1-1-1986

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TRIP B-8

PETROLOGY AND FIELD RELATIONS OF M2 METAMORPHISM IN WEST-CENTRAL MAINE

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INTRODUCTION

This field trip deals with metamorphism of pelitic rocks, designated M2, in an area which includes Bingham, Anson, Kingfield, and Little Bigelow Mountain 15-minute quadrangles (Fig. 1). Previously M2 has been defined (Guidotti, 1970) in rocks which also experienced effects of M3. Since that time it has been recognized by Holdaway et al. (1982) that M2 is a widespread event being seen as an early metamorphism in the Augusta area (Novak and Holdaway, 1981) and the major metamorphism in Kingfield and Anson quadrangles (Pankiwskyj, 1979) and Little Bigelow Mountain and Bingham quadrangles (Boone, 1973). In the area of this field trip M2 has been less affected by more recent events than in the Phillips and Rangeley quadrangles where it was defined.

Most of the area of study has been previously described by Boone (1973) and Pankiwskyj (1979). The metasediments are mainly Silurian or Devonian and are intruded by gabbros and quartz monzonites of the New Hampshire magma series. The only igneous age available is 400 m.y. for the Lexington batholith (Fig. 1) determined by Gaudette and Boone (1985). Other igneous rocks in the map area are believed to be not significantly different from this age based on their apparent correlation with M2.

The best formations for pelitic specimens are the Silurian Perry Mountain and the Devonian Carrabassett and Seboomook Formations, but most other units have yielded satisfactory specimens on occasion.

This field trip guide represents a progress report on our studies of M2. The sampling detail is greatest in southern Bingham and least in Little Bigelow Mountain quadrangle. Thin sections have been studied from most of the area, but microprobe data are mainly from Bingham quadrangle (Dickerson, 1984).

The Lexington batholith (Fig. 1) has three intrusive phases: a northern coarse equigranular biotite quartz monzonite, a central coarse porphyritic biotite quartz monzonite, and a southern medium equigranular binary quartz monzonite (Boone, 1973; Pankiwskyj, 1979; Koller, 1979). Exposures of the granitic rocks are generally poor. Several phases of basic intrusive activity west and north of the Lexington have been described by Boone (1973).

SUMMARY OF METAMORPHIC EVENTS

The area in question has been affected, at least to some degree, by three metamorphic events as summarized below.


Little Bigelow Mountain
Bingham
1 Chlorite
2 Biotite + chlorite
3 Garnet + biotite + chlorite
4 Staurolite + biotite
5 Andalusite + staurolite + biotite
6 Andalusite + biotite
7 Sillimanite + biotite
A Cordierite + biotite + chlorite
B Andalusite + cordierite + biotite
C Sillimanite + K feldspar + cordierite + biotite
All + muscovite + quartz + ilmenite + graphite
Granitic rocks
Gabbroic rocks
•2 Field trip stop
Northern phase
Central phase
Stau.
Cord.
Sil.
Stau. Out

Figure 1. Preliminary map showing prograde mineral assemblages and isograds for M2 metamorphism in the area of this report. Bar over number indicates highest grade minerals>90% altered. Assemblages 4-7 may include garnet. Intrusive phases of the Lexington batholith are indicated. One inch equals 3 miles.

M1 is widespread chlorite-grade metamorphism which produced S2 schistosity (Guidotti, 1970) prior to 400 m.y. ago. In the study area, S2 is at low angles to bedding, generally strikes northeast, and dips steeply. Subsequent events have been mainly static, producing only local indications of deformation.

M2 is a regional[1]-contact event which produced the generalized sequence chlorite → biotite → staurolite → andalusite-staurolite → andalusite → sillimanite. Most of the sillimanite is clearly contact metamorphic in nature. Cordierite is locally important, taking the place of staurolite. Chloritoid may be seen locally in the biotite zone (Carrabassett Fm.) in northern Anson quadrangle (Fig. 1). Garnet is rarely seen in hand specimen, and in thin section it occurs in small amounts. When seen at low grades it first occurs in the upper biotite zone immediately below the first staurolite. The age of M2 is about 400 m.y. based on the age of the correlative Lexington batholith (Gaudette and Boone, 1985). Much of M2 is directly or indirectly related to the Lexington batholith and other batholiths of the region which produce andalusite in surrounding country rocks (Reddington and Skowhegan).

M3 is a regional-contact event which produced the grade sequence chlorite → biotite → garnet → staurolite → sillimanite. In contrast to M2, andalusite and cordierite are absent from normal pelitic rocks and garnet is common. The zone of sillimanite-staurolite coexistance is narrow relative to the corresponding andalusite-staurolite zone in M2. M3 is mainly developed south of the study area associated with the Hallowell and Livermore Falls groups of plutons, and Phillips Batholith, and the Mooselookmeguntic batholith with ages between 379 and 394 m.y. (Holdaway et al., 1982; Guidotti et al., 1983). Some of the retrogressive effects in the study area may relate to M3.

DEFINITION OF M2

At present there appear to be three necessary elements to any M2 metamorphism: (1) andalusite is widespread in normal pelitic rocks; (2) wherever M3 is also present M2 clearly predates M3 (however in the Augusta area, Novak and Holdaway, 1981, M2 and M3 closely approach each other in time and P-T conditions); (3) retrogressive effects are common except near M2-age plutons. M2 is the only event in this part of Maine which is known to produce andalusite in normal pelitic rocks. As a result andalusite-bearing pelites tend to be assigned to M2.

In addition to the area of Figure 1, M2 is developed in the Norridgewock and Waterville quadrangles, and predates M3 in Augusta, Dixfield, Phillips, Rangeley, and far western Farmington quadrangles. It is interesting to note that M3 rocks of the Livermore Falls group of plutons, exposed primarily in Farmington and Livermore Falls quadrangles, do not show evidence of an earlier M2 event. It appears that this area was first metamorphased at a time late enough that P was too high for development of typical M2 assemblages.

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[1]The use of the term "regional" is intended to imply the absence of a clear relationship to plutons or portions of plutons presently exposed at the surface.

SUB-EVENTS OF M2

Based on the work of Dickerson (1984) near the Lexington batholith M2 may be subdivided into three sub-events which are very closely related in time and partly overlap in P-T conditions:

M2n is contact metamorphism related to the northern phase of the Lexington batholith. The grade sequence is chlorite → biotite → cordierite → andalusite-cordierite → sillimanite-cordierite-K feldspar. Neither staurolite nor almandine garnet are present in these rocks. The rocks are relatively unaltered.

M2 is regional metamorphism which has a very general spatial relation to plutons but may ocur as far as 18 km from exposed igneous rocks. The grade sequence is chlorite → biotite → staurolite → andalusite-staurolite → andalusite, and the rocks are almost always extensively retrograded.

M2s is contact metamorphism around most of the other granitic and gabbroic rocks (including the central an southern phases of the Lexington batholith). M2s overlaps with M2 in time and P-T conditions, but the rocks are invariably less altered than M2 rocks. The grade sequence is the same as that for M2 except that sillimanite without K feldspar tops the sequence. Locally, as in southeastern Little Bigelow Mountain quadrangle, a relatively clear distinction may be made between M2 and M2s (Fig. 1). The two designations are also useful to distinguish between clearly contact-related and regional metamorphic M2, even in places where they were synchronous.

We tentatively assign the age sequence: M2n, M2, M2s. M2n is placed first because it is lowest in P and the metamorphic sequence of the region is clearly one of increasing P with time (Holdaway and Dutrow, in prep.; Dickerson and Holdaway, in prep.). Also, on the west side of the Lexington batholith in the area where northern and central phase activity have both been prominent, there is no sign of cordierite, which would have been produced had the northern phase been intruded last. M2s is considered equivalent and/or slightly later than M2 in age because of the lesser degree of alteration of M2 rocks (e.g. Boone, 1973).

ISOGRAD PATTERN

The isograds which can be traced and which reasonably approximate a univariant P-T line are (1) the first appearance of staurolite or cordierite, (2) the disappearance of staurolite, and (3) the first appearance of sillimanite (Fig. 1). The first appearance of biotite is very composition dependent and requires heavier sampling of a more consistant composition than is available in the area. In M3 rocks the first appearance of Al silicate (as sillimanite) makes a distinct isograd. However in M2, the analogous appearance of andalusite is Fe/Mg composition dependent. In psammitic-pelitic rocks andalusite without staurolite (6)[2] first apears immediately after the staurolite isograd whereas in more pelitic rocks it appears with staurolite (5) at

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[2]Numbers in parentheses refer to assemblages listed in Figure 1.

somewhat higher grades. The uneven distribution of staurolite (4), andalusite-staurolite (5), and andalusite (6) assemblages in Figure 1 illustrates this composition dependence. The disappearance of staurolite is also composition dependent, but an approximate isograd has been shown in Figure 1 based on (1) total absence of staurolite in a variety of rock compositions, and (2) presence of biotite with andalusite (6) in a range of composition (Fe/(Fe+Mg) = 0.46 to 0.70) such that staurolite would be present if grade were lower. As more microprobe work is done the accuracy of this isograd will be improved.

Contact metamorphism is signified by the cordierite isograd for M2n and the staurolite (locally) and sillimanite isograds for M2s. While sillimanite was probably stable along all igneous contacts, a sillimanite isograd is not shown in areas where sillimanite was not specifically sampled. In addition, it is clear from Boone's (1973) and Dickerson's (1984) work that around many gabbroic rocks and around the northern phase of the Lexington batholith the sillimanite zone is less than 100 m wide. One important exception is Little Bigelow Mountain where it appears that the Huston diorite-granite stock (Boone, 1973) passes beneath the mountain to produce regional sillimanite-bearing (7) assemblages (Fig. 1).

Study of Figure 1 shows that regional M2 metamorphism occurs as several "lobes" of medium grade metamorphism, each with one or more plutons within it. One lobe of activity surrounds the Lexington batholith and the neighboring gabbroic bodies. On the south M2 and M2s nearly coincide; on the east they differ by up to 15 km. A second lobe of activity begins along the western edge of Kingfield and Farmington quadrangles. The younger M3 Phillips batholith lies within this lobe. A third lobe of activity may surround the Reddington batholith in the Phillips and Stratton quadrangles (C.V. Guidotti, pers. comm.), and a fourth lobe of activity surrounds the Skowhegan batholith and extends south into the Augusta quadrangle (Holdaway et al., 1982).

Heat sources for these lobes of M2 metamorphism are probably tabular igneous bodies which were in part below or above the present level of exposure (Lux, DeYoreo, Guidotti, and Decker, ms.). Geophysical evidence for a heat source for the complex pattern of staurolite-grade metamorphic rocks east of the southern and central phase of the Lexington batholith does not exist (Mattick, 1965; Kane and Bromery, 1966, 1968). A single gabbro outcrop and abundant gabbro float occur 9 km ENE of Bingham near the north end of the metamorphic high suggesting that the heat source may be thin sheets of gabbroic rocks. The gabboric bodies west and north of the Lexington batholith appear to have little or no affect on gravity for the area (Kane and Bromery, 1968).

Metamorphic reactions and mineral compositions for the Bingham and Little Bigelow Mountain quadrangles are given by Dickerson (1984) and Dickerson and Holdaway (in prep.).

CONDITIONS OF METAMORPHISM

Geothermobarometry in M2 suffers from a shortage of microprobe data at present and from the high degree of alteration of many of the rocks. M3 occurred at conditions where andalusite was no longer stable as a staurolite reaction product. However, the common preservation of M2 andalusite in M3 rocks, and the relatively short time interval between M2 and M3 ($\sim$6 m.y.)

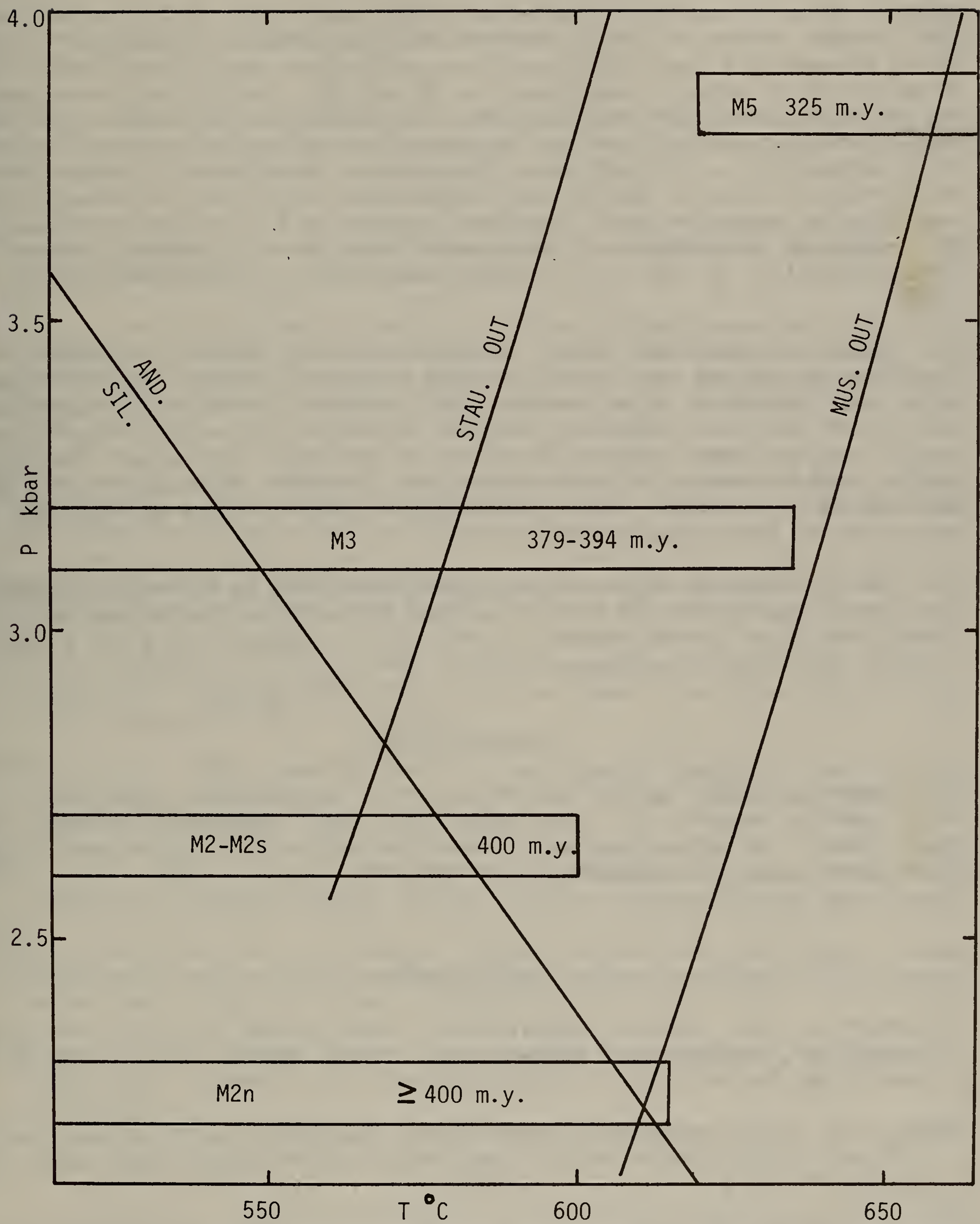

Figure 2. P-T conditions and ages for various metamorphic events in west-central Maine. Sources: Dickerson and Holdaway (in prep.), Holdaway and Dutrow (in prep.), Gaudett and Boone (1985), Aleinikoff (1984).

suggest that M3 conditions passed slightly above the andalusite P-T field. The average garnet-biotite T for the M3 staurolite-out reaction is 580°C. Using reasonable slopes, the staurolite-out reaction may be projected to lower P to provide a range of conditions for M2 and M2s. For M2n muscovite reacted to the first K feldspar and the first sillimanite in the same rocks. Using these data Dickerson (1984) and Dickerson and Holdaway (in prep.) conclude that metamorphic conditions were those shown in Figure 2. There were P differences of several hundred bars between M2n and M2-M2s and between M2-M2s and M3. It should be noted that this increase of P with time continued, and M5 (Hercynian metamorphism) experienced P of about 3.9 kbar north of the Sebago batholith at 325 m.y. (Holdaway and Dutrow, in prep; Guidotti et al., 1986).

This P increase over 75 m.y. throughout a large area of the Central Maine Synclinorium implies that rock was added above the present level of exposure at a faster rate than it was erroded over this time period. Two possibilities to explain this are extensive shallow intrusion and extrusion of igneous rocks, and continued westward thrusting at shallower levels once the present levels were buttressed by metamorphism and intrusion (Holdaway et al., 1982; Guidotti et al., 1983). The P increases may well have been episodic and both processes may have been operative.

The locus of intrusion and related metamorphism in the region appears to have moved toward the SSW with time from M2 to M3 to M5. Thus it is also likely that to a limited extent P increased to the SSW at any given time.

ACKNOWLEDGEMENTS

We are grateful to Charles Guidotti for many helpful suggestions. The high quality mapping of Gary Boone and Kost Pankiwskyj is very much appreciated. We acknowledge with thanks the support of The National Science Foundation, grants EAR-8306389 and EAR-8606489.

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ITINERARY

Assembly point is Arnold's Way Rest Area on U.S. Route 201, east side of road, 2.3 miles north of downtown Solon (1.75 hour drive from Lewiston). Note change from original announcement. Assembly time is 9:15 A.M. Topographic maps: Bingham, Anson, Kingfield, Little Bigelow Mountain, and Farmington quadrangles. Only the key mineral(s) of assemblages are given in the guide. Number in parentheses designates complete assemblages as given in legend to Figure 1.

Mileage

0.0	Proceed north from Rest Area on U.S. Route 201 and enter Bingham quadrangle at 1.2 miles.
1.5	Roadcuts of purple and light green layered Madrid Fm.
3.3	Tooth and Claw Jewelry Shop on left.
3.5	Turn right (east) on Mahoney Hill Rd.
4.0	Discontinuous roadcuts of Madrid and Carrabassett Fms. represent decreasing grade from andalusite (6) to biotite (2).
5.8	STOP 1: Johnson Brook, south of road. Walk 100 m downstream to outcrops of possible psammitic Madrid Fm. and pelitic Carrabassett Fm. This represents the southwestern limit of a closed M2 high which extends 3.5 miles NE. Pelitic rocks contain staurolite (4) whereas chlorite-bearing psammitic rocks contain neither staurolite nor andalusite. Continue east on Mahoney Hill Rd.
6.5	STOP 2: Just beyond top of the hill on Johnson Mountain. Typical staurolite schist (4) of Carrabassett Fm. Much of the staurolite is altered to fine sericite and chlorite. One mile NNE of here is chiastolite-staurolite schist (5) which extends for a mile along the top of Johnson Mountain, making the core of the eastern high. Turn cars around and return to U.S. Route 201.
9.5	Turn right (north) on U.S. Route 201.
10.3	Bingham city limit.
11.4	Turn left (west) on ME Route 16 across the Kennebec River.
11.6	After bridge, turn right (north). Massive rusty roadcuts are Smalls Falls Fm., mainly sulfidic-graphitic and psammitic rocks.
13.3	Wyman Dam. Around bend to north metapelites of the Perry Mountain Fm. are retrograded andalusite-staurolite schist (5).
13.7	Perry Mountain Fm. contains retrograded andalusite-staurolite schist (5). Rusty Smalls Falls roadcuts begin.
15.0	Trail to Houston Brook Falls on right, in psammitic rocks of Madrid Fm.
15.8	Take left (northwest) fork toward Rowe Pond.
17.5	Longfellow School.
17.8	STOP 3: Low outcrops on left. Slightly altered staurolite schist (4) of Carrabassett Fm. (Andalusite may occur locally). The M2 staurolite isograd crosses the road (in Madrid rocks) several hundred meters north of here and trends WNW toward the junction between the northern and central phases of the Lexington batholith.

18.05 Small outcrop of staurolite schist (4) on left.

18.15 Small outcrop of biotite psammite in Madrid Fm. on left.

18.4 Pavement ends. Continue north.

19.8 Low outcrops on left are Carrabassett Fm. cordierite hornfels (A) of M2n.

20.1 STOP 4: Stop at road to south end of Clear Pond. Cordierite hornfels (A) of M2n in Carrabassett Fm. Glaciated outcrop on right before road and better outcrop and float for collecting on left 0.1 mile after road. Most or all of these rocks contain only cordierite (A), but rocks on the hill 0.5 mile WSW also contain 2 x 15 mm sharply defind andalusite with the cordierite (B). These assemblages, without staurolite, occur on the east and north sides of the northern phase, Lexington batholith. On the west side, later gabbroic rocks and central phase intrusives have destroyed the cordierite. Continue north.

20.4 STOP 5: Rubbly outcrop of northern phase coarse biotite quartz monzonite. This rock differs distinctly from the porphyritic central phase. Continue north.

20.6 Turn cars around. Watch for cars coming over hill. Return to U.S. Route 201 in Bingham.

25.4 Turn right (south).

29.6 Turn left (east) on ME Route 16 across Kennebec River.

29.8 Turn right (south) on U.S. Route 201.

31.8 Mahoney Hill Rd.

34.0 Enter Anson quadrangle.

35.2 LUNCH STOP: Arnold's Way Rest Area.

36.6 Solon city limit.

36.9 Turn right (west) on Falls Road.

37.2 Continue straight on dirt road.

37.3 STOP 6: Park on dirt road to left. Arnold's Landing. CAUTION: dam gates may be opened without warning. Staurolite (4), commonly rimmed by alteration products, dominates in pelitic Carrabassett layers, whereas coarse andalusite pseudomorphs (6) occur without staurolite in the more psammitic (Fall Brook Fm.?) layers. Return to U.S. Route 201.

37.6 Turn right (south) on U.S. Route 201.

38.2 Psammitic Fall Brook Fm. in stream to left.

38.3 Turn right (east).

38.8 Take right fork on Athens Rd.

39.0 STOP 7: Park on top of Rise. Roadcuts on left are slates of the Carrabassett Fm. which contain chlorite and no biotite (1). Note that the distance separating stops 6 and 7 is 1.2 miles. Turn cars around and return to the center of Solon.

39.7 Cross U.S. Route 201 and continue west on U.S. Route 201A across Kennebec River.

40.9 Continue left (south) on U.S. Route 201A.

41.4 Turn right (west).

42.2 New roadcuts in Fall Brook Fm. contain bioite (2) in pelitic layers.

42.5 Power line.

43.4 Roadcuts of andalusite-staurolite schist (5) in Carrabassett Fm.

43.9 Cross Dunbar Hill Rd. Carrabassett Fm. andalusite-staurolite schist (5) 0.1 mile south, Fall Brook Fm. and Perry Mountain Fm. andalusite schist (6) north and northwest of here.

45.6 Turn left (south)

45.7 Turn right (west) on Wentworth Rd.

46.9 Outcrops in this area are psammitic Fall Brook Fm. 0.9 mile northwest of here is andalusite schist (6) in Perry Mountain Fm., 0.4 mile from the southern phase of the Lexington. M2 and M2s merge here (Fig. 1).

48.3 Turn right (north) on ME Route 16.

49.5 Roadcuts of Fall Brook and Smalls Falls Fms. Madrid Fm. hornfels at East New Portland (2 miles west of here) contains diopside.

49.8 Road to East New Portland on left. Continue north on ME Route 16.

50.7 Enter Lexington batholith, southern phase.

50.9 Enter Kingfield quadrangle.

51.3 STOP 8: Roadcuts of southern phase, Lexington batholith on both sides. The rock is a medium-grained binary quartz monzonite with a high inclusion content at this locality. According to Koller (1979) there is no sharp boundary between the southern and central phases. Although sillimanite occurs in country rock close to the igneous rock contacts, appropriate compositions are rare around the southern phase (Fig. 1). Continue northwest on ME Route 16.

52.6 Sharp left (west) in North New Portland. Stay on ME Route 16.

52.7 Granitic outcrops 100 m left of bridge on east side Gilman Stream.

57.3 Leave Lexington batholith.

57.5 Roadcuts of psammitic Madrid Fm.

58.5 On left, glacial boulder of coarse, porphyritic biotite quartz monzonite of the central phase, Lexington batholith. Microcline phenocrysts are up to 10 cm long and commonly define a flow pattern.

60.2 After crossing Carrabassett River in Kingfield turn right (north), staying on ME Route 16. Psammitic Madrid Fm. below bridge.

62.0 River outcrops of Carrabassett Fm. andalusite schist (6) which occur discontinuously nearly to stop 9.

63.3 Enter Little Bigelow Mountain quadrangle.

66.5 Roadcuts in Seboomook Fm.

66.9 STOP 9: Roadcuts show large, sharply defined andalusite pseudomorphs in Seboomook andalusite schist (6). The higher aspect ratio and better crystal face development are more characteristic of andalusites close to gabbro or granite contacts. These characteristics are apparently not a function of lithologic unit; Carabassett schists 0.5 mile up Hammon Field Brook (in this same area) have the same texture. Andalusites closer to igneous contacts are commonly smaller. West of the highway are staurolite schists (4) in these M2 rocks. To the east andalusites eventually become less altered, (M2s) and, within 0.2 mile of the granite, relatively fresh sillimanite hornfels (7) occurs (Fig. 1). Continue north to Rest Area.

67.0 Carrabassett Valley Rest Area. Turn cars around and head south.

68.4 STOP 10: Roadcuts in Carrabassett Fm. show smaller, more sievy, and less well defined andalusite pseudomorphs (6). This character is comparable to that of other regional M2 andalusites. Continue south.

74.0 Turn right (west) on ME Route 142 in downtown Kingfield. Route 142 lies mainly on glacial outwash.

77.6 Turn left (south) on ME Route 145. This point is the junction between two lobes of M2. Northwest of here are biotite-grade (2) rocks. To the southeast, Freeman Ridge belongs to the Lexington lobe; to the southwest Foster Hill belongs to the western lobe which becomes important in Phillips and Dixfield quadrangles. The route south winds between garnet schists (3), staurolite schists (4), and andalusite-staurolite schists (5) of this western lobe. (Fig. 1).

81.1 Road to Salem. Hill 1.2 mile northwest contains andalusite-staurolite (5), and hill 1 mile southeast contains staurolite (4), both in Seboomook Fm. Continue south.

84.7 Stream outcrops on left in Seboomook Fm. contain garnet and biotite (3) which have been totally replaced by chlorite.

87.3 Junction with ME Route 149 in Strong. Continue on Route 145.

87.7 Junction with ME Route 4. Proceed south on 4.

89.6 Roadcuts on right are Carrabassett Fm. biotite schist with occasional retrograded garnets (3).

90.0 STOP 11: Roadcuts on right. Carrabassett Fm. retrograded staurolite-garnet schist (4) in more pelitic layers. Rocks to the east are mainly chlorite grade (1). Along the western side of Kingfield and Farmington quadrangles garnets are more common in M2 and a garnet zone is mapable at least in the Farmington quadrangle (Dutrow, 1985). This and a wider M2 staurolite zone in Farmington and Dixfield quadrangles suggest that here M2 may have occurred at slightly higher P than near the Lexington batholith.

91.5 Enter Farmington quadrangle. Between here and Farmington most roadcuts are quartzitic and sulfidic-graphitic compositions.

96.2 Intersection with ME Route 27. Continue south on ME Route 4 through Farmington.

99.3 Intersection with U.S. Route 2. Continue south on Routes 2 and 4.

99.9 Roadcuts of garnet schist of the Sangerville Fm. Rocks in the area south of Farmington have suffered M2 and M3 garnet-zone conditions. Dutrow (1985) has observed two stages of garnet growth.

101.3 Roadcut on left of M3 staurolite-garnet-biotite schist, Sangerville Fm.

102.3 Intersection with ME Route 133. Continue south on Routes 2 and 4.

104.3 STOP 12: Long roadcut on left. These Sangerville Fm. staurolite-zone M3 rocks are provided for comparison with M2. The mineral assemblage of pelitic rocks is staurolite-garnet-biotite-muscovite-quartz with minor chlorite alteration. The M3 isograds trend WSW while the M2 isograds trend approximately south. Retrograded M2 staurolites are seen near Temple and Varnum Pond in west-central Farmington quadrangle, and the last remnants of M2 disappear north of Wilton. The M3 rocks of Farmington quadrangle have their heat source in the Livermore Falls group of plutons which occupy much of the southern 40% of the quadrangle. The Farmington M3 rocks are unusual for M3 in that most of them apparently did not experience an earlier M2 event (except along the western side). M3 rocks elsewhere have occasional coarse andalusite remnants from earlier M2. Along Route 4, the first M3 sillimanite appears, without andalusite, in large roadcuts immediately south of Wilton. Continue south on ME Route 4 to Lewiston-Auburn, about 40 miles.