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A PRELIMINARY ASSESSMENT OF THE SEISMIC HAZARD OF THE SOUTHERN RIO GRANDE RIFT, NEW MEXICO

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Abstract—To integrate information from recent paleoseismological studies of active faults in the southern Rio Grande rift, probabilistic hazard maps of the area were prepared. Using fault slip-rate information from paleoseismological studies in the southern rift, estimates of moment-rate and seismic-moment release were used to determine earthquake recurrence intervals. These recurrence intervals and an empirical relationship for predicting seismic accelerations provide estimates of frequency of specific levels of strong ground motion. From these frequency estimates, Poissonian probabilities are calculated in a grid covering the southern rift. This map shows the highest 100-yr probabilities of 0.1 g acceleration to be in the center of the Tularosa and Palomas Basins, with peak 100-yr probabilities of almost 2.5%. The 100-yr probability of one or more of the 16 faults breaking in a large event is 5%.

INTRODUCTION

In the past decade, a series of paleoseismological investigations (Machette, 1987a, b; Foley et al., 1988; Gile, 1987) have studied the active faulting in the southern Rio Grande rift (SRGR). These studies supplement previous geologic investigations that identified recent faulting and began to quantify slip rates. One conclusion of both types of studies was the high degree of activity of faults in the southern rift. Prominent among these faults is the Organ Mountains fault, the bounding fault on the east side of that range (Fig. 1). This fault has been interpreted as having two earthquakes with cumulative fault offset of 6 m in the past 10,000–15,000 yrs (Gile, 1987; Beehner, 1990). Other faults in the SRGR also show significant Late Quaternary, and possibly Holocene activity. The Caballo and central Alamogordo faults appear to be the most recently active of these faults with mid-Holocene events. Faults that have events at around 10,000 yrs are the East Franklin Mountains, southern San Andres and Artillery Range faults (Machette, 1987b).

Another indication of the high activity of faults in this area is the relatively short recurrence intervals on these faults. The work of Machette (1987b) shows strong evidence that many of the faults around the Tularosa Basin have average recurrence intervals of 20,000 yrs or less. With seven fault segments in this group, the average recurrence interval for the basin as a whole is less than 3000 yrs. Considering all of this strong evidence for recent and active faulting, I integrate the previous research into a preliminary assessment of the seismic hazard of the region, and using the method of Wesnousky (1987) as a pattern, I present these data as probabilistic hazard maps. This approach requires the estimation of the characteristic earthquake of each fault segment, and recurrence intervals are calculated using the moment of the characteristic earthquake and the moment accumulation rate.

DATA

Data on fault segmentation, length and slip rates come from two groups of studies. Two regional studies by Machette provide a great deal of information about faults in the Truth or Consequences (T or C) area (Machette, 1987a) and the Tularosa Basin (Machette, 1987b). Both are reconnaissance reports and cover only surficial offset and fault-scarp morphology. Two other reports provide more detailed, but fault-specific, information within the regions of the two reconnaissance reports. Foley et al. (1988) investigated the paleoseismicity of the Caballo fault, particularly the northern or Williamsburg segment. Along the Organ Mountains fault, a similar study by Gile (1987) provides a detailed picture of the seismic history there. Both of these studies used fault trenching and soil chronology, as well as the Pleistocene geomorphic surfaces, to constrain ages and rates of fault offset.

Mack et al. (1991) provided information on two more faults, the Robledo and Jornada, and constrained the age of offset surfaces in the

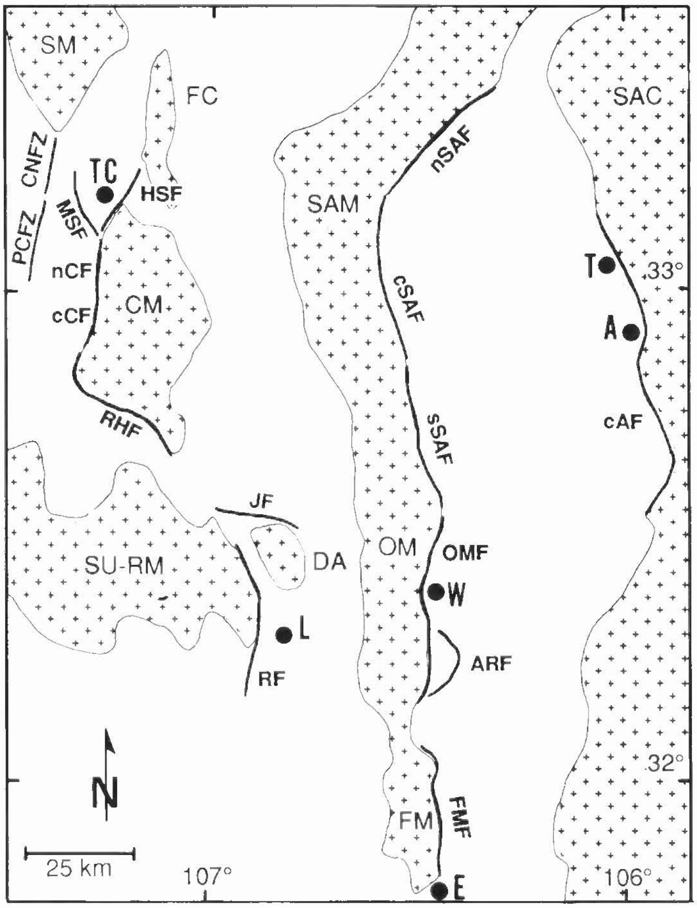

FIGURE 1. Simplified map of the southern Rio Grande rift showing the major mountain ranges (patterned areas) and faults with identified Quaternary motion (heavy lines). Faults: cAF—central Alamogordo fault; FMF—Franklin Mountains fault; ARF—Artillary Range fault; OMF—Organ Mountains fault; SAF—San Andres fault, southern, central and northern segments; RF—Robledo fault; JF—Jornada fault; RHF—Red Hills fault; CF—Caballo fault, central and northern segments; HSF—Hot Springs fault; MSF—Mud Springs fault; PCFZ—Palomas Creek fault zone; CNFZ—Cuchillo Negro fault zone. Mountain ranges: SAC—Sacramento Mountains; SAM—San Andres Mountains; OM—Organ Mountains; FM—Franklin Mountains; SU-RM—Sierra de las Uvas and Robledo Mountains; DA—Doña Ana Mountains; CM—Caballo Mountains; FC—Fra Cristobal Mountains; SM—San Mateo Mountains. Communities: E—El Paso; L—Las Cruces; W—White Sands Missile Range Headquarters; A—Alamogordo; T—Tularosa; TC—Truth or Consequences.

other studies. In this study, we found that deposition of the Camp Rice Formation ceased before the beginning of the Brunhes epoch. Based on this result, I used an age of 0.750 Ma for the age of the mid-Pleistocene La Mesa or Doña Ana surface in slip-rate calculations (Gile et al., 1981). This age applies to a surface that is offset over 20 m by the Jornada fault, providing a slip-rate estimate of 0.03 mm/yr for that fault. Across the Robledo fault, an upper La Mesa surface probably three times as old is offset by at least the same amount, providing a minimum slip rate of 0.01 mm/yr.

From these studies I compiled a list of active faults and fault segments with their lengths and slip rates (Table 1). For most of the faults, several different offsets on several different age surfaces are reported. As a general procedure for arriving at a preferred slip rate for each fault I took the multiple ranges and found regions of overlap. Within this preferred range, the preferred slip rate is the mean of the overlapping region. This estimate was usually close to the median of all of the slip-rate ranges for a fault, so the mean of the overlapping region was used to avoid biasing the slip rate by single, extreme measurements.

Some faults have negligible slip-rate information. For the northern segment of the San Andres fault, Machette (1987b), lacking ground-based information, simply concluded that the slip rate is lower than the central segment of the San Andres fault. For the Robledo fault, Mack et al. (1991) determined the age of abandonment of the surface on the upthrown block, but correlation with a level on the hanging wall has not been determined. In these cases a minimum slip rate of 0.01 mm/yr is used in the calculations. Quaternary motion is evident on these faults and so this is considered a minimum slip rate for these faults. This is one area where further studies would provide significant information in our analysis of seismic hazard.

METHOD AND RESULTS

Several assumptions are necessary to develop a model that will be used to calculate the seismic hazard. First, I use the characteristic earthquake model (Schwartz and Coppersmith, 1984) to describe the activity on each fault. The implication of this model is that the "characteristic earthquake" and its aftershock sequence dominate the long-term moment release on a fault.

Since the characteristic earthquake model allows us to describe the seismic hazard on a fault by a single earthquake on that fault, I use the empirical relationship between fault length and maximum earthquake moment derived by Wesnousky (1986). Wesnousky found that although there was significant scatter in the data, two populations of earthquakes were observed, those with fault slip rates above 1 cm/yr and those with slip rates below 1 cm/yr. Because all faults in this study have slip rates in the latter category I use his regression line between fault length L in km and moment release M_0 in N•m: $M_0 = 16.75 + 1.73L$. The difference in this equation from that published by Wesnousky (1986) reflects the difference in units; the published equation gave moment in dyne•cm.

The assignment of fault length requires another assumption about the length of the fault segment. All of the studies used discuss segmentation of the faults. Whether one or multiple segments would break in an earthquake is unknown. Some fault segments, like the 57 km central Alamogordo fault segment (Machette, 1987b), would probably break alone in an event (if not in smaller unrecognized segments). However, short segments, like the 16-km-long segments of the Caballo fault, may rupture alone or together in an earthquake. Lacking any evidence about multiple segment rupture, I decided to assume that in an event, the smallest recognized fault segments will rupture. This decision is a trade-off between many smaller events and fewer larger earthquakes.

The average recurrence time T_r on a fault is calculated from the earthquake-moment release M_0 and the fault-moment accumulation rate $\dot{M}_g$ (in N•m/yr) by $T_r = M_0/\dot{M}_g$. The equation giving the moment-accumulation rate from the fault slip rate $\dot{u}$ is $\dot{M}_g = \mu dL\dot{u}$, where μ is the shear modulus of the crust (3×10^{11} dyne/cm^2) and d is the depth of the seismogenic zone. Studies of instrumentally recorded basin-range earthquakes (such as Smith, 1978) suggest that d is approximately 15 km.

Finally, for each model earthquake we need to know the expected ground acceleration at a given distance from the fault. For this we use the empirical relationship of Joyner and Fumal (1985). I have followed Wesnousky's (1986) example and used 0.1 g acceleration as our minimum level of acceleration. I base this choice upon the observation that this represents the threshold acceleration for failure of unreinforced masonry structures, a common structural style in southern New Mexico.

From this model I can calculate the seismic hazard at any specific location. Briefly, the procedure is: (1) for each fault, calculate whether it could produce 0.1 g acceleration at the location; (2) for those faults that are capable of 0.1 g acceleration, calculate the recurrence frequency from the recurrence interval ($f = \Sigma(1/T_r)$); and (3) calculate the Poisson probability of experiencing this shaking within a given time interval, in this case 100 yrs ($P = 1 - e^{-fy}$; where P is the probability, f is the recurrence frequency, and y is the time interval of interest).

I calculated these probabilities on a 9 km grid spacing and contoured the resulting map (Fig. 2). The grid interval of 9 km was chosen because it is about 0.1° of longitude at this latitude and provides a convenient unit to specify the grid boundaries in latitude and longitude. As expected, areas within the rift, specifically within the basins, have the highest hazard with a maximum of almost 2.5% reached in the Tularosa Basin. Areas along the edges of the rifts have lower probabilities because of the lack of faults outside the rift. Faults in surrounding areas are probably rarer, and some are probably unrecognized. At the south and north ends of the map, the probabilities are unreasonably low. No faults outside the boundaries of the map were included in the calculation, and so the identified active faults farther north in the rift will increase the probabilities in the T or C area.

Finally, I addressed the probability of one or more events occurring on this group of faults. From the estimated recurrence intervals, the 100-yr probability of at least one characteristic earthquake occurring is 5%.

TABLE 1. Preferred fault parameters for seismic hazard calculation.

Fault	Length (km)	Slip-rate (mm/yr)	Source
Organ Mountain	42	0.15	Machette, 1987b
Alamogordo-Central Segment	57	0.11	Machette, 1987b
Franklin Mountain	45	0.10	Machette, 1987b
Artillery Range	20	0.01	Machette, 1987b
Robledo	48	0.01	Mack et al., 1991
Jornada	30	0.03	Mack et al., 1991
San Andres - South Segment	36	0.15	Machette, 1987b
San Andres - Central Segment	48	0.05	Machette, 1987b
San Andres - Northern Segment	22	0.02	Machette, 1987b
Red Hills	28	0.04	Machette, 1987a
Caballo - Central Segment	16	0.04	Machette, 1987a
Caballo - Northern Segment	16	0.02	Machette, 1987a
Hot Springs	30	0.03	Machette, 1987a
Mud Springs	20	0.01	Machette, 1987a
Palomas Creek	24	0.015	Machette, 1987a
Cuchillo Negro	30	0.02	Machette, 1987a

CONCLUSIONS

These hazard estimates must be considered minimum estimates for three reasons. Only faults with published slip-rate information are included in this analysis. Faults without recognized Quaternary motion and those without slip-rate estimates are not considered. Another problem is that for some faults, the slip rate is only a minimum rate. When aggradation continues on the downthrown side of the fault but the upthrown side becomes abandoned, measurement of surface offset only provides a lower limit on the fault offset. Finally, for all of the faults used, only the vertical slip rate was used; any lateral offset will increase

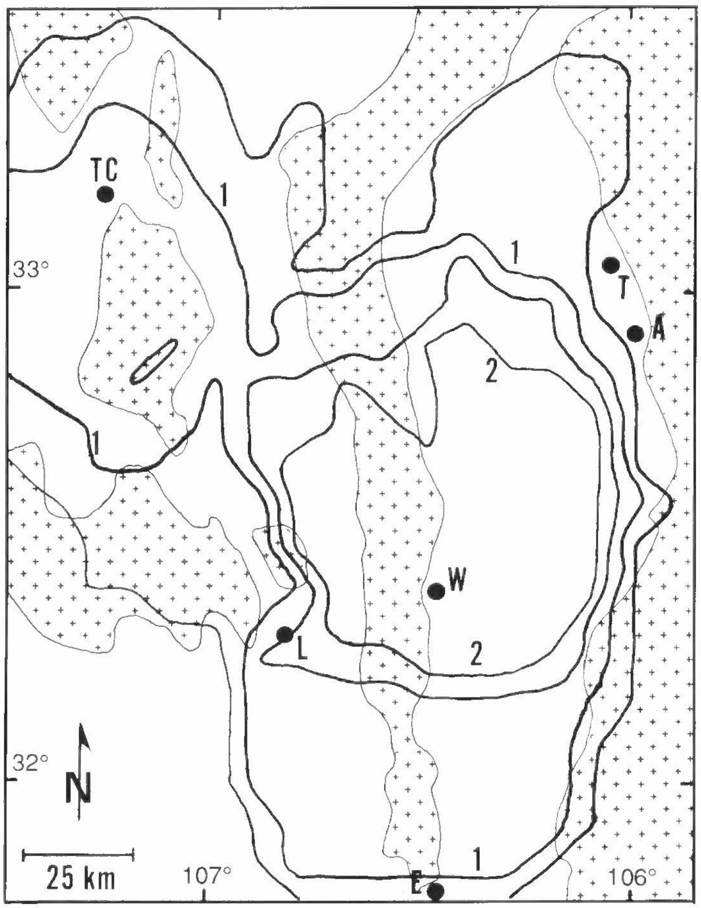

FIGURE 2. Simplified geologic map from Fig. 1 with contours of seismic hazard. Contours are percent probability of experiencing 0.1 g seismic acceleration of a 100-yr interval. Contour interval is 0.5%; 1% and 2% contours are labeled. Communities are the same as in Fig. 1.

the slip rate. Because most of the faults are range-bounding faults, the amount of lateral offset should be minimal. However, for fault zones transverse to a range, such as the Jornada fault, the vertical slip rate may significantly underestimate the total slip rate on the fault.

Several faults in this area have identified Quaternary offset but no published information on their slip rates. In the southwest corner of the region, the Fitzgerald and Potrillo faults offset the Camp Rice Formation (Hoffer, 1976), and on the western side of the Robledo Mountains the Cedar Hills fault also breaks Camp Rice (Seager et al., 1987). In addition, Seager et al. (1976) identified motion on a fault on the southwest side of the Doña Ana Mountains. Assigning a nominal slip rate of 0.01 mm/yr to these faults and repeating the calculation of probabilities results in a slight increase in the probabilities in the southwest quadrant of the map. The minimum 0.5% contour now extends to the western edge of the map, while the probability at Las Cruces increases from 1.4% to 1.8%.

Compared to a tectonically active region like California, these probabilities are relatively small. Fifty-year probabilities for the occurrence of 0.1 g in the Los Angeles basin are between 10% and 60% (Wesnousky, 1986). However, the estimates produced here are reasonable when compared to other regions of the Basin and Range Province. Specifically, the 50-yr estimates for the Mojave Desert and the Owens Valley (Wesnousky, 1986) are between 1% and 19%, so our 100-yr probabilities fall within the lower portion of this range.

Two previous studies have calculated the seismic hazard for New Mexico and this calculation agrees with them. Sanford et al. (1981) obtained the magnitude-frequency relationship for instrumental seismicity in New Mexico. Using this relationship, a magnitude 6 or larger event would have a 0.2% probability of occurring in this region in 100 yrs. This is significantly less than my estimate of 5%. This discrepancy could be attributed to our overestimating slip rates or Sanford et al. (1981) sampling a low seismicity period. Sanford et al. (1981, p. 15) suggested the latter case as they compared their result to the geologic record. In fact, one of my basic assumptions was using the characteristic earthquake model to describe fault activity, an assumption which means that the frequency-magnitude relationship will underestimate seismicity for short periods of time. In a study that overlaps this study's southern edge, Barnes (1990) made the same observation that the record of instrumental seismicity appears to underestimate the geologic record.

In another study of seismic hazard, Algermissen et al. (1982) calculated that in 250 yrs a level of acceleration of 0.06 g has a 10% probability of being exceeded. Recalculating my grid for a 250-yr time interval I find the same level of hazard. The best constrained regions within the grid have a 10% probability of experiencing an acceleration between 0.04 g and 0.06 g.

It should be emphasized that these are probabilistic hazard estimates. Deterministic hazard estimates could also be calculated taking into account the elapsed time since the last earthquake and how that influences the hazard. For a region this small, it is difficult to predict what effect this will have, but for New Mexico as a whole it is interesting to note that there has been no historical earthquake with identifiable surface rupture or felt reports which would suggest a magnitude above 6 (Foley et al., 1988).

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Compare this circa 1890 view of White Oaks, New Mexico, taken from the upper end of town looking toward Baxter Mountain, to the more "conventional" view on page 342, this guidebook. The road leading up White Oaks Canyon to the springs and coal mines is plainly visible, left foreground. New Mexico Bureau of Mines collection No. 1333, courtesy of Bruce C. Dunham.