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STRUCTURE OF THE SANGRE DE CRISTO MOUNTAINS BETWEEN TAOS AND MORA BASED ON AN INTEGRATED GEOPHYSICAL ANALYSIS

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ABSTRACT.-The southern Sangre de Cristo Mountains in New Mexico record much of the geological history of southwestern North America. Here we use a combination of geophysical data with geological ground truth to define the subsurface structure of part of this region. Our analysis indicates that a Proterozoic ductile fold and thrust belt exposed in the northern Rincon Range extends in the subsurface at least 25 km to the southwest of its surface expression. This fold and thrust belt likely links to similar fold and thrust structures exposed to the south and west in the Rio Mora, Truchas, Picuris and Tusas Mountains. Cross-cutting these structures, and offsetting the Great Unconformity, is a series of gently west dipping normal faults. These faults likely developed during Rio Grande rifting, although their gentle dips may be inherited from Laramide compressional structures. No structures related to Ancestral Rocky Mountains deformation were imaged in the subsurface. However, the distributions of Paleozoic rocks require that the Rainsville and Taos Troughs were major basins formed during Ancestral Rocky Mountain deformation. No evidence for the reactivation of Proterozoic structures was observed on the seismic data. Thus the structure of the southeastern Sangre de Cristo Mountains is the result of superposed deformation events that occurred in the Proterozoic, Late Paleozoic and the Cenozoic.

INTRODUCTION

In this study, we use seismic reflection data released by industry, gravity readings and remote sensing data to investigate upper crustal structures in the southeastern Sangre de Cristo Mountains. We use these data to constrain the geological evolution of this region. We use the seismic data to show that a previously recognized Proterozoic fold and thrust belt in the northern Rincon Range extends at least 25 km to the southwest of its surface exposure and is likely regionally extensive. There is also a marked gravity low (herein called the Mora gravity low) that extends from the Rainsville trough, northeast of Mora, to the high elevation Precambrian basement outcrops of the Rincon Mountains with no noticeable change in its pattern [Cordell and Keller, 1984]. We also use these data to show that this gravity low is produced by low density granitic rocks in the Precambrian basement and low density sedimentary rocks deposited during Ancestral Rocky Mountains deformation.

Structurally, the southern Sangre de Cristo Mountains of northern New Mexico consist of a series of basement-cored blocks defined first by the Paleozoic age uplift of the Ancestral Rockies and later on by Laramide and post Laramide deformation. These north-trending blocks are bounded on the east by high-angle, west-dipping reverse faults. The easternmost uplifts define the boundary between the Laramide-age Rocky Mountain front and the westernmost extent of the Great Plains (Fig.1). To the west, these mountains are bound by the San Luis and Española Basins of the Rio Grande rift. However, Paleozoic exposures along the western boundary contain complex structures including faults with significant strike-slip movement such as the Pecos-Picuris (Fig. 1) and the Borrego faults [Baltz and Myers, 1999].

The Precambrian rocks of interest in this study consist of gneisses, meta-rhyolites and schists and quartzites exposed in the El Oro-Rincon uplift and along the Pecos-Picuris fault south of Taos, New Mexico (Fig. 1). Also exposed in the Rincon Range is the metamorphosed Guadalupita pluton that is exposed south of Guadalupita (Fig. 1) and was initially recognized by Karlstrom [1998]. Detailed descriptions of these rocks and their metamorphic history can be found in Grambling [1990], Williams et al. [1999], Read et al. [1999], and Baltz and Myers [1999]. Rocks in the northern Rincon Range have been correlated with the Vadito and Hondo Groups, which are regionally extensive stratigraphic units exposed throughout northern New Mexico (Grambling, 1990). The Vadito Group is dominated by metamorphosed volcanic and sedimentary rocks interpreted to have formed in a rift environment (Mawer et al., 1990). These rocks are overlain by the Hondo Group which includes pelitic schists and quartzites metamorphosed to amphibolite grade. The Hondo Group is interpreted to have been deposited in a marine environment (Mawer et al., 1990). Both units are Paleoproterozoic in age.

In the northern Rincon Range Grambling (1990) mapped six ductile thrust faults that repeat the Hondo-Vadito stratigraphic sequence. In each of the thrust sheets preserved sedimentary structures in quartzite of the Hondo Group indicate that the stratigraphic section is overturned. Grambling (1990) interpreted this to indicate the existence of an earlier generation of recumbent folds that were subsequently imbricated by a second phase of thrusting.

DATA EMPLOYED

A variety of geophysical data were used in this study and new gravity and seismic data are presented. Gravity data have been collected in north-central New Mexico since the early 1960's. However, the rugged terrain has been the major factor contributing to the scarceness of data in this area. During the summer of 2000, we conducted gravity surveys near the town of Mora, New Mexico with the purpose of improving data coverage. These new readings were added to the previous coverage available and an edited database was constructed. Gravity readings in this database were reduced to Bouguer values using standard reduction equations [Cordell et al., 1982] and a reduction density of 2.67

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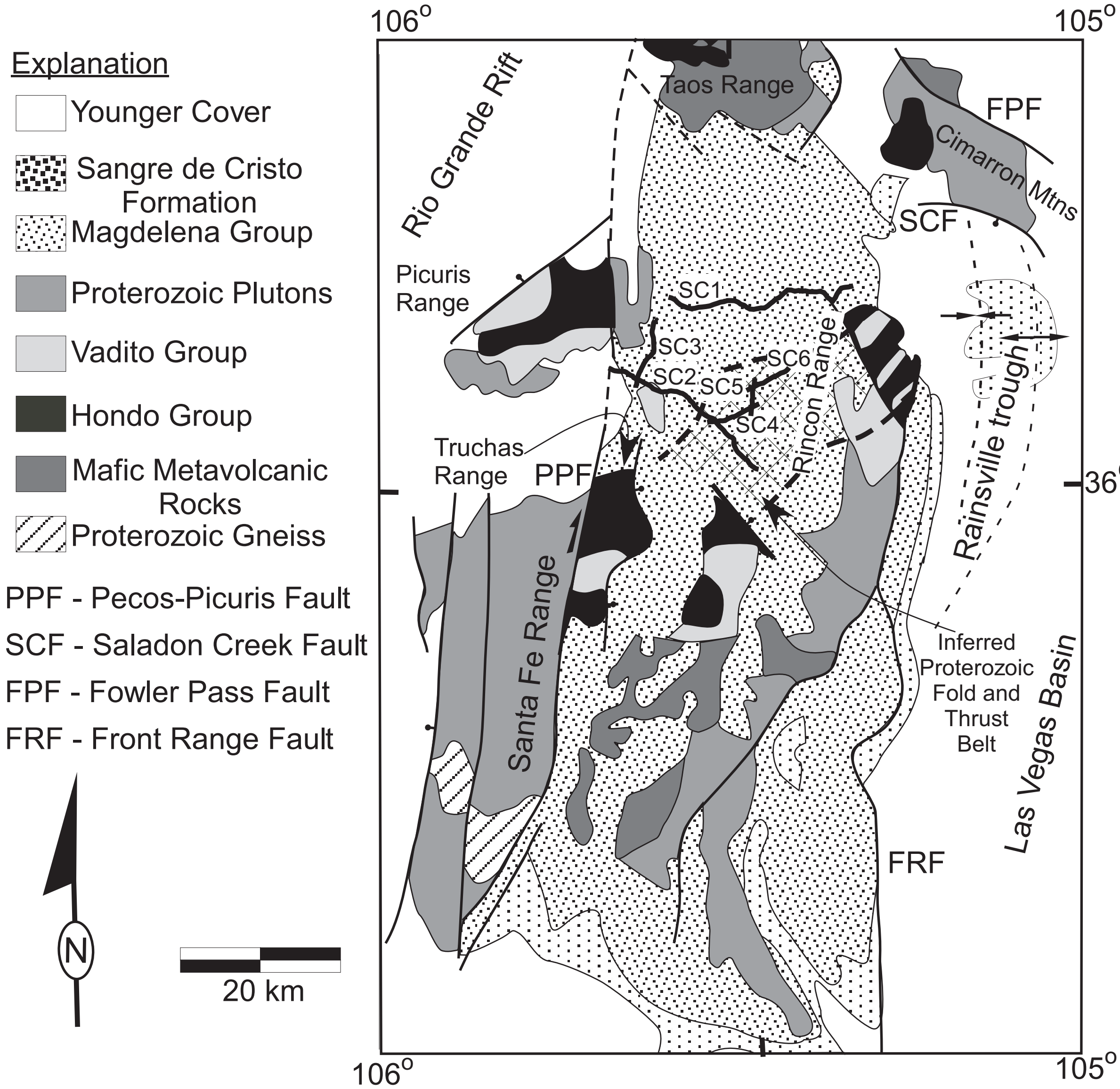

FIGURE 1. Tectonic index map of the Sangre de Cristo Mountains region, New Mexico. Modified from Karlstrom and Daniel (1993).

g/cm^3. These data were used to produce the gravity maps shown in Treviño et al. (2004, this guidebook). These maps show that the Sangre de Cristo Mountains in northern Mexico are associated with low Bouguer anomaly values even though Precambrian basement outcrops are extensive in them. The anomaly centered near Mora, New Mexico (36.2 N, 105.2 W) is of particular interest in this study and will be referred to as the Mora gravity low.

Georeferenced satellite imagery (Landsat Thematic Mapper – TM) was used as a base on which to clarify the spatial relationships between the different datasets. Standard spectral enhancement procedures such as band stretching, band ratios and saturation stretching were not able to enhance the weak spectral signatures from Precambrian outcrops. A spectral algorithm was then designed in order to minimize the reflectivity of the overlying vegetation and allow the sparse rock signatures to be enhanced (Quezada, 2000). This image and published geologic maps were used to produce the index map for this study (Fig. 1)

SEISMIC REFLECTION DATA

The main new data presented here are six seismic reflection profiles provided by Conoco-Phillips (Fig. 1). The surface geology where these lines were acquired consisted of Paleozoic sedimentary rocks with the exception of the western end of SC2, which traverses a Precambrian outcrop and a thin section of Tertiary sedimentary rocks south of Taos. These seismic data were used to constrain the upper 1- to 12 km of the crust and as a base on which to build the gravity models.

Seismic Data Processing

All processing for these data was done post stack using PROMAX and is discussed in detail in Quezada (2000). The processing flows for lines SC2 and SC1 were fairly similar since both lines are of comparable length and consist of 4 s data at 4ms sampling rate., but the flow for lines SC3, SC4, SC5 and SC6 was simpler since these lines are shorter, shallower and did not show as many steeply dipping reflectors. These shorter lines were used unmigrated to verify the continuity of the reflectors related to sedimentary strata on the Sangre de Cristo uplift. The processing included deconvolution and filtering to obtain as much reflector resolution as possible, to eliminate as much random noise as possible. The migration for lines SC2 and SC1 included careful velocity analysis and use of the Kirchoff method for the final migration.

INTERPRETATION

Line SC2

SC2 is a 26-km long, 36-fold seismic reflection profile shot at a group interval of 28 meters (Fig. 1). The line is in a NW-SE direction through the western Sangre de Cristo uplift. It shows a series of prominent shallow sub-horizontal reflectors from the surface to 1.5 s that were correlated with maps and interpreted to be Tertiary and Quaternary sedimentary strata. These high amplitude reflectors lie northwest of a Precambrian outcrop that is clearly imaged on the reflection section by a region absent of coherent reflectors. This outcrop extends on the seismic section approximately from CDP 1000 to 800 extending from the surface down to 4 s. A second series of prominent reflectors appear to ramp up onto the Precambrian outcrop at the surface and truncate it at depth (Fig. 2). We have interpreted this boundary as the top of the crystalline basement. The top-of-basement reflector flattens out at a depth of 1 s and can be followed throughout the length of the seismic section (Fig. 2). Overlying these basement features is a series of prominent and continuous reflectors that are interpreted as the Pennsylvanian and Permian age sedimentary strata. The bottom of this sedimentary section and the top of the crystalline basement make up what is known as the northern New Mexico "Great Unconformity", where Pennsylvanian and Permian age rocks directly overlie Precambrian basement rocks.

SC2 shows many intra-basement reflectors (Fig. 2). Intra-basement reflectors appear to have two different orientations at different depths. The deeper set (1.5-2.5 seconds) is relatively linear and follows a ramp-up pattern parallel to the top-of-basement reflector. Overlapping these reflectors is another set of reflectors that appear to be concave downward (1.0-1.5 seconds) and do not appear to be due to under-migration or diffractions. We interpret these reflectors as sets of imbrications and possibly duplex structures related to Precambrian age deformation.

The orientation of this seismic profile is roughly perpendicular to the strike of Precambrian thrusts, which crop out in the northern Rincon Range. These features include the previously mapped ductile thrusts and the six-fold repetition of the Precambrian Hondo and Vadito Group contact in the northern Rincon Mountains [Grambling, 1990; Read et al., 1999]. The intra-basement reflectors interpreted in this line are likely to be the along strike continuations of these features. Assuming this correlation is correct, it implies that this fold and thrust belt extends a minimum of 25 km to the southeast of their surface exposures in the northern Rincon Range.

Line SC1

Seismic profile SC1 is a 48 fold, 29-km long line (Fig. 1) that was recorded at a different group interval (55 m) than the other the lines. This line is also displayed as a migrated section (Fig. 3). The western end of SC1 is located roughly 3 to 4 km southeast of Ranchos de Taos. It then extends for 27 km toward the east (Fig. 1). Even though SC1 is located only approximately 15 km north of line SC2, it reveals vastly different structures (Fig. 3). The entirety of the section shows continuous reflectors through

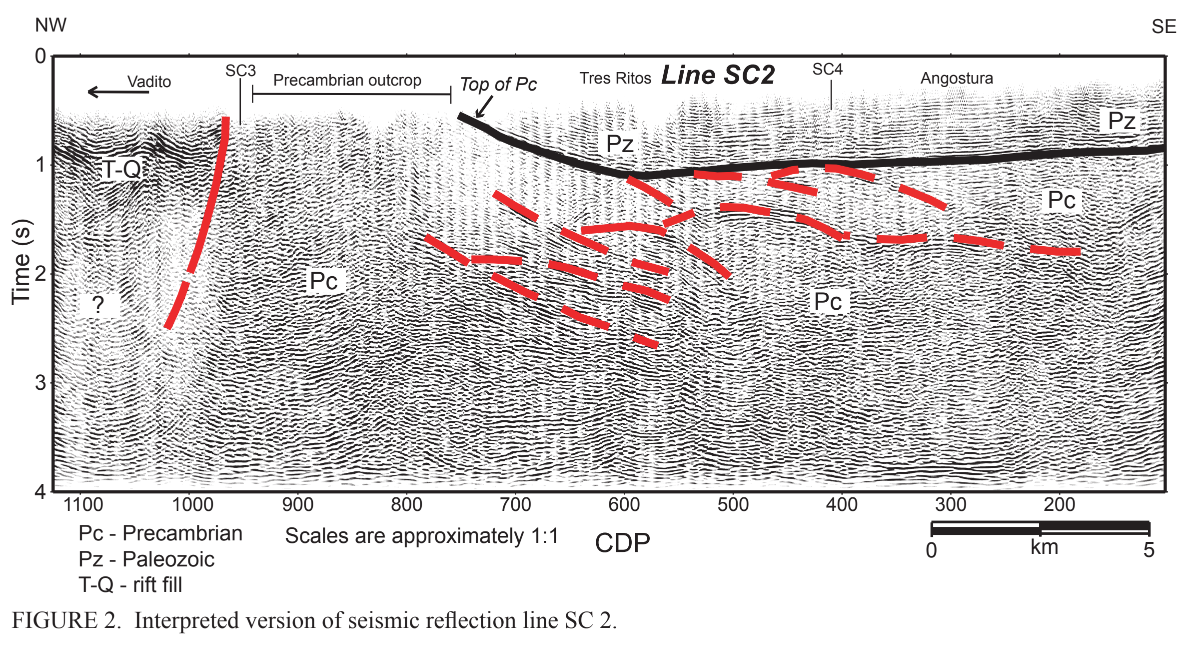

FIGURE 2. Interpreted version of seismic reflection line SC 2.

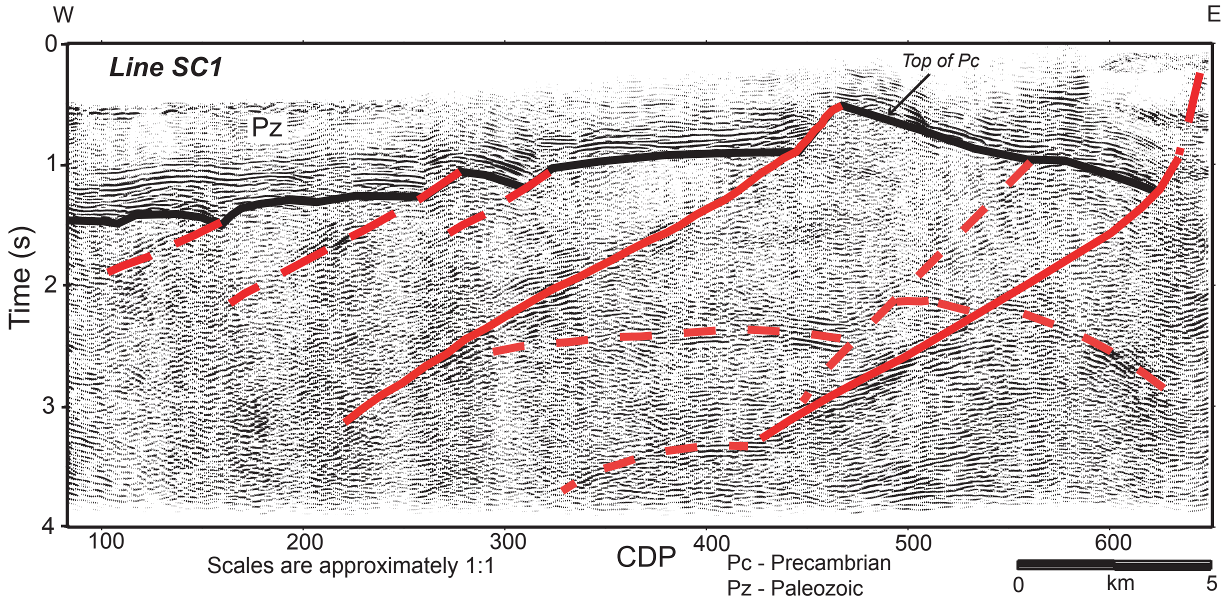

FIGURE 3. Interpreted version of seismic reflection line SC 1.

the first 0.5 to 1.5 seconds. These reflectors are interpreted as Paleozoic sedimentary rocks. The top of the Precambrian basement was estimated from the more constrained depth seen on line SC2. This shows up as a bright, continuous reflector starting at 1.5 seconds on the western side of the section that, although visibly offset by faults, can be followed throughout the entirety of the line (Fig. 3). The top of the basement reflectors along SC1 is discontinuous at several points. Between CDP 450 and 500, there is a pronounced break and change in dip. The basement reflector dip is gently sloping toward the west from CDP 1 to CDP 450, at the break, it is offset upward and changes dip toward the east. This abrupt change in dip corresponds to a prominent reflector that, as previously described, offsets the top of the Precambrian basement by as much as 0.5 s. This prominent reflector can be followed dipping to the west at approximately 35º – 40º to a depth of 3.5 s. Even though faulting in this area is generally compressional, the geometry and character of this reflector suggests that it is a low angle normal fault. Apparent throw on this fault was interpreted to be approximately 1.5 km based on a minimum seismic velocity of 3.0 to 3.5 km/s for Paleozoic sandstones. Overall, line SC1 shows tilting of basement blocks along what appear to be normal faults. Imaging of the strata directly overlying the shallowest part of these faults is poor. This could indicate near-vertical or highly deformed beds. Intra-basement reflectors are present in SC1 but show different patterns than the reflectors analyzed in line SC2. For instance there is no evidence for imbrication or folding of the basement, as seen on line SC2. We interpret this to indicate that the fold and thrust structures imaged on line SC2 as lying to the southeast of the line SC1. Intra-basement reflectors on line SC1 appear to change dip throughout the section. These reflectors could indicate the remains of a dome-like geometry cut be later brittle faults. Several large dome-like structures have been mapped in the Precambrian basement of the Rincon Mountains and include the El Oro anticline, south of Mora, the Romero Hills anticline, northeast of Mora and the Comanche Peak anticline the north-northwest of Mora (O'Neil, 1990). These structures have been correlated with the last stage of folding during Proterozoic orogenesis in the Rincon Mountains (Read et al., 1999). SC1 lies on a localized positive gravity anomaly. This localized high is probably an effect of the shallower basement depth controlled by the tilting of basement blocks previously described.

Line SC3

Line SC3 is a 15 km long line located south of the Ranchos de Taos (Fig. 4). It is oriented N-S and intersects line SC2 approximately at CDP 610. The reflector associated with the top of the basement on this line is not as prominent as the other lines. It is only partly visible in the southern portion of the section and on its northern margin (Fig. 4). On the southern edge of the section, the Tertiary-Quaternary sedimentary rocks visible on line SC2 are clearly noticeable on SC3 as the upper 0.5 s of high amplitude reflectors. These reflectors abruptly terminate near the SC2 tie point. The area around CDP 300 to 350 marks the beginning of an intra-basement reflector that starts at the basement surface and then dips to the north (Fig. 4). This feature is interpreted as an along strike view of the normal faults visible further north in SC1. SC3 crosses through the southern boundary of the local gravity high on which SC1 is located. If projected northward, line SC3 would intersect the western section of SC1. In this area, normal faults are clearly visible but do not offset the top of the basement as much as normal faults seen further to the east.

Lines SC4, SC5 and SC6

Lines SC4-6 (Fig. 1) are short and shown together to simulate a longer continuous profile. Line SC4 is a 7 km long profile that ties into the eastern section of line SC2. This is the longest of

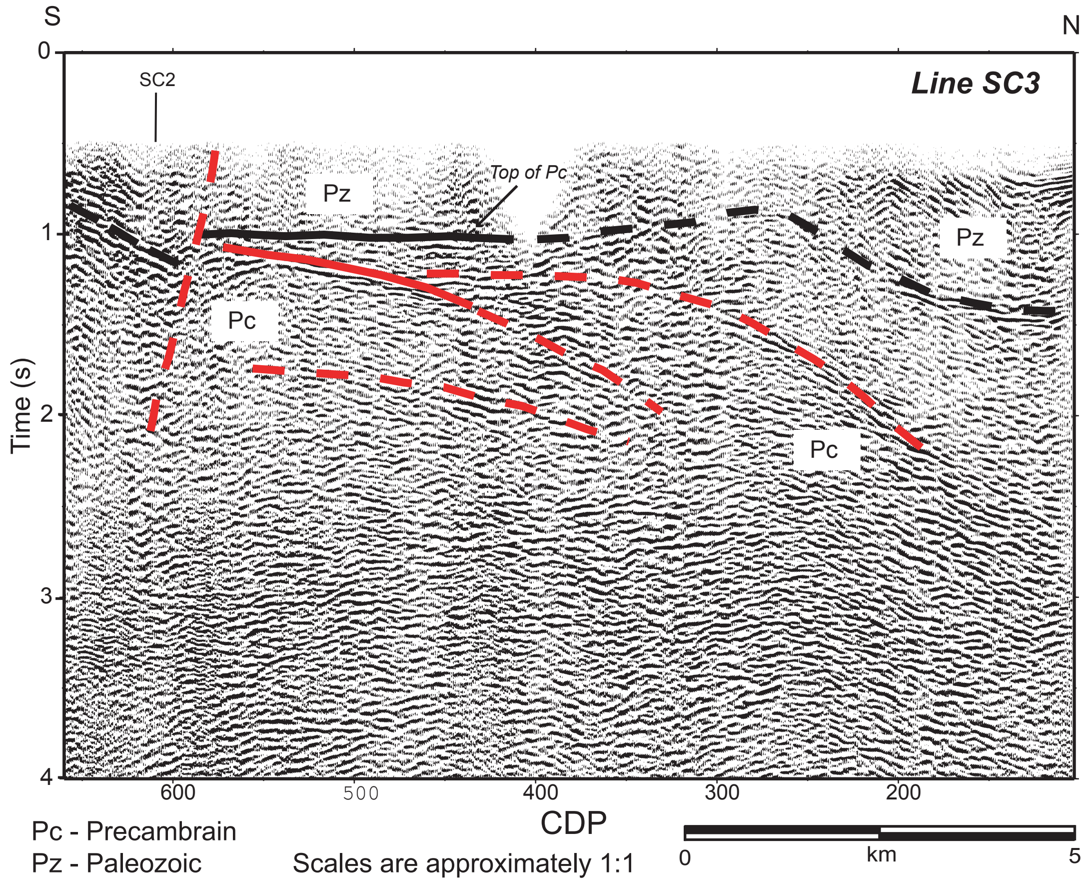

FIGURE 4. Interpreted version of seismic reflection line SC 3.

these lines, and only 2 seconds of data were made available to us. It shows the same depth to basement of approximately 1 second, or 1.5 – 2 km, as the longer lines (Fig. 5). There are two prominent crisscrossing intrabasement reflectors. The main reflector appears at 1.5 seconds on the southern end of the line and dips toward the north. It then crosses a second reflector dipping south at CDP 350 (Fig. 5). This intrabasement crisscrossing pattern is also seen on SC2 where it was interpreted as imbricate fans and possibly duplex structures. Therefore, these reflectors are interpreted to represent the same structures imaged from a different angle. Special emphasis has to be given here to the fact that these compressional structures are entirely different in dip and geometry than those seen on SC1 and SC3 and interpreted as normal faults.

Lines SC5 and SC6 are 5 and 6 km long, respectively. For line SC6, the data made available to us only extends to 1.5 seconds (Fig. 5). The depth to basement does not show any major variation from lines previously described. The intrabasement reflectors described in line SC4 can be followed perfectly across both of these lines dipping toward the southwest (Fig. 5). The most interesting feature in these lines can be seen in line SC6 around CDP 50 – 100. At 0.5 seconds deep, the basement seems to have down dropped sharply by 0.5 seconds (0.5 to 1.0 km). This fault has the same geometry and amount of basement offset as the major normal fault interpreted in SC1. Furthermore, if projected northwest from line SC6, this fault matches the location of the same major normal fault interpreted in SC1. These two features on two different lines are therefore interpreted as the same fault.

The gravity model presented by Quezada (2000), and summarized in Treviño et al. (2004, this guidebook), show that the low gravity values associated with the Mora gravity low are caused by a combination of two coincident geological features. The first is low-density Paleozoic rocks deposited in the Rainsville trough (e.g., Baltz and Meyers, 1999). These rocks contain a great deal of clastic material that was reworked from Proterozoic basement which was uplifted during Ancestral Rocky Mountains orogenesis (Baltz and Meyers, 1999) and form a basin with depths down to 7000 meters below the surface adjacent to the El Oro-Rincon uplift. The second geological feature controlling the low gravity values is interpreted to be the 1.68 Ga Guadalupita pluton (Read et al., 1999). This pluton has been extensively metamorphosed and deformed during Proterozoic orogenesis. It contains extensive retrograde muscovite that formed during the late stages of metamorphism. The occurrence of extensive retrograde micas in this felsic lithology gives it a lower density then the surrounding gneisses, quartzites and amphibolites. Thus including this body in gravity modeling (Treviño et al., this guidebook) reproduces the Mora gravity low without having to call on allochthonous basement emplaced over sedimentary cover, a localized crustal root, or deeper seated felsic intrusions (Quezada, 2000).

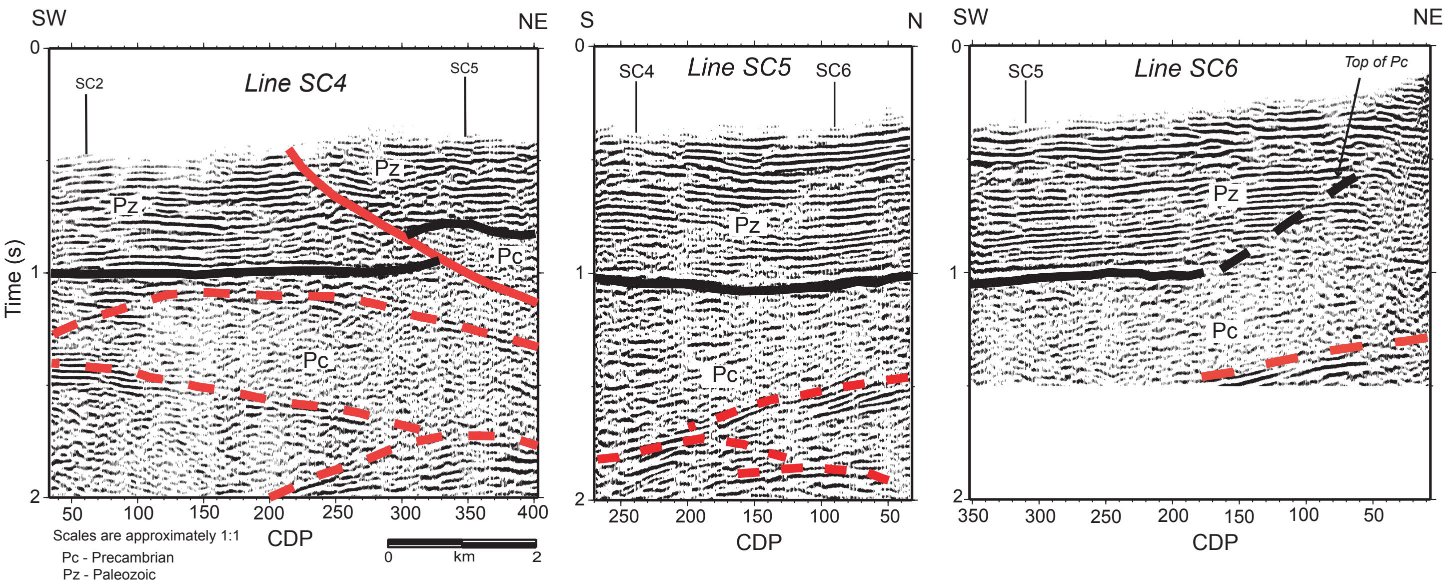

FIGURE 5. Interpreted versions of seismic reflection lines SC 4, SC 5 and SC 6.

DISCUSSION AND CONCLUSIONS

The southeastern Sangre de Cristo Mountains record a long and complex geological history beginning with Paleoproterozoic tectonism. The subsurface geometry of many of the geological features in this part of the southern Rocky Mountains is constrained by our geophysical data. Seismic reflection profiling reveals that the fold and thrust belt exposed in the northern Rincon Range extends at least 25 km to the southwest where it is imaged in the subsurface beneath line SC2. This fold and thrust belt may connect with the Proterozoic fold and thrust belt described by Karlstrom and Daniel, (1997), which crops out in the Rio Mora, Truchas, Picuris and Tusas Mountains. If these belts are connected, it requires any right lateral structures that offset the fold belt to lie farther west than the position of seismic line SC2. Alternatively, this fold and thrust belt may be a tectonically distinct feature in the Precambrian of the southern Sangre de Cristo Mountains. The six-fold repetition of the Vadito-Hondo contact originally identified by Grambling (1990) indicates this fold and thrust belt records significant crustal shortening. These Proterozoic structures are crosscut by Phanerozoic structures. One of the most important of these structures is the Rainsville trough, which formed a major depocenter during Ancestral Rocky Mountain deformation. This depocenter combined with the low density Guadalupita pluton is the likely cause of the Mora gravity low. The geometry of isopachs in the Rainsville trough (Baltz and Meyers, 1999) requires that faults that bound the trough crosscut the northeast striking structural grain in the Precambrian basement.

Numerous normal faults are imaged on line SC1, beginning southeast of Taos, and extending well into the Sangre de Cristo Mountains. The timing of these normal faults is not well known, however we speculate that they are normal faults related to extension along the Rio Grande rift. If this time correlation is correct, it requires that extension related normal faults extend well beyond the physiographic margins of the rift, into the mountains bounding the rift. As such, normal faulting associated with the rift should be considered in reconstruction of the southeastern Sangre de Cristo Mountains. The faulting interpreted from line SC1 is radically different than the relatively unbroken base of the Paleozoic section seen further south. Due to their relatively low angle, these faults could be related to east-verging Laramide-age compressional structures that were later reactivated by rift related extension (Adam Read, personal communication, 2003).

The major structures interpreted in this study can be classified into two distinct deformational episodes: (1) Proterozoic accretion (1.7-1.6 Ga), which we propose is represented by the imbricate intra-basement reflectors on the seismic reflection data as well as the intrusion and 1.6 Ga metamorphism of the Guadalupita pluton in the Rincon Range, and (2) Laramide-age compression with extensional Tertiary reactivation. Paleozoic basin and uplift deformation associated with the Ancestral Rocky Mountains was not directly observed in the seismic data. However, previous studies as well as our gravity modeling indicate that the Taos and Rainsville troughs were created during this period.

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REFERENCES

Baltz, E. H., and J. M. O'Neill, 1984, Geologic map and cross sections of the Mora River area, Sangre de Cristo Mountains, Mora County, New Mexico, U. S. Geol. Survey, Map I-1456, 1:24000.

Baltz E. H., and D. A. Meyers, 1999, Stratigraphic framework of upper Paleozoic rocks, southeast Sangre de Cristo Mountains, New Mexico, with a section on speculations and implications for regional interpretation of Ancestral Rocky Mountains paleotectonics, New Mexico Bur. Mines and Mineral Res, Memoir 48, 269 p.

Cordell, L., G. R. Keller, and T. G. Hildenbrand, 1982, Bouguer gravity map of the Rio Grande rift, U.S. Geol. Survey, Map GP-949, 1:1,000,000.

Cordell, L. and G. R. Keller, 1984, Regional structural trends inferred from gravity and aeromagnetic data in the New Mexico-Colorado border region, New Mexico Geol. Soc., 35th Field Conf. Guidebook, p. 21-23.

Grambling, J. A., 1990, Proterozoic geology of the Rincon Range north of Guadalupita, New Mexico, New Mexico Geol. Soc., 41st Field Conf. Guidebook, p. 207-210.

Karlstrom, K. E., and C. G. Daniel, 1993, Restoration of Laramide right-lateral strike slip in northern New Mexico by using Proterozoic piercing points; tectonic implications from the Proterozoic to the Cenozoic, Geology, v. 21, p. 1139-1142.

Read, A. S., K. E. Karlstrom, J. A. Grambling, S. A. Bowring, M. Heizler, and C. Daniel, A middle-crustal cross section from the Rincon Range, northern New Mexico: Evidence for 1.68 Ga, Pluton-influenced tectonism and 1.4 Ga regional metamorphism, 1999, Rocky Mountain Geol., v. 34, p. 67-91.

Williams, M. L., K. E. Karlstrom, A. Lanzirotti, A. S. Read, J. L. Bishop, C. E. Lombardie, J. N. Pedrick, and M. B. Wingstead, 1999, New Mexico middle crustal cross sections: 1.65 Ga macroscopic geometry, 1.4 Ga thermal structure and continued problems in understanding crustal evolution, Rocky Mountain Geol., v. 34, p. 53-66.