Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

memorandum

TO: J. Gardner, EES-1, MS D462

DATE: November 14, 1990

FROM: D. Vaniman
K. Wohletz

MAIL STOP/TELEPHONE: D462/7-1863
D462/7-9202

SYMBOL: EES-1, Geology/Geochemistry

Memo No: EES1-SH90-17

SUBJECT: RESULTS OF GEOLOGICAL MAPPING/FRACTURE STUDIES: TA-55 AREA

ABSTRACT

A geological map of 5.60 square miles (scale = 1:6,000) around the TA-55 area has been completed. This map (Plate 1 in this report) shows that the Rendija Canyon and Guaje Mountain fault zones can be located by geological field observations and fracture studies. The faults lie within a roughly N-S trend about 500 ft west and 1,500 ft east, respectively, of TA-55. Within this zone, the Bandelier Tuff is tectonically deformed. Important structural features include rock fractures, micrograbens caused by downdrop of tuff blocks up to several feet, and "zipper joints" where sets of joints have been incised and along which tuff surfaces have been down dropped several or more feet.

Along with the geological mapping study, detailed structural mapping and measurement of 1,625 fractures along Pajarito and East Jemez roads (Plates 2 and 3) demonstrate notable increases in the abundance of and opening on fractures over areas of the fault projections. The measurements show that fracture linear density increases from background levels averaging 20 fractures/100 ft to about 50 fractures/100 ft over the fault zones. Average fracture openings are about 1.0 cm, and observed vertical displacements along these fractures is a similar amount, making these fractures evidence of fault movement. Cumulative surface deformation calculated over the Rendija Canyon Fault zone along Pajarito Road is about 6.2 ft horizontal and 8.6 ft vertical, dispersed over 900 horizontal feet. Surface deformation on the Guaje Mountain Fault zone along East Jemez Road is calculated to be 5.8 ft horizontal and 6.1 ft vertical, spread out over 1,600 horizontal ft.

We conclude that vertical movement of at least 10 ft has likely occurred in bedrock below the Bandelier Tuff along both of these faults, but that this displacement is accommodated by fractures dispersed over 1,000 horizontal feet across the faults in the tuff.

We recommend that additional fracture measurements be made along blade cuts into the tuff over the fault zones near TA-55. Also our mapping shows a considerable hazard of cliff failure and mass wasting above TA-2, which should be studied further.

Attachment: a/s

Cy: EES-1, MS D462
Seismic Hazards File

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memorandum

TO: J. Gardner, EES-1, MS D462

DATE: July 29, 1991

FROM: D. Vaniman, EES-1 [signature] 8/6/91

MAIL STOP/TELEPHONE: D462/7-1863

SYMBOL: EES-1, Geology/Geochemistry

MEMO NO: EES1-SH91-12

SUBJECT: **REVISIONS TO REPORT EES1-SH90-17**

Recent work by Steven Reneau on comparisons between various stratigraphies used for the upper Bandelier Tuff requires a revision to Table 1, on p. 3 of report EES1-SH90-17. The direct correlations between units 1, 2, and 3 for all workers are not valid, because the nonwelded intervals between zones of welding are inconsistently assigned to either the overlying welded zone (most earlier workers) or the underlying welded zone (Crowe et al., 1978). The inconsistency in assignment of nonwelded intervals is in part a difference in flow-unit versus cooling-unit treatment of stratigraphic subdivisions. In order to allow for either assignment or for further subdivision within the nonwelded intervals, the stratigraphy used for this report is herewith modified to leave the suspect nonwelded units unassigned. The necessary revisions to Table 1, text, and figures/plates are listed below.

Table 1. Approximate Comparison of Stratigraphic Units within the Tshirege Member.

Balitz et al. (1963)	Crowe et al. (1978)	Our units
		unit 4
	.....	.....
		nonwelded
.....	cooling unit 3	.....
		unit 3
unit 3	.....	.....
		nonwelded
.....	cooling unit 2	.....
unit 2b		unit 2
.....	.....	.....
unit 2a		nonwelded
.....	cooling unit 1	.....
unit 1b		unit 1v (vapor phase)*
.....		.....
unit 1a		unit 1g (glassy)

*Note: all numbered units and nonwelded intervals above 1v also contain abundant vapor-phase crystallization.

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of resistant cliffs via underlying weak tuffs, leading to mass wasting of cliff edges. The instability of cliff margins, with massive failures that occur either in the course of progressive erosion or triggered by seismic events, appears to be a major geologic hazard in the area shown in Plate 1. Areas most at risk are those closest to mesa margins (particularly at southern mesa edges in unit 3, the yellow map unit in Plate 1), and those at the bottoms of canyons within or beneath unit 2 (the blue map unit in Plate 1).

The physical stratigraphy used in this study is generally similar to other stratigraphies of the Bandelier Tuff that are based on cooling units (see, e.g., Crowe et al., 1978, and Baltz et al., 1963). The three units described by Crowe et al. and by Baltz et al. are generally correlative in numbering to units 1 through 3 as used in this report; we have a unit 4 at the top (the sections measured by these two other reports did not include unit 4, which is outside of their map areas). The previous map units and our map units are compared in Table 1.

Table 1. Comparison of Stratigraphic Units within the Tshirege Member*.

Baltz et al. (1963)	Crowe et al. (1979)	Our units
		unit 4
		unit 4b
unit 3	unit 3	unit 3
		unit 3b
unit 2b	unit 2	unit 2
unit 2a		unit 2b
unit 1b	unit 1	unit 1
unit 1a		unit 1b

western part of the map area. A significant feature of the unit is a continuous, mappable surge interval that occurs near its base. This particular surge interval is typically 1-2 ft thick and pumice-poor; its most significant feature is that it is the only surge that can be traced continuously over distances up to hundreds of feet (where it is exposed). Other surge intervals can be found within unit 4 and 4b, but they are not as continuous.

Unit 4b: weak (map color = orange; see Fig. 1)

Nonwelded white tuff with relatively uniform grain-size, thickness 0-20 ft in the map area. This unit is similar to 4, but is less indurated and may have larger pumices. In the northern part of the map area, 4b is absent and the continuous surge interval at the base of unit 4 rests directly on unit 3.

Unit 3: resistant (map color = yellow; see Fig. 1)

Brown nonwelded to moderately-welded tuff, thickness 50-100 ft in the map area. Welding is most intense to the west of TA-55, and the upper 20 ft are devitrified and very dense at the western margin of the map area, but even the less-dense nonwelded portions at the eastern margin of the map area are resistant and cliff-forming. Pumices are as hard as the groundmass in welded intervals, and only slightly softer than the groundmass in nonwelded vapor-phase indurated intervals.

Unit 3b: weak (map color = green; see Fig. 1)

White nonwelded tuff, thickness 15-80 ft in the map area. Vapor-phase alteration is less intense than in unit 3, and the pumices are extremely soft. Macroscopic pumices are also large (typically >2 inches) and abundant (~20%).

Unit 2: resistant (map color = blue; see Fig. 1)

the pumices and the groundmass are glassy and soft, this unit is generally resistant to erosion and it does form cliffs (probably due to the lack of differential hardness between groundmass and pumices, as well as the susceptibility of the glassy tuff to surface reactions and "case-hardening").

Underlying units (left uncolored in Plate 1 and Fig. 1)

The underlying units include a complex series reworked tuffs, Cerro Toledo fall out, and Otowi Member tuff exposed in Los Alamos Canyon. Excellent exposures of Cerro Toledo fall out occur within TA-41 and elsewhere along the walls of Los Alamos Canyon, but exposures of the other units beneath the Tshirege Member are generally poor.

3. Mapped Features

The discrete fault scarps that characterize the Rendija Canyon and Guaje Mountain faults north of Los Alamos are not observed in the map area around TA-55. There is abundant evidence, however, that broadly-dispersed flexure and some displacement of the Tshirege Member has occurred in the TA-55 area. The evidence leading to this conclusion is based in part on fracture analysis (see section 5.), but is also based on the following features shown in the geologic map (Plate 1):

Micrograbens. These features (see Fig. 1 for map explanation) are most prominent and concentrated in the northwest part of the Plate 1 map area. They are small graben-like structures, with down-dropped central blocks, that mostly occur along mesa margins in unit 3. The largest micrograbens are concentrated along the southern margin of South Mesa, between the Los Alamos County landfill (near TA-61) and the trailer park. Here the micrograbens may be over 20 ft across and 75 ft long. Actual displacements of the central blocks are difficult to measure because they have commonly been eroded by water flow from the mesa tops, but the relief between micrograben walls and central blocks is as much as 10 ft or more, particularly along the southern margin of South Mesa.

4. Fault Projections

The Rendija Canyon Fault (RCF) and the Guaje Mountain Fault (GMF) project across the Los Alamos townsite toward the map area of Plate 1. Based on the mapping and fracture studies completed for this project, the traces of these faults can be extended south through TA-48 (RCF) and TA-2/TA-35/TA-15 (GMF). These projections are not of discrete surface ruptures, but rather represent the likeliest axial trace of broadly dispersed surface effects above the extensions of these faults south of Los Alamos Canyon.

The Rendija Canyon Fault (RCF) appears to have at least two major splays south of the Los Alamos townsite. One of these splays passes through a major slide block in the north wall of Los Alamos Canyon and passes to the west of TA-48. The other splay may pass much farther to the south, crossing Los Alamos Canyon after passing beneath Ashley Pond, passing beneath TA-48, and extending south beneath a major zipper-joint drainage, a small micrograben, and an area where large blocks of tuff have fallen into a tributary to Twomile Canyon. Where these splays cross Pajarito Road near TA-48, they are defined by zones of abundant and open fractures in units 4 and 3 of the Tshirege.

The Guaje Mountain Fault (GMF) appears to project across Los Alamos Canyon just to the west of TA-2. The northern wall of Los Alamos Canyon at this point has a large slide block that is beginning to form near the fault projection. This slide block is still ~150 ft above the canyon floor, but has slipped ~13 ft along its bounding fractures. We estimate that the minimum mass of material held in this block above the western edge of TA-2 is 50,000 tons. It is probably not fortuitous that the two massive slide blocks in Los Alamos Canyon occur along the projections of the RCF and the GMF.

South of Los Alamos Canyon, the GMF appears to pass through a major zipper-joint drainage opposite the turnoff to LAMPF from East Jemez Road. Fracture mapping indicates a zone of abundant and open fractures where this fault projection crosses the mesa. Further south, the fault projection passes through a major zipper-joint drainage in Mortandad Canyon, beneath TA-35, and into the bend in drainage where Twomile Canyon intersects Pajarito Canyon. At this point the GMF projection appears to disperse

circumvent the need to distinguish cooling fracture joints from tectonic fractures in the field, leaving that problem to statistical analysis of their measurements

Method. In order to make statistical analysis of fracture characteristics, we make a linear analysis of fracture abundance, strikes, dips, and widths along lines crossing the fault traces hypothesized during geological mapping. Road cuts along Pajarito Road and East Jemez Road provided rock faces where these fracture measurements could be repeated in a systematical fashion. Because of irregular exposure and vegetation, these measurements were not attempted on cliff exposures in the canyons.

The line along Pajarito Road begins about 235 ft west of the blockade emplaced at the west end of the old turnoff to TA-48 (see map for locations) and runs eastward nearly 2,800 ft to a point along a line drawn from the southeastern fence of TA-55. From the geological map (Plate 1), this line crosses the southern extension of the Rendija Canyon Fault (RCF). The line along East Jemez Road begins about 200 ft east of the turnoff to the dirt access road going down South Mesa (where the 7,255 foot contour crosses the road), and the line continues nearly a mile down East Jemez Road past the LAMP turnoff to where the 7,000 ft contour crosses the road. The middle section of this line cuts across the southerly trace of the Guaje Mountain Fault (GMF). 704 fractures are documented along the Pajarito Road line, and 921 fractures are documented along the East Jemez Road line.

Fractures are documented by fracture maps, constructed from polaroid photo- mosaics (Plates 3 and 4). Each photo covers about 15 ft of rock exposed along measured lines. Gaps in road-cut exposures have been measured such that the fracture data can be analysed as a continuum. The photomosaics have attached maps with traced fractures that have been numbered for specific documentation in field notes and a data base. Fracture strikes and dips were measured with a Brunton compass (accuracy of 2 degrees), and fracture widths by ruler to within 2 mm accuracy. Because all variations of fracture visibility were encountered, only fractures that these measurements could be made were included in the study. The fracture data were entered into an RS/1 data base for analysis (ESSXRF VAX, RS/1 directory = [WOHLETZ.RSUSERHOME]@ken@ta55).

case for the data set gathered. Of the 704 fractures measured along Pajarito Road, 460 belong to the NE set and 244 to the NW set.

Table 2. Fracture Data*.

	Number	Strike	Dip	Width	Cumulative Width
Pajarito Road					
All	704	N16E (48)	76 (19)	1.81 (4.52)	905.85
NE	460	N45E (25)	73 (20)	1.81 (5.14)	585.40
NW	244	N39W (27)	81 (14)	1.81 (3.04)	320.45
East Jemez Road					
All	921	N4E (48)	75 (18)	0.92 (1.74)	850.85
NE	520	N39E (26)	75 (18)	1.01 (1.89)	524.85
NW	401	N42W (27)	75 (18)	0.81 (1.53)	326.00

* Strikes and Dips are in degrees with standard deviations shown in parentheses. Widths are in cm, and cumulative widths for Pajarito Road line exclude measurements on sections P1 and P5, which cover area along the line already included.

For the 921 fractures measured along East Jemez Road, 520 are NE and 401 are NW. Over the RCF zone NE fractures outnumber NW fractures by about 2.16:1, and over the GMF zone, this ratio is 1.69:1. Over areas not suspected of being affected by fault zones, such as along section 4 on the East Jemez Road, the

cumulative fracture opening along this line is 9.06 m, 3.56 m accounted for across the RCF branch and 2.45 m across the RCF. Figure 13 shows fracture opening per 100-foot interval along the Pajarito line, and noticeable peaks occur over projected fault traces. Across the RCF opening of NW fractures is greater than that of NE fractures. The opposite relationship however is apparent across the fault branch, with NE fractures showing the greatest opening.

There are several zones along the Pajarito Road line of notable fracture openings where fractures are filled with or adjacent to brecciated rock and possibly gouge. Figure 14 shows the locations and openings of fractures that are filled with over 10 cm of breccia or detritus for the Pajarito Road line. There are noticeable occurrences over the RCF and the RCF branch. Specific examples over the RCF branch include fracture number 22 (Plate 2, section P2A), which consists of two fractures separated by 1.26 m of detrital fill and breccia, fracture 43 (Plate 2, section P2A) with an opening of 15 cm filled with breccia, and fracture 4 (Plate 2, section P1), which is two fractures separated by a 68 cm wide zone of rubble, and a zone of completely broken tuff 2 m wide but with no measurable fracture surfaces between fractures 6 and 7 (Plate 2, section P3A). Possible fault breccia and gouge zones over RCF exist between fracture 5 and 6 (Plate 2, section P4A), between fractures 54 and 68 (Plate 2, section P4A), and between fractures 83 and 88 (Plate 2, section P4B). Across Pajarito Road from sections P4A and P4B, a brecciated zone 90 cm wide exists between fractures 5 and 6 (Plate 2, section P5A), another breccia zone over 1 m wide exists between fractures 23 and 26 (Plate 2, section P5A), fracture 39 (Plate 2, section P5B) has 15 cm of breccia fill, and a breccia zone between fractures 64 and 65 (Plate 2, section P5B) has 5 parallel fractures in a crumbled zone about 1 m wide. These zones on section P5A and P5B correlate in relative location to zones identified in sections P4A and P4B.

Along the East Jemez Road line, average fracture opening widths (Figure 15) are about 0.9 cm. There is an apparent decrease in width to about 0.4 cm in crossing the GMF from west to east. In general NW fractures are opened slightly more than NE ones, although for the cumulative fracture opening along this line of 8.51 m, 5.25 m is accommodated by the NE set while only 3.26 m is due to the NW set (Table 2), because there are fewer NW fractures than NE ones. Figure 16 shows fracture opening per 100-foot

The increase in abundance of fractures over the fault zones and the likelihood of average displacement on the order of a cm on each of these fractures are an indication that if the calculated vertical movement of several m or more has occurred in bedrock below the tuff along the fault traces, its surface manifestation has been spread out over zones of several hundred feet across the fault, so that surface rupture is diffuse and difficult to recognize.

6. Topographic Gradients

Topographic gradients are commonly affected by fault movements. Along mesa tops where the regional gradient slopes at a few degrees easterly, there are a few very gentle inflection points of this gradient. Along stream beds, topographic inflections caused by fault movement are termed "nick points." Several such features of up to 10 ft vertical relief were noted in canyons. We plot mesa top gradients and stream gradients to see if inflection points correspond to fault zone projections.

Mesa Top Gradients. Even though surface displacement of mesa tops by the RCF and GMF is likely diffused over distances of several hundred feet, there might be slight changes in topographic gradient. Figure 18 shows mesa top elevations from west to east on Los Alamos Mesa (Trinity Drive - DP Road), South Mesa, Sigma Mesa, and Mesita Del Buey (Pajarito Road). Topographic gradient inflections are prominent at areas where the RCF and GMF are projected. The same is true for Twomile Mesa, Twomile Mesa (south), and Pajarito Mesa (Figure 19). While the topographic effect of the RCF is greatest to the north it becomes less distinct to the south, while the opposite is true for the GMF, which is expressed by captured drainage canyons that develop on its trace.

Although it is difficult to prove that these topographic gradient inflections are an indication of the presence of the faults, the gradient along Trinity Drive - DP Road is especially interesting in the area just west of Ashley Pond (Figure 20). Gardner and House (1987) and Wachs et al. (1988) extend the RCF south to Ashley Pond, and just west of the point the mesa top takes a very unusual dip towards the west. In Figure 17 the average topographic gradient west of Ashley Pond is compared with that to the east of the

washed clean by water hoses. This method could expose fractures in a regular fashion such that measurements could be made similar to those on road cuts.

Further work should be done in Los Alamos Canyon. In particular, the large slide block forming above TA-2 has been mapped only in reconnaissance scale. This block is the most prominent example in the map area of potential mass-wasting hazards to established sites (in this case, the reactor at TA-2). It is likely that similar slide blocks exist near other laboratory technical areas, and these require hazard study as well.

Related work that can further document the seismic hazard in the mapped area includes study of geomorphic surfaces (e.g., raised meadows and terraces in canyons) and detailed topographic surveys of stratigraphic markers over the fault zones. This is work we also strongly recommend.

Figure Captions

Plate 1. Geological map of the Pajarito Plateau around TA-55.

Plate 2. Fracture maps along Pajarito Road. Green lines denote NW striking fractures, red lines denote NE striking fractures.

Plate 3. Fracture maps along East Jemez Road. Green lines denote NW striking fractures, red lines denote NE striking fractures.

Fig. 1. Composite stratigraphic column showing the lithostratigraphy of the Tshirege Member of the Bandelier Tuff in the TA-55 area. This column serves as a key to the geological map (Plate 1.)

2. Stratigraphic section of the Tshirege Member near TA-55.

3. Stratigraphic section of the Tshirege Member near TA-50.

4. Plot of linear fracture density along Pajarito Road. Curves for sections p1 and p5 parallel the line and show the repeatability of fracture abundances along strike with the inferred tectonic fabric.

5. Plot of linear fracture density along East Jemez Road.

6. Histogram of fracture strikes along Pajarito Road.

7. Histogram of fracture strikes along East Jemez Road.

19. Plot of topographic gradients of mesa tops for Twomile Mesa, Twomile Mesa southern branch, and Pajarito Mesa.

20. Detailed plot of topographic gradient along Trinity Drive - DP Road showing the prominent break in slope near Ashley Pond where the Rendija Canyon Fault zone runs. Linear fits to gradient segments on either side of the RCF show that up to 150 ft of downdrop to the west could have caused this break in slope.

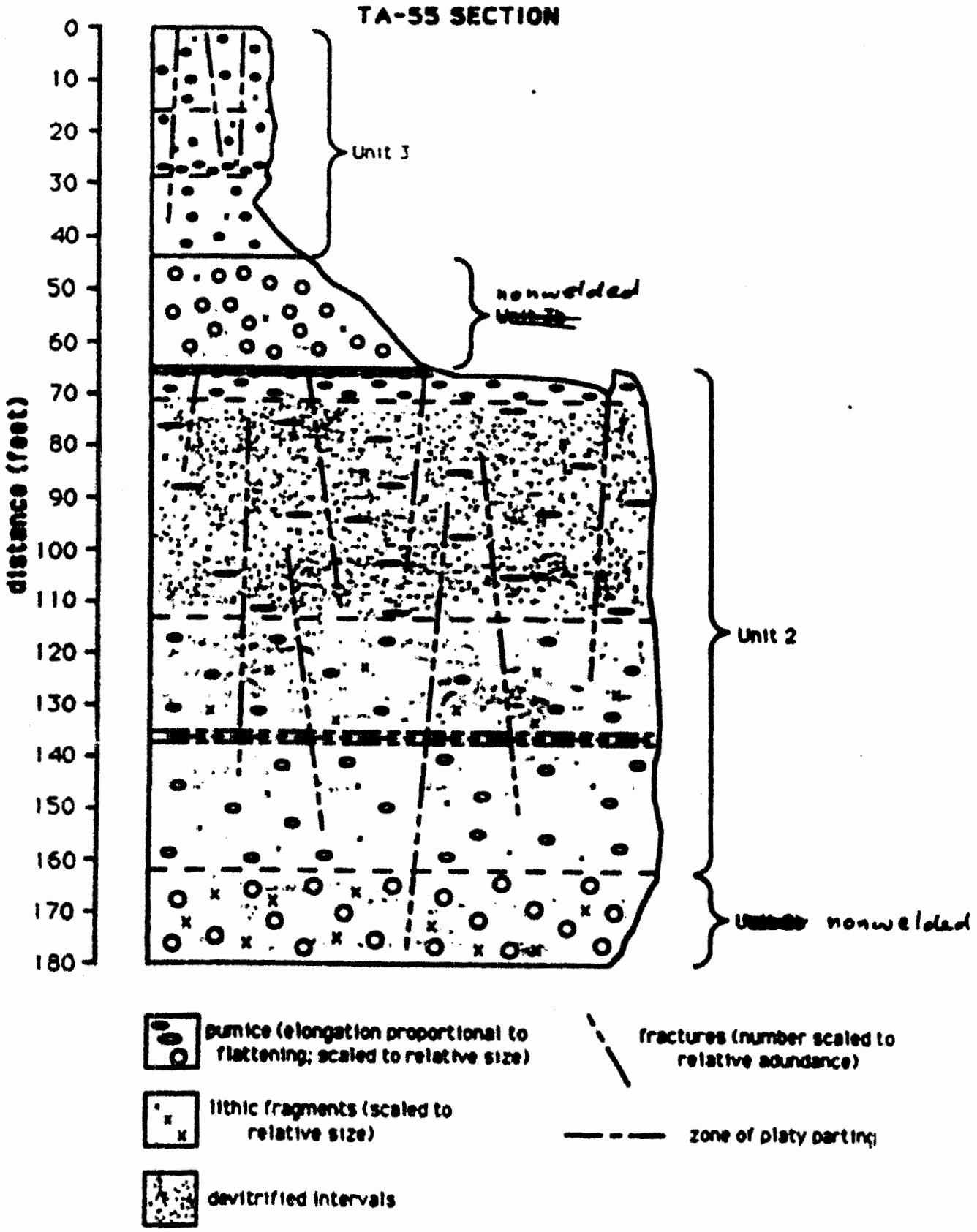
21. Los Alamos canyon gradient.

22. Sandia canyon gradient.

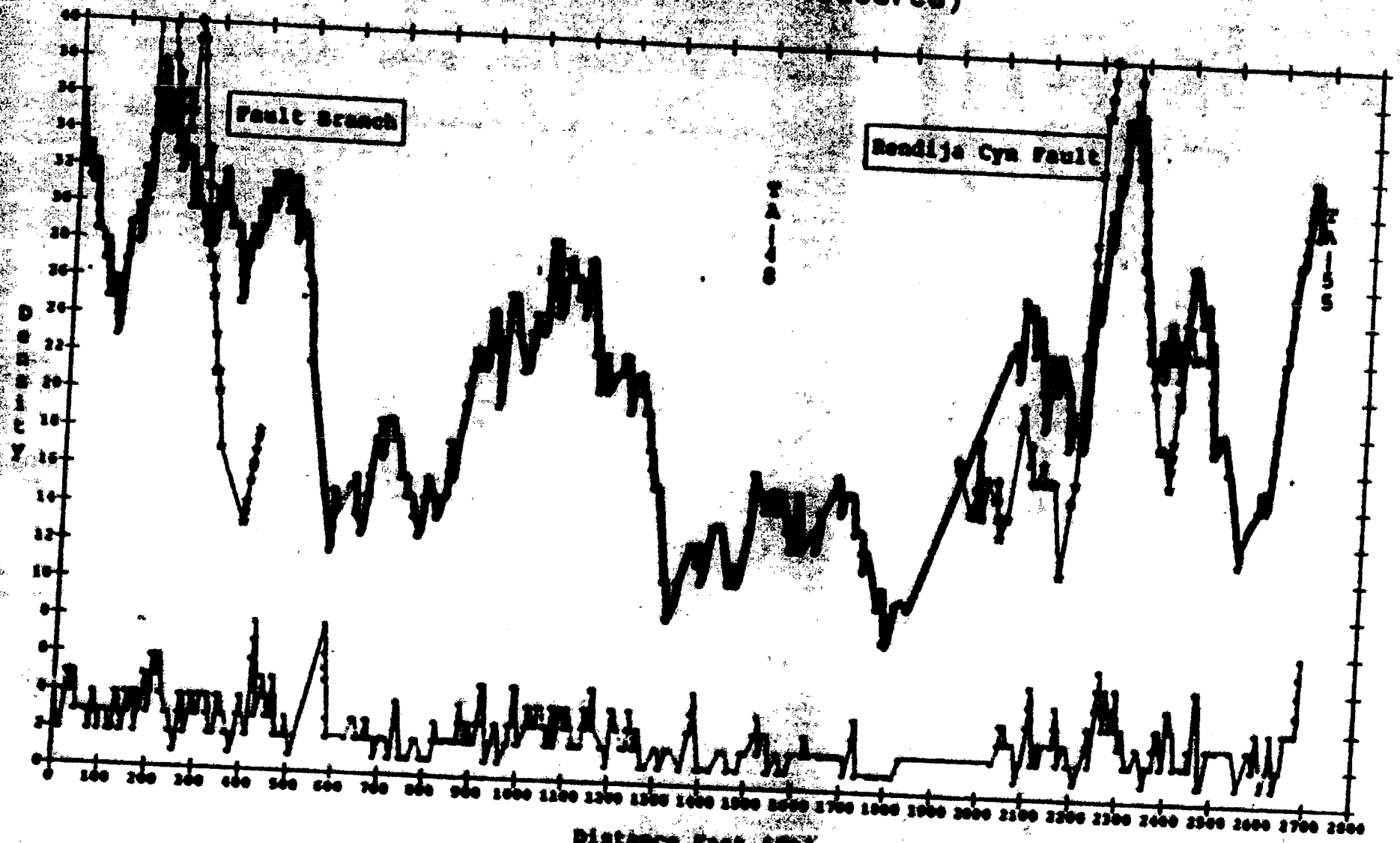
23. Mortandad canyon gradient.

24. Two mile/Pajarito canyon gradient.

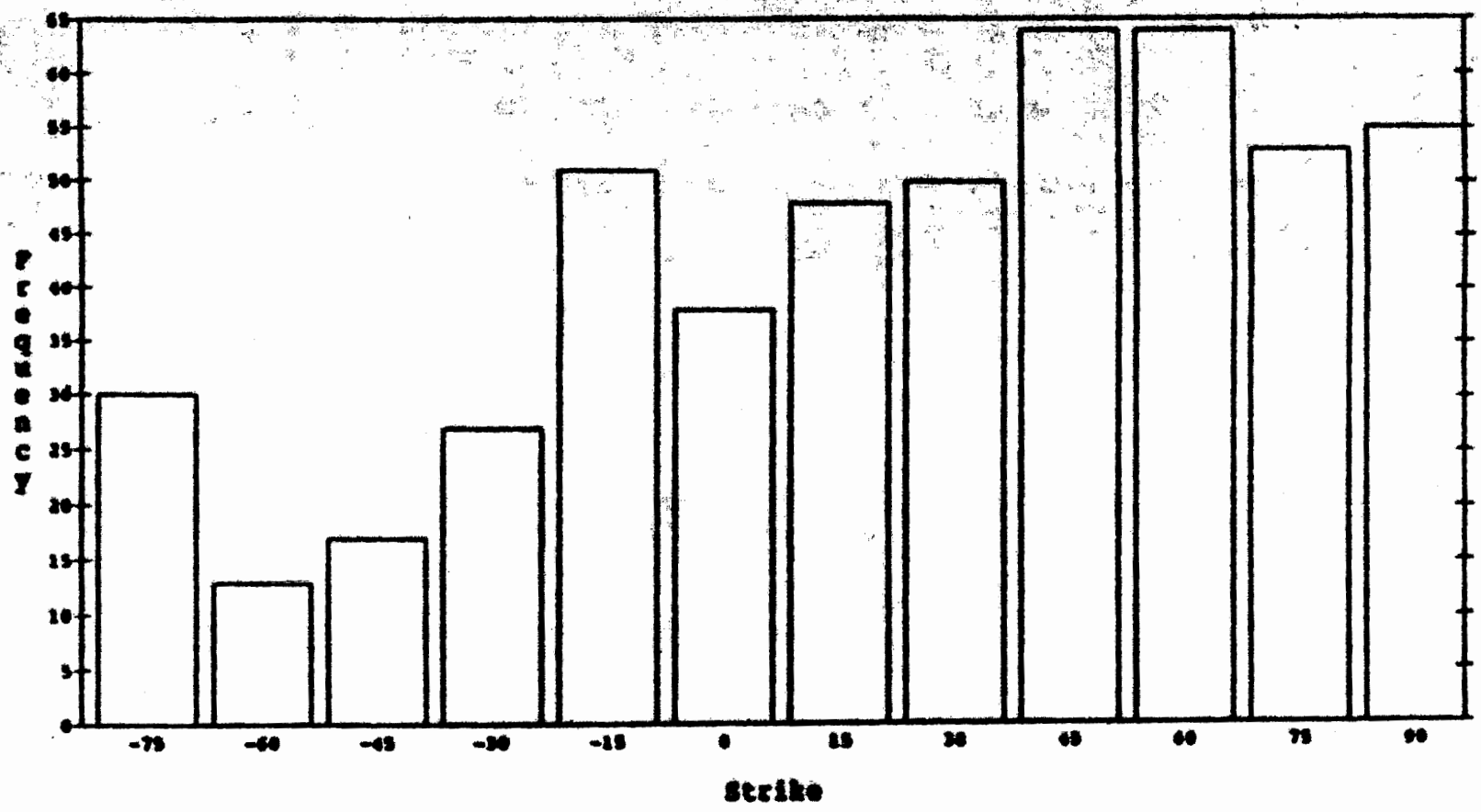
25. Pajarito canyon gradient.


TA-55 SECTION
distance (feet)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Unit 3
nonwelded
Unit 2
nonwelded
pumice (elongation proportional to flattening; scaled to relative size)
lithic fragments (scaled to relative size)
devitrified intervals
fractures (number scaled to relative abundance)
zone of platy parting

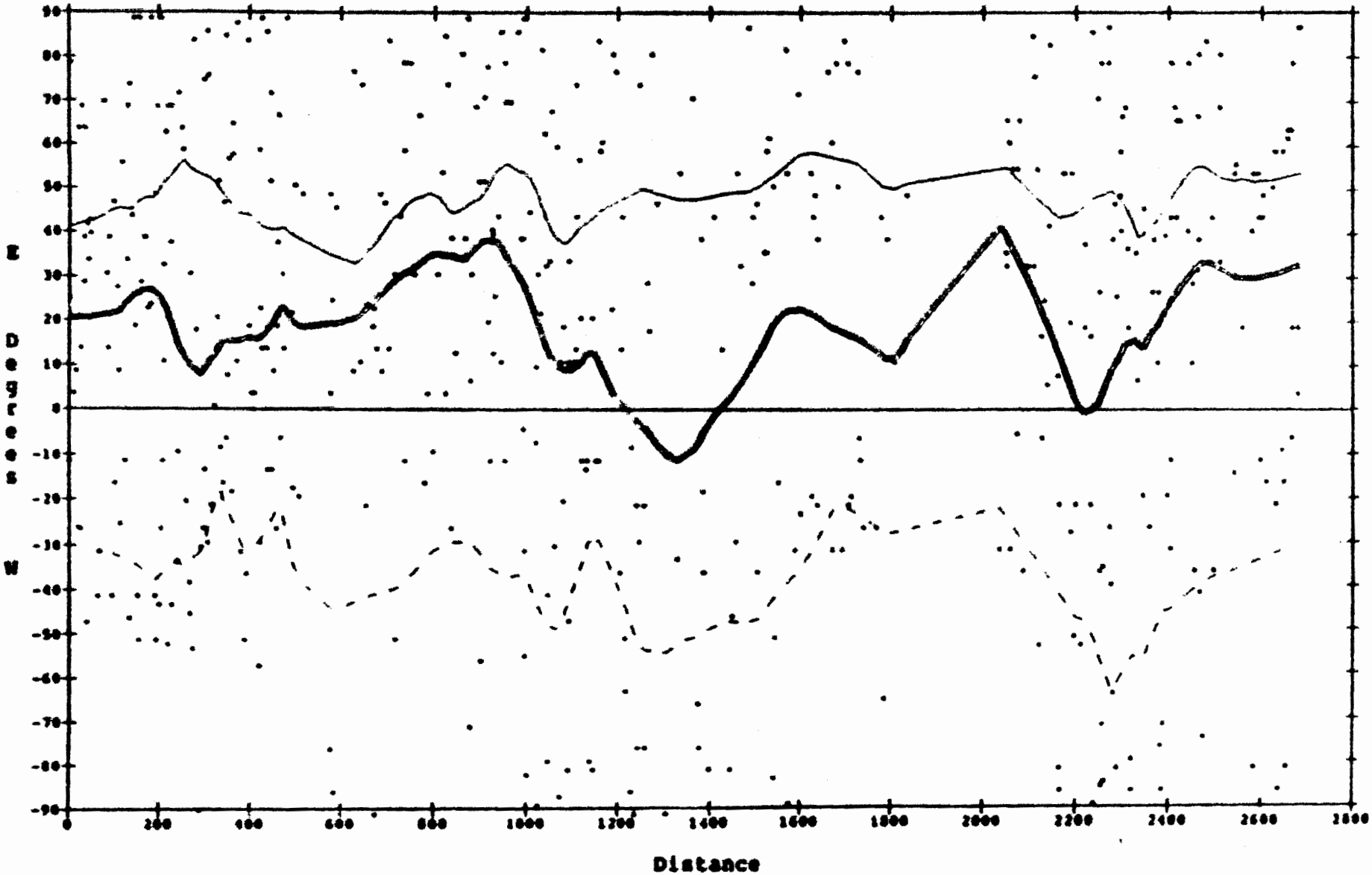
PAJARITO ROAD
(703 Fractures Measured)



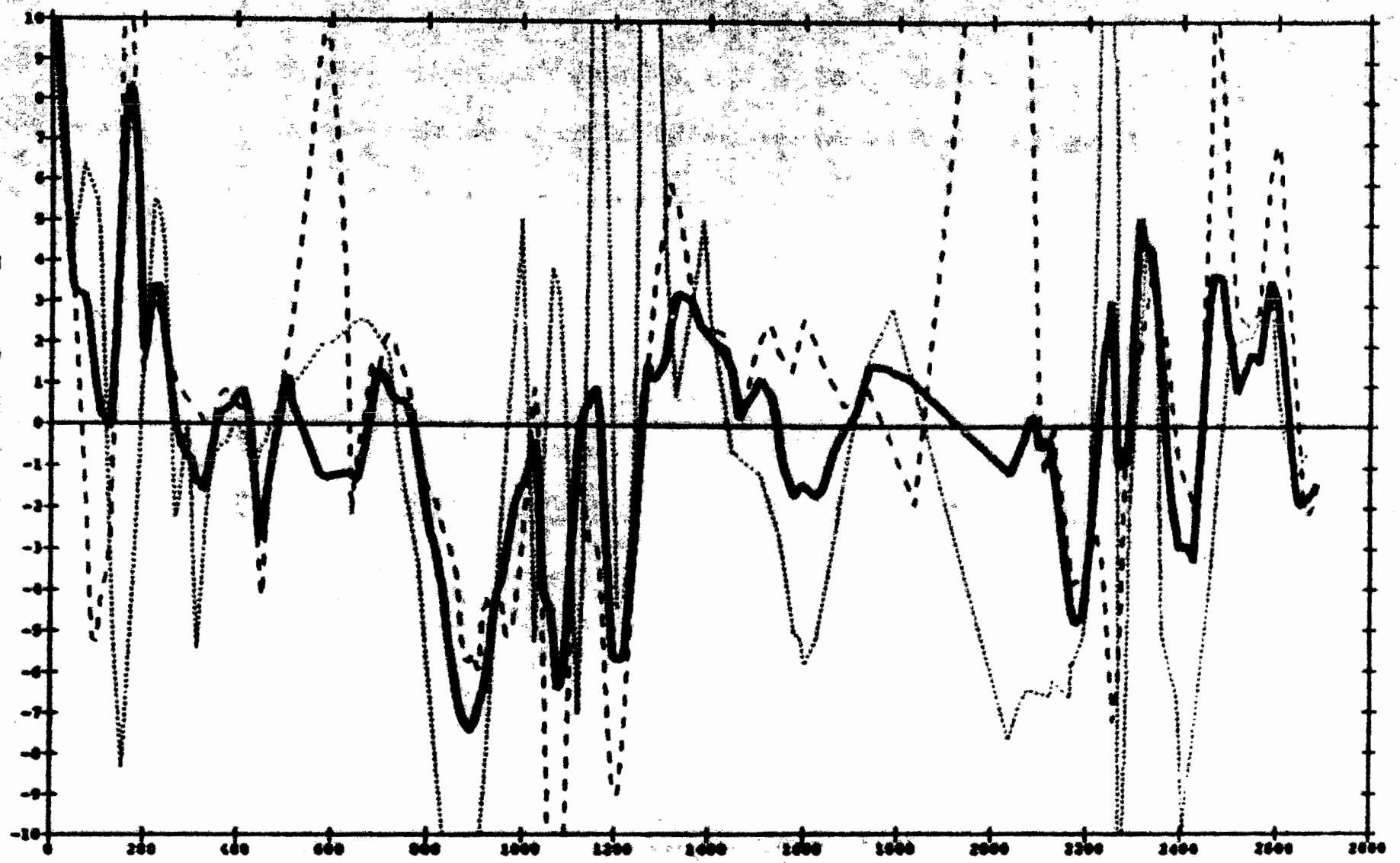
Pajarito Road Fracture Strikes



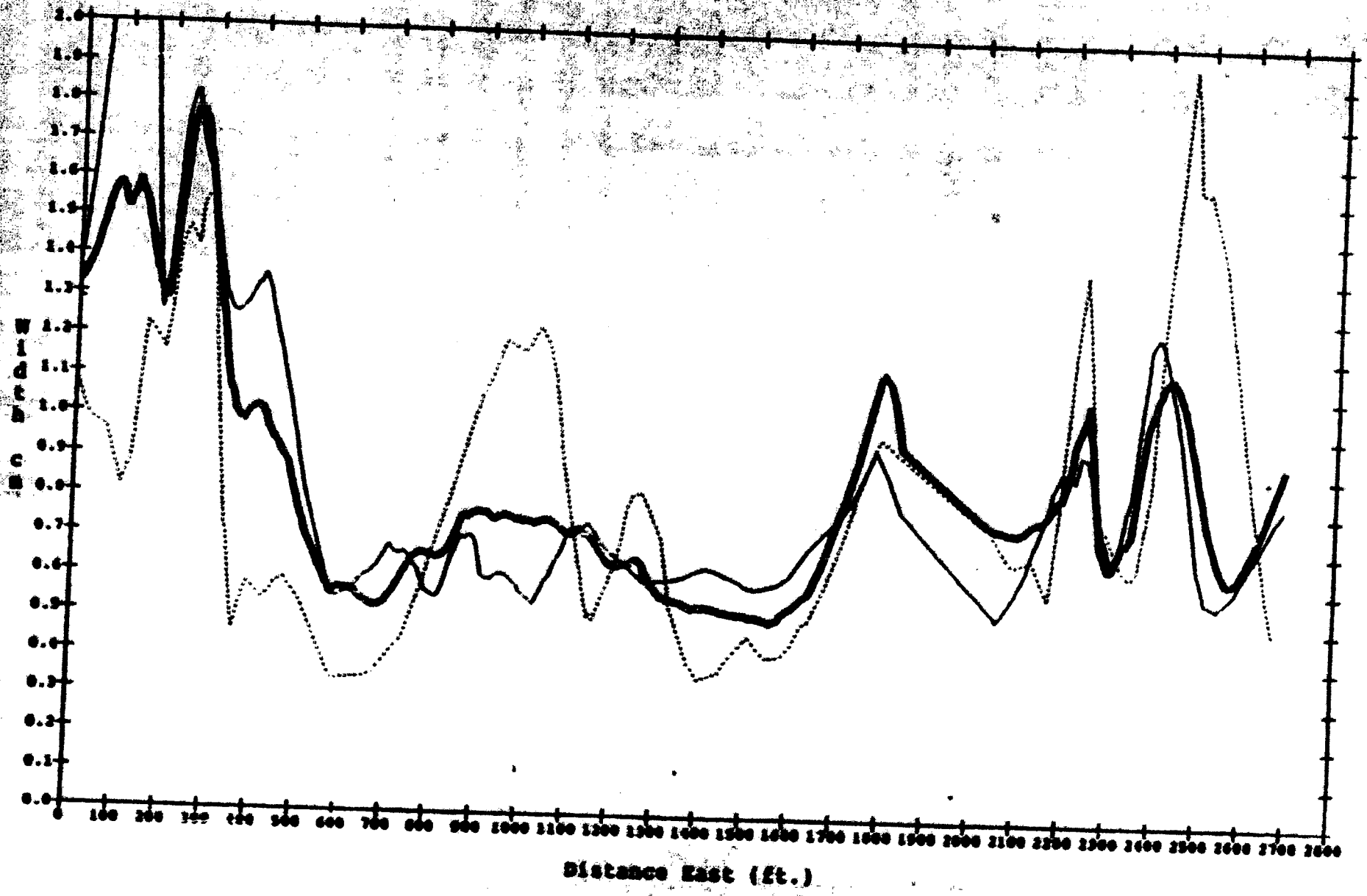
Pajarito Fracture Strikes



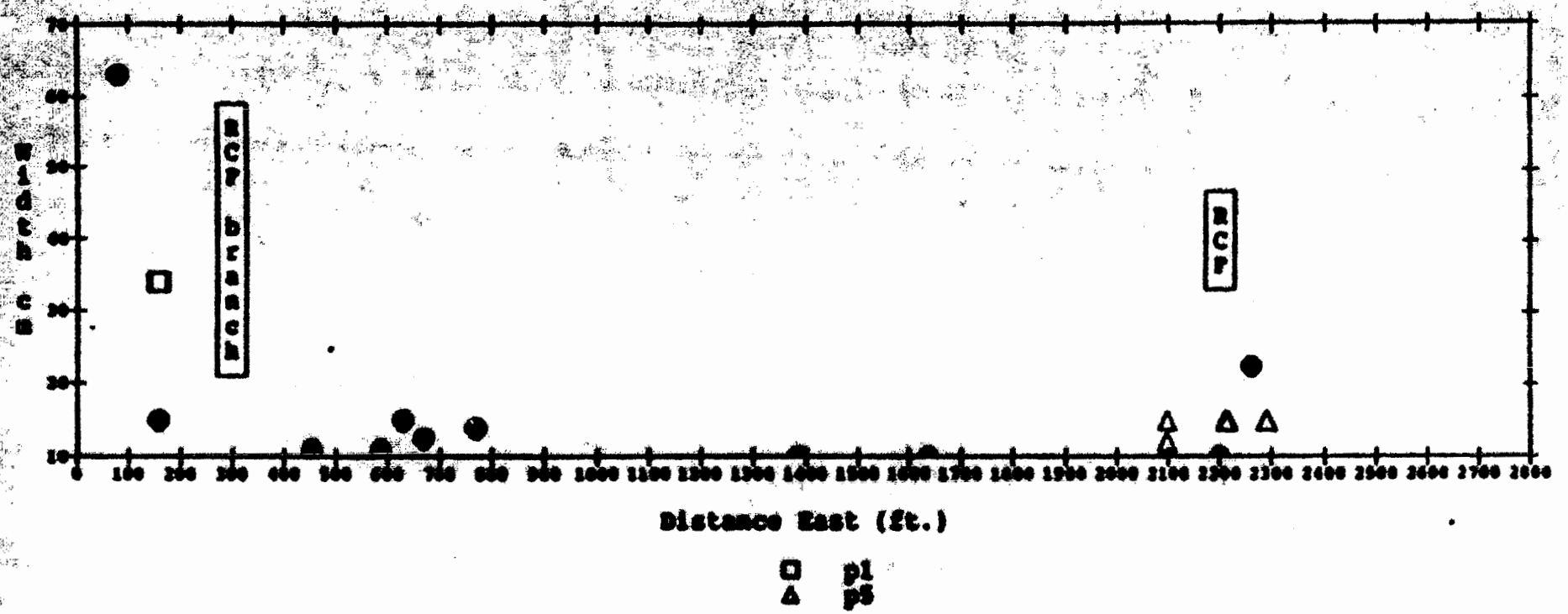
Pajarito Fracture Dips



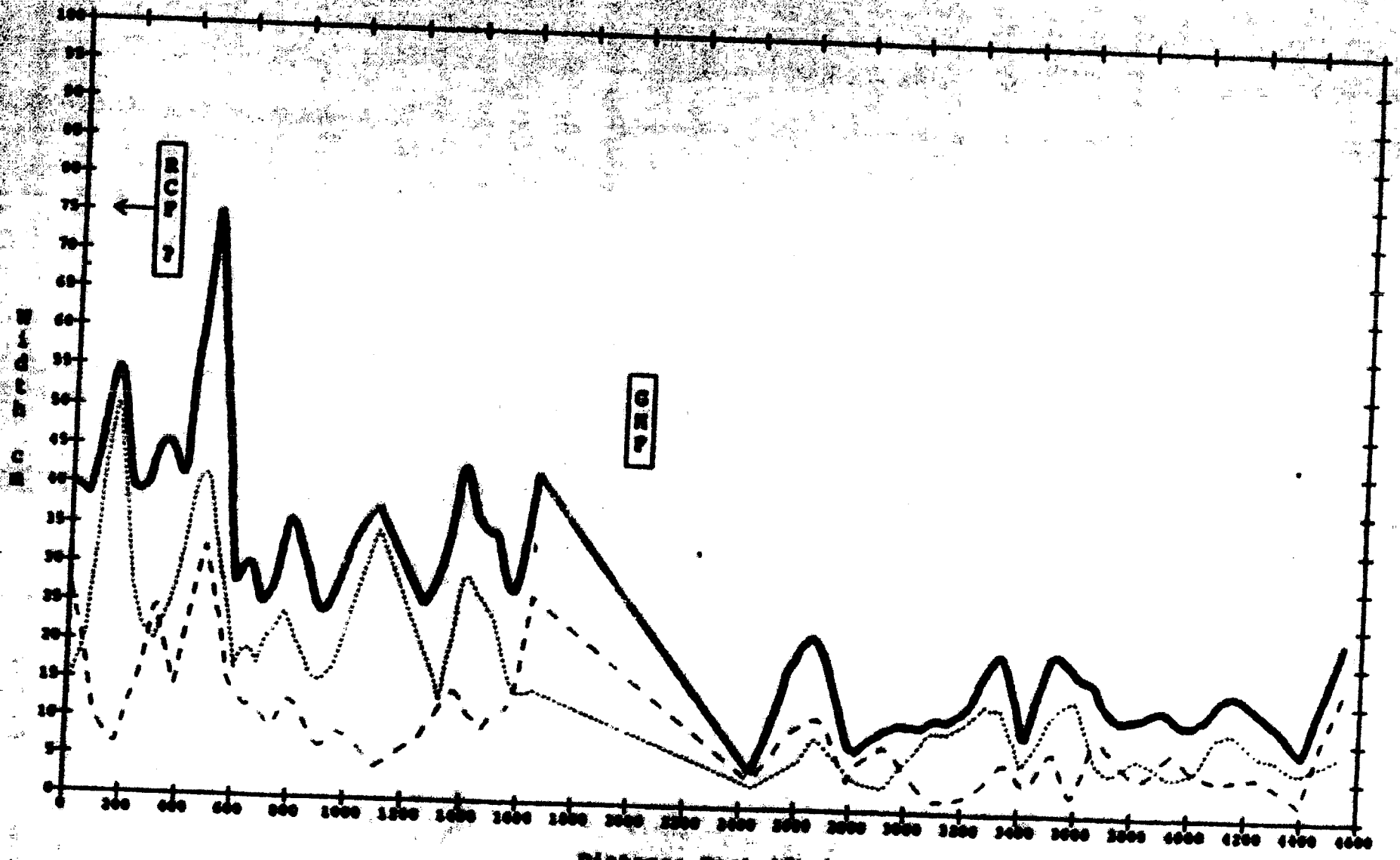
Pajarito Fracture Widths



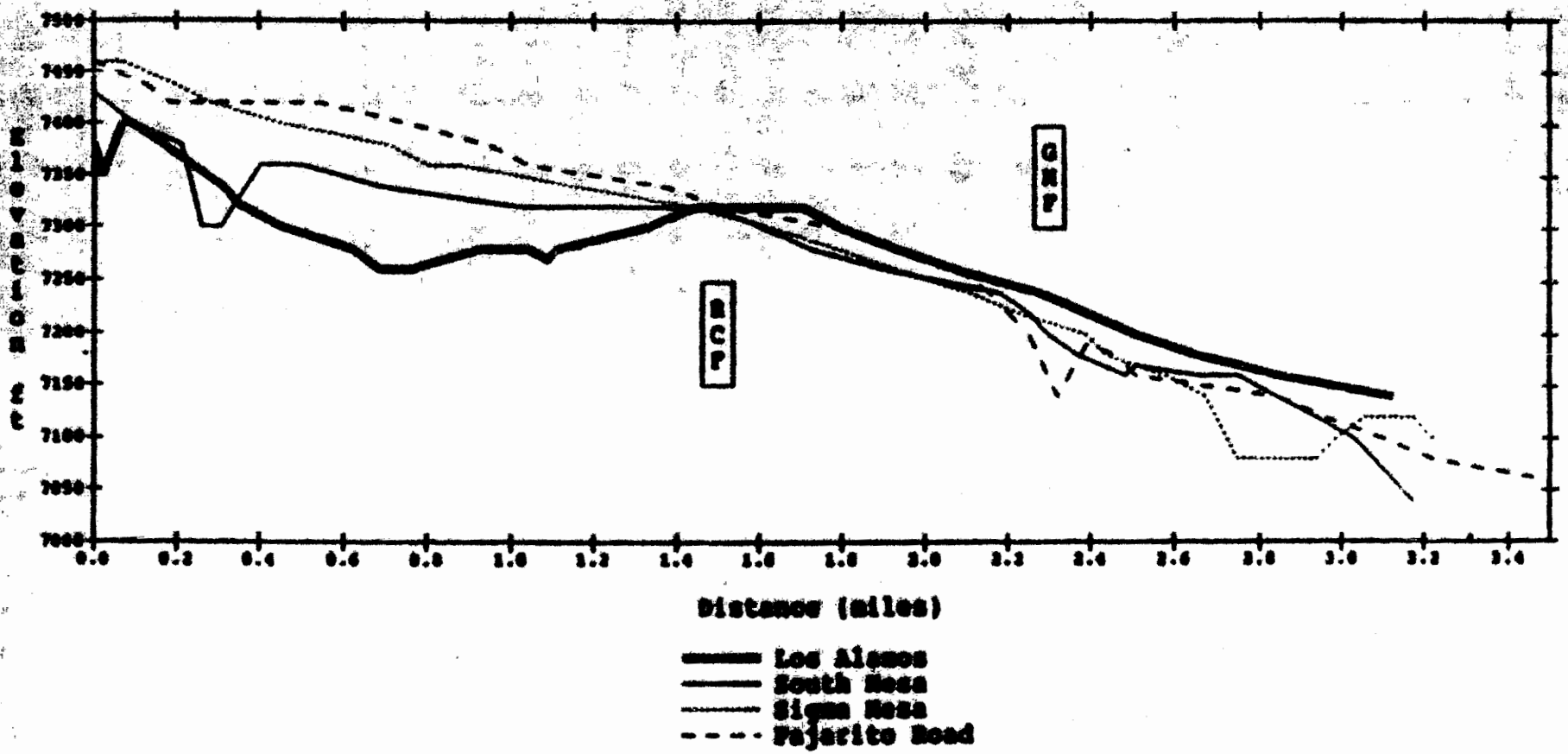
Pajarito Fracture Widths



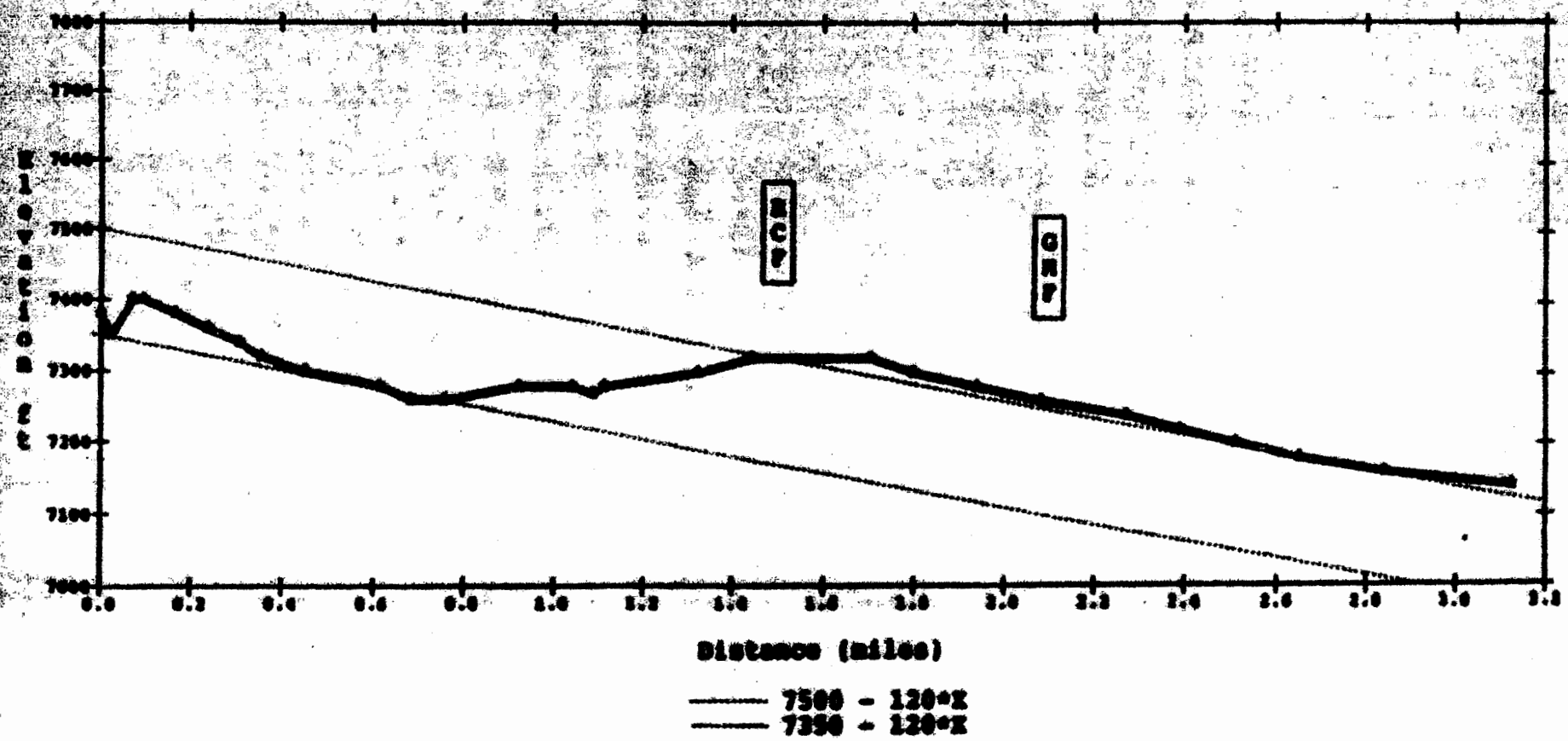
East Jemez Fracture
Widths / 100 ft



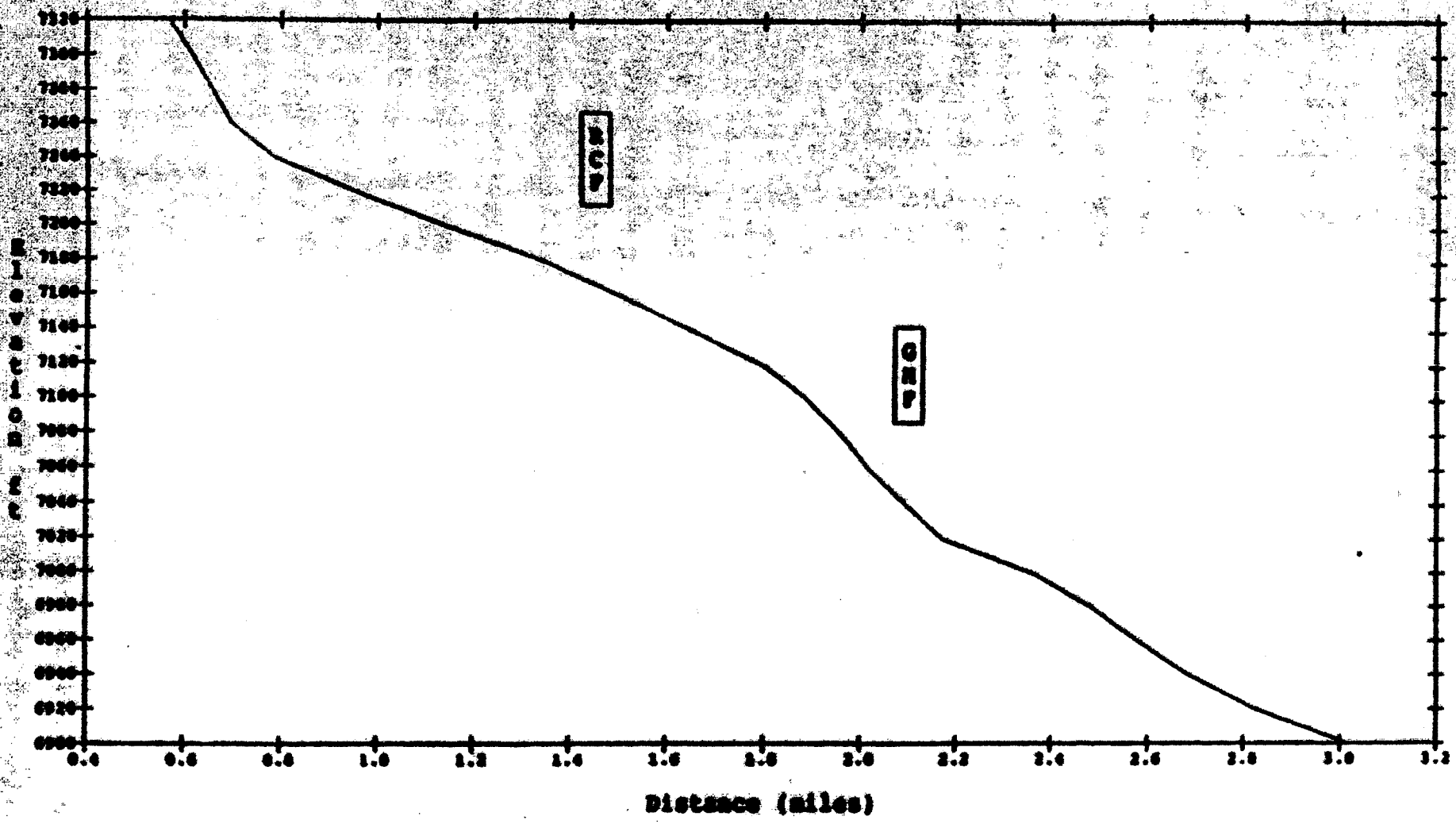
Mesa Elevations

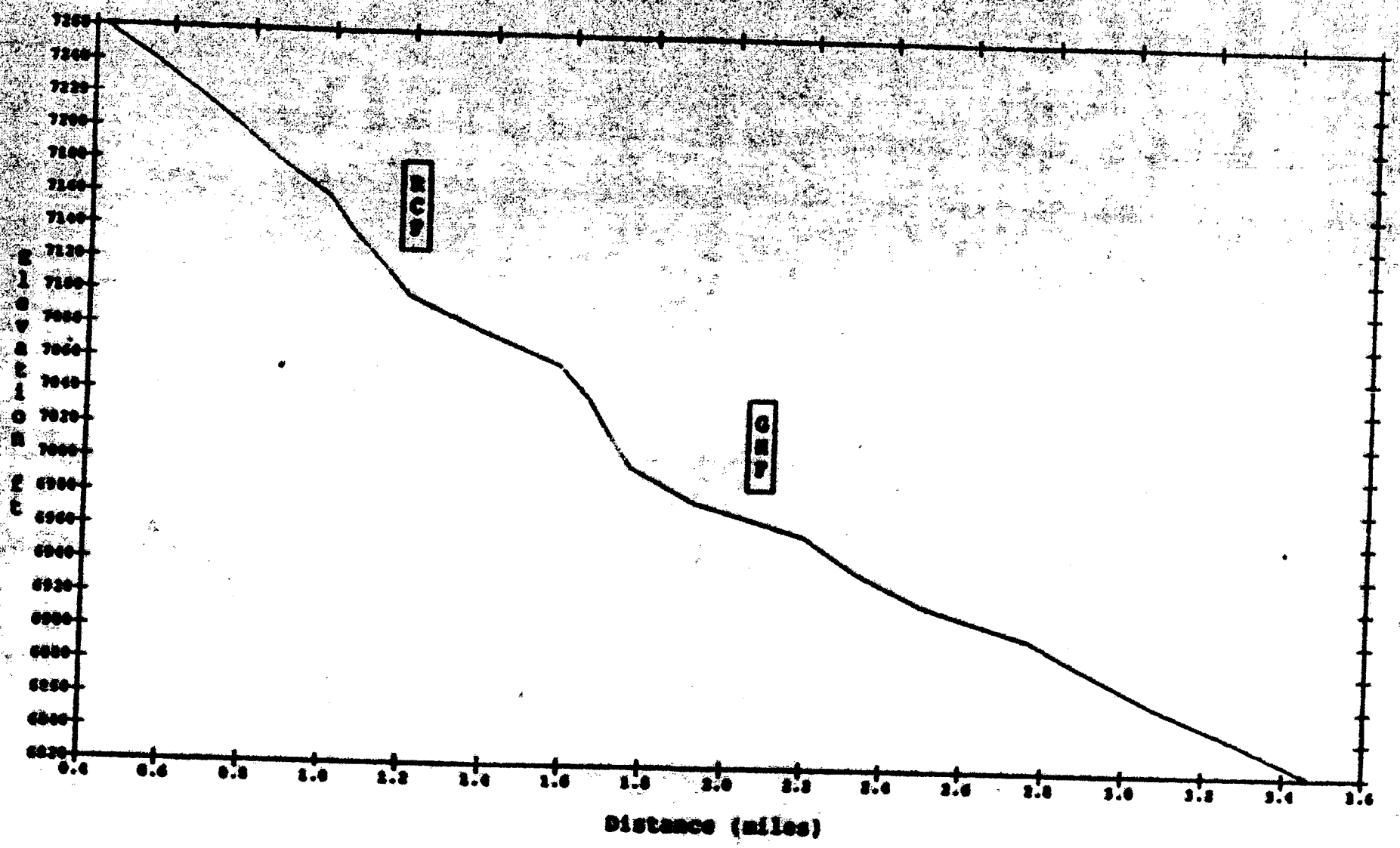


Trinity Drive - DP Road



Sandia Canyon Gradient




Twomile/Pajarito Canyon Gradient
Elevation ft
Distance (miles)
RCF
GHF