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CARBONIFEROUS METAMORPHISM ON THE NORTH (UPPER) SIDE OF THE SEBAGO BATHOLITH

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INTRODUCTION

Until recently the high-grade metamorphism in western Maine was routinely accepted as Devonian in age. Initially, only a single Devonian event was assumed and Pankiwskyj (1965) appears to have been the first worker to tentatively suggest the existence of more than one Devonian metamorphism. Subsequently, Guidotti (1970) described explicitly at least three Devonian metamorphisms. The most recent overviews of the Devonian metamorphic events in central and western Maine have been given by Holdaway et al. (1982) and Guidotti et al. (1983). Through this time there were only vague suggestions of possibly younger high-grade regional metamorphic rocks, Osberg (1968) and Guidotti (1970).

The first really suggestive evidence for a post-Devonian high-grade metamorphism in western Maine was the independent radioactive age determinations of the Sebago batholith (see Fig. 1) by Hayward and Gaudette (1984), Aleinikoff (1984), and Aleinikoff et al. (1985). These studies indicated that the S-type granite of the Sebago Batholith has a crystallization age of 325 Ma. Moreover, Aleinikoff et al. (1985) briefly discussed the possibility that the high-grade metamorphism surrounding the pluton might have the same age. Inasmuch as the abundant metapelites around the Sebago pluton are migmatitic and much intruded by pegmatites that seem to be derived from the Sebago body, this possibility seemed to merit further consideration.

The convincing evidence for this suggestion was provided by Lux and Guidotti (1985). They showed that:

(a) Although the Songo pluton (Fig. 1) has a crystallization age of 382 Ma (Lux and Aleinikoff, 1985), the hornblendes in it were re-set so that they passed below their blocking temperature (Ca. 500°C) at about 308 Ma.

(b) Hornblende in the southern portions of the Mooselookmeguntic pluton (Fig.1) have strongly disturbed Ar spectra but hornblende from the northern part gives ages close to the pluton's crystallization age (371 Ma, Moench and Zartman, 1976).

(c) The areal distribution of the K-feldspar + sillimanite isograd as mapped in the Bryant Pond quadrangle (Evans and Guidotti, 1966) and in the Buckfield quadrangle (Guidotti et al. 1973) is spatially related to the outcrop pattern of the Sebago batholith.

(d) Textural features were noted (see below) which strongly suggested

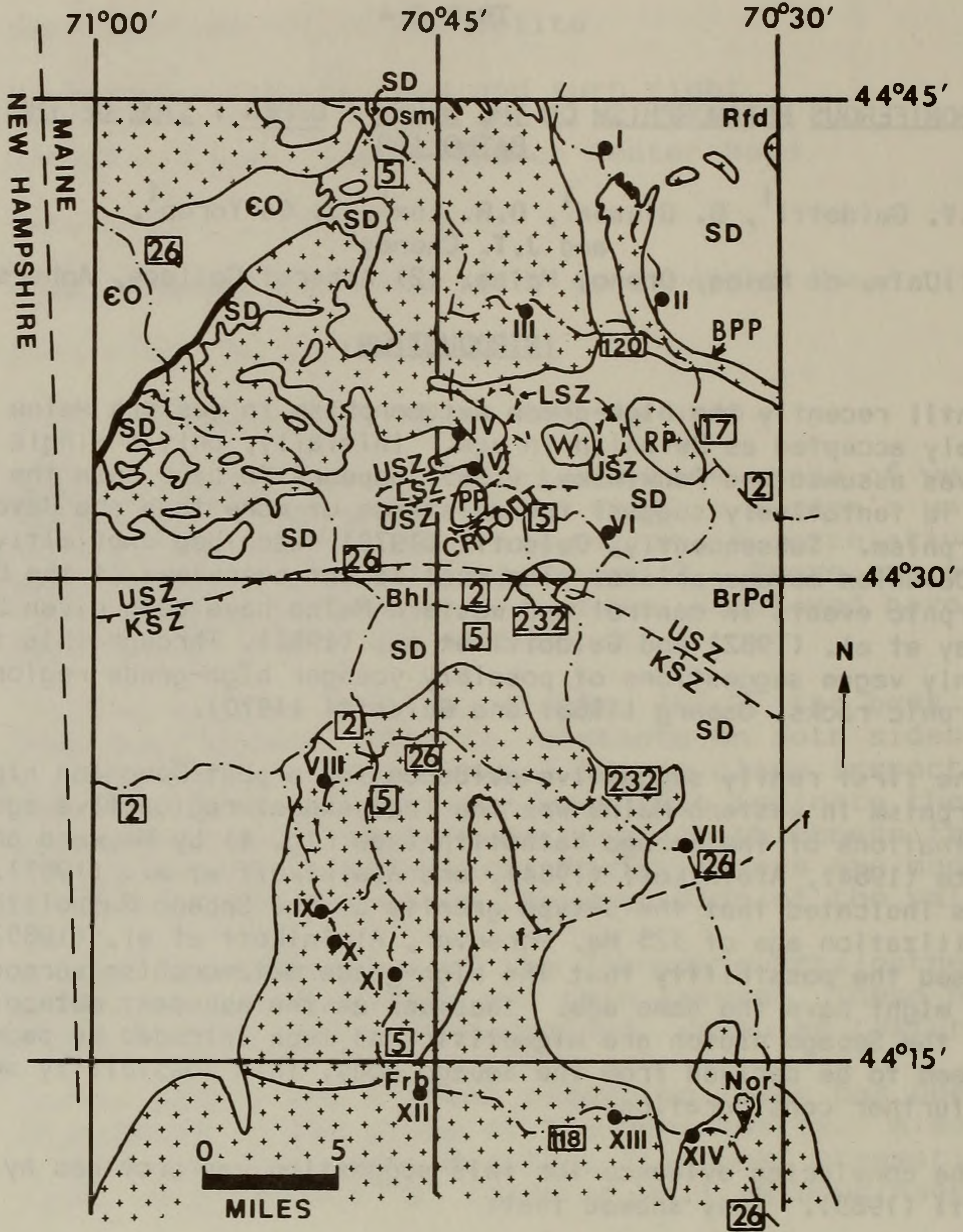


Figure 1. Roadlog and location of plutons and metasediments. ЄO - Cambro-Ordovician strata; SD - Siluro-Devonian strata. Dot-dash lines - roads; Boxed numbers - State routes. Roman numerals - localities visited. Hachured line - isograds; LSZ, USZ, KSZ - lower sillimanite, upper sillimanite, and K-feldspar + sillimanite zones; CRD-out - breakdown of cordierite. Heavy black line - boundary of ЄO and SD strata. f-fault. PP, W, RP, and BPP - Plumbago, Whitecap, Rumford, and Bunker Pond Plutons. (+) Granitic bodies differentiated on Figures (2) and (3). Osm, Rfd, Bhl, BrPd, Frb, Nor - Old Speck Mountain, Rumford, Bethel, Bryant Pond, Fryeburg, and Norway 15' quadrangles.

post-Acadian recrystallation in the central and northern portions of the Rumford quadrangle.

Subsequently, thermal modelling (DeYoreo et al. 1985) in the context of the Sebago pluton being a thin (ca.1 km thick; Hodge et al. 1982) north-dipping sheet strongly supported the suggestion of the pluton being the heat source for the areally extensive Carboniferous metamorphism suggested by Lux and Guidotti (1985).

GOALS OF THE FIELD TRIP

The goals of this field trip are aimed at the following:

(a) To inspect the igneous and metamorphic rocks that are involved in the Carboniferous metamorphism

(b) To discuss, in the context of the field outcrops, the nature of the Carboniferous metamorphism and the evidence for it.

(c) To discuss some interesting new mineralogic data for the Songo pluton which may be related to the metamorphism caused by the Sebago batholith.

(d) To elaborate on some details of a model for the thermal regime established by intrusion of the Sebago batholith.

GENERAL GEOLOGIC SETTING

The area involved in this discussion of Carboniferous metamorphism includes the Rumford, Old Speck Mountain, Bryant Pond, Bethel, and the northern parts of the Norway and Fryburg 15' quadrangles, see Fig. 1. Geologic control has been provided by the mapping of Milton (1961), Moench and Hildreth (1976), Guidotti (1965) and Fisher (1962) and the new State map (Osberg et al. 1985).

All of the meta-sediments of concern are Siluro-Devonian age and lie within the Merrimack Synclinorium. Most are meta-pelites but some biotite granulites, conglomerates and calc-silicates are also present. The strata are tightly folded, mainly into NE trending folds, but some NW trending folds are also present in the Bryant Pond quadrangle.

A great variety of igneous rocks is present, most of which are granitoids and range from tonalite to granites, though some small gabbroic bodies are observed. The major granitic plutons are shown on Fig. 1 and those discussed specifically herein are named. Also present are very abundant pegmatites and aplites, especially in the Bryant Pond and Bethel quadrangles and southward. Generally they increase in abundance as the Sebago batholith is approached and in many areas the metamorphic country rocks are merely screens and inclusions amounting to about 50% of the total rock. (e.g. see Guidotti, 1965).

INTRUSIVE ROCKS

A major part of the area affected by the Carboniferous metamorphism associated with the Sebago pluton is composed of two large intrusions - the Mooselookmeguntic and Songo plutons. Indeed much of the evidence for this metamorphic event comes directly from the igneous rocks. Within these plutons the rock types vary from quartz - diorites and tonalites to two mica leucocratic granites and span the meta - to peraluminous compositional range. The field and petrographic characteristics of these plutons (Mooselookmeguntic, Songo and the Sebago) are detailed below along with geochemical data for the Songo. In addition, two other important aspects - the geometry of the plutons and their geochronology - are also discussed as they have particular relevance to the Carboniferous metamorphism observed in Western Maine.

Field Relations and Petrography.

The Mooselookmeguntic pluton exhibits a wide variety of igneous rock types and thus is probably a composite intrusion. Various phases have been mapped by Moench and Hildreth (1976) in the Rumford quadrangle and these are also observed in adjacent areas to the N and W (i.e. in the Old Speck Mt., Oquossoc and Rangeley quadrangles), Fig. 2.

The major rock type in the northern part of the pluton (Rangeley and Oquossoc quadrangles) is a light colored, two-mica granite which has a medium grained, equigranular texture. Some small garnet euhedra are observed in this rock indicating its peraluminous character, and Apatite and zircon are the main accessory phases. This two mica granite is also observed in southern parts of the pluton as seen at Locality 4 of the fieldtrip.

A granodiorite - tonalite rock type forms the major part of the Mooselookmeguntic pluton along part of its eastern contact (Fig. 2). This is usually a medium grained granodiorite which is often foliated and contains abundant hornblende (in addition to biotite) and sphene. Accessory phases present are allanite, zircon and epidote. In some parts of this granodiorite metasedimentary xenoliths are abundant as is observed close to the outer contact of the Mooselookmeguntic in exposures east of Little Ellis pond.

Much of the central zone of this pluton is mapped by Moench and Hildreth (1976) as a two mica granite which contains abundant inclusions of hornblende and sphene-bearing granodiorite (Fig. 2). Such inclusions are often several meters across and their foliation is often truncated by the presumably later two mica granite. Both of these rock types are observed at Ellis Falls (Locality 3 of fieldtrip) and there is a clear distinction between the dark gray mafic rich granodiorite blocks and the fine grained, leucocratic two mica granite.

The field and petrogenetic relationships between the various phases of the Mooselookmeguntic pluton are at present unclear but it is hoped that ongoing research will clarify the composite nature of this intrusion.

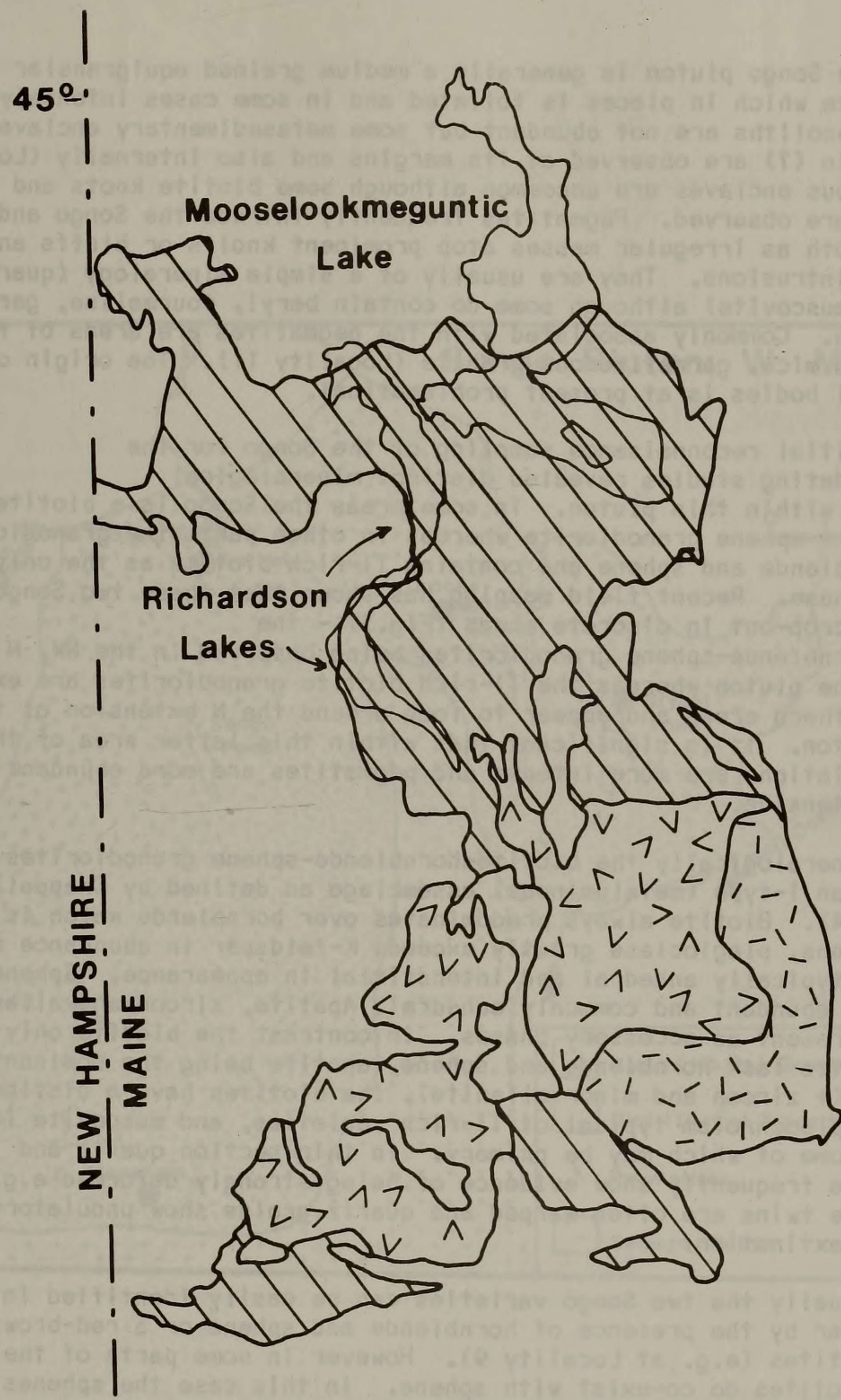


Figure 2. Map illustrating the various phases of the Mooselookmeguntic pluton; diagonal lines = two mica granite, / = hornblende, sphene granodiorite and V = two mica granite with abundant inclusions of granodiorite; unshaded areas within the pluton are large country rock inclusions. After Moench and Hildreth (1976).

The Songo pluton is generally a medium grained equigranular granodiorite which in places is foliated and in some cases intensely banded. Xenoliths are not abundant but some metasedimentary enclaves of local origin (?) are observed at its margins and also internally (Locality 10). Igneous enclaves are uncommon although some biotite knots and schlieren are observed. Pegmatites frequently intrude the Songo and are observed both as irregular masses atop prominent knolls or bluffs and as dike-like intrusions. They are usually of a simple mineralogy (quartz, feldspar, muscovite) although some do contain beryl, tourmaline, garnet and apatite. Commonly associated with the pegmatites are areas of fine grained two mica, garnetiferous granite (Locality 11). The origin of these small bodies is at present problematical.

Initial reconnaisance sampling of the Songo for the $^{40}Ar/^{39}Ar$ dating studies revealed distinct mineralogical variations within this pluton. In some areas the Songo is a biotite + hornblende + sphene granodiorite whereas in other parts the granodiorite lacks hornblende and sphene and contains Ti-rich biotite as the only mafic silicate phase. Recent field mapping has shown that these two Songo varieties crop-out in discrete areas (Fig.3) - the biotite-hornblende-sphene granodiorites being observed in the NW, N and E parts of the pluton whereas the Ti-rich biotite granodiorites are exposed in the southern areas and appear to loop around the N extension of the Sebago pluton. It is significant that within this latter area of the Songo, foliations are more intense and pegmatites are more abundant and areally extensive.

Mineralogically the biotite-hornblende-sphene granodiorites are obviously an I-type (metaluminous) assemblage as defined by Chappell and White (1974). Biotite always predominates over hornblende which is absent in some areas, plagioclase greatly exceeds K-feldspar in abundance and the latter is typically anhedral and interstitial in appearance. Sphene is relatively abundant and commonly euhedral. Apatite, zircon and allanite are also present as accessory phases. In contrast the biotite only granodiorites lack hornblende and sphene, apatite being the dominant accessory (+ zircon and minor allanite), the biotites have a distinctive red-brown pleochroism typical of Ti-rich varieties, and muscovite is present, some of which may be primary. In thin section quartz and plagioclase frequently show evidence of being strongly deformed e.g. plagiocalse twins are often warped and quartz grains show undulatory and sectorial extinction.

Usually the two Songo varieties can be easily identified in the field either by the presence of hornblende and sphene or a red-brown sheen of the biotites (e.g. at Locality 9). However in some parts of the Songo, Ti-rich biotites do co-exist with sphene. In this case the sphenes are usually anhedral and the biotites do not show the extreme red-brown pleochroism evident in rocks in which sphene is totally absent. Therefore, there may be a gradation between the two Songo varieties. Hence, no definite contact is shown on Fig. 3.

Modal analyses reveal that most samples from both Songo varieties plot in the granodiorite field of Streckeisen's classification diagram (Fig. 4) although some are strictly speaking, tonalites. Importantly,

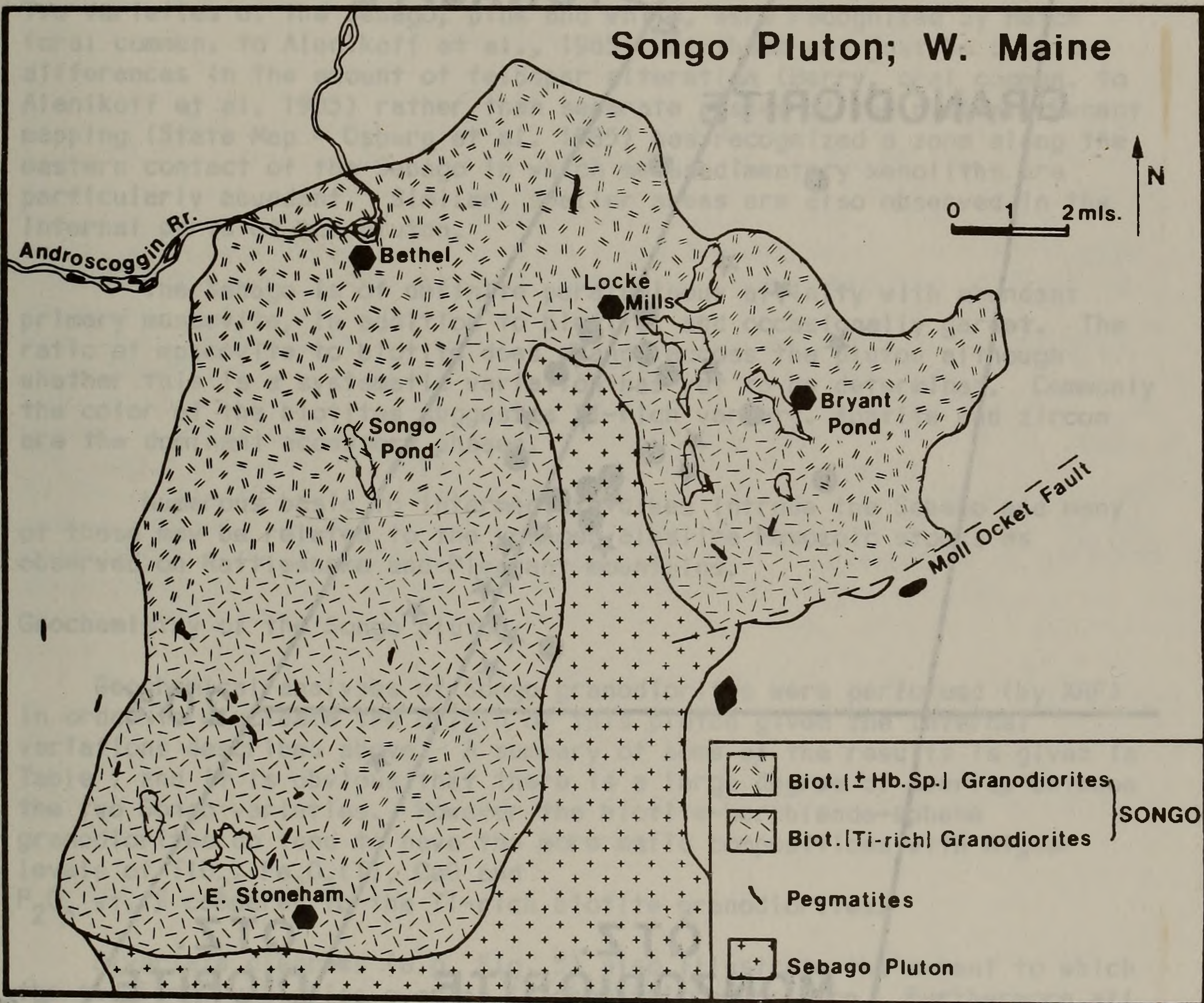


Figure 3. Generalized map of the Songo pluton showing the disposition of the biotite + hornblende + sphene granodiorites and the Ti-biotite granodiorites.
Also shown are some of the larger pegmatite bodies as well as the N part of the Sebago pluton.

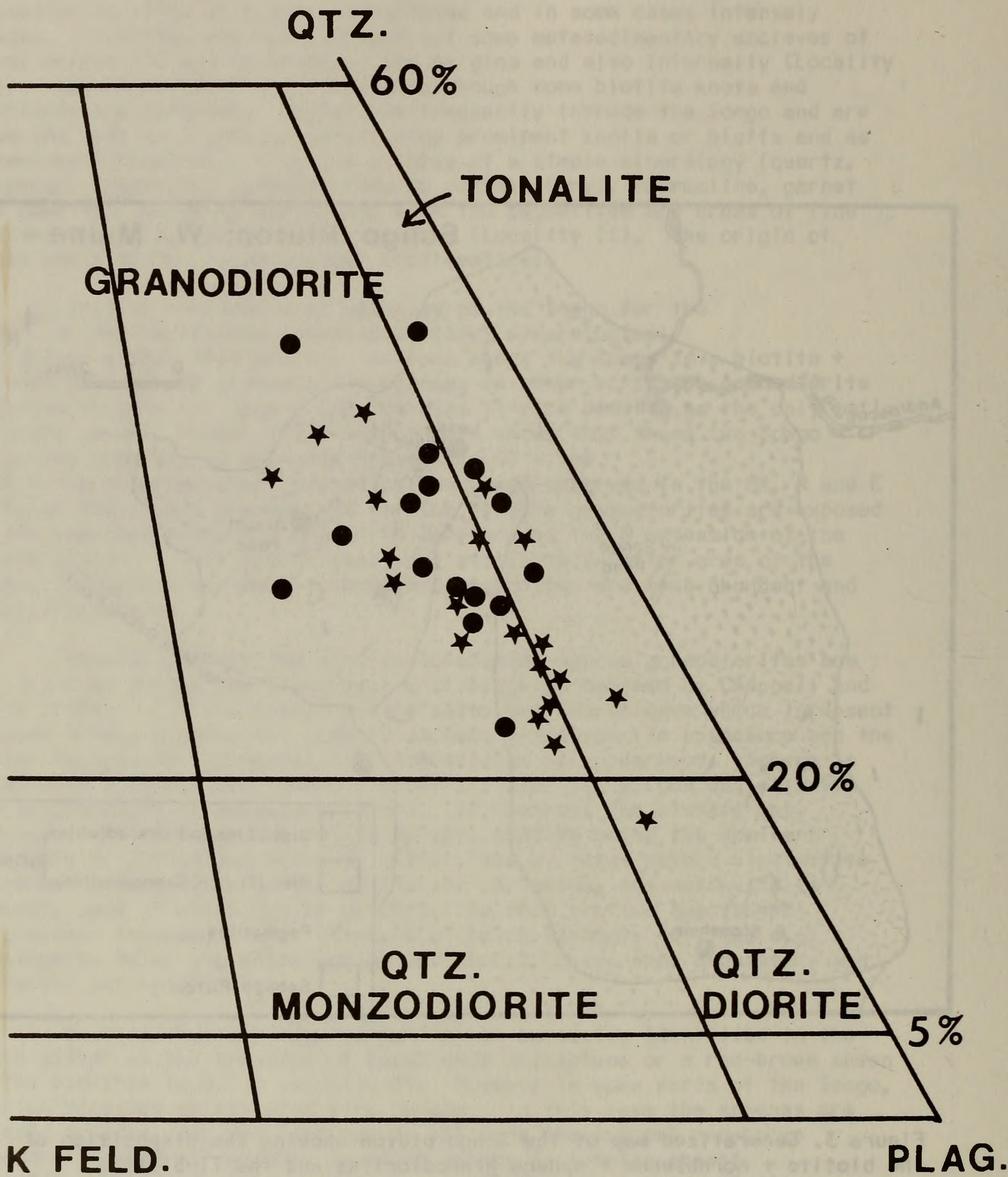


Figure 4. Streckeisen's Q-A-P classification diagram showing modal data for the biotite - hornblende - sphene granodiorites (stars) and the Ti-rich biotite granodiorites (filled circles) of the Songo pluton.

neither variety can be distinguished using these modal parameters and there is a large degree of overlap between them.

In summary, the Songo exhibits distinct internal mineralogical variations -- parts of the pluton are a typical I-type granodiorite but significant areas do appear to have a peraluminous 'S-Type' affinity.

The granite of the Sebago pluton is essentially a medium to coarse grained equigranular rock, although finer grained examples are observed. Two varieties of the Sebago, pink and white, were recognized by Hatch (oral commun. to Aleinikoff et al., 1985) but these may just be due to differences in the amount of feldspar alteration (Berry, oral commun. to Aleinikoff et al. 1985) rather than separate phases of the pluton. Recent mapping (State Map - Osberg et al. 1985) has recognized a zone along the eastern contact of the Sebago in which metasedimentary xenoliths are particularly abundant. Similar, smaller areas are also observed in the internal parts of the pluton.

The Sebago is of definite peraluminous affinity with abundant primary muscovite, in addition to biotite, and occasionally garnet. The ratio of muscovite to biotite does change across the pluton although whether this is a systematic variation has yet to be determined. Commonly the color of the biotites suggest a Ti-rich variety. Apatite and zircon are the dominant accessory phases.

Numerous basic to intermediate dikes intrude the Sebago and many of these may be related to the younger alkaline Mesozoic stocks as observed on Rattlesnake and Pleasant mountains.

Geochemistry of the Songo pluton

Geochemical analyses of Songo granodiorites were performed (by XRF) in order to elucidate the origin of this pluton given the internal variations described above. A summary of some of the results is given in Table 1 and it is obvious that there is a large degree of overlap between the two Songo varieties. However the biotite-hornblende-sphene granodiorites do tend to have the more mafic compositions with higher levels of TiO_2, Fe_2O_3(T), CaO and P_2O_5 wt. % compared to the Ti-rich biotite granodiorites.

Bivariate diagrams (e.g. Fig. 5) also illustrate the extent to which the two Songo varieties overlap in chemical composition. Furthermore all the samples define single, essentially continuous compositional trends with TiO_2, Fe_2O_3(T), MgO, CaO and P_2O_5 wt.% all decreasing as SiO_2 wt% increases. However there is a greater degree of scatter on some plots among the Ti-rich biotite granodiorites. It may also be significant that Na_2O and K_2O wt. % as well as some trace elements (e.g. Ba ppm) do not show any definite trends with increasing SiO_2 content.

In discussing the origin of the Songo pluton it is important to take into account the distinct mineralogical variations evident in this intrusion and the close spatial relationship between the Ti-rich biotite granodiorites and the later Sebago granite. Furthermore, the geochemical

TABLE 1.

Summary of Major/Minor Element Results (wt. %) for the Songo Pluton in the form of mean (top line) and range values (in parentheses). Analyses are by XRF.

	Biot. (± Hornblende, Sphene) Granodiorites (N = 19)	Biot. (ti-rich) Granodiorites (N = 18)
SiO_2	63.59 ± 2.5	66.01 ± 2.2
	(57.28 - 67.72)	(63.36 - 70.9)
TiO_2	0.804 ± 0.12	0.698 ± 0.13
	(0.643 - 1.027)	(0.404 - 0.926)
Fe_2O_3(T)	4.45 ± 0.71	3.92 ± 0.65
	(3.28 - 5.87)	(2.48 - 5.06)
CaO	4.18 ± 0.50	3.78 ± 0.56
	(3.36 - 4.91)	(2.69 - 4.55)
P_2O_5	0.296 ± .10	0.241 ± 0.058
	(0.179 - 0.652)	(0.129 - 0.329)

variations described above are also relevant in discussing the petrogenesis of the Songo granodiorite. Possible mechanisms which should be considered are i) the mixing of an I-type magma and an anatectic melt, ii) the fractional crystallization of an I-type magma which has been progressively contaminated with a sedimentary component and iii) a process of restite unmixing (White and Chappell, 1977). However, field and petrograpic evidence for the latter process is largely absent from the Songo. Further critical assessment of these petrogenetic mechanisms must await future Sr and O isotopic analyses.

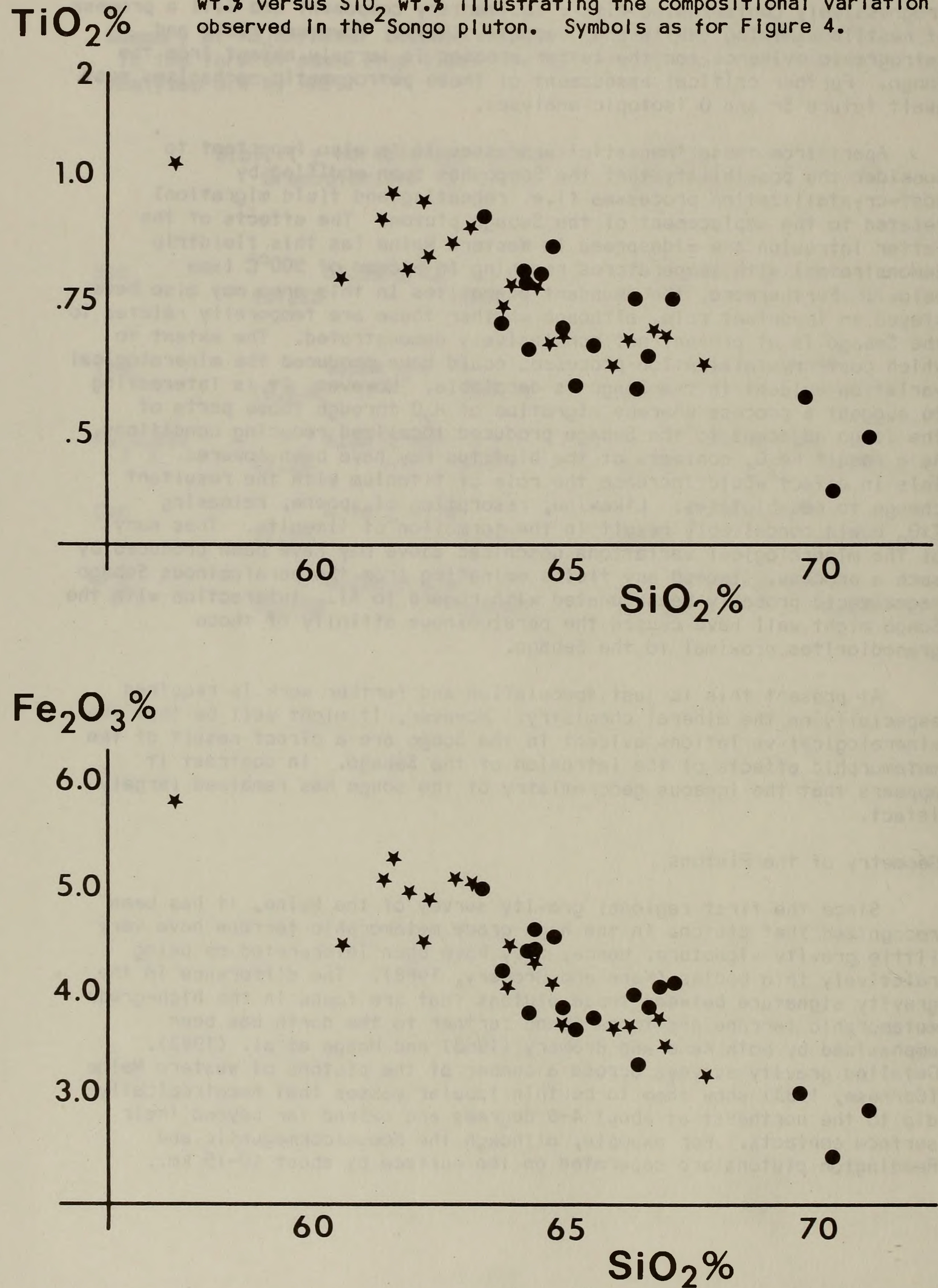
Apart from these 'magmatic' processes it is also important to consider the possibility that the Songo has been modified by post-crystallization processes (i.e. reheating and fluid migration) related to the emplacement of the Sebago pluton. The effects of the latter intrusion are widespread in Western Maine (as this fieldtrip demonstrates) with temperatures reaching in excess of 500°C (see below). Furthermore, the abundant pegmatites in this area may also have played an important role, although whether these are temporally related to the Sebago is at present not conclusively demonstrated. The extent to which post-crystallization processes could have produced the mineralogical variation evident in the Songo is debatable. However, it is interesting to suggest a process whereby migration of H_2O through those parts of the Songo adjacent to the Sebago produced localized reducing conditions. As a result Fe_2O_3 contents of the biotites may have been lowered. This in effect would increase the role of titanium with the resultant change to red biotites. Likewise, resorption of sphene, releasing TiO_2 could conceivably result in the formation of ilmenite. Thus many of the mineralogical variations described above may have been produced by such a process. Indeed any fluids eminating from the peraluminous Sebago magma would probably be saturated with regard to Al. Interaction with the Songo might well have caused the peraluminous affinity of those granodiorites proximal to the Sebago.

At present this is just speculation and further work is required especially on the mineral chemistry. However, it might well be that the mineralogical variations evident in the Songo are a direct result of the metamorphic effects of the intrusion of the Sebago. In contrast it appears that the igneous geochemistry of the songo has remained largely intact.

Geometry of the Plutons

Since the first regional gravity survey of the Maine, it has been recognized that plutons in the high-grade metamorphic terrane have very little gravity signature. Hence, they have been interpreted as being relatively thin bodies (Kane and Bromery, 1968). The difference in the gravity signature between those plutons that are found in the high-grade metamorphic terrane and those found further to the north has been emphasized by both Kane and Bromery (1968) and Hodge et al. (1982). Detailed gravity surveys across a number of the plutons of western Maine (Carnese, 1983) show them to be thin tabular masses that homotropically dip to the northeast at about 4-6 degrees and extend far beyond their surface contacts. For example, although the Mooselookmeguntic and Reddington plutons are separated on the surface by about 10-15 km.,

Figure 5. Bivariate (Harker) diagrams of TiO_2 and Fe_2O_3(T) wt.% versus SiO_2 wt.% illustrating the compositional variation observed in the Songo pluton. Symbols as for Figure 4.



interpretation of gravity measurements suggests that the Mooselookmeguntic pluton is about 2 km thick and actually extends underneath the Reddington pluton staying within about one km of the surface in the intervening region. Hodge et al. (1982) reached a similar conclusion for the Sebago Batholith and suggested that although it has a surface area of 2600km^2 its thickness is on the order of only 1 km. It is reasonable to assume that it also may extend beyond its surface contacts to the northeast.

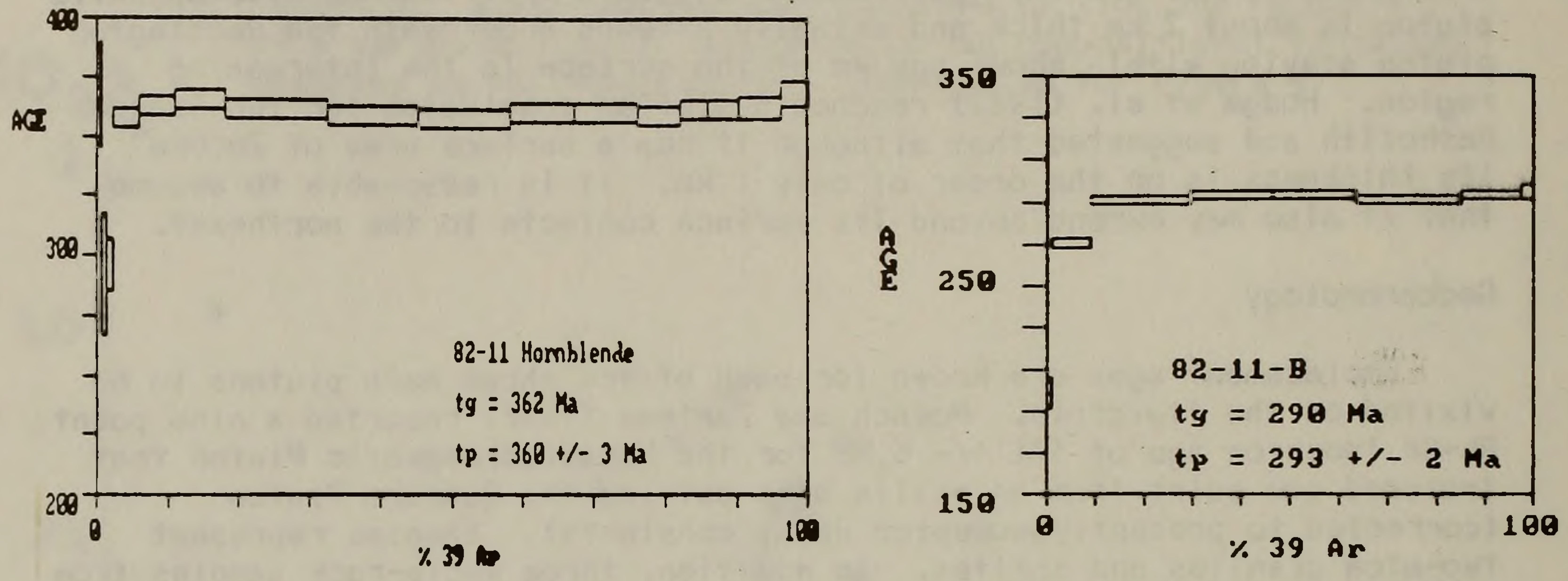
Geochronology

Emplacement ages are known for each of the three main plutons to be visited on the fieldtrip. Moench and Zartman (1976) reported a nine point Rb-Sr isochron age of 371 +/- 6 Ma for the Mooselookmeguntic Pluton that included one point from an aplite dike cutting the Rumford Pluton (corrected to presently accepted decay constants). Samples represent two-mica granites and aplites. In addition, three whole-rock samples from the Whitecap Mountain Pegmatite gave model dates of 350 +/- 6, 356 +/- 6 and 380 +/- 6 Ma, where an initial ratio of .706 was assumed. Interestingly, the three pegmatite samples are roughly colinear and suggest an age of 337 Ma with an initial ratio of 0.737. These dates are consistent with field relationships that indicate the pegmatites are younger than the two-mica granite. Field relationships also indicate that the two mica granite is younger than the hornblende granodiorite and therefore the granodiorite must be older than 371 Ma.

The age of the Sebago Batholith is well defined. Aleinikoff et al. (1985) presented U-Pb data for zircons from two samples collected at different localities. Though distinctly different chords were defined by the two samples both gave upper intercept ages of 324 Ma. Independently, Hayward and Gaudette (1984) used the Rb-Sr whole-rock isochron method and determined an age of 325 Ma for the pluton.

The Songo Pluton appears to be about 380 Ma old, though a precise age has not yet been determined. Four zircon fractions from a single sample (field trip Locality 8) loosely constrain discordia intercepts of 0 and 380 Ma that were interpreted as the result of recent lead loss and crystallization 380 Ma ago (Lux and Aleinikoff, 1985). The samples are not precisely colinear and the cause of this anomalous behavior is unknown at present but may be related to a thermal disturbance at the time of intrusion of the Sebago batholith. The sample is distinctly metaluminous and based on the Zr solubility relationship of Watson and Harrison (1983) and major and trace element data for the sample, it is unlikely that the disturbance is related to the presence of inherited zircons. Rb-Sr whole-rock isochron dating is currently underway which we hope will define a more precise age for the Songo Pluton.

A few representative $^{40}Ar/^{39}Ar$ ages for minerals from a number of the field trip Localities are presented in Fig. 6. With the exception of several hornblendes from the northern part of the Mooselookmeguntic Pluton, mineral ages are younger than the crystallization age of the plutons (Lux 1985; unpublished data). Nonetheless, mineral ages can provide useful information about the ambient temperature in the vicinity of the plutons at the time of intrusion, heating of rocks surrounding plutons, and about the regional cooling



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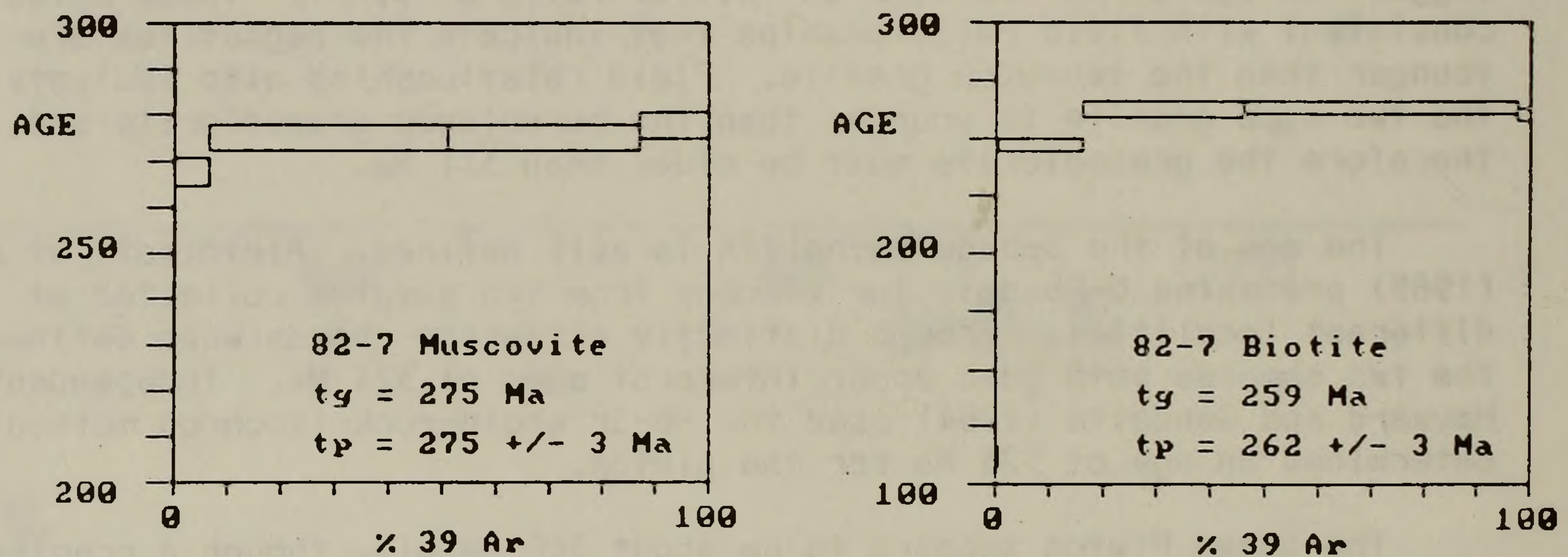

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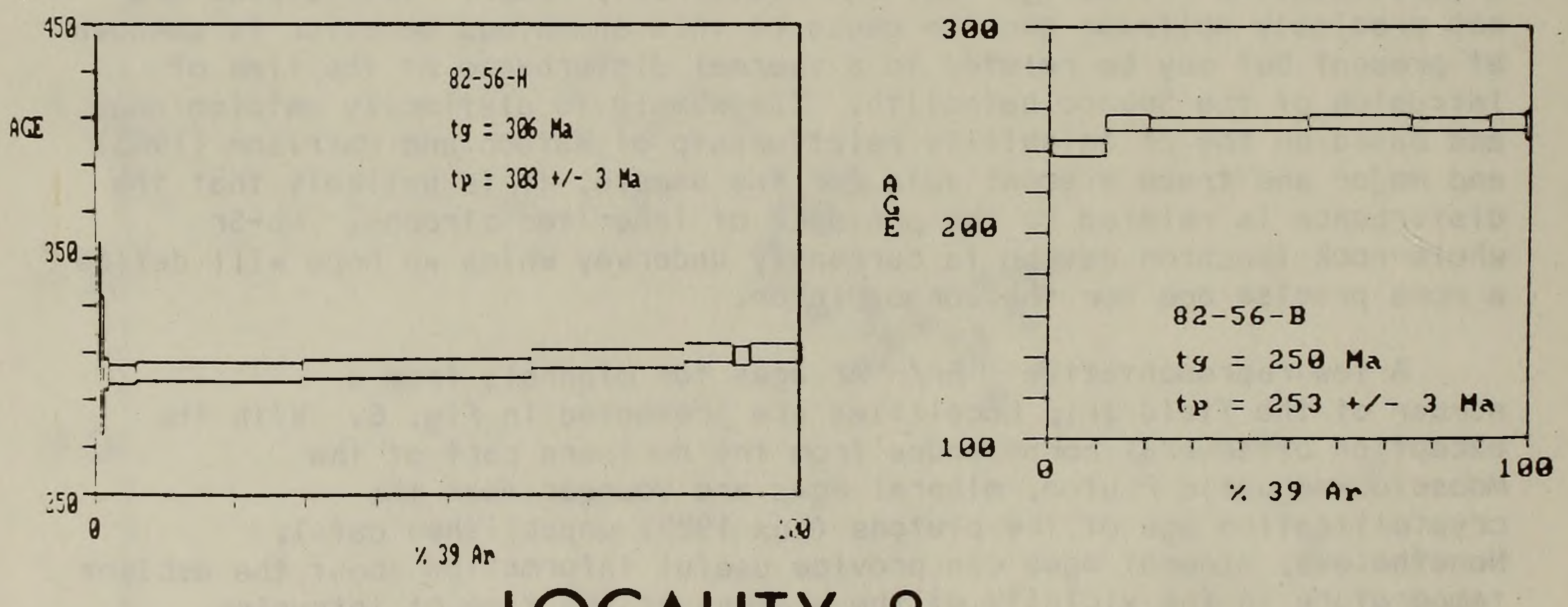

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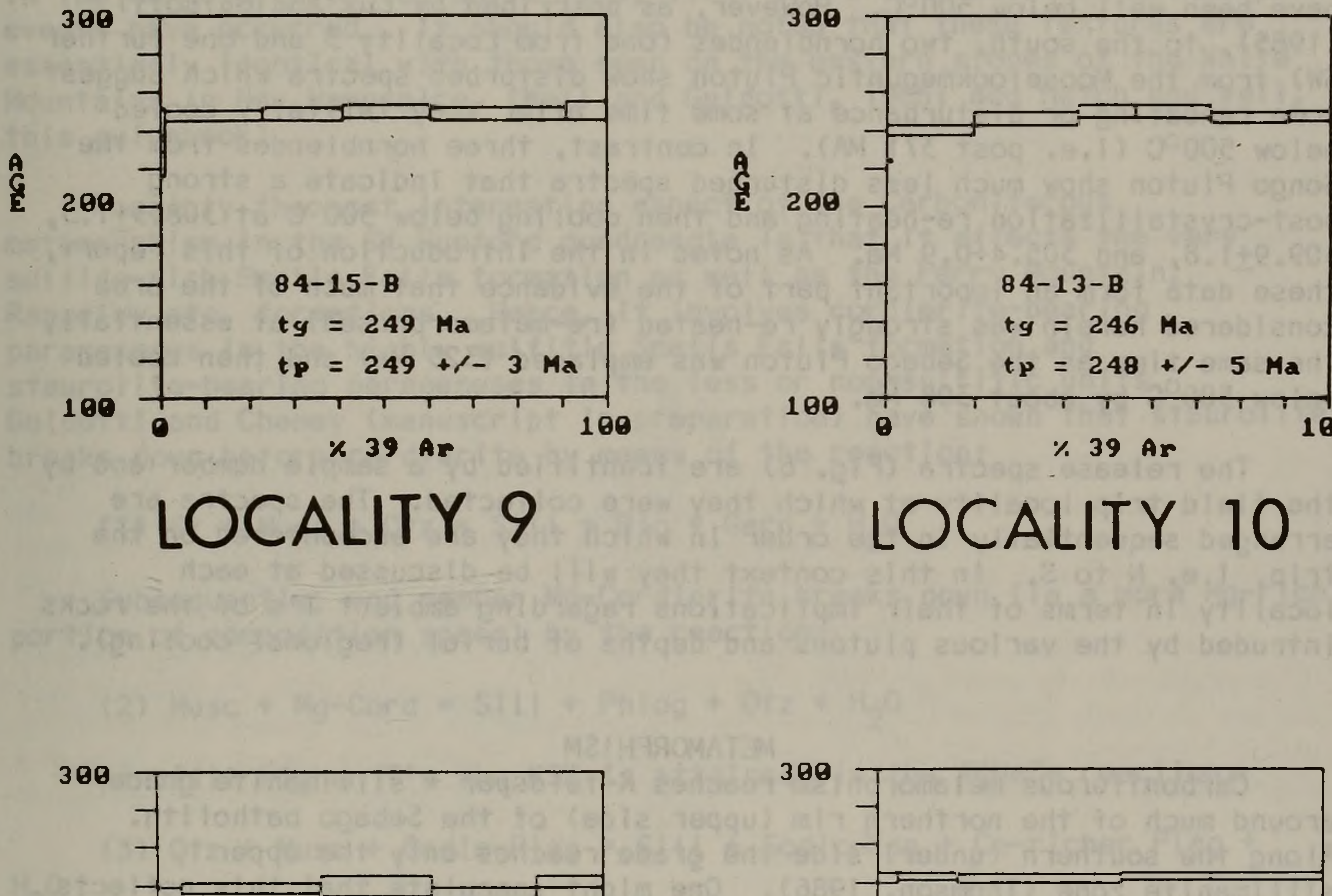

Figure 6. $^{40}Ar/^{39}Ar$ incremental heating release spectra for hornblende, biotite and muscovite. Field trip localities where the samples were collected are given below the spectra.

(depth of burial) of the terrane.

In the context of the Carboniferous metamorphism considered herein, it is the hornblende ages that are of greatest interest. As noted above, hornblendes from the northern portions of the Mooselookmeguntic Pluton have mineral ages coinciding with the crystallization ages. Hence, the rocks must have cooled below 500°C very quickly and experienced no subsequent heating. Moreover, the ambient T of the surrounding rocks must have been well below 500°C. However, as described by Lux and Guidotti (1985), to the south, two hornblendes (one from Locality 3 and one further SW) from the Mooselookmeguntic Pluton show disturbed spectra which suggest some reheating or disturbance at some time after they initially cooled below 500°C (i.e. post 371 MA). In contrast, three hornblendes from the Songo Pluton show much less disturbed spectra that indicate a strong post-crystallization re-heating and then cooling below 500°C at 308.5±1.3, 309.9±1.8, and 305.4±0.9 Ma. As noted in the introduction of this report, these data form an important part of the evidence that much of the area considered herein was strongly re-heated (re-metamorphosed) at essentially the same time as the Sebago Pluton was emplaced (325 Ma) and then cooled below 500°C by about 308 Ma.

The release spectra (Fig. 6) are identified by a sample number and by the field trip locality at which they were collected. The spectra are arranged sequentially in the order in which they are encountered on the trip, i.e. N to S. In this context they will be discussed at each locality in terms of their implications regarding ambient T's of the rocks intruded by the various plutons and depths of burial (regional cooling).

METAMORPHISM

Carboniferous metamorphism reaches K-feldspar + sillimanite grade around much of the northern rim (upper side) of the Sebago batholith. Along the southern (under) side the grade reaches only the upper sillimanite zone (Thomson, 1986). One might speculate that this reflects greater ease of pegmatites and associated fluids escaping upward rather than downward. Textural observations, especially on the south side, (Thomson, 1986) suggest that this metamorphism was largely a static event.

The transition from the upper sillimanite zone (USZ) to K-feldspar + sillimanite zone (KSZ) was studied and described in detail by Evans and Guidotti (1966). The upper stability limit of muscovite was never exceeded and so assuming that P-total was about 3.5Kb (see below) and that PH_2O was high, they estimated T-max to be in the range somewhat below 650°C. More recently, Cheney and Guidotti (1979), using the exchange geothermometer based upon the reaction:

$$(NaAl_3Si_3O_{10}(OH)_2)Musc + (SiO_2)Qtz =$$

$$(NaAlSi_3O_8)Plag + (Al_2SiO_5)Sill + H_2O$$

obtained more quantitative estimates (623 -643°C for the KSZ). Based on fluid inclusion studies on these rocks, Burruss (1977) obtained very similar estimates. In the USZ and KSZ the rocks are so recrystallized that there is little evidence left of any earlier Devonian textural features. However, in the S.W. Rumford quadrangle and S.E. Old Speck Mountain quadrangle (on Puzzle Mountain) the rocks are only lower sillimanite zone (LSZ) (Cheney, 1975) and it is believed that some of the textural features (annealed slip cleavages, partial pseudomorphs of staurolite etc) may be remnants from earlier Devonian metamorphism(s). For example, the LSZ rocks are texturally extremely similar to those seen in the Rangeley area (Guidotti 1970, 1974) where only Devonian metamorphic events have occurred. It should also be noted that these textures are essentially identical with those seen on the eastern slopes of the White Mountains in New Hampshire, (Wall and Guidotti, 1986; and Hatch and Wall, this guidebook).

Possibly the most interesting aspect of the Carboniferous metamorphism in the SW Rumford quadrangle is that it affects the very sulfide-rich Smalls Falls formation as well as the Perry Mountain, Rangeley etc. formations. Hence, it involves cordierite-bearing parageneses in the highly sulfitic Smalls Falls formation and staurolite-bearing parageneses in the less or non-sulfitic units. Guidotti and Cheney (manuscript in preparation) have shown that staurolite breaks down before cordierite by means of the reaction:

(1) St + Musc + Qtz = Sill + Bio + Garn + H_2O

Subsequently, end member Mg-Cordierite breaks down (in a more Mg-rich portion of composition space) by the reaction:

(2) Musc + Mg-Cord = Sill + Phlog + Qtz + H_2O

At still higher T's the KSZ is attained via the AKNaCa reaction:

(3) Qtz + Musc + Sodic-Plag = Sill + Sodic-Ksp + Ca-richer Plag + H_2O

As developed in Guidotti and Cheney (Ms), at higher P, the order of reaction (1) and (2) would probably be reversed. It should be noticed from the order of reaction (2) and (3) (See Fig. I also), that in the muscovitic rocks of this area, cordierite breaks down before the KSZ is reached. At grades exceeding the stability of muscovite, as in Massachusetts, end member Mg-cordierite becomes stable again in K-feldspar-bearing rocks (Robinson, pers.comm) and via the subsequent continuous reaction it becomes Fe-richer. Thus, in muscovite-bearing rocks, cordierite becomes Mg-richer until its demise via reaction (2). In contrast, in higher grade K-feldspar-bearing rocks it comes in again as end member Mg-Cordierite which then becomes Fe-richer as T increases further.

The mineral facies diagrams determined for the Carboniferous metamorphism in the SW and SE portions of the Rumford and Old Speck Mountain quadrangles respectively, and southward through the Bryant Pond quadrangle are shown in Fig. 7. Fig. 8 shows the relevant PT curves and suggested PT path (i.e. metamorphic field gradient) for the Carboniferous

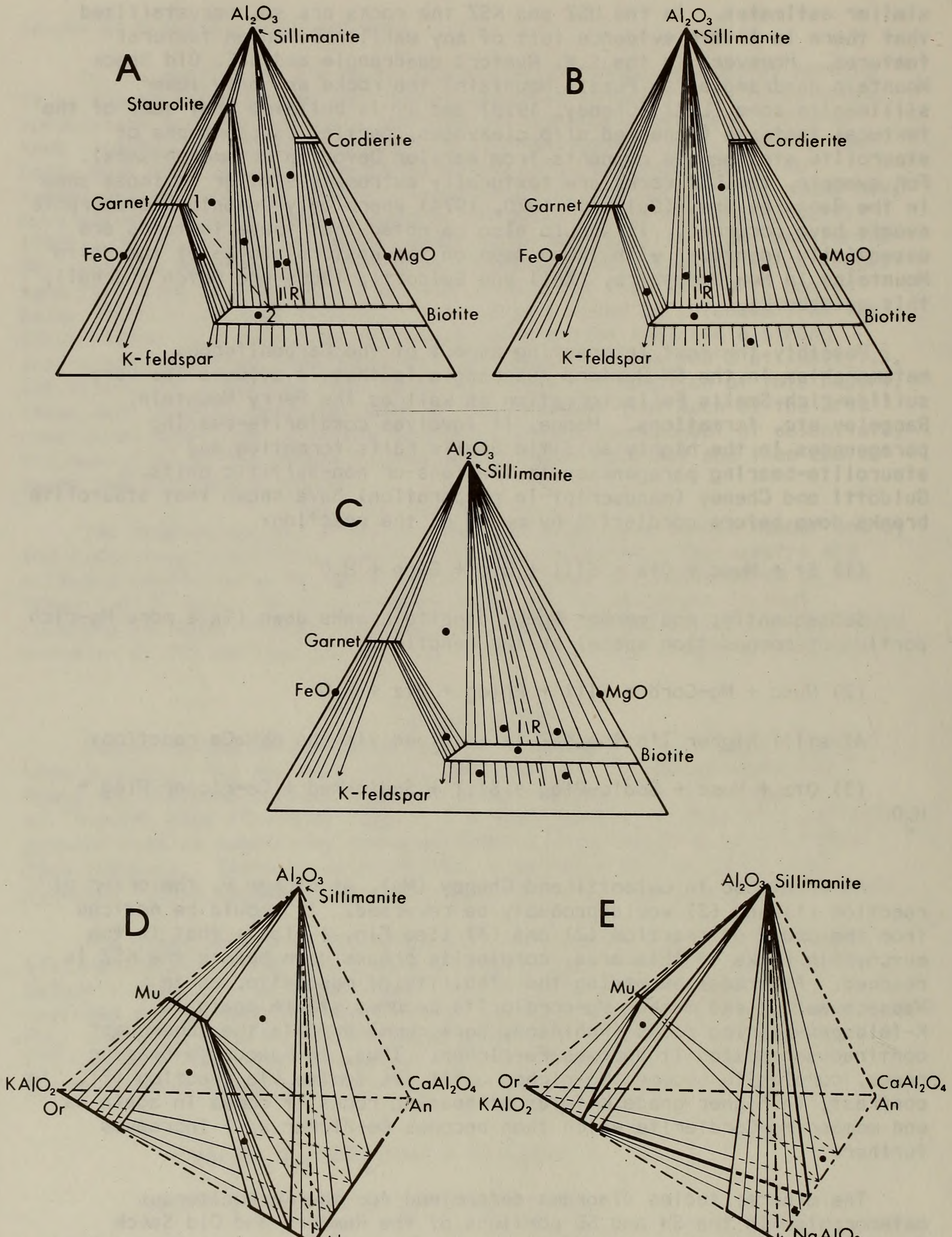
A
Al2O3
Sillimanite
Staurolite
Cordierite
Garnet
1
FeO
MgO
R
2
Biotite
K-feldspar
B
Al2O3
Sillimanite
Cordierite
Garnet
FeO
MgO
R
Biotite
K-feldspar
C
Al2O3
Sillimanite
Garnet
FeO
MgO
R
Biotite
K-feldspar
D
Al2O3
Sillimanite
Mu
KAlO2
Or
CaAl2O4
An
Ab
NaAlO2
E
Al2O3 Sillimanite
Mu
Or
KAlO2
CaAl2O4
An
NaAlO2
Ab

Figure 7. Mineral facies diagrams for S.W. Rumford, S.E. Old Speck Mountain, and Bryant Pond quadrangles. (A)-(C) - AFM projections; quartz, muscovite, and uniform a (H_2O) in all assemblages; I:R indicates boundary between assemblages with ilmenite vs rutile as the Ti-saturating phase. (A) Lower Sillimanite zone; Line 1-2 to indicate garnet in assemblages not shown by AFM projection. (B) Upper sillimanite zone, below the breakdown of cordierite. (C) Upper sillimanite zone and K-feldspar + sillimanite zone, above cordierite break-down. (D) AKNaCa mineral facies diagram for lower and upper sillimanite zones. (E) AKNaCa mineral facies diagram for the K-feldspar + sillimanite zone. Dots-observed assemblages.

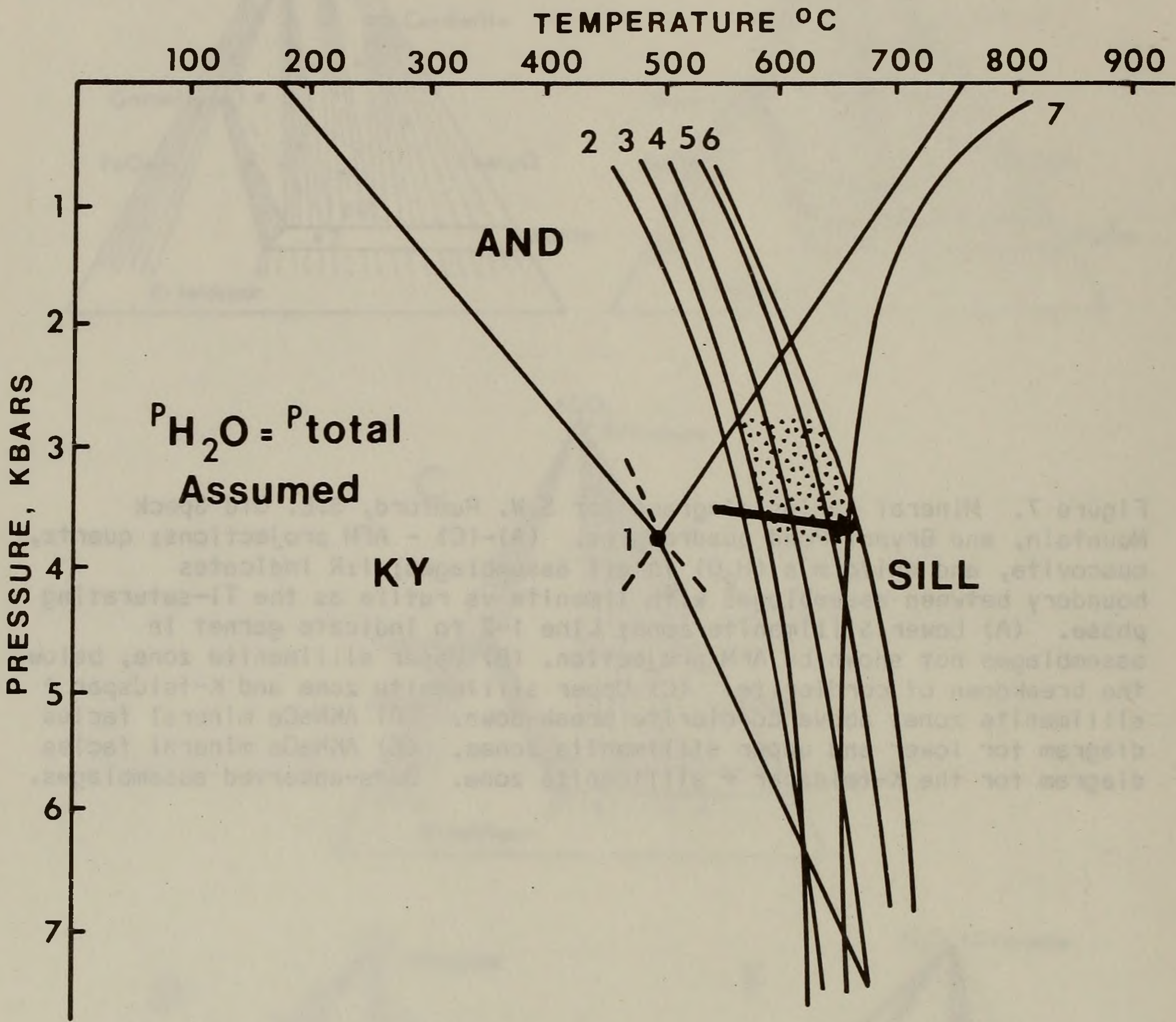

Figure 8. PT grid of equilibria relevant to this report. (1) Al-Silicate curves, Holdaway (1971). (2) Paragonite breakdown, Chatterjee (1972). (3) St + Chl = Al-Sil + Bio, Guidotti (1974). (4) St = Al-Sil + Gn + Bio, Hoschek (1969). (5) Ab + Mu = Al-Sil + Ksp, Chatterjee and Froese (1975). (6) Muscovite breakdown, Chatterjee and Johannes (1974). (7) Granite minimum, Tuttle and Bowen (1958). Stippled area - suggested range of PT conditions for metamorphism considered herein. Heavy arrow - suggested PT path.

metamorphism. It should be noted that in the context of metamorphism due to the thermal effects of the Sebago Batholith (see below) that the PT path is nearly isobaric and because the rocks underwent nearly static recrystallization, the PTt paths of individual horizons were also nearly isobaric.

Another very interesting aspect of the Carboniferous metamorphism in the Bethel and Bryant Pond quadrangles is the effect of the Sebago pluton on the 380 Ma Songo pluton. As noted earlier, the Ar work on the hornblende from the Songo pluton shows that it was re-heated to above 500^{0} C sometime after its initial crystallization and cooling, and then cooled again to below 500^{0}C by 308 Ma. In additon, a number of quite systematic chemical and mineralogic variations were described above for the Songo pluton.

Of particular interest is that these variations are spatially related to the Sebago batholith and its concentration of associated pegmatites. Moreover, several of the variations are exactly those that would result from chemical transfer of material as well as heat from the per-aluminous Sebago pluton into an initially sub-aluminous Songo pluton. Hence, one can at least entertain the suggestion that the Songo pluton is now a metamorphic rock affected by an essentially static heating so that it retains much of its original igneous texture.

Finally, if we consider the effects of the Carboniferous metamorphism to the north in the central and northern portions of the Rumford Quadrangle, we are faced with the more difficult task of detecting the effects of the low grade portions of the metamorphism where it is superimposed on relatively high grade Devonian metamorphism. In the northern part of the Rumford Quadrangle where only Devonian metamorphism has occurred, the rocks are now at staurolite grade (see Locality 1) and involve the assemblage staurolite + biotite + chlorite + garnet. However, it is clear from textural evidence that they were once at higher grade and had the assemblage andalusite + staurolite + biotite + garnet. These two distinct grades would be described to M_3 and M_2 of Guidotti (1970) and Holdaway et al. (1982). Southward, (along the Swift River and Route 17) one finds that the rocks coarsen and that flat lying aplite and pegmatite sills start to occur. Subsequently sillimanite comes in by breaking the staurolite + chlorite join and eventually the rocks become coarse, contorted, migmatitic gneisses as seen at Locality 2.

To date, only modest efforts have been directed at detecting overprinting of the lower grade portions of the Carboniferous metamorphism on the Devonian metamorphism described above. However, several features in part described by Guidotti (1970), clearly reflect a metamorphism post-dating the two Devonian events described above. These features seem best interpreted in terms of the northern effects of the heating caused by the low northerly dipping Sebago batholith. They include:

(I) "In the N and NE sections commonly occur small, euhedral staurolite crystals (Imm) or aggregates of crystals growing on grain boudnaries of quartz and plagioclase. In some cases the euhedra occur in the same rock with larger, ragged staurolite grains which contain coarse needles of sillimanite. The euhedral staurolite "appears" fresh and as if it formed in a later event" (Guidotti, 1970, p. 18).

(2) Further south, in the north central part of the Rumford quadrangle (Roxbury, Locality 2) the Devonian metamorphism was USZ or possibly even KSZ. Now it is at least at garnet grade as garnet and biotite are perfectly fresh but sillimanite is strongly resorbed. For example, sillimanite commonly occurs only as inclusions in quartz and plagioclase, does not cross grain boundaries, and tends to avoid contact with biotite.

(3) Further south in the Rumford quadrangle in the vicinity of Frye and Hale, Guidotti (1970, p. 18) noted: "In the S part of the area, aggregates of fine grained euhedral sillimanite needles occur on quartz and plagioclase grain boundaries. Such aggregates are present in rocks containing coarser sillimanite which is partially resorbed. Again, it "appears" as if the euhedral needles are the result of a late event."

Not enough petrographic work has been done to determine if there is a regular, progressive sequence in the grades established during the Carboniferous metamorphism. In the southernmost Rumford quardangle and into the Bryant Pond quadrangle where the grades are highest there is a simple transition from USZ to KSZ. (Only a very few specimens display any resorbtion textures for the sillimanite.) However, the extensive Devonian dehydration in the central and northern portion of the Rumford Quadrangle may cause complexity in the establishment of diagnostic middle and low grade Carboniferous assemblages. Obviously much additional, detailed work will be required to address this possibility.

THERMAL CONSEQUENCES OF THE INTRUSION OF THE SEBAGO BATHOLITH

As we have discussed, petrologic and geochronologic data suggest that the intrusion of the Sebago batholith was linked to a regional, high-grade metamorphic event. However it may not be immediately clear which is the primary and which is the secondary feature. Here we present a thermal analysis which indicates that the Sebago itself is likely to have provided the heat necessary for the metamorphism.

The Sebago batholith is a laterally extensive sill-like body and, as was concluded above, it is reasonable to assume that the exposed area of the Sebago is a surface expression of a much larger granitic sheet that extends northeast below the present erosion surface and presumably once extended to the southwest above the present erosion surface. With this geometry, the metamorphic terrane to the north of the Sebago lies above its upper surface.

Petrologic observations (Holdaway et al., 1982) of the surrounding rocks indicate that the depth of emplacement of the Sebago was greater than 10km.. Since the thickness is much less than both the width of the batholith and the depth of emplacement, we can approximate the Sebago at the time of the intrusion as an infinite magmatic sheet with uniform temperature, TM, in an infinite solid with uniform temperature, TC. This renders the problem tractable up until the time of solidification. After solidification is completed the thermal evolution can be followed numerically and the finite thickness of the roof rocks as well as the depth dependence of the country rock temperature can be taken into account.

The important parameters are the specific heat, C, the thermal diffusivity, D, the latent heat, L, the magma temperature TM, and the temperature of the surrounding rock, TC(x), where x is the depth. Varying C, D, and L over the range of reasonable values has little effect on the result. In contrast, variations in TM and TC can have significant effects. Fortunately, studies of plutons of similar composition and depth of emplacement provide reasonable limits on TM. The Strathbogie batholith was found to have had an emplacement temperature of between 750° and 850° C (Phillips et al., 1981) and the Victorian S-type granites of Australia are claimed to have been intruded at 750° to 850°C (Clemens and Wall, 1981; Clemens, 1984). Tewhey (1975) concluded that the Cupsuptic pluton in western Maine had an intrusion temperature of about 800°C. Consequently we have taken TM = 800°C. (Lowering TM to 700°C reduces the maximum attained temperatures near the pluton by about 50°C.)

The initial temperature distribution, TC(x), is much more uncertain. Taking a geotherm inferred by modern day heat flow measurements would no doubt underestimate crustal temperatures since over 10km of crust with its compliment of radioactive elements have been removed since the time of intrusion. Likewise, calculating an equilibrium temperature distribution assuming an extra 10 to 15 km of crust neglects the delay between thickening and warming as well as the effect of erosion and would overestimate TC(x) (see, for example, England and Thompson, 1984). These two procedures would surely give extreme lower and upper limits on TC(x). Instead we have chosen to numerically model the thermal history of the region given geologic and geochronologic constraints on the burial and erosion history. The results shown in Fig. 9, indicate that the Acadian deformation resulted in a significant warming of the crust by the time of the intrusion of the Sebago, but in the absence of the batholith only low grade metamorphism would have occured at depths of 10 to 15 km. The thermal effect of the intrusion, also shown in Fig. 9, is quite dramatic. The modelling predicts a maximum temperature of about 650° C at the upper boundary of the pluton and an array of maximum temperatures in the 2km above the pluton giving an apparent thermal gradient of 80°to 100°C/km. Temperatures in excess of 500°C are predicted up to 2km from the pluton. For a sufficiently extensive sheet dipping at 5°this corresponds to 25 km away from the contact. These predicted conditions are in good agreement with those observed through petrographic and geochronologic studies.

We conclude that the Sebago batholith is likely to have been the source of heat for the surrounding Carboniferous metamorphism, provided that it has a shallow northeastward dip and extends more than 30km beyond its northeastern boundary. If the Sebago is not sufficiently extensive then this model may still be appropriate if, alternatively, the Sebago is one of a number of interconnected sill-like granitic bodies that intruded into the region about 325 Ma ago.

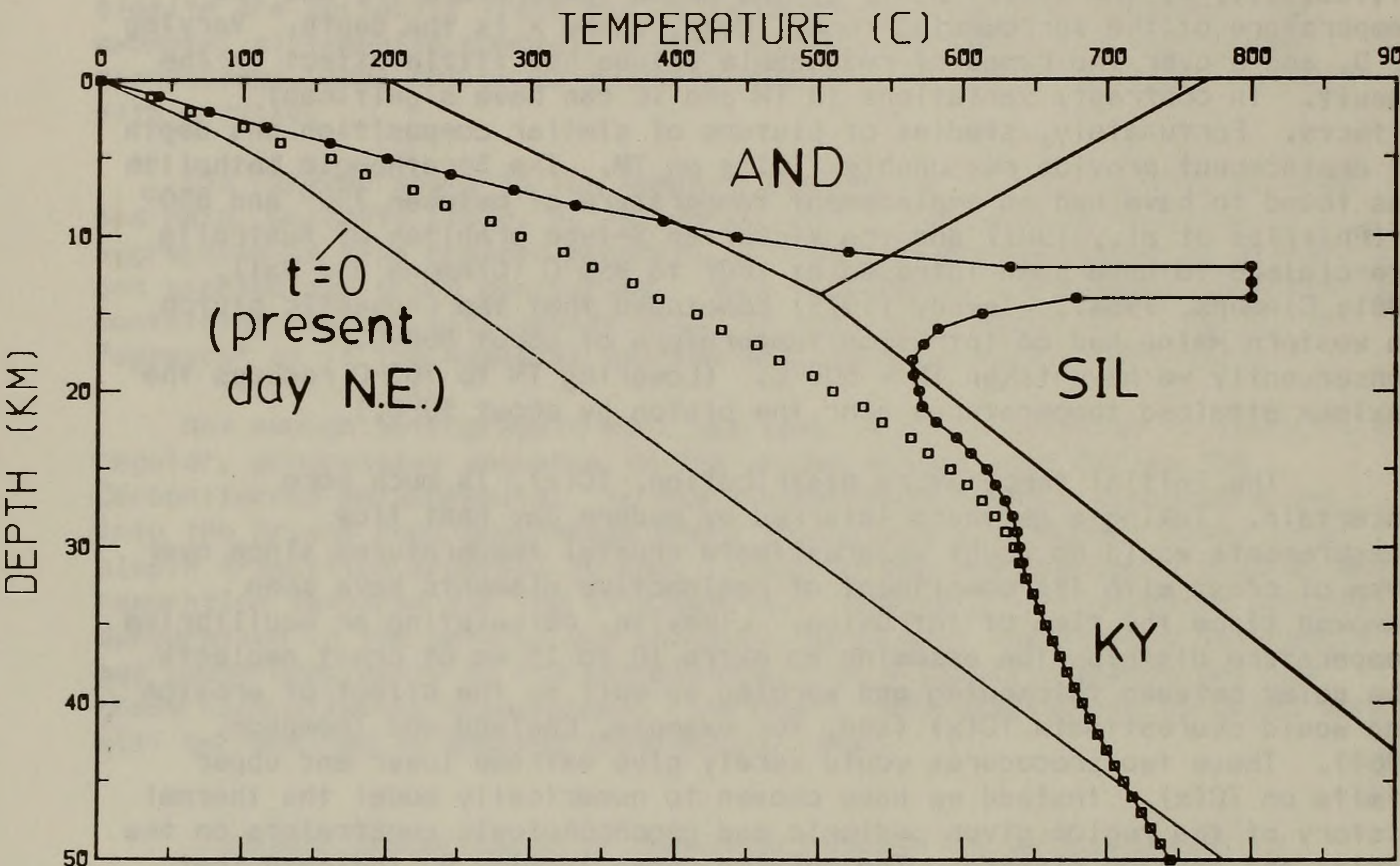

Figure 9. Thermal effect of Acadian thickening and subsequent igneous intrusions. Initial temperature profile, t=0 (440Ma), is that of present day New England. Open boxes: Temperature profile after 115 MY (325Ma). Burial and erosion parameters are: 12.6 km of sedimentation at 0.3 km/MY for 40 MY (440-400 Ma); homogeneous thickening of the sediments from 12.6 to 25 km at 40 MY (400Ma); erosion at 0.05 km/MY from 40 to 115 MY (400 to 325 Ma). Open circles: Array of maximum temperatures near a 2 km thick 800^{o}C infinite magmatic sheet centered at 13km. Burial and erosion history preceding intrusion is the same as for open boxes.

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ITINERARY

The assembly point for this field trip is at the Coos Canyon School in Byron. This site is easy to find as it coincides with the picnic area on the East side of Route 17, about 20 miles north of Rumford. Assembly time is 8:30 AM. Bring lunch materials with you. Topographic maps: Rumford, Bethel, and Bryant Pond 15' quadrangles.

Mileage

0.0 LOCALITY 1 :

Only Devonian metamorphism can be discerned here and the rocks are now at staurolite grade. The diagnostic assemblage is staurolite + biotite + chlorite + garnet + ilmenite + pyrrhotite. This assemblage formed during the M_3 event of Holdaway et al. (1982). In the northern part of the exposure (down on the river edge) staurolite euhedra up to 1 cm in length are found.

Textural evidence for an earlier, higher grade metamorphism (M_2) is seen on bedding-slab surfaces. It consists of coarse muscovite, "Turkey Track" pseudomorphs after andalusite. These pseudomorphs are up to 10X2 cm in size and in a few cases still retain some fresh andalusite. The assemblage formed in this earlier event involved andalusite + staurolite + biotite + garnet.

Note how the pseudomorphs are unoriented within bedding planes. In addition, they are undeformed plus the muscovite in them is unoriented. Moreover, staurolite euhedra and tablets of coarse biotite are also largely unoriented. Although evident mainly from thin section study, these megascopic observations provide some indication that both M_2 and M_3 were largely static events. The rocks here are part of the Perry Mountain fm., (Moench, 1971). Some isoclinal folds are evident on the eastern wall of the gorge and a few scattered aplite dikes are also present in these outcrops. Although these rocks have been affected by two fairly high-grade metamorphisms, it is remarkable how well graded beds and cross-beds are preserved. Possibly this reflects the static nature of the two metamorphisms. Some chemical data is available for the minerals at this outcrop - see specimen 1-8/7/63 of Evans and Guidotti (1966).

For those using this field guide at a later time it would be worthwhile to inspect the rusty - weathering outcrops just to the south on Route 17. These outcrops are unusual for the Perry Mountain formation in that usually this unit is gray-weathering. Because of the abundant pyrrhotite in these outcrops some sulfide silicate reactions come into play. For example, garnet is absent, staurolite becomes much less abundant or absent and in some of the latter the titanium phase is rutile rather than ilmenite.

The outcrops downstream of the Route 17 bridge are also worth visiting to view nice folds and axial plane cleavages.

Head south on Route 17.

0.2 Bridge over Swift River

4.2 Roxbury post office - Mobil station

5.5 Outcrops of coarse gneiss on left

5.9 More outcrops of the gneiss

6.3 Continued outcrops of gneiss

6.45 <u>LOCALITY 2</u>

River outcrops along Rte 17, south of the village of Roxbury. The rocks here are coarse, swirled, migmatitic gneisses. Bedding is difficult to find. Coarse spangles of muscovite are prominent and in some cases have shapes reminiscent of staurolite crosses. Many spangles contain euhedral garnets similar to those seen in lower grade rocks that retain clear muscovite pseudomorphs after staurolite. Pegmatite veins and irregular masses are prominent throughout this outcrop.

These rocks were originally in the USZ or possibly even KSZ. However, sillimanite is now largely resorbed (not sericitized!) and seen mainly in thin section as inclusions in quartz and feldspar. Hence, the present assemblage is biotite + garnet. Minor chlorite seems to be present only as a very late alteration phase. A few parts of the outcrop and associated loose blocks do retain coarse sillimanite visible to the unaided eye! Can you find it?

Inasmuch as the sillimanite is now largely resorbed but garnet and biotite are fresh, it would appear that these rocks have been affected by a later, medium grade metamorphism. Moreover, because hornblende in plutonic rocks this far north shows disturbed spectra, we would suggest that this later metamorphism reflects the Carboniferous heating event.

The rocks at this outcrop have been mapped by Moench and Hildreth (1976) as undivided Siluro - Devonian.

7.9 Turn to the right on Route 120

8.0 Cross Swift River

8.2 Stop sign - Turn right on Route 120

10.8 Roxbury Notch Summit

13.8 Fork in road - stay left on Route 120

15.4 Bridge over river

15.5 LOCALITY 3 :

Outcrops at Ellis Falls and at roadside along Route 120.

In this part of the Mooselookmeguntic pluton the rock type is a two mica granite which contains abundant inclusions of hornblende + sphene bearing granodiorite (see above). Therefore at this locality two varieties of the intrusion can be examined.

The two mica granite is a fine grained, equigranular rock and is quite leucocratic. Both muscovite and biotite are obvious in hand specimen. In thin section K-feldspar predominates over plagioclase, muscovite is more abundant than biotite and is obviously a primary phase and apatite is the principal accessory.

In contrast to the above are the blocks of granodiorite which are seen in the roadside exposures. The granodiorite is a much darker gray color, has a medium grained, equigranular texture and is distinctly richer in mafic minerals. Biotite and hornblende are abundant, the latter commonly being 6 mm in length. Euhedral sphene is frequently observed in hand specimen.

In many ways the granodiorite, observed here as large inclusions in the two mica granite, is comparable to that which Moench and Hildreth (1976) mapped on the eastern side of the Mooselookmeguntic pluton (see Fig.2).

Release spectra for biotite and hornblende from the granodiorite at this locality are given in Fig. 6 (82-11).

Continue on Route 17.

17.2 Stop sign - turn right, continuing on Route 120

17.5 Road to right is Route 5 north. Stay on Route 120.

17.6 Cross Ellis River

18.05 Downtown Andover - Turn left (south) on Route 5

19.5 View of Whitecap mountain (Pluton) to the south.

23.1 LOCALITY 4 :

Large road cut south of Andover along Route 5.

Present at this locality is the two mica granitic phase of the Mooselookmeguntic pluton. Enclaves of possible metasedimentary origin are also observed along with abundant pegmatites.

The granite here is a light gray, medium grained equigranular rock which is extremely fresh. In places it is slightly porphyritic with larger plagioclase grains. Biotite and muscovite are obvious in hand specimen and significantly small garnet euhedra are also present. In thin section K-feldspar > plagioclase, biotite exceeds muscovite and has the distinctive red-brown pleochroism typical of Ti-rich varieties. Zircon is the dominant accessory phase.

The granite is cut by numerous pegmatitic dikes the largest of which is Ca. 75cm across, though most are <20 cm. Two sets of pegmatites are apparent at this outcrop, however their relative ages are not clear. They have a simple mineralogy (feldspar, quartz, muscovite) with some garnet present along their edges and internally. In contrast, on Plumbago mt. gem tourmaline has been mined and another large pegmatite body is present on the top of Whitecap mt.

In some parts of this outcrop there are abundant biotite rich enclaves. Some of these appear to have been entrained into the pegmatites whereas others are cut by them. The mineralogy of these enclaves (biotite + feldspar + some garnet) may suggest that they are mafic schists (?) but their origin at present is problematical.

Biotite schlieren are also quite common within the granite. In places there is some evidence to suggest that they are modified basic inclusions but some may simply be biotite rich segregations.

Release spectra for muscovite and biotite from this locality are given in Fig. 6 (82-7).

Continue South on Route 5.

25.2 <u>LOCALITY 5</u> :

This outcrop involves well-bedded Perry Mountain formation. Graded beds show that the strata are overturned at this locality.

The grade here is LSZ and the typical assemblage involves sillimanite + staurolite + biotite + garnet + ilmenite + pyrrhotite. Staurolite is mostly replaced by coarse muscovite to form the conspicuous white "eyes" seen in the pelitic portion of the graded beds. For the most part the staurolite is seen only in thin section but occasionally it is visible in hand specimen. In some places the muscovite "eyes" approximate the shape of staurolite and contain euhedral garnet inclusions. The rough weathering surface of the pelitic beds is largely due to very abundant clots of fibrolitic sillimanite.

A slip cleavage at high angles to bedding is evident in parts of this outcrop. In thin section it is seen that this slip cleavage has been annealed to form polygonal arcs. Moreover, this cleavage has no effect on the muscovite pseudomorphs after staurolite.

These LSZ rocks trace directly up grade to the USZ and then SKZ and so it is believed that the last equilibration occurred during the Carboniferous heating event.

25.7 Leave Route 5, turn left and cross Ellis River

26.1 Bear right

27.5 Continue on the main road

30.2 <u>LOCALITY 6</u> :

Just north of Rumford Center.

This outcrop consists of coarse mica schist and is interbedded on a thick scale with biotite granulite. Moench and Hildreth (1976) map this rock as part of the Perry Mountain formation.

The grade here is USZ (Carboniferous age) and only indestinct eyes of coarse muscovite persist. Fibrolitic sillimanite is abundant on biotite plates and some sheath-like sillimanite covered surfaces occur. The main assemblage is sillimanite + garnet + biotite + ilmenite + pyrrhotite.

A good lineation is present due to a finely spaces slip cleavage which intersects bedding at a high angle.

30.6 Route 2 is encountered - bear right

31.5 Outcrop of Perry Mountain Fm.

33.6 Rumford Animal Park

34.4 Rumford Point - turn left on Route 232 and cross Androscoggin River

34.9 Bear left on Route 232

37.0 Bear right, staying on Route 232

40.8 Crossing through an esker

41.1 Riding on the esker

43.6 Outcrop of Songo granodiorite

43.75 Stop sign - junction with Route 26; bear left.

44.9 Outcrop of Songo on the left

45.7 More Songo

47.5 <u>LOCALITY 7</u> :

These rocks are in the SKZ. Sillimanite is extremely abundant and K-feldspar is abundant both in the groundmass and as coarse megacrysts. The latter commonly contain quartz inclusions that simulate bipyramids such as one would see in volcanic rocks. Muscovite is still stable so that the full assemblage is sillimanite + garnet + biotite + K-feldspar (orthoclase) + muscovite + plagioclase (An_{30}) + ilmenite + pyrrhotite. This outcrop is part of the extensive SKZ that surrounds the Sebago batholith on its northern side.

47.8 Intersection with small cross road - carefully make a U-turn and head back up Route 26.

51.9 Pass the junction with Route 232, continue on Route 26.

52.1 Outcrop of Songo

53.1 Downtown Bryant Pond, post office - bear right, staying on Route 26

53.5 Outcrop of Songo

55.25 Outcrop of Songo

55.45 View to the right, across lake - Bucks Ledge, an exfoliation dome in Songo Pluton

56.3 Locke Mills - Songo outcrop

57.0 Bethel Town Line

60.1 Telstar High School

61.4 Entering town of Bethel

61.5 Cross railroad track - leave Route 26 and continue straight on Route 35 - Main street of Bethel

61.7 Continue up Main street of town - do not follow Route 35

61.95 Stop sign at top of hill. Bear left to village green and immediately bear right on Route 5. Bethel fire Station in view. Stay on Route 5 turning right at the Opera House Condominiums.

62.15 Stop sign where Route 5 takes sharp left; proceed straight across onto minor forest road.

64.25 LOCALITY 8 :

Small ridge outcrop approximately 25 yds off the forest road, NE of Sparrowhawk mt. This outcrop consists of the biotite + hornblende + sphene variety of the Songo pluton. The granodiorite is a medium grained, relatively mafic rich rock which contains hornblende + biotite with sphene as the dominant accessory phase. Both hornblende and sphene are obvious in hand specimen as is the distinctive black coloration of the biotites (cf. to Locality 9). In thin section plagioclase greatly predominates over the commonly anhedral (interstitial) K-feldspar, biotite has 'normal' brown/green pleochroism and apatite and zircon are also present. The granodiorite at this outcrop is foliated, this being defined by the biotite, hornblende and plagioclase grains. However in places the deformation is more intense and small scale folding is observed. In general the texture and mineralogy evident in the granodiorite here is typical of most of the NW, N and NE parts of the Songo pluton. (see Fig. 3). However in some areas hornblende is not present and the granodiorites are not as deformed as is apparent at this outcrop. Release spectra for hornblende and biotite from this locality are given in Fig. 6 (82-56).

66.7 Sharp right turn in the road

67.5 Intersection of forest roads. Take a left turn and proceed south.

69.7 <u>LOCALITY 9</u> :

A series of small pavement outcrops alongside the forest road at the abandoned schoolhouse.

In travelling further south into the central zone of the Songo pluton, the Ti-rich biotite granodiorites are observed along with well developed deformation features.

At this locality the granodiorite is essentially medium grained but is somewhat porphyritic with larger plagioclase grains. Biotite is the only mafic phase and on close examination it has a distint red - brown sheen, in contrast to those observed at Locality 8. The red - brown pleochroism is more clearly observed in thin section. Other main differences to the previous stop are a) the absence of hornblende and b) a lack of sphene, with apatite now being the dominant accessory.

The granodiorite at these outcrops displays an intense foliation this trending generally N - S and orientated along this are large plagioclase grains some of which are up to 3 cm in length. In some places incipient mafic and felsic banding is observed.

A release spectrum for biotite from this locality is given in Fig. 6 (84-13).

70.0 Take road to Crocker Pond Campground (sign posted)

71.5 Crocker Pond campground. Park at sign for campground 5 close to the restroom (!). Proceed to this campsite and then take trail which goes south along lakeshore for approximately 50 yds.

<u>LOCALITY 10</u> :

Lakeside outcrops of the Songo granodiorite at the SE end of Crocker Pond.

The granodiorite is medium grained and strongly foliated and deformed which is typical for this general area of the pluton. The red - brown color of the biotites is again observed and there is also some sparse muscovite present.

Of note at this outcrop is the intense foliation and possible folding. Some of the banding is comparable to that seen at the previous locality.

Also observed here is a large metasedimentary xenolith which is possibly a block of the local country rock (Madrid fm.?). These are not particularly common but are present in this area. They do not appear to have interacted to any large extent with the granodiorite.

Proceed back along the road to main forest road.

73.2 Turn right at end of Crocker Pond road.

76.2 Junction with Route 5. Turn right and proceed South.

78.1 Junction with Route 35, keep on Route 5.

79.0 Pass Bumpus Mine pegmatite quarry on Route 5.

80.5 LOCALITY 11 :

Large roadcut along Route 5.

This outcrop exhibits an association of rock types which is frequently observed at many outcrops in this general area of the Songo pluton. The granodiorite is cut by a large pegmatite body and a two mica, garnet-bearing granite is seen within the latter.

The darker, foliated/banded Songo granodiorite is easily recognized. It again contains Ti-rich biotite, no hornblende and very rare sphene. In thin section some muscovite is present and apatite is abundant. The foliation observed trends NE dipping at 35 to NW.

The granodiorite is cut by a large two mica, feldspar, quartz pegmatite. In some places blocks of Songo granodiorite are observed within the pegmatite and these are seen to be strongly deformed.

The two mica garnetiferous granite is seen in close association with the pegmatite. It is a fine to medium grained leucocratic rock with obvious muscovite and garnet clots. Its field relations to the pegmatite are ambiguous - in some cases it appears to have cut the pegmatite whereas in others this is not so clear pointing to synpegmatite emplacement.

In this part of the Songo, the close association of pegmatite and two mica garnet granite is a frequent occurrence. The origin of the latter rock is problematical and depends to a large extent on the age of pegmatite emplacement.

This outcrop may have been faulted as is suggested by the large vertical face in the pegmatite on the E side of Route 5. Some limited mineralisation is observed along this face.

A release spectrum for biotite from this locality is given in Fig. 6 (84-15).

84.3 Junction of Routes 35 and 5. Turn left at the signpost and proceed east along Route 35.

85.2 Fork in road at North Waterford - stay left which is Route 118.

86.4 LOCALITY 12 :

Small roadside outcrop along Route 118 and in the adjacent Crooked River.

At this locality the two mica - Sebago granite is observed at one of its closest points to the Songo pluton.

The Sebago granite here is a medium-grained, equigranular rock with an overall light brown color due largely to the K-feldspars. Biotite and muscovite are obvious in hand specimen and present in roughly equal amounts. However, in other parts of the pluton muscovite predominates.

Proceed to the east on Route 118.

90.5 Junction of Routes 118 and 37. Keep going east on Route 118.

93.9 LOCALITY 13 :

Roadside outcrop of the Sebago granite at Little Penessawassee Pond.

The Sebago granite observed here and at Locality 12 are fairly typical of this N part of the pluton.

Again the rock is medium grained and equigranular with obvious biotite and muscovite. In thin section the biotites display a distinct red-brown pleochroism (cf. to some parts of the Songo) and exceed muscovite in abundance. K-feldspar is dominant and apatite, zircon and some opaque oxides are present as the accessory phases.

Release spectra for biotite and muscovite from this locality are given in Fig. 6 (SBG-10).

96.7 LOCALITY 14 :

Discussion of Thermal Modelling of the Sebago pluton

For those heading south, continue east on Route 118 to junction with Route 26. Turn right on 26 and it will take you to the Maine Pike. Before heading down Route 26, you may want to note the symbol in the lower, right-hand corner of Fig. 1.