A Structural Interpretation of a Portion of the Big Bug Group near Mayer, Arizona

by

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Abstract

Structural movements appear to have influenced the form, orientation, and size of ore deposits in the rocks of the Precambrian (1770 ± 10 m.y.) Big Bug Group of the Yavapai Series near Mayer, Arizona. The Big Bug Group has been divided into five facies: (1) chlorite schist (andesite to basalt), (2) quartz-sericite-chlorite schist (latite to dacite), (3) quartz-sericite schist (rhyolite), (4) metachert, and (5) metaconglomerate. Rocks younger than the Big Bug Group and probably also Precambrian include: (1) bull quartz veins, (2) carbonate (predominantly calcite with some dolomite and ankerite) veins, and (3) mafic intrusive rocks.

Principal structural elements in the Big Bug Group are lithologic contacts (S_0); foliation, indicated by schistosity and axial plane cleavage (S_1); flexural-flow and passive-slip to passive-flow folds (F_1); flexural-flow folds (F_2); joints; and faults. Subparallel lithologic contacts and foliation strike north to north-northeast and dip steeply west. The F_1 folds trend south to southwest and plunge 50 to 75 degrees. Attitudes of these structural elements suggest that the layered rocks of the Big Bug Group were isoclinally folded and that layering was transposed parallel to the foliation planes. The rocks were simultaneously rotated and (or) tilted. North-south and subvertical stretching during folding extended the lithologic contacts subparallel to the foliation, except in fold hinge areas where foliation is perpendicular to lithologic contacts. The amount of stretching increases along the flanks away from the fold hinges. The F_2 folds plunge north, 25 to 65 degrees, unlike the F_1 folds, which plunge south. Lineations include elongate relict phenocrysts, slickensides, crenulations, boudin lines, and fold axes. Prominent joint sets are subparallel and subperpendicular to the linear elements. Minor faults appear unrelated to the other structural elements of this area.

Mineralization in the rocks of the Big Bug Group appears to be both syngenetic and epigenetic. Because of the folding and simultaneous stretching of these rocks, an economically mineable syngenetic orebody would more likely occur in the fold hinge areas where stretching is less. Along fold flanks, where stretching is greater, syngenetic ore would be drawn apart and would less likely be economic. Therefore, a syngenetic orebody would occur as a cigar-shaped mass, plunging subparallel to the fold axes, lineations, and boudin lines.

Introduction

Field mapping near Mayer, Arizona (Fig. 1) has revealed structural elements in the Precambrian (1770 ± 10 m.y., Anderson and others, 1971) Big Bug Group of the Yavapai Series that appear to be important in understanding the massive sulfide deposits in these rocks. The investigation includes: (1) mapping 5 km^2, 1 km north-northeast of Mayer (Fig. 2); (2) plotting the attitudes of fold axes in an arroyo 6 km northeast of Mayer; and (3) studying a portion of the Shylock zone near the Binghampton-Copper Queen mines, about 8 km northeast of Mayer.

Foliated rocks of the Big Bug Group in the areas of investigation have been divided into five major facies on the basis of composition: (1) chlorite schist (andesite to basalt), (2) quartz-sericite-chlorite schist (latite to dacite), (3) quartz-sericite schist (rhyolite), (4) metachert, and (5) metaconglomerate. Metachert facies are the marker horizons used for mapping, and they consist of ferruginous metacherts and iron formations, which contain up to 30 percent hematite and magnetite. Three postdeformation units of probably Precambrian age are identified that are younger

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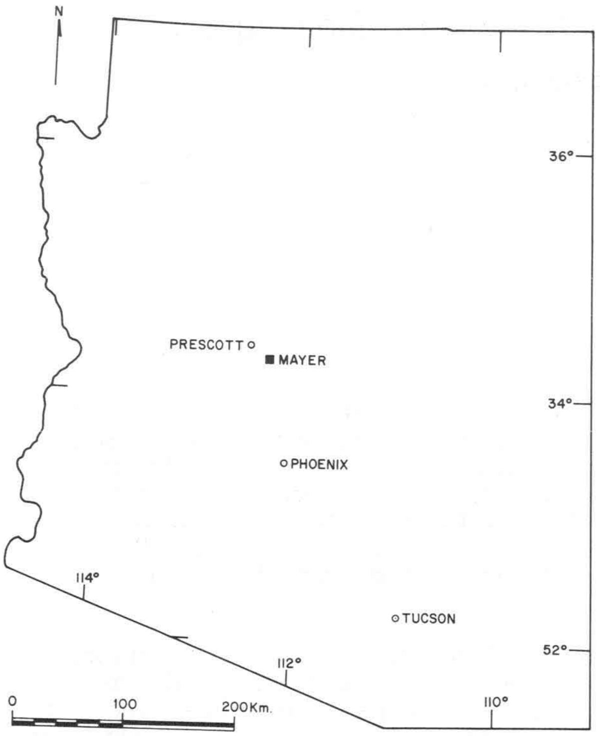


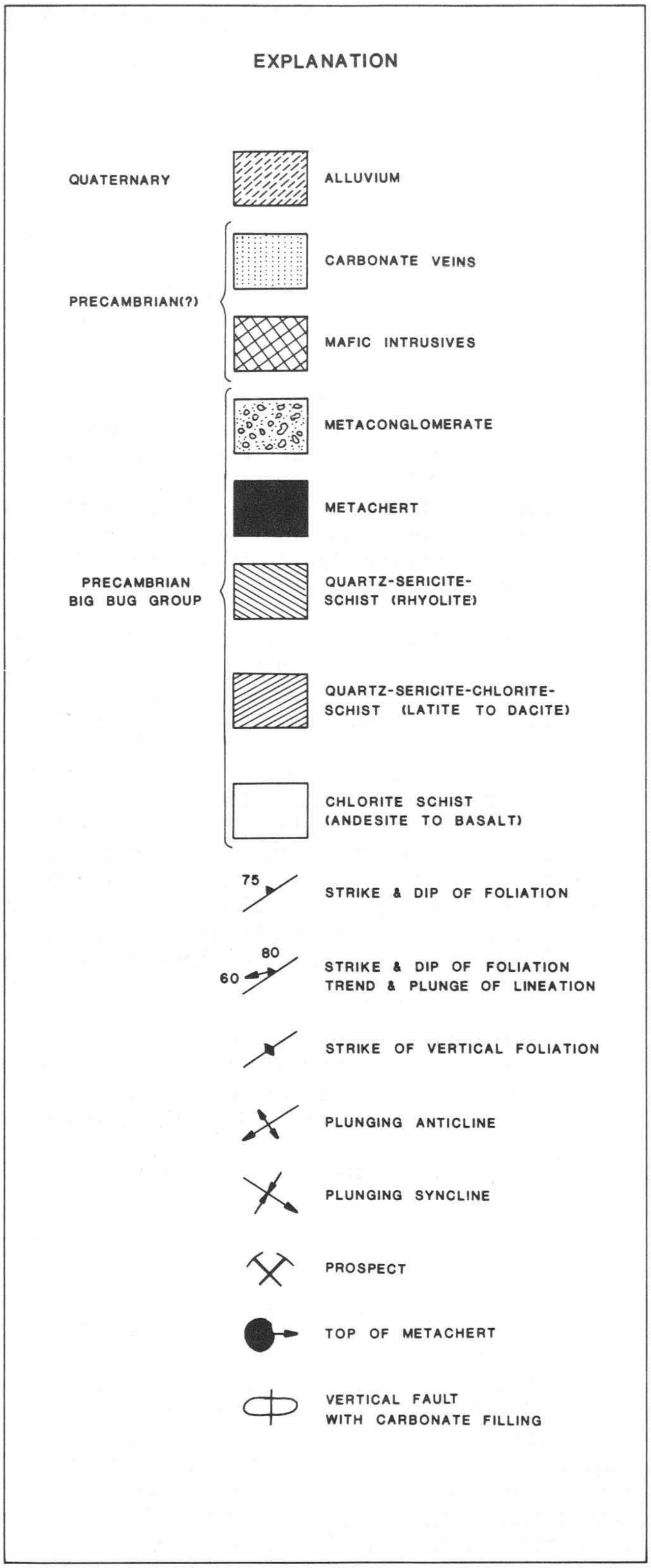
Fig. 1. Index map of Arizona showing location of the Mayer area

than the foliated rocks of the Big Bug Group: (1) bull quartz veins, (2) carbonate veins, and (3) mafic intrusive rocks.

The rocks of the Big Bug Group represent a series of submarine volcanic, volcaniclastic, and sedimentary rocks that have generally been metamorphosed to the greenschist facies and locally metamorphosed to the amphibolite facies adjacent to younger intrusive bodies south of Mayer (Anderson, 1972; DeWitt, 1976).

White milky bull quartz is found throughout the rocks of the Big Bug Group, but the occurrences are too small to map because the quartz occurs only in small pods and postfoliation fracture fillings (Fig. 3). The bull quartz is spatially related to some sulfide ore, and this proximity is significant in the interpretation of the origin of mineralization in this area. Many relict quartz grains in the quartz-sericite schist facies that predate the metamorphism have a preferred "c" axis orientation perpendicular to the foliation. Bull quartz does not possess a preferred crystallographic alignment and is therefore postdeformation (Evensen, 1969).

Carbonate minerals (predominantly calcite, but with some dolomite and ankerite) fill postdeformation fractures which both cut and parallel the foliation in the rocks of the Big Bug



Explanation for Figure 2, facing page

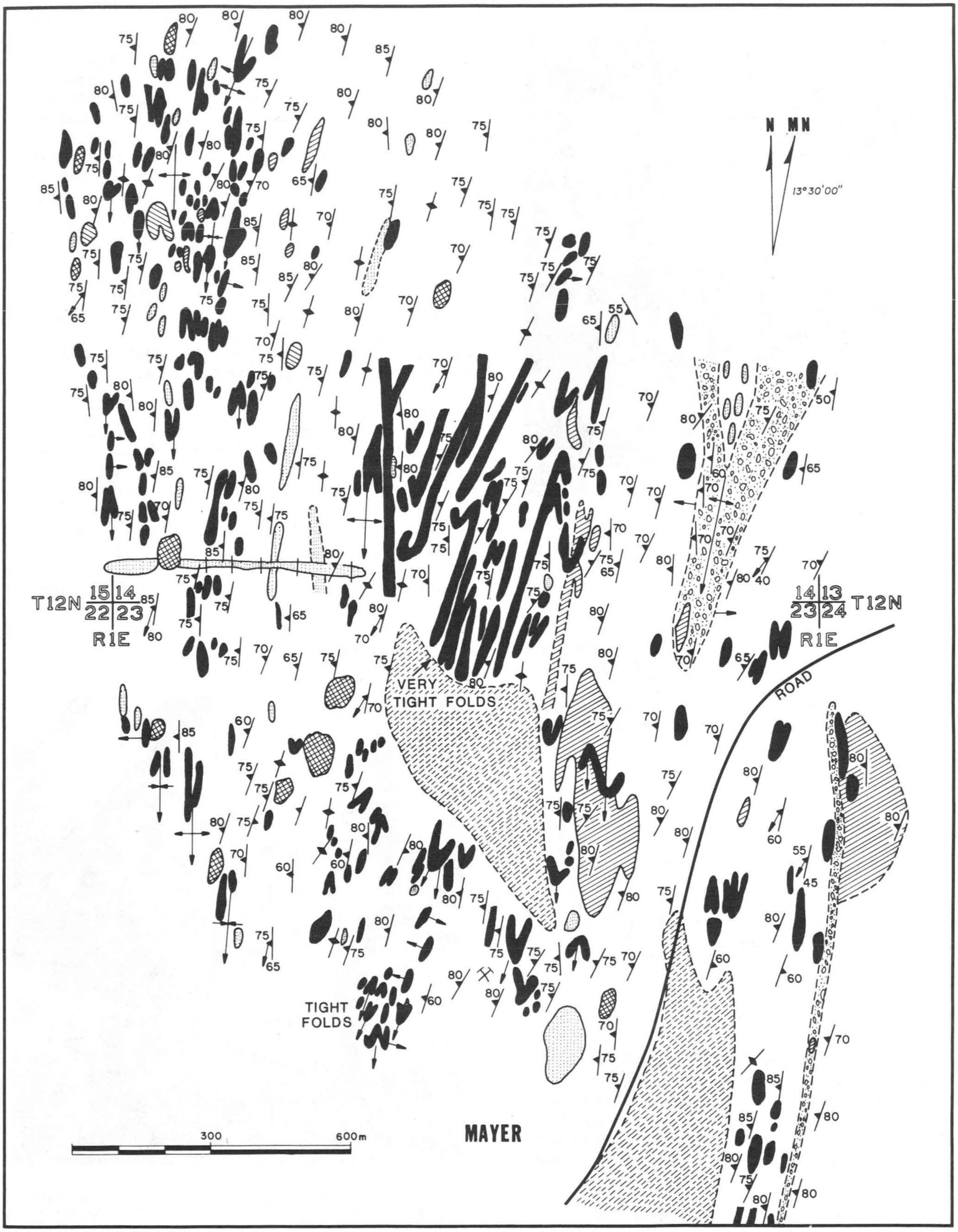


Fig. 2. Geology of a portion of the Big Bug Group, Mayer, Arizona. See explanation on facing page.

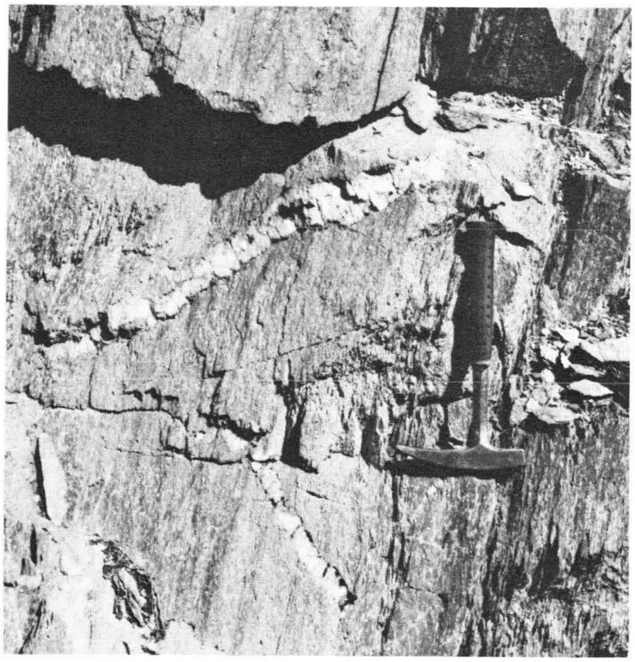


Fig. 3. Bull quartz veins intruding rocks of Big Bug Group in a road cut, 2 km south of Mayer on Highway 69.

Group. Carbonate material paralleling the foliation commonly appears "foliated" because it fills small fractures in the deformed rocks. Some of these rocks may be related to possibly late Pliocene travertine deposits located in the Mayer area (Anderson and Blacet, 1972).

Mafic rocks, both plugs and sills, invade the rocks of the Big Bug Group. These mafic intrusive rocks have been chloritized and are either unfoliated or exhibit weak foliation adjacent to the highly foliated rocks.

Detailed petrographic and (or) chemical analyses of the rocks of the Big Bug Group were described by Evensen (1969), Anderson and Blacet (1972), Anderson (1972), Brook (1974), and DeWitt (1976).

Structure

Principal structural elements in the rocks of the Big Bug Group in the areas of consideration are lithologic contacts (S_0), foliation (S_1) (schistosity and axial plane cleavage), lineation (L_1), flexural-flow and passive-slip to passive-flow folds (F_1), flexural-flow folds (F_2), joints, and faults.

Lithologic Contacts (S_0) and Foliation (S_1)

The rocks of the Big Bug Group in the areas of study represent a series of stratified metavolcanic and metasedimentary rocks. Lithologic contacts between facies strike north to north-northeast and dip steeply west. Foliation is defined by fold axial plane cleavage and schistosity due to the parallel alignments of phyllosilicate minerals, which recrystallized during dynamic greenschist metamorphism. Except in fold hinge areas lithologic contacts are subparallel to the pervasive foliation. On fold flanks, away from hinges, the angle between these contacts and the foliation is small (5 degrees or less); however, in fold hinge areas the foliation (S_1) is perpendicular to lithologic contacts (S_0). The rocks have been isoclinally folded (F_1) and the layering has been transposed into subparallelism with the foliation. For example, near the Binghampton mine lithologies that subparallel the foliation can be traced for several hundred meters.

Lineation (L_1)

The most clearly defined linear elements within the rocks of the Big Bug Group in the areas of consideration are elongate relict quartz and feldspar phenocrysts, but other linear elements include slickensides, crenulations, boudin lines, and fold axis. These linear elements lie within the plane of the foliation (Fig. 4). Lineations (B lineation) trend south to S. 40° W. and plunge 50 to 75 degrees, subparallel to the fold (F_1) axes (Fig. 4) and subperpendicular to a prominent joint set (N. 50-80° W., 10-45° NE.).

Fig. 4. View looking east. Lineation on plane of foliation plunging 60° S. Note fold in lower right of photograph. Fold axis is subparallel to the lineation.

F_1 *Folding*

Over a hundred mesoscopic F_1 folds have been identified in the area mapped in detail, 1 km north-northeast of Mayer (Figs. 2, 5, and 6). Flexural-flow folding characterizes the metachert facies (Donath and Parker, 1964), and passive-slip to passive-flow folding characterizes the metavolcanic and metapelitic units (Donath and Parker, 1964). Mesoscopic folds plunge south to south-southwest 50 to 75 degrees. In the eastern part of the area folds trend S. 20° W. and in the western part of the area they trend south to S. 5° W. These mesoscopic fold attitudes indicate closure in a southerly direction and therefore suggest a south-plunging anticlinorium, the hinge of which lies approximately under Mayer (Fig. 2). Therefore, spacings between fold axial planes range from microscopic distances to more than a kilometer.

The confirmation that a mesoscopic fold may occur in these rocks is shown by a slight closure of the trends of two closely spaced metachert horizons (Fig. 5). Stratigraphic age relations and locations of anticlines and synclines were determined by correlating clasts of metachert within adjacent rocks (Figs. 7 and 8) and noting locations of oxidation zones below ferruginous metacherts.

The more reliable method for determining age relationships (absolute facing) is the correlation of clasts of metachert within adjacent foliated rocks. In all places where this method was used the folds plunge steeply south and are subparallel to the linear elements of these rocks (B lineation).

Fig. 5. South-plunging anticline in the Big Bug Group, view looking south, 2 km north of Mayer, Arizona. Note separated metachert pods (boudins) along fold flanks.

Fig. 6. South-plunging anticline in the Big Bug Group, 2 km north-northeast of Mayer. Minor fold in metaconglomerate.

Also useful, but not always possible, is the identification of oxidation zones in foliated rocks adjacent to ferruginous metachert units. If ferruginous metacherts were deposited in an oxidizing environment, the upper surface of the underlying rocks probably also experienced oxidation. Oxidation zones and the attitude of linear elements were used to substantiate stratigraphic age relationships and the attitudes of folds that were determined by identifying clasts of one unit within another unit.

Pseudo-folding appears to occur in a facies of meta-pillow lava on the ridge above the adit to the 400-foot level of the Copper Queen mine. Patterns on joint surfaces through the pillows appear as folds; however, the bands probably represent zonal weathering or liesegang rings.

F_2 *Folding*

F_2 folding of the initial isoclinal F_1 folding has occurred in the rocks of the Big Bug Group in a section of fine-grained, clastic, metasedimentary rocks in an arroyo about 6 km northeast of Mayer. Attitudes of 50 flexural-flow fold axes (Donath and Parker, 1964) were measured. The F_2 folds plunge 25-65° NNE., unlike

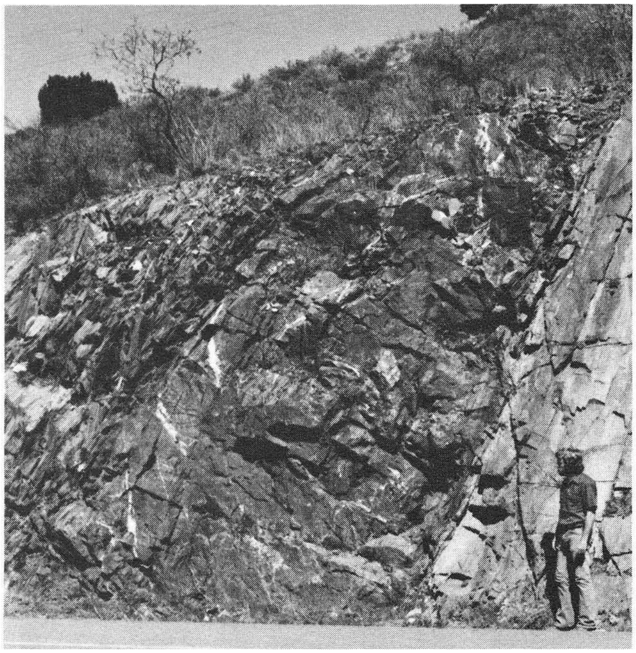


Fig. 7. Metachert and quartz-sericite-chlorite schist in road cut, 2 km south of Mayer, Arizona, on Highway 69. View looking north. Note subparallelism between lithologic contacts and foliation.

the F_1 folds in this area, which plunge south to south-southwest. Evidences for F_2 folding are:

1. The foliation, which is associated with F_1 folding, is folded.
2. The bull quartz, which is post-F_1 folding and characteristically undeformed in this area, is folded.
3. The F_2 fold axial plane cleavage transects the earlier F_1 fold axial plane foliation.
4. The areas containing F_2 folding coincide with areas containing abundant kink folding of foliation (also a post-F_1 folding).

Joints

Joints in the rocks of the Big Bug Group occur principally in the more brittle facies such as metacherts and iron formations. Attitudes of over two hundred joints were measured in the area of detailed mapping 1 km north-northeast of Mayer. Two prominent joint sets are apparent. The attitude of one joint set is N. 75° E. to N. 75° W., 55-80° SE. to southwest and subparallels the fold axes, lineations, and boudin lines. The other is N. 45-85° W., 10-25° NE. and is subperpendicular to the fold axes, lineations, and boudin lines. Because downslope creep has occurred in jointed rocks, these variations in attitude exist within joint sets.

Faulting

Faulting is not common in the rocks of the Big Bug Group in the area of consideration because plastic deformation rather than brittle deformation characterizes the history of these rocks. In the southwestern part of the area mapped in detail, 1 km north-northeast of Mayer, a nearly vertical east-west fault shows vertical slickensides on the north wall. The fault plane is filled with carbonate minerals, which are stained with limonite because of oxidation of associated pyrite. This fault appears unrelated to the major Precambrian deformational history of the rocks of the Big Bug Group.

Stretching

Transposition of the layered volcanic and sedimentary rocks parallel to the foliation (Turner and Weiss, 1963) appears to be the dominant structural characteristic in the rocks of the Big Bug Group in the area of consideration. Transposition has resulted in extensive north-south and subvertical stretching in these rocks. Elongation is indicated by separation of metachert units (Fig. 5) and flattened clasts in both a metaconglomerate (Fig. 9) and a metalahar (Fig. 10).

Separate metachert units in sausage-linklike arrangements suggest boudinage (Fig. 5). The boudin line subparallels fold axes and other linear elements and lies within the plane of a prominent joint set.

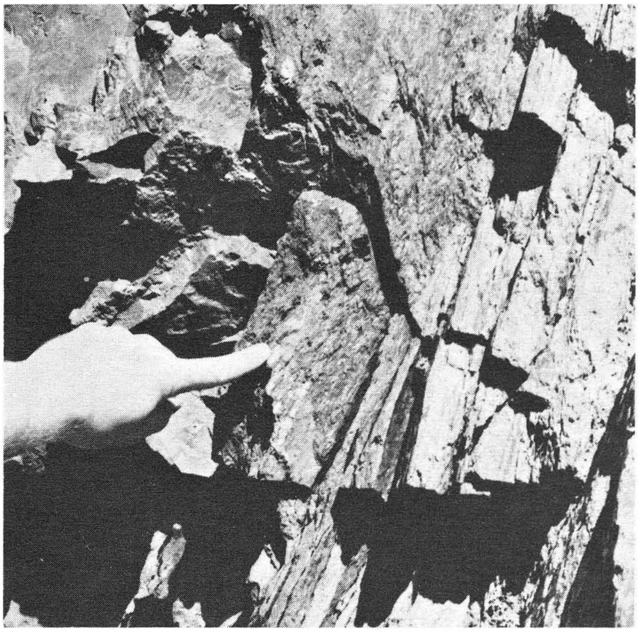


Fig. 8. Clast of metachert in quartz-sericite-chlorite schist on east side of metaquartzite. View looking north in road cut 2 km south of Mayer, Arizona, on Highway 69. Younger rocks to the east.

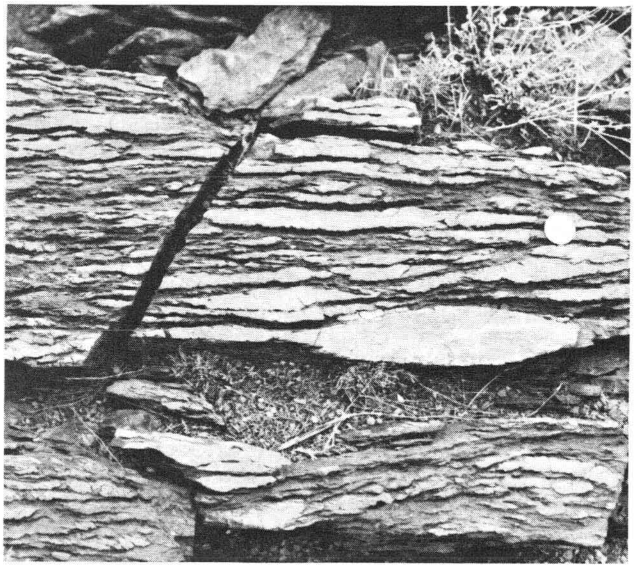


Fig. 9. Deformed chert clasts in a metaconglomerate, 2 km north-northeast of Mayer, Arizona.

Stretching measurements were made by dividing the flank length of the fold by the sum of the total lengths of the metachert pods in each flank unit (Fig. 11). Stretching values of 2 to 5 times were determined. These values of 2 to 5, however, represent minimum stretching values because:

1. Flattening that occurs within each metachert pod lengthens the pod and reduces the stretching ratio.
2. Measurements were taken near fold hinges where the stretching is not as great as along fold flanks. Distances were measured between metachert pods in five mesoscopic folds from hinge along flank. Spacing between successive pods increased rapidly away from the hinge with an average spacing ratio increasing as follows: 1.0:1.6:4.0:20.0.

The Shylock zone, which is a 70-km-long , north-south-trending Precambrian structure (Anderson, 1972), is located about 3 km east of Mayer and may represent a zone of unusual stretching and ductility during deformation. Ferruginous metachert pods, which are subparallel to the strike of the foliation, are separated in this zone by distances of 0.25 to over 2 km.

Undeformed clasts are unknown in the rocks of the Big Bug Group in the area of study. However, stretching is apparent in clasts of a metaconglomerate (Fig. 9) 1 km northeast of Mayer and in clasts of a metalahar (Fig. 10) within the Shylock zone 1 km south of the Binghampton mine. Clasts from these rocks commonly appear as pancakes, and this shape has been interpreted to represent strain resulting from the deformation. Intermediate and greatest strain axes of these clasts are large compared to the least strain axis. Strain axis ratios of 100 clasts in the metaconglomerate average 1.0:8.0:10.4 and have a maximum of 1.0:34.7:39.3. Strain axis ratios of 100 clasts in the metalahar average 1.0:3.7:8.0 and have a maximum of 1.0:8.0:22.0. The least strain axis is oriented nearly east-west, the intermediate strain axis is oriented nearly north-south, and the greatest strain axis is steeply plunging south and subparallel to the fold axes and other linear elements of this area. These ratios represent minimum stretching values, however, because most deformation occurred within the more ductile matrix of the metaconglomerate and metalahar rather than in the brittle clasts.

Stretching may have extended the rock units 25 times in the area 1 km north-northeast of Mayer and by possibly greater distances in other areas such as the Shylock zone.

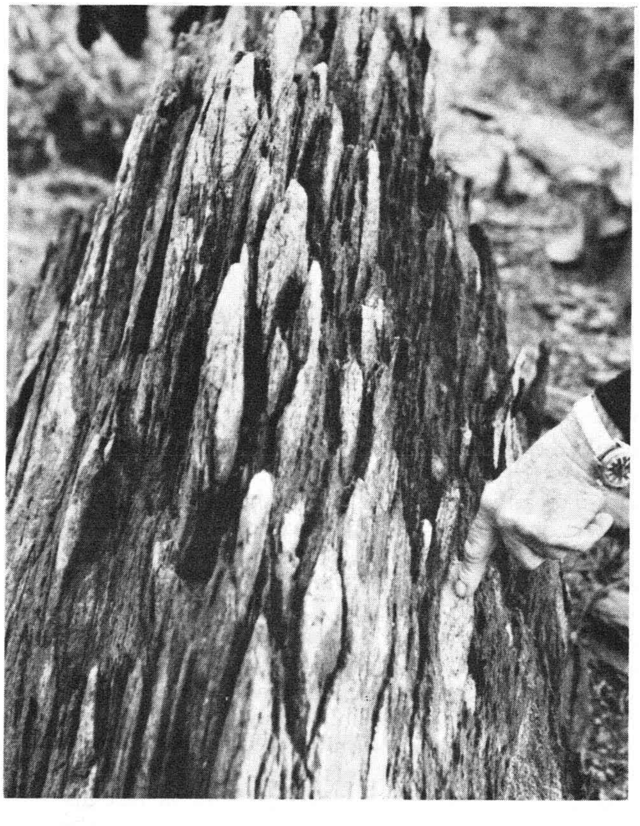


Fig. 10. Deformed clasts in a metalahar, 1 km south of the Binghampton mine

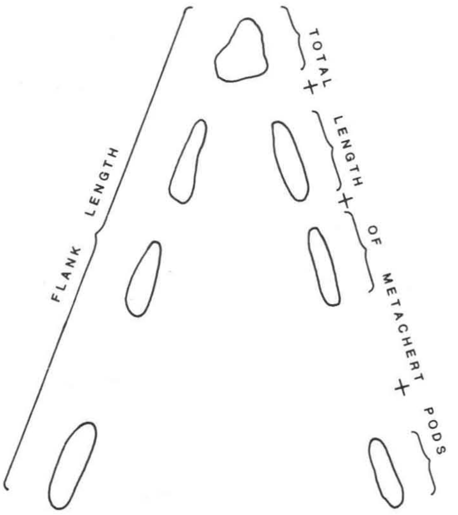


Fig. 11. Map view of idealized fold. Stretching measurements in folds were determined by dividing the flank length of the fold by the sum of the lengths of the metachert pods in each flank unit.

Structural History

In the rocks of the Big Bug Group in the areas of consideration, the subparallelism between lithologic contacts and the foliation suggests a genetic relationship between the two. Some workers have suggested that the subparallelism could result from F$_1$ isoclinal folding that produced folds with subhorizontal fold axes. Maximum stretching would probably be nearly vertical and would produce subvertical linear elements (slickensides) that are subperpendicular to the nearly horizontal fold axes (Ramsay, 1967).

Subsequent erosion of the anticlinal crests would expose a series of steeply dipping rocks whose contacts are subparallel to the foliation and fold axial planes. Because fold axes in the rocks of this area plunge steeply south, it could be suggested that tectonic movement (i.e., tilting) caused the subhorizontal fold axes to assume a steeply plunging orientation. However, this is not supported by field evidence. Examination of folds in metacherts about 15 km north of the study area and 2 km east of Dewey, Arizona, indicates that fold axes plunge steeply south as in the area of study. Furthermore, fold axes and lineations in these rocks are subparallel and not subperpendicular as would be suggested by the interpretations of these workers. Therefore, merely producing isoclinal folds whose axes were steepened by subsequent uplift does not appear to be a satisfactory explanation for the subparallelism that exists between lithologic contacts and foliation.

A more likely explanation for the parallelism between lithologic contacts and foliation involves transposition of the layered rocks parallel to the foliation planes. Transposition of the initial layering (bedding) is characterized by the rotation of the layering during folding into a subparallel orientation with fold axial planes (Hobbs, Means, and Williams, 1976). In advanced stages of transposition "tightly oppressed fold hinges" occur (Turner and Weiss, 1963, p. 93).

Two possible solutions to explain the south to S. 20° W., 50-75° S. to SSW., trend and plunge of the L$_1$ linear elements and F$_1$ fold axes are:

1. Turner and Weiss (1963) described a homogeneous strain component in slip folding; this is a strain that uniformly affects all parts of the fold. During homogeneous strain, fold axes would rotate toward the axis of extension and become subparallel to the other linear elements present in the rocks. Ramsay (1967) stated that homogeneous strain and shear (slip) strain probably develop simultaneously as a part of a single deformation process. The rocks of the Big Bug Group in the area of consideration may have experienced a deformation characterized by both homogeneous strain and slip strain to produce the parallel attitudes of the structural elements. North-south and subvertical stretching due to slip strain (transposition) during folding drew the lithologic contacts into parallelism with the foliation.

2. More than one period of deformation may have occurred to the rocks of the Big Bug Group in the area of study. An initial period of deformation may have been the tilting of the subhorizontal volcanic and sedimentary rocks, producing a nearly east-west strike and a 50-75° S. dip. Tilting was followed by a second period of deformation, which included F$_1$ folding and simultaneous north-south and subvertical stretching associated with transposition of original layers. This drew the linear elements and F$_1$ fold axes as well as the lithologic contacts and foliation into subparallelism. Slippage during stretching occurred along foliation planes.

Cursory examination of metamorphic rocks in a 750-km^2 area surrounding the study localities indicates an orientation of the structural elements similar to that identified in the area mapped in detail. The second explanation would therefore require a regional homoclinal tilting of an extremely large mass of rock preceding transposition, which appears unlikely. Thus, the author favors the more simple, single deformational episode presented in the first explanation as the more reasonable interpretation of the structural elements in the area of consideration.

Brook (1974) has identified steeply plunging isoclinal folds in the rocks of the Big Bug Group at the Copper Queen mine. DeWitt (1976, 1978) has indicated steeply plunging isoclinal folds in the rocks of the Big Bug Group south of Mayer and has suggested that these rocks should be stratigraphically reinterpreted.

The cause of the F_2 folding of the rocks of the Big Bug Group in an arroyo 6 km northeast of Mayer is unknown. DeWitt (1976) indicated that the post-F_1 foliation igneous intrusions south of Mayer are associated with F_2 folding; however, this relationship cannot be demonstrated in the area of consideration.

Mineral Deposits

The rocks of the Yavapai Series in central Arizona contain many mines that have been economically significant. The mines and the investigators who have described them include: Jerome (Lindgren, 1926; Anderson and Creasey, 1958; Kothavala, 1963; Anderson and Nash, 1972), Iron King (Gilmour and Still, 1968), Blue Bell and De Soto (DeWitt, 1976), Binghampton-Copper Queen (Lindgren, 1926; Evensen, 1969; Brook, 1974), and Stoddard (Lindgren, 1926). Dunning (1966) gave the history of ownership, production, and value for many mines of this area.

Most early workers considered that the mineralization in these deposits was epigenetic and that the ore minerals were brought in by hydrothermal fluids associated with plutonic events. However, in recent years investigations in the Canadian Shield by Sangster (1972) and others have caused many workers to reevaluate the deposits in the Yavapai Series. Some authors now suggest that these deposits had a syngenetic origin and that the ores were related to brines associated with submarine volcanic rocks. This interpretation was made by Gilmour and Still (1968) for the Iron King mine, by DeWitt (1976) for the Blue Bell and De Soto mines, by Brook (1974) for the Copper Queen mine, and by Anderson and Nash (1972) for the Jerome orebodies.

Strong arguments can be made for either a syngenetic origin or an epigenetic origin for the mineralization of this area. If syngenesis is preferred, certain epigenetic characteristics of the mineralization must be considered in a syngenetic model:

1. Veins of quartz, ankerite, and chalcopyrite (in that paragenetic sequence) cut the foliation along fractures and appear to be unaffected by stretching (Evensen, 1969). These fractures represent brittle deformation in rocks that characteristically have been plastically deformed.

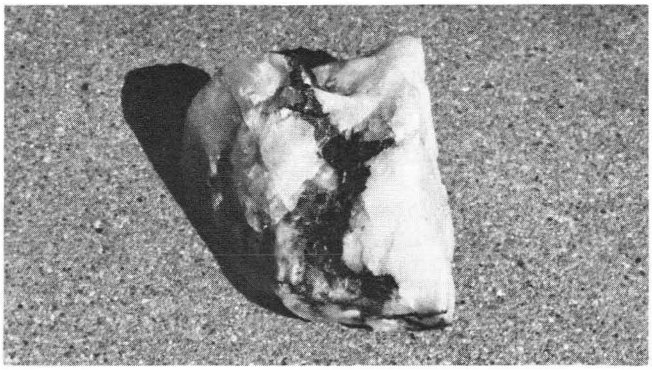


Fig. 12. Vein of chalcopyrite cutting bull quartz facies

2. Veins of chalcopyrite cut bull quartz, which is characteristically post-F_1 folding (Fig. 12).

3. The foliation is disorganized near known orebodies, e.g., Binghampton, Copper Queen, Half Moon, and Stoddard (Evensen, 1969).

Some authors suggest that sulfide deformation proves syngenesis, but this proof would appear to assume that only one period of deformation occurred. However, as shown in this study of the area near Mayer, there are indications of multiple periods of folding (F_1 and F_2). Any multiplicity of deformation weakens that proof for a syngenetic origin and opens the possibility of either a syngenetic or epigenetic origin or both; hence, there exists the possibility of more than one period of mineralization.

The question, however, is: "What would be the effect of isoclinal folding, stretching, and transposition of original layering on a syngenetic orebody occurring in the Big Bug Group?" It would appear that on fold flanks, where stretching has been greatest, any mineralized zones would be drawn apart and extended over a larger area, thereby reducing the chances for the deposit to be economic. In the hinge areas, where stretching is less, the mineralization would occur as cigar-shaped bodies plunging subparallel to the fold axes and lineation and would therefore more likely be economically significant. Steeply plunging orebodies subparallel to fold axes and (or) lineation occur at Jerome (Anderson, 1958), at the Blue Bell and De Soto mines (DeWitt, 1976), at the Copper Queen mine (Brook, 1974), and at the Iron King mine (Gilmour and Still, 1968).

It is clear that the mineralization and structural histories of the rocks of the Big Bug Group are complex. It is also clear that understanding the mineralization history requires understanding the structural history as well.

An incomplete understanding of this structural history may be the reason for the apparent lack of exploration success in this area in recent years.

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References

Anderson, C. A., 1972, Precambrian rocks in the Cordes area, Yavapai County, Arizona: U.S. Geol. Survey Bull. 1345, 36 p.

Anderson, C. A., and Blacet, P. M., 1972, Precambrian geology of the northern Bradshaw Mountains, Yavapai County, Arizona: U.S. Geol. Survey Bull. 1336, 82 p.

Anderson, C. A., Blacet, P. M., Silver, L. T., and Stern, T. W., 1971, Revision of the Precambrian stratigraphy in the Prescott-Jerome area, Yavapai County, Arizona: U.S. Geol. Survey Bull. 1324-C, p. C1-C16.

Anderson, C. A., and Creasey, S. C., 1958, Geology and ore deposits of the Jerome area, Yavapai County, Arizona: U.S. Geol. Survey Prof. Paper 308, 185 p.

Anderson, C. A., and Nash, J. T., 1972, Geology of the massive sulfide deposits of Jerome, Arizona—A reinterpretation: Econ. Geology, v. 67, p. 845-863.

Brook, D. K., 1974, Relative ages of strataform sulfide ore and wall rock determined by a structural analysis of the Copper Queen mine, Yavapai County, Arizona: M.S. thesis, University of Arizona, Tucson, 60 p.

DeWitt, E. H., 1976, Precambrian geology and ore deposits of the Mayer-Crown King area, Yavapai County, Arizona: M.S. thesis, University of Arizona, Tucson, 150 p.

DeWitt, E. H., 1978, "Massive sulfide" deposits and Proterozoic volcanism in north-central Arizona—A major revision of existing structure and stratigraphy [abs.]: Geol. Soc. America, Cordilleran Section, Tempe, Arizona: Abstracts with Programs, v. 10, no. 3, p. 102.

Donath, F. A., and Parker, R. B., 1964, Folds and folding: Geol. Soc. America Bull., v. 75, p. 45-62.

Dunning, C. H. (with E. H. Peplow, Jr.), 1959, Rocks to riches: Phoenix, Arizona, Southwest Publishing Co., 406 p.

Evensen, J. M., 1969, Geology of the central portion of the Agua Fria mining district, Yavapai County, Arizona: Ph.D. dissertation, University of Arizona, Tucson, 121 p.

Gilmour, P., and Still, A. R., 1968, The geology of the Iron King mine, *in* Ridge, J. S., ed., Ore deposits of the United States 1933-67 (Graton-Sales Volume): New York, A.I.M.E., Vol. 2, p. 1238-1257.

Hobbs, B. E., Means, W. D., and Williams, P. E., 1976, An outline of structural geology: New York, John Wiley and Sons, Inc.

Kothavala, R. F., 1963, Wall rock alteration at the United Verde mine, Jerome, Arizona: Ph.D. thesis, Harvard University, 112 p.

Lindgren, W., 1926, Ore deposits of the Jerome and Bradshaw Mountains quadrangles, Arizona: U.S. Geol. Survey Bull. 782, 192 p.

Ramsay, J. G., 1967, Folding and fracturing of rocks: New York, McGraw-Hill Co., 568 p.

Sangster, D. G., 1972, Precambrian volcanogenic massive sulfide deposits in Canada: A review: Canada Geol. Survey Paper 72-22, 44 p.

Turner, F. J., and Weiss, L. E., 1963, Structural analysis of metamorphic tectonites: New York, McGraw-Hill Co., 545 p.