



## *Magma bodies in the Rio Grande rift in central New Mexico*

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# MAGMA BODIES IN THE RIO GRANDE RIFT IN CENTRAL NEW MEXICO

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## INTRODUCTION

Magmatism is considered an important component in the development of many continental rifts, yet the small number of active volcanoes along continental rifts (MacDonald, 1972) suggests that movement of detectable amounts of magma from the upper mantle into the crust may be a relatively rare geologic occurrence. Geologic studies in the Rio Grande rift indicate that large-scale volcanic activity has indeed taken place at widely separated locations at widely spaced times (Lipman and Mehnert, 1979; Luedke and Smith, 1978). Hence, there are geologic reasons for believing that magma bodies will not be found along the entire length of the Rio Grande rift, and geophysical studies to date appear to bear this out.

The Socorro area is the one region of the Rio Grande rift where a suite of geophysical observations indicates the existence of magma in the crust. Particularly well established is the depth and extent of a sill-shaped magma body at mid-crustal levels.

## MIDCRUSTAL MAGMA BODY

In 1973, Sanford and others (1973) presented data on the strengths and times of reflected S-phases on microearthquake seismograms that indicated the existence of an extensive crustal discontinuity underlain by magma beneath the Socorro area. In the following years, several papers refining the interpretation of the microearthquake data were published, for example, Sanford and others (1977), Rinehart and others (1979), and Rinehart and Sanford (1981).

In 1975 and 1976, deep crustal profiling was conducted by a consortium of universities (COCORP) along 155 km of line in the vicinity of Socorro (fig. 1) using P-wave reflection techniques developed for oil exploration (Brown and others, 1979; Brown and others, 1980). Appearing on the seismic sections, particularly those for lines 1, 1A, and 2A, were exceptionally strong P-wave reflections from the same crustal depth as the S-phase reflections on the microearthquake seismograms. Detailed analyses of the P-wave reflections by Brocher (1981) indicate that their strength and other characteristics are best explained by the presence of magma.

Listed below are physical parameters for the mid-crustal magma body determined from microearthquake, COCORP, and other geophysical studies.

1. The position and extent (minimum of 1700 km<sup>2</sup>) of the magma body (fig. 1) correlate closely with local seismicity (Sanford and others, 1979) and observed surface uplift (Reilinger and others, 1980).
2. The depth to the top surface is 19.2 km ( $\pm 0.6$  0.6 km s.d.) which coincides closely with the position of the Conrad discontinuity.
3. To a first approximation, the top surface is flat; however, local relief up to 0.8 km is possible.
4. Northward dip on the upper surface is possible, but if present it can be no greater than 2°.
5. Assuming a full melt, the thickness of the magma body cannot exceed 0.6 to 1.2 km.

6. The bottom of the magma body has never been detected seismically, which suggests a gradual transition in density and velocity at its base; conditions expected for a crystal mush.

Two important characteristics of the magma layer related to its mode of emplacement have not been resolved; its internal structure and its lateral continuity over the 1700-km<sup>2</sup> area. The COCORP data appear to require that the magma body consist of thin alternating layers of solid rock and magma (Brown and others, 1979; Brown and others, 1980; Brocher, 1981), whereas much of the microearthquake data are best explained by a single layer of magma. Because of strong lateral changes in the strength of COCORP reflections, Brocher (1981) believes that the mid-crustal magma body is not continuous but composed of discrete horizontal pods. However, because the strength of reflections above the magma body (on Line 2A) show the same lateral variability as the magma body reflections, lateral changes in transmitted energy rather than reflectivity is an alternate interpretation.

Many investigators have speculated on the origin of the mid-crustal magma body. The author favors blocking of the upward migration of basaltic magma from the mantle by a ductile zone located immediately above the Conrad, a velocity discontinuity between the upper and lower crust (Sanford and Einarsson, 1982).

## MAGMA BODIES IN THE UPPER CRUST

Efforts to map magma bodies in the upper crust using microearthquake data have been conducted intermittently since 1975. Most of these studies have followed a more or less similar pattern: (1) identification of some anomalous characteristic on microearthquake seismograms, (2) determination of raypaths for events with anomalous character, and (3) location of anomalous volumes of the crust from intersection of raypaths. Studies of this type were carried out using the following parameters measured from the microearthquake seismograms:

1. Unusually high Poisson's ratios (Caravella, 1976; Fender, 1978; Frishman, 1979).
2. Abnormally low dominant frequency for the S-wave (Johnston, 1978).
3. Abnormally high amplitude ratios for direct P to direct S (Shuleski, 1976; Roach, 1982).

A disturbing result of these studies was that anomalous volumes of crust defined in each study did not coincide exactly, although their general geographic placement was similar. Initially it was believed that these discrepancies arose because of: (1) differences in the data sets used, (2) improvements in hypocenter locations with time, and (3) difficulties in uniquely defining the location of anomalous crust from the intersection of raypaths. A re-examination of all of the above studies by the author indicates that a serious flaw in the design of the studies probably accounts for the observed differences.

A major omission in all of the research was a parallel analysis for nonanomalous data, that is, determination of raypaths along which travel is normal for the particular parameter under study. This omission

THE FIRST EVENT IS ON  
MAY 20, 1975

THE LAST EVENT IS ON  
MAY 15, 1983

808 EVENTS WERE PLOTTED

0 5 10 15 20 KM

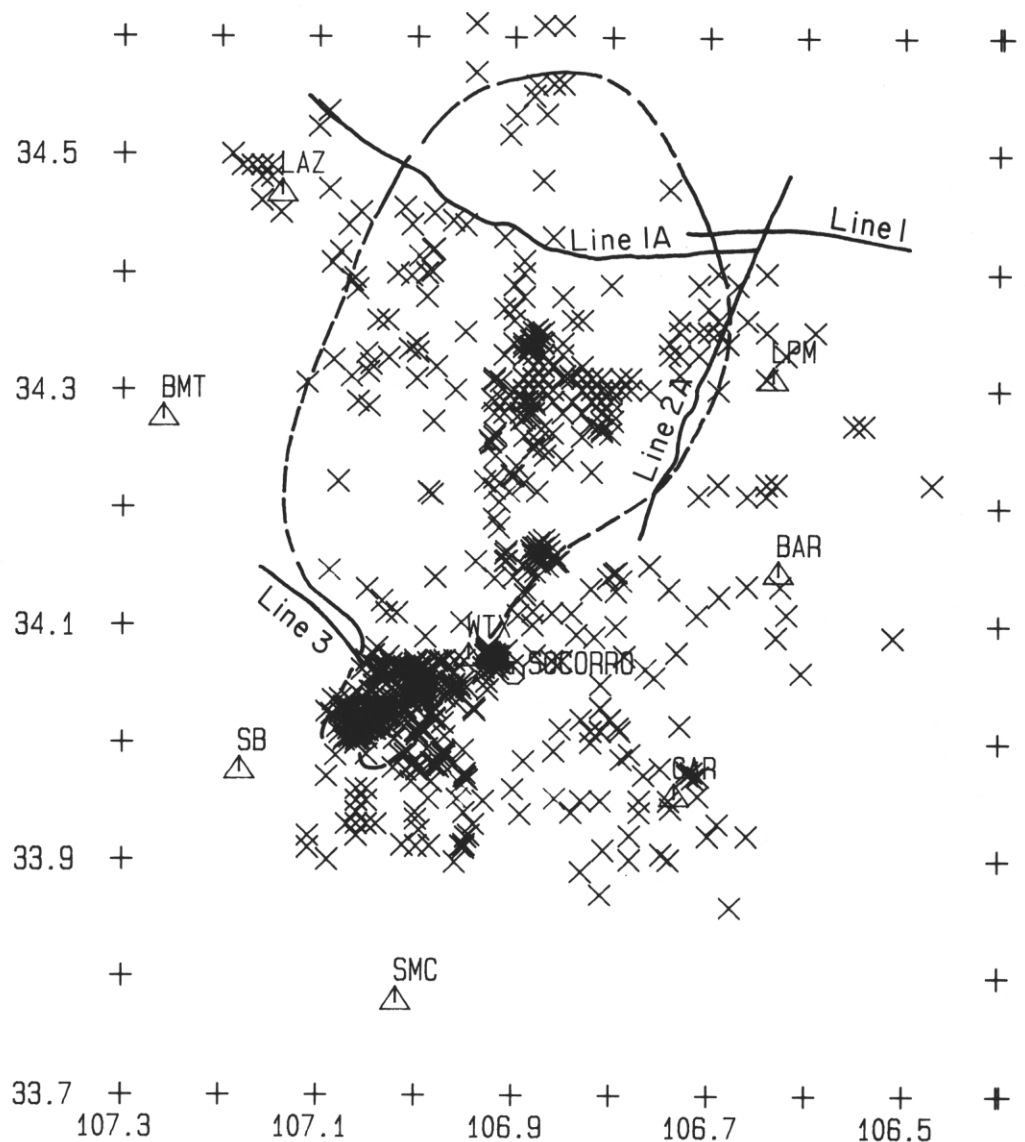


Figure 1. Seismicity of the Socorro area for the period May 20, 1975, through January 20, 1978, and June 13, 1982, through May 15, 1983. Also shown is the outline of the mid-crustal magma body (Rinehart and others, 1979) and the position of the Consortium for Continental Reflection Profiling (COCORP) profiles (Brown and others, 1979). The triangles mark the position of seismic stations currently operating in the Socorro area.

is particularly serious inasmuch as seismograms with anomalous character were always a small fraction of those with normal character in all studies. Re-examination of the data used in the studies of Poisson's ratio ( $\nu$ ) indicates that, out of a total 423 events, at most 18 percent could safely be considered anomalous ( $\nu \sim -0.300$ ). Only 5 percent of the 1600 seismograms examined by Johnston (1978) were found to have abnormally low dominant S frequencies. In the early study on ratios of amplitudes of direct P to direct S, Shuleski (1976) believed only 11 percent of the 387 ratios examined could safely be considered anomalous because of uncertainties in accounting for the focal mechanism. In a later study where fault mechanism was carefully considered, Roach (1982) found that 22 percent of the 281 ratios examined were anomalous. In addition, Roach found that the regions of anomalous crust defined by raypath intersections were almost as frequently penetrated by raypaths for normal events as by raypaths for abnormal events. It appears likely that if raypaths for all normal observations in all studies were traced through the crust, little space would remain for anomalous crust except in the immediate vicinity of the hypocenters.

Other observations suggest that magma is most likely to be found in close proximity to the hypocenters. Nearly all earthquake activity in the Socorro area occurs in swarms (Sanford and others, 1979) and most seismologists believe swarms are the consequence of the movement of magma, although the precise mechanism is not clearly understood. Recently Ryan and others (1981) demonstrated how close the association of earthquake hypocenters and magma might be. They were apparently successful in defining the conduits for the transport of magma beneath Kilauea volcano by carefully mapping earthquake hypocenters. By analogy, the most likely place for magma in the upper crust in the Socorro area is within the dense clusters of epicenters shown in Figure 1 because these are the regions where the swarm sequences of earthquakes are most prevalent. The vertical extent of the magma would coincide with the vertical extent of the hypocenters, from 4 to 14 km beneath the surface, but most would reside between 6.5 and 11.5 km because 88 percent of the hypocenters fall within this interval (Wieder, 1981).

One of the largest and most dense clusters of seismic activity is located in the area from 34.0°N to 34.1°N and from 107.0°W to 107.1°W.

In a study which involved inversion of microearthquake P-arrival data to simultaneously determine hypocenters and velocity structure, Ward (1980) found that the velocity beneath this region was anomalously low. In the depth interval from 4 km to the deepest hypocenters, the calculated velocity was  $5.17 \pm 0.11$  (1 s.d.) km/sec, which is nearly 0.7 km/sec less than the average crustal velocity in the area (Ward and others, 1981). In absence of any other reasonable explanation, travel through magma is considered the most probable cause of the low velocity. Ward did not find significantly lower velocities beneath other areas where clustering of events is great, possibly because raypaths crossing these regions did not intersect sufficient quantities of magma.

Placement of small quantities of basaltic magma in a complex network of dikes and sills in the immediate vicinity of the hypocenters can explain all of the abnormal observations described above, including the low velocity found by Ward (1980). The magma need only occur along raypaths used in his analysis in amounts sufficient to explain the low velocity. The quantity of magma in the upper crust is believed to be small because the level-line data (Reilinger and others, 1980) are not obviously anomalous where they cross the dense cluster of epicenters.

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*What a way to change a flat! (photo courtesy Socorro County Historical Society).*