FRANK W. TRAINER*
U. S. Geological Survey
Washington, D. C.

ROBERT L. ELLISON
University of Virginia
Charlottesville, Va.

Fracture Traces in the Shenandoah Valley, Virginia

Linear features of value for geology and hydrology identified on aerial photographs.

(*Abstract on page 192*)

WHERE BEDROCK IS EXTENSIVELY COVERED by soil and vegetation the direct study of fractures is difficult because of the scarcity and small size of outcrops. Linear features which may be inconspicuous on the land surface in such regions but which are seen on aerial photographs, and which are thought to be the surface expression of fractures in the bedrock, offer a promising means of studying fractures in these regions. We have studied such linear features in the Shenandoah Valley, in Rockingham County, Virginia, to determine the geologic controls on their formation.

The Shenandoah Valley (Figure 1, shown on the next page), is a northeast-trending lowland in the Valley and Ridge physiographic province. In Rockingham County the Valley is about 20 miles wide, and the maximum relief in local areas on its floor is commonly a few hundred feet. The geology has been described and mapped by Brent (1960), and the geomorphology by Hack (1965). The valley floor is underlain by folded and faulted sedimentary rocks of Paleozoic age, chiefly Cambrian and Ordovician carbonate rocks and shales. Fold axes, the traces of thrust faults, and formation boundaries all trend generally northeastward.

THE FRACTURE TRACES

The lengths of the natural linear features on aerial photographs range from less than 100 feet to several miles. Lattman (1958, p. 569–570) terms those which are less than one mile long *photogeologic fracture traces* and interprets them as the surface expression of joints and small faults. Because nearly all the fracture traces we found are straight or nearly so, regardless of land-surface topography (Figure 2), the fractures must be vertical or nearly vertical. Fracture traces are linear elements expressed as differences in plant types or lushness, as differences in soil tone, as aligned discontinuities in outcrops, and as topographic features such as shallow grooves in the land surface and straight segments of streams. Many of these features are found with difficulty, or cannot be identified, on the ground. However, Lattman and Parizek (1964, p. 79) found some fracture traces in carbonate rocks to be discontinuous linear topographic depressions that are about 2 to 10 feet deep. We identified a few fracture traces in the Shenandoah Valley as shallow linear depressions or lines of shallow, closely spaced sinkholes, or as aligned discontinuities in outcrops which clearly are widened joints. The formation of fracture traces commonly is attributed to such factors as differences in moisture content or in degree of development of soils along linear zones, the settling of soil into underlying fractures, and the preferential development of gullies or streams along fractures or fracture systems.

Studies by other workers (Lattman and Nickelson, 1958; Hough, 1960; Boyer and McQueen, 1964) have shown that, in regions of flat-lying sedimentary rocks, the dominant modes for the strikes of joints correspond to the dominant modes for the trends of fracture traces. In regions of folded rocks, how-

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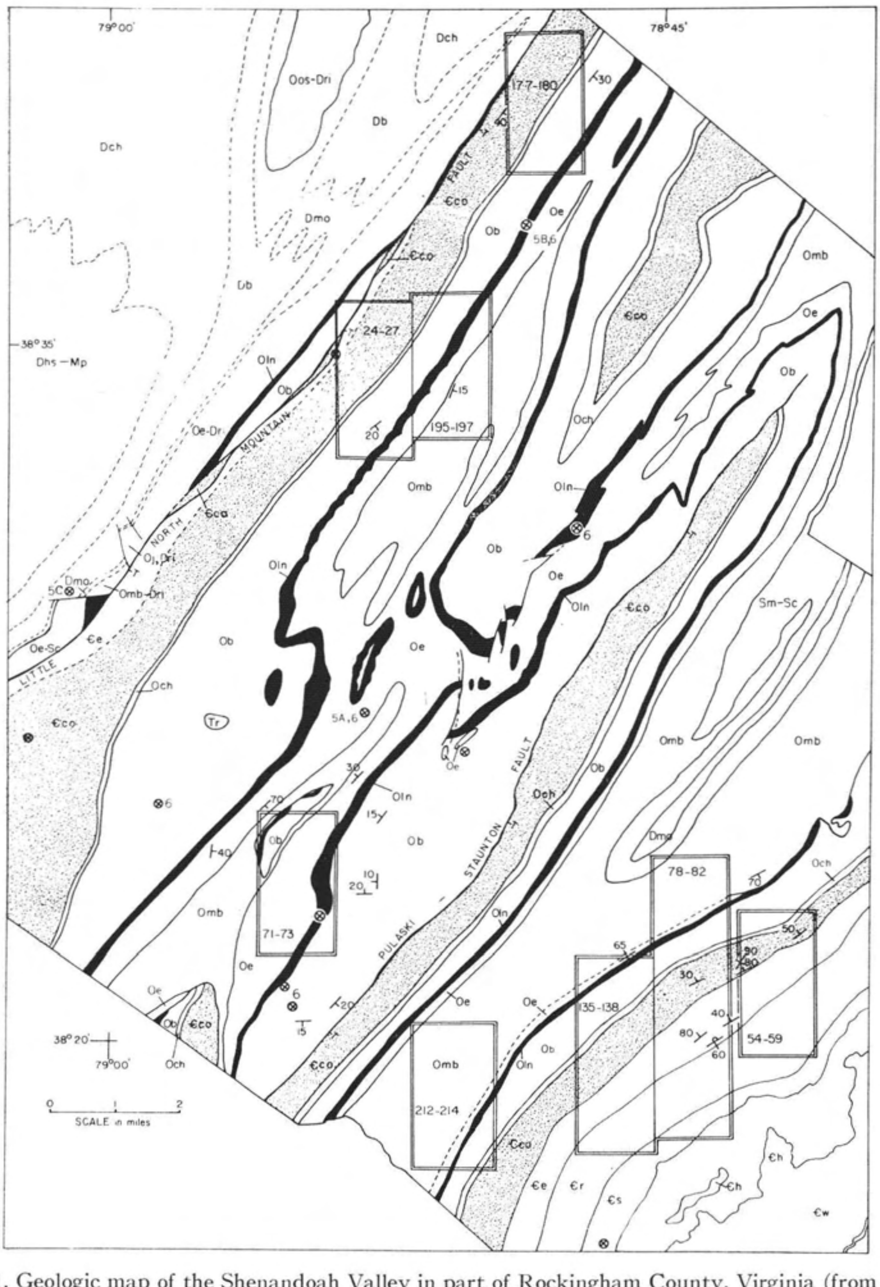

FIG. 1. Geologic map of the Shenandoah Valley in part of Rockingham County, Virginia (from Brent, 1960, pl. 1). Numbered rectangles show areas of aerial photographs. Circles indicate localities of joint studies; symbols 5*A*–5*C* indicate localities where joints shown on Figure 5 were studied, and symbol 6 indicates localities where joints shown on figure 6*C*–6*F* were studied. Rock units shown by letter symbols are, beginning with the oldest: *Cambrian*(?), Ꞓh, Hampton Formation, and Ꞓer, Erwin Quartzite; *Cambrian*, Ꞓs, Shady Dolomite; Ꞓr, Rome Formation; Ꞓe, Elbrook Dolomite; Ꞓco, Conococheague Limestone. *Ordovician*, Och, Chepultepec Dolomite; Ob, Beekmantown Group; Oln, New Market and Lincolnshire Limestones; Oe, Edinburg Formation of Cooper and Cooper (1946); Omb, Martinsburg Shale; Oos, Oswego Sandstone; Oj, Juniata Formation. *Ordovician and Silurian*, Sc, Clinch Sandstone; Sm, Massanutten Sandstone (of former usage). *Silurian*, Scl., Clinton Formation. *Silurian and Devonian*, Scy, Cayuga Group. *Devonian*, Dhl, Helderberg Limestone; Dri, Ridgeley Sandstone; Dmo, Millboro Shale of B. N. Cooper (1939) and Onondaga Formation; Db, Brallier Shale; Dch, Chemung Formation; Dhs, Hampshire Formation. *Mississippian*, Pocono Formation.

ever, the modes for joints have been found to differ from those for fracture traces (Matzke, 1961; Lattman and Matzke, 1961; Meisler, 1963). Clearly, explanation of the relation between the strikes of joints and the trends of fracture traces is a basic problem in the interpretation of the origin and significance of fracture traces.

Abstract. *Fracture traces in the Shenandoah Valley are interpreted as the surface expression of joints or groups of joints in the bedrock. The traces (natural linear features, less than one mile long, seen on aerial photographs) are considered to represent vertical fractures or zones of vertical fractures because they are straight regardless of topography. The folded carbonate rocks and shales in this area, unlike bedded rocks which are horizontal over broad areas in other parts of the Appalachian region, are cut by several important joint sets which are not vertical. Differences between the preferred orientation of the fracture traces and that of the joints in these folded rocks are therefore attributed to selective formation of the traces along only the vertical joints. The dip of the strata is believed to control the abundance of fracture traces because both vertical joints and fracture traces appear to be more numerous in gently dipping strata than in those which dip more steeply.*

Controls on Trends of the Fracture Traces

We studied fracture traces in the tracts indicated on Figure 1, using aerial photographs at a scale of 1:21,400. We measured trends (azimuths) and lengths of the fracture traces, and investigated three potential controls on trends of the fracture traces: rock type, topography, and rock structure. Structure appears to be the principal control.

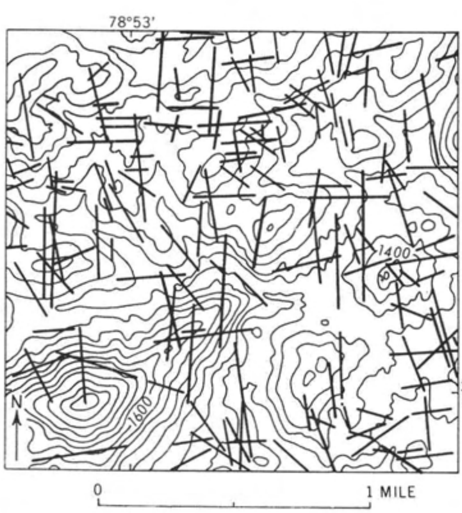

Fig. 2. Topographic map showing fracture traces on parts of photographs 25–26 (see Figure 1); base from U. S. Geological Survey, Broadway quadrangle, 1:62,500, contour interval 40 feet.

The graphs in Figure 3, which summarizes trends in 16 samples of fracture traces, provide a means of considering the effects of these potential controls. In several graphs (*F*, *G*, *H*, *J*, *L*, and *M*) the prominent modes (the dominant trends) are north and east (or west). In other graphs (*A*–*E* and *N*–*Q*), however, northeast and northwest modes also are conspicuous; in histogram *K* they are dominant. The relative absence of northeast trends from many graphs reflects, at least in part, our effort to avoid mapping northeast-trending features of beds where the rock is at or near the surface. Nevertheless, the association of northwest modes with northeast modes in some graphs (*B*, *E*, *K*, and *Q*) and the general consistency of the data lead us to believe that the distributions presented are real.

After plotting the orientations of 60 fracture traces from a relatively small tract we found that the further addition of data did not significantly alter the positions of the modes. Samples of 60 or more traces were used for this study.

Figure 3 shows that the carbonate rocks are characterized by several different patterns of trends (for example, graphs *A*, *F*, and *P*); that shales also exhibit several patterns (graphs *E*, *K*, and *Q*); and that one pattern (graphs *A* and *E*) is common to both rocks. The patterns of trends cannot be correlated convincingly with rock type.

Consideration of topography as a control on the trends of fracture traces is based on the premise that potential fractures open more readily under tension if they strike parallel to the land-surface contour rather than at a large angle to it. Because of the northeast strike of the folded and eroded strata the topographic grain of the valley floor trends generally northeastward. However (with the qualification stated above with

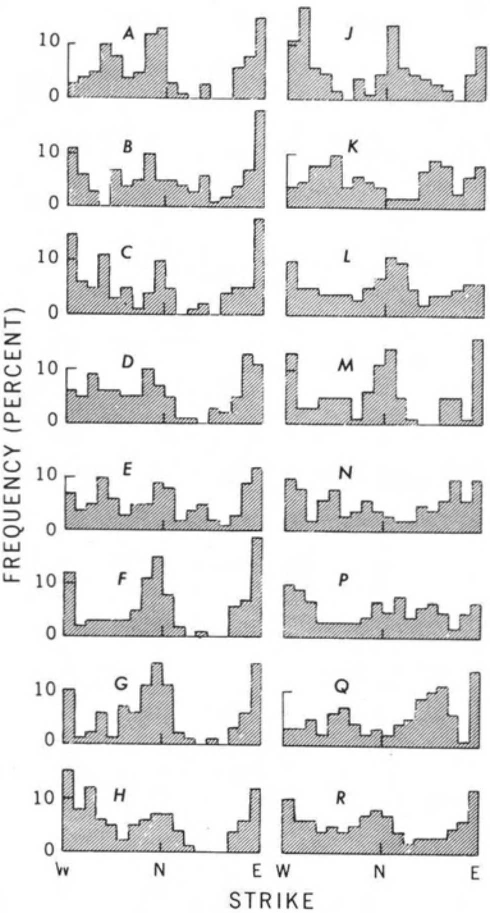

FIG. 3. Frequency of trends of fracture traces, by 10-degree classes. See Figure 1 for locations of photographs on which trends were measured. *Photographs* 178–181: graph *A*, Conococheague Limestone, 159 traces; *B*, Beekmantown Group, 83 traces. 195–197: *C*, Beekmantown Group, 79 traces; *D*, Edinburg Limestone, 144 traces; *E*, Martinsburg Shale, 126 traces. 25–27: *F*, Conococheague Limestone, 119 traces; *G*, Beekmantown Group, 120 traces. 71–73.—Edinburg Formation of Cooper and Cooper (1946): *H*, rock with strike of bedding about N30E, 112 traces; *J*, rock with strike of bedding about N15W, 81 traces. 212–214: *K*, Martinsburg Shale, 101 traces. 135–138: *L*, Conococheague Limestone, 82 traces; *M*, Beekmantown Group, 63 traces. 79–81: *N*, Conococheague Limestone, 120 traces. 57–59: *P*. Elbrook Dolomite, 98 traces; *Q*, Martinsburg Shale, 91 traces. *Graph R*, mean trends for carbonate rocks and shale, all photographs studied, 2,463 traces.

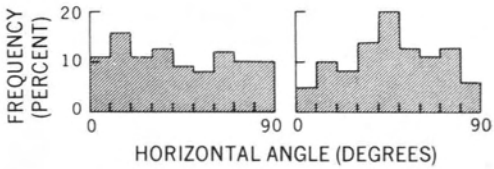

FIG. 4. Graphs showing frequency of horizontal angles between fracture traces and vertical planes tangent to contour lines at centers of traces. Conococheague Limestone and Beekmantown Group: Left, photographs 79–82, 174 traces; right, photographs 25–27, 228 traces.

regard to our method of mapping), relatively few fracture traces seem to trend northeast (Figure 3). Moreover, histograms of the frequency of horizontal angles between fracture traces and contour lines (Figure 4) show that the fracture traces commonly are not parallel to the contour lines. Evidently, the orientation of fracture traces is largely independent of topography.

Table 1 summarizes the structural setting in the tracts where trends of fracture traces were measured. Graphs *E*, *K*, *N*, and *Q* (Figure 3), which exhibit northwest and northeast modes, represent tracts where the rocks are inclined more steeply than in the other tracts studied. It therefore seems likely that the angle of dip of the strata in some way affected the orientation of joints and hence the trends of the fracture traces.

In relating patterns of fracture traces to joint patterns we were not able to study joints in the tracts where we studied fracture traces because outcrops are too scarce or too small in those tracts. An indirect means of study was therefore necessary. The geometry of the joints appears to be consistently related to the attitude of the strata, and therefore to offer a means of using data on joints in one tract to interpret fracture traces in another tract where the structure of the rocks is similar. In order to make this interpretation we measured the orientation of 70 or more joints at each of 13 localities (Figure 1), and examined small numbers of joints at many other places.

The geometry of joints in the well stratified sedimentary rocks of this part of the central Appalachian region may be characterized (Trainer, report in preparation) by three simple patterns (Figure 5). Three or more sets of joints are present at a given locality. One of these sets parallels the bedding, whatever its attitude. At one structural extreme (Figure 5, top), where the bedding joints are nearly horizontal, two other sets

TABLE 1. STRUCTURAL SETTING OF TRACTS IN THE SHENANDOAH VALLEY WHERE FRACTURE TRACES WERE STUDIED

Aerial photographs[1]	*Graph in Figure 3*	*Average strike and dip of strata*[2]
DJN-5T-178–181	*A, B*	N35°E, 35°SE
DJN-5T-195–197	*C, D, E*	N35°E, 30°SE; in part of tract underlain by Martinsburg Shale dip ranges from 30°SE to 40°NW (in axial region of syncline)
DJN-6T-25–27	*F, G*	N35°E, 20°SE
DJN-6T-71–73	*H, J*	N30°E to N15°W, 30°NW
DJN-5T-212–214	*K*	N40°E; dip ranges from 70°SE to 80°NW (in axial region of syncline)
DJN-5T-135–138	*L, M*	N50°E, 30°NW
DJN-5T-79–81	*N*	N65°E, 40°NW (some complex structure and steeper dips present)
DJN-5T-54–59	*P, Q*	N65°E, 40°NW (some complex structure and steeper dips present)

[1] See Figure 1 for locations, U. S. Department of Agriculture photographs, taken in October 1957.
[2] Data from Brent (1960, pl. 1) and from field observations.

are vertical and, in many places, mutually perpendicular. At the other extreme (Figure 5, bottom), where the bedding joints are vertical or nearly so, another vertical set is perpendicular to the bedding and one or more sets are horizontal or moderately inclined. Where bedding is neither horizontal nor vertical (Figure 5, middle), the joints include bedding joints; one or more sets that are vertical or nearly so; and, at many localities, a set of strike joints perpendicular to the bedding.

Consideration of this idealized geometry of joints suggests the following hypothesis about fracture traces and joints. Because the fracture traces developed along vertical fractures, their orientations and those of steeply dipping joints exhibit the same preferred trends in either horizontally bedded or near-vertical rocks. In moderately inclined strata many of the steeply dipping joints are not vertical, and these joints are unfavorable for the development of fracture traces. In these inclined rocks the preferred trends of fracture traces and of the entire population of nonhorizontal joints are therefore markedly different.

This hypothesis is consistent with the findings of other workers. Thus, in the Appalachian Plateau of Pennsylvania, Lattman and Nickelson (1958) found that the trends of fracture traces and the strikes of joints in flat-lying sandstone and shale have similar orientations. Hough (1960), in West Virginia, and Boyer and McQueen (1964) in Texas, arrived at similar conclusions in other studies of flat-lying rocks. On the other hand Matzke (1961) found in folded rocks in Pennsylvania that the dominant sets of joints and of fracture traces differ in trend by as much as 30° to 40°; and Meisler (1963, p. 15), also investigating folded rocks in Pennsylvania, found that fracture traces are numerous along one but not the other of the two dominant joint trends. Our samples of fracture traces are chiefly from tracts where the strata are neither flat-lying nor vertical. We have also found disparities between the most common strikes of joints and the most common trends of fracture traces.

Figure 6*A* summarizes strikes of joints at 13 localities (quarries, road cuts, or fields) where the orientations of 70 or more joints were measured. The rectangular shape of the graph shows that the total population of measured joints has little or no preferred orientation. Figure 6*B* summarizes the strikes of joints at these 13 localities which dip more steeply than 80° (that is, which are about vertical). These joints are preferentially oriented northwest, north, and east. The 13 localities sampled for Figures 6*A* and 6*B* represent a variety of structural settings, and the dip of the strata ranges from nearly horizontal to nearly vertical. Data from five of the localities are summarized in Figures 6*C* and 6*D*. At these five localities, all of which are in the western part of the Shenandoah Valley, the dip of the bedding ranges from 8° to 32°. The modes in these graphs are similar to those in Figure 6*B* but they are more pronounced.

The similarity of graphs *C* and *D* in Figure 6, summarizing data on joints, and of graphs *F, G, H, J, L,* amd *M* in Figure 3,

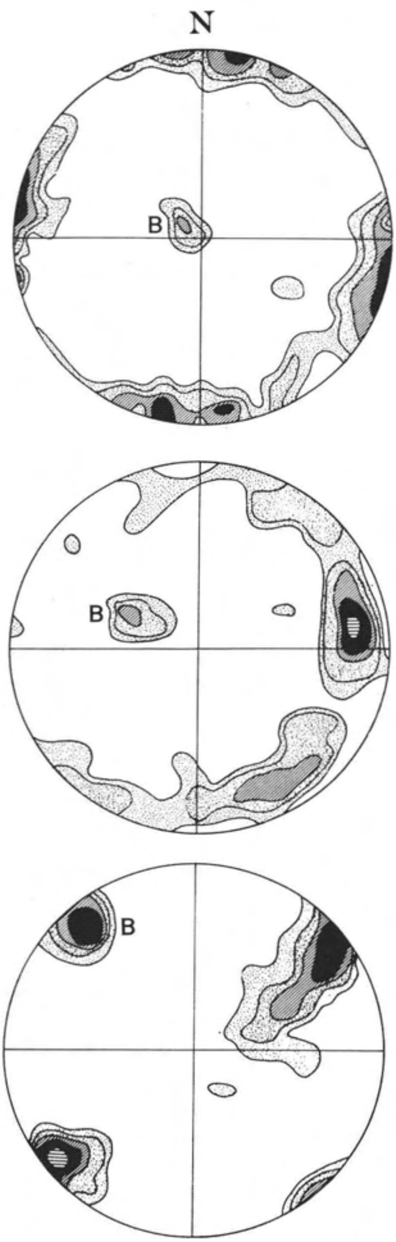

FIG. 5. Representative patterns of joints shown by equal-area diagrams of poles plotted on the lower hemisphere. Patterns and concentrations (in per cent of poles per 1 per cent of area) are: light stipple, 1–2; dark stipple, 2–4; inclined lines, 4–8; black, 8–16; and horizontal lines, greater than 16. Symbol "B" on diagram identifies set of bedding joints. See Figure 1 for localities where joints were studied. *Top*, Edinburg Formation of Cooper and Cooper (1946), average dip of bedding 9°SE; 100 joints. *Middle*, New Market Limestone, average dip of bedding 32°SE; 132 joints. *Bottom*, Sandstone in Brallier Shale, average dip of bedding 76°SE; 75 joints.

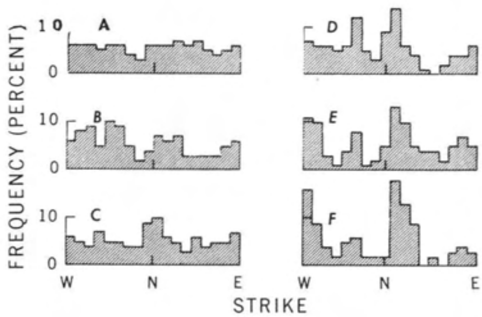

FIG. 6. Graphs which summarize the frequency of strikes of joints. Data are from localities marked by solid circles on Figure 1: *A*, all joints at 13 localities; *B*, all joints, at these 13 localities, which dip more steeply than 80°; *C*, all joints at the 5 localities marked with symbol "6" on Figure 1; *D*, all joints, at the five localities, which dip more steeply than 80°; *E*, all weathered joints at the 5 localities; and *F*, all weathered joints, at the five localities, which dip more steeply than 80°.

which presents data on fracture traces, is striking. We believe, on the basis of this similarity, that the prominence of the north and east trends among the fracture traces in the folded rocks reflects the selective development of traces along the near-vertical joints; and that this selective development explains the dissimilarity of the preferred trends of fracture traces and the preferred strikes of the total population of joints.

The trends of weathered joints (those which have been perceptibly affected by solution) at the five localities (Figure 6, *E*, *F*) are similar to those already noted, but their preferred orientation is even more accentuated. This finding suggests to us that although the fundamental factor favoring the formation of fracture traces from fractures is verticality, there may be an additional important factor (such as, for example, width of joint opening) which influences the effectiveness of the weathering.

We lack data on fracture traces in tracts where all the strata are horizontal or where all are vertical. However, in the axial regions of two synclines (photographs 195–197 and 212–214 in Figure 1) the dips of the strata range from 30°SE to 40°NW and from 70°SE to 80°NW, respectively; in the first of these regions the strata are inclined and (at the axis) horizontal, and in the second they are near-vertical, inclined, and horizontal. The preferred trends of fracture traces in samples from these axial regions (graphs *E* and *K*, Figure 3) include north and east modes suggestive of moderately in-

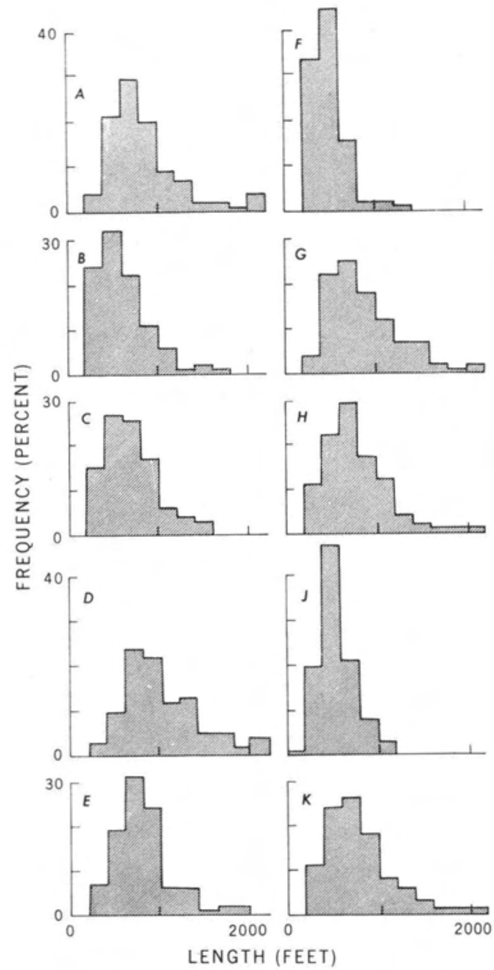

FIG. 7. Histograms which show the frequency of lengths of fracture traces, by 200-foot classes of length (traces longer than 2,000 feet grouped in 2,000- to 2,200-foot class). *Photographs* 177–180: Graph *A*, Conococheague Limestone and Beekmantown Group, 242 traces. 195–197: *B*, Beekmantown Group and Edinburg Formation of Cooper and Cooper (1946), 222 traces; *C*, Martinsburg Shale, 126 traces. 25–27: *D*, Conococheague Limestone and Beekmantown Group, 239 traces. 71–73: *E*, Edinburg Formation of Cooper and Cooper (1946), 246 traces. 212–214: *F*, Martinsburg Shale, 121 traces. 78–83: *G*, Elbrook Dolomite and Conococheague Limestone, 195 traces. 54–59: *H*, Elbrook Dolomite and Conococheague Limestone, 174 traces; *J*, Martinsburg Shale, 91 traces. *K*, mean lengths for 9 samples of carbonate rocks and shale, 1,653 traces.

clined strata, and northwest and northeast modes suggestive of vertical or horizontal strata.

LENGTHS OF FRACTURE TRACES

In Rockingham County the lengths of fracture traces (as seen on photographs having a scale of 1:21,400) average about 750 feet. The lengths are commonly between 300 and 1,200 feet; few are less than 200 feet, and few greater than 2,000 feet. The graphs in Figure 7, which illustrate the frequency of lengths of the fracture traces, show that the total population of lengths is rather homogeneous. However, the histograms suggest that the samples of traces in carbonate rocks commonly are more skewed and have greater dispersion than those in shale. The skewness is due in part to the fact that very short traces were not seen, but the greater skewness in the carbonate rocks reflects the presence in them of a few very long traces.

Figure 8, which illustrates the average lengths of fracture traces by strike classes, shows that the population of lengths is not so simple as is implied by the graphs in Figure 7. In nearly all the samples shown in Figure 8 the longest traces trend north, east, northwest, or northeast. On the average the north-trending fracture traces are conspicuously longer, and the east-trending traces markedly longer, than any of the others. For example, in graph *K* the north-trending traces are

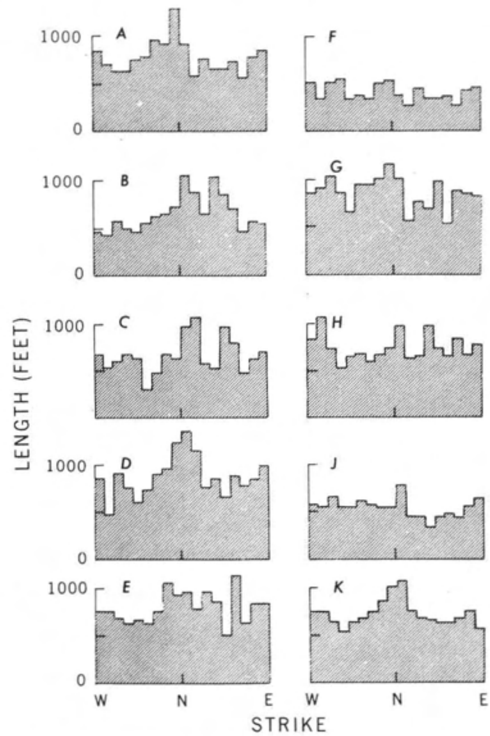

FIG. 8. Histograms which show the average lengths of fracture traces, in feet, by 10-degrees classes of trend (azimuth). The graphs represent the samples shown by corresponding letters in Figure 7.

TABLE 2. ABUNDANCE OF FRACTURE TRACES IN STRATIGRAPHIC UNITS EXPOSED ON PHOTOGRAPHS USED IN THIS STUDY, IN ROCKINGHAM COUNTY, VIRGINIA. VALUES SHOWN ARE SUMS FOR ALL PHOTOGRAPHS STUDIED

Formation	*Lithology**	*Area of exposure (sq. mi.)*	*Abundance*	
			Number (traces per sq. mi.)	*Total length (mi. per sq. mi.)*
Martinsburg Shale	Shale, calcareous shale, and siltstone; subordinate sandstone and limestone	10.3	38	4.3
Edinburg Formation of Cooper and Cooper (1946)	Limestone and shale	7.1	62	8.7
Lincolnshire and New Market Limestones	Limestone, in part cherty	1.7	56	7.3
Beekmantown Group	Dolomite, cherty; subordinate limestone	15.6	39	6.0
Chepultepec Dolomite	Limestone; subordinate dolomite and chert	0.3	83	13.6
Conococheague Limestone	Limestone, siliceous; subordinate sandstone	15.1	37	5.7
Elbrook Dolomite	Dolomite; subordinate limestone and shale	9.0	38	4.3
Rome Formation	Shale; subordinate sandstone, limestone, and dolomite	4.4	11	2.1

* Summarized from Brent, 1960.

about 50 per cent longer than the average of all the others. At least three hypotheses can be used to explain this association of greatest lengths and commonest trends: (1) each fracture trace represents a single joint, and north- and east-trending joints are notably longer than others; (2) each fracture trace is a single joint, but the association of length and trend is a matter of chance because the north- and east-trending classes, being the largest, have the greatest probability of including unusually long traces; and (3) some fracture traces may be single joints but many were formed from two or more adjacent, parallel joints which coalesced as a result of widening; and the north- and east-trending joints, being commonest, are most likely to coalesce in this manner. The occurrence of greater lengths of traces and the greater dispersion of lengths, in the carbonate rocks than in the shales, suggest to us that many fracture traces in the more soluble carbonate rocks were lengthened by coalescence of parallel joints, as is envisioned in the third hypothesis. It seems likely that one of the other hypotheses is applicable to relatively insoluble rocks such as the shales.

ABUNDANCE OF FRACTURE TRACES

On the photographs of each group studied we found 25 to 54 fracture traces per square mile, with an average of 39. For individual formations on a given group of photographs, not considering size of outcrop area, the range is from 16 to 85 traces per square mile. Expressing abundance in terms of total length, we found 3.7 to 8.6 miles of traces per square mile, with an average of 5.4 miles. For individual formations, regardless of area, the range is from 1.6 to 13.6 miles per square mile. In the Appalachian Plateau in West Virginia, underlain by sandstone and shale, Hough (1960, p. 13, 20) found a range of total lengths of about 1 to 7 miles per square mile, with lengths of 1 to 4 miles per square mile in most of the area he studied.

Table 2 lists the stratigraphic units represented on the photographs we studied, in order of relative age with the oldest at the bottom, and summarizes the abundance of fracture traces in these formations. It is noteworthy that fracture traces are less abundant in formations which are predominantly shale and more abundant in the carbonate rocks. Further, among the carbonate-rock formations, several of those with abundant fracture traces are predominantly limestone with a high content of calcium carbonate, although several with less abundant fracture traces are more shaly, more cherty, or more dolomitic. Chemical analyses of samples of limestone and of dolomite listed

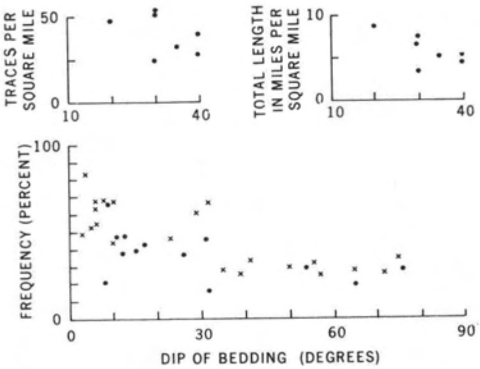

FIG. 9. Graphs which show relations between (1) the abundance of fracture traces and of near-vertical joints and (2) the dip of the bedding. Upper left—number of fracture traces per square mile *vs* dip of bedding, for carbonate-rock formations in Rockingham County. Upper right—total length of fracture traces, in miles per square mile, *vs* dip of bedding, for carbonate-rock formations in Rockingham County. Below—frequency of joints inclined more steeply than 80 degrees, in per cent of total number of joints measured, *vs* dip of bedding, for carbonate-rock and sandstone formations; a dot indicates a value for a locality in the Shenandoah Valley in Rockingham County, and an *x* a value for a locality in the Appalachian region near Rockingham County (after Trainer, report in preparation).

by Edmundson (1945, p. 98–100) show approximately the following contents of calcium carbonate: Elbrook Dolomite (three samples), 53 to 55 per cent; Beekmantown Group one sample), 53 per cent; New Market and Lincolnshire Limestones (many samples), 94 to 99 per cent; and Edinburg Formation of Cooper and Cooper (1946) (one sample), 90 per cent. Thus the solubility of the rock seems to be an important control on the abundance of fracture traces developed in it.

Consideration of the geometry of joints in the Shenandoah Valley and surrounding region, as described in an earlier part of this report, suggests that the relative abundance of vertical joints is in part controlled by the attitude of the strata. Data collected in the field are thought to confirm this suggestion. Thus, the points in the lower graph in Figure 9 define a line which slopes downward to the right (decrease in relative abundance of joints with increase in dip of the strata). This plot appears to curve, so that it levels off at intermediate dips; farther to the right it may steepen again, indicating increase in abundance as the inclination of the bedding approaches the vertical. Statistical analysis shows, however, that the plot can alternatively be interpreted as being rectilinear. A regression line having the equation

$$Y = 57.2 - 0.471X$$

has been computed for the points in the graph. The regression coefficient (-0.471) is significantly different from zero at the 5-per cent level of probability. The 95-per cent confidence interval for the slope of the line is from -0.269 to -0.673, and the 95-per cent confidence interval for the y-intercept is from 52.6 to 61.8. Clearly, additional data are needed, particularly from the more steeply dipping rocks, to clarify the relationship between abundance of vertical joints and dip of bedding.

In the Shenandoah Valley and surrounding region joints are on the average somewhat more numerous in moderately inclined strata than in gently inclined or horizontal beds. However, the abundance of vertical joints, relative to the total number of joints, seems to overbalance that disparity, so that vertical joints are more numerous in horizontal and gently inclined beds than in those which dip at intermediate angles. In the upper graphs in Figure 9 the abundance of fracture traces has been plotted against the dip of the bedding. Despite dispersion of the points these plots suggest that fracture traces, like joints, are more abundant in gently dipping rocks than in those which dip more steeply. Thus, we conclude that the gross structure of the folded strata is an important control on the abundance of fracture traces.

The chief value of study of the abundance of fracture traces appears to be in hydrology and geomorphology because it relates to the porosity, permeability, and weathering of the rocks. In a study of data from wells in carbonate rocks in Pennsylvania, Lattman and Parizek (1964) found that the rocks there have greater porosity and permeability near fracture traces than in areas between the traces. Areal study of the abundance of fracture traces offers promise as an approach to the study of ground water in fractured rocks.

CONCLUSIONS

Structure and lithology are the primary controls on formation of fracture traces in the Shenandoah Valley. The traces are formed chiefly along vertical fractures, and because several sets of joints are not vertical in folded strata, structure controls both the preferred trends and the abundance of potential fracture traces. Lithology is a strong control on the abundance and lengths of fracture traces but seems to have no appreciable effect on their preferred trends. An unidentified factor, which may be initial width of joint opening, is thought to favor the widening of some sets of vertical joints by weathering, over that of other sets. We believe the chief value in study of the preferred trends of fracture traces lies in its bearing on the origin of the traces Study of the abundance of fracture traces offers a potentially valuable means of investigating the development of porosity in the rocks. Fracture traces are therefore of interest in a wide range of fields, including structural geology, hydrology, and geomorphology.

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