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STRUCTURAL ANALYSIS OF DIVERGENT FOLDS
IN THE MARTINSBURG AND ORANDA FORMATIONS
MIDDLETOWN 7.5-MINUTE QUADRANGLE, VA.
*(Report to accompany the geologic map
of the Middletown quadrangle, Virginia
Orndorff and others, 1993)*

by
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**STRUCTURAL ANALYSIS OF DIVERGENT FOLDS
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The Martinsburg Formation in the Middletown quadrangle is complexly folded (Orndorff and others, 1993). Half wavelengths of folds range from several tens of feet up to about 2,000 feet and average about 500 feet. Cleavage is omnipresent, forming convergent fans. The belief by some geologists that bedding is obliterated by cleavage is incorrect; bedding is quite apparent, especially by the presence of abundant thin to thick beds of siltstone and graywacke sandstone. Cleavage, rather than being a detriment to bedding attitude determination, aids in indicating whether beds are right side up or are overturned. Fold form is typically similar, with orthogonal thinning of the limbs, but with the length of the "split" (the distance between beds along cleavage) remaining constant. The folds are of two types: chevron folds (kink bands) with planar limbs and very abrupt hinges, and broader, curvilinear folds.

As seen on the geologic map (Orndorff and others, 1993) and from stereographic plots of bedding (fig. 2A), the regional orientation of folds in the Martinsburg and Oranda Formations is N.37°E. However, there is a more northerly cross-trend of bedding paralleling a syncline whose axis parallels Molly Booth Run in the extreme southeast corner of the map. Figure 1 is a histogram showing the variation in trend of the strike of bedding in the Martinsburg and Oranda Formations in the Middletown quadrangle. It shows one peak at N.35-40°E., the average trend of all folds, and a secondary orientation at N.10-15°E., the more northerly trend of bedding along Molly Booth Run. Poles to bedding in the cross-trend is shown in fig. 2C and the remaining general regional trend is plotted in Figure 2B. These diagrams show that the average regional trend is a combination of the "normal" regional trend (N.42°E.) and the cross-trend (N.16°E.). Figures 2D-F are the poles to bedding that are contoured. Figure 2G is a summary diagram that illustrates the various differences in strike of bedding. The more northerly cross-trend might represent a later period of deformation. Alternatively, the variation in trend might be the result of essentially coeval deformation and variable strain vectors. The regional trends do not appear to be folded by the cross-trend along Molly Booth Run, suggesting the former possibility. Also, if the cross-trends are a later feature, then the regional cleavage should have been rotated by that later deformation, and possibly, a second-generation cleavage might have been developed. A second-generation regional cleavage was not seen. Figure 3 shows plots of poles to cleavage in the Middletown quadrangle. All

cleavages have an average trend of N.38°E. (Figure 3A). Note that the cleavage of the other two domains vary by only 2 degrees (Figures 3B and C), not the amount of rotation suggested by the 26° difference in bedding trends between the regional and cross-trend orientations. The summary diagram (Figure 3G demonstrates the similarity of all cleavage readings).

These data suggest that the cross-trend does not represent a distinct later period of deformation. Northerly trending folds have been mapped in the carbonate rocks north of the Martinsburg belt in the Middletown quadrangle. These possibly represent the same variation in stress direction as seen in the Martinsburg. The regional plunge of folds in the Martinsburg and Oranda Formations is to the southwest. The direction and amount of plunge can be estimated from the plots of bedding (fig. 2) and from the plots of the intersections of bedding and cleavage (fig. 4). In figure 2A the great circle of poles to bedding defines all the folds having an average plunge of 7.4° to S.33°W. Plunges of 3.7° and 5.9° to the southwest are indicated for the other orientations of bedding (fig. 2B and C). The intersections of bedding and cleavage, which statistically approximate the direction and amount of plunge, indicates a plunge of 3° to the southwest for all plots (Figures 4 A, B, C). The data for all these plots are summarized in fig. 4G.

The dip of the axial planes of the folds in the Martinsburg and Oranda Formations may be approximated from the plots of poles to cleavage (Figure 3). The folds are upright and cleavage forms convergent fans in the folds, that is, cleavage generally dips northwest in the southeast limbs of folds and dips southeast in northwest limbs of folds. The maxima in all plots of fig. 3 indicates that the southeast-dipping cleavage is more abundant. Therefore, the axial planes of the folds also dip to the southeast, about 79°, judging from the maxima in fig. 3A.

The equal-area projections in Figures 2-4 indicate the following for all folds in the Martinsburg and Oranda Formations in the Middletown quadrangle:

Strike of axial planes: N.37°E.

Dip of axial planes: 79°SE.

Plunge: 3-7°, southwest (probably closer to 7°)

This study defines the folding in the Martinsburg Formation. Comparison of these folds with larger-scale folds in both the underlying carbonate rocks and the overlying Massanutten Sandstone indicates that the folding is disharmonic. This may be due to either a strain gradient or detachments within the Martinsburg. A similar disharmony exists between the heterogeneous rocks of the Middle Ordovician New Market, Lincolnshire, and Edinburg, and the brittle rocks of the

underlying dolomites. Another possibility for the complex folding in the Martinsburg, suggested by several workers, is that these folds, as well the Massanutten synclinorium itself, are structures in the footwall of the Blue Ridge thrust.

Reference cited

Orndorff, R.C., Epstein, J.B., and McDowell, R.C., 1993, Preliminary geologic map of the Middletown quadrangle, Virginia: U.S. Geological Survey Open-file map 93-24, scale 1:24,000

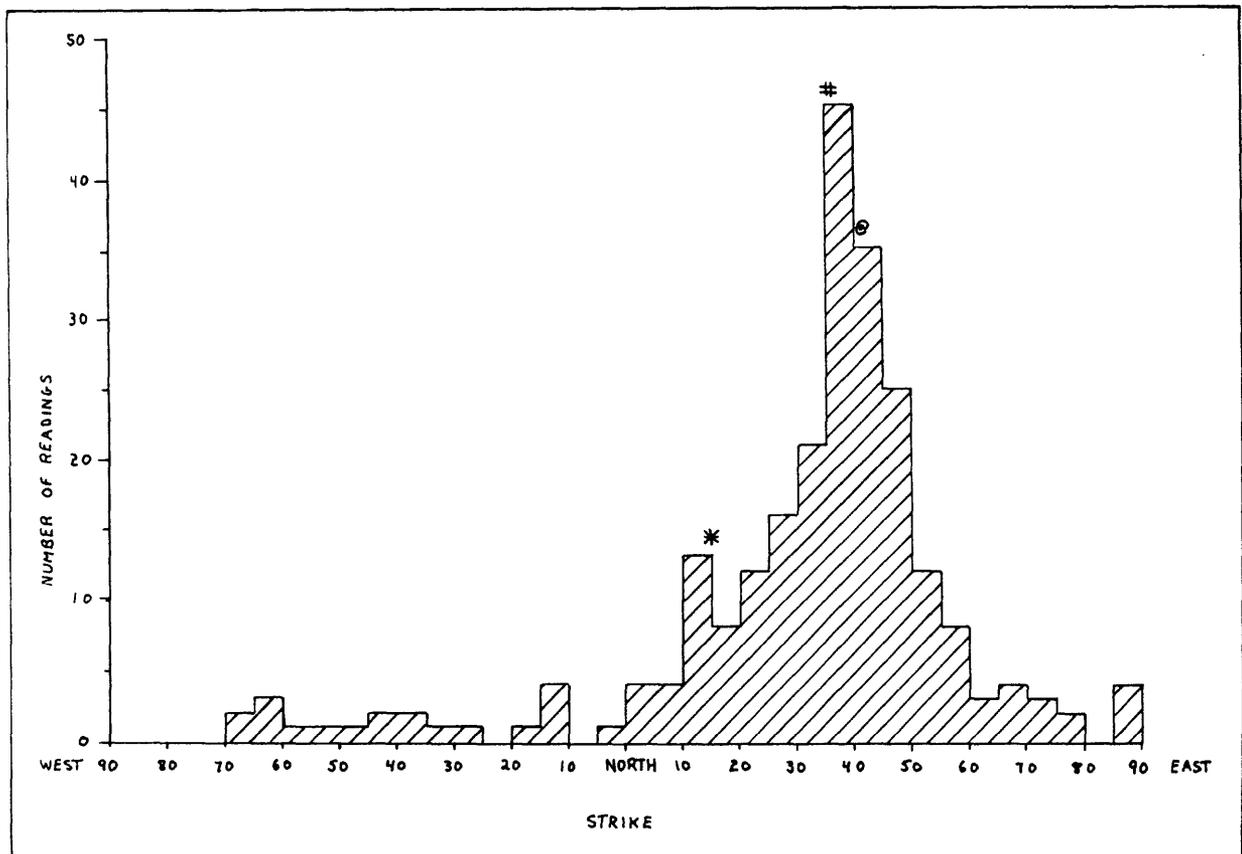


Figure 1. Histogram showing variation of strike in the Martinsburg and Oranda Formations, Middletown 7.5-minute quadrangle. n=237.

#, maxima of all bedding from fig. 2A (N.37°E.)

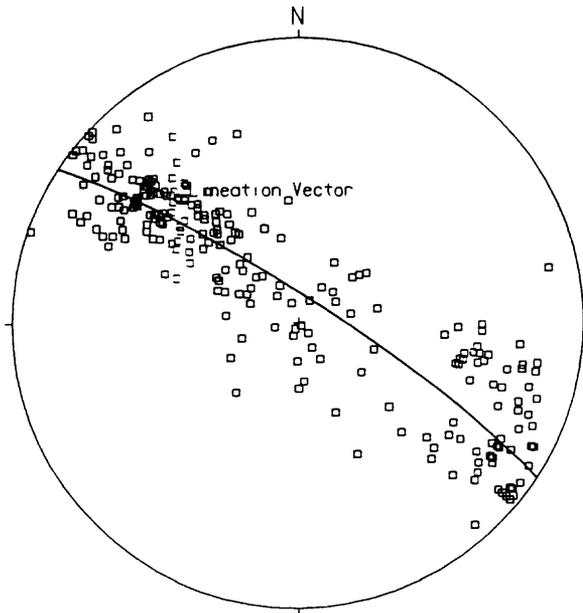
@, Maxima of bedding in regional orientation from fig. 2B (N.42°E.)

*, Maxima of bedding in cross-trends from fig. 2C (N.16°E.)

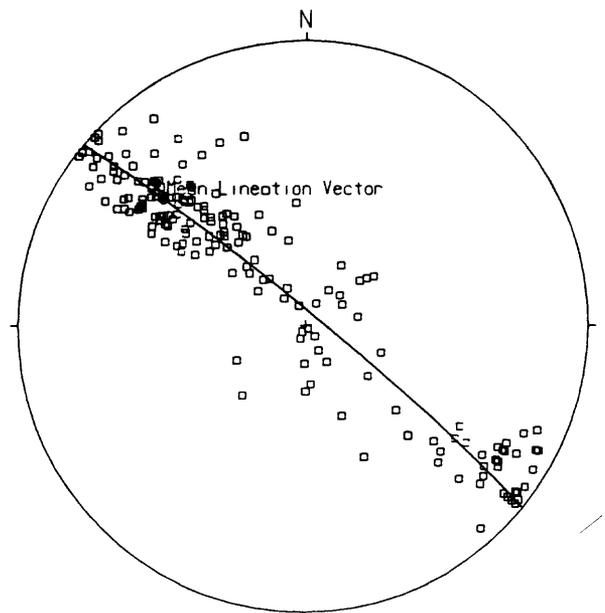
Figure 2. Equal-area projections (lower hemisphere) of poles to bedding in the Martinsburg and Oranda Formations, Middletown quadrangle.

- A. All bedding. Maxima at N.37°E., 62°SE. The great circle defines all the folds having an average plunge of 7.4° to S.33°W. n=237.
- B. Bedding with regional orientation (@ in fig.1). Maxima at N.42°E., 67°SE. The great circle defines the folds having an average plunge of 3.7°, S.40°W. n=179.
- C. Bedding with cross-trends (* in fig. 1). Maxima at N.16°E., 75°NW. The great circle defines the folds having an average plunge of 5.9°, S.18°W. n=237.
- D. All bedding (# in fig. 1, same as A, contoured, showing great circle and β . Contour intervals at 0.5, 3, 6, 9, and 12 percent per 1 percent area.
- E. Bedding with regional orientation (@ in fig.1, same as B, contoured, showing great circle and β . Contour intervals at 1, 3, 6, 9, 12, and 15 percent per 1 percent area.
- F. Bedding with cross-trends (* in fig. 1, same as C, contoured, showing great circle and β . Contour intervals at 1, 5, 9, 13, 17, 21, and 25 percent per 1 percent area.
- G. Summary diagram (equal area projection, lower hemisphere) of bedding in the Martinsburg and Oranda Formations, Middletown quadrangle, showing maxima, β , and great circles (solid line, all bedding readings; long-dashed line, bedding in regional trends; short-dashed line, bedding in cross-trends). Also shown are the maxima for the intersections of bedding and cleavage (IBC) from fig.4.

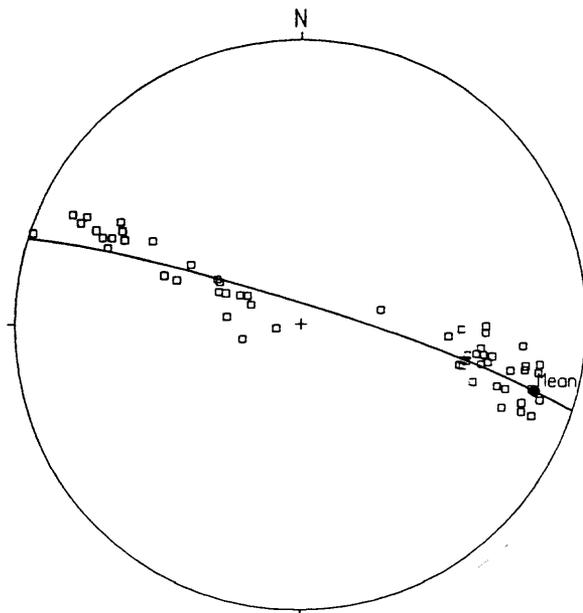
Figure 2.-Continued



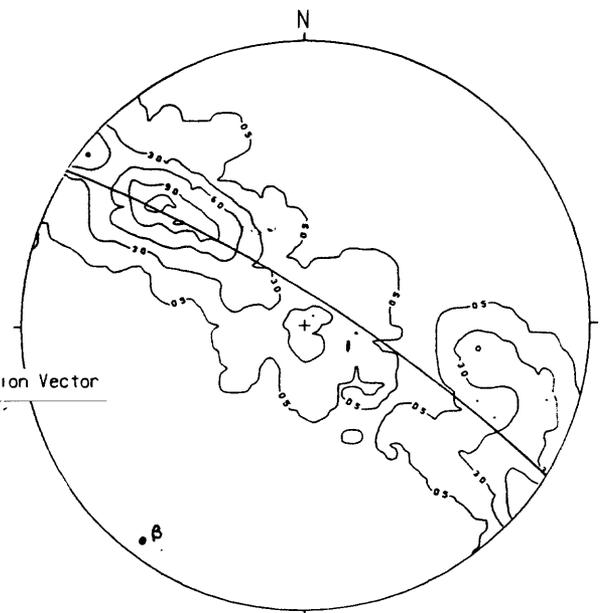
A



B

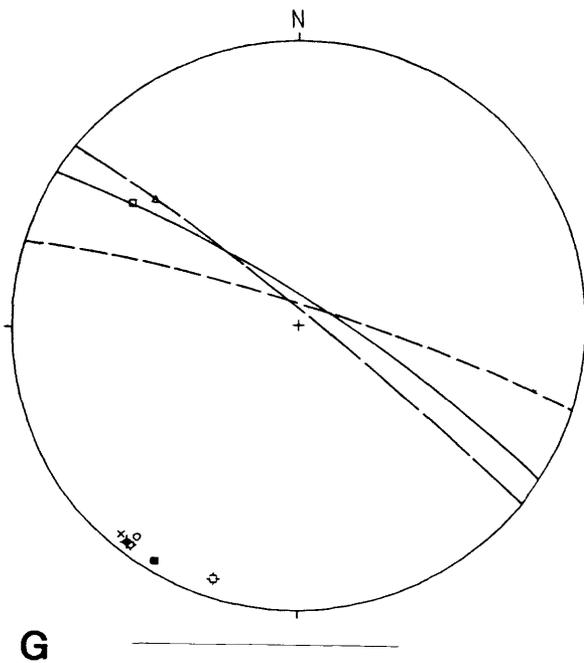
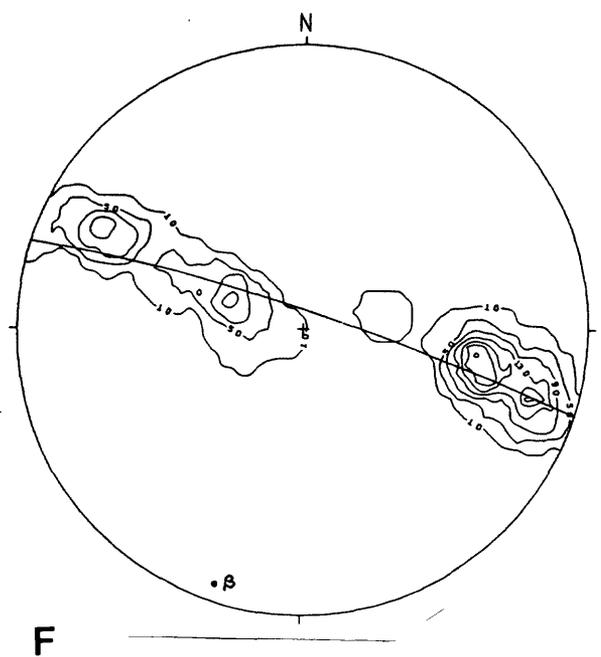
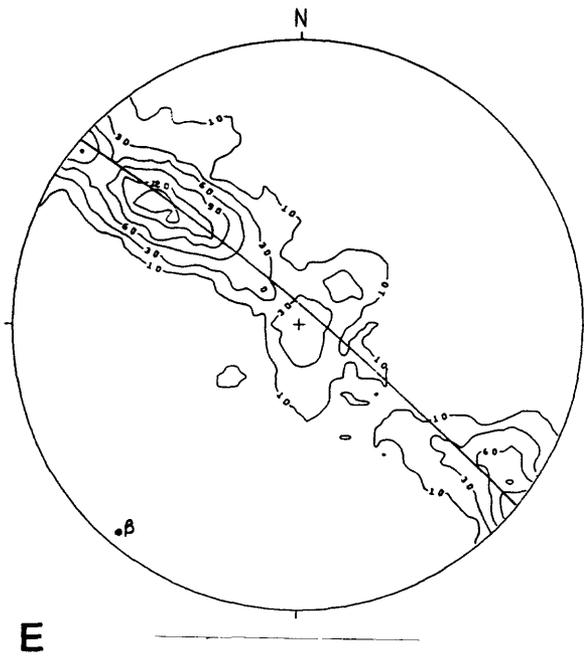


C



D

Figure 2.-Continued



- Maxima, all
- △ Maxima, regional-trends
- + Maxima, cross-trends
- b, all
- × b, regional trends
- ◇ b, cross-trends
- ◇ IBC all
- ◆ IBC regional trends
- IBC cross-trends

Figure 3. Equal-area projections (lower hemisphere) of poles to cleavage in the Martinsburg and Oranda Formations, Middletown quadrangle.

- A. Cleavage associated with all bedding readings (# in fig. 1). Maxima at N.38°E., 79°SE. n=151.
- B. Cleavage associated with bedding with regional orientation (@ in fig. 1). Maxima at N.40°E., 79°SE. n=121.
- C. Cleavage associated with bedding with cross-trends (* in fig. 1). Maxima at N.36°E., 83°SE. n=29.
- D. Cleavage associated with all bedding readings (# in fig. 1, same as A, contoured, showing great circle. Contour intervals at 0.5, 3, 6, 9, 12, 15, and 18 percent per 1 percent area.
- E. Cleavage associated with bedding with regional orientation (@ in fig. 1, same as B, contoured, showing great circle. Contour intervals at 0.5, 4, 8, 12, and 15 percent per 1 percent area.
- F. Cleavage associated with bedding with cross-trends (* in fig. 1, same as C, contoured, showing great circle. Contour intervals at 3, 6, 9, 12, 15, and 18 percent per 1 percent area.
- G. Summary diagram (equal area projection, lower hemisphere) of cleavage in the Martinsburg and Oranda Formations, Middletown quadrangle, showing maxima, and great circles (solid line, all bedding readings; long-dashed line, bedding in regional trends; short-dashed line, bedding in cross-trends).

Figure 3.-Continued

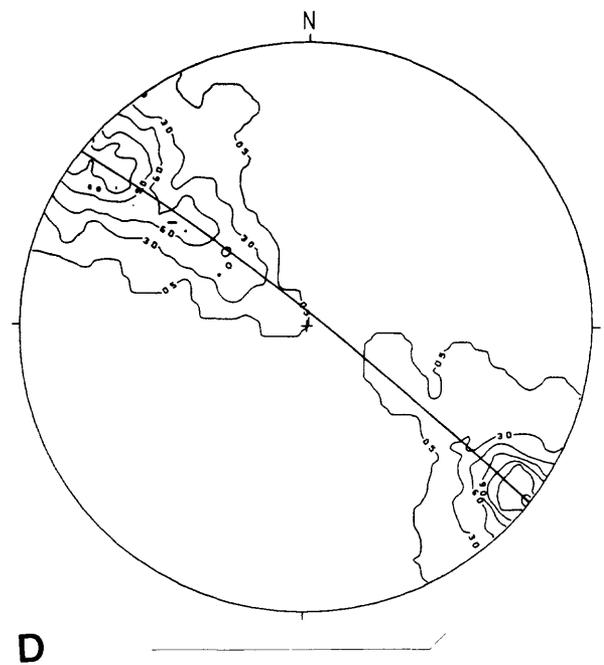
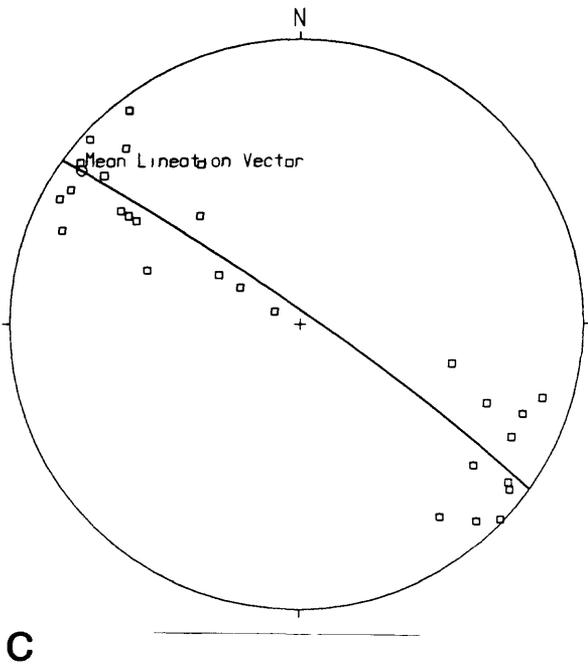
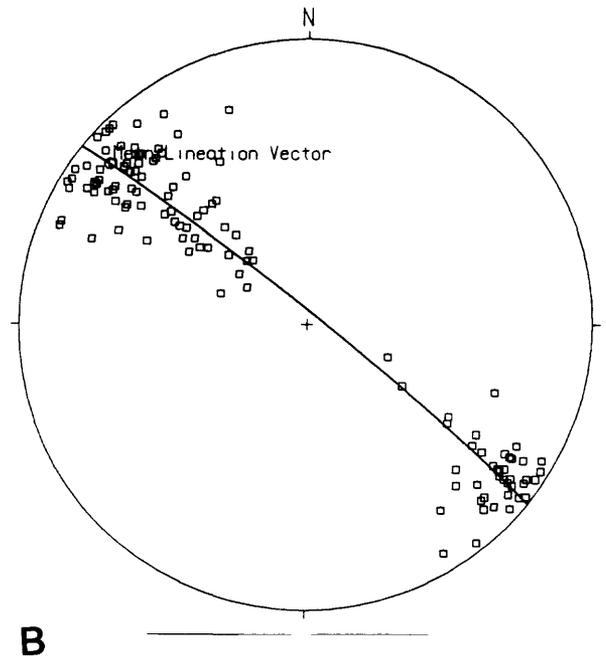
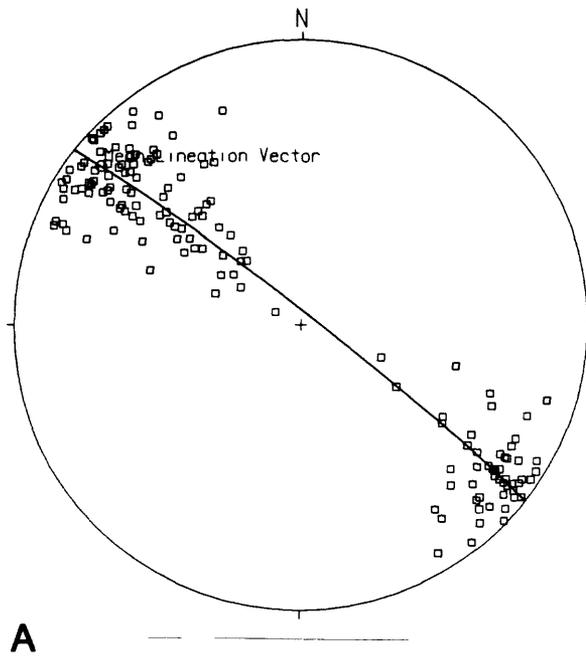


Figure 3.-Continued

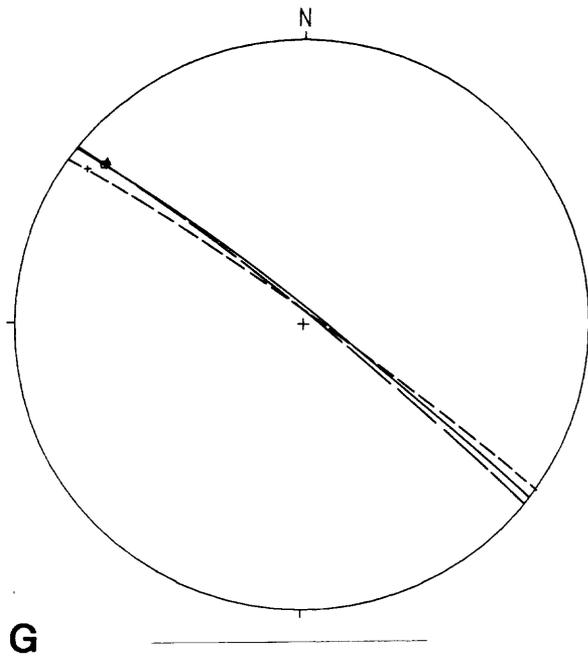
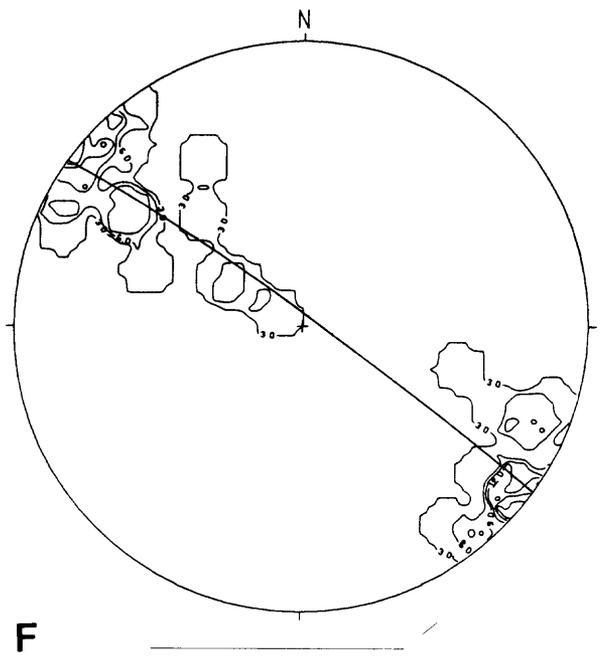
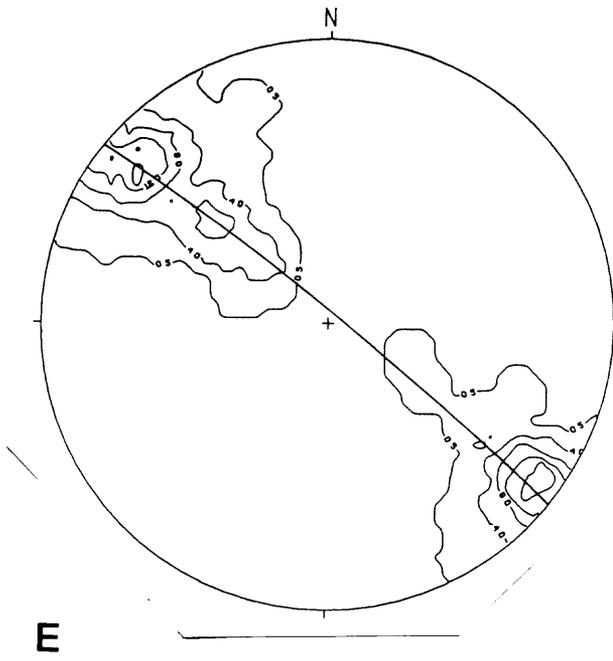


Figure 4. Equal-area projections (lower hemisphere) of intersections of bedding and cleavage (IBC) in the Martinsburg and Oranda Formations, Middletown quadrangle.

- A. IBC associated with all bedding readings (# in fig. 1). Maxima at 3° , S.37 $^{\circ}$ W. n=147.
- B. IBC associated with bedding with regional orientation (@ in fig. 1). Maxima at 3° , S.38 $^{\circ}$ W. n=117.
- C. IBC associated with bedding with cross-trends (* in fig. 1). Maxima at 3° , S.31 $^{\circ}$ W. n=30.
- D. IBC associated with all bedding readings (# in fig. 1, same as A, contoured, showing great circle. Contour intervals at 0.8, 7, 14, 21, 28, and 35 percent per 1 percent area.
- E. IBC associated with bedding with regional orientation (@ in fig. 1, same as B, contoured, showing great circle. Contour intervals at 1, 9, 17, 25, 33, 41, and 49 percent per 1 percent area.
- F. IBC associated with bedding with cross-trends (* in fig. 1) same as C, contoured, showing great circle. Contour intervals at 3, 6, 9, 12, 15, 18, and 21 percent per 1 percent area.
- G. Summary diagram (equal area projection, lower hemisphere) of intersections of bedding and cleavage (IBC) in the Martinsburg and Oranda Formations, Middletown quadrangle, showing maxima, and great circles (solid line, all bedding readings; long-dashed line, bedding in regional trends; short-dashed line, bedding in cross-trends).

Figure 4.-Continued

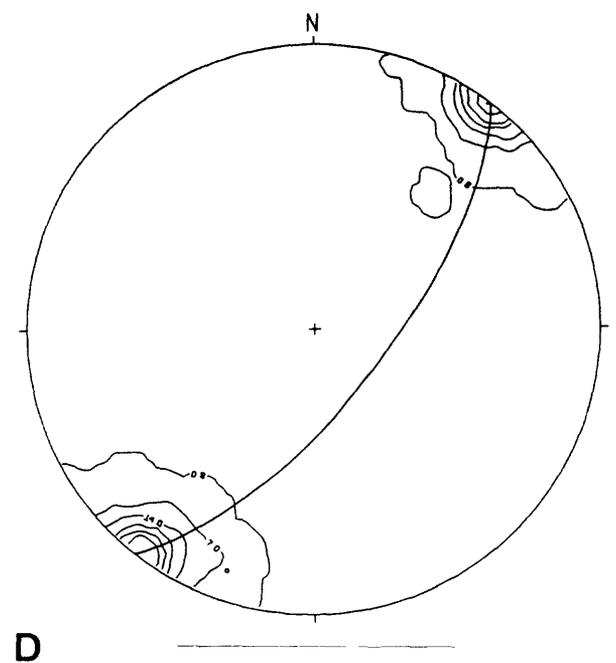
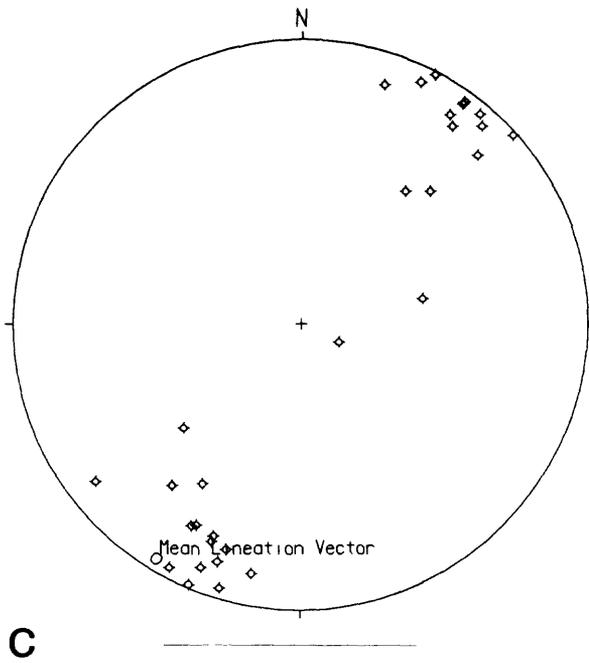
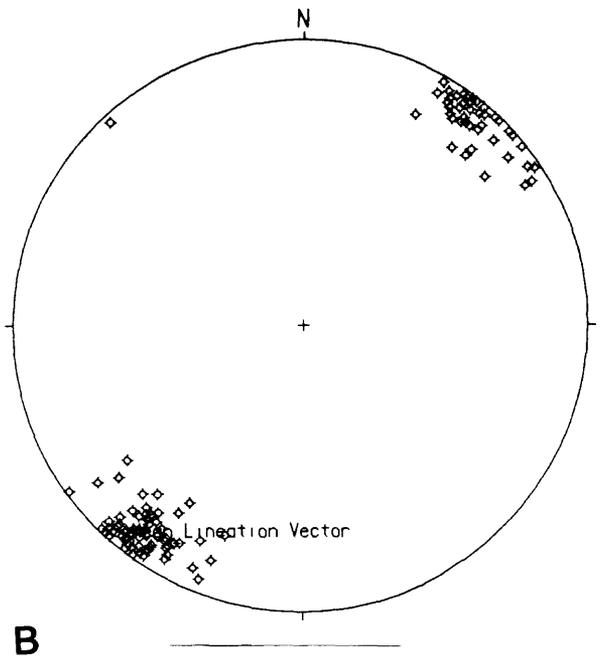
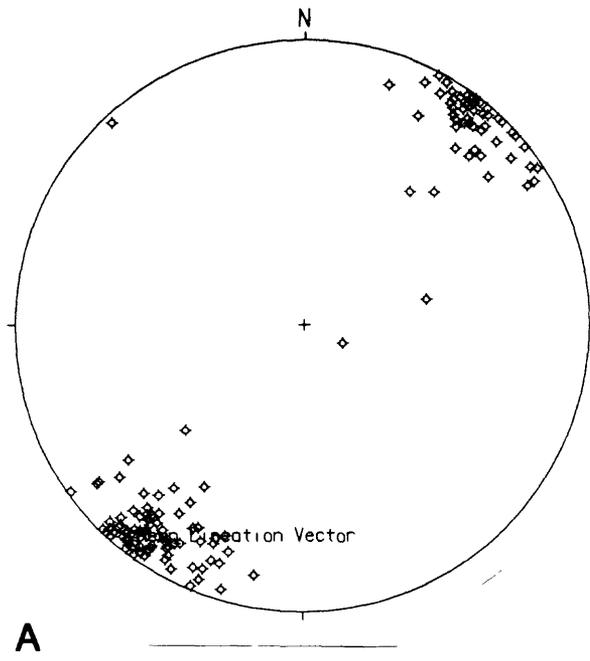


Figure 4.-Continued

