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Tectonic stability of the San Luis Hills, northern Rio Grande rift, Colorado: Evidence from paleomagnetic measurements

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Abstract. The San Luis Basin is the largest of four tilted, fault bounded Neogene basins of the northern Rio Grande rift in New Mexico and Colorado. It formed during the second of two episodes of extension beginning in middle Oligocene and extending to the present. The San Luis Hills are an intrarift horst of Oligocene intermediate and basalt rocks preserved in the middle of the San Luis Basin. Previous paleomagnetic and structural studies in the Espanola Basin to the south indicate counterclockwise rotation of that region during the most recent extension. Paleomagnetic samples from the two exposed formations in the San Luis Hills yield a mean direction of inclination = 55.6° and declination = 347.2° (α_{95} = 6.8°, N=23) that is coincident with the expected Oligocene direction for North America. These rocks show no indication of rotation or severe tilting during rift extension.

Introduction

The Rio Grande rift is an intracontinental rift that extends from northern Mexico to central Colorado. The central and northern part of the rift is composed of the north-trending Albuquerque, Espanola, San Luis and upper Arkansas basins, which are filled with Neogene (mostly Miocene) sedimentary and volcanic rocks. The largest of these basins, the San Luis basin, is covered in the southern part by the Taos Plateau volcanic field, a Pliocene dominantly basaltic volcanic field (Lipman and Mehnert, 1979). An intrarift horst of Oligocene igneous rocks, the San Luis Hills, is present just north of the Taos Plateau in southernmost Colorado (Figure 1).

The rift appears to have undergone two distinct phases of extension beginning in the middle Oligocene (Morgan and Golombek, 1984; Morgan et al., 1986). The early phase of extension was temporally and spatially associated with major magmatic events and locally involved very large strains, typically on closely spaced low-angle or listric normal faults. Magmatic centers active in the northern Rio Grande rift at this time include the Ortiz mountains between the Albuquerque and Espanola basins; the Latir volcanic field east of the San Luis Basin; the San Luis Hills within the San Luis Basin; and the extensive San Juan volcanic field to the west of the San Luis Basin in Colorado (Figure 1). Available evidence suggests that both the southern San Luis and Espanola basins began forming about 26 Ma as broad shallow basins in response to this early phase of extension (e.g., Lipman and Mehnert, 1975; Chapin, 1988; Chapin and Cather, 1994).

Following a significant reduction in volcanism along the Rio Grande rift in the middle Miocene the present basins formed along widely spaced high-angle normal faults. Present day basins are comparatively simple block-faulted half-

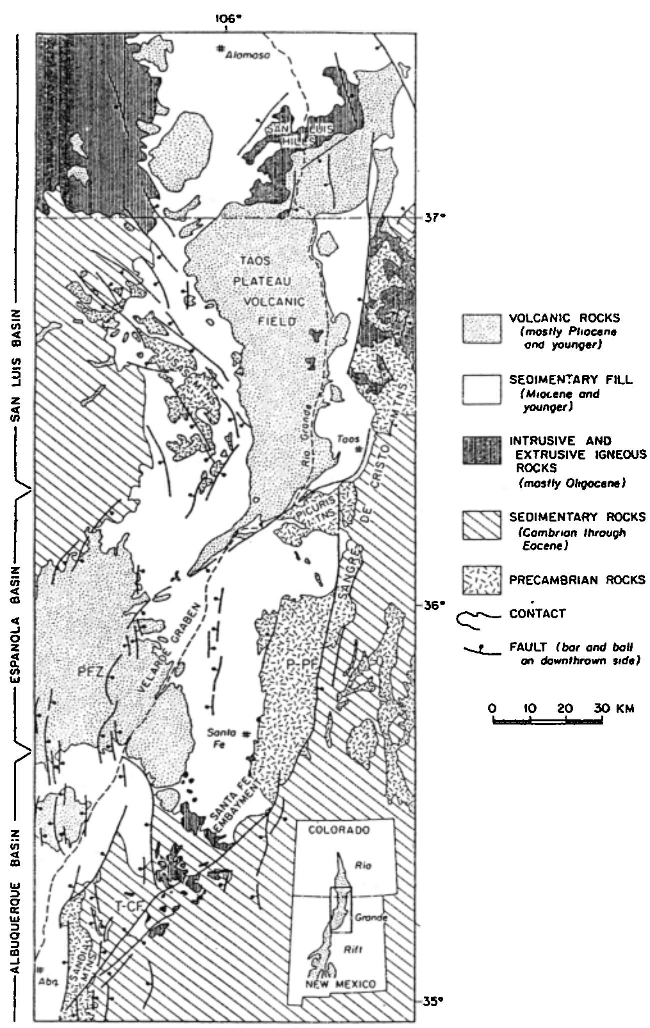

Figure 1. Generalized geologic map of a portion of the Rio Grande rift from Albuquerque, New Mexico to southern Colorado, including parts of the San Luis, Espanola and Albuquerque basins. The San Luis Hills crop out in the northern part of the map. Rio Grande shown by dashed line.

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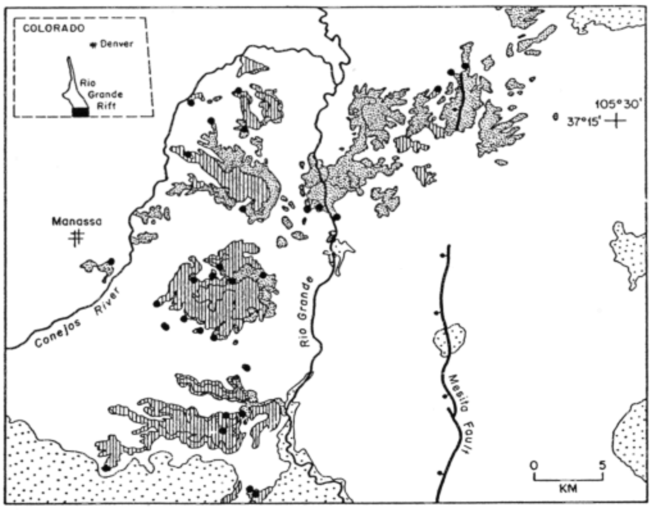

Figure 2. Generalized geologic map of the San Luis Hills, southern Colorado. Fine stippled pattern, Conejos Formation; vertical lined, Hinsdale Formation; dotted pattern, Pliocene volcanic rocks of the Taos Plateau volcanic field; white, Quaternary surficial deposits; black dots, paleomagnetic sites. Geology adapted from Thompson and Machette (1989).

grabens involving low to moderate strains, with adjacent uplifted horsts that formed coevally along much of the rift after about 10 Ma. During the latter half of this phase of extension, a large diamond shaped block (referred to as the Espanola block), extending from the San Luis Basin in the north to the Albuquerque Basin in the south (and including the eastern part of the intervening Espanola basin), appears to have rotated counterclockwise (Muehlberger, 1979; Dungan et al., 1984; Brown and Golombek, 1985; 1986; Salyards et al, 1994). Structural and paleomagnetic work (Brown and Golombek, 1986) suggests that rotation began about 5 Ma, resulting in uplift of the acute corners (Picuris and Sandia mountains) and subsidence of the obtuse corners (Velarde graben and Santa Fe embayment). Although the San Luis Basin does not appear to be rotated (Brown et al., 1993), compression across the Embudo fault has downwarped the Taos Plateau volcanic field (Muehlberger, 1979; Dungan et al., 1984; Brown et al., 1993).

In this paper we investigate the San Luis Hills, an intrarift horst of Oligocene igneous rocks in the central part of the San Luis Basin. Geologic mapping (Thompson and Machette, 1989) shows no evidence of these rocks being involved in locally pervasive faulting associated with the early phase of rifting. In addition, available paleomagnetic data from the southern San Luis Basin (Brown et al., 1993) suggest that this part of the San Luis Basin has not participated in the vertical axis counterclockwise rotation of the Espanola block to the south. As a test of both of these hypotheses, we investigated the paleomagnetism of the San Luis Hills to determine if these rocks had been tilted by early phase deformation or rotated by later rifting events. Results provide additional evidence for the relative stability of this portion of the Rio Grande rift since the late Oligocene.

Geologic Setting

The San Luis Basin, extending from south of Taos, New Mexico, northward into Colorado, is an east-tilted half-graben with a master fault at the base of the Sangre de Cristo Mountains (Tweto, 1979; Kluth and Schaftenaar, 1994; Brister and Gries, 1994). The San Luis Hills are the surface expression of an intrarift horst cored by Precambrian basement (Brister and Gries, 1994). The hills are a series of flat-topped mesas exposing two Oligocene units, the Conejos Formation of intrusive and extrusive intermediate composition igneous rocks, and the younger Hinsdale Formation of basaltic composition; both formations consist of a series of mapped units distinguishable by rock type (Thompson and Machette,

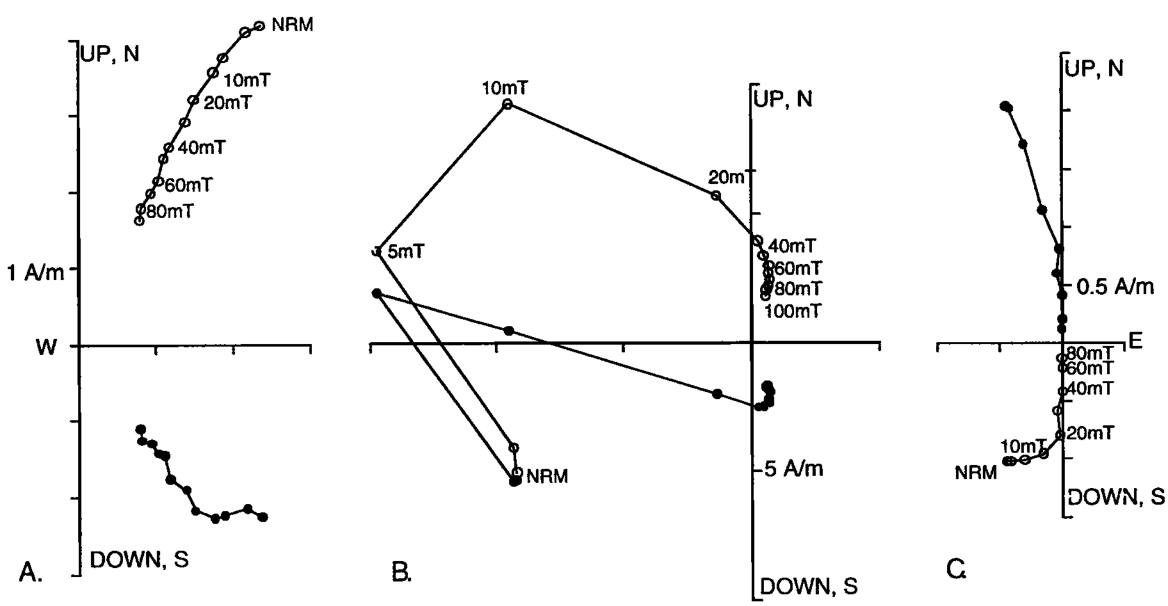

Figure 3. Vector end point diagrams of alternating field demagnetization of selected samples from the San Luis Hills. Open circles, projections onto the vertical plane; closed circles , projections onto the horizontal plane. Demagnetization level in mT. A. Volcanic mudflow unit of the Conejos Formation, site 26, with univectoral decay. B. Volcanic mudflow unit of the Conejos Formation, site 25, showing removal of large overprint. C. Andesite sample of the Conejos Formation, site 30, with small overprint.

Table 1. Paleomagnetic Data from the San Luis Hills

SITE	GEOL	N	I	D	k	a_{95}	LAT	LONG
1	Thb	5/3/8	56.3	18.7	109	6.2	75.1	339.1
2	Tca	4/3/8	68.5	359.8	67	9.0	75.2	253.7
4	Tht	9/9	63.5	355.2	510	2.3	81.4	230.7
5	Thb	3/3/7	40.2	5.9	18	17.2	75.0	52.8
7	Tclm	9/9	-44.7	166.8	118	4.8	-74.5	304.0
8	Tclm	9/9	-52.0	158.8	246	3.5	-72.1	335.9
9	Tca	7/7	53.7	352.6	401	3.0	83.3	140.5
12	Tdbh	7/7	64.1	309.9	61	7 8	52 1	193.6
13	Thb	6/7	54 1	338.7	(-11,-1)	(16.8,20.6)	72.6	162.0
14	Thb	7/9	59.7	323.4	(-26,-1)	(9.6,12.9)	61.5	182.3
15	Thb	8/8	32.1	338.0	585	2 3	62.3	124.4
16	Thx	7/7	60.6	293.5	(-49,-1)	(7.5,7.9)	39.7	191.2
18	Tcu	7/2/9	-63.4	176.0	26	10.4	-81 8	54.2
20	Tcl	2/1/6	-57.2	182.8	133	12.6	-87.7	147.7
21	Thb	4/3/7	73.5	353.5	26	12.7	67.4	245.5
23	Tclm	7/7	-51.9	177.6	295	3.5	-85.0	277.9
24	Tca	7/7	-56.8	149.1	106	5.9	-65.5	354.2
25	Tclm	8/8	-50.7	166.6	84	6.1	-77.6	320.8
26	Tclm	9/9	-49.5	156.7	329	2.8	-69.5	331.7
27	Tca	3/2/7	27.8	318.5	132	7.2	47 0	144.0
28	Tca	8/8	41.5	51.4	(-19,-3)	(9.3,22.4)	44.3	346.0
29	Tcl	7/8	57.3	356.4	227	4.0	87 1	179.6
30	Tca	8/8	46.2	351.7	108	5.4	78.1	112 5
MEAN		23/23	55.6	347.2	21	6.8	79.7	162.6

GEOL, Geologic units sampled, see text for descriptions; N, either number of samples used in calculations/ total number measured or number of direct measurements/ number from remagnetization circles/total number measured; I, site mean inclination in degrees; D, site mean declination, in degrees; k, precision parameter; a_{95}, radius, in degrees, of cone of confidence at the 95% level; (both are from Fisher statistics, numbers in parentheses are k and a values from Bingham statistics;) LAT, LONG, latitude and longitude, in degrees, of magnetic pole.

1989). The Conejos Formation is assumed to be related to pre-caldera rocks of the same name in the San Juan Mountains, although a younger radiometric age has been reported (Thompson et al., 1991). Radiometric determinations on Hinsdale Formation rocks yield an age of 26 Ma (Thompson et al., 1991). Although within the exposed San Luis Hills there is no evidence of ash flows from the contemporary calderas of the San Juan Mountains to the west, ash flow tuffs are observed between the Conejos and Hinsdale formations in drill holes in the San Luis Basin to the north (Brister and Greis, 1994).

Sampling and Measurements

Paleomagnetic samples were collected from selected outcrops of both the Conejos and Hinsdale formations (Figure 2). A portable gas-powered drill was used to obtain cores in the field; orientations were measured with both a Brunton compass and a solar clinometer. Ten sites were collected from the Hinsdale Formation, seven of silicic alkaline-olivine basalt (Thb), and one each of tholeiitic basalt (Tht), xenocrystic basaltic andesite (Thx) and associated biotite-hornblende dacite porphyry dike (Tdbh). A total of 15 sites were drilled from the Conejos Formation with an attempt to sample a wide range of lithologies present. This included six sites in the lower andesite unit (Tca), five sites in a volcanic mudflow unit (Tclm), three sites in the lower dacite unit (Tcl) and one site in the upper andesite unit (Tcu).

Remanent magnetizations were measured on a Molspin spinner magnetometer at the University of Massachusetts. Natural remanent magnetization (NRM) values for the samples varied widely from 0.5 A/m to 160 A/m, with the stronger intensities being related to lightning strikes on the exposed Hinsdale flows. All samples were step-wise demagnetized in alternating magnetic fields up to 80 or 100 mT. Linear segments of decay were recognized in many samples and often only one component of magnetization was revealed (Figure 3A) or obvious overprints were removed in fields of 20 to 60 mT (Figure 3B, C). Pilot thermal demagnetization studies

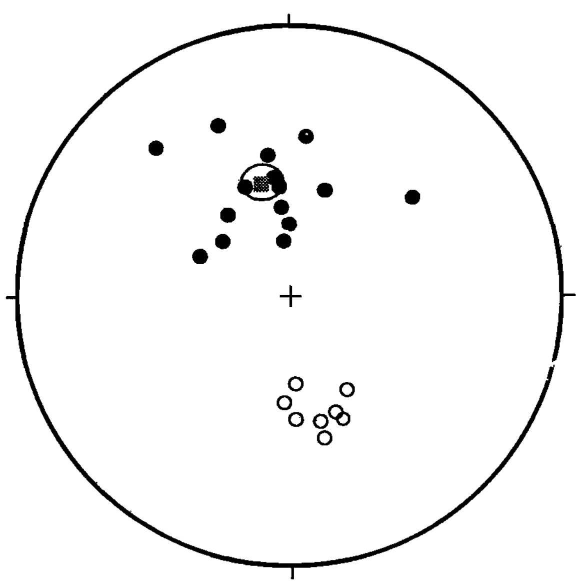

Figure 4. Equal area plot of site mean directions for 23 sites from the San Luis Hills. Closed circles are projections on the lower hemisphere and open circles are projections on the upper hemisphere. Shaded square is the mean direction for all sites, shown with 95% confidence circle. Expected direction for latitude of the San Luis Hills lies within this circle.

yielded similar directions and indicated, along with saturation studies, that magnetite is the primary magnetic carrier.

Results

Over half of the sites showed high internal consistency and using methods of principal component analysis yielded mean directions with a_{95} less than 8° (Table 1). These included all the mudflow sites, as well as several andesite and basalt flows. The remaining sites showed much more scatter even after detailed step-demagnetization on all samples. Seven sites have directions determined from combined linear paths and circles, following the methods of McFadden and McElhinny (1988). Additionally, four sites required remagnetization circles on all the samples; they are listed in Table 1 with associated Bingham statistics. Two sites, one each of Hinsdale and Conejos formations, gave scattered directions and no data are reported for them.

Mean directions for the accepted 23 sites are plotted in Figure 4. No tectonic corrections have been applied to any of the units as they appear horizontal in the field. Both normal and reversed polarities are present, although the normal sites show much greater scatter. Even so, the means for the two polarities are nearly identical and the population passes the reversal test at the 99% level. After inverting the reversed sites, the mean for the study is inclination of 55.6° and a declination of 347.2° with an a_{95} of 6.8°. The corresponding pole lies at 79.7°N and 162.6°E. The combined directions from the Conejos Formation and the Hinsdale Basalt agree well with the Oligocene expected direction at this latitude for North America (Diehl et al., 1988).

Conclusions

The initial phase of extension in the northern Rio Grande rift (26 Ma) was accompanied by intermediate volcanism followed by basaltic volcanism as represented by the Conejos and Hinsdale formations. Paleomagnetic directions coincident with the expected direction indicate that these units have not been measurably tilted or rotated since that time. This is in direct contrast to units further to the south, such as the Espinosa Formation in the Ortiz Mountains, which show 18° of counterclockwise rotation (Brown and Golombek, 1986). The nonrotation of the San Luis Hills do agree with data from younger units on the Taos Plateau, which also are not rotated (Brown et al., 1993). It appears that the San Luis Hills are a high, stable block throughout the formation of the Rio Grande rift, and were not tilted or rotated significantly during extension.

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