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GEOLOGIC FRAMEWORK OF THE MASSABESIC ANTICLINORIUM AND THE MERRIMACK TROUGH, SOUTHEASTERN NEW HAMPSHIRE

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Introduction

The purpose of this trip is to examine the field relations between the gneisses of the Massabesic Anticlinorium and the uppermost units of the Merrimack Trough in southeastern New Hampshire and some of the igneous rocks that intrude them. Based on ongoing mapping, isotopic, structural, and petrologic studies, both the Massabesic gneisses and the Merrimack Group (Kittery, Eliot, and Berwick Formations) are interpreted as late Precambrian in age. The age of the Merrimack Group itself cannot be fixed with certainty, yet minimum ages are established by dates of the numerous plutonic rocks that intrude it. These rocks likely represent a separate lithotectonic belt between the Gander and Avalon zones of Williams (1978) (Lyons and others, 1982; Olszewski and others, 1984).

Geologic Setting and Previous Work

In southeastern New Hampshire northeast-trending, polydeformed, low to high grade metamorphic rocks crop out within the Massabesic Anticlinorium and the Merrimack Trough (figure 1). To the northwest a sequence of Siluro-Devonian rocks, in part dated by fossils, occupy the Kearsarge-Central Maine Synclinorium as recently redefined by Lyons and others (1982) (see Eusden and others, this volume). To the southeast and along the New Hampshire and southwesternmost Maine coast, variably mylonitized rocks of the high grade Rye Formation define the Rye Anticlinorium (see Swanson and Carrigan, this volume).

The Massabesic Anticlinorium is composed of high grade felsic gneisses, migmatite, and crosscutting felsic igneous rocks. The Merrimack Trough is composed of metaclastic rocks of the Merrimack Group (Kittery, Eliot, and Berwick Formations from oldest to youngest) which are intruded by the 473 Ma Exeter Diorite (Gaudette and others, 1984) and other mafic and felsic igneous rocks (figure 2). No fossils have ever been found in any of the metasedimentary rocks despite diligent search by many workers. Isotopic ages from the Massabesic gneisses and the Exeter Diorite provide the basis for our evolving reinterpretation of the geology of southeastern New Hampshire.

As the study of these rocks began more than a century ago and there has been no concensus of opinion about their age and correlation, we begin with a brief historical review. Billings (1956) elevated the stratigraphic name "Merrimack," first used by Hitchcock (1877), to the rank of Group. He included three formations, the Kittery, Eliot, and Berwick, as established by Katz (1917) and assigned an age of Middle Silurian based on correlation with similar rocks in central Maine (see Billings, 1956, p. 44, 104). This package

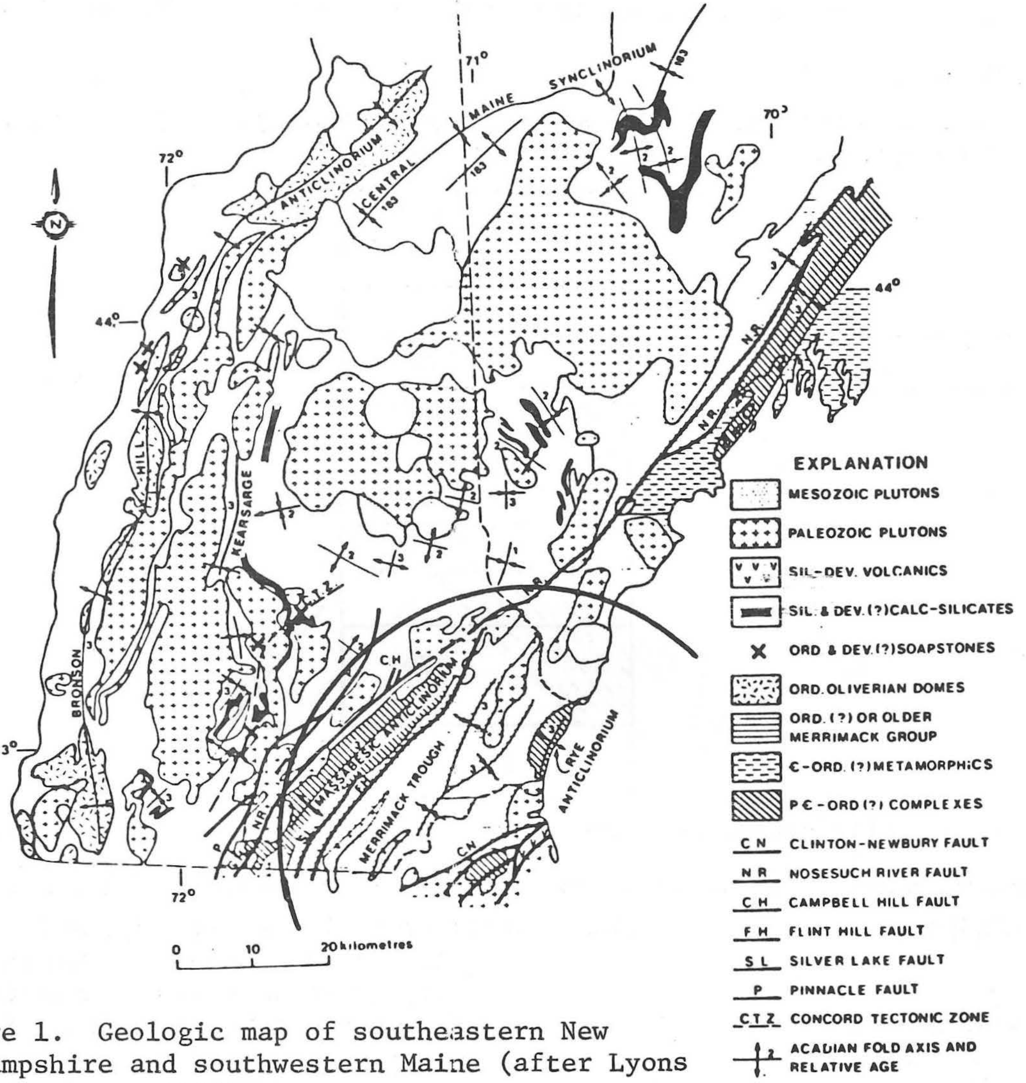


Figure 1. Geologic map of southeastern New Hampshire and southwestern Maine (after Lyons and others, 1982)

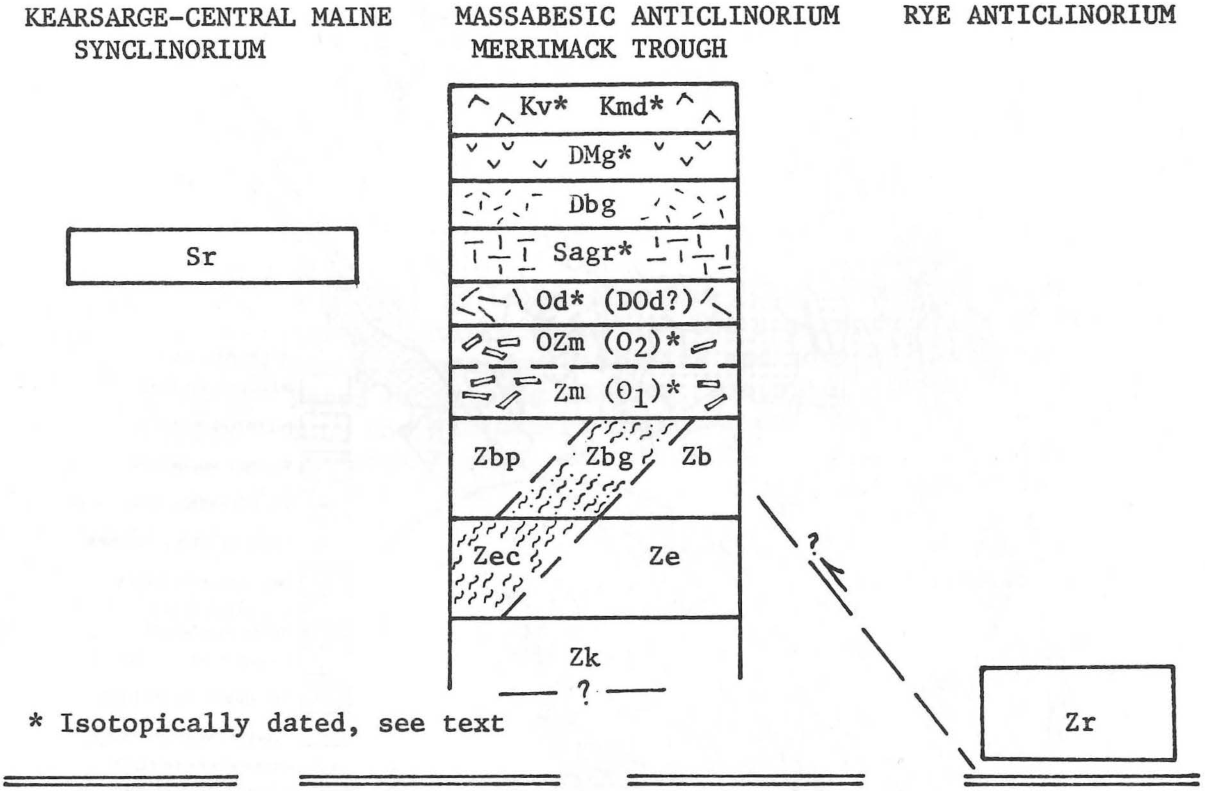
was interpreted to constitute the southeastern limit of the Merrimack Synclinorium and was observed by Billings (1956, p. 67) to be cross-cut by the Fitchburg Pluton, which he recognized then as a more complex igneous sequence than a simple pluton.

Isotopic dating within southeastern New Hampshire (Besancon and others, 1977; Aleinikoff, 1978; Aleinikoff and others, 1979; Kelly and others, 1980) suggested a late Precambrian age for some, if not all, of the Merrimack Group rocks. Lyons and others (1982) suggested that the Merrimack Group rocks should be separated from those of the Merrimack Synclinorium of Billings and reassigned to their own structural succession, the Merrimack Trough. This structure was originally and perceptively proposed by Emerson (1911). In order to avoid further confusion Lyons and others (1982) also recommended that the name Merrimack Synclinorium be discontinued and a new name, the Kearsarge-Central Maine Synclinorium (KCM) be adopted for the layered rocks northwest of the Fitchburg (Massabesic) "pluton." The metasedimentary rocks of the KCM are demonstrably of Silurian and Devonian age (Hatch and others, 1984; see also other references therein).

EXPLANATION

The geologic map is modified after Lyons and others (1983) and Zen (1983)

LITHOLOGIC KEY



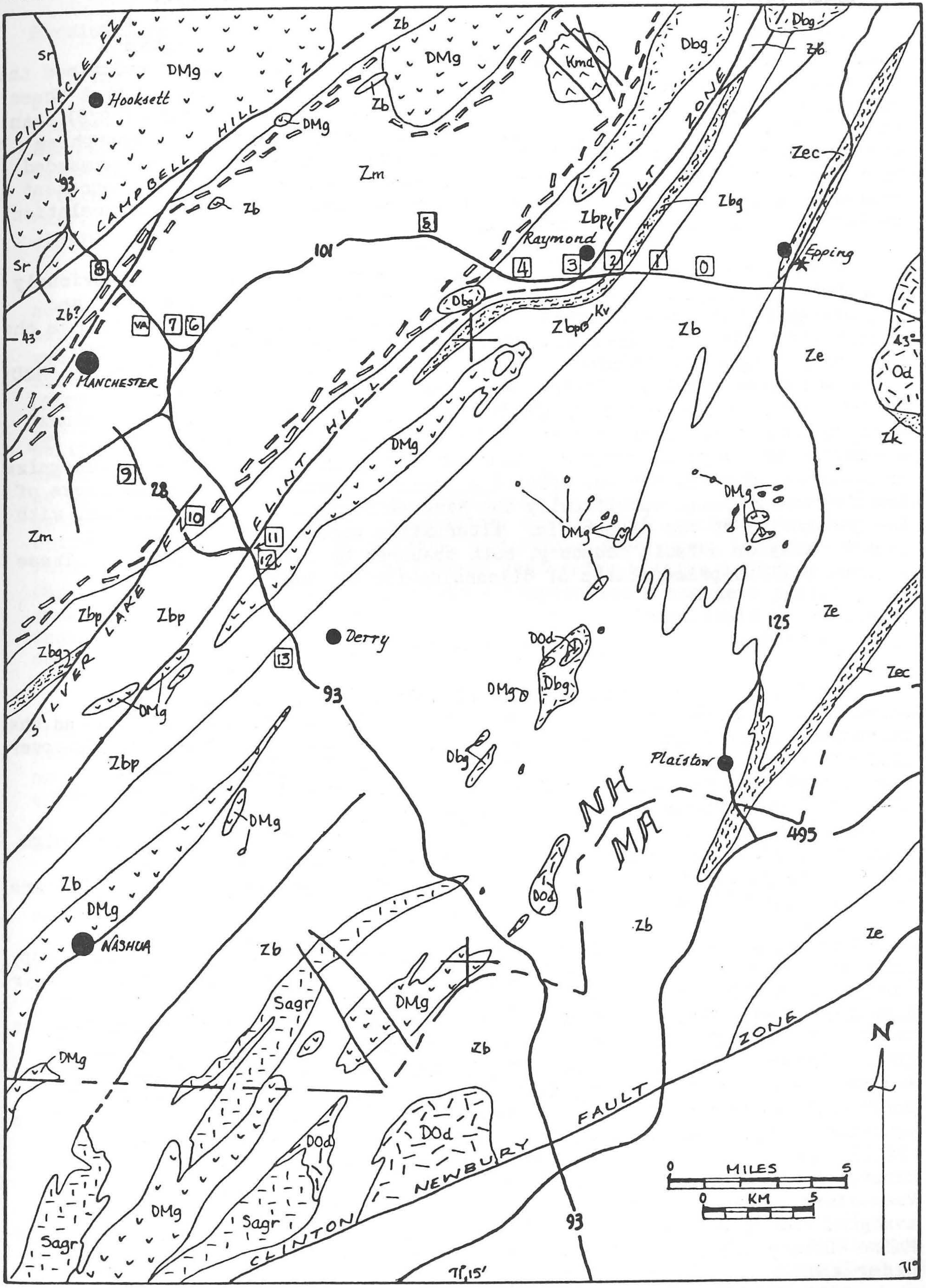
* Isotopically dated, see text

CRETACEOUS	Kv,Kmd	White Mountain Series (Little Rattlesnake Hills volcanics, Mt. Pawtuckaway Complex monzonites and diorites)
DEVONIAN-MISSISSIPPIAN	DMg	New Hampshire Plutonic Series - Two-mica granites
DEVONIAN	Dbg	Biotite granites
DEVONIAN to ORDOVICIAN?	DOd	Diorite (Dracut and Sweepstakes)
SILURIAN	Sagr	Ayer Granite and associated rocks
	Sr	Rangeley Formation
ORDOVICIAN	Od	Exeter Diorite and associated rocks
ORDOVICIAN to PRECAMBRIAN	OZm(O_2)	Massabesic orthogneiss
PRECAMBRIAN	Zm	Massabesic Gneiss Complex (ortho and para)
	Zb	Merrimack Group - Berwick Formation
	Zbp	Berwick Formation high pelite component
	Zbg	Gove Member
	Ze	Eliot Formation
	Zec	Calef Member
	Zk	Kittery Formation
	Zr	Rye Formation (not shown on this map)

✳ STARTING POINT

☐ FIELD TRIP STOPS

FIGURE 2 GEOLOGIC MAP OF SOUTHEASTERN NEW HAMPSHIRE AND ADJACENT MASSACHUSETTS



Lyons and others (1982) also found no basis for the Rockingham Anticlinorium in the region occupied by the Merrimack Group and redefined the Rye anticline of Billings as the Rye Anticlinorium. They believed that these rocks more closely resembled those of the Avalon zone of Williams (1978) than those of his Gander zone. Based on lithic sequence, timing of metamorphism and plutonism, and deformation, Olszewski and others (1984) have recommended that the Merrimack Group and bounding Massabesic and Rye complexes represent a separate exotic terrane between the Gander and Avalon terranes. Its relation to Zen's (1983a) Craton X is unknown.

The rocks along the northwest margin of the Merrimack Trough, previously included within the Fitchburg pluton, are paragneisses, orthogneisses, and migmatites cut by numerous two-mica granites that have been referred to as the Massabesic Gneiss (Srirarmidas, 1966; Aleinikoff and others, 1979), the Massabesic migmatite (Boudette, 1977), and the Massabesic Gneiss Complex (MGC; Kelly and others, 1980). Their distribution defines the Massabesic Anticlinorium of Lyons and others (1982), but they note a lack of structural data to support the interpretation of a broad structural arch (STOP 5). The migmatite and gneisses contain enclaves of high grade rocks that we recognize as the Berwick Formation and provide a basis for suggesting that the rocks of the Merrimack Group, specifically the Berwick Formation, are gradational with the paragneiss of the Massabesic. Alternative possibilities include an unconformity or a fault boundary, both obscured by late migmatization. These we hope will be prime points of discussion for the trip.

Stratigraphic Framework

The immediate concern of this trip are lithologic, petrologic, and structural data from the Berwick Formation and the Massabesic gneisses and the isotopically dated igneous rocks that cross cut them. The other units however deserve brief comment. The rocks of the Rye Anticlinorium will not be examined on this trip although they play an important part in the geologic history of southeastern New Hampshire (see Hussey, 1980; Carrigan, 1984a, 1984b; and Swanson and Carrigan, this volume). They represent a belt of high grade metasedimentary and very minor metavolcanic rocks cut by felsic metaigneous gneisses nearly parallel to the Massabesic Anticlinorium. All are strongly mylonitized.

The Kittery and Eliot Formations, the lower units in the Merrimack Group, similarly will not be examined. Sriramades (1966) and Sundeen (1971) consider the rocks at "STOP 0" and STOP 13 to be Eliot Formation; however, the lithologies are virtually identical to the Berwick Formation to be examined at STOPS 1 and 8. The interested reader is referred to Katz (1917), Billings (1956), Hussey (1968), Rickerich (1984), and Hussey and others (this volume) for details concerning the stratigraphic evidence supporting a conformable, northwest-facing homoclinal sequence for the Merrimack Group. Merrimack Group equivalents in Massachusetts have been treated by Peck (1976), Robinson (1979), Barosh and Pease (1981), and Zen (1983b) among others. In Maine Osberg (1968, 1978) considered the Merrimack Group equivalent to the Vassalboro sequence. Most previous workers have followed Billings and assigned the Merrimack Group to the Silurian, although the new geologic map of Maine (Osberg and others, 1984) allows the possibility of an Ordovician or older age.

Berwick Formation

The Berwick Formation lies stratigraphically above the Eliot Formation and in places, above the discontinuous, black, graphitic, phyllitic Calef Member of the Eliot Formation (fig. 2) as recognized by Freedman (1950) in the Mt. Pawtuckaway 15-minute quadrangle. Freedman (1950) also mapped rocks that he assigned to the Littleton Formation and the very pelitic Gove Member of the Littleton Formation in that area. Billings (1956) reassigned the Littleton there to the Berwick Formation which we retain, noting that a lithic distinction is present and probably traceable to the southwest.

The Berwick Formation within the field trip area is divisible into three subunits based on lithologic grounds and degree of partial melting. In areas least affected by partial melting the Berwick Formation is best described as a well bedded, laminated, purplish-gray biotite granofels with thin often discontinuous calc-silicate layers, stringers, pods, and occasional boudins (STOP 1). Bedding, some graded, in the granofels ranges from a few centimeters to 20 centimeters and contains thin, often rusty weathering pelitic interlayers. On average, biotite granofels occupies 70%; calc-silicate, 20% (max); and nonrusty to rusty pelitic schist or phyllite, 10% of an outcrop. The biotite granofels typically includes biotite + plagioclase + quartz with accessory pyrite, tourmaline, zircon, and apatite. Chlorite, white mica, calcite, sphene, epidote, and rutile also occur locally. The intercalated dark gray, sometimes rusty weathering biotite schist (or phyllite) consists of quartz + biotite + plagioclase + sphene + pyrite ± graphite ± white mica ± tourmaline at low grade. Calc-silicate assemblages include quartz + plagioclase + calcic amphibole + epidote ± biotite + accessory sphene, carbonate, and pyrite.

The Gove Member is exposed southeast of the Flint Hill Fault Zone (FHFZ) from Nottingham Square through Raymond, and again near Merrimack and South Merrimack, NH. It is magnificently exposed along the new section of Rt. 101 southwest of Raymond (STOP 2). It is best characterized as a strongly crenulated, silvery gray white mica + quartz + biotite + staurolite + garnet + sillimanite schist with accessory tourmaline and apatite. Chlorite occurs as an alteration product of biotite.

The Berwick Formation adjacent to the Gove Member both to the west <u>and</u> east is much like that already described in that it is dominantly biotite granofels with calc silicate interlayers. However, the proportion of pelitic intercalations is greater, overall grain size is coarser, and calc-silicate lenses are more irregular and pinstriped. West of the Gove Member near the MGC, pegmatite and foliated biotite granite are abundant (STOPS 4, 10). The increased pelitic component was probably the reason that Freedman originally assigned this to the Littleton Formation and A.M. Hussey (1983 personal communication) has indicated that this zone is a bit atypical for the Berwick Formation at the type locality of Berwick, ME. We indicate the change by Zbp on Figure 2 and suggest that the changes are a function of continuously increasing metamorphic grade as the Massabesic gneiss contact is approached, and perhaps facies change, within the Berwick Formation.

This part of the Berwick Formation is strongly brecciated in the FHFZ (STOP 3). Importantly, however, there does not appear to be a discontinuity in metamorphic grade across the fault either along Route 101 or along I-93 (see section on Metamorphism). Furthermore, biotite granofels and calc-silicate interlayers, typical of the Berwick Formation, occur on both sides of the fault.

Massabesic Gneiss Complex (MGC)

The Massabesic Gneiss Complex occupies the core of the Massabesic Anticlinorium and is approximately bounded by the Campbell Hill-Nonesuch River (CHNR) fault zone on the northwest and by a gradational contact with the Berwick Formation on the southeast (Fig. 2). To the northeast it is terminated by intrusive rocks of the New Hampshire Plutonic Series (Anderson, 1978) Roadcuts along Rts. 43 and 202 to the northeast in Northwood and Rochester, as well as in Manchester show that the Berwick Formation also crops out along the northwest margin of the Massabesic Anticlinorium southeast of the CHNR (Lyons and others, 1983). The MGC consists of two major lithologic phases: a paragneiss that we believe is the high grade equivalent of the Berwick Formation previously described (also noted by Sriramadas, 1966, and Carnein, 1976); and an orthogneiss. A clear distinction between the two gneisses is often very difficult (and occasionally generates hot debate). For the purposes of the trip, orthogneiss contains unequivocal xenoliths of felsic and calcsilicate rock, among others, and paragneiss may contain enclaves of calc-silicate rock. Both gneisses are cross-cut by a variety of foliated to unfoliated biotite granite and two-mica granite bodies of varying sizes, mineralogies, and ages.

The <u>paragneiss</u>, usually a "swirly" gray migmatite, is coarse-grained and compositionally banded. Quartzofeldspathic layers are 1 to 20 cm thick separated by 1-5 mm biotite-rich layers and occasional discontinuous green calc-silicate enclaves (STOPS 5, 7). The felsic layers consist of quartz + plagioclase + microcline (often pink and may reach sizes up to 7 cm) + lesser biotite. The biotite-rich layers are dominated by large oriented biotite plates interspersed with white mica, and fibrolitic and/or prismatic sillimanite. Magnetite is present as a ubiquitous accessory, often locally abundant (1 cm euhedra), particularly in or near cross-cutting pegmatites. Calc-silicate layers and pods typically consist of hornblende + diopside + quartz + plagioclase ± epidote. Detrital zircons from paragneiss in the Milford, NH, area have yielded a provenance age of 1237 Ma (Pb^{207}/Pb^{206}) which corresponds closely to a 1188 Ma (Pb^{207}/Pb^{206}) age from detrital zircons from the Berwick equivalent Oakdale Formation in Massachusetts (Aleinikoff, 1979). This implies that the protolith (Berwick) was deposited after 1200 Ma.

<u>Orthogneiss</u> crops out throughout the MGC. Cross-cutting relations can usually be found in any large outcrop between orthogneiss and "country rock." The usually strongly foliated orthogneiss is typically gray or pink, medium- to coarse-grained microcline (white or pink) + quartz + plagioclase (oligoclase-andesine) + biotite gneiss (Kelly, 1980). White mica and garnet may be additional phases. Accessory zircon is homogeneous and euhedral. The best evidence for an igneous origin for this rock is the character of the zircons (Poldervaart, 1956) and the presence of frequently rotated xenoliths of paragneiss, biotite + plagioclase + quartz granofels, sillimanite-bearing pelitic schist, aluminous calc-silicate, and massive amphibole and epidote rock (STOP 6). The xenoliths that we equate with the Berwick Formation represent at present our best evidence for the subdivision of the MGC. Furthermore the xenoliths plus the facts that: (1) the foliation in the Berwick Formation strikes parallel to that in the MGC and (2) a continuous

increase in metamorphic grade toward the MGC that reaches temperatures near the granite minimum are the bases for the close genetic relationship between the MGC and the Berwick Formation that we are proposing.

Intrusive Rocks and Available Geochronological Data

Intrusive rocks within both the Massabesic Gneiss Complex and the Merrimack Trough (MT) span late Precambrian to Cretaceous (?) time. The earliest intrusion is the 650 Ma (Bescancon and others, 1977; Kelly and others, 1980; Rb/Sr whole rock and U/Pb zircon) Massabesic orthogneiss previously described near Raymond and Manchester, NH. This rock was apparently intruded as semi-conformable sheets into the paragneiss. Aleinkoff and others (1979) have dated the paragneiss itself by U/Pb zircon methods and obtained an age of 646 Ma (maximum ^{207}Pb/^{206}Pb). They consider the zircons to be of volcanic origin which implies that the protolith of the paragneiss was deposited in the late Precambrian. They also report another orthogneiss within the MGC dated at 475 ± 48 Ma (U/Pb zircon) whose relationship with the older orthogneiss is still uncertain.

Early Ordovician igneous activity within the MGC and MT are now corroborated by a new 473 ± 37 Ma Rb/Sr whole rock age of the Exeter Pluton (Gaudette and others, 1984) and a similar but metamorphosed diorite on Appledore Island (Olszewski and others, 1984). Other diorites in the same strike belt (Sweepstakes Diorite, Dracut Diorite) may be of similar age as suggested on Figure 2. The Newburyport Quartz Diorite as dated by Zartman and Naylor (1984) is slightly younger (450 ± 15 Ma ^{207}Pb/^{206}Pb, zircon). These intermediate intrusive rocks place a minimum early Ordovician age for the rocks of the Merrimack Group. The nearby Ayer Granite and associated gneisses and the Chelmsford Granite also intrude the Merrimack Group and its equivalents in Massachusetts and have yielded ages of 433 ± 5 Ma (^{207}Pb/^{206}Pb, zircon) and 389 ± 5 (^{207}Pb/^{206}Pb, zircon) respectively (Zartman and Naylor, 1984).

Two-mica granites in this region are of special interest because of their possible genetic relationship to the metamorphic and tectonic events that shaped southeastern New Hampshire. At least three types can be catalogued: (1) an early gray biotite-schlieren bearing two-mica granite (STOP 7); (2) a younger usually pegmatitic pink granite (STOPS 5,6,7); and (3) the "footballs" in biotite or amphibole-rich host rock that are thought to represent a partial melt/restite assemblage (between STOP 8 and VA). Types (1) and (2) are in general conformable to host rock and sheet-like but there are local discordant relationships that will be seen at some of the stops (e.g., 7, between 8 and VA,figure 2). Of the two-mica granites in the immediate vicinity of this trip, the Hooksett Granite and the "footballs" have been dated at 402 Ma (Rb/Sr whole rock; Hayward, 1983; Hayward and others, 1984) and 385 Ma (U/Pb zircon, J.B. Lyons, 1983, personal communication), respectively, and the Milford granite to the southwest has been dated at 275 Ma (U/Pb zircon, monazite, Aleinikoff and others, 1979). Two-mica granite generation and emplacement as semiconcordant sheets within the MGC and MT occurred over a fairly long time span. Most of the granite bodies are relatively undeformed indicating that deformation and metamorphism in the Massabesic Anticlinoriium was pre-Devonian. The Exeter Diorite is also undeformed and suggests that metamorphism and deformation of the Merrimack Group was pre-Middle Ordovician.

The latest intrusive activity in this region is represented by the Mesozoic White Mountain Volcanic-Plutonic Series and younger diabase and lamprophyric dikes. Foland and Faul (1977) report K/Ar ages of 121 and 111 Ma for the alkalic Mt. Pawtuckaway Complex (see Eby, this volume) and Little Rattlesnake Hills Complex, respectively. Diabase dikes throughout the region represent a range of ages between the Permo-Triassic and Cretaceous (McHone, 1978; Public Service Company of NH, 1981).

Metamorphism

Petrologic study of the aluminous calc-silicate rocks and the pelitic rocks confirms the earlier work by Freedman (1950) and Sriramadas (1966) that metamorphic grade increases from east to west and from south to north toward the MGC. Northeast of the area covered by this trip the assemblage quartz + plagioclase + carbonate + chlorite + white mica + biotite is stable in the Berwick Formation; amphibole is not found. The assemblage quartz + plagioclase + calcic amphibole + epidote + biotite composes the aluminous calc-silicate layers that crop out at STOP 0. Following the petrogenetic analysis of Ferry (1976; p. 850 and figs. 4 and 16), STOP 0 is higher grade than rocks to the northeast and the following reactions may be mappable east of STOP 0: chlorite + epidote + quartz = calcic amphibole + plagioclase + H_2O and chlorite + calcite + quartz = calcic amphibole + plagioclase + H_2O + CO_2.

The mineral assemblage in aluminous calc-silicate layers observed at STOP 0 also occurs at STOP 1. The grain size appears to be greater at STOP 1, suggesting perhaps that the metamorphic grade is somewhat higher there. The assemblage plagioclase + quartz + garnet at STOP 1 and 6.3 miles west of the beginning of the trip (see road log for description) indicates temperatures of metamorphism between 500 and 600° C at 2 Kbar and 600 to 700° C at 4 Kbar based on experimental data within the CaO - Al_2O_3 - SiO_2 - H_2O - CO_2 system (fig. 3a). "Dirtying" the system with Na_2O in the plagioclase would decrease the temperature range over which this assemblage is stable, while the presence of FeO + MnO + MgO in garnet would increase the temperature range.

STOP 2 is lithologically distinct from STOP 1 in that pelitic schist is much more abundant [at Stop 2]. However, metamorphic grade may not be appreciably different. The assemblage quartz + muscovite + biotite + garnet + staurolite + sillimanite at STOP 2 indicates temperatures within the sillimanite stability field below the melting of pelitic schist and between the reactions garnet + chlorite + muscovite = staurolite + biotite + H_2O and staurolite + muscovite = sillimanite + garnet + biotite + H_2O (fig. 3b, also see Eusden and others, fig. 6, this volume). (Petrographically staurolite does not appear to be breaking down to sillimanite + garnet + biotite.) As discussed by Eusden and others (this volume) with respect to their figure 6, it is difficult to determine the exact pressure-temperature relations of these assemblages. However, using the Al_2SiO_5 triple point of Holdaway (1971) and the experimental data of Kerrick (1972) for the system K_2O - Al_2O_3 - SiO_2 - H_2O gives the same temperature range as estimated for the calc-silicate rocks at STOP 1 is obtained, i.e., 500° C to no more than 700° C (fig. 3b). The temperature must be below the intersection of the reaction muscovite + quartz = sillimanite + K feldspar + H_2O with the granite melting curve as muscovite + quartz occurs here and the evidence for partial melting occurs farther west.

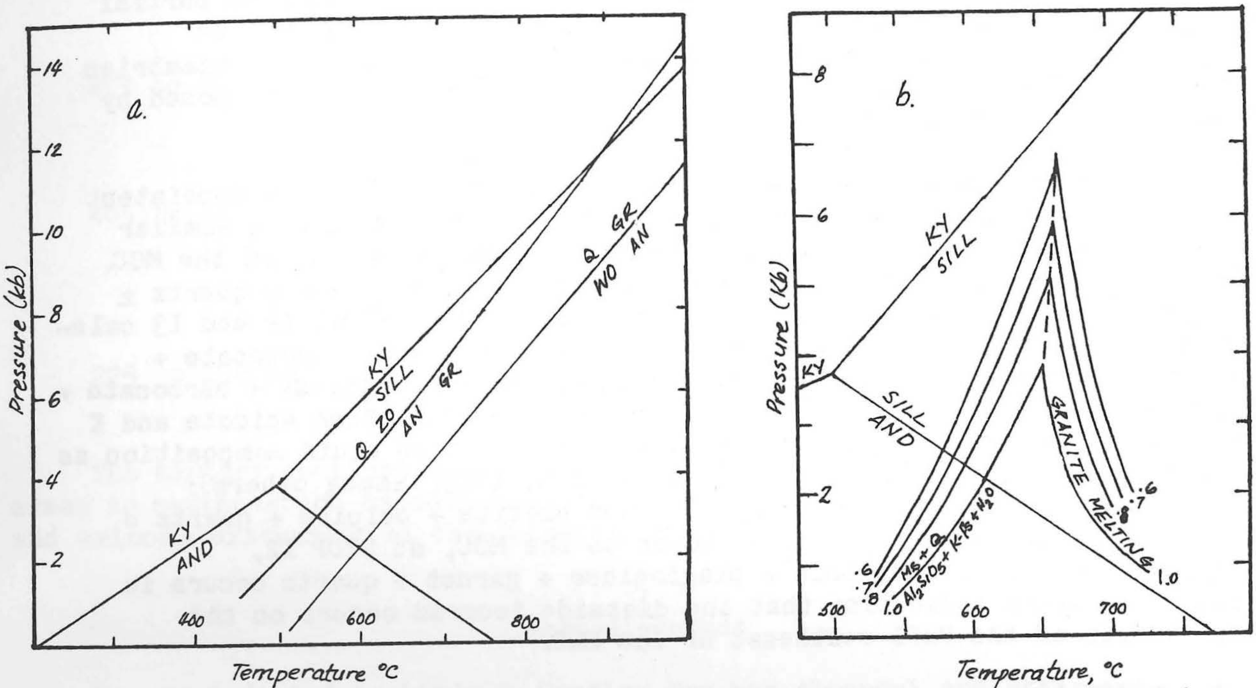


Figure 3. Simple system phase equilibria pertinent to calc-silicate and pelitic assemblages. a) Al_2SiO_5 phase diagram from Holdaway (1971) and P-T relations of the reactions quartz (Q) + zoisite (ZO) = anorthite (AN) + grossulartite (GR) + H_2O and quartz + grossularite = wollastonite (WO) + anorthite. The assemblage Q + AN + GR is stable in between these two reactions. After Perkins and others, 1980. b) Al_2SiO_5 phase diagram from Holdaway (1971) and P-T-X_{H_2O} relations for the reaction muscovite (Ms) + quartz = andalusite/sillimanite + K-feldspar (K-fs) + H_2O and the granite melting minimum. X_{H_2O} is indicated as is the intersections of both equilibria for equal values of X_{H_2O}. After Kerrick (1972). AND = andalusite, SILL = sillimanite, KY = kyanite.

Metamorphic grade increases westward toward the MGC based on the presence of quartz + white mica + biotite + sillimanite without staurolite in pelitic layers at STOP 4 and quartz + plagioclase + clinopyroxene + amphibole + carbonate in calc-silicate layers. The prograde reaction staurolite + muscovite = sillimanite + garnet + biotite + H_2O may be mappable in the pelitic layers between STOPS 2 and 4 (see Eusden and others, fig. 6, this volume). In the calc-silicate layers the diopside isograd (calcic amphibole + calcite + quartz = diopside +H_2O + CO_2, see Ferry, 1976, p. 857, among many others) occurs between STOPS 1 and 4. Further sampling is needed to determine if the diopside isograd occurs west or east of the Flint Hill Fault Zone (FHFZ, STOP 3) east of the MGC.

East of the MGC between STOPS 4 and 5 an increase in pegmatitic material seemingly due to partial melting is seen. The metamorphic temperature estimated for the pelitic rocks at STOP 4 is close to that of the granite minimum, above the staurolite out reaction and below the second sillimanite isograd (fig. 3b; also Eusden and others, this volume, fig. 6). Presence of calc-silicate enclaves within the MGC at STOPS 5-7 with assemblages bearing clinopyroxene + calcic amphibole + plagioclase + quartz ± microcline incidate equilibrium at high temperatures. These data are consistent with the interpretation that some of the MGC rocks may have been formed from partial melting of the Berwick Formation and that some of the enclaves may be xenoliths within the Massabesic orthogneiss. Consequently, late Precambrian metamorphism appears to be recorded in the Berwick Formation as proposed by Olszewski and others (1984).

The petrologic data presented above indicate that there is a consistent increase in metamorphic grade from east to west toward the MGC. A similar increase in metamorphic grade occurs from STOP 13 northwest toward the MGC. At STOP 13 calcic amphibole + epidote + carbonate + plagioclase + quartz ± biotite represent the calc-silicate assemblage. Between STOPS 12 and 13 calc-silicate layers are composed of calcic amphibole + epidote + carbonate + plagioclase + quartz ± biotite and calcic amphibole + orthoclase + carbonate + plagioclase + quartz ± biotite. The following reactions bring epidote and K feldspar into the assemblage, respectively, and depend on fluid composition as well as temperature (see Ferry, 1976, and Hewitt, 1973, among others): calcite + anorthite + H_2O = epidote + CO_2 and biotite + calcite + quartz = tremolite + K feldspar + CO_2 + H_2O. Closer to the MGC, at STOP 12, clinopyroxene + calcic amphibole + plagioclase + garnet + quartz occurs in calcsilicate layers indicating that the diopside isograd occurs on the southeast side of the FHFZ southeast of the MGC.

The formation of clinopyroxene in the calc-silicate layers occurs before the formation of sillimanite + biotite + quartz + muscovite in the pelitic layers (seen at STOP 9) toward the MGC from the southeast, consistent with the correlation Thompson and Norton (1968, tbl. 24-1) have made for calc-silicate and pelitic rocks in general.

Evidence for more than one period of mineral growth is seen at several stops. At STOP 2 grains of staurolite and garnet have inclusion-choked cores and nearly inclusion free rims. Also biotite is being replaced by chlorite. Discontinuously-zoned amphibole with darker-colored cores than rims occurs at STOP 1. Anhedral, embayed clinopyroxene rimmed by calcic amphibole ± carbonate occur at STOPS 12 and 4. Further petrologic and related field and structural studies are underway to discern the relative effects of polymetamorphism versus changes in mineral assemblage/compositon due to progressive metamorphism.

Summary

Field criteria for a gradational contact between the proposed late Precambrian Merrimack Group and the bulk of the Massabesic gneissess are emphasized in the following outcrop descriptions in the road log. Considerable work remains to be done, however, before a full understanding of the rocks of the Massabesic Anticlinorium and Merrimack Trough and concensus on the sequence of events is reached. Isotopic results, however, imply the following geologic framework:

1200 to 650 Ma -	Deposition of the Merrimack Group on unknown basement
650 Ma	Metamorphism and deformation of the Berwick Formation and generation and intrusion by orthogneiss in the area of the Massabesic Anticlinorium

- Deformation, metamorphism, and intrusion

473 to 435 Ma - Intrusion of the Exeter Diorite (and similar diorites), Newburyport Quartz Diorite, and Ayer Granite

405 to 275 Ma - Intrusion of two-mica granites, probably accompanied by migmatization and partial melting of country rock in many areas (e.g., Milford granite and Massabesic paragneiss)

225 to 100 Ma - Intrusion of the White Mountain Series and Mesozoic diabase and lamprophyre dikes

The history outlined above is significantly different from other nearby areas in southeastern Massachusetts and central New Hampshire. We anticipate and welcome discussion at the outcrop!

Acknowledgment

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References

Aleinikoff, J. N., 1978, Structure, Petrology, and U-Th-Pb Geochronology of the Milford (15') Quadrangle, NH, unpub. Ph.D. dissertation, Dartmouth College, 235 p.

__________, Zartman, R. E., and Lyons, J. B., 1979, U-Th-Pb geochronology of the Massabesic Gneiss and granite near Milford, south-central NH: New evidence for Avalonian basement and Taconic Alleghenian disturbances in eastern New England: Contr. Min. Pet. V. 71, p. 1-11.

Anderson, R. C., 1978, The northern termination of the Massabesic Gneiss, NH: unpub. MA thesis, Dartmouth College, 111 p.

Barosh, P.J. and Pease, M. H., Jr., 1981, Correlations of the Oakdale and Paxton Formations with their equivalents from eastern Connecticut to southern Maine: Geol. Soc. America Abstracts with Programs, v. 13, p. 122.

Besancon, J. R., Gaudette, H. E. and Naylor, R. S., 1977, Age of the Massabesic Gneiss, Southeastern NH: Geol. Soc. America Abstracts with Programs, v. 9, p. 242.

Billings, M. P., 1956, The Geology of NH: Part II Bedrock Geology: NH State Planning and Devel. Comm., 200 p.

Boudette, E. L., 1977, Two-mica granite and uranium potential in the Northern Appalachian orogen of New England: U.S. Geol. Survey Circular 753, p. 23-24.

Carnein, C. R., 1976, Geology of the Suncook 15' quadrangle, NH: unpub Ph.D. dissertation, The Ohio State University, 196 p.

Carrigan, J. A., 1984a, Ductile faulting in the Rye Formation, southeastern New Hampshire: Geol. Soc. America Abstracts with Programs, v. 16, p. 7.

__________, 1984b, Metamorphism of the Rye Formation: A reevaluation: Geol. Soc. America Abstracts with Programs, v. 16, p. 7.

Eby, N., 1984, Mt. Pawtuckaway ring-dike complex: in Hanson, L., ed., NEIGC Guidebook for 1984, Trip B7.

Emerson, B. K., 1917, Geology of Massachusetts and Rhode Island: U.S. Geol. Survey Bull. 597, 289 p.

Ferry, J. M., 1976, Metamorphism of calcareous sediments in the Waterville-Vassalboro area, south-central Maine: mineral reactions and graphical analysis: American Jour. of Sci., v. 276, p. 841-882.

Eusden, J. D., Bothner, W. A., Hussey, A. M. II, and Laird, J., 1984, Silurian and Devonian rocks in the Alton and Berwick quadrangles, NH-ME: in Hanson, L., ed., NEIGC Guidebook for 1984, Trip C5.

Foland, K. A. and Faul, H., 1977, Ages of the White Mountain intrusives - New Hampshire, Vermont, and Maine, USA: American Jour. Sci., v. 277, p. 888-904.

Freedman, J., 1950, Stratigraphy and structure of the Mt. Pawtuckaway quadrangle, southeastern NH: Geol. Soc. America Bull., v. 61, p. 449-506.

Gaudette, H. E., Bothner, W. A., Laird, J., Olszewski, W. J. Jr., and Cheatham, M. M., 1984, Late Precambrian/Early Paleozoic deformation and metamorphism in southeastern New Hampshire - Confirmation of an exotic terrane: in a review for Geol. Soc. America Nat. Meeting, Nov. 1984, Reno, Nevada.

__________, Kovach, A., and Hussey, A. M. II, 1982, Ages of some intrusive rocks of southwestern Maine, U.S.A.: Canadian Jour. of Earth Sci., v. 19, p. 1350-1357.

Hatch, N. L. Jr., Moench, R. H., and Lyons, J. B., 1983, Silurian-Lower Devonian stratigraphy of eastern and south-central NH: extensions from western ME: American Jour. Sci., v. 283, p. 739-761.

Hayward, J. A., 1983, Rb-Sr geochronology and the evolution of some peraluminous (two-mica) granites in New Hampshire. Geol. Soc. America Abstracts with Programs: v. 15, p. 146.

Hayward, J. A. and Gaudette, H. E., 1984, Carboniferous age of the Sebago and Effingham plutons, Maine and New Hampshire: Geol. Soc. America Abstracts with Programs, v. 16, p. 22.

Hewitt, D. A., 1973, The metamorphism of micaceous limestones from south-central Connecticut: American Jour. Sci., v. 273A, p. 444-469.

Hitchcock, C. H., 1877, The Geology of New Hampshire, Vol. 2: Concord, NH, 684 p.

Holdaway, M. J., 1971, Stability of andalusite and the aluminum silicate phase diagram: American Jour. Sci., v. 271, p. 97-131.

Hussey, A. M. II, 1968, Stratigraphy and structure of southwestern Maine; in Zen, E-an, White, W. S., Hadley, J. B., and Thompson, J. B. Jr. (eds), Studies in Appalachian Geology-Northern and Maritime: Interscience, NY, p. 291-301.

__________, 1981, Gerrish Island revisited, the Rye Formation of Gerrish Island, Kittery, Maine: a reinterpretation: The Maine Geologist, v. 7, p. 2-3.

Hussey, A. M. II, Rickerich, S. F., and Bothner, W. A., 1984, Multiple deformation and sedimentology of the Kittery Formation in southwest Maine: in Hanson, L., ed., NEIGC Guidebook for 1984, Trip A4.

Katz, F. J., 1917, Stratigraphy in southwestern Maine and southeastern New Hampshire: U.S. Geol. Survey Prof. Paper 108-I, p. 165-177.

Kelly, W. J., 1980, An isotopic study of the Massabesic gneiss: southeastern New Hampshire: unpubl. MS thesis, Univ. of New Hampshire, 121 p.

Kelly, W. J., Olszewski, W. J. Jr., and Gaudette, H. E., 1980, The Massabesic orthogneiss, southern NH; Geol. Soc. America Abs. with Programs, v. 12, p. 45.

Kerrick. D. M., 1972, Experimental determination of muscovite + quartz stability with $P_{H_2O} < P_{total}$: Am. J. Sci., v. 272, p. 946-958.

Lyons, J. B., Bothner, W. A., Moench, R. H., and Thompson, J. B. Jr., 1983, Preliminary Geologic Map of New Hampshire: submitted to U.S. Dept. of Energy.

__________, Boudette, E. L., and Aleinikoff, J. N., 1982, The Avalonian and Gander Zones in central eastern New England: in St. Julien, P. and Beland, J. (eds.), Major Structural Zones and Faults of the Northern Appalachians: Geol. Assoc. Canada, Spec. Paper 24, p. 43-66.

McHone, J. G., 1978, Distribution, orientations, and ages of mafic dikes in central New England: Geol. Soc. America Bull., v. 89, p. 1645-1655.

Miyashiro, A., 1973, Metamorphism and Metamorphic Belts: New York, John Wiley and Sons, 492 p.

Olszewski, W. J. Jr, Gaudette, H. E., Bothner, W. A., Laird, J, and Cheatham, M. M., 1984, The Precambrian(?) rocks of southeastern New Hampshire--A forgotten land: Geol. Soc. America Abstracts with Programs, v. 16, p. 54.

Osberg, P. H., 1968, Stratigraphy, structural geology and metamorphism of the Waterville Vassalboro area, Maine: Maine Geol. Survey Bull. 20, 64 p.

__________, 1978, Synthesis of the geology of the northern Appalachians, USA: Geol. Survey Canada Paper 78-13, p. 137-147.

Osberg, P. H., Hussey, A. M. II, and Boone, G. M., 1984, Bedrock Geologic Map of Maine: Maine Geol. Survey Open-File No. 84-1.

Peck, J. H., 1976, Silurian and Devonian stratigraphy in the Clinton quadrangle, central Massachusetts: in Page, L. R. (ed.), Contributions to the Stratigraphy of New England: Geol. Soc. America Memoir 146, p. 241-252.

Perkins, D. III, Westrum, E. F. Jr., and Essene, E. J., 1980, The thermodynamic properties and p[hase relations of some minerals on the system CaO - Al_2O_3 - SiO_2 - H_2O: Geochim. Cosmochim. Acta, v. 44, p. 61-84.

Poldervaart, A., 1956, Zircons in rocks: 2-igneous rocks: American Jour. Sci., v. 254, p. 521-544.

Public Service Company of New Hampshire, 1981, Final safety analysis report, v. 2: Seabrook, New Hampshire, 155 p.

Rickerich, S. F., 1984, Sedimentology and stratigraphy of the Kittery Formation near Portsmouth, New Hampshire: Geol. Soc. America Abstracts with Programs: v. 16, p. 59.

Robinson, G. R., 1979, Bedrock geology of the Nashua River area, Massachusetts - New Hampshire: Ph.D. thesis, Harvard University, 172 p.

Sriramadas, A., 1962, The geology of the Manchester quadrangle, New Hampshire: New Hampshire Dept. Res. and Econ. Devel., Bull. 2, 78 p.

Sundeen, D. A., 1971, The bedrock geology of the Haverhill 15' quadrangle, New Hampshire: NH Dept. Res. Econ. Devel., Bull. 5, Concord, NH, 125 p.

__________, 1971, The Hillsboro Plutonic Series in southeastern New Hampshire; field criteria in support of a partial melting petrogenetic model: in Lyons, J. B. and Stewart, G. W., eds. NEIGC Guidebook for 1971, p. 53-63.

Thompson, J. B. Jr. and Norton, S. A., 1968, Paleozoic regional metamorphism in New England and adjacent areas: in Zen, E-an, White, W. S., Hadley, J. B., and Thompson J. B. Jr. (eds.), Studies in Appalachian Geology, Northern and Maritime: Interscience, NY, p. 319-338.

Swanson, M. T. and Carrigan, J. A., 1984, Ductile and brittle structures in the Rye Formation, coastal Maine and New Hampshire: in Hanson, L., ed., NEIGC Guidebook for 1984, Trip B4.

Williams, H., 1978, Tectonic Lithofacies Map of the Appalachian Orogen: Memorial Univ. of Newfoundland, Map No. 1, scale 1:1,000,000.

Zartman, R. E. and Naylor, R. S., 1984, Structural implications of some radiometric ages of igneous rocks in southeastern New England: Geol. Soc. America Bull., v. 95, p. 522-539.

Zen, E-an, 1983a, Exotic terranes in the New England Appalachians--limits, candidates, and ages: A speculative essay: in Hatcher, R. D. Jr., Williams, H., and Zietz, I., eds., Contributions to the tectonics and geophysics of mountain chains: Geol. Soc. America Memoir 158, p. 55-82.

__________, ed., 1983b, Bedrock Geologic Map of Massachusetts: U.S. Geol. Survey, scale 1:250,000.

Road Log for Trip B5

Access to the new section of Rt. 101 from Raymond to Candia has been made possible by permission from the Midway and Palazzi contractors. We travel and examine road cuts AT OUR OWN RISK. For this trip we have tentative approval to stop along I-93 in the vicinity of Manchester, NH, and access roads to I-93. Do not stop at other times without contacting the NH Dept. of Highways, Concord, NH.

The assembly point is a large parking lot (Gulf Station) at the intersection of NH Rts. 125 and 47 (old 101 from Raymond) in Epping, NH, just east of the Lamprey River Bridge. Actual mileage may be different from Raymond to Candia than that reported here and will depend on work progress on the new highway. There will be several opportunities to reset odometers (*).

Mileage

Epping 7-1/2-minute quadrangle

0.0 Gulf Station parking lot; junction Rts. 125/47, Epping, NH; proceed S on 125

1.4 Rt. 101W turn right toward Raymond, low outcrop of Berwick on northside

3.9 "STOP 0": S Side 101, long continuous crop of typical Berwick Formation (Stop 2 of Sundeen in the 1971 NEIGC Guidebook in which he considered this the Eliot Formation). The crop consists of brown weathering well bedded, purplish-gray medium-grained biotite + plagioclase + quartz granofels and thin, green calc-silicate layers composed of quartz + light green calcic amphibole + plagioclase + epidote + sphene + carbonate + pyrite. Rusty pelitic schist occurs as thin interbeds and layers locally, as do very minor pinky brown weathering carbonate-rich layers. All are tightly folded about shallow northeast plunging axes. Axial surfaces are filled with quartz and quartzo-feldspathic veins. A Mesozoic porphyritic diabase dike, presumably from the nearby Rattlesnake Hills Complex, cross-cuts the Berwick Fm. here. No stop this year, but an instructive crop for future wanderings.

4.1 If still here, with all the construction. Crops of Freedman's microcline granite, Berwick Formation, and dikes from the Rattlesnake Hills (Mz, White Mountain Series volcanic center, 111 Ma K/Ar, Foland and Faul, 1977)

Mt. Pawtuckaway 7-1/2-minute quadrangle

5.5 Turn right at lights off exit from 101 construction onto Rt. 107/156

6.3 Left at lights on old 101 (107, 156) toward Raymond and Manchester, low crops just before lights and a few hundred meters E are Berwick with calc-silicate layers carrying quartz + plagioclase + calcic amphibole + garnet + biotite + sphene + opaque.

6.6 Turn left at fork (Cumberland Farms Store) and into the town of Raymond

7.4 Raymond Common, turn left on Main Street

*8.2 Left between underpass and up onto new Rt. 101 and continue E about 0.1 mi to crops.

8.3 STOP 1: Berwick Formation is exposed on both E and W bound lanes and perhaps best in the median strip. Fresh purple brown biotite granofels (quartz + biotite + chlorite + plagioclase + sphene) composed of frequently laminated 10-20 cm beds intercalated with thin pelitic schist "partings," and 3-5 cm green calc-silicate (calcic amphibole + quartz + plagioclase + biotite + chlorite + sphene ± garnet) frequently as discontinuous stringers, pods, and occasional boudins. Tops have not been observed here; rocks dip steeply southeast and are cut by pegmatite carrying muscovite books + garnet + beryl + fluorite (S-side and median strip). We consider this typical Berwick. It is essentially the same as the crop at "STOP 0."

8.4 Turn vehicles around and head W, carefully recross Main Street to continue on the new highway.

8.9 STOP 2: Pelitic schist (Gove Member of the Berwick Formation=Gonic in the Rochester, NH area) crops out on both sides and the median strip as shiny, silvery gray, medium to coarse-grained biotite + muscovite + quartz + staurolite + garnet + minor sillimanite schist. Biotite is aligned and plunges about down dip; larger (3-5 cm) staurolite grains, occasionally twinned, are cross-foliate. Perhaps "staurolumps" is an appropriate term (☺). Late crenulation cleavage plunges gently SW. Minor biotite granofels and calc-silicate is exposed at the east end of the crop.

9.5 STOP 3: West end of Batcheldor Road exchange, brief stop. Flint Hill FZ crosses the highway about here. Dark green sulfidic and brecciated biotite granofels of the Berwick. Small clasts in much silicified microbreccia may be seen locally in outcrop. Milky quartz typical of the Flint Hill FZ is exposed here. Undated, light gray, fine-grained, two-mica garnet-bearing granite is exposed just west of brecciated Berwick. On the exit ramp White Mountain series dikes cross-cut the granite and perhaps the FHFZ. Very sheared metasedimentary rocks characterize the fault zone on the ramp and may reflect later movement than that responsible for the silicified microbreccia.

*Depending on construction conditions we will either proceed about 1.8 miles directly on the new highway, or exit at Lane Road.

9.8 Turn right onto Lane Road

10.0 Left at Lane Road/Batcheldor Road

10.1+ Left at Lane Road/Old Manchester Road and again left onto Green Road

12.0 Right, back onto new 101

12.0 STOP 4: Crops just west of Green Road/New 101 and west of the FHFZ, about 0.5 km east of contact with Massabesic gneiss. Steep southeast dipping, medium grained, biotite granofels (biotite + plagioclase + quartz) in 10-20 cm layers with 1-2 cm, light green,quartz + plagioclase + clinopyroxene + calcic amphibole + sphene ± carbonate ± garnet ±calcite calc-silicate layers of the Berwick Formation, rusty and nonrusty weathering quartz + sillimanite + biotite + white mica ±garnet pelitic schist (a few very large sillimanite bundles near pegs, please don't hammer upon them) dominates the western part of the crop. Glacial pavement atop the median strip and along the S-side of the east bound lane reveal probable tops, cross-cutting biotite granodiorite, and thick diabase.

Candia 7-1/2-minute quadrangle

12.8 Possible stops between here and STOP 5 will depend on time and interest. The crops for the next two miles are dominantly gray foliated biotite + hornblende + quartz + plagioclase + microcline gneiss and is cross cut by pink coarse-grained quartzofeldspathic gneiss with large (4-5 cm) microcline grains, minor garnet, and some magnetite and biotite. Foliation in the gray gneiss is parallel to that of the Berwick at the last stops, contains abundant small tight to isoclinal folds at scales of 10's of cm's, and dismembered layers of biotite quartzite and granofels. Much of this rock is considered to be paragneiss. We recognize no major dislocation between STOPS 4 and 5.

14.6 STOP 5: "The Big Bend" low near continuous median crop dominated by gray biotite quartzofeldspathic gneiss with relict quartzite layers slightly transverse to foliation and clinopyroxene-bearing calc-silicate xenoliths to 25 cm. Interfoliated, undated pink granite (microcline granite of Freedman, 1950?) is slightly discordant. Both are cross-cut by coarse-grained pink pegmatite. Foliation is flat to moderately NW dipping providing some evidence for a structural arch for the Massabesic Anticlinorium.

Depending on road conditions we will exit the construction area and rejoin old 101 between Patten Hill Road and the end of construction or drive directly to the end of the new road and proceed W on 101 toward Manchester.

*0 Start new mileage at the Auburn/Candia town line

Manchester North 7-1/2-minute quadrangle

4.5 STOP 6: 0.2 mi east of Rt 101/I-93 exchange, park as far off the road as possible. We will examine only the crops along the north side of the westbound lane. This outcrop is dominated by medium- to coarse-grained, light gray quartz + plagioclase + perthite + biotite + magnetite ±white mica gneiss (orthogneiss) containing magnificent rotated xenoliths of light gray, medium-grained, biotite + quartz + plagioclase ±magnetite ±garnet ±white mica ±pyrrhotite gneiss with biotite rich borders. Flow foliation in the orthogneiss, particularly around the xenoliths, is very well devleoped. Enclaves of medium coarse-grained, green gray, banded calc- silicate gneiss here are interpreted to be xenoliths of Berwick Formation. Mineral assemblages within distinct layers include quartz + plagioclase + calcic amphibole + biotite + sphene + zircon, clinopyroxene + epidote + quartz + plagioclase + magnetite + sphene, plagioclase + quartz + epidote + amphibole + garnet + biotite + magnetite + zircon, and clinopyroxene + calcic amphibole. Amphibole and plagioclase contain vermicular inclusions of quartz.

4.7 Stay right onto I-93 N.

5.4 Take Exit 8 to Wellington Road. Parking will be difficult here and it is likely that we will have traffic safety escort.

STOP 7: Wellington Road. Much to see! Exposed here in near continuous three-dimensional cuts are paragneiss and migmatite cut by relatively large bodies of pink and gray two-mica granite and pink magnetite-bearing pegmatite. Light gray quartz + feldspar rock and dark gray amphibole + feldspar rock (resembling diorite) make up the bulk of the migmatite and intergrade with greenish calc-silicate rock. These are highly gradational, perhaps representing partial melt and restite. Two mica granites are mutually cross-cutting; no clear cut age relation has yet been established although the schlieren-bearing granite appears earliest. An anatectic origin from bimodal volcanic or calcareous pelitic-felsic volcanic protoliths will be discussed. A typical assemblage within calc-silicate enclaves is commonly: clinopyroxene + plagioclase + quartz + microcline + biotite + calcic amphibole + sphene.

Continue to Exit 9S

~6.2 Exit 9S, Follow the cloverleaf system. Probably parking on Rt. 28 and walking back along the S-bound exit ramp.

STOP 8: I-93, just north of the 9S Exit. An important stop to demonstrate the presence of banded calc-silicate rock northwest of the Flint Hill (Silver Lake) Fault Zone (and southeast of the Campbell Hill fault system) and to provide a basis for comparison with the Berwick seen and to be seen farther south. Polydeformed thin-bedded calcareous subgraywacke is intercalated with sulfidic carbonaceous metapelite and metagraywacke on the southeast and are probably downdropped by a fault (098,50N) against dark gray popcorn migmatite intruded by two-mica pegmatite dikes on the northwest. The calc-silicate rock is composed of quartz + carbonate + feldspar

+ biotite + diopside (as STOP 7). The rusty weathering rock is probably equivalent to the rusty pelitic schist seen at STOP 4. We suggest this sequence is correlative with the Berwick Formation.

~6.5 Rejoin I-93 and continue S - We will have a slow drive by the next set of crops between STOP 8 and the Wellington Road exit (STOP 7) near the VA Hospital.

8.2 Large two-mica mica granite "footballs" are well displayed in the median strip. These are thought to represent insitu melts "frozen in ascent" and may correlate with the 385 Ma (U/Pb zircon) dated footballs on I-93 near Windham (J.B. Lyons, oral communication, 1983).

Manchester South 7-1/2-minute quadrangle

11.4 Continue S on I-93 to I-293. Depending on time we will EITHER follow I-293 (1.6 mi) to Exit 1 (Rt. 28) S of Manchester. Follow Rt. 28 S about 0.8 mi, turn right onto Harvey Road for 0.5 mi. and right into the parking lot of True Value Hardware Distributors.

OPTIONAL STOP 9: If made we will follow Harvey Road S to Grenier Field Road to its intersection with Rt. 28; STOP 10 is 0.2 mi S of this intersection.

This outcrop shows many elements of the MGC migmatite; coarse-grained gneiss, restitic xenoliths, two-mica granite, and pegmatite. The compositional banding of the coarse-grained gneiss is defined by continuous layers of coarse-grained biotite, commonly with abundant sillimanite + white mica, alternating with light gray feldspathic layers. The banding strikes about N50E and generally dips steeply to the southeast. The orientation of the banding is more irregular near the granite and near the xenoliths. The xenoliths are concentrated in the west part of the outcrop. They are so similar in appearance to the surrounding gneiss that it can be difficult to distinguish them from the gneiss. The two-mica granite at the east part of the outcrop clearly truncates the banding of the coarse-grained gneiss, although the contact is somewhat obscured by aplite and pegmatite.

Proceeding south, Harvey Road turns into Grenier Field Road, which curves around a hill to the northeast. On the south end of the hill restitic xenoliths of biotite + plagioclase + quartz schist are intermingled with two-mica granite. The coarse-grained gneiss crops out on the north end of the hill.

OR Continue S (~4.1 mi) on I-93 to Exit 5.

15.5 Exit 5, turn west on Rt. 28 for 1.8 mi.

16.3 STOP 10: park just south of the intersection of Rt. 28 and Page Road. There are several outcrops along this stretch of road. The northernmost of these shows the coarse-grained gneiss of the Massabesic migmatite juxtaposed against weakly pinstriped biotite granofels and schist typical of the more pelitic Berwick Formation.

The foliation of the schist roughly parallels the compositional layering of the coarse-grained gneiss. Calcareous lenses in the schist are contorted about axes plunging moderately to the northeast. Boudin-like lenses of two-mica granite are oriented roughly parallel to the foliation of the schist. Biotite-rich layers from the schist protrude through the granite lenses. Gradational transitions from pegmatite to granite can be observed here.

Derry 7-1/2-minute quadrangle

*18.1 Return to I-93, Exit 5

18.3 STOP 11: South bound entrance ramp I-93/Rt. 28, Londonderry, NH. A very fine-grained, chloritized, broken, and somewhat brecciated outcrop marks the trace of the Flint Hill Fault Zone. Porphyroblasts of amphibole are present as well as some pegmatite.

Continue S

18.8 STOP 12: 0.5 mi S of Rt. 28 (south-bound lane).
The thick-bedded, fine- to medium-grained biotite granofels typical of the more pelitic Berwick Formation has been highly sheared and broken here. The shearing is especially apparent in the more pelitic layers. Fractures may be filled with chlorite. The calcareous lenses here are folded and distinctly zoned with rims of hornblende + amphibole with vermicular quartz + biotite + plagioclase + quartz + sphene ± garnet and cores of diopside + hornblende + amphibole with vermicular quartz + plagioclase + quartz + sphene ± garnet. The diopside and amphibole with vermicular quartz are generally embayed and rimmed by amphibole and may be relict phases. The garnet is isotopic and anhedral. Diopside has not been identified between here and Derry, NH.

Continue S

22.0 Exit 6, Derry, NH

22.2 STOP 13: Southbound entrance ramp to I-93 from Rt. 102, Derry, NH
The fine-to medium-grained, purple-gray granofels of the Berwick Formation is well-bedded here, although poorly graded. Calcareous lenses are poorly zoned and contain tremolitic amphibole, epidote, sphene, biotite, quartz, plagioclase, and calcite. The granofels is interbedded with finer grained, dark gray, moderately rusty schist composed of quartz, plagioclase, white mica, biotite, chlorite, sphene, pyrite, and tourmaline. All of the rocks are folded isoclinally with axes plunging shallowly to the southwest and axial planes dipping steeply to the northwest. Intrafolial fold hinges have the same orientation.

END OF TRIP - Head S to "Headquarters" and dinner (not too late we hope)!