University of New Hampshire

University of New Hampshire Scholars' Repository

NEIGC Trips

New England Intercollegiate Geological Excursion Collection

1-1-1989

Mineralogic and Textural Evidence for Polymetamophism Along a Traverse from Oquossoc to Phillips to Weld, ME

Guidotti, C.V.

TRIP B-1

Mineralogic and Textural Evidence for Polymetamorphism Along a Traverse from Oquossoc to Phillips to Weld, Maine

By

C.V. Guidotti
Department of Geological Sciences
University of Maine
Orono, Maine 04469

INTRODUCTION

This trip is aimed at examining some of the textural and mineralogic features that have resulted from polymetamorphism of the Cambrian through Devonian strata that underlie much of western Maine. Because these features are strongly influenced by the nature of the metamorphism which have affected the rocks, it will be necessary below to provide a brief review of the metamorphic styles that are present. Evidence will be examined for one Ordovician and several Devonian metamorphism. The latter occurred as part of the Acadian Orogeny.

Outcrops will be examined in portions of the Oquossoc, Rangeley, Phillips and Dixfield 15' quadrangles. In order to best accommodate with the field trip time constraints, we will begin the trip at the stop which is most distant from our Farmington base and work our way back to Farmington during the day.

By way of acknowledgements, it should be noted that most the author's petrologic work in Maine has been supported by various NSF grants since 1965. Support for the author's mapping of the Oquossoc quadrangle was provided by the Maine Geological Survey during the summers of 1962-64. In addition, the author would like to acknowledge his gratitude to Dr. R.H. Moench for providing detailed geologic base maps of the Rangeley and Phillips quadrangles such that the author then merely had to collect speciments in these areas. Moreover, Dr. Moench provide other valuable assistance for my collecting goals, including provision of a considerable number of samples from more remote areas.

REGIONAL GEOLOGY

Geologic mapping of the four 15' quadrangles to be visited has been provided by Pankiwskyj (1964) (Dixfield), Guidotti (1977) (Oquossoc), Moench (1971) (Rangeley and Phillips). In addition to numerous topical geologic reports by Moench on western Maine, a broad synthesis which includes the four quadrangles of concern has been provided in Moench and Zartman (1976). One should also consult the new Geologic Map of Maine (Osberg et al. 1985) for a broader overview placing the geology of western Maine into the context of the geology of the whole state. For our purposes the most important aspects of the geology in western Maine are:

(1) The stratified rocks range in age from Cambro-Ordovician to Devonian. Most of the pre-Silurian units occur in the northwestern part of the Rangeley quadrangle and in the Oquossoc quadrangle. By far the bulk of the stratified units consist of interbedded metapelites and impure metasandstone to greywacke. However, some units consisting of metabasalt, impure quartzites, and calcareous sandstones are also present. Nonetheless, pelitic bulk compositions are so abundant and widespread that the metamorphisms that have taken place can be studied in terms of this bulk composition.

(2) All of the strata have been intensely deformed into mainly, northeast-trending folds and faults. Some northwest-trending structures are also present but they are clearly subordinate. Most of the folding and faulting occurred before any of the high-grade metamorphic events. However, the deformation was probably accompanied by low-grade metamorphism throughout much of the area. Moreover, in the case of the Cambro-Ordovician units, deformation and low-grade metamorphism may have also occurred during pre-Silurian events (Harwood, 1973). Post-metamorphic structures include a few faults and in a few cases one finds minor microscopic evidence of post-metamorphic kinking of micaceous minerals.

(3) Various types of plutonic bodies are present with a range in sizes and shapes. Most of the smaller bodies occur as dikes and sills or have irregular shapes. Compositionally these are mainly granitic pegmatites and two-mica adamellites. As expected, they are most common in the areas of higher metamorphic grade.

The larger plutons are identified on Figure 2 and include:

(a) <u>Mooselookmeguntic</u> (371 Ma) and Phillips Plutons. According to Osberg et al. (1985) these bodies include lithologies ranging from two-mica granite to tomalite. Of particular importance is the fact that they occur as large, low-dipping sheets. For our purposes it should also be noted that they are intimately interrelated with most of the metamorphism we will be inspecting.

(b) <u>Reddington Granite</u>. This body consists of coarse-grained granite with distinctive feldsapr phenocrysts. It does not include abundant binary granite phases. Moreover, the small amount of muscovite present may be due to later metamorphism. Inasmuch as the hornfels around the Reddington granite appears to have been affected by the M_3 metamorphism which, it will be argued below, was caused by the intrusion of the (371 Ma) Mooselookmeguntic batholith, it would appear that the Reddington granite is a somewhat older Devonian pluton.

(c) Unbagog granodiorite. This body outcrops in the southwestern part of the Oquossoc quadrangle. It is not of importance for the goals of this field trip.

(d) Adamstown granite. This granite was first mapped as part of the study by Guidotti (1977). It is a member of the Highlandcroft magma series and has a crystallization age of 452 ± 4 Ma (Lyons et al. 1986). For the purpose of this field trip it is of interest because it produced an Ordovician contact metamorphic aureole. Later, it was deformed during the Acadian Orogeny and also variably metamorphosed. The effects of the deformation and the variable degrees of annealing by the subsequent, static metamorphic events are readily observed even in outcrop.

OVERVIEW OF METAMORPHISM

Polymetamorphism in western maine was first discussed by Pankwiskyj (1964). Later, Guidotti (1970a) provided more detailed documentation for two, post-tectonic, high-grade Devonian metamorphism in portions of the Rangeley and Oquossoc 15' quadrangles. These two events were superimposed on an earlier low-grade Devonian metamorphism. Subsequently, multiple Devonian metamorphic events were recognized elsewhere in western and central Maine, (e.g. Henry (1974), Cheney (1975), Novak and Holdaway (1981) and adjacent New Hampshire (Wall, 1988).

Much of this work was drawn into a synthesis by Holdaway et al. (1982). They described, in a general way, a total of four metamorphic events.

M_1 - a low-grade event which was probably syntectonic.

M_2 - a regionally extensive, post-tectonic event which in wide areas resulted in the establishment of the AFM join connecting andalusite and biotite. This event affected a wide area in western and central Maine.

M_3 - a regionally extensive, post-tectonic event which over a broad area resulted in the establishment of the AFM join connecting sillimanite and biotite. As with M_2, this event affected much of western and central Maine.

M_4 - a high-grade, low pressure metamorphism, closely concentrated around plutons such as the Reddington granite.

The first three events were recognized as being essentially the same as those recognized by Guidotti (1970a). The fourth event, M_4, has subsequently been found to be earlier than M_3 and possibly M_2 -- at least in the Rangeley-Phillips areas where it is well developed as a contact-hornfels around the Reddington granite.

Holdaway et al. (1982) emphasized that M_2 and M_3 may not have been completely synchronous throughout the whole area they considered. They also suggested that a close genetic relationship existed between the M_3 isograds and large sheet-like plutons such as the Mooselookmeguntic batholith. However, they stopped short of attributing the M_3 isograds directly to the heat imparted by the intruding plutons. The distribution of M_3 metamorphic grades as well as the gross distribution of the high-grade portion of M_2 have been shown by Guidotti (1985) on the new Goelogic Map of Maine.

Subsequent work (e.g. Holdaway et al. (1986) (1988), Lux and Guidotti (1985) has modified the suggested distribution of the M_2 and M_3 isograds and recognized the existence of an even later Carboniferous event. In addition, combining the petrologic studies with $^{40}Ar/Ar^{39}$ work and thermal modelling has enabled Lux et al. (1986), Guidotti et al. (1986), DeYoreo et al. (1989A,B) to develop an integrated model for the interrelationship between the plutons and metamorphism in western Maine. Briefly the model suggested includes:

(1) The post-tectonic high grade metamorphism are directly caused by heat convected in by the emplacement of sheet-like plutons. Basically the metamorphism involves shallow to deep level contact metamorphism (see Fig. 1).

(2) The extensive areal development of these contact events can be attributed to the shallow dips of the sheet-like plutons that brought in the heat.

(3) Inasmuch as heating is direclty tied to pluton emplacement, the lack of rigorous, regional synchroniety of M_2 or M_3 is made understandable. Moreover, the post-tectonic aspect of virtually all of the high-grade metamorphisms in western Maine is also explained by this means.

(4) An important aspect of the model developed is that it involves short-lived, thermal pluses, each one being essentially isobaric. As seen on Fig. 1, the various metamorphic paths suggested occur over a range of pressures, but the vast majority involve pressures less than that of the Al-silicate triple point (e.g. see also Tewhey (1975), Holdaway et al. (1986, 1988), Cheney (1975), Henry (1974)).

(5) The model argues for cooling to ambient temperatures before each succeeding thermal pulse. As a result, where the metamorphic pulses overlap spatially it has resulted in polymetamorphism. In some cases an area affected by an earlier metamorphism will be pograded in one portion and downgraded in another. As will be seen on the field trip, this aspect, plus the static nature of the heating events, has resulted in extreme development of pseudomorphs -- either prograde or downgrade as the case may be.

Most of the above discussion has been directed at the events, M_2 and M_3, which in much of western Maine attained high-grades. It was implied above that these events were statically superimposed on an earlier, greenschist grade M_1 event. The evidence for such a superposition can be seen best in thin section although sometimes evident megascopically in outcrop.

In thin section one commonly observes that the earliest foliation has been cut by a later slip cleavage. Subsequently, both of these cleavages have been helicitically overprinted and truncated by both staurolite and andalusite and in some cases by biotite and chlorite plates. The point to note is that these observations indicate development of a micaceous foliation before any of the later events which attained high grades. This implies at least some early recrystallization of these rocks -- probably syntectonically. It is this early recrystallization which is designated as M_1.

As seen on Fig. 2, the area around the village of Rangeley and to the north and west shows no evidence of ever having been affected by metamorphic grades exceeding garnet zone or greenschist facies. It is quite possible that much of that area has been affected by all three (M_1, M_2, and M_3) Devonian metamorphism. Unfortunately, greenschist grade superimposed upon greenschist grade leaves little evidence of more than one event -- especially if the later events involved static re-crystallization. Indeed as suggested above, some of the Cambro-Ordovician units we'll see in the early part of the field trip may have experienced an even earlier, pre-Silurian greenschist facies metamorphism.

Only in one case is there clear evidence for a pre-Silurian metamorphism. It will be seen at Stop 2 as a "fossil" hornfels which developed around the Ordovician, Adamstown granite (452 ± 4 Ma, Lyons et al. 1986). In turn, we will also be able to see clear evidence that this granite was deformed and metamorphosed by subsequent Devonian events.

For the purposes of this trip, the above general review should suffice. Any additional required elaborations will be given in the context of the specific field trip stops. Fig. 2 shows the areal distribution of the M_3 isograds in the portion of western Maine relevant to our needs. Also shown is the approximate trace of the M_2 isograd marking the establishment of the AFM join connecting biotite and andalusite (or staurolite).

Guidotti (1989) has presented a more complete review of the nature of the metamorphism that have affected western Maine. However, for details one should consult the papers by Holdaway et al. (1986) (1988), Lux and Guidotti (1985), Lux et al. (1986), DeYoreo et al. (1989A)(1989B), and Guidotti et al. (1986).

REFERENCES CITED

Carnese, M.J. (1983) Gravity studies of intrusive rocks in west-central Maine. M.S. thesis, University of New Hampshire, Durham, NH 97 p.

Chatterjee, N.D. (1972) The upper stability limit of the assemblage paragonite and quartz and its natural occurrence. Contr. Mineral. Petrol. v. 34, p. 288-303.

Chatterjee, N.D. and Johannes W. (1974) Thermal stability and standard thermodynamic properties of synthetic $2M_1$ muscovite $KAl_2(AlSi_3O_{10})(OH)_2$, Contr. Miner. Petrol., v.48, p. 89-114.

Chatterjee, N.D. and E. Froese (1975) A thermodynamic study of the pseudobinary join muscovite-paragonite in the system $KAlSi_3O_8$ - $NaAlSi_3O_8$ - Al_2O_3 - SiO_2 - H_2O. Amer. Mineral. v.60, p. 985-993.

Cheney, J.T. (1975) Mineralogy and petrology of lower sillimanite through sillimanite + K-feldspar zone, Pelitic schists, Puzzle Mountain area, Northwest Maine. Ph.D. thesis, Univ. of Wisconsin, Madison, WI 291 p.

DeYoreo, J.J., Lux, D.R., Guidotti, C.V., Decker, E.R. and Osberg, P.H. (1989a) The Acadian thermal history of western Maine, J. Metamorphic Geol. v. 7, pp. 169-190.

DeYoreo, J.J., Lux, D.R. and Guidotti, C.V. (1989b) A thermal model for Carboniferous metamorphism near the Sebago batholith in western Maine. Maine Geol. Survey, C.T. Jackson Commemorative Volume. 30 P.Ms.

Guidotti, C.V. (1968) Prograde muscovite pseudomorphs after staurolite in the Rangeley - Oquossoc areas, Maine. Amer. Mineral. 53, p. 1368-1376.

Guidotti, C.V. (1970A) Metamorphic petrology, mineralogy, and polymetamorphism in a portion of N.W. Maine. In: Boone, G.M., ed. 1970 New England Inter. Coll. Geol. Conf. 62nd Ann. Mtg. Field Trip B-1, p. 1-29.

Guidotti, C.V. (1970B) The mineralogy and petrology of the transition from lower to upper sillimanite zone in the Oquossoc area, Maine. Jour. Petrol. 11, p. 277-336.

Guidotti, C.V. (1974) Transition from staurolite to sillimanite zone, Rangeley quadrangle, Maine. Geol. Soc. Amer. Bull. 85, p. 475-490.

Guidotti, C.V. (1977) The Geology of the Oquossoc 15' Quadrangle, West central Maine. Maine Geol. Survey, Open-File No. 77-2. 26 P. report & map. Augusta, Maine.

Guidotti, C.V. (1985) Metamorphic Map of Maine. in Osberg, P.H. et al. eds., Bedrock Geologic Map of Maine. Maine Geol. Survey, Augusta, Maine.

Guidotti, C.V. (1989) Metamorphism in Maine: An Overview. Maine Geol. Survey. Studies in Maine Geology: 3, p. 1-17.

Guidotti, C.V., & Cheney, J.T. (1976) Margarite pseudomorphs after chiastolite in the Rangeley area, Maine. Amer. Mineral., 61, p. 431-434.

Guidotti, C.V., Gibson, D., Lux, D.R. and DeYoreo, J.J. and Cheney, J.T. (1986) Carboniferous metamorphism on the north (upper) side of the Sebago Batholith. in Newberg, D.W. ed. New England Intercoll. Geol. Conf. Guidebook for field trips in southwestern Maine. p. 306-341.

Harwood, D.S. (1973) Bedrock geology of the Cupsuptic and Arnold Pond quadrangles, west-central Maine. U.S. Geol. Survey Bull. 1346, 90P.

Harwood, D.S. and Berry, W.B.N. (1967) Fossiliferous Lower Paliozoic rocks in the Cupsuptic Quadrangle, west-central Maine. U.S. Geol. Survey, Prof. Paper, 575D, p. D16-D23.

Henry, W.E. (1974) Metamorphism of the pelitic schists in the Dixfield Qumorphism in west-central Maine. in Newberg, D.W. ed., New England Intercoll. Geol. Conf., Guidebook for field trips in southwestern Maine. p. 240-253.

Holdaway, M.J., Dutrow, B.L. and Hinton, R.W. (1988) Mineral chemistry and metamorphic conditions of M3 and M5, west-central Maine: the muscovite-almandine-geobarometer; the staurolite problem revisited. Amer. Mineral., 74, p. 20-47.

Hoschek, G. (1969) The stability of staurolite and chloritoid and their significance in metamorphism of pelitic schmorphism in west-central Maine. in Newberg, D.W. ed., New England Intercoll. Geol. Conf., Guidebook for field trips in southwestern Maine. p. 240-253.

Holdaway, M.J., Dutrow, B.L. and Hinton, R.W. (1988) Mineral chemistry and metamorphic conditions of M_3 and M_5, west-central Maine: the muscovite-almandine-geobarometer; the staurolite problem revisited. Amer. Mineral., 74, p. 20-47.

Hoschek, G. (1969) The stability of staurolite and chloritoid and their significance in metamorphism of pelitic schists. Contrib. Mineral. Petrol., 22, p. 208-232.

Lux, D.R. and Guidotti, C.V. (1985) Evidence for extensive Hercynian metamorphism in western Maine. Geology. 31, p. 696-700.

Lux, D.R., DeYoreo, J.J., Guidotti, C.V., Decker, E.R. (1986) The role of plutonism in low pressure/high temperature metamorphic belt formation. Nature, 323, p. 794-797.

Lyons, J.B., Aleinikoff, J.N., and Zartman, R.E. (1986) Uranium-Thorium-Lead ages of the Highlandcroft Plutonic Suite, Northern New England. Amer. Jour. Sci., 286, p. 489-509.

Moench, R.H. (1971) Geologic map of the Rangeley and Phillips quadrangles, Franklin and Oxford counties, Maine. U.S. Geol. Survey Misc. Geol. Inv. Map. I-605.

Moench, R.H. and Zartman, R.E. (1976) Chronology and styles of multiple deformation, plutonism, and polymetamorphism in the Merrimack synclinorium of western Maine. in: Lyons, P.C. and Brownlow, A.H. eds, Studies of New England Geology: Geol. Soc. Amer. Mem. 146, p. 203-238.

Novak, J.M. and Holdaway, M.J. (1981) Metamorphic petrology, mineral equilibria, and polymetamorphism in the Augusta quadrangle, south-central Maine. Amer. Mineral., 66, p. 51-69.

Osberg, P.H., Hussey, A.M., II, and Boone, G.M. (1985) Bedrock Geologic Map of Maine. Dept. of Conservation, Maine Geol. Survey, Augusta, Maine.

Pankiwskyj, K.A. (1964) The geology of the Dixfield quadrangle, Maine. Ph.D. thesis, Harvard University, Cambridge, Massachusetts.

Teichmann, F. (1988) The geochemistry of chlorites as a function of metamorphic grade, mineral assemblage and bulk composition in the Rangeley and Rumford areas, Maine. M.S. thesis, Univ. of Maine, Orono, Maine. 175P, plus Appendicies.

Tewhey, J. (1975) The controls of chlorite-garnet equilibria in the contact aureole of the Cupsuptic Pluton, west-central Maine; and the two-phase region in the $CaO-SiO_2$ system: experimental data and thermodynamic analysis. Ph.D. thesis, Brown University, Providence, Rhode Island. 147P.

Tuttle, O.F. and Bowen, N.L. (1958) Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$ - $KAlSi_3O_8$ - SiO_2 - H_2O. Geol. Soc. Amer. Mem., 71, 153P.

Wall, E.R. (1988) The Occurrence of Staurolite and its Implications for Polymetamorphism in the Mt. Washington Area, New Hampshire. M.S. thesis, University of Maine, Orono, Maine. 124P.

ITINERARY

This trip will meet in Farmington at MacDonalds. From there we will drive northward to the first stop which is near the north-central border of the Oquossoc 15' quadrangle. We will assemble at MacDonalds and drive northward on Rte 4, passing through Rangeley. At the east edge of the village of Oquossoc, turn right (north) on Rte 16 and loop around the north end of Cupsuptic Lake. After the loop, the first stop is at the top of the first large hill.

It would be well to bring lunch with you although in mid to late morning we'll be passing through Rangeley and you could pick up lunch material at Stubby's market. 15' topographic maps that will be useful are: Oquossoc, Rangeley, Phillips, and Dixfield. However, the road log is based upon the 2° Lewiston sheet.

Milage

0.0 STOP 1: Over the last mile we have been driving through outcrops of the Adamstown granite, an Ordovician, Highlandcroft Magma Series pluton. All of these outcrops show significant amounts of deformation and low-grade metamorphism of the original granite. This deformation and metamorphism are due to effects of the Acadian Orogeny. As seen on Fig. 2 one can trace the Devonian metamorphic isograds through the Adamstown Granite -- at least in a rough fashion. Here, at Stop 1 we are in the low grades of the Devonian metamorphism.

At this stop one can see a saussuritized plagioclase groundmass enclosing quartz lenses and K-spar augen. Note on the weathered surfaces how the quartz lenses do not form an interlocking texture. In thin section one finds the quartz lenses to be surrounded by fine-grained granular quartz grains.

At these low grades the biotite has been altered to chlorite. Some newly formed epidote can be seen even in hand specimen whereas metamorphic muscovite can be seen only in thin section. Typically the K-spar megacrysts are pink in this low grade portion of the pluton.

You may find it useful to collect a small piece of this low-grade meta-granite so you can compare it to specimens seen at Stop 4 where the metamorphic grade is in the lower sillimanite zone.

Return to cars and continue on Rte 16.

1.0 Turn right on old paved road - this is the old location of Rte 16. It is drivable but requires considerable care to avoid holes etc.

1.75 Adamstown granite on the right.

1.9 STOP 2: Here we see several, scattered outcrops of a dense, massive, hornfelsic rock that has a hackly fracture. We are essentially on the contact with the Adamstown granite and it caused a narrow hornfels to develop in the Cambo-Ordovician Aziscohos fm. Hence, we are seeing the effects of an Ordovician metamorphism upon which later, low-grade Devonian metamorphism has been superimposed.

Look closely and you can find the thin laminae typical of the Aziscohos fm. On some of the glacially smooth surfaces you can find light colored patches which are pseudomorphs after highes grade minerals which formed during the Ordovician metamorphism. Hence, we are looking at a "fossil" hornfels.

Return to cars and continue in same direction.

2.2 More outcrops of the hornfels. Some may involve metavolcanics.

3.05 The washed out gully on the left has good exposures of the more typical greenschist grade Aziscohos fm. We are now out of the "fossil" hornfels and one finds green phyllites with quartz stringers.

3.87 Intersection with the new Rte 16 - turn left.

4.10 Very large outcrops of the phyllites.

4.45 Adamstown-Cupsuptic town line.

5.45 Massive greenstones and some phyllites.

5.60 Green phyllites with abundant, vein quartz stringers.

6.55 Rangeley-Cupsuptic town line and Oxford-Franklin county line.

9.80 Outcrops of massive metavolcanics (greenstones).

10.10 More outcrops of massive metavolcanics (greenstones).

10.20 Outcrops of foliated to massive metavolcanics (greenstones). Some involve very coarse-grained material as well as epidote-rich patches.

10.55 Intersection with Rte 4 - Turn right (west).

10.90 Downtown Oquossoc and the Oquossoc Hotel.

11.85 STOP 3: Park and walk back to the outcrop. For the cars at the back of the line, note that a public parking area is available on the left, just across the road from the outcrops.

Here we will see the green phyllites of the Cambro-Ordovician Dead River fm. The Acadian metamorphism here are about at biotite zone.

Two things to note are the occurrence of abundant quartz stringers and magnetite octahedra. The origin of the quartz stringers can be debated, but the point of interest here is that when seen at higher grades (next Stop) one could mistake them for migmatites.

The magnetite is of interest because its presence is typical of many of the Cambro-Ordovician units in western Maine whereas few of the Siluro-Devonian units seem to have any magnetite present. Work by the author and M. Darby Dyar (University of Oregon) has shown that the biotite coexisting with magnetite in these units typically has about 20% of its Fe as Fe^{3+} whereas the biotites of the Siluro-Devonian units (typically containing graphite) have only 10% of their total Fe as Fe^{3+}. Moreover, only in the former is there significant VI Fe^{3+}. Probably reflecting these differences, one finds that biotites from the Cambro-Ordovician units has a dark, greenish-brown color. Biotite from the Siluro-Devonian units typically occurs in shades of orange to dark reddish brown, depending upon the metamorphic grade-controlled Ti content.

11.95 Turn left (south) on Bald Mtn. road.

14.00 STOP 4: Park carefully on both sides of the road and walk back to the outcrops. This outcrop was Stop 2 of Guidotti (1970a). Here, we see three rock types - all in lower sillimanite zone or upper staurolite zone of M_3. Possibly these rocks were also affected by M_2 high-grade metamorphism although Fig. 2. indicates otherwise. Insufficient detailed work has been done to answer this latter question.

(1) The phyllites containing quartz stringers which we saw at the last stop are now dark-grey metapelites due to abundant biotite and only minor chlorite remaining. In some cases, thin section study shows development of some late, coarse clots of chlorite after biotite. Such chlorite is especially common in the NW corner of the Oquossoc quadrangle and in the Errol quadrangle to the west. Its origin is not yet understood.

At the present outcrop one can find good 1/4", euhedral garnets and tourmaline; occasionally staurolite is also seen in hand specimens. Sillimanite is always microscopic. Note how the quartz stringers simulate a migmatite.

(2) Some metavolcanics are common as interbeds in the Cambro-Ordovician units. While driving, we saw them as greenstones in the lower metamorphic grades. Here they are dark amphibolites reflecting that higher grade has destroyed the epidote, actinolite, albite etc mineralogy and produced a rock composed largely of hornblende, calcic plagioclase and quartz.

(3) Here we can also see good outcrops of the Adamstown granite where it has been affected by the post-tectonic, high-grade M_3 metamorphism. Although it has some development of a foliation here, in comparison with what we saw at Stop 1 it looks much more like a normal granite. This is probably a reflection of metamorphism at high grade. Moreover, the clastic texture so evident at Stop 1 is now absent.

Return to cars and continue southward.

14.23 Make a U-turn at the junction with the woods road coming in from the left and head back to the north.

16.50 Stop Sign: Turn right on Rte 4 heading to the east toward Oquossoc village.

17.50 Oquossoc village again - continue to the east on Rte 4, past the junction with Rte 16.

18.00 STOP 5: Metavolcanics on both sides of the road. This was Stop 1 of Guidotti (1970a). These outcrops belong to the Ordovician Kamankeag fm.

The rocks are typical greenstones (nearby pelites indicate biotite zone) containing actinolite-chlorite-epidote-albite and some calcite, quartz, sulfides, etc. The protolith is presumed to be basaltic flows but some pyroclastics are also present in other outcrops.

Notice the epidote-rich pods and clots in the otherwise massive to foliated volcanics. Possibly these represent volcanic bombs.

In some cases, remnant plagioclase and pyroxene grains have been found in these rocks.

18.7 Outcrops of the Kamankeag slates. About four miles northward along strike these rocks contain graptolites, Berry and Harvard (1967).

Continue eastward through Rangeley. For those who need to buy lunch materials, Rangeley will be your last chance.

26.00 At the Farm House Inn on the east side of Rangeley Village. We've been driving past many outcrops of the Quimby fm. All are at low grades - biotite zone at most. For our purposes, the key point is that there is no evidence of any sort that these rocks were ever affected by higher grades, nor any evidence as to how many metamorphic events have affected them.

26.43 Town line of Rangeley and Rangeley Plantation.

26.77 STOP 6: Outcrop across the road from the Terraces. Park on wide shoulders. This is the Greenvale Cove fm. It consists of fine-grained, thin bedded slates. Tiny biotite tablets are visible in hand specimen.

As with all of the outcrops since Stop 5, there is no sign of garnet or any kind of pseudomorphs in the metapelites. Hence, the rocks at this outcrop have probably never been at any higher grade than biotite zone. Some thin calc-silicate beds at the lower portion of the outcrop do contain garnet but none occurs in the metapelites.

At the lowermost outcrops one gets into grits of the Rangeley fm.

27.00 Grits of the Rangeley fm - also Town line.

27.12 Large crops of the cgl facies of the Rangeley fm.

27.82 Bear left (carefully) onto old Rte 4.

27.97 STOP 7: At Greenvale School on the old 15' quadrangle (now the Town Office of Sandy River Plantation). There is plenty of parking here so please take care not to block peoples driveways.

Walk up the old road in back of the Town Office and into the small quarry on the power line. The rocks here are metapelites of the Rangeley fm. Some calc-silicate nodules are also present.

The key thing to note are the excellent, euhedral pseudomorphs of staurolite. Garnet also appears to be wholly pseudomorphed. Can anyone find any fresh (remnant) garnet? You will note that the orientation of the original staurolite seems to be nearly perpendicular to bedding.

Head up along the path parallel to the brook to Cascade Falls. As you walk note the loose blocks along the trail as they show spectacular development of the euhedral pseudomorphs after staurolite (PLEASE DON'T HAMMER).

On the brook you can inspect the large faces containing abundant pseudomorphs. Here you can hammer at will! Can anyone find evidence of pseudomorphs after andalusite? To this point I've found only the staurolite pseudomorphs.

Hence, I interpret these rocks as having attained only staurolite grade during M_2 but having been downgraded to biotite zone by M_3. Inspection of the spatial relationships between the pseudomorphs and groundmass foliations at many outcrops suggests that both M_2 and M_3 were largely static recrystallizations.

Return to cars and continue in same direction.

28.02 Encounter new Rte 4 again - bear left.

29.42 Road to Long Pond (Edelheid Road).

30.32 On the left - fairly rusty weathering Rangeley schist. Probably more recrystallized than at Stop 7 as indicated by the groundmass being a "white schist". This is a reflection of the groundmass muscovite being more coarse grained. Pseudomorphs can be found in the more pelitic beds and some garnet seems to be present although it is very sparse due to the sulfitic nature of this rock.

31.42 <u>STOP 8</u>. Large outcrops of Rangeley fm on the right. Here, there is a great display of pseudomorphs in a groundmass that is generally coarser grained than at Stop 7.

I've shown this on Fig. 2 as being in the M_3 garnet zone but garnets are hard to find due in part to the moderately sulfitic mature of the outcrops.

Can anyone find "live garnet" or psuedomorphs after andalusite?

This is a good outcrop for collecting.

36.03 Town line between Sandy River Plantation and Letter E Township. We have been driving by many outcrops of Rangeley fm. In most of them there is development of euhedral pseudomorphs of staurolite. However, in some of the outcrops where the Appalachian trail crosses Rte 4 one can find samples with staurolite ranging from fresh to wholly pseudomorphed. This is a localized zone forming on "island" in a broad area within which the staurolite has been totally pseudomorphed. In a later stop we will inspect some similar outcrops.

36.20 STOP 9. On the sharp, hairpin curve. Good parking at and beyond the curve but use extreme care watching for cars. Go to the lower grey outcrops. This is the Perry Mtn fm. and we are just below the type locality.

Notice the well preserved bedding features; cross beds, graded beds etc. The main foliation is essentially parallel to bedding but a slip cleavage is also present and shows up in outcrop as a pronounced crinking.

The groundmass of the pelitic beds is a nice "white schist" due to recrystallized muscovite. Garnet is partially replaced by coarse chlorite but minor "live garnet" has been observed. Hence, these rocks are shown on Fig. 2 as M_3 garnet zone.

The staurolite pseudomorphs are well developed and obvious - but can you find the pseudomorphs after andalusite?

Return to cars and continue down hill.

37.85 STOP 10. Turn right into the Smalls Falls picnic area and drive to the end of the parking area.

This is the type locality of the Smalls Falls fm. From a petrologic view point it is an intersting unit because it contains 5-10 modal % of pyrrhotite and also is graphite-rich. As a consequence it shows the effects of sulfide-silicate mineral reactions to an extreme degree. The most straight forward aspect of these reactions is that the silicate bulk composition is moved to a very Mg-rich portion of composition space. Hence, at the appropriate grades one finds assemblages like andalusite or sillimanite + Mg-cordierite + phlogopite. Fe-rich minerals like garnet or staurolite never occur in this unit. Moreover, the Ti phase is rutile instead of ilmenite as in the other Siluro-Devonian metapelites.

Walk to the outcrop at the edge of the plunge pool. On the smoothed surfaces you will find large chiastolite crystals -- except that, as shown in Guidotti and Cheney (1975) they are now pseudomorphs composed mainly of margarite. As your eyes become more focused on the details of the textures present, you will see that other 1" pseudomorphic knots are present. They consist of aggregates of chlorite and phlogopite after cordierite. The original chiastolite and cordierite formed during M_2 but during M_3 they have been pseudomorphed.

Please don't hammer on the outcrops in the park area. The best opportunity for collecting margarite is at the road outcrops just uphill from where the cars are parked.

Return to cars and drive back to Rte. 4.

38.10 Rte 4. Turn right (south).

41.00 STOP 11. Downtown Madrid - Walk to outcrop on the river by the bridge across the road coming in from the east.

This is the type locality of the Madrid fm which consists of an interbedding of dense biotite granulite and calc-silicate.

For our purposes note the nice examples of bulk composition control of mineralogy. In particular, note that a few pelitic beds are present and they display good pseudomorphs after staurolite. Some of the pseudomorphs appear elongate parallel to a slip cleavage so that they look deformed. However, others are clearly undeformed. The elongation may reflect growth of the original staurolite along the direction of the slip cleavage.

In a few cases, the shapes of the pseudomorphs make one speculate if they were originally andalusite.

Some of the calc-silicate beds show evidence of metasomatic zoning suggesting some degree of diffusion across strong compositional gradients. Note the slightly purplish cast to the biotites in the beds associated with the calc-silicates. Many people have noted that cast for biotites of calcareous rocks, but I am not aware of any explanations that have been advanced for this color effect.

Finally, some pegmatite veins and adamellite veins are present in places along these extensive outcrops.

Return to cars and continue southward.

41.90 STOP 12. Park just before the bridge. NO SMOKING at this coutcrop at the request of the owner.

Walk down along river for about 50 yards and one encounters extensive outcrops of the Devonian, Carrabasset fm.

The point of this outcrop is that it is in one of those "islands" within the M_3 garnet zone in which M_2 staurolite is variably pseudomorphed. Indeed, with a little searching you can also find variably pseudomorphed andalusite at these outcrops.

Focus on the nature of the staurolite pseudomorphs in some detail. Here, they are formed as the result of downgrade effects. At Stop 14 we'll see pseudomorphs of staurolite resulting from prograde effects.

Return to cars and head to the south.

53.00 STOP 13. Park carefully on the right taking care not to get stuck in soft sand. Watch out for cars.

On the left is a large outcrop of Carrabasset fm with perfectly fresh staurolite. It contains St + Bio + gn + chte and so is a typical staurolite-grade assemblage for this part of western Maine. However, it appears to be another one of these "islands" of M_2 staurolite that has withstood the M_3 downgrading. This could reflect inability of H_2O entering some areas so that the downgrading was not effected.

One other possibility is that the areas in which M_2 staurolite is preserved represents hot spots. This suggestion is based upon the geophysical study of Carnese (1983) which indicates that the sheet-like Mooselookmeguntic pluton extends beneath this whole area, reaching as far to the northeast as the Reddington Pluton. His cross sections suggest that it is not far below the surface such that local apophyses to higher levels may have produced M_3 temperatures still within the staurolite stability field.

Obviously, resolution of such a suggestion will require a lot of detailed petrologic study.

Back to the cars and continue to the south.

54.13 Outcrops of Smalls Falls fm.

56.20 Turn to the right (south) on Rte 142.

58.50 STOP 14. Just north of the 1230 point shown on Rte 142 in the 15' Phillips sheet.

Coarse-grained, lower sillimanite zone metapelites. Fibrolitic sillimanite is visible in biotite.

Note the large aggregates of coarse muscovite and some biotite. Some of these aggregates contain remnants of fresh staurolite as well as abundant fibrolitic sillimanite in the biotitic outer rims of the psuedomorphs.

The concentration of coarse muscovite with some garnets in the psuedomorphs is very similar to the prograde pseudomorphs reported in the Oquossoc area, Guidotti (1968). This coarse grained aspect plus the presence of the garnets seems to be typical of staurolite that has been pseudomorphed in a prograde fashion. You can contrast it with the numerous examples of downgrade pseudomorphs we've seen previously on this field trip.

Return to cars and continue southward.

66.00 Weld Corner - continue southward on Rte 142.

68.35 Stop sign in Weld village - continue straight across the intersection onto Rte 156.

71.10 Outcrops of the Phillips Pluton.

71.55 Calc-silicates, marbles etc.

72.15 STOP 15. Dangerous soft shoulders. Take care not to get stuck in the sand.

This outcrop is in the upper sillimanite zone as the metamorphic grade has exceeded the stability limit of staurolite.

Good development of fibrolite and small spangles of muscovite can be observed in the western most outcrop.

The main point of this outcrop is to discuss the occurrence of a late chlorite-forming event that can be detected in these rocks. Henry (1974) studied in some detail the petrology of the rocks in the NE 1/4 of the Dixfield 15' quadrangle. In most respects they are quite similar to the polymetamorphism described by Guidotti (1970A,B) (1974) in the Rangeley and Oquossoc areas.

However, it appears that a late, low T event has affected these rocks and produced a new generation of chlorite. In some cases it is clearly an alteration after biotite but in other cases the chlorite occurs as clean laths and plates. Henry (1974) discussed the pros and cons of whether it was in equilibrium with the rest of the assemblage in a given rock. It can be suggested that much of it may not be in equilibrium, mainly on the basis of three observations: (a) Some of this chlorite occurs in the upper sillimanite zone - something that does not occur in other parts of western Maine. (b) It does not show the compositional variation expected as grade changes (Teichmann, 1988). (c) In the staurolite and sillimanite zones the chlorite has a relatively Fe-rich composition (as evident even from its optical properties - purple brown colors in crossed nicols).

In addition to the questions raised by the nature of the chlorite, careful inspection of Henry's data for biotite and muscovite also suggests some anomalous features. The net assessment one arrives at is that subsequent to the M_2 and M_3 events, the rocks in much of Henry's study area have been affected by still another event, but one which attained only low temperatures. The cause and extent of this event can only be speculated about at this point. For example, it may represent an effect reflecting the northernmost extent of the Carboniferous event believed to have affected the southern portion of the Dixfield 15' quadrangle, Lux and Guidotti (1985).

Return to cars and continue southward.

81.53 Stop sign in town of Wilton at intersection. Turn left (east) and continue straight on this road (not Rte 156). It will take you to Rtes 2 and 4. Then go east to Farmington.

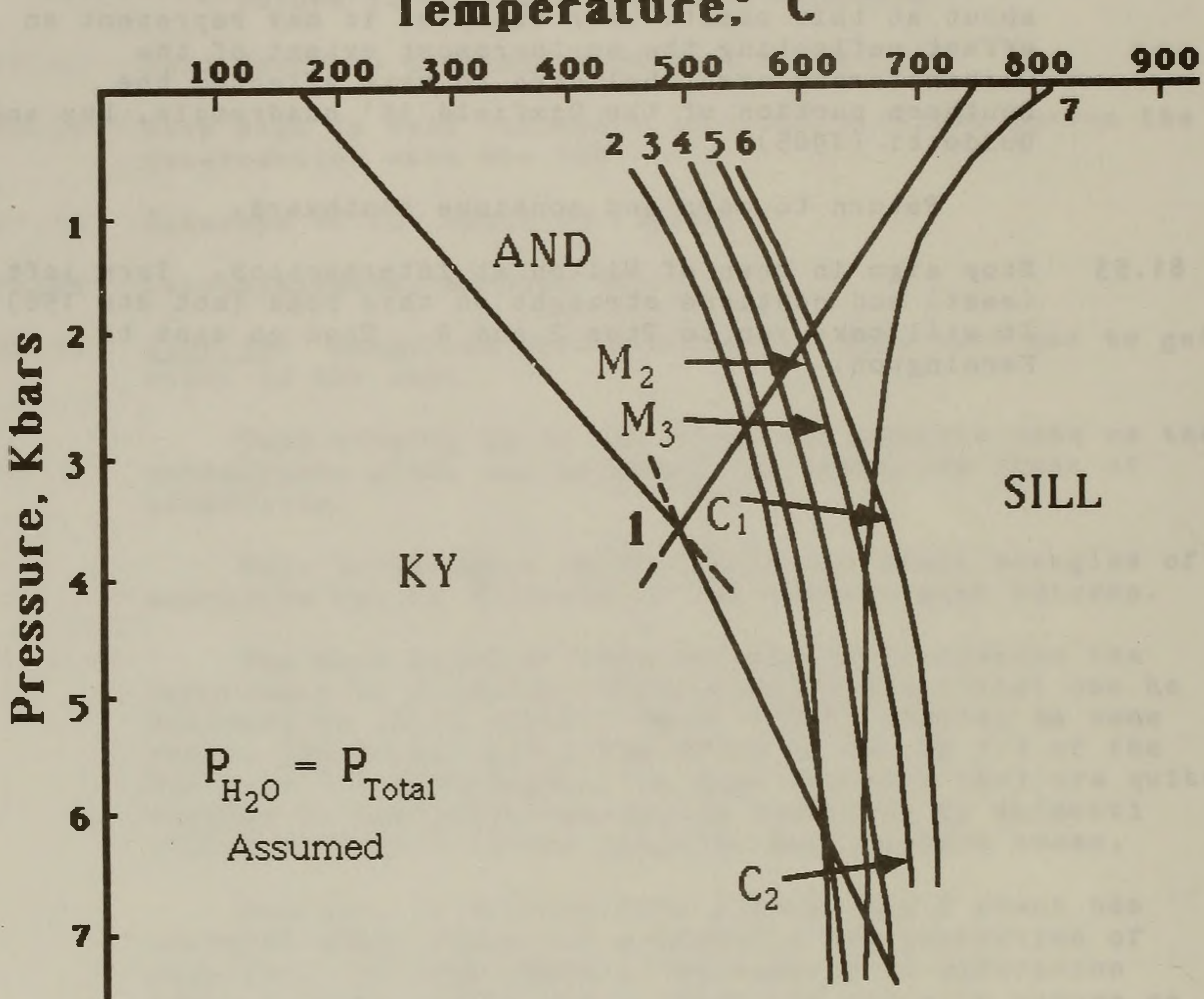

FIG. 1. PT GRID OF EQUILIBRIA RELEVANT TO THIS REPORT. (1) AL-SILICATE CURVES, HOLDAWAY (1971). (2) PARAGONITE BREAKDOWN, CHATTERJEE (1972). (3) ST + CHL = AL-SIL + BIO, GUIDOTTI (1974). (4) ST = AL-SIL + BIO, HOSCHEK (1969). (5) AB + MU = AL-SIL+KSP, CHATTERJEE AND FROESE (1975). (6) MUSCOVITE BREAKDOWN, CHATTERJEE AND JOHANNES (1974). (7) GRANITE MINIMUM, TUTTLE AND BOWEN (1958). M_2, M_3 - PT PATHS OF FIRST AND SECOND HIGH-GRADE ACADIAN METAMORPHISMS RESPECTIVELY, C_1, C_2 - PT PATHS OF CARBONIFEROUS METAMORPHISMS ON THE UPPER AND LOWER SIDES OF THE SEBAGO PLUTON RESPECTIVELY.

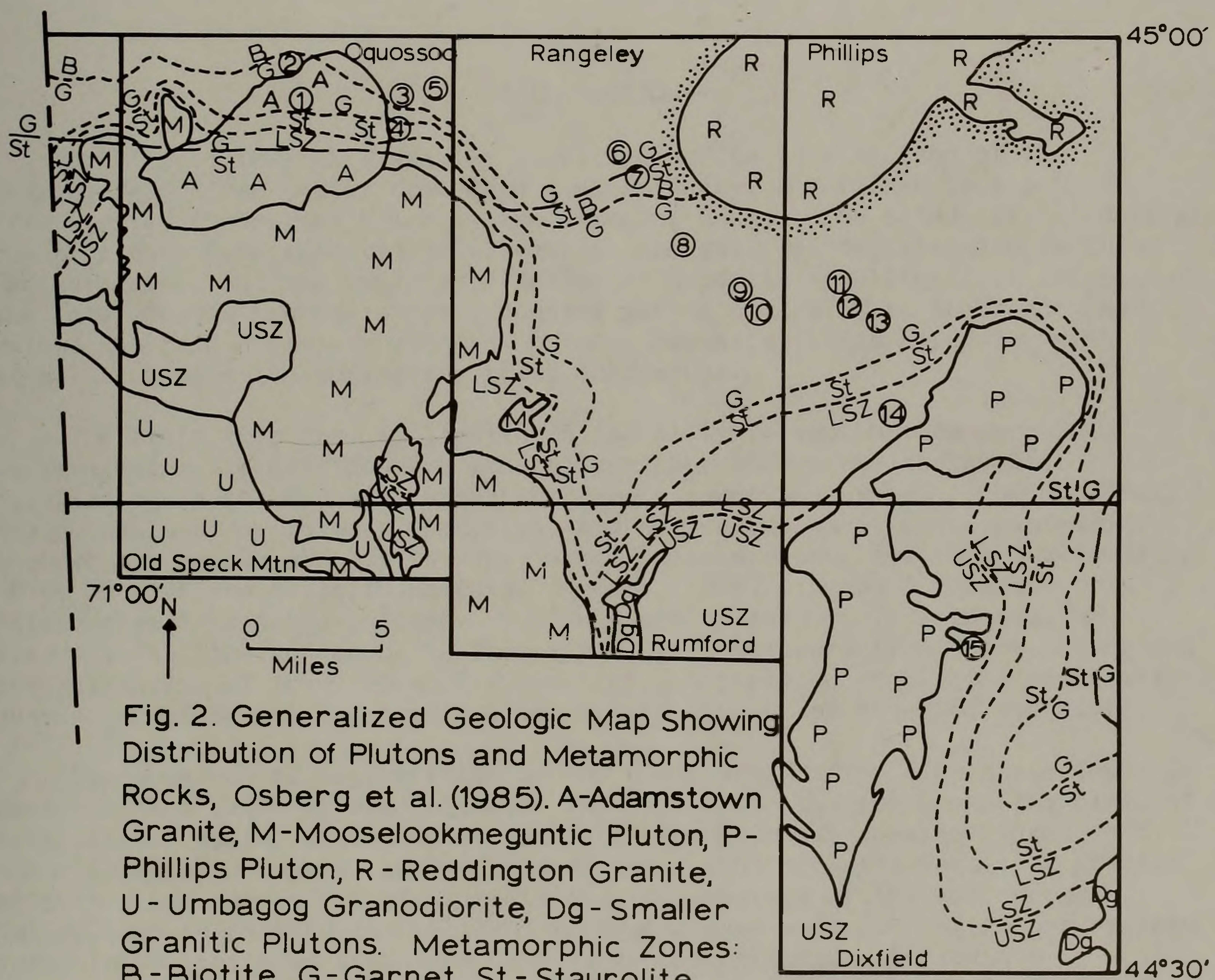

Fig. 2. Generalized Geologic Map Showing Distribution of Plutons and Metamorphic Rocks, Osberg et al. (1985). A-Adamstown Granite, M-Mooselookmeguntic Pluton, P-Phillips Pluton, R-Reddington Granite, U-Umbagog Granodiorite, Dg-Smaller Granitic Plutons. Metamorphic Zones: B-Biotite, G-Garnet, St-Staurolite, LSZ-Lower Sillimanite, USZ-Upper Sillimanite, Stipple-Contact Hornfels. —— M_2 Isograds, ---- M_3 Isograds, ② - Field Trip Stops.