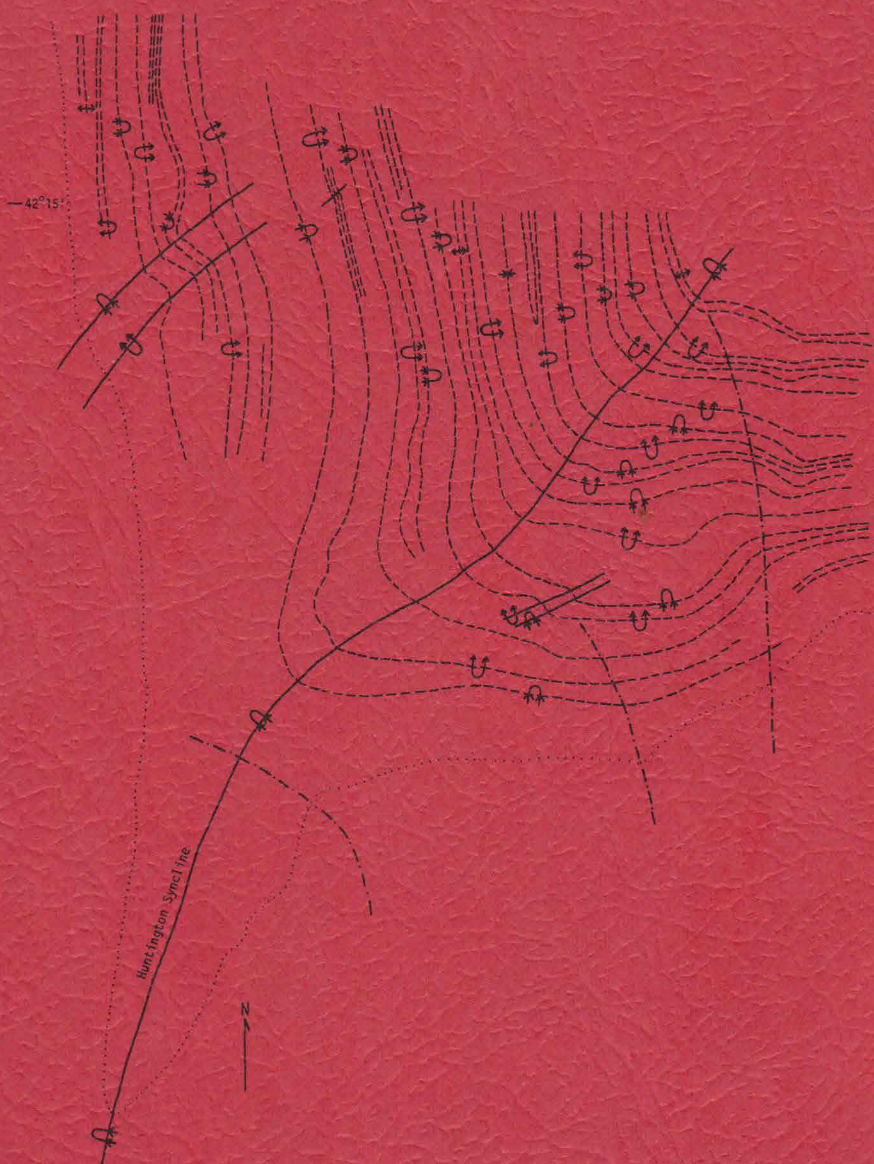
STRUCTURAL GEOLOGY AND STRATIGRAPHY OF THE HUNTINGTON AREA, MASSACHUSETTS

BY RICHARD ALLAN JACKSON



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STRUCTURAL GEOLOGY AND STRATIGRAPHY OF THE HUNTINGTON AREA, MASSACHUSETTS

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Contribution No. 21

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ABSTRACT

The Huntington area in western Massachusetts is underlain by metamorphosed Ordovician, Silurian and/or Devonian sedimentary and volcanic rocks. The Ordovician is represented by quartz-mica schist, micaceous quartzite, feldspathic schist, micaceous gneiss, amphibolite lenses and calc-silicate rocks of the Hawley Formation. Micaceous quartzite and conglomeratic quartzite of the Russell Mountain Formation is Silurian. The Goshen Formation which is Silurian and/or Devonian has been subdivided into three members. From oldest to youngest these are: the Schist and Granulite Member consisting of thin, graded beds of granulite and schist along with some calc-silicate rock; the Quartzite Member consisting of thick-bedded mica-quartz schist, quartzite, micaceous quartzite and calcareous granulite; and the Great Moose Member consisting of thick-bedded calcareous granulite with mica-quartz schist and micaceous quartzite. Sills and dikes of quartz monzonite and coarse-grained granitic pegmatites occur throughout the Huntington area.

Four phases of folding have been recognized in the Huntington area. 1). The earliest phase produced large isoclinal folds in bedding with an axial plane schistosity that is generally the major planar feature of the rocks in the area. The early isoclinal folds are displayed by repetition of the Schist and Granulite Member and the Quartzite and Great Moose Members of the Goshen Formation on the geologic map. The granitic rocks were intruded during or shortly after the early phase of deformation. 2). Locally in the western and northwestern sections of

the field area minor folds of the next later Moose stage of deformation deform earlier structural features. Kyanite grade metamorphism occurred during the early and Moose stages of deformation. 3). The Huntington stage of deformation produced a large overturned syncline, the Huntington syncline, with an associated northeast-trending and northwest-dipping slip cleavage. 4). The latest stage of folding produced open folds, with an associated axial plane slip cleavage, that deform the Huntington syncline and the early isoclinal folds.

INTRODUCTION

Location

The Huntington area in Western Massachusetts (Figure 1), is 11 square miles between latitudes 42° 10' and 42° 17' 30" north and longitudes 72° 57' 30" and 72° 50' west. Portions of the Chester, Blandford and Woronoco 7 1/2 minute quadrangles make up the study area (Figure 1).

Topography and Drainage

The Huntington area is one of moderately rugged topography with a few areas of rugged or sharp relief. The south-facing slope immediately north of the West Branch of the Westfield River consists of nearly vertical cliffs with maximum local relief of 350 feet. The total relief in the area is 1,323 feet between 1608 feet at the top of Dug Hill, 2 miles north of Blandford, in the western part of the area and 285 feet in the Westfield River valley in the southeast corner of the area. An outcrop map (Plate 1-B) indicates the extent of bedrock exposure in the Huntington area.

The ridge north of the West Branch of the Westfield River consists of Great Moose Hill at the east end and several unnamed hills further west. North Rockhouse and South Rockhouse Mountains are located approximately two miles east of Great Moose Hill. Most of the hills south of the West Branch of the Westfield are unnamed with the exception of Holiday Hill in the southeast corner of the mapped area and Green Hill and Dug Hill, both located along the west edge of the area.

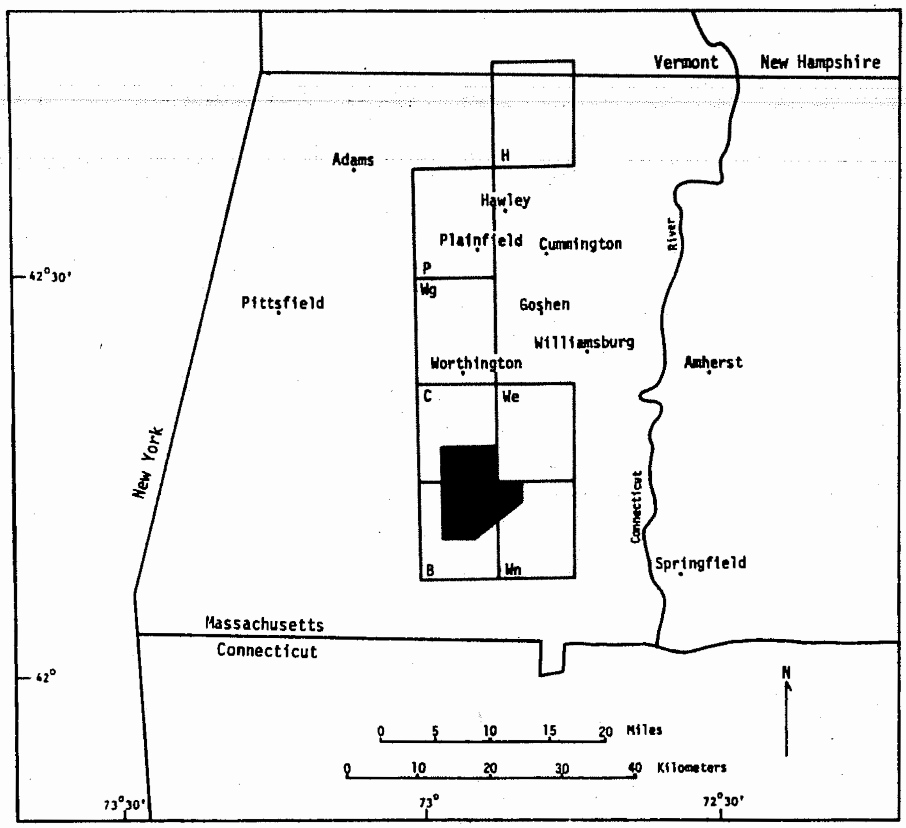


Figure 1. The location of the Huntington area, solid black, in western Massachusetts. The quadrangles indicated are Blandford (B), Woronoco (Wn), Chester (C), Westhampton (We), Worthington (Wg), Plainfield (P), and Heath (H).

The West Branch of the Westfield River flows east-southeast to the town of Huntington where it joins with the combined Middle and East Branches. The Westfield River flows east from Huntington to the Connecticut River. The more important minor streams that flow into the West Branch are Goldmine Brook, Cold Brook and Roaring Brook.

Purpose

The purpose of this study was to map and interpret the stratigraphy and structure of bedrock in the Huntington area, Massachusetts, with emphasis on the sequence of deformational events. Osberg (1972) presented evidence for a nappe in the Goshen and Waits River Formations in the Heath quadrangle (Figure 1) several miles north of the Huntington area. It was hoped that this study would test whether a similar nappe involved the rocks of the Huntington area. Time(s) of metamorphism with respect to deformation were also considered during this study. This research is a detailed analysis of a small area. This being a portion of a much larger area mapped previously by others.

Field Procedure

A total of 28 weeks were spent in the field during 1972 and 1973. Portions of the 7 1/2 minute United States Geological Survey topographic maps of the Chester, Blandford and Woronoco quadrangles, enlarged to 1:12,000 were used as base maps. Outcrops were located directly on the enlarged topographic base map in the field on the basis of topography, culture, altimeter readings and pace and compass traverses (Plate 1-B).

Acknowledgements

Grateful acknowledgement is given to Dr. Leo M. Hall who spent several days in the field and numerous hours in the office assisting and supervising in the completion of this work. Dr. Peter Robinson and Dr. Howard Jaffe gave their advice freely on many occasions. Thanks are also extended to Dr. Donald Wise, who visited the area and gave advice on several problems. Dr. Norman L. Hatch of the U.S. Geological Survey is thanked both for his advice and for the use of his unpublished geological map of the Blandford quadrangle.

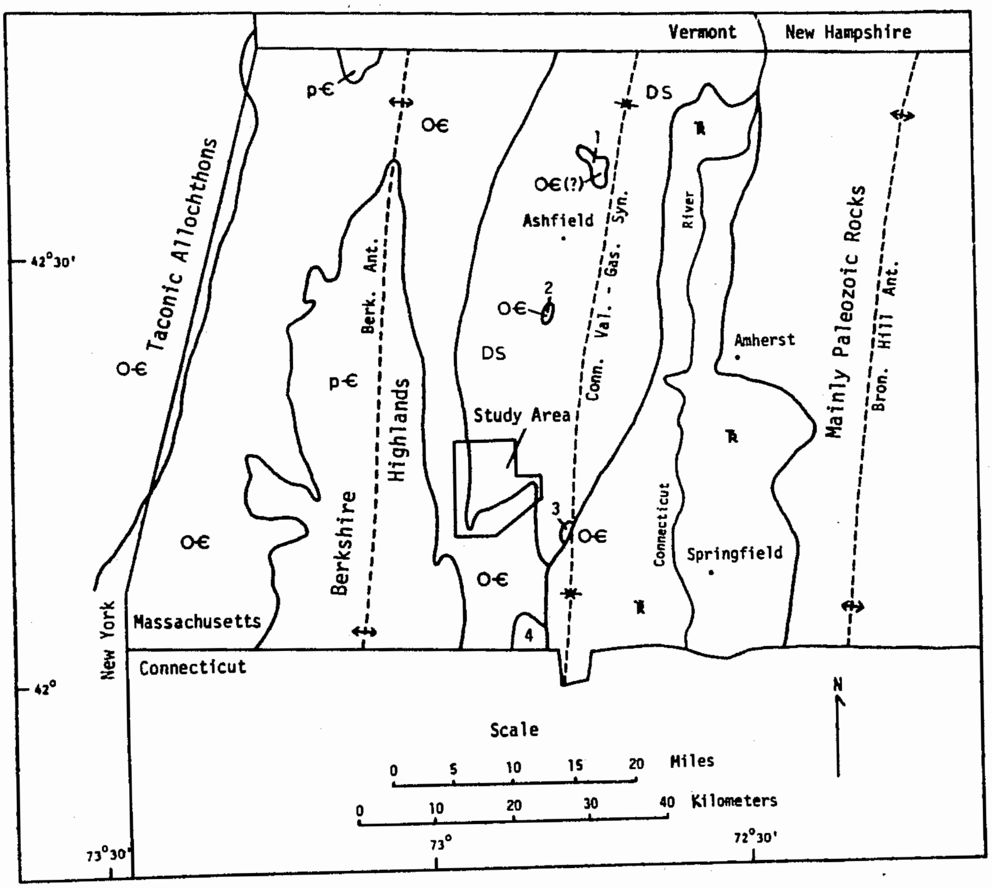
The Department of Geology at the University of Massachusetts provided many of the thin sections studied as well as a portion of the field expenses. A Grant-in-Aid of Research from the Society of the Sigma Xi paid for other thin sections and field expenses.

Previous Work

An early geological investigation of the Huntington area was made by B.K. Emerson (1898, 1917). More recent work has been done by N.L. Hatch, S.A. Norton, R.G. Clark, R.S. Stanley and S.F. Clark (Hatch, Norton and Clark, R.G., 1970; Hatch, Stanley, and Clark, S.F. unpublished geologic maps of the Blandford and Woronoco quadrangles; Stanley, 1967; Hatch, Stanley and S.F. Clark, 1970).

Geologic Setting

The rocks in western New England are deformed into large anticlinoria and synclinoria. These large folds are, from west to east, the Middlebury Synclinorium, the Green Mountain-Berkshire Anticlinorium, the Connecticut Valley-Gaspe Synclinorium and the Bronson Hill Anticlinorium (Figure 2). The Green Mountain-Berkshire Anticlinorium



EXPLANATION

Ɽ -Triassic (Jurassic ?) sedimentary and igneous rocks.

DS -Silurian and/or Devonian metamorphic rocks.

O€-Cambrian and Ordovician metamorphic rocks.

p€-Precambrian and/or probable Precambrian metamorphic rocks.

Domes

1-Shelburne Falls
2-Goshen
3-Montgomery
4-Granby

Figure 2. Generalized regional geological map of western Massachusetts.

contains Precambrian rocks in its core in Vermont, Massachusetts and Connecticut (Figure 2). The Connecticut Valley-Gaspe Synclinorium is characterized by a system of domes in Western Massachusetts (Figure 2), Vermont and Connecticut. The area under consideration lies between this domal system and the east limb of the Green Mountain-Berkshire Anticlinorium (Figure 2). Cady (1969) has described the Green Mountain-Berkshire Anticlinorium as a broad arc, convex to the northwest, that extends more than 400 miles northeastward from western Massachusetts through Vermont and Quebec. The Connecticut Valley-Gaspe Synclinorium occupies a long curvilinear tract, chiefly on the west side of the Connecticut River in New England and southeast of the Notre Dame and Schickshock Mountains, in southeastern Quebec and northernmost New England (Cady, 1969).

The Paleozoic stratigraphy of the east limb of the Berkshire Anticlinorium in western Massachusetts is shown in Figure 3. These units occur in age sequence, oldest to youngest, from west to east on the east side of the Berkshire Highlands (Hatch, Schnabel and Norton, 1968). The rocks in the east limb of the anticlinorium are a eugeosynclinal sequence including schists, amphibolites, quartzites and gneisses (Hatch, et. al., 1967). Three regional unconformities are noted in this sequence. The Cambrian Hoosac Formation lies unconformably on Precambrian rocks exposed in the core of the Berkshire Anticlinorium. The Taconic unconformity, marked locally by the presence of a Silurian quartzite and conglomerate quartzite, separates Lower Paleozoic eugeosynclinal rocks from Silurian and Devonian eugeosynclinal rocks which

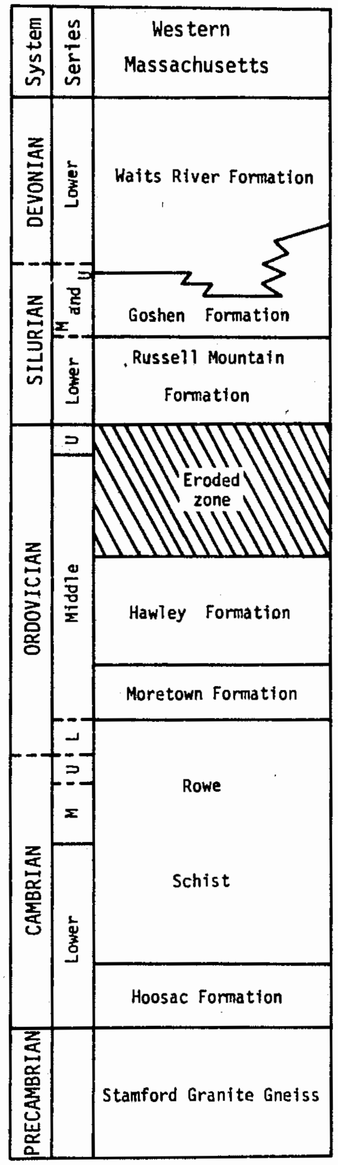


Figure 3. Stratigraphy of western Massachusetts (from Hatch, Schnabel and Norton, 1968).

consist of schist, quartzite, calcareous granulite and calc-silicate rock. Intrusive granitic rocks of possible Devonian age are noted locally on the east limb of the Berkshire Anticlinorium. Triassic sedimentary and igneous rocks occupy the Connecticut Valley area and cover the Paleozoic eugeosynclinal rocks.

STRATIGRAPHY

General Statement

The rocks in the Huntington area are chiefly schists, quartzites, calcareous granulites, calc-silicates and volcanics that have been divided into four mappable units. The rock units range from Middle Ordovician through Devonian. A major unconformity separates the Ordovician from the Silurian and younger rocks. From the oldest to youngest these units are: the Hawley Formation, Russell Mountain Formation and the Goshen Formation with the Schist and Granulite, Quartzite, and the Great Moose Members (Figure 4).

The unconformity between the Hawley Formation and the overlying rocks presents a problem in that the Hawley does not appear to be involved in folds within the Goshen. The reason for this has not yet been conclusively resolved, but the break is a regional unconformity with some possible faulting along it.

All formation names and member names are those conventionally used by geologists working in Western Massachusetts (Hatch, 1967; Hatch, 1968; Hatch, Stanley and Clark, 1970), except the Great Moose Member of the Goshen Formation which is named here. The origin of these names and their type localities are given individually below.

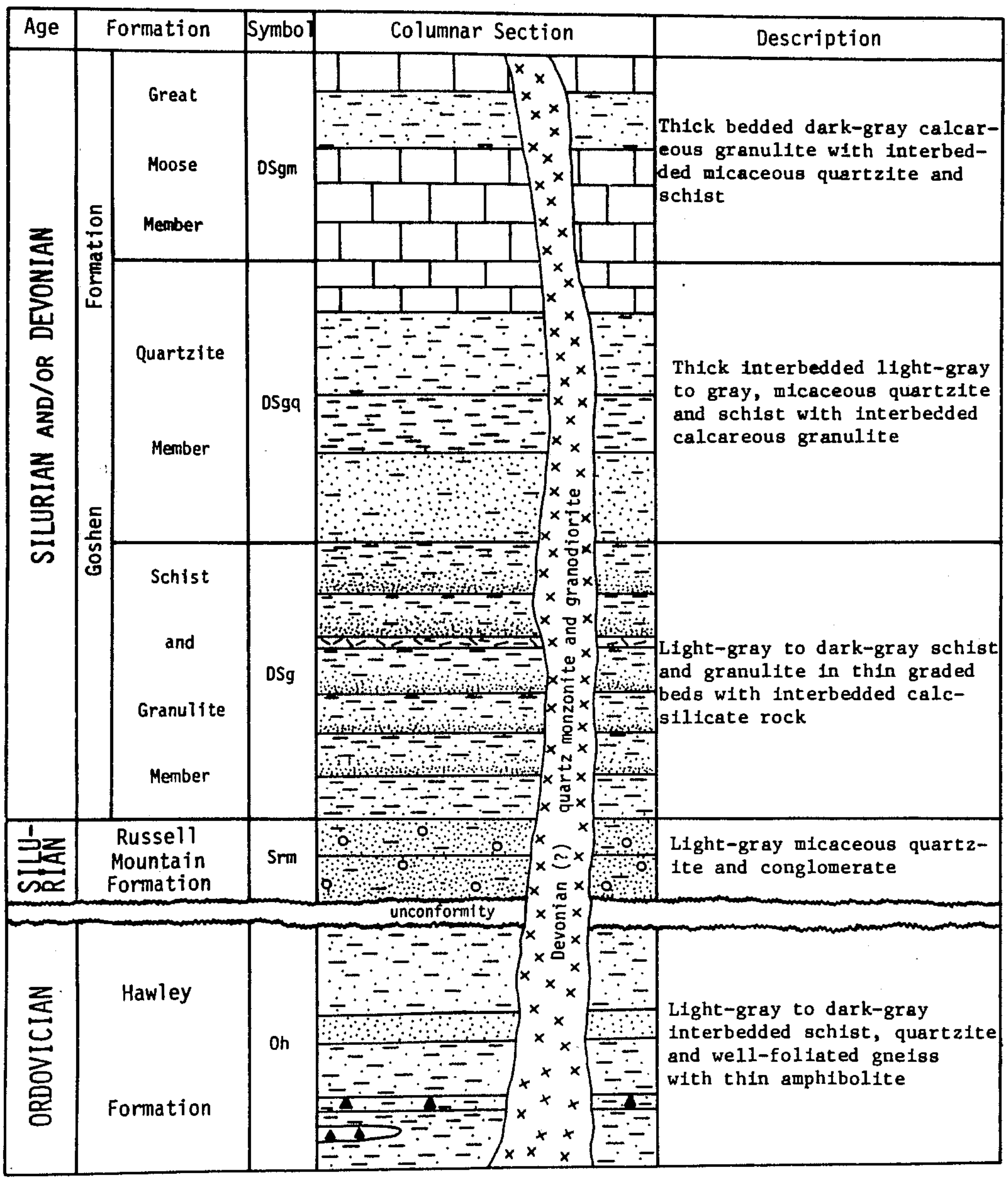


Figure 4. Columnar section for the Huntington area, Massachusetts.

Hawley Formation

Name. B.K. Emerson (1898) proposed the name Hawley Schist. He described it as a ferromagnesian formation with abundant hornblende and showed it entering Massachusetts from the southwest corner of Halifax, Vermont and continuously increasing in thickness southward. Hatch (1967) renamed the unit the Hawley Formation.

Distribution. The Hawley Formation occurs in the western portion of the Huntington area, where it trends north-south. The trend changes to northeast in the vicinity of the town of Blandford where it turns and trends northeastward and continues toward Crescent Mills, at the eastern border of the map area (Plate 1-A). A few thousand feet further east of this point the trend of the Hawley changes to north-south.

Lithology. In the study area only rocks near the top of the Hawley Formation are described (Table 1, specimens 923, 2057 and 2064). These rocks consist of thick-bedded, rusty-weathering, gray to dark-gray quartz-mica schists; thin-bedded, light-gray to gray micaceous quartzites; massive gray feldspathic schists; gray to dark-gray micaceous gneisses, thin amphibolite lenses; and thin calc-silicate beds.

Thickness. The base of the Hawley Formation is not exposed within the Huntington area and consequently the thickness was not determined. Hatch (1967) states that the Hawley Formation is 2,550 feet to 5,450 feet thick in the Plainfield quadrangle and reports a thickness of 585 feet along Sam Hill Road in the south-central portion of the Worthington quadrangle (1969) (Figure 1).

Correlation. The Hawley Formation can be traced continuously along

TABLE 1. MODES OF THE HAWLEY FORMATION

Specimen	923	2057	2064
Quartz	1	55	41
*Plagioclase	2	10	15
Alkali feldspar	-	3	-
Muscovite	69	3	21
Biotite	14	t	15
Chlorite	t	-	t
Garnet	4	7	8
Staurolite	1	-	-
Apatite	t	t	t
Tourmaline	9	22	t
Zircon	t	t	t
Sphene	t	-	-
Rutile	t	-	-
Ilmenite	t	-	-
Magnetite	t	t	t
Graphite	t	-	-
*Anorthite % of Plagioclase	Ab	6	Ab

*Approximate composition of plagioclase feldspar in mol. % anorthite based on the Michel-Levy method. If untwinned plagioclase the composition is generalized as indicated by name based on relative relief and optic sign.

t = Trace amounts

923. Well foliated medium- to coarse-grained, gray to dark-gray, (staurolite)-garnet-tourmaline-mica schist with tourmaline crystals up to 1 inch long. Specimen location approximately 1000 feet north of the West Branch of the Westfield River in the northwesternmost section of the field area.

2057. Well foliated medium-grained, light-gray to gray, garnet-mica-tourmaline-feldspar-quartz gneiss with tourmaline crystals up to 1/8 inch in length. Specimen location approximately one mile south-southeast of Green Hill.

2064. Moderately-well foliated fine-grained, light-gray to gray, garnet quartzose schist. Specimen location approximately 2000 feet northeast of Green Hill, located on the west-central edge of the field area several miles north of the town of Blandford.

strike northward through the Chester and Worthington quadrangles to its type locality at Parker Hill in the Plainfield quadrangle.

Age. No fossils have been found in the Hawley Formation. Hatch (1967) reported that the Hawley Formation is continuous with the Barnard Volcanic Member and the Black Schist Member of the Missisquoi Formation in Vermont. Based on this relationship to rocks in Vermont which in turn have been correlated with the fossiliferous rocks in the Beauceville Formation in Southern Quebec (Cady, 1960) the Hawley Formation is believed to be Middle Ordovician. Osberg, Hatch and Norton (1971) correlate blackschists and volcanics of the Hawley Formation with the Partridge Formation and the Ammonoosuc Volcanics, respectively in New Hampshire.

Russell Mountain Formation

Name. N.L. Hatch, R.S. Stanley and S.F. Clark (1970) proposed the name Russell Mountain Formation for a thin discontinuous unit of calc-silicate granulite, quartzite and conglomeratic quartzite that outcrops on Russell Mountain in the Woronoco quadrangle, Massachusetts (Figure 1).

Distribution. The Russell Mountain Formation occurs in one outcrop inside the racetrack on the fairgrounds in the village of Blandford in the Huntington area (Plate 1-A).

Lithology. The Russell Mountain Formation that is exposed at the racetrack is light-gray, rusty-weathering, well foliated, micaceous, conglomeratic quartzite (Table 2, specimen 2028). Hatch, Stanley and Clark (1970) have described transparent quartz pebbles up to 3/4 inch

(2 cm) in diameter at this particular outcrop. Most of the quartz grains are ellipsoidal with the longest and intermediate dimensions in the foliation.

At other locations, south of the Huntington area, the Russell Mountain Formation consists of calc-silicate granulite, carbonate-calc-silicate rock and/or quartzite (Hatch, Stanley and Clark, 1970). Any or all of these rock types may be present at any given locality.

Thickness. The Russell Mountain Formation at Blandford is 10 to 15 feet thick. Hatch, Stanley and Clark (1970), have estimated a thickness of 110 feet at the northeast end of Westfield Mountain in the Woronoco quadrangle.

Correlation. The outcrop of quartzite at the racetrack in Blandford cannot be traced continuously along strike to the type locality of the Russell Mountain Formation in the Woronoco quadrangle, but the rocks of this exposure in Blandford have been correlated with those at the type locality (Hatch, Stanley and Clark, 1970).

Hatch, Stanley and Clark (1970), further asserted that no rocks lithically similar to the Russell Mountain Formation have been found in the stratigraphic position above the Hawley Formation and below the basal section of the Goshen Formation in Massachusetts north of the town of Blandford. Similar rocks, the Shaw Mountain Formation, occur in this position as a discontinuous series of lenses throughout eastern Vermont. Thus, based on stratigraphic position and lithologic similarity, the Russell Mountain Formation is correlated with the Shaw Mountain Formation (Hatch, Stanley and Clark, 1970).

Age. Since the Russell Mountain Formation has been correlated with the fossiliferous Shaw Mountain Formation in Vermont, it is assigned to the Wenlock (Hatch, Stanley and Clark, 1970).

Goshen Formation

Name. The Goshen Schist is the name given by B.K. Emerson (1898, 1917) to dark-gray, graphitic, quartz-mica-garnet schists that lie stratigraphically above the Hawley Formation in western Massachusetts. The typical section of the Goshen Schist "is that surrounding the oval of Hawley schist in Goshen, where the Goshen dips away from the Hawley in all directions," (Emerson, 1917, p. 46). Hatch (1967) redefined the Goshen Schist to be compatible with the redefined Hawley Formation. Some of the black schists of Emerson's Goshen Schist and some rocks of the overlying Conway Schist (Emerson, 1917) are incorporated within the Goshen Formation. The type section of the Goshen Formation is along State Route 9 east of a point 2 1/2 miles west of Cummington, Massachusetts (Hatch, 1967).

Distribution. The Goshen Formation is widely distributed and underlies approximately 95% of the Huntington area. It occurs east of the Taconic unconformity in the west and generally north of it in the south portion of the area (Plate 1-A).

General Lithology. In the Huntington area the Goshen Formation consists of thin-bedded gray schist and granulite, calc-silicate rocks, thick-bedded quartzite, schist, and calcareous granulite. These rocks are grouped into three members.

Emerson (1898, 1917) described the Goshen Schist as "splitting into flags 2 to 3 inches thick, which have been used in the large towns in the Connecticut Valley for sidewalks" (Emerson, 1917, p. 46). Hatch (1967) described the rocks of the Goshen Formation at the type locality as being gray schists, cyclically bedded gray-schist and quartzite, thick-bedded, gray-quartzite and rare brown-weathering sandy carbonate granulite.

Lithology of the Schist and Granulite Member. Hatch (1967) first described this member as the cyclically bedded rocks that form the bulk of the Goshen Formation in the Plainfield and Worthington quadrangles (Figure 1) in western Massachusetts.

Thick-bedded, rusty-weathering, gray to dark-gray, garnet-kyanite-staurolite-quartz-mica schists compose the basal portion of the Schist and Granulite Member. This basal section of the Schist and Granulite Member of the Goshen, a short stratigraphic distance above the base of the formation, shows the cyclic character of the bulk of the rocks in the member. The cyclically bedded rocks consist of thin beds, one-half inch to nine inches thick, in which light-gray, (garnet)-mica-quartz granulite grades upward into light-gray to gray garnet-mica-quartz sandy-schist and schist, which in turn grades upward into gray to dark-gray garnet-kyanite-staurolite-quartz-mica schist (Table 2, specimen 4). A sharp break separates one graded bed from the next higher or lower in sequence. The average thickness of individual cyclic beds in this member is 3 inches and the unit has been called the thin-bedded or cyclically bedded member of the Goshen Formation (Hatch, 1967). Another

TABLE 2. MODES OF THE SCHIST AND GRANULITE MEMBER (THIN BEDDED) OF THE GOSHEN FORMATION AND THE RUSSELL MOUNTAIN FORMATION

	Russell Mtn. Formation	Goshen Formation (Schist and Granulite Member)					
Specimen	2028	4	880	909	1116	1165	2057
Quartz	91	18	45	37	33	61	28
*Plagioclase		16	4	5	29	17	t
Alkali feldspar		-	-	-	-	-	7
Muscovite	9	28	43	48	-	7	42
Biotite		21	6	4	t	14	13
Chlorite		-	t	t	-	-	t
Garnet		2	1	5	2	1	2
Kyanite		10	t	-	-	-	-
Staurolite		5	1	1	-	-	8
Diopside		-	-	-	8	-	-
Epidote		-	-	-	7	-	-
Hornblende		-	-	-	19	-	-
Apatite		t	t	t	t	t	t
Tourmaline		t	t	t	t	t	t
Zircon		t	t	t	t	t	t
Sphene		-	-	t	2	t	-
Rutile		-	-	t	-	t	-
Magnetite		t	t	t	t	t	t
Graphite		t	t	t	-	-	t
*Anorthite % of plagioclase		12	Ab	Olig	72	Olig	Ab

*Approximate composition of plagioclase feldspar in mol. % anorthite based on the Michel-Levy method. If untwinned plagioclase the composition is generalized as indicated by name based on relative relief and optic sign.

t = Trace amounts.

2028. Well foliated coarse-grained, tan to light-gray, muscovite quartzite, conglomeratic in part. Specimen located at the racetrack in the Blandford fairgrounds.

4. Well foliated coarse-grained, gray, garnet-staurolite-kyanite-mica schist. Specimen located approximately 200 feet west of the intersection of Fiske Avenue and Route 112 just north of the Huntington Bridge.

880. Well foliated fine-grained, gray, staurolite-garnet-mica schist. Specimen located approximately 1000 feet north of the West Branch of the Westfield River in the northwesternmost section of the field area.

909. Well foliated medium- to coarse-grained, gray to dark-gray, staurolite-garnet-mica schist with staurolite crystals up to 1/2 inch long. Specimen is located approximately 1000 feet north of the West Branch of the Westfield River in the northwesternmost section of the field area.

1116. Poorly foliated, coarse-grained, light-gray to gray garnet-diopside-hornblende calc-silicate granulite. Specimen located approximately 150 feet east of point on Huntington Road about one mile north of Cochran Pond.

1165. Poorly foliated fine-grained, tanish-gray, garnet-mica quartzite. Specimen located in the spillway of the Russell Dam (not shown on the topographic map) on Black Brook approximately 500 feet west of the junction of Stony Gutter Road and Phelps Road in the southern part of the field area.

2057. Well foliated fine-grained, gray, garnet-staurolite-mica schist. Specimen located approximately one mile south-southeast of Green Hill, located on the west-central edge of the field area several miles north of the town of Blandford.

rock type in the Schist and Granulite Member is a dark-gray weathering, light-gray to gray, thin-bedded calc-silicate rock (Table 2, specimen 1116).

Lithology of the Quartzite Member. Hatch (1967) first described this member in the Plainfield and Worthington quadrangles (Figure 1) where it contains thick-bedded to massive gray and buff sandy quartzite and micaceous quartzite. Fine-to medium-grained, brown punky-weathering, gray, mica-quartz-calcite granulite is also present.

The Quartzite Member is stratigraphically above the Schist and Granulite Member of the Goshen Formation. In the Huntington area the Quartzite Member consists of thick bedded, light-gray weathering quartzite and micaceous quartzite or sandy schist (Table 3, specimens 1, 43, 43a, 71 and 498), massive, gray to dark-gray, garnet-quartz-mica schist (Table 3, specimens 117, 766 and 1079), brown punky-weathering calcareous granulite and thick-bedded gray to dark-gray, mica-quartz calcareous granulite (Table 3, specimens 26, 132, 358 and 1110). Calcareous granulites are locally present, but make up less than 10% of the rocks in the Quartzite Member. Kyanite is rare, but locally present in some thick-bedded garnet-biotite-muscovite schists. Graded beds are present at a few localities, but are uncommon and do not characterize this member as a whole. The beds of the Quartzite Member are approximately 6 inches to 25 feet thick, with most ranging from 6 to 10 feet.

The rocks of the Quartzite Member are distinguished from the older Schist and Granulite Member both in mineralogy and thickness of beds. Everywhere the contact between the two members is well exposed in the field area, the following sequence, from older to younger, is noted.

TABLE 3. MODES OF THE QUARTZITE MEMBER (THICK BEDDED OF THE GOSHEN FORMATION

Specimen	1	26	43	43a	71	117	132	358	377	498	766	1079	1110
Quartz	53	64	51	61	47	13	25	28	64	66	39	44	39
*Plagioclase	1	10	8	t	20	18	3	3	9	t	15	–	1
Alkali feldspar	31	–	–	–	t	–	2	–	–	–	–	10	t
Muscovite	3	14	18	27	11	43	–	1	6	22	24	31	–
Biotite	10	9	21	12	20	25	12	20	21	8	19	15	13
Chlorite	1	t	t	t	t	t	–	–	–	–	t	–	t
Garnet	–	1	1	t	t	t	–	1	t	1	3	–	1
Kyanite	–	–	t	–	–	1	–	–	–	3	–	–	–
Calcite	–	2	–	–	–	–	36	1	t	–	–	–	9
Scapolite	–	–	–	–	–	–	10	44	–	–	–	–	22
Diopside	–	–	–	–	–	–	8						
Epidote	–	–	–	–	–	–	4						
Hornblende	–	–	–	–	–	–	–	–	–	–	–	–	15
Apatite	1	t	t	t	t	t	t	t	t	t	t	t	t
Tourmaline	–	–	1	t	t	t	t	t	t	t	t	t	t
Zircon	t	t	t	t	t	t	t	t	t	t	t	t	t
Sphene	t	t	t	–	–	–	t	1	–	–	–	–	t
Rutile	–	–	–	–	–	–	–	–	t	t	–	–	–
Magnetite	t	t	t	t	2	t	t	1	t	t	t	t	t
Graphite	–	–	–	–	t	–	–						
*Anorthite % of Plagioclase	Ab	And	Olg	Olg	Olg	20	?	37	Olg	?	Ab	–	Olg

*Approximate composition of plagioclase feldspar in mol. % anorthite based on Michel-Levy method. If untwinned plagioclase the composition is generalized as indicated by name based on relative relief and optic sign.

t = Trace amounts.

1. Weakly foliated fine-grained, gray, mica quartzite with feldspar crystals 1/8 inch across. Specimen located in a small road cut on Fiske Avenue about one mile west of the junction of Fiske Ave. and Basket Street, that is about 1/4 mile north of the town of Huntington.

26. Poorly foliated fine-grained, light-gray to gray, garnet-calcite-mica-quartz granulite with muscovite crystals up to 1/4 inch across. Specimen located on the knob approximately 3000 feet south-southwest of the summit of great Moose Hill.

43. Well-foliated, fine-grained, gray, garnet quartzose schist with biotite crystals up to 1/8 inch across. Specimen located approximately 2000 feet south of the summit of Great Moose Hill.

43a. Poorly foliated fine-grained, light-gray, mica quartzite. Specimen located approximately 2000 feet south of the summit of Great Moose Hill.

71. Well foliated, fine-grained, gray, garnet-mica quartzose schist. Specimen located approximately 2000 feet southwest of the summit of Great Moose Hill.

117. Poorly foliated fine-grained, light-gray to gray, (kyanite)-(garnet)-mica-quartz-feldspar granulite. Specimen located approximately 500 feet southeast of the summit of Great Moose Hill.

132. Moderately-well foliated fine-grained, light-gray to gray, diopside-scapolite-quartz-calcite granulite. Specimen located 100 feet east of a knob approximately 2500 feet south-southwest of Great Moose Hill.

358. Moderately-well, foliated, medium-grained, gray, garnet-mica-quartz-scapolite granulite. Specimen located approximately 300 feet east of the summit of Great Moose Hill.

377. Poorly foliated, fine-grained, light-gray, micaceous quartzite. Specimen located approximately 2000 feet southwest of the summit of Great Moose Hill.

498. Well foliated, medium-to coarse-grained, light-gray, garnet-kyanite-mica quartzose schist with kyanite crystals up to 1 inch long and biotite crystals up to 1/8 inch across.

766. Well foliated, medium- to coarse-grained, gray, garnet-feldspar-mica schist with feldspar crystals up to 1/4 inch long. Specimen located approximately 2000 feet west of knob 1114 on the northwestern section of Great Moose Hill ridge.

1079. Well foliated, fine-grained, light-gray, micaceous quartzite. Specimen located approximately 2500 feet south of the Huntington Reservoir.

1110. Moderately-well foliated, medium-grained, gray, biotite-calcite-quartz granulite. Specimen located in a roadcut approximately 100 feet northwest of Cochran Pond on the Huntington Road about 2 miles north of the town of Blandford.

Thin cyclic beds of schist and granulite grade upward to a 2 to 4 foot thick, light-gray quartzite bed. Stratigraphically above this quartzite bed is 2 to 3 feet of very thin, 1/2 to 1 inch, dark-gray cyclic beds of schist and granulite that grade upward to a massive, gray to dark-gray, garnet-quartz-biotite-muscovite schist. Above this sequence are the typical massive schists, quartzites and calcareous granulites of the Quartzite Member.

Lithology of the Great Moose Member. The type locality for this member in the Goshen Formation is on Great Moose Hill, northwest of the town of Huntington in the Blandford quadrangle (Plate 1-A). Here the Great Moose Member consists of thick, interbedded garnet-quartz-biotite-muscovite schist, gray to dark-gray, mica-quartz calcareous granulite, brown punky-weathering calcareous granulite (Table 4, specimens 400 to 580) and gray micaceous quartzite. Carbonate-bearing rocks are common and compose approximately 30 to 40% of the unit. Most of the beds in the Great Moose Member range from 5 to 10 feet thick.

The Great Moose Member is stratigraphically above the Quartzite Member and is distinguished from it by its calcareous nature. A 3 to 5 foot thick brown-weathering, light-gray to gray calcareous granulite bed (Table 4, specimen 400) marks the contact between the two members. Hatch (1967, p. D14) defines the Goshen - Waits River contact, "... as the base of the lowest dark-brown-weathering sandy limestone bed that is more than 1 foot-thick". Stratigraphically above this bed most of the thick-bedded rocks are calcite-bearing granulites and massive gray schists. The brown, punky-weathering, calcareous granulites in the

TABLE 4. MODES OF THE GREAT MOOSE MEMBER OF THE GOSHEN FORMATION

Specimen	400	580
Quartz	11	36
*Plagioclase	10	9
Muscovite	5	3
Biotite	17	6
Chlorite	-	t
Garnet	-	1
Calcite	57	39
Scapolite	-	6
Apatite	t	t
Tourmaline	t	t
Zircon	t	t
Magnetite	t	t
*Anorthite % of Plagioclase	Lab	?

*Approximate composition of plagioclase feldspar in mol. % anorthite based on the Michel-Levy method. If untwinned plagioclase the composition is generalized, as indicated by name based on relative relief and optic sign. Modes are indicated in the second row.

t = Trace amounts.

400. Weakly foliated fine-grained, brown weathering, gray, mica-calcite granulite. Specimen located approximately 2000 feet southwest of the summit of Great Moose Hill.

580. Weakly foliated fine-grained, brown punky weathering, light-gray, (garnet)-scapolite-mica-calcite granulite. Specimen located approximately one mile west of the summit of Great Moose Hill.

Quartzite Member range in thickness from 3 to 6 inches, and are present only locally whereas the lithically similar punky-weathering calcareous granulites in the Great Moose Member range in thickness from 3 to 24 inches and compose about 10% of the calcareous rocks of the unit.

Thickness. In the study area the thicknesses of the members of the Goshen Formation are as follows. The Schist and Granulite Member is 300 feet thick and the Quartzite Member is 500 feet thick. An error in the figures is possible because of multiple stages of folding that effect the rocks in this area. The thickness of the Great Moose Member could not be determined because the top of the member is not exposed in the Huntington area, but a minimum thickness of approximately 100 feet was measured. This determination was made from the Great Moose Hill vicinity near the town of Huntington, where the bedding is vertical to subvertical. The total thickness of the Goshen Formation, measured normal to the bedding planes, in the field area is therefore, at least 800 feet.

Hatch (1967) has reported a thickness of 6000 feet in the Goshen Formation west of the Plainfield village in the Plainfield quadrangle and 6000 feet along Sam Hill Road in the south-central portion of the Worthington quadrangle (Sections D and E, respectively).

Correlation. The Goshen Formation can be traced directly from this field area north through the Chester and Worthington quadrangles to the type locality in the Plainfield quadrangle. Based on stratigraphic position and lithology (Hatch, 1967) the Great Moose Member of the Goshen is believed to be a transition rock to the even more carbonate-rich Waits River Formation. The Waits River Formation is stratigraphically above the Goshen in the Heath quadrangle (Hatch and Hartshorn, 1968).

The Goshen Formation in Massachusetts is correlated with the Northfield Formation in Vermont, as shown by Doll, et. al. (1961). Hatch (1967) stated that lateral facies changes between the Goshen and Waits River produce irregularities in the upper contact of the Goshen Formation. There is a considerable problem in mapping this upper boundary in Vermont because of the facies changes.

Age. No fossils have been found in the Goshen Formation but based on correlations with the section in Vermont the Goshen may include rocks that range from Middle Silurian to Lower Devonian. The Goshen Formation is thus dated Silurian and Devonian (Hatch, 1967).

Taconic Unconformity

The Taconic Unconformity (Hatch, Stanley and Clark, 1970) separates the Hawley Formation from the base of the Goshen Formation or locally, the Russell Mountain Formation. In the Huntington area rocks in the Goshen above the unconformity are very similar to the rocks in the Hawley Formation below the unconformity. The basal Goshen (Table 2, specimens 880, 909 and 2057) is thick-bedded, rusty-weathering gray to dark-gray, quartz-mica schist and the top of the Hawley is thick-bedded, rusty-weathering gray to dark-gray, quartz-mica schist. Table 5 summarizes the criteria that were used in the Huntington area to differentiate the two formations. Some characteristics of the Hawley Formation are found throughout the field area, but additional local

TABLE 5. CRITERIA USED
TO DEFINE THE TACONIC UNCONFORMITY

Hawley	Goshen
1. Locally rare garnets, most 1/8 inch.	1. Abundant euhedral "BB"-size garnets, most 1/16 inch.
2. Quartz-feldspar stringers, most 1/4 inch thick.	2. Locally quartz-(feldspar) stringers, most <1/4 inch thick.
*3. Thin interbedded gray quartzites are common.	3. Quartzite interbeds rare.
*4. Schist commonly feldspathic.	4. Schist locally feldspathic.
*5. Kyanite and staurolite locally present but not abundant.	5. Kyanite and staurolite very abundant.
*6. Thin amphibolite beds.	6. No amphibolite beds.
7. Coarse tourmaline crystals locally abundant (Table 1).	7. Coarse tourmaline crystals not present.
8. Micaceous gneissic beds.	8. Locally, graded beds near the contact.

*Refers to criteria that can be used throughout the field area to differentiate the units.

differences between Hawley and Goshen Formations are noted. Throughout the region from Crescent Mills to the town of Blandford the schists of the Hawley Formation are generally poor in garnet, but where present the garnets are greater than one eighth inch across and are commonly distorted. The Goshen schists, on the other hand, are characterized by numerous "BB"-size garnets, approximately one-sixteenth inch, with the larger garnets only present locally. The schists of the Hawley Formation in this vicinity have many quartz-feldspar stringers parallel to the foliation. These are typically one-quarter inch or greater compared to the thinner quartz (feldspar) stringers present in the Goshen schists. Near Crescent Mills the Hawley schists are more biotite-rich than the Goshen schists.

The schists of the Hawley Formation at the Blandford racetrack are sandy and feldspathic compared to the thick-bedded schists in the Goshen Formation and the thick-bedded conglomeratic quartzite of the Russell Mountain Formation that lies between the Goshen and the Hawley.

Several miles north of the town of Blandford near Green Hill, located on the west-central edge of the field area, massive, rusty-weathering, dark-gray Goshen schists are contrasted with the Hawley schists that are characterized by very small garnets and small feldspar crystals that give the schists a sprinkled effect. These Hawley schists are interbedded with sandy schists, micaceous quartzites and gneissic beds. The petrographic modes of the Hawley "sprinkled" schist (specimen 2064) and a well-foliated gneiss (specimen 2057) are shown in Table 1.

In the Chester-Blandford State Forest east of hill #1467 the contact between the Hawley schists and the Goshen schists is especially difficult to define. The basal schists of the Goshen Formation contain "BB"-size garnets, but resemble the Hawley schists in that they are more sandy and feldspathic in nature than noted anywhere else in the Huntington area.

Hatch (1967) distinguished the Hawley Formation and the Goshen Formation in the Worthington and Plainfield quadrangles according to the following criteria: "The black schists are distinguished from the Goshen gray schists by their darker color, higher graphite content, more complex folding, harder and less micaceous interbedded quartzites and rusty-weathered surfaces" (Hatch, 1967, p. D11). These criteria are not adequate to establish the contact in the Huntington area.

The contact of the pre-Silurian and Silurain-Devonian rocks has been problematical since Emerson (1898, p. 180) stated his confusion over a "doubtful border layer" of black schists. Emerson (1898) thought the contact represented an unconformity. Observing the contact between the Goshen Schist and the Hawley Schist, Emerson (1898, p. 179) noted, "A considerable unconformity is probably present, although the black schists (Goshen Schist) are crushed into apparent conformity with the older Flaggy schists (Hawley Schist)". White and Jahns (1950) noted that the Northfield Slate (Goshen equivalent) lies unconformably over Ordovician Cram Hill formation in east-central Vermont. Osberg, Hatch and Norton (1971) also recognized the possibility of a regional unconformity at the base of the Goshen Formation on the east limb of the

Berkshire Anticlinorium. The contact in the Plainfield quadrangle was based on the comparison of structural features in the Goshen Formation with those of the older rocks as well as apparent stratigraphic pinch outs in the Hawley Formation against the Goshen Formation along this contact. It is also postulated (Hatch, 1969) that the contact may represent a fault that separates rocks of differing composition and age.

GRANITIC INTRUSIVE ROCKS

In this report the term granitic rocks is used in a general sense to include granodiorite, quartz monzonite and granite pegmatite.

Distribution

Intrusions of granite and granitic pegmatites are more numerous south of the West Branch of the Westfield River and are generally larger than in the area north of the river (Plate 1-A). Some of the larger granitic bodies north of the river are found on Great Moose Hill, along Route #112 approximately one-half mile north of Huntington and on both North Rockhouse and South Rockhouse Mountains. South of the Westfield River large massive granitic plutons or dikes are found in the Chester-Blandford State Forest and also near hill #1374 north of Cold Brook, approximately 3 miles north of the town of Blandford. Other bodies are located west of Blandford Road near the Hampshire-Hampden County boundary northeast of Holiday Hill near Crescent Mills and both north and south of hill #1142 located south of St. Thomas Cemetary in Huntington. Granitic dikes are found in both the Goshen

Formation and Hawley Formation.

Inclusions of the local country rock are common in the granitic intrusives. Most of the intrusions in the area do not seem to have been forcefully injected because a majority of bedrock inclusions in the granitic rock maintain the regional trends of stratified rocks that surround the intrusion.

Lithology

Coarse-grained, muscovite-biotite-quartz-feldspar pegmatite with locally abundant tourmaline is the dominant granitic rock in the Huntington area. The knob north of hill #1142, mentioned above, is held up by a massive fine- to medium-grained pluton of quartz monzonite (Table 6, specimen 1247) and coarse pegmatite. Veins and pods of milky to colorless quartz are commonly associated with the granitic intrusions. The granite, pegmatite and quartz veins in the Chester quadrangle are probably related to the granite, pegmatite and quartz veins of the Williamsburg Granodiorite (Hatch, Norton, and R.G. Clark, 1970) located several miles to the northeast near Williamsburg, Massachusetts (Figure 1). On the basis of their mineralogy, texture and field relations the granitic rocks are assumed to be related to the binary granites and associated pegmatites of the New Hampshire Plutonic Series in New Hampshire and Vermont (Hatch, Norton, and R.G. Clark, 1970).

Age Relations

All the granitic rocks intrude the stratified rocks in the field area and are considered younger. However, no granitic rocks are noted

TABLE 6. MODE OF GRANITIC INTRUSION

Specimen	1247
Quartz	27
*Plagioclase	35
†Alkali feldspar	26
Muscovite	4
Biotite	8
Apatite	t
Zircon	t
Magnetite	t
*Anorthite % of Plagioclase	12

*Approximate composition of plagioclase feldspar in mol. % anorthite based on the Michel-Levy method.

†Alkali feldspar consists of microcline, microperthite and orthoclase.

1247. Poorly foliated, fine-grained, light-tan to light-gray, mica-feldspar quartz monzonite. Specimen located on a small knob approximately 2000 feet southwest of St. Thomas Cemetery that is 3/4 mile southeast of the town of Huntington.

cutting the Great Moose Member probably because of its limited distribution in the Huntington area. Detailed work concerning cross-cutting relations within granitic intrusions by granite, pegmatite and quartz veins was not attempted in this study. However, it is noted that in many of the more massive large intrusive bodies fine-grained granite and coarse-grained pegmatite cross-cut each other.

Most of the granitic rocks in the study area are concordant or subconcordant with respect to the regional foliation or bedding. Some granite bodies display a poor foliation. The plutons in the field area commonly occur parallel to the axial traces of isoclinal folds of the earliest stage of deformation in the Schist and Granulite Member of the Goshen Formation. Granitic rocks are also commonly found along formation contacts or along the contact between the Schist and Granulite and Quartzite Members of the Goshen Formation.

STRUCTURAL GEOLOGY

General Statement

The Huntington area (Figure 2) lies between the domal system of the Connecticut Valley-Gaspe Synclinorium and the east limb of the Green Mountain-Berkshire Anticlinorium. Four stages of folding are recognized. The structural features of the Hawley Formation were not studied in detail, but no pre-Silurian structural features were identified. All of the recognized stages of folding are Acadian or younger.

The first recognized stage of deformation in the area is referred to here as the early stage. It consists of large gentle- to moderately-plunging isoclinal folds with axial plane schistosity. The repetitive pattern of the members of the Goshen Formation define the early folds on the geologic map (Plate 1-A).

A later stage of folding, that does not significantly effect the map pattern, consists of gentle- to moderately-plunging tight- to open-folds with a well developed axial plane slip cleavage. This stage of deformation is referred to here as the Moose stage of deformation, named for the Great Moose ridge where it is present locally.

The third stage of folding, one that results in folding which influences the map pattern, consists of a large moderately-plunging open syncline (Plate 1-A), the Huntington syncline, which has a well developed northeast-trending slip cleavage parallel to its axial plane. The Huntington syncline refolds the large early isoclinal folds and changes their north-south axial surface trends in the northern section of the study area, to east-west trends in the southern portion. This stage of deformation, here called the Huntington stage, may be related to the development of the domes.

Large open folds that warp the Taconic unconformity in southern sections of the study area (Plate 1-A) are the result of the latest stage of folding.

Hatch (1968) reports four regionally significant stages of folding as well as a fifth stage of minor folds that are localized around a small pluton east of the Berkshire anticlinorium. The first of these occurred during the Taconic orogeny and produced northwest-trending tight folds that have been found in a few exposures of pre-Silurian rocks in the Worthington quadrangle (Hatch, 1969). A major deformation affected all of the rocks during the Acadian orogeny (Hatch, 1968). North- to northeast-trending isoclinal folds with generally steeply dipping axial surfaces developed at this time. The dominant regional schistosity is parallel to the axial surfaces of these folds. Hatch (1968) further describes a less severe stage-3 deformation, also believed to be Acadian, that developed a conspicuous northeast-trending northwest-dipping slip cleavage parallel to the axial surfaces of small open, commonly chevron, folds. This slip cleavage deforms both the bedding and the major regional schistosity. The fourth stage of folding (Hatch, 1968) produced north-trending folds with subvertical axial surfaces parallel to a well-developed axial-plane slip cleavage. This locally deformed the stage-3 slip cleavage.

Granitic rocks in the Huntington area are concordant and locally discordant with respect to the early stage schistosity. Commonly the granites are parallel to the axial traces of the early stage isoclinal folds. These granitic rocks were emplaced during or slightly later than the early stage of folding because all three later stages of folding deform the intrusions (Plate 1-A).

The field area has been subdivided into eleven sub-areas (Figure 5) for compilation of structural data on equal area nets (Figures 8, 9, 12, 15 and 16). The four phases of folding recognized in the Huntington area are summarized in Table 7. The three earliest of the phases are illustrated in Figure 6.

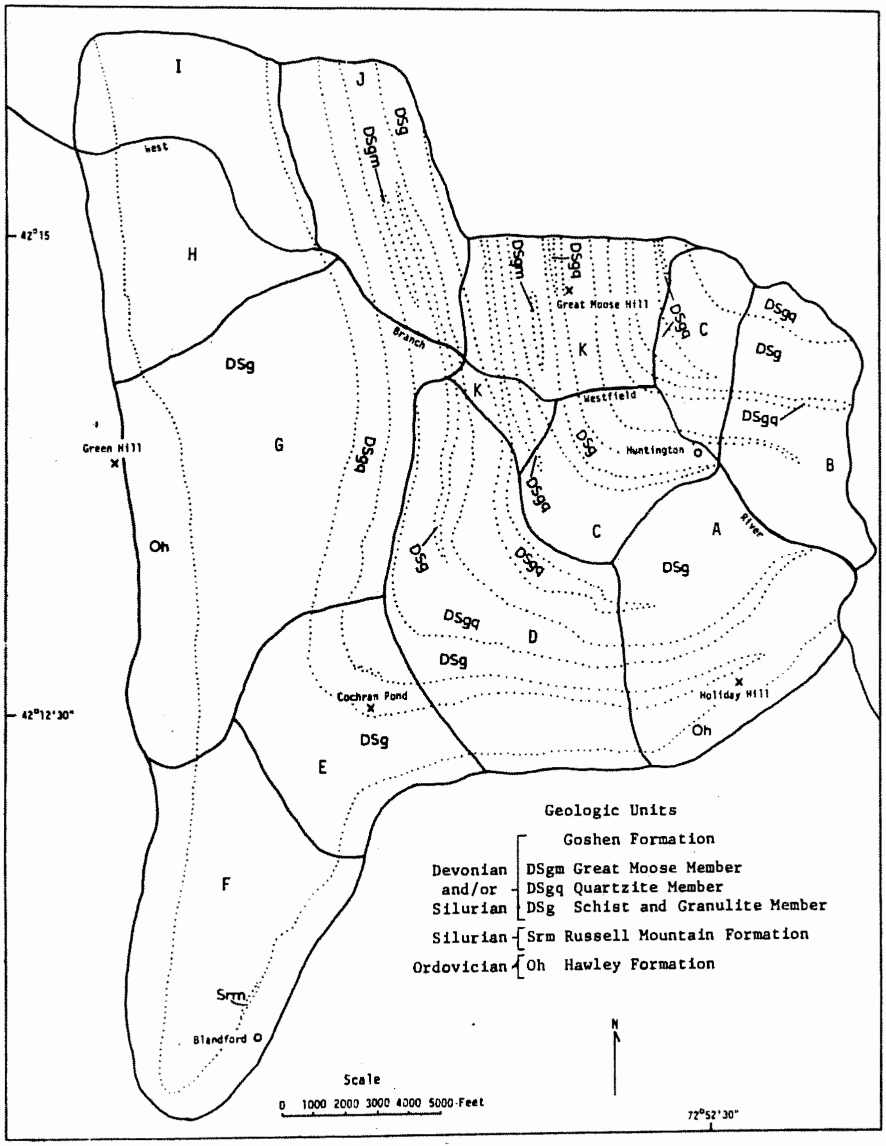


Figure 5. Subareas of the Huntington area, Massachusetts.

Minor Structural Features

General Statement. Schistosity, slip cleavage, minor folds, and the lineations: bedding-schistosity intersection, bedding-slip cleavage intersection and aligned minerals are the minor structural features that are described here.

Planar structural features that result from the parallel arrangement of platy minerals, such as mica and chlorite are called schistosity (Billings, 1954).

Slip cleavage is a planar structural feature that is parallel to the axial surfaces of small crinkle-folds. Rocks tend to break parallel to the slip cleavage in zones where it is the dominant planar feature. In the hinge regions of many late minor folds slip cleavage has evolved into a schistosity that truncates the bedding and a weakly preserved early stage schistosity. This late schistosity can be readily seen as a very well developed slip cleavage in thin section.

Minor folds are those that are too small to be shown on the geologic map. The wavelength of such minor folds ranges from less than an inch up to approximately 20 feet.

Description of early stage minor structural features. There is one pervasive schistosity in the rocks of Huntington and, except where slip cleavage is the dominant planar feature, the rocks tend to break roughly parallel to it. This schistosity is parallel to the axial surfaces of folds of the early stage of deformation and has been described as the prominant regional schistosity that parallels the axial surfaces of north-trending isoclinal folds elsewhere on the east limb of the Berkshire Anticlinorium (Hatch, et. al., 1967; Hatch, 1967). Because the early folds are isoclinal, the schistosity is parallel or subparallel to the bedding except in the axial region of the folds (Plate 3-A). Where bedding and schistosity coexist parallel or subparallel at the same outcrop only the bedding symbol is used on Plate 3-A. Along the Taconic unconformity the basal portion of the Goshen Formation is thick, uniform schist and in many rock exposures along this contact, schistosity is the only planar feature noted.

Only three minor folds that are definitely related to the early stage of deformation were found (Plate 3-F). One of these is located approximately 2000 feet south of the summit of Great Moose Hill and another is approximately 2000 feet south-southwest of the summit. These early minor folds are gentle- to moderately-plunging, north-south-trending isoclinal folds with essentially vertical axial plane schistosity. There are also hinges of possible early minor folds (not indicated on Plate 3-F) noted in an outcrop located in the northwest section of Great Moose ridge. The third early minor fold is south of the West Branch of the Westfield River approximately 400 feet east of Holiday Hill in the southeastern section of the field area (Plate 3-F). This early minor fold has an essentially east-trending axial plane schistosity that dips moderately north and an axis that plunges gently northwestward.

Except for local instances where slip cleavage has developed into a schistosity, most of the bedding-schistosity intersections represent the axes of early isoclinal folds (Plate 3-B). This is the case since schistosity is parallel to the axial surfaces of folds of the early stage. In general the intersections plunge gently to steeply north, or northwest and south or southeast in the northern region of the field area and the intersection lineations plunge moderately approximately N40W in the southeastern and eastern sections.

The tightness of the early folds appears to be related to the rock types. The moderately-plunging early minor fold on Great Moose Hill which is isoclinal with an amplitude of approximately 5 feet is developed in thin bedded schist and granulite beds and a calc-silicate bed two feet thick. The other early minor fold noted on Great Moose Hill occurs in thick (7-10 feet) beds of schist and calcareous granulite of the Great Moose Member of the Goshen and is an open fold with an amplitude greater than twenty feet. All folds, regardless of age, in the Schist and Granulite Member of the Goshen Formation are tighter than those in rocks of the Quartzite or Great Moose Members. Minor folds are more numerous in the thin calc-silicate beds than in any other rock type possibly because they are easier to observe. The early minor folds noted show a slight thickening in the hinge areas and a thinning in the limbs. None of the early stage minor folds studied has a distinguishable shear sense.

Oriented micas are the most commonly noted mineral lineation and are found either on bedding or schistosity surfaces. Kyanite and staurolite are noted parallel or subparallel to the early fold axes, as indicated by bedding-schistosity intersections. In the northern subareas the trend of mineral lineations is approximately N10W, plunging

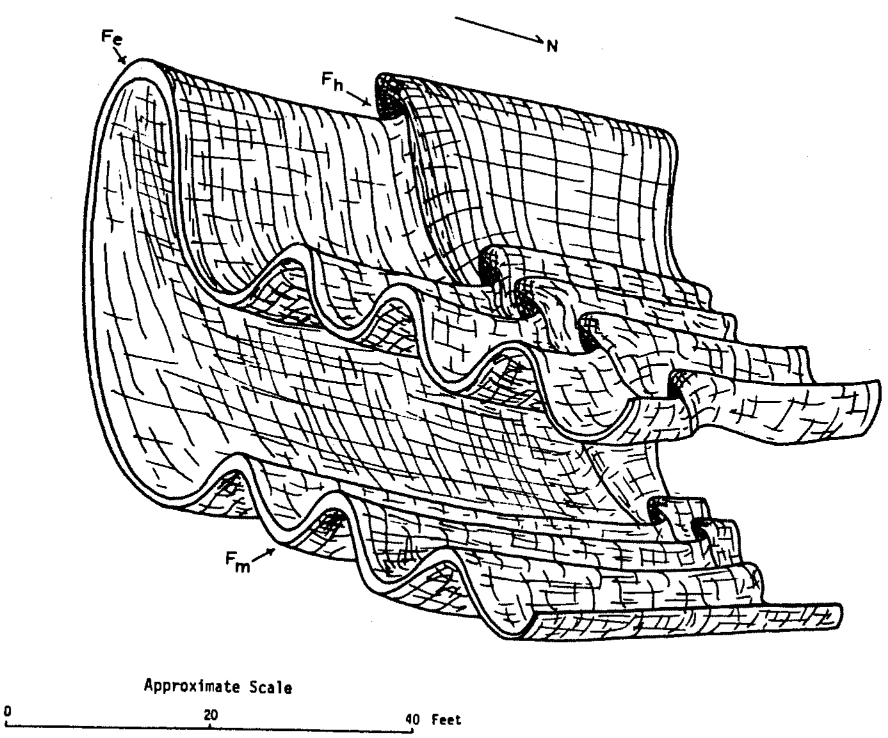


Figure 6. Diagramatic sketch showing folds of the early stage (F_e), the Moose stage (F_m), and the Huntington stage (F_h). Sketch based on data from station #813 on Great Moose Hill ridge in the northwest portion of the field area.

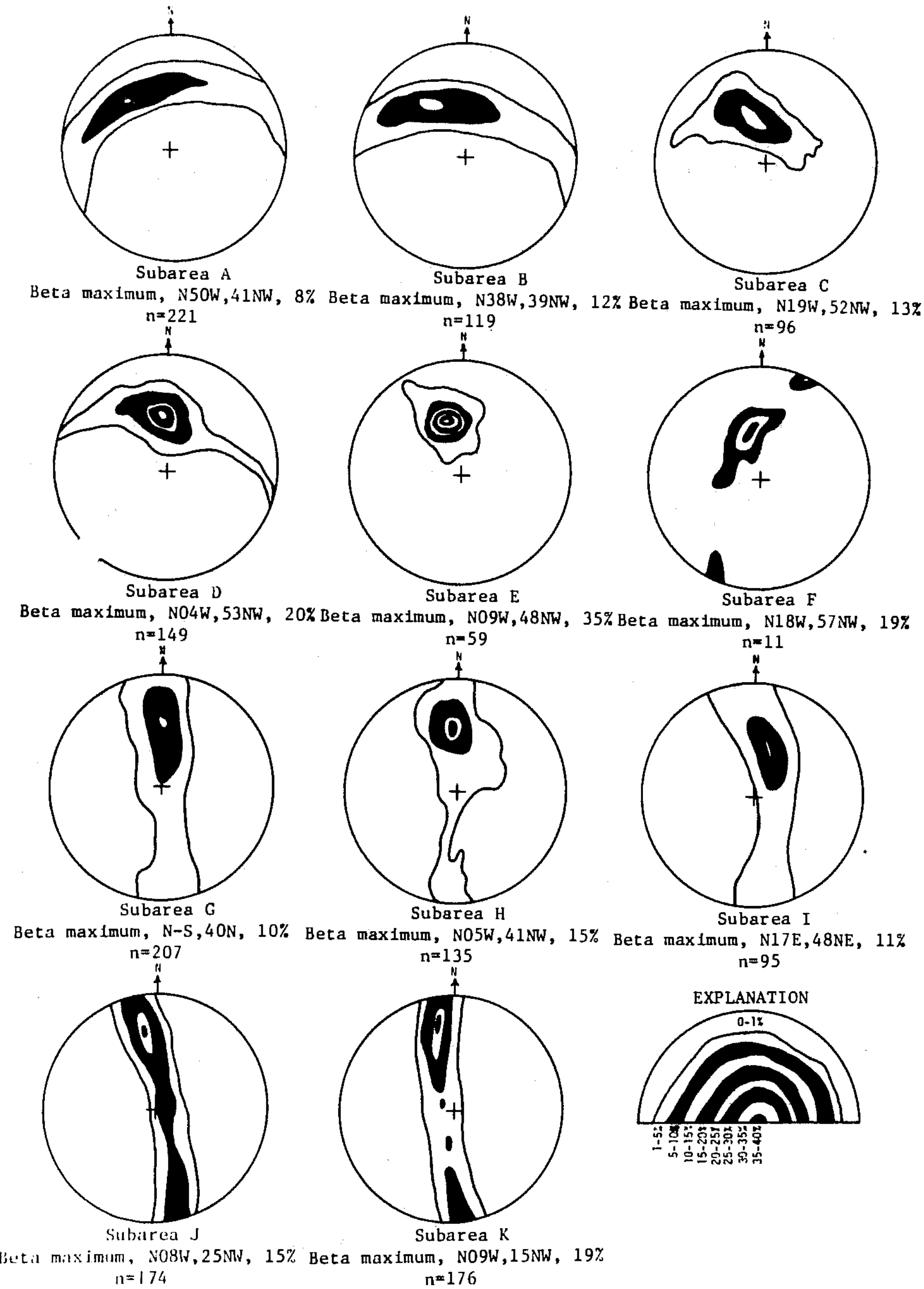


Figure 7. Beta diagrams indicating bedding intersections for all subareas.

moderately north. In the eastern and southeastern sections the mineral lineation plunges moderately approximately N40W (Figure 9).

Equal area nets (Figures 8, 9, 12, 15 and 16) and beta diagrams (Figure 7) for each subarea of Huntington indicate the relations of structural features.

Analysis of early stage deformation. In the northwestern region of the area along the Great Moose Hill ridge the influence of the Huntington syncline is less than in southern subareas, although many minor folds of this stage are noted. In subarea K (Figure 7) the beta maximum for bedding plunges 15° approximately N9W, with some variations toward the south. Subarea J (Figure 7) also shows a gentle plunge northward, while subarea I (Figure 7) shows a moderate plunge to the northeast. The beta diagrams are possibly indicating the fold axes of the early isoclinal folds because Hatch (1968) has reported that fold axes of this stage, in the Chester quadrangle and several miles to the north, are north or north-east trending with gentle plunges. Examination of the equal area nets showing intersections of schistosity and bedding for these same three subareas (Figure 8), indicate a scatter of points that is thought to be the result of Huntington stage folding that locally deforms the early structural features. These stereograms also show a generally moderate plunge of early fold axes with variations probably due to the effects of later stages of deformation. Of the two definite early minor folds noted in this region, one has a moderate northward plunge of approximately 40° and the other a 10° northward plunge. Early stage mineral

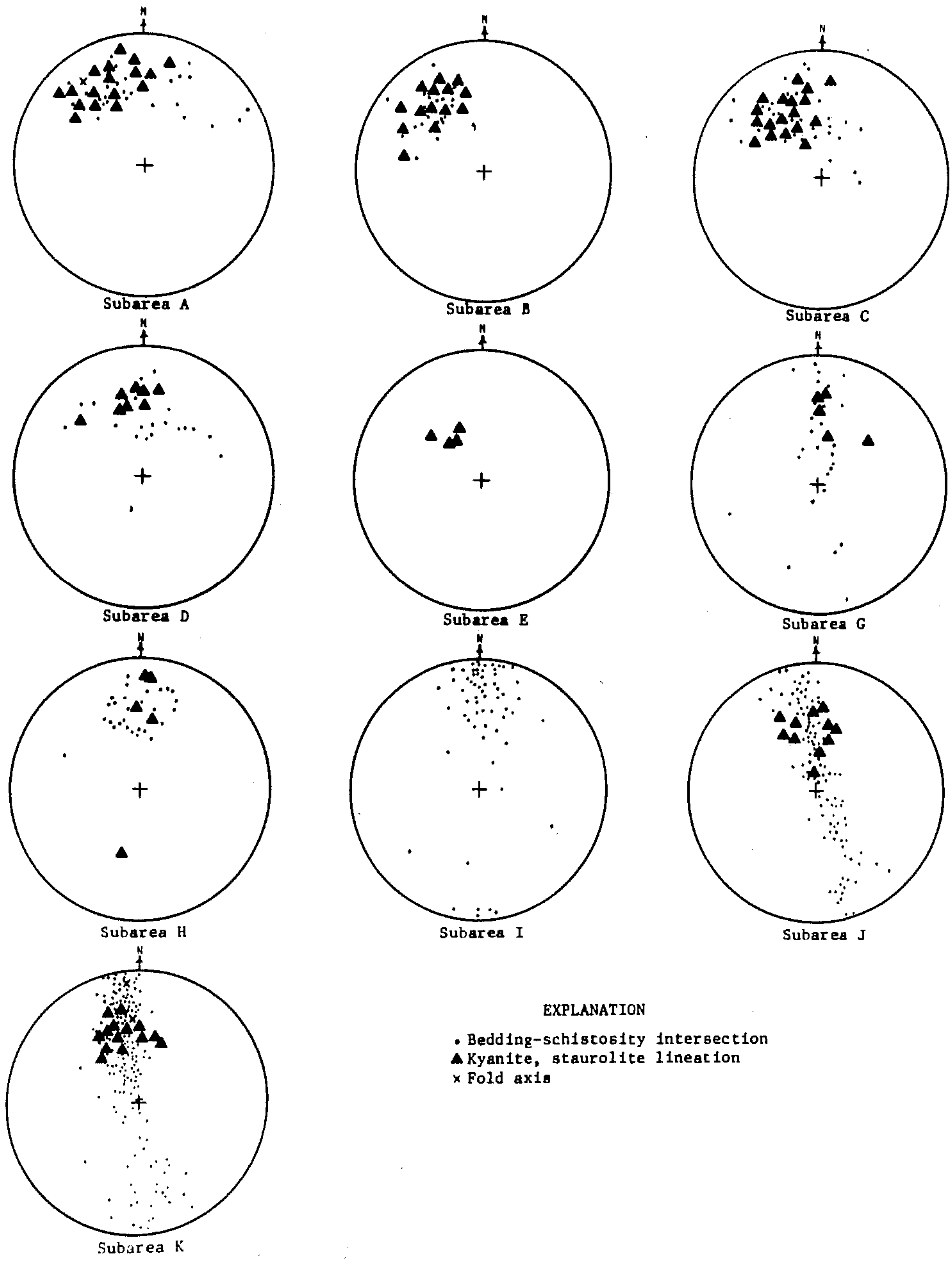


Figure 8. Equal area diagrams of early stage structural features in the Huntington area.

lineations in this area cluster approximately N10W with a gentle to moderate plunge.

Subareas C, D, E and F (Figure 5) are located in the axial area of the Huntington syncline. The effect on the trends of the early isoclinal folds is great. This is reflected in the distribution of minor structural features. The vertical to sub-vertical axial plane schistosity trends north on the Great Moose Hill ridge and in these subareas it trends generally west-northwest to east-west. Despite limited data in subarea E and lack of data in subarea F, the equal area plots (Figure 8) of the intersection of schistosity and bedding and of early mineral lineations generally indicate a parallelism of scatter with a cluster of points approximately N20-25W with a moderate northwest plunge. Subarea H (Figure 8) which contains a major fold related to the Huntington stage of deformation shows a similar scatter of bedding-schistosity intersections.

The attitudes of bedding and schistosity in subareas A and B are east-west or east-northeast with a gentle to moderate northward dip. The equal area plots of data from these subareas (Figure 8) show the trends of the minor features of the early stage of folding. The one early minor fold axis noted in this region has a gentle plunge trending about N40W. The bedding-schistosity intersections and early mineral lineations are approximately parallel and have coincident maxima approximately N40W with a moderate plunge of about 40° northwest.

<u>Moose stage minor structural features</u>. Minor folds associated with the Moose stage of deformation have axial plane slip cleavage that

is the earliest of the three slip cleavages noted in the Huntington area. It deforms the schistosity related to the early stage of deformation. In the northwest portion of the field area on Great Moose ridge the axial surface of an early isoclinal fold is refolded by minor folds of the Moose stage of deformation. This exposure is illustrated in the diagram in Figure 6. In part of this exposure the minor folds related to the Moose stage of deformation consist of anticlines and synclines that show inverted stratigraphy on the overturned limb of the early isoclinal fold. At this exposure as well as several others minor folds and small amplitude crinkle folds with axial surfaces trending northeast and dipping northwest fold both the early schistosity and the axial plane cleavage associated with the minor folds of the Moose stage. One thin section shows a dominant foliation, seen in hand specimen as a very well-developed slip cleavage with an attitude of N13E, 74NW, cut by a more northeasterly trending slip cleavage. The earlier surface is believed to be of the Moose stage and the later more northeasterly-trending slip cleavage is related to the Huntington stage.

The axial plane slip cleavage of Moose stage minor folds, most commonly found in the northwest and western portions of the area, trends approximately north and dips steeply east or west (Plate 3-D). There is however, a variation in the trend of this slip cleavage from 25° east to 25° west of north that is noted in subareas G, H, I and K (Figure 9). A later stage of deformation superimposed on the minor features of the Moose stage could explain this variation or it could represent an original variation in the trend of Moose stage cleavage.

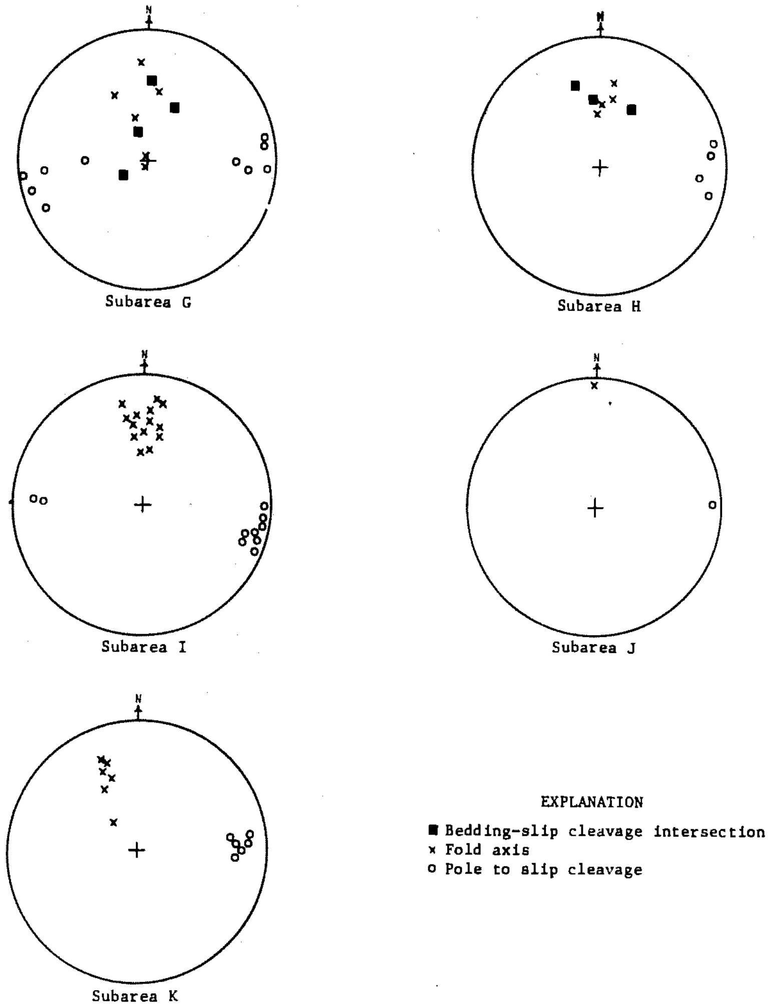
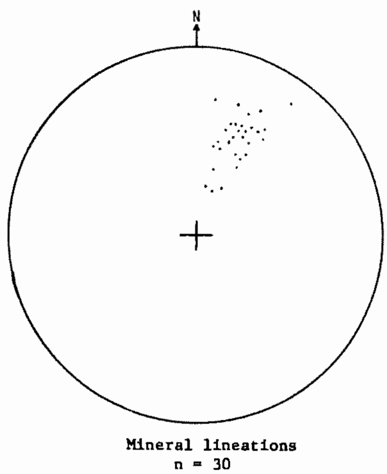
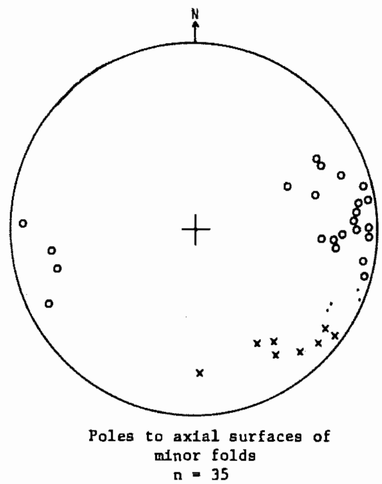


Figure 9. Equal area diagrams of Moose stage structural features in the Huntington area.

The axial plane slip cleavage of minor folds associated with the Moose stage is locally developed into a schistosity in the hinge areas of minor folds. This development from slip cleavage to schistosity is well documented in rocks in Vermont by White and Billings (1951) and Hall (1959).

Minor folds of the Moose stage of deformation occur in the northwestern section of the field area on the Great Moose ridge and south of the West Branch of the Westfield River in the Chester-Blandford State Forest area. The Schist and Granulite Member of the Goshen Formation is the only rock unit in which minor folds of this stage have been observed. Minor features of the Moose stage of deformation are indicated on equal area plots for the subareas G, H, I, J and K (Figure 9) and in Figure 10. Plate 3-F shows the minor folds believed related to this phase of folding. The fold axes trend within 15°-20° of north-south. The axes plunge north or south varying from gentle to steep or vertical. The lineation formed by the intersection of bedding and slip cleavage of this stage of deformation is shown on Plate 3-E and in subareas G and H (Figure 9). The limited data show a scatter of points with a weak cluster that indicates a northwest trend and a moderate plunge. These variations in the attitudes of the minor folds of the Moose stage are probably related to refolding by the Huntington stage of deformation. Though a mica, (kyanite) and (staurolite) lineation is most frequently observed parallel to early phase minor fold axes, it is locally noted parallel to the minor folds of the Moose phase of folding.





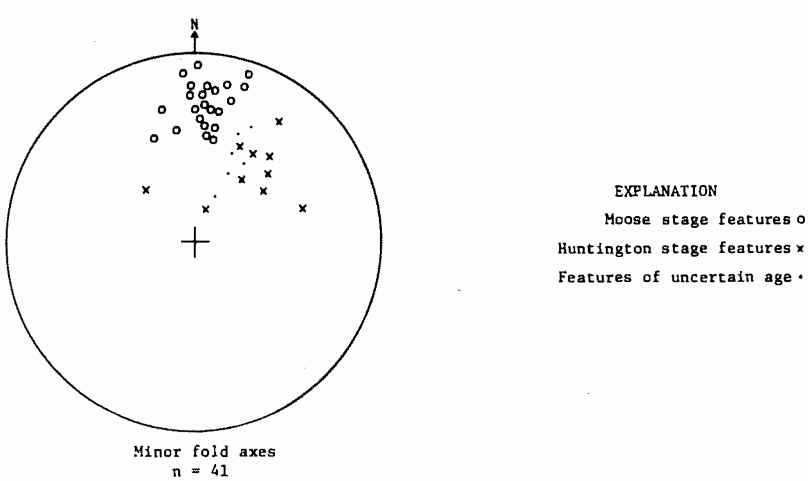


Figure 10. Equal area diagrams of mineral lineations, poles to axial surfaces of minor folds and axes of minor folds of station #813 located in the northwest section of Great Moose Hill ridge.

In summary, it is known that minor folds assigned to the Moose stage of deformation are positively later than the early stage of deformation and local limited evidence indicates that they are older than the minor folds related to the Huntington stage of deformation.

Description of Huntington stage minor structural features. Minor folds of the Huntington stage of deformation have axial plane slip cleavage that deforms the schistosity of the early stage of deformation and locally deforms the slip cleavage related to the Moose stage (Figure 6). Microscopic textures clearly reveal that the dominant early regional schistosity is deformed by the later Huntington stage of deformation.

Axial plane slip cleavage associated with the Huntington stage strikes northeast and dips northwest throughout the entire field area (Figure 11, Figure 12, and Plate 3-D). Toward the hinge region of the Huntington syncline subarea F, the trend changes gradually to approximately north-south dipping steeply east or west (Figure 12 and Plate 3-D). Later folding probably accounts for the scatter noted in Figure 11. It is also in this region that the slip cleavage locally has developed into a schistosity in the axial regions of some minor folds.

Hatch, and others (1967) have recorded an early slip cleavage effecting the rocks on the east limb of the Berkshire anticlinorium. This cleavage according to Hatch (1968, p. D109) is a "conspicuous northeast-trending, northwest-dipping slip cleavage parallel to the axial surfaces of small, open, commonly chevron, folds". It is probably the same age as the northeast-trending slip cleavage of the Huntington stage of deformation.

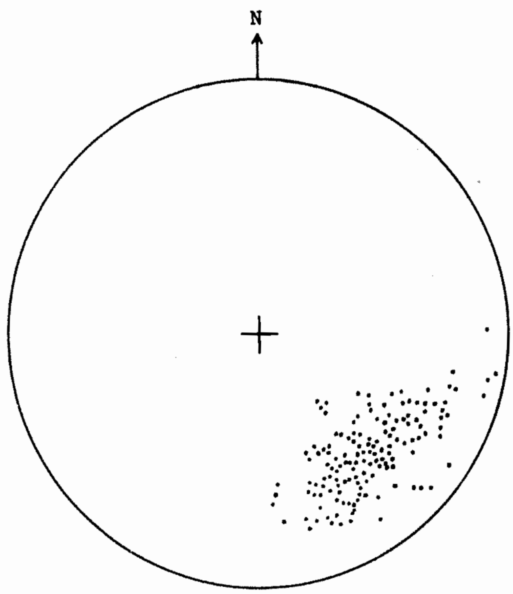


Figure 11. Equal area diagram indicating poles to slip cleavage related to the Huntington stage of deformation as noted throughout the field area.

Minor fold axes and crinkles, in the early schistosity related to the Huntington phase of folding are shown on the equal area nets for all of the subareas (Figure 12) as well as on Plate 3-F. Generally, the fold axes trend within 20° of north and plunge moderately north throughout the field area. Variations more northwesterly or northeasterly in trend are found in subareas I, J and K as well as in Figure 10. These variations are believed to be either a function of the varied orientation of bedding prior to the Huntington stage of deformation or are related to rotation due to later deformation.
If the same amount of movement occurred along slip cleavage planes associated with the Huntington stage of deformation throughout the field area, it would follow that beds dipping in opposite directions prior to this stage of deformation would, after the deformation, have minor folds that plunge in opposite directions. This assumes that the strike of the movement plane is at a high angle to the strike of bedding. These folds with varied plunge are thus related to the same stage of deformation. Beds dipping moderately west would have resultant minor fold axes that trend more to the northwest and those fold axes formed on bedding that dips moderately to the east would trend more to the northeast. In the eastern section of subarea K (Plate 3-A) the beds locally dip moderately to the west. Fold axes of the Huntington stage of deformation trend from N40W to N60W at these specific localities (Figure 12). Most of the rocks in subarea I, however dip moderately east. The equal area net (Figure 12) as well as Figures 10 and 13 indicate that axes of minor folds of this stage trend east-northeast.

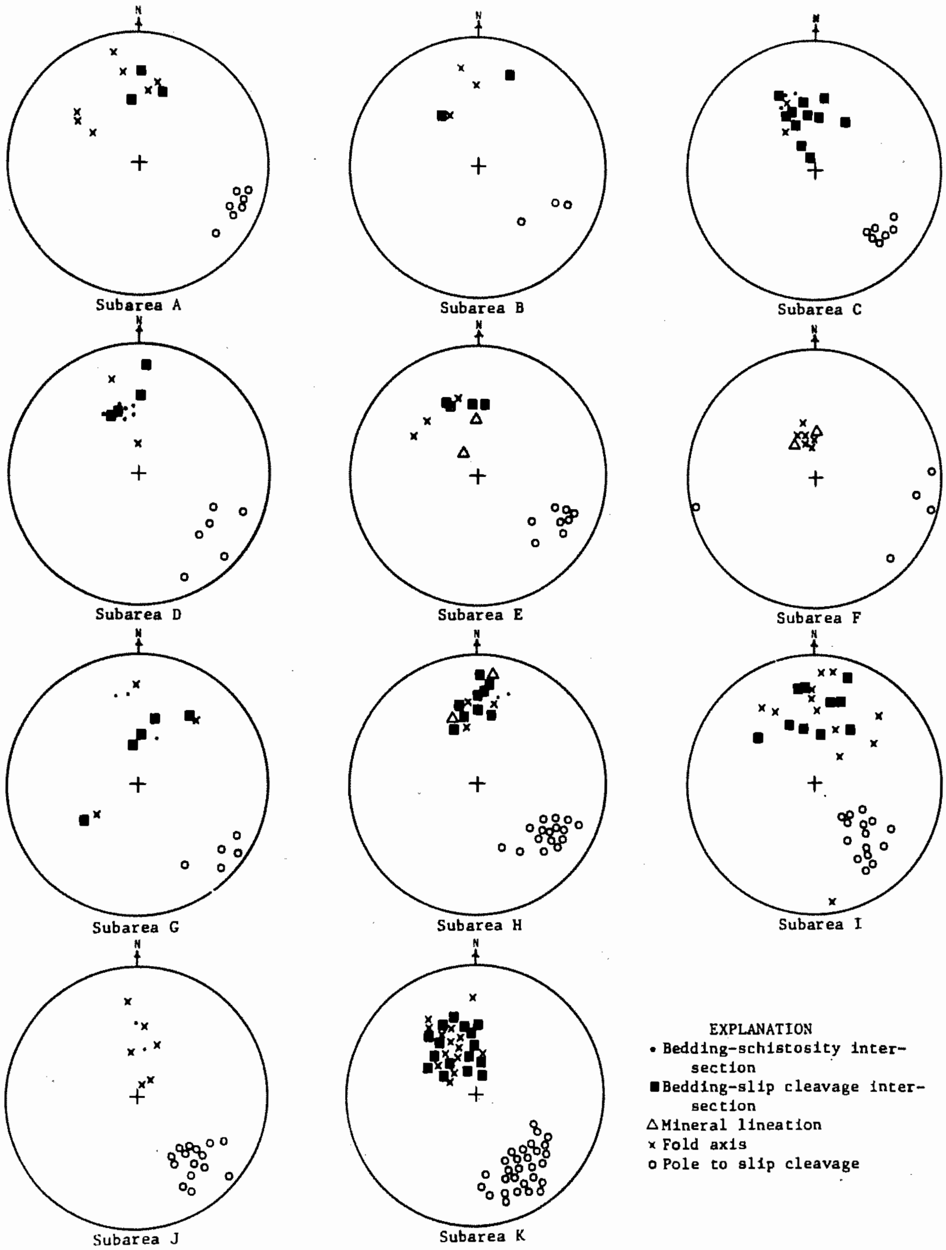


Figure 12. Equal area diagrams of Huntington stage structural features in the Huntington area.

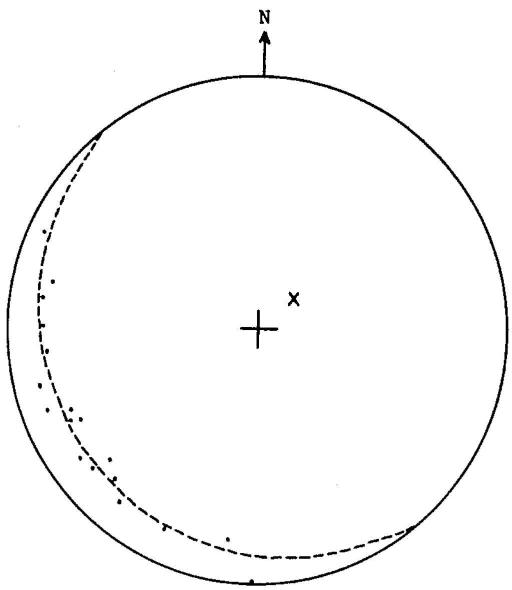


Figure 13. Equal area net of poles to bedding indicating the general fold axis (X) of a series of Huntington stage minor folds, located on Great Moose Hill ridge north of the West Branch of the Westfield River in the northeast section of the Huntington area.

Where the beds are vertical or subvertical in the western portion of subarea K, these minor fold axes trend approximately N10W.

Lineations related to the intersection of bedding and slip cleavage of the Huntington stage of deformation are present throughout the field area. These lineations have a moderate plunge to the northwest or northeast parallel to the axes of associated minor folds (Plate 3-E , Figure 12). There is a mica lineation noted parallel to minor fold axes of the Huntington stage.

The Huntington stage folds are open, parallel folds. Of the many minor folds of this phase of deformation, most show a neutral or indeterminate shear sense. Those that do show a shear sense are located on the west limb of the Huntington syncline and are north plunging sinistral folds that indicate east side up.

Analysis of Huntington stage deformation. Beta diagrams (Figure 7) of bedding in subareas A and B illustrate the influence of the latest stage of deformation, while similar beta diagrams of subareas I, J and K possibly show the effect of the early stage of deformation. The remaining beta diagrams of subareas C, D, E, F, G and H directly reflect the nature of the Huntington syncline. Despite the influence by other stages of deformation, certain relevant information concerning the Huntington stage of deformation can be noted in subareas I, J and K. In these three subareas the slip cleavage related to the axial surface of folds of this stage of deformation trends N50-60E and dips moderately to steeply northwestward (Figure 12). Plots of bedding-slip cleavage intersections, and minor fold axes related to this stage in subarea K show that the fold axes trend about N20W with a moderate plunge northward.

Similar plots for subarea J show late fold axes plunging moderately due-north.

Subareas C,D, E and F are all located in the hinge area of the Huntington syncline. Subarea C (Figure 12) shows a beta maximum for bedding intersections at N19W, 52NW, while subareas D and E show beta-maxima at N4W, 52NW and N9W, 48NW, respectively. Equal area plots of bedding-slip cleavage intersections, mineral lineations, and minor fold axes for subarea C (Figure 12) show a maximum cluster of points nearly coincident with the beta-maximum of bedding intersections. Equal area plots for the same minor features for subareas D and E also show a maximum cluster nearly coincident with the beta-maxima. Minor fold axes in subarea F (Figure 12) indicate that the general plunge of fold axes related to the Huntington stage of deformation in this area is about N9W, 65NW. Poles to axial plane slip cleavage in subareas C, D, E and F indicate a trend change from about N40E in the subareas C and D, to about N30E in subarea E, to N10E in subarea F. This change in axial trend is illustrated in Figure 14.

Subarea G is located northwest of the hinge area of the Huntington syncline and in the southern region of this subarea, beds trend about N10-15E and dip steeply northwest. In the northern region they trend N10-15W with a northeasterly dip. The beta-maximum plunges north, 40°N (Figure 7). There is a scatter and limited data, but a weak maximum cluster of points for mineral lineations related to the Huntington stage of deformation, slip cleavage-bedding intersections, and minor fold axes (Figure 12) is approximately coincident with the beta maximum.

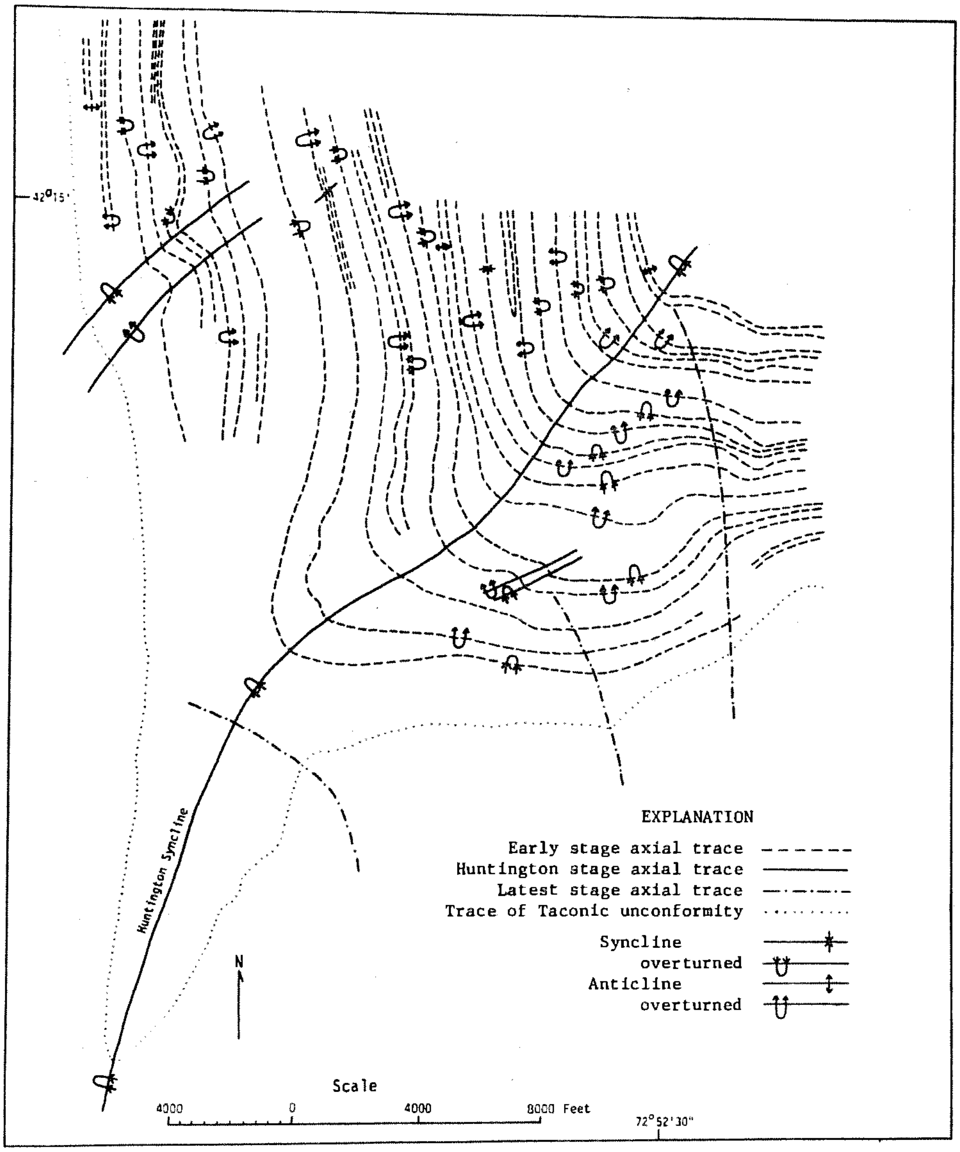


Figure 14. Map showing traces of axial surfaces of major folds in the Huntington area.

Subarea H is located in the Chester-Blandford State Forest area and contains a major fold developed during the Huntington stage of deformation. The beta maximum plunges N5W at 41° and is parallel to the axis of this fold. Equal area plots showing minor structural features related to this stage folding have a maximum cluster of points coincident with the fold axis orientation.

Description of latest stage minor structural features. Minor folds of the latest stage of deformation have an associated slip cleavage that deforms the early stage schistosity and the minor features of the Huntington stage. Minor folds of the latest stage have not been noted refolding minor Moose stage structural elements, but in a thin section muscovite crystals, possibly related to the latest stage of deformation transect a well developed slip cleavage of the Moose stage of deformation.

Slip cleavage parallel to the axial surface of minor folds of the latest stage changes from an essentially north-south trend in the south-eastern and eastern parts of the Huntington area to approximately N50W in the west and northwest. Slip cleavage related to the latest stage of folding is shown in equal area nets that indicate poles to late slip cleavage planes for subareas A, B, C, D, E, F, G, H, and K (Figure 15) and on Plate 3-D. As in the earlier stages of deformation, the associated axial plane slip cleavage locally develops into schistosity in the hinge region of minor folds of the latest stage of deformation. Microscopic textures show that a schistosity identified in hand specimen in the hinge area of minor folds of this latest stage is actually a very well developed slip cleavage that folds an earlier stage schistosity.

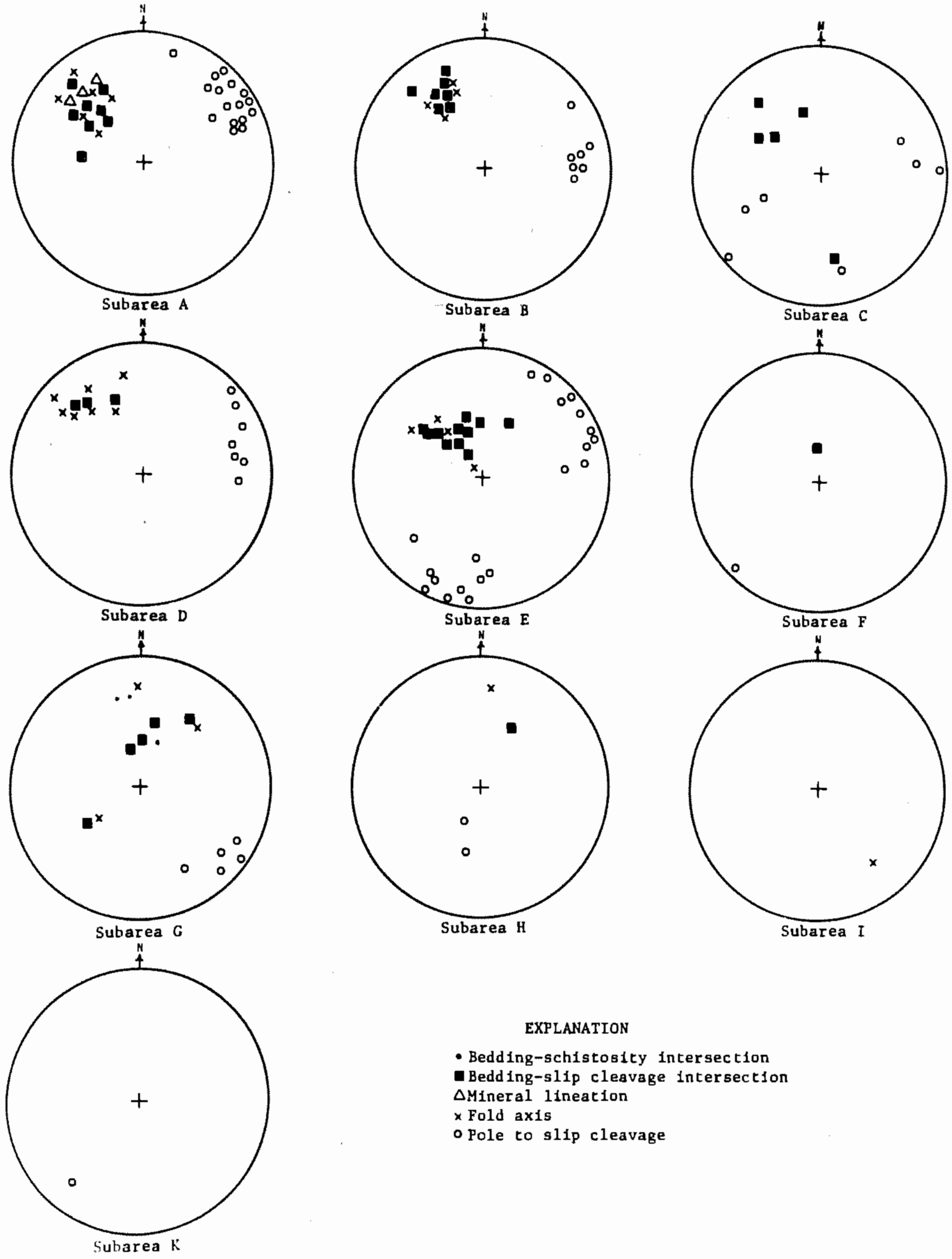


Figure 15. Equal area diagrams of latest stage structural features in the Huntington area.

Hatch, and others (1967) describe a late slip cleavage that is parallel to subvertical axial planes of north-trending folds on the east limb of the Berkshire Anticlinorium, which may be the same age as the slip cleavage of the latest stage of deformation in the Huntington area.

Minor folds and crinkle folds of the latest stage of deformation are abundant in the southern portion of the field area, but northwest trending slip cleavage that may be related to this stage does occur in the northern area (Plate 3-D). Fold axes of minor folds related to the latest stage of folding in the field area are shown on the equal area nets of subareas A, B, C, D, E, H, and I (Figure 15). These axes trend N25W to N50W and plunge moderately northwest or southeast. Lineations resulting from the intersection of slip cleavage and bedding of the latest stage of deformation are shown on Plate 3-E. The lineations are plotted on equal area nets for subareas A, B, C, D, E, F, G, H and K (Figure 15) and plunge moderately toward N40W. This is in agreement with the attitudes of minor fold axes of this stage of folding. A mica lineation has locally been observed parallel to the late minor folds in the Huntington area.

The minor folds attributed to the latest stage of deformation are open parallel folds. Many of the minor structures related to this stage of deformation are crinkle folds or larger minor folds that show indeterminate shear sense. Both sinistral and dextral folds are present in the field area and their relation to the overall regional picture is not known.

Analysis of latest stage deformation. The earlier minor structural features in subareas A and B are deformed to a great extent by this stage of deformation. Lesser effects are also evident in all other subareas except J.

Beta maxima in subareas A and B are N50W, 41NW and N38W, 39NW, respectively (Figure 7). Equal area diagrams for late bedding-slip cleavage intersections and fold axes related to this stage of deformation show a maximum cluster of points coincident with the beta maxima of bedding intersections. This is assumed to be the appropriate attitude of the axes of the latest stage folding in the region. Poles to axial plane slip cleavage of the late stage show a range in trend from a few degrees east or west of north to N74W. There are variations in the trend of late slip cleavage from essentially north-south in the southeastern and eastern regions of the field area to west-northwest in the northwestern sections. There is no apparent explanation for these variations in attitude of the minor features of the latest stage of folding in the Huntington area.

Subareas C, D and E have sufficient data to make general statements on the nature of this latest stage of folding. The average maximum cluster of late slip cleavage-bedding intersections is N40W with a moderate plunge. The maximum cluster of the latest stage minor fold axes also plunges moderately N40W. Subareas F, G, H, I and K had limited data, from which no definite conclusion can be drawn.

Minor features of uncertain age. Problems are encountered in determining the relative ages of many minor folds that occur north of the

West Branch of the Westfield River on the Great Moose Hill ridge. Schistosity is parallel to the axial surfaces of these minor folds. Generally the axial plane schistosity trends north and dips steeply east or west (Plate 3-F). Minor structural features of uncertain age are indicated on equal area nets in Figure 16. The fold axes plunge gently to moderately north. Locally these minor folds have kyanite and staurolite lineations parallel to the fold axes. As presented in earlier sections kyanite and staurolite are not thought to be involved in the Huntington stage or the latest stage of deformation but are related to the early and Moose stages of folding. The folds are varied in style from isoclinal to open. Many of these minor folds display a thickening in the hinge area and thinning in the limbs, but others are parallel folds. The shear sense of most of these folds indicates the east side moved up although a few, as indicated on Plate 3-F, show that the west side moved up. Some of these folds have an amplitude of 50-75 feet and cross-cutting by later folds generally is not noted.

The axial surfaces of minor folds associated with the Huntington stage of deformation have constant northeast trending, northwest dipping attitudes throughout the field area. The orientation of the axial surfaces of the folds of uncertain age make it unlikely that they are related to the Huntington stage. On the other hand the shear sense (east side up) of these minor folds is appropriate for the west limb of the Huntington syncline.

Northwest trending slip cleavage probably related to the latest stage of deformation is present locally on the Great Moose Hill ridge,

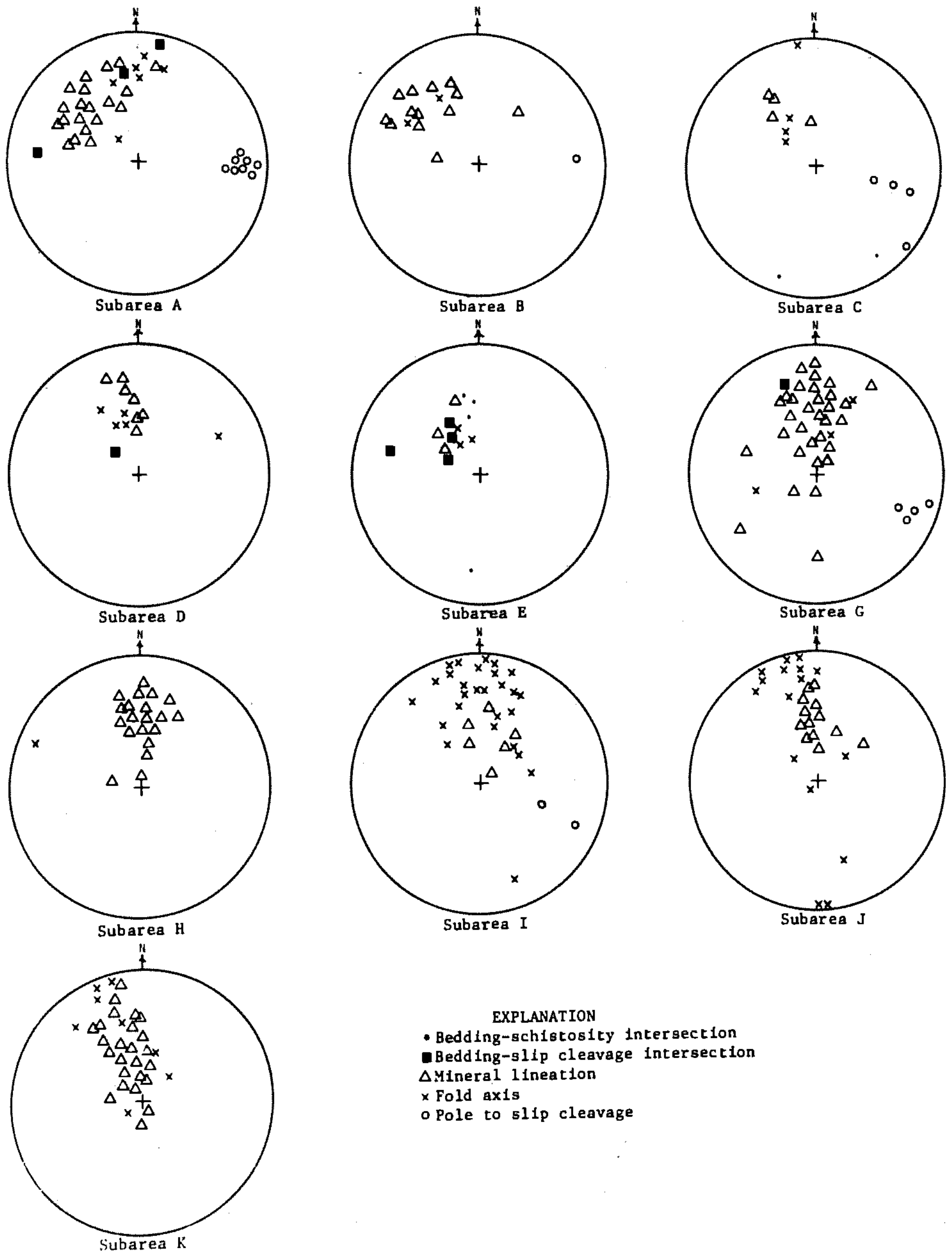


Figure 16. Equal area diagrams of structural features of uncertain age in the Huntington area.

TABLE 7. SUMMARY OF THE PHASES OF FOLDING IN THE HUNTINGTON AREA, MASSACHUSETTS

Stage	Axial Plane	Axes	Geometry
Early	Schistosity of variable trend	Gentle to moderate plunge north to northwest	Isoclinal to open, similar
Moose	North-trending slip cleavage	Gentle to steep plunge north	Isoclinal to open, similar to parallel
Huntington	Northeast-trending slip cleavage	Moderate plunge north-northwest	Open, parallel
Latest	Northwest to north-trending slip cleavage	Moderate plunge northwest	Open, parallel

but it does not deform any of the minor folds of uncertain age. Based on trends alone and the fact that schistosity and not slip cleavage is parallel to the axial surfaces of the folds of unknown age it seems unlikely that they are related to the latest stage of deformation.

It is proposed that the bulk of these folds of uncertain age are related to the early stage of deformation and/or to the Moose stage of deformation. A few of the minor folds in question show anticlines and synclines with inverted stratigraphy. These particular folds must then be Moose stage deformation. A word of caution is added here to put this age proposal in the proper perspective. The conclusion is based on trends of axial surfaces to a very large degree. Since a given stage of deformation can produce minor folds with varying attitudes (i.e. the latest stage of deformation in the field area) any proposal based on trends alone is weak at best. Also, little is known about the nature of the Moose stage of deformation and there are apparently no major folds in the field area that they are related to.

Major Structural Features

The major structural features identified in the field are the major folds associated with the various stages of deformation (Plates 1, 2, and 3). Although a possible fault at the Goshen-Hawley contact has been suggested (Hatch, 1969) no direct evidence for it is noted in the field area.

Major folds are those that are large enough to be shown on the geologic map (Plate 1-A). All stages of deformation except the Moose stage, on which there is limited data, result in major folds. It is possible that deformation associated with this stage is only a local phenomenon and is of minor significance in the overall regional setting of the east limb of the Berkshire Anticlinorium. This problem of the Moose stage will be discussed under the regional interpretation section.

Major folds of the early stage of deformation. Graded beds exist throughout most of the Schist and Granulite Member of the Goshen Formation and the axial traces of the early isoclinal folds have been determined from reversals in the direction of tops of beds. The axial traces of early stage major folds in the field area are shown in Figure 14. It is this stage of folding that is responsible for the repetitive pattern of the Schist and Granulite Member and Quartzite and Great Moose Members throughout the field area (Plate 1-A). The wavelengths of large isoclinal folds that occur in areas where only the Schist and Granulite Member is exposed at the present surface of erosion are compared with wavelength measurements in areas where both the Schist and Granulite and the Quartzite Members occur. The wavelengths of the folds in the Schist and Granulite Member only, in the northwestern portion of the field area, are 100 feet to 800 feet. The axial traces of these folds are about 50 to 400 feet apart and nearly vertical. This compares well with wavelength data figured in the Worthington quadrangle to the north (Hatch, 1969). The average wavelengths measured along a section on Great Moose Hill where both the Schist and Granulite and the Quartzite Members occur average approximately 200 to 300 feet larger. The tightness of the folds appears to be related to the rock type.

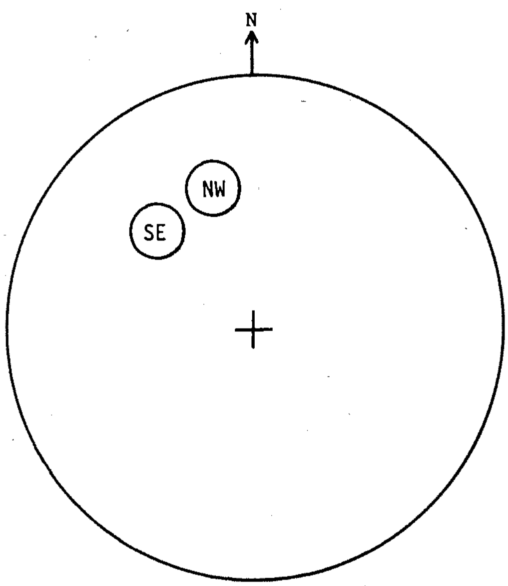
The contact between the Schist and Granulite and Quartzite members of the Goshen shown on cross section AA' (Plate 2) illustrates the geometry and nature of the large early isoclinal folds. Most of the anticlines are assumed to close a few hundred feet above the ground surface. Due to the gentle to moderate plunge, early isoclinal folds extend to the north through at least two quadrangles (Hatch, 1969; Hatch, Norton and Clark, 1970) before the hinges are exposed at the ground surface. For instance the early synclines, cored by the Quartzite Member, that close in the southern section of the Huntington area (Plate 1-A) also close a distance of from 3 miles to greater than 10 miles in quadrangles to the north (Hatch, Norton and Clark, 1970; Hatch, 1969; Osberg, Hatch and Norton, 1971). The Schist and Granulite Member is exposed in the cores of the anticlines and many of the core regions of the synclines expose the Quartzite Member and locally the Great Moose Member where the synclines are especially deep.

The geologic map (Plate 1-A) of the field area shows that the early stage folds are refolded by the Huntington syncline and locally, in the vicinity of Rockhouse Mountain, by the latest stage of folding. The refolding is indicated by the variations in the attitudes of minor structural features such as fold axes, mineral lineations and bedding-schistosity intersections throughout the Huntington area (Figure 8). This refolding dramatically alters the original attitudes of the major isoclinal folds in the area.

In summary major early isoclinal folds with vertical to subvertical north-trending axial plane schistosity, plunge gently to moderately north in the northern section of the field area on the northwest limb of the Huntington syncline. In the axial region of the Huntington syncline both bedding and the early axial plane schistosity trend west-northwest to east-west and dip moderately north. Early fold axes, as indicated by such minor features as bedding-schistosity intersections and early mineral lineations, trend about N20-25W and plunge moderately northwest. On the southeast limb of the Huntington syncline bedding and early axial plane schistosity trend east-west or east-northeast and dip moderately north. Here, the early fold axes, indicated by minor features, trend about N40-45W and plunge approximately 45° northwest. This summary is illustrated on a summary equal area diagram (Figure 17).

Large isoclinal folds related to the early stage of deformation have not been found in pre-Goshen rocks. This may be due to a lack of sedimentary structures that indicate stratigraphic tops of beds and the rarity of traceable marker beds that could be shown to repeat due to isoclinal folding (Hatch, 1968).

The Taconic unconformity is folded by the Huntington syncline as well as by the latest stage folds in the field area. Approximately four thousand feet north of the town of Blandford a few hundred feet east of the taconic unconformity in the north branch of Freeland Brook (not indicated on the geologic map), 20-30 feet of massive, gray rusty-weathering mica-quartz-garnet schist with only a few quartz stringers is exposed. A fresh surface on the rock displays a purple hue due to the numerous "BB"-size garnets. This schist is similar in appearance



NW - Maximum cluster of fold axes, bedding-schistosity intersections, and mineral lineations related to the early stage of deformation on the northwest limb of the Huntington Syncline.

SE - Maximum cluster of fold axes, bedding-schistosity intersections, and mineral lineations related to the early stage of deformation on the southeast limb of the Huntington Syncline.

Figure 17. Summary equal area diagram indicating early stage trends that are deformed by the Huntington Syncline.

to the exposure of Goshen schist in the Westfield River near Crescent Mills. Rocks just above and below this schist consist of rusty schist and thin quartzite interbeds believed to be Hawley. It is possible that this massive schist is actually Goshen and that it is exposed in the core of an early stage isoclinal syncline. This would mean that the large early isoclinal folds extend into the pre-Silurian rocks. Further analysis of this area is necessary before any definite conclusion can be made as to whether a large early isoclinal fold repeats the Taconic unconformity.

There are two examples of an interesting variation in the type of folding involved with the early stage of deformation. One occurs on Great Moose Hill in subarea K (Plate 1-A). Here the axial traces of an early anticline and syncline converge southward and apparently die out. This is illustrated in Figure 18 and is believed to be due to en echelon folding. En echelon folds are those that overlap one another but can be related to the same stage of deformation. Campbell (1958) states that in the folding of stratified rocks varying responses to the deforming forces give rise to a complexity in the stress system. This can lead to the development of en echelon effects in the fold pattern. Generally, a series of minor synclines and anticlines breaks obliquely through a larger fold. The en echelon folds die out in the limb region of the larger fold. Cross sections AA'-DD' (Figure 18) illustrate the nature of this type of folding as it occurs in the field area. a_1 and s_1 are the two en echelon folds involved. Cross sections drawn progressively southward indicate a

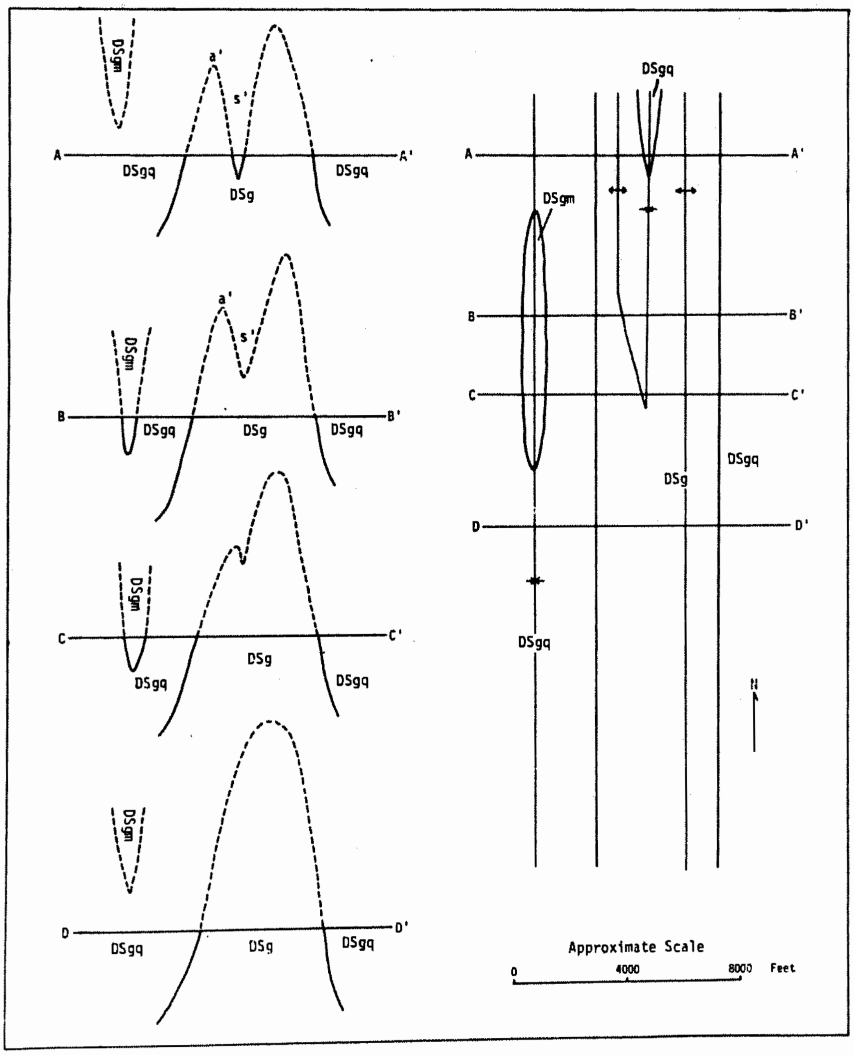


Figure 18. Diagrammatic sketch of en echelon early folds located on Great Moose Hill.

gradual dying out of the minor folds on the west limb of the major anticline until the two minor folds completely die out in the limb of the large anticline. The other example of possible en echelon folding occurs approximately 1 1/2 miles to the west (Plate 1-A). It consists of an early anticline with the Schist and Granulite Member exposed in its core that dies out toward the north and toward the south. It is illustrated in Figure 19. Based on Campbell's (1958) observations, suitable cross sections, AA'-FF' are drawn to illustrate the nature of this folding. The northern cross sections AA' and BB' show that the minor anticline is thought to form on the east limb of the major syncline. As the cross sections indicate, progressively to the south this anticline is exposed at the ground surface in CC'. Further southward the anticline eventually dies out on the east limb of the major syncline as shown in EE' and FF'.

Major folds of the Huntington stage of deformation. One of the most striking major folds in the field area is the Huntington syncline which affects the large early stage isoclinal folds, the Taconic unconformity and the pre-Goshen rocks. The approximate trace of the axial surface of the Huntington syncline is shown in Figure 14. Bedding planes, a short distance to the northwest of the axial region of the fold dip steeply to the northwest and beds on the southeast limb dip moderately north. The fold is overturned to the southeast. Two smaller scale folds on the map (Plate 1-A) are associated with the syncline. One is in the Chester-Blandford State Forest area south of the West Branch of the Westfield River in the northwestern section of

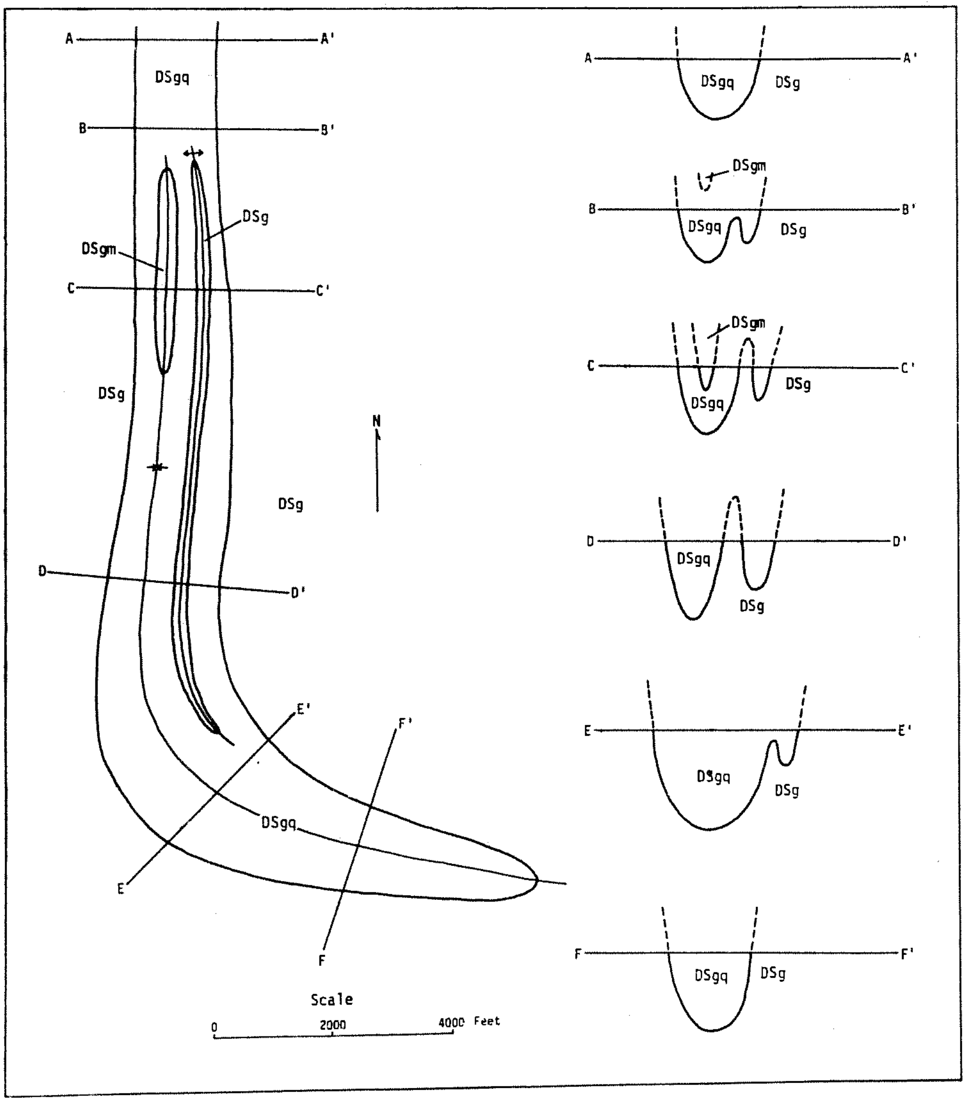


Figure 19. Diagrammatic sketch of en echelon early folds located in the center part of the Huntington area.

the field area, where the axial traces of early isoclinal folds are deformed by the Huntington stage of deformation. The other is east of the axial area of the Huntington syncline in the south-central region of the field area. These two smaller folds are compatible in rotation sense and plunge with the major Huntington syncline. The fold that occurs in the northwest limb of the syncline has a shear sense indicating a movement up on the east and the fold that is on the southeast limb and has a shear sense indicating upward movement on the west. Both of these smaller scale folds are shown on the cross section AA' (Plate 2).

Summarizing minor and major structural features of the Huntington syncline, it is a feature that has an axial plane slip cleavage that trends about N40E in the northeastern section of the field area and N10E near the nose of the syncline near the village of Blandford. The axis of this fold trends approximately N20W with a 40°-50° plunge northwest in the northeastern region of the field area and trends about N10W plunging 40°-50° northwest in the central and southwestern sections of the field area.

The geometry of the Huntington syncline is illustrated in cross section AA' (Plate 2). The geometric appearance of this cross section is similar to the Townshend-Brownington syncline shown in cross section DD', north and west of the Chester Dome, on the Centennial Geologic Map of Vermont (Doll, et. al, 1961). A similar geometry is described by Stanley (1964) near the Collinsville Dome in west-central Connecticut and is illustrated in his cross sections B"-B'", C-C' and D'-D".

Stanley's (1967) cross section a few miles south of the Huntington area through the pre-Silurian rocks also shows the geometry of the Huntington syncline. The axial surface of the Huntington syncline (Plate 2) displays a gentle dip in the region where it lies along the northern extension of the Granby Dome (Figure 2). In the western portion of the structure section (Plate 2), several miles north of the west flank of the dome, the axial surface is vertical or subvertical. Stanley (1972) believes that the formation of the Huntington syncline is related to the rise of the Granby Dome (Figures 2 and 20).

Major folds of the latest stage of deformation. Large-scale folding is noted on the Geologic Map (Plate 1-A) deforming the Taconic unconformity as well as the Huntington syncline in the southern sections of the field area. Large open folds that involve members of the Goshen Formation are present on Rockhouse Mountain in the east-central section of the study area. These open folds are related to the latest stage of deformation. The approximate locations of axial traces of this folding are indicated in Figure 14.

The latest stage major folds are correlated with Stanley's (1967) N+2 stage of folding. Stanley described this deformation several miles south of the Huntington area in pre-Silurian rocks north of the Granby Dome. This stage of deformation is not recognized by Stanley on the scale of single outcrops as minor folds or related slip cleavage, but only appears on the axial surface map of earlier N+1 stage. Minor folds as well as axial plane slip cleavage of the latest stage of folding are definitely present in the Huntington area. They occur in the Goshen Formation and also in the Hawley Formation exposed in Nye Brook located in the southwest region of the field area.

Regional implications of the Huntington area. Most of the stratified rocks that overlie the domes in Vermont, Massachusetts and Connecticut are thought to have undergone a stage of recumbent folding prior to the rise of the domes. Figure 20 is a generalized drawing indicating the distribution of the Goshen and Waits River Formations in western Massachusetts. In the Heath quadrangle to the northeast of the study area, Osberg (1972) has proposed evidence for recumbent folding in the Goshen and Waits River Formations. The crenulated outcrop pattern of the Waits River-Goshen contact is interpreted as the result of symmetrical isoclinal folds that refold the core of an east facing, recumbent fold.

On the southeast limb of the Huntington syncline, south of the Westfield River, the axial surfaces of early isoclinal folds dip gently northward. Early isoclinal folds have vertical or subvertical axial surfaces north of the Westfield River except near the Shelburne Falls dome and Goshen dome (Figure 20), where the axial surfaces of the folds dip gently northward and southward. There are two possible explanations for the present attitudes of early stage axial surfaces. The early stage of deformation may have initially produced north trending isoclinal folds in the Goshen Formation throughout western Massachusetts. Later stages of deformation, the Huntington stage of deformation in the Huntington area, deformed the early folds so that their axial surfaces dip gently northward or southward. On the other hand the early deformation may have initially produced recumbent folds that were later deformed

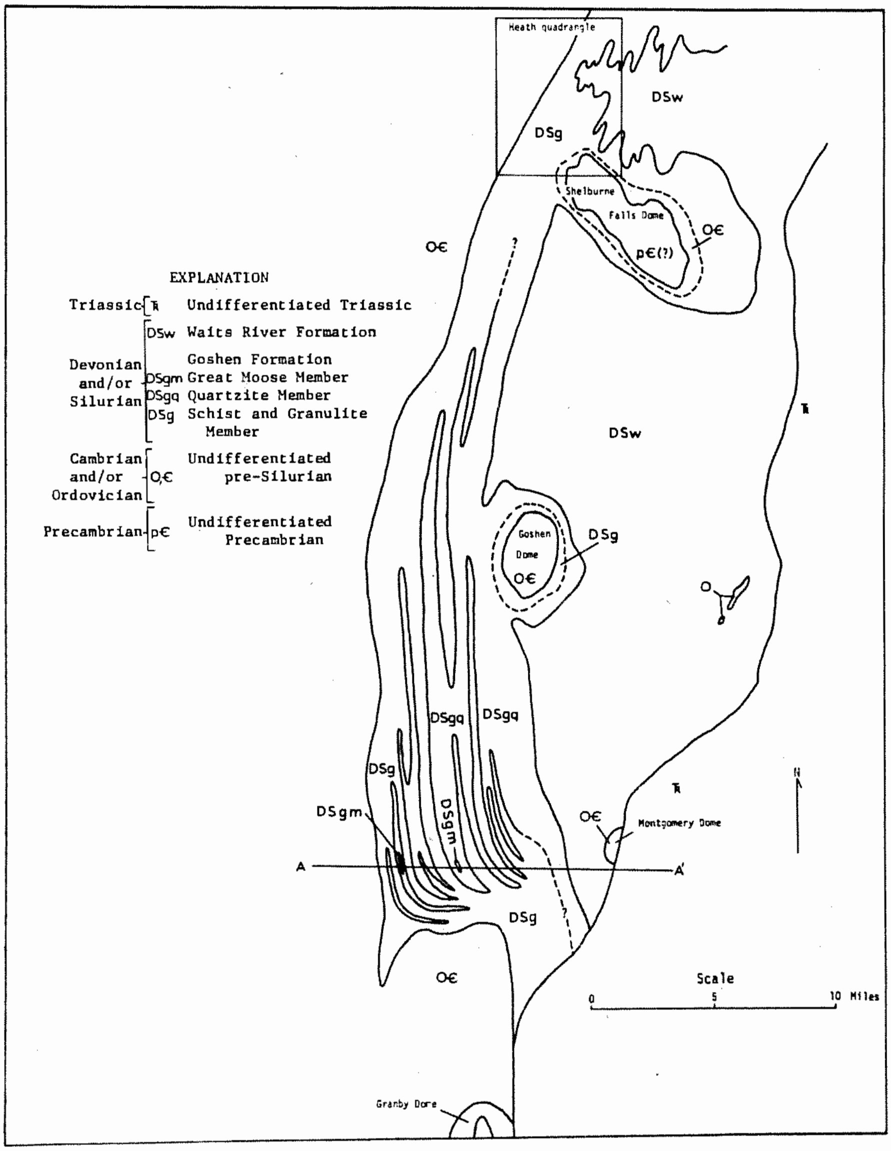


Figure 20. Generalized geologic map indicating the distribution of Devonian/Silurian rocks in part of western Massachusetts.

so that the axial surfaces became vertical or subvertical except in areas near domes.

The explanation (Figures 21 and 22) in this paper differs with the Osberg (1972) model of recumbent folding in that early recumbent folds are thought to be west facing with the youngest units in the cores of the eastward facing synclines. Figures 21 and 22 indicate the proposed explanation for the present distribution and attitudes of the Goshen Formation and Waits River Formation. The crenulation pattern in the Waits River-Goshen contact north of the Shelburne Falls dome is caused by a phase of folding later than an early stage because Osberg (1972) reports minor folds, believed the same age as the crenulations, with inverted stratigraphy on the overturned limb of the early fold. If the large early stage recumbent fold north of the Shelburne Falls dome is correlated with the early stage of deformation in the Huntington area, the crenulation pattern is the result of later folds that could be correlated with the Moose stage of deformation. Recall that Moose stage folds locally display inverted stratigraphy in the cores of minor folds.

METAMORPHISM

General Statement

North-trending steeply dipping metamorphosed rock units occur along the east limb of the Berkshire Anticlinorium in Massachusetts. Ratcliffe (1969) reports an increasing grade of metamorphism, possibly related to Taconic orogenic events east-southeast from the New York-Massachusetts border. Sillimanite is present in the Ordovician Walloomsac Formation in the Ashley Falls quadrangle, a few miles west of the Precambrian

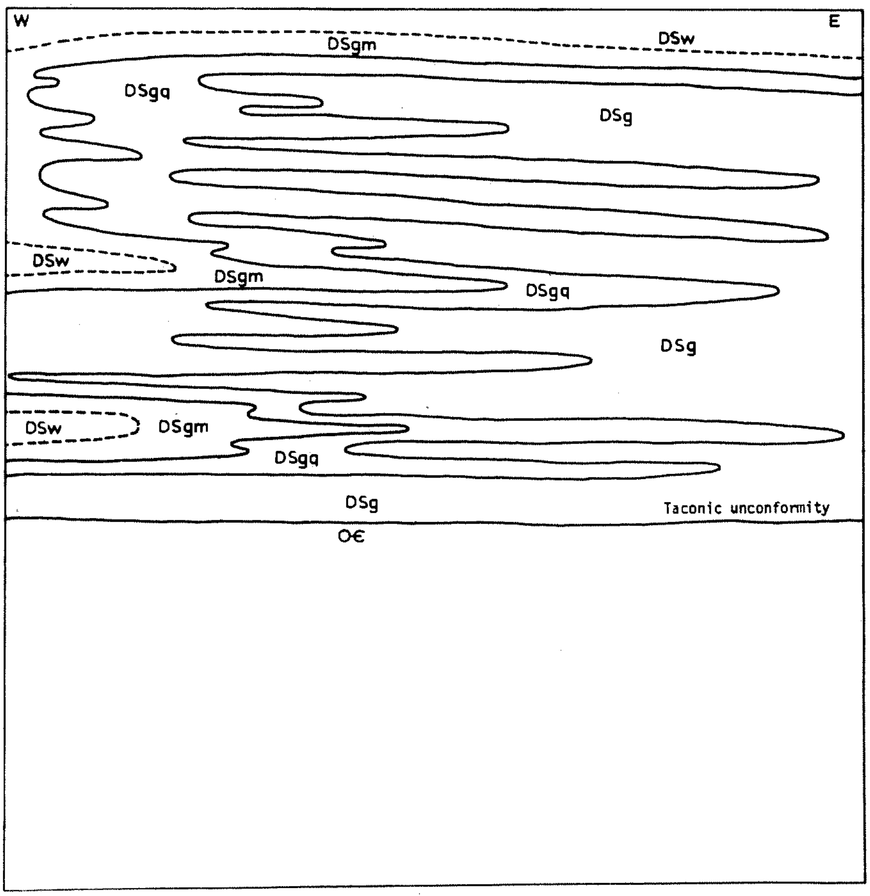


Figure 21. Structural profile indicating large early recumbent folds prior to later deformation.

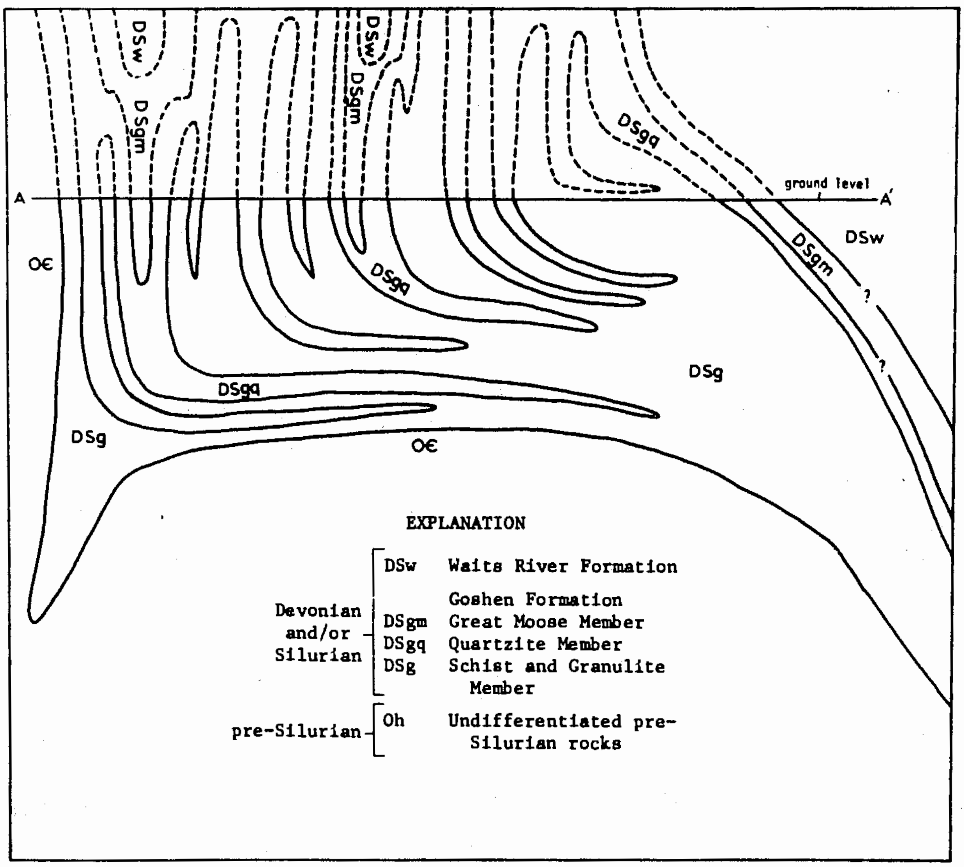


Figure 22. Structural profile AA' indicating the large early recumbent folds after the later Huntington stage of deformation.

Berkshire Highlands. This formation is approximately the same age as the Hawley Formation in the Huntington area. The grade of metamorphism affecting the Hawley Formation during the Taconic deformation in the Huntington area is not known. All of the Paleozoic rocks on the east limb of the Berkshire Anticlinorium underwent extensive medium to high grade metamorphism during the Devonian Acadian orogeny (Hatch, 1968).

Grade of Metamorphism

All the rocks of the Goshen, Russell Mountain, and Hawley Formations in the Huntington area have been metamorphosed to the kyanite-staurolite zone. Kyanite and staurolite are abundant constituents of the Schist and Granulite Member of the Goshen Formation, are rare in the Quartzite Member and are absent from the Great Moose Member. Kyanite and staurolite have been identified in the Hawley Formation in this area but they are uncommon.

At one locality on a small knob approximately 1000 feet northeast of Holiday Hill in the southeastern region of the field area, several nodules of sillimanite, 2-3 inches long are present in the basal schists of the Goshen Formation. The kyanite-sillimanite isograd is inferred several miles south of the Huntington area (Thompson and Norton, 1968).

Hatch (1969) has proposed the possibility of a fault along the Hawley-Goshen contact. This occurrence of sillimanite in the Huntington area, near the Hawley-Goshen contact, may represent the displacement of the isograd surface. There is no granitic body exposed at the surface near the sillimanite nodule bearing rocks that would give a local temperature anomaly producing sillimanite. Further study in the area of the sillimanite occurrence is necessary to establish a plausible explanation for its origin.

Hatch et. al. (1970) mapped the kyanite isograd in the Goshen Formation in the northern section of the Chester quadrangle, indicating a progressive increase in metamorphic grade southward. This isograd is truncated at the Taconic unconformity and is not present in the pre-Silurian rocks in the Chester quadrangle (Hatch, et. al., 1970). This suggests that the distribution of kyanite and staurolite in the pre-Goshen and Goshen rocks is caused either by a difference in bulk chemical composition or by a fault along the Hawley-Goshen contact that offsets the isograd (Hatch, 1969).

The mineral assemblages in the pelitic rocks of the Goshen Formation in the Huntington area are:

quartz-muscovite-biotite

quartz-alkali feldspar-muscovite-biotite

quartz-alkali feldspar-albite-muscovite-biotite

quartz-alkali feldspar-oligoclase-muscovite-biotite-garnet

quartz-albite-muscovite-biotite-garnet-kyanite-staurolite

quartz-oligoclase-muscovite-biotite-garnet-kyanite

quartz-muscovite-biotite-garnet

quartz-albite-muscovite-biotite-garnet

quartz-oligoclase-muscovite-biotite-garnet

quartz-muscovite-biotite-garnet-staurolite

quartz-albite-muscovite-biotite-garnet-staurolite quartz-muscovite-biotite-garnet-kyanite

quartz-muscovite-biotite-garnet-sillimanite

The mineral assemblages in the calcareous rocks and calc-silicate rocks of the Goshen Formation in the Huntington area are:

quartz-bytownite-biotite-garnet-diopside-epidote-hornblende-sphene

quartz-muscovite-biotite-garnet-calcite-scapolite

quartz-labradorite-muscovite-biotite-calcite

quartz-andesine-muscovite-biotite-garnet-calcite-sphene

quartz-oligoclase-muscovite-biotite-garnet-calcite

quartz-alkali feldspar-oligoclase-biotite-garnet-calcite-scapolite-hornblende-sphene

The general conditions of metamorphism can be approximated based on the observed mineral assemblages in the Goshen Formation. Excluding the one sillimanite occurrence the rocks are apparently kyanite-staurolite grade. Muscovite in the pelitic rocks and the assemblage muscovite-calcite-quartz in the calc silicate rocks are stable in the field area. Experimental work of Richardson, Gilbert and Bell (1969) gives the andalusite-kyanite-sillimanite triple point 622°C, 5.5 kbars. Evans (1965) shows muscovite stable up to temperatures ranging from 600°C to approximately 720°C with increasing pressure. Hewitt (1973) notes that the assemblage muscovite-calcite-quartz is stable up to temperatures from about 450°C to approximately 650°C with increasing pressure at .5 CO_2 pressure. From this experimental data it is postulated that the mineral assemblages in rocks of the Goshen Formation in the Huntington area were metamorphosed at approximately 5 kilobars pressure within the temperature range 450-550°C.

Relations Between Structural Features and Metamorphism

As observed in thin section, coarse crystals of feldspar, kyanite and staurolite, as well as elongate grains of quartz are parallel to the early schistosity and the early fold axes. Field observations confirm that kyanite, staurolite, mica and quartz lineations are parallel to the intersection of early schistosity with bedding, which is in turn parallel to the early fold axes.

Minor folds of the Moose stage of deformation also show kyanite and staurolite lineations parallel to their axes. One thin section shows a dominant foliation of Moose stage, noted as slip cleavage in hand specimen, with micas, quartz and feldspar grains parallelling it. A northeast-trending slip cleavage, related to the Huntington stage of deformation, locally deforms the foliation and related mineral lineations of the Moose stage.

Slip cleavage, related to the Huntington stage of deformation, noted in thin sections as well as in hand specimens deforms the early schistosity into crenulations, that vary from broad, open, to sharp, chevron folds. The crenulations locally bend large staurolite crystals that formed in association with the early stage of deformation, as well as crystals of kyanite, feldspar, garnet,and quartz. Crystals of biotite and/or muscovite are found parallel or subparallel to the slip cleavage surfaces. Some of the biotite grains are at angle to the dominant early schistosity and appear, in hand specimen, as crossed-biotites. Hatch (1969) noted that biotite porphyroblasts are randomly oriented with respect to both the dominant regional schistosity and slip cleavages. He infers that these crystals formed later than all stages of folding and cleavage development. Muscovite and biotite lineations are locally parallel to the fold axes of the Huntington stage minor folds.

A few rare localities show some large crystals of kyanite that appear oriented parallel or subparallel to the late slip cleavage surfaces. The possiblity exists that these large crystals are of early age and are simply rotated by the Huntington stage slip cleavage into alignment with this later feature. It is believed that the grade of metamorphism associated with the Huntington stage of deformation was not high enough to produce kyanite or staurolite.

Thin sections from the hinge areas of minor folds of the latest stage of deformation show crenulations in muscovite and biotite related to the early stage of deformation. These crenulations also fold quartz and feldspar crystals associated with this early schistosity. A few mica grains are parallel or subparallel to the surfaces of this latest stage slip cleavage. One thin section shows large crystals of muscovite possibly related to the latest stage of deformation, that are across both a foliation thought to be associated with the Moose stage of deformation, and a slip cleavage related to the Huntington stage of deformation.

In summary, crystals of kyanite, staurolite, mica, feldspar and quartz are formed along schistosity planes and are parallel to the fold axes of minor folds produced by the early stage of deformation. These minerals have also been noted parallel to the minor fold axes of the

Moose stage of deformation. The two later stages of deformation in the Huntington area did not produce minerals of kyanite grade metamorphism. The Huntington stage of deformation produced a slip cleavage that deforms the minerals associated with the early stage of deformation and locally the minerals related to the Moose stage. Crystals of muscovite and biotite form along Huntington stage slip cleavage planes and are noted parallel to the axes of minor folds of this stage. Slip cleavage produced by the latest stage of folding in the field area deforms minerals of the early stage and minerals related to the Huntington stage of deformation. Muscovite crystals, thought to be formed during the latest stage of folding, are noted in thin section as forming across earlier stage minor features and associated minerals.

Retrograde Metamorphism

Examples of retrograde metamorphism are common in the thin sections analyzed. Biotite crystals commonly are either partially altered to or completely replaced by, chlorite. Garnet is generally fresh, but locally is partially altered to chlorite. There is no particular distribution of the retrograde effects in the field area. It is not known if all the chlorite formed during the post-deformational history of rocks.

GEOLOGIC HISTORY

Geologic history as recorded by the rocks in the Huntington area began with the deposition of shales, sandstones and volcanics of the Hawley Formation in the Middle Ordovician. Subsequent uplift and erosion associated with the Taconic Orogeny, was followed by deposition of the Russell Mountain Formation unconformably upon the Hawley in the Silurian.

Deposition of the thin bedded Schist and Granulite Member of the Goshen Formation occurred after this and may possibly be turbidites that formed in the eugeosynclinal zone of the Silurian and/or Devonian sea. Deposition of thick, massive beds of quartz sandstone and shale of the Quartzite Member followed, with later deposition of massive carbonate beds and shales of the Great Moose Member.

During the Acadian Orogeny (Hatch, 1968) in the Devonian the rocks were metamorphosed and deformed. The earliest stage of deformation produced large, possible recumbent, isoclinal folds with a related axial plane schistosity. These early folds show a westward transport direction in the Huntington area and trend north-south with vertical or subvertical axial plane schistosity. However, on the east limb of the Huntington syncline bedding and schistosity trend northeast-southwest, dipping moderately to the north with early fold axes plunging moderately northwest. This early schistosity is the major planar feature in the rocks of the Huntington area. During this stage of deformation the rocks were metamorphosed up to kyanite grade. Locally, minor isoclinal to open folds associated with the next later Moose stage of folding, deformed the early stage folds. These folds are now north-south trending with vertical or subvertical axial plane slip cleavage. The minor folds produced during the Moose stage of folding possibly represent a final minor phase of the major early stage of deformation. The early stage of deformation was probably accompanied by intrusion of granitic sheets parallel to the axial traces of the large isoclinal folds and at lithologic contacts between the Schist and Granulite Member and the Quartzite Member of the Goshen Formation. Subsequently a large overturned open syncline, the Huntington syncline, with associated northeast-trending, northwest dipping slip cleavage formed. This stage of folding, the Huntington stage is associated with the development of the Granby dome and resulted in the rotation of the axial surfaces of the recumbent folds of the early stage of deformation to the steep dipping surfaces that are now noted in the area. Finally, a late stage of folding produced large open folds that alter the earlier features of the area.

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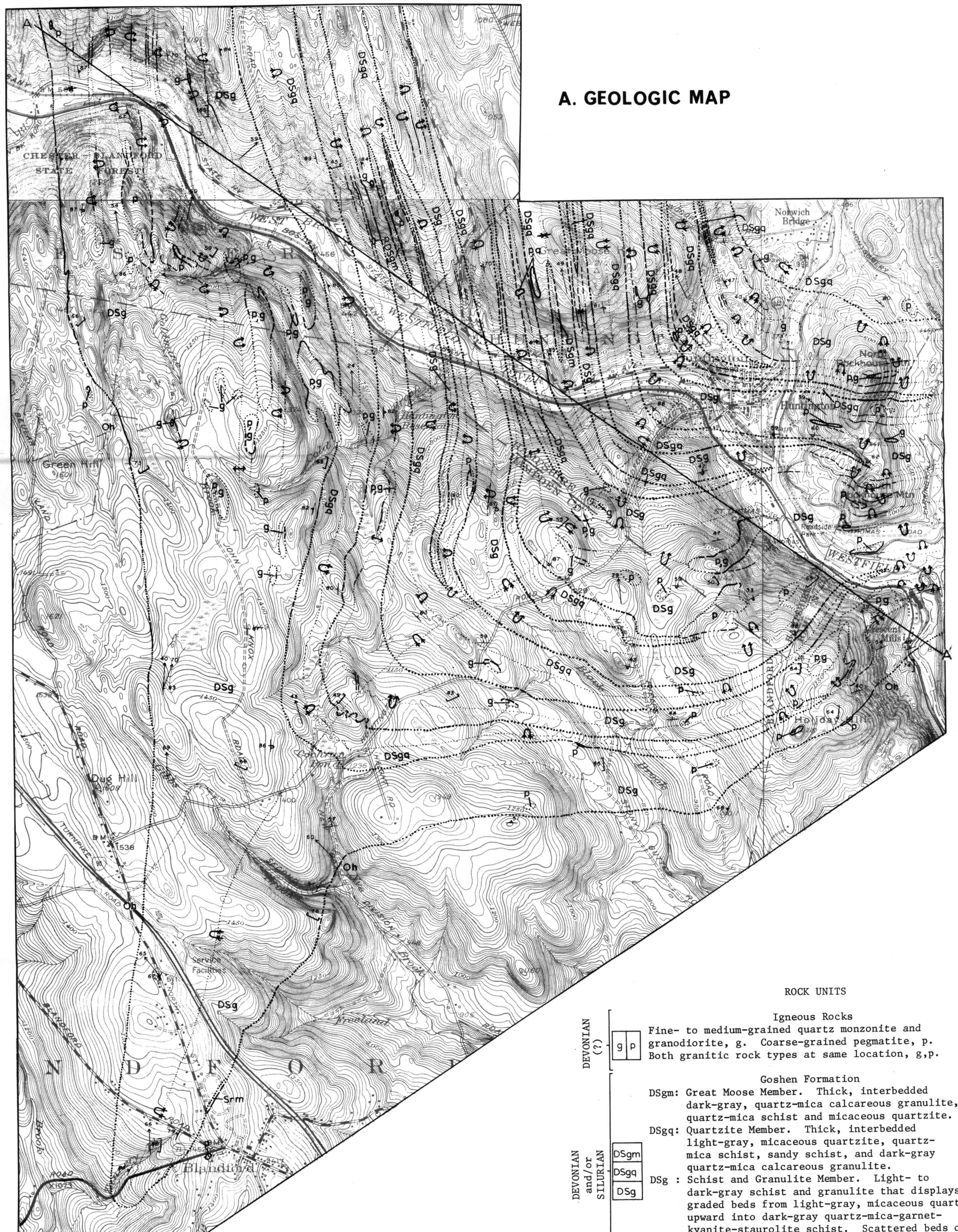
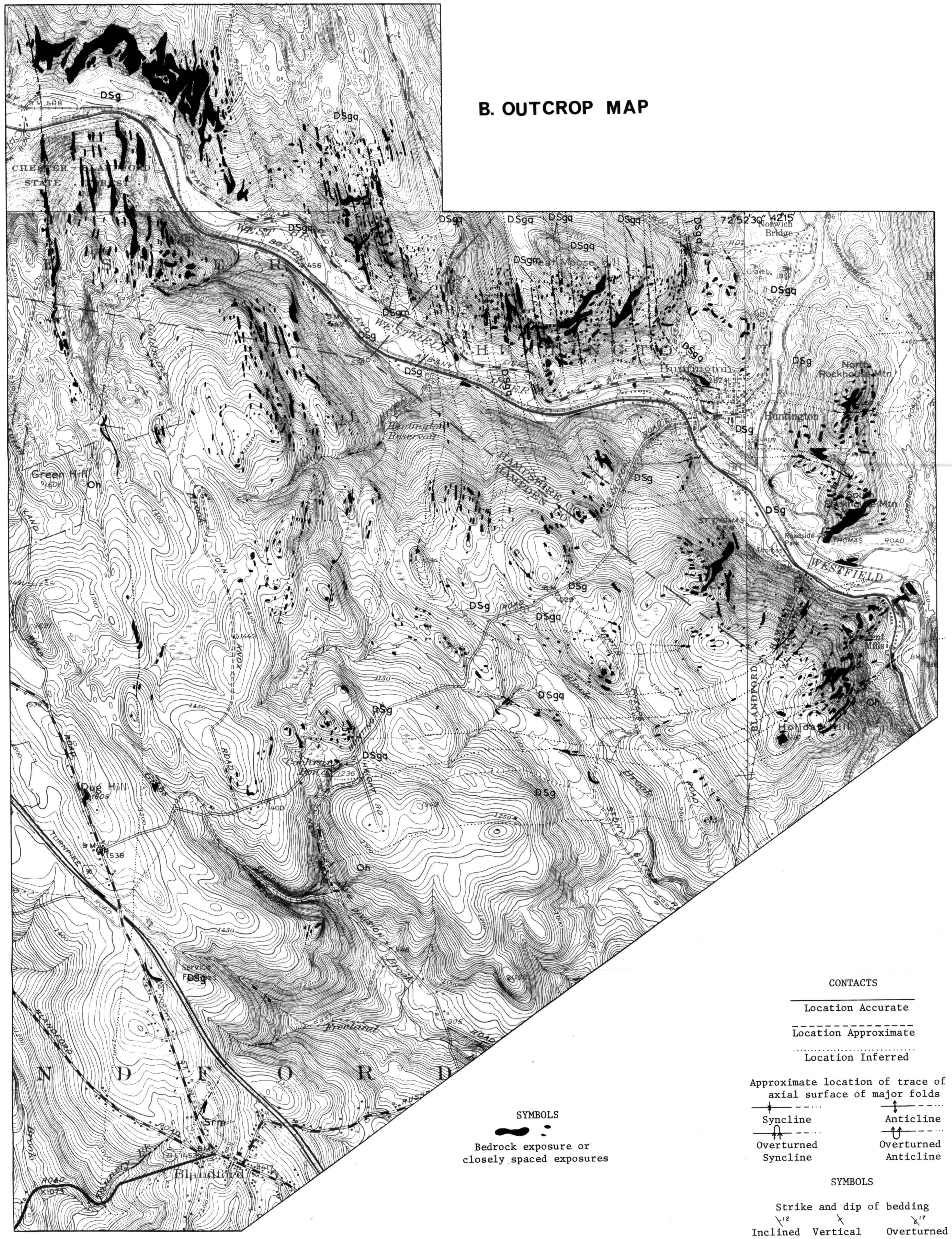
PLATE I - GEOLOGIC and OUTCROP MAP





ROCK UNITS

DEVONIAN (?)	g p	**Igneous Rocks** Fine- to medium-grained quartz monzonite and granodiorite, g. Coarse-grained pegmatite, p. Both granitic rock types at same location, g,p.
DEVONIAN and/or SILURIAN	DSgm, DSgq, DSg	**Goshen Formation** DSgm: Great Moose Member. Thick, interbedded dark-gray, quartz-mica calcareous granulite, quartz-mica schist and micaceous quartzite. DSgq: Quartzite Member. Thick, interbedded light-gray, micaceous quartzite, quartz-mica schist, sandy schist, and dark-gray quartz-mica calcareous granulite. DSg : Schist and Granulite Member. Light- to dark-gray schist and granulite that displays graded beds from light-gray, micaceous quartzite upward into dark-gray quartz-mica-garnet-kyanite-staurolite schist. Scattered beds of calc-silicate.
SILURIAN	Srm	**Russell Mountain Formation** Light-gray to light-brown micaceous quartzite, and some conglomerate.

Unconformity

MIDDLE ORDOVICIAN	Oh	**Hawley Formation** Thick bedded gray quartz-mica-garnet schist, massive feldspathic schist, thin bedded micaceous quartzite, dark-gray well-foliated quartz-mica gneiss and well-foliated dark-gray amphibolite.

SYMBOLS

Bedrock exposure or closely spaced exposures

CONTACTS

Location Accurate

Location Approximate

Location Inferred

Approximate location of trace of axial surface of major folds

Syncline — Anticline

Overturned Syncline — Overturned Anticline

SYMBOLS

Strike and dip of bedding: Inclined, Vertical, Overturned

Strike and dip of schistosity: Inclined, Vertical

Strike and dip of slip cleavage

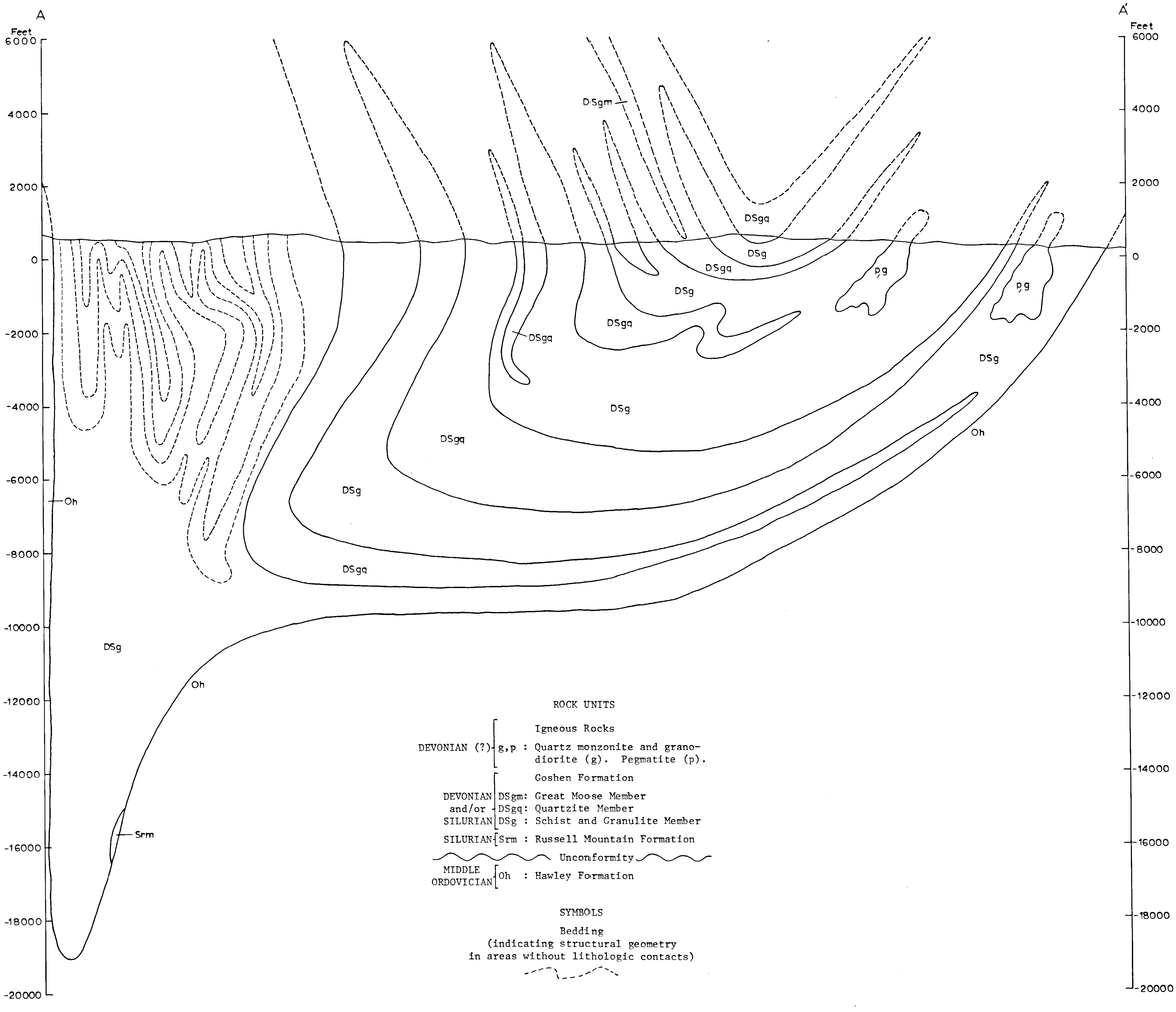
Direction and amount of plunge of mineral lineation

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET

DATUM IS MEAN SEA LEVEL

PLATE 2-STRUCTURE SECTION



ROCK UNITS

DEVONIAN (?) — Igneous Rocks
g,p : Quartz monzonite and granodiorite (g). Pegmatite (p).

DEVONIAN and/or SILURIAN — Goshen Formation
DSgm: Great Moose Member
DSgq: Quartzite Member
DSg : Schist and Granulite Member

SILURIAN — Srm : Russell Mountain Formation

Unconformity

MIDDLE ORDOVICIAN — Oh : Hawley Formation

SYMBOLS

Bedding
(indicating structural geometry in areas without lithologic contacts)

PLATE 3 - MINOR STRUCTURAL FEATURES