The Structural Framework and Petrology of the Southern Adirondacks

James McLelland
Department of Geology, Colgate University, Hamilton, NY

Ennis Geraghty
97B Shafer Road, Apt. 1B, Albany, NY

with a section on Ledge Mountain by

Gary Boone
Department of Geology, Syracuse University, Syracuse, NY

INTRODUCTION

The area referred to as the southern Adirondacks is shown in Figure 1. Within this region, the Precambrian is bounded approximately by the towns of Lowville and Little Falls on the west and Saratoga Springs and Glens Falls on the east.

Mapping in the southern Adirondacks was done first by Miller (1911, 1916, 1920, 1923), Cushing and Ruedemann (1914), Krieger (1937), and Cannon (1937); more recent investigations were undertaken by Bartholomé (1956), Thompson (1959), Nelson (1968), and Lettney (1969). At approximately the same time Walton (1961) began extensive field studies in the eastern portion of the area (Paradox Lake, etc.), de Waard (1962) began his studies in the west (Little Moose Mt. Syncline). Subsequently de Waard was joined by Romey (de Waard and Romey, 1969).

Separately and together, Walton and de Waard (1963) demonstrated that the Adirondacks are made up of polydeformational structures, the earliest of which consist of isoclinal, recumbent folds. Their elucidation of

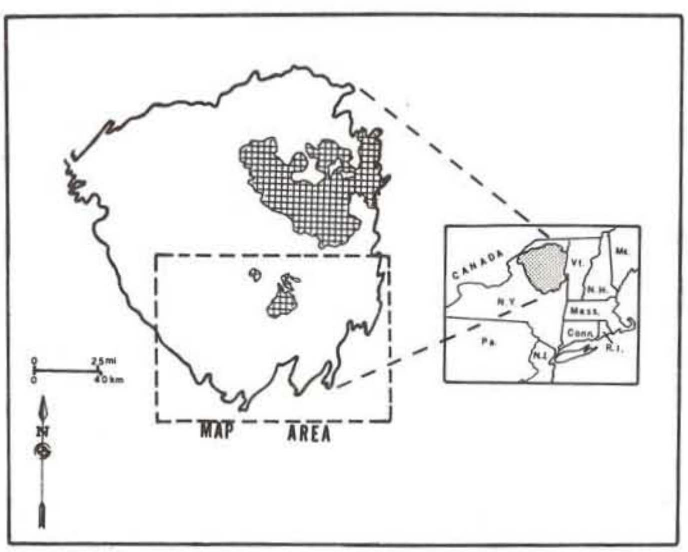

Figure 1. Location of map area. Major anorthosite bodies patterned.

Adirondack geology set the tone for future workers in the area. In this regard one of their most important contributions to the regional picture was that the stratigraphy of the west-central Adirondacks is correlative with that of the eastern Adirondacks.

Beginning in 1967 McLelland (1969, 1972) initiated mapping in the southernmost Adirondacks just to the west of Sacandaga Reservoir. This work was extended subsequently north and east to connect with that of Walton and de Waard. Geraghty (1973) and Farrar (1976) undertook detailed mapping in the eastern half of the North Creek 15' quadrangle. This tied into investigations in the Brandt Lake region by Turner (1971). Recently, Geraghty (1978) completed a detailed study of the structure and petrology in the Blue Mt. Lake area.

The foregoing investigations have increased our knowledge of the southern Adirondacks, and this fieldtrip is designed to show as many examples of the region's structure, lithology, and petrology as time allows.

STRUCTURAL FRAMEWORK OF THE SOUTHERN ADIRONDACKS

The southern Adirondacks (Figs. 2, 3, 4) are underlain by multiply deformed rocks which have been metamorphosed to the granulite facies. The structural framework of the region consists of four unusually large fold sets, F_1-F_4 (Figs. 2, 4). Relative ages have been assigned to these fold sets, but no information exists concerning actual time intervals involved in any phase of the deformation. It is possible that several, or all of the fold sets, are manifestations of a single deformational continuum.

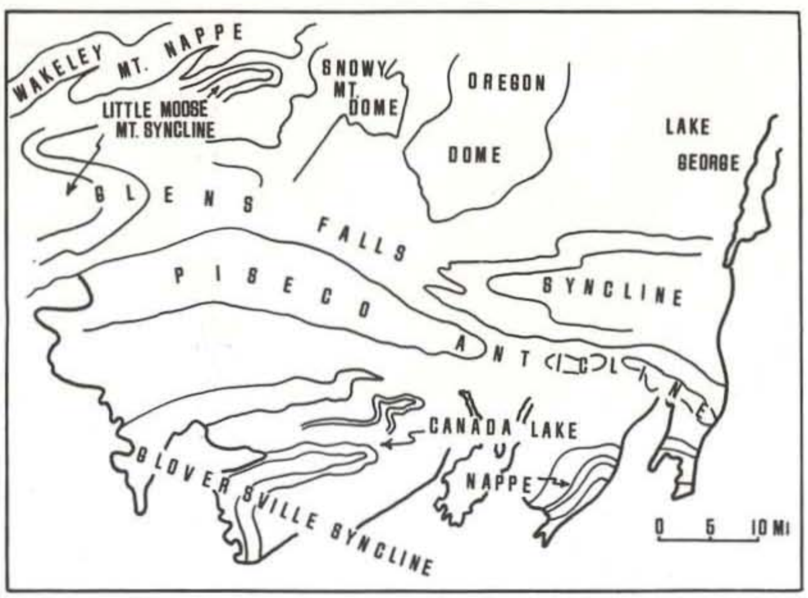

Figure 2. Major structural elements of southern Adirondacks.

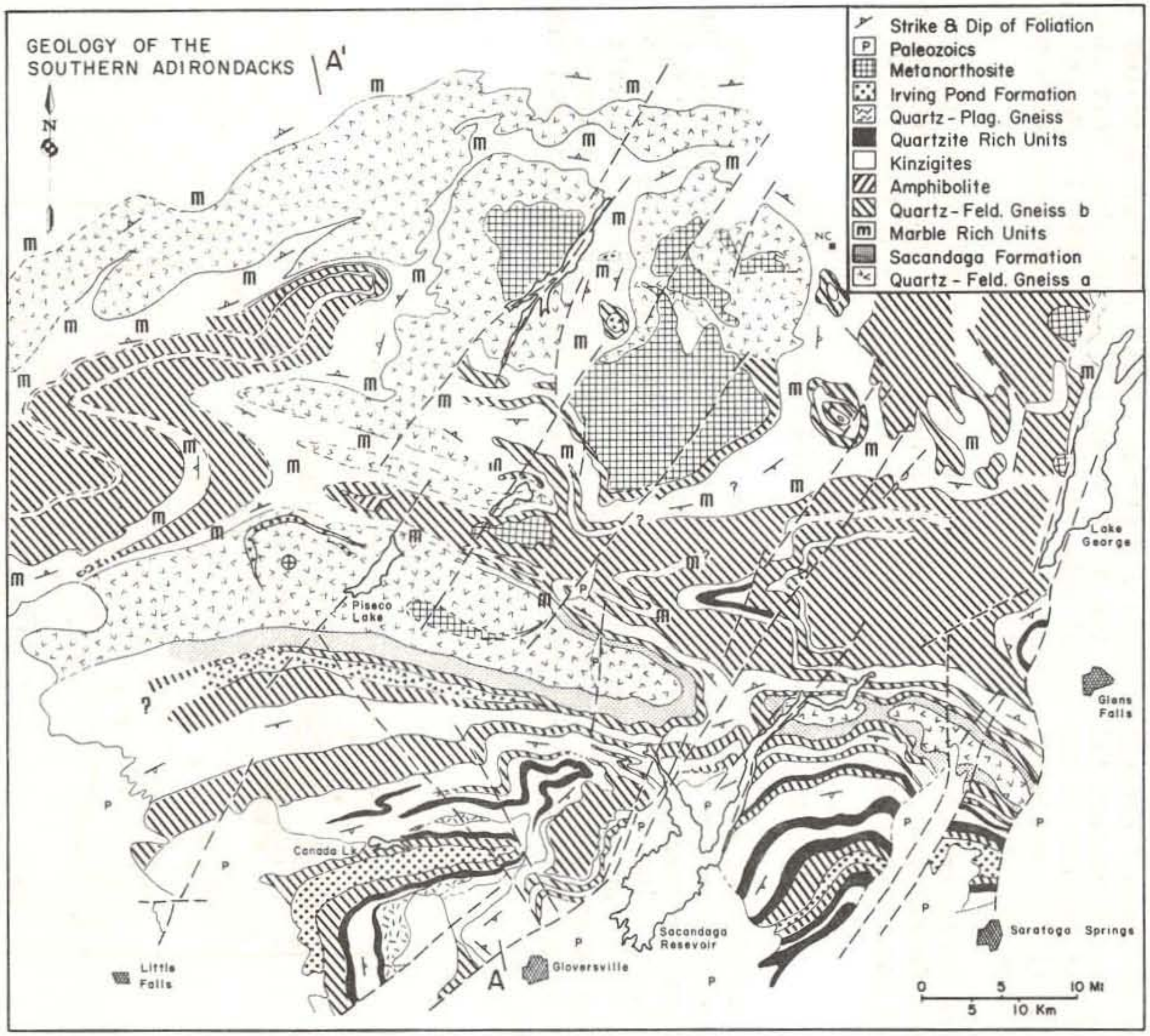

Figure 3. Geologic map of southern Adirondacks.

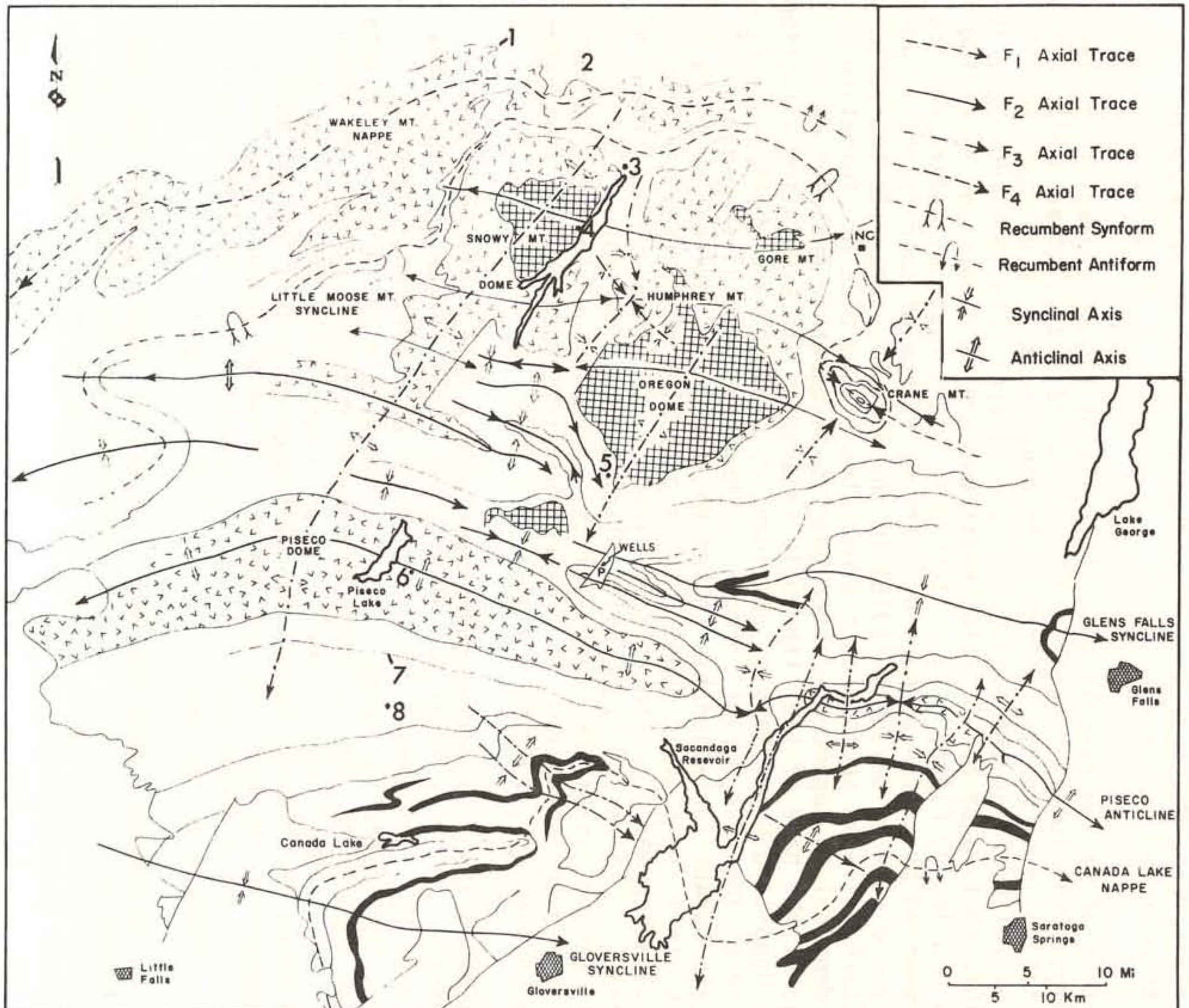

Figure 4. Axial traces of major folds in southern Adirondacks. Field trip stops 1-8 indicated.

The earliest and largest of these folds are recumbent, isoclinal structures (F_1) -- for example Little Moose Mt. Syncline (de Waard, 1962) and Canada Lake Nappe (McLelland, 1969)(Figs. 3 and 4). These isoclines have axes that trend approximately E-W and plunge within 20° of the horizontal. As seen in Figure 4 the axial traces of each of the F_1 folds exceeds 100 km. They are believed to extend across the entire southern Adirondacks. Subsequent useage of the terms "anticline" and "syncline," rather than "antiform" and "synform," is based on correlations with rocks in the Little Moose Mt. Syncline where the stratigraphic sequence is thought to be known (de Waard, 1962).

Close examination reveals that the F_1 folds rotate an earlier foliation defined principally by plates of quartz and feldspar. Although this foliation is suggestive of pre-F_1 folding, such an event does not seem to be reflected in the regional map patterns (Fig. 3). However, it is possible that major pre-F_1 folds exist but are of dimensions exceeding the area bounded by Figure 3. If this is the situation, their presence may be revealed by continued mapping. The existence of such folds is suggested by the work of Geraghty (1978) in the Blue Mt. area. In the vicinity of Stark Hills it seems that charnockites of the Blue Mt. Formation may be identical to supposedly older quartzo-feldspathic gneisses "A" which lie at the base of the lithologic sequence. If this is the situation then the Upper and Lower Marbles are identical and there emerges a pre-F_1 fold cored by the Lake Durant Formation. However, careful examination of the Lake Durant Formation has failed to reveal the internal symmetry implied by this pre-F_1 fold model. It is possible, of course, that the pre-F_1 foliation may not be related directly to folding (e.g. formed in response to thrusting, gravity sliding, etc.; Mattauer, 1975). Currently the origin of the pre-F_1 foliation remains unresolved. In most outcrops the preF_1 foliation cannot be distinguished from that associated with the F_1 folding.

Following the F_1 folding, there developed a relatively open and approximately upright set of F_2 folds (Figs. 3 and 4). These are coaxial with F_1. In general the F_2 folds are overturned slightly to the north, the exception being the Gloversville Syncline with an axial plane that dips 45°N. The F_2 folds have axial traces comparable to those of the F_1 set. The Piseco Anticline and Glens Falls Syncline can be followed along their axial traces for distances exceeding 100 km until they disappear to the east and west beneath Paleozoic cover. The similarity in size and orientation of F_1 and F_2 suggests that both fold sets formed in response to the same force field.

The third regional fold set (F_3) consists of large, upright NNE folds having plunges which differ depending upon the orientation of earlier fold surfaces. The F_3 folds are observed to tighten as one proceeds towards the northeast.

The fourth fold set is open, upright, and trends NW. Within the area these folds are less prevalent than the earlier sets. However, Foose and Carl (1977) have shown that within the NW Adirondacks, northwest-trending folds are widespread and play an important role in the development of basin and dome patterns.

The regional outcrop pattern is distinctive because of the interference between members of these four fold sets (Figs. 3 and 4). For example, the "bent-index-finger" pattern of the Canada Lake Nappe west of Sacandaga Reservoir is due to the superposition of the F_2 Gloversville Syncline on the F_1 fold geometry (Fig. 5). East of the reservoir the reemergence of the core rocks of the Canada Lake Nappe is due to the superposition on F_1 of a large F_3 anticline whose axis passes along the east arm of the reservoir (Fig. 6). The culmination-depression pattern along the Piseco Anticline results from the superposition of F_2 and F_3 folds. The structure of the Piseco Dome is due to the intersection of the Piseco Anticline (F_2) with the Snowy Mt. Anticline (F_3). Farther to the north, Crane Mt. is a classic example of a structural basin formed by the interference of F_1, F_2, and F_3 synclines (Fig. 4 and 7).

DISCUSSION AND SYNTHESIS OF STRUCTURAL RELATIONSHIPS

Over a decade ago Walton and de Waard (1963) proposed that rocks of the anorthosite-charnockite suite comprise a pre-Grenvillian basement on which a coherent "supracrustal" sequence was deposited unconformably. Rocks which would be assigned a basement status in this model are designated as quartzo-feldspathic gneisses, "a" in Figure 3. The basal unit of the overlying "supracrustal" sequence consists of marbles, quartzites, and various calc-silicates. This lowermost unit is followed upward by various quartzo-feldspathic gneisses, marbles, and other metasedimentary sequences shown in Figure 8. Although our own research agrees with the generalized lithologic sequences of de Waard and Walton, two major provisos are necessary and are given here.

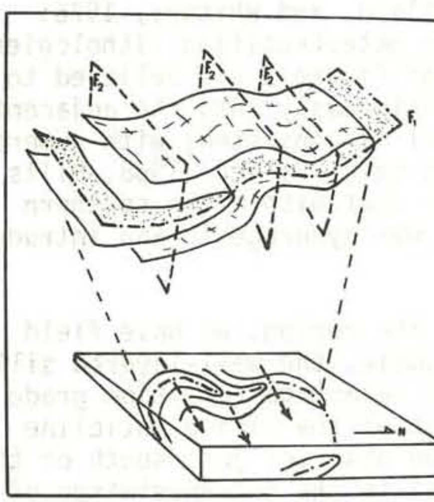

Figure 5. F_1-F_2 fold interference resulting in "bent-index-finger" pattern of Canada Lake Nappe.

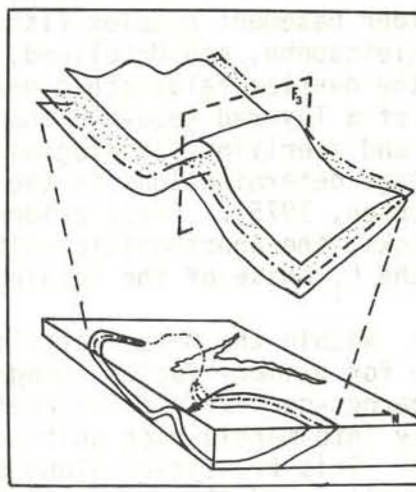

Figure 6. F_1-F_3 fold interference resulting in reemergence of core of Canada Lake Nappe east of Sacandaga reservoir.

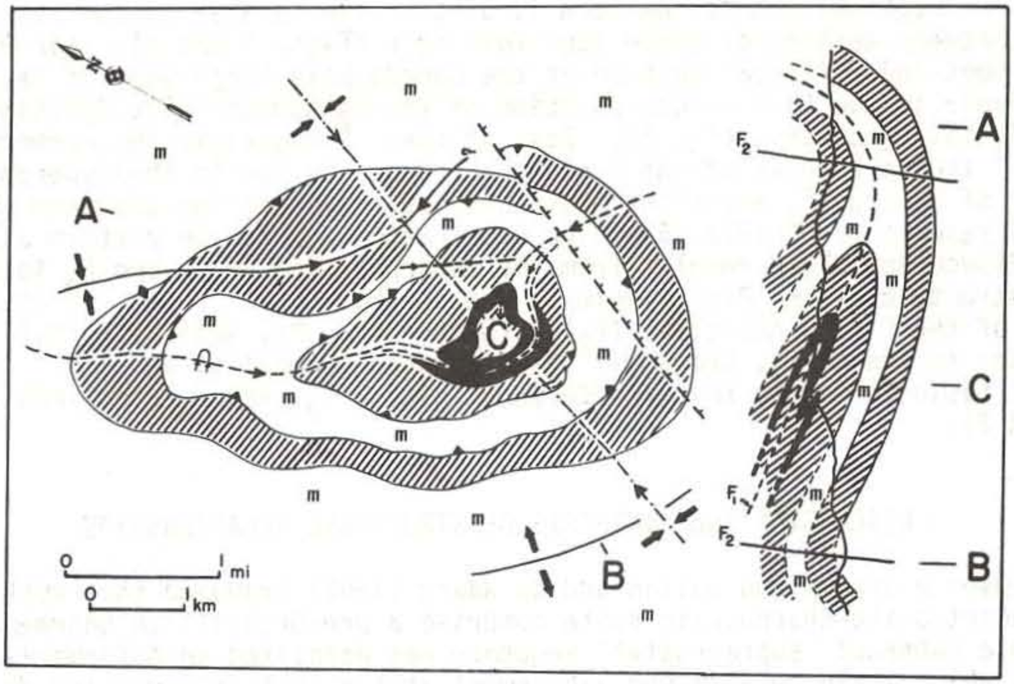

Figure 7. Geologic map and cross section of Crane Mt. area. Note bend in section at c. Rock unit symbols as in Figure 3 except for black unit which is rich in calc-silicates. F_1 synform involved here is believed to be eastern continuation of Little Moose Mt. Syncline.

(1) Anorthositic rocks intrude the so-called supracrustal sequence, and therefore the anorthosites post-date these units and cannot be part of an older basement complex (Isachsen, McLelland, and Whitney, 1976; Husch, Kleinspehn, and McLelland, 1976). The metastratified lithologies within the quartzo-feldspathic gneisses "a" of Figure 3 are believed to be part of a layered sequence that passes continuously into the adjacent marbles and overlying lithologies. This model is consistent with numerous isotope age determinations in the Adirondacks (e.g. Silver, 1968; Hills and Isachsen, 1975). Field evidence suggests that within the southern Adirondacks, the anorthositic suite of rocks was synorogenic and intruded during the F_1 phase of the folding.

(2) Within the metastratified units of the region, we have field evidence for primary facies changes. For example, the well-layered sillimanite-garnet-quartz-feldspar gneisses of the Sacandaga Formation grade laterally into marble-rich units exposed north of the Piseco Anticline (Fig. 3). This transition along strike can be observed just south of the town of Wells, and its recognition is critical to the interpretation of the regional structure. Thus the great thickness of kinzigites (granulite-facies metapelites) south of the Piseco Anticline gives way to the north to thinner units marked by marbles, cal-silicates, and quartzites. We interpret this lithologic change as due to a transition from a locally deep basin in which pelitic rocks were accumulating to a shallow-water shelf sequence dominated by carbonates and quartz sands.

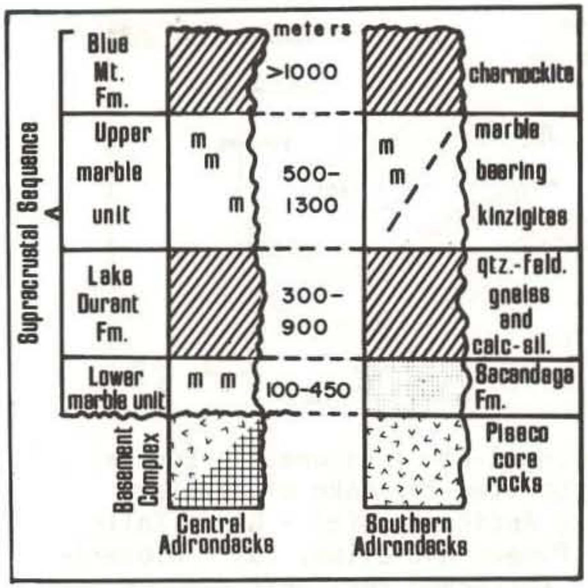

Figure 8. Stratigraphic sections for Little Moose Mt area (central Adirondacks) and Piseco Anticline region (southern Adirondacks). Central Adirondacks data from de Waard (1964a).

Given the foregoing information, it has been possible to map and correlate structures and lithologies on either side of the Piseco Anticline. In the northwest the sequence on the northern flank proceeds without structural discontinuity into the core of the Little Moose Mt. Syncline. There occurs on the southern flank a mirror image of the northwestern lithologic sequence as units are traced towards the core of the Canada Lake Nappe. It follows that the Canada Lake Nappe and Little Moose Mt. Syncline are parts of the same fold (Fig. 9). The amplitude of this fold exceeds 70 km, and it can be followed for at least 150 km along its axial trace. The major F_2 and F_3 folds of the area are exposed through distances of similar magnitude, but their amplitudes are less than those of the F_1 isoclines. The structural framework that emerges is one dominated by exceptionally large folds.

Accepting that the Little Moose Mt. Syncline and Canada Lake Nappe are the same fold, and noting that the fold axis is not horizontal, it follows that the axial trace of the fold must close in space. The axial trace of the Canada Lake Nappe portion of the structure can be followed from west of Gloversville to Saratoga Springs. Therefore, the axial trace of the Little Moose Mt. Syncline also must traverse the Adirondacks to the north. Mapping strongly suggests that the hinge line of this fold passes through North Creek and south through Crane Mt. (Fig. 10). From here the axial trace swings eastward along the north limb of the Glens Falls Syncline and passes under Paleozoic cover in the vicinity of Lake George. This model is depicted schematically in Figure 10 where the southern Adirondacks are shown as underlain largely by the Canada Lake-Little Moose Mt. Syncline. Later folding by F_2 and F_3 events has resulted in regional doming of the F_1 axial surface, and erosion has provided a window through the core of this dome. Note the western extension of the Piseco Anticline beneath the Paleozoic cover. This extension is consistent with aeromagnetics of the area.

Currently attempts are underway to synthesize the structural framework of the entire Adirondacks by extending the elements of the present model to other areas. A preliminary version is shown in Figure 11 and suggests that most Adirondack structure is explicable in terms of the four large fold sets described here.

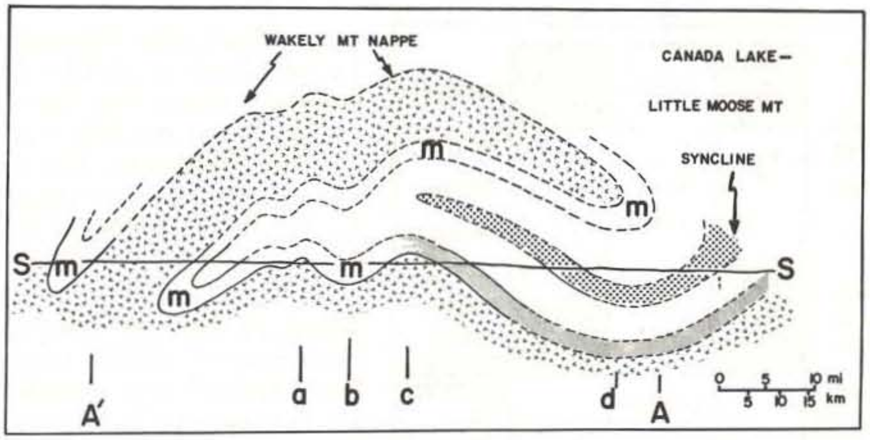

Figure 9. Cross section along A-A' of Figure 2. Several units have been omitted for sake of clarity. (a) - Spruce Lake Anticline, (b) - Glens Falls Syncline, (c) - Piseco Anticline, (d) - Gloversville Syncline. Patterned rock unit symbols as in Figure 3.

METAMORPHISM

Introduction

Metamorphism of rocks in the Adirondack highlands has been investigated extensively for the past fifteen years (see e.g. Buddington, 1963, 1965, 1966; de Waard, 1964a, 1965a, 1965b, 1967, 1969, 1971; Whitney and McLelland, 1973; McLelland and Whitney, 1977; Bohlen and Essene, 1977;

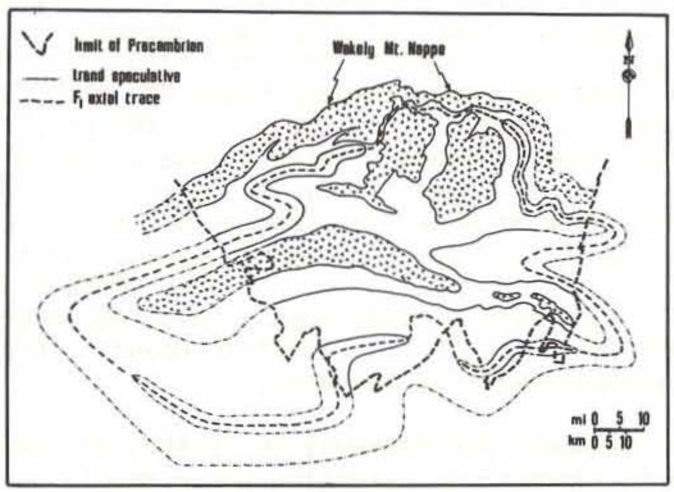

Figure 10. Generalized map showing known and projected axial trace of Canada Lake-Little Moose Mt. Syncline. Heavy dashed line marks Proterozoic-Paleozoic boundary as shown in Figures 1 and 2.

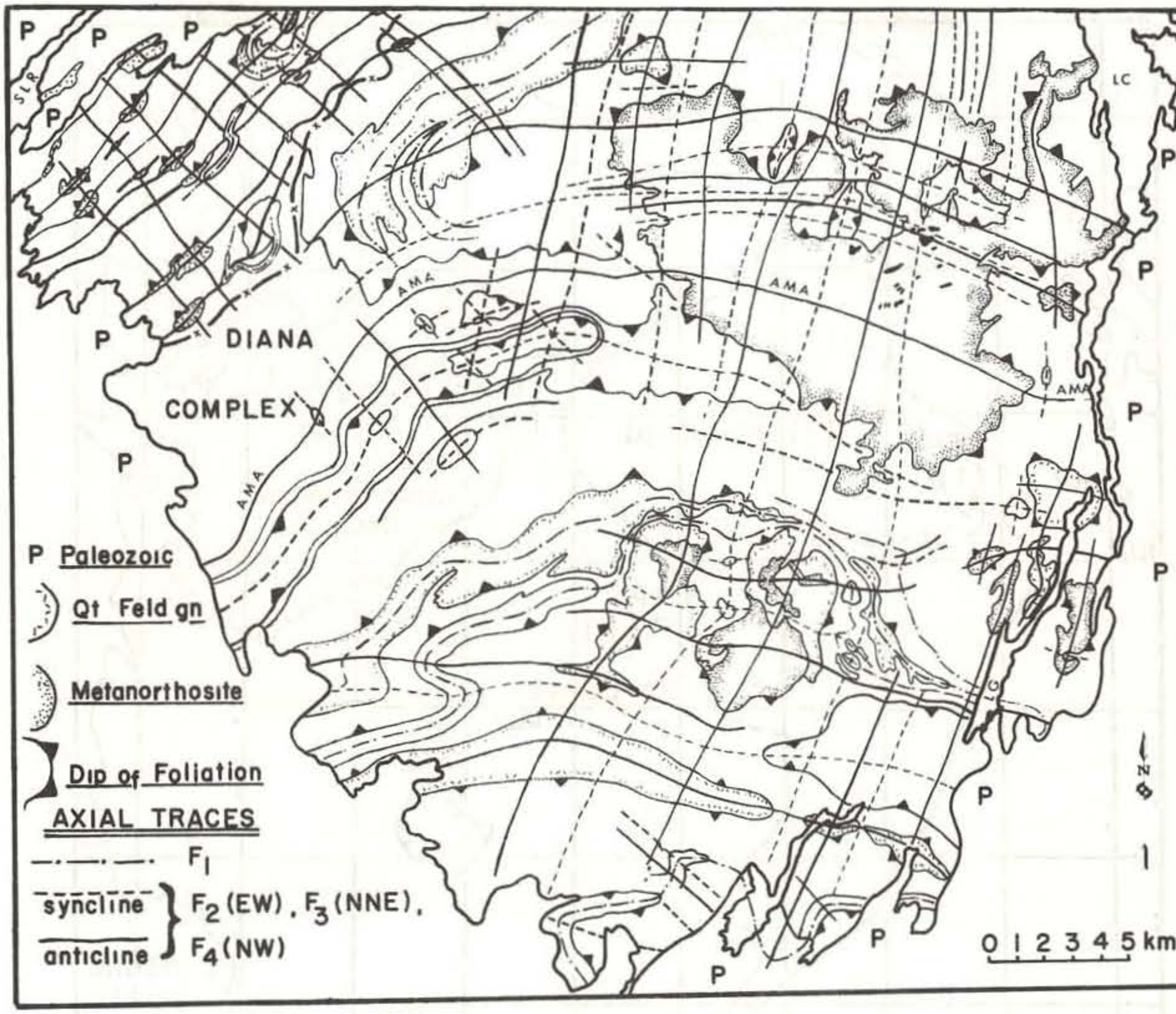

Figure 11. Hypothetical structural framework for Adirondacks. AMA-Arab Mt. Anticline.

Essene and others, 1977; Boone, 1978; Boone and others, in prep.; Valley and Essene, 1976; Jaffe and others, 1977; Stoddard, 1976). Engel and Engel (1962) made an early and fundamental contribution when they delineated in part the orthopyroxene isograd in the northwestern Adirondacks (see Fig. 12). Orthopyroxene is the diagnostic mineral of high-grade metamorphism and its regional stable occurrence with plagioclase and garnet demonstrates that metamorphic conditions of the granulite facies were attained to the east of the orthopyroxene isograd.

de Waard (1971) proposed a three-fold subdivision of the granulite facies in the Adirondack highlands (Fig. 12). The three zones, in order of progressive metamorphism, are the (1) biotite-cordierite-almandite subfacies, (2) hornblende-orthopyroxene-plagioclase subfacies, and (3) hornblende-clinopyroxene-almandite subfacies. de Waard (1971) believed the subfacies represent three stages of increasing granulite-facies metamorphism constituting an Adirondack Type of metamorphic series. All stops

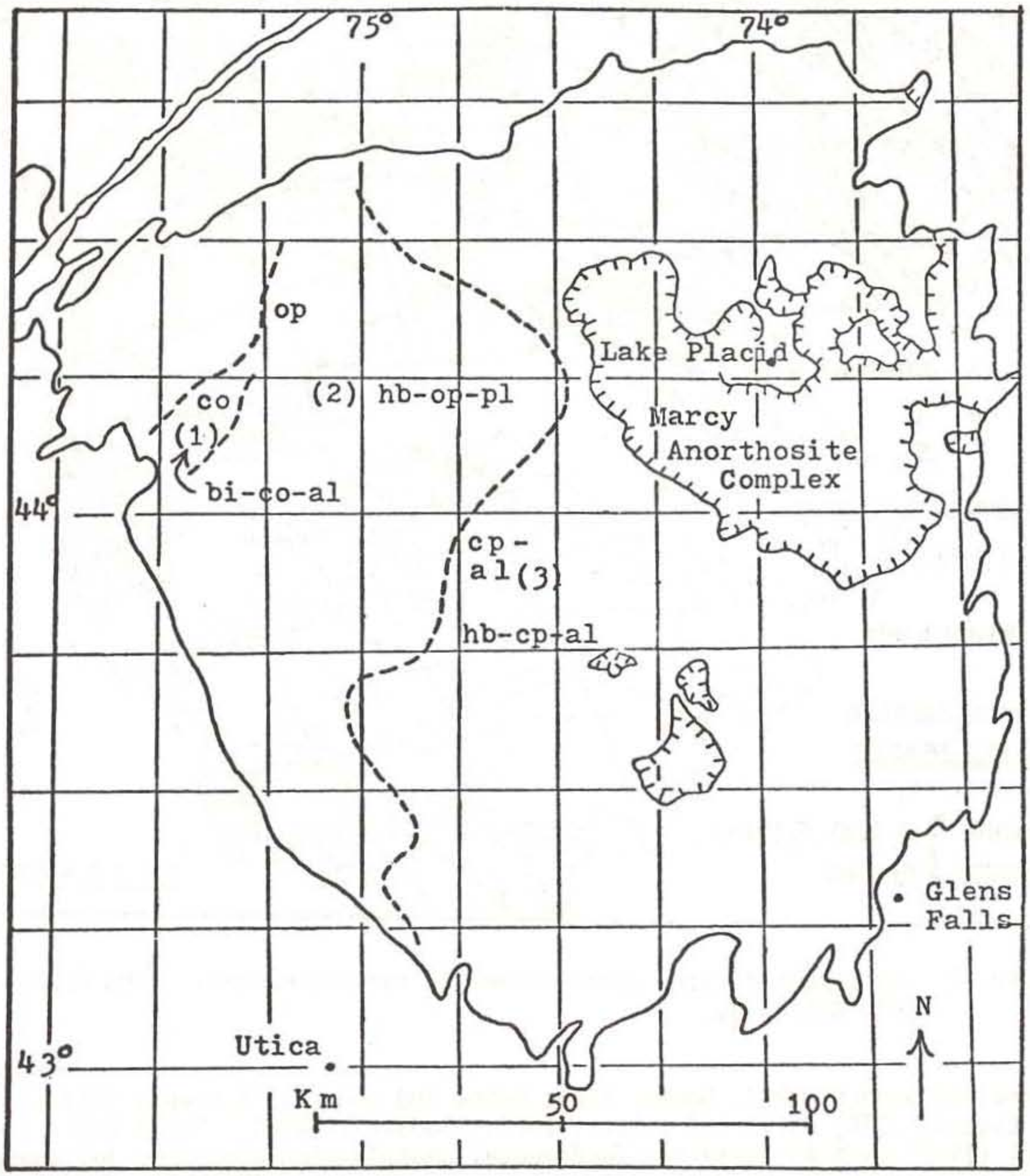

Figure 12. Outline map (modified after de Waard, 1971) of Precambrian terrane of Adirondack Mountains and Northwest Lowlands showing de Waard's proposed subdivision of granulite facies of Adirondack highlands: (1) biotite-cordierite-almandite subfacies, (2) hornblende-orthopyroxene-plagioclase subfacies, and (3) hornblende-clinopyroxene-almandite subfacies. Three isograds are shown; parts of isograds were mapped by de Waard (1971), Engel and Engel (1962), and Buddington (1963). Solid contact is trace of Precambrian-Paleozoic boundary; hatchured contacts delineate boundaries of relatively larger anorthosite complexes.

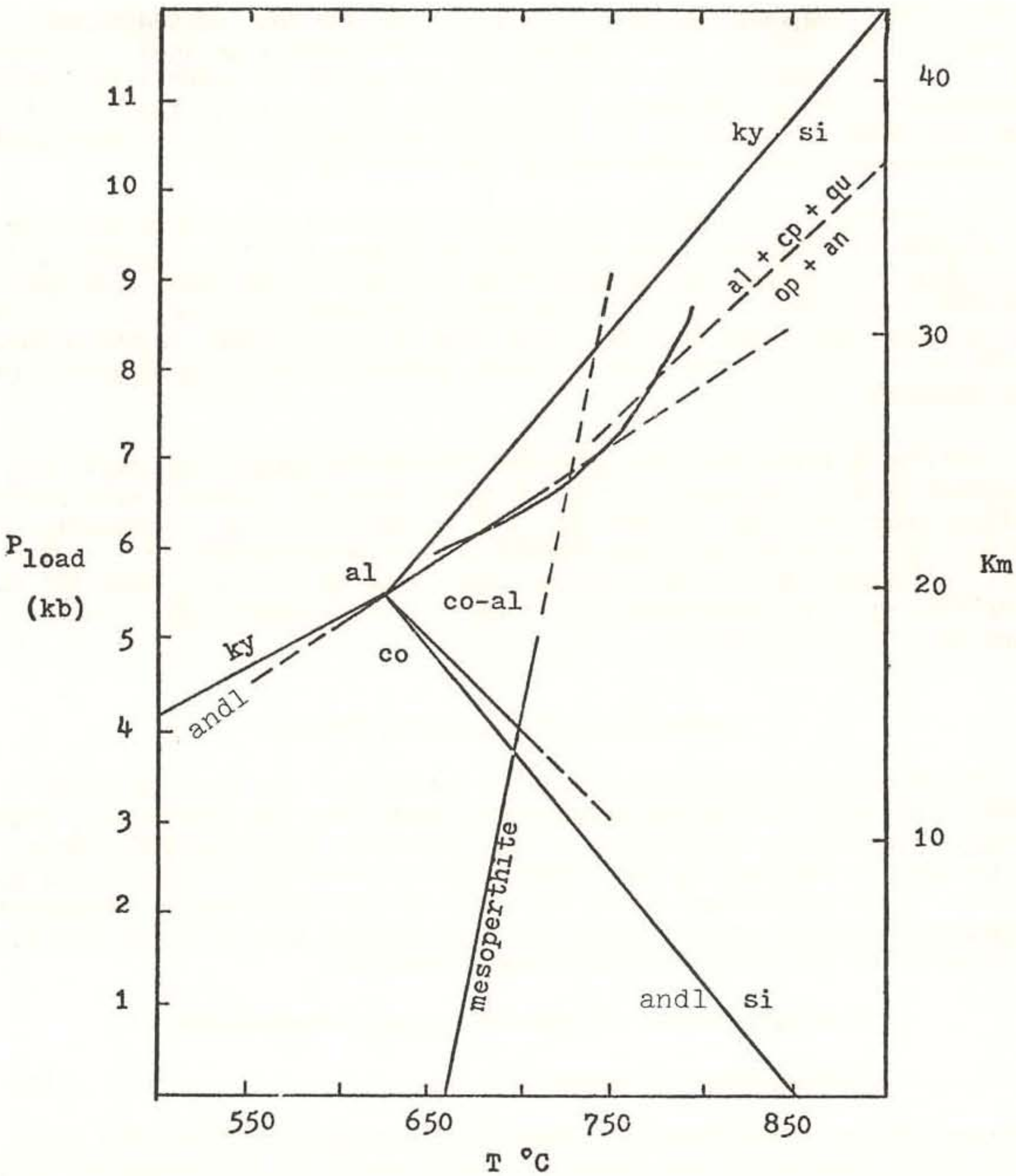

Figure 13. Petrogenetic grid (modified after de Waard, 1969, p. 129) composed of stability boundaries for solid-solid reactions involving anhydrous phases only. Curved line is geothermal gradient representing P_{load}-T conditions of metamorphism favored by de Waard. Grid is based upon following experimentally derived curves: reaction orthopyroxene + plagioclase $\rightleftharpoons$ clinopyroxene + almandite + quartz after Ringwood and Green (1966); triple point of aluminum silicates after Gilbert, Bell, and Richardson (1968) and Holdaway (1968); kyanite-sillimanite boundary after Richardson, Bell, and Gilbert (1968); cordierite and almandite stability fields after Hirschberg and Winkler (1968); and solvus temperature maximum of alkali feldspars after Orville (1963).

on this field trip are located in zone (3), to the east of the garnet-clinopyroxene isograd. This isograd, far from sharply defined, is based upon the first recognition, in the field, of garnet in quartzo-feldspathic (charnockitic) rocks (de Waard, 1971). Thus, all rocks in the field-trip area have been subjected to P-T conditions appropriate for the hornblende-clinopyroxene-almandite subfacies of the granulite facies.

In addition, the area of the biotite-cordierite-almandite subfacies has greater areal extent than exhibited in Figure 12 (P.R. Whitney, 1977, pers. comm.). Cordierite and garnet-bearing pelitic gneisses have been reported by Stoddard (1976) to occur north-northeast of zone (1). It can be inferred from these locations that zone (1) now extends north-northeast, ~parallel to the orthopyroxene isograd, almost to the Precambrian-Paleozoic boundary.

Only rock types that have yielded information about P-T conditions of metamorphism are discussed in the following section. Mineral-name abbreviations used are: al - almandite; andl - andalusite; an - anorthite; bi - biotite; ca - calcite; co - cordierite; cp - clinopyroxene; Kf - K-rich alkali feldspar, chiefly microcline, usually perthitic; ky - kyanite; ma - magnetite; op - orthopyroxene; pf - plagioclase feldspar; qu - quartz; sc - scapolite; si - sillimanite.

Charnockitic and Granitic Gneiss

Hornblende-clinopyroxene-almandite subfacies: de Waard proposed (1964a) that with increasing metamorphic conditions the typomorphic orthopyroxene-plagioclase association of the granulite facies becomes imcompatible and is replaced by the higher density almandite-clinopyroxene association. This replacement marks the start of the hornblende-clinopyroxene-almandite subfacies, and de Waard proposed (1964a) the following reaction to account for the garnet-clinopyroxene formation:

$$\text{6 orthopyroxene} + \text{2 anorthite} \rightleftharpoons \text{clinopyroxene} + \text{2 almandite} + \text{2 quartz} \qquad (1)$$

Reaction (1) has a positive P-T slope (see petrogenetic grid, Fig. 13). de Waard (1967) considered two manners in which reaction (1) proceeded to the right. In one instance, the reaction progression may indicate a gradual increase in both T and P_{load} during progressive regional metamorphism in which the central and eastern Adirondacks were subjected to hornblende-clinopyroxene-almandite-subfacies conditions. In the second instance, the reaction may have been produced by a decrease in T with little change in P_{load} during retrogressive metamorphism. However, de Waard (1967) favored the first instance of increasing P_{load} and T for the following reasons: (1) the clinopyroxene-garnet-quartz assemblage has a higher density than the orthopyroxene-anorthite assemblage and represents a reduction in molar volume of ~14 percent, thus favoring higher P_{load}, and (2) cordierite, considered indicative of relatively lower P_{load} (or higher T), is present in pelitic gneisses in the northwestern portion of the highlands, but absent in gneisses of comparable composition to the SE (Fig. 12).

Martignole and Schrijver (1971) contended that reaction (1) proceeds to the right as a consequence of de Waard's second instance: decrease in T with little change in P_{load}. They believe the formation of garnet and clinopyroxene does not represent a reaction due to progressive regional metamorphism, but, rather, represents a retrograde metamorphic reaction during slow cooling at relatively constant P_{load}. They base their interpretation on field and petrographic observations associated with their work in the Morin anorthosite complex of southern Quebec, located ~120 km north of the Adirondack highlands portion of the Grenville Province. In their field area, the garnet-quartz-clinopyroxene assemblage is restricted virtually to norites, ferrogabbros, jotunites, and mangerites that surround the anorthosite mass. Martignole and Schrijver believe this areal restruction suggests the garnet-forming reaction is genetically linked to the anorthosite complex. In addition to de Waard's reaction (1), they propose reaction

$$\text{orthopyroxene + plagioclase} \rightleftharpoons \text{Ca-Fe-Mg garnet + quartz} \quad (2)$$

and imply (1971, p. 700) that reaction

$$\text{orthopyroxene + plagioclase + Fe oxide} \rightleftharpoons \text{garnet +}$$
$$\text{quartz + clinopyroxene} \quad (3)$$

involving reduction of Fe^{3+} from left to right, also was active in the formation of garnet-quartz symplectites.

Rare occurrences of cordierite (Martignole and Schrijver, 1971, p. 701) are present at the immediate contact between the anorthosite complex and supracrustal rocks. Martignole and Schrijver believe this rare occurrence of cordierite precludes using an increase of P_{load}-T near the complex to explain garnet formation as de Waard does for the Adirondack highlands. Their alternative explanation for the association of garnet-quartz symplectites and the anorthosite complex is that the anorthosite completed solidification under high load pressure and retarded regional cooling. This retarded regional cooling permitted reactions (1), (2), and (3) to proceed slowly to the right as retrograde reactions in the "dry" environment of granulite-facies metamorphism. Thus, Martignole and Schrijver contend the highest grade of metamorphism in the Adirondack highlands is preserved as the hornblende-orthopyroxene-plagioclase subfacies, zone 2 in Figure 12. Zone 3 (Fig. 12) is considered by them representative of retrograde metamorphism associated with close spatial relationship to anorthosite complexes.

McLelland and Whitney (1976, 1977) studied the origin of garnet in the anorthosite-charnockite suite of rocks in the Adirondacks. Their analysis of textural and chemical relationships suggests that the onset of the hornblende-clinopyroxene-almandite subfacies of de Waard (1964a) is marked by the following reaction:

$$2\ CaAl_2Si_2O_8 + (6-\alpha)(Fe,\ Mg)SiO_3 + \alpha Fe\text{-oxide} +$$

$$(\alpha-2)SiO_2 \rightleftharpoons Ca(Fe,Mg)_5Al_4Si_6O_{24} + Ca(Fe,Mg)Si_2O_6 \qquad (4)$$

where α is a function of the distribution of Fe and Mg between the several coexisting ferromagnesian phases. Reaction (4) is a general garnet-forming reaction for saturated rocks. It differs from de Waard's reaction (1) in that (a) quartz is a reactant instead of a product and (b) Fe-oxide is a reactant, as it is for reaction (3) of Martignole and Schrijver. McLelland and Whitney (1977) consider reaction (1) to be a special situation of reaction (4) where there exists, in charnockitic gneiss, a relatively high Mg/(Mg + Fe) ratio. An interesting feature of their study is that most garnet-quartz symplectites are actually garnet-plagioclase symplectites on the basis of microprobe analysis.

P-T Conditions of Metamorphism: de Waard (1969) and Bohlen and Essene (1977) estimated P-T conditions of metamorphism for the Adirondack highlands.

Figure 13 is the petrogenetic grid used by de Waard (1969) in arriving at P_{load}-T conditions of $\sim$ 7.8 kb and 770°C at the garnet-clinopyroxene isograd (see Figure 12). de Waard estimated maximum P_{load}-T conditions to be perhaps $\sim$ 8.3 kb and 800°C to the east of the garnet-clinopyroxene isograd (see de Waard, 1969, for a fuller discussion).

Bohlen and Essene (1977) report that pressure estimates increase from 6 kb at Balmat (northwest Adirondacks, in zone 2 of Fig. 12) to 8 kb in the central Adirondack highlands. Temperature estimates are almost 800°C in the central highlands as determined by plagioclase-orthoclase and ilmenite-magnetite thermometers (see Bohlen and Essene, 1977, for a fuller discussion).

McLelland and Whitney (1977) have estimated equilibrium temperatures for one charnockite from the Adirondack highlands assuming a P_{load} of 7.5 kb. The temperatures range from 610°C by the method of Wood (1974) to 792°C by the method of Wood and Banno (1973). The temperature methods are based on the distribution of Mg and Fe between clinopyroxene, orthopyroxene, and garnet as functions of temperature and pressure.

Metagabbro and Metadiabase

Origin of corona structures: Whitney and McLelland (1973) studied the origin of corona structures in metagabbros of the Adirondack Mountains. In the southern Adirondacks, Area I, two types of coronas are observed: (1) olivine-pyroxene-spinel coronas and (2) oxide-hornblende coronas. In the central and eastern Adirondacks, Area II, two types are also observed: (1) olivine-pyroxene-garnet coronas and (2) oxide-amphibole-garnet coronas.

Whitney and McLelland (1973) propose three partial reactions took place in the formation of olivine-cored coronas in Area I:

$$\text{olivine} \rightleftharpoons \text{orthopyroxene} + (Mg,Fe)^{++} \qquad (a)$$

plagioclase + $(Mg,Fe)^{++}$ + $Ca^{++} \rightleftharpoons$ clinopyroxene +

spinel + Na^{+} (b)

plagioclase + $(Mg,Fe)^{++}$ + $Na^{+} \rightleftharpoons$ spinel + more

sodic plagioclase + Ca^{++} (c)

Reaction (a) occurs in the inner shell of the corona structure adjacent to olivine. Reaction (b) occurs in the outer shell and reaction (c) occurs in the surrounding plagioclase, giving rise to spinel clouding in plagioclase. Summed together these partial reactions are equivalent to:

olivine + anorthite $\rightleftharpoons$ aluminous orthopyroxene +

aluminous clinopyroxene + spinel (5)

Garnet develops in olivine-cored coronas of Area II by the following partial reactions proposed by Whitney and McLelland (1973):

orthopyroxene + $Ca^{++} \rightleftharpoons$ clinopyroxene + $(Mg,Fe)^{++}$ (d)

clinopyroxene + spinel + plagioclase + $(Mg,Fe)^{++} \rightleftharpoons$

garnet + Ca^{++} + Na^{+} (e)

plagioclase + $(Mg,Fe)^{++}$ + $Na^{+} \rightleftharpoons$ spinel + more

sodic plagioclase + Ca^{++} (f)

These partial reactions [(d)-(f)] involve the products of reactions (a)-(c) and (5). Balanced, and generalized to account for aluminous pyroxenes and variable An content of plagioclase, partial reactions (d)-(f) are equivalent to:

orthopyroxene + anorthite + spinel $\rightleftharpoons$ garnet (6)

Whitney and McLelland (1973) propose the following net reaction to account for oxide-cored coronas:

olivine + anorthite + albite + ilmenite + diopside +

$H_2O \rightleftharpoons$ hornblende + hypersthene + spinel (7)

The garnet shell observed in oxide-amphibole coronas of Area II is believed (Whitney and McLelland, 1973, p. 93) to have formed by a complex reaction consuming hornblende, spinel, and plagioclase, yielding garnet, clinopyroxene (as inclusions in garnet), and a bright red, titaniferous biotite.

P-T Conditions of Corona-Structure Formation: Whitney and McLelland (1973) also have investigated the P-T conditions of corona-structure formation. Reactions (5) and (6) have been studied experimentally by Kushiro and Yoder (1966) and Green and Ringwood (1967), respectively. Figure 14 is modified after Whitney and McLelland (1973, fig. 5, p. 95). They cite several reasons for exercising caution in applying experimental results to natural systems. With those reservations, Whitney and McLelland are able to give a general estimate of P_{load} and T of corona formation. Broken lines A and B in Figure 14 illustrate two possible metamorphic histories for corona-structure formation. For garnet-bearing rocks, both paths must pass through the pyroxene spinel field prior to entering the garnet field. Path A is the prograde-metamorphic path in which gabbro and diabase intruded at shallow depths prior to maximum P-T conditions of metamorphism. Path B is the retrograde metamorphic path in which gabbro intruded at depth and cooled at constant, or increasing, pressure. A path similar to path A is favored for metagabbro of Area I (but at lower pressure

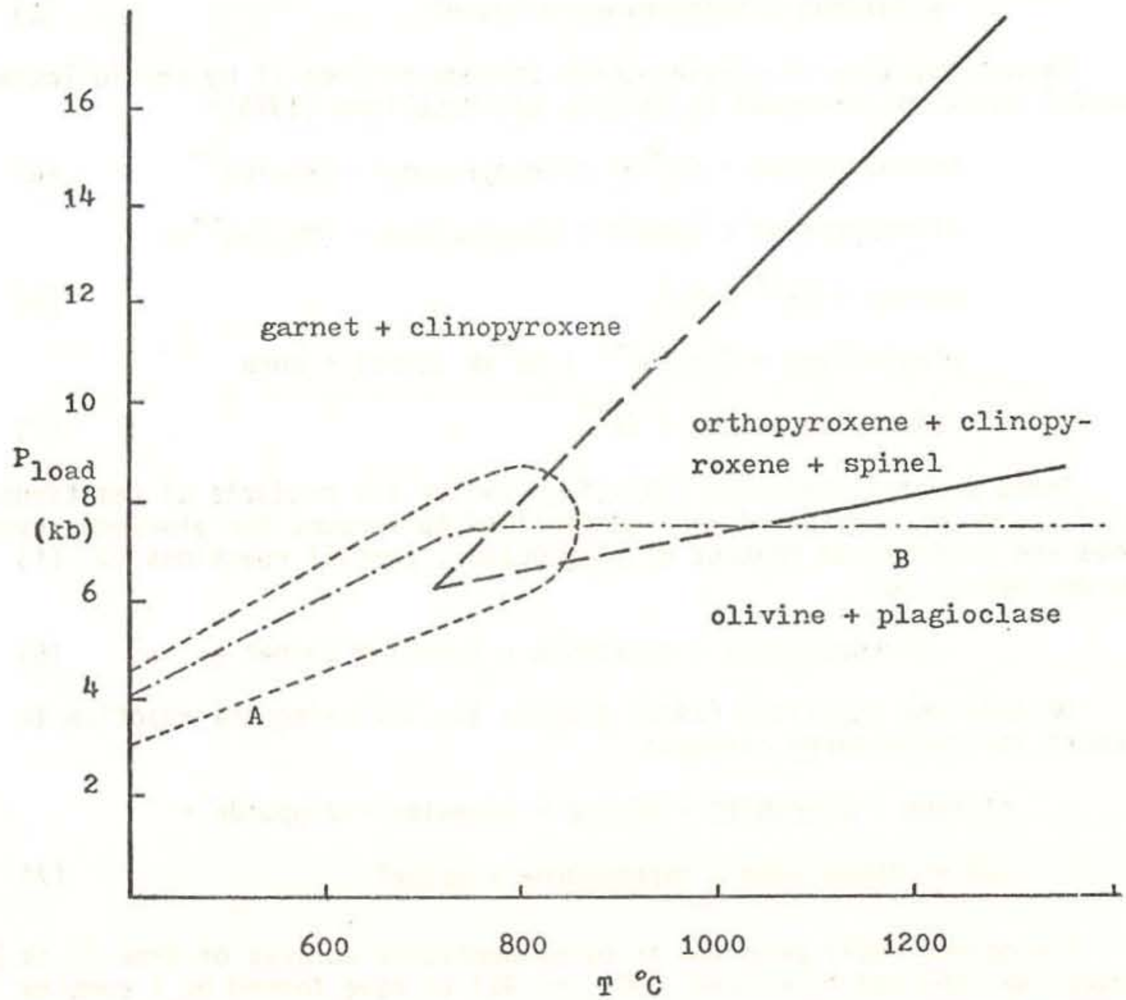

Figure 14. Stability fields of corona-structure mineral assemblages (modified after Whitney and McLelland, 1973, p. 95, fig. 5). Reaction boundaries (solid) are from Kushiro and Yoder (1966); dashed reaction boundaries are extrapolations of their work. A - path for prograde origin of garnet-bearing, olivine-cored coronas. B - path for retrograde origin of garnet-bearing, olivine-cored coronas.

because no garnet formed) whereas path B is favored for metagabbro of Area II, which is in close spatial association with the Marcy anorthosite complex. Regardless of the path followed, minimum pressure of ~ 8 kb and minimum temperature of $\sim 800°C$ were necessary for formation of garnet-bearing coronas (see Whitney and McLelland, 1973, for a complete discussion).

Kyanite - Sillimanite-bearing Aluminous Gneiss

Description: Boone (1978) and Boone and others (in prep.) have determined mineral compositions in sillimanite-rich, quartz-feldspar gneiss at Ledge Mountain. The gneiss is situated in the core of a south-facing, recumbent antiform, and is structurally - if not also stratigraphically - the lowest unit exposed in the central Adirondack highlands (Geraghty, 1978). The gneiss consists predominantly of microcline perthite, plagioclase, quartz, sillimanite, biotite, magnetite, garnet, and minor hercynite. Lenses and alternating layers of sillimanite, magnetite, and quartz with minor garnet and hercynite, make up the remaining 20 to 30 percent of the gneiss in the central part of the mountain. Abundance of these lenses and layers decreases westward toward Route NY 28-30. Only two small patches of kyanite have been found; these occur as relatively coarse-grained, blue crystal aggregates in the feldspathic portions of the gneiss. Pegmatite lenses and discordant bodies abound.

P-T Conditions of Metamorphism: The following relationships are of interest: (1) kyanite-sillimanite; (b) biotite-magnetite-feldspar; (c) Fe/Mg distribution between biotite and garnet; and (d) Ca-contents of garnet and plagioclase. Almandine-hercynite-magnetite-quartz relationships are puzzling, and may not conform to other reaction relationships in the gneiss perhaps owing to low reaction rate. The preponderance of sillimanite effectively argues against the notion that the gneiss equilibrated on the kyanite-sillimanite univariant boundary (or divariant field in Al-Fe). Insofar as kyanite is present, however, the following enquiry was made: Taking into account the Fe^{3+}, F^- and Cl^- contents of biotite, the reaction

$$\text{Biotite } (0.4\,{}^{VI}Fe^{2+}) + \text{Quartz} \rightleftharpoons \text{K-rich feldspar} + \text{Sillimanite} + \text{Magnetite}$$

$$+ H_2O + H_2 + F + Cl, \qquad (8)$$

was examined with reference to the redox equation of Czamanske and Wones (1973) across the temperature range of 650° - 800°C using a range of f_{O_2} compatible with the coexisting impure phases magnetite and hercynite (Turnock and Eugster, 1962). Values of calculated $P_E\ H_2O$ range from 120 bars at approximately 700°C to 600 bars at 770°C. These and volumetric data for the reaction abbreviated in equation (8) were applied to Greenwood's (1961) modification of Thompson's (1955) equation for the projected slope on P_s and T coordinates of a dehydration reaction boundary under steady-state outward diffusion conditions of H_2O with effective H_2O "pressure" less than total pressure. The resulting steep biotite dehydration boundaries are shown in Figure 15; inasmuch as they are nearly parallel to the pressure axis, the values of 695°C and 790°C may be taken as minimum and maximum for the temperature of granulite facies

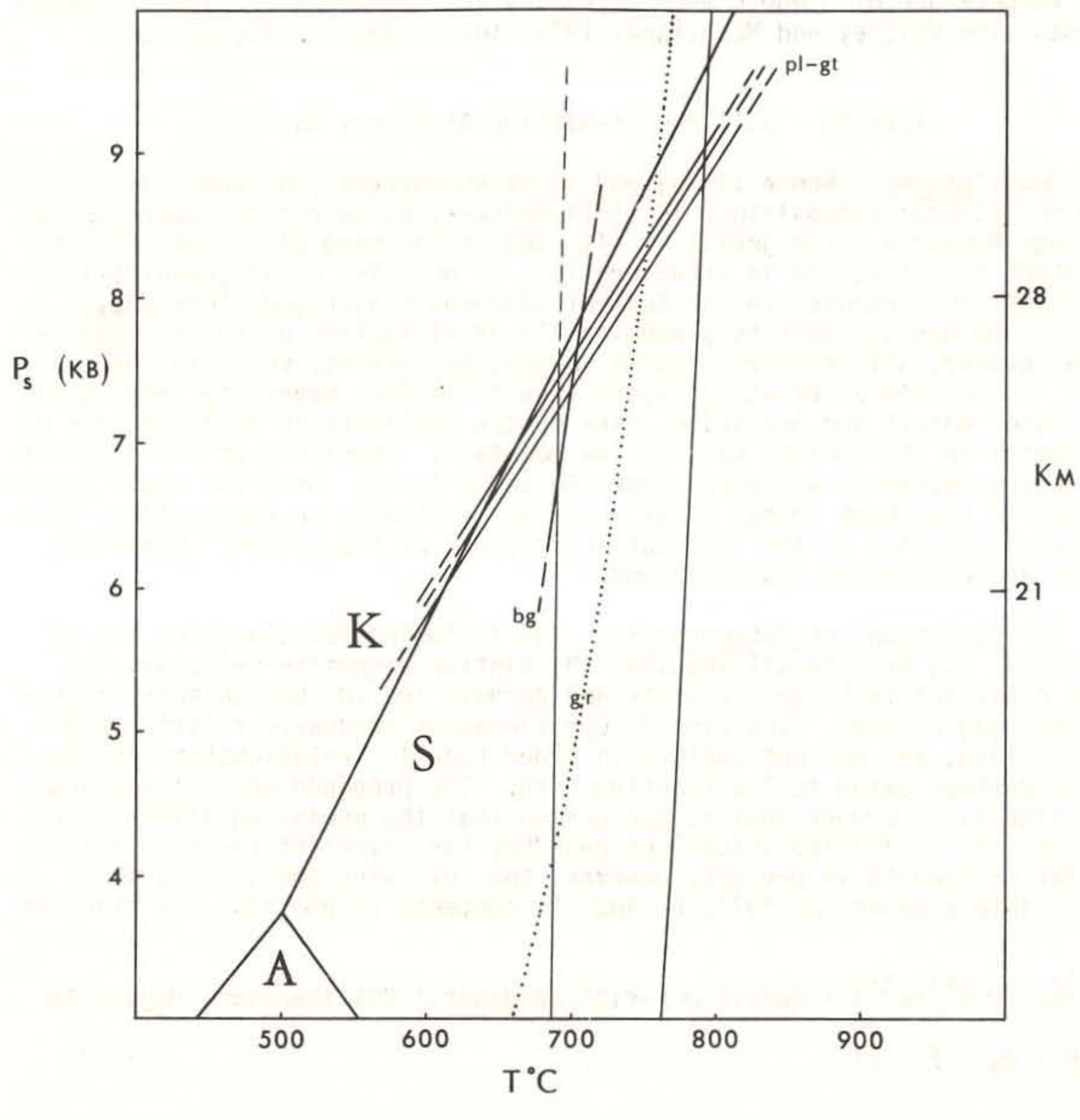

Figure 15. Petrogenic grid for Ledge Mountain aluminous gneiss showing biotite-K-rich feldspar-magnetite redox equilibria at P_EH_2O = 120 bars (left) and 600 bars (right) unlabelled boundaries. bg: biotite-garnet-Al_2SiO_5-Kf Fe/Mg equilibrium at P_EH_2O = 500 bars. pl-gt: Plagioclase-garnet equilibria. gr: muscovite granite solidus at 0.6 wgt. percent H_2O (P_EH_2O=~200 bars) from Huang and Wyllie (1973). Al_2SiO_5 phase boundaries after Holdaway (1971). Intersection of boundaries gr and pl-gt are interpreted as representing upper P_s-T limits for granulite facies metamorphism and anatexis of Ledge Mountain gneiss. Cf. text and road log (stop 2) for additional explanation.

metamorphism. Fe/Mg ratios for garnet, and biotite external to garnet porphyroblasts, when applied to Schmid and Wood's (1976) equation 11, give results shown by curve b-g (Fig. 15) for which P_{EH_2O} = 500 bars. The lack of agreement between curves b-g and P_{EH_2O} = 600 bars for equation (8) (they should be closer) probably is largely due to the lack of direct thermochemical data for the Mg end-member reaction: phlogopite + Sillimanite + quartz $\rightleftharpoons$ pyrope + Kfeldspar + H_2O.

Limiting values for total pressure were sought via the anhydrous mineral reaction relation involving plagioclase and garnet:

$$3 \text{ anorthite} \rightleftharpoons \text{Grossular} + 2\, Al_2SiO_5 + \text{Quartz}. \qquad (9)$$

Based on the estimation of mixing parameters for pairs of garnet end-members (Henson, Schmid, and Wood, 1975; Ganguly and Kennedy, 1974), grossular activity coefficients, (γ_{Gr}^{Gt}), across the above temperature range were taken between 1.23 and 1.37. Values of γ for anorthite in plagioclase were taken from Orville (1972). These and data for X_{An}^{Pl} and X_{Gr}^{Gt} were applied to the van't Hoff equation

$$-10{,}300 + 31.83T - 1.2746(P-1) = -RT\,ln \left[\frac{(X_{Gr}^{Gt}\gamma)^3(0.99)^2}{(X_{An}^{Pl}\ \gamma)^3}\right] \qquad (10)$$

to obtain the reaction boundaries collectively labelled Pl-Gt summarized in Figure 15. It can be seen that within the temperature range of interest shown in Figure 15 that the plagioclase-garnet equilibria lie within the sillimanite field of stability. (One which does not is discussed in the trip log under Stop 2.) These intersect the biotite oxidation equilibrium boundaries at approximately 7.3 and 9 kb. Owing to the set of assumptions which lead to the calculation of the biotite equilibrium boundary P_{EH_2O} = 600 bars, the temperatures along this curve are thought to be too high, and therefore the value of P_s = 9 kb, also too high. Some confirmation of this view is that, with reference to the curve for the beginning of melting of aluminous granite (Huang and Wyllie, 1973), labelled gr on Figure 15, it is unlikely that temperatures much above 750°C were maintained during the metamorphism because much of the feldspathic portions of the Ledge Mountain gneiss is of granitic composition, and therefore ought to have been removed largely as anatectic granitic magma. This aspect of the problem presently is under field and analytical investigation by Ellen Metzger of Syracuse. For these reasons, the upper limit of load pressure is taken at approximately 8.2 kb (Table 1). Paths of P-T change are discussed under the heading of Stop 2.

Plagioclase-Scapolite Phase Relations

Phase relations in the systems plagioclase-calcite-halite-scapolite, high albite-halite-marialite, anorthite-calcite-meionite, and anorthite-anhydrite-sulfate meionite have been studied experimentally (Orville, 1975; Newton and Goldsmith, 1975, 1976; Goldsmith, 1976; Goldsmith and Newton,

Table 1. Summary of inferred and calculated P-T conditions of metamorphism for Adirondack highlands.

	T	P_{load}	Source
Charnockitic and granitic gneiss	>770°C<800°C	>7.8<8.3 kb	de Waard (1969)
	>700°C<750°C	~8.0 kb	Bohlen and Essene (1977)
Metagabbro	~800°C	~8.0 kb	Whitney and McLelland (1973)
Kyanite and sillimanite-bearing granulite	695°-770°C	>7.4<8.2 kb	Boone (1978)
Marble	650°-756°C		Geraghty (1978)

1977). Newton and Goldsmith (1976), in all instances, and Orville (1975), in most instances, observed that scapolite is stable in preference to plagioclase, calcite, and halite at high temperatures and pressures. This is in marked contrast to earlier discussions that gave the impression that scapolite is a metamorphic mineral resulting from retrogressive processes (see, e.g., Fyfe and Turner, 1958).

The assemblages plagioclase-calcite-scapolite and plagioclase-scapolite are observed in several thin sections of calc-silicate rock and marble from the mapped area (see Fig. 16). Compositions have been determined by microprobe. In addition, plagioclase compostions were determined optically, using the zone method of Rittman. The compositions of coexisting scapolite and plagioclase are presented graphically in Figure 17.

On the basis of analyzed compositions, it is believed the idealized reaction

$$\text{Albite} + \text{anorthite} + \text{calcite} + \text{halite} \rightleftharpoons \text{scapolite} \qquad (11)$$

took place in samples 116, 130, 215, and 289.

Direct textural evidence that reaction (11) took place is expressed in a thin section of sample 116 by the spatial association of reactants (except for halite) and product of (11). It is inferred that halite was present originally in small amount based on relatively low content of Cl in scapolite of sample 116. Textural evidence for reaction (11) is not as pronounced in other thin sections. Usually, reactants (except for halite) and product coexist in close spatial association without the development of reaction rims or corona structure. Calcite is absent in many samples, indicating that it could have been consumed in reaction (11).

Microprobe analyses were not made for all mineral phases in thin sections containing assemblages plagioclase-calcite-scapolite or plagioclase-scapolite. Thus, it is not possible to analyze in detail whether chemical equilibrium was attained in these rocks. However, it is possible to

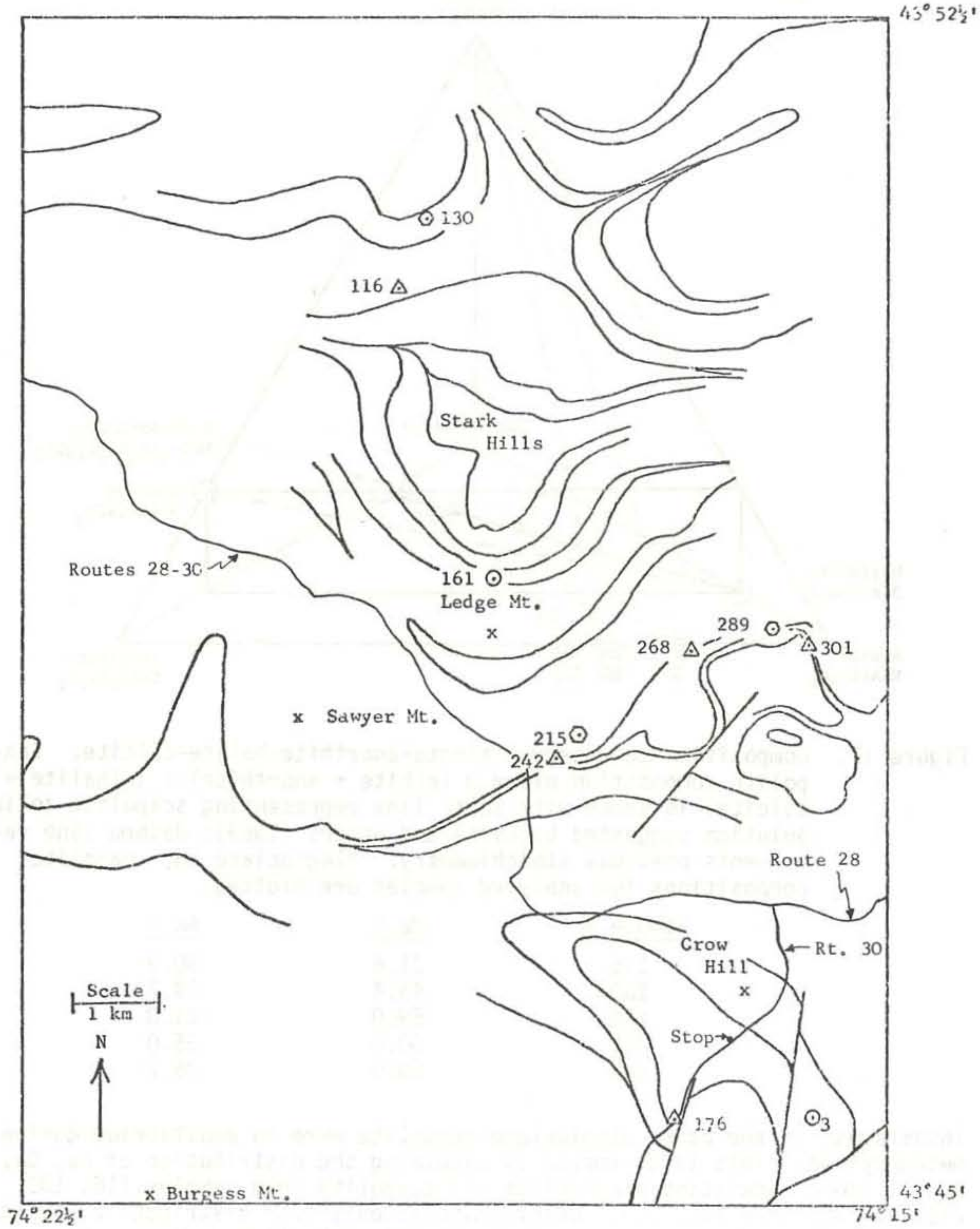

Figure 16. Location of samples used in discussion of plagioclase-scapolite phase relations (Δ - assemblage sc-ph-ca, ⬡ - assemblage (sc-pf) and in calcite-dolomite geothermometry ⊙). Map is SE ¼ of Blue Mountain 15' quadrangle; contacts between major rock units are shown for reference.

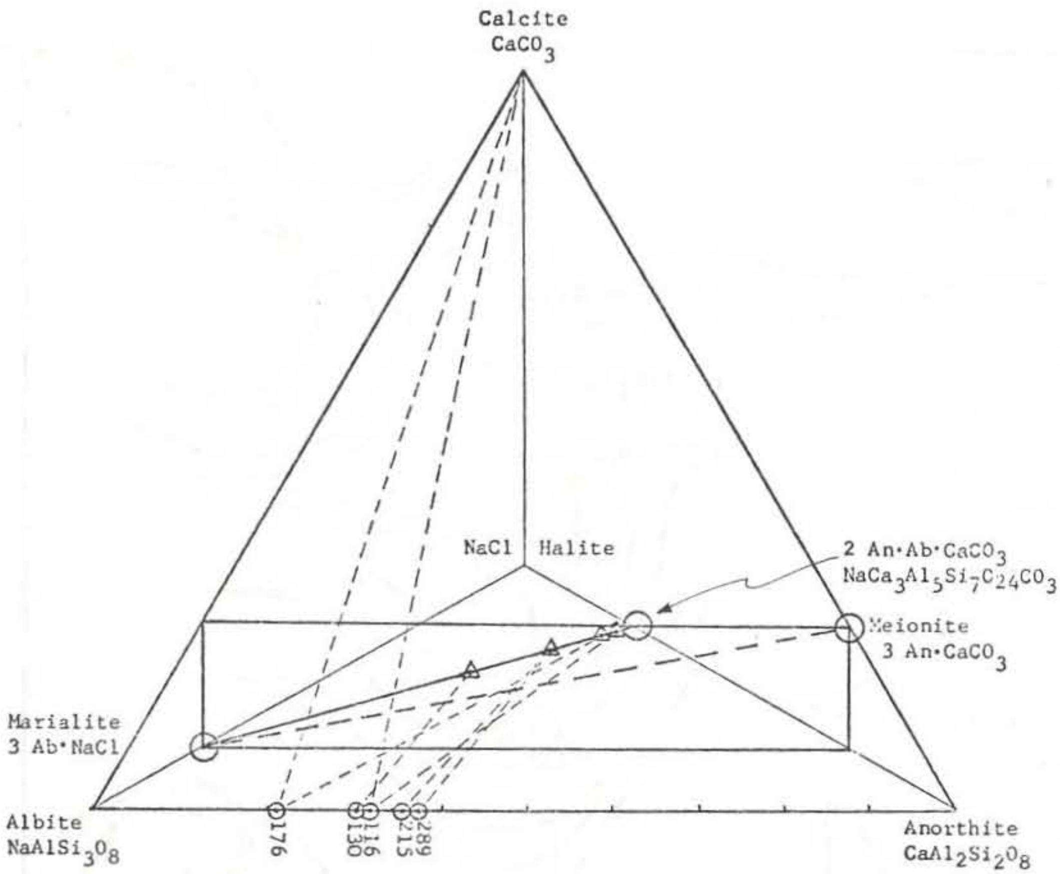

Figure 17. Composition tetrahedron albite-anorthite-halite-calcite. Scapolite composition plane 3 (albite + anorthite) : 1 (halite + calcite) is shown with solid line representing scapolite solid solution suggested by Evans and others (1969); dashed line represents previous stoichiometry. Plagioclase and scapolite compositions for analyzed samples are plotted.

Sample #	Me %	An %
116	71.6	30.9
130	45.4	29.7
176	69.0	21.0
215	60.0	35.0
189	60.0	36.7

investigate if the pairs plagioclase-scapolite were in equilibrium during metamorphism. This is attempted by examining the distribution of Na, Ca, and Al among coexisting plagioclase and scapolite from samples 116, 130, 215, and 289 (see Fig. 18). Unfortunately, only four distribution points are plotted and the clustering of points does not allow a distribution curve to be drawn. Equilibrium is suggested if the distribution curve is a straight line or smooth curve as defined by the distribution points. However, excluding data from sample 116 and using data from 130, 215, and 289, a straight line passing through or near these three samples and through the origin could be constructed for all three distribution diagrams.

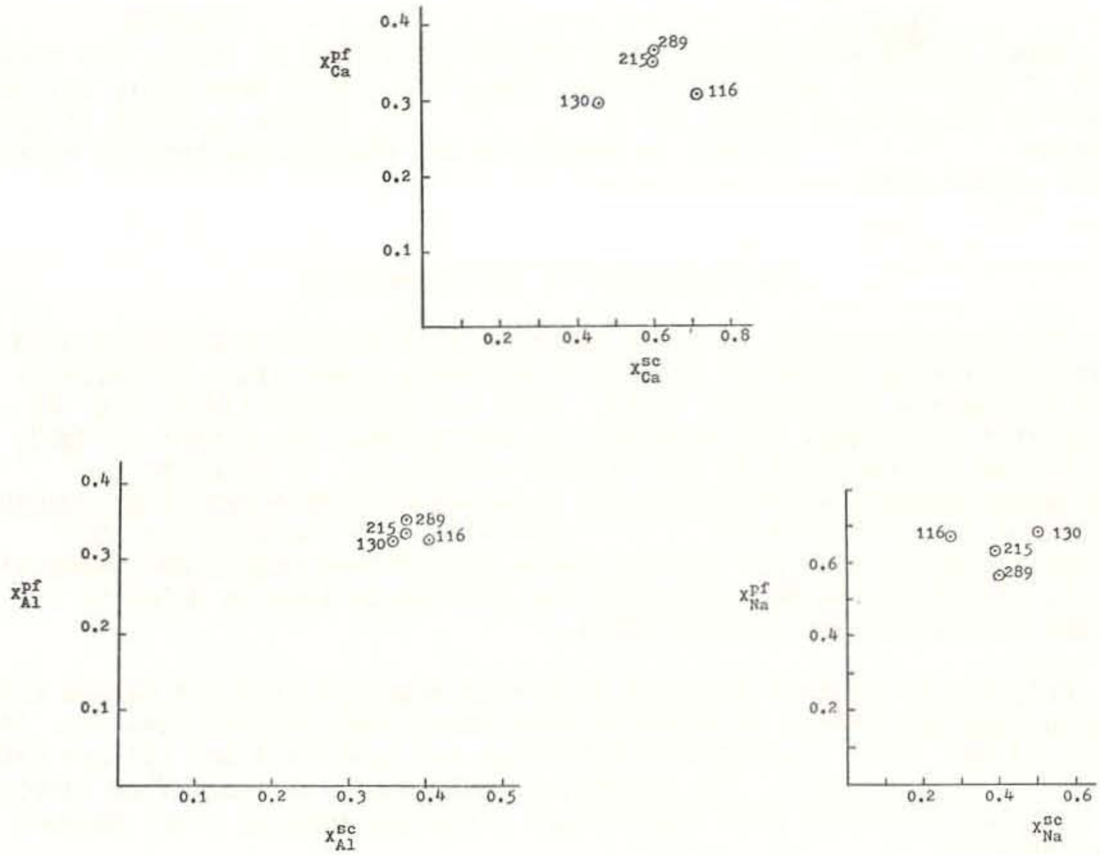

Figure 18. Distribution of calcium, sodium, and aluminum between plagioclase and scapolite.

This meager evidence argues for equilibrium between plagioclase and scapolite in these samples. The data points for sample 116, a marble, lie off the hypothetical distribution curves for data from samples 130, 215, and 289, calc-silicate rocks. The difference between sample 116 and samples 130, 215, and 289 also is expressed in Figure 17. Crossing tie lines are exhibited between two groups of samples: (1) samples 130, 215, and 289 form one group that exhibit nearly parallel tie lines between coexisting scapolite and plagioclase, (2) samples 116 and 176 exhibit tie lines between coexisting scapolite and plagioclase that cross tie lines of group (1). Group (2) samples contain calcite (see Fig. 17) and the scapolites exhibit relatively low contents of chlorine. One possible explanation for these relations between samples 116 and 176 and samples 130, 215, and 289 is that reaction (11) proceeded to the left upon falling temperature following the thermal peak of metamorphism in samples 116 and 176.

No estimate of metamorphic temperature and pressure can be made from coexisting scapolite and plagioclase, with or without calcite, of the mapped area. Newton and Goldsmith (1976) have determined experimentally the stability relations of anorthite, calcite, and meionite. However, their data can be used confidently to estimate metamorphic temperature only where the plagioclase composition is $>An_{70}$ (Goldsmith and Newton, 1977).

Based on the experimental work of Orville (1975, p. 1104), the presence of relatively sodic plagioclase (An_{21}-An_{37}) with relatively calcic scapolite (Me_{45}-Me_{72}) argues for a higher activity of $CaCO_3$ compared to NaCl in scapolite and plagioclase-bearing rocks of the mapped area.

Calcite-Dolomite Geothermometry

The amount of $MgCO_3$ in solid solution with calcite coexisting with a separate dolomite phase can be used to estimate temperature of metamorphism (Goldsmith and Newton, 1969). Graf and Goldsmith (1955, fig. 4) showed that the higher the temperature, the greater the amount of $MgCO_3$ that can be accommodated in the calcite structure. In order to use this geothermometry effectively, CO_2 pressure must have been high enough to prevent decomposition of dolomite. If noncarbonate, Mg-containing phases also are present under equilibrium conditions, they will have no effect on the Mg content of the calcite as long as dolomite is present (Goldsmith and others, 1955).

Only two of 22 thin sections of marble examined from the mapped area contain discrete grains of dolomite coexisting with calcite (see Fig. 16, samples 3 and 161). Temperature estimates for samples 3 and 161 are 650°C and 756°C, respectively. The estimated temperature recorded from sample 161 compares favorably with temperature estimates made by other methods (see Table 1).

CONCLUDING SPECULATIONS

The ultimate origin of the structural and petrologic features of the Adirondacks remains obscure. A possible clue to the mechanisms involved is Katz's (1955) determination of 36 km as the present depth to the M-discontinuity beneath the Adirondacks. Because geothermometry-geobarometry place the peak of the Grenville metamorphism at 8-9 kb (24-36 km), a double continental thickness is suggested. Such thicknesses presently exist in two types of sites, both plate-tectonic related. The first is beneath the Andes and seems related to magmatic underplating of the South American plate (James, 1971). The second is beneath the Himalayas and Tibet and is due to thickening in response to collision (Dewey and Burke, 1973) or continental underthrusting (Powell and Conaghan, 1973).

Because of the wide extent of the Grenville metamorphic belt, we prefer the Dewey-Burke model of crustal thickening in response to a continent-continent collision accompanied by reactivation of basement rocks. Mobilization of the lower crust could lead to the upward displacement of large, recumbent folds in a manner similar to some of Ramberg's (1967) scaled centrifuge experiments. This model is shown diagramatically in Figure 19.

Although it seems that the tectonic style and framework of the Adirondacks are explained satisfactorily by the Tibetan model, there are no good candidates for even a cryptic Indus-type suture in the area or within the Grenville Province itself. Dewey and Burke (1973) suggest that the collisional suture is most likely buried beneath the folded Appalachians. The

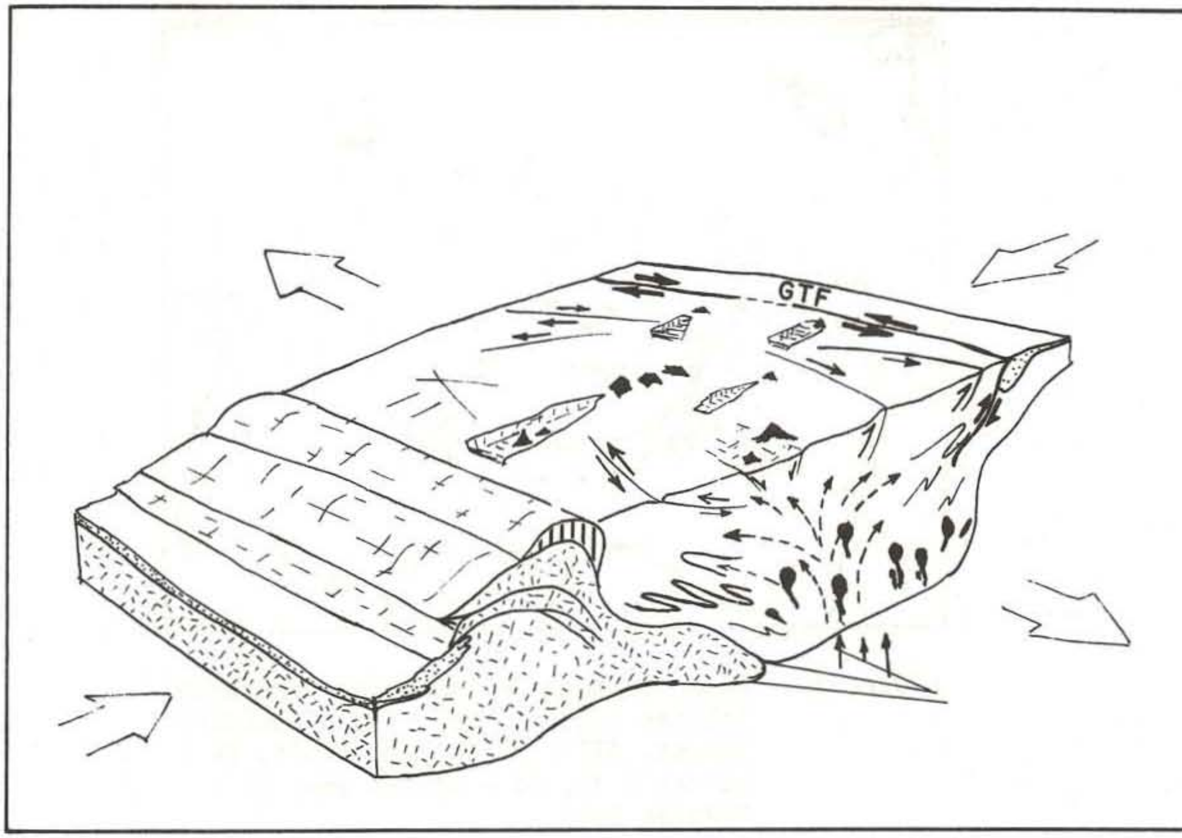

Figure 19. Himalayan type collision and associated tectonic elements. GTF - Grenville Type Front.

Grenville Front itself cannot be a suture, and, as shown by Baer (1977), it has a large component of right lateral motion associated with it. We suggest that the Grenville Front is analogous to features such as the Altyn Tagh Fault in northern Tibet (Molnar and Tapponier, 1975), and, similar to the Altyn Tagh, accommodates the sideways displacement of large crustal blocks by strike-slip motions (Figs. 19, 20). In places the Altyn Tagh Fault lies some 1000 km distant from the Indus Suture. A similar distance measured southeast from the Grenville Front would place the corresponding suture beneath the Appalachians. Perhaps it is this buried suture that gives rise to the New York Alabama aeromagnetic lineament of Zietz and King (1977).

ACKNOWLEDGMENTS

We wish to acknowledge the editorial assistance of Daniel F. Merriam and we are grateful to Janice Potak for typing the final copy.

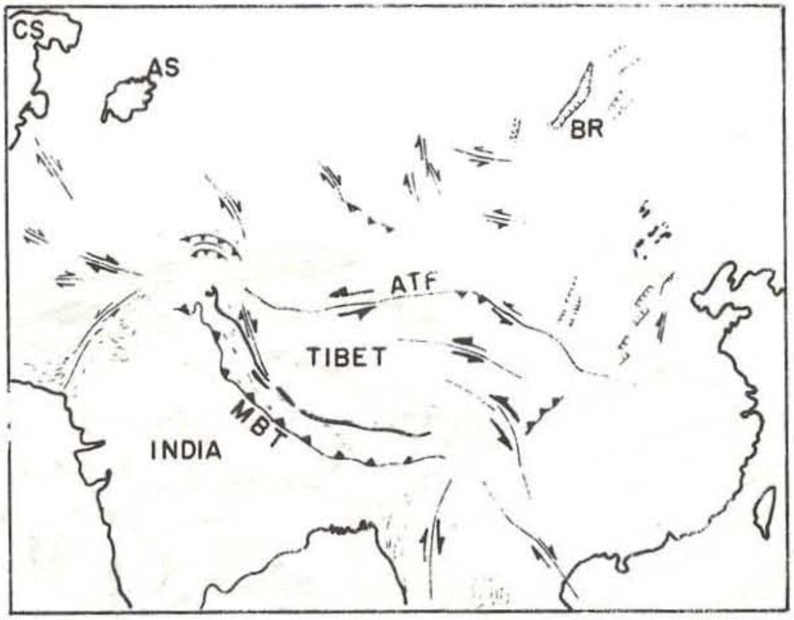

Figure 20. Major tectonic elements of Himalayan - Tibetan region. MBT - Main Boundary Thrust, ATF - Altyn Tagh Fault, BR - Baikal Rift, AS - Astral Sea, CS - Caspian Sea.

REFERENCES

Baer, A.J., 1977, The Grenville Province as a shear zone: Nature, v. 267, no. 5609, p. 337-338.

Bartholomé, P., 1956, Structural geology and petrologic studies in Hamilton Co., New York: unpubl. doctoral dissertation, Princeton Univ., 113 p.

Bohlen, S.R., and Essene, E.J., 1977, Feldspar and oxide thermometry of granulites in the Adirondack Highlands: Contr. Min. Petrol., v. 62, no. 2, p. 153-169.

Boone, G.M., 1978, Kyanite in Adirondack highlands sillimanite-rich gneiss, and P-T estimates of metamorphism: Geol. Soc. America Abstracts with Programs, v. 10, no. 2, p. 34.

Buddington, A.F., 1939, Adirondack igneous rocks and their metamorphism: Geol. Soc. America Memoir 7, 354 p.

Buddington, A.F., 1963, Isograds and the role of H_2O in metamorphic facies of orthogneisses of the northwest Adirondack area, New York: Geol. Soc. America Bull., v. 74, no. 9, p. 1155-1182.

Buddington, A.F., 1965, The origin of three garnet isograds in Adirondack gneisses: Min. Mag., v. 34, (Tilley Volume), p. 71-81.

Buddington, A.F., 1966, The occurrence of garnet in the granulite-facies terrain of the Adirondack highlands, a discussion: Jour. Petrology, v. 7, no. 2, p. 331-335.

Buddington, A.F., 1972, Differentiation trends and parental magmas for anorthositic and quartz mangerite series, Adirondacks, New York: Geol. Soc. America Mem. 132, p. 477-487.

Cannon, R.S., 1937, Geology of the Piseco Lake quadrangle: New York State Mus. Bull. 312, 107 p.

Cushing, H.P., and Ruedemann, R., 1914, Geology of Saratoga Springs and vicinity: New York State Mus. Bull. 169, 177 p.

Czamanske, G.K., and Wones, D.R., 1973, Oxidation during magmatic differentiation, Finnmarka complex, Oslo area, Norway: Part 2, The mafic silicates: Jour. Petrology, v. 14, no. 3, p. 349-380.

de Waard, D., 1962, Structural analysis of a Precambrian fold - The Little Moose Mountain syncline in the southwestern Adirondacks: Kon. Ned. Akad. Wetensch., Amsterdam, Ser. B, v. 65, no. 5, p. 404-417.

de Waard, D., 1964a, Mineral assemblages and metamorphic subfacies in the granulite facies terrain of the Little Moose Mountain syncline, south-central Adirondack highlands: Proc. Kon. Ned. Akad, Wetensch., Amsterdam, Ser. B, v. 67, no. 4, p. 344-362.

de Waard, D., 1964b, Notes on the geology of the south central Adirondack highlands: New York State Geol. Assoc., 36th Ann. Meeting, Guidebook, p. 3-24.

de Waard, D., 1965a, The occurrence of garnet in the granulite-facies terrain of the Adirondack highlands: Jour. Petrology, v. 6, no. 1, p. 165-191.

de Waard, D., 1965b, A proposed subdivision of the granulite facies: Am. Jour. Sci., v. 263, no. 5, p. 455-461.

de Waard, D., 1967, The occurrence of garnet in the granulite-facies terrain of the Adirondack highlands and elsewhere, an amplification and reply: Jour. Petrology, v. 8, no. 2, p. 210-232.

de Waard, D., 1969, Facies series and P-T conditions of metamorphism in the Adirondack Mountains: Proc. Kon. Ned. Akad. Wetensch., Amsterdam, Ser. B, v. 72, no. 2, p. 124-131.

de Waard, D., 1971, Threefold division of the granulite facies in the Adirondack Mountains: Kristallinikum, v. 7, p. 85-93.

de Waard, D., and Romey, W.D., 1969, Petrogenetic relationships in the anorthosite-charnockite series of the Snowy Mountain Dome, south central Adirondacks, In Isachsen, Y.W., ed., Origin of anorthosites and related rocks: New York State Sci. Service Memoir 18, p. 307-315.

Dewey, J.F., and Burke, K.C.A., 1973, Tibetan, Variscan, and preCambrian basement reactivation: products of a continental collision: Jour. Geology, v. 81, no. 6, p. 683-692.

Emslie, R.F., 1971, Liquidus relations and subsolidus reactions in plagioclase bearing systems: Ann. Rept. Director Geophys. Lab., Carnegie Inst. Washington, 1969-70, p. 148-155.

Engel, A.E.J., and Engel, C.G., 1962, Progressive metamorphism of amphibolite, northwest Adirondacks, in Engel, A.E.J., James, , H.L., and Leonard, B.F., eds., Petrologic studies, a volume in honor of A.F. Buddington: Geol. Soc. America, p. 37-82.

Essene, E.J., Bohlen, S.R., Valley, J.W., 1977, Regional metamorphism of the Adirondacks (abst.): Geol. Soc. America Abstracts with Program, v. 9, no. 3, p. 260.

Evans, B.W., Shaw, D.W., and Haughton, D.R., 1969, Scapolite stoichiometry: Contr. Min. Petrol., v. 24, p. 293-305.

Farrar, S.S., 1976, Petrology and structure of the Glen 7 ½' quadrangle, southeast Adirondacks, New York: unpubl. doctoral dissertation, SUNY Binghamton, 241 p.

Foose, M., and Carl, J., 1977, Setting of alaskite bodies in the northwestern Adirondacks, New York: Geology, v. 5, no. 2, p. 77-80.

Fyfe, W.S., and Turner, F.J., 1958, Correlation of metamorphic facies with experimental data, in Fyfe, W.S., Turner, F.J., and Verhoogen, J., eds., Metamorphic reactions and metamorphic facies: Geol. Soc. America Mem. 73, p. 149-185.

Ganguly, J., and Kennedy, G.C., 1974, Energetics of natural garnet solid solution 1. Mixing of the aluminosilicate end-members: Contr. Min. Petrol., v. 48, no. 2, p. 137-148.

Geraghty, E.P., 1973, Stratigraphy, structure, and petrology of part of the North Creek 15' quadrangle, southeastern Adirondack Mountains, New York: unpubl. masters thesis, Syracuse Univ., 72 p.

Geraghty, E.P., 1978, Structure, stratigraphy and petrology of part of the Blue Mountain 15' quadrangle, central Adirondack Mountains, New York: unpubl. doctoral dissertation, Syracuse Univ., 281 p.

Gilbert, M.C., Bell, P.M., and Richardson, S.W., 1968, Andalusite-sillimanite equilibrium and the kyanite-andalusite-sillimanite triple point: Geol. Soc. America, Program with Abstracts, 1968 Ann. Meeting (Mexico City), p. 112-113.

Goldsmith, J.R., 1976, Scapolites, granulites and volatiles in the lower crust: Geol. Soc. America Bull., v. 87, no. 2, p. 161-168.

Goldsmith, J.R., and Graf, D.L., and Joensuu, O.I., 1955, The occurrence of magnesian calcites in nature: Geochim. et Cosmochim. Acta, v. 7, nos. 5/6, p. 212-230.

Goldsmith, J.R., and Newton, R.C., 1969, P-T-X relations in the system $CaCO_3$-$MgCO_3$ at high temperatures and pressures: Am. Jour. Sci., v. 267-A (Schairer Volume), p. 160-190.

Goldsmith, J.R., and Newton, R.C., 1977, Scapolite-plagioclase stability relations at high pressures and temperatures in the system $NaAlSi_3O_8$-$CaAl_2Si_2O_8$-$CaCO_3$-$CaSO_4$: Am. Mineralogists, v. 62, nos. 11-12, p. 1063-1081.

Graf, D.L., and Goldsmith, J.R., 1955, Dolomite-magnesian calcite relations at elevated temperatures and CO_2 pressures: Geochim. et Cosmochim. Acta, v. 7, nos. 3/4, p. 109-128.

Green, D.H., and Ringwood, A.E., 1967, An experimental investigation of the gabbro to eclogite transformation and its petrologic applications: Geochim. et Cosmochim. Acta, v. 3, no. 5, p. 767-834.

Greenwood, H.J., 1961, The system $NaAlSi_2O_6$-H_2O-Argon: total pressure and water pressure in metamorphism: Jour. Geophys. Res., v. 66, no. 11, p. 3923-3946.

Henson, B.J., Schmid, R., and Wood, B.J., 1975, Activity-composition relationships for pyrope-grossular garnet: Contr. Min. Petrol., v. 51, no. 3, p. 161-166.

Hills, A., and Isachsen, Y., 1975, Rb/Sr isochron date for mangeritic rocks from the Snowy Mt. massif, Adirondack Highlands and implications from initial Sr87/Sr86 (abst.): Geol. Soc. America Abstracts with Program, v. 7, no. 1, p. 73-74.

Hirschberg, A., and Winkler, H.G.F., 1968, Stabilitatsbeziehungen zwischen chlorit, cordierit und almandin bei der metamorphose: Contr. Min. Petrol., v. 18, p. 17-42.

Holdaway, M.J., 1968, Stability of analusite (abst.): Geol. Soc. America Program with Abstracts, 1968 Ann. Meeting (Mexico City), p. 140.

Holdaway, M.J., 1971, Stability of andalusite and the aluminum silicate phase diagram: Am. Jour. Sci., v. 271, no. 2, p. 97-131.

Huang, W.L., and Wyllie, P.J., 1973, Melting relations of muscovite granite to 35 kbar as a model for fusion of metamorphosed subducted oceanic sediments: Contr. Min. Petrol., v. 42, no. 1, p. 1-14.

Husch, J., Kleinspehn, K., and McLelland, J., 1975, Anorthositic rocks in the Adirondacks: basement or non-basement? (abst.): Geol. Soc. American Abstracts with Program, v. 7, no. 1, p. 78.

Isachsen, Y., McLelland, J., and Whitney, P., 1975, Anorthosite contact relationships in the Adirondacks and their implications for geologic history (abst.): Geol. Soc. America Abstracts with Program, v. 7, no. 1, p. 78-79.

Jaffe, H.W., Jaffe, E.B., and Ashwal, L.D., 1977, Structural and petrologic relations in the High Peaks region, northeastern Adirondacks (abst.): Geol. Soc. America, Abstracts with Programs, v. 9, no. 3, p. 279-280.

James, D.E., 1971, Andean crustal and upper mantle structure: Jour. Geophys. Res., v. 76, no. 14, p. 3246-3271.

Katz, S., 1955, Seismic study of crystal structure in Pennsylvania and New York: Bull. Seism. Soc. America, v. 45, p. 303-325.

Kushiro, I., and Yoder, H.S., Jr., 1966, Anorthite-fosterite and anorthite-enstatite reactions and their bearing on the basalt-eclogite transformation: Jour. Petrology, v. 3, no. 3, p. 337-362.

Krieger, M.H., 1937, Geology of the Thirteenth Lake Quadrangle, New York: New York State Mus. Bull. 308, 124 p.

Lettney, C.D., 1969, The anorthosite-charnockite series of the Thirteenth Lake dome, south-central Adirondacks, in Isachsen, Y.W., ed., Origin of anorthosite and related rocks: New York State Mus. and Sci. Service Mem. 18, p. 329-342.

Martignole, J., and Schrijver, K., 1970, Tectonic setting and evolution of the Morin anorthosite, Grenville Province, Quebec: Bull. Geol. Soc. Finland, v. 42, p. 165-209.

Martignole, J., and Schrijver, K., 1971, Association of (hornblende) - garnet-clinopyroxene "subfacies" of metamorphism and anorthosite masses: Can. Jour. Earth Sci., v. 8, no. 6, p. 698-704.

Mattauer, M., 1975, Sur le mechanisme de formation de la schistosité dans l'Himalaya: Earth Plan. Sci. Lett., v. 28, no. 2, p. 144-154.

Miller, W.J., 1911, Geology of the Broadalbin quadrangle: New York State Mus. Bull. 153, 65 p.

Miller, W.J., 1916, Geology of the Lake Pleasant quadrangle: New York State Mus. Bull. 182, 75 p.

Miller, W.J., 1920, Geology of the Gloversville quadrangle: New York State Mus. and Sci. Service, open-file maps.

Miller, W.J., 1923, Geology of the Luzerne quadrangle: New York State Mus. Bull. 245-246, 66 p.

McLelland, J., 1969, Geology of the southernmost Adirondacks: New England Intercol. Geol. Conf., Guidebook, v. 61, sec. 11, p. 1-34.

McLelland, J., 1972, Stratigraphy and structure of the Canada Lake Nappe: New York State Geol. Assoc., 44th Ann. Meeting, Guidebook, p. E1-E27.

McLelland, J., and Whitney, P., 1977, Origin of garnet coronas in the anorthosite-charnockite suite of the Adirondacks: Contr. Min. Petrol., v. 60, no. 2, p. 161-181.

Molnar, P., and Tapponier, P., 1975, Cenozoic tectonics of Asia: effects of a continental collision: Science, v. 189, no. 4201, p. 419-426.

Morse, S.A., ed., 1975, Nain anorthosite project Labrador: Field Report 1975: Contr. No. 26, Dept. Geology and Geography, Univ. Massachusetts, 93 p.

Nelson, A.E., 1968, Geology of the Ohio quadrangle: U.S. Geol. Survey Bull. 1251-F, p. F1-F46.

Newton, R.C., and Goldsmith, J.R., 1975, Stability of the scapolite meionite ($CaAl_2Si_2O_8$-$CaCO_3$) at high pressures and storage of CO_2 in the deep crust: Contr. Min. Petrol., v. 49, no. 1, p. 49-62.

Newton, R.C., and Goldsmith, J.R., 1976, Stability of the endmember scapolites: 3 $NaAlSi_3O_8 \cdot NaCl$, 3 $CaAl_2Si_2O_8 \cdot CaCO_3$, 3 $CaAl_2Si_2O_8 \cdot CaSO_4$: Zeitschr. Kristallographie, v. 143, p. 333-353.

Orville, P.M., 1963, Alkali ion exchange between vapor and feldspar phases: Am. Jour. Sci., v. 261, no. 3, p. 201-237.

Orville, P.M., 1972, Plagioclase cation exchange equilibria with aqueous chloride solution: results at 700°C and 2000 bars in the presence of quartz: Am. Jour. Sci., v. 272, no. 3, p. 234-272.

Orville, P.M., 1975, Stability of scapolite in the system Ab-An-NaCl-$CaCO_3$ at 4 kb and 750°C: Geochim et Cosmochim. Acta, v. 39, no. 8, p. 1091-1105.

Powell, C.McA., and Conaghan, P.J., 1973, Plate tectonics and the Himalayas: Earth Planet. Sci. Lett., v. 20, no. 1, p. 1-12.

Raheim, A., and Green, D.H., 1974, Experimental determination of the temperature and pressure dependence of the Fe-Mg partition coefficient for coexisting garnet and clinopyroxene: Contr. Min. Petrol., v. 48, no. 3, p. 179-203.

Ramberg, H., 1967, Gravity, deformation, and the Earth's crust as studied by centrifuged models: Academic Press, New York, 241 p.

Richardson, S.W., Bell, P.M., and Gilbert, M.C., 1968, Kyanite-sillimanite equilibrium between 700 and 1500°C: Am. Jour. Sci., v. 266, no. 7, p. 513-531.

Ringwood, A.E., and Green, D.H., 1966, An experimental investigation of the gabbro-eclogite transformation and some geophysical implications: Tectonophysics, v. 3, no. 5, p. 383-427.

Schmid, R., and Wood, B.J., 1976, Phase relationships in granulitic metapelites from the Ivrea - Verbano zone (Northern Italy): Contr. Min. Petrol., v. 54, no. 4, p. 255-279.

Silver, L., 1969, A geochronologic investigation of the Anorthosite Complex, Adirondack Mts., New York, in Isachsen, Y.W., ed., Origin of Anorthosites and related rocks: New York State Mus. and Sci. Service Mem. 18, p. 233-252.

Simmons, E.C., 1976, Origins of four anorthosite suites: unpubl. doctoral dissertation, SUNY Stony Brook, 190 p.

Stoddard, E.F., 1976, Granulite facies metamorphism in the Colton-Rainbow Falls area, northwest Adirondacks, New York: unpubl. doctoral dissertation, Univ. California, Los Angeles, 271 p.

Thompson, B., Jr., 1959, Geology of the Harrisburg 15' quadrangle, southern Adirondacks: New York State Mus. and Sci. Service, open-file maps.

Thompson, J.B., Jr., 1955, The thermodynamic basis for the mineral facies concept: Am. Jour. Sci., v. 253, no. 2, p. 65-103.

Turner, B.B., 1971, Structural-stratigraphic relationships among metasedimentary, meta-igneous, and other gneissic rocks, southeastern Adirondack Mountains, New York (abst.): Geol. Soc. America Abstract with Program, v. 3, no. 1, p. 58.

Turnock, A.C., and Eugster, H.P., 1962, Fe-Al oxides: Phase relationships below 1000°C: Jour. Petrology, v. 3, pt. 3, p. 533-565.

Valley, J.W., and Essene, E.J., 1976, Calc-silicate reactions in Grenville marble (abst.): Geol. Soc. America Abstracts with Program, v. 8, no. 6, p. 1151-1152.

Walton, M.S., 1961, Geologic maps of the eastern Adirondacks: New York State Mus. and Sci. Service, open-file maps.

Walton, M.S., and de Waard, D., 1963, Orogenic evolution of the Precambrian in the Adirondack Highlands: a new synthesis: Proc. Kon. Ned. Akad. Wetensch., Amsterdam, Ser. B, no. 66, p. 98-106.

Wiebe, R., 1975, Contact between adamellite and anorthosite and the occurrence of dioritic rocks near Zoar, Labrador, in Morse, S.A., ed., Anorthosite Project, Labrador: Field Reprt 1975: Contr. No. 26, Dept. Geology and Geography, Univ. Massachusetts, p. 27-33.

Wood, B.J., 1974, Solubility of alumina in orthopyroxene coexisting with garnet: Contr. Min. Petrol., v. 46, no. 1, p. 1-15.

Wood, B.J., and Banno, S., 1973, Garnet-orthopyroxene and orthopyroxene-clinopyroxene relationships in simple and complex systems: Contr. Min. Petrol., v. 42, no. 1, p. 109-124.

Yoder, H.S., and Eugster, H.P., 1954, Phlogopite synthesis and stability range: Geochim. et Cosmochim. Acta, v. 6, no. 4, p. 157-185.

Zietz, I., and King, E.R., 1977, The New York-Alabama Lineament: a possible plate boundary (abst). Geol. Soc. America Abstracts with Program, v. 9, no. 3, p. 333.

Road Log

Mileage

0 Intersection of Routes NY28N-30 and NY28-30 in Blue Mt. Lake. Head south on Rt. 28-30.

1.6 - ASSEMBLY POINT IN ROADSIDE PARKING AREA, E, END, NORTH SHORE OF LAKE DURANT. ASSEMBLY TIME 7:30 AM, SATURDAY, 23 SEPTEMBER.

Stop 1: Large roadcut on north shore of Lake Durant. This location is the type section of Lake Durant Formation (D. de Waard, 1970, pers. comm.).

This stop has been described by de Waard (1964b) as follows: "The section of diverse, layered metamorphic rocks includes pink and greenish leucocratic gneisses with thin metabasic layers, marble, and calc-silicate rocks. The section forms part of the supracrustal sequence which overlies the leptites of the Wakely nappe exposed in the hills visible towards the south across the lake, and which underlies the Blue Mountain charnockite sequence towards the north. Lineations on foliation planes indicate a 30° NE plunging fold axis. The intrusive nature of marble into boudinaged layered gneiss is shown on the west end of the north side of the road cut."

Outcrop mapping to the east and south has revealed that the Lake Durant Formation contains large amounts of hornblende granitic gneiss and biotite-hornblende granitic gneiss both above and below the well-layered sequence exposed in the type section at Lake Durant. In addition, a distinctive rock sequence of biotite granitic gneiss (bottom), calc-silicate rock, and platey-quartz gneiss (top) makes up the basal portion of the Lake Durant Formation in areas to the south.

8.0 Trail-side parking area (south) on Route NY28-30. (This is about 1.25 mi north of intersection of Rt. NY28-30 and the Cedar River Road.)

Stop 2: Ledge Mt. Hike 1 mi east through open woods, to well-exposed south-facing cliffs. This is on the southward culmination of the recumbent Ledge Mountain antiform. Quartz-sillimanite lenses increase in size and relative amount from west to east, until they assume the proportions of major layering in the gneiss. Kyanite occurs here in two feldspar-rich portions of the gneiss. We have sought more, without success. If you should discover additional kyanite, PLEASE OBSERVE PETROLOGIC ETIQUETTE OF PHASE PRESERVATION! NOTIFY TRIP LEADER, WHO WILL OFFER SUITABLE REWARD. Note different proportions of magnetite, garnet, and biotite in feldspathic portions of gneiss, as well as in pegmatite. The structural relationships of pegmatite to host gneiss also differ. Note in Figure 21A that biotite compositions within garnet porphyroblasts are Mg-richer and Al-poorer than "Free" matrix biotite. Also, of the four plagioclase - garnet equilibria shown in Figure 21B (representing five pairs), all represent 'probed rims of grain pairs each of which is in mutual contact. The highest-P boundary is that calculated for a relatively large plagioclase grain within a garnet porphyroblast; the others are of small plagioclases within garnet porphyroblasts, and of "free" plagioclases against garnet rims.

It is deduced from these relationships, and from ubiquitous but small-scale late corona structures of albite on magnetite, that the path of P-T

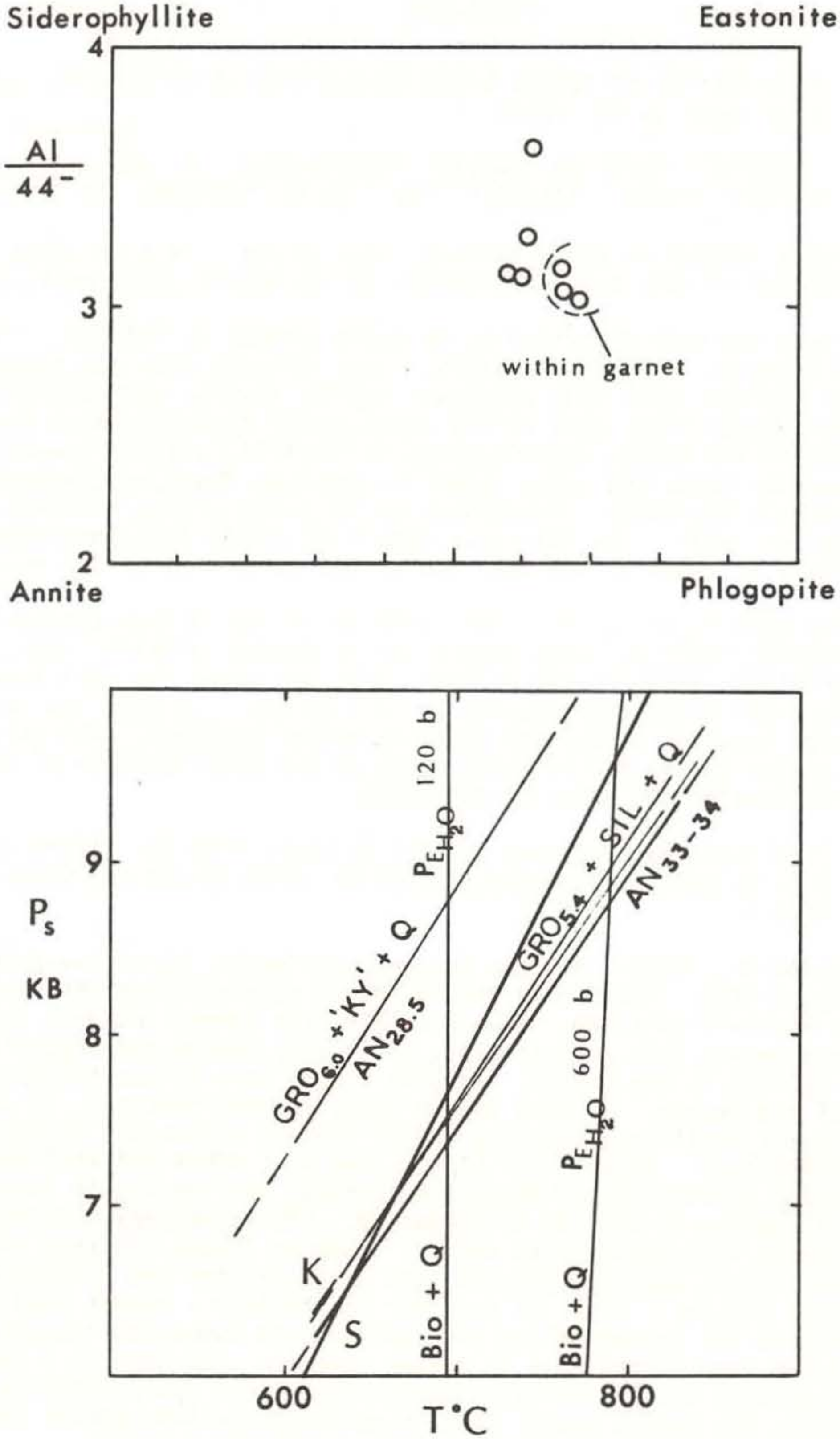

Figure 21. Biotite-garnet-plagioclase relationships. Ordinate in A is number of Al atoms per total of 44 anionic charges. Grossular 6.0% - $An_{28.5}$ (moles) in B refers to large plagioclase inclusion within garnet porphyroblast.

change was prograde along a geothermal gradient which penetrated the kyanite field, followed by partial melting and decrease of lithostatic pressure into the sillimanite field and retrograde cooling within that field, with residual kyanite being trapped within feldspar-rich (solidus?) portions of the gneiss.

11.3 Intersection of Routes NY 28 and 30 in hamlet of Indian Lake. Head south of Rt. NY30.

12.5 Stop 3: Scenic overlook on east side of Route NY30.

Mountainous area to the southeast is part of the Thirteenth Lake complex, cored by anorthosite and charnockite. Overlying gneisses dip to the north (left) and west (towards us) off the complex. To the south metasedimentary rocks dip to the northeast off of Snowy Mountain dome (not visible), which also is cored by anorthosite and charnockite.

Walk south on highway NY30 to roadcut on west side of road. This roadcut is composed of a distinctive "diopside-clot" gneiss and is situated close to the axial core of the Crow Hill synform. The rock is a zircon-apatite±plagioclase±calcite±garnet-sphene-scapolite-clinopyroxene-quartz-microcline granulite. It is part of the distinctive basal portion of the Lake Durant Formation.

Chemical compositions of scapolite and clinopyroxene from this unit at another location were determined by electron-probe microanalysis to be Me_{69}, $(Na_{1.17},Ca_{2.63})_{3.80}(Al_{4.67},Si_{7.33})_{12.00}O_{24}((CO_3)_{0.97},Cl_{0.03})_{1.00}$ and salite, $(Ca_{0.93},Na_{0.06})_{0.99}(Mg_{0.62},Fe_{0.39},Mn_{0.01},Al_{0.02})_{1.04}(Si_{1.96}Al_{0.04})_2O_6$, respectively. Plagioclase composition is oligoclase, An_{21}, based on petrographic determinations using the zone method of Rittman.

17.2 Stop 4: Described by de Waard (1964) as follows: "Large roadcut on the hill 0.4 miles southwest of the intersection of highway 30 with the lake shore road through Sabael. Anorthosite at the lower end of the outcrop is overlain by metanorite (unfoliated andesine-pyroxene-hornblende gneiss) which is in turn overlain by streak andesine-pyroxene-hornblende augen gneiss. Both "Marcy-" and "Whiteface-" type anorthosites are present. The grain size of metanorites ranges from coarse to fine, and the original texture of the rock is preserved to various degrees in different parts of the exposure. Several small amphibolite (metadolerite) lenses may be observed in the streak gneiss. Foliation is nearly horizontal. Walk up the steep hillside above the road to see massive ledges of anorthosite, metanorite, and a rock which is texturally and compositionally intermediate between these two types."

The origin of, and relationships within, the anorthosite-charnockite suite of rocks has been debated for decades. Those favoring a comagmatic association have tended to postulate a dioritic parent magma which yields plagioclase (anorthositic) cumulates and charnockitic residua (de Waard and Romey, 1969). Those who do not accept a comagmatic relationship between these rocks, have generally postulated a parent of gabbroic anorthosite composition (Buddington, 1972). A variant of the gabbroic anorthosite parent is the high-alumina basalt of Morse (1975).

The snowy Mt. Dome is the type area of de Waard and Romey's (1969) comagmatic differentiation process. By detailed mapping beginning at the core of the dome, they showed that there exists an outward gradation from central anorthosite through metanorite, to noritic augen gneiss, to charnockitic gneisses (see Fig. 22). This they interpreted as reflecting a differentiation sequence and variation diagrams were constructed to portray these trends.

A critical aspect of the compositional variation within this suite is that grains (xenocrysts) of andesine occurs within the charnockitic rocks. These xenocrysts increase in abundance as the anorthositic core rocks are approached. Concomitantly the amount of K-feldspar and quartz decrease. Although these changes do result in a gradation of rock types, the transition seems to be mechanical rather than chemical. This is suggested by the constancy of xenocryst composition and the widespread presence of cross-cutting relationship between end-member rock types.

Based upon field and chemical data Buddington (1939, 1972), suggested that the charnockitic rocks are distinctly later than, and unrelated to, the anorthositic rocks. He presented variation diagrams of major oxides demonstrating that the anorthositic and charnockitic rocks follow separate differentiation trends and that discontinuities exist between their paths. Simmons (1976) and Goldberg (1977) have studied trace element and REE patterns in Adirondack anorthosite-charnockite lithologies and concur with Buddington that the two are unrelated. They also show that a gabbroic anorthosite parent is consistent with their trace-element studies. Simmons suggests that such a parent can be produced from dry melting at high load pressure of a gabbroic source rock. Figure 23 shows Emslie's (1971) results for such a system at P_L = 15 Kb and at 1 atm. The minimum melt generated at 45-50 km is essentially a gabbroic anorthosite. As it rises the field boundaries move so as to enlarge the domain of plagioclase crystallization. In this manner anorthosites may result from reasonable petrogenetic processes.

The origin of the charnockitic rocks in the suite remains largely unresolved. Buddington (1972) suggests that they represent an independent magma series in which contamination of granitic magma by garnetiferous amphibolite has been important. Husch, Kleinspehn, and McLelland (1975), as well as Isachsen, McLelland, and Whitney (1975), have suggested that the charnockite-mangerite envelope results from fusion of quartzo-feldspathic country rocks of the intruding anorthositic magma (crystal mush ?). Early in the process the anorthositic rocks attain complete crystallization and are subsequently intruded by the lower melting temperature quartzo-feldspathic lithologies. Wiebe (1975) has suggested a similar mechanism for adamellites near Zoar (Nain), Labrador. All fusion models of this sort depend critically on the initial temperature of the charnockitic rocks and the heat budget within the system. Although the lack of data on heat capacities, heats of fusion, etc., preclude detailed calculations, it does seem possible that at 8-10 Kb anorthositic intrusives with temperatures of 1200-1300°C can melt substantial quantities of quartzo-feldspathic gneisses initially at 800°C. Whether or not this mechanism actually operates is a question deserving of extensive research. It is certainly consistent with field evidence suggesting that stratigraphically continuous units undergo increasing anatexis as anorthositic rocks are approached. Some examples of this anatexis will be seen at Stop 7.

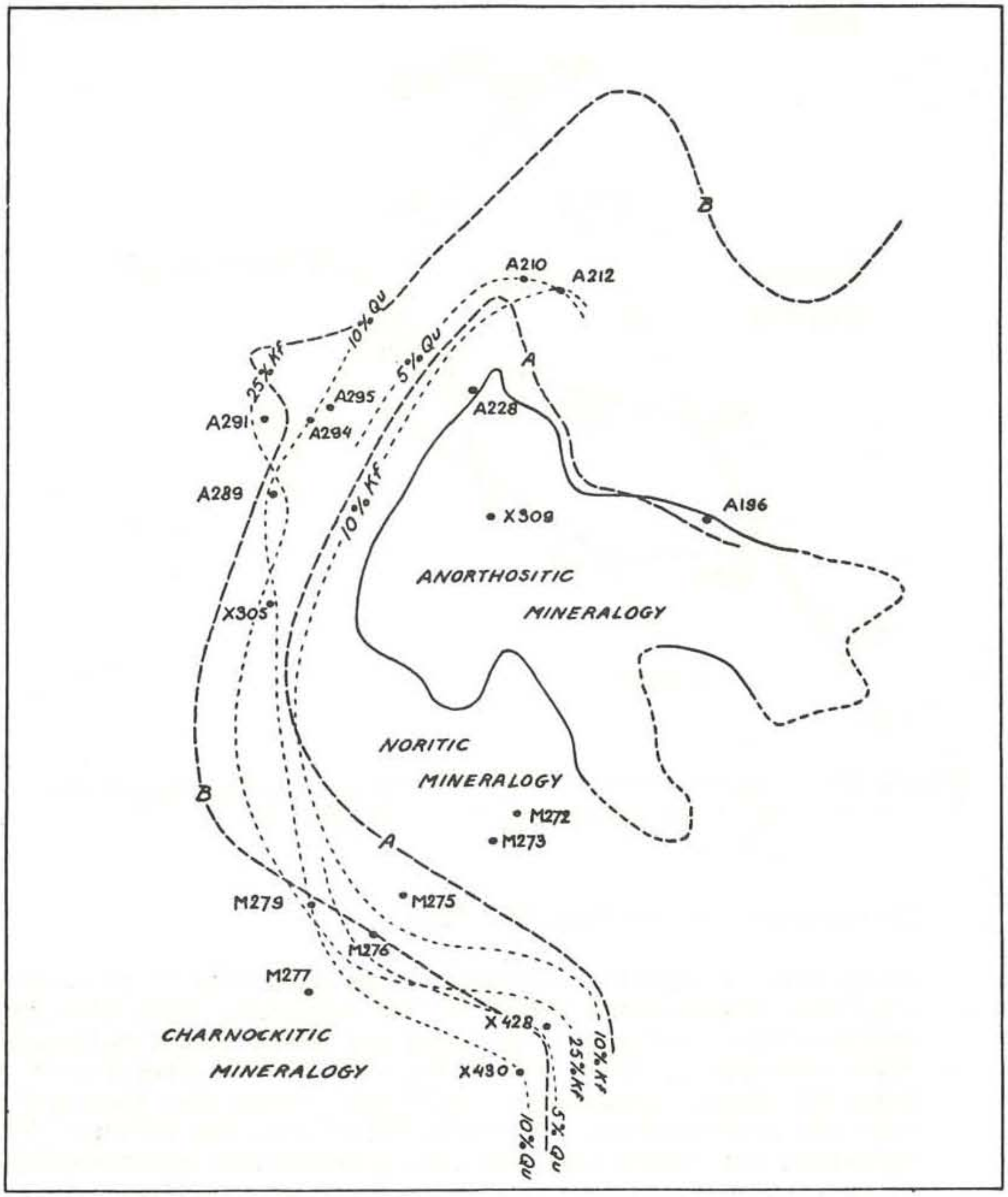

Figure 22. Textural and compositional boundaries and gradations in central part of Snowy Mountain dome. Arbitrary textural lines from center outward: (A) indicates the approximate location of transition from deformed blastonoritic texture to augen-gneiss texture; (B) indicates approximate zone in which number of andesine augen decreases to less than one per square meter. Compositional boundaries and isopleths: solid line indicates boundary zone between anorthosite and metanorite; dashed lines are isopleths of 10 and 25 percent modal K feldspar, and 5 and 10 percent modal quartz. Intersection of structural line A with anorthosite-metanorite boundary zone reflects occurrence of finer grained and foliated Whiteface-type anorthosite developed along this part of the boundary (from de Waard and Romey, 1969 and de Waard, 1964b).

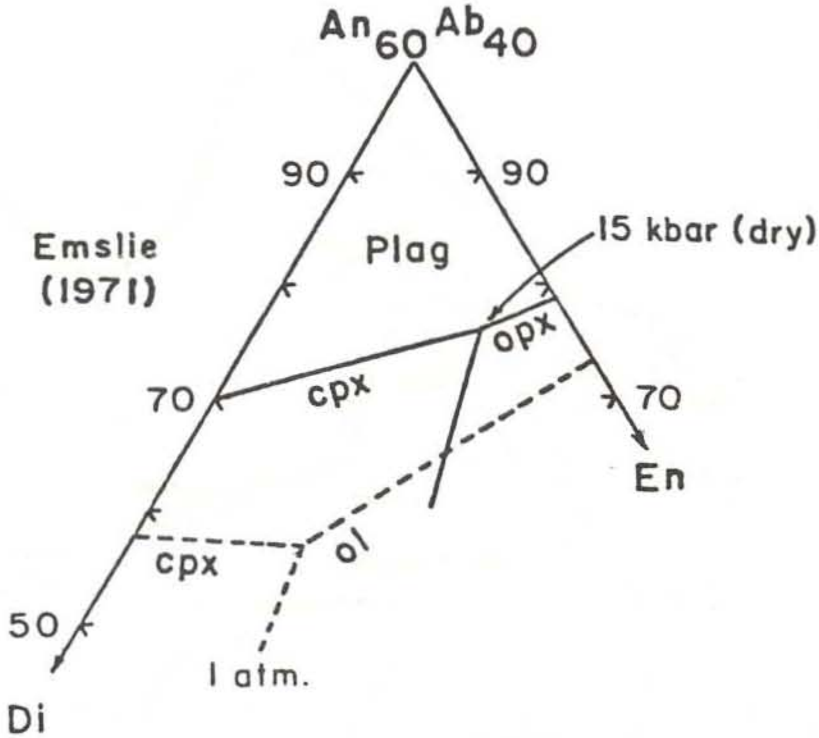

Figure 23. Liquidus phase relations in system $An_{60}Ab_{40}$-Di-En at 15 Kb load pressure, from Emslie (1971).

21.2 Charnockites of the Snowy Mt. Dome.

These type "a" quartzo-feldspathic gneisses tend to be more massive than charnockites higher in the sequence. They also contain xernocrysts of andesine. de Waard and Romey (1969) believed that these charnockites were comagmatic with the anorthosites of the Snowy Mt. Dome. Buddington (1963) has argued that they are later than the anorthosites. Isachsen, McLelland, and Whitney (1975) suggested that these, and similar, charnockites are the products of melting accompanying intrusion of the anorthosites into quartzo-feldspathic country rocks. Rb/Sr whole rock ages obtained by Hills and Isachsen (1975) yield results of ~ 1.2 by and do not suggest that these charnockites are part of an "older" basement complex.

23.2 State Campsite.

27.4 Mason Lake Parking Area. The lower Lake Durant Fm. and the Lower Marble are exposed in this general vicinity.

27.9 Contact of the Lower Marble with the Lake Durant Fm.

28.7 Contact of the Lake Durant Fm. with the Upper Marble.

29.6-30.2 Passing through thick charnockite layer in the Upper Marble.

30.2 Passing through units of the Upper Marble. Generally low dips have resulted in broad exposure of this unit. Note horizontal foliation in some roadcuts. At 32.9 cross contact with Blue Mt. Fm. which cores a local F_2 syncline.

34.3 Contact of Blue Mt. Fm. with Upper Marble. Passing into the southern limb of the F_2 syncline.

34.7 Long roadcuts of garnetiferous amphibolite in Upper Marble. Some garnets attain diameters of 5-6". A large pegmatite is also present. Note that this outcrop sites astride the hinge line of an F_2 anticline.

34.8 Contact of Upper Marble amphibolites and Blue Mt. Fm.

35.4 Junction of Routes NY30 and 8 in center of Speculator.

-- Side trip, no cumulative mileage --

0 Head southeast on Rt. NY30

1.5-2.8 Charnockites of Blue Mt. Fm. At 2.8 cross into Upper Marble.

3.4 Stop 5: Northern intersection of old Rt. NY30 and new Rt. NY30, 3.3 miles east of Speculator, New York.

The Upper Marble Fm. is exposed in roadcuts on both sides of the highway. These exposures show typical examples of the extreme ductility of the carbonate-rich units. The south wall of the roadcut is particularly striking, for here relatively brittle layers of garnetiferous amphibolite have been intensely boudinaged and broken. The marbles, on the other hand, have yielded plastically and flowed with ease during the deformation. As a result the marble-amphibolite relationships are similar to those that would be expected between magma and country rock. Numerous rotated, angular blocks of amphibolite are scattered throughout the marble in the fashion of xenoliths in igneous intrusions. At the eastern end of the outcrop tight isoclinal folds of amphibolite and metapelitic gneisses have been broken apart and rotated. The isolated fold noses that remain "floating" in the marble have been aptly termed "tectonic fish." The early, isoclinal folds rotate on earlier foliation.

Features such as those seen within this roadcut have led this writer to question the appropriateness of assigning an unconformity to the base of the Lower Marble Fm. Tectonic phenomena in rocks of high viscosity contrast can account for the fact that the marbles are able to come into contact with a variety of lithologies.

A variety of interesting lithologies are present in this roadcut. The marble itself contains diopside (now serpentinized), tremolite, tourmaline, graphite, sphene, phlogopite, and a variety of pyrites. Interesting reaction rims, or selvages, exist between the marbles and quartz-rich boudins. Presumably these selvages reflect the influence of compositional gradients during metamorphism. Quartz and calcite coexist in these rocks, and wollastonite is not known to occur at this location.

Most of the amphibolites in the outcrop are highly garnetiferous and some layers seem to contain 60-70 percent garnet. The garnets are almandine-rich and are similar to those at Gore Mt. However, it is not known whether these amphibolites represent metamorphosed sedimentary or igneous rocks. Note that a number of the garnets are separated from surrounding hornblende by narrow light colored rims. These consist of calcic plagioclase and orthopyroxene and represent products of the reaction:

Garnet + Hornblende = Orthopyroxene + Calcic Plagioclase + Water.

This reaction is characteristic of the granulite facies wherein the association garnet + hornblende is unstable (de Waard, 1965a, 1965b).

Also present in the outcrop are various layers rich in calc-silicates. One of these contains coarse, pale diopside crystals several inches across. Others consist almost entirely of green diopside. Tremolite also occurs in some layers. Rusty weathering, metapelitic units are rich in graphite, calc-silicates, and pyrite. Neither grossular nor scapolite, seems to have developed here.

Near the west end of the outcrop a deformed layer of charnockite is well exposed. In other places the charnockite-marble interlayering occurs on the scale of one to two inches.

Exposed at several places in the roadcut are striking, cross-cutting veins of tourmaline and quartz displaying a symplectic type of intergrowth. Other veins include hornblende and sphene-bearing pegmatites.

Usually included in the Upper Marble, but not exposed here, are quartzites, kinzigites; sillimanite-rich, garnetiferous, quartz-microcline gneisses; and fine-grained garnetiferous leucogneisses identical to those characterizing the Sacandaga Fm. These lithologies may be seen in roadcuts 0.5 mi to the south.

Almost certainly these marbles are largely of inorganic origin. No calcium carbonate secreting organisms seem to have existed during the time in which these carbonates were deposited (> 1 by ago). Presumably the graphite represents remains of stromatolite-like binding algae that operated in shallow-water, intertidal zones. If so, the other roadcut lithologies formed in this environment as well. If so, the other roadcut lithologies formed in this environment as well. This seems reasonable enough for the clearly metasedimentary units such as the quartzites and kinzigites. The shallow-water environment is much more interesting when applied to the charnockitic and amphibolite layers. The fine-scale layering, and ubiquitous conformity of these, strongly suggests that they do not have an intrusive origin. Perhaps they represent the metamorphosed products of volcanic material in a shelf-like environment. Such intercalation is now occurring in many island arc areas where shallow-water sediments cover, and in turn are covered by, ash and lava. Alternatively they may represent metasediments.

Turn around and head back north to Speculator.

35.4 Junction Routes NY8 and 30 in Speculator. Head southwest on Rt. NY8.

46.0 Stop 6: Core rocks of the Piseco Anticline.

Hinge line of Piseco Anticline near domical culmination at Piseco Lake. The rocks here are typical quartzo-feldspathic gneisses "a" such as occur in the Piseco Anticline and in other large anticlinal structures, for example Snowy Mt. Dome, Oregon Dome.

The pink "granitic" gneisses of the Piseco Anticline do not exhibit marked lithologic variation. Locally grain size is variable and in places megacrysts seem to have been largely granulated and only a few small remnants of cores are seen. The open folds at this locality are minor folds of the F_2 event. Their axes trend N70W and plunge 10-15° SE parallel to the Piseco Anticline.

The most striking aspect of the gneisses in the Piseco Anticline is their well-developed lineation. This is expressed by rod, or pencil-like, structures. These may consist of alternating ribbons of quartzite, quartzo-feldspathic gneiss, and biotite-rich layers. In many instances these ribbons represent transposed layering on the highly attenuated limbs of early, isoclinal minor folds. Near the northeast end of the roadcut such minor folds are easily seen due to the presence of quartzite layers in the rock. Slabbed and polished specimens from this and similar outcrops demonstrates that these early folds are exceedingly abundant in the Piseco Anticline. Examination of these folds shows that the dominant foliation in the rock is axial planar to them. Similarly, layer transposition is related to flattening parallel to the axial planes of the early folds. The intersection of this axial plane foliation and compositional surfaces helps to define the strong lineation in the outcrop. Also present is an earlier foliation subparallel to the one associated with the visible folds. Again intersections between these foliations, compositional surfaces, etc., result in a strong intersection lineation. In addition to this a number of rod-like lineations are probably the hinge line regions of isoclinal minor folds which are difficult to recognize because of relative lithologic homogeneity. Lineation in the outcrop is intensified further by the fact the upright and relatively open F_2 folds are coaxial with F_1. Thus the intersection of the F_2 axial planar foliation with earlier foliations results in a lineation parallel to the F_2 trend. Moreover, F_2 minor folds may be of the crenulation variety and their sharp hinge lines define a lineation in the earlier foliation.

As described previously, a number of parallel elements combine to produce an extremely strong lineation in the Piseco Anticline. Past observers have remarked that the lineation appears to be the result of stretching parallel to the long axis of the Piseco Dome. However, the lineation is probably unrelated to "stretching" and is explained more realistically as an intersection lineation of planar fabrics. Moreover, the intensity of the lineation is more the result of the early recumbent folding and flattening than it is of the later, coaxial F_2 Piseco Anticline.

48.5 Junction of Rt. NY8 and Rt. NY10. Turn south towards Canada Lake.

49.0 On both sides of Rt. NY10 are red-stained quartzo-feldspathic gneisses "a" that have been cataclastized by a large N20E fault zone. For the next 5.5 mi we shall pass through a number of road-curves as Rt. NY10 makes its way through the core rocks on the south limb of the Piseco Anticline.

52.5 Cross into the Sacandaga Fm.

55.0 Parking area on east side of highway. The rocks here are quartzo-feldspathic gneisses believed to be part of the Sacandaga Fm.

55.3 Stop 7: Lake Durant and Scandaga Fms. intruded by anorthositic gabbros and gabbroic anorthosites.

These roadcuts are located on Rt. NY10 just south of Shaker Place.

The northernmost roadcut consists of a variety of metasedimentary rocks. These lie directly above the Piseco Anticline and are believed to be stratigraphically equivalent to the Sancandaga Formation. The outcrop displays at least two phases of folding and their related fabric elements. These are believed to be F_1 and F_2. A pre-F_1 foliation is thought to be present. Both axial plane foliations are well developed here. Several examples of folded F_1 closures are present and F_1 foliations (parallel to layering) can be seen being folded about upright F_2 axial planes.

Farther to the south, and overlooking a bend in the west branch of the Sacandaga River, there occurs a long roadcut consisting principally of pink and light green quartzo-feldspathic gneisses belonging to the Lake Durant Fm. About half-way down this roadcut there occurs a large and impressive boudin of amphibolite and diopsidic gneiss. To the north of this boudin the quartzo-feldspathic gneisses are intruded pervasively by anorthositic gabbros, gabbroic anorthosites, and various other related igneous varieties. At the north end of the cut and prior to the meta-stratified sequences these intrusives can be seen folded by upright fold axes. They are crosscut by quartzo-feldspathic material.

Within this general region the Lake Durant Fm. and other quartzo-feldspathic gneisses seem to have undergone substantial anatexis. This is indicated by the "nebular" aspect of the rocks. Good examples of this are seen in the manner in which green and pink portions of the quartzo-feldspathic gneisses mix. Note also the clearly cross-cutting relationships between quartzo-feldspathic gneiss and mafic layers at the south end of the roadcut. Here it seems that mobilized Lake Durant is cross-cutting its own internal stratigraphy. Also note that the quantity of pegmatitic material is greater than usual. This increase in anatectic phenomena correlates closely with the appearance of extensive metagabbroic and metanorthositic rocks in this area. We believe that these provided a substantial portion of the heat that resulted in partial fusion of the quartzo-feldspathic country rock.

56.4 Roadcut on west side of highway shows excellent examples of anorthositic gabbros intrusive into layered pink and light green quartzo-feldspathic gneisses. The presence of pegmatites and cross-cutting granitic veins is attributed to anatexis of the quartzo-feldspathic gneisses by the anorthositic rocks.

56.7 Fine-grained metagabbro on west side Rt. NY10.

57.1 Excellent roadcut in coarse anorthositic gabbro. Ophitic to subophitic texture well preserved. Garnets are sporadically developed and tend to be associated with coarse gabbroic pegmatites showing mineral growth perpendicular to contacts. Compositional layering may be primary.

57.6 Small cut in megacrystic granitic gneiss on east side of highway.

57.8 Begin half-mile of roadcuts exhibiting intrusion of quartzo-feldspathic gneisses by members of the anorthositic gabbro suite, several phases of which seem to be present and in cross-cutting relationships. Source metasedimentary areas may be xenoliths. Pods of megacrystic gneiss may be anatectic in origin.

58.4 Kennels Pond - Avery's Fishing Site.

59.5 Lake Catherine to east of highway; metasediments intruded by anorthositic gabbros in roadcut on west.

60.3 Avery's Hotel on west of highway at top of hill.

60.4 Steeply dipping kinzigites with white, anatectic layers.

61.2 Stop 8: On the west side of Rt. NY10 is a rounded roadcut consisting of typical examples of sillimanite-garnet-biotite-quartz-oligoclase gneisses (kinzigites). These rocks are widespread south of the Piseco Anticline and are thought to represent metapelites associated with a locally deeper sedimentary basin in this region. Throughout the Adirondacks kinzigites are rich in white pods and lenses consisting of perthitic feldspars, garnet, and quartz. These are believed to be anatectic in origin. These anatectic areas seem to pre-date F_1. In places they exhibit the pre-F_1 foliation. Locally they show "fishhook-like" terminations suggesting that they have been involved with substantial transposition.

The kinzigites at this locality have been intruded by anorthositic gabbro which may be seen at the north end of the roadcut. The gabbroic rocks seem to gently transect the earliest foliation but have been involved in all other deformations.

Towards the southern end of the roadcut several generations of minor folds may be seen together with their associated foliations. The earliest recognizable folds have near-horizontal axial planes where they are located on the hinge lines of the upright set of folds that dominates the outcrop. The older set seems to fold a foliation and is assigned to the F_1 generation. This requires that the dominant, upright set with its steep foliation belongs to the F_2 generation of folds. If this is so we note that the F_2-related axial plane foliation can be locally intense.

There seem to be two generations of garnet within most kinzigites. One may be flattened in the plane of foliation and may have formed by an amphibolite facies reaction similar to:

biotite + muscovite + quartz $\rightarrow$ garnet + K-feldspar + H_2O

(Engel and Engel, 1962). The later generation of garnets grow across foliation planes and in several areas form coronitic rims around sillimanite. These garnets are believed to result from a reaction of the following type:

sillimanite + (Fe,Mg,Ti)Biotite + Quartz $\rightarrow$

(Fe,Mg)Garnet + Ti-Biotite $\pm$ Ilmenite + H_2O

(Kretz, 1966).

61.4 Extremely garnetiferous kinzigites.

62.0 Road sign: Canada Lake - 10 miles.

62.5 Crossing Swamp.

63.2 Crossing swamp that marks contact between the Sacandaga Fm. and megacrystic gneisses of the Rooster Hill Fmm.

63.5 Megacrystic gneisses of Rooster Hill Fm.

63.6 Megacrystic gneisses of Rooster Hill Fm.

64.0 Kinzigite in Rooster Hill Fm.

64.7 North end of Stoner Lake. Type locality of Rooster Hill Fm. The Rooster Hill Formation is characteristic of a wide spread lithology throughout the Adirondacks. Its most characteristic feature is the presence of striking 1-4" megacrysts of K-feldspar. These are almost always flattened within the plane of foliation. Nonetheless, a number of these megacrysts preserve evidence of approximately euhedral crystal outline.

Compositionally the Rooster Hill megacrystic gneisses consist of orthopyroxene, garnet, hornblende, biotite, perthitic microcline, some plagioclase (oligoclase), and quartz. An igneous analogue would be quartz monzonite.

The parentage of the Rooster Hill megacrystic gneisses is obscure. It is not known whether the megacrysts are phenocrysts or porphyroblasts. The fact these lithologies are conformable with the enclosing stratigraphy over broad areas is consistent with a metastratified origin but does not rule out intrusion as sills. The lack of substantial banding across units thousands of feet thick is less consistent with a metasedimentary origin than with an igneous one. However, the problem remains unresolved and requires further research.

Regardless of parentage, the Rooster Hill Fm. seems to correlate with the Blue Mt. Fm.

65.5 Crossing contact of Rooster Hill Fm. and kinzigites of the Peck Lake Fm. Near the contact the Rooster Hill megacrystic gneisses become equigranular. This is probably due to cataclasis.

66.4 Kinzigites in the Peck Lake Fm.

67.3 Junction of Rt. NY10 and Rt. 29A.

End Road Log