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AUTHOR(S): Ken Wohletz (EES-1)

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Fracture Characterization of the DP Tank Farm

by

Kenneth Wohletz, EES-1

SUMMARY

In order to understand possible fracture-controlled infiltration of petroleum products spilled at the DP Tank Farm when it was in use, fractures in the Tshirege Member of the Bandelier Tuff exposed along a road cut on the west side of this area have been characterized. For the 157 documented fractures, photomosaic maps and fracture characteristics (strike, dip, aperture, and location) are augmented by similar data from 288 fractures measured along Los Alamos Canyon ~750 feet to the south. These data are statistically analyzed to make a hypothetical fracture distribution map for the region surrounding the west filling station at the DP Tank Farm. A major concern as to the degree of fracture control is the location of the Guaje Mountain Fault Zone (GMFZ) in relationship to the Tank Farm and how much it may influence fracture spacing, orientation, and aperture.

CONCLUSIONS

Fracture data confirms the existence of the N-S trending GMFZ on the west side of the Tank Farm, extending from about 250 to 600 feet east of the intersection of Trinity Drive with DP Road. The west filling station exists on the eastern shoulder of the fault zone, and the fractures there are expected to be affected by its presence. In general, fracture spacing averages ~5 feet for the DP Tank Farm, but over the GMFZ, average fracture spacing is about 2 feet (typical in the area of the west filling station). Most fractures strike between NW and NE, but there is a prominence of nearly E-W trending fractures. Average fracture dips are ~50°, but nearly vertical and horizontal fractures are also present. Average fracture apertures are ~0.5 cm, such that the cumulative aperture in a 30-foot region around the west filling station is ~8 cm. A hypothetical model developed for probable fractures in the Tuff below the west filling station shows a preferred northerly strike, westward dip, and a 2-foot spacing. If infiltration of petroleum has occurred in this region, then the plume is expected to have migrated mostly in a N-S direction (intersecting the drainage running on the north side of the Tank Farm) with a slight slant to the west. From this model, drilling along an E-W slant should intersect a maximum number of fractures along which this potential fracture infiltration can be investigated.

BACKGROUND

Infiltration of petroleum liquids/vapors into the Tshirege Member of the Bandelier Tuff at the DP Tank Farm is controlled by bulk rock properties, including fractures that are a common feature of the tuff. This study characterizes fractures in the upper few meters of the Bandelier Tuff exposed at the Tank Farm and uses statistical analysis of measured fracture geometry and linear density in order to predict fractures at depth below filling stations.

Fracture documentation follows the standard procedure outlined in outlined by the *ER Fracture Characterization SOP* (LANL-ER-SOP-03.06) and described in more detail in other reports (e.g. Vaniman and Wohletz, 1990; Wohletz, 1993). The fractures characterized are exposed in an old road cut running east from the NE side of the Knights of Columbus hall. Figure 1 shows a topographic map, showing the location of the section in the DP Tank Farm where fractures were measured as a function of distance east from the intersection of Trinity Drive and DP Road. Because of the limited fracture exposure at the DP Tank Farm, fracture data measured along the north wall of Los Alamos Canyon (Wohletz, 1995b) are also included in this study to give a more complete picture of E-W trends in fracture characteristics (see Fig. 1). As will be shown, there is enough similarity in trends between the Tank Farm and the Los Alamos Canyon data sets to justify projection of the latter data set onto the former.

From Figure 1, one can see the Guaje Mountain Fault Zone (GMFZ) running through the DP Tank Farm. Mapped by Vaniman and Wohletz (1990), this fault produces no sharp offset in the Bandelier Tuff (hence it is referred to as a fault zone), but its presence is inferred by a notable increase in linear fracture density as shown by Wohletz (1995b). In discussion of the present data, some consideration of the consequences of the GMFZ will be covered.

FRACTURE DATA

157 fractures are exposed in the old road cut running west towards the Knights of Columbus Hall from test bore hole (####), located at the west filling station. In addition, 288 fractures were measured along Los Alamos Canyon's north wall in the interval delineated by the section on Figure 1. Figures 2 and 3 show reproductions of the photomosaic and fracture maps made at the Tank Farm, section one extending eastward ~130 feet from the west end of the road cut (Fig. 2) and section two continuing another 152 feet east to test bore hole (####). East fracture was numbered and entered into a data base along with its strike, dip, and aperture. From the data base, fracture linear density (number of fractures per 100-foot interval centered on each fracture), and strike, dip, and aperture, mean values and variation with position were calculated.

Linear Density. Data shown in Figure 4 show fracture densities expressed as number of fractures per 100-foot interval centered on each fracture. Density values increase from a background value of ~20 fractures per 100 feet (a 5 foot spacing which is a characteristic of Tshirege Member background values documented by Vaniman and Wohletz (1990) and Wohletz (1994) to values of 60 (LA Canyon) and 80 (DP Tank Farm) over the Guaje Mountain Fault Zone (GMFZ). The west filling station is located on the eastern shoulder of the GMFZ within a region

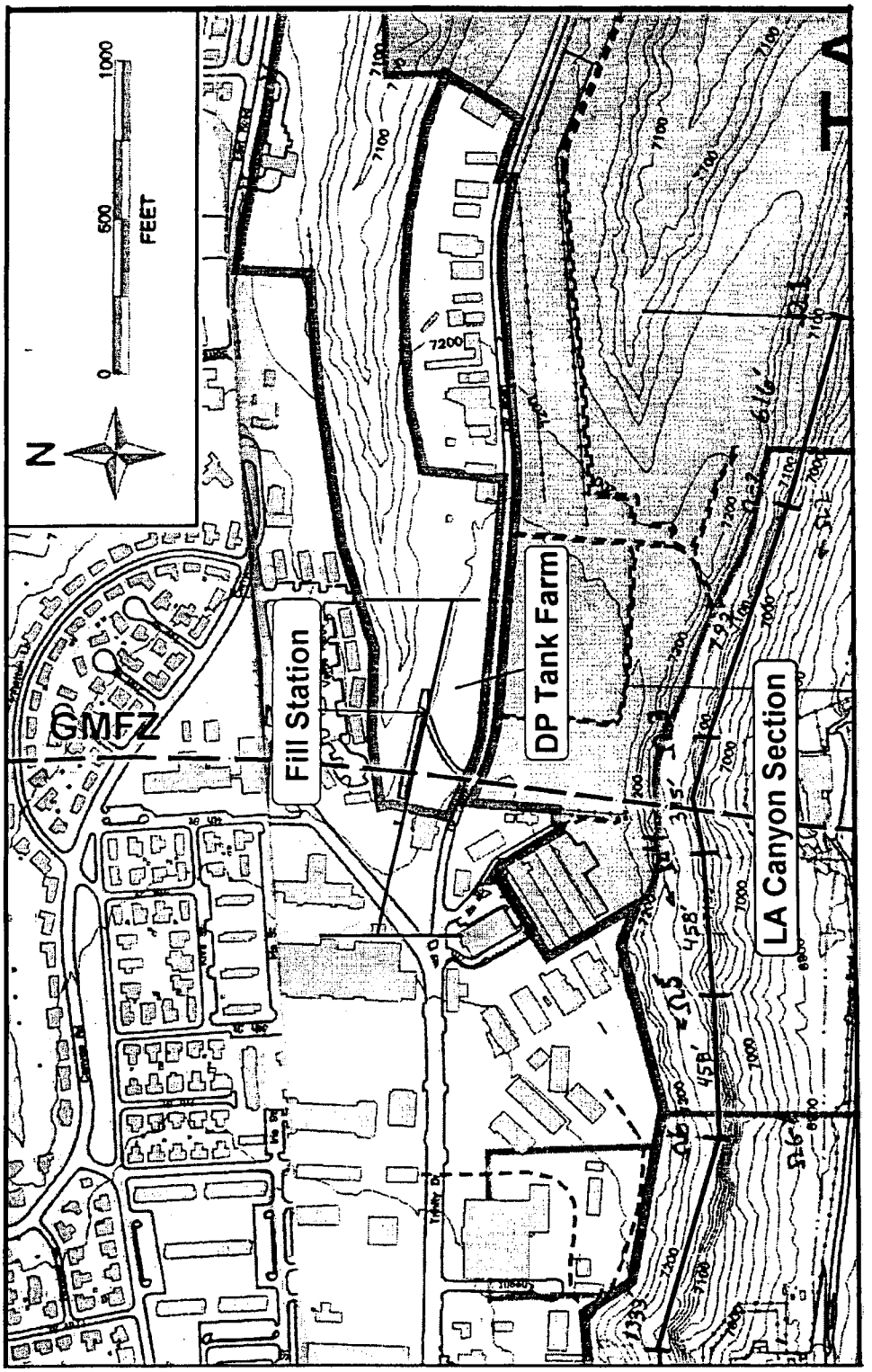

Figure 1. Topographic map showing the location of the DP Tank Farm, the west filling station, and the section along which fracture characterization was completed. Note the section along Los Alamos Canyon where data from Wohletz (1995b) were used to evaluate the Tank Farm data. Also note the projection of the Guaje Mountain Fault Zone (GMFZ), mapped by Vaniman and Wohletz (1990), which runs through the Tank Farm.

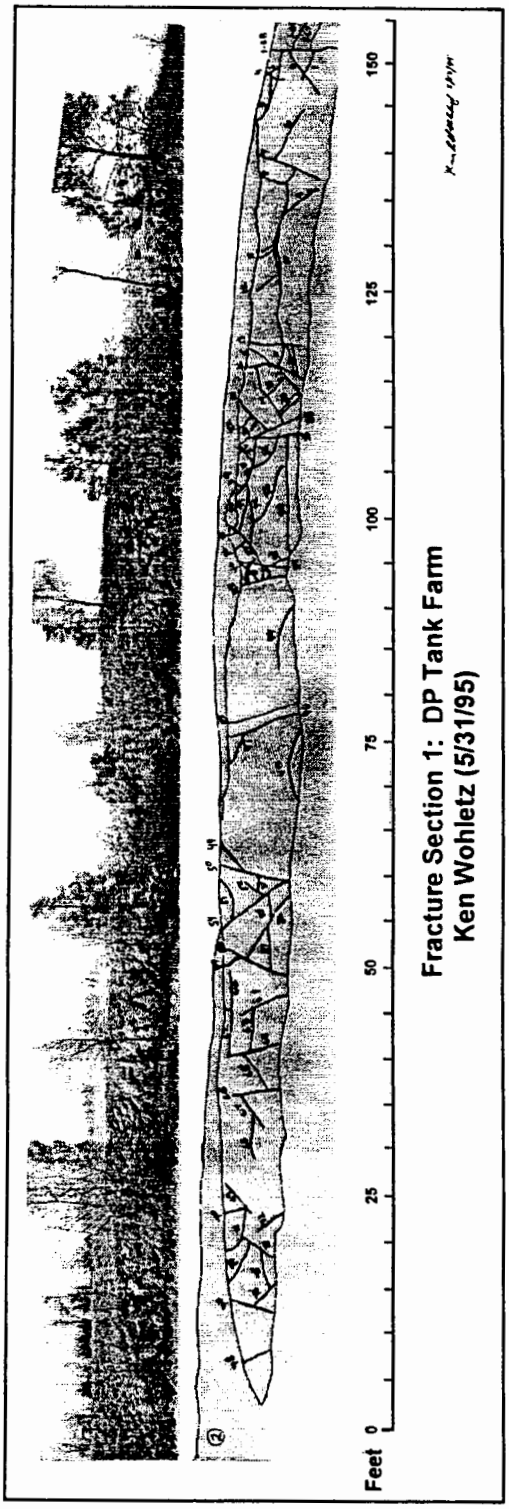

Figure 2. Photomosaic and fracture section 1 map along road cut extending from test well (####) ~150 feet westward

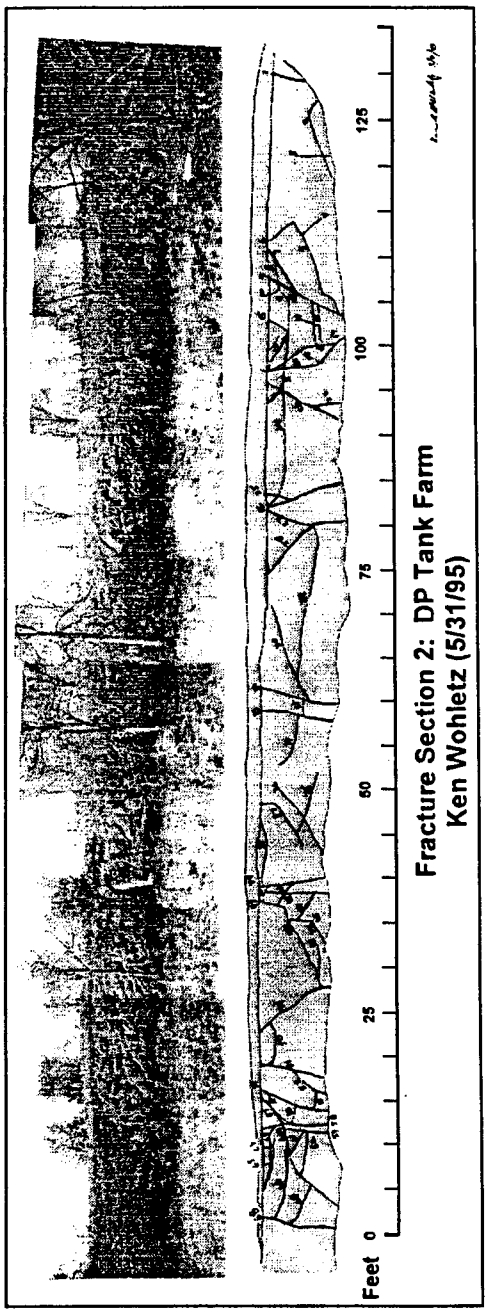

Figure 3. Photomosaic and fracture section 2 map along road cut extending from ~130 feet west from the west end of section 1.

showing where average fractures are closely spaced (~1.7 feet). The DP Tank Farm section shows a more distinct peak in fracture density over the GMFZ than does the LA Canyon section, but variability of peak fracture densities over fault zones is not unusual, considering other studies mentioned above.

Fracture Strike. Table 1 compares fracture strike statistics of the DP Tank Farm and LA Canyon sections. These data are graphically illustrated in Figure 5 by rose diagrams, that show a distinct difference in mean strike for all fracture for the DP Tank Farm data (mean = N16W) compared to those of LA Canyon (mean = N32E). Previous studies have shown that where measured along E-W exposures, fractures in the Tshirege Member show a crude bimodal distribution of strikes defining NW and NE trends. While this distribution is certainly evident in the LA Canyon data, the DP Tank Farm data show a peak at about N80W, and another mode trending roughly N-S, possibly reflecting a rotation of fracture trends of about 40 degrees towards the west. The discrepancy in fracture trends for the two sections likely reflects to some degree the relatively small number of fractures measured, such that the statistical values are crude. However, Figure 6 shows variation in smoothed fracture strikes along section with those of the DP Tank Farm section closely mimicking the LA Canyon data but offset by ~25 degrees towards the west. From Table 1, average NW fractures are about 50% more abundant than NE trending ones, and the average trends of each will be N44W and N40E, respectively.

Table 1. Fracture Strike Data.

Fracture Set	*Number*	*Mean Strike*	*Standard Deviation (1 σ)*
DP Tank Farm			
NE	65	N40E	±26
NW	92	N44W	±30
LA Canyon			
NE	162	N48E	±23
NW	126	N38W	±23

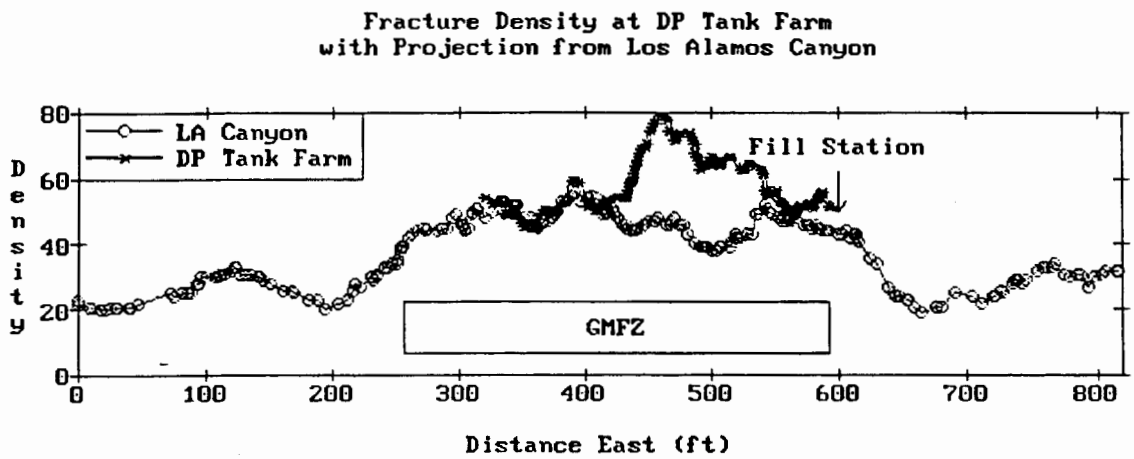

Figure 4. Fracture density shown a number of fractures per 100-foot interval centered on each fracture along the DP Tank Farm traverse (~300 feet) and Los Alamos Canyon (~800 feet). The distance is shown as feet east of the intersection of Trinity Drive and DP Road Note the increase in density from about 250 to 560 feet, which is the signature of the Guaje Mountain Fault Zone (GMFZ). The west fill station, site of test well (####) is shown at 600 feet east.

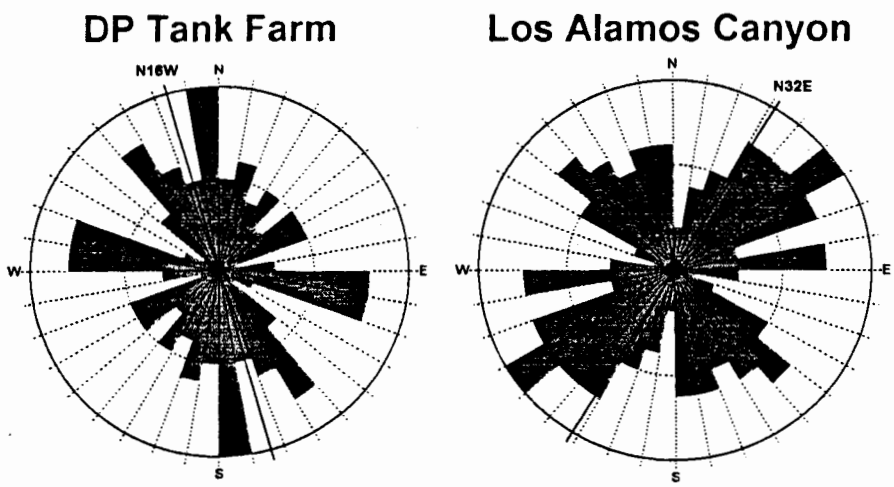

Figure 5. Rose diagram showing the frequency of measured fracture strikes for the DP Tank Farm and Los Alamos Canyon traverses with vector mean values for all fractures at N16W and N32E, respectively. While the Los Alamos Canyon data show NW and NE strike modes, the DP Tank Farm data show crude WNW and N modes.

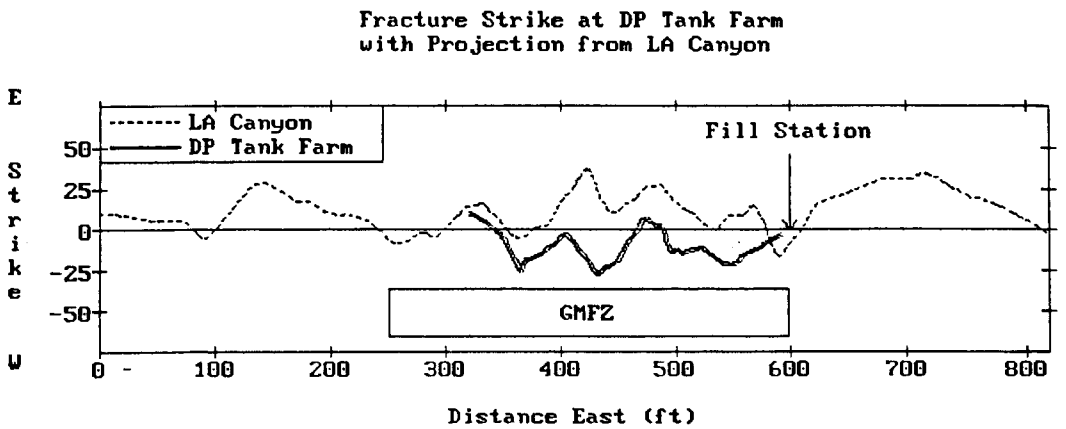

Figure 6. Variation of mean fracture strike with distance along the two measured sections. Data are shown as 28 point (0.1) LOWESS (Locally Weighted Regression Scatter Plot Smoothing) and 31 point (0.2) LOWESS curves for the Los Alamos Canyon and DP Tank Farm data, respectively. Note the similarity of variations of strike in both sections, but that the DP Tank Farm data are offset ~20° west from the LA Canyon data.

Fracture Dip. Data shown in Table 2 record statistics for fracture dips measured along the DP Tank Farm and Los Alamos Canyon sections. As discussed above for strike measurements, the data have been categorized into NW and NE trending populations in addition to northerly and southerly dipping ones. Mean dips range from ~40 to ~60 degrees (30 to 50 degrees from vertical) for both southerly and northerly dipping strikes. Averaging all fractures

Table 2. Fracture Dip Data*.

Fracture Set	*Number*	*Mean Dip (°)*	*Standard Deviation (1 σ)*
DP Tank Farm	157	49 (89)	±30
NE	65	53 (83)	±30
N	43	57N	±34
S	22	47S	±20
NW	92	46 (89)	±30
N	40	38N	±35
S	52	52S	±24
LA Canyon	288	63 (74)	±28
NE	162	60 (69)	±30
N	138	60N	±30
S	24	61S	±25
NW	162	60 (81)	±30
N	103	70N	±25
S	23	50S	±21

*Mean dips shown in parentheses reflect values derived from complimentary dip (degrees from vertical) where southerly dips are expressed as negative values.

(expressing dips a degrees from vertical and assigning southerly dips as negative and northerly dips as positive) shows fractures to be dominantly vertically oriented (parenthetical numbers in Table 2). Such averages are portrayed in Figure 7, which shows smoothed curves of dips as a function of location along measured sections. Generally fractures dip northerly with exception of the DP Tank Farm data in a region around 500 feet east. For fractures near the west filling station, fractures average about 40 degrees from vertical (50 degrees from horizontal).

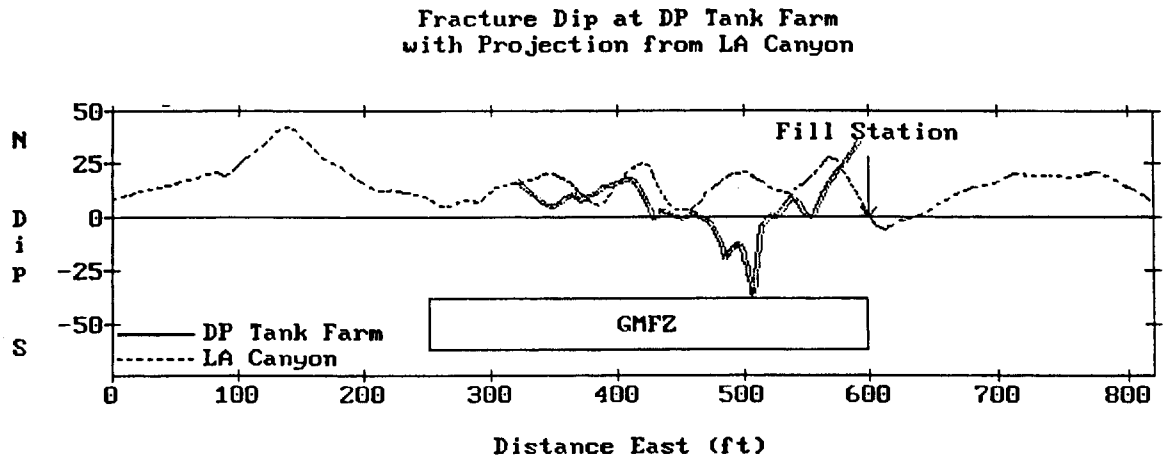

Figure 7. LOWESS (0.1) and (0.2) smoothed curves for fracture dips along the LA Canyon and DP Tank Farm sections, respectively. Dips are shown as degrees from vertical where positive dips are northerly and negative dips are southerly oriented. Both curves show a dominance of northerly dips with exception of the DP Tank Farm data at around 500 feet. At the west fill station, DP Tank Farm dips are dominantly ~50° (~40° from vertical).

Fracture Aperture. Table 3 shows that mean apertures at DP Tank farm are 0.5 cm, whereas those in LA Canyon are slightly wider (0.6 cm), suggesting little variation from mesa tops to mesa margins. The apertures for NE-trending fractures (0.7) average nearly twice those of NW-trending fractures (0.4) at the DP Tank Farm. Less than 5% of measured fractures in this area are closed or exceed 1.5 cm in aperture. While average fracture aperture does not vary much over the GMFZ (Figure 8), cumulative aperture increases due to the increase in fracture density over this interval (Figure 9). Near the west filling station, average fracture aperture shows and apparent rise to values near 0.75 cm (Fig. 8).

Table 3. Fracture Aperture Data.

Fracture Set	*Number*	*Mean Aperture (cm)*	*Standard Deviation (1 σ)*
DP Tank Farm	157	0.5	±0.8
NE	65	0.7	±0.8
NW	92	0.4	±0.7
LA Canyon	288	0.6	±0.9
NE	162	0.6	±0.9
NW	126	0.6	±0.9

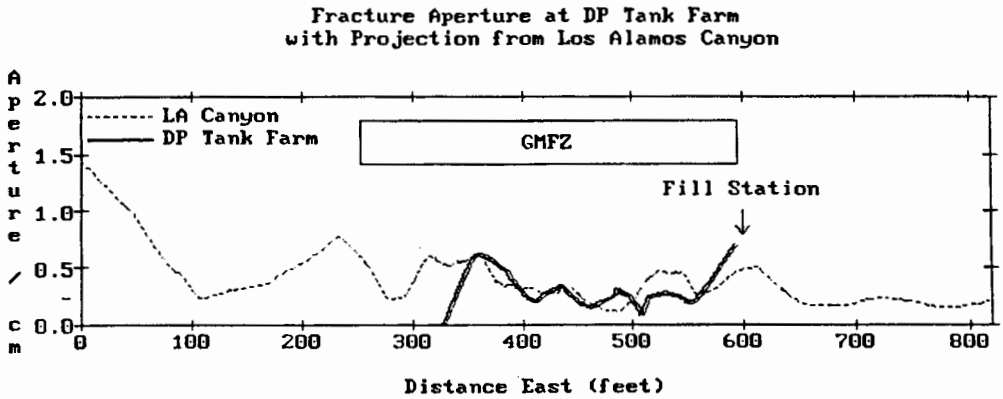

Figure 8. LOWESS (0.1) and (0.2) smoothed curves for fracture aperture for the LA Canyon and DP Tank Farm sections, respectively. Fracture apertures average ~0.5 cm for DP Tank Farm data and are very similar to those measured in LA Canyon. At the west fill station, apertures average ~0.75 cm. Note that there is no distinct signature of the GMFZ.

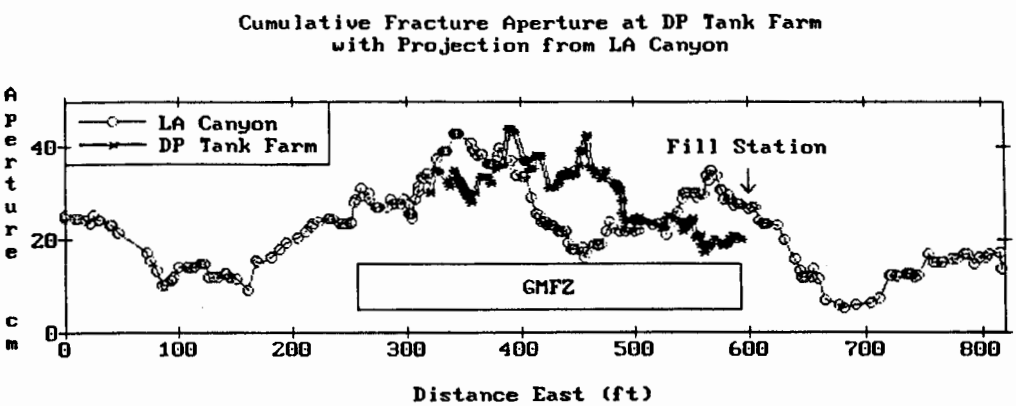

Figure 9. Cumulative fracture aperture per 100 feet centered on each fracture for the LA Canyon and DP Tank Farm sections. Fracture apertures average 20 cm per 100 feet for these data but show higher values near 40 cm per 100 feet in the GMFZ.

INTERPRETATIONS

Previous studies (Vaniman and Wohletz, 1990; Wohletz, 1994; Wohletz, 1995a,b) have shown that fracture density and cumulative aperture increase over mapped fault zones, allowing identification of possible unmapped faults. Fractures in the Tshirege Member of the Bandelier Tuff at the DP Tank farm likewise show these signatures of the Guaje Mountain Fault Zone running adjacent to the west filling station. Comparison of fracture statistics at the DP Tank Farm with those measured along LA Canyon show enough consistency to support development of a statistical model. Since fractures below and immediately to the east of the west filling station are not exposed, I infer their existence and character based on extrapolation from measured fractures in the vicinity. In developing a hypothetical map and cross section of fractures at the west filling station, one may extrapolate fracture density (50 fractures/100 feet; an average 2-foot spacing), strike (3:2 NW:NE trending fracture ratio, and dips (averaging ~ 50°) but with presence of prominent nearly vertical ones and subordinate horizontal ones). To represent the variations of these statistical variations, I have attempted to make the hypothetical model (Figure 10) look like mapped fractures seen in the section at DP Tank Farm. Figure 10 also includes mapped fractures shown as solid lines, whereas inferred ones are shown as dashed lines.

While an infinite number of variations of this hypothetical model are possible, the general use of it is to infer preferred direction of infiltration possible along fractures likely to be present in the tuff below the west filling station. The fracture fabric suggest a N-S elongation of infiltration with a slight incline to the west (note: fracture dips in Figure 10 are apparent, because the angle between the E-W line of the cross section and the inferred fracture strike). A total fracture aperture in this region is expected to be ~8 cm. While it is incorrect to apply the model in Figure 10 directly, it does serve to illustrate the documented statistical variation. From this model, one may conclude that a contaminant plume moving downward along fractures expanding preferentially in a N-S direction would intersect the drainage running along the north side of the Tank Farm. Exploratory drilling would intersect the greatest number of fractures if it were slanted towards the east. Such a model can be applied to other areas east of the GMFZ in the DP Tank Farm, except fracture spacing should be increased to average 5 feet (20 fractures/100 feet).

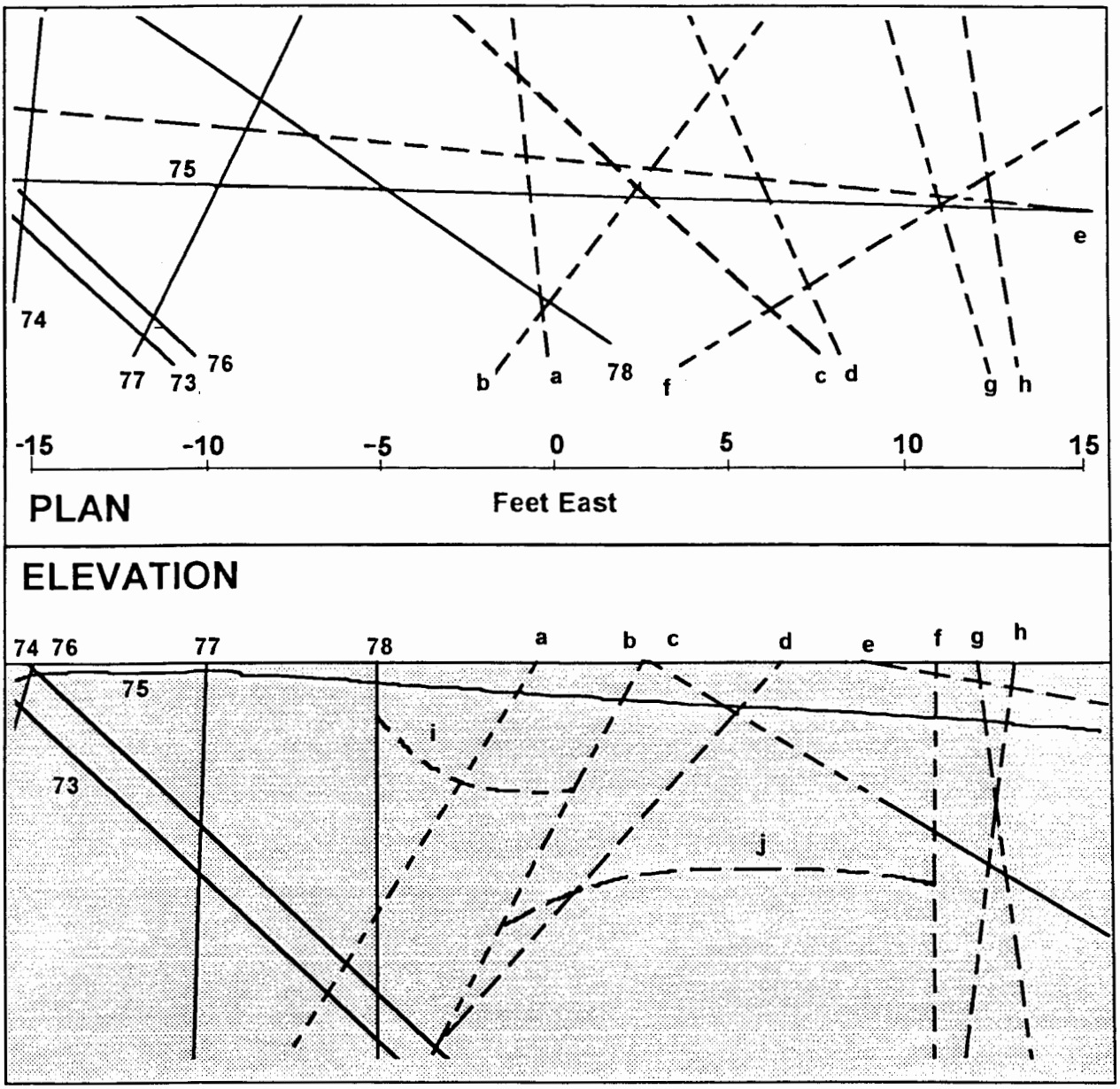

Figure 10. Fracture model depicted by plan view (top, north is up) and elevation (E-W cross section, bottom) for area centered on the west fill station (at 0 feet on the scale). Solid lines represent mapped fractures (numbered from Figure 2) existing west of the station while dashed ones (arbitrary letter designation) are hypothetical, drawn to represent average spacing, strikes, and dips. The frequency of fractures is modeled at 50 fractures per 100-foot interval (2 foot average spacing). In this model, statistically constructed strikes and dips suggest that if infiltration is largely controlled by fractures, then an infiltration plume would show a N-S elongation and a westerly slope with depth.

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