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Late Cenozoic Faulting in the Rio Grande Rift Valley Near Socorro - T. R. Toppozada

An Independent Study submitted to Dr. A. J. Budding as partial requirement for the M.Sc. degree in Geophysics

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ABSTRACT

A forty mile stretch of the Rio Grande Rift Valley around Socorro was studied for evidence of Late Cenozoic faulting. The study was based on aerial photographs, with complementary information obtained from pre-existing maps. The youngest faults were found to be concentrated in the downthrown blocks, and to have a dominant trend of N 10° W. A method is outlined for calculating the seismicity of the region from the lengths and displacements of these faults, provided their ages are known. A simple model is proposed to account for the Pleistocene erosion surfaces which occur at progressively lower levels with contemporaneous increase in depth of the valley, also for the development of horsts within the graben. Finally, a tabular inventory of Miocene and younger faults is given, presenting the information that is known about each fault.

INTRODUCTION

The purpose of this study is to extend our knowledge of the seismicity of the Rio Grande rift valley back to Pleistocene time. Instrumental information regarding the seismicity is available only for the last decade, and historical information is available only for the last century or so. Features, such as pediment surfaces, which are thought to be Pleistocene or younger, when offset by faulting, give some idea of the seismic event which produced the faulting. In this way it is hoped to extend our knowledge back from one hundred years to one million years, that is one hundred thousand fold. The new information covering the last million years will not be as accurate as the historical information covering the past hundred years, but it should at least give some idea of the long-range seismicity. Moreover some measure of long-range seismic risk may result from this information. Thus we may divide our total knowledge of the seismicity of this region into three portions: the final portion being the last ten years of instrumental data, the intermediate or historical portion covering the last hundred years and confined to reports of felt shocks, and lastly the coarse data confined to those shocks large enough to produce surface fractures during the last million or so years.

The area studied extends for 40 miles along the Rio Grande from San Antonio northwards to Bernardo, and for 30 miles in an east-west direction. According to both the historical and instrumental information, this is the most seismically active stretch of the Rio Grande rift valley.

References

Mention of Kelley's work.

METHOD OF STUDY

Aerial photographs having a scale of about 1:40,000 and numbering one hundred and forty were viewed. The photographs were obtained from U.S.G.S., and are in two sets: ninety photos in flight lines trending north-south, and fifty photos in flight lines trending east-west. The photographic coverage as well as the location of individual photograph centers is shown on fig. 2. This map shows that the photographs are not distributed uniformly over the entire area, but are concentrated along the central trough. In the upthrown borders every other photograph is available giving complete coverage with no overlap, while in the central trough each photograph is available giving the overlap necessary for stereoscopic viewing.

Faults appear clearly on aerial photographs as lineations marking a change in color or ground texture. When they offset the present surface either as fault or fault-line scarps, then their relief is particularly evident under the stereoscope. Some of the photolineations in the Santa Fe and younger rocks were checked in the field to confirm or reject them as faults.

STRUCTURAL SETTING

The area lies in the Basin and Range province, to the south of the Rocky Mountain province and to the west of the Great Plains province.

The Rio Grande in this portion of its course flows in a tectonic valley, between the Ladron, Polvadera, Socorro and Chupadera mountains on the west, and Los Pinos mountains, Joyita hills, Mesa del Yeso and Loma de las Canas on the east. Both sides of the valley are structurally high to the north, where Precambrian is extensively exposed in the Ladron and Polvadera mountains and across the river in the Los Pinos mountains and the Joyita hills; to the south in the Socorro and Chupadera mountains and across the river from them, Precambrian outcrops are rare. To the west of the Ladron-Polvadera-Socorro horst La Jencia Basin is downthrown, and is bounded to the west by a fault system along the eastern flank of the Bear and Magdalena mountains.

GEOMORPHOLOGY

The topographic relief is some 5500', from about 10,000' at the top of the Magdalena mountains to about 4500' at the Rio Grande near San Antonio. The structural relief is much greater and is of the order of 20,000', with the Precambrian elevated 5000' above the river in the Magdalena mountains and depressed some 12,000' below the river (Sanford, 1968) in the trough.

Within the area are several peneplained pediment surfaces at different elevations, which indicate long periods of erosion and stability separated by spasmodic changes in base level. The first post-Santa Fe (post-Pliocene) pediment is the Ortiz surface, which is graded to a level 450' to 500' above the present flood plain. The sole remnant of the Ortiz surface in the area is the southern tip of the Llano de Albuquerque where the Rio Puerco joins the Rio Grande. The Llano de Albuquerque is a caliche capped mesa bounded on the east by the Rio Grande and on the west by the Rio Puerco, and extending for 70 miles from the latitude of Bernardo northward. Of this mesa, Bryan (1938) wrote:

> "The northern 30 miles of the scarp which bounds the Llano de Albuquerque on the west is coextensive with a system of en-echelon faults having their downthrow to the east.

> Such faulting should produce an irregular east-facing scarp. The present scarp faces west. It, then, must be a fault line scarp and clearly a reverse fault line scarp, since it faces in a direction opposite to that of the original movement... The southern 40 miles of the scarp is a purely erosional feature..."

Despite the last sentence quoted, a possible fault is plotted on the map along the Rio Puerco towards its mouth, with downthrow to the east. This fault is indicated by the lining up of a tributary on the eastern bank of the river, along the southern extension of the Rio Puerco. Moreover this fault with downthrow to the east would explain why the Ortiz surface is only 370' to 400' (Denny, 1949, p. 236) above the Rio Grande flood plain at this point.

The second post-Santa Fe pediment in this area is the Tio Bartolo surface, which is graded to a level 250' above the present flood plain and again is largely capped with caliche. According to Denny, 1941, the Tio Bartolo pediment covers most of La Jencia basin.

The third pediment surface is the Valle de

Parida, which is graded to a level 150' above the present flood plain. Remnants of the Valle de Parida surface occur north of the Ladrons, north and east of Polvadera peak and across the river east of the Joyita hills.

"Cut and fill" terraces near Socorro

The fourth and youngest pediment identified by Denny is the Canada Mariana surface, which flanks the present arroyos and the Rio Grande and is graded to a level 50-75' above the present flood plain. The Canada Mariana surface covers most of the area east of the Sierra Ladrons, and is of particular interest as it is extensively offset by faulting.

Incorrect

Little can be said about the absolute age of these pediments. Their relative age is evident - the highest is the oldest. Even the time of commencement of pediment formation is only vaguely assigned to the Pleistocene.

It appears that the latest stage of arroyo cutting started around the year 1880 with the advent of the settlers, and is responsible for the steep walled channels from ten to forty feet deep. This

Reference

is due to the increased runoff resulting from overgrazing.

THE GEOLOGIC SECTION

For the purpose of constructing the map (fig. 1), the local geologic section was divided into 7 units, as follows:

1. Precambrian rocks
2. Paleozoic rocks (Carboniferous and Permian) - (4000')
3. Mesozoic rocks (Triassic and Cretaceous) - (1500')
4. Pre-Miocene Cenozoic sediments (Baca formation) - (1500')
5. Pre-Miocene Cenozoic (Datil) volcanics - (2200')
6. Miocene to Recent sediments, consisting of the Popotosa formation, the Santa Fe group, and the younger fill material - (3000')
7. Miocene to Recent volcanics, associated with the Santa Fe and younger rocks

The figures in brackets being the estimated maximum thickness.

The geology on the east side of the river was modified after Wilpolt and Wanek (1951) for the area south of the 34°15' parallel, and from Wilpolt and McAlpin (1946) for the area north of 34°15'. On the west side of the river the geology was for the most part obtained from the half million scale state geologic map, with information in the southern Ladrons modified after Black (1964).

For the purpose of constructing the three east-west cross sections (fig. 4) the subsurface extrapolation of thickness was governed by a gravimetric survey by Sanford (1968), who computed thicknesses to match the observed gravity data.

THE UPTHROWN BORDERS

The eastern border of the rift valley is taken at the first Santa Fe pre-Santa Fe contact. This contact is transgressive at places, but is more commonly fault defined. At the latitude of San Antonio, the eastern border is 5 miles east of the river, and it trends in a direction slightly west of north and comes right up to the river two miles north of San Acacia. At this point the sedimentary contact makes a right angle and swings due east. Here the structural border diverges from the contact and presumably trends NE parallel to the Los Pinos faults.

The western border of the rift valley is taken along the east side of the Magdalena and Bear mountains, on the assumption that the Socorro-Polvadera block is an intergraben horst. West of San Antonio and Socorro, the border is a NNE trending fault bounding the Magdalena mountains on the east and lying 12 miles west of the river. At about the latitude of Socorro the border curves to NW and follows this trend for eleven miles parallel to the Magdalena mountains, up to where U.S. 60 turns west between the Magdalena and Granite mountains. At this point the border curves to a northward trend and proceeds thus for some ten miles along the eastern front of the Bear mountains. Then the border presumably swings to northeast to join the Cerro Colorado fault which has that trend and bounds the Sierra Ladrons on the southeast. La Jencia structural basin ends at this point since Mesozoic and Paleozoic rocks outcrop a few miles to the north.

How about the Ladron Mountains?

Evidence of northeasterly faults at this location has been found on the aerial photographs but has yet to be checked in the field (these are the two dashed faults near latitude $34^{\circ}20'$N and longitude $107^{\circ}10'$W). The border circumnavigates the Sierra Ladrons, turning from NE to N to NW at the northern limit of the map.

From the foregoing, the borders of the rift valley appear to diverge at a latitude of $34^{\circ}20'$, producing the wider Albuquerque-Belen basin to the north. The western border proceeds from the Sierra Ladrons to the Lucero uplift, while the eastern border proceeds from the Joyita hills en echelon to the Manzano mountains.

Within the area studied, the maximum width of the rift valley is 21 miles at latitude $34^{\circ}12'$N, and the minimum width is 16 miles at latitude $34^{\circ}00'$. This compares well with the average width of the Rhine graben of 25 miles, and the average width of the East African rift valleys, also of 25 miles. This figure is of the same order of magnitude as the thickness of the continental crust (20-40 miles).

THE DOWNTHROWN BASINS

The axial part of the basin contains a thickness of 3000' of Santa Fe fill, La Jencia basin contains about 1500'. Reference

It is interesting that inter-Santa Fe and post-Santa Fe faults are always basinward from pre-Santa Fe faults, indicating that the tectonic rift valley is progressively contracting from the borders towards the axis. This can be seen from the tectonic map (fig. 1) where the youngest faults are concentrated towards the center of the valley. Also the seismic data indicate a general clustering of events towards the center. This is in agreement with Wright's (1946) observation that "the Rio Grande depression is therefore smaller now than it was in the late Tertiary." An example of this is the western border along the base of the Magdalena and Bear mountains, which was the tectonic border during the Santa Fe and into Pleistocene time as witnessed by the Santa Fe deposits up to that line and by the young fault scarp in the alluvium, but is now seismically inactive, — Dangerous statement the seismicity together with the younger fault scarps being concentrated towards the center of the rift valley. A rose diagram (page 17) was constructed for the downthrown basins. It indicates an overwhelmingly dominant trend around ten degrees west of north, with a much lesser trend around east-west. Other trends are poorly represented to absent. It was not possible to represent the faults on a stereographic projection due to lack of information regarding attitudes of the fault planes.

SEISMICITY

Speculation regarding the prehistoric seismicity of the area depends on the ages of the scarps. Carbon fourteen ages may be obtained if datable material (preferably charcoal) is found several feet below the surface at the foot of the scarp, assuming that this material came from the upthrown side and was buried when the scarp was young. This would be a minimum age for the fault. A maximum age for the fault would be the age of the pediment surface it offsets.

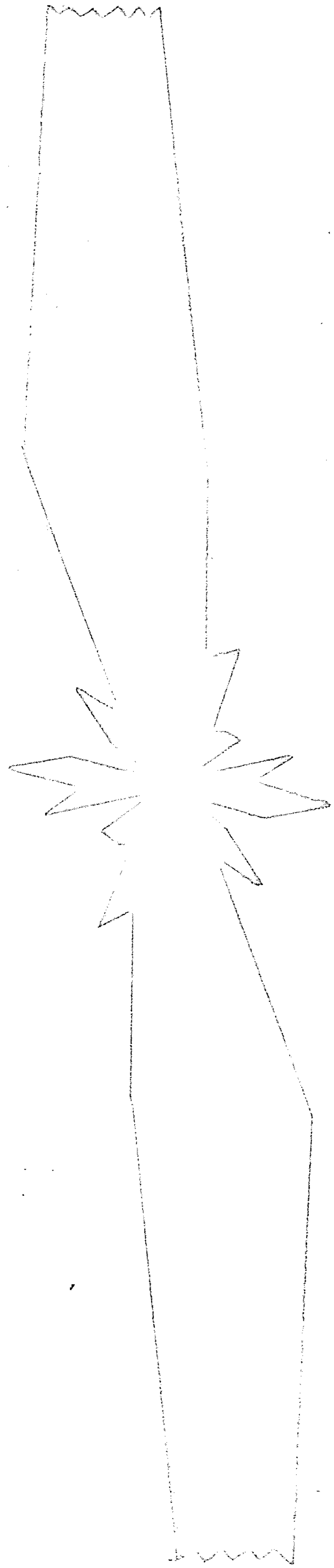


Fig-1

Rose Diagram

Explanation?

Thus, for example, if the Canada Mariana pediment surface were dated at 20,000 years, the group of faults east of the Ladrons which offset this surface would be younger than that. The largest scarp in this group is approximately 1,440,000 centimeters long and 600 centimeters high, and would have produced an earthquake of magnitude M, related to the scarp parameters by

$$\mathrm{Log}_{10} LD^2 = 2.24M - 4.99$$

according to King and Knopoff (1968).

Substituting 1,440,000 and 600 for L and D respectively, we get M = 7.45.

From

$$\mathrm{Log}_{10} N = a - bM \qquad (b = 1)$$

(Richter, 1968), where N is the number of shocks of magnitude M, we see that for unit decrease in magnitude the number of shocks increases by a factor of ten. Assuming that this scarp is 20,000 years old, we can say than an M = 7.45 shock occurs once in 20,000 years, also that ten M = 6.45, and one hundred M = 5.45, and one thousand M = 4.45, and ten thousand M = 3.45 shocks occurred during the same interval. This would mean that an M = 3.45 shock would be expected on the average every $\frac{20,000}{10,000}$ or every two years, an M = 5.45 every two hundred years, and so on. This would be for the specific area, measuring some 13 miles north to south and 6 miles east to west and lying east of the Ladrons, from which the largest scarp was selected. The above estimates of seismicity could then be compared to the present level of seismicity. This same area of 80 square miles is known to have produced four shocks of magnitude 3 or greater during the past ten years. In this way we can find out References whether the present level of seismicity is higher or lower than the long range level.

CENOZOIC GEOLOGIC HISTORY

This concluding section deals with the historical development of the rift valley during the Cenozoic Era, and proposes a simple model to explain the observations.

The highlands produced by the Laramide movement resulted in this area being one of erosion rather than deposition, during the early and middle Tertiary. However a remnant of Baca formation in the southeastern corner of the area indicates that there was local terrestial sedimentation during early Tertiary.

During the middle Tertiary extensive volcanic rocks were developed, in the form of flows, ash beds and intrusives of the Datil group. These form the flanks of the Socorro and Magdalena mountains, and the bulk of the Chupadera mountains. This extensive vulcanicity is in keeping with the observation that, "...volcanic activity is invariably associated with rifted upwarps" (Holmes, 1965, p. 1051). Indeed, vulcanicity proceeded through Santa Fe time and beyond.

After the vulcanism reached a climax in the middle Tertiary, basins started to form which received tuffaceous as well as non-volcanic sediments. These sediments are the Popotosa formation, which is grouped with the Santa Fe as rift valley fill by some writers, and considered pre-rift valley by others. In this report, the Popotosa is included with the Santa Fe as Miocene and younger basin fill.

In early Miocene time there existed a number of structural depressions along the present Rio Grande rift valley, in which the Santa Fe formation was deposited. The Santa Fe rocks are playa clays, silts, sands and fanglomerates. Accelerated subsidence in late Santa Fe time is indicated by the coarsening of the fan deposits. This is further indicated by faults on which there was movement before the end of the Santa Fe, in other words contemporaneous faulting and deposition. As stated above, vulcanicity continued through the Santa Fe, although on a reduced scale compared to the Datil group, producing shallow intrusives and intercalated flows.

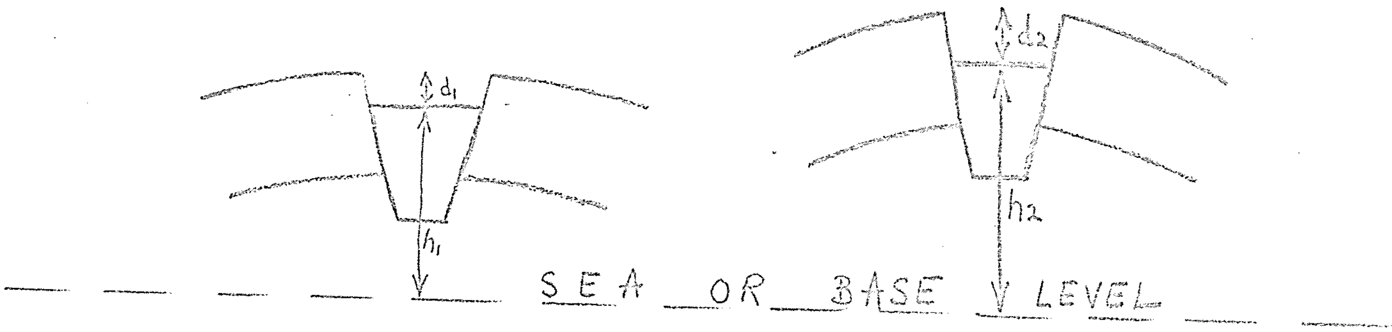
The end of Santa Fe time was marked by the uplift of the Socorro and Polvadera and Los Pinos mountains and the re-elevation of the Sierra Ladrons (Denny, 1941), resulting in the present rift valley with through flowing drainage. According to Denny, the Socorro-Polvadera block was not elevated above the Santa Fe basins, nevertheless it must have been a submerged horst (positive area in the past,) as the Permian and entire Mesozoic section is missing from this block.

Good point

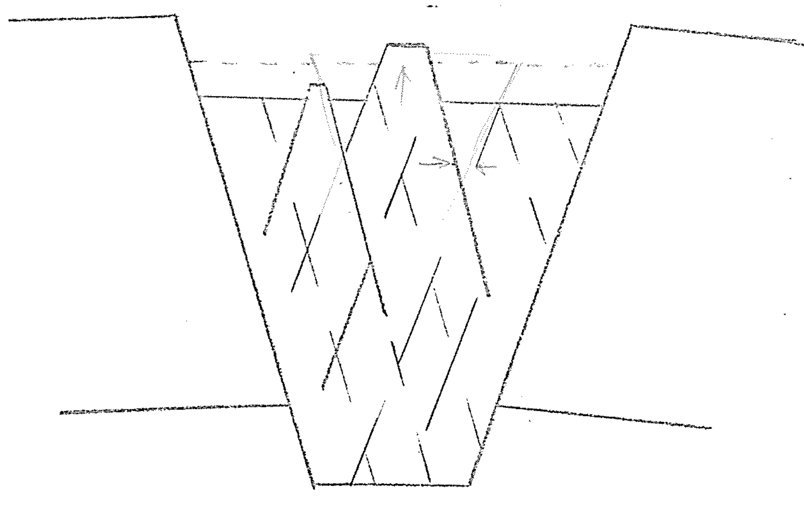
The uplift which marked the close of Santa Fe time was spasmodic rather than continuous. Periods of uplift were separated by periods of stability, during which the extensive Quaternary erosion surfaces developed. It appears that the entire area was uplifted after the development of each erosion surface, as implied by the progressive lowering of base level. Within this regional uplift there must have been relative movement between the rift valley and its borders, the former being lowered relative to the latter. In other words, the Rio Grande valley subsided relative to its borders, but was raised relative to sea or base level in order to develop the progressively lower pediment surfaces.

Capture of ancestral Rio Grande (which flowed into Mexico) near El Paso at beginning of Pleistocene

The classical model of a keystone slipping down at the top of an arch illustrates the situation well. Sketch (a) on page 23 illustrates the

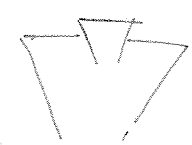


(a) (b)



(c)

situation in early Pleistocene, with a rift valley having a width on the order of the crustal thickness and depth d_1 and height above sea level h_1. Sketch (b) illustrates the situation at a later time after increased arching and uplift, with d_2 and h_2 greater than d_1 and h_1 respectively. Thus lowering of base level (or uplift) is accompanied by slipping down of the rift block in keystone fashion. Moreover, as the rift block slips down between the converging fault planes it is compressed. As this compression builds up, failure would occur along planes parallel to the conjugate pair of master faults, and blocks would "pop up" to relieve the compression as shown in sketch (c). This would account for the horsts seen on the accompanying cross sections (fig. 4). The fractures could also serve as conveyance channels for the magma, leading to development of the extensive volcanic rocks associated with the graben.



Popping up might occur most easily on steep reverse faults rather than normal faults.

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APPENDIX I

FAULT INVENTORY

Attached is a tabular listing or inventory of the faults in the Miocene and younger rocks. All these faults, with few exceptions, offset the present surface in varying amounts. Each fault is given a number; this number is put approximately at the center point of the fault which is marked by a red circle on the inventory map (fig. 3). If the number in the table is followed by X, the fault is certain and is plotted as a solid line, if the number is not followed by X the fault is uncertain and is plotted as a dashed line on the map. The latitude and longitude of the center points are given to within half a minute in the second and third columns. The average trend and length of the faults are given in the fourth and fifth columns. In the sixth column the number of the aerial photograph on which the fault appears is listed; if this number is followed by (E) the photo belongs to the east-west set, otherwise it belongs to the north-south set. The next to last column headed "Throw," contains a number followed by a bearing (e.g. 12, E), the former is the throw in feet where it is known, and the latter indicates the downthrown side. The last column headed "Remarks" indicates if the fault has been visited in the field, and if a photograph of it is available, as well as any other pertinent information.

faults offsetting geomorphic surfaces marked with ✓

No.	Lat.	Long.	Length (Units Miles)	Trend	Photo No.	Throw (Units Feet)	Remarks
✓1	34°30.0'	107°03.0'	3.4	45W	3-23,3-24	NE	Unable to locate in field
2	29.0	05.5	0.6	55E	3-36		
3	29.5	05.0	1.1	55E	3-36,3-23		
4	29.5	04.0	0.7	55E	3-23		
5X	28.0	04.0	2.3	18W	3-23		After Black, 1964
6	29.5	03.5	0.9	55E	3-23,3-24		
7X	28.0	02.5	1.3	33W	3-23,3-24		After Black, 1964
8	28.5	01.0	1.6	83E	3-23,3-161		
9X	26.5	01.0	4.2	1W	3-160	E	Jeter fault, ? reversed ?
✓10	29.5	106°56.0	1.5	4E	10-80(E)	E	
✓11X	27.0	57.0	11.7 km 7.0	6W	10-117(E)	~25' E	Visited, slide available
12X	24.0	107°02.0	2.1	2W	3-21	E	
13	24.5	00.5	1.4	0(N)	3-159		
14X	23.0	03.0	5.4	45E	3-20	SE	
15X	21.0	04.0	2.3	23E	3-19	E	
16X	22.5	03.0	1.2	61W	3-19,3-20	SW	

No.	Lat.	Long.	Length	Trend	Photo No.	Throw (Ft)	Remarks
17X	34°22.0'	107°03.0'	1.0	59W	3-19,3-20	SW	
18X	22.5	03.0	0.5	1E	3-19,3-20	E	
19X	22.0	03.0	0.8	3E	3-19,3-20	E	
20	23.0	01.0	0.7	0(N)	3-158		
21	22.5	01.0	0.9	0(N)	3-158		
22	22.0	01.0	0.8	7W	3-157		
23X	21.5	01.0	2.7	9E	3-157		
24	20.5	01.5	1.6	33E	3-19		
25X	23.5	106°59.0	8.7	2W	3-158,3-159	50' 20,E	Visited, alternately reversed fault line scarp, Santa Fe against Popotosa
26X	22.0	59.5	0.8	18W	3-157	W	After Evans(Date) Not referenced
27X	22.0	59.5	0.7	20W	3-157	E	After Evans
28X	23.0	58.0	1.6	5W	10-166(E)		
29X	22.0	57.5	7.0	8W	10-165(E)		Surface change in slope
30	20.0	58.0	1.1	83E	1-67(E)		
31X	22.0	107°07.0	0.8	48E	3-40	NW	
32X	18.0	106°57.5	4.8	20W	1-28(E)	E	Visited, slide available, Santa Fe against Popotosa

Units

No.	Lat.	Long.	Length	Trend	Photo No.	Throw	Remarks
33	34°20.0'	106°55.0'	3.8	85W	1-65(E)	S	Surface change in slope
34	25.0	54.0	1.2	0(N)	10-128(E)	E	Visited, identified vaguely
35	20.5	55.0	2.7	3W	10-175(E)	E	Surface change in slope
36X	21.0	54.0	4.3	0(N)	10-175(E)	? W	Visited, exhumed antithetic fault
37	24.5	51.0	9.6	19W	10-178(E)	E	On evidence of lining up of tributaries
38	17.0	107°14.0	3.2	74W	3-92	S	Appears convincing on aerial photo
39	19.0	11.0	5.0	75E	3-92,3-72	S	Appears convincing on aerial photo
40X	20.0	106°05.0	2.4	59E	3-40	S	
41X	19.0	05.0	3.4	86W	3-18	N	
42X	16.5	02.0	0.9	16W	3-18		
43X	16.0	03.0	6.5	7W	3-17	W	
44X	18.0	107°01.5	5.3	21W	3-18,3-155	E	
45X	15.0	01.0	4.9	12W	3-154	E	
46	17.0	01.5	1.7	6E	3-17		
47X	16.0	01.5	6.8	6W	3-16,3-17	W	
48	18.0	106°59.0	1.5	1E	3-155		

No.	Lat.	Long.	Length	Trend	Photo No.	Throw	Remarks
49X	34°17.0'	106°59.0'	0.8	0(N)	3-155	E	
50	17.5	59.0	0.6	79W	3-155	E	
Bear Mountain - Magdalena							
51X	12.5	107°11.5	10.6	0(N)	3-65,3-67	E	Bear Mountains alluvial fault
52	10.5	02.0	10.7	5W	3-14,3-15	20,E	Based on gravity data
53	00.0	106°57.5	4.3	82E	3-154	S	
54	15.0	57.5	2.8	72E	3-119,3-154		
55	14.5	56.5	1.0	18W	3-119		
56X	15.5	58.5	0.4	2W	1-20(E)		Highly disturbed area
57	17.5	58.5	0.5	0(N)	1-28(E)		Highly disturbed area
58	16.5	58.0	0.7	2W	1-20(E)		Highly disturbed area
59	16.0	57.5	1.3	12W	1-20(E)		Highly disturbed area
60	16.0	57.5	1.4	20W	1-20(E)		
61X	17.5	58.0	0.8	6W	1-28(E)		
62X	17.5	56.5	12km 7.6	5W	3-120	~20'	Visited, slide available, Evan's clastic dike
63	15.5	51.5	21.0	1W	1-16(E)	W	
64	20.0	50.0	2.2	68W	1-62(E)	N	

No.	Lat.	Long.	Length	Trend	Photo No.	Throw	Remarks
65	34°19.0'	106°50.0'	0.9	35E	1-29	W	
66	18.5	50.0	0.7	59W	1-29		
67	18.5	50.5	0.8	53E	1-29		
68	20.0	45.0	6.0	40E	1-60(E)	E	East Joyita fault, buried
69X	16.0	50.0	3.3	0(N)	1-30	W	West Joyita fault, [illegible]
70X	20.0	37.5	9.0	23E	1-55(E)	W	Los Pinos mountains front
71	15.0	56.5	0.5	13E	3-119		Visited, highly disturbed area
72	14.5	56.5	0.3	54W	3-119		Visited, highly disturbed area
73	14.5	56.5	0.6	87W	3-119		Visited, highly disturbed area
74	12.5	56.5	2.0	71E	3-118		
75X	12.5	57.5	4.2	3W	3-153	E	Visited in San Lorenzo Arroyo
76X	12.5	58.0	~9km 5.1 0.6	75W	3-153	~20' S	
77X	10.0	58.5	2.9	31E	3-151	E	
78X	15.0	53.0	3.3	6W	1-18(E)	W	San Acacia basalt fracture
79	12.5	52.5	0.5	0(N)	1-32		Highly disturbed area
80	11.5	52.5	0.6	13W	1-33		Highly disturbed area

No.	Lat.	Long.	Length	Trend	Photo No.	Throw	Remarks
81X	34°11.5'	106°51.5'	4.1	2E	1-33		Highly disturbed area
82	13.0	51.5	0.4	69E	1-32		Highly disturbed area
83	13.0	51.0	0.7	70E	1-32		Highly disturbed area
84	12.5	51.5	0.9	5W	1-32		Highly disturbed area
85X	12.0	51.5	1.7	18W	1-33		Highly disturbed area
86X	10.0	51.5	2.7	7W	1-33		Highly disturbed area
87X	11.5	51.0	2.1	0(N)	1-33		Highly disturbed area
88X	11.0	51.0	2.3	14W	1-33		Highly disturbed area
89X	10.5	51.0	2.5	14W	1-33,1-34		Highly disturbed area
90X	10.5	50.0	2.7	13E	1-33		Highly disturbed area
91X	07.5	107°11.0	2.3	50W	3-65	25,NE	Magdalena alluvial fault
92X	06.5	10.0	2.7	38W	3-65	20,NE	Magdalena alluvial fault
93	06.0	09.5	1.2	36E	3-65,3-46		Magdalena alluvial fault
94X	07.5	106°58.0	4.1	15W	3-150	E	Visited, slide available, Kelly basalt
95	07.5	59.0	1.7	25E	3-150,3-151	SE	
96	09.5	57.5	1.6	0(N)	3-151,3-116	E	

Bear Mtn. Mag. Mtn

No.	Lat.	Long.	Length	Trend	Photo No.	Throw Feet	Remarks
97X	34°09.0'	106°59.0'	1.5	89W	3-151		
98X	07.0	55.5	1.7	13W	3-115	W	Visited, surface antithetic fault
99X	06.0	57.0	1.6	7E	3-150,3-115	E	Unable to locate in Nogal (north) arroyo
100X	08.5	51.0	2.1	30E	1-34		
101X	08.5	50.5	1.9	9W	1-34		
102X	09.5	49.5	4.2	9E	1-34	W	
103X	06.5	49.0	3.5	14E	1-35		
104	05.5	50.5	1.1	20W	1-35,1-36		
105	05.5	50.5	0.7	20W	1-35,1-36		
Bear Mountain – Magdalena Mountain							
106X	04.0	107°08.0	1.6	15W	3-48	20,E	Magdalena alluvial fault
107X	02.0	07.5	1.3	38W	3-48	20,E	Magdalena alluvial fault
108X	01.5	07.5	3.7	26E	3-48	SE	Water Canyon fault
109X	02.5	05.5	1.8	58W	3-48	NE	Magdalena alluvial fault
110	05.0	00.5	1.6	86E	3-149	N	May be an intrusive
111	04.5	00.0	2.4	88W	3-149	N	May be an intrusive
112X	03.5	106°57.5	1.0	33W	3-148		After Lowell Reference

No.	Lat.	Long.	Length	Trend	Photo No.	Throw	Remarks
113	34°00.0'	106°58.0'	1.6	10W	3-147	E	Visited, sill with strike- slip slickensides in roadcut
114X	01.5	56.5	1.6	6E	3-112		After Lowell Reference
115	04.5	49.5	1.9	17E	1-36		
116X	04.5	49.5	3.3	8W	1-36	W	
117X	04.0	48.0	1.9	15W	1-36	W	
118X	03.0	48.5	1.4	16W	1-36	W	
119	02.5	47.5	1.8	89E	1-37		
120	01.0	47.5	2.6	76E	1-38	N	
121X	01.0	48.5	1.0	23W	1-37	W	
122X	33°57.0	107°00.0	1.3	28W	3-146		
123	59.5	106°57.0	1.0	0(N)	3-112,3-147		
124X	57.0	57.5	1.9	11W	3-146	E	East Chupadera fault
125X	55.5	57.0	3.2	4W	3-145	E	East Chupadera fault
126X	58.5	56.5	3.9	8W	3-111		
127	58.5	55.0	3.4	25W	3-111		
128X	58.5	54.5	16.5 km 9.9 0.6	28W	3-111,3-112	20' E	Visited, slide available

No.	Lat.	Long.	Length	Trend	Photo No.	Throw	Remarks
129X	34°00.0	106°55.0	4.0 (6.6 km)	28W	3-112	15 ft E	
130X	33°59.5	46.0	1.8	4E	2-131	W	After Wilpolt and Wanek (Date)
131	55.5	46.0	2.2	57W		SW	Spotted on old 1:62,500 photo
132	54.0	45.0	1.9	43W		SW	After Wilpolt and Wanek (Date)

N.B. The trends in the above table are in degrees measured from NORTH.