Deformation of the Roberts Mountains Allochthon in North-Central Nevada

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1060

Deformation of the Roberts Mountains Allochthon in North-Central Nevada

By JAMES G. EVANS *and* TED G. THEODORE

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1060

A study of minor and major structures of the allochthon at Battle Mountain and in the southern Tuscarora Mountains

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1978

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, *Secretary*

GEOLOGICAL SURVEY

H. William Menard, *Director*

Evans, James George, 1938-
Deformation of the Roberts Mountains allochthon in north-central Nevada.
(Shorter contributions to general geology)
(Geological Survey Professional Paper 1060)
Bibliography: p. 17-18
1. Rock deformation–Nevada–Roberts Mountains. 2. Geology–Nevada–Roberts Mountains. I. Theodore, Ted G., joint author. II. Title. III. Series: United States. Geological Survey. Shorter contributions to general geology. IV. Series: United States. Geological Survey. Professional paper 1060.
QE604.E89 551.8'09793'32 78-12333

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402
Stock Number 002-001-03119-1

CONTENTS

	Page
Abstract	1
Introduction	1
Regional setting	1
Purpose	1
Method	2
Battle Mountain area	2
General geology	2
Allochthon of the Roberts Mountains thrust	3
Geometry of minor structures	3
Kinematic implications of minor structures	7
Southern Tuscarora Mountains area	8
General geology	8
Allochthon	9
Description	9
Minor structures in areas 1–4	9
Autochthon	14
Conclusions	15
References cited	17

ILLUSTRATIONS

[Plates are in pocket]

PLATE 1. Map showing attitudes of folds in the Scott Canyon Formation in the Battle Mountain area and fabric diagrams of areas 1–4.
2. Generalized geologic map and sections of the southern Tuscarora Mountains area.

	Page
FIGURE 1. Index map of Nevada showing the areas studied in the Roberts Mountains allochthon	2
2. Geologic sketch map of the Battle Mountain area	4
3. Photograph showing folds in chert of the Scott Canyon Formation	6
4. Photographs showing folds of various styles in the Battle Mountain area	7
5. Fabric diagram showing statistically determined mean-outcrop-scale fold orientations	7
6. Contoured fabric diagram showing poles to bedding in carbonate assemblage in the Lynn window, southern Tuscarora Mountains area	8
7. Photographs showing disrupted bedding in chert of Roberts Mountains allochthon, southern Tuscarora Mountains area	10
8. Fabric diagrams showing poles to bedding, fold axes, and poles to axial planes in areas 1, 2, and 3	11
9. Sketched profiles of minor folds in chert areas 1 and 2, southern Tuscarora Mountains area	12
10. Summary fabric diagram for areas 1, 2, and 3	13
11. Fabric diagrams showing poles to bedding, fold axes, and poles to axial planes in area 4	14
12. Sketched profiles of minor folds in limestone in area 4	15
13. Fabric diagrams showing poles to bedding, fold axes, and poles to axial planes in area 5	16
14. Summary fabric diagram for areas 4 and 5	17

DEFORMATION OF THE ROBERTS MOUNTAINS ALLOCHTHON IN NORTH-CENTRAL NEVADA

By JAMES G. EVANS and TED G. THEODORE

ABSTRACT

During the Antler orogeny in Late Devonian and Early Mississippian time, early and middle Paleozoic siliceous rocks, largely chert and shale, were thrust eastward for 90 to 160 km over coexisting carbonate rocks. Minor and major structures of two small areas of the allochthon at Battle Mountain and in the southern Tuscarora Mountains were studied in order to characterize the deformation and test the consistency of the movement plan with respect to the large eastward displacement. In the Battle Mountain area, the lower Paleozoic Scott Canyon and Valmy Formations were deformed in the Antler orogeny but were unaffected by later tectonism during late Paleozoic or early Mesozoic. In the southern Tuscarora Mountains area, the Ordovician and Silurian siliceous rocks deformed in the Antler Orogeny were deformed by later, possibly Mesozoic, folding and thrusting.

Most of the minor folding visible in the allochthon is in the cheret, but proportionally more of the strain was taken up in the shale and argillite, both poorly exposed but predominant rock types. Most minor folds, concentric in form, plunge at small angles to the north-northeast and south-southwest with steeply dipping or vertical axial planes. The b-fabric axis, parallel to these folds, is identical apparently to the B-kinematic axis. The horizontal component of tectonic shortening of the allochthon, N. 70°–75° W. both in the Battle Mountain area and in the southern Tuscarora Mountains area, is therefore consistent with an eastward direction of movement of the allochthon. Folds with west-northwest trends locally present in the allochthon, may have formed in the direction of tectonic transport. In the southern Tuscarora Mountains, local strain in and below the allochthon was different from the prevailing strain in the allochthon, and tectonic shortening was locally at large angles to the accepted direction of movement of the allochthon.

INTRODUCTION

REGIONAL SETTING

The Roberts Mountains thrust, a major structure in northern Nevada, divides the siliceous or western assemblage (allochthon) from the carbonate or eastern assemblage (autochthon). Major juxtaposition of these two distinct sedimentary assemblages occurred during the Antler orogeny in Late Devonian and Early Mississippian time (Merriam and Anderson, 1942; Roberts and others, 1958). Rocks intermediate in character between the two assemblages are assigned to the transitional assemblage. The transitional assemblage occurs mainly in the autochthon, although some, including that described here, occurs in the allochthon.

Conclusions of previous workers concerning the direction of tectonic transport have been based on inferred initial distributions of sedimentary rock facies in the Cordilleran geosyncline (Kirk, 1933; Merriam and Anderson, 1942; Roberts and others, 1958; Gilluly and Masursky, 1965; Roberts and others, 1971). The siliceous assemblage, consisting of chert, argillite, shale, greenstone (andesite and basalt), quartzite, limestone, and siliceous carbonates of early and middle Paleozoic age, was originally deposited west of the carbonate assemblage, consisting of limestone, dolomite, limy shale, and quartzite of early and middle Paleozoic age. The present occurrence of the siliceous rocks overlying the carbonate rocks of equivalent age in north-central and northeastern Nevada implies many kilometers of generally eastward movement of the upper plate of the Roberts Mountains thrust.

The Roberts Mountains allochthon covers a large area of northern Nevada (fig. 1). Windows in the allochthon in which the carbonate assemblage is exposed occur as far as 90 km west of the inferred eastern margin of the thrust, thereby providing a minimum estimate of the magnitude of the thrust separation.

Possibly not all of this displacement is attributable to the Antler orogeny. At the end of this orogeny, part of the eastern edge of the Roberts Mountains thrust was at the longitude of the northern Piñon Range, near the town of Carlin, Nev. (Smith and Ketner, 1968; Ketner, 1970b). The siliceous rocks from Elko, Nev., eastward may have been emplaced in part in post-Antler time (Riva, 1970).

PURPOSE

For the present study, we undertook to examine large and minor structures within and below the allochthon of the Roberts Mountains thrust in the Battle Mountain area and in the southern Tuscarora Mountains area (fig. 1) in an attempt to define the deformation and movement plan of the allochthon. Although the data from these small areas cannot represent the overall deformation in

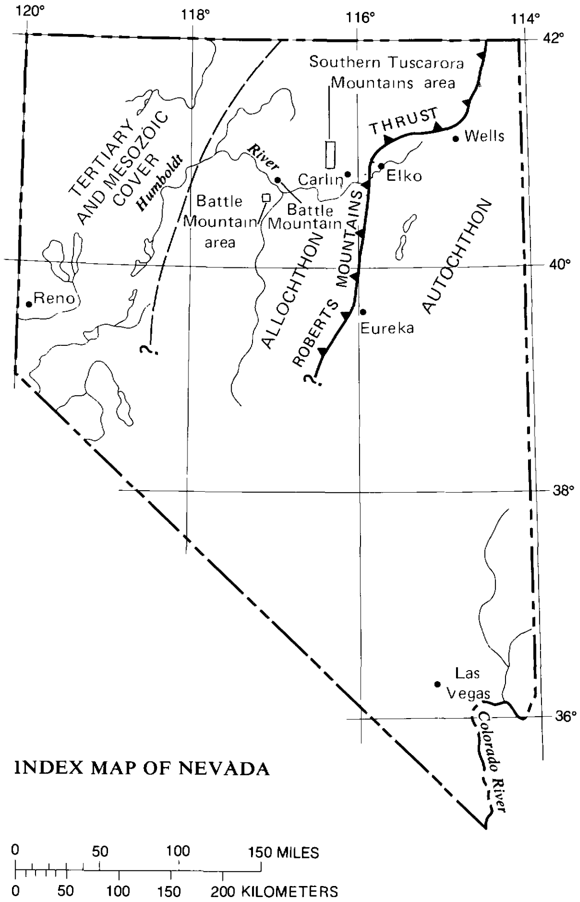


FIGURE 1.—Index map of Nevada showing the areas studied in the Roberts Mountains allochthon. Dashed line is approximate boundary between allochthon and Tertiary and Mesozoic cover. Eastern limit of the allochthon is from Stewart and Poole (1974).

an allochthon as extensive as that of the Roberts Mountains thrust, we can characterize certain aspects in a general way; orientations and character of the fabric elements, degree of homogeneity of deformation within the allochthon, and the consistency of the movement plan within the allochthon with respect to its presumed large eastward displacement. Clearly more study of the deformation in many parts of the allochthon is needed to define adequately its deformation picture during the Antler orogeny.

The structures and deformation in each of the areas are described separately, first, of the Battle Mountain area, then of the southern Tuscarora Mountains area. A concluding section brings together the similarities and differences of the two areas of study and the significance of the data for the allochthon as a whole. Preliminary results of some of these data are discussed by Wrucke and Theodore (1970).

METHOD

Standard techniques of structural analysis were used (Turner and Weiss, 1963; Ramsay, 1967): gathering numerous attitudes of bedding, axial planes, lineations, and fold axes, and detailed observations of fold types or styles and their geometric relations.

Most structural data in this study were contoured on equal-area lower hemisphere projections by a modified version of a method originally described by Kamb (1959) wherein a variable counting area is used. This area is a function of the number of data points and the frequency of significant deviation from a uniform spatial distribution. The counting area varies inversely with the number of data points, and the data sets were limited in size such that the diameter of the counting area could not be less than the grid spacing used during computer contouring. The sets were contoured using a program written by C. E. Corbato (written commun., 1966) and modified by W. J. Nokleberg (written commun., 1969). All stereograms are contoured in various intervals of 2σ where 2σ is the expected number of data points within a counting area for a uniform distribution across the entire stereogram.

BATTLE MOUNTAIN AREA

GENERAL GEOLOGY

Four major tectonic blocks of Paleozoic rock crop out in the Battle Mountain area (fig. 2). The Roberts Mountains thrust plate, the lowest of the four exposed tectonic blocks, is made up of the Lower and Middle Cambrian Scott Canyon Formation (now known to contain Devonian radiolarians, Jones and others (1978)) and the Ordovician Valmy Formation. The Roberts Mountains thrust does not crop out here but probably lies at least 1,400 m below present erosion levels (Theodore and Roberts, 1971). The second tectonic block, the Dewitt thrust plate, consists of the Upper Cambrian Harmony Formation that has been thrust, generally eastward, over the Scott Canyon and Valmy Formations along the Dewitt thrust, an imbricate thrust related to the Roberts Mountains thrust system (Roberts, 1964). The Roberts Mountains allochthon consists of all of the preceding formations. Unconformably overlying the Roberts Mountains allochthon is the third major tectonic block, the autochthonous Antler sequence. These autochthonous rocks occur below the Golconda thrust indicating that the Roberts Mountains allochthon was not deformed in the Battle Mountain area by Golconda thrusting during the Sonoma orogeny in Late Permian to Early Triassic time (Silberling and Roberts, 1962; Roberts, 1964; Nichols, 1971; Speed, 1971; Silberling, 1975). The upper Paleozoic Pumpernickel and Havallah Formations in the upper plate of the Golconda thrust make up the fourth major tectonic block of Paleozoic rock in the Battle Mountain area.

ALLOCHTHON OF THE ROBERTS MOUNTAINS THRUST

Structural data for our study of the Roberts Mountains allochthon were gathered from the Scott Canyon Formation, structurally the lowermost of the formations in the plate in the Battle Mountain area. The lithology of the Scott Canyon is extremely variable throughout an estimated aggregate stratigraphic thickness of about 1,500 m (Roberts, 1964). Poorly exposed, slope-forming gray argillite and well-exposed, locally cliff-forming, gray to black chert, interbedded at the meter and centimeter scale, make up about 95 percent of many studied sections in the Scott Canyon Formation. Poorly exposed, greenish-brown, altered andesite and (or) basalt is the next most common rock type. Quartzite crops out at some places, and there are a few isolated exposures of light-gray limestone. Chert outcrops provided about 90 percent of the 1,600 structural attitudes gathered for study of the Scott Canyon Formation.

The discontinuous and lensoid nature of chert masses within argillite, some as much as 100 m wide, suggests the extreme tectonic disruption of the upper-late rocks. This style of deformation persists at much larger scales. Under the microscope, examination of apparently undisturbed (in hand specimen) chert reveals that it commonly is composed of an almost phyllonitic mosaic of wedge-shaped fragments, about 0.4 mm long, of microcrystalline quartz. These fragments are separated one from another by discontinuous interleaved stringers of dark organic material. Rounded detrital quartz grains are sparse. Folded chert-argillite layers, several centimeters across, also show this disruptive style (fig. 3A). Chert phacoids swim in the apparently more ductile argillite matrix. Accordingly, strain in the upper-plate rocks at Battle Mountain appears to have been concentrated in the argillite-rich horizons. Concomitant with deformation of the argillite, chert layers yielded by folding.

GEOMETRY OF MINOR STRUCTURES

Exposures of chert of the Scott Canyon Formation are typified by partings, about every several centimeters, parallel to bedding (fig. 3). Possible postdiagenetic transposition of bedding in chert, parallel to preexisting sedimentary layering, has been recognized under the microscope. Bedding has a fairly consistent attitude over many outcrops, some of which measure up to 50 m wide. There are some local changes in bedding attitudes. Some steeply dipping chert sequences typically are warped into broad open folds containing horizontal or gently plunging fold axes (fig. 3*B*).

The outcrop area of the Scott Canyon Formation (pl. 1) has been divided into four smaller areas, and the orientation of bedding in each of these studied (pl. 1). Poles to bedding form a broad girdle in all four areas, the axes of which (geometric fold axis) plunge about 10° east of due north and 10° west of due south. Two of the areas, 1 and 3, have poles to bedding that form strong single maxima that plunge steeply to the southwest (area 1) or due east (area 3), reflecting the strong concentration in these areas of beds that dip at shallow angles to the northeast and west, respectively. The other two areas, 2 and 4, have poles to bedding that form strong paired maxima; one group of poles plunges steeply to the east, the other moderately to the west. Single pole-to-bedding maxima within the girdles suggest the homoclinal nature of bedding in areas 1 and 3, but this is only statistically defined. The paired maxima of areas 2 and 4 may reflect fold limbs statistically resolvable throughout these two areas. Absence of a uniform geographic distribution of recorded bedding attitudes, resulting primarily from uneven outcrop distributions, precludes construction of average fold profiles from the pole-to-bedding diagrams.

Individual antiforms and synforms (facing is generally unknown in the Scott Canyon Formation) that can be inferred beyond the extent of a given outcrop are not common in the Battle Mountain area. This relation is a result of both the locally extreme tectonic disruption of the rocks and the absence of suitable marker beds. Only six such folds have been recognized (pl. 1); several of these have fold widths (Hansen, 1971) of about 250 m. Their northerly trend suggests east-west shortening of the Scott Canyon Formation.

No compelling evidence of superposition of fold systems such as refolded folds and interference domes and basins (Ramsay, 1967; Hansen, 1971) were noted. At the macroscopic scale, however, some small antiforms and synforms are found in the limbs of a large antiform in the southeastern part of the Battle Mountain area. Such a geometric relation suggests that some of the large-scale east-west shortening followed development of the smaller structures (pl. 1), although age relations cannot be demonstrated with certainty because the axes of the small folds are approximately at right angles to the axis of the large antiform.

Several features are characteristic of many folds in the Scott Canyon Formation. Most folds are concentric (Turner and Weiss, 1963; Ramsay, 1967); generally they are upright or slightly overturned (fig. 3*C*), and they have rectilinear or cylindrical axes. The overturned folds have monoclinic symmetry, with the symmetry plane perpendicular to the fold axis; the upright folds have orthorhombic symmetry. Some folds have a marked down-plunge variation in axial orientation, perhaps re-

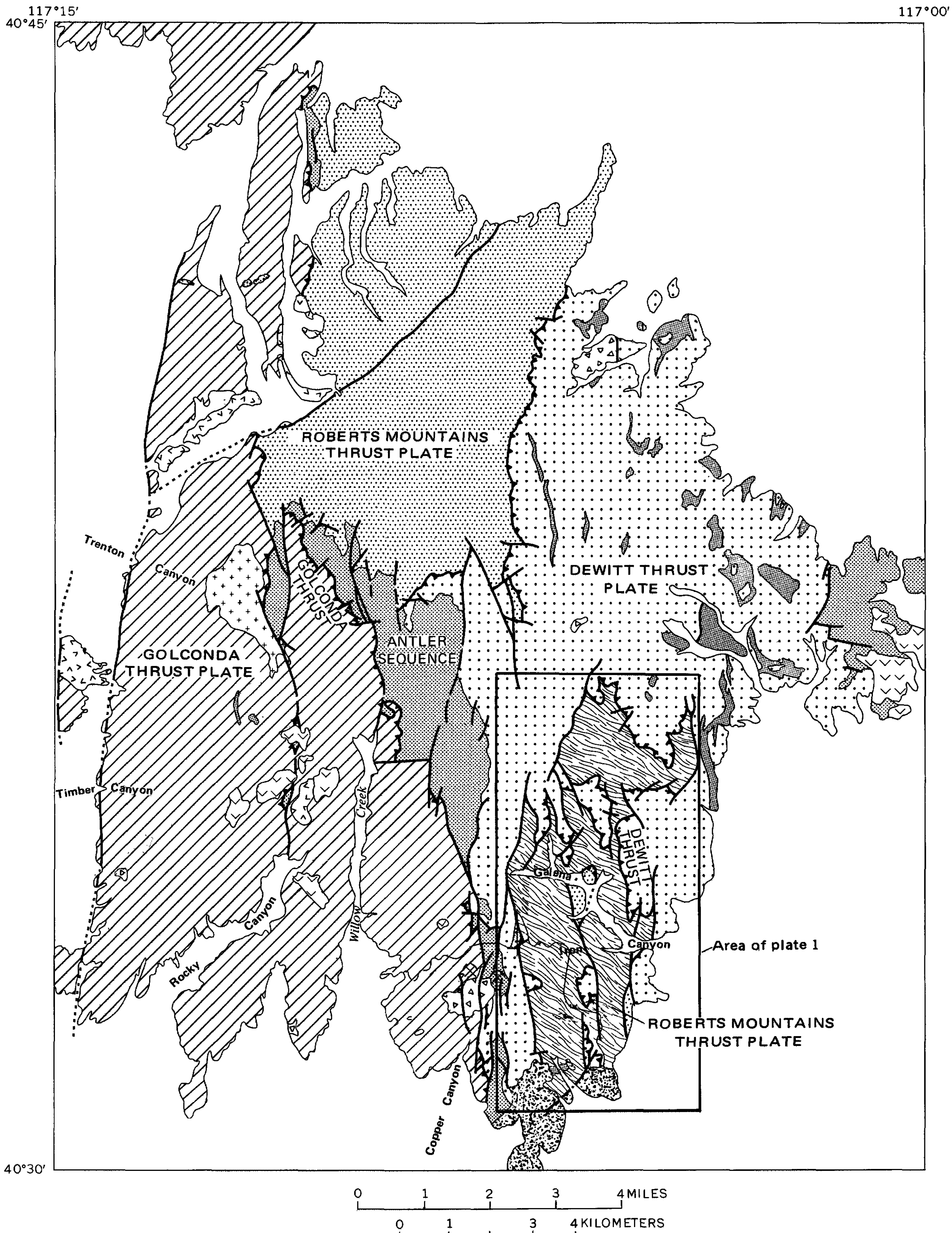
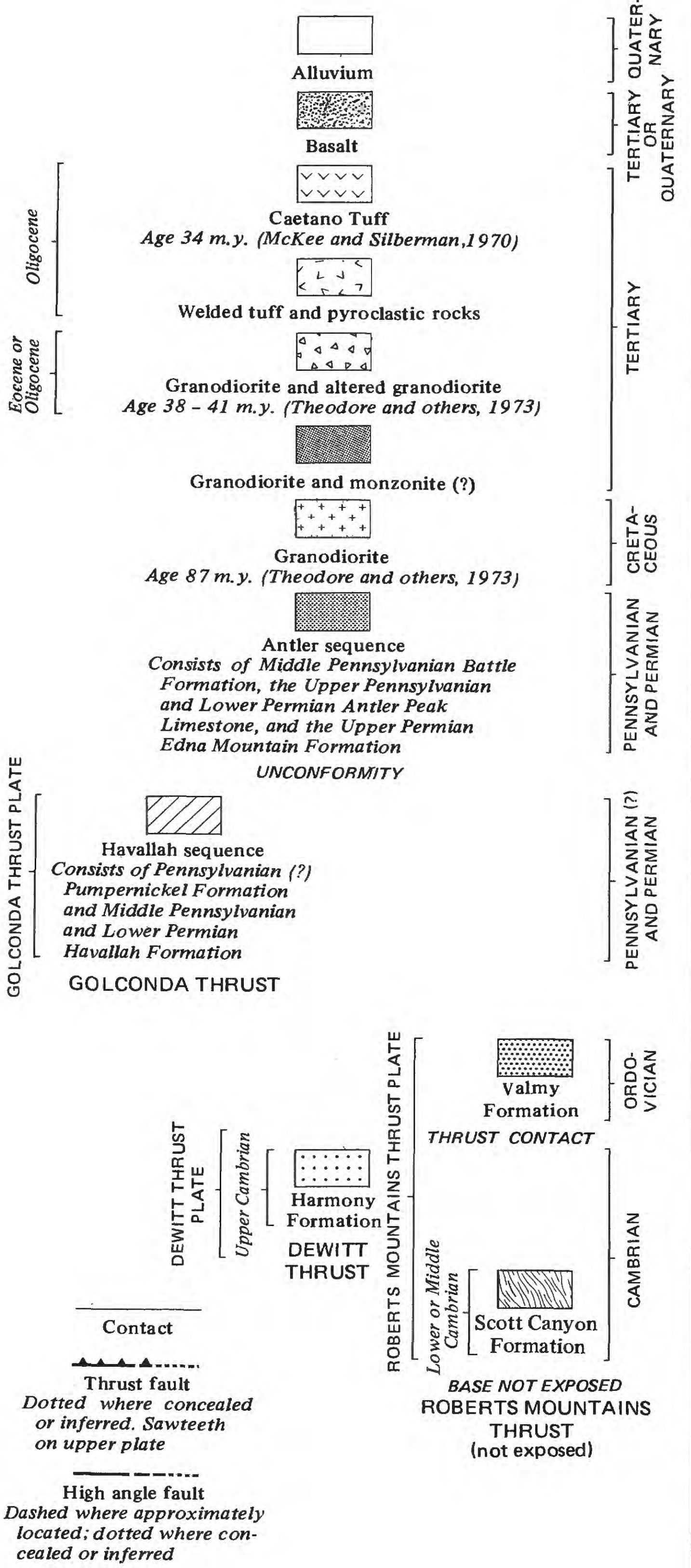


FIGURE 2.—Geologic sketch map of the Battle Mountain area. Geology modified from Roberts (1964, pl. 4).



flecting variations in mechanical response during deformation because of slight differences in lithology. These folds should be termed cylindroidal rather than cylindrical (Hansen, 1971). The uniform thickness of chert beds, especially in the hinge regions of the folds, strongly suggests that the concentric folds were formed by flexural slip; slip along bedding planes must have been the dominant mechanism of fold formation in chert of the Scott Canyon Formation.

Angular folds are rare. A chevron-type fold, shown in fig. 3*D*, grades through an intermediate zone of thin-bedded chert showing abundant flowage into the more common concentric-type fold.

Similar folds are rare; they were found in only one area, 50 m^2, in SE¼ sec. 26, T. 31 N., R. 43 E. Two of these structures are shown in figures 4*A* and *B*. Folds here are commonly tightly appressed to isoclinal, with very areally restricted hinge regions. Chert generally makes up less than 40 volume percent of the rock, argillite the rest (fig. 4*A*, *B*). Flowage toward the hinges of similar folds is common. Some folded layers display a disharmonic style of folding with polyclinal axial planes. Apparently brittle failure of some layers along microfaults occurred contemporaneously with the development of the folds.

Variability of attitudes of the outcrop-scale folds from one locality to another is apparent throughout the Scott Canyon Formation (pl. 1). Because of space limitations, only representative fold measurements from many of the studied localities are included on the map. It is readily apparent, however, that folds have a a fairly strong preferred orientation throughout the area. They generally plunge at shallow angles in a northerly or southerly direction. Two areas show some marked scatter. In the western part of area 3 (pl. 1), the folds have somewhat more northwesterly trends, and in area 4, some steeply plunging folds have approximately east-west trends. These steeply plunging folds we described above as possibly having formed before the larger ones. The style of all these folds whose attitudes are apparently aberrant from the norm is the same as the style of the northerly shallow-plunging folds predominant in the Battle Mountain area.

Fabric diagrams of all measured fold axes reveal the strong preferred orientations of folds in the Scott Canyon Formation (pl. 1). The fold axes define very strong single maxima in each of the four grouped data sets. Each of these maxima has about a 60° spread in both trend and plunge. In addition, they all have northeast-southwest trends. The centers of the maxima in areas 1, 2, and 4 plunge 15°, N. 15°–20° E.; in area 3, the center

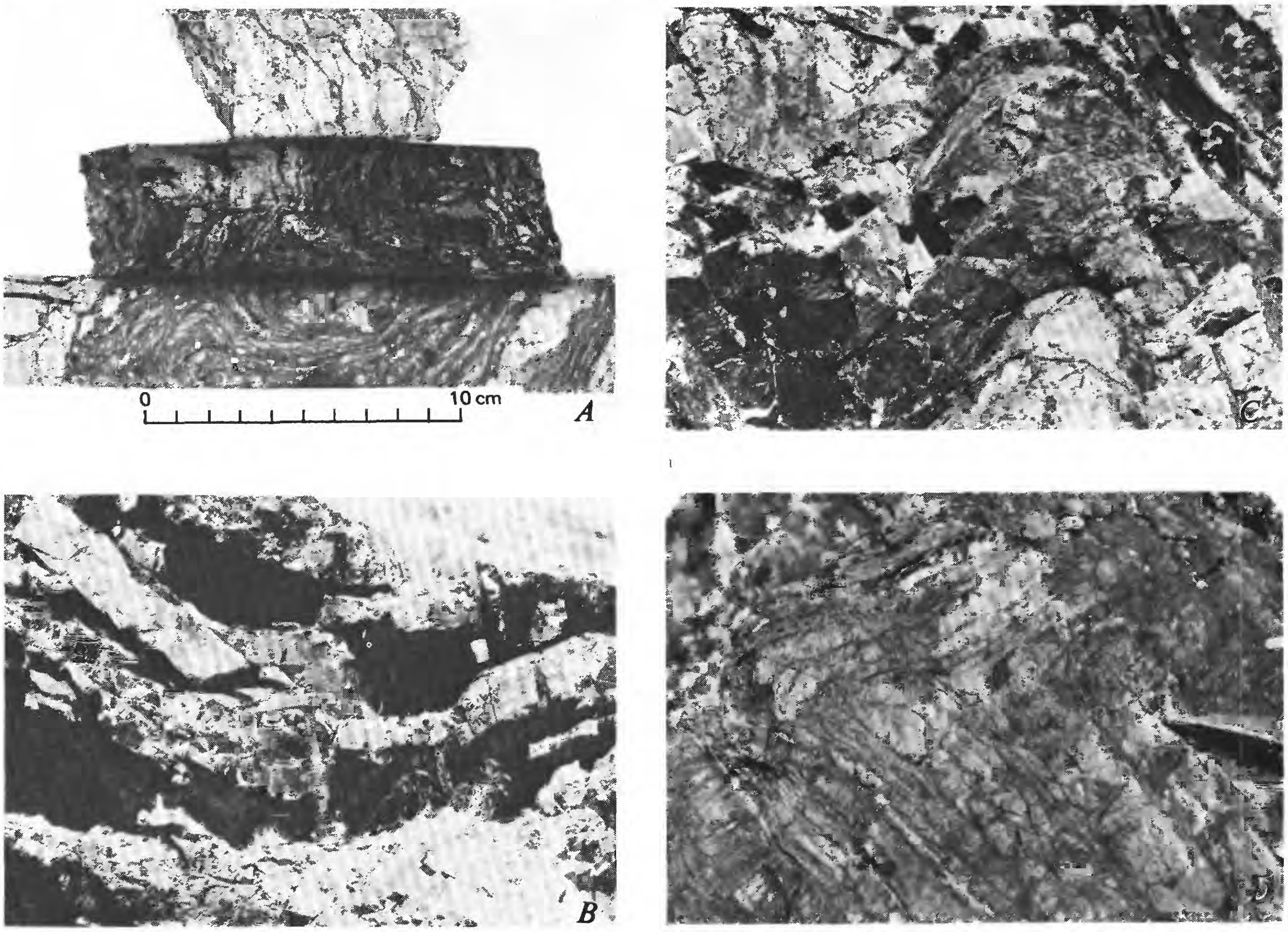


FIGURE 3.—Folds in chert of the Scott Canyon Formation. *A*, Folded chert-argillite layers. Light-colored chert phacoids surrounded by apparently more ductile, organic-rich dark-colored argillite in drill core. *B*, BNroad open fold. *C*, Concentric synform and antiform. See dime (right center) for scale. *D*, Angular chevron-type fold (right), which becomes concentric fold (left). Planar axial surface is approximately horizontal. Point of rock pick is 5 cm long.

plunges 15°, S. 20° W. The low-density perturbations in fold-axis concentrations in areas 3 and 4 (pl. 1) are produced by axes of northwest-trending and east-west-trending minor folds in these areas. These perturbations, however, are defined by the 2σ contour (pl. 1), which is the expected density for no preferred orientation. Accordingly, because these deviations apparently fail to attain statistical significance, we conclude that they probably have no geologic significance.

About 50 percent of the minor fold structures whose axes we recorded were exposed such that their axial plane attitudes could be determined (pl. 1). These axial surfaces are generally planar; some are curviplanar. Fabric diagrams of these data reveal that the poles to the axial planes mostly define a single maximum for all four areas (pl. 1). Scatter in the data spread the maxima into girdles of various types. A high-density partial horizontal girdle (area 1) results from variations in strike of vertical or near-vertical axial planes. Areas 2, 3, and 4 are characterized by axial-plane attitudes whose maxima grade into low-density girdles defined predominantly by the 2σ contour.

Throughout the Scott Canyon Formation, profile views of the outcrop-scale folds suggest that they are not consistently overturned to either east or west. The absence of uniformly overturned folds is reflected in fabric diagrams of the axial-plane data (pl. 1). A 4σ concentration of poles to axial planes plunges about 45° E, in areas 1 and 2; this suggests some statistically resolvable folds are overturned to the east. The high density (12σ) of vertical axial planes in area 1, however, indicates their statistical prominence over the inclined ones. Further, the maximum in area 3 has a shallow plunge to the west which implies a dominance of folds slightly overturned to

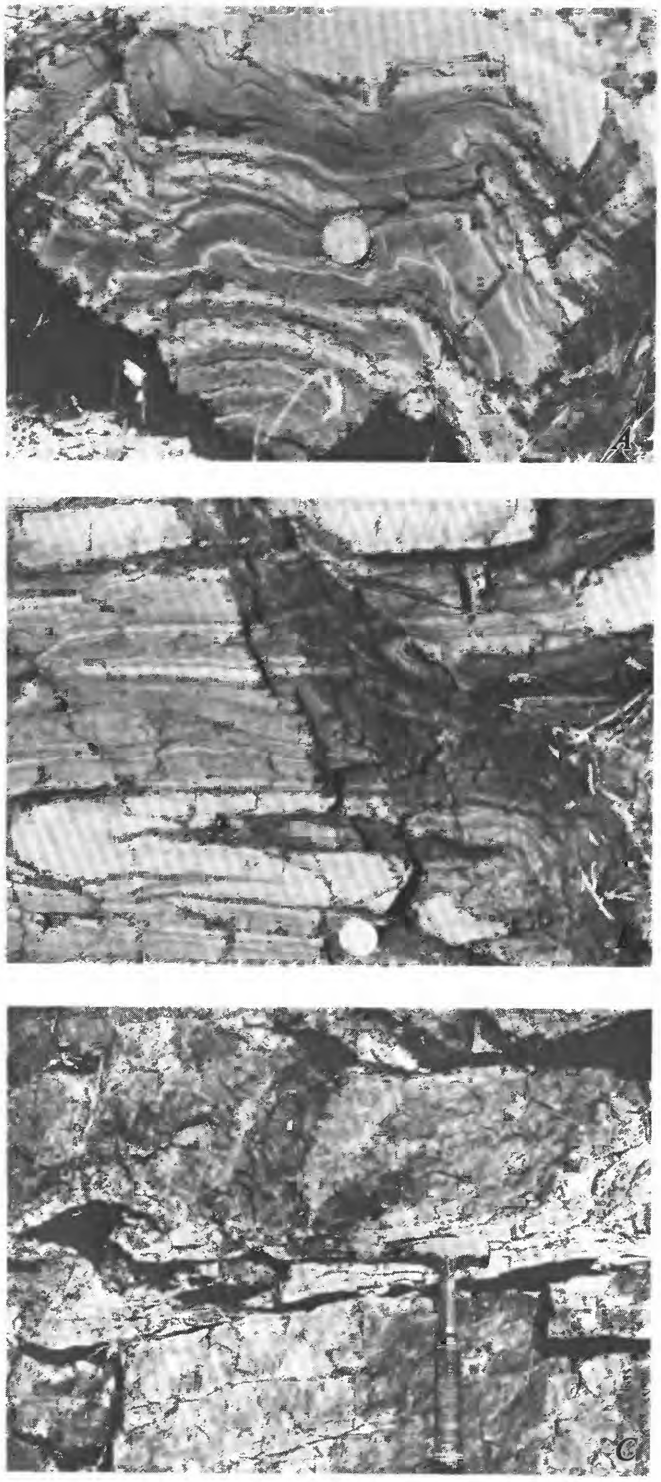


FIGURE 4—Folds of various styles in the Battle Mountain area. *A*, Complex, partly disharmonic similar folds in predominantly argillite-rich layered sequence of rock, with minor chert (light-colored layers). *B*, Tight isoclinal folds in argillite-rich rock. *C*, Opposed sense of overturning in thin-bedded sequence of chert (light-colored layers), bounded by thick-bedded chert (dark-colored layers).

the west in this part of the Scott Canyon Formation. Yet over many outcrops there is no persistent sense of overturning; some complex structures have axial surfaces inclined to both east and west (fig. 4*C*).

KINEMATIC IMPLICATIONS OF MINOR STRUCTURES

From the geometry and types of structures in the Scott Canyon Formation, we can make some judgments concerning their tectonic implications. Since a summary diagram of the fold axes (B) and β axes in all four areas (fig. 5) indicates shear displacements on the bedding planes normal to the fold axes as the dominant type of fold development, the geometric fold axes must have coincided with their kinematic fold axes. The statistically determined mean attitudes for fold axes in the four areas can thereby be designated B axes (axes of rolling) for these areas. For three of the areas studied at Battle Mountain (areas 1, 2, and 4), fold axes (B) are statistically parallel to one another. The B axes at Battle Mountain, however, are parallel to but one of their β axes determined from the plots of the bedding-plane attitudes. This relation may in part reflect inaccurate plac-

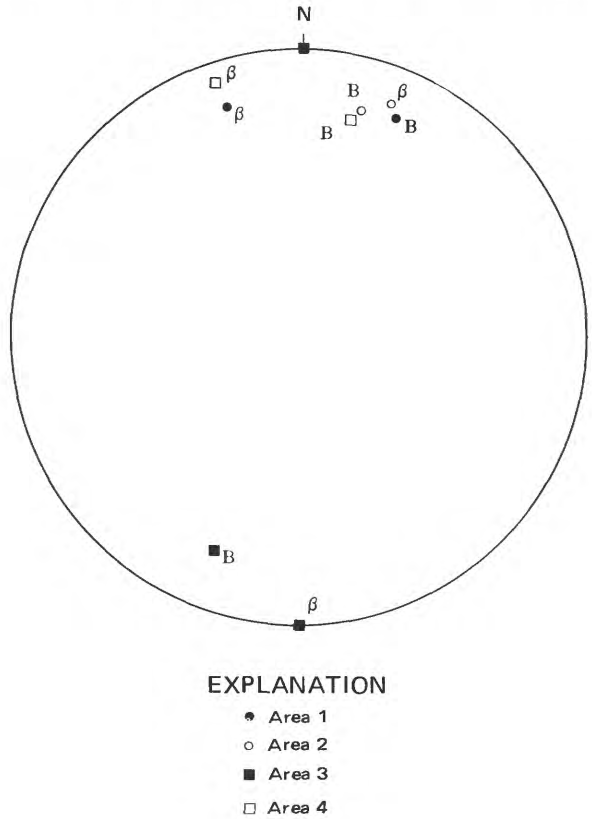


FIGURE 5.—Fabric diagram showing statistically determined mean-outcrop-scale fold orientations (B) and β axis orientations for areas 1–4 of the Scott Canyon Formation (pl. 1).

ing of the pole-to-bedding girdles owing to their poorly defined character (pl. 1).

From the axial-plane data (pl. 1), we infer that most folds have vertical or near-vertical axial planes. Orthorhombic folds are dominant throughout many outcrops of chert in the Scott Canyon Formation. Accordingly, we make no judgments about the sense of tectonic transport in the Roberts Mountains plate from these data. The apparent horizontal component of tectonic shortening, however, is remarkably uniform throughout these rocks and it trends N. 70°–75° W.; the mean azimuthal bearing for all folds here is 15° to 20°. The chert layers in the Scott Canyon Formation may have behaved more or less rigidly after initially buckling during early stages of deformation; most of the strain probably was concentrated in the argillite during deformation.

SOUTHERN TUSCARORA MOUNTAINS AREA

GENERAL GEOLOGY

The Roberts Mountains allochthon in the Rodeo Creek NE and the Welches Canyon quadrangles, southern Tuscarora Mountains area, is made up chiefly of Ordovician and Silurian chert, shale, and minor quartzite and limestone of the siliceous assemblage (pl. 2; Evans, 1974a, b). This assemblage is represented by at least 3,050 m of strata. Upper Devonian limestone assigned to the transitional assemblage (pl. 2) occurs within the allochthon and is at least 915 m thick. This limestone was assigned to the transitional assemblage because it contains angular grit, rounded cobbles of chert, and beds of siliceous shale up to 15 m thick. Autochthonous rocks are exposed in the Lynn window and consist largely of Cambrian through Devonian limestone, dolomite, and quartzite of the carbonate assemblage (pl. 2). These strata total 2,720 m.

In the southern Tuscarora Mountains area, as in the Battle Mountain area, fine to very fine grained rocks with delicate laminations in the Ordovician and Silurian siliceous assemblage of the allochthon are evidence of deposition in quiet water. Sets of laminations, as much as a few centimeters thick, locally folded or truncated indicate minor flowage. Coarse sand and grit composed of chert and shale clasts and angular limestone conglomerate suggest some penecontemporaneous deformation. Evidence of large-scale penecontemporaneous deformation, such as angular uncomformities within the siliceous assemblage is absent. The extremely poor outcrops of the siliceous rocks, however, may not be adequate to permit conclusions to be drawn concerning the mobility of the sedimentary rocks prior to their more spectacular translation during the Antler orogeny.

Chert clasts in the Upper Devonian transitional limestone in the southern Tuscarora Mountains area point to the beginning of the Antler orogeny somewhere west of the Tuscarora Mountains by Late Devonian. The Webb Formation of Early Mississippian (Kinderhook) age, described by Smith and Ketner (1968), unconformably overlies the allochthonous Ordovician and Devonian rocks and the autochthonous Ordovician and Silurian rocks in the northern Piñon Range, thereby giving an upper-age limit to the Antler orogeny in northeast Nevada.

The northeast trend of the Antler orogenic belt through the southern Tuscarora Mountains suggests that large folds and minor folds trending northeast in the Roberts Mountains allochthon of the study area could be correlated with the Antler orogeny. The allochthon in the southern Tuscarora Mountains could also have been affected by the late Paleozoic and Mesozoic folding and thrusting identified in the Adobe Range, 50 km east of the southern Tuscarora Mountains (Ketner, 1970a). These later folds also trend northeast.

Clear evidence for some post-Antler deformation in the southern Tuscarora Mountains is the asymmetric anticline in the carbonate assemblage (plunge 20°, trend N. 15° W.; fig. 6) in the Lynn window (pl. 2). This anticline lies at an angle to the northeast trend of the Antler orogenic belt and therefore presumably postdates the

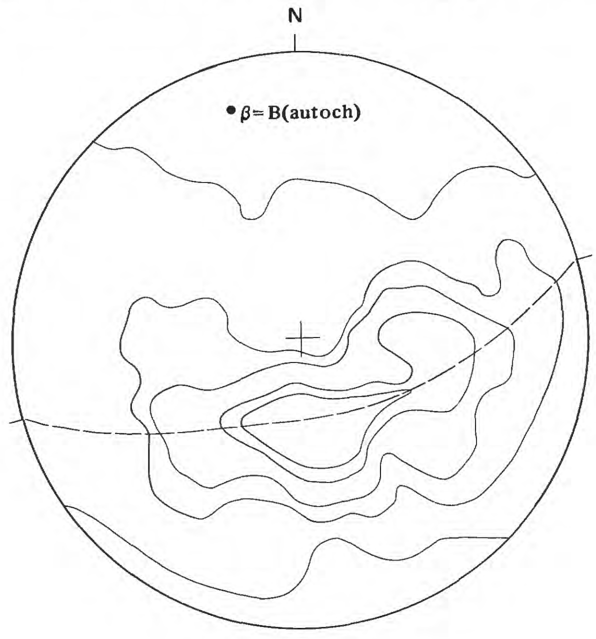


FIGURE 6.—Contoured fabric diagram showing poles to bedding in carbonate assemblage in the Lynn window (pl. 2), southern Tuscarora Mountains area. 300 points. Contoured in 2σ intervals where 2σ is the expected number of data points within a counting area for a uniform distribution across the entire stereogram (see Kamb, 1959). Contours 2σ, 4σ, 8σ, 12σ, and pole-free area. Fold axis B plunges 20° in the direction N. 15° W. Great circle (dashed line) is distribution of poles to bedding and defines fold axis.

Antler orogeny. In addition, on the west side of the range, the carbonate assemblage is thrust over the siliceous assemblage along the West Lynn thrust, clearly of post-Antler age.

The Paleozoic rocks were intruded in the Mesozoic (granodiorite, 121±5 m.y., Hausen, 1967, p. 36; granite, 106±2 m.y., M. L. Silberman, written commun., 1971) and in the Tertiary (granodiorite, 37±0.8 m.y., M. L. Silberman, written commun., 1971; quartz latite, 36±0.7 m.y., McKee and others, 1971, p. 41). The present small exposures of the Mesozoic intrusions may be apophyses of larger buried plutons, as the Paleozoic rocks surrounding the intrusions have been metamorphosed (recrystallization resulting in coarsening of grains, partial destruction of bedding features and fossils, bleaching, and neomineralization) in aureoles several thousand meters wide. Emplacement of one or more plutons could have been associated with a stage of post-Antler deformation of the Paleozoic rocks and may have resulted in uplift of the autochthon at the Lynn window (Roberts, 1966).

ALLOCHTHON

DESCRIPTION

Most of the outcrops of the Roberts Mountains allochthon in the southern Tuscarora Mountains area are chiefly of chert and exhibit thin planar beds and laminae with little sign of the intense deformation seemingly implied by many kilometers of transport from the west. Many lithologic units are mappable for several hundred meters before being truncated by faults, or more commonly, disappearing beneath thick Cenozoic regolith. To all appearances, much of the siliceous assemblage arrived in the southern Tuscarora Mountains in fault slices that were relatively little deformed internally, although disrupted bedding is present. Some of the intensely fragmented bedding could have been produced by penecontemporaneous deformation (fig. 7*A*). Minor bedding-plane thrusts, possibly of penecontemporaneous origin, occur locally (fig. 7*B*). Some intricate folding and boudinage may be related to strains developed around small Mesozoic intrusions (fig. 7*C*). Locally, bedding features have been nearly obliterated by intense fracturing (fig. 7*D*), possibly associated with the Antler orogeny.

Large folds in the siliceous assemblage trending north-northwest, north, and north-northeast (pl. 2), can be traced for 1½ to 3 km. Profiles of the folds (pl. 2) show them to be generally open and apparently concentric in general form and to have steeply dipping or vertical axial surfaces.

Minor folds subparallel to the larger ones plunge at low angles, chiefly to the northeast and southwest. Such folds are not common in the allochthon. In fact, minor folds were found in only 81 chert outcrops in the 125 km² underlain by the siliceous assemblage in the study area.

Fault-faceted phacoids of chert and quartzite as much as a few hundred meters long, some elongate parallel to the bedding, occur near the Roberts Mountains thrust and near other shear zones within the allochthon. The bedding in some of the phacoids is contorted, but the internal structure of the phacoids has little relation to the shape of the phacoid or to the structure of the surrounding shale. The chert, after folding plastically in an early part of the deformation, thereafter behaved in a brittle manner; rigid pieces of the chert swim in relatively ductile shale. In some parts of the allochthon, much of the strain must have been taken up within the shale. As the outcrops are chert, however, the data of this study principally describe deformation in the chert beds, which are subordinate to shale in the allochthon.

MINOR STRUCTURES IN AREAS 1–4

The Roberts Mountains allochthon in the southern Tuscarora Mountains area was divided into four areas of study. Areas 1, 2, and 3 are several square kilometers each and cover most of the allochthon in the southern Tuscarora Mountains area (pl. 2). Area 4 is smaller and is in the eastern assemblage.

The bedding in areas 1 and 2 dips predominantly to the northwest (figs. 8*A*, *C*). In area 3, the bedding attitudes are more varied (fig. 8*G*), and the poles to bedding lie along a great circle, defining a β axis, β_3, which plunges 15° in the direction S. 18° W.

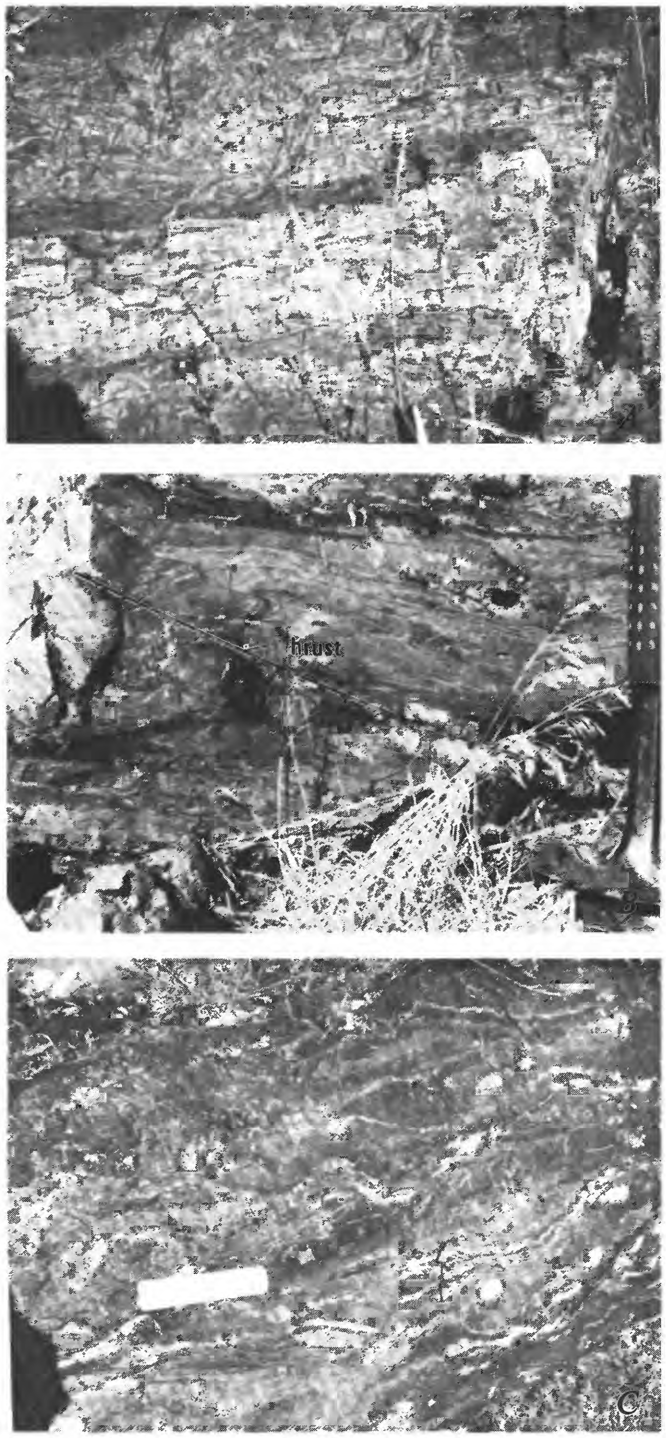
The minor folds of the allochthon are generally concentric and cylindrical. Antiformal hinges tend to have a smaller radius of curvature than the synformal ones (figs. 9*A*–*E*). The beds are slightly thicker in the antiformal hinges than on the fold limbs. A few folds are tightly appressed, nearly isoclinal. Some of these folds have narrow zones of breccia along the axial surface.

Most folds in area 1 plunge at low angles to the north-northwest, north, and north-northeast (fig. 8*B*). At a few localities, folds plunge at low angles to the west-northwest. The folds in the north-northeast and west-northwest directions will be referred to here as B (1:nne) and B (1:wnw), respectively. At one locality the folds B (1:wnw) are the dominant set. No evidence was found there to determine the relative ages of B (1:nne) and B (1:wnw).

In area 2, the folds plunge at low angles to the north-northeast and northeast (fig. 8*D*). At one locality, horizontal folds trending west-northwest were observed. The folds of northeast and west-northwest directions are designated B (2:nne) and B (2:wnw), respectively. In the western part of area 2 the bedding of several chert outcrops, concluded to be phacoids of chert, are intricately folded, as shown in figures 9*F* and *G*. The folds in the western part of area 2 plunge principally at small angles in northeast and southwest directions with a wide scattering to the north-northwest and west (fig. 8*E*). The pattern is not greatly different from the pattern in the remainder of area 2 (fig. 8*D*).

The folds of area 3 are more varied in orientation than the folds in areas 1 and 2 (fig. 8*H*). Most of the folds in area 3 plunge at low angles to the northeast and southwest. Others are steep. These fold axes may be distributed along a great circle of the orientation diagram. The pole to a great circle that seems to fit this distribution plunges at a small angle to the east-southeast. This pole, possibly an axis of rotation of the folds, is designated P_3.

The subordinate west-northwest-trending folds of areas 1 and 2 are at high angles to the dominant, generally north-northeast-trending group of folds. This angular relation, B (nne), approximately perpendicular to B (wnw), may be fortuitous, or it could indicate a syngenetic relation between the two sets of folds (fig. 10). The suggestion from the data of area 3 is that the north-



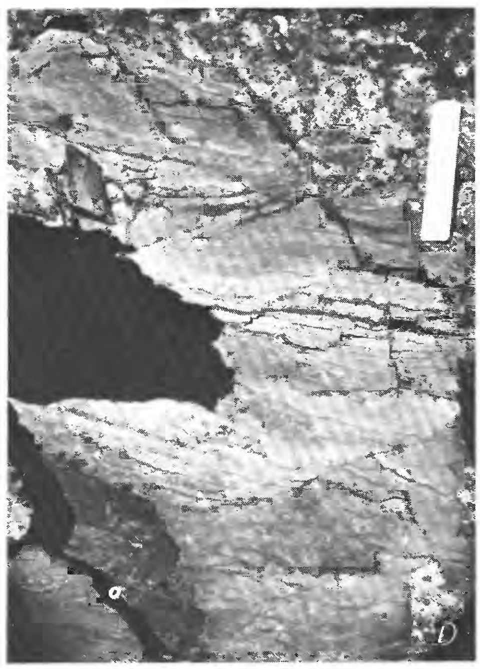


FIGURE 7.—Disrupted bedding in chert of Roberts Mountains allochthon, southern Tuscarora Mountains area. *A*, Fragmented bedding in chert 2.3 km north of Carlin mine (sec. 1, T. 35 N., R. 50 E.). Prominent band of dark chert across center is 7 cm wide. *B*, Minor thrust in chert (sec. 21, T. 34 N., R. 50 E.). *C*, Folding and boudinage in chert near large Mesozoic granodiorite dike 4 km north of Carlin mine (T. 36 N., R. 50 E., unsurveyed). Six-inch ruler in lower left of photograph. *D*, Faulted bedding in cherty shale 3 km south of Lynn window (sec. 21, T. 34 N., R. 50 E.). Six-inch ruler in upper right of photograph.

northeast-trending folds, B (3:nne), were rotated about an axis, P_3, plunging east-southeast subparallel to B (3:wnw), and that therefore the two sets could represent consecutive stages of deformation with northeast-trending minor folds better developed in the initial stage. These stages could have occurred very close in time, however, and both could have occurred during the Antler orogeny.

In general, the axial planes of the minor folds in areas 1, 2, and 3 are steeply dipping or vertical. A preferred sense of overturning of the axial planes is not evident. In the western part of area 2, the axial planes of the folds in

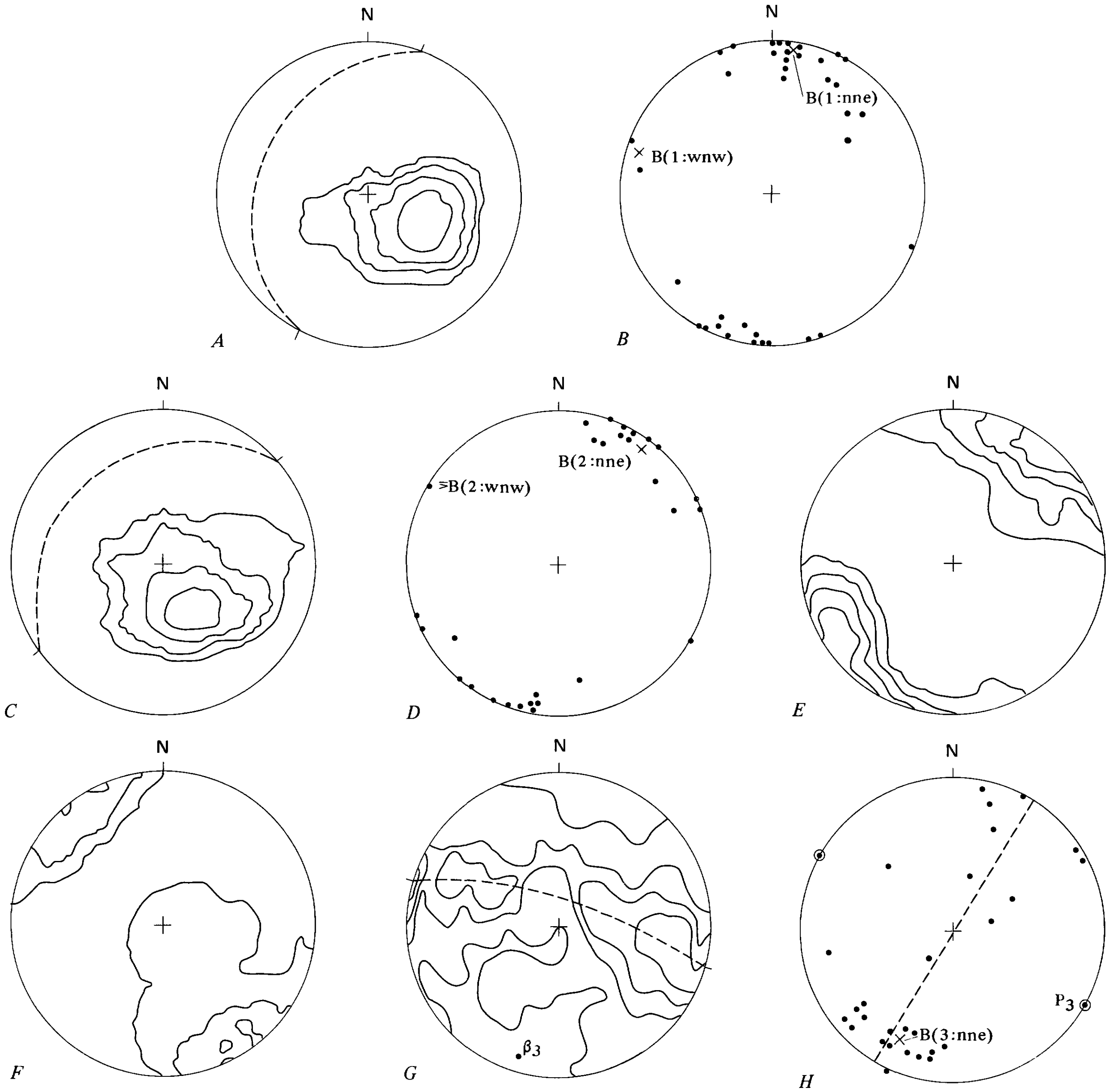


FIGURE 8.—Fabric diagrams showing poles to bedding, fold axes, and poles to axial planes in areas 1, 2, and 3 (pl. 2). See text for explanation. *A*, Contoured poles to bedding in area 1. 175 points. Contours 2σ, 4σ, 8σ, and 16σ. Great circle (dashed line) represents a plane striking N. 28° E. and dipping 30° NW. *B*, Fold axes at 27 localities in area 1. 27 points. *C*, Contoured poles to bedding in area 2. 176 points. Contours at 2σ, 4σ, 8σ, and 12σ. Great circle (dashed line) represents a plane striking N. 53° E. and dipping 30° NW. *D*, Average orientations of fold axes at 22 localities in area 2. *E*, Fold axes from 13 localities in western part of area 2. 55 points. Contours 2σ, 4σ, 8σ, and pole-free area. *F*, Contoured poles to axial planes in folds in western part of area 2. 35 points. Contours 2σ, 4σ, and pole-free area. *G*, Contoured poles to bedding in siliceous assemblage in area 3. 300 points. Contours 2σ, 4σ, 8σ, 12σ, and pole-free area. Great circle (dashed line) is distribution of poles to bedding. B_3 is pole to great circle. β axis plunges 15° in the direction S. 18° W. *H*, Fold axes at 24 localities in area 3. 27 points. P_3 (circled dots) is pole to the great circle (dashed line).

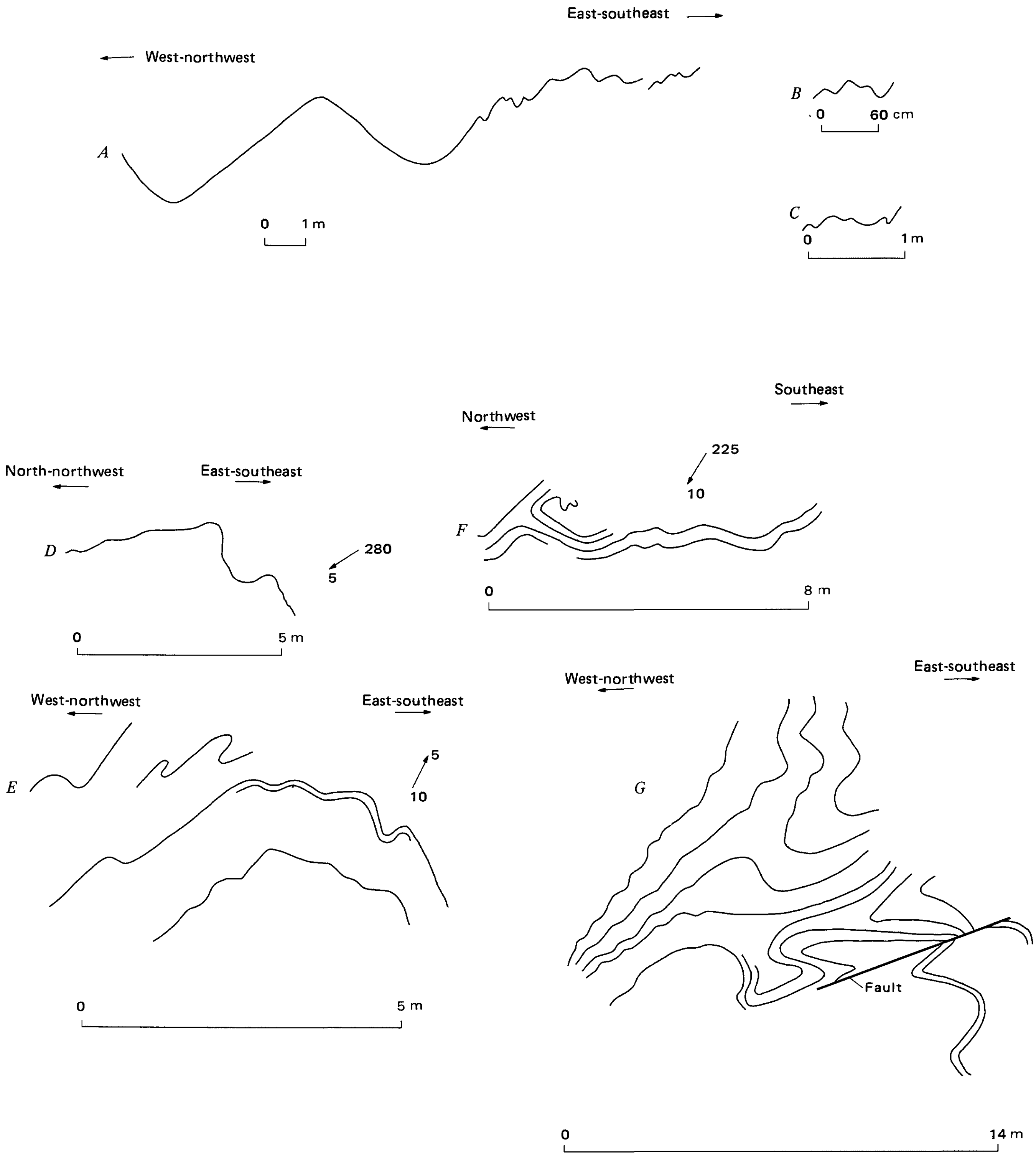


FIGURE 9.—Sketched profiles of minor folds in chert in areas 1 and 2, southern Tuscarora Mountains area. *A–C*, area 1; *D–G*, area 2. In *A–C*, *E*, and *G*, folds plunge at low angles to the north-northeast, in *D* and *F*, to the south-southwest. Arrow points in the direction of plunge and away from the number giving the azimuth of the trend in degrees related to a 360° compass. Zero degrees (north) is assumed to be at the top of the page. The angle of plunge is written at the point of the arrow.

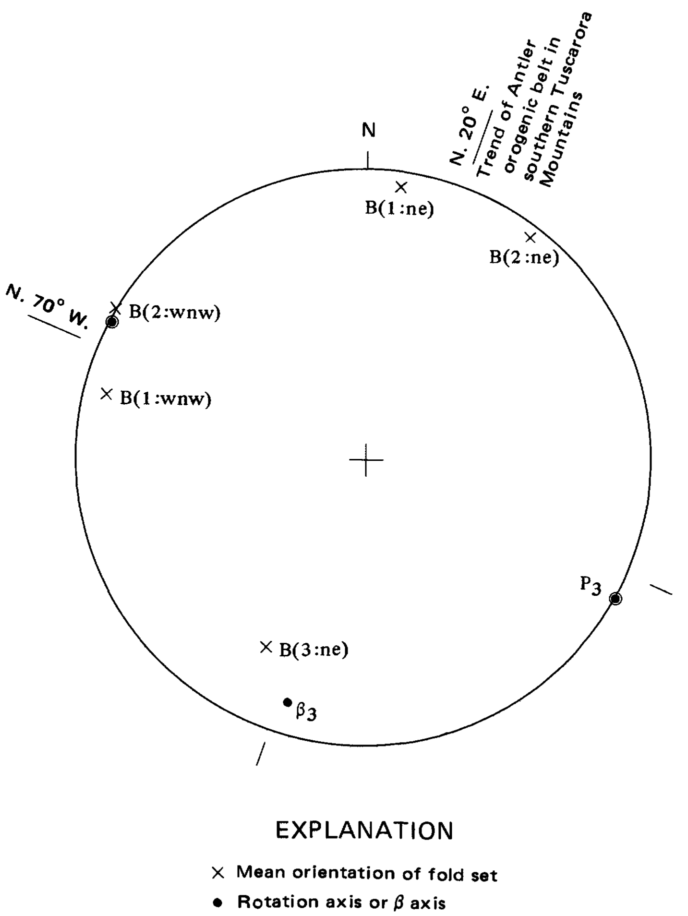


FIGURE 10.—Summary fabric diagram for areas 1, 2, and 3. See text for explanation.

chert phacoids are also mostly steeply dipping or vertical (fig. 8*F*). Some of the axial planes, however, are flat lying, occur adjacent to minor thrusts, and dip northwest and southwest (fig. 9*G*). The axial planes that dip at low to moderately steep angles in westerly directions in figure 8*F* indicate that the sense of overturning in these folds had a large eastward component. Other axial surfaces are folded around axes coincident with the dominant northeast-trending fold axes (fig. 9*F*).

The most common fold-axis direction in areas 1, 2, and 3 is north-northeast. In folds of this orientation, predominantly of concentric form, slip took place on the bedding in a direction perpendicular to the fold axis. The b-fabric axis is identical to the B-kinematic axis, and the direction of tectonic shortening is generally N. 70° W. These fabric features are consistent with the accepted easterly direction of movement of the allochthon. As stated here, however, only part of the total deformation of the allochthon is revealed in the chert outcrops. Minor local shortening within the allochthon could have occurred in the relatively ductile shale, while, for example, the allochthon glided eastward over an irregular thrust surface. Minor shortening could have occurred perpendicular to the principal movement direction of the allochthon, possibly resulting in local development of west-northwest-trending folds in the chert.

Area 4 is in the thin-bedded limestone member, about 120 m thick, of a 1,400-m-thick section of chert and shale west of the Lynn window (pl. 2). The limestone member is folded into an antiform and synform plunging north-northwest at low angles. Bedding generally dips steeply and strikes north-northwest. The poles to bedding define a β axis, β^4, plunging 35° in the direction N. 8° W. (fig. 11*A*).

In the hinge zone of the major antiform, the folds are characteristically concentric although the beds are slightly thicker in the hinges than on the fold limbs (fig. 12). Folds are more conical than cylindrical. Many are faulted, and bedding in some is pinched off in the cores.

The fold axes of area 4 appear to fall into two groups (fig. 11*B*): (1) a set designated B (4:nnw) that plunges at low angles in northerly directions and (2) a set of more steeply plunging folds, designated B (4:sc), that varies in trend from northeast to northwest. Many of the folds of set B (4:sc) are more intricate and more tightly appressed than the folds in set B (4:nnw). The steeper folds B (4:sc) lie along a small circle about 45° from the center of the cluster of folds B (4:nnw). These relations, possibly more apparent than real, suggest that the folds B (4:sc) have been rotated about an axis, A^4, which is subparallel to B (4:nnw), and that therefore the folds B (4:sc) are older than the set B (4:nnw).

Poles to the axial planes of all the minor folds of area 4 are shown in figure 11*C*. Most of the axial planes dipping northeast are from the more numerous folds of the set B (4:sc). The axial planes of folds B (4:nnw) have nearly vertical axial planes. The asymmetry of the folds B (4:sc), with steeper southwest limbs, could be an original characteristic or a feature developed during a superposed deformation.

The small-circle distribution of the folds B (4:sc) around a north-northwest plunging axis, A^4, and the subparallelism of that axis and the folds B (4:nnw) with the large post-Antler anticline in the autochthon strongly suggest that area 4 was subjected to two episodes of deformation, the later stage occurring after the allochthon was emplaced. The early folds of area 4, B (4:sc), might have formed in the limestone at the time of the Antler orogeny. If these folds originated at that time, the evidence does not clearly indicate whether the original orientation of these folds was north-northeast or west-northwest, the two major fold directions developed

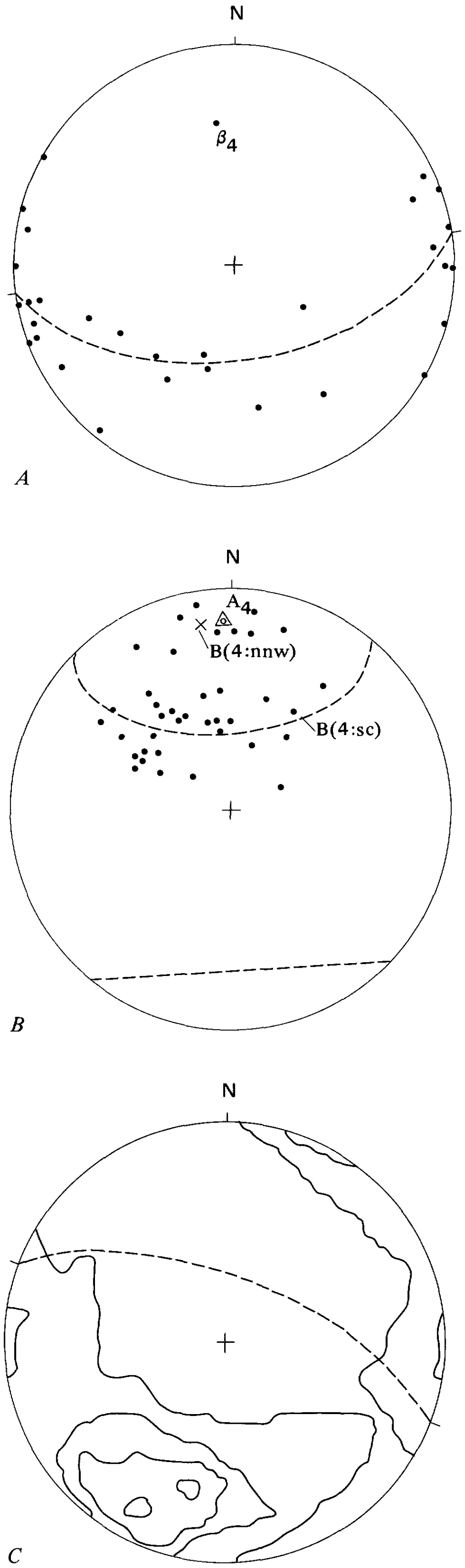


FIGURE 11.—Fabric diagrams showing poles to bedding, fold axes, and poles to axial planes in area 4 (pl. 2). See text for explanation. *A*, Poles to bedding. 25 points. β axis plunges 35° in the direction N. 8° W. Great circle (dashed line) is distribution of poles to bedding and defines B^4 axis. *B*, Fold axes. 38 points. Triangle with dot lies at center of 45° small circle (dashed line). *C*, Contoured poles to axial planes. 35 points. Contours 2σ, 4σ, 6σ, and 8σ. Great circle (dashed line) represents a plane striking N. 70° W. and dipping 65° NE.

in the allochthon in areas 1, 2, and 3. Most of the folds B (4:sc) trend northwest, and on the strength of that observation, most of them may once have trended northwest and west-northwest.

Folds B (4:sc), tentatively assigned to the Antler orogeny, may be correlative with the west-northwest folds of areas 1 and 2. This suggests that the deformation of area 4 was not typical of most of the allochthon during the Antler orogeny. The presence of the limestone member may have resulted in localized anomalous strain within the allochthon. Some of the local tectonic shortening may have been at a high angle to the dominantly eastward direction of movement of the allochthon.

AUTOCHTHON

Minor folds are generally absent in the autochthon except near large thrust faults. An exceptionally intensively folded area, area 5 (pl. 2), is located about a half mile south of the Roberts Mountains thrust and is in the upper plate of a large thrust within the autochthon. Area 5 is chiefly in laminated siliceous siltstone, believed to be silicified Silurian and Devonian strata of the carbonate assemblage.

The shapes of the minor folds in area 5 are varied. Some of them, like the ones in the chert of the allochthon, are concentric in general form, but with some thickening of bedding in the sharp fold hinges. Other folds are broad open warps or are tightly appressed and disharmonic. Some folds have polyclinal and folded axial surfaces.

Poles to bedding in area 5 lie along a great circle girdle whose pole plunges 40° in the direction N. 55° E. (fig. 13*A*), close to, but steeper than, most of the northeast-trending folds in areas 1, 2, and 3.

The folds plunge at low to steep angles, chiefly in the northwest quadrant (fig. 13*B*). Many of the folds plunge at low to moderate angles to the west-northwest, a fold direction present, but not prominent, in the allochthon. At one locality, the folds seem to be divisible into two groups (fig. 13*C*): (1) a few folds, designated B (5:nnw),

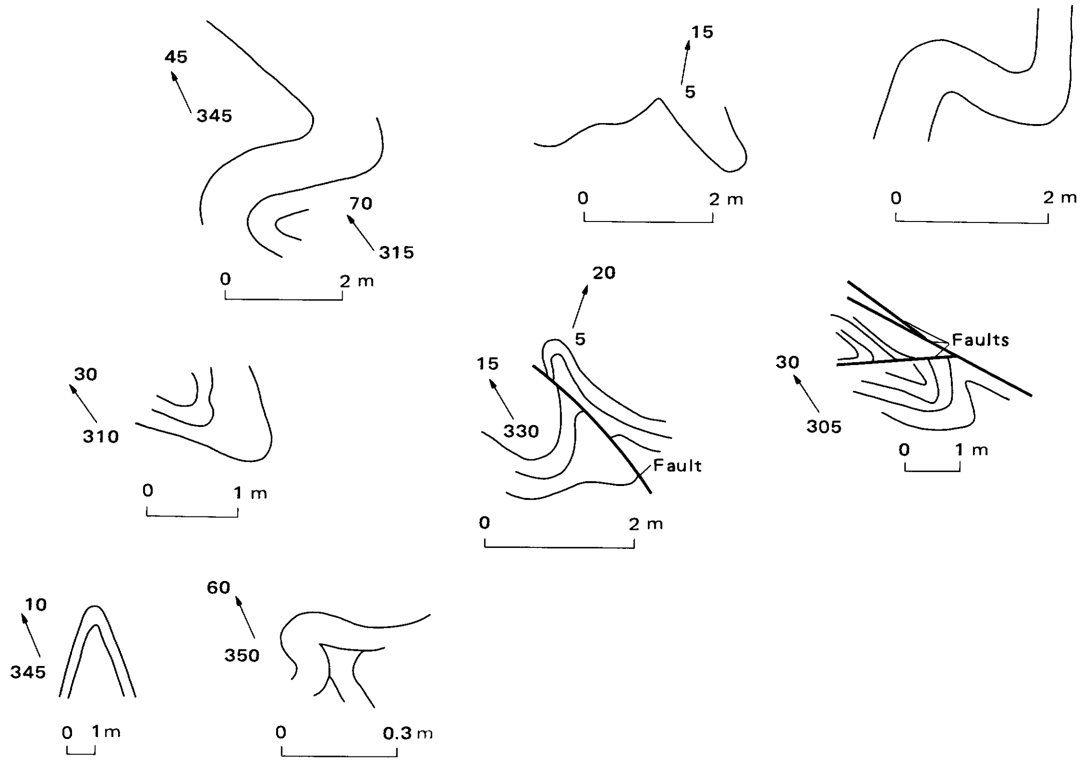


FIGURE 12.— Sketched profiles of minor folds in limestone in area 4. Arrow points in the direction of plunge and away from the number giving the azimuth of the trend in degrees related to a 360° compass. Zero degrees (north) is assumed to be at the top of the page. The angle of plunge is written at the point of the arrow.

plunging at small angles to the north-northwest and (2) more numerous folds, designated B (5:sc), plunging at low to steep angles from the northeast to the west that appear to lie along a 45° small circle. The axis, A_5, of the small circle is subparallel to the folds B (5:nnw). The folds B (5:sc) appear to be the older ones that were rotated during the later north-northwest folding. Axial planes of the minor folds of area 5 show no preferential direction of overturning (fig. 13*D*).

The geometry of the minor folds in area 5 is very similar to that in area 4 (fig. 14). The small-circle distribution of the folds B (5:sc) about a north-northwest-trending axis and the parallelism of that axis to the few minor north-northwest-trending folds, B (5:nnw), and to the north-northwest-trending post-Antler anticline in the autochthon strongly suggest that area 5 underwent two stages of folding. The later stage was presumably coincident with the post-Antler folding. The earlier folds could date from the Antler orogeny. The concentration of west-northwest-trending folds in figure 13*B* suggests that many of the early minor folds of area 5 originally plunged at small to moderate angles to the west-northwest. Local strain during the Antler orogeny, in this case below the allochthon, was probably different from the strain in the allochthon; as reflected in at least some of the minor folds in area 5, tectonic shortening below the allochthon was locally at high angles to the accepted direction of movement of the allochthon.

CONCLUSIONS

Study of minor and major structures of the Roberts Mountains allochthon by outcrop-scale structural analysis in two small areas, one in Battle Mountain and another in the southern part of the Tuscarora Mountains area, reveal:

1. Most of the minor folding visible in the Roberts Mountains allochthon is in the chert, is of the concentric type, and is developed by slip on bedding at right angles to the fold axes. Minor flowage occurred toward the fold hinges.

2. The chert does not accurately reflect the total strain of the allochthon. Masses of chert after early ductile folding behaved in a brittle manner in the more ductile shale and argillite matrix. Thereafter, much of the strain was taken up in the shale and argillite.

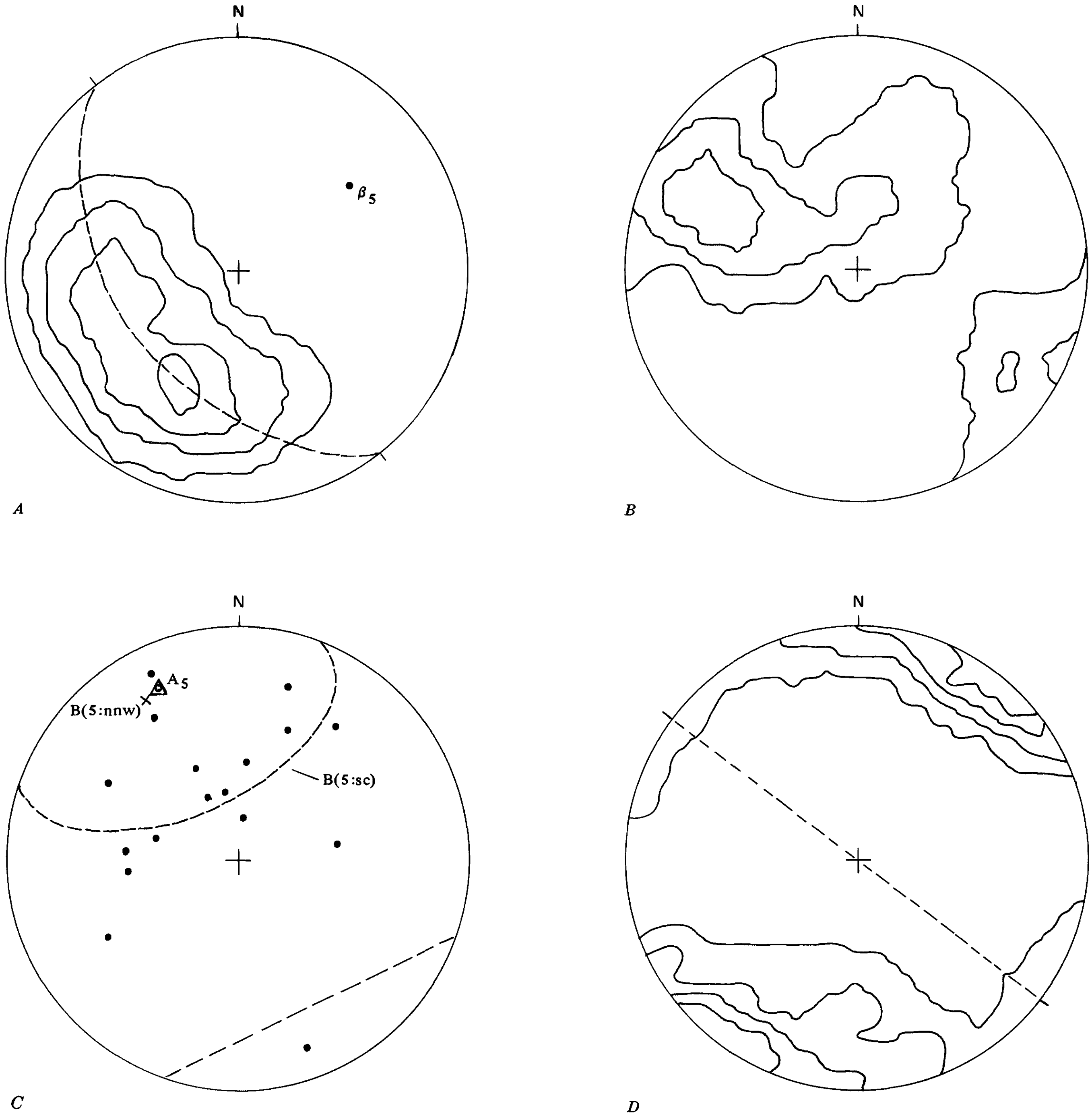
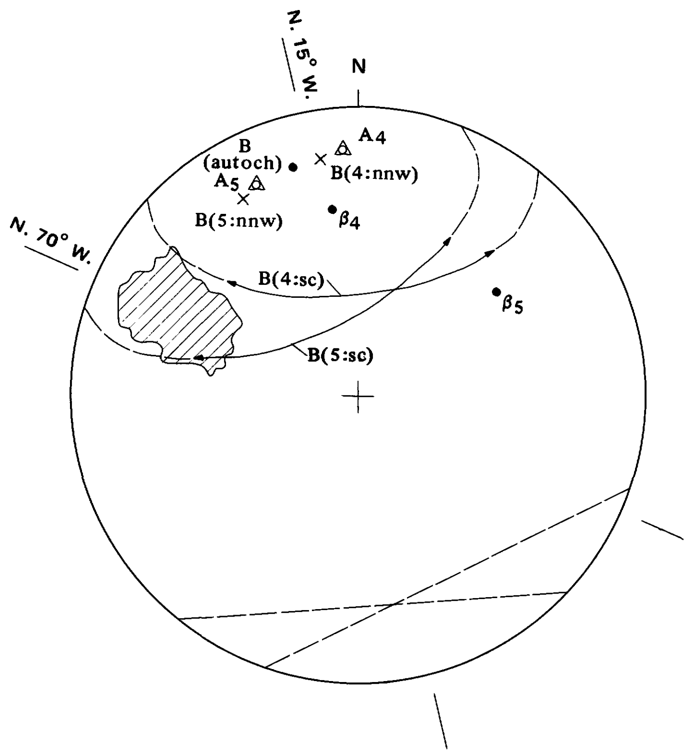


FIGURE 13.—Fabric diagrams showing poles to bedding, fold axes, and poles to axial planes in area 5. *A*, Poles to bedding. 57 points. Contours 2σ, 4σ, 6σ, and 8σ. Great circle (dashed line) is distribution of poles to bedding. B^5 is pole to great circle. β axis plunges 40° in the direction N. 55° E. *B*, Fold axes. 81 points. Contours 2σ, 4σ, and 6σ. *C*, Fold axes. 18 points. Triangle with dot lies at center of 50° small circle (dashed line). A^5 is rotation axis of small circle. *D*, Poles to axial planes. 48 points. Contours 2σ, 4σ, 6σ, and 8σ.

3. Most of the minor folds in the chert plunge at low angles to the north-northeast and south-southwest and have steeply dipping or vertical axial planes.

4. The b-fabric axis, parallel to the north-northeast-trending folds, is identical to the B-kinematic axis and therefore the apparent horizontal component of tectonic shortening of the allochthon is N. 70°–75° W. in the Battle Mountain area and in the southern Tuscarora Mountains area (figs. 5, 14). This direction is consistent with the eastward direction of movement accepted for



EXPLANATION

× Mean orientation of fold set

• β axis

Δ Rotation axis

FIGURE 14.—Summary fabric diagram for areas 4 and 5. B (autoch) is fold axis of anticline in autochthon. B (4:sc) and B (5:sc) are fold sets with small-circle (dashed line) distribution areas 4 and 5, respectively. Angle of spread of fold axes along small circle is indicated by solid line and arrows. Lined area is 6σ concentration of fold axes in area 5.

the allochthon. Folds with west-northwest trends are present and may have formed during the Antler orogeny in the direction of tectonic transport.

5. The similarity of the general features of the deformation in the Battle Mountain area and of the early deformation in the southern Tuscarora Mountains area, 65 km apart, suggests that the deformation of the allochthon during the Antler orogeny must have been moderately homogeneous over large segments of the allochthon.

6. A post-Antler episode of folding, evident in the southern Tuscarora Mountains area, is manifest in part of the allochthon and the autochthon by folding about an axis plunging gently to the north-northwest. Preexisting folds, modified during this deformation, may have originated during the Antler orogeny. Most of these older folds plunge west-northwest and northwest and could reflect local tectonic shortening, both within and below the allochthon, at high angles to the eastward direction of movement of the allochthon.

REFERENCES CITED

Evans, J. G., 1974a, Geologic map of the Rodeo Creek, NE. quadrangle, Eureka County, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ–1116, scale 1:24,000.

——1974b, Geologic map of the Welches Canyon quadrangle, Eureka County, Nevada: U.S. Geol. Survey Geol. Quad. Map GQ–1117, scale 1:24,000.

Gilluly, James, and Masursky, Harold, 1965, Geology of the Cortez quadrangle, Nevada: U.S. Geol. Survey Bull. 1175, 117 p.

Hansen, Edward, 1971, Strain facies: Berlin, New York, Springer-Verlag, 207 p.

Hausen, D. M., 1967, Fine-gold occurrence at Carlin, Nevada: Columbia Univ., New York, N. Y., Ph.D. thesis, 166 p.

Jones, D. L., Wrucke, C. T., Holdsworth, Brian, and Suczek, C. A., 1978, Revised ages of chert in the Roberts Mountains allochthon, northern Nevada: Geol. Soc. America Abstracts with Programs, v. 10, no. 3, p. 111.

Kamb, W. B., 1959, Ice petrofabric observations from Blue Glacier, Washington, in relation to theory and experiment: Jour. Geophys. Research, v. 64, p. 1891–1909.

Ketner, K. B., 1970a, Geology and mineral potential of the Adobe Range, Elko Hills and adjacent areas, Elko County, Nevada, *in* Geological Survey research 1970: U.S. Geol. Survey Prof. Paper 700–B, p. B105–B108.

——1970b, Limestone turbidite of Kinderhook age and its tectonic significance, Elko County, Nevada, *in* Geological Survey research 1970: U.S. Geol. Survey Prof. Paper 700–D, p. D18–D22.

Kirk, Edwin, 1933, The Eureka quartzite of the Great Basin region: Am. Jour. Sci., 5th ser., v. 26, no. 151, p. 27–44.

McKee, E. H., and Silberman, M. L., 1970, Geochronology of Tertiary igneous rocks in central Nevada: Geol. Soc. America Bull., v. 81, no. 8, p. 2317–2328.

McKee, E. H., Silberman, M. L., Marvin, R. E., and Obradovich, J. D., 1971, A summary of radiometric ages of Tertiary volcanic rocks in Nevada and eastern California—Pt. 1, central Nevada: Isochron/West, no. 2, p. 21–42.

Merriam, C. W., and Anderson, C. A., 1942, Reconnaissance survey of the Roberts Mountains, Nevada: Geol. Soc. America Bull., v. 53, p. 1675–1728.

Nichols, K. M., 1971, Overlap of the Golconda thrust by Triassic strata, north-central Nevada: Geol. Soc. America Abstracts with Programs, v. 3, no. 2, p. 171.

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

Regnier, Jerome, 1960, Cenozoic geology in the vicinity of Carlin, Nevada: Geol. Soc. America Bull., v. 71, no. 8, p. 1189–1210.

Riva, John, 1970, Thrusted Paleozoic rocks in the northern and central HD Range, northeastern Nevada: Geol. Soc. America Bull., v. 81, p. 2689–2716.

Roberts, R. J., 1964, Stratigraphy and structure of the Antler Peak quadrangle, Humboldt and Lander Counties, Nevada: U.S. Geol. Survey Prof. Paper 459–A, 93 p.

——1966, Metallogenic provinces and mineral belts in Nevada: Nevada Bur. Mines Rept. 13, p. 47–72.

Roberts, R. J., Hotz, P. E., Gilluly, James, and Ferguson, H. G., 1958, Paleozoic rocks in north-central Nevada: Am. Assoc. Petroleum Geologists Bull., v. 42, no. 12, p. 2813–2857.

Roberts, R. J., Radtke, A. S., and Coats, R. R., 1971, Gold-bearing deposits in north-central Nevada and southwestern Idaho: Econ. Geology, v. 66, p. 14–33.

Silberling, N. J., 1975, Age relationships of the Golconda thrust fault, Sonoma Range, north-central Nevada: Geol. Soc. America Spec. Paper 163, 28 p.

Silberling, N. J., and Roberts, R. J., 1962, Pre-Tertiary stratigraphy and structure of northwestern Nevada: Geol. Soc. America Spec. Paper 72, 58 p.

Smith, J. F., Jr., and Ketner, K. B., 1968, Devonian and Mississippian rocks and the date of the Roberts Mountains thrust in the Carlin-Piñon Range area, Nevada: U.S. Geol. Survey Bull. 1251–I, 16 p.

Speed, R. C., 1971, Golconda thrust, western Nevada—regional extent: Geol. Soc. America, Abstracts with Programs, v. 3, no. 2, p. 199–200.

Stewart, J. H., and Poole, F. G., 1974, Lower Paleozoic and uppermost Precambrian Cordilleran miogeocline, Great Basin, western United States, *in* Dickinson, W. R., ed., Tectonics and sedimentation: Soc. Econ. Paleontologists and Mineralogists Spec. Pub. 22, p. 28–57.

Theodore, T. G., and Roberts, R. J., 1971, Geochemistry and geology of deep drill holes at Iron Canyon, Lander County, Nevada: U.S. Geol. Survey Bull. 1318, 32 p.

Theodore, T. G., Silberman, M. L., and Blake, D. W., 1973, Geochemistry and K-Ar ages of plutonic rocks in the Battle Mountain mining district, Lander County, Nevada: U.S. Geol. Survey Prof. Paper 798–A, 24 p.

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

Wrucke, C. T., and Theodore, T. G., 1970, Direction of movement of the Roberts Mountains thrust determined from folds, northern Shoshone Range and Battle Mountain, Nevada: Geol. Soc. America, Abstracts with Programs, v. 2, no. 5, p. 356.

☆