Redefinition of the Hawley and Goshen Schists in Western Massachusetts

By NORMAN L. HATCH, JR.

CONTRIBUTIONS TO STRATIGRAPHY

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Two Paleozoic units are revised and renamed as formations

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By NORMAN L. HATCH, JR.

ABSTRACT

Emerson's Hawley Schist, renamed the Hawley Formation, is redefined to include the graphitic schists that are interbedded with the metavolcanic rocks of the original definition. A Middle Ordovician age is assigned to the formation. Emerson's Goshen Schist, renamed Goshen Formation, is redefined to include all gray schists, cyclically bedded rocks, and quartzites between the top of the underlying Hawley and the base of the lowest calcareous bed in the overlying Waits River Formation. The Goshen is dated as Silurian and Devonian.

INTRODUCTION

Emerson (1898, 1917) divided the Paleozoic rocks on the east side of the Berkshire Massif in western Massachusetts into the Hoosac, Rowe, Savoy, Hawley, Goshen, and Conway Schists. Emerson's descriptions, however, do not clearly define the limits of, or the criteria for, distinguishing between, some of these units, and restudy of these units in northwestern Massachusetts has shown that a somewhat different subdivision of the rocks would be desirable (fig. 1). In the present report, therefore, the Hawley and Goshen Schists of Emerson are redefined on the basis of lithologic evidence from current mapping. A similar redefinition has also been made for the Rowe Schist (Hatch and others, 1966).

Much of the fieldwork on which this report is based was done with Philip H. Osberg, and the system of stratigraphic subdivisions and nomenclature being used in this area evolved from many hours of discussion with him. The author, however, must take full responsibility for the discussion that follows. The fieldwork was done in cooperation with the Massachusetts Department of Public Works.

HAWLEY FORMATION

Emerson (1898) applied the name Hawley Schist to the sequence of green chloritic and hornblendic schists and feldspathic schists between his Savoy Schist and Goshen Schist (fig. 2). In his description of the

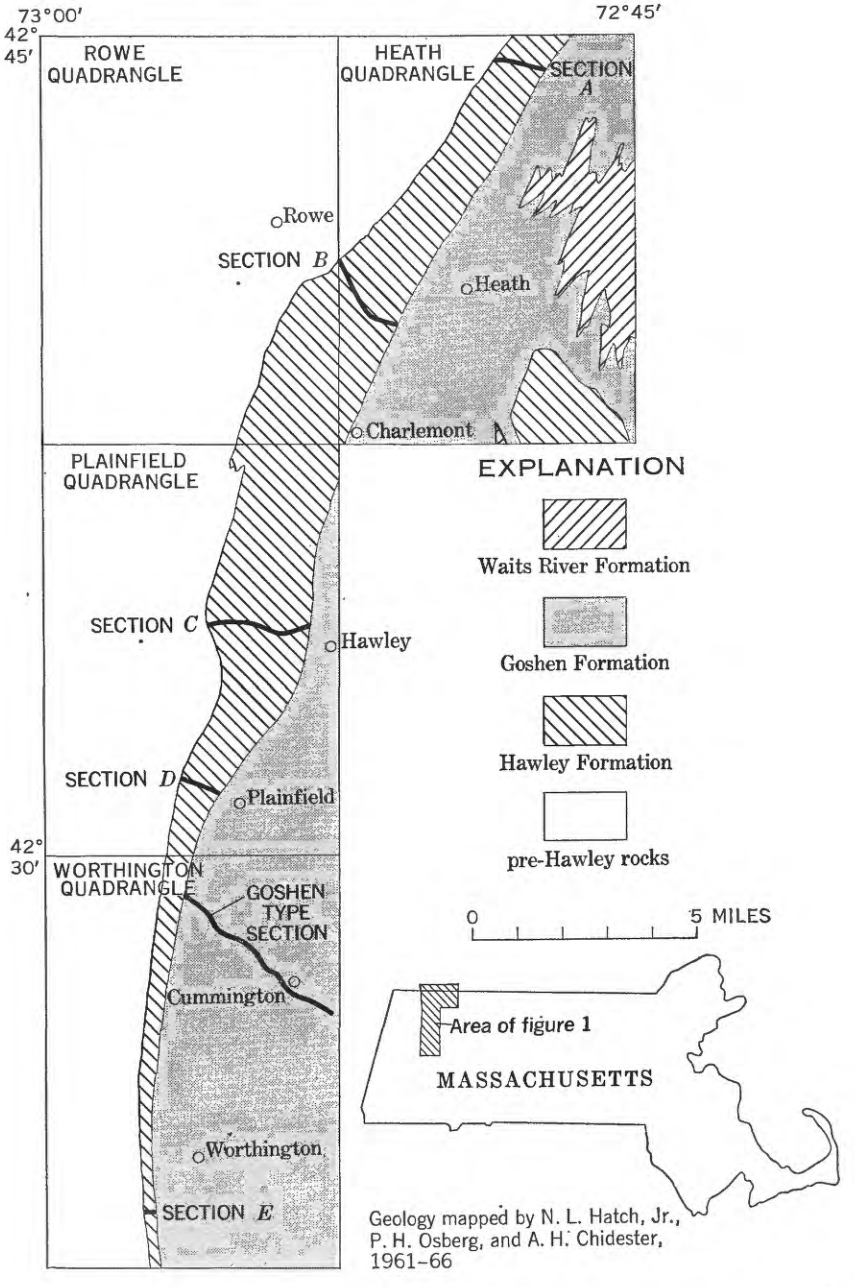

FIGURE 1.—Distribution of the Hawley and Goshen Formations in recently restudied areas of northwestern Massachusetts. Stratigraphic sections of the Hawley Formation described in text and the proposed type section for the Goshen Formation are indicated by heavy lines.

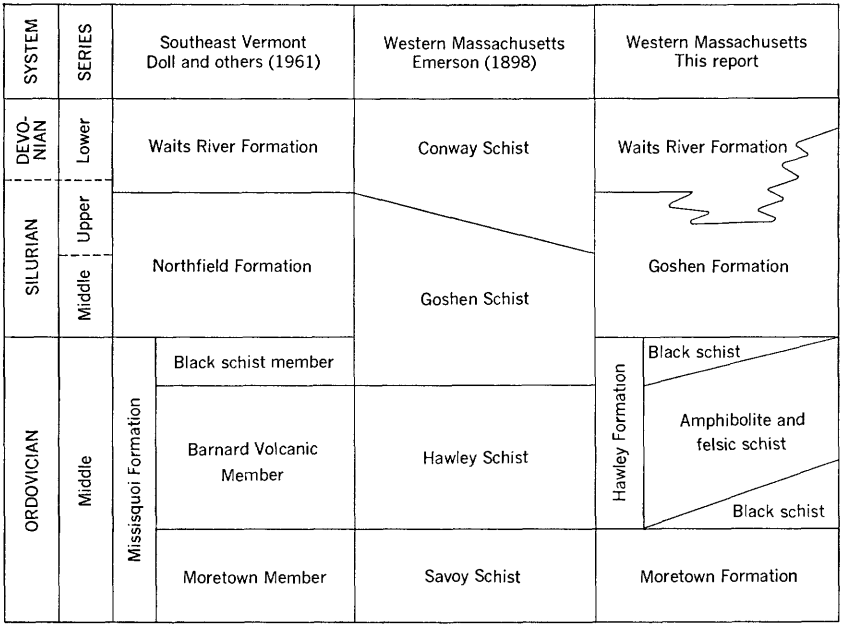

FIGURE 2.—Correlation of the rock units of western Massachusetts (Emerson, 1898; this report) and southeast Vermont (Doll and others, 1961).

Hawley, Emerson (1898, p. 163–169) emphasized the widespread distribution of hornblende and the richness in iron as distinguishing characteristics of the formation. Although many rocks in the Hawley contain both hornblende and abundant iron, these criteria were not found to be sufficient or reliable to define the unit, which is here renamed the Hawley Formation.

LITHOLOGIC DESCRIPTION

The dominant rocks of the Hawley Formation in the area shown in figure 1 are light- to dark-green fine- to medium-grained schistose to massive, locally porphyritic or fragmental amphibolites. Greenstone schists and buff, light-green, or light-gray fine- to medium-grained schistose to massive feldspar rocks with accessory hornblende, garnet, quartz, or muscovite are common.

The amphibolites are composed principally of hornblende (or actinolite), plagioclase, epidote, and chlorite, with minor biotite, garnet, and quartz. Most abundant is a medium-grained massive hornblende-plagioclase rock; chloritic, garnetiferous, or schistose amphibolites are present as thin beds or lenses throughout the formation. A local subunit 500–1,000 feet thick of medium- to dark-gray-green plagioclase-hornblende-chlorite schist contains conspicuous

angular to rounded crystals of plagioclase 2–4 mm in diameter and angular rock fragments as much as 15 cm across; some fragments are darker and some lighter than their matrix (P. H. Osberg, N. L. Hatch, Jr., and S. A. Norton, unpub. data). Somewhat similar dark-gray-green massive amphibolite with conspicuous megacrysts of plagioclase 3 mm in diameter, but without rock fragments, is interbedded with black schists at the top of the formation in the northern part of the Heath quadrangle (fig. 1; N. L. Hatch, Jr., and J. H. Hartshorn, unpub. data). Also common throughout much of the formation are intermediate- and light-colored amphibolites in which distinct blades, or groups of blades, of hornblende as much as 1 inch long are set in a fine-grained matrix of plagioclase, chlorite, and epidote. Locally present in the Plainfield quadrangle (P. H. Osberg, N. L. Hatch, Jr., and S. A. Norton, unpub. data) are outcrops of probable pillow lava. The "pillows" have interiors of dark-green hornblende-chlorite-albite-epidote-carbonate schist. Concentrations of green epidote-albite-carbonate rock are generally concentric with, or form the centers of, the "pillows," which are rimmed with hornblende.

Light-gray, light-green, or buff feldspathic rocks are present in the formation. Most are fine grained and either schistose or granulose depending on the abundance of white mica. A zone of these rocks a few hundred feet thick has been traced for about 7 miles; also, scattered thin beds are present, but not mapped, in other parts of the area. The spectacular "fasciculite" sprays of Emerson (1898, p. 164) consist of bundles of hornblende needles as much as 6 inches long and garnets ¼–¾ inch in diameter set in a white or near-white fine-grained granulose or schistose felsitic matrix. Medium-grained plagioclase-quartz gneiss with accessory biotite, muscovite, and garnet forms a few scattered thin beds and a zone about 100 feet thick that has been traced for 5 miles south of the Vermont–Massachusetts State line. Angular feldspar crystals and faint compositional layering suggest that this rock may be a metamorphosed crystal tuff.

An area of amphibolites and felsic gneisses in the southeast corner of the Heath quadrangle is mapped as Hawley Formation (N. L. Hatch, Jr., and J. H. Hartshorn, unpub. data). These rocks form part of an elliptically shaped area (Balk, 1946; Segerstrom, 1956) known as the Shelburne Falls dome, which is surrounded and unconformably overlain by schists of the Goshen Formation. The stratigraphic position and the chemical composition of the rocks in the Shelburne Falls dome form the basis for assigning them to the Hawley Formation. The amphibolites are all fine- to medium-grained hornblende-plagioclase rocks and show none of the textural variations of the amphibolites in the rest of the Hawley Formation. Fine-grained sandy-textured plagioclase-quartz-biotite-hornblende rocks are tex-

turally similar to the amphibolites and form scattered beds within the dome. Medium- to coarse-grained plagioclase-quartz-biotite-muscovite-garnet gneiss similar to the narrow band in the Hawley to the west is abundant in the dome and probably represents both metamorphosed crystal tuffs and intrusive sills and dikes (Hatch and Hartshorn, unpub. data).

The black schists and quartzites which form mappable subunits within the Hawley Formation are fine-grained sooty-black, rusty-weathering quartz-muscovite-biotite-graphite-pyrite rocks. Garnet and chlorite are present locally. These rocks are characteristically complexly folded and sheared.

Because most of the beds and subunits are discontinuous, no one stratigraphic section can represent the entire Hawley Formation. The sections given below are as representative of the formation as any can be.

STRATIGRAPHIC SECTIONS

In the following stratigraphic sections, minerals preceding rock names are listed in decreasing order of abundance. Minerals in parentheses occur only locally and generally form less than 10 percent of the rock. Percentages, which are given only for minerals forming more than 10 percent of the rock, are estimated averages. Locations of stratigraphic sections are indicated in figure 1. Lowercase letters in the right-hand column are the symbols used for stratigraphic intervals in the columnar sections in figure 3.

SECTION *A. Approximate stratigraphic section through the Hawley Formation across Clark Hill, Heath quadrangle*

[N. L. Hatch, Jr., and J. H. Hartshorn, unpub. data. Section 1,500 ft north of the Massachusetts-Vermont State line. Correlations with the Vermont State map (Doll and others, 1961) are as follows: Upper 1,000 ft of Hawley, rusty-weathering carbonaceous schist and quartzite member (Omc) of Missisquoi Formation; lower 1,700 ft, Barnard Volcanic Member of Missisquoi Formation]

	Thickness (feet)	*Symbol in figure 3*
Goshen Formation:		
Gray fine-grained crinkly quartz (55 percent)-muscovite (35 percent)-biotite-garnet-chlorite phyllite and schist. Bedding indistinct	6,000+	---
Hawley Formation (2,700 ft):		
Gray to black fine-grained dull to shiny quartz (50–95 percent)-muscovite (2–40 percent)-chlorite-biotite-graphite schist. Dark-gray to dark-green medium-grained porphyritic (plagioclase crystals as much as 5 mm long) to equigranular plagioclase (50–70 percent)-hornblende (25–45 percent) amphibolite, both intrusive and extrusive, forms about 50 percent of unit as beds, sills, and dikes 2–25 ft thick	1,000	*a*

SECTION *A. Approximate stratigraphic section through the Hawley Formation across Clark Hill, Heath quadrangle*—Continued

	Thickness (feet)	Symbol in figure 8
Hawley Formation (2,700 ft)—Continued		
Dark-gray to dark-green medium-grained porphyritic and equigranular plagioclase-hornblende amphibolites. Green schistose plagioclase-hornblende-(or actinolite)-chlorite-epidote amphibolite and white medium-grained feldspar-quartz granulite form about 10 percent of interval. One 3-foot-thick bed of gray hard dense quartz(70 percent)-garnet(25 percent)-cummingtonite rock	900	*b*
Pale-buff medium-grained banded schistose plagioclase(75 percent)-quartz(20 percent) gneiss with minor biotite, garnet, chlorite and muscovite	200	*c*
Dark-gray to dark-green fine- to medium-grained, locally schistose, generally compositionally layered (⅛- to 1-in.-thick layers of feldspar- and hornblende-rich rock) plagioclase-hornblende-amphibolite	600	*d*
Moretown Formation (quartz-mica schist unit):		
Buff to light-silvery-gray fine- to medium-grained quartz-plagioclase-mica-garnet schist	1,100	----------

SECTION *B. Approximate stratigraphic section through the Hawley Formation along Davis Mine Brook, west-central Heath quadrangle*

[N. L. Hatch, Jr., and J. H. Hartshorn, unpub. data]

	Thickness (feet)	Symbol in figure 8
Goshen Formation:		
Gray fine-grained crinkly quartz(55 percent)-muscovite(35 percent)-biotite-garnet-chlorite phyllite and schist. Generally poorly bedded, but locally cyclically bedded	4,000	----------
Hawley Formation (4,150 ft):		
Sooty-black fine-grained graphitic quartz(50–95 percent)-muscovite(2–40 percent) schist and quartzite. Interlaminated with 5- to 50(?)-foot-thick beds and sills of dark-green medium-grained plagioclase (50–70 percent)-hornblende (25–45 percent) amphibolite with scattered plagioclase megacrysts as much as 4 mm in diameter	500	*e*
Dark-green medium-grained massive plagioclase-hornblende amphibolite with white plagioclase megacrysts forms about 40 percent of interval. Dark-green medium-grained schistose to massive intermediate to mafic plagioclase(50–90 percent)-hornblende(10–45 percent) amphibolites with minor chlorite and epidote form about 50 percent of interval. White feldspar granulite and schist forms scattered beds 10–20(?) ft thick	1,200	*f*

SECTION *B. Approximate stratigraphic section through the Hawley Formation along Davis Mine Brook, west-central Heath quadrangle*—Continued

	Thickness (feet)	Symbol in figure 3
Hawley Formation (4,150 ft)—Continued		
White or pale-green fine-grained schistose to massive feldspar rock with minor hornblende, biotite, and garnet. Hornblende locally forms blades ½–¾-inch long. Scattered beds 5–50(?) ft thick of dark-green coarse-grained plagioclase-hornblende amphibolite and fine-grained slabby schistose needly plagioclase-hornblende amphibolite	2,000	*g*
Dark-green fine- to medium-grained schistose plagioclase-hornblende amphibolite with minor chlorite and gray-green medium-grained punky-weathering plagioclase-hornblende-chlorite-carbonate-epidote schist	450	*h*
Moretown Formation (quartz-mica schist unit):		
Buff to light-silvery-gray fine- to medium-grained quartz-plagioclase-mica-garnet schist	600	----------

SECTION *C. Approximate stratigraphic section through the Hawley Formation across Parker Hill, Plainfield quadrangle*

[P.H. Osberg, N. L. Hatch, Jr., and S. A. Norton, unpub. data]

	Thickness (feet)	Symbol in figure 3
Goshen Formation:		
Gray fine-grained quartz-muscovite-biotite-chlorite-garnet schist	1,500+	----------
Hawley Formation (5,450 ft):		
Black fine-grained graphitic quartz-mica schist	25	*i*
White fine-grained granular feldspar rock (about 40 percent) and dark-green medium-grained amphibolite (60 percent)	100	
Black fine-grained graphitic quartz-mica schist	25	
Interbedded dark-gray-green medium-grained plagioclase-hornblende amphibolites and white light-gray or light-brown fine- to medium-grained schistose to granulose feldspar and feldspar-mica schists	1,100	*j*
Medium- to dark-gray plagioclase-hornblende-chlorite schist with conspicuous 2- to 4-mm plagioclase insets and angular rock fragments	200	*k*
Dark-green fine- to medium-grained schistose to massive plagioclase(65 percent)-hornblende(25 percent)-(chlorite)-(epidote) amphibolites	500	*l*
Medium- to dark-gray plagioclase(65 percent)-hornblende(25 percent)-chlorite schist with conspicuous 2- to 4-mm plagioclase insets and angular rock fragments	800	*m*

SECTION *C. Approximate stratigraphic section through the Hawley Formation across Parker Hill, Plainfield quadrangle*—Continued

	Thickness (feet)	Symbol in figure 3
Hawley Formation (5,450 ft)—Continued		
Green to dark-green fine- to medium-grained, schistose to massive plagioclase(65 percent)-hornblende (25 percent)-(chlorite)-(epidote) amphibolites	1,100	*n*
White to light-green plagioclase granulite with minor white to light-gray plagioclase(90 percent)-calcite-chlorite granulite and plagioclase(80 percent)-quartz-hornblende-garnet gneiss	300	*o*
Green to dark-green fine- to medium-grained schistose to massive plagioclase(65 percent)-hornblende (25 percent)-(chlorite)-(epidote) amphibolites	1,300	*p*
Moretown Formation (quartz-mica schist unit):		
Buff to light-gray fine- to medium-grained quartz-plagioclase-mica-garnet schist and minor graphitic schist	700	----------

SECTION *D. Approximate stratigraphic section through the Hawley Formation west of Plainfield village, Plainfield quadrangle*

[P. H. Osberg, N. L. Hatch, Jr., and S. A. Norton, unpub. data]

	Thickness (feet)	Symbol in figure 3
Goshen Formation:		
Gray fine- to medium-grained generally cyclically bedded quartz-muscovite-biotite-chlorite-garnet schist and gray fine-grained quartzite	6,000	----------
Hawley Formation (2,550 ft):		
Dark-gray fine-grained graphitic quartz(60–90 percent)-muscovite (10–35 percent)-biotite schist	100	*q*
Dark-gray-green medium-grained plagioclase-hornblende-(chlorite)-(epidote)-(ankerite) schist	200	*r*
Dark-gray fine-grained graphitic quartz(60–90 percent)-muscovite(10–35 percent)-biotite schist	500	*s*
Dark-gray-green medium-grained plagioclase-hornblende-(chlorite)-(epidote)-(ankerite) schist	500	*t*
Medium- to dark-gray plagioclase-hornblende-chlorite schist with conspicuous 2- to 4-mm plagioclase insets and 15-cm angular rock fragments	350	*u*
Dark-gray-green medium-grained plagioclase-hornblende-(chlorite)-(epidote)-(ankerite) schist	500	*v*
Dark-gray fine-grained graphitic quartz-muscovite-biotite schist	400	*w*
Moretown Formation (quartz-mica schist unit):		
Buff to light-gray fine- to medium-grained quartz-plagioclase-mica-garnet schist	1,700	----------

SECTION *E. Approximate stratigraphic section through the Hawley Formation along Sam Hill Road, south-central Worthington quadrangle*

	Thickness (feet)	*Symbol in figure 3*
Goshen Formation:		
Gray fine- to medium-grained thin-bedded, generally cyclically bedded quartz-muscovite-biotite-chlorite-garnet-staurolite schist and gray fine-grained quartzite	6,000	---
Hawley Formation (585 ft):		
Dark-green medium-grained plagioclase-hornblende amphibolite, in part compositionally layered with 1-inch felsic and mafic bands	250	*x*
Gray fine-grained quartz-muscovite-plagioclase-biotite-garnet schist with graphitic streaks	20	*y*
Dark-green medium-grained plagioclase-bornblende amphibolite	75	
Dark-gray fine-grained graphitic quartz-muscovite schist and brown sandy quartz-feldspar-mica-garnet schist	40	
Dark-green medium-grained plagioclase-hornblende amphibolite	200	*z*
Moretown Formation (quartz-mica schist unit):		
Buff to silvery-gray medium-grained quartz-plagioclase-mica-garnet schist	800	---

The lenticular character of many of the lithologic subunits of the Hawley is shown diagrammatically in figure 3, in which the lateral relations between the stratigraphic sections described above are portrayed. The thinning of the volcanic pile both north and south of the general Hawley-Charlemont area (fig. 1) is clearly shown.

Black schists that locally are present at or near the top and base of this sequence of metavolcanic rocks have ambiguous stratigraphic relationships. In his descriptions of the Hawley Schist and the overlying Goshen Schist, Emerson (1898, p. 165, 179–180) was apparently uncertain how best to deal with them. He stated (p. 165), in describing a section across the Hawley Schist, that:

> this [the hornblende schists and chlorite schists] is followed by a series of thin-fissile, very fine-grained, friable, dark gray mica schists, made up almost wholly of muscovite, and without accessories; this band can be followed clear across the town of Worthington and lies beneath the undoubted flaggy schists of the next series (Goshen), to which I have usually, but with some hesitation, referred it.

Emerson referred again to a "doubtful border layer" (p. 180) of black schist above the Hawley hornblende schists but separated from the main body of the Goshen Schist by a thin band of amphibolite.

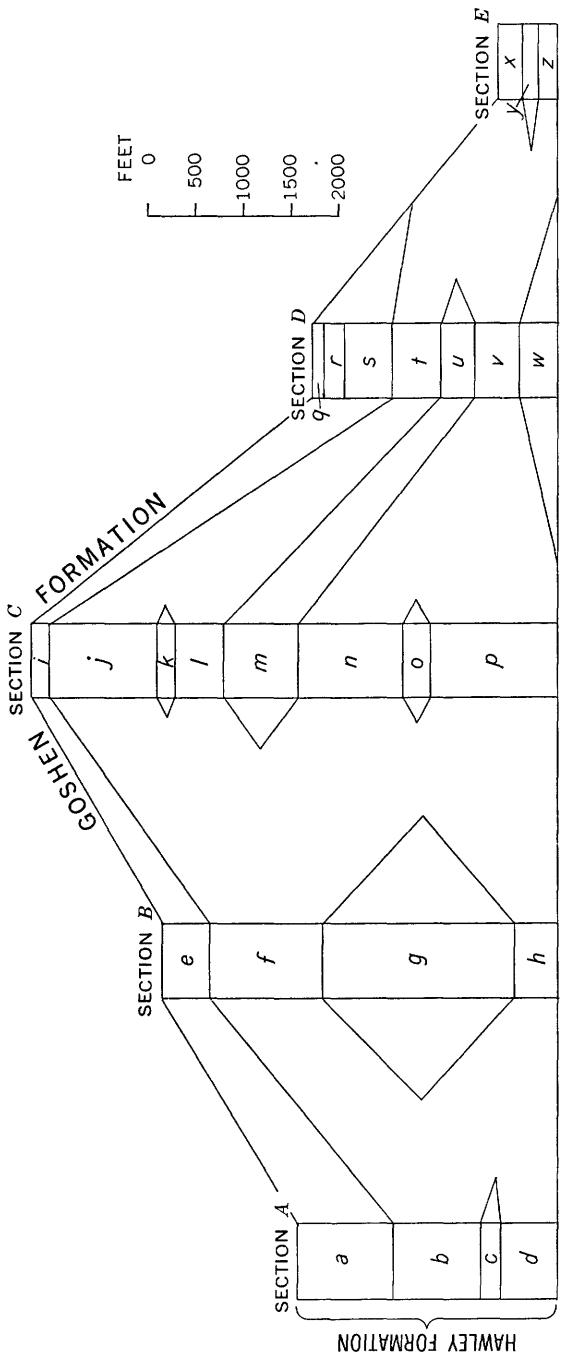

FIGURE 3.—Lateral relations between the stratigraphic sections through the Hawley Formation. Lowercase letters identify intervals described in measured sections.

In his earlier report Emerson (1898, pls. 24, 34) also interpreted a band of black schists and quartzites at the base of the Hawley as a wedge of Goshen Schist, downdropped along two faults. On his later map (1917, pl. 10), however, this lower belt is not indicated and the rocks are included in the Hawley. Finally Emerson (1917, p. 45) noted the similarity between the Ordovician graptolite slates at Magog, Quebec, and "certain black slates in Heath and Charlemont which I have put in the Hawley Schist." Despite this comment, however, his accompanying map (pl. 1) shows these "certain black slates in Heath and Charlemont" as a band of Goshen Schist west of (stratigraphically below) a band of "hornblende schist in the Goshen Schist." This band may be the same "doubtful border layer" referred to above. Although Emerson's final conclusion as to the identification of these bands of black schist within the Hawley is not clear, one can infer from his discussion of these schist bands (above) that he was aware of their ambiguity and consequently fluctuated some in his interpretation of their stratigraphic and structural position.

Recent mapping by the author in the Heath and Worthington quadrangles and by the author and P. H. Osberg in the Plainfield quadrangle (P. H. Osberg, N. L. Hatch, Jr., and S. A. Norton, unpub. data) clearly demonstrates that these black schists, about which Emerson expressed concern, are interbedded with the metavolcanic rocks of the Hawley. The black schists are distinguishable 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. They generally are also physically separated from the Goshen gray schists by a sharp stratigraphic break. Further, three separate mappable bands of black schist and quartzite are present in some areas—at the bottom as well as at the top of the Hawley sequence. (See strat. section *D*.) Finally, although these rocks have been studied in detail only as far south as the south edge of the Worthington quadrangle (fig. 1), reconnaissance mapping farther south suggests that the Hawley Formation may change laterally into a sequence that is about 80 percent graphitic schists and only 20 percent metavolcanic rocks. The Hawley, therefore, is here redefined to include these black schists and quartzites, as well as the interbedded chloritic, hornblendic, and feldspathic rocks of Emerson's original definition. The formation thus includes all rocks between the top of the Moretown Formation and the bottom of the Goshen Formation as redefined below.

The base of the Hawley Formation is here defined as the top of the highest bed of light-silvery-gray quartz-mica-garnet schist or quartz-feldspar granulite characteristic of the underlying Moretown Forma-

tion. The top of the Hawley is here defined as the top of the highest bed of metavolcanic schist or of the black schist and quartzite just described.

Representative sections of the Hawley Formation can be seen along Hunt Road, west of Hawley Village, in the eastern part of the Plainfield quadrangle, and in Davis Mine Brook between the Davis Mine and Mill Brook in the southwestern part of the Heath quadrangle. The author proposes that the section across Parker Hill in the Plainfield quadrangle—between Moody Spring on the west and East Hawley Road on the east—be taken as the type section for the redefined formation (strat. section *C*, p. D7–D8). Although this type section is characteristic of the formation in the central part of the area of figure 1, it is not truly representative of the formation either north or south of Parker Hill as shown by the stratigraphic sections (p. D5–D9) and figure 3.

CORRELATION, AGE, AND THICKNESS

The Hawley Formation in Massachusetts is continuous with the Barnard Volcanic Member and the black schist member of the Missisquoi Formation of the Vermont State map (Doll and others, 1961; see also fig. 2, present report). Because no fossils have been found in these rocks in Massachusetts, the Middle Ordovician age assigned to the Hawley is based entirely on this correlation with Vermont and on correlations of these Vermont units with the fossiliferous rocks in the Beauceville of Quebec (Cady, 1960).

In the area studied (fig. 1), the Hawley Formation ranges in thickness from about 6,000 feet in Charlemont to about 600 feet in Worthington.

GOSHEN FORMATION

Emerson's (1898, 1917) Goshen Schist is here redefined to make its definition compatible with the above redefinition of the Hawley and to clarify its internal stratigraphy and its upper boundary. Its designation is here changed from Goshen Schist to Goshen Formation.

The redefinition of the Hawley described above assigns to the Hawley some black schists that Emerson included in his Goshen Schist. This change alone necessitates some restatement of the boundaries of the Goshen. A further complication stems from Emerson's division of the rocks above the Hawley into the Goshen and Conway Schists. At the Vermont-Massachusetts State line, Emerson's Goshen-Conway boundary approximates the boundary of Doll, Cady, Thompson, and Billings (1961) between the Northfield and Waits River Formations. This boundary in Vermont is based on the presence of brown sandy carbonate beds more than a foot thick in the Waits

River Formation. About a mile or more south of the Vermont-Massachusetts State line, however, Emerson's Goshen-Conway boundary does not even approximate the contact mapped by the author at the base of the Waits River Formation (N. L. Hatch, Jr., and J. H. Hartshorn, unpub. data). Even Emerson's (1898, p. 177–185; 1917, p. 45–46) written descriptions fail to make clear his criteria for mapping the Goshen-Conway boundary. He (1898, p. 178) emphasized the "flaggy schists" of the Goshen in contrast with the "corrugated schists" of the Conway, yet most of the flagstone quarries and flaggy-weathering rocks are in areas mapped as Conway by Emerson. For the above reasons, Emerson's term Goshen cannot stand without modification and clarification.

The name Northfield Formation is used in eastern Vermont for a sequence of gray phyllites and slates (Skehan, 1961; Chang and others, 1965) which, at the State line, are essentially continuous with the rocks of Emerson's Goshen Schist. A few miles south of the State line, however, these rocks grade laterally into cyclically bedded schists and quartzites that are like no rocks described from the Northfield in Vermont. For this reason, the term Northfield is not suitable for these rocks in Massachusetts. Rather than introduce a new name, the following redefinition of the Goshen, henceforth Goshen Formation, is proposed as the simplest and least confusing solution to the problem.

LITHOLOGIC DESCRIPTION

The Goshen Formation, as shown in figure 1, is composed of gray quartz-muscovite-biotite-garnet-chlorite-(staurolite)-graphite schist, cyclically bedded gray schist and quartzite, thick-bedded (1–2 ft) gray quartzite, and rare, scattered beds as much as 10 inches thick of brown-weathering sandy carbonate granulite.

The gray schist contains megacrysts of garnet, biotite, and chlorite 1–3 mm in diameter and, within the staurolite isograd, crystals of staurolite ¼–1½ inches in diamater set in a fine-grained phyllitic matrix of muscovite, quartz, and graphite. Bedding is absent or indistinct. This rock constitutes about 95 percent of the formation in the northernmost few miles of the State, but it changes laterally into the cyclically bedded rock described below.

The cyclically bedded rock is composed of individual beds, 2–6 inches thick, in which fine-grained very light gray sandy quartzite grades upward into light-gray quartz-mica schist, which in turn grades upward into gray phyllitic schist similar to that described in the previous paragraph. This cyclically bedded rock forms the bulk of the Goshen Formation in the Plainfield and Worthington quadrangles (fig. 1). Although the relations between the poorly bedded gray schists

and the cyclically bedded rock will not be positively known until the area between the Heath and Plainfield quadrangles is mapped in detail (fig. 1), major lateral facies changes must be involved.

Thick-bedded to massive gray and buff sandy quartzite and micaceous quartzite form a locally mappable subunit above the cyclically bedded rocks along the east edge of the southern half of the area. Fine- to medium-grained punky brown-weathering gray carbonate-quartz-mica granulite forms widely scattered beds as much as 10 inches thick and constitutes less than 1 percent of the formation. The redefined Goshen includes all these rocks—in any stratigraphic sequence or relative abundance in which they may occur—between the formational boundaries defined below.

The base of the redefined Goshen Formation is believed from regional relations to be a major regional unconformity. Where exposed in outcrop in northern Massachusetts, this contact is sharp and separates gray quartz-mica-garnet schists above from amphibolites, feldspathic schists, and black schists below. No chlorite schists, feldspathic schists, or amphibolites, other than calc-silicate bands a few inches thick, have been seen in the areas mapped to date (1967) (fig. 1) in the Goshen Formation.

The upper boundary of the Goshen is here defined as the base of the lowest dark-brown-weathering sandy limestone bed that is more than 1 foot thick. This definition is similar to the definition of the boundary between the Northfield and Waits River Formations described by Chang, Ern, and Thompson (1965). Although this boundary is fairly straight across most of Vermont (Doll and others, 1961), it is very irregular in the small area of Massachusetts in which it has recently been mapped (fig. 1; N. L. Hatch, Jr., and J. H. Hartshorn, unpub. data). These irregularities are interpreted as being due to lateral facies changes in which Goshen rocks pass laterally into Waits River rocks. For this reason, it should be emphasized that the upper boundary of the Goshen is a lithologic boundary known to diverge markedly—at least locally—from time lines. Structural interpretations based on this boundary should therefore be made only with great caution.

Representative sections through the Goshen Formation can be seen along State Route 2 east of Charlemont, where the formation is mostly poorly bedded schist, and along State Route 9 east of a point 2½ miles west of Cummington. This latter section is taken as the type section for the redefined Goshen Formation. Here the formation consists of about 1,500 feet of relatively indistinctly bedded schists overlain by about 4,500 feet of cyclically bedded rock, overlain in turn by about 1,000 feet of thick-bedded quartzite and micaceous

quartzite. Although the rocks have not been mapped in detail east of the Worthington quadrangle (fig. 1), both Emerson's report (1898) and the author's reconnaissance suggest that the thick-bedded quartzites are stratigraphically the highest rocks exposed in this area.

Although all possible lithologic variations will be distinguished in the mapping of these rocks, the mappable extent of any of them is impossible to know at this time. Hence, no formal member names are being used or proposed at this time.

CORRELATION, AGE, AND THICKNESS

Because no fossils have yet been found in the Goshen, the only age assignment that can be given to the formation is based on correlations with the section in Vermont (fig. 2; Doll and others, 1961). Lateral facies changes are known to displace the upper boundary of the Goshen horizontally, so it is not known how much of the Silurian and Devonian section in Vermont is correlative with the Goshen Formation. The Goshen may therefore include rocks that range in age from Middle Silurian to Lower Devonian. Thus, the redefined Goshen is dated as Silurian and Devonian.

Tight isoclinal folds greatly complicate any effort to calculate or even estimate the thickness of the Goshen Formation. The top of the formation has only been mapped in the Heath quadrangle, where the minimum outcrop width of the formation is 4,300 feet. This minimum section is considered to be a homoclinal sequence in which the dips average about 75° E.; the total thickness of beds, measured normal to the bedding planes, is 4,150 feet. If a correction factor of 60 percent is applied to compensate for the isoclinal folds, a figure of 2,500 feet is obtained for the estimated original stratigraphic thickness of the formation at this one locality, where the formation is thinnest.

Only minimum thicknesses for the formation can be estimated south of the Heath quadrangle because the top of the formation is not exposed. If present interpretations of the structure are correct, a homoclinal sequence of beds at least 12,000 feet in outcrop width is exposed in the vicinity of Cummington (fig. 1). With dips averaging 85° E. in this area, if the same 60-percent factor is applied to correct for the isoclinal folds, the estimated minimum thickness for the Goshen Formation in the Cummington area is about 7,000 feet. If, as is tentatively believed, the Goshen beds immediately east of the Worthington quadrangle are a structural repetition of the beds in the Worthington quadrangle, this figure may be close to a true thickness for the formation in this area.

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