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SEISMIC ACTIVITY NEAR SOCORRO

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INTRODUCTION

Nearly all the strong and a majority of the weaker earthquakes in New Mexico have occurred along the Rio Grande Valley between Albuquerque and Socorro (Northrop, 1961). The most active area along this narrow seismic zone lies near Socorro. This area is historically and currently the single most active spot in the state. In the past, about 50 percent of the known shocks have originated near Socorro and because many of these shocks were strong, they account for about 80 percent of the total seismic energy released in this state. Recent studies indicate that the present level of seismic activity near Socorro continues high relative to other sections of the state.

CURRENT SEISMIC ACTIVITY

In mid-1960, an instrumental study of the seismic activity in the vicinity of Socorro was initiated (Sanford and Holmes, 1961, 1962). This study has revealed an abnormally high rate of seismic activity in a small segment of the crust centered beneath Socorro Mountain 10 kilometers west of the city (fig. 1). Approximately three quarters of all shocks recorded at Socorro originate in this region. A good percentage of the remaining shocks have epicenters near or in the Sierra Ladrones where strong earthquakes occurred in 1960 (Sanford and Holmes, 1960). At the present, these two areas are the only regions having significant activity within 50 kilometers of Socorro. In these two areas, the level of activity appears to be consistently higher at Socorro even when allowances are made for attenuation of the elastic waves from the more distant shocks at the Sierra Ladrones.

INSTRUMENTATION

Seismographs used in the study of Socorro shocks are located in abandoned mines along the base of Socorro Mountain approximately five kilometerrs northwest of the Socorro plaza. One of the instruments is a single-channel seismograph which operates continuously at a magnification of about 10 million (at 20 cps) and a recording speed of 3.3 mm/sec. The other instruments are multichannel seismographs which operate at magnifications ranging from 2 to 50 million (at 20 cps) and recording speeds from 15 to 60 mm/sec. Because of the high recording speeds, the latter instruments are programmed for operation a few hours each day, generally at night when the background noise is minimum.

The high-speed seismographs are presently being used in a closely spaced five-station network. From the differences in time of arrival of the initial P-phase at these stations and the measured S-P intervals, the relative positions of foci for the Socorro shocks can be determined to within 2 kilometers.

EARTHQUAKE STATISTICS

On the average, two or three earthquakes with epicenters within 16 kilometers of Socorro are recorded each day. Because magnifications of the seismographs are very high and the shocks are very close to the recording stations, a majority of the earthquakes registered are actually very weak events with Richter magnitudes of less than zero (Richter, 1958, p. 338). As in all other seismic areas, the shocks are progressively more numerous as they become weaker. For Socorro, we have found that the number of shocks increases by a factor of 5.5 for each unit decrease in magnitude.

The large number of shocks originating near Socorro is definitely anomalous and not simply the result of using high-magnification instruments. The number of shocks beyond 16 kilometers of the stations drops sharply, much more sharply than would be expected if wave spreading and attenuation were the only factors decreasing the number of detectable shocks. Second, a 220-hour test of activity in the Magdalena Mountains with a high-magnification seismograph showed no shocks originating beneath that mountain block. During the same period, a similar seismograph operating at Socorro detected nine shocks originating beneath Socorro Mountain. Last, six shocks have been felt in Socorro since the seismic research program began. Two of these shocks are known to have originated in the Sierra Ladrones (Sanford and Holmes, 1960). All evidence suggests the remaining four shocks had foci very close to Socorro.

Table 1 lists times, distances, directions, and intensities for these four shocks. In general, these felt shocks were poorly recorded because their strengths far exceeded the dynamic range of the seismographs. However, good records of the numerous foreshocks

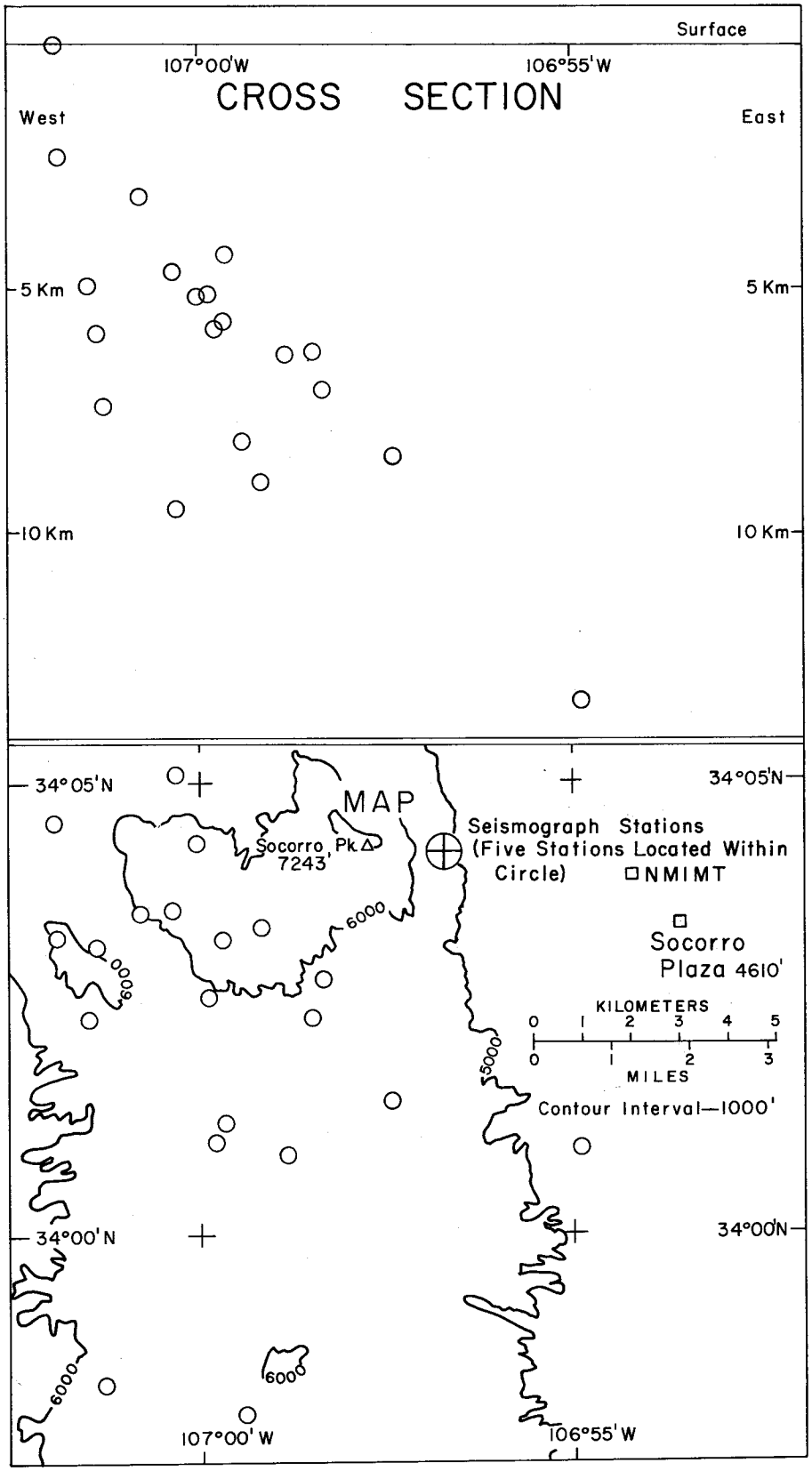

FIGURE 1

Cross section and map showing the location of weak earthquakes which occurred in the Socorro area from Sept. 1960 through Jan. 1961 and from Nov. through Dec. 1962. The distribution of these shocks is probably a good representation of the spatial distribution of all recent Socorro earthquakes.

and aftershocks that occurred within a few hours of the felt shocks were obtained. Distances and the one direction listed in Table 1 were determined from records of these smaller shocks. The S-P interval (the time interval from which distance is calculated) for the shock of October 25, 1960 was verified by the agreement of origin times calculated from Socorro and Albuquerque records. This evidence is not absolutely conclusive, but it does strongly support the idea that a few strong shocks have occurred in the same region that produces the numerous weak shocks.

TABLE 1. SOCORRO EARTHQUAKES, 1960 THROUGH 1962

Date	Time (MST)	S-P sec.	Distance to Focus - km	Direction	Intensity
1960					
Oct. 25	12:21	1.8	15	S32W	III
Dec. 19	16:28	1.2	10	SW?	IV - V
1961					
Jan. 27	23:33	1.8	15	SW?	III-IV
July 3	00:06	1.4	12	SW?	IV

LOCATIONS

Locations for twenty of the weaker shocks originating near Socorro have been determined. These shocks represent the few instances that we have been able to obtain good high-resolution records of small shocks on a three- or five-station network.

Epicenters for these shocks are plotted in Figure 1 as the small open circles. All the shocks lie within a 140-square-kilometer area centered about 10 kilometers west of Socorro. These shocks were recorded during the periods Sept. 1960 through Jan. 1961 and Nov. through Dec. 1962. Although these are rather limited time periods, we believe the distribution of these 20 shocks represents in a general way the geographical distribution of all recent Socorro shocks.

If the foci for the 20 shocks are projected along north-south lines into a vertical east-west section, an interesting pattern emerges (fig. 1). All foci lie on or west of a line which dips 50 degrees toward the valley. The average depth of focus for the located shocks is 6 kilometers.

HISTORICAL SEISMIC ACTIVITY

The present pattern of seismic activity near Socorro appears to be a continuation of activity which has persisted for at least 60 years. Shocks have occurred frequently in the past and a considerable amount of useful qualitative information on locations, strengths, and mode of occurrence has been obtained. Locations for the shocks which occurred prior to 1960 are based on noninstrumental determination of the point of maximum intensity. Intensity is determined from what people feel or observe during a shock and also from the degree of damage to structures (Richter, 1958, p. 135). Unfortunately, these factors are dependent on the type of ground as well as proximity to the epicenter. Therefore, locations based on intensity have a degree of uncertainty.

LIST OF SOCORRO EARTHQUAKES

Listed in Table 2 are the shocks which, on the basis of maximum observed intensity, are believed to have originated near Socorro since 1855. The table is believed to be complete for this period except for the probable omission of weaker shocks prior to 1900. Records of shocks occurring before 1855 have not been found, but it is almost certain that the Socorro area had earthquakes before this date.

SWARMS OF 1904 AND 1906

The two most important and interesting periods of seismic activity occurred in 1904 and 1906-1907. At these times, Socorro was rocked by long series of shocks characterized by a random distribution of large and small events and the absence of a single outstanding earthquake. Sequences of this type are called earthquake swarms and they frequently occur in regions of contemporary or recent volcanism (Richter, 1958, p. 71).

The swarm of 1904 commenced on January 19 and terminated in September (see Table 3 for description of major shocks in this swarm). At least 34 shocks ranging up to intensity VII were felt during this period. Reports in the Socorro *Chieftain* indicate no significant damage to structures and no injuries. However, the swarm did precipitate an interesting journalistic squabble between Socorro and El Paso, an example of which is quoted below.

> The El Paso *Herald* of March 16 contains a column article on the recent earthquakes in the vicinity of Socorro. The article is remarkable. In fact, it is a masterpiece; for without the sensible and true avouch of one's own eyes it would be beyond belief that there could be crowded into so small a space so much airy and fantastic nonsense resulting apparently from a too liberal indulgence in the fluid extract of either Texas corn or Arizona cactus.
>
> For example, the *Herald* writer says that one of the recent earthquakes in this vicinity "lasted three minutes" that "pedestrians were caused to reel on their feet," that the walls of adobe houses

have "'become cracked and rendered almost unsafe as places of abode," that the spring which supplies the city with water "has commenced to boil since the trouble has been going on" and is "now a seething cauldron," and that there are those who say that Socorro because of past wickedness "is getting a touch of the experience that was administered to Sodom and Gomorra."

Let us see. Within the last six weeks Socorro has suffered perhaps 15 earthquake shocks not one of which lasted twenty seconds. As a result not a single wall is one-half as badly cracked as the brain pan of the *Herald* writer must be. During this earthquake period a few pedestrians have been seen to "reel on their feet," but a little investigation by the proper authorities has revealed the fact that such pedestrians were Texas Democrats and that the reeling was habitual. The waters of the Socorro spring still come from the mountain at the same temperature as for years past. If the *Herald* man will drink of them for a short time and abstain from his usual beverages, it is quite possible that he will be able to suppress the fantastic workings of his own imagination. Socorro was once a wicked city. There is no doubt of that. However, judging from the fact that newspaper men are among the most moral citizens of any community, the performance of the *Herald* writer is ample proof (that) Socorro in its wickedest days was an Elysium as compared with that present El Paso, the moral cesspool of two great republics. (Socorro *Chieftain*, March 19, 1904).

The second earthquake swarm started on July 2, 1906 and ended sometime in the early part of 1907 (see Table 4 for description of major shocks in this swarm). The number and intensity of shocks during this period is unequalled in the seismic history of the state. Shocks were felt almost every day and at times reached a frequency of about one tremor an hour. Three shocks of this swarm (05.10 MST, July 12; 12:00 MST, July 16; 05:20 MST, Nov. 15) reached intensity VIII at Socorro and were felt over areas of about 100,000 square miles.

Property damage during the strong shocks was considerable but no one was injured. After the first shock, many residents wisely abandoned their adobe houses for tents or temporary wooden structures. (At least one of these wooden structures still stands in Socorro.) Part of the fear that existed in Socorro at this time is probably related to the severe earthquake which struck San Francisco earlier in 1906.

The actual number of felt shocks and the extent of the damage during this swarm is difficult to determine. Reports on the shocks in the Socorro *Chieftain* became progressively vague as the swarm continued, probably because they feared detailed reports might have a detrimental effect on the Socorro economy.

LOCATION

All the shocks listed in Table 2 were felt most strongly at Socorro or in the case of the weaker shocks only at Socorro. Where information is available, the stronger shocks show a progressive decrease of intensity with distance from Socorro. Of special interest are the intensities reported in 1906 for the villages of San Antonio (15 kilometers south of Socorro) and Sabinal (52 kilometers north of Socorro). Like Socorro, these villages lie within the Rio Grande Valley and are built on alluvial fill or loosely consolidated Santa Fe sediments. Although the effect of the ground on earthquake intensity is probably the same at these three locations, the intensities of the strong shocks of 1906 were one half to one intensity unit less at San Antonio and one to three intensity units less at Sabinal. For Magdalena (33 kilometers northwest of Socorro), which may lie on somewhat better consolidated ground than Socorro, the intensity of these shocks was one to two intensity units less than Socorro.

Other evidence related to the location of the older shocks is (1) a pendulum located at NMIMT recorded cast-west motion for a strong shock of the 1904 swarm (Bagg, 1904); (2) chimneys toppled in the strong shocks of 1906 fell to the east (Reid, 1911); (3) a report of broken ties and loose rock (one with an estimated weight of ten tons) along the railroad bed on the west flank of Socorro Mountain after the July 12, 1906 (Socorro *Chieftain*, July 14, 1906); and (4) the duration of perceptible motion was relatively short (15-20 seconds) for the strong shock on July 12, 1906 (Reid, 1911). The relative intensities at the four towns and the items listed above indicate epicenters close to Socorro and most likely in the Socorro Mountain block west of the town.

DISCUSSION

On the basis of the historical data, it appears likely that the small segment of the crust beneath Socorro Mountain which is active at the present time has been the seat of abnormally high seismic activity for at least sixty years. As to the cause of this activity, one can only speculate. The shocks could be related to recent intrusives in the mountain (Smith, 1963) or even possibly to contemporary magmatic action at depth. Evidence in support of a magmatic-action hypothesis is (1) the high tempera-

TABLE 2. SOCORRO EARTHQUAKES, 1868 THROUGH 1959

Year	Month & Day	Intensity	References	Remarks
1855			Northrup (1961)	
1868	April 28	VI	Heck (1938), Bagg (1904)	
1869	?	VII	Heck (1938), Bagg (1904)	Affected rate of flow and muddied water at Socorro springs.
1879	?	V - VI	Heck (1938)	
1886	July 6	(VI)[1]	Heck (1938), Bagg (1904)	Heavy rumbling sound preceding shock.
1895	Oct. 31	VII	Heck (1938)	
1897	Nov. 4	VI	Heck (1938), Bagg (1904)	Overturned chairs and small objects.
1904	Jan. 19 to Sept. 10	VIII?[2] and smaller	Heck (1938), Bagg (1904), Socorro Chieftain (1904)	Earthquake swarm. Total of 34 shocks felt during this period.
1906 to 1907	July 2 to early 1907	VIII and smaller	Heck (1938), Reid (1911) Socorro Chieftain (1906)	Prolonged earthquake swarm. Numerous shocks; three of intensity VIII. Considerable damage to buildings.
1913	July 18	?	Heck (1938)	
1919	Jan. 31	IV - V	Heck (1938)	
1919	Feb. 1	V	Heck (1938)	
1931	Apr. 7	(II)[1]	Neumann (1932)	Feeble.
1934	Jan. 7	IV	Neumann (1936)	Not felt 7 miles from Socorro.
1934	May 7	III	Neumann (1936)	May have been closer to Magdalena.
1935	Jan. 17	III	Neumann (1937)	Two shocks.
1935	Jan. 19	IV	Neumann (1937)	
1941	Aug. 4	(V)[1]	Neumann (1943) Socorro Chieftain (1941)	Many awakened and a few fled houses.

[1]Intensity assigned by author.
[2]Heck (1938) gives strongest shock an intensity of VIII. Descriptions of the shocks in the Socorro *Chieftain* indicate a somewhat lower intensity.

TABLE 3. PRINCIPAL SHOCKS OF THE 1904 SWARM

Date	Time (MST)	Description - Quotations from Socorro *Chieftain*
Jan. 19	19:00 +	". . . severest earthquake. . . . felt in Socorro for 20 years . . ."
Jan. 20	02:00 −	". . . roused people from their slumbers . . ."
Jan. 30	05:30	". . . woke probably every sleeper in the city . . ."
Jan. 30	07:00	(no mention made of its relative intensity)
Jan. 30	07:15	". . . violent rocking of the earth that made equilibrium uncertain for a few moments."
Feb. 21	23:00	". . . rocking of the ground, a rattling of doors and windows and other things movable, and an ominous swaying and creaking of walls and roofs."
Feb. 21	6 to 8 shocks	". . . . repeated six to eight times during the night."
March 9	00:30	"Many citizens were awakened and the seismograph at the School of Mines showed an oscillation of three inches in the pendulum."
Sept. 6	11:00-12:00 (2 shocks)	". . . a violent shaking of walls and roofs and a rattling of doors, windows, chinaware, and, in fact, almost everything movable. This shock was followed in about ten minutes by another fully as violent."

TABLE 4. PRINCIPAL SHOCKS OF THE 1906 SWARM

Date	Time (MST)	Description - Quotations from the Socorro *Chieftain*
July 2	03:15	". . . awakened the city's population . . ." ". . . sent the frightened ones scurrying into the open air . . ." ". . . a general rattling of things and a bit of loose plaster here and there was thrown down, but no damage was done . . ."
July 2 to July 12		". . . slight shocks at frequent intervals . . ."
July 12	05:10	". . . frightened inhabitants to rush into the yards and streets for safety. Walls were cracked, chimneys and plastering fell, shelf goods, book cases, dishes, bric-a-brac were hurled to the floor."
July 12	06:10	". . . a second shock nearly as severe as the first . . ." ". . . many of (residents) have slept out of doors since."
July 12 to July 13		". . . from (second shock) until yesterday morning light shocks were felt at intervals of about an hour . . ."
July 16	12:00	"Buildings were shaken violently and a good many chimneys thrown down . . ."
July 16		Minor shock before and after large one.
Nov. 15	5:20	"Four chimneys that had recently been rebuilt on the court house were thrown down . . ."

ture of water in springs located at the base of the mountain (Hall, 1963), (2) the high air temperatures in the tunnels at the base of the mountain (as high as 35°C 135 meters beneath the surface), and (3) the occurrence of earthquake swarms.

An alternate explanation for these shocks is that they represent crustal adjustments to a regional stress field which could be the same as the one that produced the Rio Grande graben. The interaction of this stress field with a heterogeneous upper crust would most likely produce isolated pockets of relatively intense seismic activity (such as Socorro Mountain and the Sierra Ladrones) rather than uniform seismicity along the entire length of the graben.

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