ANALYSIS OF LINEATIONS IN THE EAGLE FLAT STUDY AREA, HUDSPETH COUNTY, TEXAS

E. G. Wermund

J. A. Raney (Project Director)

Prepared for the Texas Low-Level Radioactive Waste Disposal Authority
under Contract No. IAC (92-93)-0910

Bureau of Economic Geology
W. L. Fisher, Director
The University of Texas at Austin
Austin, Texas 78713-7508

September 1992

CONTENTS

Figures

Text Tables

Appendix Tables

ABSTRACT

The purpose of this study of the Eagle Flat study area, Hudspeth County, Texas, is to determine the density and orientation of lineaments as part of a characterization study of a proposed site for the Texas low-level radioactive waste repository. Because both the number and total length of lineations per unit area are low at the proposed site (north Faskin Ranch), the results of lineation analyses do not impact repository siting. The lineation study may, however, be a useful adjunct to other ongoing investigations of recharge, Quaternary faulting, geomorphology, and fissures.

The scope of this study is to examine the occurrence of lineations on aerial photographs and lineaments on Landsat imagery as they reflect topography and slopes, drainage, bedrock, soils, and geologic structure, as well as the degree to which analysis of linear elements contributes to understanding of both the geologic history of an arid area and the active geologic processes altering the ground surface. Lineations were identified on black-and-white, 1:22,000-scale, stereographic pairs of aerial photographs and transferred to 7.5-minute quadrangles, digitized, statistically analyzed (number, length, and azimuth) per unit area, and printed on maps that were hand-contoured. The study area was divided into 96 unit areas (4 mi^2) for analysis. Thirty rectangular areas were selected to characterize the lineations associated with particular stratigraphic, structural, or geomorphic properties.

Histograms and scattergrams with straight-line curve-fitting of linear and geologic properties were computed to evaluate the characteristics of the lineations in the 30 selected areas. Five separate areas of Cretaceous outcrop have 26, 27, 28, 29, and 32 lineations per square mile; two Precambrian hills have 59 and 58/mi^2. For straight-line curve-fitting of lineation lengths to age and type of bedrock, the R values display correlations of 0.918 to 0.982 for three Precambrian outcrop areas, 0.969 for Permian Hueco Limestone outcrop areas, and 0.886 and 0.873 in two Cretaceous outcrop areas. Azimuth R values are: 0.918, 0.950, and 0.988 (Precambrian), 0.823 (Permian), and 0.919 and 0.983 (Cretaceous). The best correlation of number of lineations per grid and relief is 0.473, but 0.657 is the R factor of all selected slopes.

Lineations were interpreted on seven scenes of Landsat imagery containing the Eagle Flat study area. No lineations pass through or near the proposed site on Faskin Ranch; most lineations parallel structure and drainage.

INTRODUCTION

In 1990, the Texas Legislature selected the six 7.5-minute quadrangles that comprise the Eagle Flat study area of this report for locating a potential site of a Texas low-level radioactive waste repository (fig. 1). The Bureau of Economic Geology is conducting geologic and hydrologic characterization investigations for the Texas Low-Level Radioactive Waste Disposal Authority. The lineation study is one of many related Bureau geologic studies. Since this study began, the Bureau has focused its geologic and hydrologic investigations on a proposed site in the Faskin Ranch (fig. 2) while continuing its regional studies.

The purpose of this report is to determine the density and orientation of lineations as they may relate to other characterization investigations. The scope of this study is to examine the occurrence of linear features on aerial photography and satellite imagery as they reflect topography and slopes, drainage, bedrock and soils, and geologic structure, as well as the degree to which analysis of linear elements contributes to understanding both the geologic history of an arid area and the active geologic processes occurring on the ground surface.

PHYSICAL GEOGRAPHY

The Eagle Flat study area in Trans-Pecos Texas (fig. 2) includes a shallow bolson that is oriented east-southeast nearly parallel to U.S. Interstate 10 and the Southern Pacific Railroad. The Eagle Flat bolson is bounded by the Diablo Plateau on the north, the Carrizo and Van Horn Mountains on the east, and the Eagle Mountains and Devil Ridge on the south and southwest. The principal ephemeral drainages in the Eagle Flat bolson are Blanca Draw, which leads to Grayton Lake in the west half of the bolson, and Eagle Flat Draw to the east. These two drainages are separated by a very

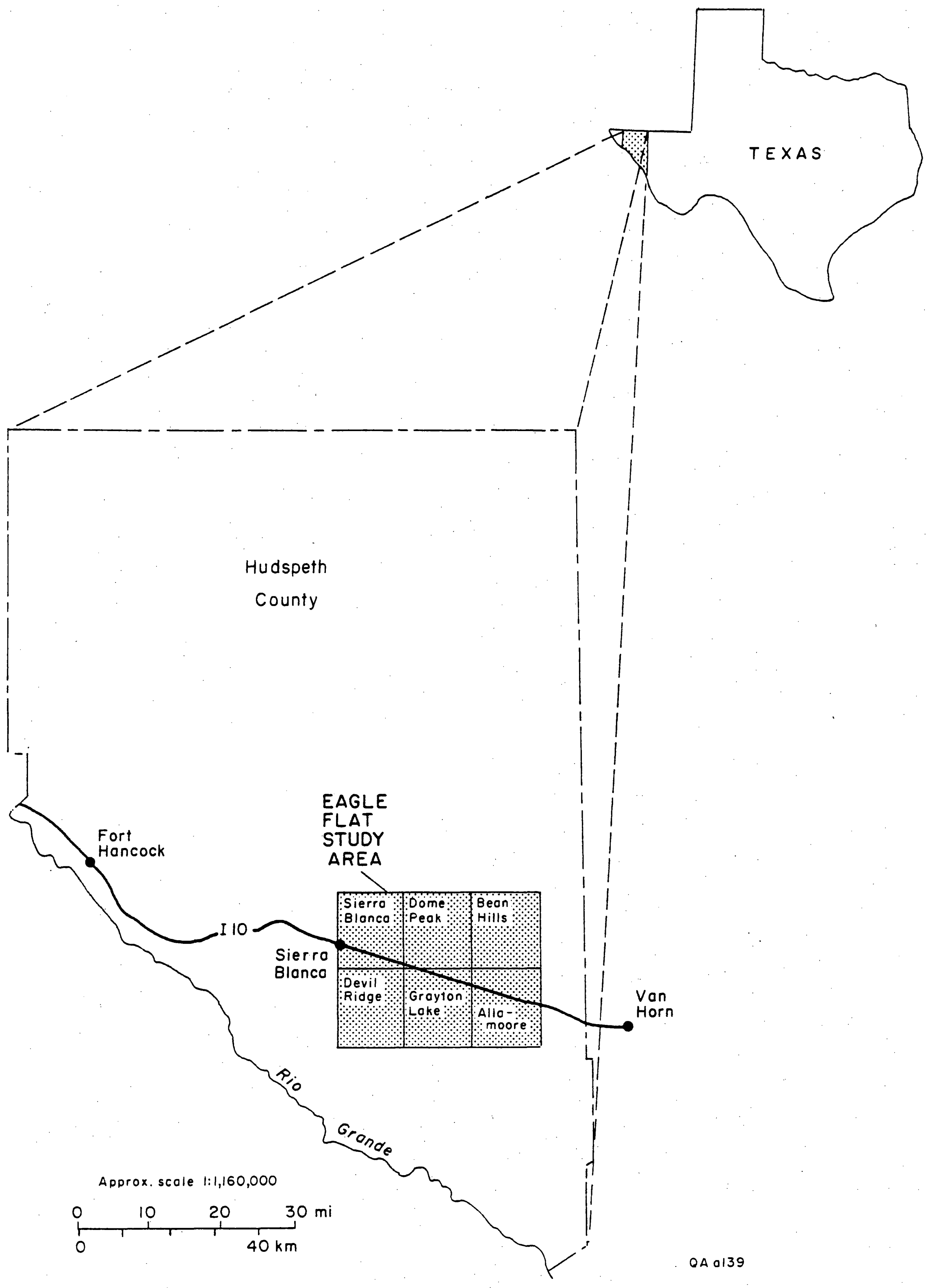


Figure 1. Location of the Eagle Flat study area in Texas.

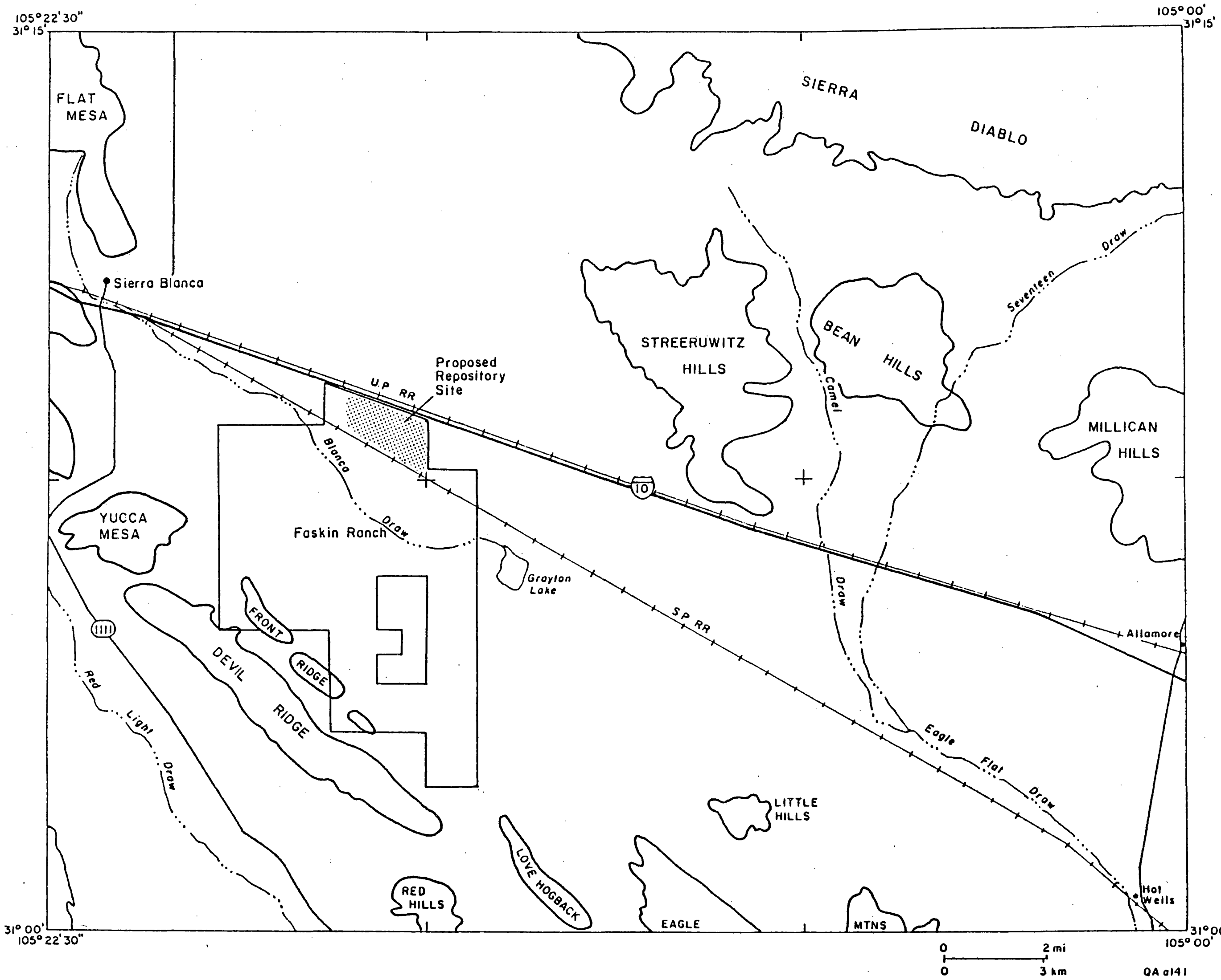


Figure 2. Principal physical geographic features in the Eagle Flat study area.

low relief, north-south drainage divide that nearly bisects Eagle Flat. This divide passes through the Streeruwitz Hills, the Eagle Flat railroad siding, and the Eagle Mountains. Between the Diablo Plateau and Eagle Flat Draw the general southward drainage of principal tributaries is interrupted west to east by the Streeruwitz, Bean, and Millican Hills.

According to measurements from USGS 7.5-minute quadrangles, the drainage basin of Blanca Draw is ≥200 mi^2, and the entire basin is internally drained into Grayton Lake, an ephemeral playa lake. Of Blanca Draw tributaries, 77 percent flow south and east, 13 percent flow east and north, and 9 percent flow west into Grayton Lake. Relief in the western half of the study area is about 2,635 ft—from elevations of 6,894 ft at the head of Blanca Draw to less than 4,260 ft at Grayton Lake.

Streams of the Eagle Flat Draw drainage basin appear better integrated than those in the Blanca Draw basin. Relief in the Eagle Flat Draw drainage basin is about 3,175 ft in the eastern half, from elevations of 7,424 ft in the Eagle Mountains to less than 4,250 ft in the constricted basin at Hot Wells.

The southwestern 10 to 15 percent of the study area is drained by Red Light Draw. Its northeastern bounding divide passes through Texan Mountain, Yucca Mesa, hills north of the Front Ridge, and the area immediately west of Little Hills.

The climate is subtropical arid according to Larkin and Bomar (1983). Average annual rainfall is approximately 9 inches. March and April are the driest months (≤0.25 inches); August and September are the wettest months (≥2 inches). The average monthly low temperature of 30°F occurs in December and January, and the average monthly high temperature of 96°F occurs in June and July. The nearest wind-observation location is El Paso, where, from 1961 to 1979, 14.7 percent of the annual winds were from the west succeeded by west-southwest and west-northwest. The lower velocity and less well represented wind directions are, in order of increasing strength, north-northwest, east-northeast, northeast, and northwest. This climate controls a sparse vegetation making lineation analysis a valuable tool.

GEOLOGIC SETTING

Stratigraphy

The oldest rocks are Precambrian units that crop out in the northeast quarter of the Eagle Flat study area. The Carrizo Mountains, located southeast of Millican Hills (fig. 2) and beyond the bounds of the study area, are the type area for the Carrizo Mountain Group, where Dietrich and others (1983) subdivided the group into (1) meta-igneous rocks composed of granodiorite, amphibolite, and meta-rhyolite (thickness of ~7,700 ft) and (2) meta-sedimentary rocks including limestone, phyllite, meta-arkose and meta-quartzite, and schist (thickness of ~19,000 ft). In the Millican, Bean, and Streeruwitz Hills, the Allamoore and the Hazel Formations are the principal bedrock (King, 1965). The Allamoore Formation includes interbedded cherty limestone, limestone pebble conglomerate, phyllite, pyroclastics and lavas, and numerous shallow igneous intrusives, with an aggregate thickness of several thousand feet. The Allamoore Formation contains numerous talc prospects and deposits. The Hazel Formation is principally interbedded sandstone and conglomerate with a thickness of about 5,000 ft. The basal strata appear to be composed of debris flows and alluvial fan deposits, the coarser clasts being derived from the Allamoore Formation. On the upthrown side of the south Diablo Fault in the northeast part of the study area, the Hazel Formation is unconformably overlain by a 7- to 8-mi long linear outcrop of the Van Horn Sandstone, which was identified by McGowen and Groat (1971) as an alluvial fan deposit.

No lower Paleozoic units are present near Eagle Flat. Upper Paleozoic strata are represented by the Permian Hueco Limestone, which crops out in a southern prong of the Carrizo Hills, in scattered outcrops in the Streeruwitz Hills, at the rim of the southern escarpment of the Diablo Plateau (Dietrich and others, 1983; Twiss, 1979), and in an elongate exposure flanking the northeast side of the Eagle Mountains. The Hueco Limestone is the rimrock of the Diablo Plateau northeast of Eagle Flat. The Hueco Limestone is composed of mostly dolomitic limestone, dolomite, and in the lower part, marl and thin beds of sandstone grading downward to shale, sandstone, and conglomerate. Thickness is 100 to 300 ft.

Cretaceous rocks are common in the Eagle Flat region, but only Lower Cretaceous rocks; no Gulfian rocks are present (King, 1965; Albritton and Smith, 1965). The oldest Cretaceous units are the red-brown Yucca Formation, mostly micritic limestone with interbedded shale, sandstone, and sparse conglomerate (<600 ft thick), and the Bluff Mesa Formation, dominantly limestone with calcareous sandstone and shale interbeds, and abundant marine fossils (1,100 to 1,700 ft thick). These formations are found in the foothills of Devil Ridge and in the Quitman Mountains. The Campagrande Formation, equivalent to the Bluff Mesa Formation, crops out on the downthrown side of the South Diablo Fault. The Campagrande Formation is composed of varicolored limestone and chert conglomerate in the lower part and interbedded sandstone and sandy shale in the upper part.

The Cox Sandstone Formation crops out in the Devil Ridge and in parallel ridges above a disconformable contact with the Bluff Mesa Formation. The Cox Sandstone is composed principally of sandstone but is conglomeratic at the base and has minor shale and limestone interbeds. The Cox is thin bedded, displays parallel-, ripple-, and cross-stratification, and thins along Devil Ridge from 1,700 ft thick at the southeast to 550 ft thick at the northwest. The Cox Sandstone is also extensively exposed in fault contact against the base of the Sierra Diablo escarpment, where it lies on rocks of the Campagrande Formation (Dietrich and others, 1983). At Devil Ridge, the overlying Finlay Formation is mostly a micritic limestone with a few clastic interbeds low in the section, but it changes to mainly limestone and marl northeastward in the Diablo Plateau. It is not a rimrock here as it is to the west.

In ridges north of and parallel to the Devil Ridge and Eagle Mountains, the Loma Plata and Buda Limestones compose a small linear outcrop belt (Smith and Albritton, 1965). The brownish-gray Loma Plata Formation is micritic, thin bedded, and intercalated with marl and black shale. The Loma Plata is about 2,200 ft thick. The Loma Plata is capped by the pale orange Buda Limestone. The Buda is micritic, nodular, and thin bedded, with a thickness of about 240 ft.

The Quaternary deposits are composed entirely of alluvium. Albritton and Smith (1965) mapped alluvial fan deposits of two probable ages. King (1965) mapped only one alluvial fan unit.

The Quaternary alluvium of the low areas, where slopes are less than 2 percent, are a complex of fluvial, lacustrine, and eolian deposits.

Structural Geology

Determination of the structural setting has been based mostly on the faults and folds observed in outcrop by King (1965), Albritton and Smith (1965), and Underwood (1963). Limited subsurface data are available from a few deep exploration wells and shallower water wells.

In the southwestern part of the study area, Albritton and Smith (1965) mapped two parallel thrust faults that trend about 130° and delineate the southern limits of the Eagle Flat bolson. The Red Hills thrust is the farthest south and occurs on the southwest side of Love Hogback (Underwood, 1963). This structure is separated from the parallel-striking Devil Ridge overthrust, which is projected from the exposed thrust mapped in the Eagle Mountains to the southeast. In the Devil Ridge–Yucca Mesa block between these two faults are numerous small displacement normal faults and folds. North of the town of Sierra Blanca, in Flat Mesa, is a thrust fault segment and several subparallel arcuate but intersecting normal faults, down to the north.

The structure on the north side of Eagle Flat bolson is also controlled by two parallel faults. The Streeruwitz Thrust strikes 90° to 120° and is present south of the Streeruwitz, Bean, and Millican Hills. It is a Precambrian fault (King, 1965) that affects only the Allamoore and Hazel Formations in the study area. Along the south and west margins of the Streeruwitz Hills, Permian Hueco Limestone is displaced by normal faults. About 4.5 mi to the northeast, the South Diablo Fault strikes 100° to 150° nearly parallel to the Streeruwitz Thrust. It is a normal fault that displaces rocks as young as the Cox Sandstone (King, 1965) down to the south.

METHODS

The lineations occurring in the Eagle Flat study area were identified on black-and-white, stereographic pairs of 1:22,000-scale, aerial photographs. During interpretation, the linear elements were identified and transferred to the U.S. Geological Survey 1:24,000-scale, 7.5-minute quadrangle sheets using a Zoom-Transfer Scope. For quality control, approximately the same amount of time, about 16 hours, was spent on interpreting lineations in each quadrangle. Lineations that were readily observed to superpose cultural features were deleted. In extensive alluvial areas it was also necessary to delete certain lineations that were normal to the dominant slope and subparallel to topographic contour lines, whereas in mountainous areas lineations subparallel to topographic contours were accepted where they are inferred to reflect bedding planes, joints, and faults.

The southwest, northeast, and northwest corners of each quadrangle were digitized and given latitude-longitude coordinates in a decimal format. Lineations on each 7.5-minute quadrangle sheet were numbered and consecutively digitized. Test printouts of digitized lines of each quadrangle were overlaid on the original maps to verify that each lineation was correctly located. This required several iterations to achieve accuracy and precision, although there was only about 2 percent error in the original work. The lines were then numbered consecutively to permit selection of lineations in specific areas for geologic and terrain comparisons. Nearly 5,800 lineations were identified: 908 in Sierra Blanca quadrangle, 1,678 in Dome Peak, 1,164 in Bean Hills, 1,093 in Devil Ridge, 924 in Grayton Lake, and 888 in Allamoore.

For unbiased regionalized examination of the linear data, the six quadrangles were further subdivided into 16 polygons 1.875 minutes on a side, slightly smaller than 4 mi^2 (fig. 3). This yields 96 polygons of data to be examined by traverses, box by box, or by moving averages. The 16 grids of each quadrangle are arbitrarily numbered by rows 1 to 4 west to east and continuing through 16 north to south. However, by this method of subdividing the area, it is a rare polygon that contains only one geologic unit or one geomorphic type. Therefore, 30 rectangular areas were located to bound outcrops of one age and/or lithology, major structural elements, orientation of stream valleys, and other geomorphic features (fig. 3).

Three data bases were created to describe the linear elements. One contains all the lineations listed by unique numbers with end points identified in UTM coordinates, azimuths in degrees, and lengths in meters. A second data base is ordered by quarter segments for each quadrangle, labeled 1

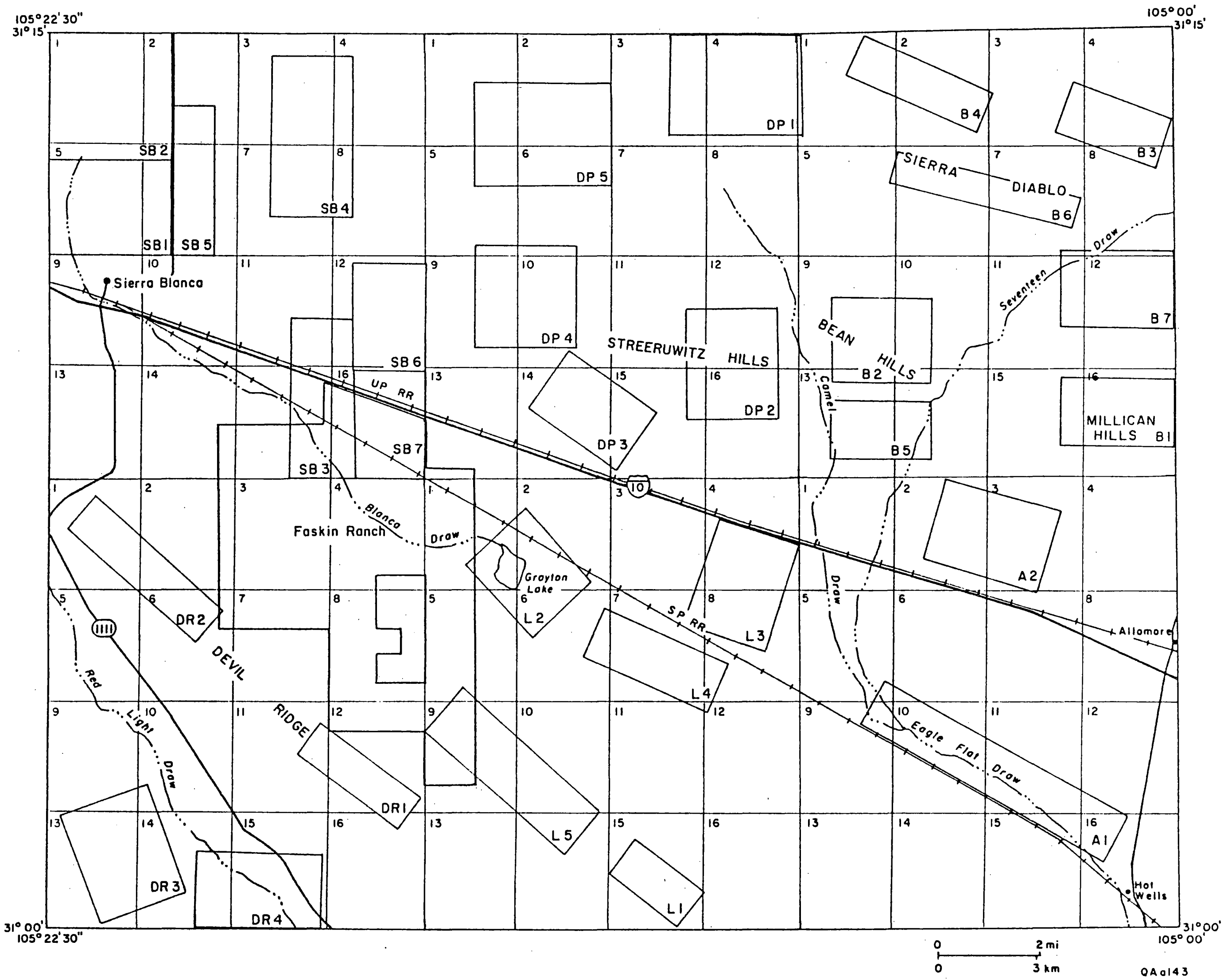


Figure 3. Distribution of equal grids and selected areas in which statistical analyses of lineations were made for the Eagle Flat study area.

to 16 in rows increasing west to east and north to south. Each quarter segment lists the uniquely numbered lineations in or touching the quarter segment, the lengths, and azimuths in 10° classes (bins). A third data base contains azimuths and lengths, ordered smallest to largest, in 31 areas selected from the 6 quadrangles on the basis of bedrock, structure, and/or geomorphology. The last reflects principally slopes and alluvial materials.

Software to analyze the distribution of lineations was modified from that used in prior Bureau studies by Dix and Jackson (1981) and Baumgardner (1987). The algorithm of Dix and Jackson was the model for program modification (table 1). The program calculated the number of lineations per unit area (fig. 4), length of lineations per unit area (fig. 5), and rose diagrams of the azimuths of lineations in 10° classes per grid area selected. Two sets of rose diagrams were constructed: (1) normalized to the strongest 10° azimuth class in the 96 grids and (2) normalized to each grid (fig. 6). For the 30 select areas, the orientation of azimuths was determined by a histogram with 10° bins.

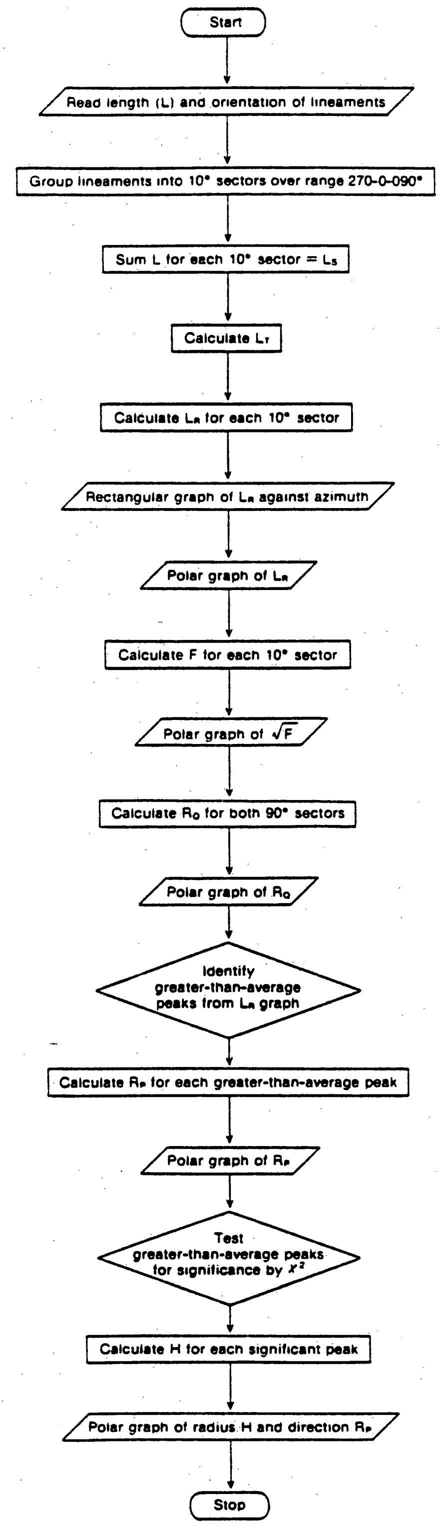
Maps were constructed that display number from the moving average of grids displaced half south and half east and length of lineations in feet per mile. In addition, maps were constructed that display the two rose distributions of linear azimuths. Statistics of variations in distributions of azimuths and lengths of lineations were determined using commercial software. From these statistics, maps were made that display the median azimuths as well as the mean accompanied by the standard deviation of azimuths. Tables including these statistics along with number, skewness, and kurtosis are compared to geology and terrain (appendix tables A1 and A2). Finally the statistical parameters were graphed for correlation.

Numerous histograms were made to compare the number, lengths, and azimuths of lineations to age, lithology, structure, and slopes. Where potential correlations were observed, quantitative methods such as scattergrams were used to evaluate correlations. To compare lineation properties with slopes, individual areas, commonly 1 mi^2, were evaluated by hand. The counting and measuring were performed on the map, tabulated, and placed in a computer file. A scattergram and fitted linear curve were then computed. The lengths of lineations per unit area are provided in appendix tables A1 and A2.

Table 1. Flow chart for statistical analysis of lineations and list of definitions (after Dix and Jackson, 1981).

TERM, SYMBOL, & FORMULA		EXPLANATION
	n	Number of lineaments in quadrangle
	L	Length of individual lineament
Total length $L_T = \sum_{i=1}^{n} L$	L_T	Total lineament length in quadrangle
Sector length	L_S	Total lineament length in 10° sector
Relative length $L_R = \frac{L_S}{L_T}$	L_R	Total lineament length in 10° sector relative to total lineament length in quadrangle
Mean length $\bar{L} = \frac{L_T}{18}$	$\bar{L}$	Arithmetic mean of lineament length in quadrangle
Length-weighted frequency $F = \frac{L_s \cdot n}{L_T}$	F	Total lineament length in 10° sector, weighted in proportion to number of lineaments in quadrangle (Frost, 1977)
Quadrant vector sum $R_Q = (x_1 + x_2 ..... + x_n, y_1 + y_2 ..... + y_n)$	R_Q	Vector sum of lineaments in one quadrant of quadrangle, where x_n and y_n are the rectangular coordinates of individual lineaments based on length and azimuth
Peak vector sum	R_P	Vector sum of lineaments in greater-than-average peak (Curray, 1956; Pincus, 1956) composed of k contiguous 10° sectors whose sector lengths (L_S) exceed the mean length ($\bar{L}$)
Greater-than-average peak $> \bar{L}$	P	
Chi square $\chi^2 = \sum_{i=1}^{k} \frac{(L_S - \bar{L})^2}{\bar{L}}$	χ^2	Test to determine goodness of fit of observed sector lengths in greater-than-average peaks with mean length (Siegel, 1956, p. 42)
Bernshtein accuracy criterion $H = \frac{\chi^2}{\nu}$	H	Measure of the degree of significance of a greater-than-average peak, where $\nu = k - 1$ = degrees of freedom (Vistelius, 1966, p. 53)
Index of preferred orientation $IPO = \frac{\sum_{i=1}^{18} \lvert L_R - 0.0\bar{5} \rvert \times 100}{1.\bar{8}}$		Measure of the degree of preferred orientation of lineaments in a quadrangle. Obtained by (1) summing the differences between mean relative length (always $^1/_{18}$ or $0.0\bar{5}$) and relative lengths in each sector; (2) dividing sum by maximum possible value of this parameter; (3) multiplying by 100. Range of IPO is 0% (no preferred orientation) to 100% (perfect unimodal distribution)
Correlation coefficient $r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{[\sum_{i=1}^{n} (x_i - \bar{x})^2 \cdot \sum_{i=1}^{n} (y_i - \bar{y})^2]^{1/2}}$	r	Measure of the degree of correlation between any two variables, x and y. Limits of r are -1 and +1 (Gellert and others, 1977)

FLOW CHART FOR DATA PROCESSING IN EACH QUADRANGLE



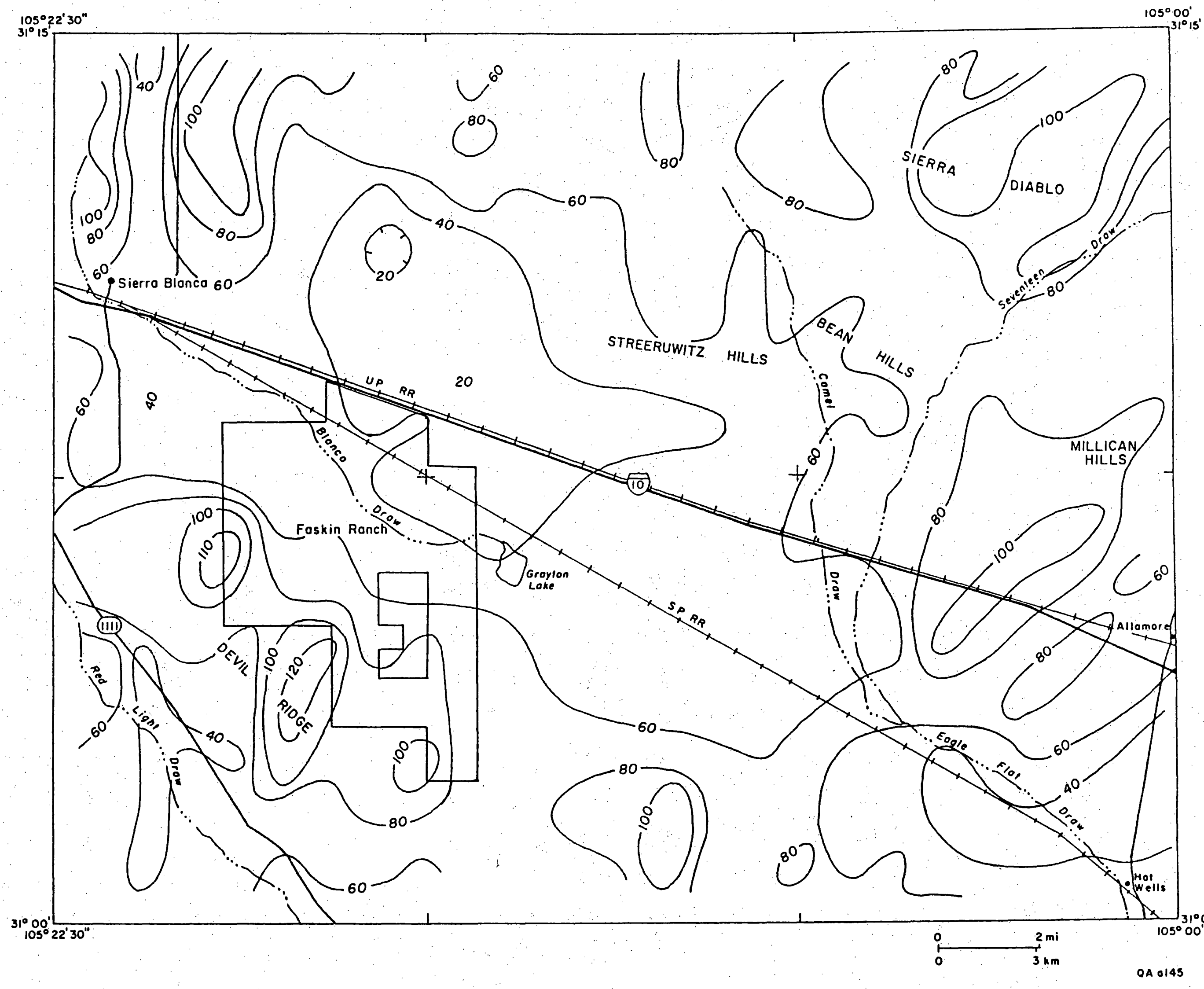


Figure 4. Moving average distribution of the number of lineations per grid cell in the Eagle Flat study area. Cells used in moving average counts are about 2 mi^2.

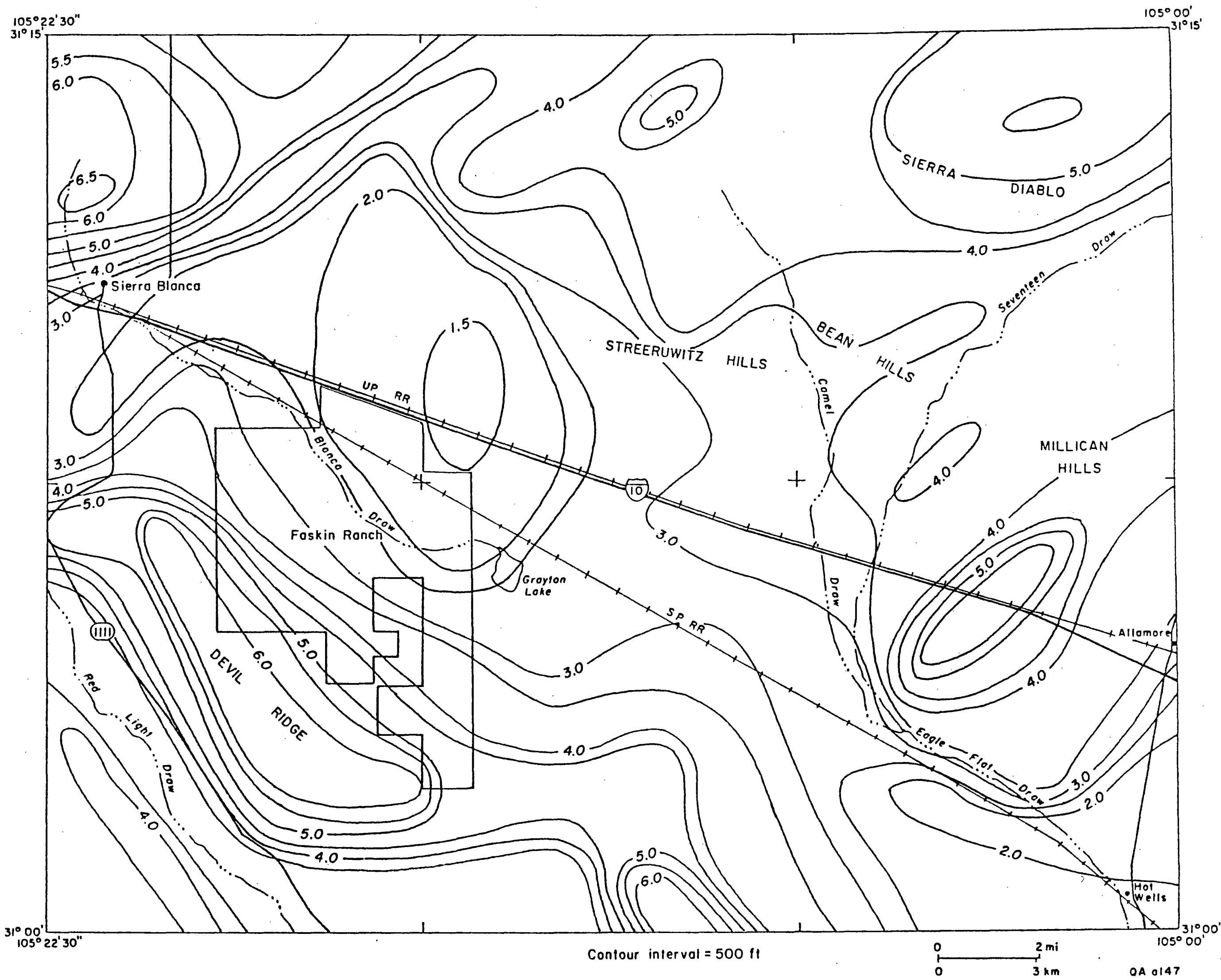


Figure 5. Location of Landsat lineations in an area enclosing the Eagle Flat study area.

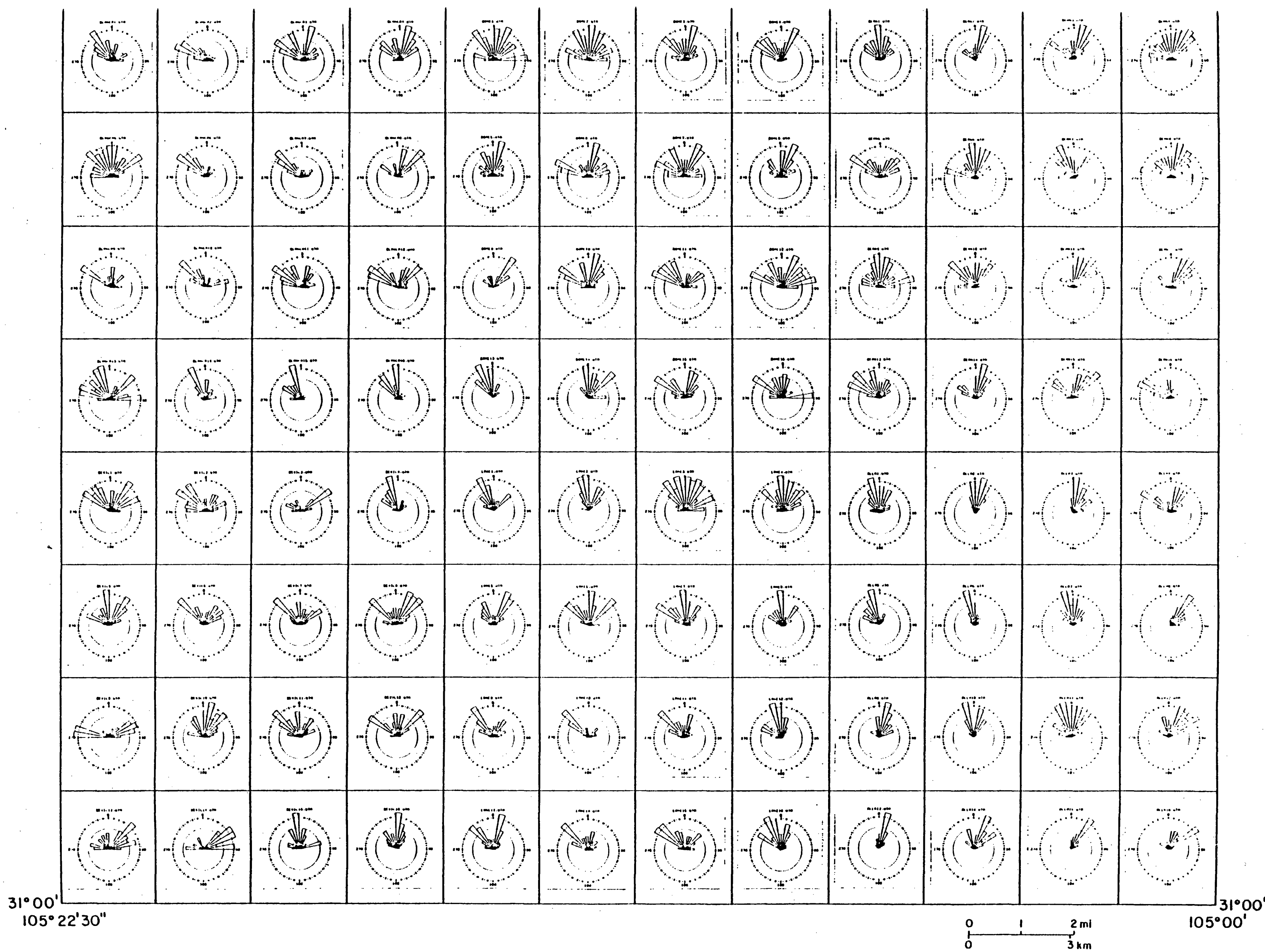


Figure 6. Distribution of the total feet of lineations per square mile in the Eagle Flat study area.

Seven different Landsat scenes were located that cover the Eagle Flat study area. These scenes had been collected at different times and reproduced for differing bands at selected scales. For one date, November 16, 1972, a set of images includes bands 4, 5, and 7, 1:250,000-scale, on black-and-white prints as well as a band 7, 1:1,000,000-scale, film positive. Other available scenes at 1:250,000-scale were: (1) a September 25, 1975, multicolored positive, (2) May 26, 1976, band 5 print, and (3) December 27, 1978, band 5 print. At 1:1,000,000-scale, additional scenes were a September 1972, multicolored print and a June 27, 1977, band 5 film positive. All these scenes had been system corrected.

The Landsat scenes were interpreted on a lighted table from a viewing angle approximating 30°. The end points of lineations were marked with paste-on transferrable arrows. Overlays were made of each scene on which principal geomorphic elements, longitude-latitude designations of the Landsat scenes, and the interpreted lineations were traced. Next, the lineations were transferred to a 1:250,000-scale AMS quadrangle map by locating the lineations relative to geomorphic features (fig. 7). Lineations identified in all seven scenes were drawn as solid lines, and lineations identified in fewer than seven but more than two scenes were drawn as dashed lines (type II).

This method accounted for the lack of terrain and precision corrections in the donated Landsat scenes. It also mitigated for the common differential shrinking and stretching of photographic prints that distort accuracy in transferring lineations, problems described by Woodruff and others (their Appendix F, 1982).

RESULTS

General Area Observations

During identification of lineations on the aerial photographs, it was noted that the density, length, and orientation of lineations are influenced by the lithology of the exposed bedrock and by structures, slopes, and drainages. Where bedrock is exposed, lineations were identified that included bedding planes, joints, and faults. The longest lineations measured in the study area were present in

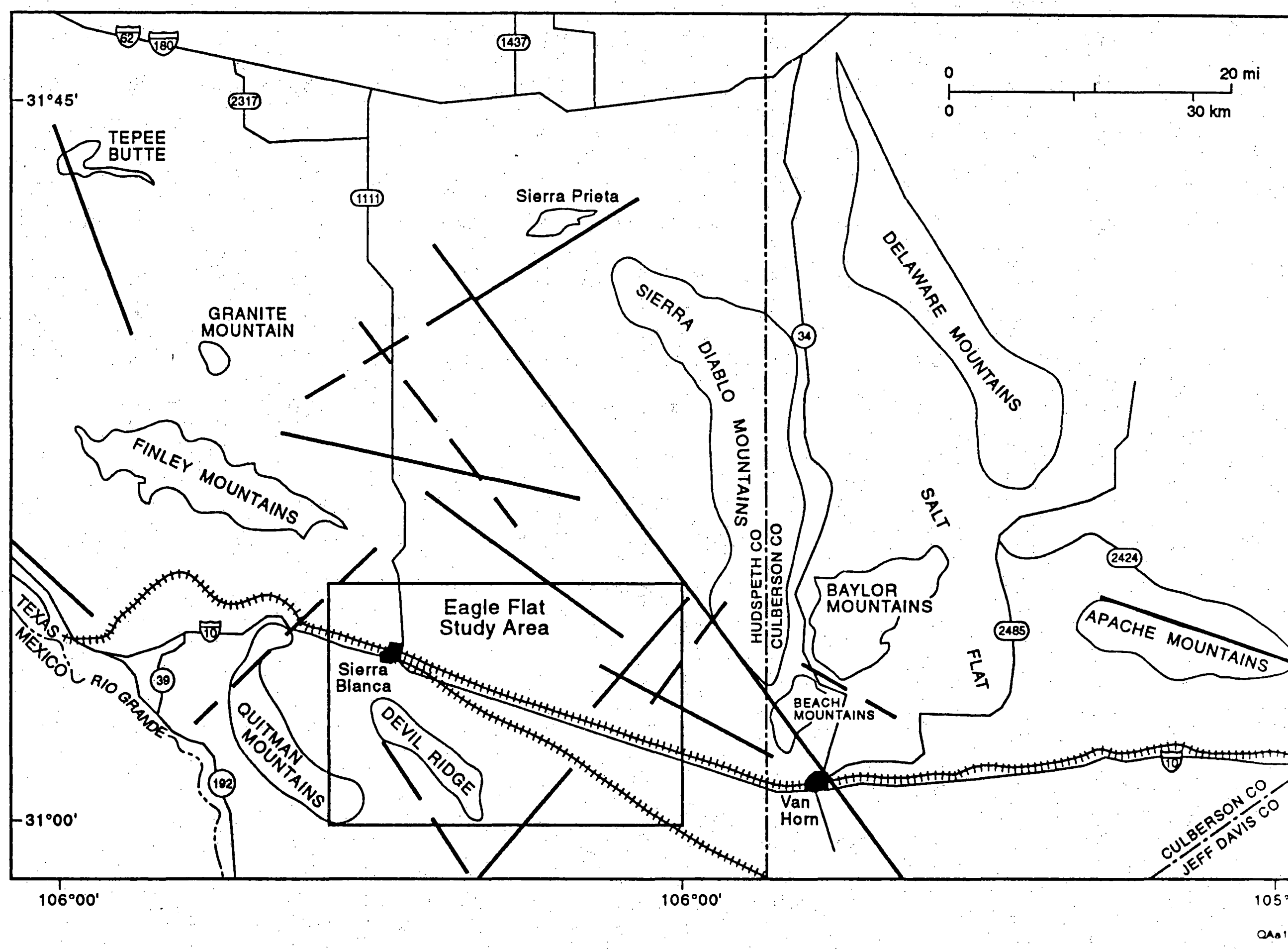


Figure 7. Azimuth roses calculated for the grid cells of the Eagle Flat study area.

exposed bedrock. On alluvial fans and slopes, lineations reflect complexly bifurcating and intersecting drainage courses similar to braided streams. In the steeper, higher, older gravel-rich alluvial fans, many lineations reflect drainage courses and perhaps joints in underlying bedrock. In more gently sloping areas, lineations generally followed dendritic drainage and vegetation concentrated along intermittent streams. The eolian cover sheets do not contain wind-related linear elements of the size measured in this study.

Lineations per unit area are generally more numerous in areas of exposed rocks. Four examples in which the number of lineations per grid exceeds 100 are: (1) in the northeast, where the Permian Hueco Limestone is exposed in the Diablo Plateau; (2) in the northwest, where Cretaceous Cox Sandstone overlain by Finlay Limestone crops out in Flat Mesa; (3) in the southwest, where Cretaceous Yucca Formation, Bluff Mesa Formation, Cox Sandstone, and Finlay Limestone compose Devil Ridge and Yucca Mesa; and (4) in the south-central area, northwestern Eagle Mountains, where Cretaceous Loma Plata Formation, Eagle Mountains Sandstone, Buda Limestone, and Chispa Summit Formation crop out (fig. 4). The lowest values occur in the alluvial plains near Blanca Draw north and west of Grayton Lake.

Table 2 shows the density of lineations and the number of lineations per square mile in the four principal terrains of the gridded map. Values are tabulated where a single terrain type occupies more than 80 percent of a grid. The number of usable grids totals 73. For the column labels, "Only Outcrop" equates to indurated bedded rocks, "Outcrop + Structure" to the same rocks overprinted by faults and some folds, "<0.5% slope" to Quaternary alluvium with less than a half percent slope, and ">2% slope" to Quaternary alluvial fan deposits. The mean values indicate a greater density of lineations in structurally disturbed indurated rocks, in bedrock, in alluvial fans, and in alluvial valleys, in descending order. The variance and standard deviation of lineation density data follow the same distribution.

Both the number and length of linear elements per unit area (1/4 quadrangle) display like distributions of values. The highest values occur in outcrop areas of the eastern Diablo Plateau, the

Table 2. Comparison of the number of lineations per square mile versus the types of terrains observed in the gridded data area B6 of this study.

		Only outcrop	Outcrop + structure	>0.5% slope	>2% slope
1	Minimum	10.600	8.9000	5.0000	5.9000
2	Maximum	26.500	30.000	12.600	25.300
3	Sum	347.90	421.32	84.800	356.60
4	Points	20.000	22.000	9.0000	22.000
5	Mean	17.395	19.151	9.4222	16.209
6	Median	16.950	19.350	8.9000	15.600
7	RMS	17.861	19.916	9.7140	16.889
8	Std Deviation	4.1574	5.5952	2.5064	4.8547
9	Variance	17.284	31.305	6.2819	23.568
10	Std Error	0.92961	1.1929	0.83546	1.0350
11	Skewness	0.21568	-0.073246	-0.30719	0.036185
12	Kurtosis	-0.38838	-0.86196	-0.90862	-0.20896

QA a 169

mountains north of Sierra Blanca, in Devil Ridge, and the Eagle Mountains, and in a lineation that includes gravel pediments south and west of the Millican Hills.

Results are not greatly different using a moving average matrix of the same grid size (fig. 4). The exception is the presence of 125 to 130 lineations per grid in the center of Devil Ridge and on the Front Range. Areas with the fewest lineations per unit area are in fluvial and eolian alluvium in which as few as 18 lineations per grid were measured with moving averages west of Grayton Lake.

A histogram (fig. 8) of the distribution of the azimuths for all the lineations recognized in the study area displays the principal regional elements. The concentration of lineations at 120° to 140° reflects the trends of major faults, strike of bedding, and major ridges. A large number of lineations at 20° to 50° and 150° to 180° appear to parallel the major slopes. If there is a regional set of joints, the components could be expected to occur within the 20° to 40° and 120° to 140° ranges, as indicated by interpretation of the histogram and the grid sets of roses. There is a noteworthy lack of lineations occurring from 70° to 110° that reflects a decrease of lineations along the basin axis in areas of extremely low slopes, generally less than 1 percent. Few lineations in classes of 0° or 90° reflect a conservative interpretation that attempted to avoid manmade features that often trend north-south and east-west. The nearly absent 10° to 20° bin is not understood, but it may be a result of the deliberate omission of fence lines.

The areal distribution of the azimuths is shown in the rose diagrams for the gridded cells (fig. 6). The most distinctive roses occur on relatively steep alluvial fans. Good examples are cells 6, 8, 13, and 15 in the Allamoore quadrangle. On the other hand, roses in the mixed alluvial slopes and outcrop areas are most diverse, as in cells 1 and 2 of the Dome Peak quadrangle.

In addition to constructing rose diagrams for each grid and histograms for each of the selected areas, the mean, median, standard deviation, variation, skewness, and kurtosis were determined. These values are given in appendix tables A1 and A2. The mean azimuth is a poor indicator of lithology and structure, but it parallels very steep slopes with minimal standard deviation. Median azimuths commonly orient normal to the length of linear ranges of outcrop; examples occur in grids SB1, SB2, DR1, DR2, DP1, GL1, GL5, BH3, and BH4. This may reflect headward-eroding

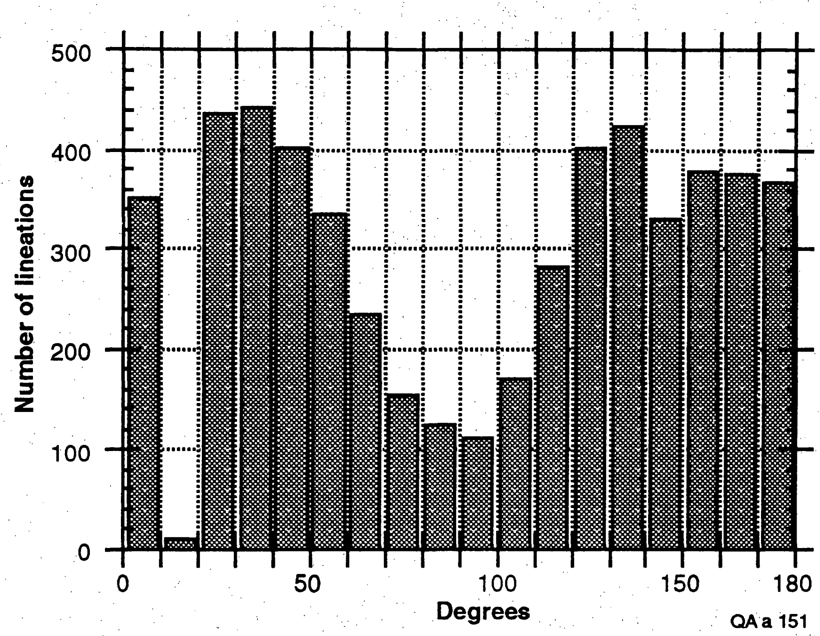


Figure 8. Distribution of the azimuths of all lineations identified in the Eagle Flat study area.

drainages parallel to joints and may indirectly indicate areas of outcrop. The median azimuth is also locally parallel to major faults including the South Diablo fault, the Streeruwitz Thrust, and the Red Hills thrust. On most alluvial fan slopes, where a grid or selected rectangle covers most of the fan, the median azimuth agrees with the principal slope.

Previous Work

Previous measurements of lineations in the study area are limited. Woodruff and others (1983) produced lineation maps of the Trans-Pecos region from interpretations of Landsat 1:250,000-scale, black-and-white imagery. These maps show six lineations that either touch or lie within the study area. In the southwest, parallel traces of the Red Hills thrust and the Devil Ridge thrust are identifiable. On the eastern border, the Streeruwitz Thrust and a northern parallel lineation relate to faults mapped by King (1965). In the northeast, on the Diablo Plateau, they show a short lineation that can be related to normal faulting. A lineation touches the northeast corner, which trends about 20°; it agrees with no feature determined in this Eagle Flat study.

King (1965) measured joints in Precambrian, Permian, and Cretaceous rocks in the Millican, Bean, and Streeruwitz Hills and on the Diablo Plateau. He presented his results as roses for each stratigraphic unit and as polar stick orientations at each outcrop measured. The results of King's study and this study closely agree both by visual comparison of roses and by quantitative summation of the stick measurements. The roses of King and this study were compared without knowing the exact boundaries of the field areas represented by King's roses. In the Streeruwitz Hills there is general agreement of the principal rose classes.

The polar stick plots along the Diablo escarpment provided data for a unique test. At the southern outcrop area of the Diablo Plateau and including the escarpment within the B6 selected area of this study, the orientation of each stick (joint) was measured from King's map (1965, plate 15). There is a general agreement between histograms (fig. 9) displaying measurements of King and this study. Although the lineations of this study include traces of bedding, joints, and drainage, the

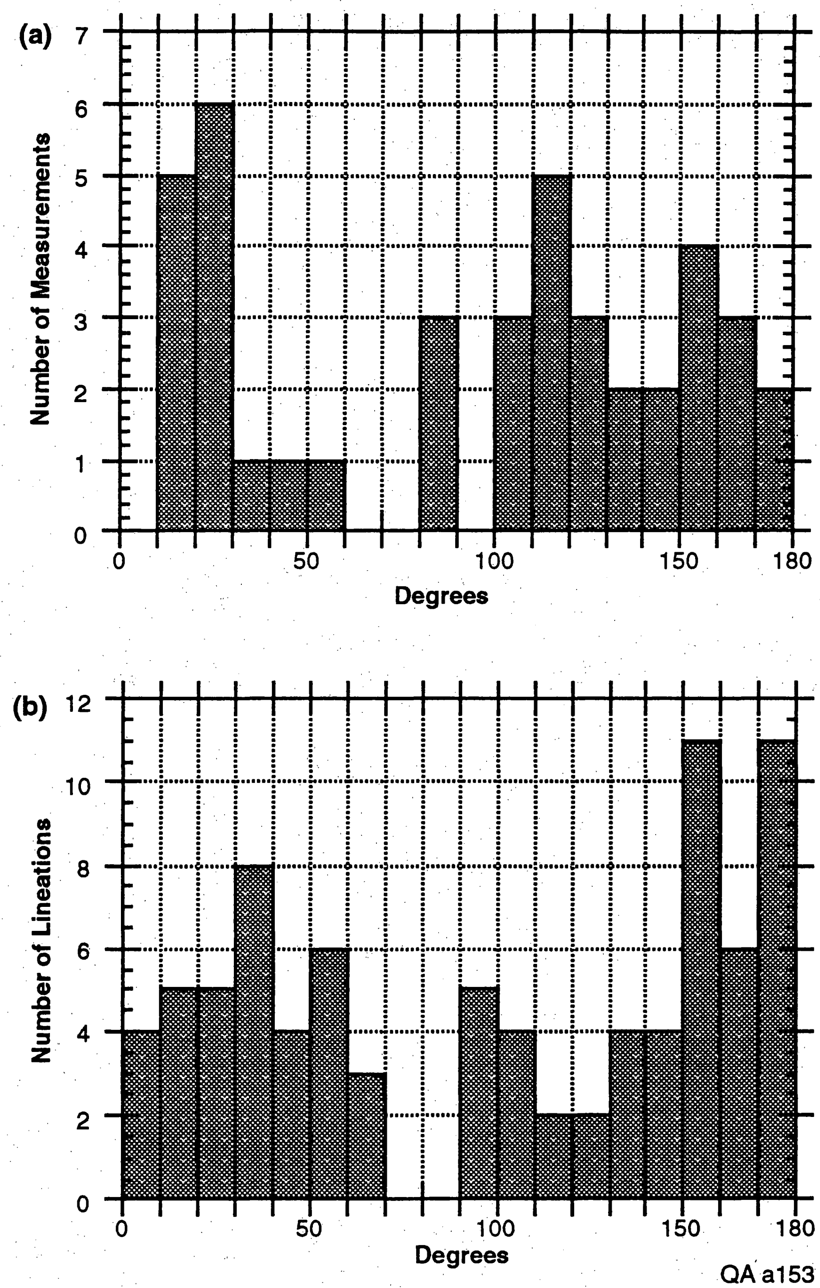


Figure 9. Histograms of joint measurements by (a) King (1965) and (b) lineations measured in selected area B6 of this study, the southern limits of the Diablo Plateau in the Bean Hills quadrangle. See table 3 for statistical relationships.

bimodal agreement of the two methods is a good quality control. Moreover, a comparison of the statistical measurements of each result (table 3) provides further supporting evidence. The mean, median, standard deviation, and other calculations are closer than might be expected for two different methods of measurement and the more numerous measurements, twice as many, in this present study.

Stratigraphy and Lithology

Number of Lineations

There is an indication in the data that the number of lineations per unit area correlates with the lithology of the outcrops (fig. 4). For example, the two Cretaceous Flat Mesa areas (SB1 and SB2) calculate 26 and 27 lineations/mi^2; in the Diablo Plateau two areas of Hueco Limestone (B3 and B4) have 27 and 29 lineations/mi^2. The Cretaceous Devil Ridge and Yucca Mesa (DR1 and DR2), not all the same formations, have respectively 28 and 32 lineations/mi^2. Two Precambrian areas (B2 and DP2), Bean and Streeruwitz Hills, contain 59 and 58 lineations/mi^2, and the Millican Hills Precambrian outcrop (B1) shows 70 lineations/mi^2. Clearly areas with Precambrian outcrops contain more numerous lineations than do those with Cretaceous or Permian outcrops.

Length of Lineations

The length of lineations per unit area (ft/mi^2) in the selected areas demonstrates that each age of outcrop has a unique character, as shown in figure 5. In the Precambrian Millican, Bean, and Streeruwitz Hills, lengths of lineation are 4,000 to 4,500 ft/mi^2; in Hueco outcrops in the Diablo Plateau, the range is from 5,978 to 6,073 ft/mi^2; in Flat Mesa, the Cretaceous outcrops lie within the 6,500 ft/mi^2 contour; and Devil Ridge and Yucca Mesa, which have the largest variance, are mostly within the 5,500 ft/mi^2 contour. The length histograms of Precambrian Allamoore and Hazel Formations are comparable for the Millican, Bean, and Streeruwitz Hills (fig. 10a, 10b, and 10c,

Table 3. Comparison of the statistics derived from joint measurements of King (1965) along the Diablo Plateau escarpment with those determined from measurements of lineations in selected area B6 of this study.

		King	B6
1	Minimum	11.000	2.0000
2	Maximum	180.00	179.60
3	Sum	4056.0	8338.6
4	Points	42.000	84.000
5	Mean	96.571	99.269
6	Median	113.00	105.55
7	RMS	111.65	115.53
8	Std Seviation	56.719	59.453
9	Variance	3217.0	3534.6
10	Std Error	8.7519	6.4868
11	Skewness	-0.24499	-0.14291
12	Kurtosis	-1.3768	-1.5365

QA a171

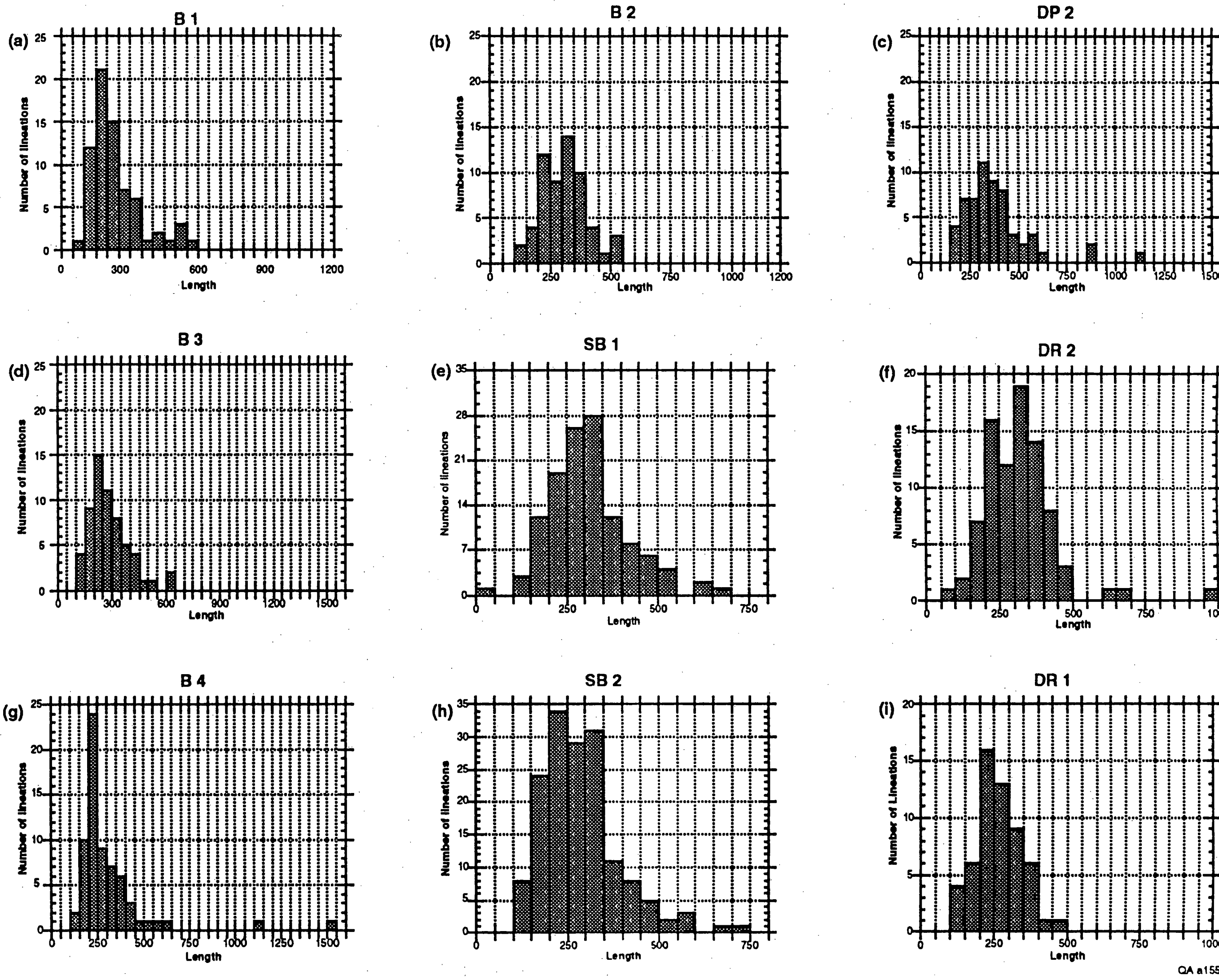


Figure 10. Comparison of the lengths of lineations in comparable areas of outcrop. Millican Hills (a), Bean Hills (b), and Streeruwitz Hills (c) are Precambrian Allamoore and Hazel outcrops. Selected areas B3 (d) and B4 (g) are Permian Hueco Limestone in the Diablo plateau. North Flat Mesa (e) and South Flat Mesa (h) are Cretaceous Cox Sandstone and Finlay Limestone. Yucca Mesa (f) and Devil Ridge (i) are also Cretaceous Cox and Finlay Formations.

respectively). In these same areas the structure and topography are also very similar. The length histograms are also comparable for the Permian Hueco Limestone outcrops of the Diablo Plateau, as shown in figure 10d and 10g. The eastern area (fig. 10g) contains a larger number of normal faults.

The length per unit area distribution in the Cretaceous Cox Sandstone and Finlay Limestone, which crop out in Flat Mesa north of Sierra Blanca, are nearly alike, as shown in figure 10e and 10h. The northern area has more faulting, and the southern area contains more Tertiary intrusive dikes. The length frequency distribution is also similar for Devil Ridge (fig. 10i) and Yucca Mesa (fig. 10f). Devil Ridge is entirely composed of Cretaceous Cox Sandstone and Finlay Limestone, whereas the Yucca Mountain area is dominantly Bluff Mesa Limestone and Yucca Formation in addition to some Cox and Finlay outcrops. Yucca Mesa also contains more normal faulting than Devil Ridge, which may explain the larger number of longer lineations (fig. 10f). The author also sees considerable agreement in the distribution of length per unit area in all the Cretaceous areas analyzed. It is impossible to equally identify outcrops from the distribution of number of lineations per area.

Visual observations of the similarity of length histograms of like outcrops are supported quantitatively by simple curves fit to scattergrams. The R values for comparisons of lineation length for outcrops of Precambrian rocks in the Millican, Bean, and Streeruwitz Hills vary from 0.918 to 0.988. The R value is comparable to a correlation coefficient representing how well a like property in two separated areas compare when a line is fitted to a scattergram. The R value for the Permian scattergram with fitted linear curve is 0.969 in the Diablo Plateau. The R value for two analyses of Cretaceous outcrops is 0.886 for Devil Ridge compared to Yucca Mesa, and 0.873 for the two areas of Flat Mesa.

Azimuths of Lineations

The distribution of lineation azimuths can be used to distinguish age and lithology of different outcrops, even though the outcrops may be widely separated. The weakest evidence may be in the roses, especially from grids, but there is good correlation between histograms. A histogram in which the distribution of lineations in three Precambrian outcrops, Allamoore and Hazel Formations, is shown in figure 11a. In this illustration, DP2 is in the Streeruwitz Hills, B1 is in the Millican Hills, and B2 is in the Bean Hills. In reading the histogram, note that a characteristic of the software is to put the largest number of azimuths in the bin at the bottom of each stack. All three areas are represented by azimuths in all bins except 60° to 70°, 80° to 90°, 90° to 100°, and 140° to 150°. Each of the latter bins has at least two Precambrian areas represented, and the first three bins are poorly represented regionally (fig. 11a). In nearly half of the bins with all areas represented, their values are equally proportional. The R value in linear curve-fitting for scattergrams of the three areas (R = 0.918, 0.950, and 0.988) demonstrates correlation, and correlation increases as the distance between outcrops diminishes. Streeruwitz and Bean Hills are 2 mi apart; the Bean and Millican Hills are 3 mi apart. There are similar geologic structures in the three outcrop areas.

The two Permian Hueco Limestone outcrop areas in the Diablo Plateau also show a distinctive correlation. In 12 of 18 bins in a histogram of the respective azimuths, both areas are represented (fig. 11b). Again, the middle ranges of these Hueco azimuths are poorly represented. The R value of 0.923 expresses the excellent correlation of the distribution of azimuths in the two outcrops. The centers of the two areas are 2 mi apart. No major faults are present in either outcrop area.

Tests of the selected Cretaceous outcrops also display excellent correlation of azimuths of like outcrop areas whether the areas are nearby or distant from one another (fig. 12). A test of azimuth distributions in the previously described outcrops of Devil Ridge and Yucca Mesa areas in the same linear mountainous trend has an R value of 0.886. The two Cretaceous Cox–Finlay outcrops in Flat Mesa have an R value of 0.963 for the distribution of azimuths. Even comparisons of Flat Mesa azimuths with those of Devil Ridge and Yucca Mesa show R values of 0.880 and 0.961, respectively.

On the other hand, no test for azimuth distribution of similar outcrops identified in the grids suggests correlation of outcrops with identical stratigraphy. What appeared to be the most probable correlation from visual inspection proved to be noncorrelative statistically. A comparison of Precambrian grids containing Allamoore and Hazel rocks in the Bean and Millican Hills gave an R value of 0.008, even though 16 of 18 histogram bins had both areas represented (fig. 13). A

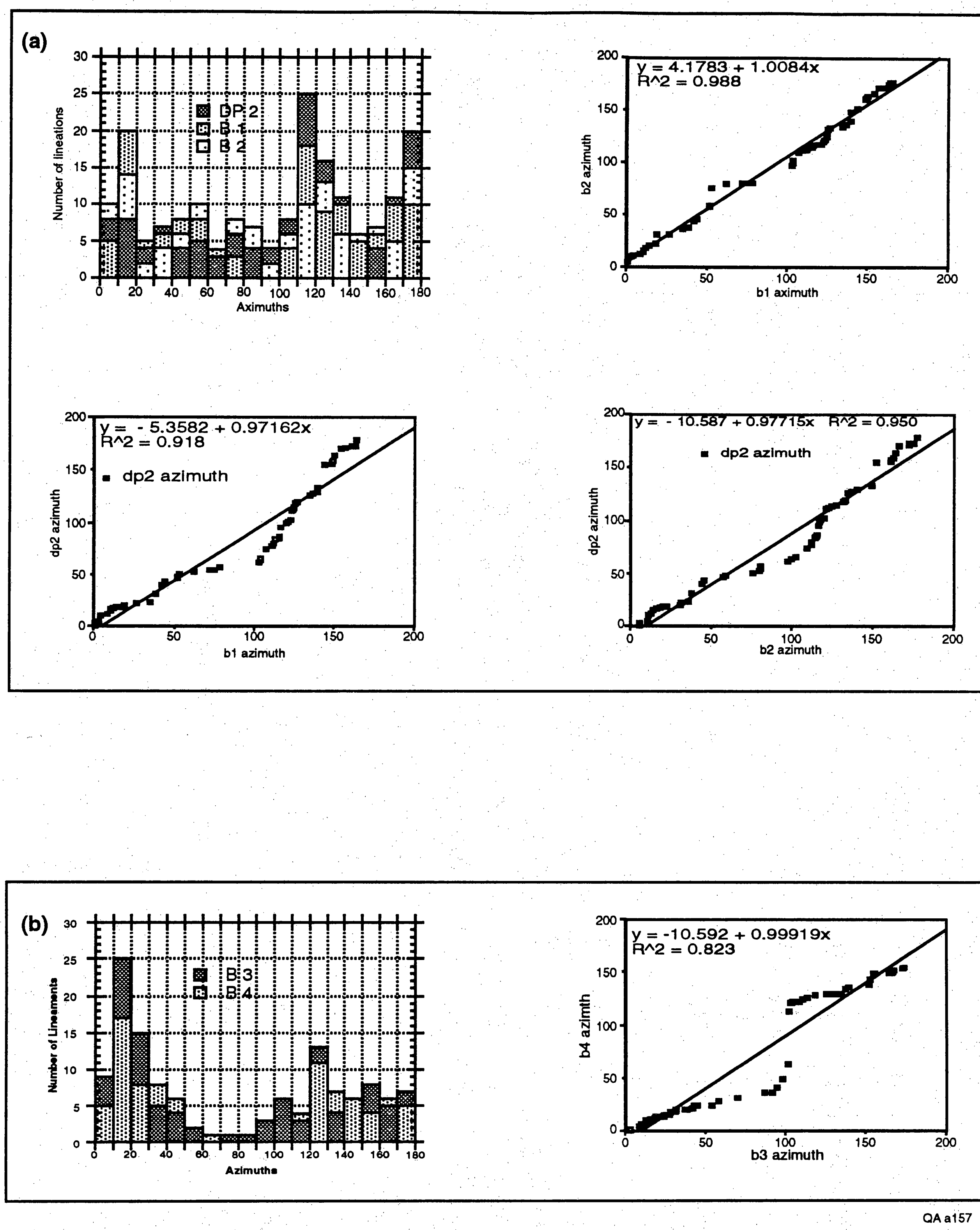


Figure 11. Relation of the distribution of linear azimuths and outcrops of a particular age. (a) Comparison of the distribution of linear azimuths in the Precambrian Millican, Bean, and Streeruwitz Hills, histogram and scattergrams. (b) Comparison of two Hueco Limestone outcrops in the Diablo Plateau, histogram and scattergram.

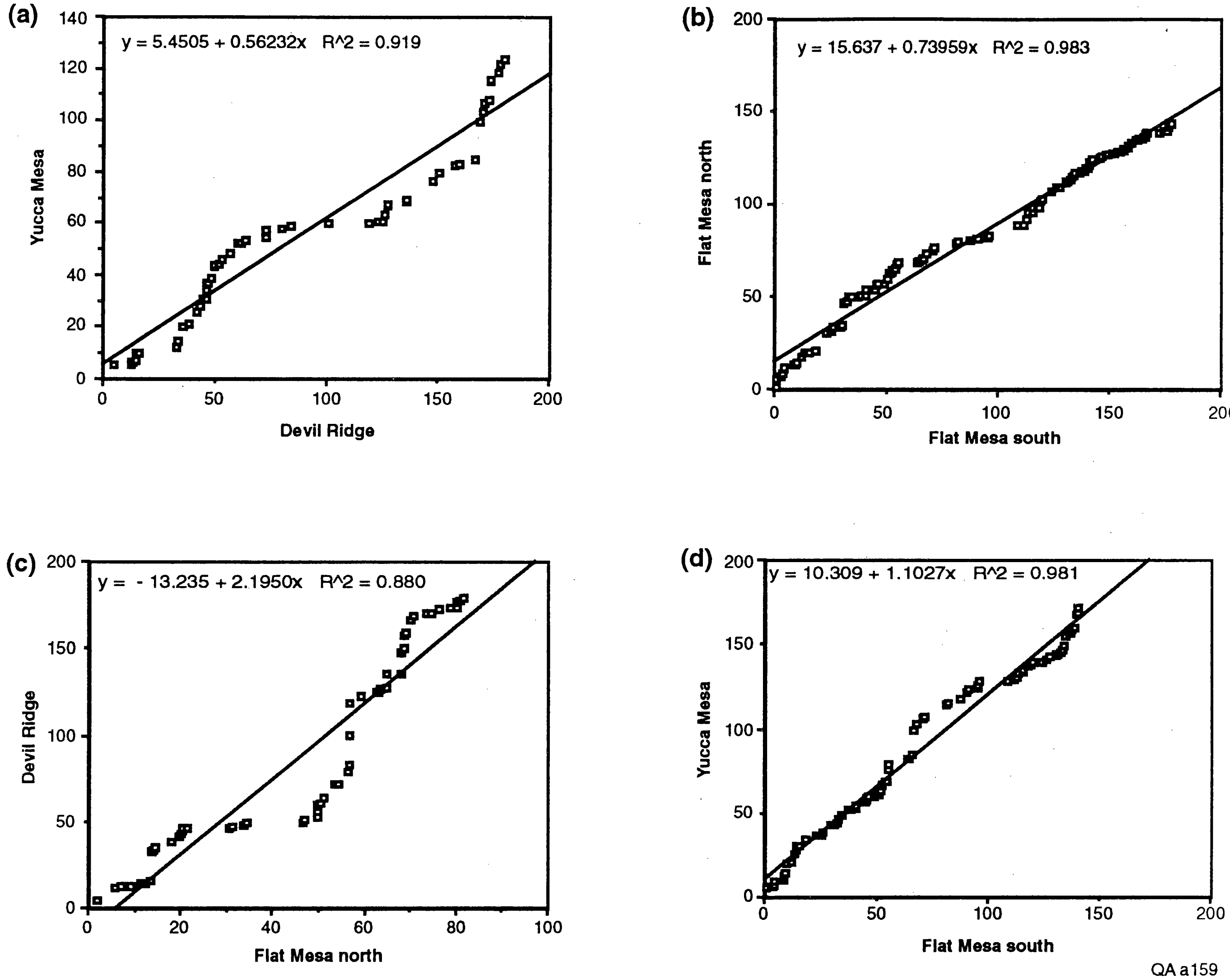


Figure 12. Comparison of scattergrams of the azimuth populations for lineations in Cretaceous outcrop areas in the Devil Ridge, Flat Mesa, and Yucca Mesa.

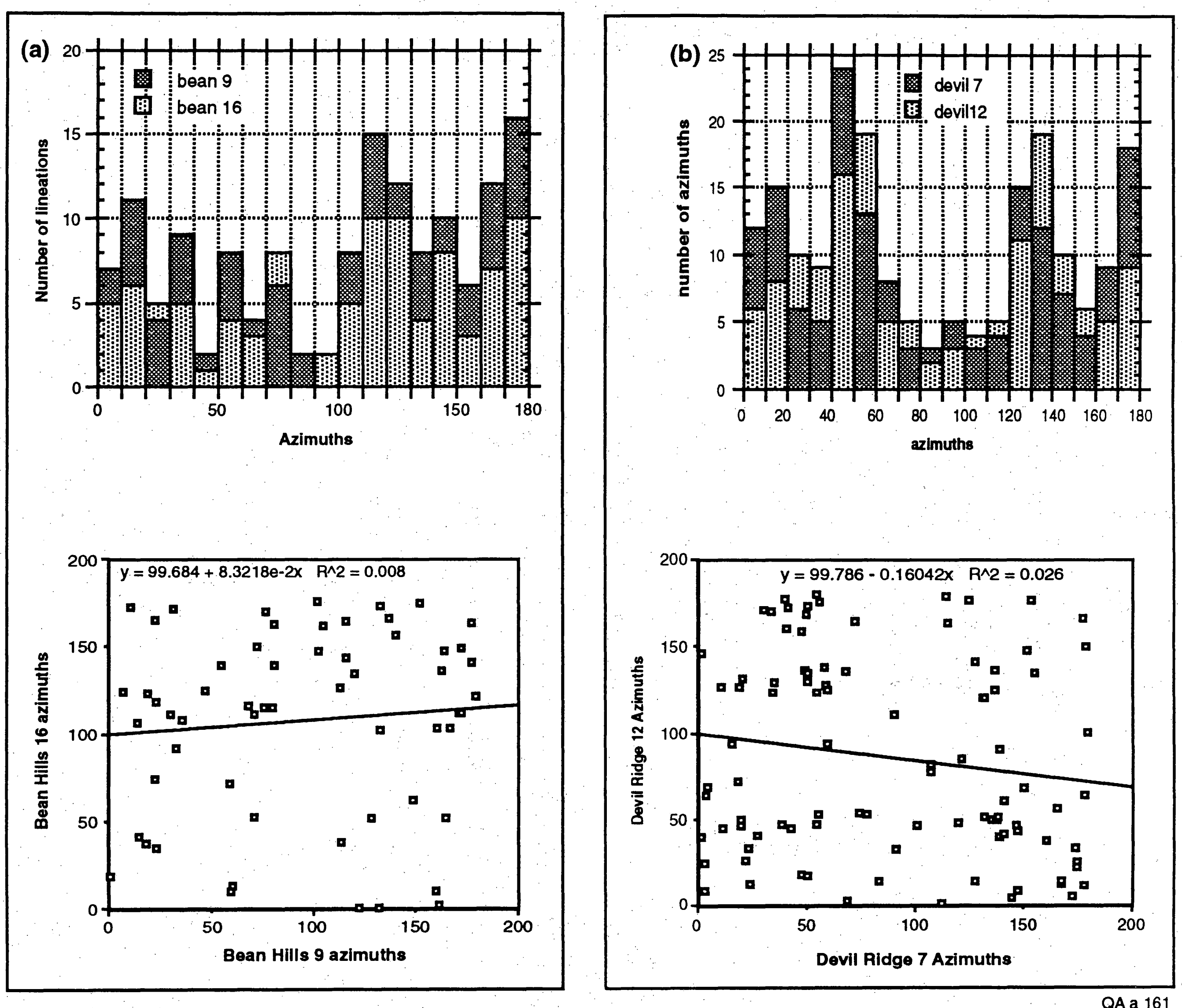


Figure 13. Plots showing lack of correlation for distribution of linear azimuths with outcrops of the same stratigraphic age, chosen from the best visual likenesses of roses, histograms, and scattergrams for grid cells of (a) Precambrian Bean Hills and Millican Hills and (b) Cretaceous outcrops on the northeast flank of Devil Ridge.

comparison of azimuths in two Cretaceous grids with the east flank of Devil Ridge has an R value of 0.026. Because the 4 mi^2 grids of this study area are too large to confine rocks of a single age and are oriented at an angle to the regional trends of bedding and structures, it is difficult to compare outcrops of similar age or lithology.

Structure

In a general sense, the number of lineations per grid is larger in areas where faults are more abundant (fig. 4). There are 100 lineations per grid in the northern Flat Mesa area, 125 in the Front Range, 100 in the northern Red Hills, and an average of 89 in the grids transected by the South Diablo fault. East to west along the Streeruwitz fault, as the density of associated faults increase, the number of lineations per grid increases, from 40 in the Millican Hills to 73 in the Bean Hills to 84 in the Streeruwitz Hills. In the Little Hills and southern Front Range, where folding is intense, there are 60 and 70 lineations per grid, respectively.

The length per unit area is moderate in the faulted Diablo Plateau; the South Diablo fault is partly adjacent and generally parallel to the 4,500 ft/mi^2 contour (fig. 5). Flat Mesa faulting occurs between the 6,000 and 6,500 ft/mi^2 contours. The block defined by the Devil Ridge and Red Hill thrusts, an area including Devil Ridge, Yucca Mesa, and the Front Range, lies within the 5,000 ft/mi^2 contour and contains some of the largest length per unit area measurements. The steep contour gradient on the southwest side of Devil Ridge nearly overlies the Red Hill thrust. In the Streeruwitz Hills, where the deformation was most intense north of the Streeruwitz Thrust, the mean length of lineations is largest.

Assuming a simple compressional model with compression oriented at about northeast 40°, the regional distribution of lineation azimuths, probably related to faults and fractures, (fig. 8) can be explained in part. The model would result in thrust faults oriented about 130°, a principal azimuth component. Tensional joints, reflecting the strain, would trend about 40°, the second strongest azimuth population. Shear phenomena might be expected at 100° and 160°. The first orientation is weak in the regional picture, but the trend about 160° is well represented.

In the rose diagrams that were made for selected and gridded areas containing the major basin faults, the principal bin is generally the strike of the fault. This is evident for the Red Hills, Devil Ridge, and South Diablo faults; it is not evident for the Streeruwitz Thrust (fig. 8).

The median azimuths plotted in the 30 selected areas have distinctive relationships with structures mapped by King (1965) and Albritton and Smith (1965). In the Devil Ridge, Front Range, northwestern Eagle Mountains, and Yucca Mesa, the medians trend 45° northeast from the strike of the Red Hills and Devil Ridge thrusts, the direction of tensional release. In the northern Flat Mesa, the median trends parallel to the average strike of a thrust and several associated normal faults. In the Diablo Plateau escarpment, the median azimuth trends parallel to the strike of the South Diablo fault. A few miles to the northeast inside the Diablo block, the median trends 45° to normal faults that are parallel to the South Diablo fault. There is only slight agreement among trends of median azimuths and the Precambrian Streeruwitz Thrust fault. There is poor agreement with structures occurring within the gridded polygons, probably because lithologies and slopes are heterogeneous in grids.

The mean azimuth and standard deviations plotted for both the select and gridded areas correlate poorly with mapped structures. Exceptions occur in selected areas displaying the South Diablo and Streeruwitz faults where the mean azimuth of the lineations is parallel to the faults. Many Grayton Lake grids have skewness values >5.0, 5.7 to 11.2 in statistics of the azimuth populations (appendix A1), and are interpreted to reflect shallow jointed bedrock underlying slopes of consistent orientation and gradient. Grids and rectangles with kurtosis >5.0, 5.2 to 26 in statistical length populations (appendix A1 and A2), appear to be dominated by outcrops. As a result, the large kurtoses reflect highly peaked distributions of numerous joints of nearly equal length.

Fissures

Previous investigations of potential siting areas for a low-level radioactive waste repository in Hudspeth County reveal that lengthy fissures occur that are open linear cracks at the ground surface in basin-fill sediments (Baumgardner, 1992). They usually display piping features, and vegetation commonly concentrates along the trend of the fissure. Fissures were not identified separately in this analysis of lineations. However, fissures in Red Light Draw (plate 2, appendix) were identified as elongate stretched rectilinear patterns. Recent fissure-line features have been identified on 1:12,000-scale black-and-white photographs in the Eagle Flat study area, and field studies are in progress.

Terrain

There is a modest correlation of the number of lineations per square mile with the amount of relief in feet. As with previous tests of correlation, the correlation is best with terrain isolated by a selection process (R value = 0.473, fig. 14a), and poorest with geomorphology selection by equal grid spacing (R value = 0.143, fig. 14b). Correlation is also poorest in areas of low relief compared to areas of steeper gradient and greater relief. The correlations could be improved if irregular multisided polygons rather than equal-area rectangles were used to surround the tested areas.

The number of lineations per unit area commonly reflects the slope of the terrain (fig. 15). As the slope increases, the density of lineations increases. In this analysis all the slopes are located on alluvial materials; no measurements were made over outcrops. The modest correlation (R value = 0.657) reflects the global choice of slopes on which the number and types of stream valleys vary widely. Some slopes are nearly planar and subject to sheetwash. On the other hand, many test slopes have abundant well-defined stream courses with different degrees of entrenchment.

Histogram analyses of the lengths of linear elements in the selected areas visually correlate with varied topographic types. Generally, histograms in alluvial areas contain shorter lineations, less than 1,640 ft, and have normal distribution. For outcrop areas, histograms display normal

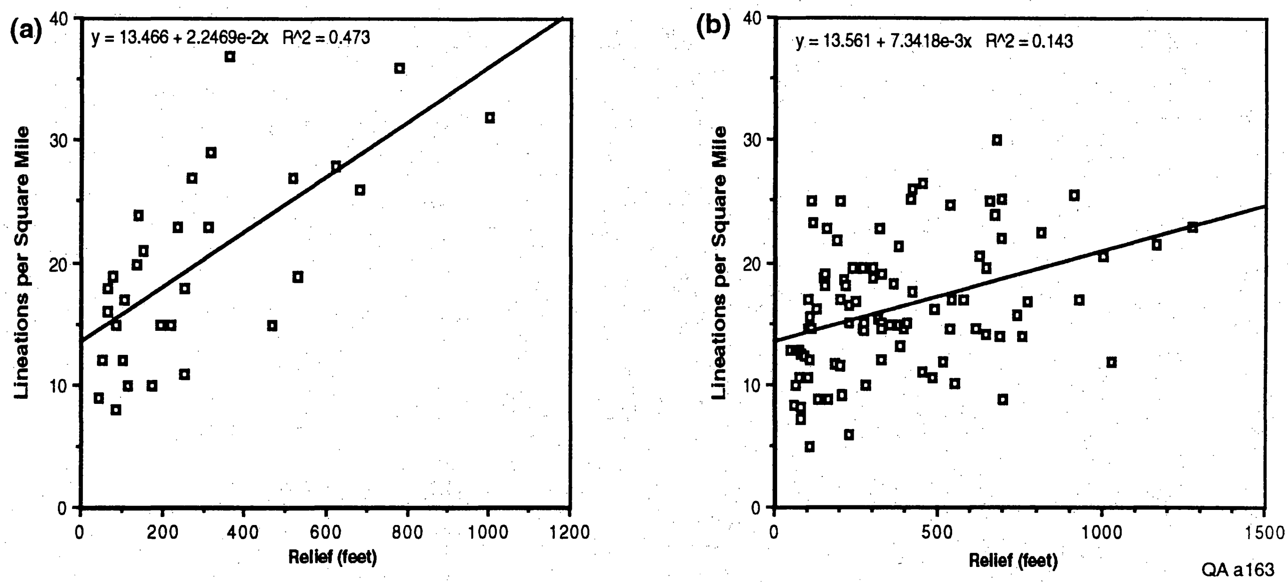


Figure 14. Plots showing lack of correlation of relief with the number of lineations per square mile in (a) the selected areas and (b) grid cells.

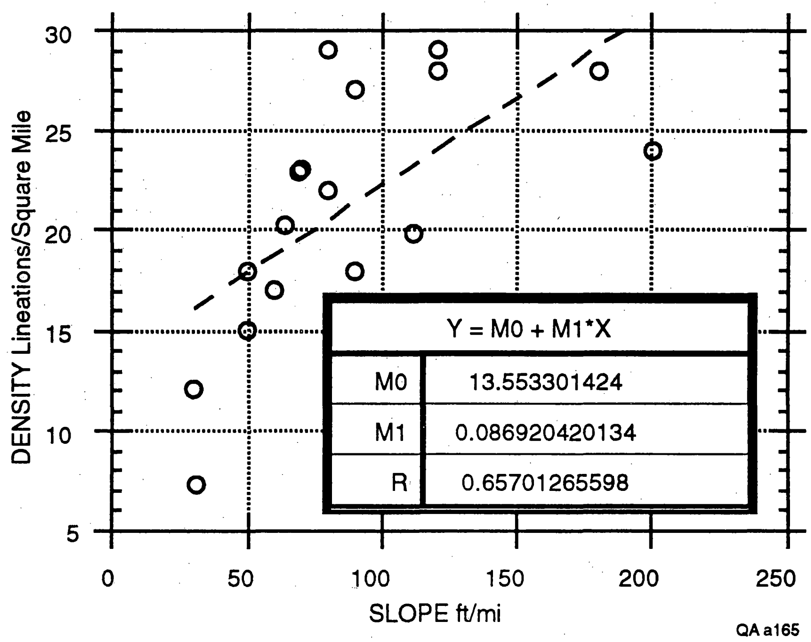


Figure 15. Comparison of the number of lineations per square mile with varied alluvial slopes measured in feet per mile.

distribution for length of lineations up to 2,600 ft; uniquely longer elements up to 3,300 ft are suspected to be faults, bedding traces, or dominant joint sets.

Histograms of azimuths (10° classes) generally display few or no azimuths in the classes 80° to 100° in alluvial areas except Eagle Flat Draw. Most histograms of azimuths in alluvial slopes are bimodal, reflecting both dendritic tributaries of lesser slopes and bifurcating streams of steeper alluvial fans. The skewness and kurtosis of azimuth populations in alluvial areas are generally negative.

Landsat Lineations

In this Eagle Flat study of Landsat lineations, most lineations are type I occurring in all seven scenes (fig. 7 and table 4). The lineations orient in seven clusters, comparable to 10-degree bins (fig. 16). The lengths vary from 4.2 to 41.8 mi. There are only four locations where lineations intersect. Because the lineations are sparsely distributed, they cannot be related as to density, number, or length per unit area. The longest lineation passes through the areas of the Streeruwitz and South Diablo faults (fig. 7). The northern half of this lineation exemplifies the control of drainage.

Several lineaments cluster about 118°, 140°, and 143° parallel to major trends of the Streeruwitz and South Diablo faults. The lineations about 40° may relate to Laramide tensional structures. The clusters at 105° may be parallel to shear orientations; one lies along the northern side of the Apache Mountains. The lineations oriented at 152° in Red River Draw are subparallel to the Red Hills thrust fault. The orientation of all the Landsat lineations (fig. 16) produces a similar distribution to the orientation of all the photographic lineations (fig. 8). Few lineations are present between 1°–20° and 70°–100° in both sets.

Table 4. Distribution of type I and type II lineations.

Lowef landsat lineaments

Type	Azimuth	Length mi
II	35	5.3
I	40	7.8
I	41	7.6
II	44	15.2
I	58	11.6
II	58	6.8
I	102	20.7
I	107	16.2
I	118	11.1
II	118	5.8
I	126	14.8
I	130	9
I	143	41.8
I	143	5.6
I	143	5.2
II	143	14.8
I	152	7.8
I	152	4.2
I	152	4.2
I	158	12.2

QAa1059c

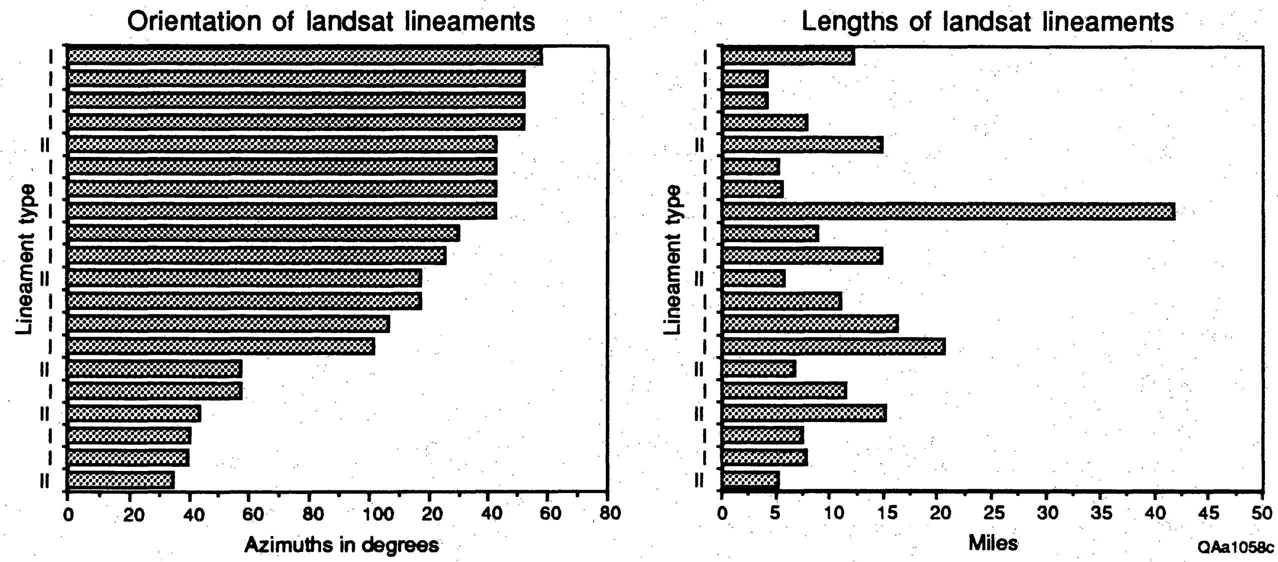


Figure 16. Bar graphs showing the orientation and lengths of Landsat lineations.

SUMMARY AND CONCLUSIONS

A low density of lineations is present on the proposed repository site of the Faskin Ranch, where investigative work is now concentrated. In the vicinity of the Faskin Ranch headquarters, both the number and length of lineations per unit area are among the lowest values in the study area. There are less than 10 lineations/mi^2 compared to a low of 5.0 and a high of 32.1 lineations/mi^2 for the entire study area. Total length of lineations on the northern Faskin Ranch is about 1,800 ft/mi^2 compared to a low of 1,100 ft/mi^2 and a high of about 13,200 ft/mi^2. The slope of the surface outside the Blanca Draw floodplain is less than 1 percent.

Also, no Landsat lineation passes through the proposed site, unlike a problem cited at the New York proposed site (Jacobi, 1992). The nearest Landsat lineation is located 7 mi distant in Red Light Draw and is not aligned toward the Faskin Ranch site.

Comparing data in rectangles ordered in a checkerboard fashion—a common method of regional analysis—with data in rectangles selected for a geological reason, was enlightening. The regional analysis provides a qualitative view of relationships among lineations and geologic properties. On the other hand, a group of rectangles selected for geological properties permits stronger quantitative evaluation of the significance of lineations against stratigraphy, structure, and geomorphology. For the Eagle Flat bolson, the latter method demonstrated that there were signatures formed by the distribution of lineations that indicated discrete stratigraphic (lithologic), structural, and geomorphic properties.

The test of the results of this study with a study performed more than 35 years ago (King, 1965) provided additional quality assurance for the method chosen here. The positive correlation of the older joint analysis on the outcrop with stereoscopic interpretation of lineations on aerial photographs supports the validity of the aerial method.

ACKNOWLEDGMENTS

Funding for this research was provided by the Texas Low-Level Radioactive Waste Disposal Authority under Contract No. IAC (92-93)-0910. Rick Edson programmed the calculations of linear properties and assisted in editing the digitized lineations. Richard L. Dillon drafted the figures. Jay Raney, Ruben Alvarez, Eddie Collins, and Mary L. W. Jackson provided technical editing. Word processing of the text and lengthy tables was by Susan Lloyd. Report assembly was by Kitty Challstrom. The 1:22,000-scale aerial photographs and all but one of the Landsat scenes were provided by the Texas Natural Resources Information System (TNRIS).

REFERENCES

Albritton, C. C., and Smith, J. F., Jr., 1965, Geology of the Sierra Blanca area, Hudspeth County, Texas: U.S. Geological Survey Professional Paper 479, 131 p.

Baumgardner, R. W., Jr., 1987, Landsat-based lineament analysis, East Texas basin and Sabine uplift area: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 167, 52 p.

Baumgardner, R. W., Jr., and Scanlon, B. R., in preparation, Surface fissures in the Hueco Bolson and adjacent basins, West Texas: The University of Texas at Austin, Bureau of Economic Geology Geological Circular, 92-2, 41 p.

Collins, E. W., and Raney, J. A., 1991, Tertiary and Quaternary structure and paleotectonics of the Hueco Basin, Trans-Pecos Texas and Chihuahua, Mexico: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 91-2, 44 p.

Dietrich, J. W., Owen, D. E., and Shelby, C. A., 1983, Geologic atlas of Texas Van Horn–El Paso sheet; Barnes, V. E., project director: The University of Texas at Austin, Bureau of Economic Geology, scale 1:250,000.

Dix, O. R., and Jackson, M. P. A., 1981, Statistical analysis of lineaments and their relation to fracturing, faulting, and halokinesis in the East Texas basin: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 110, 30 p.

Jacobi, R., 1992, Lineaments found near waste disposal sites; Geotimes, v. 37, no. 7, p. 7.

King, P. B., 1965, Geology of the Sierra Diablo region Texas; U.S. Geological Survey Professional Paper 480, 185 p.

Larkin, T. J., and Bomar, G. W., 1983, Climatic atlas of Texas: Texas Department of Water Resources, LP-192, 151 p.

McGowen, J. H., and Groat, C. G., 1971, Van Horn Sandstone, West Texas: an alluvial fan model for mineral exploration: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 72, 57 p.

Smith, J. F., and Albritton, C. C., Jr., 1965, Geology of the Sierra Blanca Area, Hudspeth County, Texas: U.S. Geological Survey Professional Paper 479, 131 p.

Twiss, P. C., 1979, Geologic atlas of Texas Marfa sheet; Barnes, V. E., project director: The University of Texas at Austin, Bureau of Economic Geology, scale 1:250,000.

Underwood, J. R., Jr., 1963, Geology of the Eagle Mountains and vicinity, Hudspeth County, Texas: The University of Texas at Austin, Bureau of Economic Geology Quadrangle Map No. 26, 32 p.

Woodruff, C. M., Jr., Caran, S. C., Gever, C., Henry, C. D., MacPherson, G. L., and McBride, M. W., 1982, Geothermal resource assessment of Texas, final report, Appendices E through H: report prepared for U.S. Department of Energy, DOE/ID/12057, 273 p.

Appendix

Table A1. Descriptions of the geology, terrain, and statistics measured for the lineations in the 96 equal-area grids.

			Lineation Characteristics												
						Azimuths degrees					Lengths feet				
Grid Area	Geology	Terrain Orientation and gradient of slopes in degrees and ft/mi	No.	No. per mi^2	Length ft/mi^2	Median	Mean	Std. Dev.	Skew.	Kurt.	Median	Mean	Std. Dev.	Skew.	Kurt.
ALLA-1	Outliers of Campagrande Fm (15%). Quaternary alluvial, eolian, and fan deposits	Relief=214 ft (30%). Rounded outlying hills and moderately dissected fan slopes 155° at 75 ft/mi	73	18.1	3,336	72	86	64	0.06	–1.7	699	692	305	0.72	1.3
ALLA-2	Quaternary alluvial, colluvial, and eolian deposits	Relief=155 ft. Highly dissected fan slopes 197° at 49 ft/mi	92	22.8	3,891	54	82	66	0.16	–1.7	715	718	312	0.60	0.73
ALLA-3	Quaternary alluvial, colluvial, and eolian deposits	Relief=200 ft. Highly dissected fan slopes 215° at 68 ft/mi	101	25.0	5,514	42	60	56	1.1	–0.18	774	827	410	0.99	2.6
ALLA-4	Millican Hills folded and faulted Precambrian Allamoore and Hazel Fms. 40% Qal	Relief=490 ft (50%). Rounded Millican Hills lapped by moderately dissected fan 217° at 83 ft/mi	66	16.3	3,894	64	81	53	0.18	–1.5	869	892	400	1.6	5.3
ALLA-5	Quaternary alluvial, colluvial, and eolian deposits	Relief=90 ft. Slightly dissected distal fan slopes 166° at 27 ft/mi	50	12.4	2,913	136	116	55	0.94	0.58	837	883	394	0.46	–0.30
ALLA-6	Quaternary colluvial and eolian deposits on a Holocene fan	Relief=110 ft. Moderately dissected distal fan slopes 192° at 47 ft/mi	101	25.0	5,455	144	111	64	–0.51	–1.5	787	817	305	0.47	0.09
ALLA-7	Quaternary colluvial and eolian deposits of a Holocene fan	Relief=147 Moderately dissected medial fan slopes 205° at 53 ft/mi	76	18.8	4,498	127	97	65	–0.18	–1.7	768	896	456	1.3	2.0
ALLA-8	Quaternary alluvial, colluvial, and eolian deposits	Relief=200 ft. Moderately dissected upper medial fan slopes 215° at 69 ft/mi	69	17.1	3,610	42	57	46	1.5	1.5	699	794	394	0.90	0.42
ALLA-9	Quaternary fan and fluvial alluvium	Relief=200 ft. Slightly dissected distal fan slopes 18° at 95 ft/mi	47	11.6	2,466	38	64	60	0.87	–0.87	801	794	318	–0.03	0.11
ALLA-10	Quaternary fan and fluvial alluvium	Relief=131 ft. (50%) Eagle Flat Draw slopes 120° at 10 ft/mi; (50%) dissected distal fan 20° at 70 ft/mi	36	8.9	1,894	100	92	66	–0.04	–1.8	876	768	364	0.57	0.69
ALLA-11	Quaternary distal fan and fluvial alluvium	Relief=128 ft. Highly dissected distal fan slopes 219° at 54 ft/mi	66	16.3	3,613	112	93	62	–0.12	–1.6	761	830	364	0.55	1.1

ALLA-12	Quaternary fan and minor fluvial deposits	Relief=164 ft. Well-dissected medial fan slopes 213° at 59 ft/mi	36	8.9	1,758	46	66	56	1.0	−0.45	718	741	272	0.45	0.13
ALLA-13	Cox Sandstone and Bluff Fm (15%) onlapped by Holocene alluvial fan	Relief=753 ft. Steep-sloping Eagle Mountains (20%) draped by strongly dissected fan 17° at 168 ft/mi	56	13.9	2,988	45	72	64	0.50	−1.5	758	807	295	0.58	0.31
ALLA-14	Permian Hueco Limestone (5%) onlapped by Holocene alluvial fan deposits	Relief=452 ft. Steeply sloping Eagle Mountain ridge (5%) draped by strongly dissected fan 25° at 118 ft/mi	45	11.1	2,228	51	71	54	0.85	−0.79	725	751	364	1.4	3.0
ALLA-15	Quaternary fan and fluvial deposits	Relief=276 ft. Moderately dissected fan slopes 35° at 114 ft/mi	40	9.9	2,278	33	38	31	2.6	7.4	909	863	295	−0.02	−0.18
ALLA-16	Quaternary fan and fluvial deposits	Relief=65 ft. Moderately dissected distal alluvial fans 217° at 80 ft/mi and 56° at 118 ft/mi; constrict Eagle Flat Draw	40	9.9	2,091	54	72	53	0.81	−0.78	787	791	367	0.17	−0.33
BEAN-1	Permian Hueco Limestone overlying Precambrian Van Horn Sandstone; Quaternary alluvium with trace of South Sierra Diablo fault	Relief=577 ft. Young valley flowing north between mesa-shaped, elongate divides of Sierra Diablo plateau	69	17.1	4,113	56	83	62	0.20	−1.6	810	889	367	0.33	0.13
BEAN-2	Hueco Limestone and Quaternary alluvial and colluvial deposits	Relief=319 ft. Sierra Diablo plateau in mesa-remnant highs dissected by W-flowing valley	92	22.8	5,243	54	82	66	0.16	−1.7	791	863	617	4.5	26
BEAN-3	Hueco Limestone and Quaternary alluvial and colluvial deposits	Relief=414 ft. Two young valleys parallel NW-oriented mesa-shaped ridge of Sierra Diablo plateau	102	25.3	5,452	44	77	60	0.42	−1.5	758	810	387	1.2	2.4
BEAN-4	Hueco Limestone and Precambrian Hazel Fm adjacent to trace of Sheep Peak fault	Relief=1,212 ft. Sierra Diablo plateau entrenched by young W-NW-flowing valley	93	23.0	5,161	54	82	59	0.22	−1.5	804	840	364	0.78	1.3
BEAN-5	Permian Hueco Limestone and Precambrian Van Horn Sandstone on N in fault contact (South Diablo fault) w/Campagrande Limestone and Cox Sandstone. Minor Tertiary basalt, 15% Qal	Relief=1,003 ft. Dissected Sierra Diablo escarpment	83	20.6	4,353	111	90	53	−0.06	−1.5	764	794	322	1.5	5.1

BEAN-6	Hueco Limestone and Van Horn Sandstone in fault contact (South Diablo fault) w/Campagrande and Precambrian Hazel Fms. 20% Qal	Relief=911 ft. Dissected Sierra Diablo escarpment	103	25.5	4,700	87	89	62	–0.06	–1.6	689	692	367	3 1	20
BEAN-7	Hueco Limestone, Van Horn and Hazel Sandstones, and Allamoore volcanics faulted by South Diablo fault. 40% Qal	Relief=813 ft. Sierra Diablo escarpment and frontal plateau surface cut by W-flowing valley	91	22.5	4,765	132	106	58	–0.48	–1.4	810	794	276	0.19	–0.24
BEAN-8	Hueco Limestone overlying Hazel Fm w/numerous normal faults of the Circle Ranch fault zone. 60% Qal, primarily fan deposits	Relief=644 ft. Sierra Diablo escarpment (60%); fan and valley walls have slopes which average 208° at 169 ft/mi	79	19.6	3,772	88	87	55	0.09	–1.3	686	722	361	1.1	4.3
BEAN-9	Faulted and folded Precambrian Allamoore Sandstone and volcanics and Hazel conglomeratic Sandstone. 15% Qal	Relief=265 ft. Mesa-formed Bean Hills	59	14.6	3,607	101	94	56	–0.05	–1.4	922	925	364	–0.49	0.20
BEAN-10	Faulted and folded Allamoore and Hazel Fms. 20% Qal	Relief=275 ft. Numerous mesa outliers (80%) with S-flowing valley	61	15.1	3,290	112	93	58	–0.23	–1.5	778	817	295	0.75	1.1
BEAN-11	Precambrian Hazel Sandstone overlain by Cretaceous Campagrande Fm and outliers of Precambrian Allamoore Sandstone and volcanics onlapped by Quaternary fans (80%)	Relief=301 ft (20%). Linear ridges paralleled by strongly dissected fan 222° at 86 ft/mi	76	18.8	3,914	46	64	51	0.79	–0.76	778	781	305	0.52	1.4
BEAN-12	Quaternary alluvial fan (95%) surrounding Precambrian Hazel Sandstone and Allamoore volcanics	Relief=245 ft. Strongly dissected fan oriented 210° at 83 ft/mi	68	16.8	3,173	52	71	49	0.75	–0.86	722	705	344	0.15	0.52
BEAN-13	Precambrian Allamoore Fm (15%); minute Campagrande outliers lapped by Holocene fans. Trace of Streeruwitz thrust fault	Relief=213 ft. Rounded outlying hills (40%) divide two broad valleys	73	18.1	3,850	112	93	57	–0.15	–1.5	732	801	361	0.78	2.5

BEAN-14	Precambrian Allamoore and Hazel Fms (25%). Holocene alluvial fan (75%). Trace of Streeruwitz thrust fault	Relief=269 ft. Rounded outlying hills (50%) lapped strongly by dissected fan 200° at 62 ft/mi	79	19.6	3,962	46	71	58	0.45	−1.3	755	761	348	0.23	0.18
BEAN-15	Folded and faulted Precambrian Allamoore and Hazel Fms. 30% Qal	Relief=362 ft. Rounded Millican Hills (70%) onlapped by dissected fan 180° at 111 ft/mi	74	18.3	3,678	55	76	54	.25	−1.4	751	751	262	0.26	0.06
BEAN-16	Folded and faulted Precambrian Allamoore and Hazel Fms. 20% Qal	Relief=376 ft. Rounded Millican Hills	86	21.3	4,328	119	106	55	−0.54	−0.98	656	761	367	1.2	1.6
BLANCA-1	Finlay Limestone and Cox Sandstone with minor Tertiary intrusives. E 1/2 is an alluvial fan. A thrust fault and three normal faults, down to NE, strike about 135° to 180°	Relief=535 ft. High ridge with mesa-like high points (60%) with stream dissection W and fan sloping 90° at 140 ft/mi	100	24.8	6,007	118	102	50	−0.43	−1.1	827	902	417	1.1	1.6
BLANCA-2	Quaternary alluvium w/ a 135° normal fault trace, down to NE	Relief=187 ft. W side of S-flowing drainage slopes 108° at 94 ft/mi	88	21.8	5,078	119	103	43	−0.68	−0.42	853	873	361	1.1	3.7
BLANCA-3	Scattered Cox Sandstone outcrops on east slopes of major south-flowing drainage to Blanca Draw	Relief=100 ft. Scattered low-K outliers (40%) playa in SE corner, principal broad valley (50%) slopes 190° at 25 ft/mi	69	17.1	4,151	114	97	53	−0.44	−1.2	856	912	512	2.6	11
BLANCA-4	Scattered Cox Sandstone outcrops in a Holocene alluvial fan, sloping 206°, along S-flowing tributary to Blanca Draw	Relief=235 ft. 60% K outliers of Sierra Diablo plateau on slopes 202° at 41 ft/mi	79	19.6	4,808	59	80	56	0.28	−1.4	961	922	351	−0.21	0.32
BLANCA-5	Cox Sandstone intruded by small Tertiary dikes; alluvial fans on E 118° and W 200°	Relief=451 ft. Ridge of K mesa-like hills, dissected on W and on E, sloping 118° at 109 ft/mi	107	26.5	6,565	111	98	57	−0.25	−1.4	935	928	377	49	1.7
BLANCA-6	Several Cox Sandstone outliers in an alluvial fan. Trace of a normal fault, 135°, down to NE	Relief=115 ft. W side of S-flowing drainage slopes 118° at 33 ft/mi	94	23.3	5,750	123	107	47	−0.84	−0.59	971	925	358	0.20	0.33
BLANCA-7	Outliers of Cox Sandstone on E side of S-flowing drainage, Qal	Relief=110 ft. 40% low-K mesa in NW; most of grid dominated by S-flowing drainage, 172° at 22 ft/mi	59	14.6	3,572	126	106	48	−0.64	−0.84	827	919	502	1.9	5.3
BLANCA-8	One small Cox Sandstone outcrop, Qal and dunes on a Holocene alluvial fan	Relief=80 ft. Broad arcuate fan-like divide slopes 196° at 31 ft/mi	33	8.2	1,908	58	81	55	0.24	−1.5	876	909	482	0.75	0.22

BLANCA-9	Finlay Limestone and Cox Sandstone containing Tertiary dikes. SW corner contains trace of Devil Ridge fault	Relief=1,030 ft. Steep Texan Mountain from which E fan slopes 109° at 148 ft/mi	48	11.9	3,105	75	81	60	0.13	−1.4	965	981	397	−0.07	−0.46
BLANCA-10	Qf and Qal S of Blanca Draw. Three traces of 150° normal faults down to NE	Relief=100 ft. Divide between SE-flowing Blanca Draw and its N tributary slopes 95° at 30 ft/mi	43	10.6	2,331	119	106	48	−0.49	−0.97	889	820	384	−0.25	−0.19
BLANCA-11	Quaternary alluvium including eolian sheet sands	Relief=72 ft. Tributary of Blanca Draw dominates terrain and flows 154° at 22 ft/mi	43	10.6	2,355	111	98	54	−0.33	−1.3	853	830	443	0.88	2.8
BLANCA-12	S-sloping Quaternary alluvium	Relief=77 ft. Broad flat divide slopes 191° at 28 ft/mi	29	7.2	1,612	69	79	50	0.18	−1.5	853	843	351	0.25	0.32
BLANCA-13	Yucca Limestone ridge and Quaternary fan	Relief=484 ft. Arcuate K ridge (30%) with fan sloping 90° at 200 ft/mi	43	10.6	2,468	110	102	48	−0.35	−1.1	784	869	282	0.32	1.4
BLANCA-14	Cox Sandstone and Finlay Limestone ridges with normal faults 150°, down to NE	Relief=102 ft. NW–SE elongate ridge divides Blanca Draw from drainage of Red Light Draw headwaters	59	14.6	3,467	103	91	59	−0.16	−1.6	906	889	377	0.41	0.47
BLANCA-15	Quaternary alluvium with eolian sheet sand in Blanca Draw	Relief=73 ft. Broad valley of Blanca Draw slopes 127° at 26 ft/mi	52	12.9	2,730	134	118	51	−0.91	−0.45	787	794	377	0.06	−0.56
BLANCA-16	S-sloping Quaternary alluvium	Relief=60 ft. Arcuate low divide slopes 180° at 23 ft/mi	34	8.4	1,783	139	118	53	−0.72	−0.84	791	794	312	0.21	−0.24
DEVIL-1	Bluff Mesa and Yucca Limestones w/Quaternary alluvial fans N and SW. Numerous normal faults strike 50° to 70° and 135° to 170°	Relief=1,164 ft. Dominated by the W 2/3 of Yucca Mesa w/fans extending NW and SE 219° at 151 ft/mi	87	21.5	5,079	76	88	57	0.05	−1.6	906	886	433	1.7	8.5
DEVIL-2	Bluff Mesa and Yucca Limestones w/Quaternary alluvial fan E	Relief=690 ft. Dominated by E 1/3 of Yucca Mesa with fan extending 90° at 86 ft/mi	102	25.3	6,345	103	97	48	−0.22	−1.1	909	942	361	0.67	2.1
DEVIL-3	Small outcrop of Bluff Mesa and Yucca Limestones in S (10%) mostly Holocene alluvial fan	Relief=350 ft. Dominantly distal fan sloping 73° at 64 ft/mi	60	14.9	3,408	92	92	40	0.16	−1.1	863	860	430	0.48	0.26
DEVIL-4	Washita Limestone in south-central (20%) mostly Quaternary alluvium	Relief=95 ft. Blanca Draw wide valley slopes 70° at 13 ft/mi	43	10.6	2,574	131	112	52	−0.59	−1.2	866	906	417	0.36	−0.15

DEVIL-5	Finlay Limestone in 10% NE, S-sloping Holocene alluvial fan and Quaternary alluvium in Red Light Draw	Relief=688 ft. Broad valley of Red Light Draw slopes 149° at 48 ft/mi	56	13.9	3,231	77	91	57	0.16	–1.5	886	873	381	0.06	–0.48
DEVIL-6	Bluff Mesa Limestone, Cox Sandstone, and Finlay Limestone, Quaternary alluvium sloping SW	Relief=693 ft. Elongate NW-SE Devil Ridge (50%); alluvial fan (50%) sloping 216° at 123 ft/mi	89	22.0	4,887	61	82	56	0.29	–1.4	843	830	322	0.02	0.37
DEVIL-7	Bluff Mesa and Yucca Limestones and Cox Sandstone strike 135° (60%) and Quaternary alluvium (40%) of Red Hills Arroyo. Trace of Devil Ridge Thrust	Relief=653 ft. Dominantly NW-trending parallel ridges with moderate dissection	101	25.0	5,868	78	89	57	0.07	–1.4	866	879	315	0.24	0.44
DEVIL-8	Washita, mainly limestone, ridges strike 170°, normally faulted. Trace of Devil Ridge Thrust in Red Hills Arroyo	Relief=323 ft. Between 2 NW ridges the Red Hills Arroyo flows 138° at 34 ft/mi	77	19.1	4,620	52	76	52	0.57	–1.1	912	909	436	0.43	0.04
DEVIL-9	Holocene fans sloping east toward Red Light Draw	Relief=225 ft. Alluvial fan and W valley wall of Red Light Draw slopes 98° at 90 ft/mi	61	15.1	4,012	75	80	34	0.33	0.03	965	997	302	0.38	1.1
DEVIL-10	Red Light Draw Quaternary deposits	Relief=324 ft. NW-trending ridge (20%) with slopes 222° at 48 ft/mi	49	12.1	3,338	44	59	46	0.92	–0.39	951	971	387	0.59	0.63
DEVIL-11	Cox Sandstone, Finlay Limestone, and Yucca Fm strike 135°. Outcrops offset by Red Hills Thrust	Relief=674 ft. Parallel NW-trending ridges	113	30.0	6,233	116	98	54	–0.18	–1.4	797	837	397	0.77	0.70
DEVIL-12	Yucca and Bluff Mesa Fms, Cox Sandstone, and Finlay Limestone. Several small normal faults strike 55° and 125°	Relief=669 ft. Parallel NW-oriented ridges	96	23.8	5,995	68	86	57	0.23	–1.4	991	945	387	0.31	0.65
DEVIL-13	Finlay Limestone and Kiamichi Fm, lapped by Quaternary fan on E side. One normal fault strikes 110° down to E	Relief=616 ft. N-NW-trending ridges (40%) lapped by a fan, 71° at 120 ft/mi	59	14.6	3,642	76	85	43	0.53	0.81	856	935	433	0.28	–0.65
DEVIL-14	Quaternary fan and Qal of Red Light Draw	Relief=185 ft. Distal fan and W valley wall 72° at 87 ft/mi into Red Light Draw	72	11.8	4,281	66	76	33	0.97	0.99	837	902	453	0.68	0.24

DEVIL-15	Quaternary fan on W slopes of Devil Ridge	Relief=392 ft. Tributaries of Red Light Draw flow S 190° at 62 ft/mi	59	14.6	3,328	103	94	61	–0.12	–1.4	837	853	348	0.57	–0.13
DEVIL-16	Cox Sandstone and Finlay Limestone segment of Red Hills overthrust forms scarps at base of Devil Ridge	Relief=325 ft. 50% rounded heights bordered by fan 210° at 90 ft/mi	61	15.1	3,367	37	68	62	–0.51	–1.4	827	837	367	0.32	0.32
DOME-1	Cox Sandstone outlier of Sierra Diablo Plateau. Quaternary alluvial fan (70%) slopes W	Relief=273 ft. W low hills of Sierra Diablo escarpment (20%); valley (80%)	58	14.4	3,557	56	76	56	0.34	–1.4	935	928	374	–0.19	–0.11
DOME-2	Cox Sandstone outliers and, at Sierra Diablo escarpment, Cox Sandstone and Campagrande Limestone. Traces of two down to W normal faults strike 100° to 110°	Relief=742 ft. Sierra Diablo escarpment (20%) western drainage sloping 240° at 93 ft/mi	64	15.8	3,987	81	84	55	0.09	–1.3	909	928	358	0.71	1.3
DOME-3	Dome Peak, Cox Sandstone, and Campagrande Limestone below the escarpment. Normal fault curves 110° to 90°, down to N below escarpment. Alluvial fan (30%)	Relief=626 ft. Dissected Sierra Diablo escarpment (60%) and headwaters of Camel Draw	83	20.6	5,101	108	93	57	–0.25	–1.4	925	932	374	0.38	1.1
DOME-4	Cox Sandstone and Campagrande Limestone in S 2/3 of area in fault contact with Hueco Limestone (N 1/3). Fault contact is the S Diablo Fault down to S	Relief=542 ft. Sierra Diablo Plateau broken by two stream valleys	69	17.1	4,202	118	95	57	–0.37	–1.4	876	922	518	1.9	6.2
DOME-5	Scattered Cox Sandstone mesas (15%) in SW-sloping Quaternary alluvial fan	Relief=228 ft. Stream flows 197° at 44 ft/mi between two outlier ridges of Sierra Diablo Plateau	67	16.6	3,996	84	82	58	0.05	–1.4	863	909	259	0.86	1.2
DOME-6	Hueco and Campagrande Limestone outliers (35%) surrounded by W-sloping Quaternary alluvial fan. Three N-striking normal fault traces down to E	Relief=376 ft. 20% dissected N–S ridge lapped by alluvial fan, 262° at 130 ft/mi	60	14.9	3,450	69	74	52	0.32	–1.2	814	869	404	0.38	0.42

DOME-7	Cox Sandstone and Campagrande Limestone unconformably overlie Precambrian Hazel conglomerate (40%). Quaternary alluvial deposits (60%)	Relief=297 ft. Western drainage heads of Camel Draw slope 109° at 68 ft/mi	79	19.6	4,403	94	92	54	−0.09	−1.4	942	843	374	−0.24	−0.89
DOME-8	Cox Sandstone and Campagrande Limestone unconformable on Precambrian Hazel Fm (40%). Quaternary deposits (60%), headwaters of Camel Draw	Relief=930 ft. Camel Draw slopes 152° at 54 ft/mi between outlier hills and ridges of Sierra Diablo Plateau	69	17.1	4,088	59	70	53	0.43	−1.2	909	899	322	−0.44	0.14
DOME-9	SW-sloping Quaternary alluvial fan	Relief=228 ft. Coalescing alluvial fans slope 215° at 53 ft/mi	24	5.9	1,478	53	77	52	0.60	−1.2	928	935	341	−0.39	0.43
DOME-10	Campagrande and Hueco Limestones on Precambrian Allamoore and Hazel Fms (40%). SW-sloping Quaternary fan. Arcuate normal faults down to SW, strike 130°–270°	Relief=512 ft. From rounded hills of Precambrian (40%) moderately dissected fan slopes 243° at 90 ft/mi	48	11.9	2,807	54	74	56	0.37	−1.4	886	886	390	−0.33	−0.23
DOME-11	Campagrande and Hueco Limestones on Precambrian Allamoore and Hazel Fms	Relief=405 ft. Rounded Streeruwitz Hills	61	15.1	4,196	114	95	48	−0.27	−1.4	1070	1043	449	−0.03	0.34
DOME-12	Faulted Precambrian Allamoore and Hazel Fms	Relief=385 ft. Rounded Streeruwitz Hills	53	13.1	3,321	75	87	51	0.24	−1.2	965	948	331	−0.40	−0.25
DOME-13	S-sloping Quaternary alluvium with eolian features	Relief=105 ft. Broad fluvial/eolian flat slopes 200° at 31 ft/mi	20	5.0	1,137	139	115	58	−0.56	−1.4	922	863	420	−0.48	−0.26
DOME-14	SW-sloping Quaternary alluvial fan	Relief=207 ft. Slightly dissected alluvial fan slopes 210° at 77 ft/mi	39	9.7	1,962	48	75	61	0.62	−1.2	784	761	341	−0.24	−0.03
DOME-15	SW-sloping Quaternary fan (50%) laps on Precambrian faulted Allamoore and Hazel Fms; scattered small Hueco Limestone caps on hills	Relief=700 ft. Rounded Streeruwitz Hills (50%) lapped by fan, 225° at 125 ft/mi	36	8.9	2,841	57	79	57	0.26	−1.5	1066	1194	633	−0.40	−0.05
DOME-16	Faulted Precambrian Allamoore and Hazel Fms w/ Precambrian metarhyolite parallel to small thrusts	Relief=553 ft. Rounded Streeruwitz Hills with fans and valley sloping 118° at 112 ft/mi	41	10.1	3,370	101	90	63	−0.14	−1.5	1030	1247	728	1.8	2.8

LAKE-1	Quaternary deposits including fluvial, eolian, and playa lake deposits	Relief=59 ft. Broad valley slopes 136° at 14 ft/mi to Grayton Lake	34	8.4	1,795	121	96	65	9.8	−1.7	814	801	335	0.02	−0.02
LAKE-2	Quaternary deposits including fluvial alluvium, eolian sheets, and alluvial fan	Relief=105 ft. Moderately dissected distal fan slopes 228° at 44 ft/mi	49	12.1	2,695	129	103	65	11.2	−1.7	712	833	495	1.8	3.9
LAKE-3	Quaternary deposits as above (95%) lap on faulted Hueco Limestone overlying Precambrian metarhyolites	Relief=535 ft. Ridge flank (10%) off which divide and broad valley slope 243° at 31 ft/mi	59	14.6	3,001	70	85	60	7.8	−1.5	797	771	305	−0.48	0.41
LAKE-4	Quaternary deposits as above (75%) lap on faulted Hueco Limestone overlying Precambrian metarhyolites	Relief=646 ft. Rounded ridge (40%) below which divide of Grayton Lake drainage–Eagle Flat Draw slopes 180°–210° at 56 ft/mi	57	14.1	3,332	69	89	59	7.9	−1.5	873	886	364	0.58	0.92
LAKE-5	Finlay and Loma Plata Limestones (40%) and Quaternary alluvium (60%). Numerous normal faults	Relief=107 ft. NW-trending low ridges	63	15.6	3,861	45	77	56	7.1	−1.5	899	928	387	0.92	2.57
LAKE-6	Yucca Limestone and Cox Sandstone (10%); Quaternary alluvial deposits that are fluvial, eolian, and colluvial	Relief=80 ft. NW-flowing drainage slopes 315° at 18 ft/mi into Grayton Lake playa	51	12.6	2,945	49	81	61	8.6	−1.6	797	876	404	0.44	0.09
LAKE-7	Bluff Mesa Limestone (5%); Quaternary fluvial and eolian deposits (95%)	Relief=47 ft. W-flowing drainage slopes 270° at 13 ft/mi toward Grayton Lake	52	12.9	3,332	123	98	60	8.4	−1.5	935	971	436	0.51	1.0
LAKE-8	Quaternary colluvial/alluvial deposits	Relief=63 ft. Divide slopes 210° at 24 ft/mi between Grayton Lake drainage and Eagle Flat Draw	52	12.9	3,020	127	108	59	8.2	−1.4	833	879	381	0.68	0.88
LAKE-9	Loma Plata Limestone, Eagle Mountains Sandstone, and Buda Limestone folded with few normal faults. Trace of the Devil Ridge Thrust	Relief=212 ft. Red Hills Arroyo flowing S between two ridges	75	18.6	4,581	90	87	52	6.0	−1.5	896	925	420	1.2	3.2
LAKE-10	Loma Plata Limestone, Eagle Mountains Sandstone, and Buda Limestone folded and normally faulted (20%). Quaternary fluvial and eolian deposits	Relief=150 ft. Rounded ridges (20%) and NW-flowing Red Hills drainage	73	18.1	4,520	121	101	49	5.7	−1.2	879	938	440	0.86	1.5

LAKE-11	Cox Sandstone outliers (20%); Quaternary alluvial fan	Relief=152 ft. 20% NW-trending ridges lapped by fan sloping 342° at 66 ft/mi	77	19.1	4,807	118	94	57	6.5	−1.4	984	945	348	−0.02	0.15
LAKE-12	Cox Sandstone (20%) and Quaternary alluvial fan	Relief=327 ft. 20% rounded ridges and broad divide slopes 355° at 72 ft/mi	59	14.6	3,575	115	99	62	8.1	−1.5	915	919	486	0.15	6.9
LAKE-13	Yucca Fm, Finlay Limestone, and Bluff Mesa Fm. Quaternary alluvium in Red Hills Arroyo. Surface expression of Red Hills Thrust	Relief=420 ft. 50% rounded hills surrounded by Red Hills Arroyo	72	17.7	3,768	111	91	58	6.8	−1.6	922	863	420	−0.48	−0.26
LAKE-14	Hueco Limestone, Yucca and Bluff Mesa Fms (50%). Quaternary alluvium and colluvium, Devil Ridge Thrust Fault	Relief=770 ft. Parallel NW-trending ridges	68	16.8	3,932	117	95	59	−0.24	−1.5	886	876	407	0.45	1.3
LAKE-15	Loma Plata and Buda Limestones, Eagle Mountains Sandstone, and Chispa Summit Fm	Relief=417 ft. Parallel NW-trending ridges	105	26.0	6,008	109	94	55	−0.15	−1.5	837	866	367	1.7	7.4
LAKE-16	Loma Plata Limestone and faulted Cox Sandstone onlapped by steep Holocene alluvium	Relief=315 ft. NW ridges (15%) lapped by steep fan 350° at 206 ft/mi	62	15.4	3,892	128	101	64	−0.39	−1.6	935	951	377	0.57	1.5

Table A2. Descriptions of the geology, terrain, and statistics measured for the lineations in the 30 specially selected areas.

				Lineation Characteristics												
							Azimuths degrees					Lengths feet				
Selected Area	Size (mi^2)	Geology	Terrain Orientation and gradient of slopes in degrees and ft/mi	No.	No. per mi^2	Length ft/mi^2	Median	Mean	Std. Dev.	Skew	Kurt	Median	Mean	Std. Dev.	Skew	Kurt
SB-1	1.87 × 2.46 = 4.60	Cox Sandstone overlain by Finlay Limestone, w/ small Tertiary intrusives, transecting Quaternary fan deposits on each flank	Relief=515 ft. Crenulate divide w/ steep east flank and fan slopes about 89 ft/mi	122	32.1	5,998	112	95	57	–0.20	–01.4	984	1,020	351	0.836	1.66
SB-2	2.46 × 2.47 = 6.08	Cox Sandstone and Finlay Limestone w/E Quaternary alluvial fan. N 70° W thrust fault w/3 semiparallel normal faults down to NE	Relief=680 ft. Mesa-like hills on W; alluvial fan slopes 90° at 132 ft/mi	157	26	4,613	117	102	49	–0.43	–0.94	876	942	344	1.22	2.28
SB-3	1.24 × 3.12 = 3.87	Quaternary alluvium	Relief=85 ft. Broad alluvial valley slopes 160° at 28 ft/mi	58	15	3,435	137	92	52	–0.94	–0.12	922	948	328	1.70	6.43
SB-4	1.62 × 3.10 = 5.02	Small mesas of Cox Sandstone surrounded by Quaternary alluvium	Relief=105 ft. Low mesa and broad, flat valley slopes 160° at 25 ft/mi	83	17	3,171	112	84	56	–0.21	–1.4	866	981	499	2.6	10.1
SB-5	0.82 × 2.50 = 2.40	Quaternary fan and alluvium. Qf=80%; Qal=20%	Relief=115 ft. Side valley slopes 110° at 55 ft/mi	24	10	4,167	78	84	49	–0.07	–1.6	866	974	279	1.1	0.42
SB-6	1.40 × 2.08 = 2.91	Quaternary alluvium; some sand dunes	Relief=75 ft. Flat terrain slopes 90°, 35 ft/mi	56	19	5,550	137	120	52	–0.99	0.32	909	938	331	1.7	64

SB-7	1.38 × 2.10 = 2.90	Quaternary alluvium	Relief=65 ft. Low flat arched divide slopes 180°, 28 ft/mi	52	18	5,791	122	108	37	−1.2	0.36	1,027	1,004	367	0.83	1.1
DR-1	0.80 × 2.50 = 2.00	Bluff Mesa Fm, Cox Sandstone, and Finlay Limestone (95%). Quaternary fan. Many normal faults down to SE	Relief=620 ft Dissected ridge oriented 245°	56	28	12,673	63	87	58	0.32	−1.4	837	866	259	0.53	0.08
DR-2	0.80 × 3.32 = 2.66	Yucca and Bluff Mesa Fms, Cox Sandstone, and Finlay Limestone (95%) surrounded by Qf. Many normal faults	Relief=1,000 ft. Dissected ridge oriented 230°, becoming mesa-formed to NW	85	32	13,188	76	85	51	0.02	−1.3	1,010	1,040	410	2.2	9.3
DR-3	1.85 × 2.22 = 4.11	Alluvial fan on NE flank Quitman Mountains. No structure	Relief=220 ft. Alluvium slopes 75°, 122 ft/mi	61	15	4,303	66	72	28	0.92	1.2	896	994	413	0.64	−0.11
DR-4	1.45 × 2.50 = 3.63	Quaternary fan 50%. Quaternary alluvium in Red Light Draw	Relief=65 ft. Stream slopes 150°, 31 ft/mi	59	16	3,752	73	84	50	0.22	−0.94	869	892	397	0.90	0.40
GL-1	0.75 × 1.96 = 1.47	Cretaceous Cox Sandstone, Finlay and Loma Plata Limestones strike 125°. Folded strata crop out immediately NE of Devil Ridge Thrust	Relief=360 ft. Elongate parallel ridges and valleys	55	37	34,028	81	87	52	0.07	−1.4	886	948	384	2.6	9.9
GL-2	1.60 × 1.96 = 3.14	Modern alluvium, playa, and stream sediments	Relief=40 ft; maximum slope <0.5%	29	9	3,098	133	105	65	0.27	−1.7	902	1,004	420	1.7	2.5
GL-3	1.70 × 2.15 = 3.66	Quaternary fan modified by sheet wash and deflation	Relief=100 ft. Divide slopes 200° at 43 ft/mi	43	12	3,138	60	85	63	0.39	1.5	902	968	413	0.88	0.53

GL-4	1.06 × 2.68 = 2.84	Quaternary fluvial alluvium modified by eolian processes. W-flowing drainage of Grayton Lake.	Relief=50 ft. Slope is 240° at 15 ft/mi	33	12	4,691	122	98	58	−0.45	−1.2	1,017	1,142	469	1.9	5.2
GL-5	1.10 × 3.68 = 4.05	Buda and Loma Plata Limestones and Eagle Mountains Sandstone (50%) strike about 115°, surrounded by Qf. Devil Ridge Thrust trace on NE side of area	Relief=150 ft. Low ridges surrounded by alluvial slopes	85	21	5,480	61	76	52	0.29	−1.4	981	1,033	390	1.5	3.6
DP-1	1.98 × 2.56 = 5.07	Cox Sandstone of dissected Sierra Diablo Plateau with Quaternary alluvium sloping SW	Relief=530 ft. Mesa-like high areas dissected by streams	95	19	3,693	109	88	57	−0.15	−1.6	925	978	463	2.1	7.0
DP-2	1.82 × 2.12 = 3.86	90% Precambrian Hazel Fm in E Streeruwitz Hills. Immediately N of Streeruwitz Thrust main trace, several slices occur	Relief=465 ft. Rounded hills dissected by E-flowing drainage	58	15	4,992	79	83	53	0.19	−1.1	1,132	1,250	577	2.0	5.2
DP-3	1.40 × 2.12 = 2.97	Quaternary fan SW of Streeruwitz Hills	Relief=170 ft. Dissected fan sloping 220° at 86 ft/mi	31	10	3,548	47	62	53	1.2	0.03	1,001	997	295	0.33	−0.70
DP-4	2.01 × 2.02 = 4.06	Alluvial fan W of NW Streeruwitz Hills (85%). Scattered small mesas of Cox Sandstone	Relief=250 ft. Fan slopes at 230° at 82 ft/mi	44	11	2,825	54	76	54	0.45	−1.3	1,014	1,043	253	0.33	−0.23

DP-5	1.98 × 2.02 = 4.00	Modern alluvial fan 70%; low Cox Sandstone mesas (30%)	Relief=195 ft. N drainage slopes at 260°, 52 ft/mi; S drainage slopes at 250°, 73 ft/mi	61	15	3,743	79	83	56	0.25	−1.3	922	961	302	1.1	2.2
B-1	1.33 × 2.28 = 3.03	Precambrian Allamoore and Hazel Fms (85%) w/ small pods of talc w/ minor Qf and Qal. Several pieces of the Streeruwitz Thrust	Relief=310 ft. Rounded and dissected northern Millican Hills	70	23	5,863	120	105	57	−0.52	−1.1	669	768	351	1.5	1.9
B-2	1.63 × 2.02 = 3.29	Precambrian Allamore and Hazel Fms (95%); remainder Quaternary fan. Thrust pieces of Steeruwitz Thrust	Relief=250 ft. Rounded and dissected Bean Hills	59	18	6,729	112	97	54	−0.31	−1.2	1,010	1,010	295	0.43	0.42
B-3	0.98 × 2.17 = 2.13	Dominantly Hueco Limestone. Southern edge has several down to S normal faults probably related to the Sierra Diablo transverse fault	Relief=270 ft. Plateau dissected by N-flowing drainage	61	27	11,969	70	78	57	0.26	−1.4	827	919	364	1.0	1.1
B-4	0.83 × 2.82 = 2.34	Hueco Limestone in an interior part of Diablo Plateau	Relief=316 ft. Plateau dissected by several streams flowing N (20°) and S (200°)	67	29	12,159	41	77	64	0.21	−1.7	807	1,020	689	4.0	18.7
B-5	1.15 × 2.02 = 2.32	Quaternary fan (90%) and minor outliers (10%) of Precambrian Allamore Formation	Relief=135 ft. Fan slopes 155° about 50 ft/mi	47	20	7,456	45	78	63	0.28	−1.6	876	968	354	1.1	1.9

B-6	0.62 × 3.74 = 2.32	Precambrian Van Horn Sandstone and Pennsylvanian Hueco Limestone (85%). N edge (15%) is Quaternary fan. Lies on Sierra Diablo Fault	Relief=775 ft. Main Sierra Diablo Plateau escarpment	84	36	4,755	106	99	59	–0.14	–1.5	722	778	351	4.3	27.4
B-7	1.48 × 2.28 = 3.37	Holocene alluvial fan along S side of Seventeen Draw	Relief=235 ft. Alluvial fan slopes 230° at 88 ft/mi	77	23	5,391	48	60	40	1.3	0.90	774	801	253	1.1	2.4
A-1	0.98 × 5.50 = 5.39	Quaternary alluvium	Relief=82 ft. Eagle Flat Draw slopes 120° at 14 ft/mi	43	8	1,663	108	96	63	–0.13	–1.7	827	896	331	1.0	1.5
A-2	1.67 × 2.25 = 3.76	Upper mid-Holocene alluvial fan	Relief=140 ft. Between Bean and Millican Hills, fan slopes 200° at 61 ft/mi	90	24	5,135	42	68	63	0.78	–1.1	774	823	322	0.81	0.88