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RECENT MEASUREMENTS OF CRUSTAL DEFORMATION RELATED TO THE SOCORRO MAGMA BODY, NEW MEXICO

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INTRODUCTION

Geophysical and geological observations indicate the existence of magma at intermediate depths in the crust beneath the Rio Grande rift in the vicinity of Socorro, New Mexico (Sanford and others, 1973, 1977; Brown and others, 1979). To a first approximation, the magma body apparently lies at a depth of 19 to 20 km and has the shape of a thin sill with a minimum areal extent of 1,700 km' (Rinehart and others, 1979). Evidence that the magma body is currently active includes: (1) anomalously high earthquake activity (including swarms) in the Albuquerque to Socorro section of the rift, as compared to other parts of the rift (Sanford and others, 1979); (2) geomorphic and other geologic evidence for post-Pliocene activity in the Socorro area (Sanford and others, 1972; Chapin and Seager, 1975; Bachman and Mehnert, 1978); and (3) geodetic evidence for historic crustal deformation above the magma body (Reilinger and Oliver, 1976; Reilinger and others, 1980).

The purpose of this study is to use new releveling measurements performed by the National Geodetic Survey during 1980, along with previously reported releveling results, to better define modern deformation associated with the Socorro magma body. The new observations confirm previously published results of crustal uplift apparently related to magma migration in the middle crust and provide new insights on the spatial and temporal behavior of deformation in this section of the Rio Grande rift.

DATA AND RESULTS

The estimates of crustal movement used in this study are derived from repeated first-order leveling surveys conducted by the National Geodetic Survey, following standard procedures (see, for example, Brown and Oliver, 1976). Relative movements are computed by determining the elevation difference between a given bench mark and a reference bench mark and subtracting from this the elevation difference between the same two bench marks measured from a previous leveling survey. The elevation change for each bench mark is computed in this way so that all movements are made relative to the same reference bench mark.

The location of the leveling routes used in this study are shown in Figure 1. The north-south elevation-change profiles from Rincon to Albuquerque (1912 to 1951) and Hatch to Bernardo (1951 to 1980) are shown in Figure 2. A remarkable similarity in terms of the pattern of deformation exists between the two independent profiles shown in Figure 2. Although the leveling routes were nearly the same for most of the two surveys (from bench marks Q230 and 110 northward) there were no bench marks in common. This is strong evidence that the movements are real and that they cannot be associated with bench mark instability.

A most important result of the new data (1951 to 1980) is the appearance of a 30-km-wide zone of relative subsidence south of Socorro. Although this prominent feature is observed in the 1912 to 1951 profile, it was not previously interpreted as subsidence (Reilinger and Oliver, 1976; Reilinger and others, 1980) because the connection of BM 110 with BM 4509 was not made between the two bench marks but occurred at a point 75 km to the south of BM 4509. This brought about an additional ± 22 mm of random error for the relative movement between the two bench marks [all error limits (± lo) represent random errors that accumulate with distance and are calculated from relations given by Brown and Oliver (1976)]. In addition, the connection occurred in a region of significant bench mark scatter (fig. 2), resulting in large uncertainty for the movement of BM 4509 (and all bench marks to the north) with respect to BM 110. As a result of these uncertainties, the subsidence features was not well defined. However, because this prominent zone of subsidence is clearly indicated in the new data, subsidence

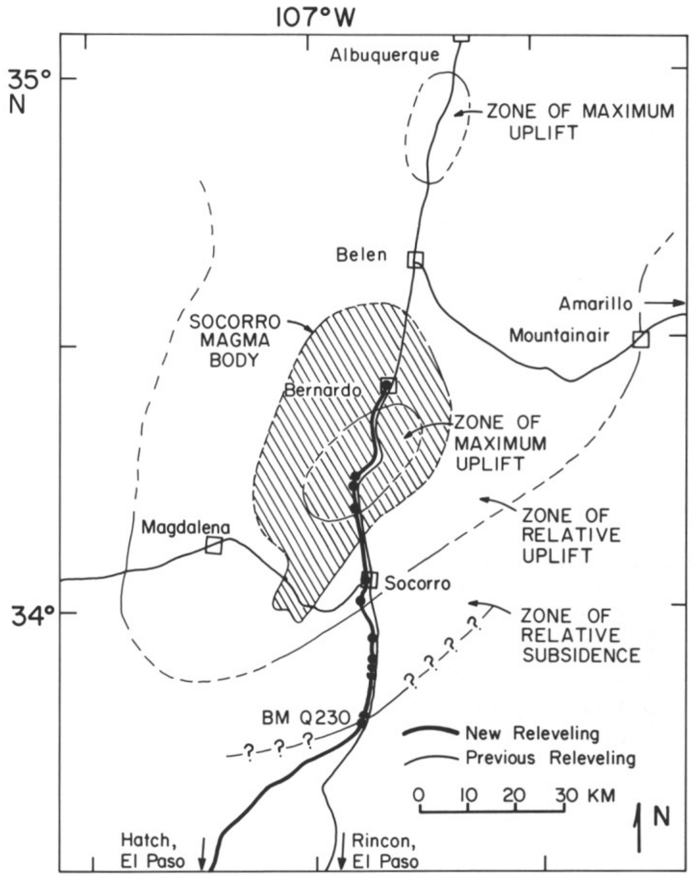

Figure 1. Location of leveling routes, including bench marks from the 1951–1980 survey (dots), in the Socorro area. Outline of midcrustal magma body (hatched pattern, boundary dashed where uncertain) is shown (from Rinehart and others, 1979). Contours indicate overall pattern of deformation as evidenced by releveling observations.

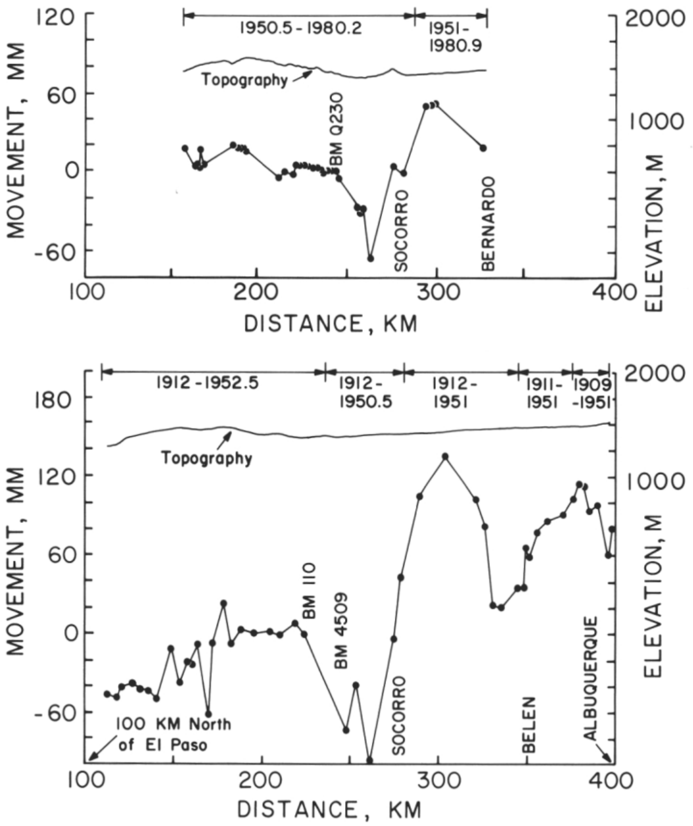

Figure 2. Elevation-change profiles and topography along north-south leveling routes shown in Figure 1. Dates of leveling are indicated at the top of each plot. Distances (km) are measured from El Paso, Texas, along each leveling route. (Top) Hatch to Bernardo, New Mexico (1951–1980); (Bottom) Rincon to Albuquerque, New Mexico (1912–1951). Note the similar pattern of deformation between the two independent profiles.

observed in the 1912 to 1951 profile also appears to represent real movement.

The two releveling profiles shown in Figure 2, along with profiles from Belen to the east (1911 to 1958) and Socorro to the west (1934 to 1978) (see Reilinger and others, 1976, 1980), indicate deformation throughout the Socorro area as shown in Figure 1. Crustal doming is roughly centered•over the Socorro magma body with zones of maximum uplift between Socorro and Bernardo and between Belen and Albuquerque. As reported above, a zone of subsidence exists to the south of Socorro. There is a strong spatial correlation between the pattern of seismicity (Sanford and others, 1972, 1979, 1981), the Socorro magma body, and the deformation pattern shown in Figure 1, with the greatest number of shocks occurring in regions of greatest tilt. In addition, most earthquakes occur in swarms (Sanford and others, 1981) which is characteristic of seismic activity in regions which are volcanically active or that have been active in the geologically recent past (Richter, 1958). Reilinger and Oliver (1976) reported that magmatic injection on the order of 1 to 2 km^3/yr into the Socorro magma body can accurately account for the pattern of relative uplift observed in the 1912 to 1951 profile. The similar pattern of deformation observed for the 1951 to 1980 interval (fig. 2), suggests that magmatic activity could also be responsible for the most recent movements in the Socorro area. However, the occurrence of subsidence adjacent to the area of uplift indicates that the magmatic processes which are apparently responsible for the observed deformation are more complex than the simple inflation originally envisioned.

There is some evidence that the average rate of deformation has decreased during the most recent time period. Total maximum uplift from 1912 to 1951 was 137 -± 29 mm, giving an average rate of 3.4 -± .7 mm/yr, measured relative to BM 110, an apparently stable bench mark south of the zone of deformation (fig. 2). Maximum uplift from 1951 to 1980 totaled 53 ± 15 mm, averaging 1.8 ± .5 mm/yr relative to BM Q230 which also lies south of the subsidence area. Similarly, maximum subsidence from 1912 to 1951 was between 60 and 100 -± 23 mm, averaging 1.5-2.6 ± 0.6 mm/yr, relative to BM 110 (this large uncertainty results from the small number and fluctuation of the bench marks involved). From 1951 to 1980 the maximum subsidence was between 28 and 67 -±- 8 mm, averaging 0.9-2.2 -± 0.2 mm/yr, measured with respect to BM Q230. As with uplift, it appears that the rate of subsidence has slowed during the latest period of releveling. The reduction in the rates of relative movement is supported by an apparent decrease in seismic activity from 1951 to 1980 compared with 1912 to 1951 (Appendix). Recent earthquake studies from June, 1982, to May, 1983 (A. R. Sanford, 1983, written commun.), indicate continued seismic activity in the Socorro area suggesting that magmatic activity and thus vertical crustal movement is continuing to the present time.

SUMMARY

Vertical crustal movements apparently resulting from magma migration involving a mid-crustal magma body are continuing over the Socorro area of the Rio Grande rift. Analysis of repeated levelings indicate uplift of more than 50 mm from 1951 to 1980 measured relative to bench marks south of Socorro. In addition, a 30-km-wide zone of subsidence is defined bordering and to the south of the uplift with maximum subsidence between 28 and 67 mm from 1951 to 1980. The new data confirm previously published results of crustal movement (1912 to 1951) and indicate that deformation is continuing at a slower rate, which is consistent with an apparent reduction in seismic activity. In view of these positive results, the rift should be a prime target for future investigations of crustal movement.

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APPENDIX:
Change in the Rate of Seismic Activity, 1912-1977

With the addition of modern seismic recording instruments at Socorro and Albuquerque in 1960 as well as at Las Cruces, Payson, Arizona, and Ft. Sill, Oklahoma, in 1962 (Sanford and others, 1972), it became possible to accurately study seismic activity in New Mexico. The number of earthquakes in a given area greater than a certain magnitude can be computed from the relation:

$$\log_{10} N = a - bM_L \quad (1)$$

where $\log_{10} N$ = logarithm of the number of shocks greater than ML
M_L = local magnitude
a,b = constants depending on the seismicity for a given region

(Richter, 1958). From analysis of earthquakes with $M_L > 1.5$ in the Socorro area (the region shown in Figure 1) from 1962 to 1977 (Sanford and others, 1981), it is found that a = 3.48, b = 0.93 so that:

$$\log_{10} N = 3.48 - 0.93M_L \quad (2)$$

The following equations relate the magnitude (MD of an earthquake with its area of perceptibility (A in sq. miles) for a given area of the United States (Wiegel, 1970).

Western U.S. M, = [2.3 log。(A + 3000)] — 5.1 (3)
Rocky Mountain = [2.3 log,„ (A + 14000)] — 6.6 (4)

If we let A = 0 (area of minimum perceptibility), we find that M_L = 2.9 for both the Western and Rocky Mountain regions of the U.S. This is the absolute minimum magnitude for an earthquake to be felt in this region of the country. If we normalize equation 2 for a 39-year period (1912 to 1951), it becomes:

log ,,,/N 3.87 — 0.93M, (5)

Therefore, if we assume that the minimum magnitude for an earthquake to be felt is 2.9, we would expect from equation 5 that only 15 shocks would have been noticed from 1912 to 1951. In addition, because of the low population density in the region during this period, the actual average minimum felt magnitude would have been greater than 2.9, so we would expect that 15 shocks would represent an upper limit for this time period. However, the observed seismic activity was much greater than the predicted 15 events. There were 81 felt earthquakes associated with the 1935-1936 Belen swarm alone (Northrup, 1961). This suggests that from 1962 to 1977, seismic activity, and thus magmatic activity, was less than from 1912 to 1951, which supports the observed reduction in the rates of vertical crustal movement from 1951 to 1980 compared with 1912 to 1951.

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WHAT DO WE DO NOW? I dunno, but if it was a horse, I'd shoot it (photo courtesy Socorro County Historical Society).

ONE WAY TO MAKE SURE YOU GOT WHERE YOU WERE GOING was to have a mounted escort (photo courtesy Socorro County Historical Society).