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Geology of the Broadtop synclinorium in the Winchester 30' X 60' quadrangle, West Virginia

by

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ABSTRACT

The Broadtop synclinorium is a regional fold of the Appalachian Valley and Ridge province extending approximately 200 miles from south central Pennsylvania to west central Virginia. Within the study area of West Virginia, bedrock at the surface consists of siliciclastic rocks ranging in age from late Lower Devonian through earliest Mississippian. Structural models suggest that the Broadtop synclinorium is a passive syncline between fault-bend fold anticlinoria. The anticlinoria are part of a regional-scale duplex chiefly consisting of Cambrian and Ordovician age rocks. The duplex is bounded above by a folded decollement in the Ordovician Martinsburg Formation.

Second-order regional-scale folds are common in the Broadtop synclinorium and have been recognized by the earliest workers. Generally, these folds are asymmetric and westward verging. Macroscopic faults are not abundant and are concentrated in the core of the synclinorium, and have limited stratigraphic offset. In general, "disturbed zones" or areas of complexly deformed rocks are parasitic fold trains and associated faults related to larger-order folds. In most cases, these mesoscopically deformed zones probably do not extent along strike for more than a several hundred meters. These observations show that shortening in the Middle and Upper Devonian rocks of the Broadtop synclinorium is chiefly by folding. Fold tightening and volume changes associated with the folding are compensated by mesoscopic deformation (folds, cleavage, faults, veins) within lithotectonic units of high anisotropy, i.e., chiefly the Brallier Formation and subordinately the Foreknobs and Mahantango Formations.

Vergence in mesoscopic structures in shales of the Needmore and Marcellus Formations do not suggest a through-going decollement in these rocks. Limited well data suggests that the second-order macroscopic folds in Middle Devonian and younger rocks reflect structures in the underlying Oriskany-Helderberg lithotectonic unit.

INTRODUCTION

The Broadtop synclinorium is a regional-scale fold in the Appalachian Valley and Ridge province extending approximately 200 miles from south central Pennsylvania to west central Virginia (Jacobeen and Kanes, 1974)(Fig.1). Within the Winchester 30'X 60'quadrangle, the Broadtop synclinorium (Plate 1, map) is bounded on the west by the Broadtop anticline and on the east by the Capon Mountain-Adams Run anticlinorium (Kulander and Dean, 1986). Bedrock within the study area consists of siliciclastic rocks ranging from upper Lower Devonian through lowermost Mississippian.

Second-order folds within the Broadtop synclinorium (Plate 1) include, from west to east, the Town Hill syncline, the Whip Cove anticline west, the Whip Cove syncline, the Whip Cove anticline east, the Spring Gap Mountain syncline, the Critton Run anticline, and the Sideling Hill syncline. These structures were first mapped in the 1920's and excellent descriptions of them are provided by Tilton and others (1927).

Modern stratigraphic analyses and correlations of rocks within the immediate study area are generally of regional scale only. Stratigraphic summaries of Middle and Upper Devonian rocks are given by in Dennison(1971), Woodrow and others(1988), Hasson and Dennison(1988) and Dennison and others(1988, 1994). Recent stratigraphic summaries of Mississippian rocks include those of Bjerstedt(1986), Kammer and Bjerstedt(1986) and, Bjerstedt and Kammer(1988). McDowell(1991) summarized the stratigraphy of the entire Winchester 30'X 60' quadrangle and conodont studies have been done by Harris and others(1994), and Weary and Harris(1994).

PURPOSE AND METHODS

This study was part of a mapping effort in the Winchester 30'X 60'quadrangle as part of the U.S. Geological Survey's National Geologic Mapping Program. The focus of this study was to characterize the structure of rocks ranging in age from Middle Devonian through lowermost Mississippian in the Broadtop synclinorium.

The study chiefly involved reconnaissance mapping in fifteen 7.5 minute quadrangles(Fig. 2). Data were collected along roads and trails, plotted on the 7.5 minute maps, and stratigraphic contacts were interpolated between the roads and trails using topographic expression of the formation. Surficial deposits were identified along roads and trails and they also were interpreted to be present elsewhere based on their topographic form. In some instances, contacts were moved slightly to conform to the 1:100,000 scale base 30'X 60' base and some smaller features were generalized.

Reconnaissance map data were augmented in selected areas with detailed outcrop studies where good rock exposures were present. Cross sections (Plate 1) were constructed along roads with fairly continuous exposures. Well data on some of the cross sections constrain parts of the subsurface interpretations. Elsewhere, published subsurface interpretations were used with minor modifications.

STRATIGRAPHY

Devonian rocks

Needmore, Marcellus and Mahantango Formations

1. Needmore and Marcellus Formations

Shale and siltstone of the Needmore and Marcellus Formations are very poorly exposed and generally are covered by Quaternary alluvium and terrace deposits.

The unconformable contact between dark-greenish-gray shales of the Needmore Formation and light-gray, course-grained, pebbly sandstone of the underlying Oriskany Formation is exposed in a road cut about 1 mile north of Hanging Rock, along North River Mountain. At Hanging Rock, dark-brown to black, sheared shale of the Marcellus Formation occur approximately 500 feet stratigraphically above the Needmore-Oriskany contact. Although folded and cleaved, the approximately 100 foot thick section of dark-gray siltstone and minor shale of the lowermost Marcellus Formation is one of the few continuous exposures in this eastern outcrop belt. The Needmore Formation at Hanging Rock is estimated to be no more than 300 feet thick. Approximately 1800 feet of Marcellus Formation occurs along the eastern side of the Broadtop synclinorium.

Exposures of the Needmore and Marcellus Formations are also very limited along the western edge of the synclinorium. Near Wapocomo, two small borrow pits expose highly fissile, very dark-gray to black shale and minor siltstone, containing thin pyrite seams and concretions. Concretions range from less than one inch to greater than 3 feet in diameter. These exposures of Marcellus Formation are approximately 400 to 500 feet stratigraphically above the underlying Needmore-Oriskany contact. Several exposures of the Marcellus Formation also occur along the southwestern side of Clifford Hollow north of Moorefield. On the west end of the section, in the lower part of the formation, highly sheared and folded, fissile, black shale are about 300 feet above the Oriskany Sandstone. Eastward and upsection, the rocks change from black to dark-gray, and are fissile but not sheared. This lithology changes gradationally upwards to gray siltstone, greenish-gray shale and siltstone and very-fine-grained, gray sandstone of the overlying Mahantango Formation. The contact is not shown on the map, but can be placed at the change from dominantly shale and mudstone to siltstone and shale. A prominent series of small knobs are along this contact. Thickness of the Marcellus estimated along Clifford Hollow is 2000 to 2500 feet. This is considerably thicker than reported for Marcellus to the south (Dean and others, 1991) Tectonic thickening is suggested by small folds and changes in dip within the section.

2. Mahantango Formation

Dark-gray siltstone and thick-bedded non-fissile olive-gray and gray shale are typical of the Mahantango Formation in the study area. Near the top of the formation, these lithologies are interbedded with medium-gray, fine to medium-grained sandstone. Spheroidal weathering is common in the thick-bedded, massive shale. Fossil clam and brachiopod shells are found throughout the unit but are very abundant in beds near the top of the formation. Numerous outcrops of the Mahantango Formation occur in bluffs, road cuts and small borrow pits on North and Lost Rivers along the entire outcrop belt on the eastern part of the study area and on the South Branch of the Potomac River along the western outcrop belt. Approximately 3 miles to the southeast of Forks of Capon, the Clearville Member at the top of the Mahantango Formation consists of a 45 foot thick section of massive, gray, very-fined-grained sandstone which forms the steep escarpment above the North River. West of Largent, a fairly continuous section of the uppermost Mahantango, Brallier and Foreknobs Formations is in roadcuts and bluffs above the Cacapon River. Here, the Clearville Member consists of approximately 30 feet of dark-gray, medium to fine-grained sandstone above fossiliferous, thin- bedded, dark-gray shale and gray siltstone.

Along the westernmost outcrop belt, in a 1000 foot long borrow pit just west of Cunningham and north of Moorefield, folded, dark-gray to gray, silty sandstone, siltstone and shale of the lower part of the Mahantango Formation are exposed. Another excellent exposure in road cuts west of Springfield consists of highly fossiliferous, light to medium-gray, very-fined-grained silty sandstone interbedded with cleaved, very-dark-gray shaley siltstone and massive, spheroidally-weathered gray shale. The Clearville Member is well exposed and consists of a 60 to 70 foot thick section of sparsely fossiliferous, dark-gray, very-fine- grained sandstone and dark-gray siltstone. Overlying this is a thick, poorly exposed section of dark-gray shale. Although the contacts of the overlying and underlying units are not exposed, the Mahantango Formation is estimated to be approximately 1200 to 1400 feet thick here. Along the North River on the east side of the Broadtop synclinorium approximately 1300 to 1500 feet of the Mahantango Formation is present.

Brallier Formation

Overlying the Mahantango Formation is gray and tan, fine to medium-grained, thin to medium-bedded sandstone interbedded with gray and tan siltstone and gray shale of the Brallier Formation. Rocks of the Brallier Formation are typically folded and faulted. The base of the Brallier Formation is placed where cyclic sequences of gray and tan, very-fine-grained sandstone, siltstone and shale overlie dark- gray, fossiliferous siltstone and shale of the Mahantango Formation, and where present, above the sandstone of the Clearville Member of the Mahantango.

The upper contact of the Brallier Formation is placed beneath the first occurrence of ridge-forming, thin to thick-bedded conglomeratic sandstone of the Foreknobs Formation (Chemung Series of Tilton and others, 1927). This mapping criteria was first established in the study area by Tilton and others(1927). Dennison (1971), Dean and others(1985), Dennison and others(1988) and Dean and others(1991) used the first appearance of a one-foot-thick-sandstone as the contact between the Brallier Formation and the base of the Greenland Gap Group (Dennison,1971) or Chemung Group(Dean and others, 1991). Because the upper part of the Brallier Formation is rarely exposed and because there is much folding and faulting within the formation, the placement of the boundary based solely on the first appearance of a one foot thick sandstone is not possible in the area of this report. Also, Rossbach(1992) has pointed out that in places, the boundary between the Brallier and Greenland Gap Group is so transitional that it is difficult to define a contact. For this study, both topography and lithology were used to differentiate the Brallier from the overlying Chemung or Foreknobs Formation.

Thickness of the Brallier Formation is difficult to determine because of the ubiquitous folding and outcrop-scale faulting. Many of the outcrops described in the section on structural geology are in lithologies within the Brallier Formation. The Brallier is approximately 2000 feet thick, which is about the same as the 1200 to 1700 reported for Hardy County in the western part of the study area (Tilton and others(1927).

Foreknobs Formation

Thick-bedded, coarse-grained and pebbly, gray and tan sandstone and gray and white quartzite are distinctive rocks in the Foreknobs Formation. Excellent outcrops are found along Clifford Hollow in the southwestern part of the study area where three parallel ridges are held up by conglomerate and quartzite with intervening valleys of finer grained rocks. The section along Clifford Hollow consists of ridge forming, 20-foot-thick beds of pebbly, white, coarse-grained sandstone and quartzite with interbedded dark-gray and brown, very-fine-grained sandstone and dark-gray siltstone. These rocks are overlain by ridge forming, 20- to 30-foot thick, coarse-grained dark-gray sandstone and gray, very-fined-grained sandstone. The third and uppermost ridge forming unit consists of massive 200-foot-thick, dark-gray to white quartzite and conglomeratic sandstone, interbedded with thick-bedded, coarse-grained, gray and brown sandstone with beds as much as 30 feet thick, and thick-bedded, coarse-grained brownish-maroon sandstone similar to that of the overlying Hampshire Formation. Crinoid and brachiopod fossils are concentrated along bedding throughout the section.

A similar 3-part ridge-forming section is exposed along Mill Run along strike to the northeast. Here too, the section contains thick-bedded, dark-gray to light-gray quartzite and conglomeratic coarse-grained sandstone. Near the top of the section, a 60-foot-thick section of gray-brown, medium to fine- grained sandstone is evenly-bedded similar to bedding forms in the overlying Hampshire Formation, however, light-gray to white quartz pebble conglomerate occurs higher in the section. The contact with the overlying Hampshire Formation is concealed, but good outcrops of maroon, medium-grained, even-bedded sandstone and interbedded maroon shale occur approximately 100 feet above the highest light-gray conglomeratic sandstone and quartzite of the Freknobs. The Foreknobs Formation along this strike belt is approximately 1300-1500 feet thick. Tilton and others(1927) reported approximately 2000-2500 feet of Chemung(Foreknobs of this report) in Hardy County and approximately 1200 feet of Chemung in Hampshire County.

Rocks of the Foreknobs Formation thin to the north and east across the area. About 4 miles northeast of Romney, the two western-most of the three ridges described above are not present and a single ridge is underlain by rocks of the Foreknobs Formation. Float blocks as much as 3 feet thick of tan and dark-gray conglomeratic quartzite are along the crest. Stratigraphically below this is massive, 20-to 30-foot thick, tan, medium to coarse-grained sandstone. These rocks overlie olive-gray to tan siltstone and shale with minor fine-grained sandstone. These rocks in turn overly approximately 10 feet of maroonish-brown siltstone that is similar to rocks in the overlying Hampshire Formation. The Foreknobs Formation is approximately 1000 to 1200 feet thick here. Underlying Town Hill, on the adjacent outcrop belt immediately to the east, outcrops of the Foreknobs Formation consist of 5-to 10-foot thick, crossbedded, light-tan, coarse-grained sandstone with thin quartz pebble conglomerate lenses and abundant brachiopods, interbedded with light-gray quartzite, gray, very-fine-grained sandstone and tan siltstone. Thickness here is approximately 1000 feet.

The Foreknbs Formation is finer grained along State Route 55 about 1.5 miles west of Pleasantdale, in the central part of the Broadtop synclinorium. Below an excellent exposure of the Hampshire

Formation, the Foreknobs Formation consists of medium-bedded tan and gray, medium to fine-grained sandstone, tan siltstone and gray and tan shale. In this section, two outcrops of thin (3 to 6 foot) coarse-grained conglomeratic sandstone are separated by approximately 2000 feet of cyclic thin-bedded, gray, fine-grained sandstone interbedded with tan and gray siltstone and gray shale, typical lithologies of the Brallier Formation. Only the lowermost coarse-grained sandstone is a prominent ridge former.

Only a few good exposures of the Foreknobs Formation were found along the eastern side of the Broadtop synclinorium. In the northeastern most part of the study area, and west of Largent, the upper part of the Brallier and the Foreknobs Formations are fairly well exposed in roadcuts. The ridge forming rocks of the Foreknobs Formation consist of two, 10-to 30-foot thick dark-gray, coarse to medium-grained sandstone and minor quartzite interbedded with dark-gray, very-fine-grained sandstone, siltstone and tan shale. A few 1-to 3-foot thick maroonish-brown shale and maroon, very fine-grained sandstone also are exposed.

The contact between the Foreknobs to Hampshire Formations is transitional through 200 to 300 feet in an exposure along State Route 55, 0.8 miles west of Needmore. For this study, the contact is placed below the first thick, medium to coarse grained, red sandstone of the Hampshire Formation. The transitional sequence lies above thick sandstone and conglomerate of the Foreknobs and contains interbedded lithologies typical of both the Foreknobs and Hampshire Formations, that is thick, massively-bedded, tan and gray, fine to medium-grained sandstone typical of the Foreknobs interbedded with maroon and brownish-red sandstone and shale typical of the Hampshire. Another similar section occurs approximately 3 miles southwest of here, where a dark to light-gray, white weathering, 10-to 15-foot thick, very-coarse-grained, quartz pebble conglomerate forms a prominent, topographic ridge about 0.5 miles long. This conglomerate is approximately 300 feet above the last dark-gray, fine to medium-grained conglomeratic, fossiliferous sandstone of the upper part of the Foreknobs Formation and is interbedded with maroon shale and sandstone. The conglomerate pinches out along strike into red and maroon beds of the Hampshire Formation.

In general, the Foreknobs Formation in the study area can be correlated with the upper members of the Foreknobs Formation of the Greenland Gap Group of Dennison(1971) and Dennison and others(1988. However, in the field, we were not able to adequately differentiate these members according to their scheme chiefly because of poor or limited exposure and great variability of lithology along strike.

Hampshire Formation

Fine to coarse-grained, massive to thin-bedded, reddish-brown and maroon sandstone, siltstone and shale with minor greenish-gray silty shale are typical of the Hampshire Formation. Numerous continuous exposures of the Hampshire Formation occur in roadcuts in the study area. Approximately 2600 feet of the Hampshire on the southeast limb of the Town Hill syncline cropsout along State Route 50 from Shanks westward to the Hampshire County High School. Approximately 800 feet of the lower part of the Hampshire is exposed along State Route 50 on the northwest limb of the Town Hill syncline about one mile east of Romney. Here, maroon and red sandstone lie above tan and gray, conglomeratic, coarse-grained sandstone of the Foreknobs Formation.

The basal contact of the Hampshire Formation with the Foreknobs Formation is placed below the first thick, medium to course grained, red sandstone. The upper contact is not exposed in the study area, but probably lies about 100 feet above rocks exposed in outcrops on the west side of Short Mountain in the Forest Service public access road. These consist of fine to medium grained reddish-brown sandstone with interbedded maroonish-red shale and siltstone and are about 100 to 200 feet below ripple marked, light to medium-brown and gray, fine to medium-grained, feldspathic sandstone and quartzite of the overlying Mississippian Rockwell Formation. In a roadcut on the southeast slopes of Short Mountain, about 30 to 50 feet of tan and brownish-gray quartzite and medium grained sandstone interbedded with dark-tan and gray fissile silty shale of the Rockwell Formation are exposed. These form a ledge about 200 feet above thin- bedded, friable, very-fine-grained reddish-brown sandstone of the Hampshire Formation. The Hampshire ranges from 2000 to approximately 3500 feet thick on the southeast side of Short Mountain. Similar thickness for the Hampshire Formation occur just to the south of the study area (Dean and others, 1991).

Mississippian rocks

Rockwell Formation

The Rockwell Formation consists of light-brown and gray, medium-grained, crossbedded, feldspathic sandstone and quartzite in beds ranging from 30 to 60 feet thick. The sandstones are interbedded with brownish-tan, thin-bedded, very-fine-grained sandstone and tan shale. In roadcuts along a logging road on the northwest side of South Branch Mountain, the lowermost Rockwell consists of alternating medium- to coarse- grained tan, friable sandstone in beds ranging from 10 to 20 feet thick. One of the sandstone beds is very course grained and contains fossil wood fragments. Along strike about 3 miles to the southwest, near the crest and southwest end of South Branch Mountain, are several pavement outcrops exposed in logging roads of very-coarse-grained, brown and gray, sandstone diamictite with small pebble to boulder clasts of sandstone, siltstone, shale and possibly granite. This distinctive unit has been reported and described in the basal part of the Rockwell Formation in Sideling Hill in Maryland by Bjersted (1986). The occurrence described above on South Branch mountain is the southwestern most occurrence of this rock type of the Rockwell Formation.

The upper contact with the Purslane Sandstone is very poorly exposed because of extensive cover by colluvium. The contact is placed just below the lowest massive light-gray conglomeratic quartzite and sandstone of the Purslane Sandstone. The Rockwell Formation is approximately 600-700 feet thick.

Previously unrecognized rocks of the Mississippian Rockwell Formation and Purslane Sandstone were found by Lessing and others(1990) on South Branch Mountain. Also, previously unmapped tan and gray feldspathic sandstone float from the Rockwell Formation occurs on a rounded knob approximately one mile east of Slanesville. This is on strike of and 2 miles southwest of the Spring Gap Mountain syncline. Mississippian Rockwell Formation is also present on the upper slope and crest of a linear ridge east of the north end of Short Mountain. Here, in road cuts on the northwest side and crest of the ridge are thick-bedded brown and gray feldspathic sandstone. Three-foot thick blocks of coarse-grained gray conglomeratic sandstone along the crest of the ridge may be the lowermost Purslane Sandstone. A secondary fold or possible faulted syncline here has preserved the outlier of Mississippian rocks.

Purslane Sandstone

Massive and crossbedded, 30-to 60-feet outcrops of white and light-gray conglomeratic coarse-grained sandstone and white quartzite interbedded with very light-tan, medium to coarse-grained sandstone are typical of the Purslane Sandstone. This resistant unit underlies the ridge and crests of the highest mountains. Excellent outcrops of the coarse-grained sandstone and conglomerate occur along Short Mountain and are accessible by the West Virginia State Forest road on the northwest side of the mountain. The Hedges Shale has been reported overlying the Purslane Sandstone near here (Tilton and others, 1927), but no evidence of it was found. Approximately 1000 feet of the Purslane Sandstone is present in the study area.

Quaternary surficial deposits

Terrace Deposits

Terrace deposits consist of sand, pebbles, cobbles and minor small boulders in a clay-rich,silty and sandy matrix. The terrace material is generally coarser on the large drainages. Also included in this unit are bedrock straths on which the terrace deposits may have been removed by erosion. In many areas, several terrace levels are present which have been combined into a single unit for purposes of mapping. The relative ages of some of these have not been determined.

A large terrace deposit is well exposed at the top of a borrow pit along the South Branch of the Potomac River, 4 miles south of Romney (Plate 1, R1). Here, highly weathered silty shales of the Mahantango Formation are overlain by approximately 3 feet of well-rounded cobbles and pebbles of sandstone and quartzite in a brown sand and silt matrix. The deposit fines upward, with the majority of cobbles in the lower foot. In places, there is a lag of cobbles at the surface. Elsewhere, silty soil is present at the surface. In this area(R1), at least two levels of terraces are present, the older and higher terrace is 140 to 200 feet above the river, and the younger terrace is 20 to 40 feet above the river. The higher terrace has a very gently sloping surface, the highest portions of which may be the remnants of an older debris deposit. A similar deposit occurs approximately 0.5 miles east of Cunningham

(Froelich and others,1992). Here, shale of the Mahantango Formation is overlain by cobbles and pebbles in a silty-sandy matrix. The clasts are dominantly sandstone and quartzite with minor chert. This is overlain by silty clay which is overlain by a sandy soil at the surface. The entire deposit is 18 feet thick and the coarse cobble basal layer is approximately 8 feet thick. This terrace is the higher of two distinct levels, approximately 180 to 200 feet above the river. The lower terrace is 20 to 60 feet above the river. The highest terraces in the study area are approximately 3 miles southwest of Moorefield. Here, extensive terraces at 4 levels are well developed, the highest at 300 feet above the South Branch Potomac River (Southworth, 1988).

Three abandoned river meanders(Plate 1, R2,3,4) in the study area were cored for oxbow lake and fluvial deposits(Froelich and others, 1992). Approximately 18 to 20 feet of terrace and lake deposits were preserved beneath colluvial and debris deposits derived from cut-bank escarpments and uplands. Froelich and others (1992) cite evidence from radiocarbon studies (Jacobsen and others, 1989), archeological studies(Carbone, 1976) and relative age estimates(Hack, 1980; Southworth, 1988) that terraces in the study area range from Late Pleistocene to Late Pliocene(?)in age.

Colluvium

Several types of colluvium occur in the study area. Colluvium of boulders and cobbles mantles most of the upper slopes of the higher mountains. It consists of angular cobbles and boulders of sandstone and quartzite within varying amounts of finer material that form thin aprons and sheets as well as discrete boulder streams and boulder fields. Only the larger boulder streams and boulder fields are shown on the map since they have a pronounced topographic expression. Colluvium in areas of higher relief and at higher elevations is generally matrix free but on the lower slopes, these deposits may have a sandy to pebbly matrix. The deposits are usually vegetated except in the high elevations where the surface of the deposit is an open framework of boulders. This colluvium generally ranges from about 10 feet to more than 30 feet in thickness. It is derived mostly from outcrops of the Mississippian Purslane Sandstone and to a lesser extent from the underlying Rockwell Formation. Typical exposures are along the West Virginia Forest Service road on Short Mountain. Colluvial deposits usually grade downslope into more debris-like deposits. The colluvium was transported by a variety of processes including rock fall, creep, gelifluction and tree throw (Hack and Goodlett, 1960; Hack, 1965; Mills, 1981, 1987, 1988; Hupp, 1983; Conners, 1986; Mills and others, 1987).

Finer-grained colluvium is found in areas of high relief but at lower elevations and consists of minor small boulders, cobbles, and pebbles generally in a sandy matrix. It is derived from weathering of sandstone of the Foreknobs Formation.

In areas below cliffs of massive sandstone of the Hampshire Formation, colluvial boulder deposits are common, however they are of limited aerial extent.

Colluvium composed of shale-chip rubble is ubiquitous in areas of local high relief underlain by shale and siltstone of the Mahantango, Marcellus, Brallier, and Foreknobs Formations. This colluvium consists of shale and minor siltstone fragments ranging from sand size to cobbles in bedded and non-stratified sequences. It occurs on very steep shale slopes, near the bottom of steep shale slopes, and in small ravines cut into steep shale slopes. It ranges from a few feet to over 20 feet thick. Because these deposits do not have an obvious topographic expression and often are concealed below vegetation, they were not mapped. Shale-chip colluvium was exposed in a small borrow pit in 1993 about 1 mile west of Augusta. The deposit is approximately 15 feet thick and is very poorly sorted and crudely bedded. Layers dip down and parallel to the slope and the surface is well vegetated. Similar deposits(grezes litees) in Pennsylvania may have formed during cold Pleistocene climates (Clark and Ciolkosz, 1988), however Sevon and Berg(1979) noted that similar deposits are forming under present conditions.

Debris deposits

Debris deposits are found on the lower slopes and in valleys below the higher mountains. Characteristically, they are matrix-dominated sandstone diamictons with a vegetated surface. A few boulders and cobbles are generally scattered across the surface. Roadcuts along a Westvaco logging road, about 2 miles northeast of McNeill(Plate 1, R5) expose approximately 10 feet of sandstone diamicton overlying weathered shale of the Brallier Formation. Cobble and boulder clasts of coarse-grained, highly weathered, friable Purslane Sandstone occur in a silty sandy matrix. This deposit is highly dissected and may have been part of the large debris complex to the east. A second exposure through the distal end of an debris deposit occurs in roadcuts approximately 3.5 miles north of Rock Oak. A 3 to 5 foot thick boulder, cobble and pebble sandstone diamicton overlies highly weathered maroon silty shale of the Hampshire Formation. The boulder and cobble clasts are weathered Purslane or Rockwell Sandstone. The distance from the source of the sandstone clasts to this location is about 0.75 miles along the northwest flank of Short Mountain. The overall shape of the deposit is fan-like and convex-up in cross section.

A core(Froelich and others, 1992; R4) of the distal end of a debris deposit in Buffalo Hollow, showed sandstone diamicton of angular and subrounded pebbles and cobbles in a matrix of sandy and silty clay. The debris deposit overlies alluvium and an oxbow lake deposit(Froelich and others, 1992).

Debris deposits have been mapped and described in similar geologic settings (Jacobsen and others, 1987; Southworth, 1988; Schultz and others, 1991; Schultz, 1993) and they may include features described as alluvial fans (Kochel and Johnson, 1984; Conners, 1986), foot-slope deposits(Mills and others, 1987), and debris fans, debris flows and debris avalanches(Scott, 1972; Williams and Guy, 1973; Pomeroy, 1983; Jacobsen and others, 1987; Gryta and Bartholomew, 1989). The deposits may have formed from multiple debris flows and have been subsequently altered by fluvial erosion, freeze-thaw cycles and tree throw (Scott, 1972; Williams and Guy, 1973; Jacobsen and others,1987, Mills and others, 1987 Gryta and Bartholomew, 1989). Relative ages of debris deposits near the study area range from at least Pleistocene to recent (Kochel and Johnson, 1984; Mills and others, 1987; Mills, 1988).

Alluvium

Alluvium consists of boulders, cobbles and pebbles in silt, sand and clay matrix along modern drainages. In general, the coarser alluvium is found only on the larger rivers. Exposures of alluvium along the floodplains of smaller drainages are found where meandering creeks have cut into their own older floodplain deposits. Alluvial deposits are fining-upward sequences, consisting of basal lag gravel on weathered bedrock, and overlain by crossbedded sand. The sand generally has thin stringers of interbedded pebbles and silty lenses. This is generally overlain by silty clay and clay, often with roots and other organic material. A mat of vegetation is present on most alluvial deposits, however these are ephemeral and often scoured or buried during storms. Alluvial deposits may have a well developed soil at the surface in areas away from the active channel.

Detailed analysis of the alluvial floodplain deposits near Moorefield(Jacobsen and others, 1989) showed they range from Late Pleistocene to Recent in age.

STRUCTURAL GEOLOGY

Introduction

The structural framework of the Broadtop synclinorium was documented by Tilton and others(1927). During the past 20 years, numerous regional structural interpretations of the synclinorium have been suggested. Jacobeen and Kanes(1974) interpreted it as a passive syncline related to ramping of a decollement in Cambrian-Lower Ordovician rocks. The site of the tectonic ramps is controlled by faults in the Precambrian basement rocks. Second-order macroscopic fault-bend folds within the synclinorium were thought to have been generated by shortening above splay faults(Rowlands and Kanes, 1972; Jacobeen and Kanes, 1974). The splay thrusts are rooted in a decollement of Middle Ordovician rocks. In this model, splay thrusts flatten into Upper Devonian decollements and gently dipping thrusts, some of which are shown emerged at the surface on their generalized geologic maps(see Fig. 3 for example in Jacobeen and Kanes,1974).

Subsequent interpretations (Mitra, 1986; Kulander and Dean, 1986; Wilson, 1985, 1989; Ferrill and Dunne, 1988; Wilson and Shumacker, 1992;, Dunne, 1989, Dean and others, 1985, 1991) suggest that a regional duplex of Cambrian and Ordovician rocks occurs above a master decollement in the Cambrian Waynesboro Formation. In common to these models is the interpretation that the Broadtop synclinorium is a regional passive syncline between fault-bend fold anticlinoria. The anticlinoria are culminations in a duplex consisting of Cambrian and Ordovician rocks. The top of the duplex is a folded decollement in the Middle Ordovician Martinsburg Formation.

Dunn (1989) has summarized existing models of deformation in cover rocks, i.e., rocks above the folded decollement in the Martinsburg Formation.

Macroscopic faults in the study area have been mapped near Augusta by Jacobeen and Kanes(1974). They used seismic and well data to delineate a series of fault-bend folds above thrust faults that are rooted in the Martinsburg Formation. At the surface, most of these faults are of minor displacement. In their model(Jacobeen and Kanes,1974), the Whip Cove anticline west is a fault-bend fold. The fault associated with the anticline flattens westward into rocks as young as the Upper Devonian Hampshire Formation. Dunn(1989) noted that this model was not intended as a regional-scale model for shortening across the Appalachian fold belt. However, regional cross sections by Jacobeen and Kanes(1974) seem to indicate that folding in the cover rocks is a consequence of fault-bend thrust faulting. In some instances, these faults cut upper Devonian rocks at the surface.

Mesoscopic structural analyses on selected outcrops in the study area are limited. Pohn and others(1985, 1988) have focused on the relationship of mesoscopic fold zones to gas fields and thrust faults at depth. Mandros(1985) has summarized the mesoscopic deformation in a series of folded rocks on the southeast limb of the Whip Cove anticline west and on geometric and kinematic analysis of folding, faulting, and cleavage at this location.

Structural data:

The structural data compiled for this study includes regional-scale axial traces of major folds, cross sections, stereonet plots of bedding, cleavage, folds and faults, and outcrop illustrations of mesoscopic structures.

1. Regional-scale folds and associated structures:

A. Town Hill syncline

The Town Hill syncline (Plate 1) is the western most regional scale fold in the Broadtop synclinorium within the study area. The fold is named for a prominent ridge, Town Hill, that is underlain by rocks of the Foreknobs and Hampshire Formations. Town Hill is in the southeast limb of the fold. In the study area, rocks of the Rockwell Formation and Purslane Sandstone are the youngest units exposed in the syncline. The Town Hill syncline is asymmetric with a steeper southeast limb. Within the Hampshire Formation, dips in the southeast limb are 70 to 80 degrees and dips along the northwest limb are 30 to 40 degrees. In Mississippian rocks and rocks of the Hampshire Formation within the syncline, mesoscopic structures are uncommon, and consist predominantly of joints in the more massive sandstones and weakly developed, fanning pencil cleavage in the massive mudstones. However, at one location (Fig. 3) between the towns of Points and Higginsville, WV, along Graybill Hollow in the Levels 7.5 min. quadrangle, parasitic southeast-verging mesoscopic folds with axial plane cleavage and northwest-dipping wedge faults are on the southeast limb of the fold near its axial trace.

B. Whip Cove anticline west:

The Whip Cove anticline west(Plate 1),lying east of the Town Hill syncline is an anticlinorium, composed of smaller plunging anticlines and synclines. Within the study area, two dominant en-echelon anticlines have traditionally been called the Whip Cove anticline west. The southeast portion of the fold, from Bean Settlement to approximately 10 miles to the northeast, consists of a single anticline topographically defined by two parallel ridges underlain by conglomeratic, coarse-grained sandstone of the Foreknobs Formation. To the northeast, the anticlinorium has a steeply dipping northwest limb and a southeast limb with several subsidiary northwest-verging anticlines and synclines. The main axis of the Whip Cove anticline shifts westward at this location and the outcrop distance between the ridges underlain by rocks of the Foreknobs Formation widens. This change is in the vicinity of Shanks where intense mesoscopic deformation is associated with several third, fourth and higher order anticlines and synclines. At Shanks and behind Ed's transmission shop,(Fig. 4) both northwest- and southeast- verging folds occur in the area of intense deformation. The fanning fold axes were first described and pictured by Jacobeen and Kanes(1974,fig. 4). These mesoscopic folds are parasitic to larger-order folds on the southeast limb of the Whip Cove anticline west.

Just west of Higginsville(R6) are continuous outcrops in the core and on both limbs of the Whip Cove anticline west. Beds on the steeper northwest limb have dips of 65-75 degrees northwest. Also present are wedge faults and southeast-verging parasitic folds. These parasitic folds have well developed axial plane cleavage. Conversely, northwest-verging folds occur on the more gentle southeast limb of the Whip Cove anticline west. In the core of the anticline, tight disharmonic mesoscopic folds are above a southeast dipping fault that displaces the southeast limb of the anticline westward over rocks of the northwest limb. The amount of displacement along the fault could not be determined across the fault and it could not be traced in the field.

Numerous zones of mesoscopic folds and faults are on the southeast limb of the Whip Cove anticline west. About 2 miles north of Barnes Mill (R7) are outcrops of a series of northwest-verging mesoscopic folds(Figs. 5A and B,) with associated cleavage, faults, joints, and extension veins. These structures have been interpreted as a "disturbed zone" by Pohn and others (1985) and as parasitic folds to the Whip Cove anticline west by Mandros (1985). The structural data (Fig. 5B) indicate that the mesoscopic folds are very gently plunging, and generally asymmetric to the northwest. Cleavage is axial planar. Slickenside lineations plunge directly down the dip of beds on the fold limbs. A similar zone of westward-verging mesoscopic-scale folds and associated faults are well exposed approximately 1.5 miles west of Levels (Fig. 6) and a more deformed zone of folds and faults is east of Higginsville (Fig. 7) also on the southeast limb of the Whip Cove anticline west. Within the deformation zone are several broken folds and northwest- and southeast-dipping thrust faults. Pohn and others(1985) interpreted this exposure as a "disturbed zone", possibly associated with an uplimb thrust on the southeast limb of the Whip Cove anticline west.

C. Whip Cove syncline:

The Whip Cove syncline(Plate 1) is a simple fold except near the northeast end where it is faulted. Where the syncline is exposed at the Devonian Hampshire and Mississippian stratigraphic level it is symmetrical and broadens southwestward in the direction of plunge. The syncline at the exposed Foreknobs and Brallier Formation stratigraphic level is a tight fold with numerous mesoscopic folds and faults in the core. The syncline near Augusta has a steeper northwest limb than southeast limb, possibly reflecting its position as a parasitic fold to the Whip Cove anticline east.

D. Whip Cove anticline east:

The northeast segment of the Whip Cove anticline east(Plate 1)consists of several subsidiary folds and in places it is southeast facing with the southeast limb steeper than its northwest limb. The southwestern segment is a single southeast-verging fold at the exposed Foreknobs-Hampshire level. Mesoscopic folds and associated faults are common on the limbs and in the core of the anticline at the exposed Brallier-Foreknobs Formation stratigraphic level. The asymmetries of these mesoscopic folds indicate that they are parasitic to the main anticline. Folds and faults in the core of the fold are well exposed along roadcuts at Kirby. A series of well exposed, high angle, southeast dipping contraction faults occur in the core of the fold (R8, Fig.8).

E. Spring Gap syncline-Critton Run anticline:

A syncline-anticline pair occurs to the west of the much larger and continuous Sideling Hill syncline. The Spring Gap syncline (Plate 1) is named for Spring Gap Mountain which is underlain by resistant course-grained sandstone, quartzite and conglomerate of the Rockwell and Purslane Formations. The Critton Run anticline(Plate 1) is east of the Spring Gap syncline and west of the Spring Gap syncline and Sideling Hill syncline. The anticline axial trace is parallel to the axial trace of the Spring Gap syncline and plunges to both the northeast and southwest.

F. Sideling Hill syncline:

The most continuous fold in the study area is the Sideling Hill syncline (Plate 1). This fold is the easternmost regional-scale structure in the Broadtop synclinorium and is named for Sideling Hill, a prominent synclinal ridge underlain by the Rockwell and Purslane Formations. Recent roadcuts through the Sideling Hill syncline just north of the study area have been described (Bjerstedt, 1986; Brezinski, 1989) and made into a geologic visitors center. In the study area and at the Mississippian stratigraphic level, the syncline is symmetrical. However, a medial subsidiary anticline is on the axis of the syncline at the northeastern end of Sharp Mountain. At the Foreknobs-Brallier Formation level, the Sideling Hill syncline is asymmetric with a steep to vertical southeast limb and a moderately dipping(25 to 55 degrees) northwest limb. Mesoscopic structures associated with the syncline are confined to rocks below the lowermost Hampshire Formation level. These structures include mesoscopic parasitic folds (Figs. 9 and 10 (R9),"disturbed zones"

(Figs. 11(R10), and 12) and northwest-dipping contraction faults (Fig. 11) on the steep southeast limb of the syncline.

2. Regional Scale Faults

Few faults in the study area are large enough to be shown on the map, and those that have been mapped are confined to the central part of the synclinorium.(Plate 1). In general, this confirms the previous interpretations of Jacobeen and Kanes (1974). The only macroscopic faults that offset stratigraphic contacts were mapped east of Higginsville at the end of the Whip Cove syncline. One well exposed fault involves conglomeratic quartzite of the Foreknobs Formation which is thrust over maroon sandstone and shale of the overlying Hampshire Formation. The thrust fault was traced for approximately four miles.

Near Frenchburg, a shear zone of brecciated, sheared and slickensided rock about 30 feet thick is exposed in an old road cut. This is the thickest single shear zone recognized in the study area. However, stratigraphic offset was not determined.

Another relatively wide fault zone is well exposed east of Pleasantdale (Figs.10, R11) and was first described by Jacobeen and Kanes(1974, Fig. 5). The fault zone consists of several discrete faults and folds. Contractional faults show dominantly dip slip movement but some fault surfaces have oblique slip slickenlines. Three detached fault-bounded synclines occur in the most deformed part of the zone. Stratigraphic offset is difficult to determine however, the fault probably placed older rocks of the lower part of the Hampshire Formation over younger rocks of the lower part of the Hampshire Formation. This fault zone could not be traced along strike although similar deformation is at isolated outcrops at approximately the same stratigraphic level both northeast and southwest of this location.

3. Cross Sections

Cross sections A-A' through E-E' (Plate 1) are based on surface field data, well data where available, and on published cross sections. Structures above the Devonian Oriskany Sandstone are interpreted from well data and field data. Structures below the Devonian Oriskany Sandstone are based on the published sections of Wilson(1985, 1989) and Wilson and Shumaker(1992) and only very minor changes have been made to their interpretations.

The elements common to all the cross sections are a flat lower Cambrian-Proterozoic basement, a basal decollement in the lower Cambrian Waynesboro Formation, a duplex system in Cambrian and Ordovician carbonate rocks, and a decollement above the duplex in rocks of the Ordovician Martinsburg Formation. For structures above the decollement in the Martinsburg Formation, three general models are presented:

1. Surface anticlines are fault propagation folds. The faults arise from the Martinsburg decollement but are blind above the Brallier level.

2. Surface anticlines are passive folds above fault bend folds in the Cambrian-Ordovician duplex.

3. Surface anticlines are a consequence of some combination of duplexing in the Cambrian-Ordovician rocks and faulting in rocks

above the Martinsburg decollement.

Synclines are consistently passive structures generally lying above structural lows in the Cambrian-Ordovician duplex.

4. Mesoscopic Structures

A. Bedding:

Poles to bedding across the study area (Fig. 13A)indicate asymmetric, very gently-plunging, chevron to cylindrical folds at all scales. The asymmetry of the contour maxima is a function of the steeper northwest limbs of anticlines and steeper southeast limbs of synclines. The greater concentration of southeasterly dipping beds is a consequence of a wider outcrop belt(larger sample area) along the southeast dipping anticlinal limbs of map scale folds.

B. Cleavage:

Cleavage (Fig. 13B)is uncommon in the study area and is best developed in zones of intense mesoscopic folds and faults. The cleavage is of two types, a spaced stylolitic cleavage and a pencil cleavage. Pencil cleavage is dominantly confined to thick-bedded siltstones of the Mahantango and Hampshire Formations and it generally fans about the fold. Spaced stylolitic cleavage is in slightly calcareous silty mudstones of the Mahantango Formation and in folded silty shales and shales of the Brallier Formation. In most instances, this cleavage appears axial planar, however, detailed orientation data in one instance (Mandros,1985) has shown that the folds are transected by the pressure solution cleavage. Because many of the folds in the more intense deformation zones are west-verging, southeast-dipping axial plane cleavage is more common than northwest-dipping cleavage. Mandros(1985) documented that tighter folds have axial planar cleavage and more open folds have fanning cleavage (Mandros, 1985).

C. Folds:

Mesoscopic folds (Fig. 13C) of several orders of magnitude are generally concentrated in areas underlain by rocks of the Brallier Formation and to a lesser degree in rocks of the Foreknobs and Mahantango Formations. The folds have wavelengths ranging from less than 3 feet to more than 30 feet, interlimb angles ranging from 40° to greater than 90°, gently plunging to sub-horizontal axes, and upright to steeply inclined axial surfaces(Fig. 14). The folds are generally similar in profile (range from Class 1C to Class 2), are disharmonic and have chevron, circular, and box shapes. Quartz slickensided bedding surfaces are common and lineations on the slickenside surfaces generally parallel the dip of beds on the fold limbs. Quartz-filled extension veins are on the steeper limbs of folds approximately perpendicular to bedding. Although most folds are asymmetric to the northwest, there are some folds with northwest-dipping axial surfaces. Mesoscopic folds are either parasitic to larger folds with asymmetries consistent with fold limb position, or are related to shortening associated with faults, which include folds above decollements, fault bend and fault propagation folds and folds in disturbed zones.

D. Faults:

Mesoscopic faults (Fig. 13D) are generally associated with zones of intense folding in the Brallier Formation but are also found in rocks of the Hampshire, Foreknobs, Mahantango and Marcellus Formations. Faults dip northwest and southeast, and dips range from nearly vertical to less than 45°. Stratigraphic offsets range from less than 3 feet to greater than 30 feet. Often, quartz mineralization is associated with the fault zones, particularly those in the Brallier and Foreknobs Formations. The quartz occurs as crystal fiber growths filling fractures in the fault zones or as crystals in vugs in highly fractured rock. Quartz slickensides are found on some fault surfaces and generally are parallel to fault dip. Structural settings and types of faults include: northwest- and southeast-dipping contraction faults on steep to vertical limbs of first- or second-order folds; contraction faults associated with fault-bend and fault- propagation folds; contraction faults associated with fold hinge collapse and fold tightening; wedge faults on the limbs of folds that cut bedding at low angles; and faults in disturbed zones.

CONCLUSIONS:

Mapping and outcrop studies across the Broadtop synclinorium in the Winchester 30'X 60' quadrangle demonstrates that macroscopic faulting is limited. This work agrees with the interpretations of Jacobeen and Kanes(1974) who concluded that the macroscopic faults are concentrated in the core of the synclinorium and have limited stratigraphic offset. They are not a ubiquitous feature across the synclinorium as suggested by Mitra's (1986) cross sections. Many of the disturbed zones (Pohn and Purdy,1988) are parasitic fold trains related to larger-order folds. They cannot be traced along strike and are generally limited to lithologies of high anisotropy. These observations suggest that shortening in the Middle and Upper Devonian rocks of the Broadtop synclinorum is chiefly by folding. Fold tightening and volume changes associated with the folding are compensated by mesoscopic deformation (folds, cleavage, faults, veins) within lithotectonic units of high anisotropy, chiefly the Brallier Formation and subordinately the Foreknobs and Mahantango Formations.

Early layer-parallel shortening is evidenced in some lithologies by fanning cleavage and wedge faults. In zones of intense mesoscopic folds and faults, cleavage is dominantly axial planar. In some cases transecting cleavage indicates syn- to post-folding cleavage development.

Mesoscopic structures in shales of the Needmore and Marcellus Formations are not suggestive of a through-going decollement in these rocks. Furthermore, limited well data suggests that the second-order macroscopic folds(such as the Whip Cove anticline west) in Middle Devonian and younger rocks are a reflection of structures in the underlying Oriskany-Helderberg litho-tectonic unit.

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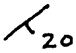
Explanation of map symbols

Contact(dotted where concealed) 

Strike and dip of beds

inclined 

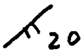
vertical 

Strike and dip of cleavage

inclined 

vertical 

Strike and dip of axial surface of fold

inclined 

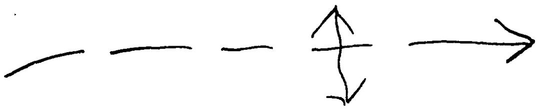
vertical 

Faults

mesoscopic with strike and dip, teeth on upper plate 

map scale thrust fault, teeth on upper plate 

Map scale folds showing bearing and plunge

anticline 

syncline 

Drill hole 

Reference locality, end of leader is location, number refers to text description 

DESCRIPTION OF MAP UNITS

Qa **Alluvium (Holocene)--** Boulders, cobbles and pebbles in silt, sand and clay matrix along creeks and rivers. Often graded, cross bedded, and cross laminated. Thickness ranges from 30 feet(?) to less than 3 feet.

Qd **Debris deposits (Holocene and Pleistocene)--** Poorly sorted cobbles and boulders in a matrix of sand, silt and clay. Deposits on lower slopes and valleys have deep soil and are vegetated. Thickness ranges from 10 feet to 50(?) feet.

Qc **Colluvium (Holocene and Pleistocene)--** Angular cobbles and boulders of sandstone and quartzite in boulder streams and boulder fields. Colluvium is generally matrix free at the surface but has a sandy to pebbly matrix on the lower slopes. Colluvial boulders mantle most of the upper slopes. Thickness ranges from about 10 feet to 30(?) feet.

Qt **Terrace Deposits (Pleistocene)--** Stratified, graded and channelled deposit of sand, pebbles, cobbles and boulders in a silty, sandy and clay rich matrix. Maximum thickness 30 feet. Includes bedrock straths.

Mp **Purslane Sandstone (Lower Mississippian)--** Light-gray and white, massive and crossbedded, conglomeratic, coarse-grained sandstone and white quartzite interbedded with very-light-tan, medium to coarse-grained sandstone. Conglomeratic sandstone beds as much as 60 feet thick. Total thickness approximately 150-200 feet.

Mr **Rockwell Formation (Lower Mississippian)--** Light-brown and gray, medium grained, crossbedded, feldspathic sandstone and quartzite in beds ranging from 30 to 60 feet thick interbedded with brownish-tan, thin-bedded, very-fine-grained sandstone and tan shale. Total thickness approximately 600 to 700 feet.

Dh **Hampshire Formation (Upper Devonian)--** Reddish-brown and maroon, fine to coarse-grained, massive to thinly-bedded, sandstone, siltstone and shale with minor greenish-gray silty shale. Thickness approximately 3500 feet.

Df **Foreknobs Formation (Upper Devonian)--** Light to dark-gray, tan and light-brown, thick to thin-bedded, medium to coarse-grained, sandstone and siltstone interbedded with gray and white, course-grained and conglomeratic, massive- bedded sandstone and quartzite and minor dark-gray, silty shale. Ridge forming quartzite and conglomeratic sandstone ranges from 30 to 200 feet thick. Thickness ranges from 1300 to 1500 feet.

Db **Brallier Formation (lower Upper and Middle Devonian)--** Gray and tan, fine to medium-grained, thin to medium-bedded sandstone, interbedded with gray and tan siltstone and shale. Thickness approximately 2000 feet.

Dmmn **Mahantango, Marcellus and Needmore Formations, undivided and uppermost Lower Devonian)--**

Mahantango Formation Dark-gray siltstone interbedded with olive-gray and gray, thick-bedded, non-fissile shale. Interbedded with medium-gray, fine to medium-grained sandstone of the Clearville Member near top. Spheroidal weathering is common in the thick-bedded, massive shale. Thickness ranges from 1200 to 1500 feet.

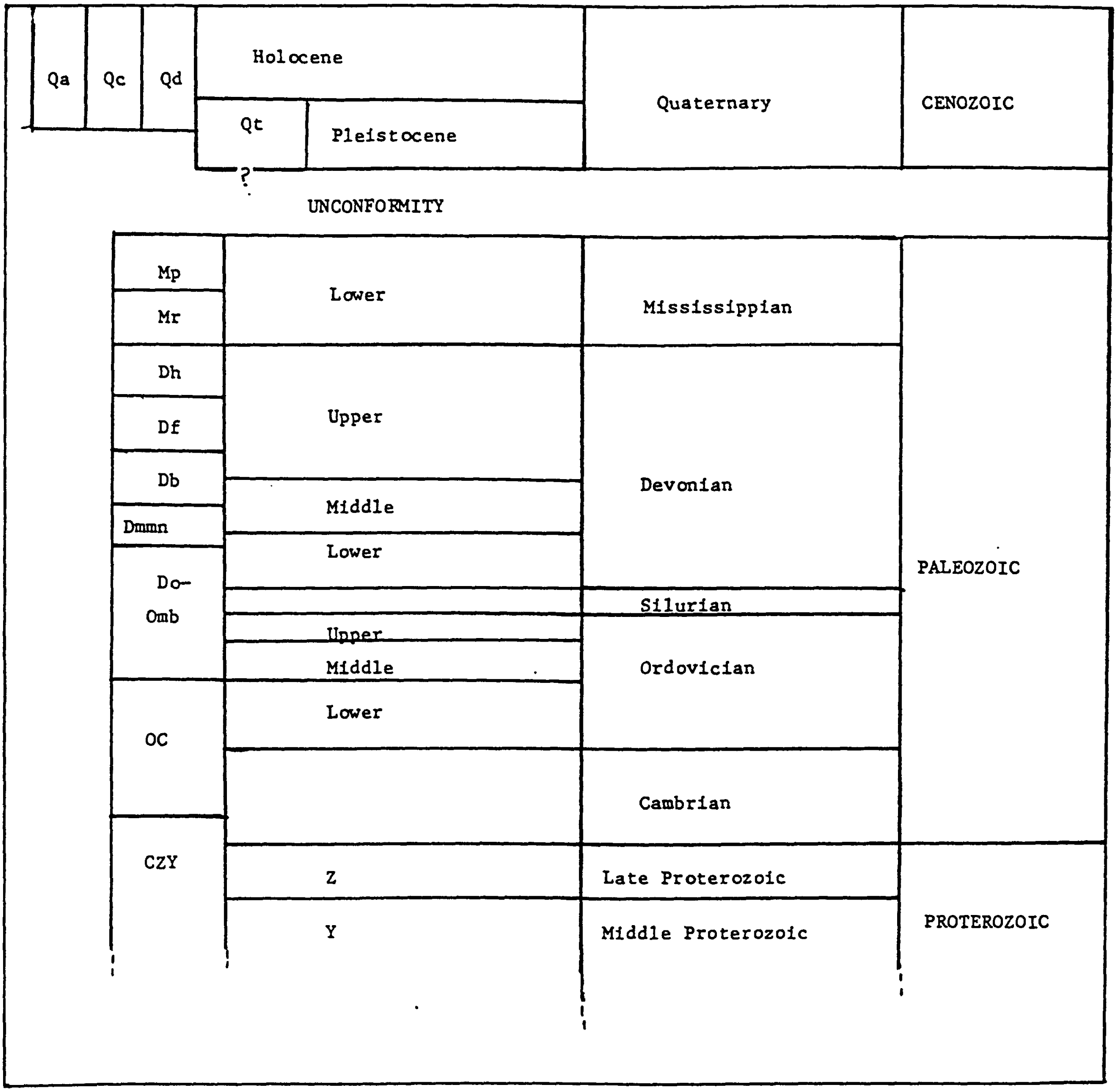
Marcellus Formation Dark-gray to black, fissile shale interbedded with dark-gray, silty shale. Concretions and thin pyrite seams in lower part. Thickness ranges from 1800 to 2500 feet.

Needmore Formation Poorly exposed, dark greenish-gray shale. Thickness estimated to be 300 feet.

Do-Omb Oriskany Sandstone through Martinsburg Formation undivided(Lower Devonian through upper Middle Ordovician).

OC Trenton Limestone through Waynesboro Formation undifferentiated(Middle Ordovician through middle Lower Cambrian)-shown in cross section only.

CZY Tomstown Dolomite through Grenville Basement undifferentiated(lower Cambrian through Middle Proterozoic)-shown in cross section only.



CORRELATION OF MAP UNITS

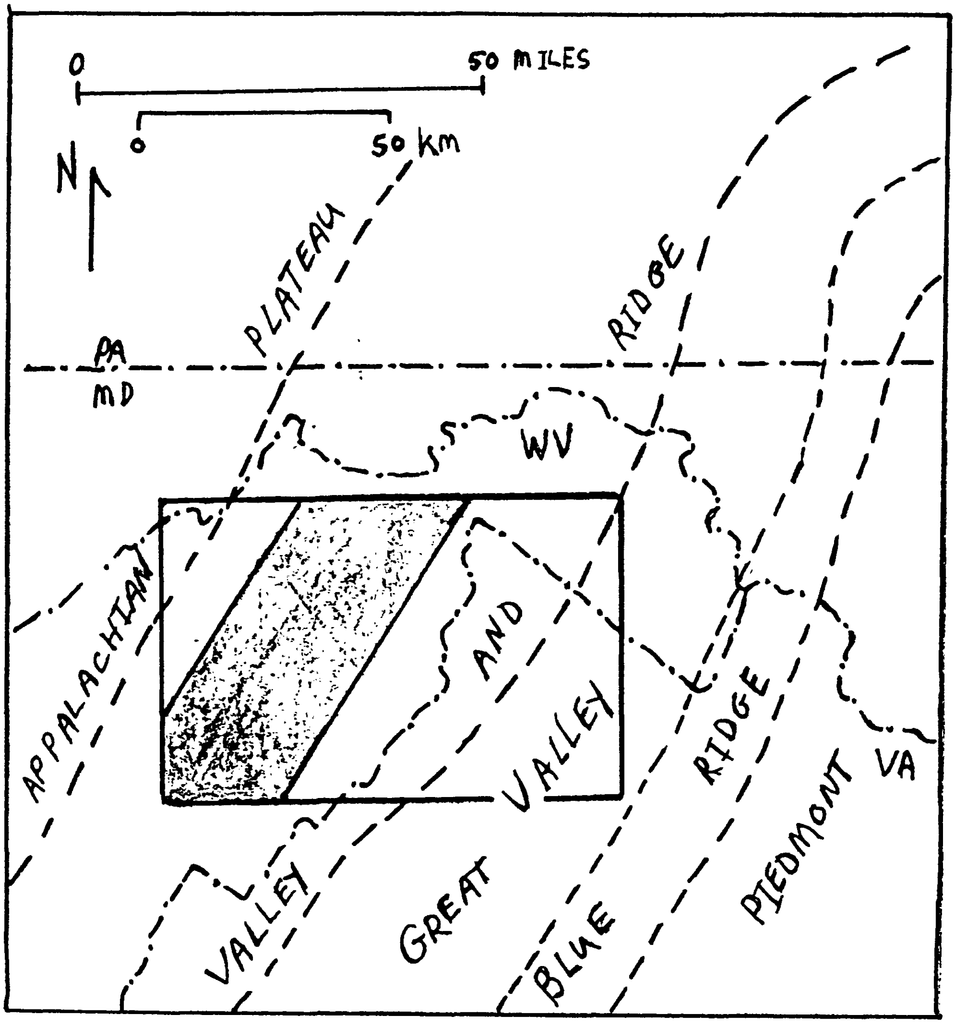


Figure 1. Index map showing the Winchester 30'X 60' quadrangle (outlined) and the area of this study(shaded).

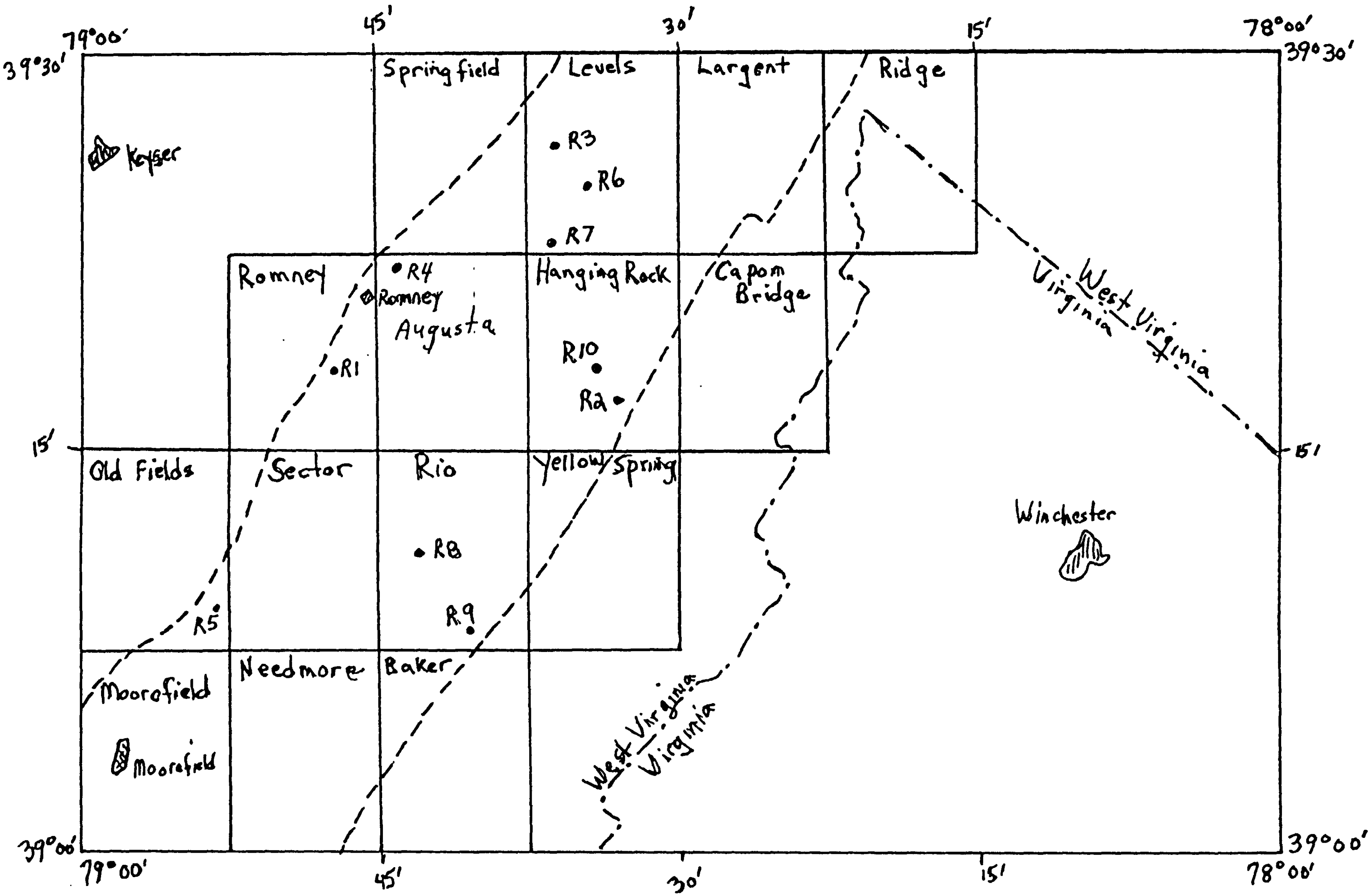


Figure 2. Index map showing 7.5 minute quadrangles coverage, the study area(dashed line) in the Winchester 30'X 60' quadrangle and location of reference localities(R1...)discussed in the text.

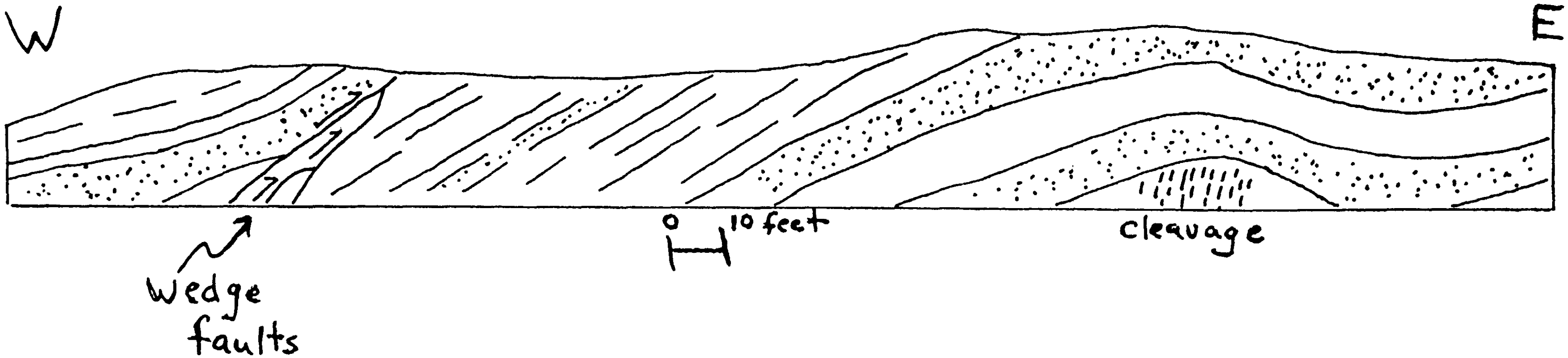


Figure 3. Outcrop sketch of wedge faults, axial plane cleavage and parasitic mesoscopic folds in sandstone and siltstone of the Hampshire Formation. Outcrop is on the southeast limb of the Town Hill syncline.

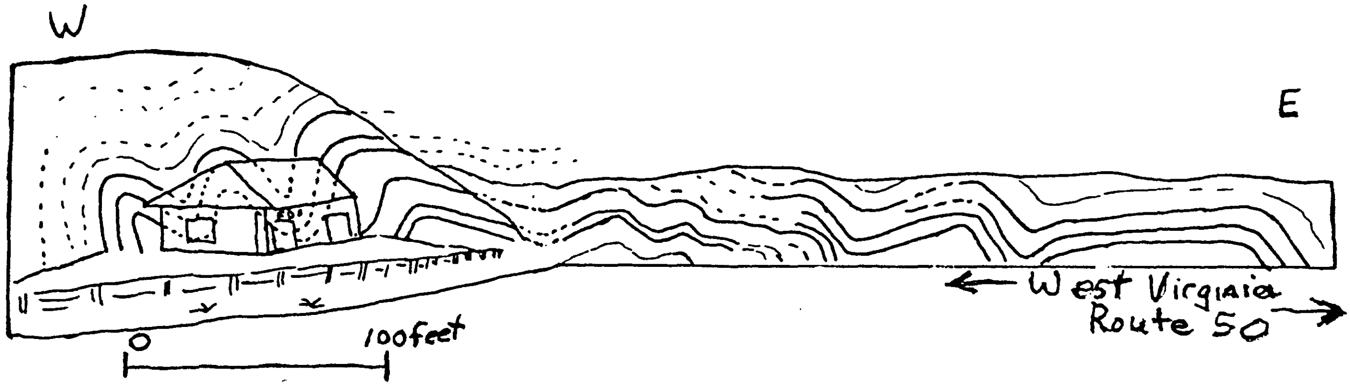


Figure 4. Outcrop sketch of folds in the Brallier Formation exposed in roadcuts along Route 50 behind Ed's Transmission Shop at Shanks, West Virginia. Northwest and southeast verging parasitic folds in a zone of intense folding between plunging segments of the Whip Cove anticline west.

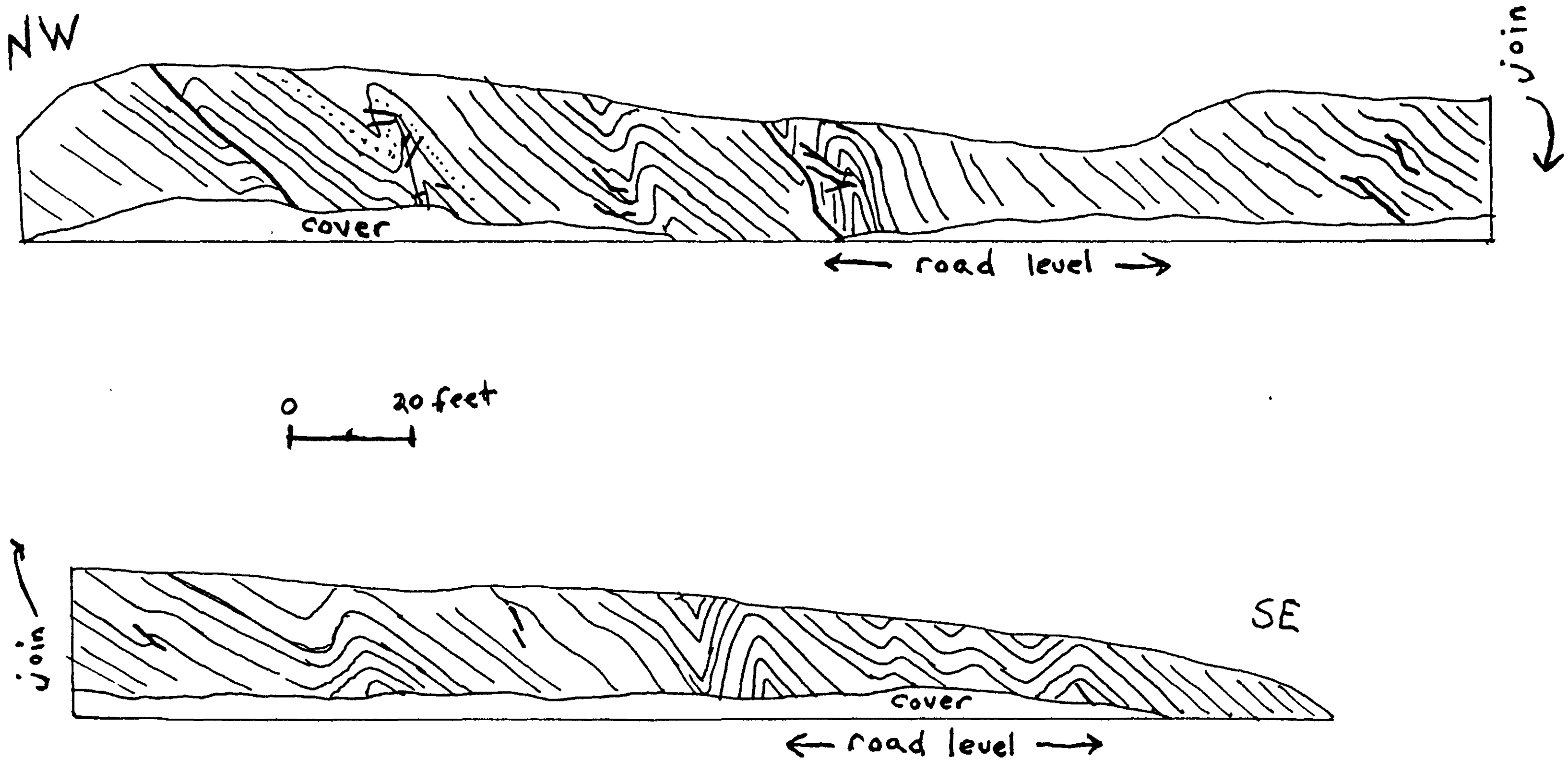


Figure 5A. Outcrop sketch (modified from Mandros, 1985) of northwest-verging folds on southeast limb of Whip Cove anticline west (R7) in the Brallier Formation.

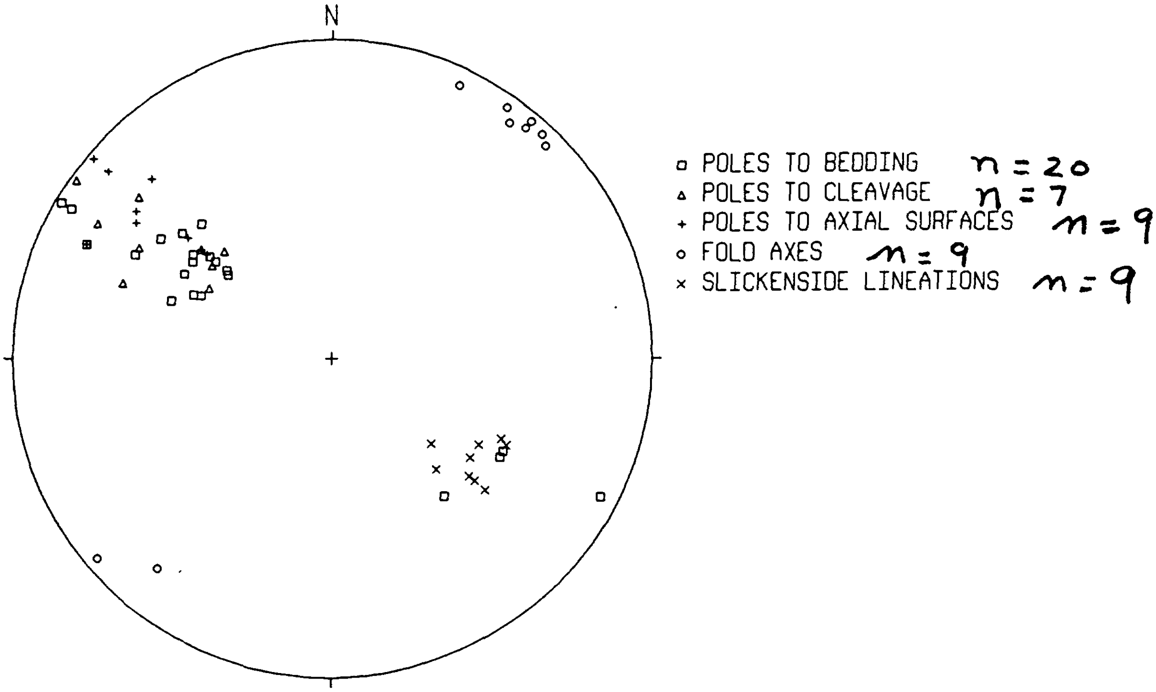


Figure 5B. Lower-hemisphere equal-area projection of structural data from outcrops in 5A.

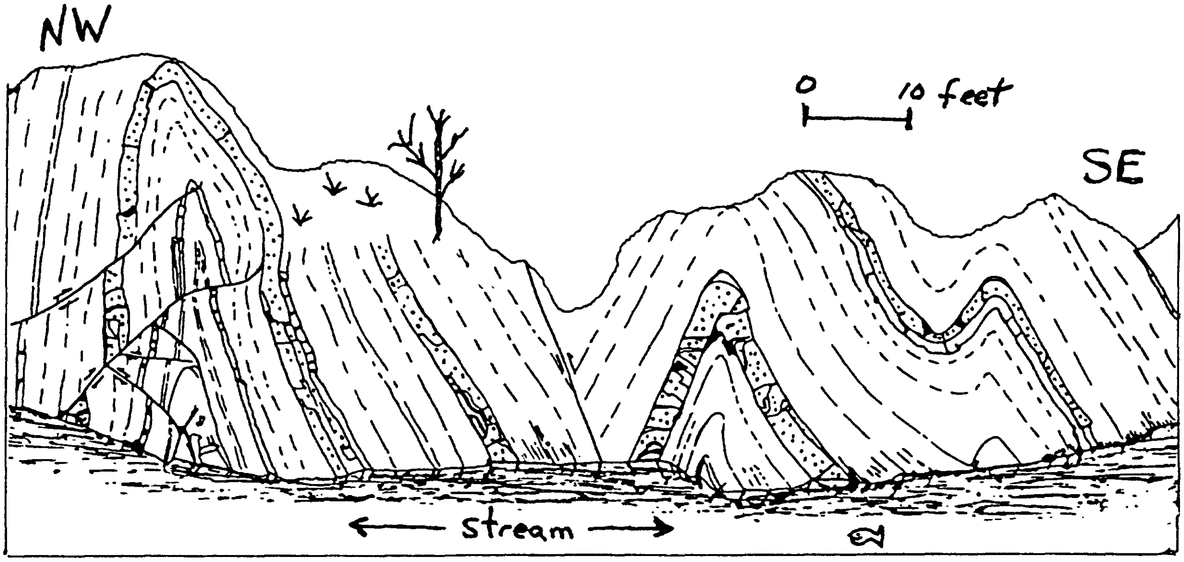


Figure 6. Folded and faulted rocks in the Brallier Formation on the southeast limb of the Whip Cove anticline west(slightly modified from Pohn and others, 1985).

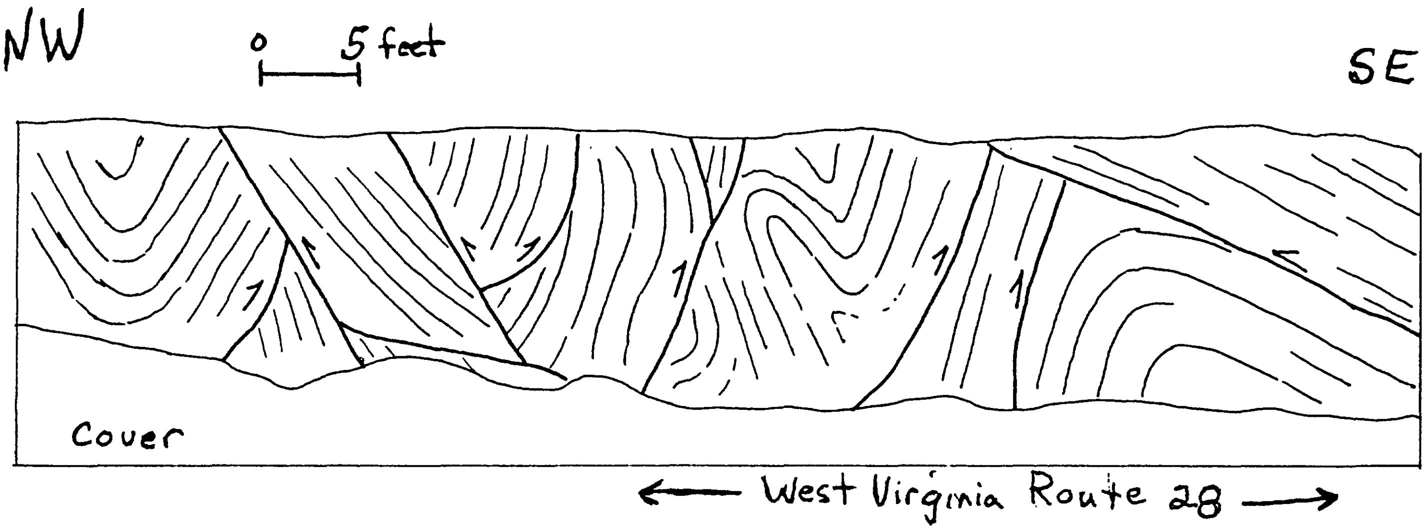


Figure 7. "Disturbed zone" in the Brallier Formation(slightly modified from Pohn and others, 1985).

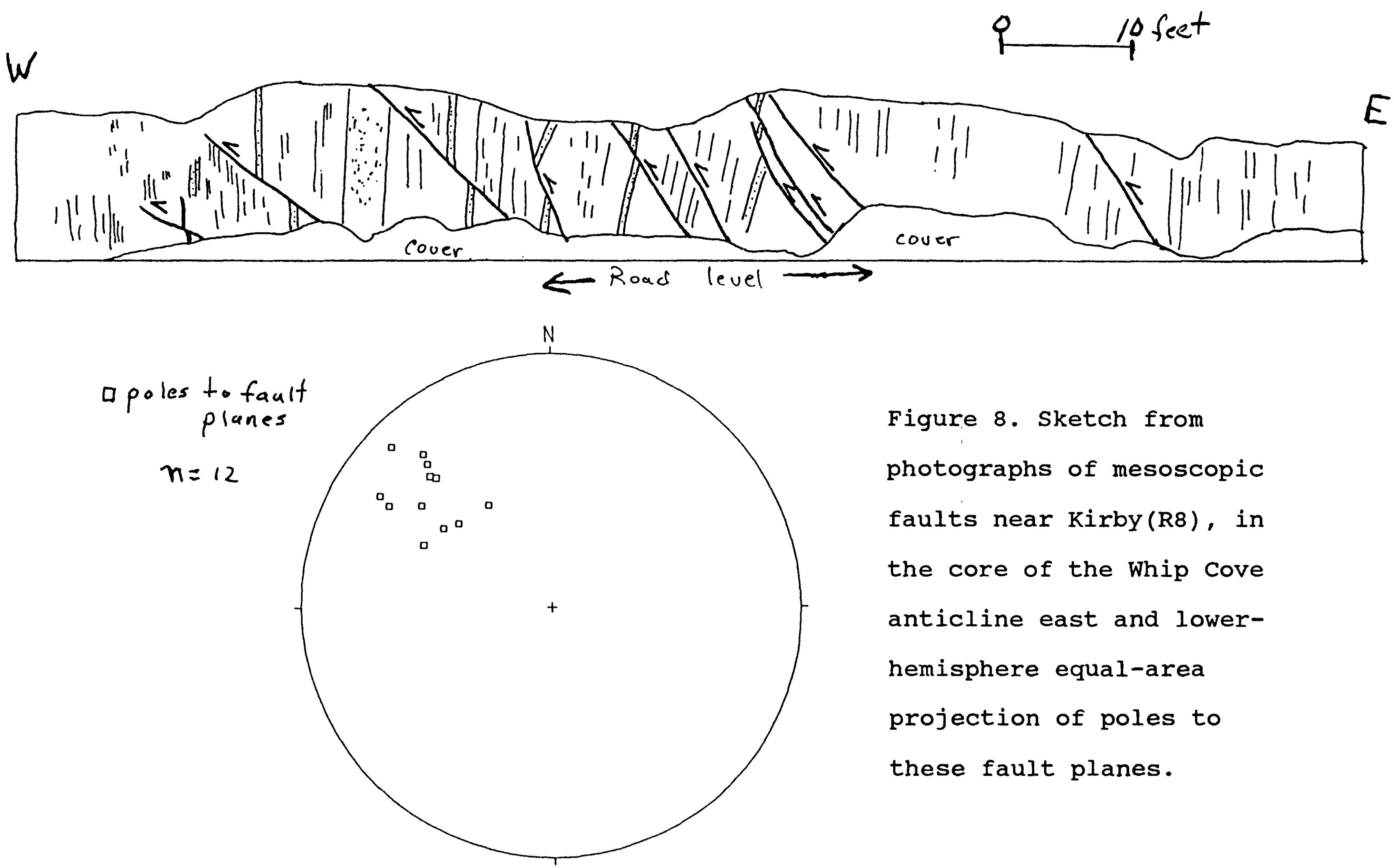


Figure 8. Sketch from photographs of mesoscopic faults near Kirby(R8), in the core of the Whip Cove anticline east and lower-hemisphere equal-area projection of poles to these fault planes.

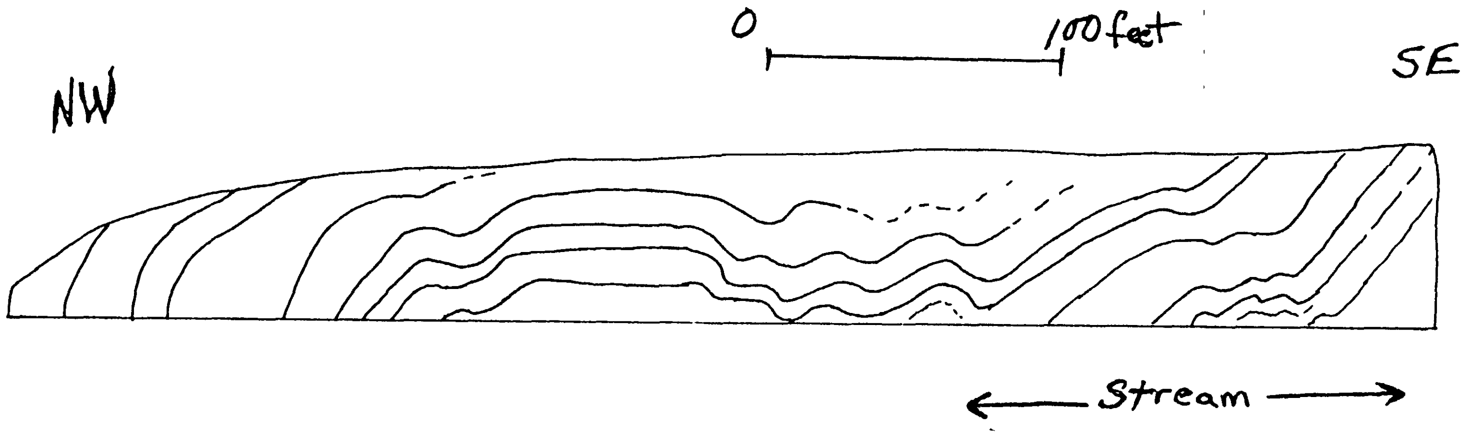


Figure 9. Southeast-verging parasitic folds on the southeast limb of the Sideling Hill syncline exposed in the cut bank of the North River, one mile southwest of North River Mills.

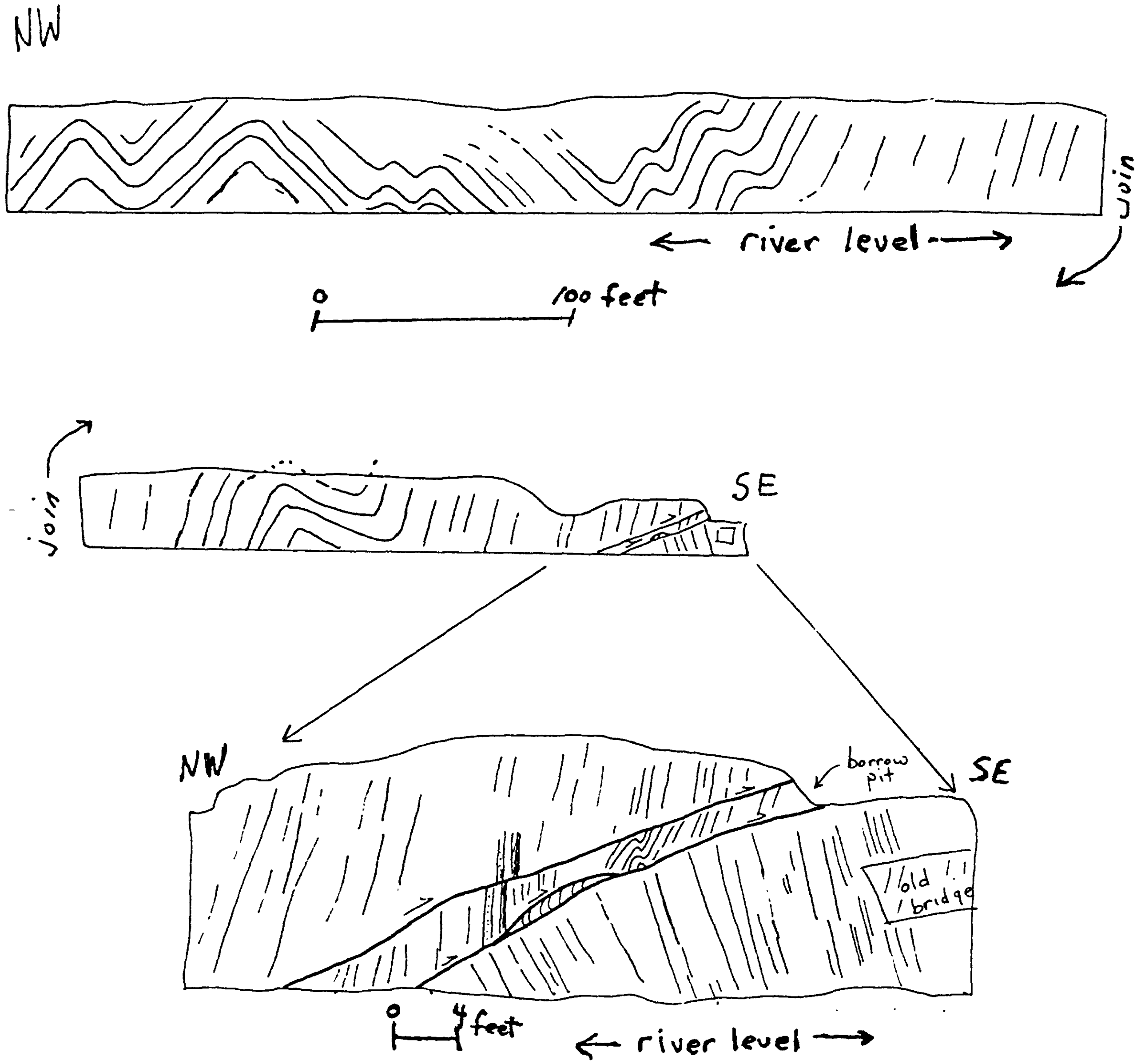


Figure 10. Sketch of several orders of parasitic folds and northwest-dipping faults on the steep southeast limb of the Sideling Hill syncline(R9).

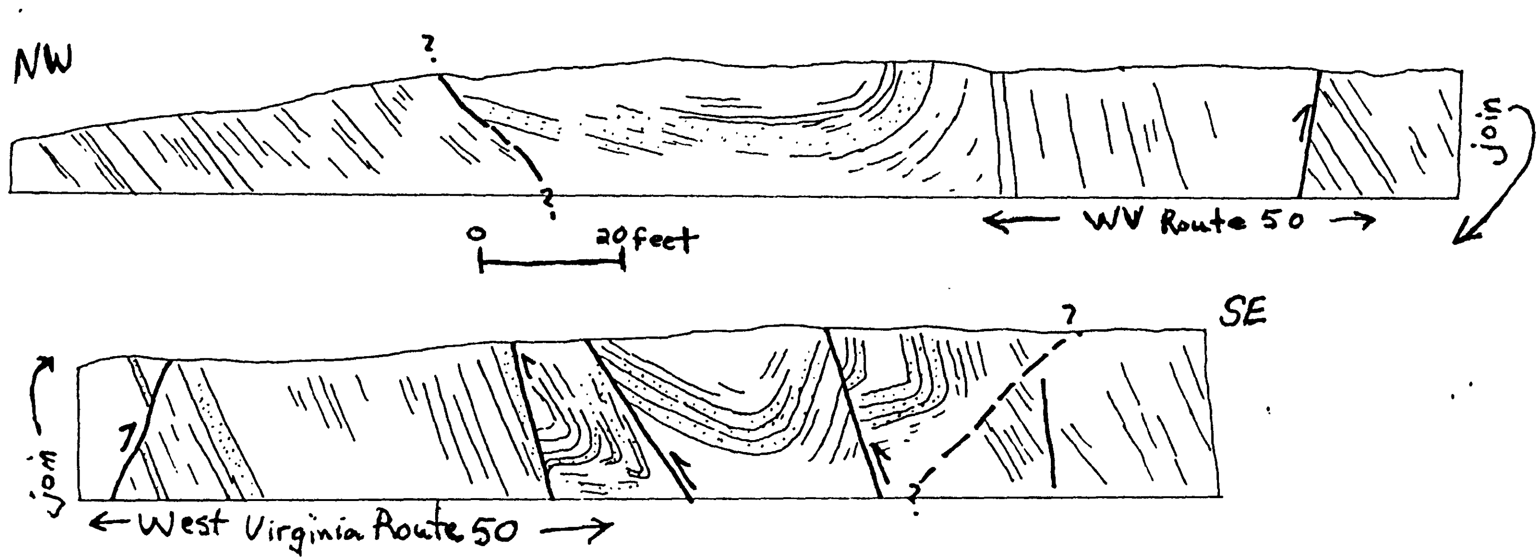


Figure 11. "Disturbed zone" with broken folds and several faults on the steep southeast limb of the Sideling Hill syncline(R10).

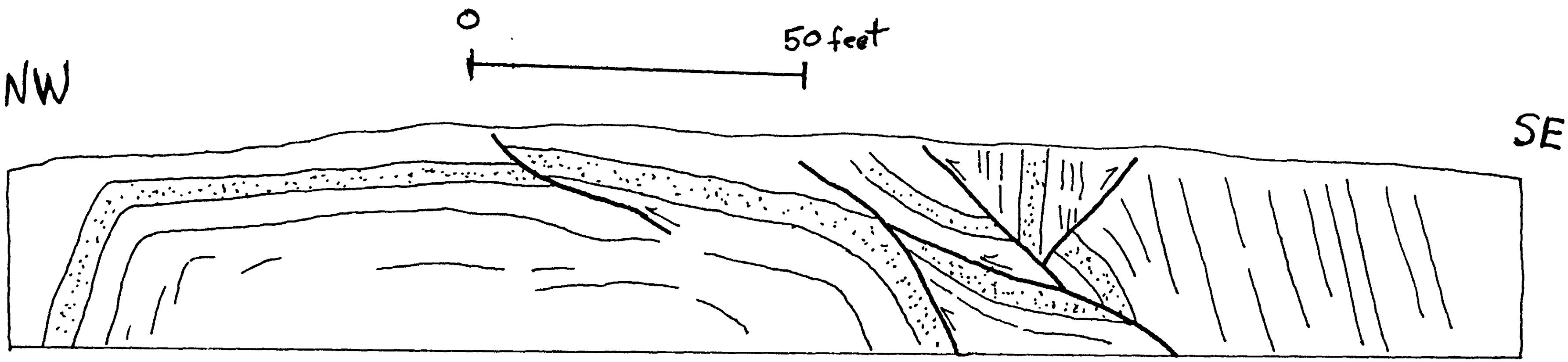


Figure 12. Box fold anticline, wedge faults, and broken syncline exposed in road cuts of State Route 9 about one mile west of Largent. Stippled bed is a thick very course grained sandstone.

A

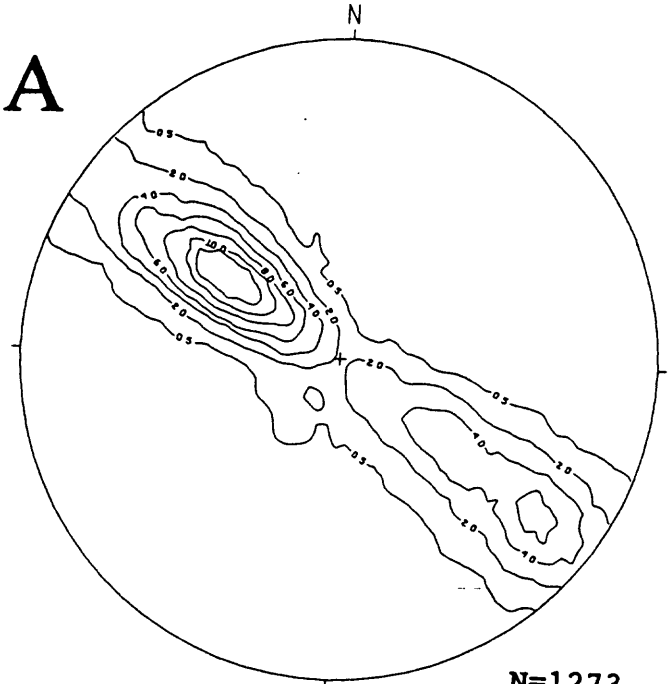


Fig. 13A. Lower-hemisphere equal-area projection of poles to bedding.

BEDDING:
Contour interval is 2 percent per one percent area except for the 0.5 percent contour

B

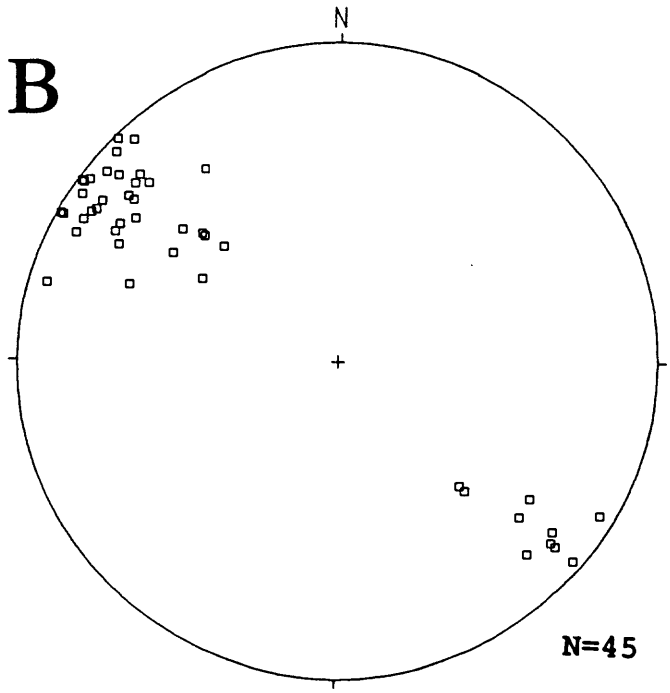


Fig. 13B. Lower-hemisphere equal-area projection of poles to cleavage.

POLES TO CLEAVAGE

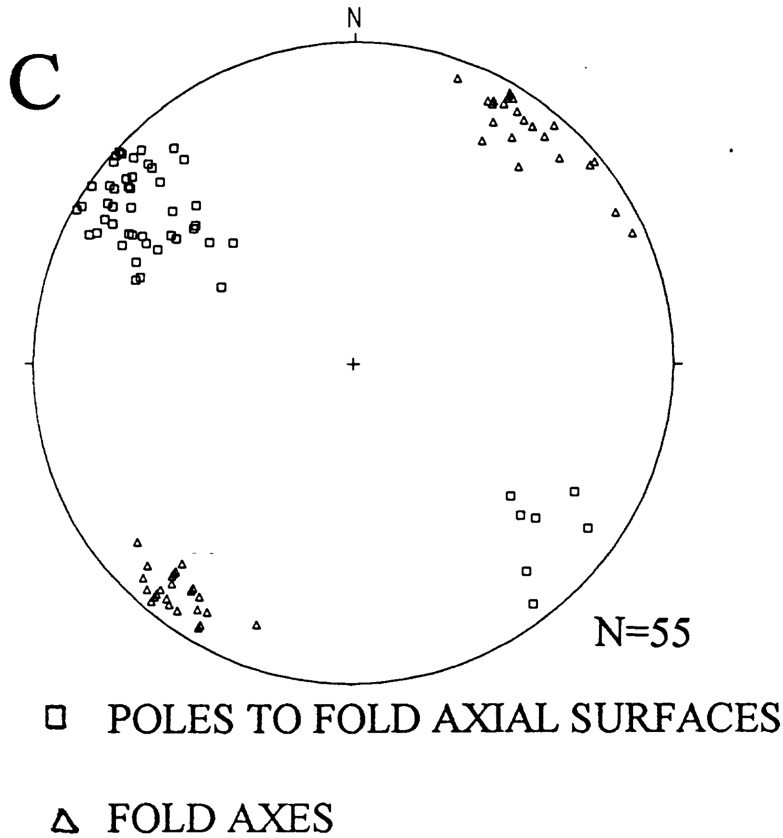


Figure 13C. Lower-hemisphere equal-area projection of fold axes and poles to axial surfaces of mesoscopic folds.

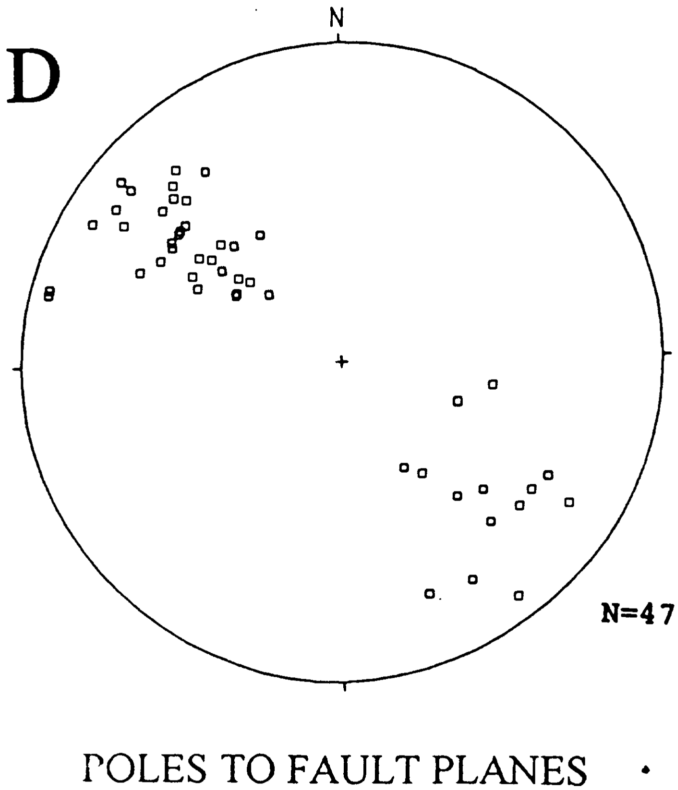


Figure 13D. Lower-hemisphere equal-area projection of poles to fault planes.

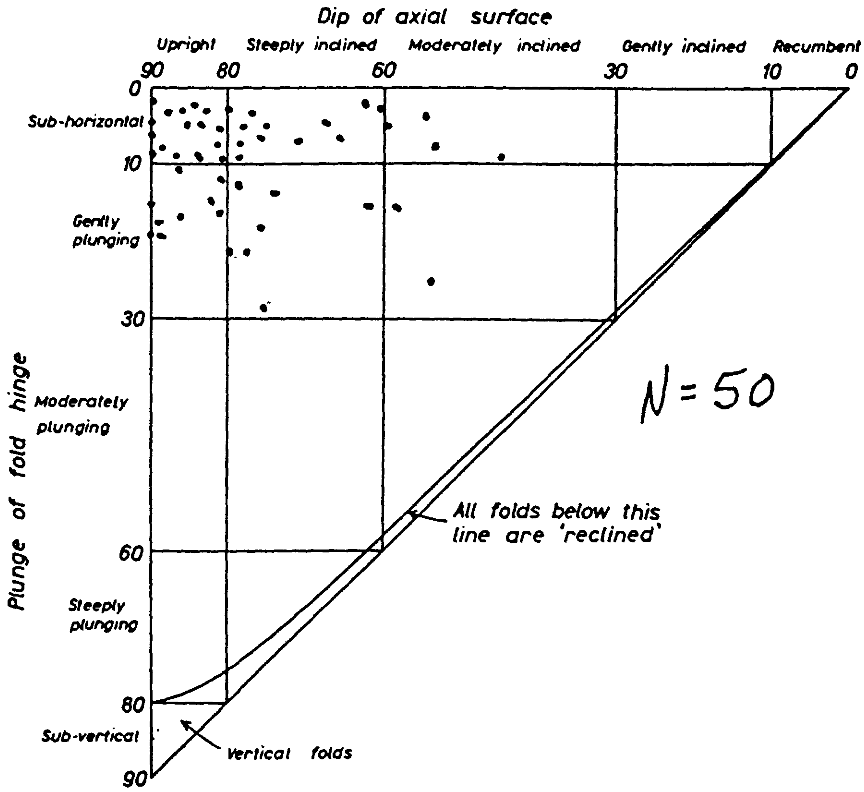


Fig. 14. Mesoscopic folds in the study area. Classification according to Fleuty(1964).