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Polyphase deformation in the metamorphosed Paleozoic rocks east of the Berkshire massif

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Polyphase Deformation in the Metamorphosed Paleozoic Rocks East of the Berkshire Massif

by

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Introduction

The purpose of this trip is to demonstrate the following; a) the age relationship and geographic distribution of four generations of minor folds, b) the relationship of each generation to the major structures outlined by detailed stratigraphic mapping, and c) the structural evolution of a segment of the eugeoclinal belt east of the Berkshire Massif. The evolution begins with intensive thrusting in the Taconic orogeny (Middle to Late Ordovician) culminates with multiple generations of regional folds in the Acadian orogeny (Middle to Late Devonian) and terminates with normal faulting of Triassic age.

The Cambrian and Ordovician stratigraphy of the area consists of metamorphosed (kyanite-sillimanite grade) shales, graywackes, mafic volcanic rocks and minor amounts of chert and serpentinite. Cyclical bedding, some of which is graded, is common in the Cobble Mountain Formation of Middle Ordovician age but is rare in the older part of the section below the Moretown Formation. Abundant feldspar in the gneiss of the upper member of the Cobble Mountain Formation suggests that this unit is a flysch deposit derived from the island arc complex now represented by the rocks along the Bronson Hill anticlinorium to the east. A complete description and regional correlation of the Cambrian and Ordovician section is discussed in Hatch and Stanley (1974).

The regional setting of the Blandford-Woronoco area is discussed in other trips in this volume and need not be repeated here. Interested readers are referred to Stanley (1975) and other papers included in U.S. Geological Survey Professional Paper 888.

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Method of Study

In order to understand the axial surface maps of each fold generation (figs. 1, 3, and 5) it is necessary to describe in some detail the methods employed in this study. Minor folds are particularly useful in revealing the finite strain of deformation, the geometry and age of major structures, and structural chronology. Before any of this can be done, however, it is essential to separate folds into coeval systems. In this study minor fold generations are designated, from oldest to youngest, F_1, F_2, ... F_n. Each generation is considered the result of a broadly coeval stress field.

Within any one area of contiguous outcrop, the age sequence of minor folds was based on the principle of superposition -- a fold was considered younger if it deformed the axial surface and, in some localities, the axes of an older set or sets of folds. After the age sequence was established in well-exposed localities, the style, orientation, and intensity of deformation for each fold generation were documented for each rock type. Data on the attitude of hinge and axial surface were recorded for a number of folds of each generation so as to evaluate the overall consistency, or lack thereof, in orientation. Although quantitative measures of strain and deformation were not used in this work, qualitative estimates were based on fold tightness and cleavage development; the latter criterion proved to be the most meaningful parameter of deformation intensity throughout the areas of study. Most of my work was centered in the Cobble Mountain Formation, because this formation in the Blandford-Woronoco area contains the most complete and best preserved sequence of superposed folds. Descriptive parameters of each generation are summarized in table 2 (Stanley, 1975).

Correlation of minor folds between localities of extensive outcrop within a quadrangle was based on relative age, style, and orientation. Although the form of the axial-surface cleavage proved to be the most reliable characteristic of each fold generation, no single criterion was consistently dependable. The age criteria are most successfully employed where the distance between outcrops is small; they become less reliable where the distance is 16 or 24 km (10 or 15 miles), at which scale orientation is usually of little value, and style and relative age can only be used with considerable caution. Any scheme of regional correlation must be evaluated by the density and aereal distribution of reliable data on superposition. Correlation of structural events among separate areas within a region can be based on the geological age of the rocks in which a given fold generation is developed and on the geometric relationship between minor and major folds. If, regarding the latter parameter, the statistical axial surface of a given generation of minor folds is parallel to the calculated axial surface of a major fold, then the two are considered coeval. Regional correlation of major structures implies that their associated minor folds are correlative in a structural sense. Using these methods, I have been able to assign and correlate approximately 2,000 minor folds to their proper fold generation within and among the areas in western Massachusetts and Connecticut (Stanley, 1975).

Field data on each minor fold generation were analyzed in spherical projection and on geologic maps (figs. 1-6). Equal-area nets of fold hinges and poles to axial surfaces were prepared for subareas within each area. Subareas were delineated on the basis of the pattern of axial-surface poles which formed either diffuse point maxima or fairly complete great-circle girdles (figs. 2, 4, 6). Geologic maps showing axial surfaces of minor folds were prepared for each fold generation (figs. 1, 3, 5). Axial surfaces were used instead of fold axes because: (1) they proved to be the most reliable age criterion; (2) they provide a qualitative estimate of the intensity of deformation; (3) they record the presence of younger fold generations because they are essentially planar before they are subsequently deformed; and (4) they represent a principal symmetry plane of finite strain (perpendicular to $\lambda 3$, axis of minimum quadratic elongation).

The axial-surface maps were constructed by plotting all available orientation data for a given minor fold generation. The orientation of axial surfaces between data points was interpolated where the surrounding coverage was dense. The density of these surfaces on each map represents the abundance of data in any one area. The resulting maps (figs. 1, 3, and 5) show: (1) the systematic change in orientation of axial surfaces from place to place; (2) the areas of intense deformation associated with each fold generation; and (3) the relationship of each minor fold generation to the major structures of the area.

Fold Generations - discussion

The minor folds in the Blandford-Woronoco area are grouped into generations F1 to F4 according to superposed relationships displayed in such well exposed areas as the southeastern part of Cobble Mountain Reservoir (Stops 1-8, fig. 8).

Of the eight style characteristics listed in table 1 (Stanley, 1975), profile form and axial surface cleavage are by far the most useful and reliable identifying features of each generation. Folds of the two older generations are commonly tight to isoclinal in profile. An excellent axial surface schistosity is everywhere present in F2 folds. Although F1 folds nowhere have a cleavage marking the axial surface, many of the F2 hinges contain micas oriented at an angle to the F2 axial surface schistosity and the bedding. These micas form limbs of very tight chevron folds whose axial surfaces are parallel to the F2 schistosity. The limb micas represent an older schistosity that has been almost totally obliterated by the developmeant of the penetrative schistosity of the F2 folds. Examples of F1 folds will be seen at stops 1-3 (fig. 9).

Folds of the two younger generations are generally crenulate in profile in the schists of the area and are commonly more open and quite distinct from the older two generations. Cleavage is commonly not present in the youngest fold generation (F4), except for a crenulate cleavage that is poorly developed in some of the tighter, more highly deformed folds of this group. F4 folds are most easily recongnized where the crenulate cleavage, slip cleavage, or spaced schistosity of F3 folds is systematically bent by F4 (stop 7, fig. 9).

Folds of generation F3 display the greatest range in cleavage development. From stop 1 to stop 7 in the Cobble Mountain area very weakly developed crenulate folds without cleavage are progressively deformed to folds first with crenulate cleavage,1/ then with slip cleavage, and finally with a well-developed spaced schistosity.

These stages represent higher levels of strain within F3 and are also used as a indicator of the intensity of deformation for other fold generations. It must be emphasized, however, that the strain represented by each generation is a summation of strain associated with the development of that generation plus the additional strain imposed on it by younger superimposed folds. No attempt has been made to separate the two in this study.

Let us now consider the intensity of strain and the range of intensities associated with each fold generation as indicated by cleavage. Little can be said for F1 because the number of observations is few. A schistosity presumable existed but it has been largely obliterated by recrystallization and repeated deformation in the three younger fold generations. F2 folds represent a uniformly high level of strain, because the associated cleavage is everywhere a well-developed, penetrative schistosity. The strain level of F3 shows the treatest range of all four generations. The strain level may vary systematically through most of the cleavage stages within an area of less than a square mile. High levels of strain are located along the hinges and east limbs of major folds in the central part of the Blandford-Woronoco area and in the synform in the south-eastern part of the area (E on fig. 3). The strain level appears to drop off both to the north and west. The major antiform in the central part of the Blandford-Woronoco area was in part developed during F4 time (B on fig. 3). The high level of strain represented by F3 folds on its eastern limb is thus a product of both the strain associated with F3 and F4.

1/ Designations for cleavages which are paralled to the axial surfaces of minor folds include the terms schistosity, crenulate cleavage, slip cleavage, and spaced schistosity. The term schistosity is restricted to cleavages where the micas are all essentially oriented parallel to the cleavage plane in the rock. Crenulate cleavage is formed by the parallelism of short limbs of crenulate folds in schist. Although discrete planes of slip or fabric discontinuity are not present on the scale of the thin section or hand specimen, a distinct surface where the micas change orientation abruptly does exist on the scale of the outcrop. Slip cleavage is a more advanced stage of crenulate cleavage. Here discrete slip has occurred across the cleavage plane and the rock commonly breaks along this surface. In both crenulate cleavage and slip cleavage the micas are oriented at an angle to the cleavage plane. Spaced schistosity refers to an advanced stage of slip cleavage in which the rock is divided into two fabric domains - the actual cleavage planes where the micas are parallel or closely parallel to the cleavage, and the intercleavage domains where the micas are discordant to the cleavage. Here the micas form the remains of small crenulate folds. Crenulate cleavage, slip cleavage, and spaced schistosity are part of an overall sequence of cleavage development. Each stage represents a higher level of strain. The boundaries between these categories are gradational and quite arbitrary since they have not been quantified. Although this sequence is commonly typical of F3, there is sufficient evidence to indicate that it is the dominant mechanism of cleavage development in all four fold generations.

F4 folds represent a relatively low level of strain with a restricted range. Generally, the minor folds are broad undulations that only develop into fairly tight crenulate folds along the antiform outlined by the eastern bend in the base of the Goshen Formation (symbol DSg, fig. 5).

Axial surface maps

Axial surface maps have been prepared for the youngest three generations of folds in the Blandford-Woronoco area, no such map for F1 was prepared because the number of reliable observations is few. However, F1 folds are numerous in the lower member of the Cobble Mountain Formation, since well-preserved graded beds are either normal or inverted on minor antiformal folds of F2.

As shown on the axial surface maps, most of the minor fold data are confined to the Ordovician rocks in the Blandford-Woronoco area, because the outdrop is very abundant in this area and is more limited to the west. The area underlain by Silurian and Devonian rocks has been mapped by Hatch and S. F. Clark, Jr. and is excluded from this study. My work, however, has included a detailed study of the basal 100 meters of the Silurian and Devonian section.

F2 folds:

Figure 1 is based on 270 axial surfaces of F2 minor folds distributed rather evenly in the area of study. The axial surfaces of these minor folds are systematically folded by most of the major folds labelled by letters A through F in figure 1 and, hence, are older than folds A-F. Two of these younger folds (A and D) are outlined by the Taconic unconformity. In the pre-Silurian rocks a large refolded antiform outlined by the contact between the lower and upper members of the Cobble Mountain Formation is the largest and most conspicuous major structure of F2 age. The nose of this fold, here called the Woronoco fold, is situated at locality 1 (fig. 1) where the schistosity trends at right angles to the bedding, and almost totally obliterates it. A smaller F2 hinge is mapped at locality 2 (fig. 1). Close inspection of the contact between the two members of the Cobble Mountain Formation (Ocl and Ocu, fig. 1) shows that south of locality 1 the axial schistosity of F2 folds cuts the map contact (bedding) at an acute angle with a sinistral sense (as indicated by an arrow drawn from the axial surface normal to the bedding normal in spherical projection). North of locality 1, except just south of locality 2, the sense has changed to dextral. The generalized trace of the axial surface of this major antiform (heavy line on fig. 1) is located in the lower member of

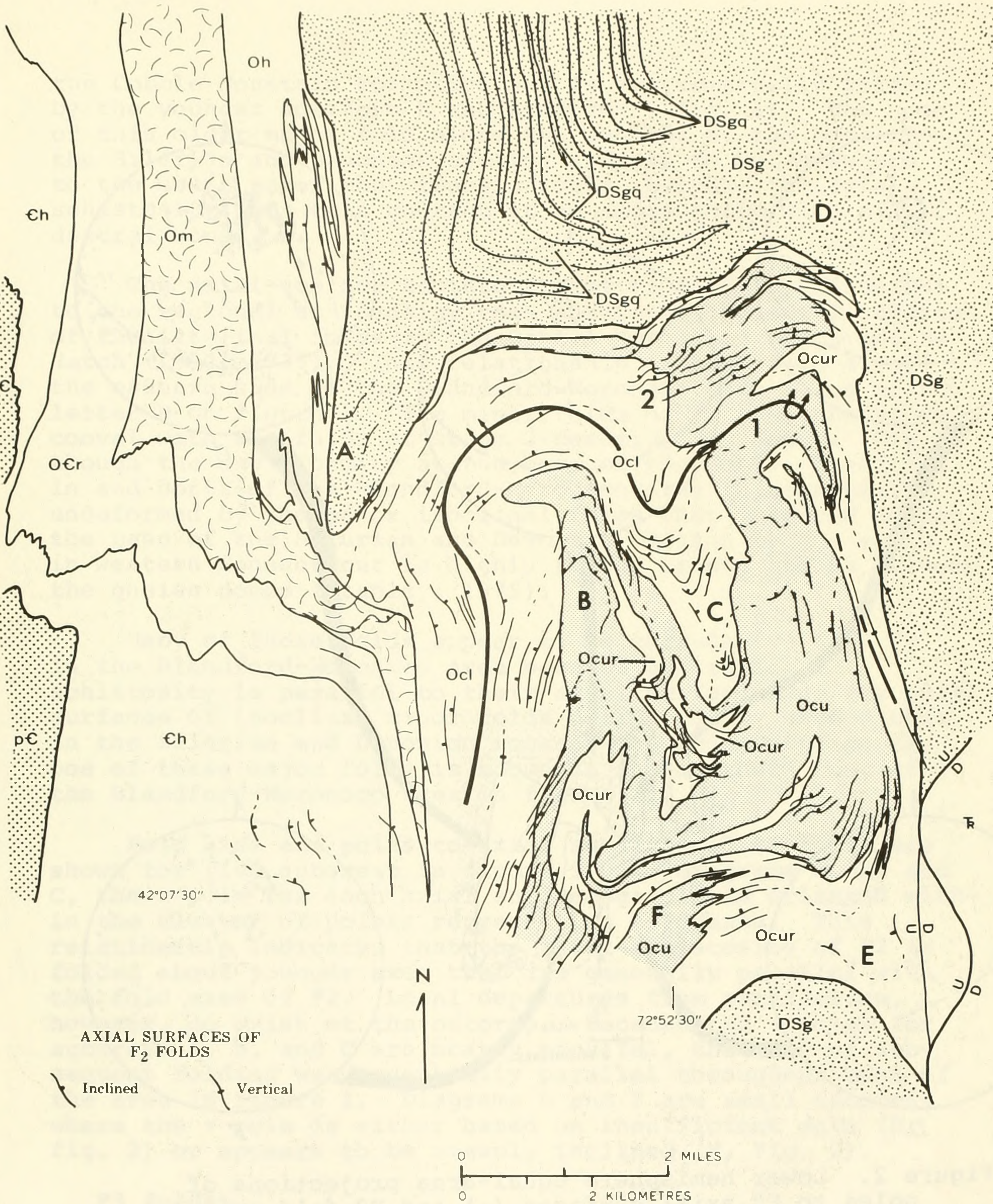

Figure 1. Geologic map of the Blandford-Woronoco area showing axial surfaces of F2 folds. Stratigraphic units and symbols are listed in Stanley 1975; also, p€, Precambrian rocks; Ocur, rusty schist and gneiss in the upper part of the Cobble Mountain Formation. Letters A through F and numbers 1 and 2 are discussed in text. Heavy curved line marks axial surface of Woronoco fold, outlined by the contact between Ocl and Ocu.

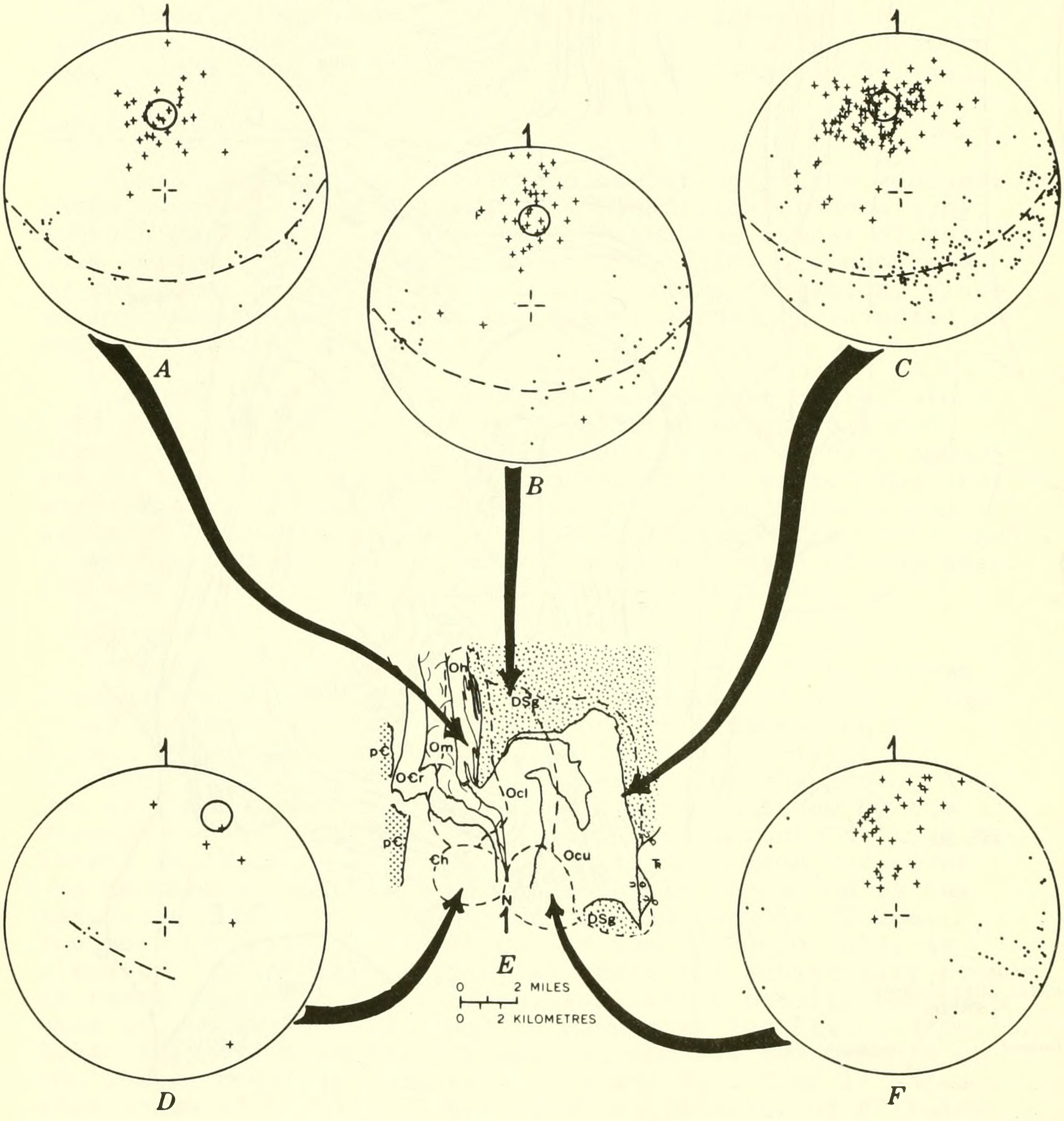

Figure 2. Lower hemisphere equal-area projections of poles to F2 axial surfaces (·) and F2 fold axes (+) for 5 subareas in the Blandford-Woronoco area. The dashed lines are great circles that approximate the distribution of poles to axial surfaces. The pole to the great circle (π pole) is shown by the center of the 1 percent circle. Subarea A, 40 axial surfaces, 26 fold axes; subarea B, 47 axial surfaces, 23 fold axes; subarea C, 165 axial surfaces, 107 fold axes; subarea D, 12 axial surfaces, 6 fold axes; subarea F, 42 axial surfaces, 32 fold axes. Plane of projection is horizontal with north indicated by arrow.

the Cobble Mountain Formation and is systematically folded by the younger antiform B and synform C (fig. 1). The nose of this older major fold along the contact at the base of the Silurian and Devonian section appears to be somewhere to the south under the Triassic rocks, because the axial schistosity cuts this contact at an acute angle with a dextral sense.

The axial-surface schistosity of F2 folds is identical to the regional schistosity that parallels the axial surfaces of the isoclinal folds in the Goshen Formation described by Hatch (1968, 1975). This relationship is best seen along the eastern side of the Blandford-Woronoco area south of the letter D on figure 1. The minor folds of F2 are, therefore, coeval with the folds of stage 2 described by Hatch. Although the unconformity at the base of the Goshen Formation in and north of the Blandford-Woronoco area is apparently undeformed by the major isoclinal folds that fold the Goshen, the base of the Silurian and Devonian section to the south in western Connecticut is highly folded around and in between the gneiss domes (Stanley, 1975).

Many of these folds appear to be correlative with F2 in the Blandford-Woronoco area because the regional schistosity is parallel to their axial surfaces and the axial surfaces of isoclinal minor folds delineated by graded beds in the Silurian and Devonian rocks. The axial surface of one of these major folds is shown in the southern part of the Blandford-Woronoco area in figure 1.

Fold axes and poles to axial surfaces of F2 folds are shown for five subareas in figure 3. In diagrams A, B, and C, the π pole for each axial surface girdle is oriented within the cluster of points representing fold axes. This relationship indicates that the axial schistosity of F2 is folded about younger axes that are generally parallel with the fold axes of F2. Local departures from parallelism, however, do exist at the outcrop. Because the π poles for subareas A, B, and C are nearly parallel, the axes of subsequent folding was essentially parallel throughout most of the area in figure 1. Diagrams D and F are small subareas where the π pole is either based on insufficient data (D, fig. 2) or appears to be steeply inclined (F, fig. 2).

F3 folds:

Figure 3 is based on the axial surfaces of 900 F3 folds of which 650 are plotted as data points for the axial surface map. Areas of high strain level are located in the major folds at H, in the fold at F, on the east limb of antiform B, and in the synform which is continuous from C to E (fig. 3).

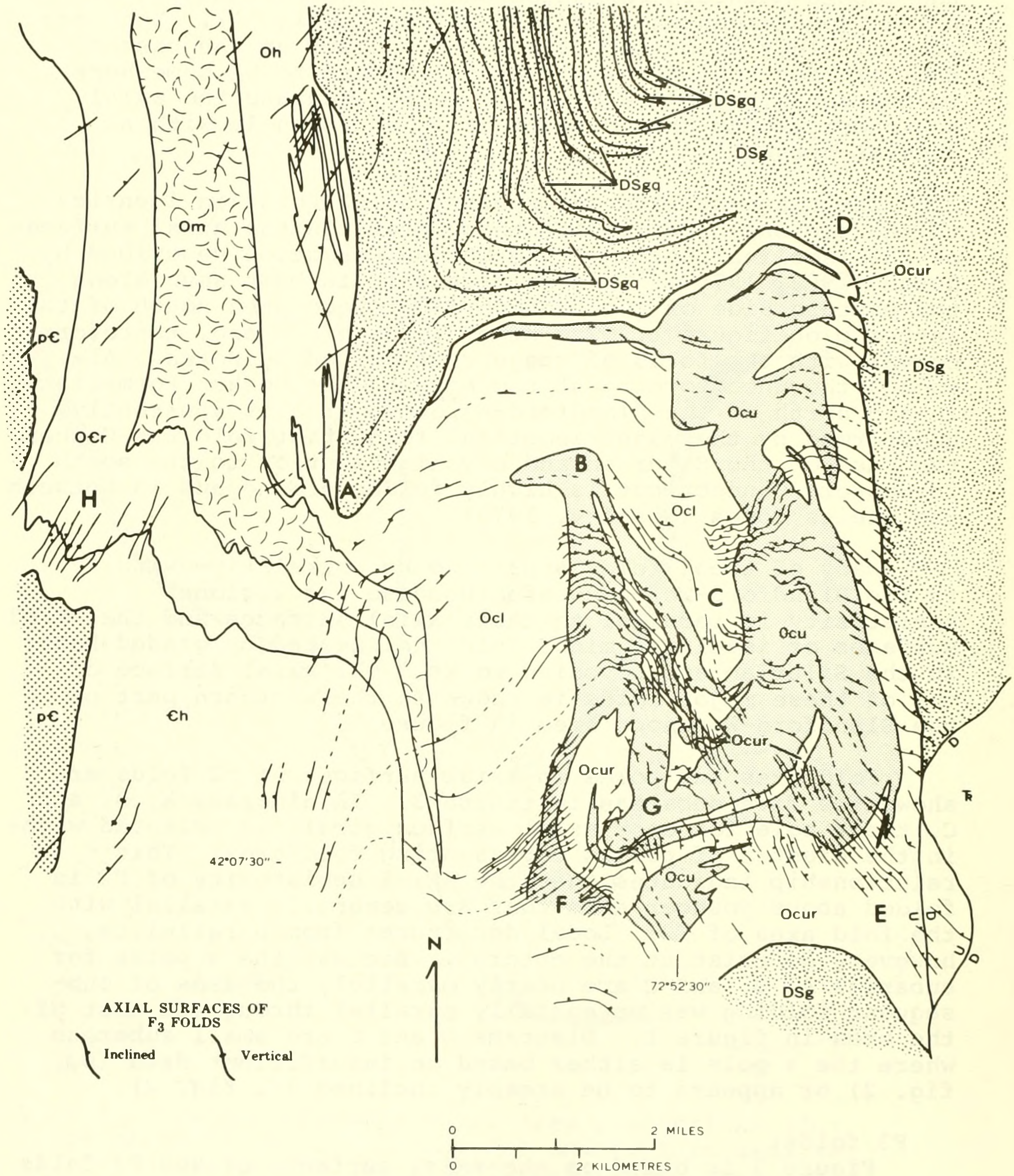

Figure 3. Geologic map of the Blandford-Woronoco area showing axial surfaces of F3 folds. Stratigraphic units and symbols are listed in Stanley (1975) and described in figure 1. Letters A through H and number 1 are discussed in text.

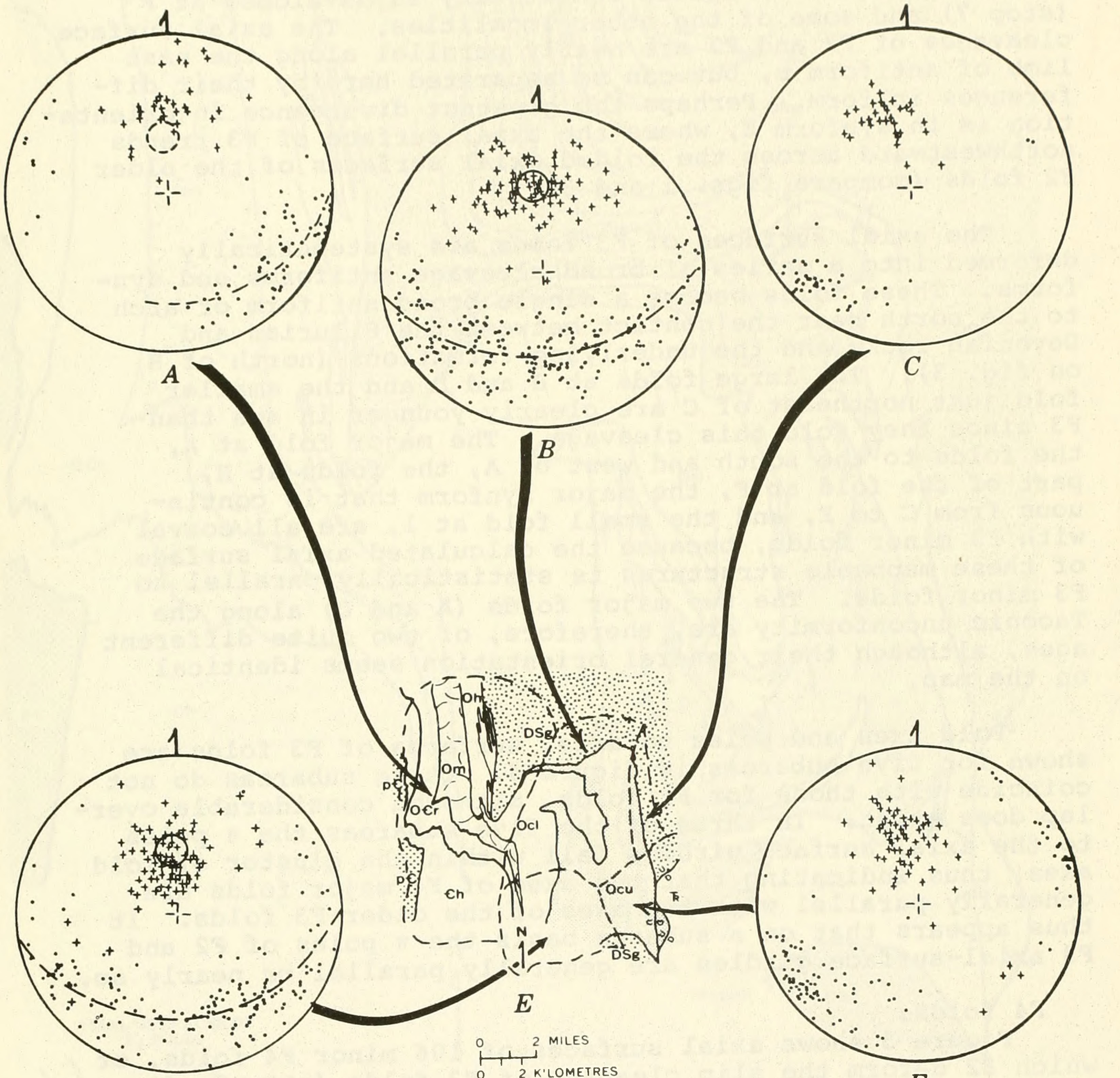

Figure 4. Lower hemisphere equal-area projections of poles to F3 axial surfaces (·) and F3 fold axes (+) for 5 subareas in the Blandford-Woronoco area. The dashed lines are great circles that approximate the distribution of axial surface normals. The center of the 1 percent circle (π pole) is the pole to the great circle. Subarea A, 79 axial surfaces, 32 fold axes; subarea B, 235 axial surfaces, 85 fold axes; subarea C, 46 axial surfaces, 32 fold axes; subarea D, 158 axial surfaces, 83 fold axes; subarea F, 118 axial surfaces, 68 fold axes. Plane of projection is horizontal with north indicated by arrow.

In these areas the slip cleavage is well developed and the folds are tight. A spaced schistosity is developed at F (stop 7) and some of the other localities. The axial surface cleavages of F2 and F3 are nearly parallel along the east limb of antiform B, but can be separated here by their differences in form. Perhaps the greatest divergence in orientation is in synform E, where the axial surface of F3 trends northwestward across the folded axial surfaces of the older F2 folds (compare figs. 1 and 3).

The axial surfaces of F3 folds are systematically deformed into a series of broad cleavage antiforms and synforms. These folds become a single broad antiform or arch to the north near the contact between the Silurian and Devonian rocks and the underlying formations (north of B on fig. 3). The large folds at B and D and the smaller fold just northeast of C are clearly younger in age than F3 since they fold this cleavage. The major fold at A, the folds to the south and west of A, the folds at H, part of the fold at F, the major synform that is continuous from C to E, and the small fold at 1, are all coeval with F3 minor folds, because the calculated axial surface of these mappable structures is statistically parallel to F3 minor folds. The two major folds (A and D) along the Taconic unconformity are, therefore, of two quite different ages, although their general orientation seems identical on the map.

Fold axes and poles to axial surfaces of F3 folds are shown for five subareas in figure 4. These subareas do not coincide with those for F2 folds, although considerable overlap does exist. In three of the five subareas the π poles to the axial surface girdles fall within the cluster of fold axes, thus indicating that the axes of F4 major folds are generally parallel with the axes of the older F3 folds. It thus appears that on a subarea basis the π poles of F2 and F3 axial-surface girdles are generally parallel or nearly so.

F4 folds:

Figure 5 shows axial surfaces of 106 minor F4 folds, of which 32 deform the slip cleavage of F3 folds (stop 7, fig. 9). The remaining 74 crenulate folds are assigned to this generation because their axial surfaces are parallel to the 32 known F4 folds and discordant to F3 folds, although the two sets are not directly superposed.

F4 folds which directly fold the older slip cleavage (heavy barbell symbol, fig. 5) are best developed and more numerous along the axial traces of major F4 folds (compare figs. 3 and 5). The strain associated with F4 folds is slightlymore intense along the easternmost antiform than those to the west.

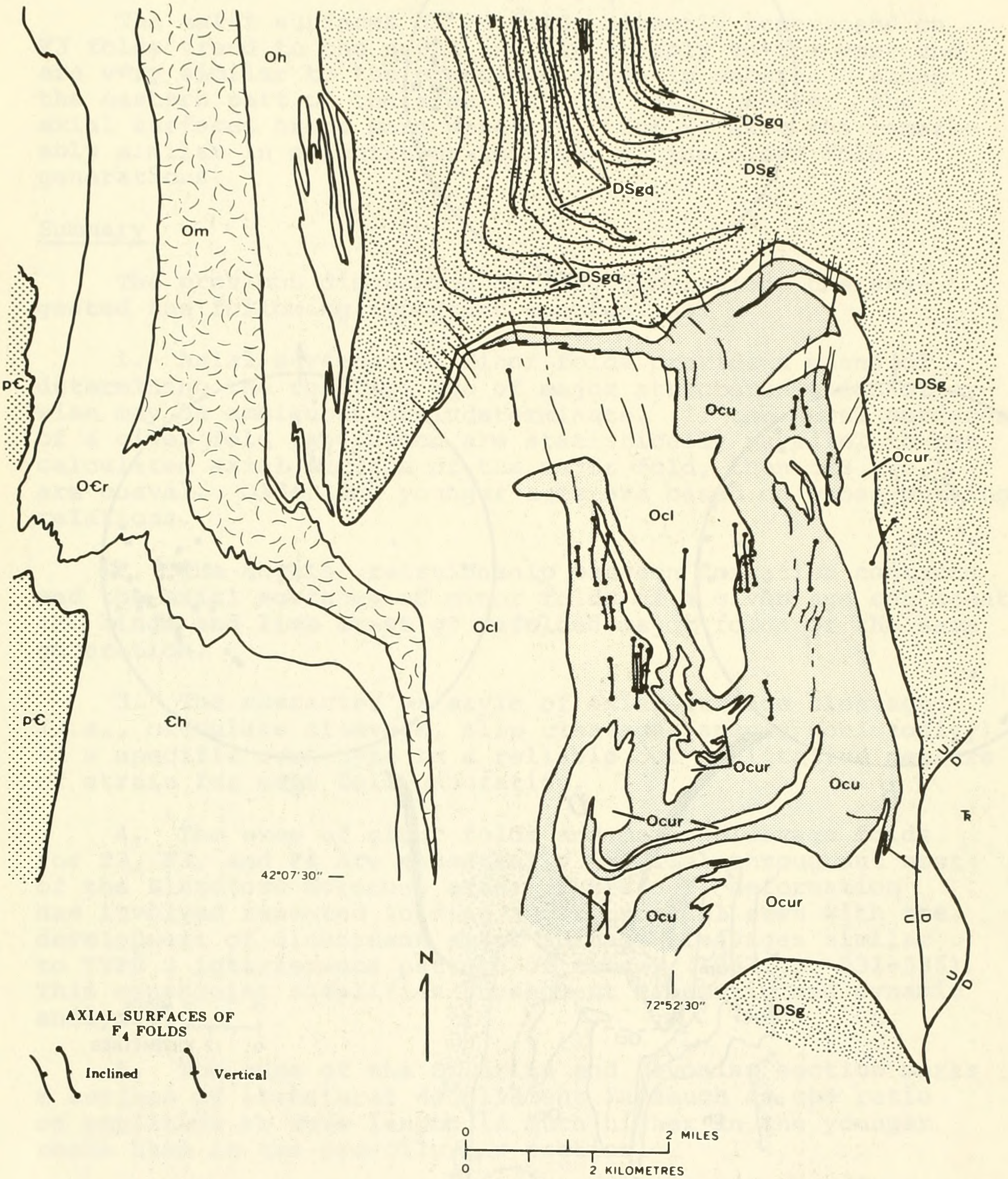

Figure 5. Geologic map of the Blandford-Woronoco area showing axial surfaces of F4 folds. Heavy barbell symbols represent F4 folds that deform slip cleavage of F3 folds. Light symbols are F4 folds that deform F2 schistosity. Stratigraphic units and symbols are listed in Stanley (1975) and described in figure 1.

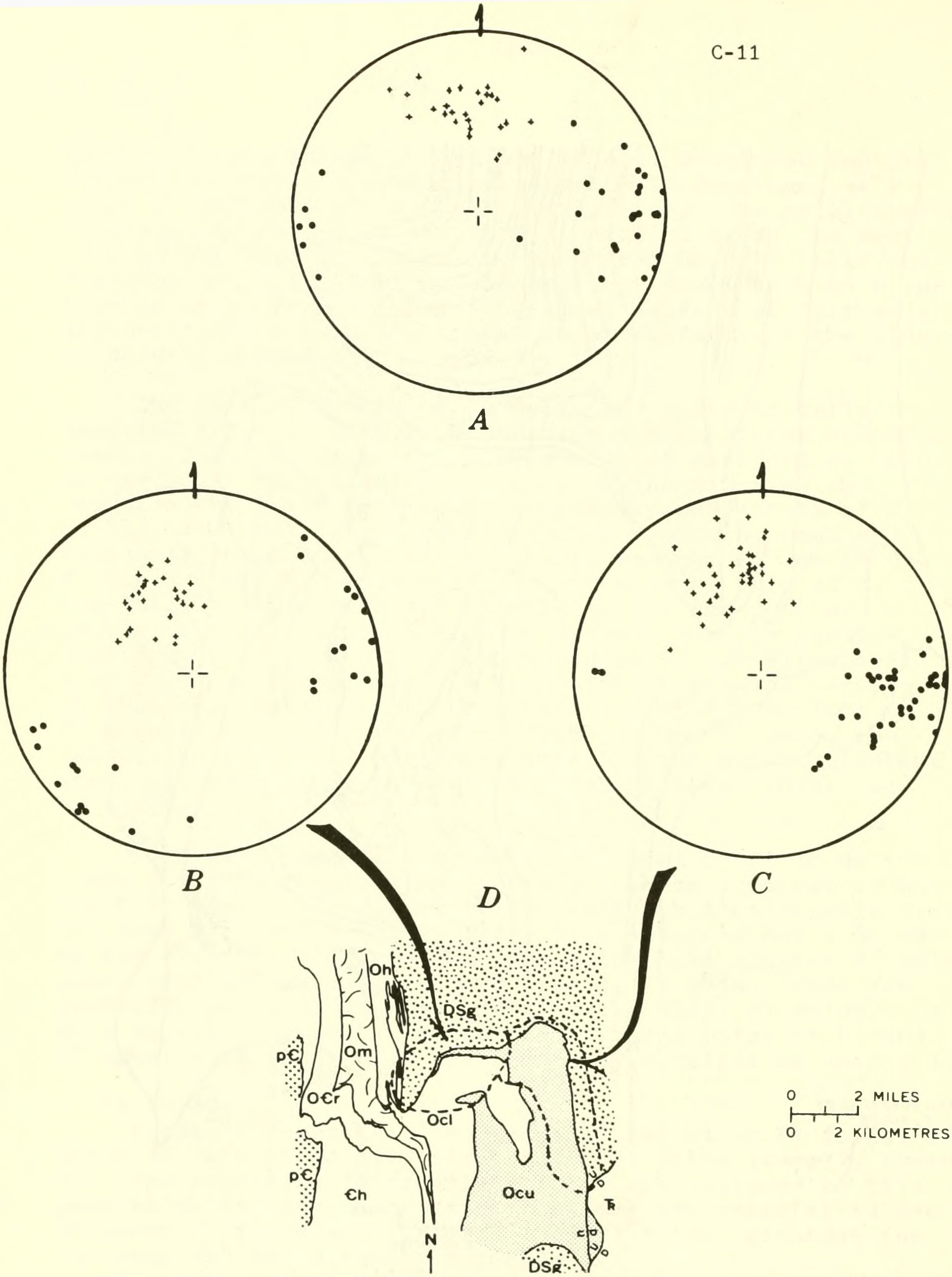

Figure 6. Lower hemisphere equal-area projections of poles to F4 axial surfaces (•) and F4 fold axes (+) for 2 subareas in the Blandford-Woronoco area. Diagram A contains folds that deform the slip cleavage of F3 folds in both of the areas shown by B and C. Diagrams B and C contain folds that deform only F2 schistosity. Subarea A, 31 axial surfaces, 27 fold axes; subarea B, 27 axial surfaces, 26 fold axes; subarea C, 41 axial surfaces, 37 fold axes. Plan of projection is horizontal with north indicated by arrow.

The axial surfaces of F4 folds directly superposed on F3 folds trend to the north and dip steeply to the west and are very similar to the crenulate folds in subarea C along the eastern part of the area. To the west, however, the axial surfaces trend more westerly. The F4 axes are remarkably similar in orientation to those of the older fold generations.

Summary

The previous discussion of fold generations has suggested the following important conclusions:

1. Axial surfaces of minor folds provide a means of determining the relative age of major structures which otherwise may be ambiguous or indeterminate. If the axial surfaces of a given fold generation are statistically parallel to the calculated axial surface of the major fold, then the two are coeval. Older and younger ages are based on cross-cutting relations.

2. The angular relationship between formation contacts and the axial surfaces of minor folds of a given age can locate the hinge and limb areas of refolded major folds of the same generation.

3. The character or style of axial surface cleavage (i.e., crenulate cleavage, slip cleavage, spaced schistosity) in a specific rock type is a reliable but qualitative measure of strain for each fold generation.

4. The axes of minor folds and major cleavage folds for F2, F3, and F4 are essentially parallel throughout most of the Blandford-Woronoco area. Therefore, deformation has involved repeated folding about parallel axes with the development of discordant axial surface cleavages similar to TYPE 3 interference pattern of Ramsay (1967, p. 531-535). This constraint simplifies subsequent kinematic and dynamic analysis.

5. The base of the Silurian and Devonian section marks a surface of structural décollement inasmuch as the ratio of amplitude to wave length is much higher in the younger rocks than in the pre-Silurian section.

Structural Evolution and Plate Tectonic Speculations

Any model of the structural evolution for the Blandford-Woronoco area must be highly qualitative and speculative. However, an internally consistent and reasonable geometric sequence based on the data presented in the foregoing pages is diagrammatically shown in the profile section in figure 7. The control for diagram 4 in figure 7 is quite good, although

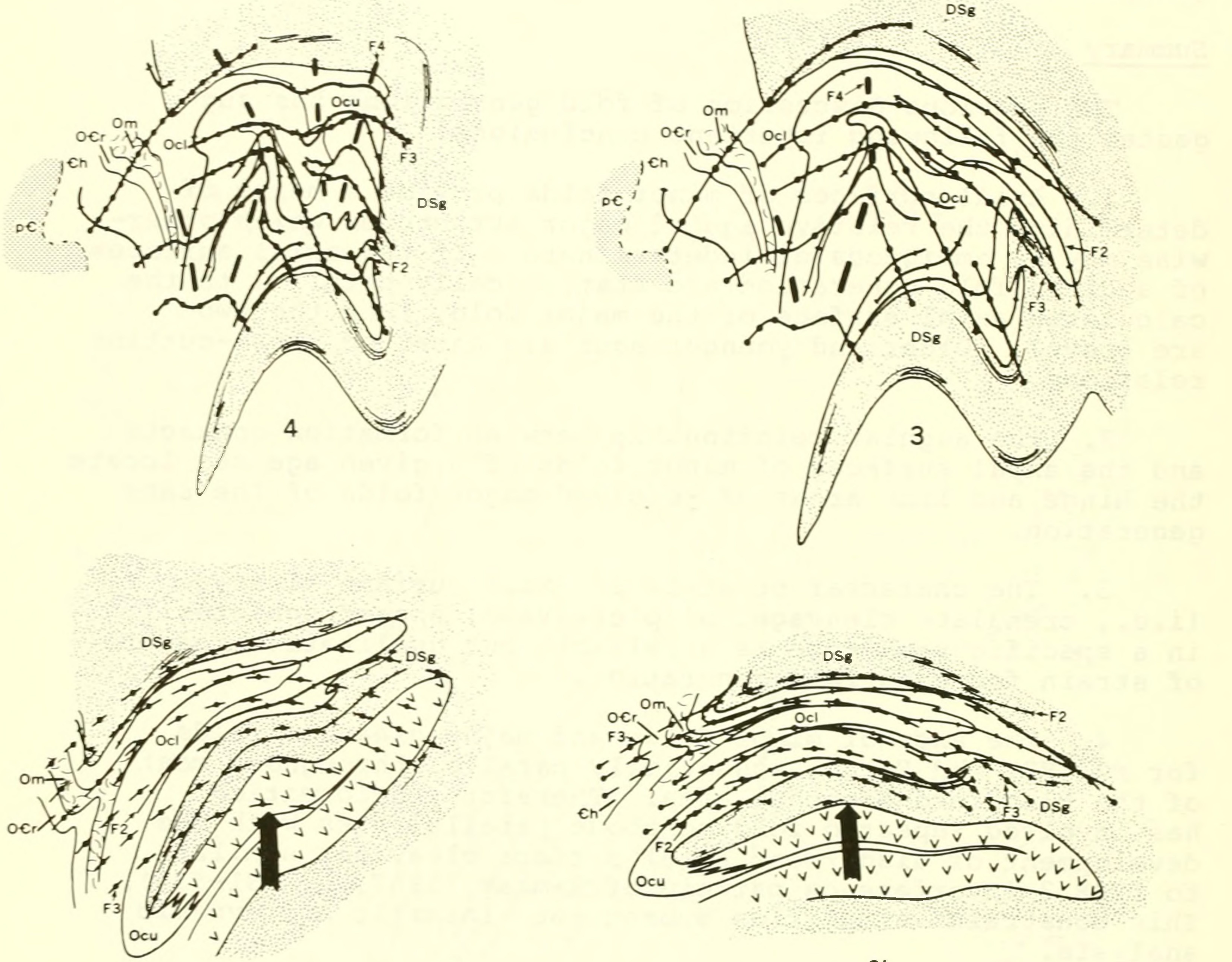

Figure 7. Structural evolution of the Blandford-Woronoco area with emphasis on generations 3 and 4. Diagrams are profile sections drawn perpendicular to an axis oriented approximately N5W at 45 degrees. Axial surfaces of each generation identified by the symbols F2, F3, and F4. Diagram 4 shows reconstruction prior to Triassic faulting; diagrams 4, 3, 2, (2') show progressively older configurations; diagrams 2 and 2' are alternative interpretations of early F3 time. Granville dome is located approximately in the position of each diagram number.

the effects of Triassic faulting have been removed. The remaining diagrams are derived by simply externally rotating the limbs of F4 folds about F4 axes until the axial surfaces of F3 are essentially planar. F2 structures are not unfolded in figure 7.

The configuration in diagram 4 represents a profile section of the Blandford-Woronoco area at the close of F4 time. The axial trace of the largest F4 cleavage antiform is offset to the west of the symmetry plane of the Granville dome (located directly over the number in each diagram).

Diagram 3 represents a stage in the progressive unfolding of F3 axial surfaces. Here the eastern limb is straightened out, forming one large cleavage anticline. In so doing the easternmost contact between pre-Silurian and younger rocks is folded into a large inverted anticline which is required by the Woronoco fold of F2 age (fig. 1). By continuing to unfold the axial surfaces of F3, the cleavage antiform of diagram 3 is reduced to the very broad arch of diagrams 2 and 2'. This arch is essentially parallel to the direction of maximum extension developed in mantling rocks as a result of the emplacement of a mantled gneiss dome, according to the mathematical model of Fletcher (1972, p. 210). During this early phase in F3 time, felsic volcanic rocks of Middle Ordovician age are thought to have moved upward, forming elongate domes and modifying the older isoclinal folds. Evidence supporting this event is found to the south in western Connecticut where these volcanic rocks appear to form the cores of several large east-facing folds that have been redeformed into gneiss domes outline by the contact between the Cambrian-Ordovician and the Silurian-Devonian rocks of figures 1 and 16 (Stanley, 1975; Dieterich, 1968a and b). In the Blandford-Woronoco area F3 folds are considered to be a product of the emplacement of the granville dome, because their axial surfaces form a cleavage antiform or arch that partly bridges the dome. Analogous structures are found in eastern Vermont where a late crenulate-slip cleavage forms the distinct arch of the Strafford-Willoughby arch (White, 1949, figs. 2 and 3). F3 folds are particularly well developed in synclines between the domes in western Connecticut (Stanley, 1975). These synclines probably developed when the domal rocks moved upward causing the intervening areas to be squeezed together.

Diagrams 2 and 2' are alternative interpretations on the attitude of the older isoclinal folds during early F3 time. In both diagrams the upward movement of the lighter volcanic rocks resulted in a fan-shaped compression field in the overlying rocks. Diagram 2, with moderate west-dipping axial surfaces, is preferred since the axial surfaces of F3 intersect rock units at a fairly high angle just north of the Granville dome (fig. 3). This is well illustrated in the lower parts of diagrams 4 and 3 just above the refolded syncline of Silurian and Devonian rocks. In diagram 2' the axial surfaces of F2 and F3 intersect at a very small angle. Furthermore, F3 folds with their associated cleavage are far more likely to form if the schistosity of F2 is compressed at a low angle to the schistosity rather than at a high angle. In diagram 2' the older schistosity would be compressed at a high angle and hence the tendency to fold it would not be as great.

Older configurations can be visualized by reducing F3 axial surfaces to planes. Although a separate diagram was not prepared for F1, the appropriate form can be imagined by unfolding the isoclinal folds and removing the Silurian and Devonian section. The development of folds in the Blandford-Woronoco area can then be visualized by following the sequence of diagrams from 2 to 4 in figure 7.

In summary, the structural evolution of the Blandford-Woronoco area in Phanerozoic time began with development of F1 folds in rocks of Middle Ordovician and older age. Although structures older than F2 and younger than F1 have been reported by Osberg (1972, 1975) in the Silurian and Devonian rocks, they do not appear to be the same age as the F1 folds. It is tentatively concluded, therefore, that F1 folds developed during the Taconic orogeny. Few if any large-scale folds of this generation have been recognized in western Massachusetts, although some small ones have been reported (Hatch, 1975) and several small folds in the upper member of the Cobble Mountain Formation are believed to be of this age (fig. 1). F1 folds may well have resulted from intense shearing due to westward thrusting of Cambrian and Ordovician rocks along the root zone of the high Taconic thrust during Middle or Late Ordovician time (Norton, 1971). This root zone appears to continue southward into western Connecticut where it is inpart represented by Cameron's Line (Hatch and Stanley 1974, Plate 1).

The remaining three generations of folds are well developed in the Silurian and Devonian section and are a result of Acadian deformation, since Acadian metamorphism outlasted two if not three of the fold generations (Hatch, 1975). This deformation has completely remolded and largely obscured the older structures. The isoclinal folds of F2 have resulted from severe east-west compression in which the axis of maximum compression was inclined at a gentle to moderate eastward angle. The intense transverse compression is compatible with active plate collision during the Middle Devonian. The westward inclination of the axial surfaces and consequent east-facing sense of the isoclinal folds may well result from local underthrusting of the orogen beneath the eastern edge of the continent.

The subsequent rise of the light felsic rocks in the Middle Ordovician section produced the gneiss domes which in turn refolded the older isoclinal folds of F2 and may reflect a pause in plate interaction. East-west compression during F4 time formed large-scale cleavage folds. Although F4 folds are fairly extensive regionally, they are only well developed locally and, hence, may reflect the irregularities of plate boundaries. In Late Triassic time normal faulting associated with the opening of the Atlantic cut the eastern part of the area.

As a closing note, I recommend the following poem:

Synclines

Synclines become synclines
  Through tens of millions of years
Of downwarping, downthrusting
  and gentle sagging.
Often to be folded
And finally eroded,
Leaving no tombstone.

A faded relict was brought to light
  By circumstantial chance.
I dined upon it, eating my bologna sandwich
And marked its outcrop upon my map.

While surmising my morning's work
  And daydreaming into nowhere,
A ray of sunlight cascaded
  Onto my old gray outcrop
And framed a lineation.

It was indeed a syncline,
  One I'd missed to see
Through metamorphism
  Of deep woods mystery.

It made my vision clearer
  Of what had happened here
In Ordovician time
  Back four hundred fifty million years.

The syncline had been folded,
  then refolded twice again
Each fold impressed upon the other
  With axial cleavage S_1, S_2, S_3.

So much it told me,
  Out there in the field
That I never expected more in the lab
  Than a basic minerologic yield.

But two months hence
Under 40X
A glaucophane appeared
  Cloaked in scientific suspense.
Then another, and one or two more
All associated, it seemed, with fold generation two.

So much it told me
That single syncline,
After waiting four hundred fifty million years.
Like an old man on his deathbed
  Reciting ancient tales
Of Custer's Last Stand
  And Abraham Lincoln
All mottled and confused.

Just a simple syncline
  Highly metamorphosed
That will weather into history
  In another million years.

Robert Badger, 1975
University of Vermont

COBBLE MOUNTAIN AREA MASSACHUSETTS

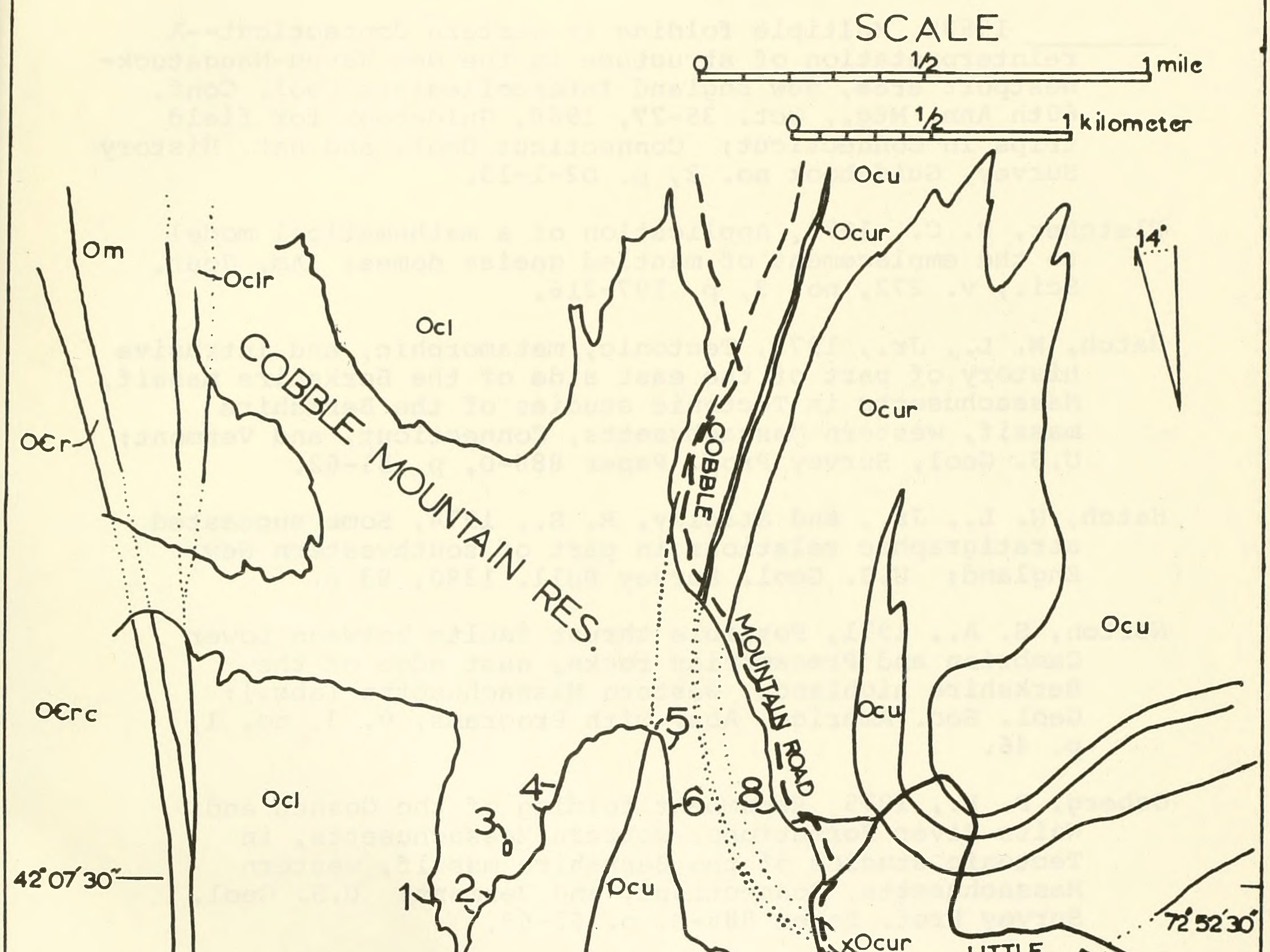

Figure 8. Traverse map for Stops 1-8.

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