Comparison of Mapped Rock Fractures and Airphoto Linear Features

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ABSTRACT: *A detailed field study was made of fractures—faults and joints—in an area of about 185 square miles in southern Burnet County, Texas. All bedrock exposures approximately 5,000 square feet or more in size were traversed and strikes of all systematic joints were measured and recorded. Joint sets were established from these data.*

Aerial photographs of the area were then scrutinized with the aid of a stereoscope. All airphoto linear features (defined as relatively straight alignments of small-scale features that may be of natural origin, visible on aerial photographs and mosaics) were marked and were then transferred to a corrected aerial photograph mosaic.

Data obtained from the two methods were placed on geologic base maps for visual comparison. The fractures measured on the ground show close parallelism with the airphoto linear features. Comparison of these airphoto linear features with the faults was particularly striking because all major faults are clearly visible on the photographs. More detailed comparisons were restricted to lithic units to avoid influences of changes in lithology and bedding thickness on the patterns. Separate distribution diagrams were made for the (Precambrian) granite and the (Ordovician Ellenburger Group) carbonate rocks; each of these units covers approximately one-third of the area studied. Diagrams of total joints measured, joint sets, and airphoto linear features for each unit are very similar.

It is concluded that airphoto linear features:

1) Are largely a reflection of fractures in the rocks, emphasized by vegetation and topography,

2) Have widespread distribution irrespective of rock exposures and thus afford a supplement to ground measurements, and

3) Are particularly useful for quickly determining major fracture (fault) trends for use in regional stress analysis.

INTRODUCTION

USE of airphoto linear features as a means of establishing fracture patterns on the ground is well documented (Gross, 1951; Hodgson, 1961; Kelley and Clinton, 1960; and others). This technique has been applied to mineral exploration (e.g. Blanchet, 1957; Mollard, 1957; Twenhofel and Sainsbury, 1958), in some cases with apparent success. That airphoto linear features may be reliably interpreted as fractures has been suggested by Lattman and Nickelsen (1958), although Brown (1961) has expressed caution in this regard. This study is a comparison of detailed ground measurements of fractures—faults and joints—and airphoto linear features in the same area to further test the correlation of fractures with linear features.

An airphoto linear feature, as herein used, is any relatively straight alignment of small-scale features that may be of natural origin, visible on aerial photographs and mosaics. Details as to the numerous conditions which may give rise to linear features as well as the techniques for mapping them have been published (Hartman and Isaacs, 1958; Hough, 1960; Lattman, 1958; Ray, 1960; and others). The term 'fracture trace' as employed by Lattman and his students (e.g. Lattman, 1958; Lattman and Matzke, 1961; Lattman and Nickelsen, 1958) has been avoided because the justification of its genetic connota-

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tion is inherent in the purpose of this study. Likewise 'lineament' is not used because of the large-scale (tens or hundreds of miles long) and world-wide significance attached to this term by some workers (Lattman, 1958, p. 569–570). The airphoto linear features observed here range from about $\frac{1}{4}$ mile to 4 miles in length, although most are less than 1 mile long.

Ground and Airphoto Techniques

Approximately 185 square miles of southern Burnet County, Texas (Figure 1) were mapped and a detailed geologic map (scale 1/24,000) compiled (McQueen, 1963, pl. 1). Traverses were made across each bedrock exposure of approximately 5,000 square feet or more. At these localities, attitudes of each joint were recorded; on granite bedrock, the attitudes of primary flow structure, pegmatites, and hydrothermal veins were also noted.

Joint data were listed separately for each rock type. Only systematic joints (Hodgson, 1961) were included in this study. Virtually all joints are high-angle (with dips greater than 80 degrees), consequently only joint strikes were recorded. All faults also dip at high angle. No prominent folding exists in the area, and most bedding is horizontal or dipping less than 5 degrees. Therefore bedding does not develop linear features on the aerial photographs as the topography is generally subdued.

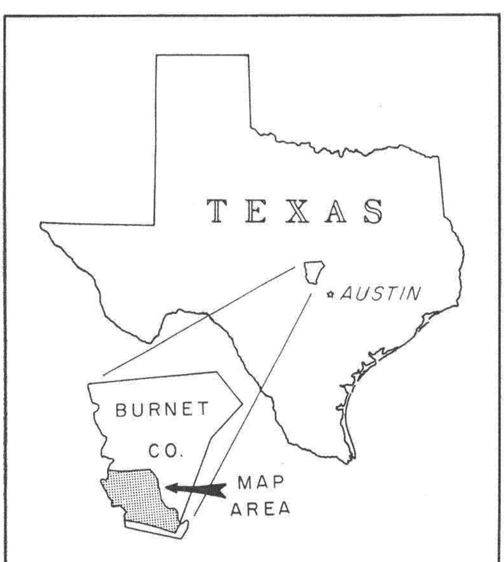

FIG. 1. Index map of project area, southern Burnet County, Texas.

Joint sets were determined in the field from the individual joint measurements. All faults and joint sets were then recorded on a generalized geologic map (Figure 2). Each joint set station of Figure 2 represents a single lithic type with relatively constant bedding thickness. The Precambrian rock is porphyritic coarse-grained granite which is uniform in this character throughout the area. The Paleozoic rocks are predominantly fine-grained carbonate rocks with bedding commonly 1 to 3 feet thick. Several sandstone units also occur in the Paleozoic section, however they are of localized areal extent.

Linear features were first observed on aerial photographs (1/16,200) with the aid of a stereoscope. Each photograph was scrutinized in stereo to detect all linear features. Special care was taken to avoid inclusion of man-made linear features and culturally controlled lines. The linear features were transferred from the individual photographs to a reduced (1/24,000) corrected aerial photograph mosaic. They were then placed on a generalized geologic map (Figure 3) similar to the one used for the ground measurements and at the same scale as the mosaic.

To avoid possible human bias, all ground measurements were made by McQueen and all aerial photograph work was done by Boyer. Results were not compared until all data had been acquired.

Comparison of Data

Figures 2 and 3 afford a visual comparison of the data obtained by each method. The airphoto linear features clearly show the strong northeast trend of faults and joints in Figure 2. Likewise, the persistent northwest joint trend is illustrated by the linear features. Careful checking indicated that each joint set at each locality of Figure 2 is represented by at least one linear feature on the aerial photographs.

An additional value of the airphoto linear features is their relatively uniform distribution (Figure 3). Whereas distribution of data measured in the field is controlled by exposures (Figure 2), the airphoto interpretation has no such limitation apparent. The value of this distribution is illustrated by the structural control on the course of the Colorado River where it crosses Paleozoic rocks (Figure 3); influence of fractures is more clearly illustrated by the linear features than by the ground measured data.

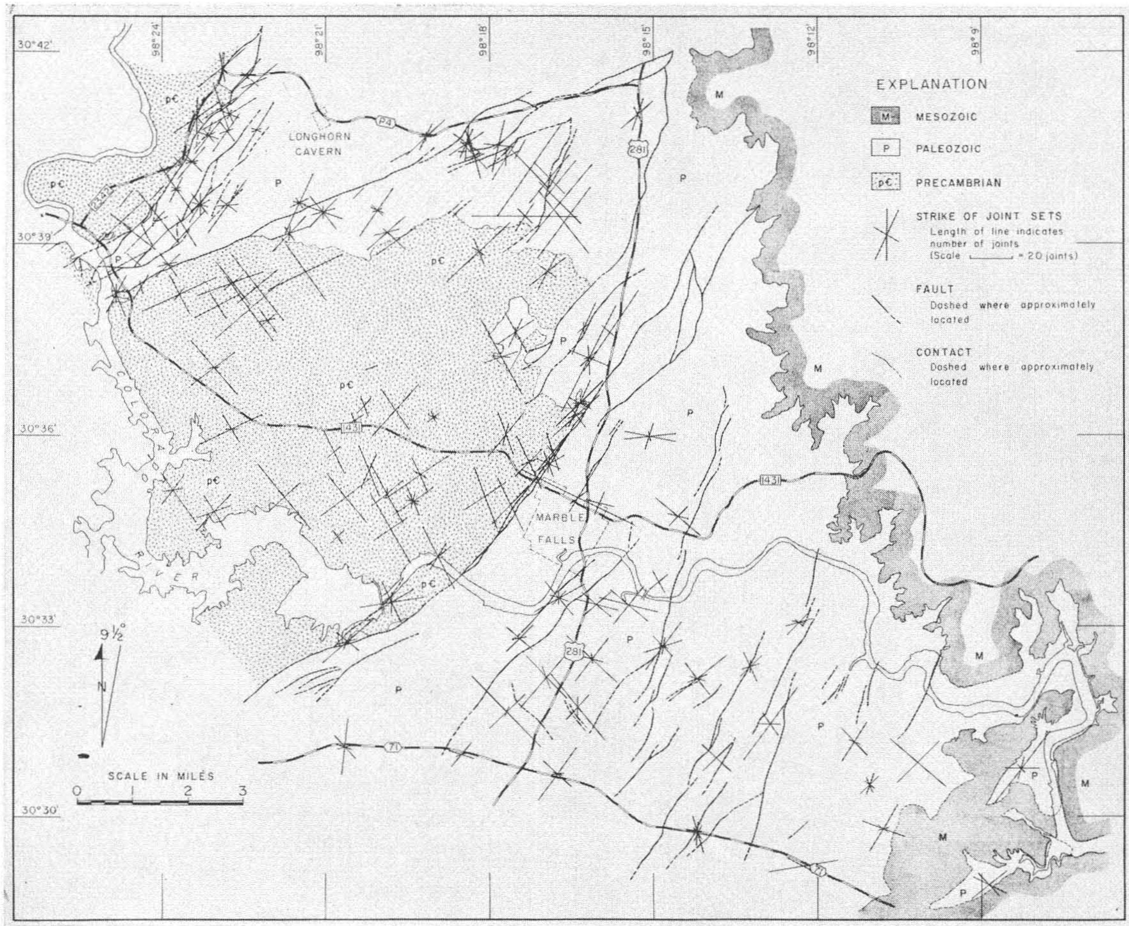

FIG. 2. Generalized geologic map of area showing mapped faults and joint sets.

Figure 4 illustrates that the airphoto linear features clearly indicate most of the faults. Although linear features are not as continuous as some of the major faults (such as the fault bounding the east side of the large Precambrian granite exposure), the trends of these major faults are clearly portrayed. The linear features also yield as accurate a pattern for stress analysis as the ground measurements of the faults.

To compare results of the two methods more carefully, distribution diagrams were made of all joints and linear features in the Precambrian granite (Figure 5). Both total joints measured and joint sets determined from the measured joints (Figure 5, A and B, respectively) are included. The near identical results of these two diagrams validate the technique of counting every joint and then portraying the joint sets as done in Figure 2. Primary flow structure of the granite trends N. 30° W.; pegmatites and hydrothermal veins trend N. 50° E. Thus these structures closely parallel the two dominant joint trends.

A pattern of the linear features in the granite (Figure 5C) closely matches that of the jointing. The same two trends are illustrated, although a wider spread of readings results from the linear features. However, no new trends are inferred from this diagram.

A similar comparison was made in the carbonate rocks of the Ordovician Ellenburger Group (Figure 6). The Ellenburger Group, the most extensive sedimentary rock exposed, includes about 50 percent of the Paleozoic area mapped. The distribution diagrams again correspond fairly well (Figure 6). The joint set diagram (Figure 6B) shows better clustering and suggests as many as five joint sets, whereas the diagrams of total joints and airphoto linear features plot with wider spreads. The diagram of linear features

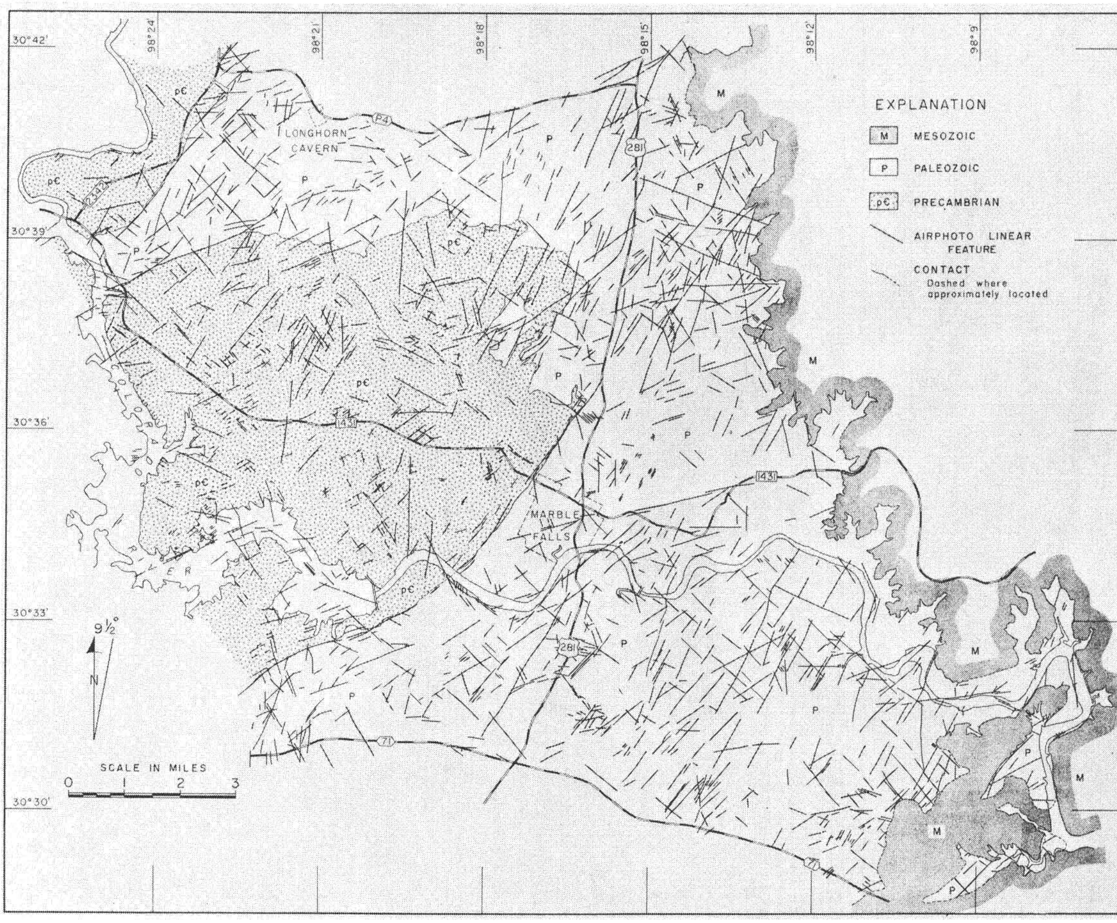

FIG. 3. Generalized geologic map of area showing airphoto linear features.

(Figure 6C) shows more distinct grouping, particularly in the northeast quadrant, than does the diagram of total joints (Figure 6A). This indicates that joints following the major trends are more discernible on the aerial photographs than joints of the less common strike orientations.

CONCLUSIONS

The comparative results of this study indicate a close parallelism of fractures measured on the ground and airphoto linear features and suggest that the airphoto linear features are largely a reflection of fractures in the rocks emphasized by vegetation and topography. These results support similar conclusions by Lattman and Nickelsen (1958, p. 2244) and tend to justify Lattman's use of the term 'fracture traces.' This study did not yield any noticeably different trends between ground measurements and airphoto linear features as was reported by Brown (1961). The apparent disagreement may be explained by the range of degrees used in grouping joint sets. In this study a maximum of five joint sets was recognized at a single locality and generally only three or four sets were noted; Brown (1961, Figs. 2 and 3) recorded as many as ten joint sets at one field station and averaged six sets. Greater segmentation, both of joint sets and linear features, would increase chances of obtaining different trends such as Brown reported.

Uniform distribution of airphoto linear features irrespective of rock exposures affords a source for data to supplement ground measurements. That these airphoto data are reliable is suggested by the results obtained here. In some cases local anomalies could alter the value of these supplemental data.

Aerial photographs are particularly useful for quickly obtaining major fracture trends.

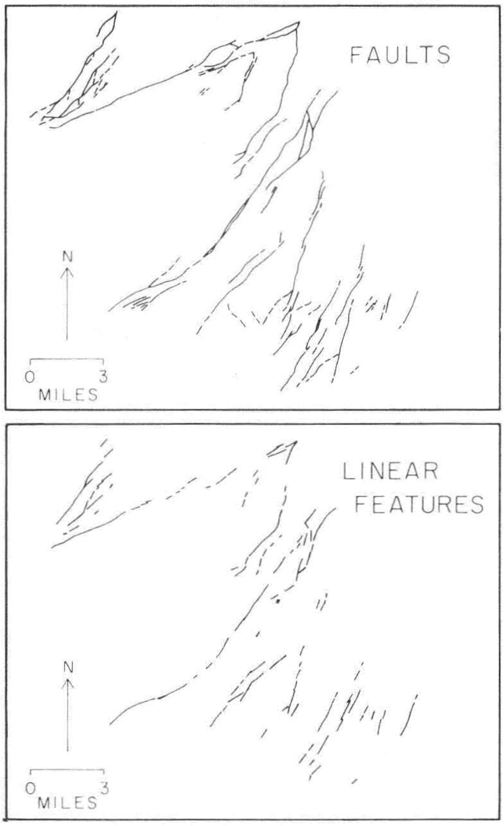

FIG. 4. Comparison of mapped faults and airphoto linear features along these faults.

These dominant trends in many cases yield insight into regional stress analyses that would otherwise be possible only as a result of detailed field study.

Additional comparative studies of this nature are warranted, but the usefulness of airphoto linear features as a mapping tool is clear. Greater application of these aerial photograph techniques to structural analysis is needed.

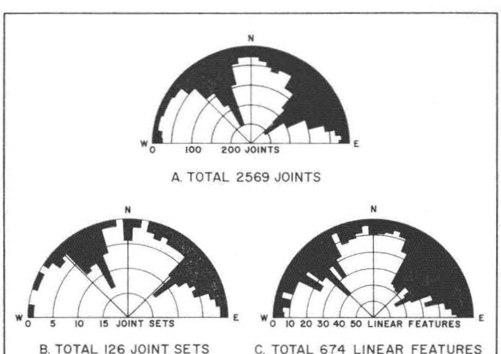

FIG. 5. Distribution diagrams in Precambrian Town Mountain Granite showing comparison of: A. Total joints; B. Joint sets; C. Airphoto linear features.

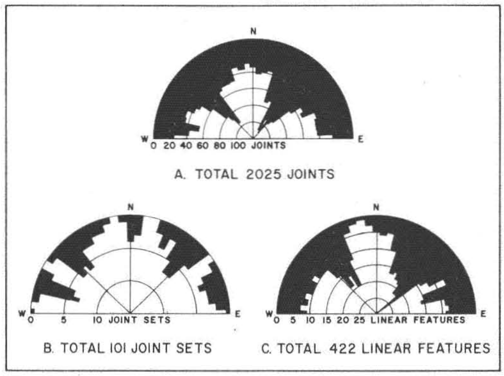

FIG. 6. Distribution diagrams in Paleozoic Ellenburger Group showing comparison of: A. Total joints; B. Joint sets; C. Airphoto linear features.

ACKNOWLEDGMENTS

A grant from the Penrose Bequest of the Geological Society of America (to Boyer) enabled this study to be undertaken. Support (to McQueen) of the Sigma Xi-RESA Committee on Grants-in-Aid of Research partially defrayed field expenses. Tobin Aerial Surveys, Inc., San Antonio, Texas generously donated aerial photographs and corrected aerial photograph mosaics. The Geology Foundation of The University of Texas paid costs for preparation of the manuscript.

The authors thank P. S. Clabaugh, L. H. Lattman, W. R. Muehlberger, and R .D. Turpin who critically read the manuscript and discussed phases of the field and airphoto work with them.

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A Trigonometric Derivation of the Formulas for the Three-Dimensional Rotation Matrix

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THE formulas for a three-dimensional orthogonal rotation matrix have already been derived by two other methods: (1) algebraic substitution[1] in the formulas for the rotation of axes in plane analytic geometry; and (2) the multiplication[2] of the ordered series of matrices that represent the component plane rotations. Here a third derivation is presented using spherical trigonometry.

Figure 1 shows the ends of the "original" axes x^*, y^*, z^* piercing the surface of a sphere whose center is the origin. The axes form an orthogonal set, being mutually perpendicular. Regarding the x^*-axis as an axis of rotation, y^* is rotated counter clockwise (positive) through an angle ω to $y^{*\prime}$ while z^* is moved the same angular amount to $z^{*\prime}$, maintaining the mutually perpendicular orientation among the points x^*, $y^{*\prime}$, $z^{*\prime}$.

A second rotation about the $y^{*\prime}$-axis as the axis of rotation through an angle ϕ sends x^* into $x^{*\prime}$ and $z^{*\prime}$ into z, retaining the relative orthogonal orientation. A third rotation about z as an axis through an angle κ sends $x^{*\prime}$ into x, and $y^{*\prime}$ into y, again preserving the orthogonality.

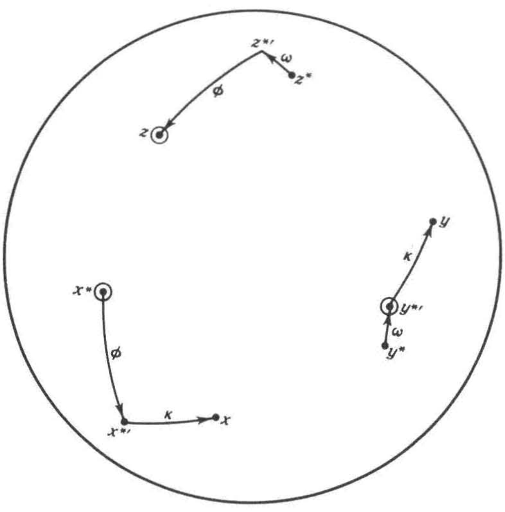

FIG. 1

It is desired to establish formulas for the nine direction cosines a_{ij} in terms of ω, ϕ, κ in the array:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} x^* \\ y^* \\ z^* \end{bmatrix}. \qquad (1)$$

[1] Harris, W. D., et al., "Analytic Aerotriangulation," Technical Bulletin No. 21, U. S. Coast & Geodetic Survey, Washington 25, D. C., p. 30, 1962.
[2] *Ibid.*, p. 9.
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