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Bedrock geology of the Rangeley Lakes-Dead River basin region, western Maine

New England Intercollegiate Geological Conference (NEIGC)

Boone, Gary M.

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Moench, Robert H.

1970

N. E. I. G. C.

RANGELEY LAKES –
DEAD RIVER BASIN REGION

NEW ENGLAND INTERCOLLEGIATE GEOLOGICAL CONFERENCE

GUIDEBOOK

for field trips in

The Rangeley Lakes - Dead River Basin Region,

Western Maine

Gary M. Boone

Editor

62nd Annual Meeting

October 2, 3, and 4, 1970

University of New Hampshire

New England Intercollegiate Geological Conference (N.E.I.G.C.)

The N.E.I.G.C. was begun in 1901 as an informal field trip, organized by William Morris Davis, to the Connecticut Valley of Western Massachusetts. The 1970 Conference in Rangeley marks the 62nd annual meeting (and 6th in the State of Maine). Throughout its history the sole purpose of the N.E.I.G.C. has been to bring together in the field those geologists interested and active in New England Geology, to consider and discuss the results of new mapping and other geologic studies.

D.W. Caldwell, Secretary, N.E.I.G.C.

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Gary M. Boone
Eugene L. Boudette — Co-chairmen
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Foreward and Acknowledgements

This fall we converge in Maine in a year that coincides with the State's sesquicentennial. The present conference, offered in the spirit of a wilderness experiment, is being held in surroundings that are still relatively rustic, and where several individuals, rather than an institution, collectively act as host.

Those in the vanguard of modern geological mapping and topical research here began their work in 1956. The results of their work, like ours, are only partially published or are still in progress.

One hundred ninety-five years ago, another group, just as determined, and perhaps as motley, came through the Dead River region on another wilderness experiment. They trekked northwestward, were beset by a hurricane, used bateaux where they could, and in that earlier winter of discontent, history reminds us that they had some difficulty when they reached Québec City. For our present Conference, however, we are concerned with the history of southeastward-encroaching ice-sheets and of deformed rocks in which much of the structure, though not all, gives southeast-facing successions of layered rocks. You will not be traversing continuously southeastward on the various trips, but the traditional purpose of the New England Intercollegiate Geological Conference, which is to spur the discussion of field geologic relationships, ensures by its very nature a more constructive approach to progress in mutual understanding than the objectives of the northwestward-marching group of nearly two centuries ago.

Since the times of Benedict Arnold and Timothy Bigelow, and of William King, Maine's first governor, the region in which the Conference convenes has become widely known for its woods products-oriented industries, and for its sporting spirit in many respects. In the beginning of this 150th year since Maine severed the cord with its Commonwealth neighbor to the south, the questionable advance of civilization has done little to erode the elemental solidarity of the Downeast viewpoint.[1]

The region is one of special bedrock stratigraphic significance, for it forms a bridge between geology which is interpreted with relative confidence in Maine, Québec, and the Maritime Provinces to the northeast, and in New Hampshire and Vermont to the southwest. To the northeast the metamorphic grade decreases, and primary depositional features and fossils are better dispersed. To the southwest regional grade increases and discoveries of critical fossil localities have been fewer. This generality would not be news to the 19th Century geologists Hitchcock or Jackson, but the problems and potential answers lurking in the metamorphic transition are still key factors with us today.

Growing interest in the Pleistocene history of the region is evident in studies that are extending the more clearly documented histories in the Atlantic and St. Lawrence lowlands headward toward the Boundary Mountains watershed. It may be that a C^{14} 'spike' will soon

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1. Cf. Strunk, Jud, 1969, Downeast Viewpoint: Columbia, CS9990; 2 sides.

be driven to unite the approaching paths of research on each side of the international boundary.

To acquaint students and professional geologists with a regional geologic setting, introductions to the bedrock and surficial geology precede the separately authored discussions of field trip localities.

Because the Rangeley Lakes-Dead River Basin Region is rural, and much of it forested, logistic responsibility for the conference has been divided among the hosting group of leaders to cope with the various demands and constraints of tall-timber geology. Although some inconvenience may be experienced in transportation, shelter, and quest for sustenance, the hosts believe that this will be more than repaid in terms of the region's October scenery, pure air and water, spectacular outcrops, and friendly residents.

None of the conference organizers nor, with one exception, scarcely any two trip leaders reside in the same part of the country. Nevertheless, though instant communication has oft-times been difficult, the ready cooperation of all colleagues in this venture is gratefully appreciated.

The work of Eugene Boudette and Robert Moench, as co-organizers, has been a key factor in accomplishing the many and varied tasks. To them, and to Tina Cotton and others of the U.S. Geological Survey offices in Boston, I offer grateful thanks. The generous cooperation of Lincoln R. Page in these respects is very much appreciated. I also acknowledge the support of the Maine Geological Survey toward the operation of the Conference. The departments of geology of Dartmouth College and of Syracuse University rendered helpful assistance. Susan Stores, of the Department of Geology, Syracuse, helped greatly in the organization of manuscripts and typing much of the guidebook.

We are mindful that the Town of Rangeley has done much to accommodate our needs, as have other residents and land-owners of the region. Their gracious support has been vital to the Conference.*

Gary M. Boone

Editor

* I am very grateful to the Maine Sesquicentennial Commission for their recent donation in support of the publication of this guidebook, and for their permission to use the Sesquicentennial seal.

Bedrock geology of the Rangeley Lakes-Dead River basin region, western Maine

by

Gary M. Boone[1], Eugene L. Boudette, and Robert H. Moench[2]

Introduction

Northwestern Maine forms a transitional zone through which the fundamental structure and stratigraphy of the less metamorphosed rocks to the northeast in Maine and Canada can be correlated with the highly metamorphosed, structurally complex rocks of southern New England. In this region (fig. 1) a nearly complete stratigraphic section is exposed from Precambrian(?) through the Lower Devonian; intrusive rocks range in age from Early Ordovician(?) to Triassic(?).

In this introduction we hope to present a synthesis of the stratigraphy and structure of the area; more detailed accounts are presented in the individual field trips. Expanding lumber operations within the past decade have opened up previously inaccessible areas, but several key exposures still remain beyond reasonable reach for conference-sized groups.

The area is large and geologically complex, and sufficient diversity of interpretation exists to provide the dynamism appropriate for a conference of this sort. Where points of contention occur in the interpretation, we hope we have presented the respective cases fairly. Modern detailed geologic investigation of the region began in 1948 when Arthur J. Boucot, then a graduate student at Harvard University and later a member of the U.S. Geological Survey, undertook his classic study of the stratigraphy of the Moose River synclinorium (Boucot, 1961, 1969; Boucot and others, 1964). C. Wroe Wolfe of Boston University began a long-term study of the southeastern part of the region in 1948, which was carried on more recently by Mohammed A. Gheith, also of Boston University. They directed an undergraduate field camp, and N.S.F.-N.A.G.T. summer institute, and graduate students in several mapping projects: Robert H. Moench (Phillips quadrangle), Robert J. Willard (Kennebago quadrangle), Victor Columbini (Rangeley quadrangle), Ross G. Schaff (Little Bigelow Mountain quadrangle), and Stanley Skapinsky (Kingfield quadrangle). Although work of the Boston University group is largely unpublished, it has stimulated further research and contributed greatly to our present geologic knowledge of the region.

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[1]Maine Geological Survey and Syracuse University, Syracuse, New York

[2]U.S. Geological Survey, Boston, Massachusetts, and Denver, Colorado

Geology modified by G.M. Boone, E.L. Boudette, and R.H. Moench from Hussey and others (1967), Harwood (1966), Harwood and Berry (1967, fig. 2), Green and Guidotti (1968, fig. 19-4), Moench (1970b), and Osberg and others (1968, fig. 18-2).

Figure 1. Bedrock geologic map of the Rangeley Lakes-Dead River basin region, western Maine

EXPLANATION

Rocks of sedimentary and extrusive origin metamorphosed in much of the region to chlorite grade and higher grades of metamorphism

Merrimack Synclinorium — Boundary Mountains Anticlinorium — Connecticut Valley-Gaspé Synclinorium

Lower to Middle Devonian

Lower Devonian and Lower Devonian(?)

IV-9 — Tomhegan Formation
Metasandstone, metapelite, and felsic to intermediate volcanic rocks

IV-8 — Tarratine Formation
Metasandstone and metapelite with subordinate quartzite and metalimestone

Moose River Synclinorium

IV-7h, IV-7s

IV-7s: Seboomook Formation and probable equivalents in southeastern and northeastern strike belts. Cyclically bedded metashale and metasandstone

IV-7h: Hildreths Formation and equivalent calc-silicate and metasandstone units; may be IV-5 in part, east of Stratton

IV-5b, IV-5a

IV-5a: Calcareous metapelite and calc-silicate rock, Pierce Pond and northeastward

IV-5b: Madrid Formation and unnamed calcareous metasandstone and metapelite near Wyman Lake, Bingham quadrangle

Lower Silurian

IV-6 — Formations of the Moose River synclinorium and unnamed units near Jackman and to the southwest
Calcareous slate and metalimestone

IV-4 — Smalls Falls Formation and unnamed units near Wyman Lake, Bingham quadrangle
Rusty-weathering, sulfidic metashale, metasandstone, and metaconglomerate

Pz — Light-hued phyllite and slate, metasandstone, metagraywacke, pillow lava, and metavolcanic rock

IV-3 — Perry Mountain Formation
Bedded metasandstone, metashale, and metaconglomerate

Lower Silurian and Lower Silurian(?)

IV-1 — Rangeley Formation
Metashale, metasandstone, and metapelite
Unnamed units near Spring Lake in the Stratton quadrangle
Banded calc-silicate rock

IV-2 — Vitreous quartzite, locally conglomeratic, feldspathic metasandstone, and metapelite

? TACONIC UNCONFORMITY

Upper Ordovician(?)

III — Quimby and Greenvale Cove Formations
Metagraywacke, felsic metavolcanic rock, metapelite, and metasandstone

Middle Ordovician

II-6, II-5

II-6: *Dark sulfidic slate, metagraywacke, and local metaconglomerate*

II-5: *Greenstone*

Upper Cambrian(?) to Middle Ordovician

II-4 — Green, locally variegated red and green metapelite and subordinate green metagraywacke; *characteristically pinstriped; laminated to thickly bedded*

II-3 — Dark sulfidic slate and phyllite, metagraywacke, and feldspathic metasandstone

II-2, II-2g

II-2: *Green, quartzose, chloritic metagraywacke and interlayered metapelite, red slate, and greenstone*

II-2g: *Greenstone of II-2 shown differentiated east of Spencer Lake*

II-1 — Dark and light greenstone, felsic metavolcanic rock, and cherty iron formation

UNCONFORMITY

I — Chain Lakes massif
Granofels, gneiss, schist, quartzite, and thinly layered amphibolite

Intrusive Rocks

Triassic(?) lamprophyre dikes, widespread throughout the region, are not shown

Devonian and Devonian(?)

4b — Quartz monzonite and granodiorite

4a — Norite, troctolite, gabbro, diorite, and quartz diorite

rhg — Garnet rhyolite and felsic hypabyssal rocks in the Moose River synclinorium

Silurian and Silurian(?)

Ordovician and Ordovician(?)

3 — Quartz porphyry and aplitic rocks

2 — Altered quartz monzonite and granodiorite; includes Attean Quartz Monzonite

Cambrian or Ordovician

1 — Altered epidiorite, serpentinite, quartz diorite, pyroxenite, gabbro, and alaskite of the ultramafic complex

Precambrian(?)

Contact
Dotted where concealed

Faults

Unclassified

Thrust or reverse
Sawteeth on upper plate

Folds
Direction of plunge shown where known

Syncline

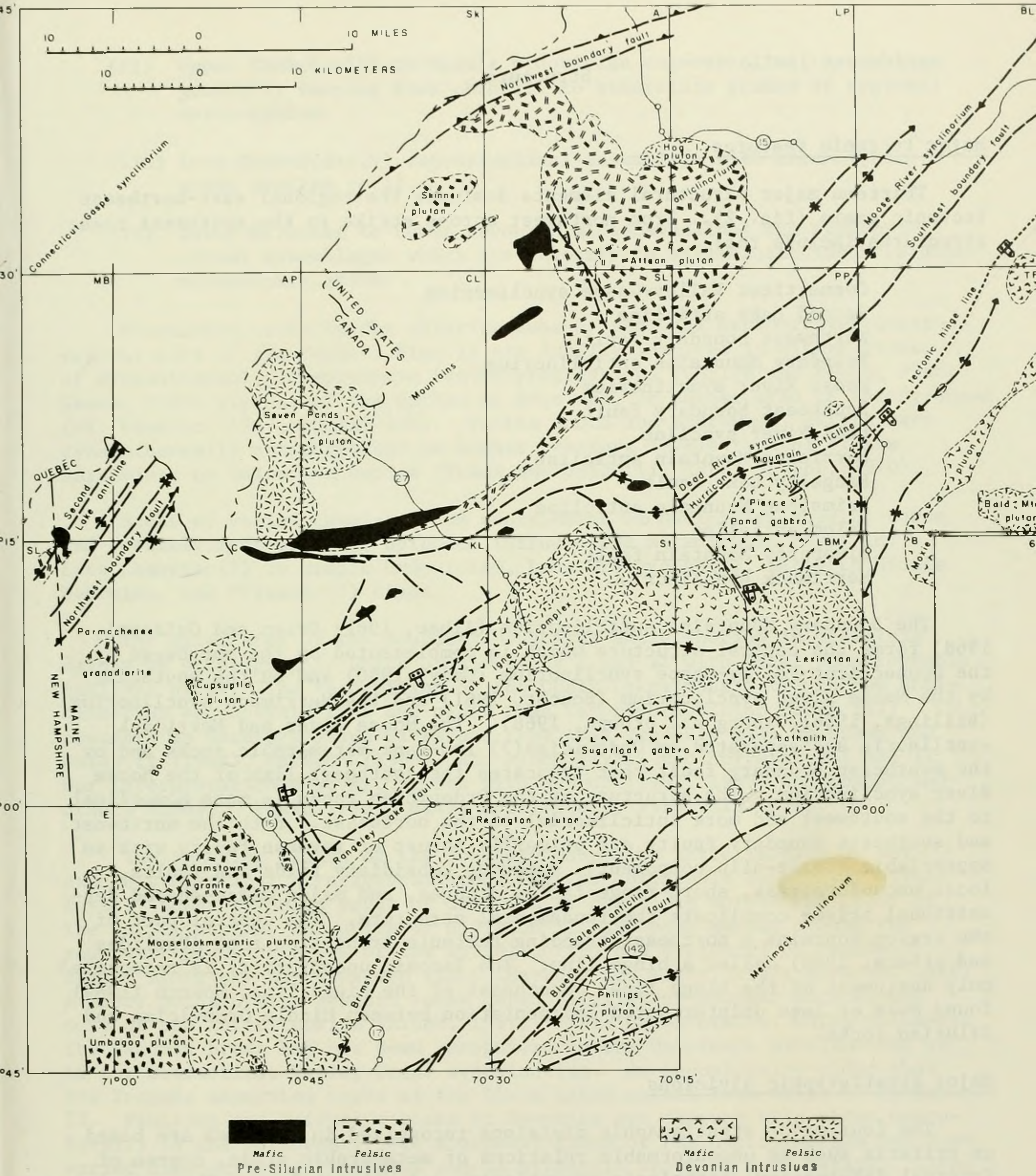
Anticline

Patrick M. Hurley and James B. Thompson, Jr. (1950) conducted an aeromagnetic-geologic reconnaissance over the northeastern part of the region.

In 1956, the U.S. Geological Survey began a broadly based research program oriented toward the economic geology of the region. This program is still in progress. It includes detailed geologic mapping at the scale of 1:62,500, geochemical and geophysical exploration, aeromagnetic mapping, and heavy-metals resource studies. Geologic quadrangle mapping that has been completed or is in progress by both Survey and non-Survey geologists is summarized in figure 2. Frank C. Canney has carried out research in geochemical exploration and remote-sensing techniques since 1958 when Edward V. Post and others were conducting geochemical reconnaissance studies. Martin F. Kane and others carried out regional gravity field studies between 1959 and 1969. Aeromagnetic maps for much of the region have been published by the U.S. Geological Survey. (Bromery and others, 1957a, 1957b; Bromery, Soday and others, 1963; Bromery, Tyson, and others, 1963; Bromery and Gilbert, 1962; Henderson and others, 1963a, b; Henderson and Smith, 1964; Boynton and Gilbert, 1964a, b, c, d; U.S. Geological Survey, 1969).

Fossils in metamorphic rocks of the area have provided a key to fit the regional stratigraphy into the geologic time scale. We are especially indebted to the following paleontologists for working with the partially metamorphosed fossils that we and others have collected: Arthur J. Boucot, Oregon State University: William B.N. Berry, University of California at Berkeley; William H. Oliver and Robert B. Neuman, U.S. Geological Survey; and Robert Finks, University of Miami in Florida. We are also indebted to many others, only a few of whom are mentioned below, for their beneficial contributions through discussion and encouragement. Lincoln R. Page of the U.S. Geological Survey has been a prime moving force behind modern geologic mapping and correlation here and elsewhere in New England. A.J. Boucot established the Silurian and Devonian stratigraphy of the Moose River synclinorium as we now know it. Raymond A. Marleau (1968) mapped the Woburn, East Megantic, and Armstrong areas, Quebec, to the northwest while a graduate student at Laval University. Marland P. Billings and J.B. Thompson, Jr., of Harvard University, John B. Lyons of Dartmouth College, Arthur M. Hussey, II, of Bowdoin College, and Robert G. Doyle, State Geologist of Maine, have made significant contributions to the regional stratigraphy through their involvement with similar problems of New England geology. Finally, we are grateful for the interest and cooperation extended by the principal landholders in the region, including the Brown Company, Scott Paper Company, Hudson Paper Company, Central Maine Power Company and affiliates, and the Dead River Company.

The geologic nomenclature used in this report is from many sources and does not necessarily reflect the usage of the U.S. Geological Survey.



Sk, Skinner - *E.L. Boudette (unpublished data)*
A, Attean - *A.L. Albee (1961), A.L. Albee and E.L. Boudette (1971)*
LP, Long Pond - *A.J. Boucot (1961, 1969)*
BL, Brassua Lake - *A.J. Boucot (1961, 1969)*
MB, Moose Bog - *J.C. Green (1968)*
AP, Arnold Pond - *D.S. Harwood (1968)*
CL, Chain Lakes - *E.L. Boudette (unpublished map)*
SL, Spencer Lake - *A.J. Boucot (1961, 1969), E.L. Boudette and G.M. Boone (unpublished data)*
PP, Pierce Pond - *A.J. Boucot (1961, 1969), G.M. Boone (unpublished map)*
TF, The Forks - *E.V. Post (unpublished map)*
SL, Second Lake - *J.C. Green (1968)*
C, Cupsuptic - *D.S. Harwood (1966)*
KL, Kennebago Lake - *E.L. Boudette (unpublished map)*
St, Stratton - *Andrew Griscom (unpublished map)*
LBM, Little Bigelow Mountain - *G.M. Boone (1970)*
B, Bingham - *B.D. Keith (unpublished map), G.M. Boone (unpublished map)*
E, Errol - *J.C. Green (1964)*
O, Oquossoc - *C.V. Guidotti (unpublished map)*
R, Rangeley - *R.H. Moench (1970)*
P, Phillips - *R.H. Moench (1970)*
K, Kingfield - *John Raabe (unpublished map)*

Figure 2. Index map of major tectonic features showing locations of 15-minute quadrangles and sources of detailed and reconnaissance bedrock geologic mapping in the Rangeley Lakes-Dead River basin region, western Maine.

Structure

Major tectonic features

Thirteen major structural elements dominate the regional east-northeast tectonic grain (fig. 2). From northwest across strike to the southeast these structures include the:

Connecticut Valley-Gaspé synclinorium
Second Lake anticline
Northwest boundary fault
Boundary Mountains anticlinorium
Moose River synclinorium
Southeast boundary fault
Dead River syncline
Hurricane Mountain anticline
Rangeley Lake fault
Brimstone Mountain anticline
Salem anticline
Blueberry Mountain fault
Merrimack synclinorium

The Boundary Mountains anticlinorium (Albee, 1961; Green and Guidotti, 1968) forms the central structure which is complemented on the northwest by the Connecticut Valley-Gaspé synclinorium (Cady, 1960) and on the southeast by the Moose River synclinorium (Boucot, 1961) and the Merrimack synclinorium (Billings, 1956; Osberg and others, 1968). The Moose River and Merrimack synclinoria are separated by Ordovician(?) low-rank metamorphic rocks and by the southeast boundary fault that truncates the southeast limb of the Moose River synclinorium. The structure of the Ordovician rocks is more homoclinal to the southwest and more anticlinorial to the northeast. Both the northwest and southeast boundary faults are primarily thrust or reverse faults with an appreciable strike-slip component. Numerous subsidiary folds and faults, local unconformities, short-range facies changes, and major wedge-shaped depositional prisms complicate the fundamental structure. The central part of the region contains a northeast-trending tectonic transition zone (Pavlides and others, 1968) called a hinge line. The Taconic unconformity is recognized only northwest of the hinge line. Southeast of the hinge line, Moench (1969) found more or less uninterrupted sedimentation between Middle Ordovician and Silurian rocks.

Major stratigraphic divisions

The four major stratigraphic divisions recognized in the area are based on criteria such as unconformable relations of metamorphic grade, degree of internal deformation, lithologic assemblages, and paleontology. These divisions are:

(I) Precambrian(?) crystalline rocks (Chain Lakes massif) of originally pervasive high metamorphic rank.

(II) Upper Cambrian(?) to Middle Ordovician eugeosynclinal assemblage generally ranging from chlorite to staurolite grades of regional metamorphism.

(III) Late Ordovician(?) eugeosynclinal assemblage with metamorphic grade similar to II.

(IV) Lower Silurian to Lower Devonian miogeosynclinal and eugeosynclinal assemblages which are chlorite to sillimanite and K feldspar metamorphic grade.

Stratified rocks in the chlorite zone of regional metamorphism (east-central part of the region, fig. 1) are locally involved in higher grades of dynamothermal, low-pressure facies progressions (Childs and Boone, 1968; Green, 1963) typical of the Buchan of Scotland, or Bosost area of the Pyrenees (cf. Winkler, 1967, p. 125-130). To the south and southwest, strata were dynamothermally metamorphosed at higher pressure levels typical of the Barrovian, or Dalradian series (Evans and Guidotti, 1966; Moench, 1970).

Rocks of varied chemistry and emplacement mechanics assigned to three and possibly four plutonic episodes intruded the metamorphic rocks in: Late Cambrian(?) to Middle Ordovician, Late Ordovician(?), Early to Middle Devonian, and Triassic(?) times.

The axial area of the Boundary Mountains anticlinorium is underlain mainly by stratigraphic units of divisions I and II with local unconformable outliers of IV. The recognition of the Chain Lakes massif (I) in the anticlinorium as separate from and older than Cambro-Ordovician rocks (II) presents an interpretation different from that recently made by Green and Guidotti (1968), Harwood (1968), and Albee (1961) who correlated I and II. Our interpretation however, agrees with Boucot (1961, 1969) and Boucot and others (1964). Field Trip C deals specifically with this topic.

The opposing flanks of the Boundary Mountains anticlinorium do not expose symmetrical stratigraphic sequences or comparable subsidiary structures. Lower Devonian rocks of division IV correlate across the crest of the anticlinorium, and units of division II have been mapped around the southwest-plunging crest of the anticlinorium and projected on regional strike along the northwestern flank (Harwood and Berry, 1967; Harwood, 1969). A major unconformity beneath rocks dated Silurian or younger defines the core of the anticlinorium (Albee, 1961). This unconformity, which documents the Taconic break has not been recognized in the Merrimack synclinorium or in the Connecticut Valley-Gaspé synclinorium. An unconformity older than the Taconic separates rocks of the Chain Lakes massif from those of division II. Faulting and intrusive rocks of Devonian age obscure this older unconformity to the northwest. The southeast flank of the anticlinorium has more varied distinctive lithologies and is presently known in more detail. Lithologic units form through-going strike belts or are draped across the nose of the anticlinorium. Despite varied tectonic events and widespread polymetamorphism, unique combinations of depositional structures and lithic sequences persist within units.

Merrimack synclinorium

The stratified rocks facing the axial trace of the Merrimack synclinorium southeast of the Chain Lakes massif are assigned to an older depositional prism (divisions II and III), and to a younger prism (division IV) which conformably overlies the older prism where the Taconic break is absent. In ascending order, from northwest to southeast, the older prism contains: greenstone; metamorphosed quartz-latitic volcanic rocks, metagraywacke, metapelite, and metamorphosed cherty iron formation; euxinic metapelite and metasandstone; chloritic metapelite and calcareous quartzite; and euxinic metapelite containing Middle Ordovician fossils, greenstone, metagraywacke, felsic metavolcanic rocks; euxinic metasandstone, metapelite, metaconglomerate, felsic metavolcanic rocks, and laminated metasiltstone. This nearly homoclinal structure passes northeastward into the Dead River syncline and the Hurricane Mountain anticline. The northwestern boundary of the younger prism is marked by the presence of orthoquartzite, metasandstone, and slate (IV-2) of late Early Silurian age which is correlated with the Clough Formation of New Hampshire (Billings, 1956 and Boucot and Thompson, 1963). The slates and younger metapelites are characteristically less magnesian than those of divisions II and III. This compositional boundary is essentially coincident with the southeasternmost extent of the Taconic unconformity, where the uppermost unit of the older prism becomes conformable with rocks of division IV. The stratigraphic sequence in the younger prism is in ascending order metapelite, metasandstone, and metaconglomerate of the Rangeley Formation (Moench, 1970; Osberg and others, 1968); cyclically bedded metasandstone and metapelite; euxinic metapelite and metasandstone; calcareous metasandstone; and metapelite of the Seboomook Formation.

The stratigraphic sequence of both prisms is repeated to varying degrees by a combination of folds and faults of regional scale including the southeastern boundary fault which repeats nearly all the section of division II south of Round Mountain. The structural interpretation presented here is largely based upon detailed tracing of lithofacies units and observation of top-facing directions, especially at contacts. Where fault repetition of division II rocks occurs on the southeastern boundary fault, the total section in II is observed to thicken remarkably toward the southeast. The same observation is true of the units in divisions III and IV, many of which thin and pinch out northwestward over the tectonic hinge line. Our conclusion is that the geosynclinal furrow receiving the sedimentary and volcanic protoliths of these rocks existed at least as early as Cambrian time.

Connecticut Valley-Gaspé synclinorium

Recent recognition of widespread units of division II in the Second Lake anticline, and fault dislocations nearby (Harwood, 1969) require a reappraisal of previous interpretations (Albee and Boudette, in press; Marleau, 1968; Green, 1968; Green and Guidotti, 1968; and Albee, 1961). The rocks here are not as clearly grouped into depositional prisms, and distinctive basal units are absent. The Taconic unconformity is exposed north of Aziscohos Lake but becomes obscured by the northwest boundary fault to the northeast. Rocks mapped directly above the unconformity are probably

Early Silurian(?) in age and are younger than their counterparts on the southeast flank of the Boundary Mountains anticlinorium. The extent of the unconformity toward the axis of the Connecticut Valley-Gaspé synclinorium is not established. If a relationship comparable to that of the Merrimack synclinorium exists, then rocks (Pz) older than the Early Silurian(?) rocks could be present, although no obvious lithofacies correlations are presently evident. The Compton Formation (Marleau, 1968), a correlative of the Seboomook Formation, is known to thicken to the northwest, and, therefore, sedimentary prisms may also apply to the northwest flank. Time-coincident environments of deposition probably vary on opposite flanks of the Boundary Mountains anticlinorium, and, until more data are available, it can only be observed that rocks younger than those of division II have less lithologic variation and include a widespread abundance of gray or green metapelite and metasandstone. Rocks of division II are correspondingly areally restricted, and the existence of division III rocks is, for the present, an equivocal matter in the Connecticut Valley-Gaspé synclinorium. Harwood and Berry (1967) correlated an euxinic metapelite on the northwest flank of the Boundary Mountains anticlinorium with a paleontologically dated, lithologically comparable unit on the southeast. This correlation is not entirely consistent with observations on the southeast in division II rocks, but the possibility remains that some euxinic units are indeed equivalent and occur in structural windows.

If an older prism is present on the northwest flank of the Boundary Mountains anticlinorium, it may be represented by greenstone and feldspathic metagraywacke in an upright sequence facing the Connecticut Valley-Gaspé synclinorium. The upright sequence of a possibly younger prism may include green metapelite and calcareous metasiltstone, calcareous metapelite and marble, metamorphosed quartz-latite volcanic rocks, red and green metapelite, and cyclically bedded gray slate of division IV. The layered rocks on the northwest are also tectonically repeated, and because of faulting, segments of the section are probably not exposed.

Internal deformation, paleotectonics, and metamorphism

The internal deformation of rock units within the major divisions is variable. This is especially true for the rocks of IV. Crowding adjacent to postkinematic Devonian plutons has produced very complex deformation patterns (see Harwood, 1966; Boone, in press), but other local, complex deformation is not clearly attributable to the emplacement of young plutons, and it must be concluded that either multiple orogeny or a combination of tectonic events, such as major submarine sliding within accumulating sedimentary prisms, may have occured (Moench, 1966, 1970).

Magnesium-rich metapelite and metagraywacke of II, which have been correlated with the Albee Formation by Harwood and Berry (1967) and Green and Guidotti (1968), consistently show intricate folding. This subject is dealt with in detail in Trip H. This may be attributed to refolding of Taconian folds by Acadian tectonism (Harwood, 1966). Thick-layered metavolcanic rocks and massively-bedded graywacke, which are conformable with and stratigraphically beneath this intensely deformed unit, show more open folding and tilting of fault blocks, probably because of bulk competency that led to buttressing mechanics.

Rocks of IV in the Merrimack and Connecticut Valley-Gaspé synclinoria are tightly folded and faulted along northeast-trending axes. In contrast, units of this group on and adjacent to the anticlinorial tract are much less deformed by folding but locally show late fault breakage and imbrication. Pre-Devonian intrusive rocks are abundantly altered and deformed, whereas the Devonian intrusive rocks are only locally faulted and deuterically altered along their margins. Polymictic conglomerates in IV contain clasts of resistant varieties of rocks and of the distinctive blue quartz of recognizable provenance in divisions II and III. Clasts from division I were not observed in the conglomerates; units of division I were probably not as emergent in Early Silurian time as they were in the Late Silurian when units of IV were deposited directly upon I. The postulated older unconformity separating the rocks of I and II was initially modified by the extrusion of mafic volcanic rocks directly upon granofels of the Chain Lakes massif. This relationship, shown by rocks near Round Mountain, was not as spectacular as the Taconic unconformity, which is commonly marked by distinctive clastic units or by well-bedded calcarenite. Initial contrasts that may have existed beyond the present contrast in metamorphic grade have been partially obscured by the conformable emplacement of the ultramafic complex along the break. At present, only one exposure is known where the direct metamorphic contrast can be seen (see Trip C).

Steeply dipping axial-plane cleavage characterizes all rocks of divisions II, III, and IV. Rocks of I have no axial-plane cleavage, but bedding foliation is common in the well-layered units. The cleavage in the younger divisions is locally folded or cut by slip cleavage. Slip cleavage and fold bands of diverse orientation are locally developed near faults and plutons.

The tectonic and metamorphic overprint of the Acadian orogeny dominates the region by the large scale rearrangement and metamorphism of the rocks. Whether rocks of division II were prograded wholly or in part in Acadian time is not certain. The tectonic environment in Early Ordovician time which accommodated the emplacement of the ultramafic complex and the Attean Quartz Monzonite suggests at least a local metamorphic event that may have resembled that in modern blueschist terranes such as in California. Devonian plutons have been variously dated by radiometric methods as 360 to 395 m.y. (Lyons and Faul, 1968; Faul and others, 1963). Well-defined contact aureoles without major retrograde effects surround many of the plutons that clearly truncate Acadian folds. These plutons were emplaced, therefore, after the principal Acadian deformation and at or slightly later than the thermal peak of regional metamorphism.

Stratigraphy

We use established stratigraphic names. Where stratigraphic problems may exist in lithologic description, sequence, or age from the type area, we briefly mention their history. The stratigraphy is reviewed within the tectonic framework discussed above, although tectonic and stratigraphic boundaries do not always coincide.

Core of the Boundary Mountains anticlinorium

Chain Lakes massif (division I). This unit is composed of the following rock types, any two or more of which are commonly interlayered in a given outcrop: Light-colored, massively bedded quartzite; black schist and massive feldspathic metasandstone interlayered with dark thinly layered amphibolite; gray biotite gneiss; gray well-layered or complexly contorted chloritic quartz-feldspar-muscovite (± sillimanite) schist and felsic metavolcanic rocks; gray massive chloritic quartzfeldspar-muscovite (± biotite ± sillimanite ± garnet ± cordierite) gneissic granofels containing lithic fragments and quartz nodules; and massive dark mafic breccia. The age of the massif has not been established. The unit is probably more than 10,000 feet thick.

Considerable debate surrounds the stratigraphic interpretation of the unit. Harwood (1969) and Green and Guidotti (1968) have recently correlated it with the Dixville Formation of Green (1964) of Ordovician age, preserving an earlier interpretation (Albee, 1961) that the unit is represented in New Hampshire by the Ammonoosuc and Partridge Formations. We believe that relative age of units along the southeastern boundary of the massif in the Chain Lakes quadrangle do not permit this correlation and that the massif lacks any clearly recognized regional counterpart. The massif includes part of the Arnold River Formation of Marleau (1968), which Marleau correlated with the Quebec Group of Cambro-Ordovician age. L.R. Page (personal commun., 1969) believes that the massif bears lithologic similarities to Cambrian(?) units in southeastern New England. We have provisionally assigned the unit an age of Precambrian(?) (see also Boucot, 1961, 1969; Boucot and others, 1964).

Upper Cambrian(?) to Middle Ordovician eugeosynclinal rocks (lower part, division II). This group includes the following lithic types in ascending stratigraphic order: (II-1) Largely massive greenstone and amphibolite with relict pillow structure and breccia preserved locally; the mafic rocks are interlayered with metamorphosed quartz latite flows and breccia near Jim Pond in the Chain Lakes quadrangle. The unit contains lenses of jasper and cherty iron-formation. (II-2) Light-green massively bedded quartz-chlorite-rich, metagraywacke, locally conglomeratic, grading to chloritic phyllite and slate, and, locally containing lenses of brick-red phyllite and slate, and greenstone. (II-3) Dark sulfidic laminated phyllite and slate interbedded with dark metagraywacke and sparse, but massively bedded light-colored feldspathic metasandstone and quartzite. This part of division II ranges in thickness from 8,000 to 15,000 feet.

Rocks of this group include, in part, the Dixville Formation of Green (1964), which has been correlated with the Partridge and Ammonoosuc Formations (see above) and assigned a Middle Ordovician age by Harwood and Berry (1967) on the basis of a dated, lithologically similar (but not contiguous) unit near Oquossoc, Maine. It is important to point out here that a stratigraphic order inversely related to ours has been interpreted by Green (1964, 1968), Green and Guidotti (1968), Harwood (1966, 1969), and Harwood and Berry (1967) which preserves the sequence of the proposed New Hampshire equivalents (Billings, 1956). We feel this interpretation is not consistent with stratigraphic top-facing directions observed at contacts in the central and eastern part of the region and furthermore, that the assigned Middle Ordovician age is not compatible with radiometric ages of intrusive rocks of Early Ordovician or older age (Holmes' scale) which cut the group. Long-range regional correlations with similar rocks in Quebec (St. Julien, 1967) which are cut by similar pre-Silurian intrusive rocks, the youngest of which is dated 480 m.y. (see Poole and others, 1963), indicates that a Cambrian or Early Ordovician age is more likely. We feel this latter interpretation of age is the more reasonable age rather than the currently accepted Middle Ordovician age.

Upper Cambrian(?) to Middle Ordovician eugeosynclinal rocks (upper part, division II). Green, red, locally green and red variegated, and black chloritic phyllite and slate interbedded with subordinate amounts of calcareous metagraywacke and locally massive calcareous quartzite, felsic metavolcanic rocks, and small greenstone lenses occur in the western part of unit II-4. The rocks are laminated to thickly bedded and characteristically pinstriped parallel to the foliation and relict bedding. White laminae range from quartz rich to plagioclase rich across a wide spectrum of metamorphic rank. Well-preserved sedimentary structures in the eastern part of the region indicate a history of redeposition of clastic sediment, reflecting sources characterized in part by mafic volcanic rocks (Trip B-1). The estimated thickness of unit II-4 ranges from 5,000 to 15,000 feet.

This sequence has been assigned in part to the Albee Formation and in part to the Aziscohos Formation of Green (1964, 1968). Harwood (1966, 1968) and Harwood and Berry (1967) assigned an age of Middle Ordovician(?) or older, and interpreted it to be the oldest stratigraphic unit in the region (see also Albee, 1961; Green and Guidotti, 1968). Although the latter interpretation preserves the essential aspects of the New Hampshire pre-Silurian section (Billings, 1956), it is not in accord with the observed sequential relationships east of the Cupsuptic quadrangle. Depositional structures in the gradational contact zone between units II-3 and II-4 in the eastern part of the map area indicate that II-4 is younger than II-3. Furthermore, these rocks, which form a continuous strike belt with the Dixville and Albee Formations, do not represent the oldest pre-Silurian units in the eastern part of the map area.

Upper Silurian(?) miogeosynclinal rocks (middle part, division IV). Rocks of IV-6 occur as scattered outliers of polymictic conglomerate, quartz pebble conglomerate and quartzite, limestone conglomerate, argillaceous or arenaceous limestone and calcareous sandstone, quartzite, and pelitic rocks with sparse felsic volcanic rocks in synclinal keels or block-faulted structures. Thicknesses as much as a few hundred feet are recorded. All these rocks are fossiliferous with locally abundant shell-fauna assemblages which date from late Llandovery to Ludlow.

Northwest limb of the Merrimack synclinorium

Middle Ordovician eugeosynclinal rocks (upper part, division II). The rocks exposed primarily north of Rangeley Lake include in approximate ascending order massive to poorly foliated greenstone (II-5) and euxinic sulfidic black slate with abundant thin beds of metagraywacke (II-6). This sequence may be as much as 13,500 feet thick. Graptolites indicative of Zone 12 of Berry (upper Middle Ordovician) were obtained from the sulfidic black slate unit (Harwood and Berry, 1967). Rocks of similar character and age are widespread in the northern Appalachians (Berry, 1968).

Rocks of the upper part of division II are in conformable contact with rocks of division III. The transition is gradational and coincides with the first appearance of felsic metavolcanic rocks and thickly bedded metagraywacke of the Quimby Formation (Moench, 1969).

Upper Ordovician(?) rocks (division III). Division III includes the Quimby and Greenvale Cove Formations which are exposed at the south end of Kennebago Lake, at Rangeley Lake, and in the core of the Brimstone Mountain anticline to the south. Rocks of this division have not been recognized elsewhere in the region. The Quimby is composed of about 1000 feet of thickly bedded metagraywacke, conglomeratic metagraywacke, felsic metavolcanic rocks, and sulfidic black metashale overlain by about 2000 feet of thinly interbedded, sulfidic metashale and metagraywacke, sparse felsic metavolcanic rocks, and local conglomeratic metagraywacke. The upper few hundred feet of the formation are particularly sulfidic and carbonaceous and contain thin beds of dense black calcareous cherty rock. Clasts in the conglomeratic rocks are chert, felsic and mafic metavolcanic rocks, quartzite, and vein quartz. No clasts that were metamorphosed before erosion and deposition have been identified.

The Greenvale Cove Formation is a thin but distinctive and extensive unit that conformably overlies the Quimby Formation and underlies the Lower Silurian(?) Rangeley Formation (IV-1). The Greenvale Cove is composed of 300 to 600 feet of light-hued, noncarbonaceous, thinly interlaminated, fine-grained clastic rocks. The silty and sandy rocks are commonly calcareous, and in the southern outcrops they form a conspicuous unit of biotite granofels and calc-silicate rock that is similar to parts of the much younger Madrid Formation (IV-5b).

The Quimby and Greenvale Cove Formations are considered Late Ordovician(?) in age, on the basis of their stratigraphic position between fossil-bearing rocks of late Middle Ordovician and Early Silurian(?) age.

Silurian and Silurian(?) rocks (lower part, division IV). These rocks include the Rangeley (IV-1), Perry Mountain (IV-3), Smalls Falls (IV-4) and Madrid Formations (IV-5b) (Moench, 1970; Osberg and others, 1968), and unnamed fossiliferous rocks in the Kennebago Lake quadrangle. As described later, probable correlatives of at least the Smalls Falls and Madrid Formations are recognized east of the Lexington batholith (IV-4, IV-5a, and IV-5b). In addition, Osberg and others (1968) have correlated the Rangeley, Perry Mountain, and Madrid Formations respectively with the Mayflower Hill, Waterville, and Vassalboro Formations exposed on the southeast limb of the Merrimack synclinorium. The Rangeley Formation is considered to be Early Silurian(?) in age, but fossiliferous rocks in the Kennebago Lake quadrangle, with which the Rangeley is correlated, are Early Silurian in age (see Trip A-1). Moench (1970) and Osberg and others (1968) have assigned a Silurian(?) age to the Perry Mountain, Smalls Falls, and Madrid Formations on the basis of correlations with fossiliferous rocks to the southeast, but recognize that the Madrid Formation may be Early Devonian in age. Silurian and Silurian(?) rocks are nearly 15,000 feet thick in the Phillips and Rangeley quadrangles. They thin drastically, however, across strike to the northwest. Facies relationships indicate a northerly or northwesterly source for at least the coarse clastic rocks of the Rangeley, Perry Mountain, and Smalls Falls Formations.

Near the east end of Rangeley Lake, the Rangeley Formation (IV-1) is nearly 10,000 feet thick and is characterized near its base by polymictic metaconglomerate with clasts of plutonic and volcanic rocks near the base, interbedded metashale and quartz-rich polymictic metaconglomerate in the middle, and interbedded metashale and quartz conglomerate near the top. To the north, near the south end of Kennebago Lake, the Rangeley thins greatly, but individual units of the formation are recognizable. The northern, coarse clastic facies of the Rangeley passes by intertonguing into a thick mass of finer-grained, gray metashale southward. The Taconic unconformity is not recognized in this area because the contact between the Greenvale Cove and Rangeley Formations is conformable and gradational. The contact between the Rangeley and Perry Mountain Formations is gradational over several tens of feet.

The Perry Mountain Formation (IV-3) is composed of nearly 2000 feet of mature, quartz-rich metasandstone cyclically interbedded with roughly equal amounts of light-hued muscovite-rich metashale. The formation is typically thin bedded, but beds of metasandstone and quartz-granule conglomerate as much as 10 feet thick are common in the middle and upper parts of the formation in the northern part of the main strike belt. Crossbedding, convolute bedding, and graded bedding are characteristic. Petrographic and chemical analyses indicate that the metasandstones are generally richer in silica than those of older and younger rocks and that the metashales are somewhat more potassic and aluminous than other metashales of the entire stratigraphic sequence. These relationships suggest that the inferred source area to the north was undergoing saprolitic weathering and shed chemically differentiated clastic rocks. The contact between the Perry Mountain and Smalls Falls Formations is sharp, conformable, and well exposed in the Rangeley quadrangle and to the southwest. Depositional structures at the contact in both formations indicate that the Smalls Falls is younger.

The Smalls Falls Formation (IV-4) is a rusty-weathering unit composed of black sulfidic metashale cyclically interbedded with sulfidic quartz-rich metasandstone. The upper few hundred feet is calcareous. Thick graded beds of commonly calcareous quartz granule metaconglomerate are abundant in northern outcrops, particularly near the faults northwest of Madrid (Moench, 1970). The Smalls Falls Formation is about 2500 feet thick west and south of Madrid, but thins and wedges out northward. The contact between the Smalls Falls and Madrid Formations is sharp and conformable.

The Madrid Formation (IV-5b) is composed of approximately 1000 feet of calcareous metasiltstone and metasandstone with subordinate amounts of metashale. The formation is divisible into a lower part, composed of thin-bedded, calcareous clastic rocks, and an upper part composed of thick-bedded, fine-grained metasandstone.

<u>Lower Devonian(?) rocks (upper part, division IV)</u>. Dominantly pelitic rocks of the Merrimack synclinorium of Early Devonian(?) age are widely exposed along the southeast margin of the area shown on Figure 1. In synclines east of Madrid and north of Kingfield, the Madrid Formation (IV-5b) is conformably overlain by an unknown thickness of medium-gray metashale, with minor amounts of metasandstone (IV-7h and IV-7s). The metashale, here in the staurolite grade of metamorphism, is variably massive, faintly cyclically bedded, and distinctively cyclically interbedded with light-gray or white beds of metasandstone. Although grouped with similar units here that are correlated with the Seboomook Formation (IV-7s), this massive metashale unit is also recognized in the Carrabassett valley as the lowermost member of a formational unit distinguished from the cyclically bedded, graded-bedded Seboomook, but correlated with the Lower Devonian(?) dominantly pelitic rocks of the region shown on Figure 1.

Southeast of the Blueberry Mountain fault is a group of rocks (IV-7h, IV-7s) called the southern sequence of Devonian(?) rocks by Moench (1970). This sequence is considered to be partly equivalent to rocks correlated with the Devonian(?) (IV-7s) northwest of the fault, but it contains a more varied lithic assemblage. In addition, the southern sequence has at least two prominent units of rusty-weathering, black sulfidic metashale; cyclically thin-bedded metashale and metasandstone similar to the Perry Mountain Formation (IV-3); and the Hildreths Formation (IV-7h, which is a thin but extensive unit of plagioclase- and biotite-rich metasandstone, calc-silicate rock, and local ribbon marble. The Hildreths and associated rocks are probably equivalent to similar rocks mapped in the upper part of the Lower Devonian sequence of the Carrabassett River valley north of Kingfield.

Silurian-Devonian correlation, Northwest flank of the Merrimack synclinorium to the southeast flank of the Moose River synclinorium

The stratigraphy and structural features of the Merrimack and Moose River synclinoria have been described (Osberg and others, 1968; Moench, 1970; Boucot, 1969), and therefore only the salient features of each that relate to fundamental regional correlation will be reviewed here. The regional map (fig. 1) extends northeastward primarily for this purpose, even though trip itineraries do not extend into the northeastern part of the map area.

Because of the scarcity of fossils in the Silurian and Devonian metamorphic rocks of the Rangeley, Phillips, northwest Kingfield, and Little Bigelow Mountain quadrangles, correlation along and across the regional strike has depended greatly on the calc-silicate-bearing rock units as markers in an otherwise uniform pelitic sequence. The lithologic sequence first established in the Phillips quadrangle, involving the Perry Mountain (IV-3), Smalls Falls (IV-4), and Madrid Formations (IV-5b), is a critical link to the stratigraphic sequence across the Sugarloaf gabbro pluton and Lexington batholith. Lack of outcrop prevents walking out the Madrid Formation from Salem (Phillips quadrangle) to Kingfield. There is little question, however, that remarkably similar lithic sequences at Kingfield are directly on strike with those near Salem and further northeastward east of the Lexington batholith. The Madrid has been mapped in detail to Wyman Lake and has been traced in reconnaissance farther northeastward.

The Smalls Falls Formation (IV-4), which directly underlies the Madrid, is not exposed in eastern Phillips quadrangle, nor in the Carrabassett valley area of the Little Bigelow Mountain quadrangle and northwestern part of the Kingfield quadrangle. What is believed to be Smalls Falls reappears southeast of the Lexington batholith. Brian D. Keith (unpublished manuscript) found top-facing sedimentary structures in the Smalls Falls and overlying Madrid equivalents in a well-exposed contact at the dam at the southeast end of Wyman Lake.

Northwest of the Salem anticline is a synclinal belt, complexly modified by intrusive-tectonic crowding, which extends to the Bigelow Mountain Range and northeastward beyond the Lexington batholith. In the northeastern area, massive metapelite grades into medium- to thinly bedded, graded-bedded metagraywacke and metapelite (all belonging to IV-7s) toward the axial zone of the synclinal belt. Where the axial zone is truncated by the Lexington batholith, infolded lenses of a younger, much more aluminous, sulfide-rich thinly layered calc-silicate and metapelite unit (IV-7h) occur.

Southeast of Pierce Pond and northeastward, G.M. Boone, and E.V. Post (unpublished data) have found southeast-facing sedimentary structures in gray massive Lower Devonian(?) slate (IV-7s) near the contact with underlying calcic metapelite (IV-5a). The calcic metapelite, forming the northwest margin of the synclinal belt noted in the paragraph above, is much thinner, more aluminous, and much less quartzose than the Madrid Formation (IV-5b) but occupies a similar stratigraphic position with respect to the overlying Lower Devonian(?) metapelite (IV-7s). Similarly, along the southeast margin of the Moose River synclinorium, thin units of predominantly calcareous slate and limestone (IV-6) are found at the base of the Silurian-Devonian stratigraphic sequence (Boucot, 1961; 1969). These basal units are in fault contact (southeast boundary fault) with underlying rocks of division II exposed in the Dead River syncline and Hurricane Mountain anticline.

The position of the basal calcareous units (IV-5a and IV-6) with respect to the immediately underlying pre-Silurian section that they flank, contrasts sharply with the thick Silurian section underlying the Madrid Formation farther southwest. Although the two calcic horizons, on the northwest and southeast sides of the synclinal belt respectively, cannot be directly correlated with each other, they are probably of similar age, later Silurian to Early Devonian. Osberg and others (1968) favor a Late Silurian(?) for the Madrid Formation (IV-5b); E.V. Post (unpublished data) reports a Wenlock to Ludlow age for fossils found in a carbonate-rich part of IV-5a. Shelly fauna from the IV-5a in the Little Bigelow Mountain quadrangle is less definitive but typical of the Silurian (A.J. Boucot, written commun., 1967, 1969). Fauna in calc-silicate rock of IV-1 in the Stratton quadrangle is dated as upper Llandoverian (Boucot, 1969).

The absence of a thick Silurian section below the thin carbonate-bearing and calc-silicate units in the central and northeastern part of the synclinal belt east of the Lexington batholith implies that the tectonic hinge formed a major control on the pattern of sediment deposition and affected lithic distribution and thickness throughout the Silurian. Varied calcic horizons in the Devonian rocks in the Merrimack synclinorium (not differentiated in Figure 1) may, therefore, project to the same apparent stratigraphic position below Lower Devonian metapelites (IV-7s) flanking the older depositional prism and the Hurricane Mountain anticline containing rocks of division II.

<u>Correlations in the southeast margin of the Connecticut Valley-Gaspé synclinorium and the Moose River synclinorium</u>

<u>Lower Paleozoic eugeosynclinal rocks, undivided</u>. Undifferentiated lower Paleozoic eugeosynclinal rocks (Pz), which include gray to interbedded gray and silver-green slate and phyllite, dark metasandstone and sparse metagraywacke, felsic metavolcanic rocks, and mafic metavolcanic rocks with pillow structure, compose the sequence here assigned to the Connecticut Valley-Gaspé synclinorium. Great variation in thickness of bedding is characteristic of these rocks, and grading and crosslamination are rarely observed. The sequence is probably more than 10,000 feet thick in western Maine. This lithologic unit was correlated with the Frontenac Formation (McGerrigle, 1935) by Marleau (1968), but Marleau thought the unit was younger than rocks mapped as the Seboomook Formation (IV-7s) of Early Devonian age or those correlated with it (Compton Formation in Québec). Boucot (1961) extended the name Frontenac Formation into Maine for rocks

on strike (Pz near Jackman), and arbitrarily correlated the unit across regional strike with the Tarratine Formation (IV-8) of Early Devonian age. The Pz unit bears a close similarity to rocks mapped beneath the Seboomook Formation in the St. John-Allagash River basins (Boudette and others, 1967), and boundary relationships between Pz and the Seboomook Formation in the northern part of the region suggest that a fault of significant magnitude separates them and transports the unit up and over the Seboomook (E.L. Boudette unpublished data). Thus its age remains uncertain (see Boucot, 1969, p. 43-46). We have provisionally shown Pz as Silurian(?) or Ordovician(?). No obvious lithologic correlatives exist southeast of the Boundary Mountains anticlinorium.

Lower Devonian rocks

The youngest metasedimentary units in the northwest and northeast part of the region are, in ascending order, the Seboomook (IV-7s), Tarratine (IV-8), and Tomhegan (IV-9) Formations (Boucot, 1961, 1969). The Tarratine and Tomhegan underlie the axial area and northwestern flank of the Moose River synclinorium in the northeast.

The Seboomook, described above, is as much as 15,000 feet thick and is dated by fossils as of Early Devonian age (Boucot, 1969, p. 35).

The Tarratine Formation is composed of interbedded dark metasandstone and metapelite with subordinate quartzite near the top and metalimestone near the bottom of the unit; its total thickness is about 10,000 feet. Bedding thickness of great variability from fractions of an inch to 50 feet characterize the unit which is dated by fossils as of Early Devonian age (Boucot, 1969, p. 27-28).

The Tomhegan Formation is composed mainly of thickbedded, dark metasandstone interbedded with thin and thick-bedded metapelite in the upper part of the unit, and felsic to intermediate metavolcanic rocks in the lower part. The unit totals about 4,000 feet in thickness and is ascribed a paleontologic age of Schoharie and possible Oriskany (Boucot, 1969, p. 20). The contact between Tarratine and Tomhegan is structurally conformable, but a disconformity is indicated by a faunal break (Boucot, 1969, p. 19-20). The Tarratine is in gradational contact with the Seboomook Formation (IV-7s) or lies unconformably upon the Attean Quartz Monzonite (unit 2).

Intrusive rocks.

Upper Cambrian(?) or Lower Ordovician(?) ultramafic complex. The complex, now metamorphosed, consists of medium- to coarse-grained epidiorite, epidiorite autobreccia, serpentinite, and altered quartz diorite with minor amounts of altered pyroxenite, gabbro, and alaskite. The complex is a differentiated sheet intruded essentially along the pre-Lower Ordovician unconformity; distinctive igneous layering is produced locally in the epidiorite facies. Serpentinite can be divided into contiguous (antigorite-bearing) and diapiric (chrysotile-bearing) types. Rocks of the complex have not been dated by radiometric methods, but the Attean Quartz Monzonite, which may be a part of the complex, is provisionally dated by the Pb-U and other methods (see below). Because the Attean cuts the ultramafic complex, the complex is older but is believed to be almost time equivalent. Both the rocks of the ultramafic complex and the Attean intrude the Chain Lakes massif and, hence, the complex is younger than the Chain Lakes and is provisionally considered to be of Late Cambrian to Early Ordovician age by correlation with similar rocks in Quebec (St. Julien, 1967).

Lower Ordovician(?) quartz monzonite and granodiorite. These units are largely leucocratic, coarse-grained, porphyritic, characterized by alteration, and locally deformed. Plutons assigned to this group include the Attean Quartz Monzonite (Albee and Boudette, in press) and the Parmachenee Granodiorite, Adamstown Granite, and Umbagog Granodiorite of Green and Guidotti (1968). The Attean has been dated by the Pb-U method; giving a radiometric age of ca. 470 m.y. (Leon T. Silver, personal commun., 1970). Because the Attean quartz monzonite has not been found intruding Middle Ordovician rocks, we consider the radiometric age indicates a probable Lower Ordovician age according to the Holmes Scale.

Quartz porphyry and related felsic rocks. Dikes and irregular bodies of quartz porphyry, granophyre, and fine- to medium-grained quartz monzonite intrude the Attean Quartz Monzonite and ultramafic complex in numerous places. The most distinctive of these localities is at Catheart Mountain in the Long Pond quadrangle where a Mo-Cu sulfide deposit is related to the porphyry. Radiometric dating of white mica in greisen associated with the porphyry at Catheart Mountain indicates that the age of the rock is between 433 m.y. and 457 m.y. (F.C. Canney, unpublished data). Textures within the quartz porphyry are suggestive of hypabyssal emplacement in an event that would require the Attean Quartz Monzonite and other host rocks to have been uplifted and exposed or nearly exposed after crystallization. Regional paleogeographic considerations suggest that such an environment was most likely in Late Ordovician or Early Silurian time. We provisionally assign the hypabyssal series to the Late Ordovician.

Lower Devonian garnet rhyolite and related felsic rocks. Hypabyssal sills, dikes, and small stocks of light-gray, fine-grained massive garnet rhyolite and felsic hypabyssal rocks cut the Tarratine Formation (IV-8) in the Moose River synclinorium. These plutonic rocks are petrochemically and spatially correlated with volcanic rocks in the Tomhegan Formation (IV-9) (Boucot, 1969, p. 59-60).

Devonian (syn- and post-tectonic) mafic intrusive rocks. A segmented, but regionally conformable belt of mafic intrusive rocks extends from the Kennebago Lake and Rangeley quadrangles northeastward beyond the conference region to Moosehead Lake and eastward (see Hussey and others, 1967). Norite, troctolite, gabbro, diorite, quartz diorite, and related rocks occur within plutons of the belt which intrude rocks as young as the Lower Devonian Seboomook Formation (IV-7s). All these rocks are associated with well-developed, commonly spectacular contact aureoles impressed upon the Acadian or older regional metamorphic assemblages which seem to have slightly predated the development of the hornfels rocks of the aureoles.

Reaction and injection hornfelses of several varieties are common, and layering comparable to that in the older ultramafic complex is not present, although flow structure and igneous layering is observed locally (Espenshade and Boudette, 1967, p. F-34). Norite near Greenville, Maine, has been dated radiometrically (biotite, K-Ar method) at 393 m.y. by Faul and others (1963). Thus, the entire belt of mafic plutons is interpreted to be Early Devonian in age.

Devonian (posttectonic) quartz monzonite and granodiorite. Widespread granitic plutons of varied size discordantly intrude metasedimentary units as young as the Seboomook Formation (IV-7s) as well as igneous rocks as young as the Devonian mafic rocks. These plutons are largely leucocratic varieties of coarse- to fine-grained quartz monzonite and granodiorite which vary from porphyritic to equigranular. These rocks have also produced well-defined contact aureoles similar to those adjacent to the Devonian mafic plutons. Radiometric dating (see Faul and others, 1963; Lyons and Faul, 1968) of the Hog Island Granodiorite near Jackman Station (Albee and Boudette, in press), gives an age of 360 m.y., but similar rocks emplaced in belts on strike to the south give slightly greater ages, to about 380 m.y. (see Faul and others, 1963, p. 4). The intrusive relationships and the radiometric dating suggest that although the granitic rocks may be younger in age than the Devonian mafic intrusives they are post-Acadian, and may also be late Early Devonian or possibly early Middle Devonian in age. Comagmatic relationships, however, are not implied.

Triassic(?) lamprophyre dikes and sills. Dark lamprophyre dikes and sills are widespread throughout the region. These rocks are nowhere abundant but apparently cut all the older rocks. The lamprophyres occur in markedly tabular bodies, ranging from a few feet to a few tens of feet thick, which usually show distinct chilled margins. Textures and modes of the lamprophyre rocks are variable, but the rocks are commonly porphyritic varieties. None of these rocks has been dated by radiometric methods. Our assignment of a Triassic(?) age to them is arbitrary.

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Introduction to the Quaternary history in the highlands region of western Maine, southeastern Québec, and northern New Hampshire

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(The authorship of each section is indicated in the text of the introduction.)

The highlands of northwestern Maine, including the Longfellow and Boundary Mountains, were overridden at least twice and perhaps several more times, by continental ice sheets during the Quaternary Period. These episodes are indicated by five, widely separated exposures displaying two-drifts sequences composed of lodgment tills separated by lacustrine and fluvial sediments. The freshness of these drifts suggest that they are probably of Wisconsin age, however this is equivocal as no way has been found to assign absolute ages to them.

Caldwell (1959) reports a two-till sequence at New Sharon, in central Maine, separated by organic materials dated at more than 38,000 years old. A recent C^{14} age determination (Stuiver, personal communication), and an analysis of the wood fragment which shows that the tree was crushed while still green, indicate that the organic material at New Sharon was overridden by ice more than 52,000 years ago. Presently there is no way of determining the relationship of the New Sharon sequence and the undated sequences to the northwest.

The last ice sheet, whose retreating margin stood along the present Maine coast approximately 13,500 years ago (Borns, unpublished), thinned, separated and stagnated over the Longfellow and Boundary Mountains of northwestern Maine, a belt 60 miles wide and rising over 3000 ft. above bordering lowlands. Nearly contemporaneous stagnation, throughout and perhaps to the southeast of the mountains, is evidenced by the distribution and volume of ice-contact stratified drift. Coupled with this is the lack of evidence of a receding active ice margin.

The separation of this ice in Maine from the still-active receding ice sheet immediately to the northwest in Québec, occurred approximately 12,800 years ago and the subsequent dissipation of stagnant ice in the mountains was complete by approximately 12,000 years ago.

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[2]Publication authorized by the Director, U.S. Geological Survey.

[3]Publication authorized by the Director, Geological Survey of Canada.

The highest glacial cirques in northwestern Maine on Crocker Mtn., with floors at an altitude of approximately 2700 ft., reveal no evidence of glacial reactivation during and subsequent to the dissipation of the last ice sheet.

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Tills of three glaciations are exposed in the Lac-Mégantic area; non-glacial fluvial sediments bearing reworked erratics from the Canadian Shield underlie the oldest till at the Grande Coulée River and indicate erosion of a terrane covered by a fourth, earlier glacial deposit. The three tills, from oldest to youngest, are named Johnville, Chaudière, and Lennoxville Tills.

Johnville Till was deposited by a glacier flowing southeast; it is overlain by the Massawippi Formation, composed of non-glacial sediments dated at >40,000 BP (GSC-1084). The Massawippi Formation contains pollen indicating climate colder than present and is tentatively correlated with the St. Pierre sediments of the St. Lawrence Lowlands.

Chaudière Till overlies Massawippi sediments. It was deposited by a glacier which first flowed southwest into and over the Lac-Mégantic region. At some time during the Chaudière glacial phase ice-flow shifted to southeast. Ice-flow directions are confirmed by fabric and petrographic data.

The Chaudière glacier is inferred to have retreated only to the St. Lawrence Lowlands. As it rested against the west- and north-facing slopes of the Appalachians, it blocked northward drainage and ponded a large lake in the Chaudière and St. Francis river basins. The lake is named Glacial Lake Gayhurst and sediments deposited in it comprise the Gayhurst Formation.

The Gayhurst Formation, consisting of a lower member of about 3400 graded silt-clay laminae, a middle member of shallow water sand and gravel, and an upper member of about 600 graded silt-clay laminae was deposited in a 380 m outlet phase (lower and middle members) and a 430 m outlet phase (upper member) of Glacial Lake Gayhurst. The 380 m outlet carried overflow east into the St. John River; the 430 m outlet carried overflow southeast through Coburn Gore, Maine and operated whenever ice stood far enough south of the Boundary Mountains to block the 380 m outlet. It is suggested that the Gayhurst Formation was deposited during the entire time interval separating deposition of Chaudière Till and overlying Lennoxville Till; 4000 couplets of laminated silt-clay may represent at least 4000 years of deposition. Presumed Gayhurst Formation sediments have been dated at >20,000 B.P. (GSC-1137).

Lennoxville Till was deposited during a major readvance over Gayhurst Formation sediments. The Lennoxville glacier is inferred to have covered all of southeastern Québec and New England. Striae, fabric, and indicator dispersal patterns indicate east-southeast movement of the Lennoxville glacier at its maximum. The Drolet Lentil of Lennoxville Till, partially derived from the clayey sediments of the Gayhurst Formation, was deposited during early south-southwest Lennoxville glacier advance up the Chaudiere valley.

The Lennoxville glacier retreated from the Mégantic area by back-wasting of actively-flowing ice. During halts or readvances the glacier built till and gravel moraines and impounded proglacial lakes in the Chaudière valley and its tributaries. As the Lennoxville glacier melted, large boulders carried in and on the ice were let down onto the surface of Lennoxville lodgment till as a one-boulder-thick ablation deposit.

No evidence was found to support the concept of late-glacial ice flow into Québec from highland centers in Maine or New Hampshire.

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Recently available exposures on Nash Stream in northern New Hampshire are the most informative to date that bear on the major controversy over the relative ages of two widespread tills in New England. This controversy considers whether the two tills are contemporaneous deposits of a single ice sheet, or are deposits of two separate glaciations.

The exposures at Nash Stream show a composite section of a lower till as much as 70 feet thick, overlain by lacustrine sediments as much as 75 feet thick. These sediments are unconformably overlain by more than 100 feet of an upper till which in turn is overlain by outwash as much as 25 feet thick. The lower till is dark olive gray, compact, silty, and has subhorizontal and subvertical joints. It is oxidized locally to a depth of about 20 feet. The depth and nature of the oxidation of the lower till is nearly identical to that in similar tills throughout southern New England, and the oxidation is believed to represent a significant weathering interval between two glaciations. The lower till is not oxidized where overlain by the lacustrine sediments, strongly suggesting that the lacustrine beds are melt-water deposits of the retreatal phase of the lower-till ice sheet.

The upper till is light olive gray to olive, compact to friable, and shows no appreciable oxidation by weathering. This till is similar to the upper till identified elsewhere in New England. At Nash Stream, the upper till truncates the lower lacustrine sediments and locally has well developed deformation (shove?) structures oriented southward. The upper outwash locally intertongues with the upper till and is therefore related in age to the younger ice sheet. At one locality, noncollapsed upper outwash truncates collapsed beds of lower lacustrine sand and gravel.

This sequence of deeply oxidized lower till associated with collapsed water-laid sediments, overlain by very thick nonoxidized till and associated outwash represents an outstanding set of exposures in New England that support the hypothesis of two major ice advances separated by a significant weathering interval.

Exposures of two superposed tills, similar to the tills along Nash Stream, are known in Connecticut, eastern Massachusetts, and southern New Hampshire. In the absence of dateable materials from these tills, regional correlation, even when restricted to southern New England, remains tentative. Extending the regional interpretation to include Maine and southern Québec is even more tenuous. However, the increasing body of field data seems to indicate that a widespread two-till stratigraphy exists throughout much of the northeast. Furthermore, the interpretation that the lower till may be pre-Sangamon in age, rather than early Wisconsinan (pre-classical Wisconsin), seems to be gaining favor. Whether more than two stratigraphically significant tills, as in southeastern Québec, are represented in interior New England remains unclear.

Several miles north of the well established stratigraphy, logs collected from till-like material are dated about 8500 years B.P. Dates from peat in till-like material stratigraphically higher than the logs are about 8300 years B.P. However, it is suggested that the logs are in landslide material composed primarily of reworked till and do not represent an ice advance at such a late date in New England.

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