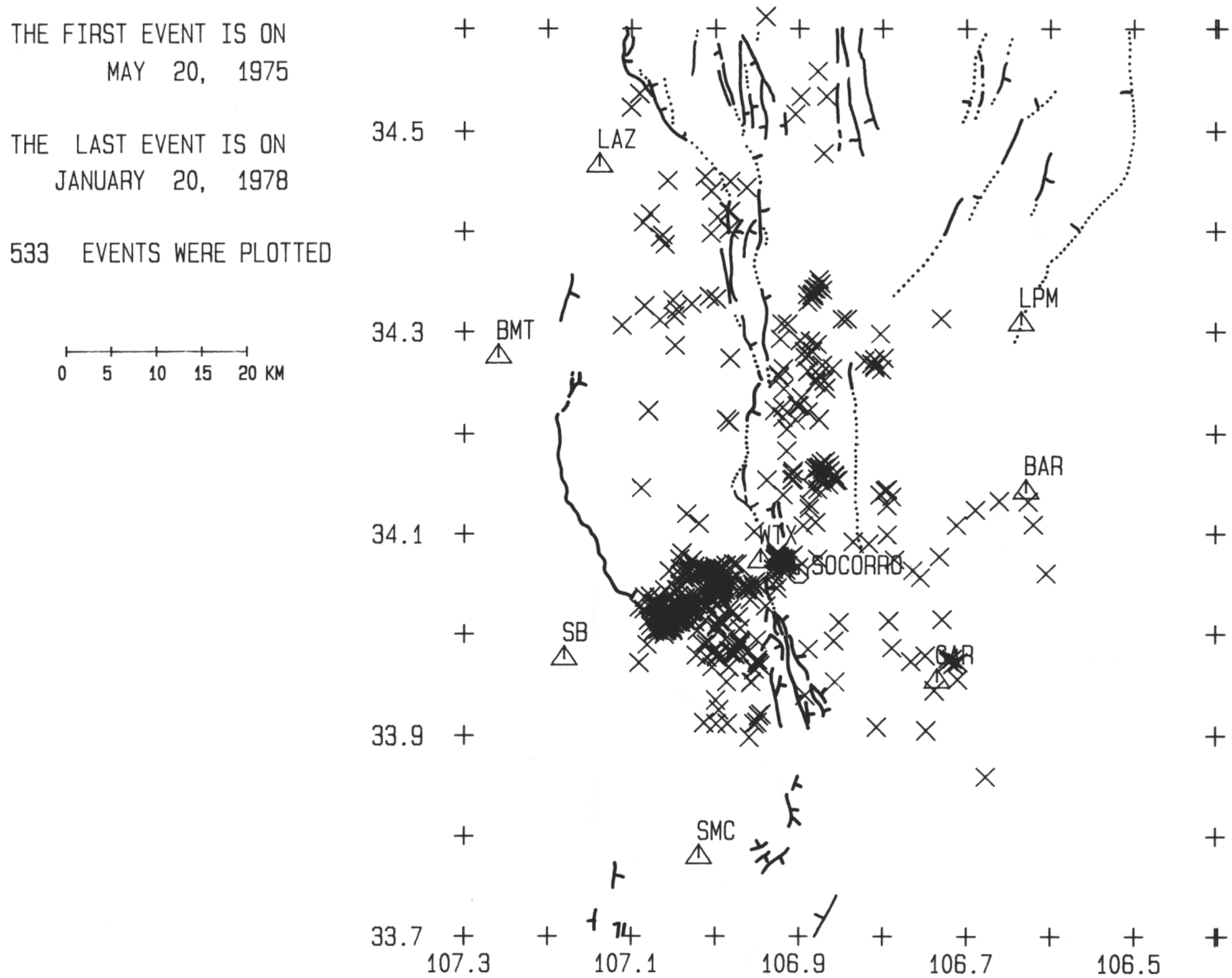

Figure 3. Seismicity of the Socorro area for the period May 20, 1975, to January 20, 1978. Faults shown are Pliocene or younger in age (Machette and McGimsey, 1982; Machette, unpublished data). The triangles mark the location of stations in the present permanent seismic network.

earthquake epicenters. All faults shown are normal and their average strike is close to north-south. As discussed earlier, the contemporary earthquakes are generated (for the most part) by normal movement on segments of fault surfaces with approximately north-south strikes and depths ranging from 4 to 14 km (88% from 6.5 to 11.5 km). Therefore, only epicenters on Figures 2 and 3 which are located several kilometers down-dip from the surface trace of a fault have a chance of being associated with the subsurface projection of that fault.

The only region on Figures 2 and 3 where the seismic activity could be associated with the subsurface projection of Pliocene or younger faults is the approximately 10-km wide zone of epicenters extending from −34.1°N to −34.4°N at longitude 106.9°W. Within this zone most epicenters are located several kilometers down-dip from normal faults dipping inward on both sides of the zone. Therefore, these earthquakes could have occurred on the subsurface projection of one or both of the bounding faults. The epicenters and focal depths are not known with sufficient precision to determine whether planar or curved (listric) projections best fit the data.

Southwest of station WTX in Figure 3, the epicenter locations, focal depths, and fault mechanisms are well constrained. With one possible exception, none of the activity within this region is occurring on listric or planar projections of the surface faults.

Away from the central zone most earthquake activity cannot be associated with the young faults, and conversely, many young faults (some of the youngest) appear to be nearly or totally aseismic.

RELATION OF SEISMICITY TO SURFACE UPLIFT

Geodolite measurements across the rift in the Socorro area indicate that general east-west crustal extension is not presently occurring (Prescott and others, 1979; Savage and others, 1980). This may explain the absence of a close spatial relationship between many of the epicenters and the faults in Figures 2 and 3. Yet the fault motions for the earthquakes are dominantly normal dip-slip which requires crustal extension in the vicinity of the hypocenters. What is required is a mechanism which produces localized tensile stresses but not an extension of the geodetic network bracketing the rift.

Shown in Figure 1 along with the earthquake epicenters are contours of surface uplift determined from releveling of elevation bench marks in the Socorro area (Reilinger and others, 1980). The contours represent deformation that accumulated during a 40-year period. The 120-mm contour closely follows the outline of a thin mid-crustal magma body at a depth of —19 km. This extensive layer of magma was first detected in microearthquake studies at New Mexico Tech (Sanford and others, 1973; Sanford and others, 1977) and later confirmed by a program of crustal reflection profiling directed by Cornell University (Brown and others, 1979; Brown and others, 1980). Reilinger and Oliver (1976) and Reilinger and others (1980) demonstrated that the observed surface uplift could be explained by inflation of the mid-crustal magma body. Inflation of a sill-like body should produce a slight positive dilation (expansion) of the geodolite network across the rift, whereas a slight negative dilation (contraction) was observed. Savage and others (1980) believe the slight contraction could be the result of a systematic error in the measuring system or the consequence of two of more processes acting more or less simultaneously. They suggest that magma injected into the horizontal mid-crustal magma body may have been squeezed from a vertical dike. The ratio of horizontal to vertical deformation is larger for a dike than it is for a sill. At present, we do not know the exact details of the inflation process, but it appears probable that a mechanism exists that satisfies both the geodolite and level-line data.

In Figure 1, the greatest concentration of seismic activity occurs where surface uplift is a maximum. The energy release for earthquakes in this region is approximately 50 times greater than for all other earthquakes on the figure. The strongest earthquakes in the 22-year period preceding Figure 1 were also in the area of maximum surface uplift. Thirteen months of continuous monitoring of seismic activity from June 1, 1969 to June 30, 1970 also showed the maximum number of shocks and energy release near the apex of surface uplift (Sanford and others, 1972). The pattern of seismicity for the latter study was also strikingly similar to that shown in Figure 1.

The most interesting feature of the distribution of seismic activity in the Socorro area is the diffuse bands of epicenters which radiate outward from the central cluster of shocks. These bands cut obliquely across the structural grain of the region and thus may be related to radial zones of extension generated by the uplift. Rift zones associated with volcanoes, such as those in Hawaii, have a similar radial pattern and presumably the same origin (Stearns, 1966).

The radial extension zones would also be preferred regions for ascent of magma from the mid-crustal source to the level of hypocenters in the upper crust. A number of observations (see Sanford, this guidebook) suggest a close spatial relationship between magma and the earthquake hypocenters.

In summary, we favor injection of magma into the crust as the primary cause of contemporary earthquake activity in the Socorro area because the geographic pattern of seismicity correlates better with surface uplift than with the distribution of young faults. The occurrence of most earthquakes in swarms also suggests movement of magma as the primary mechanism for generating crustal stress. Finally, repeat measurements on a geodolite network across the area show a slight contraction across the rift (Savage and others, 1980) which would appear to preclude general crustal extension as an explanation for the observed seismicity.

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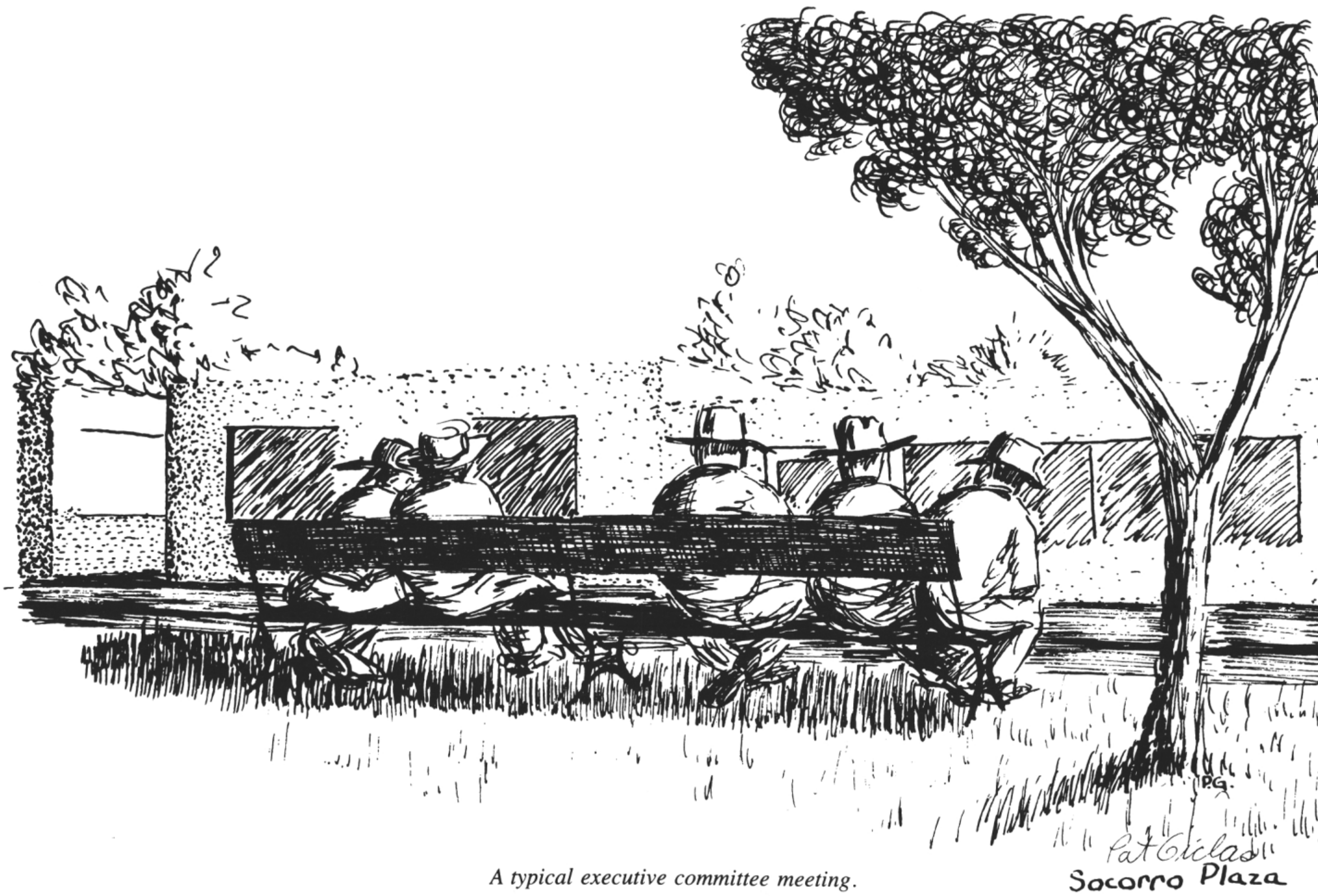

A typical executive committee meeting.

Socorro Plaza