BEDROCK GEOLOGY OF THE HIGH PEAKS REGION, MARCY MASSIF, ADIRONDACKS, NEW YORK

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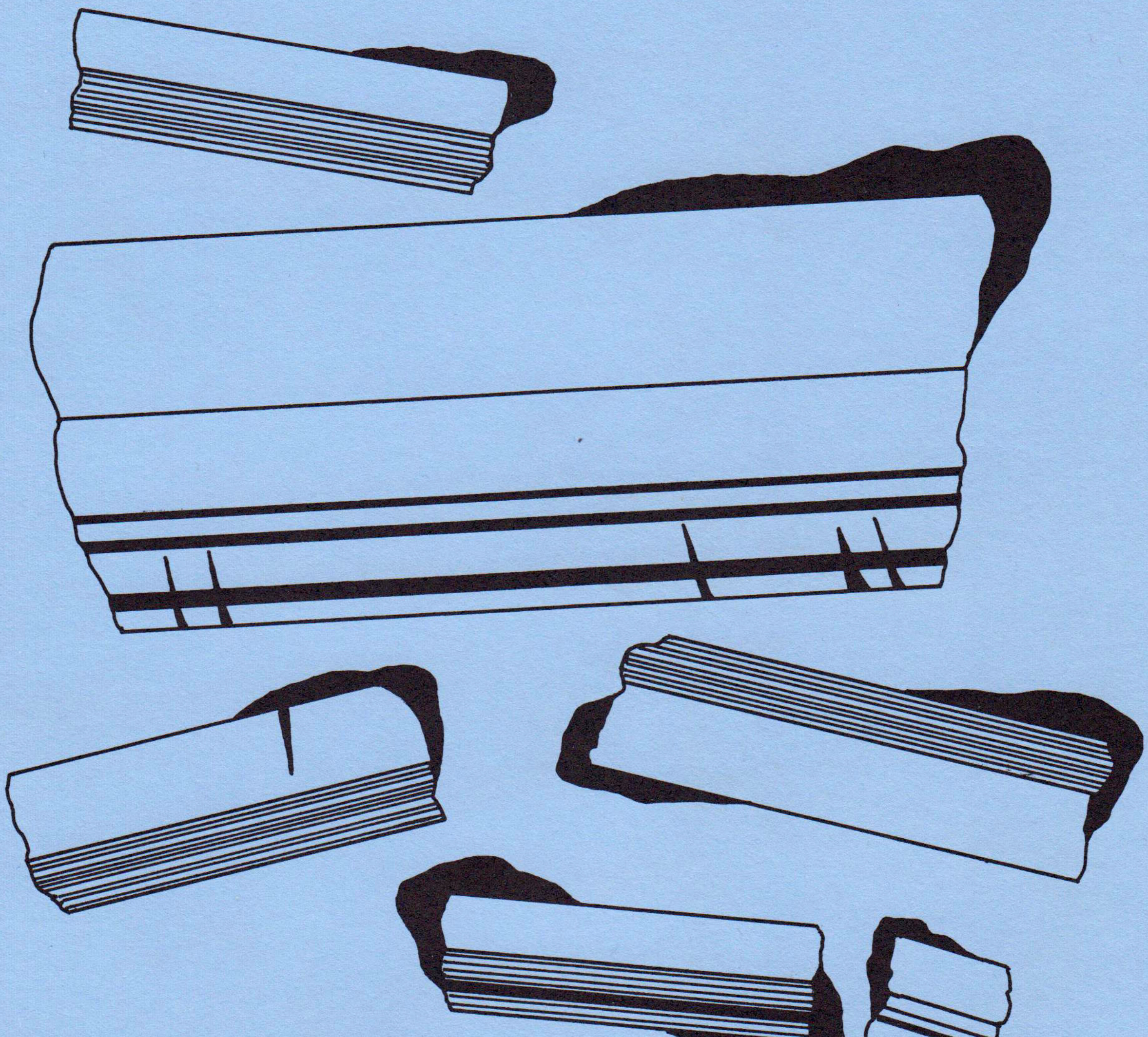

FIELD GUIDEBOOK
FRIENDS OF THE GRENVILLE
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DEPARTMENT OF GEOLOGY & GEOGRAPHY
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FIELD GUIDE

GUIDE AU TERRAIN

BEDROCK GEOLOGY of the HIGH PEAKS REGION, MARCY MASSIF, ADIRONDACKS, N.Y.

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LES AMIS du GRENVILLE

FRIENDS of the GRENVILLE
Sept. 30, Oct. 1, 2, 1983

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Plate 1. Mt. Marcy, 5344'(1629m), from the summit of Skylight Mt., 4926'(1502m), core of Marcy anorthosite massif, Mt. Marcy quadrangle.

Dedicated to

Willie and Bud :

friends, colleagues, and

Adirondack field geologists

A. Williams Postel (1909 - 1966)	A.F. Buddington (1890 - 1981)

15' quadrangles mapped in the Adirondacks

Dannemora (1951)	Antwerp (1934)
Churubusco (1952)	Hammond (1934)
Lyon Mt. (1952)	Lowville (1934)
Clinton Co.	Santa Clara (1937)
Magnetite District (1952)	Willsboro (1941)
Mooers (1954)	Big Moose (1950)
Moira (1955)	Port Leyden (1951)
Chateaugay (1956)	Saranac Lake (1953)
Loon Lake (1956)	St. Lawrence Co.
Malone (1956)	Magnetite District (1962)
Nicholville (1959)	

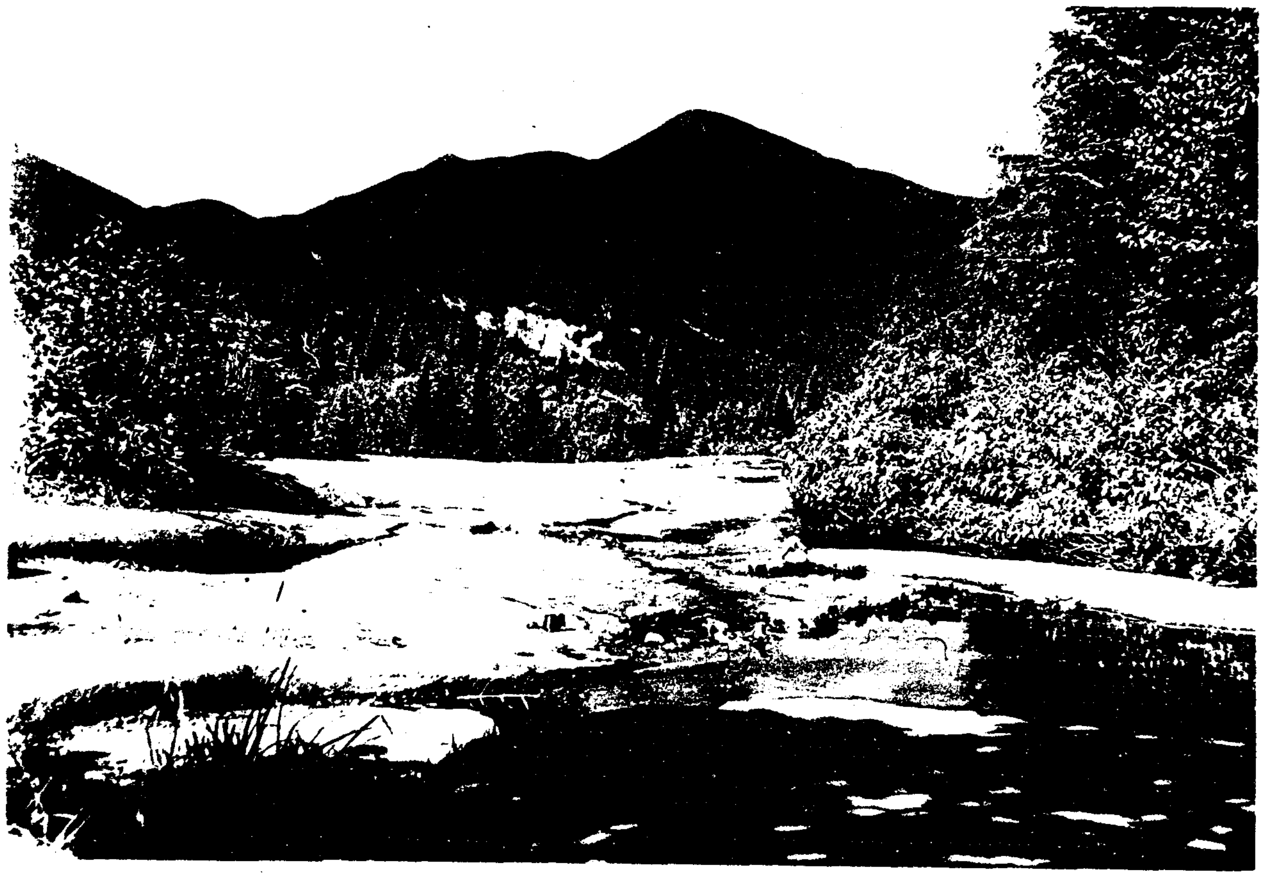


Plate 2. McIntyre Range in the anorthosite core of the Marcy Massif, showing Algonquin Peak, 5114'(1559m), Boundary Peak, 4850'(1479m), Iroquois Peak, 4850'(1479m), and Mt. Marshall, 4360'(1329m). Mt. Marcy and Santanoni quadrangles.

Plate 3. View NE from summit of Skylight Mt. across prominent cone of Haystack Mt., 4960'(1512m), to Giant Mt.(center horizon), 4627'(1411m); from left margin to center are: Basin Mt., 4827'(1472m), Gothics, 4376'(1444m), and Wolfjaw Mts., 4185'(1276m), of the Great Range, High Peaks region, Mt. Marcy quadrangle.

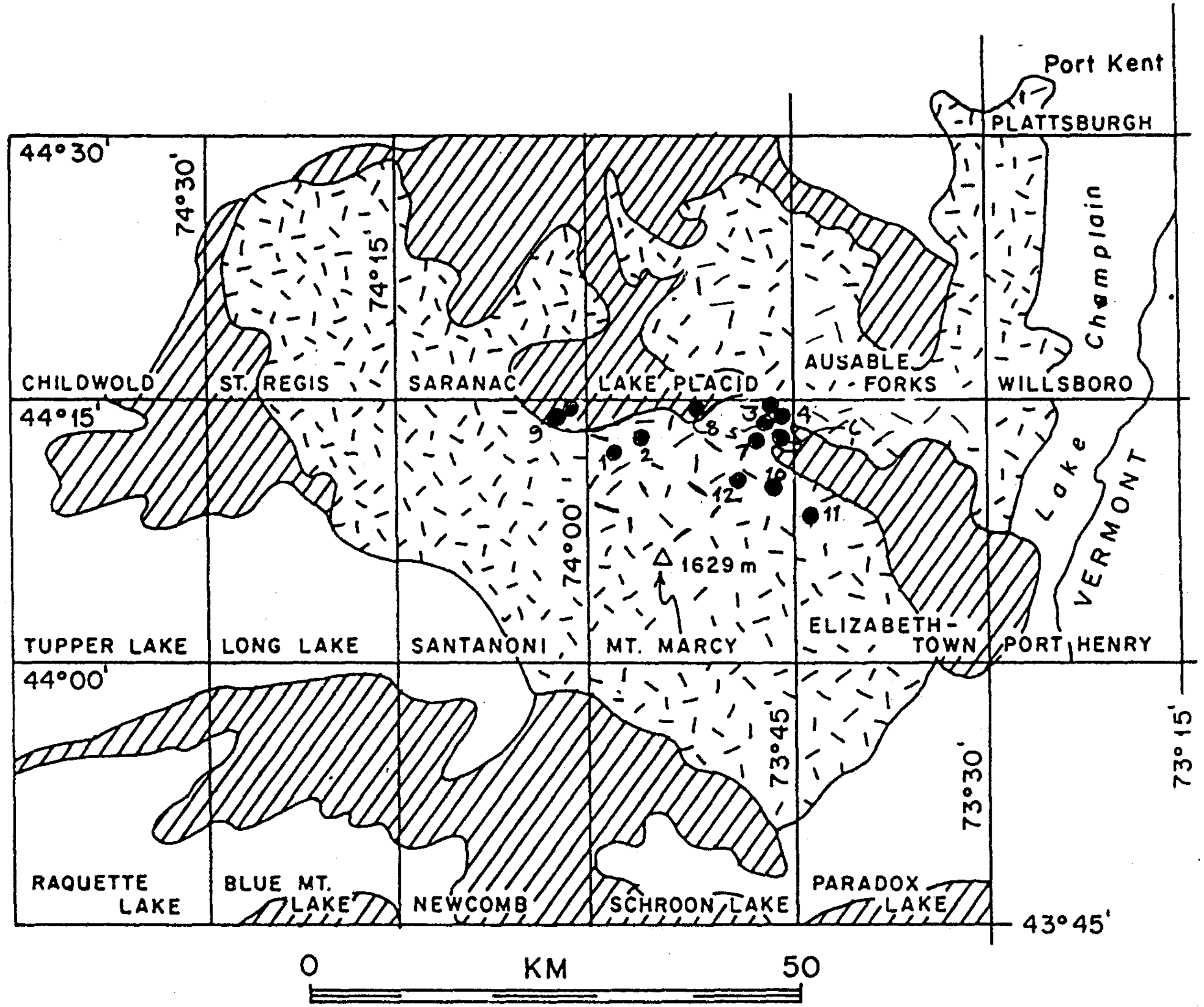


Figure 1. Generalized geologic map of the Marcy anorthosite massif and surrounding areas: anorthositic rocks , ferrosyenite-ferromonzonite gneiss , and Grenville metasediments . Grenville Club 1983 field trip stops 1-8, 10, 12, are in the Mt. Marcy quadrangle; stops 9A and 9B are in the Santanoni quadrangle; stop 11 is in the Elizabethtown quadrangle.

INTRODUCTION

Location and geologic setting

The northeastern Adirondack Highlands are an impressive mountain range dominated by a High Peaks Region embracing 43 mountains that reach above 4000'(1219 m) culminating in the summits of Mt. Marcy(Plate 1) 5344' (1629 m), Algonquin Peak(Plate 2), 5114'(1559 m), Mt. Haystack(Plate 3), 4960'(1512 m), and Mt. Skylight, 4926'(1502 m), all lying in the west-central part of the 15' Mt. Marcy quadrangle(Fig. 1 and Plate 4). Total relief in the Mt. Marcy quadrangle is 4364'(1330 m). Coarsely crystalline, felsic andesine anorthosite locally capped by mesocratic, equigranular, sub-ophitic, biotite leuconorite(Table 1) makes up the summits of these four highest mountains. At the top of the Adirondacks, Marcy summit is capped by a thin layer or raft of biotite leuconorite "floating" in coarse, megacryst-rich andesine-labradorite(An 48-50) anorthosite. Plagioclase megacrysts have been deflected by and appear to have flowed around the earlier-crystallized leuconorite raft(Fig. 2). Some of these plagioclase megacrysts show an unusual type of zoning visible on outcrop scale as concentric blue and white layers. Blue zones are labradorite, An 50, containing abundant oxide dust; white zones, also An 50, are free of oxide dust but are antiperthitic, containing abundant exsolution blebs of orthoclase(Fig. 2). Of the 43 High Peaks above 4000' (1220 m), 34 are made up of andesine anorthosite, 7 are of highly deformed gabbroic anorthosite augen gneiss(herein named Van Hoevenberg Gneiss), and 2 are represented by quartz-poor, alkali-feldspar- and iron-rich rocks, a monzonite gneiss on Armstrong Mt., 4400'(1341 m) and a monzonite granulite on Giant Mt., 4627'(1411 m).

The Marcy anorthosite massif is delineated by a major northwest-southeast trending lobe and a smaller north-south trending lobe coalescing to the south to form a heart shaped outcrop pattern covering 5000 km^2 (3100 mi^2). In section, the major northwest trending lobe approximates to a piano bench or slab 3 - 4.5 km(1.8 - 2.7 mi.) thick with two legs or feeder pipes extending at least 10 km(6 mi.) down according to the geophysical model of Simmons(1964), whereas Buddington(1969) favored an asymmetric domical shape based upon extensive field mapping and other considerations. The massif consists of a coarsely crystalline core of apparently undeformed felsic andesine anorthosite intruded into and thrust over a multiply deformed roof facies consisting of gabbroic - noritic anorthosite, gabbroic anorthosite gneiss(Van Hoevenberg Gneiss), and quartz-bearing ferrosyenite - ferromonzonite("quartz ferromangerite") facies of a Pitchoff Gneiss(Table 1). Remnants of a siliceous carbonate- and quartzite-rich metasedimentary sequence and associated garnet-pyroxene-microperthite granulites form discontinuous screens and xenoliths in the roof facies. Xenoliths of any kind are very rare inside the felsic anorthosite of the core but abound in the gabbroic anorthosite of the roof facies. Representative modes of these rock types are given in Table 1. The heart shaped Marcy anorthosite massif is surrounded by large bodies of the ferromonzonite facies of the Pitchoff Gneiss and the metasedimentary sequence of a presumed Grenville age. A conspicuous feature of the supracrustal sequence is the intimate intercalation of

Table 1. Representative modes of anorthositic and iron-rich monzonitic rocks from the Marcy Massif, N.E. Adirondacks, New York.

		Qz	Kf	Plag	Opx	Cpx	Gar	Hbl	Bio	Ox	Ap	Zr	Fe (opx)	An(plag) (gm)	(meg)
MARCY ANORTHOSITE(CORE)															
Andesine anorthosite	BA-2	-	5	92	0.5	0.5	1.5	-	-	0.5	+	-	46	48	48
Biotite leuconorite	MA-10	-	6	76	15	1	-	-	1	1	+	-	38	47	
PITCHOFF GNEISS															
Ferrosyenite gneiss	PO-2	2	84	4	2	4	1	2	-	1	+	+	86	21	
Qz ferromonzonite gn	SC-6	9	46	25	2	9	4	2	-	2	1	+	92	16	
Ferromonzodiorite gn	GO-2	2	22	57	4	2	7	1	-	2	3	+	85	22	
Oxide-rich melagabbro	CA-6	-	5	29	23	11	10	-	-	16	6	-	58	31	42
VAN HOEVENBERG GNEISS															
Gabbroic anorthosite gn.	SB-6	2	5	53	+	9	19	4	-	7	1	-	42	41	43-51
" " "	GO-5	2	6	56	2	8	9	4	-	6	7	-	52	37	43
MARCY ANORTHOSITE(ROOF)															
Gabbroic anorthosite	PR-1	-	1	74	4	14	-	6	-	1	+	-	44	44	48
ANORTHOSITE-SYENITE HYBRID (TRANSITION ROCKS)															
Microperthite granulite	JB-2	-	16	51	3	8	16	-	-	5	1	+	73	26	
" "	BA-6	-	32	46	1	3	14	-	-	2	2	-	73	20	50
" "	BA-5	-	19	25	13	14	20	-	-	5	4	-	63	23	
GRENVILLE or BASEMENT															
Microperthite granulite	BA-6f	-	18	18	7	56	-	-	-	1	+	-	73	23	-
" "	CA-17A	-	32	10	8	49	-	+	-	1	-	-	73	24	-

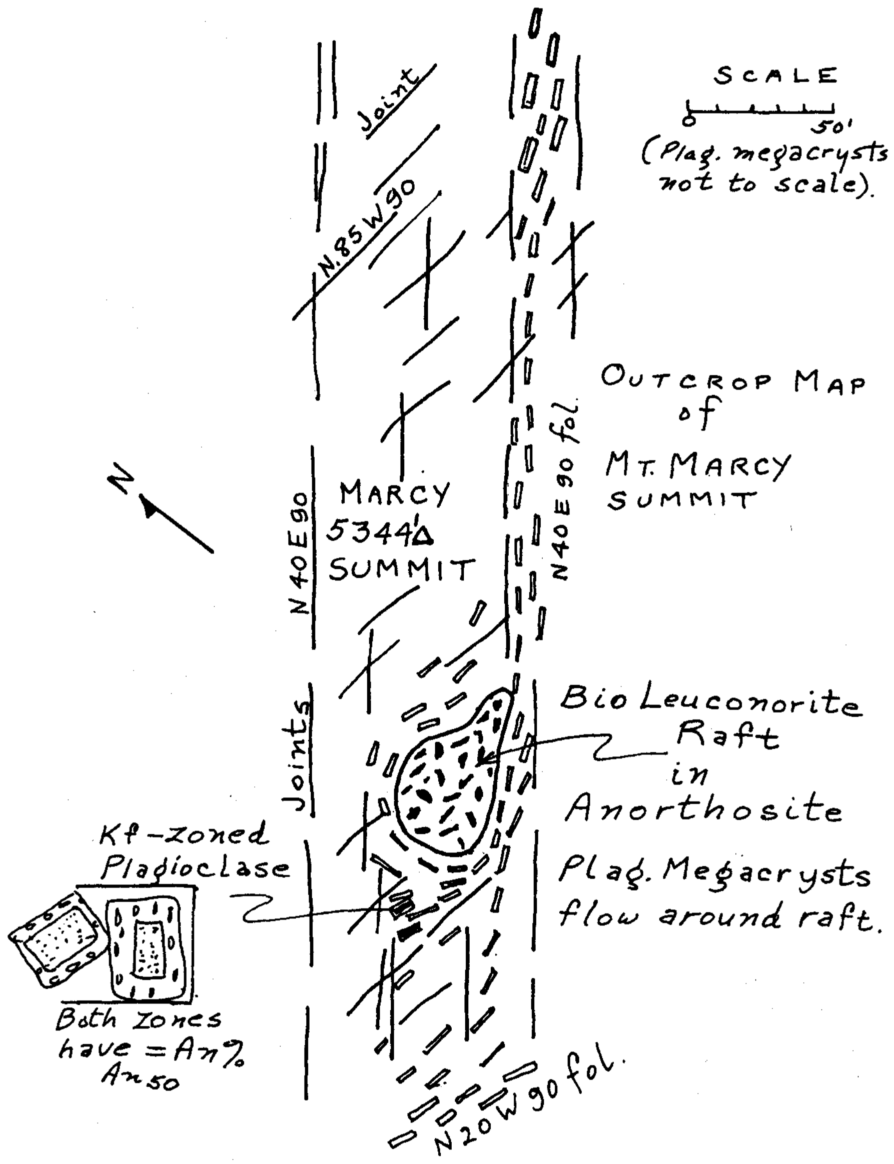
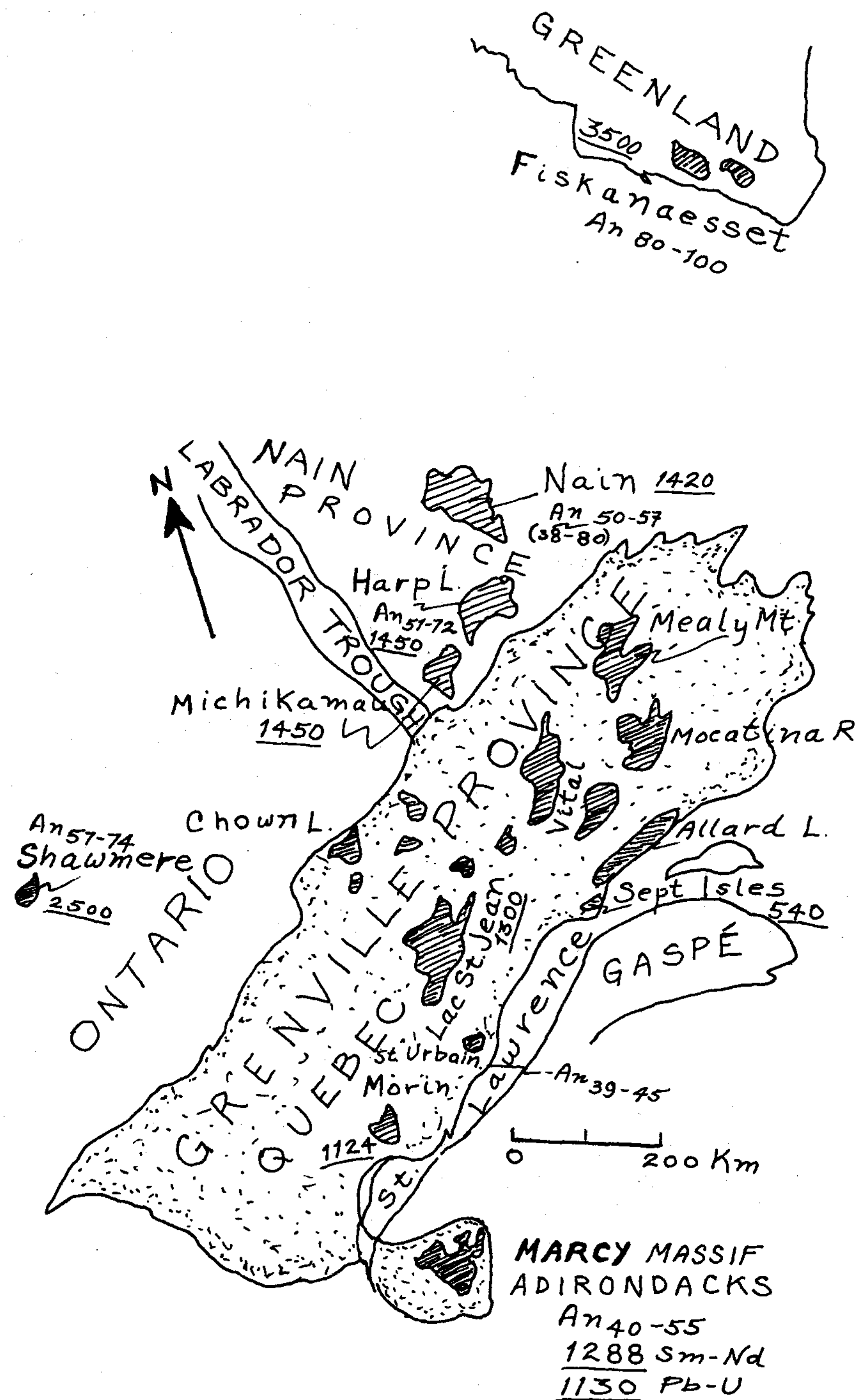


Figure 2. Schematic outcrop map of the summit of Mt. Marcy, showing a biotite leuconorite raft "floating" in felsic anorthosite. Calcic plagioclase megacrysts are deflected by and flow around the early-crystallized raft. Mt. Marcy quadrangle.

Figure 3. Generalized outline map of Nain (clear) and Grenville (stippled) provinces of the Canadian Shield and Greenland, showing location of anorthosite bodies (ruled), An contents of plagioclase, and radiometric dates where knwon. Modified after Emslie, 1974.



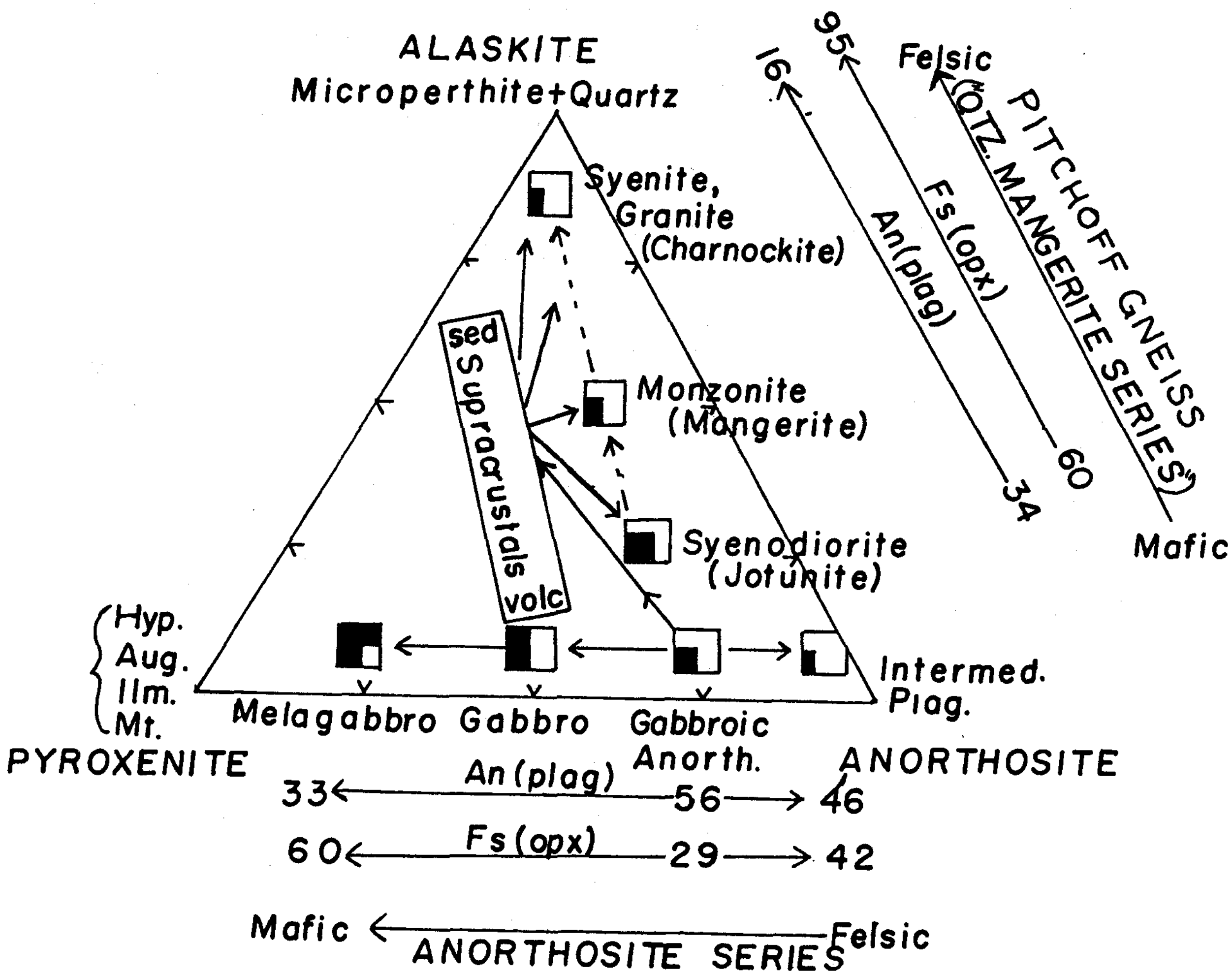
metamorphosed felsic igneous and calc-siliceous sedimentary sequences, both away from as well as inside the massif. The felsic gneiss components of this sequence may represent volcanics or sills interlayered with metasediments, both of Grenville age, or they may be remelted and remobilized portions of a basement complex(Wiener, McLelland, Isachsen, and Hall, G.S.A. Mem., in preparation).

Anorthosites

Massif type anorthosites consisting largely of cumulate plagioclase An 40-60, accompanied by subordinate amounts of orthopyroxene, clinopyroxene, olivine, ilmenite, and apatite make up a large part of the crust of the Nain and Grenville Provinces of the Canadian Shield,(Fig. 3, modified from Emslie, 1974). The Adirondack Marcy massif may be considered as a southern extension of the Grenville Province across the narrow Frontenac axis. Plagioclase cumulates(or adcumulates) in anorthosites of the Nain Province(Fig. 3) intruded about 1450 M.Y. tend to be richer in An, 50's - 60's, than those of the Grenville Province, 1288-1150 M.Y., which have An in the 40's and low 50's. This has led some investigators to suggest or propose the existence of a labradorite-type and an andesine-type of anorthosite(Isachsen, 1969). Although some dispute such a division as arbitrary and artificial, there does appear to be a correlation between An content of plagioclase and age of crystallization; the older the anorthosite, the higher the An content. Anorthosites of the Nain Province are largely unmetamorphosed and commonly contain troctolite members or olivine, in addition to having higher An contents, whereas younger anorthosites of the Grenville Province are regionally metamorphosed and olivine-free, in addition to being lower in An content. It is generally believed that anorthosites of both the Nain and Grenville Provinces intruded in an anorogenic rifting environment with the latter becoming overprinted by a granulite facies regional metamorphism(Emslie, 1977 and Morse, 1983). Buddington(1969) Martignole and Schrijver(1970), Michot(1969), and others, however, favor syntectonic emplacement under granulite facies conditions. Because sodic plagioclase is a more stable liquidus phase than calcic plagioclase at high pressures (Green, 1969, 1970) it is conceivable that andesine anorthosites of the Grenville Province such as the Adirondacks, Morin, and St. Urbain, have crystallized at deeper levels than those of the Nain Province. The average An content of plagioclase from the Harp Lake complex(Emslie, 1977) is 60 whereas that of the Adirondack massif is 46. The paucity of garnet and the low color index of felsic andesine anorthosite of the core of the Marcy massif preclude the possibility that metamorphic growth of garnet could significantly reduce the average An content of the massif from 60 to 47; the difference is real.

The essential mineralogical makeup and compositional range of both anorthositic and alkali-feldspar-rich rocks are conveniently represented on the ternary diagram: plagioclase-pyroxene+oxides-microperthite+quartz equivalent to anorthosite-pyroxenite-alaskite(Fig. 4). We recognize an anorthositic series and a Pitchoff Gneiss made up of quartz-poor, iron-rich syenitic-monzonitic-syenodioritic facies that are assumed to represent separate batches of melt rather than a true fractionation series.

Figure 4. Ternary diagram: Plagioclase - Pyroxene + oxides - microperthite + quartz = Anorthosite - Pyroxenite - Alaskite, showing variation in mineral composition with color index for anorthositic series and monzonitic (mangeritic) rocks.



Our Pitchoff Gneiss is analogous to the "quartz mangerite series" of de Waard(1969, 1970) and others only insofar as petrographic distinctions are made(Fig. 4). According to a model suggested by Buddington(1969) for the Adirondack anorthosite series, a parent gabbroic anorthosite magma made up of 60% liquid, 40% crystals, sheds and concentrates calcic andesine megacrysts by a process of flow differentiation to form a core facies, while a residual liquid fractionates towards increasingly more pyroxene+oxide-rich gabbroic anorthositic compositions characteristic of a roof or border facies; color index increases with iron enrichment in pyroxenes as plagioclase decreases in An content(Fig. 4). By contrast, in the alkali-rich rocks of the Pitchoff Gneiss(="quartz mangerite series"), color index decreases with iron enrichment in pyroxenes as plagioclase again decreases in An content. Similar, although not identical relations have been observed by Ollila(1983, in preparation) in the Santanoni quadrangle, by Davis(1971) in the St. Regis quadrangle, and by Jaffe et al, (1975, 1978) in the Mt. Marcy quadrangle from which the data of Figure 4 are plotted. Ollila in the Santanoni and Jaffe and Jaffe in the Mt. Marcy quadrangles have recorded only a small decrease in the An content of plagioclase of felsic anorthosite and noritic anorthosite accompanying the increase in the iron content, Fs, of pyroxenes. This An-Fs contrast, however, increases and becomes exaggerated in more mafic mineral-rich anorthosites because of extensive garnet-forming reactions, during subsequent metamorphism, which effected a marked An depletion in plagioclase. Most of the garnet in both anorthositic and monzonitic rocks from the Adirondacks contains 15-20% of the grossular molecule which derives entirely from the anorthite component of pre-metamorphic plagioclase.

Geologic mapping in the High Peaks Region

Field work in the Mt. Marcy quadrangle and environs was already under way in the mid-19th century when Emmons described the geology around the Cascade Lakes in his Survey of the Second Geological District in 1842. Kemp in 1898 published a geological map of part of the Lake Placid quadrangle and the northern part of the Mt. Marcy quadrangle, which the N.Y. State Museum offered for sale at 5 cents per copy. Miller in 1918 completed a geologic map of the entire 15' Lake Placid quadrangle, and Kemp in 1921 provided us with the first map of the geology of the entire 15' Mt. Marcy quadrangle. We have had to wait until the 1980's, however, for one of our trip leaders, Paul Ollila, to produce the first ever completed geological map of the relatively inaccessible 15' Santanoni quadrangle(Ollila, Jaffe and Jaffe, 1983) to the west of the 15' Mt. Marcy quadrangle. In the 1960's, Crosby remapped a large part of the 15' Lake Placid quadrangle and suggested the existence of nappe structures in the region. Many geologists were, and continue to be, skeptical of the presence of nappe structures in the High Peaks Region although McLelland and Isachsen(1980) clearly documented their occurrence in the southern Adirondacks. Northeast of our trip area Olmsted and Whitney are remapping the northern and southern parts of the Ausable Forks 15' quadrangle originally mapped by Kemp in 1925. To the south of the High Peaks Region Turner is remapping part of the 15' Schroon Lake quadrangle, originally mapped by Miller in 1918. The area to the east, the 15' Elizabethtown quadrangle which we shall visit on this trip, was mapped by Kemp and Ruedemann in

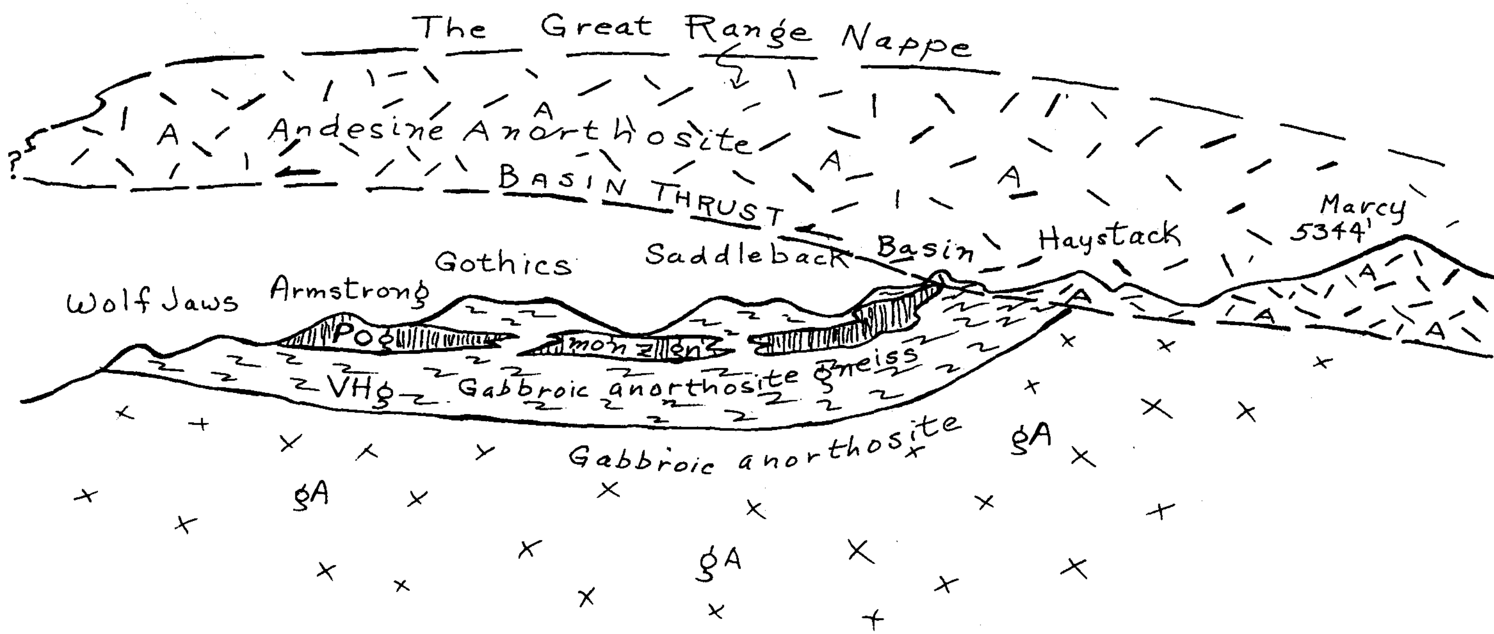


Figure 5. Schematic NE-SW geologic cross-section viewed from Cascade Summit, showing the Great Range Nappe of the High Peaks Region. Anorthosite [symbol] of a core facies is thrust over intensely deformed gabbroic anorthosite augen gneiss [symbol] and ferromonzonite gneiss [symbol] of the roof facies. Mt. Marcy quadrangle.

1910 and was partly remapped by Walton in the 1960's, and by deWaard on Giant Mt. in 1970, and in an area to the east by Gasparik in the 1970's.

Why then, remap? Although the rocks have changed but little, new concepts, new techniques, and a plethora of laboratory experimental data unavailable until recent years have combined to change the way in which geologists examine, correlate, and map outcrops. For example: Emmons after studying the marble outcrops above Cascade Lakes, concluded, in 1842, p. 228-9, that they "provide undoubted evidence that the limestone is an injected mass, or in other words, a plutonic rock". Miller in his geology of the Lake Placid quadrangle strongly denied the existence of compressive folding in the Grenville gneiss in 1916 and again in 1918, when he wrote that "If the Grenville and accompanying great intrusives had been subjected to compression severe enough to develop the foliation, is it not remarkable that the stratification surfaces have never been obliterated and cleavage developed instead, and also that the stratification and foliation are always parallel? Also, unless we assume intense isoclinal folding, so that mineral elongation could everywhere have taken place essentially at right angles to the direction of lateral pressure, the parallelism of stratification and foliation cannot be accounted for by crystallization under severe lateral pressure. But the Grenville strata were never highly folded .... Grenville foliation was developed .... in essentially horizontal strata under a heavy load of overlying material ... under conditions of static metamorphism"(Miller, 1918, p. 66). We, in the 1970's and '80's can decipher at least four or five periods of folding of these same Grenville strata. Kemp, mapping in the same years as Miller, had more insight, and was indeed impressed with the evidence for folding in marble and syenite lithologies and, in 1921, writing of the Grenville marbles, noted "No great section, however, is free from included masses of silicates or of fragments of the wall-rock or of intrusive tongues torn off in the great compression to which the region has been subjected." With regard to the gneisses, Kemp wrote "A candid observer cannot, however, disguise from himself the possibility that old Grenville shales may, under extreme metamorphism, assume a mineralogical composition not appreciably different from the acidic phases of the syenite series."(Kemp, 1921, p. 17). Thus, at the turn of the century, Kemp envisioned the anatexis of the syenites of the Pitchoff Gneiss that we will visit on Stop 8.

Geologic mapping by Jaffe and Jaffe during 1970-1982 in the Mt. Marcy quadrangle, and by Ollila during 1978-1982 in the Santanoni quadrangle has delineated the existence of thrust slices of sizeable dimension. The Jaffes recognize and have delineated a Great Range anorthosite thrust nappe (1977) in the Mt. Marcy quadrangle that may be correlative with the Jay-Whiteface anorthosite nappe described by Crosby(1966) from the Lake Placid and Ausable Forks quadrangles to the north and northeast of the Marcy area. Mineral lineations and fold axes indicate an arcuate trending mappe transported to the north and northeast from a root zone in the High Peaks region. This nappe is well exposed on the eastern slope of the main summit of Basin Mt.(Plate 3). Here, the Basin Thrust(Fig.5) separates the overriding, undeformed, coarsely crystalline andesine anorthosite of the core of the Marcy massif from the underlying highly deformed section of

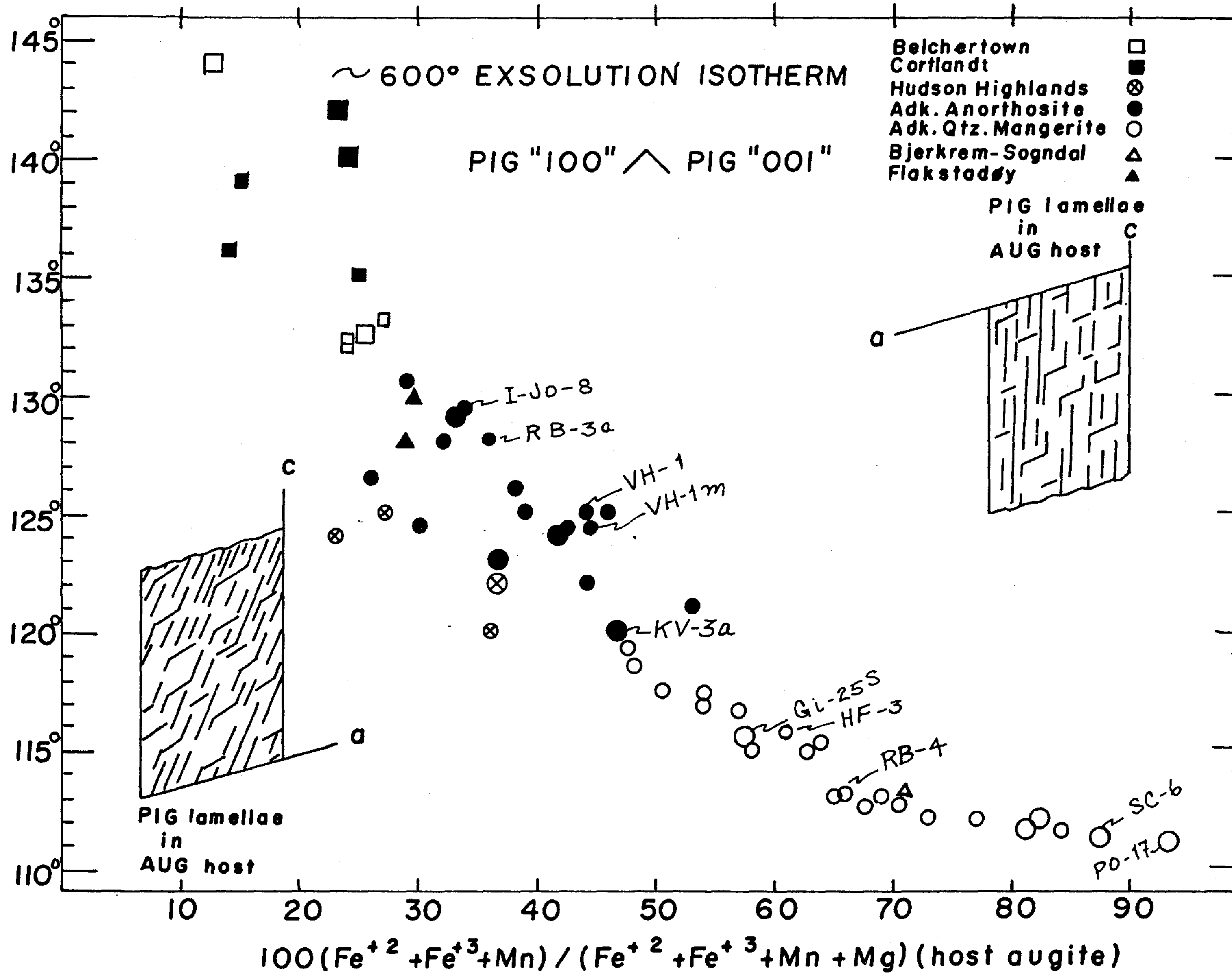


Figure 6. Diagram relating the (Fe^{2+} + Fe^{3+} + Mn)/(Fe^{2+} + Fe^{3+} + Mn + Mg) ratio with angle of intersection of two sets of pigeonite exsolution lamellae('001'∧'100') in host augite. Exsolution angles are for a 600°(metamorphic) isotherm. After Jaffe et al., 1975.

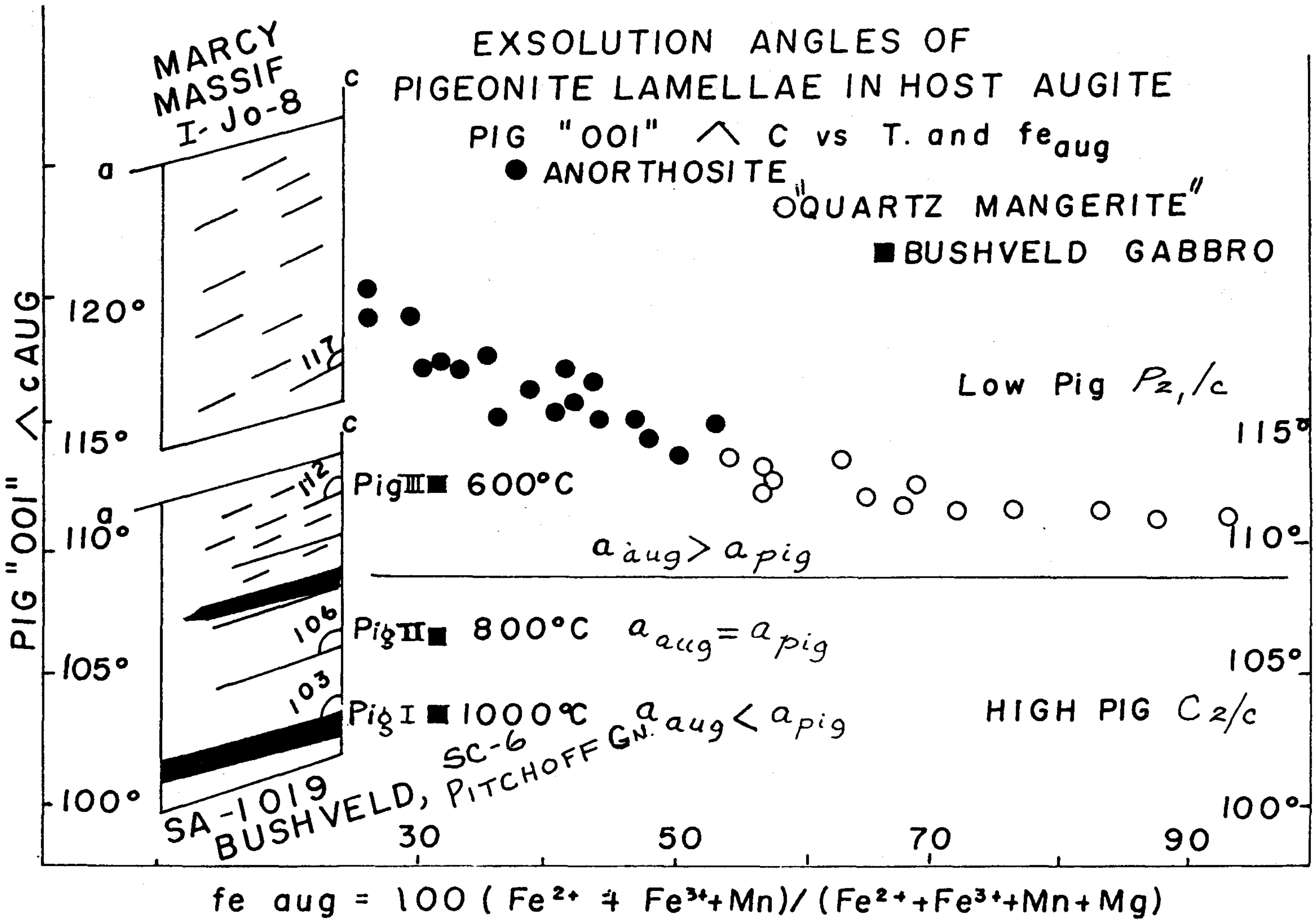


Figure 7. Diagram relating the (Fe^{2+} + Fe^{3+} + Mn + Mg) ratio with angle between '001' pigeonite exsolution lamellae and c-axis of host augite. Both low temperature(metamorphic)(Jaffe et al., 1975) and higher temperature exsolution patterns are shown(Robinson et al., 1977).

quartz-bearing ferromonzonite gneiss(Pitchoff Gneiss) intimately infolded with gabbroic anorthosite augen gneiss(Van Hoevenberg Gneiss) that make up most of the roof facies of the massif. The summits of Saddleback, Gothics, Armstrong, and Wolfjaws Mts. are all in roof facies(Fig. 5).

That regional metamorphism took place at high pressure, in the range of 8-10 kb at about 800°, is indicated by the occurrence of orthoferrosilite, Fs_{95} + quartz, and the absence of any vestiges of fayalite in the ferrosyenite facies of the Pitchoff Gneiss on Pitchoff Mountain, and in similar rocks from Scott's Cobble and the Great Range(Jaffe et al, 1975, 1978). Because recent Sm^{147}-Nd^{143} age dating yields 1288 M.Y. for the age of magmatic crystallization of the Marcy anorthosite(Ashwal and Wooden, 1983, in press) and older Pb-U age dating by Silver(1969) yield about 1130 M.Y. for crystallization and about 1100-1020 for metamorphism, the Grenville orogeny may have spanned as much as 200 M.Y. and it is difficult to fix the peak of metamorphism with a specific thermal or tectonic event in this time span.

Angles of exsolution of metamorphic pigeonite lamellae with the c-crystal axis of host augite decrease regularly with increasing Fe/(Fe+Mg) ratios of the host in all members of the anorthositic series, and the ferrosyenite-ferromonzonite series(Pitchoff Gneiss) indicating a pervasive low temperature metamorphic equilibration in the range of 500-700°, Fig.6 and Jaffe et al, 1975. These subsolidus metamorphic exsolutions of pigeonite in host augite show an orientation pattern, abundance, and size distribution very similar to those described by Jaffe, 1972 and by Jaffe and Jaffe, 1973, from Proterozoic gneisses from the Hudson Highlands. These have now been identified in all granulite facies terrain rocks of appropriate bulk composition. They differ markedly, however, from subsolidus igneous high temperature(800-1050°) pigeonite exsolution textures seen in host augites of rocks from the large layered intrusions such as Bushveld, Skaergaard, and Nain, and indeed from ferrosyenite-ferromonzonite(ferromangerite) facies of the Pitchoff Gneiss of the Marcy quadrangle(Ollila and Jaffe, in preparation). The latter show much greater solid solution, hence coarser and more abundant exsolution lamellae, and, most important, a different orientation pattern of lamellae from that observed in the much lower temperature metamorphic granulite facies rocks (Fig.7 and Robinson et al, 1977). Textures of relict high temperature igneous pigeonite lamellae in host augite and of coarse augite lamellae in inverted pigeonite are preserved in some of the anorthositic and syenitic rocks even though these have been overprinted by the pervasive low temperature metamorphic exsolution pattern. The discovery of such relict high temperature lamellae in pyroxenes with Fs>90 in the high iron syenite-monzonite series indicates that these rocks were molten at temperatures on the order of 850° or greater and pressures of 8 kb or greater(Lindsley, 1983) as no traces of a potential earlier fayalite quartz assemblage are to be found(Ollila and Jaffe, in preparation). Heating of a depressed segment of Grenville supracrustal rocks containing biotite, hornblende, carbonates and felsic volcanics by anorthositic melts at 28 km(17 mi) could produce the quartz-poor, alkali- and iron-rich anatectic melts in the presence of a CO_2-rich fluid phase. According to the data of Wendlandt(1981) such melts would become progressively richer in feldspar and lower in quartz compared to lower pressure melts.

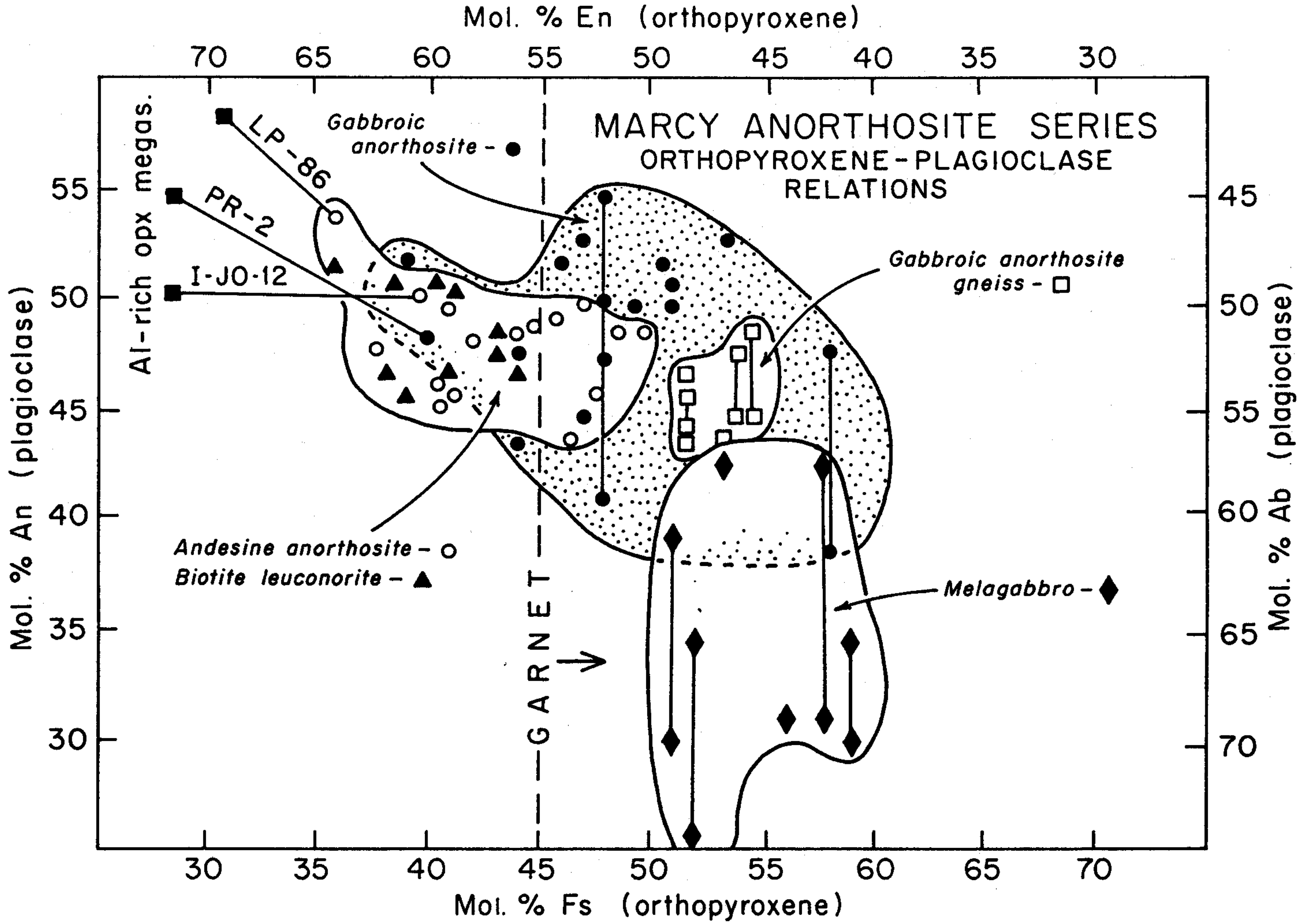


Figure 8. Diagram showing orthopyroxene-plagioclase relations in anorthosite series rocks. Tie lines connect disequilibrium assemblages of: giant Al-rich orthopyroxene + plagioclase megacrysts with their analogues in host anorthosite, and megacrysts and matrix in gabbroic anorthosite, gabbroic anorthosite gneiss, and oxide-rich melagabbro. Garnet "isograd" is at 45% Fs in orthopyroxene. Mt. Marcy quadrangle.

Ensuing magma mixing with anorthositic melts carrying calcic andesine megacrysts might produce the hybrid or transition rocks found in the Adirondacks near ferro-monzonite-anorthosite contact zones.

Equilibrated and unequilibrated orthopyroxene and plagioclase assemblages also occur in the anorthositic series(Fig. 8) and may result from magmatic convection, multiple intrusion, and perhaps from metamorphic processes such as garnet-, hornblende- and scapolite-producing reactions. Thus, Al-rich bronzite megacrysts, Fs_{29}, accompanied by labradorite, An_{55}, occur in host gabbroic or felsic anorthosite containing hypersthene, Fs_{40} and labradorite, An_{50}(Fig. 8). Some of these giant Al-rich bronzites contain spectacular, doubly terminated exsolution lamellae of pyrope-rich garnet in addition to lamellae of bytownite-anorthite. Such megacrysts are obviously exotic xenocrysts either convected into crystallizing anorthosite magma from a deep crustal or mantle source(Emslie, 1975) or intruded into crystallized anorthosite from a deep crustal or mantle source(Jaffe et al, 1983, and in press).

Apparently undeformed andesine anorthosite commonly shows a well-developed magmatic alignment of euhedral, 3-6 cm (1.2-2.4") long, conspicuously Carlsbad twinned, dark blue gray megacrysts of calcic andesine, most often An_{46-48} lying in a white matrix of plagioclase of identical composition. Gabbroic or noritic anorthosite, when undeformed, shows ophitic fabric and contains one plagioclase, An_{45-55}. Deformed and crushed gabbroic anorthosite is often hornblende-, scapolite-, or garnet-bearing and may contain plagioclase megacrysts of varying An content. A single hand specimen of gabbroic anorthosite from Cascade summit in the Mt. Marcy quadrangle contains unzoned megacrysts of composition: An_{47}, $An_{48.5}$, $An_{49.5}$, and $An_{54.5}$(Fig. 8), all in a granulated matrix of fine-grained, zoned plagioclase, $An_{41.5-43}$. Gneissic varieties of anorthosite show similar differences in composition of megacryst and matrix plagioclase composition(Fig. 8).

Garnet may appear in all anorthositic and monzonitic(mangeritic) rocks when the orthopyroxene composition exceeds Fs_{45}(Fig. 8) provided that ilmenite and/or magnetite is present. It is, however, always absent from an early crystallizing ophitic leuconorite which is low in oxides and contains biotite. Garnet occurs in three principal textural types: 1) in anorthositic rocks as coronas made up of small euhedra surrounding ilmenite, orthopyroxene, or even apatite, 2) in quartz monzonite(mangerite) gneisses(Pitchoff Gneiss) as a finer grained aggregate of anhedral symplectite with vermicular quartz, as well as in single euhedra in contact only with plagioclase, and 3) in anorthositic rocks as anhedral grains or elongate rods nucleating inside of and replacing zoned sodic andesine along albite twin lamellae. Formation of garnet with increasing iron enrichment in orthopyroxene accompanied by opaque oxides supports similar findings by McLelland and Whitney(1977) and by Martignole and Schrijver (1973) for both the Marcy and Morin complexes. They believe that garnet forms in these rocks due to a retrograde cooling at pressure whereas the present authors agree with Buddington(1969) who favored a regional metamorphic origin for most of the garnet. In view of the different textural varieties observed, it is probable that more than a single process is responsible for nucleation of garnet.

Further complicating the metamorphic history of the region is the presence of monticellite in silicated marbles in contact with quartz syenite gneiss infolded with gabbroic anorthosite on Cascade Slide and elsewhere in the Mt. Marcy quadrangle where the assemblages: calcite-forsterite-diopside-magnetite-spinel, calcite-forsterite-monticellite-diopside-spinel-andradite and calcite-forsterite-diopside-monticellite-spinel-idocrase were reported by Tracy, Jaffe and Robinson, 1978. Jaffe in Baillieul(1976) also reports the second occurrence of the rare calcium borosilicate, harkerite, at this locality, and Valley and Essene, 1979, 1980, report the occurrence of åkermanite, from the same locality. Wollastonite occurs in calcareous quartzites and siliceous marbles at several localities in the quadrangle and may occur in proximity to monticellite-bearing assemblages. One additional sample contains the assemblage calcite - quartz-diopside-grossular without wollastonite. The presence of monticellite in rocks metamorphosed at high pressure may be due either to a low activity of CO_2 in the metamorphic fluid(Tracy et al, 1978), a complex metamorphic history of regional superposed on earlier contact metamorphism, or marked variations in the CO_2 and H_2O fluid compositions during regional metamorphism(Valley and Essene, 1980).

Retrograde metamorphic effects are seen mostly in highly deformed rocks where communication with water, halogens and carbon dioxide was possible, these being available in, and supplied by, the Grenville supracrustal sequence. In deformed gabbroic-noritic anorthosite roof rocks, hornblende rims augite, often with the development of quartz; scapolite replaces andesine in fracture zones, and garnet is at least, in part, later than hornblende. Prehnite, pumpellyite, chlorite, calcite, sericite, and albite occur in very late fractures that post-date scapolite-hornblende assemblages. Microperthite and ferroaugite of syenitic-monzonitic gneisses commonly show two and often three different sets of exsolution lamellae attesting to repeated subsolidus re-equilibration. Extensive retrograding is found in mylonitic contact zones of the larger pre-metamorphic garnetiferous gabbro dikes that intrude the andesine anorthosite of the core facies of the Marcy massif. An example of these is the 75'(23 m) wide Avalanche dike in Mt. Colden, in which hornblende replaces augite, serpentine replaces hypersthene, and scapolite replaces plagioclase, and where slickensided joints are coated with mylonitic smears of cryptocrystalline quartz, serpentine, and calcite(Jaffe, 1946). Post-metamorphic diabase dikes show total retrograding of all mafic minerals to fine-grained aggregates of calcite, chlorite, talc, and magnetite. The geologically much younger camptonite dikes show only slight serpentinization of olivine phenocrysts and extensive deuteric alteration of clinopyroxene only in very narrow zones that immediately border spherical calcite+sodic plagioclase-filled amygdules(Jaffe, 1953 and Fig. 10).

Stratigraphic succession and structural history of the Mt. Marcy quadrangle.

Geochronologic setting:

An extensive geochronologic investigation of syenitic and anorthositic

Table 2. Stratigraphic succession and tectonic history-Mt. Marcy quadrangle.

Map symbol	Unit	Event	Orientation
		DIKE INTRUSION Camptonites	NE-SW
		DIKE INTRUSION Diabases	NE-SW
		BLOCK FAULTING	NE-SW
		OPEN FOLDING Axes	NE-SW, NNW-SSE
CORE FACIES	Map symbols are not distinct from those of roof facies below		
	Metagabbro dikes NW-SE	INTRUSION	
gb	Gabbro includes melagabbro, oxide-rich gabbro, pyroxenite, and anorthositic gabbro	INTRUSION	
ga	GABBROIC ANORTHOSITE includes gabbroic and noritic anorthosite, C.I. 10-35	INTRUSION NW-SE	
a	ANORTHOSITE - andesine $\pm$ hypersthene, C.I. < 10, containing rafts of biotite leuconorite		
		OVERTHRUSTING	SW-NE
ROOF FACIES	Map symbols not distinct from those of core facies above	RECUMBENT FOLDING Axis	NW-SE
pog	PITCHOFF GNEISS - syenite-monzonite gneiss with opx Fs_{80-95}	ANATEXIS AND INTRUSION	
vhg	VAN HOEVENBERG GNEISS - gabbroic anorthosite augen gneiss with layers of oxide-rich gabbro and pyroxenite		
ga	GABBROIC ANORTHOSITE - hornblende gabbroic and noritic anorthosite		
gac	Gabbroic anorthosite with prominent garnet coronas		
ap	Percalcic anorthosite contaminated with calc-silicate and amphibolite	INTRUSION	
a	ANORTHOSITE - andesine anorthosite, C.I. < 10, enclosed in block structure	INTRUSION	
		RIFTING	NW-SE
		RECUMBENT FOLDING Axis	E-W
sgb	MICROPERTHITE GRANULITE - garnet-orthopyroxene(Fs_{60-80})-clinopyroxene-plagioclase-K-feldspar granulites, C.I. 5-50, of igneous parentage (sills or volcanics)	RECUMBENT FOLDING Axis	E-W
gvu	GRENVILLE SUPRACRUSTALS UNDIFFERENTIATED including calc-silicate, quartzite, marble, pyroxene microperthite granulite, amphibolite, hornblende granite gneiss, scapolite gneiss	SEDIMENTATION AND VOLCANISM	

rocks of the northeastern Adirondacks was carried out by Silver(1969) using Pb-U isotopic compositions of zircon. Because of the paucity of zircon in anorthositic rocks and its abundance in the syenitic gneisses, the bulk of Silver's data may be more applicable to the metamorphic, rather than to the igneous events. Nevertheless, Silver obtained values of 1130 x 10^6 yrs, believed to represent anorthositic intrusion, and 1100-1000 x 10^6 yrs. for the metamorphic(Grenville orogeny) event. He believed, with Buddington, that these events were largely synchronous or syntectonic. Ashwal and Wooden(1983, in press) recently used Sm^{147}-Nd^{143} isotopic dating to establish a 1288 x 10^6 yr plagioclase-pyroxene isochron believed to represent a crystallization age for andesine anorthosite of a core facies, and 995-973 x 10^6 yr from garnetiferous oxide-rich melagabbro dikes that intruded anorthosite, and are thought to represent the prograde metamorphic(Grenville orogeny) event. If the recent Sm-Nd dates are more correctly interpreted, we are dealing with an interval of about 300 x 10^6 yr. between the crystallization of a core anorthosite and the peak of the Grenville orogeny. How much younger the melagabbro dikes are than the anorthosite they intrude has not been established. Nonetheless, these Sm-Nd data would appear to cast doubt upon a syntectonic origin for intrusion and deformation. Because no dates older than 1300-1350 x 10^6 yr have been reported for Grenville province rocks, the Sm-Nd dates leave but 12 - 67 x 10^6 yr for sedimentation, induration, and two periods of recumbent folding prior to anorthosite intrusion(Table 2). The geochronologic data and the field relations(Table 2) thus indicate that the Grenville orogeny began before the intrusion of anorthosite, at perhaps 1300 x 10^6 yr, then culminated at about 1000 x 10^6 yr, and subsequently diminished to perhaps 975 x 10^6 yr in a retrograde phase. The duration of the Grenville orogeny is thus on the order of 350 x 10^6 yr and should not be thought of as the 1000 x 10^6 yr event so often recorded in the literature.

Field relations: Roof facies(Table 2)

In the Proterozoic, perhaps about 1350 x 10^6 yr, a succession of sedimentary and volcanic rocks here referred to as the Grenville Series (Table 2, gvu) was deposited in a marine environment. These were limestones, siliceous carbonate rocks, sandstones, and marls, with intercalated mafic and felsic volcanics or sills(Table 2, sgb). These strata were then folded and metamorphosed once and possibly twice. The direction of the axes of these earlier folds is obscure, but may be east-west like those of the early folds in the southern Adirondacks(McLelland and Isachsen,1980).

Anorthosite of the present roof facies(Table 2, a, ga, gac, ap) was then intruded into these folded layers along a NW-SE rift, which is defined by the long axis of the principal lobe of the anorthosite massif (Fig. 1). This may have occurred at a depth of 35 km(21 miles) or perhaps may have taken place at a shallower level(Valley and O'Neil, 1982), with the anorthosite-Grenville complex then being buried, depressed, or dragged down to 35 km(21 miles), where it was metamorphosed.

The anorthosite of the roof facies did not intrude as a single body which, on cooling, developed a chilled border and coarse-grained interior. Instead, there were multiple pulses of intrusion of anorthositic magmas with different plagioclase:pyroxene:ilmenite ratios. Some were liquid, and others were partly or almost wholly crystalline. Xenoliths of one type of anorthosite in another are common, as are xenoliths of Grenville series rocks with high melting points. Dikes of anorthosite occur in different types of anorthosite. Alkali-rich members of the Grenville series, with lower melting temperatures(Table 2, pog) were partly to completely melted by the invading anorthosites, to intrude the solidifying anorthosites in their turn.

The early anorthosite intrusions, the Grenville series rocks, and their hybrids, were isoclinally and recumbently folded together along an east-west axis more or less parallel to fold axes developed during the two early phases of folding. The Pitchoff and Van Hoevenberg gneisses (Table 2, pog and vhg) were formed at this time.

Field relations: Core facies(Table 2)

The core facies consists predominantly of relatively undeformed felsic andesine anorthosite intruded by smaller bodies of gabbroic and noritic anorthosite, and by dikes of pyroxenite, garnet+oxide-rich melagabbro, and garnetiferous gabbro, also relatively undeformed. In the Santanoni quadrangle, gabbroic anorthosite clearly intrudes felsic andesine anorthosite along a NW-SE trend with two short lobes oriented NE-SW. In the Mt. Marcy quadrangle, NNW-SSE-trending pyroxenite dikes intrude felsic anorthosite on Roaring Brook in the easternmost part of the map area(Plate 4). These dikes and the anorthosite they intrude were both fragmented and healed by the later intrusion of gabbroic anorthosite. Pre-metamorphic garnetiferous gabbro dikes(Jaffe, 1946) commonly intrude the core anorthosite along NW-SE fractures.

Typical felsic anorthosite of the core facies has a protoclastic texture characterized by angular to sub-rounded, dark blue-gray andesine-labradorite megacrysts in a white, granular andesine-labradorite matrix; both megacryst and matrix have the same An content; commonly 46-48, but occasionally greater than 50. The core anorthosite has retained a characteristic alignment of plagioclase megacrysts interpreted to represent a flow foliation. Proof of its igneous origin can be found near contacts with biotite leuconorite rafts where the plagioclase megacrysts of the anorthosite have been deflected by and appear to have flowed around the rafts(Fig. 2). Foliation of megacrysts in the core anorthosite is generally steep to vertical, but otherwise randomly oriented; notable exceptions to this are at the top of Haystack and Basin Mts., where they are flat to horizontal. Intrusive contacts of core anorthosite with rocks of the roof facies have nowhere been observed. Instead, near the top of Basin Mt., undeformed core anorthosite has overriden intensely deformed rocks of the roof facies(Fig. 5). This contact, named the Basin Thrust, is exposed at the 4760'(1451 m) level on the eastern slope of Basin Mt. Here, the underlying and deformed ferromonzonitic gneiss of the roof facies is shattered and sheared from 4740'(1445m) to 4760 '(1451 m). Immediately above this shear zone lies relatively undeformed, coarsely-crystalline, megacryst-rich, felsic andesine anorthosite which forms the rest of Basin Mt. and all of the highest Adirondack Mts. immediately to the west (Mts. Haystack, Marcy, Skylight, Colden, Algonquin, etc., Plate 4). To the east of this contact, all rocks of the roof facies, including anorthositic members are intensely deformed. The core has been thrust over the roof.

Field relations summarized in Table 2 indicate that two periods of folding of Grenville strata were followed by intrusion of anorthositic melts and in turn, by syenitic-monzonitic melts, of a roof facies. All of these rocks underwent pervasive recumbent folding followed by overthrusting of a core anorthosite facies as nappe structures. The actual mode of emplacement of the anorthosite of the little-deformed core facies remains an enigma and any of the following scenarios are possible:

1) The anorthosite core facies was crystallized at considerable depth and thrust over the anorthosite-syenite-Grenville complex of the roof facies after the peak of the Grenville orogeny.

2) The anorthosite core facies was emplaced into or over the roof facies either by faulting or by diapyric rise of an essentially crystallized mush. A major orogenic compressive event followed during which the roof facies was recumbently folded and the core facies subsequently thrust over the roof facies. During this event the rigid, homogeneous core facies may have functioned as a battering ram.

3) The anorthosite of the core facies was intruded late, and more or less syntectonically, into the same NW-SE rift environment as the roof facies anorthosite, induced folding in the latter, and was eventually thrust over the latter. Here the waning stages of an extensive rifting event would be the harbinger of a major compressive event.

On the basis of field relations alone we cannot discriminate among these hypotheses.

The extent to which the undeformed, but sheared and garnetiferous anorthosite of the core has been subjected to a granulite facies regional metamorphism may be debated. Much of the evidence rests upon the extensive crushing of plagioclase megacrysts, the common occurrence of garnet in reaction rims between ore or pyroxenes and plagioclase in granulation zones, presence of pervasive low temperature (500-600^{o}) exsolution textures that have supplanted relict higher temperature (800-1050^{o}) exsolution textures in pyroxenes (Figs. 6 and 7), and upon the geochronological evidence discussed above. Although the lower temperature pyroxene exsolution textures are often ascribed to metamorphic reequilibration under granulite facies conditions, they need not be so derived. They may alternatively be due to the slow cooling of magmatic pyroxenes in host rocks held between 500 and 800^{o} for a long duration at pressure. If the formation of garnet in anorthositic rocks is caused by retrograde cooling at pressure (Martignole and Schrijver, 1973, McLelland and Whitney, 1977), the crushing of plagioclase megacrysts by protoclasis, and the low temperature pyroxene exsolution textures by slow cooling from 700-800^{o}, one may question whether the anorthosite of the core facies was indeed post-orogenic or pre-orogenic. The preservation of flow foliation and a 1288 x 10^6 yr Sm-Nd date ascribed to crystallization of core anorthosite may suggest post-orogenic emplacement; the larger number of isotopic ages in the range, 973-1100 x 10^6 yr suggest a high grade, pre-orogenic event. Melagabbro dikes intrusive into the core anorthosite are dated at 950-995 x 10^6 yr but the interval between the anorthosite crystallization and dike intrusion is not known.

We do not favor a post-orogenic emplacement of the core anorthosite but wish to call attention to an alternative hypothesis.

At some time after the core anorthosite was emplaced, by whatever process, open folds developed along NNW-SSE axes in the Mt. Marcy quadrangle, and NE-SW axes in the Saranac and Santanoni quadrangles. This folding affects both the earliest anorthosite-Grenville series complex or roof facies, and the late, overthrust anorthosite or core facies.

Block faulting, principally NE-SW in direction, began in the Precambrian and continued at least through Middle Ordovician. The Mt. Marcy quadrangle may be divided into three principal fault blocks: the Pitchoff Block, NW of the Cascade Lakes-Henderson Lake fault is the most downdropped; the Mt. Marcy Block, in the center of the quadrangle, and north of the Ausable Lake fault which was downdropped less; and the Dix Block, south of the Ausable Lakes fault zone, is the least downdropped. The north-south Keene Valley fault zone is probably later than the Ausable and Cascade-Henderson Lakes faults.

Post-metamorphic dikes of Late Precambrian or Paleozoic age and camptonite dikes of Cretaceous age, both intruded in NE-SW fractures.

1983 FRIENDS OF THE GRENVILLE FIELD TRIP STOPS

The 1983 Annual Friends of the Grenville Field Excursion will make 12 stops, 10 in the 15' Mt. Marcy quadrangle, and 1 each in the 15' Santanoni and Elizabethtown quadrangles to visit representative outcrops of anorthositic rocks, ferrosyenitic-ferromonzonitic gneiss, and Grenville series rocks. The 12 stops are located by number on Plate 4, the topographic map bound in the back cover of this guide. The 12 stops are also telescoped in Figure 1, a generalized geologic map of the Marcy massif.

Because most of the outcrops are on state land and preserve an often delicate rock record of some 1350 x 10^6 yr, it is requested that <u>no hammers be used on outcrops</u>; samples should be collected from rubble. It is, in fact, a violation of New York State law to collect samples of rock on state land without express permission.

<u>CAUTION</u>: Parties of 30-60 people on trails with loose rubble and on narrow and sometimes precipitous ledges may generate hazards. Please exercise caution, particularly on stops: 2, 4, 8, and 9.

Stop 1. The MARCY ANORTHOSITE-CORE FACIES-MT. JO

Mt. Jo, elev. 2876'(877 m.), which lies just north of Heart Lake, elev. 2178'(664 m), and is the only mountain owned by the Adirondack Mountain Club, offers a full range of anorthosite lithologies for study of the primary igneous textures associated with the core of the Marcy anorthosite massif. Although the massif has been metamorphosed under granulite facies conditions of about 8 Kb and 800°C during the 1100 M.Y. old Grenville orogeny, the homogeneity and rigidity of the core has permitted preservation of many of the textures associated with magmatic emplacement such as primary flow structure expressed by aligned andesine megacrysts in andesine anorthosite, and ophitic texture in noritic-gabbroic anorthosite, and in norite pegmatite. A well-developed primary magmatic foliation commonly observed in the felsic anorthosite core of the Marcy massif is formed by the rude to perfect parallelism of: (010) crystal faces, conspicuous, simple, but broad Carlsbad twin slabs, and less obvious albite twin lamellae of the calcic andesine-labradorite megacrysts. This megacryst foliation, although often strongly developed on a single outcrop, may vary appreciably in azimuth over a large outcrop pavement. Frictional resistance, convection, and impedance by crystallized masses of leuconorite may combine to produce the various foliation patterns observed. Extensive size-reduction of plagioclase megacrysts may often result from intrusion tectonics or protoclasis, rather than from regional metamorphism or cataclasis.

There are two trails to the summit of Mt. Jo; we will climb the mountain via the Short Trail and return via the Long Trail. Our 700' (213 m) climb takes off from the N.E. corner of Heart Lake and climbs at a moderate grade to the trail junction at 0.2 mi (0.32 km). Bearing right, up the Short Trail, we will pass our first low pavement outcrop at 2300'(701 m). Near 2400' (731 m), the trail narrows and a prominent, west-facing vertical wall of anorthosite rises abruptly. This first cliff(sample locality I-Jo-14, Fig. 9) consists of very crushed felsic or andesine anorthosite with a megacryst percentage(M.I.)=10-30 and a color index(C.I.)=5. Calcic andesine megacrysts average 3 x 0.6 cm;coarse megacrysts, 6 x 3 cm, are sparse and markedly anhedral because of granulation. Occasional 30-60 cm ovoid clots of coarse andesine and smaller, broken megacrysts lie in a fine-grained matrix, often noritic. Garnet and ilmenite tend to be associated with the coarser andesine anorthosite component, whereas biotite may be found in the finer noritic component. Although the extensive fracturing and abrasion of the megacrysts could be interpreted as metamorphic in origin, we believe it occurs because of intrusion protoclasis produced during a stage when single megacrysts and clots of early-formed megacrysts mingled with, and were embayed and forcibly injected by, residual leuconoritic liquid.

Megacryst foliations over most of Mt. Jo trend near E.-W. and dip nearly vertically, but those in fractured areas and in areas near leuconorite inclusions often show gentle dips. On this fractured face of the cliff, a gently north-dipping foliation is apparent, but not representative, and conclusions regarding megacryst orientation are best deferred until we examine pavement outcrops near the summit.

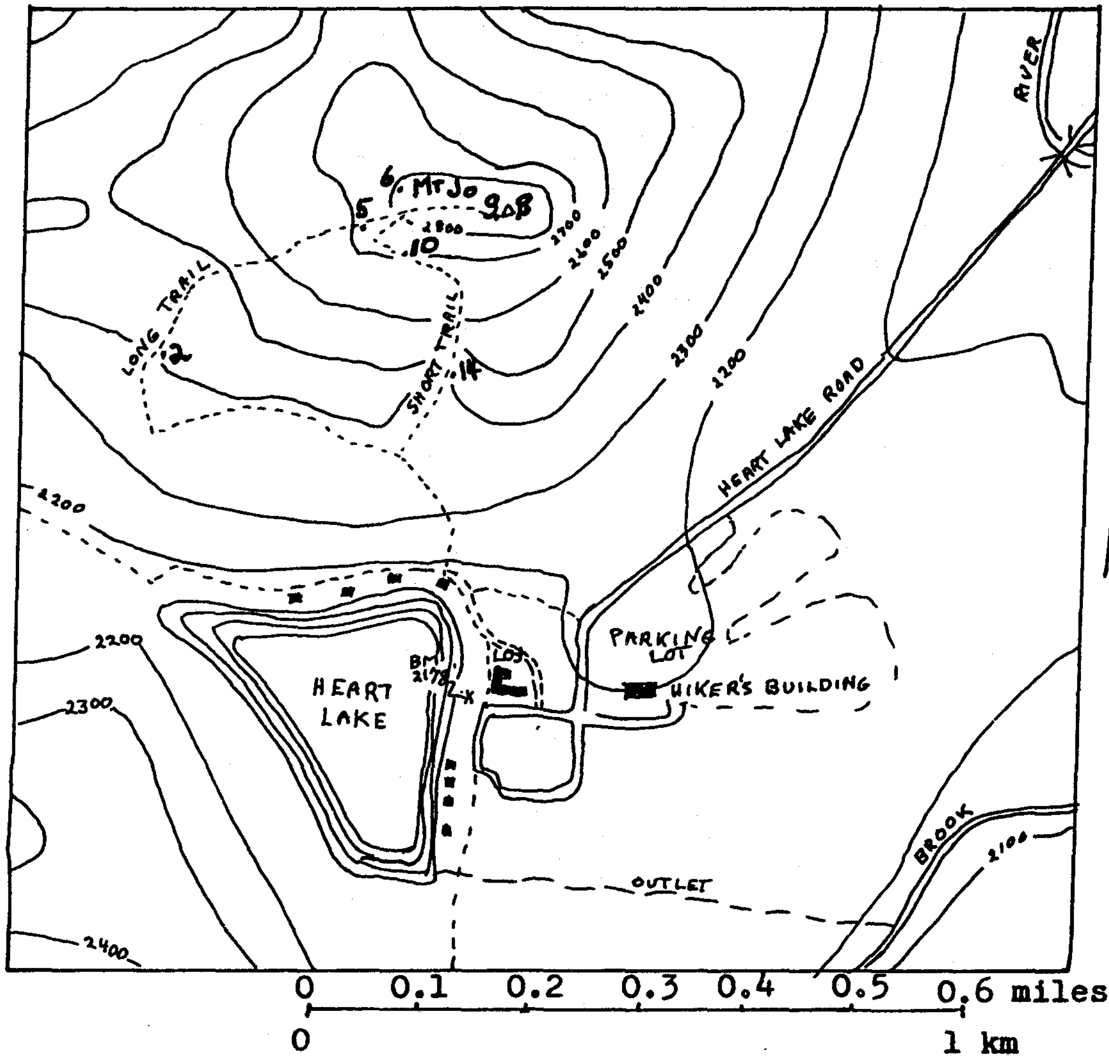


Figure 9. Map of Adirondack Mountain Club property, showing Heart Lake, Adirondak Loj, and geologic locations on Mt. Jo. Mt. Marcy quadrangle.

At about 2700'(823 m) near a good lookout, south, to Heart Lake, at locality I-Jo-10(Fig. 9) a garnetiferous gabbroic anorthosite(C.I.=15) shows garnet, ilmenite, and pyroxenes, with plagioclase megacrysts showing a N55E80N foliation. As we scramble up the main summit, near 2860' (872 m) we see bare pavement outcrops that show coarse andesine anorthosite(M.I.=45, C.I.=5), with 4-7 x 1-2 cm(1.6-2.8 x 0.4 x 0.8') plagioclase tablets defining a marked N80W90 foliation. Characteristic coronas of garnet around ilmenite and pyroxene may be seen in the matrix and in fractures in megacrysts. A bit further along we encounter a small ovoid inclusion or raft of biotite leuconorite "floating" in the felsic anorthosite. These rafts have leuconoritic-leucogabbroic composition, C.I.= 20-25, and subophitic texture(see modes, Table 3). The rafts always contain biotite but no garnet whereas the enclosing host anorthosite has C.I.=only 5, but always contains garnet and lacks biotite. Andesine megacrysts flow around and were deflected by the earlier crystallized leuconorite raft(Fig. 2). On the summit at 2876'(877 m), at locality I-Jo-8,(Fig. 9), the two rock types are in a less well defined relation. The summit rock consists of a 1-3'(30-90 cm) layer of biotite leucogabbro containing megacrysts of andesine which show the same foliate orientation seen in the adjoining host anorthosite. Here, the megacrysts are interpreted to have been streaming away from incompletely crystallized residual leucogabbroic liquid. Both megacrysts and pockets of residual liquid were nucleating at about the same time. A small, but significant H_2O content and a low ilmenite content appear to favor the formation of biotite in the leuconorite, whereas the reverse, dry, oxide-richer composition favors the growth of garnet in the host anorthosite. Biotite leuconorite rafts are a characteristic feature of the Marcy anorthosite and occur throughout the 3000'(915 m) of exposed section of the core of the massif.

Another minor, although conspicuous, outcrop feature of the Marcy anorthosite is the occurrence of arcuate "ridge veins" rich in garnet. In the Marcy massif, all other lithologic types of dike rocks are consistently less resistant to erosion than the anorthosite and are commonly the loci for waterfalls in anorthosite terrain. The "ridge veins", alone, are more resistant to erosion due to the presence of abundant quartz and garnet. The veins contain garnet, quartz, magnetite, plagioclase, and smaller amounts of augite, hypersthene, and potassium feldspar. The source of these very late stage solutions is not apparent but may be anorthositic.

Retracing our steps about 0.1 miles(0.16 km) brings us to the junction of the Short and Long Trails, where, time permitting, we will detour on a short bushwhack to view a part of the west summit where two narrow amygdular olivine-bearing camptonite dikes, samples DMJ-1 and 2 at locality I-Jo-6(Fig. 9) form steep sided erosional slots in the more resistant anorthosite host rock. The camptonites(Jaffe, 1953 and Fig. 10) carry phenocrysts of fresh olivine, zoned titanaugites with good hourglass structure, kaersutite or titanian hornblende, and spherical calcite+sodic plagioclase filled amygdules, all lying in an andesine, An_{30-35}, groundmass. These fine grained lamprophyres are distinguished from diabases only by the presence of vesicles derived from the weathering of calcite-

Table 3. Modes of anorthositic rocks from Mt. Jo, Marcy Massif, N.E. Adirondacks.

	Biotite leuconorite		Andesine anorthosite		Norite Pegmatite
	I-Jo-6B	I-Jo-8	I-Jo-6a	I-Jo-9	I-Jo-2
Plagioclase					
Megacryst	-	-	56.1	43.2	57.
Matrix	80.0	75.6	36.9	50.5	-
Hypersthene	15.6	4.6	1.0	3.0	40.
Augite	1.0	17.4	0.8	1.2	2.
Biotite	2.6	0.2	0	0	1.
Ilmenite	0.4	2.0	0.8	1.0	-
Magnetite	-	+	-	-	-
Garnet	0	0	4.4	1.1	0
Apatite	0.4	0.2	+	+	+
Total	100.0	100.0	100.0	100.0	100.
Plagioclase					
An, Megacryst			46.5	47.5	51.5
An, Matrix	48.5	46.5	46.5		
Fs, Hypersthene	39.5	44.		45.	34.
Fs, Augite	27.	33.		31	
Color Index	20	24	7	6	43

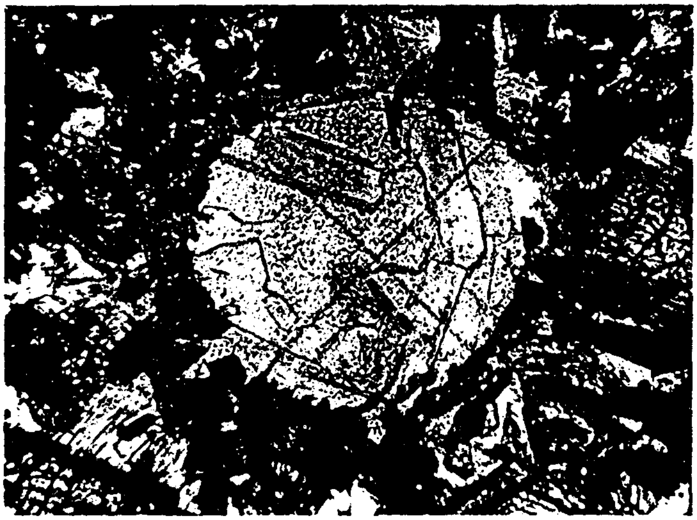


Fig. 6. Plagioclase laths and calcite in an amygdule.

(Plane polarized light ×150.)

Fig. 3. Hourglass structure in clinopyroxene

(Crossed nicols ×150.)

Table 2. Modes* of Three Camptonite Dikes from Mount Jo, Essex County, N. Y.

	DMJ-1	DMJ-2	DMJ-3
Olivine†	12.5	14.2	10.8
Augite+pigeonite	32.3	16.0	28.0
Brown hornblende	16.8	32.5	23.2
Biotite	2.0	3.1	2.0
Magnetite	10.2	14.2	8.4
Plagioclase (An_{22-35})	24.0	18.0	25.8
Calcite	2.2	2.0	1.8
Apatite	Trace	Trace	Trace
	100.0	100.0	100.0

* All percentages by volume.
† Includes some secondary serpentine and talc.

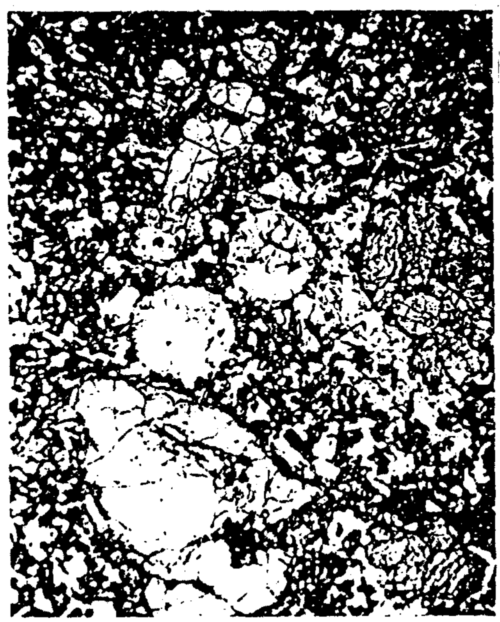


Figure 10. Amygdular and hourglass textures, and modes of camptonite dikes from Mt. Jo. Jaffe, 1953. Mt. Marcy quadrangle.

filled amygdules, and by abundant ferromagnesian mineral phenocrysts, both lacking in diabases. The undeformed spherical amygdules suggest that these dikes are geologically young and presumably correlative with radiometrically dated Cretaceous lamprophyres that intrude Paleozoic strata to the east. The dikes are oriented N31W90 and transect the strong N78W60-90 foliation in the andesine anorthosite.

Returning to the trail junction and descending the Long Trail, we meet a third camptonite dike, DMJ-3, at locality I-Jo-5(Fig. 9) in the trail at elevation 2700'(823 m). Its silica-undersaturated and alkalic affinity, indicated by the presence of normative nepheline+orthoclase (Jaffe, 1953) which are absent modally, results from the presence of the alkalic, low-silica amphibole, kaersutite. We reach sample location I-Jo-2 elevation 2405'(753 m) after a 0.3 mile(0.46 km) descent. Here, pockets of undeformed biotite-bearing norite pegmatite are emplaced in fractured garnetiferous andesine anorthosite. The norite pegmatites consist of magnesian hypersthene, Fs_{34}, and labradorite, $An_{51.5}$, both more magnesian and calcian, respectively, than those found in the enclosing host anorthosite, which carries andesine, An_{47}, and hypersthene, Fs_{45}. The pegmatitic, magnesian hypersthene carries inclusions of sphene, lamellae of titanhematite and plagioclase, and shows strong chemical and mineralogical affinities with the giant Al-rich orthopyroxene megacrysts of anorthosites (Emslie, 1975 and Jaffe, et al, 1983). Most orthopyroxene megacrysts in the Mt. Marcy quadrangle carry calcic plagioclase exsolution lamellae, whereas others have exsolved pyrope-rich garnet.

Notes:

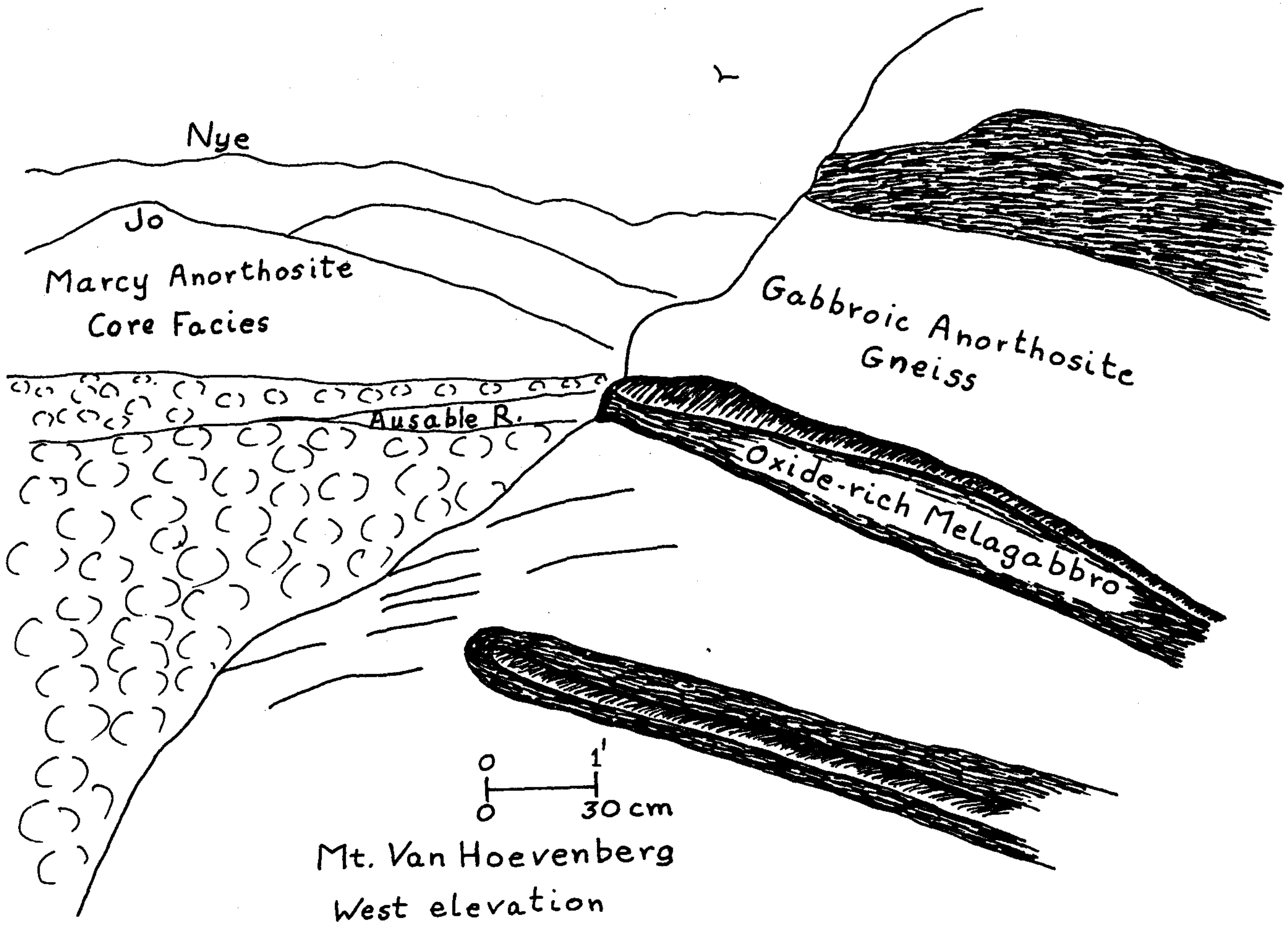


Figure 11. View west to Nye Mt. from ledge below summit of Mt. Van Hoevenberg, showing oxide-rich melagabbro cumulate layers recumbently folded in Van Hoevenberg gabbroic anorthosite augen gneiss. A schistosity cuts the folds and dips in the opposite direction. Mt. Marcy quadrangle.

Stop 2. THE VAN HOEVENBERG GNEISS-GABBROIC ANORTHOSITE AUGEN GNEISS WITH LAYERS OF OXIDE-RICH MELAGABBRO-ROOF FACIES

Drive five miles (8 km) north on Heart Lake Road, 3.5 miles (5.6 km) east on N.Y. Route 73, and one mile(1.6 km) south on entrance road to the Mt. Van Hoevenberg parking lot at the base of the site of the bob sled and luge runs of the 1932 and 1976 Olympic Games. We will be ferried by bus to the top of the bob sled run at 2500'(762 m) and will climb by foot trail to the prominent 2860'(842 m) flat summit of Mt. Van Hoevenberg. A series of flat ledges look to the southwest across the South Meadow lowlands to the prominent anorthosite cones of Mt. Colden, 4714'(1437 m) and Algonquin Peak, 5114'(1559 m) in the core of the Marcy massif.

The country rock, an excellent geologic mapping marker unit, is the hornblende-garnet gabbroic anorthosite augen gneiss. It is a highly deformed gabbroic-noritic anorthosite containing cumulate layers of inverted-pigeonite pyroxenite diluted by plagioclase melt to produce a melagabbroic composition(Table 4 and Fig. 11). It has also been contaminated by the incorporation of small amounts of granitic melt. The thin layers of the melagabbro, and the constancy of composition of plagioclase and pyroxenes of the anorthosite gneiss and the mafic layers, suggest that the latter are cumulate layers rather than sill-like injections. Gneissic foliation is enhanced by the folded mafic layers and by crenulated streaks and thin layers of hornblende+garnet+augite wrapped and bent around abraded augen of calcic andesine. Sporadic xenoliths of granulated andesine anorthosite and supracrustal rocks orient as flattened plates in the well-defined plane of foliation, which is oriented N12W15NE, a mineral lineation trends N20E15(Fig. 12). A later schistosity transects the foliation at a low angle(Fig. 11). During the Grenville orogeny, isoclinal recumbent folding was succeeded by thrust faulting, during which time andesine anorthosite of the core of the Marcy massif was thrust from the west and southwest to the north and northeast over the gabbroic anorthosite, quartz ferromangerite, and supracrustal gneisses of the roof facies of the massif. A major low angle fault, the Basin Thrust, exposed on Basin Mt. to the south, separates the anorthosite core from the gneissic rocks. Where exposed, the Basin Thrust dips gently to the west and strikes in a N20W direction. Thus, it extends from Basin Mt. along Klondike Brook to South Meadow between Jo and Van Hoevenberg summits. Below our vantage point it is transected by the Cascade Lakes Fault, one of the major N40E steeply dipping fracture zones that dominate the topography of the Northeastern Adirondacks. The Cascade Lakes Fault has down-dropped the northern block (Pitchoff block) containing the quartz ferromonzonite gneisses of Pitchoff Mt., the gabbroic anorthosite gneiss of Mt. Van Hoevenberg, and the andesine anorthosite of Mt. Jo in the core of the massif, from the adjoining Marcy Block to the Southeast.

We will return to the parking lot by foot enjoying the opportunity to view the construction and curves of the bob sled run in detail.

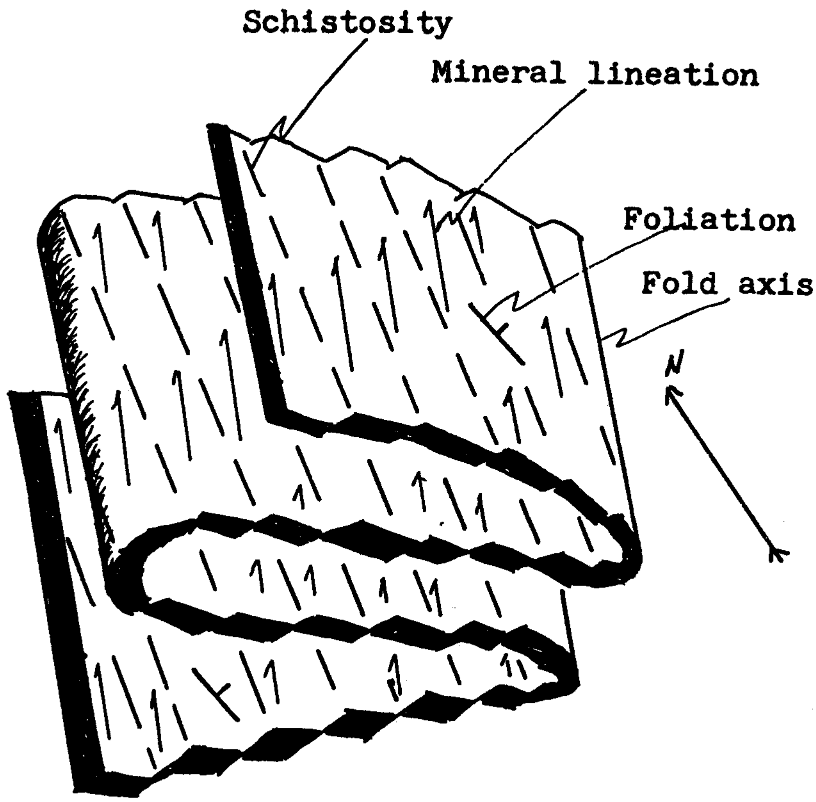


Figure 12. Detail of folded oxide-rich melagabbro cumulate layer in Van Hoevenberg gneiss; foliation N12W15E; mineral lineation N20E15 is parallel to the fold axis, and is cut by west-dipping schistosity. Mt. Marcy quadrangle.

Table 4. Modes of the gabbroic anorthosite augen gneiss(Van Hoevenberg Gneiss) and mafic layers from Mt. Van Hoevenberg summit.

	VH-1	VH-1m
Quartz	0.1	0.1
Microperthite	7.0	+
Plagioclase		
Megacryst	15.6	26.4
Matrix	58.4	+
Hypersthene	1.8	15.0(Inverted pigeonite)
Augite	8.8	28.0
Hornblende	2.2	6.4
Garnet	2.8	10.7
Ilmenite	2.4	7.3
Magnetite	0.6	6.0
Apatite	0.3	0.1
Total	100.0	100.0
An, Megacryst	45.5	43.5
An, Matrix	43.5	43.5
Fs, Hyp.	57	52.
Fs, Aug.	44.	44.
Color Index	19.	74.

Stop 3. GRENVILLE MARBLE-SYENITE-ANORTHOSITE SECTION SOUTH OF KEENE

Drive five miles(8 km) northeast on Route 73 to the first right turn after a Gulf gasoline station and almost into Keene village center. Turn right(south) on the westernmost of two small roads that parallel both sides of the East Branch of the Ausable River. Drive about 0.75(1.2 km) miles south on this western side of Hulls Falls Road and park judiciously along the edge of this little travelled road. Descend about 25'(7.6 m) to the bank of the river watching out to avoid standing or sitting in Rhus toxicodendron which commonly grows in Grenville marble terrain. A fine river outcrop of folded Grenville marble consists of calcite(white), diopside(green), fluopargasite(black), and minor glistening flakes of phlogopite(brown) along with less abundant graphite. Pink quartz leucosyenite and black-streaked gray-white gabbroic anorthosite gneiss have been dragged into highly contorted syntectonic folds enhanced by the plasticity of the marble and the probable molten state of the quartz syenite and gabbroic anorthosite(Fig. 13). Occasional tongues of gabbroic anorthosite cross-cut the syenitic rocks. A major vertical fracture zone, the Keene Fault Zone runs parallel to the river in a N-S direction, and is well exposed about one-half mile (0.8 km) south in a granulated anorthosite outcrop. The Keene Fault has dragged the preexisting, gently north dipping, isoclinally folded strata into fairly steeply plunging folds at this locality. A late, brittle stage of movement on the same fault has granulated and retrograded all of the brittle rock types. Feldspar in syenite is sericitized, intermediate plagioclase in gabbroic anorthosite has been albitized and veined by calcite, grossular-diopside calc-silicate rocks have been prehnitized and chloritized, but marble merely goes along for the glide.

At the northernmost end of the outcrop, the diopsidic marble and the quartz syenite are transected by a 4'(1.2 m) wide N80W90 trending lamprophyre dike(Fig. 13) which displays good chilled margins. It is a classic lamprophyre: a dark, dense, porphyritic dike rock in which the ferromagnesian minerals occur in two generations and in which only the dark minerals form the phenocrysts. It consists of 1-5 mm diameter phenocrysts of partially serpentinized magnesian olivine, and zoned clinopyroxene with augite cores and titanaugite rims, which display spectacular zoning, intense anomalous interference colors and dispersion, and hourglass structure. The groundmass contains a second generation of microphenocrysts of titanaugite, kaersutite, titanian biotite and abundant very thin needles of apatite in a quasi-isotropic base that has too high an index of refraction to be analcime or leucite; it has a mean index of refraction = 1.525 and is either untwinned anorthoclase or a zeolite. The dike may be classified as either a camptonite or a monchiquite, but exactly conforms to neither.

Notes:

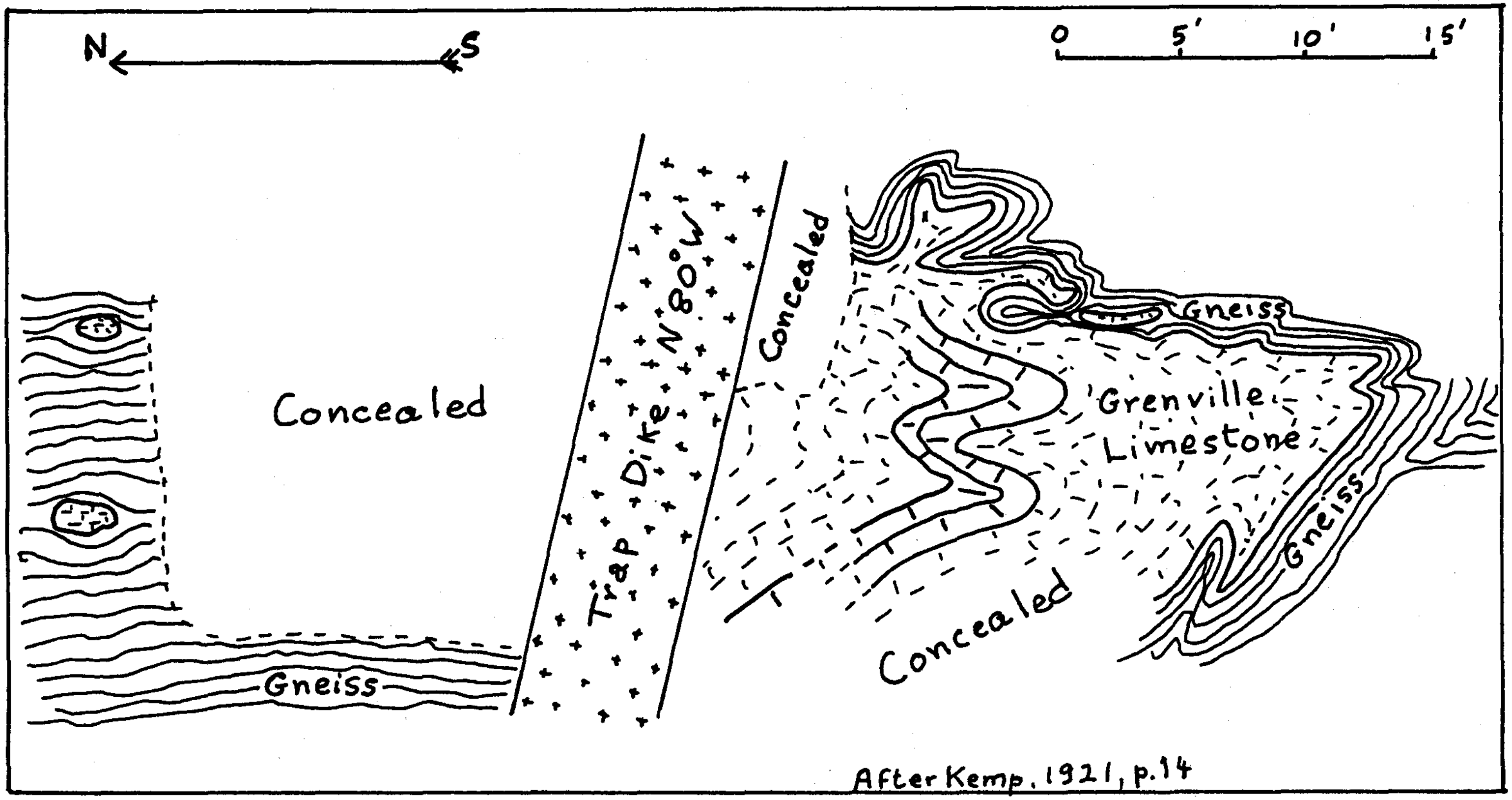


Figure 13. Contorted folding in diopside-calcite-pargasite-calcite marble, quartz leucosyenite gneiss, and anorthosite gneiss in the West Branch of the Ausable River south of Keene, N.Y. A camptonite dike cuts the marble-gneiss section. After Kemp, 1921. Mt. Marcy quadrangle.

Stop 4. THE BEEDE HILL GRENVILLE-ANORTHOSITE HYBRID GNEISS, BH-5B

Drive one-half mile(0.8 km) south, cross an old iron bridge, turn right,(south) on Hull's Falls road, and drive one mile(1.6 km) to the new bridge at Hull's Falls. Park on the north side before crossing bridge, and walk back about one-quarter mile(0.4 km) to the western edge of Beede Hill, a low, thickly wooded promontory between Hull's Falls road and Route 73 to the east. Beede Hill consists mostly of Grenville lithologies: garnet-quartz syenite gneiss, pyroxene-plagioclase gneiss, hornblende granite gneiss, amphibolite, garnetiferous alaskite gneiss, and calc-silicate granulites. A thin but conspicuous anorthosite sill outcrops at about the 1300'(396 m) elevation near the top of the 1470' (448 m) hilltop. Outcrops at the summit are of tightly folded amphibolite and granitic-syenitic-monzonitic gneisses carrying sporadic 2-4 cm (0.8-1.6") euhedral to subhedral blue-gray megacrysts or xenocrysts of calcic andesine of anorthositic parentage. Matrix plagioclase in the felsic gneisses is sodic andesine, An_{30}, and the calcic andesine xenocrysts, An_{46-50}, are markedly out of chemical equilibrium with the host rock plagioclase. In addition to plagioclase, hypersthene, augite, hornblende, and microperthite are present along with minor amounts of opaque oxides. Miller(1918) coined the name, "Keene Gneiss" for such rocks, and deWaard(1969) classed them as jotunite, a proposed name for metamorphosed hypersthene-bearing monzodioritic rocks of a supposed "charnockitic series". We suggest that these gneisses result from the mixing of anatectic felsic melts with partially crystallized anorthosite melt resulting in the incorporation of calcic andesine as xenocrysts in felsic rocks. It is a popular misconception of Adirondack geology that such xenocrysts are common in quartz syenite and granitic gneisses, which instead commonly carry blue-gray iridescent microperthite phenocrysts or porphyroblasts, but not calcic plagioclase. The xenocrysts of calcic andesine occur predominantly in monzonitic to monzodioritic gneisses near their contacts with anorthosite.

Time limitation will not allow us to climb Beede Hill but instead we will descend to the east bank of the Ausable River where a superb example of a plagioclase-xenocrystic hybrid augen gneiss is exposed. Exercise great caution in descending to the river as the slope is very steep, slippery, and treacherous. Take care not to tumble loose rock on your neighbor!

The prominent river bank outcrop shows Schiller-iridescent, blue-gray 2-5 cm(0.8-2") xenocrysts of calcic andesine, $An_{48.5}$, rimmed by white mesoperthite in a well-foliated gneiss(Fig. 14). The matrix of the gneiss contains plagioclase, An_{35}, hypersthene, Fe_{60}, augite, Fe_{44}, garnet, ilmenite, hornblende, and minor amounts of microperthite. The host rock is a two-pyroxene-plagioclase gneiss with a few thin granitic stringers. Careful examination should reveal a few thin concordant tongues of anorthosite which locally transect the gneissic foliation; presumably, these derive from the anorthosite sill on Beede Hill. If the parent rock of the sodic plagioclase gneiss had invaded an anorthosite, it would contain xenoliths and not single xenocrysts of the higher-melting-temperature anorthosite. Conversely, if the partially crystallized anorthosite melt induced anatectic melting of more alkali-

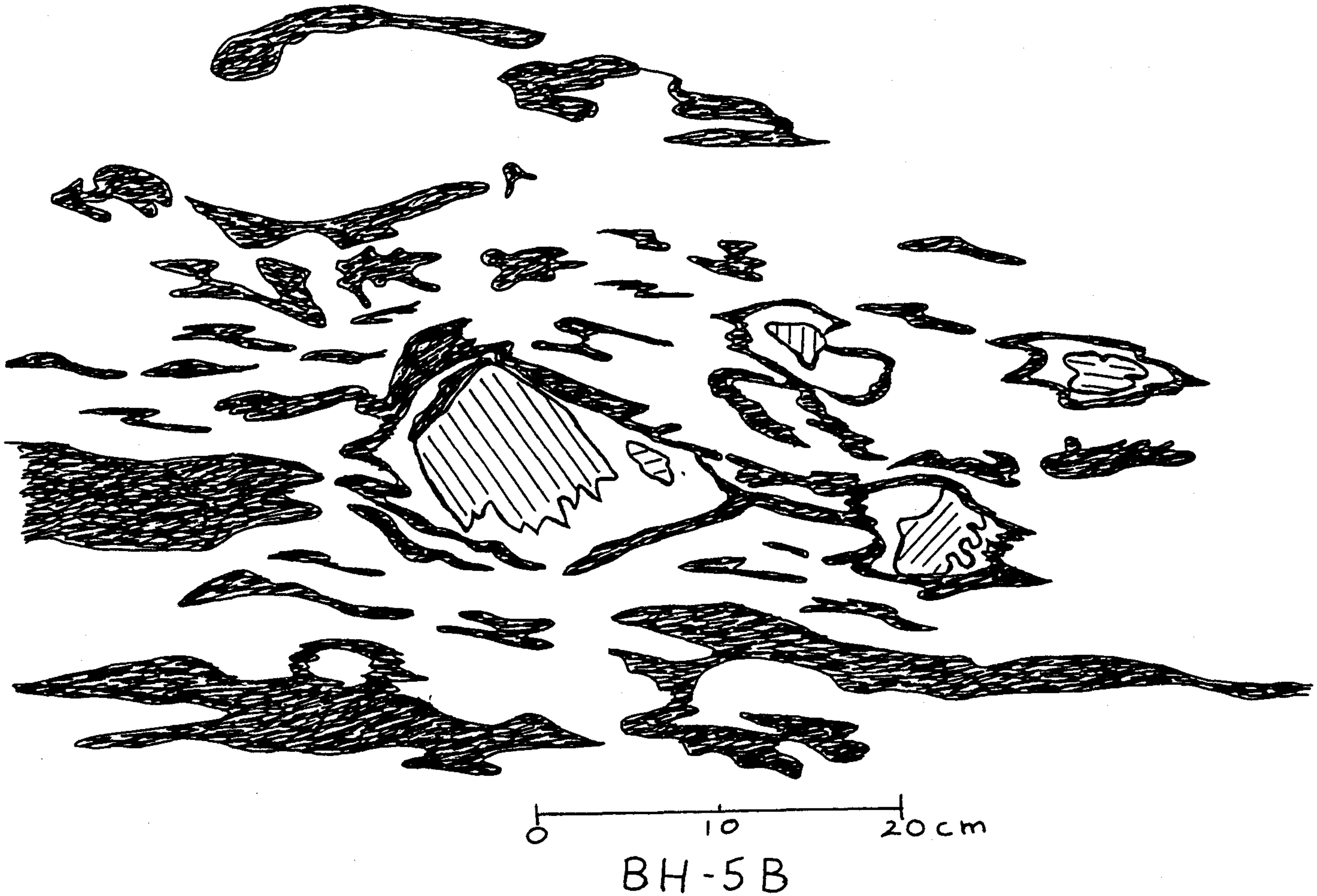


Figure 14. Blue calcic andesine megacrysts in Grenville-anorthosite hybrid gneiss in the West Branch of the Ausable River south of Keene, N.Y., at the west edge of Beede Hill. Mt. Marcy quadrangle.

rich layers, the latter would inherit and preserve the higher-melting-temperature calcic andesine as single crystal xenocrysts. The resulting rock is a Grenville-anorthosite hybrid gneiss.

Here the Grenville gneiss section strikes N85E, and dips gently (15-30°) to the north. A very short distance north, the hybrid gneiss grades to a biotite-hypersthene-augite-plagioclase gneiss devoid of both the plagioclase xenocrysts and garnet. Several pyroxenite layers containing hornblende, hypersthene, and augite are intercalated, and further north and up-section, calc-silicate granulites made up of grossular, diopside and quartz are abundant. Prehnite is common in the latter and may be retrograde. Contrast the gentle, north-dipping attitude of the layers here with the more contorted steep attitudes of the marble-syenite-anorthosite section seen at the previous stop, 0.75 miles (1.2 km) to the north.

Notes:

Stop 5. HULL'S FALLS- SYENITE-ANORTHOSITE HYBRID GNEISS, TRANSITION ROCK or CHARNOCKITE-MANGERITE-JOTUNITE?

We will stop for lunch at Hull's Falls and make a brief examination of the outcrops. The Hull's Falls section represents a more advanced stage of anatexis of the felsic supracrustal sequence of the previous Stop 4 at Beede Hill river bank. Here at Hull's Falls the prevailing E-W(N75E - N75W) strike and moderate northerly dip of the gneissic strata conform closely to those seen at Beede Hill but here the dips are steeper, from about 30N to about 30-50N. The Hull's Falls section consists of a markedly layered sequence of: hornblende-hypersthene-augite-plagioclase, An_{28-35},(garnet) gneiss carrying sporadic xenocrysts of calcic andesine(jotunite of deWaard, 1969); orthopyroxene-quartz-bearing monzonitic gneiss(mangerite to farsundite of deWaard, 1969); and eulite-bearing granitic gneiss(charnockite of deWaard, 1969). Cushing(1905) and Davis(1971) classed gneisses of this type as transition rock, placing them in the quartz syenitic series of a Tupper-Saranac sheet. A marked increase in both the volume occupied by granitic layers and in the prevalence of plagioclase xenocrysts, with respect to Beede Hill outcrops, is attributed to the proximity of the large reservoir of gabbroic anorthosite magma that crystallized here, and which dominates the eastern part of this map area. Iron-rich orthopyroxene compositions in these gneisses range from 100Fe/(Fe+Mg)=69-80, matrix plagioclase, An_{28-35}, calcic andesine xenocrysts, An_{47-50}, augite, 100Fe/(Fe+Mg), 60-72, the clinopyroxene carrying abundant metamorphic exsolution lamellae of pigeonite and hypersthene. Garnet and hornblende abound in the more mafic plagioclase-rich layers and tend to be absent from the granitic layers, an expression of the preference of garnet nucleation for Al-rich loci supplied by more anorthite-rich plagioclase.

Notes:

Stop 6. THE BAXTER FOLD IN NORITIC ANORTHOSITE OF BEEDE LEDGE

Turn east off Route 73 three-quarters of a mile north of the village of Keene Valley at trail sign to Baxter Mt. Bear left after the bridge and again left and uphill towards Lone Pine Cottage. Pass private road to the left and park along the right. Return to private road and walk uphill past gate and chain to outcrop at bend in the road.

Here we see a noritic anorthosite that has been thrown into an open fold whose axis is S12E15. On the left limb of the open fold can be seen the tight hinge of an earlier stage recumbent fold in the noritic anorthosite(Fig. 15), with an axis N8W22. At the right hand side of the outcrop, steep fluted and slickensided surfaces make further interpretation of the folding difficult. It appears that the recumbently folded anorthosite was dragged into an open fold by a fault most likely related to the N-S Keene Valley fault zone.

The noritic anorthosite consists primarily of andesine and hypersthene with very little augite. Some hornblende retrogrades the hypersthene, and minor apatite and ilmenite are present. The absence of garnet is noteworthy, and results from the low iron content of the orthopyroxene, 100Fe/(Fe+Mg)=39. Martignole and Schrijver(1973) and Jaffe et al(1983) have noted that garnet will be absent from anorthositic rocks when the Fe ratio is less than about 45.

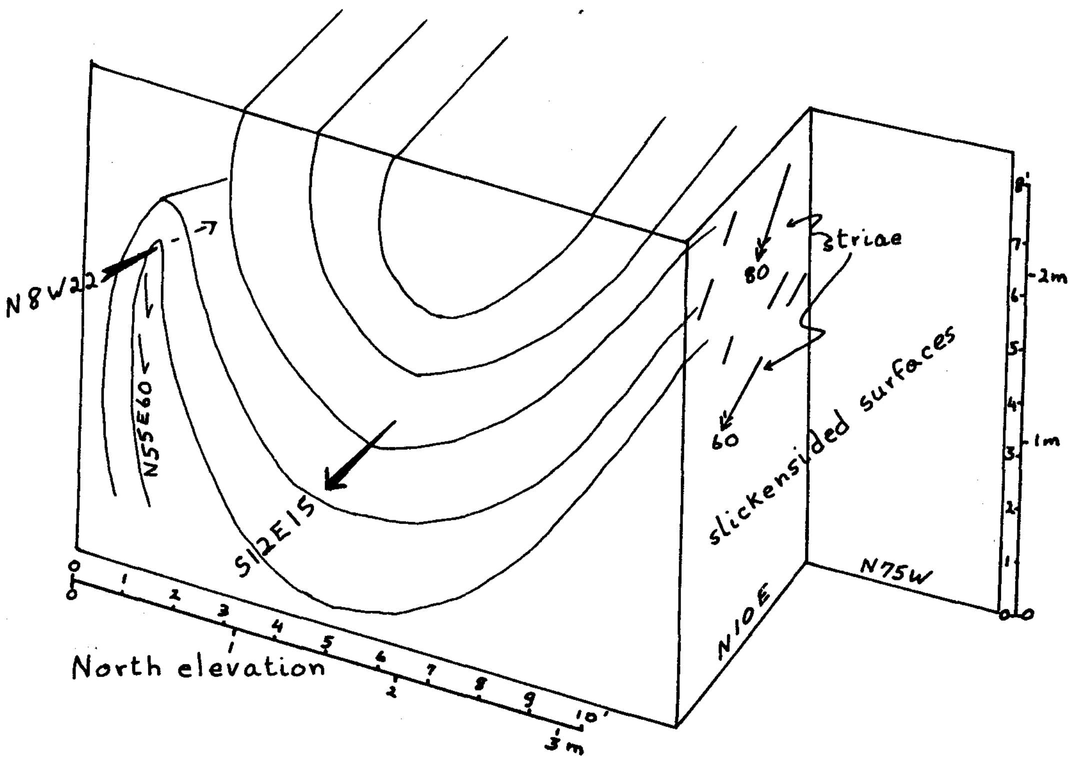


Figure 15. Refolded recumbent fold in noritic anorthosite at Beede Ledge, Baxter Mt. Mt. Marcy quadrangle.

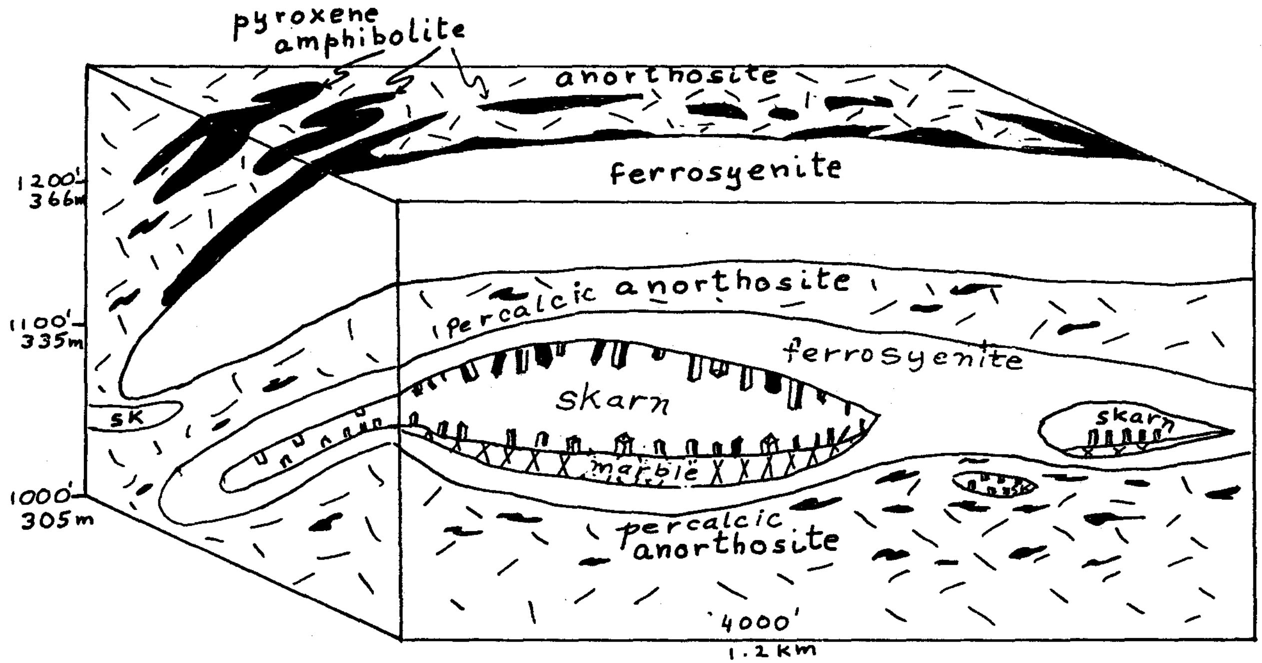
Stop 7. SCAPOLITE HILL AND KELLY'S LOGS

Return to Route 73 and drive 1.3 miles(2.1 km) north angling right on a dirt track beyond a Town of Keene garage, and parking in a small picnic area on the west bank of the Ausable River.

BE CAREFUL IN CROSSING HIGHWAY 73. Traffic is rapid here on one of the straighter sections of this highway.

Assemble at a small wooden building at the edge of the Marcy airfield. The large open meadow is sporadically used both as a trotting track and as a small landing strip for light aircraft. Walk directly across the meadow from the wind sock at the building into a wet, often swampy thicket. We will traverse or thrash through about 500' of boggy scrub growth and emerge at the talus-covered base of a steep cliff where the normally easy going has been made difficult by a recent, very sloppy attempt at a lumbering operation. Rubble and huge boulders contain the simple mineral assemblage: scapolite-hedenbergite-calcite (sphene) formed from the reaction between ferruginous siliceous carbonate rocks and anorthositic(and perhaps syenitic) magma. Some of the huge boulders contain giant single crystals, to 25 cm x 3 m (9.6" x 9.8') of pearl gray weathering, pale blue-gray, tetragonal prisms, often well terminated, of meionite-rich scapolite. We have named these megacrystals, "Kelly's Logs", after our colleague, Bill Kelly of the N.Y. State Geological Survey, who found them while working on his M.S. thesis(Kelley, 1974). The very abundant black euhedral crystals are hedenbergite, 100Fe/(Fe+Mg)=67-95. Many of the large crystals of scapolite are calcite-cored. According to Kelly(1974), the scapolite crystals occur in a 60-70 m (197-230') thick layer floored by gabbroic anorthosite and capped by a monzonite. In detail, we find the relations more complex as indicated in the block diagram (Fig. 16). Scapolite crystals occur in disconnected pods and dismembered layers of scapolite-hedenbergite-andradite-sphene-calcite skarn assemblages wrapped in a thin layer of forsterite-diopside marble and ferrosyenite-ferromonzonite gneiss. The calc-silicate horizon is succeeded by ferrosyenite and then more anorthosite, then, by a thicker layer of ferrosyenite which gives way near the hilltop to a folded pyroxene amphibolite clearly intruded by anorthosite.

At the base of the hill, gabbroic anorthosite and a thin discontinuous monzonitic layer are succeeded by a scapolite-hedenbergite gneiss and the forsterite-diopside marble, 1.5 m(4.9') thick, in turn overlain in sharp contact by a 10 m (33') thick layer of hedenbergite-scapolite-calcite-sphene rock , the outcrop source for the giant crystals seen in the huge boulders. Many of the giant crystals are oriented with their long axis perpendicular to the forsterite marble contact. At an outcrop about one-quarter mile to the north, giant scapolites are found growing from the floor and roof of a 20' x 8' elliptical pod of calc-silicate completely enclosed in gabbroic anorthosite, Fig. 17. The calc-silicate pods apparently represent pockets of CO_2-rich volatiles that were trapped in the anorthosite magma. Their growth perpendicular to the floor and roof of the elongate pods and their often well-formed pyramidal terminations are consistent with growth pattern in a vein or pod. They grew



Scapolite Hill

West elevation

Figure 16. Schematic block diagram of west-dipping folded scapolite-hedenbergite-calcite skarn, ferrosyenite, and percalcic anorthosite, of Scapolite Hill, Mt. Marcy quadrangle.

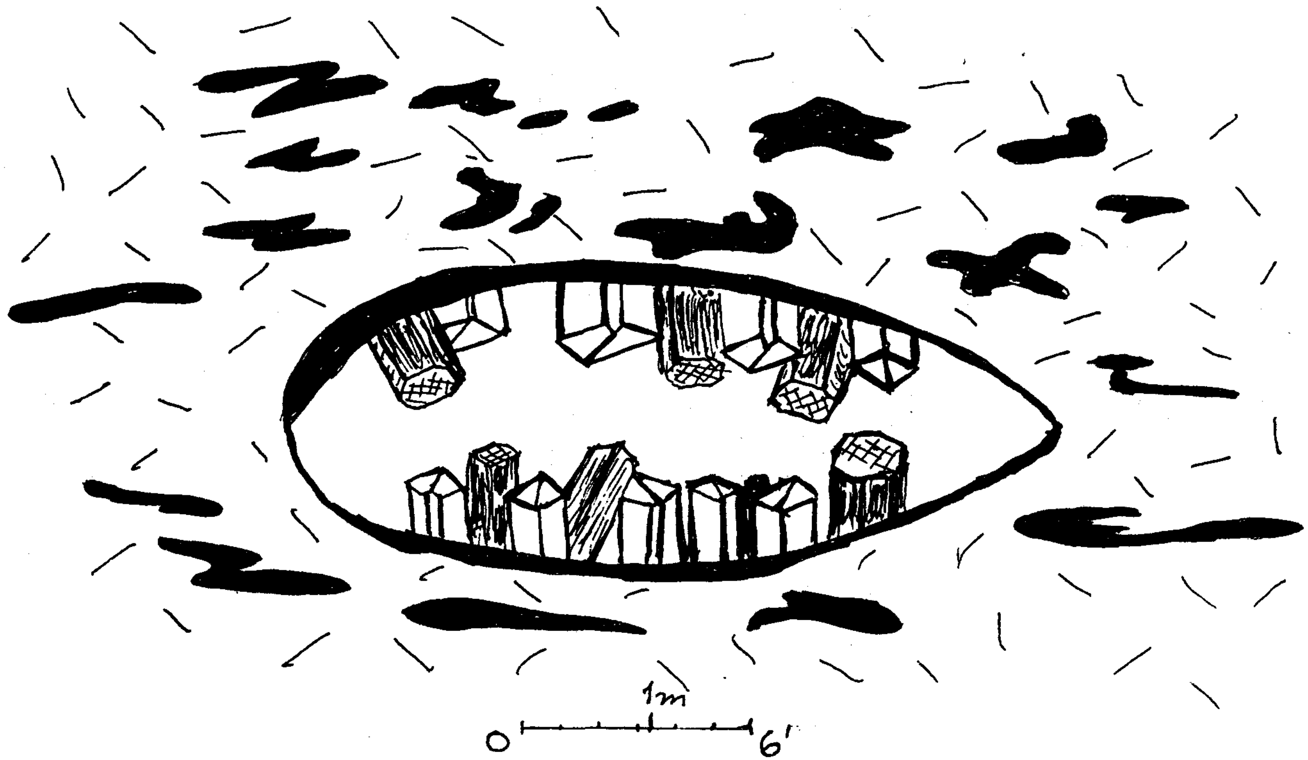


Figure 17. Detail of 20' x 8' (6.1 x 2.4m) skarn pod, showing well-terminated crystals of scapolite and hedenbergite growing perpendicular to margins of pod. Calcite is leached from center of pod, which lies in foliated percalcic anorthosite. Scapolite Hill, Mt. Marcy quadrangle.

toward the center of the pod by progressive replacement of calcite which has now been leached out leaving the voids which have a vug-like appearance. The typical assemblages found in the calc-silicates evidently grew by the following reactions, separately and in concert:

$$4CaCO_3 + FeCO_3 + Fe_2O_3 + 5SiO_2 = CaFeSi_2O_6 + Ca_3Fe_2Si_3O_{12} + 5CO_2$$
$$4Cc + Sid + Hm + 5Qz = Hed + Andradite + CO_2 \quad \ldots (1)$$

$$CaCO_3 + TiO_2 + SiO_2 = CaTiSiO_5 + CO_2$$
$$Cc + Anat + Qz = Sphene + CO_2 \quad \ldots (2)$$

$$3\ CaAl_2Si_2O_8 + CaCO_3 = Ca_4Al_6Si_6O_{24}(CO_3)$$
$$3\ An + Cc = Meionite(Me) \quad \ldots (3)$$

$$NaAl_2Si_3O_8 + 0.33\ NaCl = Na_{1.33}AlSi_3O_8Cl_{0.33}$$
$$Ab + Hl = Marialite(Ma) \quad \ldots (4)$$

Two wet chemical analyses of scapolites from these outcrops show limited ratios of Me_{64} and Me_{66} (Table 5) after Kelly, 1974.

Combining the four reactions (1 through 4), above, we may write:

$$6\ CaCO_3 + FeCO_3 + Fe_2O_3 + TiO_2 + 6SiO_2$$
$$6\ Cc + Sid + Hm + Anat + 6\ Qz \text{ from the carbonate rock}$$
$$+ 3\ CaAl_2Si_2O_8 + NaAlSi_3O_8 + NaCl$$
$$+ 3\ An + Ab + Hl \text{ from the anorthosite magma}$$
$$= CaFeSi_2O_6 + Ca_3Fe_2Si_3O_{12} + CaTiSiO_5 + Na_{1.33}Ca_4Al_7Si_9O_{32}(CO_3)Cl_{0.33} + 6CO_2 \quad (5)$$
$$Hed + Andradite + Sphene + Scapolite$$

This is the most common assemblage on Scapolite Hill.

Notes:

Table 5. Wet chemical analysis of scapolite, KV-NW1 and KV-1X

Analyst: Tadashi Asari, in Kelly(1974)

Weight per cent			Number of ions per 26 (O,F,Cl)				
SiO_2	47.47	46.98	Si	7.149		7.024	
TiO_2	0.17	0.04	Ti	0.019		0.004	
Al_2O_3	27.50	27.55	Al	4.883	12.09	4.857	11.941
Fe_2O_3	0.37	0.50	Fe^{+3}	0.042		0.056	
CaO	15.81	16.09	Ca	2.551		2.578	
FeO	0.28	0.34	Fe^{+2}	0.035		0.042	
MgO	0.14	0.19	Mg	0.032		0.042	
MnO	----	0.01	Mn	-----	3.934	-----	3.910
Na_2O	3.37	3.37	Na	0.985		0.977	
K_2O	1.72	1.42	K	0.331		0.271	
$H_2O^{(-)}$	0.49	0.55		-----		-----	
$H_2O^{(+)}$	0.58	0.65	(+) H	0.583		0.649	
F	----	0.01	F	-----		0.004	
CO_2	0.73	1.17	C	0.150	0.983	0.239	1.113
Cl	0.82	0.73	Cl	0.209		0.185	
SO_3	0.36	0.32	S	0.041		0.036	
P_2O_5	0.01	0.03					
TOTAL	99.81	99.92					
O=Cl	0.18	0.16					
TOTAL	99.63	99.76					

Stop 8. THE PITCHOFF GNEISS - FERROSYENITE FACIES, PO-2

Turn right(north) on Route 73, and go through Keene Village, where Route 73 turns west. Follow it about 4.5 miles(7.2 km) to the foot of Lower Cascade Lake. Park at the lakeside in the second parking area on the left, just past a sign FALLEN ROCK 1 1/2 MILE. Be very careful cutting across traffic: this is a busy high-speed highway. Recross the road on foot, again with great caution. Walk back toward the FALLEN ROCK sign, to a rough trail up the talus just short of the sign. The talus and cliff are both steep and full of loose rocks: be considerate of those below and behind.

The prominent, southeast-facing cliff we are climbing to is a ferrosyenite gneiss that crystallized from a melt prior to its metamorphism. It is one of a group of quartz-poor, alkali-feldspar- and ferroan-pyroxene-rich igneous rocks that acquired their gneissic fabric during an episode of isoclinal and recumbent folding associated with the Grenville orogeny at about 1100 M.Y. The persistent proximity and intimate intercalation of these gneisses with "Grenville" supracrustal rocks suggests that they may have initially been iron-rich felsic volcanics, or perhaps sills, interlayered with siliceous dolomites, calcareous quartzites, marls and basaltic flows comprising a Proterozoic series of rocks deposited about 1350 M.Y. This Grenville age is estimated from Ashwal's(1983) recent Sm^{147}-Nd^{143} date of 1288 M.Y. believed to represent the age of crystallization of the Marcy anorthosite massif-core facies. Following the model of McLelland and Isachsen(1980) for the southern Adirondacks, we suggest that, in the High Peaks Region of the northeastern Adirondacks, a "typical" Grenville supracrustal sequence correlative with rocks of the Central Metasedimentary Belt(Wynne-Edwards, 1972) was buried in a plate-tectonic event or events to a depth of about 70 km(42 mi) that of a doubly thickened crust. Following Emslie(1977), we envisage the birth of an anorthositic magma from the fractionation of copious amounts of orthopyroxene from an already-fractionated Al-rich gabbroic magma. Under these deep-seated conditions, the high pressures and temperatures plus the availability of Grenville-strata-derived CO_2-rich fluids initiated the formation of potassium- and iron-rich, relatively quartz-poor, melts of syenitic to monzonitic composition(Wendlandt, 1981). Ascent, intrusion, and emplacement of the syenitic melt at levels on the order of 25-35 km (15-21 mi) and temperatures of 800-900^{o} induced deep contact metamorphism of appropriate Grenville rock types. Here, at the easternmost part of the PO-2 outcrop, designated PO-2Gv(Fig. 18), a calc-silicate sequence infolded with the ferrosyenite contains the assemblage: wollastonite-diopside-grossular-quartz. Because anorthosite is absent, the contact-metamorphic origin of the wollastonite must be attributed to the intrusion of syenitic melt. Further, because the ferrosyenite contains relict inverted pigeonite, which now consists of host orthoferrosilite(100Fe/(Fe+Mg)=85-92), the melt must have crystallized at temperatures of 850-900^{o}(Lindsley, 1983 and Ollila and Jaffe, in preparation). Alternatively, shallow emplacement with crystallization of fayalite and quartz, later deeply buried and converted to orthoferrosilite and quartz, is conceivable, yet unlikely, because no relict olivine, whatsoever, has been observed by Jaffe or by Ollila in quartz-bearing syenitic rocks of the Mt. Marcy and the Santanoni quadrangles. Fayalite (Fa_{95}) plus quartz, but

Figure 18. PO-2gv. Folded amphibolite, marble, and wollastonite-bearing calc-silicate rock in ferrosyenite gneiss. Pitchoff Mt. cliff, above north end of Lower Cascade Lake. Mt. Marcy quadrangle.

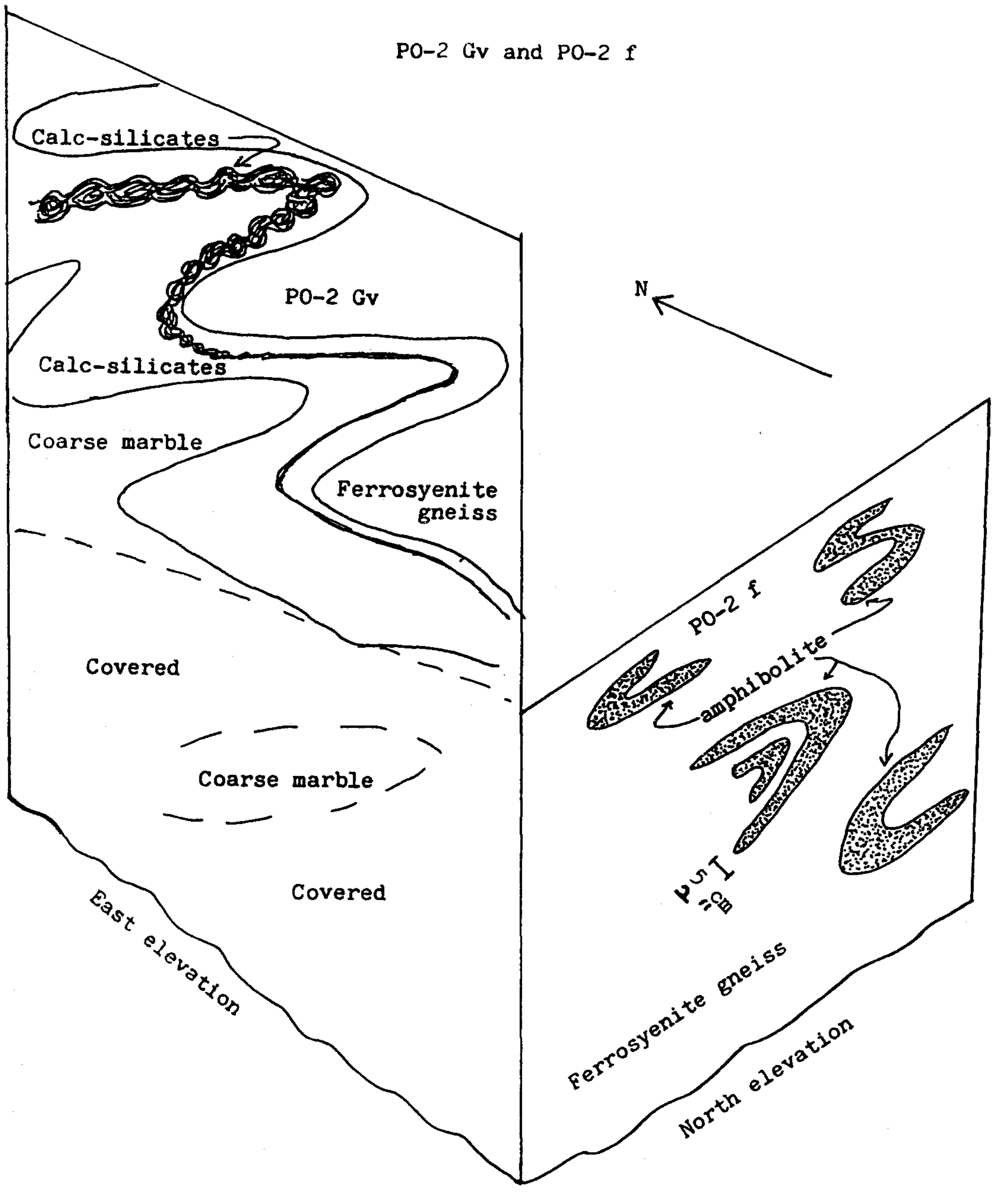


TABLE 6. Modes of rocks at Stop 8 , locality PO-2

	Ferrosyenite gneiss		Shonkinite	Amphibolite	Aplite
	PO-2	host rock	PO-2m inclusion	Inclusion	PO-2d dike
Q	1.5	2.0	-	-	23.0
Mp	84.5	84.0	50.0	-	60.0
Plag	3.6	4.0	13.0	30.0	16.0
Aug	4.1	4.0	12.7	-	-
Hy	2.4	2.0	16.6	-	-
Hb	1.8	2.0	4.1	58.0	0.9
Ore	1.0	1.0	2.6	+	0.1
Gt	0.8	1.0	+	-	0.0
Ap	0.3	+	1.0	2.0	tr
Zr	+	+	+	-	-
Bio	-	-	+	10.0	-
	100.0	100.0	100.0	100.0	100.0
An	21		21		
Fs(opx)	83-89		75		
CI	15		40	88	1

Mineral assemblages infolded in ferrosyenite gneiss host rock at locality PO-2Gv.

Amphibolite: hornblende and altered plagioclase.

Calc-silicate: hedenbergite-plagioclase-quartz
hedenbergite-plagioclase-quartz-scapolite-sphene
diopside-grossular-quartz-sphene
wollastonite-diopside-grossular-quartz
wollastonite-calcite-prehnite
diopside-calcite

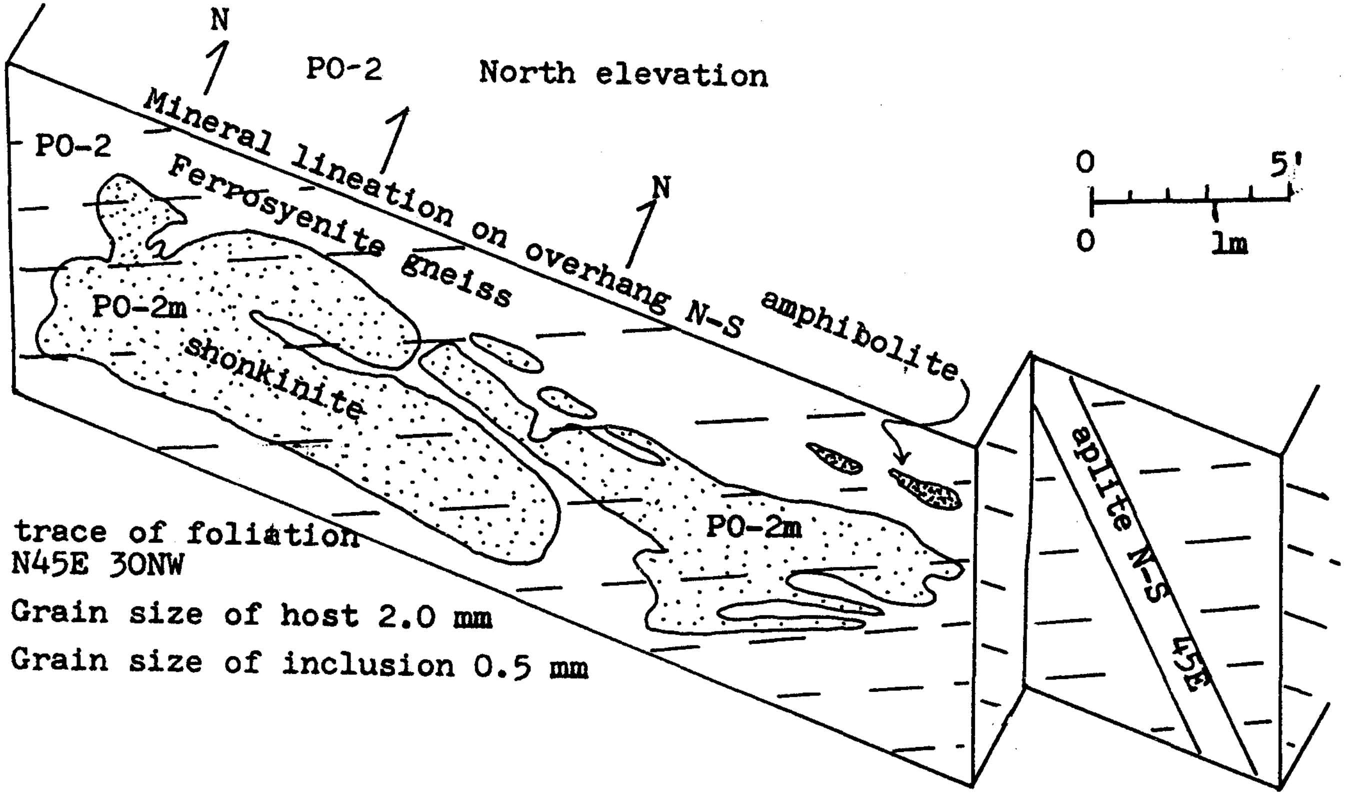


Figure 19. Xenolith of folded shonkinite layer PO-2m and amphibolite remnant in quartz ferrosyenite gneiss PO-2. Aplite dike cuts syenite gneiss. Pitchoff Mt. cliff above north end of Lower Cascade Lake, Mt. Marcy quadrangle.

with orthopyroxene absent, has been described from quartz-syenitic rocks in the Cranberry Lake quadrangle to the west(Buddington and Leonard, 1962, Jaffe et al. 1978) and in the Ausable Forks quadrangle to the northeast(Kemp and Alling, 1925 and Jaffe et al, 1978). A deep emplacement with high pressure crystallization is consistent with field observations and experimental data for all of these rocks.

At the PO-2 outcrop, we will split into several smaller groups: the footing can be a bit tricky. Remember not to step back for a better look at the outcrops. The first or westernmost cliff consists of strongly foliated ferrosyenite gneiss, N45E30W, with a large inclusion of shonkinite granulite(Fig. 19, Table 6). The foliation continues through the inclusion. The southwest end of the inclusion is sharply cut off by the gneiss but the northeast end fingers out. The inclusion is cut by a discordant vertical tongue of gneiss which becomes a subhorizontal pegmatite vein. At the northeast end of this cliff, the ferrosyenite gneiss is cut by an unfoliated aplite dike. Small amphibolite inclusions can be seen in the gneiss.

We will proceed cautiously about 300'(91.5 m) along the base of the cliff to the northeast, across a stream and a gully. Here we see several larger folded amphibolite inclusions in the ferrosyenite gneiss(Fig. 18). The axial planes of these folds are approximately parallel to the pervasive foliation. We will now crawl a few feet up the gully: in its east wall are exposed marbles and calc-silicates intimately infolded in the ferrosyenite gneiss. Wollastonite occurs in these calc-silicate beds (Fig. 18). If we make allowance for the plasticity of the marble, these folds are also approximately parallel to the pervasive foliation. There is a cave in the marble a little higher up this gully. On the opposite side of Lower Cascade Lake, in the anorthosite, another cave can be found a few hundred feet higher up. Caves are common in New York State, but these two must be among the few in Precambrian rocks.

Notes:

Stop 9. HEAVEN HILL AND ANORTHOSITE SILLS

Proceed west 7.6 miles(12 km) on Rte. 73. Bear left on Old Military Road following the signs for Saranac Lake. Proceed approximately 0.8 miles(1.26 km) and take a left just before reaching a hospital. Drive 2.3 miles (3.7 km) on the paved road and stop where the pavement ends. Stop 9A is about 0.5 miles (.8 km) further down the dirt road. The outcrop is north of the road on a steep hillside. Stop 9B is just beyond the northeast corner of the large field on the north side of the road where the pavement ends. These outcrops are on private property: obtain permission at Heaven Hill farm.

Stop 9A is an outcrop first described by Buddington(1953, p.74) as "intrusive lenses of Whiteface gabbroic anorthosite between the Grenville and quartz syenite". Stop 9B is northeast of 9A at the base of Heaven Hill. Here, marble, calc-silicates, amphibolite, and hornblende granite gneiss dip to the north and are the first rocks exposed going northward from stop 9A. These rocks are part of the Newman syncline described by Buddington. This northeast-trending doubly-plunging synclinal structure occupies an area overlapping the intersection of four 15' quadrangles: Saranac, Lake Placid, Santanoni, and Mt. Marcy. Section A-A', Fig. 20, is drawn from 9A through 9B and roughly parallels the trend of the Newman syncline.

9A. The southwest side of this hill consists of interlayered gabbroic anorthosite gneiss and garnetiferous granitic gneiss. Rocks equivalent to the Pitchoff Gneiss-ferrosyenite facies, outcrop immediately to the south of this hill and dip underneath it. The anorthositic gneiss weathers white and is white on a broken surface. It consists of plagioclase, $An_{35.5}$, and lenses and layers of augite, MG*=68, olive-green to brown hornblende, and sphene. Hornblende, augite, and sphene occur together in elongate polygonal aggregates. Sphene is relatively coarse-grained and quite abundant in this rock. Sphene is unusual in anorthositic rocks and probably results from contamination of the anorthosite sills during intrusion.

Anorthosite is commonly surrounded by a rock that is rusty brown on a broken surface. This rock consists of plagioclase, An_{29}, layers and lenses of augite, MG 50, and hornblende, and layers and lenses of microperthite. Locally the rock contains blue plagioclase augen, An_{45}. The intermediate pyroxene compositions and the blue plagioclase augen suggest that the rock is a hybrid between anorthosite and syenite.

Both of these rock types occur within a medium grained garnetiferous granitic gneiss. The gneiss weathers white to tan and contains 2 to 5 mm. garnets. It is heterogeneous, containing both hornblende- and plagioclase-rich layers and quartz-rich layers. Most of the rock consists of anhedral quartz and microperthite with minor amounts of sphene, apatite, zircon, garnet and opaques.

An approximately 1m(3.3') thick body of pink weathering hornblende granite gneiss cuts anorthositic gneiss on this hillside. A similar

*MG=100 x Mg/(Mg+Fe)

Figure 20. Section showing position of anorthosite sills near Heaven Hill, in the northeast corner of the Santanoni quadrangle.

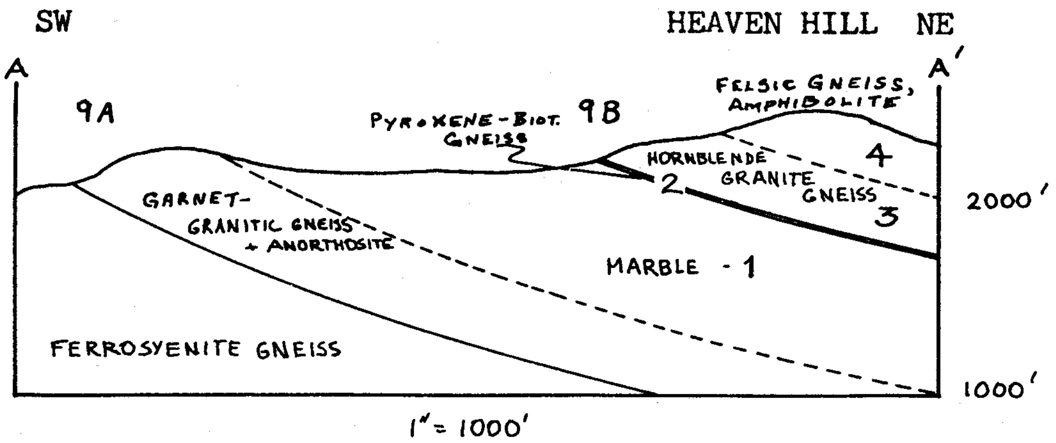
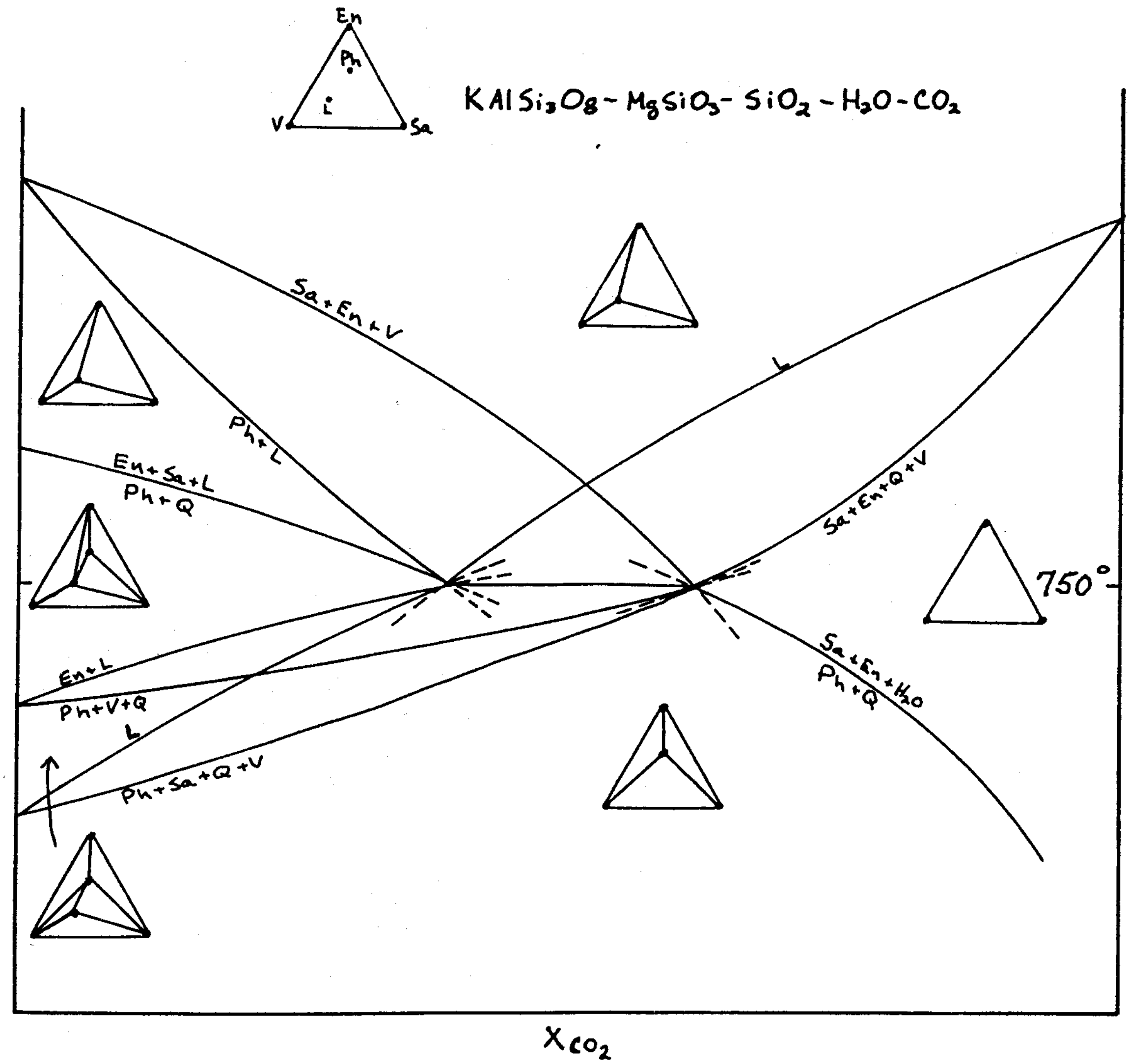


Figure 21. T - X_{CO_2} diagram for the system sa-en-q-H_2O-CO_2 showing 750° maximum stability of ph-q-V assemblage.



body has been observed in syenitic rocks further to the southwest in the Santanoni quadrangle. The rock is medium grained and consists of approximately 70% microperthite, 25% quartz, 3% green hornblende and 2% reddish-brown biotite. Accessory minerals include plagioclase, opaques and zircon. This rock is petrographically very similar to the granitic gneiss at stop 9B and is thought to be equivalent to the reddish granite described by Buddington (1953, p. 73-74) in the Saranac quadrangle.

It is uncertain whether the repetition of layers in this outcrop is caused by isoclinal folding or whether there are numerous sills of anorthosite. No folds have been observed on this hillside but isoclinally folded pyroxene scapolite gneiss and marble near the base of Heaven Hill and the folding seen at stops 8 and 12 suggest that repetition by folding is a likely possibility. A mineral lineation in biotite gneiss at the base of Heaven Hill trends northwesterly. If fold hinges are parallel to this lineation it could explain why hinges are difficult to find on this hillside. A foliation that cuts across mafic layers at a low angle has been observed at a few localities on this hillside.

9B. Mineral assemblages and optically determined mineral compositions from rocks at Heaven Hill are listed in table 7. The stratigraphic section(Fig. 20) from base to top consists of 1) coarse marble and scapolite bearing calc-silicate gneisses, 2) pyroxene-bearing amphibolites, biotite gneiss and calcareous quartzites, 3) hornblende granite gneiss, and 4) interlayered felsic gneisses, amphibolites and calcareous quartzites.

The contact between unit 1 and rocks to the southwest is not exposed. The maximum possible thickness for this unit is approximately 250 m(820'). Kemp(1921) reported wollastonite from marbles contiguous with this unit in the northwestern corner of the Marcy quadrangle. Samples HV-1, 4-4, 4-16 and presumably LP-200 are from unit 1(Fig. 20 and Table 7). Pyroxene scapolite gneiss and marble are tightly folded in an outcrop southwest of the base of the hill in the swampy area.

Samples 4-16B and C were collected from unit 2 and are samples of pyroxene bearing amphibolite and biotite gneiss respectively. Sample 4-16C is a granoblastic gneiss with an average grain size of 0.3 mm. Foliation is defined by aligned biotite. The most interesting textural feature of this rock is that coarse(up to 7mm.) poikiloblastic orthopyroxene encloses augite, plagioclase and biotite. The biotite within the orthopyroxene is aligned and the orthopyroxene has clearly grown across the preexisting foliation. Biotite gneiss is overlain by thin quartzites and then hornblende granite gneiss(unit 3), Unit 2 is no more than 10 m(33') thick.

Hornblende granitic gneiss is similar petrographically to the hornblende granite gneiss at stop 9A. It is a medium grained gneiss consisting of 70% microperthite, 25% quartz, and 5% green hornblende. The rock also contains trace quantities of plagioclase, biotite, apatite,

Table 7. Mineral assemblages and optically determined mineral compositions from rocks at Heaven Hill .

Map Unit	1	1	1	1	2	2	4
Sample No.	4-4	4-16	LP-200	HV-1	4-16B	4-16C	4-6
calcite		+	x				
clinopyroxene	x	x	x	x	x	x	x
orthopyroxene					x	x	
tremolite							x
hornblende	x				x		
biotite					+	x	
phlogopite							+
quartz			x	+	+		x
plagioclase	+			+	x	x	
K-feldspar	+	+	x		+	+	
scapolite	x	x		x			
garnet					+		
sphene		x	x	x			
apatite	+				+		
graphite		+					
opaques		+		+	+		
MG cpx	59	85			65	94	100
MG opx					55	83	
An plag	39.5				51.5	46.5	
Me scap	70	62					

x - major constituent

+ - minor constituent

MG = 100(Mg/Mg+Fe)

1 reported by Valley and Essene, 1980

zircon, opaques, garnet and orthopyroxene (MG 21). The upper contact of this granitic gneiss is not exposed but its maximum thickness is approximately 100m (328').

Unit 4 consists of interlayered felsic gneisses, amphibolites and calcareous quartzites. This unit will not be visited during the stop, however, sample 4-6 from this unit contains a potentially useful assemblage for placing upper limits on metamorphic conditions in this area. Sample 4-6 is a calcareous quartzite containing diopside (MG 100), tremolite, phlogopite and quartz.

Figure 21 is a schematic T-X_{CO_2} diagram for the system $KAlSi_3O_8$-$MgSiO_3$-SiO_2-H_2O-CO_2. The triangle Sa-En-Vapor is projected from SiO_2 and collapsed along H_2O-CO_2. The positions of the univariant curves are approximate but their relative positions are governed by Schreinemaker's rules (Zen, 1966). Univariant reactions involving both liquid and vapor are shown as binary loops, the liquid always having the more water rich composition. The position of the isobaric invariant point Ph-Sa-En-Q-L-V has been experimentally determined by Wendlandt (1981) as being near 750°C over a wide pressure range(5 to 10 kbar). The importance of Figure 21 as regards the assemblage in 4-6 is that it limits the assemblage Ph-Q-V to less than 750°C over a wide range in pressure. Vapor absent conditions would allow higher temperatures for this rock. The 750°C maximum is slightly below temperatures indicated by Bohlen et al. for this area but is within the uncertainty limits of their temperature determinations.

One of the most interesting rocks at Heaven Hill is the biotite gneiss. The poikiloblastic orthopyroxene in this rock apparently grew after deformation. Buddington(1953) presented evidence that the reddish granite in the Saranac quadrangle was intrusive into both the anorthosite and metamorphosed sediments. He believed that the granite intruded late in the deformation history of the area. Deformation must have continued after intrusion of granite but may not have been severe enough to destroy the textures in the biotite gneiss.

The occurrence of orthopyroxene in the granite at this locality may be related to its proximity to the calc-silicate rocks. As shown by Wendlandt(1981) and Figure 21, the introduction of CO_2 to a granite would tend to promote crystallization of orthopyroxene. Alternatively, biotite+quartz may have broken down in the presence of a CO_2-rich vapor base.

Notes:

Stop 10. THE 1063 MYLONITE

On the west side of Route 73, 1.3 miles (2.1 km) south of the village of Keene Valley at BM 1063 and opposite the Beer bridge across the Ausable River, the anorthosite is cut by a well-developed mylonitic zone about 2'(0.6 m) wide which trends N55E35NW. Park on the west shoulder of the road south of the outcrop and walk back. The anorthosite here appears to be the normal gabbroic type; however, the mafic minerals occur in clots and aggregates of augite+apatite, many of which are bent into mini- and microfolds. These clots and the sparse megacrysts of labradorite form a foliation which trends N70W70SW. The coarse grained contaminated felsic anorthosite and the mafic clots of partially assimilated augite+apatite represent either remnants of a Grenville phosphate-rich calc-silicate rock, or a mafic cumulate segregated from a gabbroic anorthosite melt. The iron content of the augite, 100Fe/(Fe+Mg)= 47, while too high for felsic anorthosite, is representative for anorthositic gabbro. Further, the profusion of "100" and "001" metamorphic pigeonite exsolution lamellae in the host augite(Jaffe et al., 1975 and Fig. 6) suggest that the clots may derive from anorthositic gabbro, where such are common, rather than from a Grenville calc-silicate lithology, where they are rare. Labradorite megacrysts in this rock are nevertheless higher in anorthite than felsic anorthosites of the Marcy region, and show $An_{50.5-54.5}$ rather than the typical An_{46-48}, suggesting a probable assimilation of calcium from the augite-apatite-rich clots of xenoliths. For this reason we classify such rocks as a percalcic subfacies of the gabbroic anorthosite facies.

Just north of a small waterfall, the outcrop changes dramatically: the rough foliation gives way to fine layering along which the dark minerals occur as streaks and schlieren, though occasional megacrysts have escaped granulation and appear as flaser. The mylonite is focused in a 2' (0.6 m) zone which dies out gradually to the north after about 20' (6 m) giving way again to percalcic anorthosite. Just beyond a covered interval, the north end of the outcrop contains a mafic rock, in rudely vertical attitude, but somewhat bent about a sub-horizontal axis, perhaps earlier than the mylonitization. It has been named "aproxite" by one of the authors, in allusion to its bimineralic apatite+pyroxene composition, which is identical with that comprising the mafic clots in anorthosite host rock at the south end of the outcrop. The mineralogy thus suggests that the "aproxite" is a folded layer in anorthosite rather than a mafic dike.

The mylonitic zone does not retain any of its primary magmatic or high grade metamorphic mineralogy but is totally retrograded to a fine-grained mixture of albite, prehnite, sericite, quartz, chlorite, pumpellyite, epidote, and calcite. Labradorite is altered by the following probable retrograde reaction:

$$4[Na_{0.5}Ca_{0.5}Al_{1.5}Si_{2.5}O_8] + KAlSi_3O_8 + 2H_2O$$

4 Lab + Or + Water

$$= 2[NaAlSi_3O_8] + Ca_2Al[AlSi_3O_{10}](OH)_2 + KAl_2[AlSi_3O_{10}](OH)_2 + SiO_2$$

= 2 Ab + Prehnite + Sericite + Qz

Augites have been drawn out into elongate lenses, spindles, and schlieren, and totally retrograded to a mixture of fibrous, isotropic chlorite and pumpellyite with a little calcite. Apatite, alone, remains unaltered, appearing as microflaser in the mylonitized base.

This wet assemblage is inconsistent with deep, ductile shear and suggests that the mylonitized zone originated by brittle shear or cataclasis in a wet, relatively shallow crustal setting.

That the shear zone was initially a deep, ductile mylonite, later retrograded, remains a possibility.

Notes:

Table 8. Modes of host intrusive anorthositic ferrogabbro and supracrustal xenoliths at the Roaring Brook intrusion breccia, and of ferromonzonite granulite of the summit of Giant Mt., Marcy Massif, Adirondacks, N.Y.

	Anorthositic Ferrogabbro	Grenville Supracrustal Xenoliths						Summit, Giant Mt.
	RB-4	RB-2-f	RB-4f-a	RB-4f-b	RB-4f-c	RB-4-Y	RB-4-d	Gi-25-S
Quartz	0	0	0	0	0	0	0	1.0
Microperthite	7.4	0	0	48.0	55.0	0	1.0	27.2
Plagioclase:								
Megacrysts 1/	36.0	0	0	0	0	0	0	0
Matrix 2/	10.0	39.3	77.5	3.0	20.0	42.0	54.0	42.8
Garnet	22.0	tr	0	0	0	9.0	0	14.9
Orthopyroxene 3/	4.6	4.5	10.0	1.0	17.0	tr	10.0	5.2
Augite 4/	11.0	28.1	2.0	47.0	7.5	1.0	35.0	5.4
Ilmenite	5.8	0	0	0	0	0	tr	2.1
Magnetite	tr	tr	0	0	0.5	tr	tr	0.4
Hornblende	0	5.6	0	0	0	48.0	0	0
Biotite 5/	0	22.5	10.0	0	0	0	0	0
Apatite	3.2	tr	0.5	tr	tr	tr	tr	1.0
Sphene	0	0	0	1.0	0	0	0	0
Totals	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1/ Mol. % An	40 - 48.5							
2/ Mol. % An	27 - 30		28	22	22	32	32	23
3/ Mol. % Fs	71							74
4 Mol. % Fs	64	14	15-19			47	63	57
5 Mol. % Fe			35					
Avge. grain(mm)	.2-.5(mat.) 3-10(meg.)	.12-.16	.15	.15	.15	.30	.15	.32
Color Index	47	61	22	49	25	58	45	29

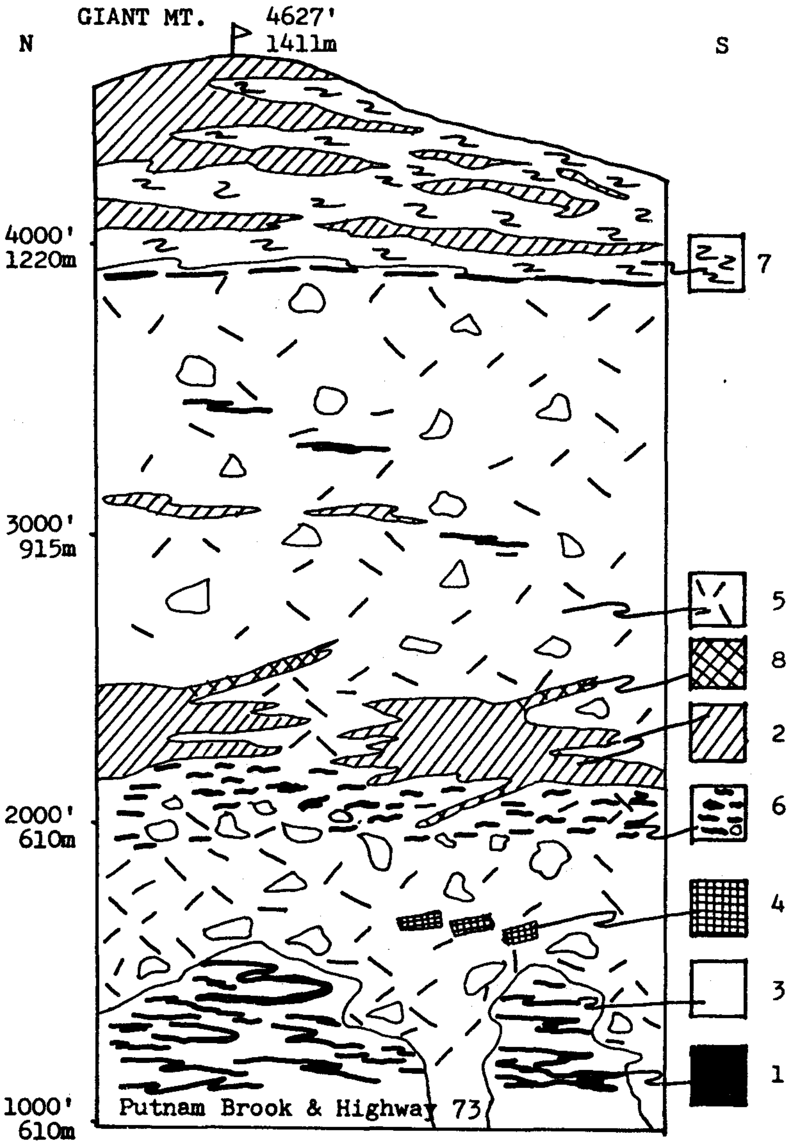


Figure 22. Schematic N-S section from Putnam Brook at Highway 73 (1200', 366m) to the summit of Giant Mt. (4627', 1411m). About 1000'(305m) of multiply deformed Grenville sediments (1) are overlain by about 2400'(732m) of felsic volcanics (2) which are remelted by the intrusion of felsic anorthosite (3); pyroxenite dikes (4) intrude anorthosite; gabbroic anorthosite (5) invades all, producing block structure and the Roaring Brook breccia (6); tectonism and shearing near the 4000'(1220m) elevation thrust the top of Giant with possible transport to the south, and deform gabbroic anorthosite to a gneiss (7). A second generation of felsic dikes (8) cuts anorthositic rocks. Elizabethtown quadrangle.

Stop 11. THE ROARING BROOK INTRUSION BRECCIA ON GIANT MOUNTAIN

From Stop 10, drive 1.6 (2.6 km) miles south on highway 73 through the village of St. Huberts to the small parking area on the east side of the road at the beginning of the Roaring Brook trail to the summit of Giant Mt., elev. 4627' (1411 m). If the small lot is filled with climbers' cars, take the next right turn off Route 73 into the larger public parking area maintained by the Ausable Club. Secure all vehicles, as we have had our cars broken into here, and had back-packs stolen while we were out mapping in the area.

We are at the base of Giant Mt., "the Giant of the Valley", near the boundary(73°45' W. Long.) joining the east edge of the Mt. Marcy quadrangle with the west edge of the Elizabethtown quadrangle. We will climb about one-third of the way up the mountain, ascending about 1000' (305 m) in 1.5 miles (2.4 km) from elev. 1260' (384 m) at the parking lot to the 2260' (689 m) level of the Roaring Brook intrusion breccia. We will spend about 3 - 3 1/2 hours on the mountain and have lunch above at the 2260' (689 m) level of Roaring Brook, where the water is potable.

DeWaard(1970) in a geologic study of the Roaring Brook intrusion breccia concluded that, except for Grenville xenoliths, all of the rocks exposed on Giant Mt. represent an "anorthosite-charnockite suite" differentiated from a single parent magma. This suite is considered to be made up of all types of his proposed sequence including: norite, jotunite, mangerite, farsundite, and charnockite. We discourage the usage of these names for orthopyroxene-bearing calc-alkaline rocks whether they be of igneous or metamorphic origin. We find no evidence of any fractionated anorthosite-charnockite suite in the Marcy massif and see the anorthosite and silica-poor, alkali- and iron-rich rocks as the products of crystallization of separate, unrelated melts. Further, the alkali-rich rocks show no convincing evidence of having fractionated at all, and more likely represent individual batches of anatectic melts of crustal material. If the alkali- and iron-rich gneisses of Pitchoff Mt., Giant Mt., and the Big Range are compared, the Fe-content of pyroxenes shows no systematic increase with the alkali+silica content(Tables 1 and 8).

We see the geology of Giant Mt. as a 3400' (1037 m) section (Fig. 22) of supracrustal sedimentary and felsic volcanic rocks of probable Grenville age, invaded first by felsic andesine anorthosite, next by pyroxenite dikes, and then by a large volume of gabbroic-noritic anorthosite which represents the most abundant rock type on Giant Mt. Block structure, featuring fractured blocks of felsic anorthosite broken and brecciated by later gabbroic-noritic anorthosite magma, is widespread all over the mountain, and can be observed in Roaring Brook and over a major portion of the Ridge Trail from Chapel Pond to the summit. During intrusion, separate batches of silica-poor, alkali- and iron-rich melts of supracrustal material were generated by, and partially mixed with gabbroic anorthosite magma carrying calcic andesine crystals. Several of these, especially the host rock of the Roaring Brook intrusion breccia, represent hybrid Grenville-anorthosite rocks, or gabbroic-noritic anorthosite magma contaminated with partially remelted crustal rocks and refractory xenoliths or restites of diverse lithology.

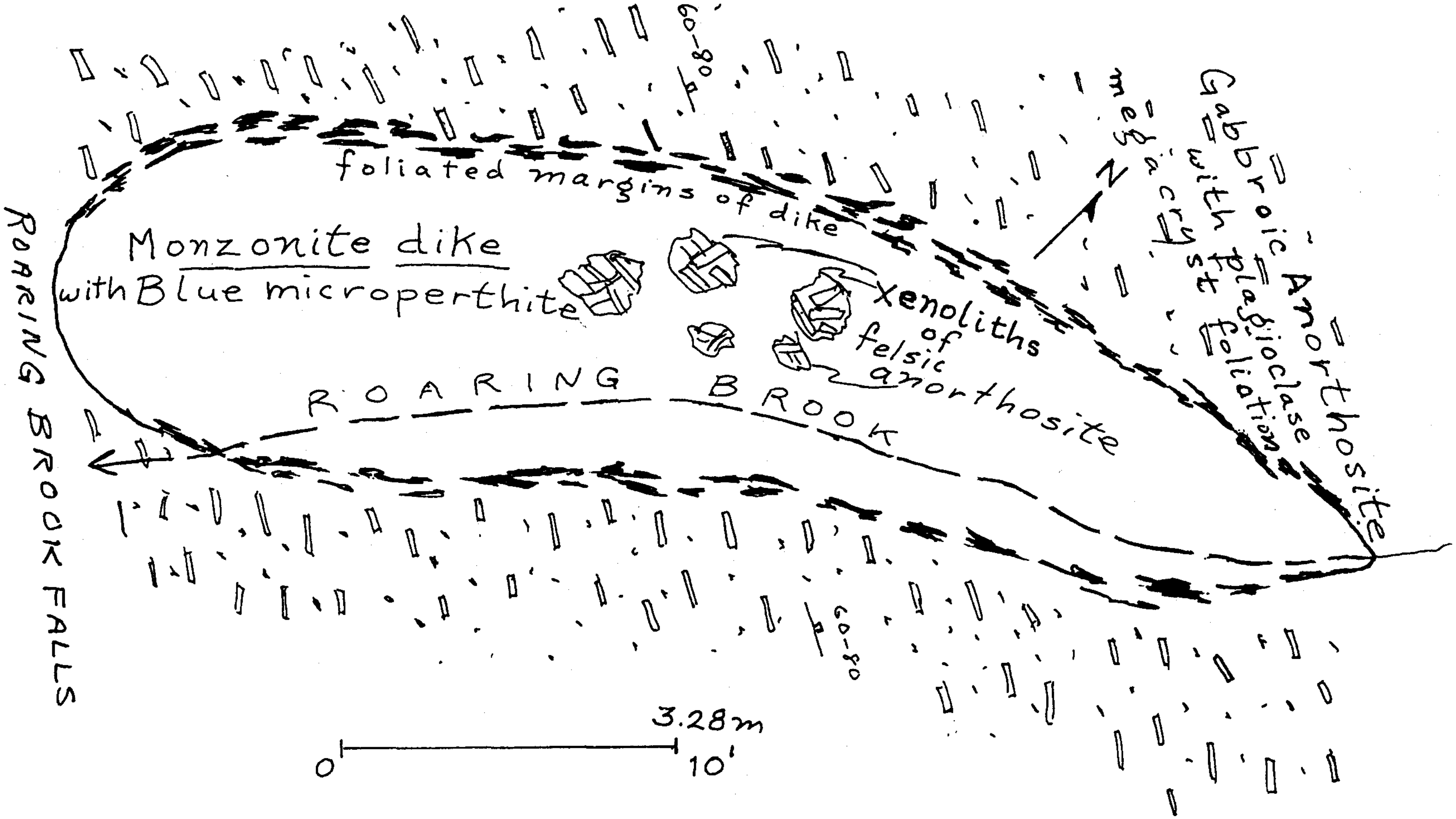


Figure 23. Schematic outcrop map at the top of Roaring Brook Falls, Giant Mt., showing blue microperthite monzonite dike with foliated margins discordantly transecting foliated gabbroic anorthosite. Mt. Marcy quadrangle.

Quartz-poor, alkali-rich anatectic melts may have been generated by the presence of CO_2-rich fluids derived from Grenville carbonates in the metasedimentary sequence(Wendlandt, 1981). Although absent from the xenolith lithologies in Roaring Brook, Grenville marbles do occur nearby on the Ridge Trail from Chapel Pond to Giant summit. Small bodies of ferrosyenite and aplite transgress the anorthositic rocks in Roaring Brook and elsewhere on Giant Mt., and at the summit itself, the rock is largely ferromonzonite(mangerite) granulite and gneiss(Table 8).

Walk one-quarter mile along the level beginning of the steep Roaring Brook trail to Giant Mt. summit. Turn left at the trail sign and begin steep ascent to the top of Roaring Brook falls. The spectacular waterfalls visible from highway 73 are formed in an E-W shear zone parallel to Roaring Brook, in which a diabase dike is contained. The shatter zone and the dike have contributed to the differential erosion and development of the falls. About one-half mile of climbing brings us to the top of the falls where there are fine outcrops and an excellent view south and southwest to the high peaks of the Great Range. Here the country rock is a well-foliated gabbroic-noritic anorthosite(C.I.= 10-12 and M.I.=30). Augites are rimmed with hornblende and a relatively high Mg/Fe ratio has inhibited the formation of garnet. Calcic andesine megacrysts define a steeply dipping N 20-38 W 60-82 NE foliation crossing the brook. In the brook, and parallel to it, is an equigranular augite monzonite dike carrying blue-gray microperthite, easy to confuse with the more common blue-gray calcic andesine megacrysts of the anorthosites. The monzonite carries irregular xenoliths of felsic andesine anorthosite such that the entire rock may be readily misidentified as anorthosite. The margins of the monzonitic dike are very strongly foliated parallel to the brook and contain exactly the same minerals found in the equigranular dike. The dike and its foliate margins sharply cross-cut the gabbroic anorthosite country rock(Fig. 23).

We will probably not take time to climb up the brook, where several hypersthene pyroxenite and gabbro dikes cross-cut felsic anorthosite, then were broken and invaded by gabbroic anorthosite, the prevalent anorthositic lithology of Giant Mt.

We return to the Roaring Brook trail and another climb of about one-quarter to one half mile(0.8km) brings us to a brook crossing. We will first make a stop near here to study a large anorthosite erratic which exhibits a variety of anorthositic textures in complex relationship.

Cross the brook carefully, turn left at the trail junction to Giant's Washbowl and Nubble, and continue the climb. After we cross two brooks, our climb brings us to the 2260'(689 m) level where a small path through the brush to the left brings us out on the open banks and rock pavements of the spectacular intrusion breccia of Roaring Brook.

About 40% of the volume of the pavement outcrops consist of xenoliths of varied size and shape(Figs. 24,25) enclosed in a host metamorphosed intrusive rock best described as a garnetiferous anorthositic ferrogabbro. It is a hybrid rock made up of broken, partly comminuted, highly garnetized crystals of calcic andesine, $An_{40-48.5}$, and mafic clots with inverted

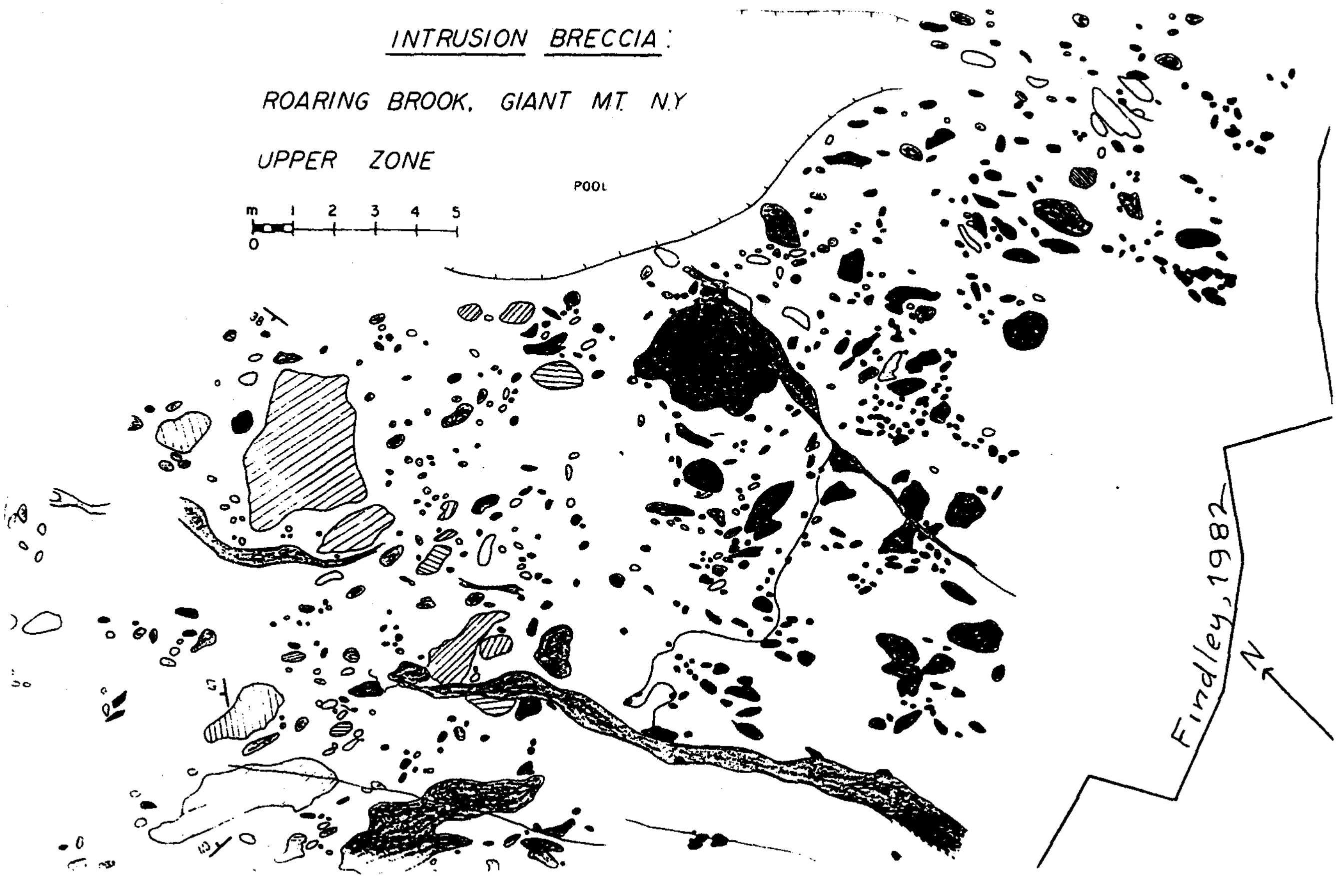
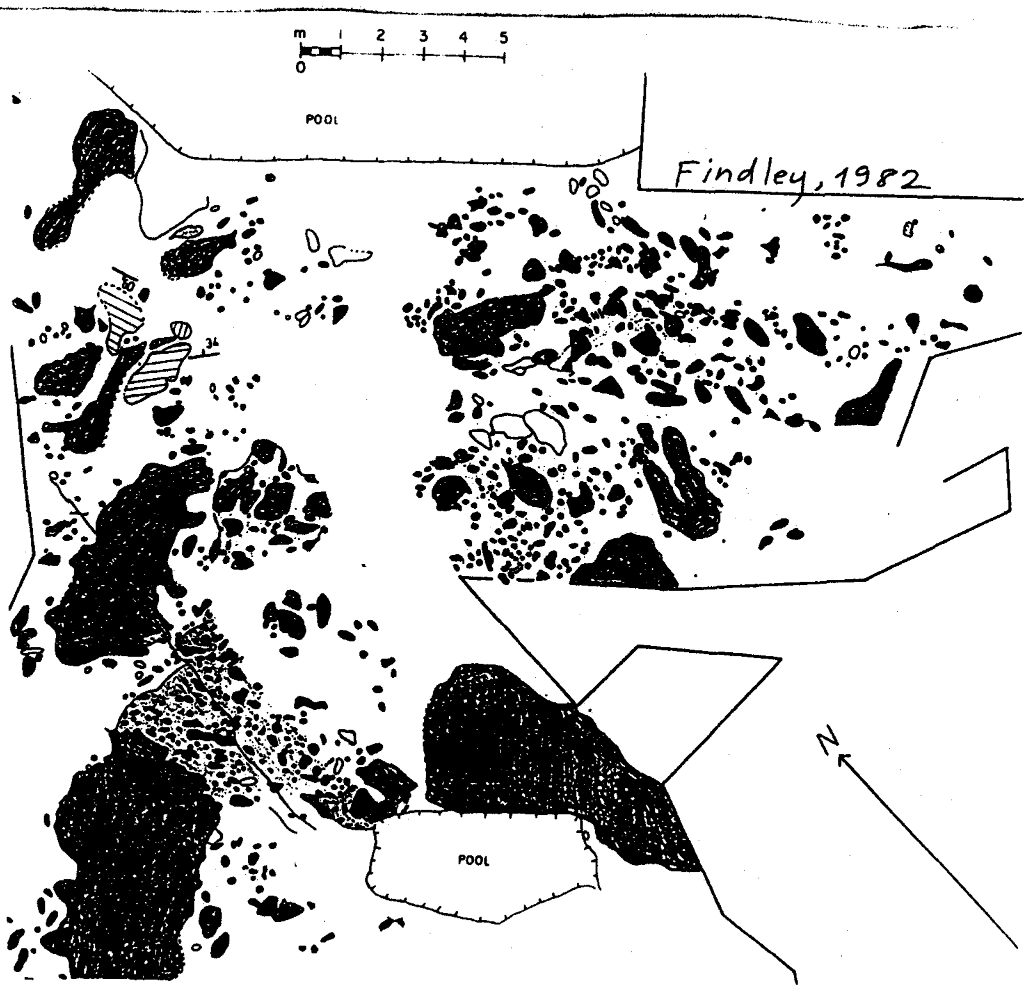

INTRUSION BRECCIA:
ROARING BROOK, GIANT MT. N.Y.
UPPER ZONE
POOL
m 0 1 2 3 4 5
Findley, 1982
N

Figure 24(above) and 25(below). Detailed geologic map of upper zone of Roaring Brook intrusion breccia showing profusion of xenoliths of metamorphosed sedimentary and volcanic (Grenville?) origin. Smallest xenoliths shown are about 15 cm(6") in diameter. Elizabethtown quadrangle.



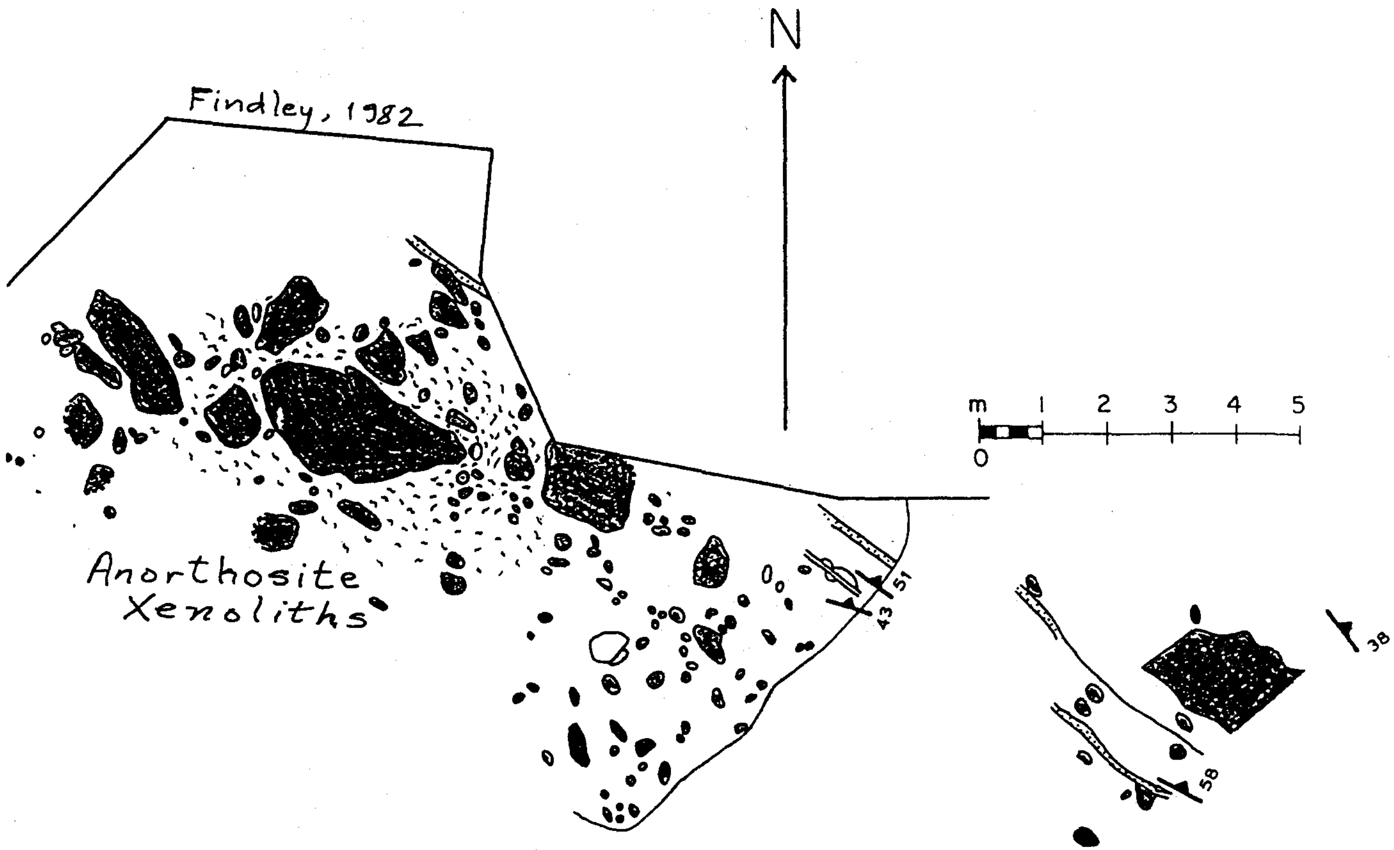


Figure 26. Detail of felsic anorthosite xenoliths in anorthositic ferrogabbro-ferrodiorite matrix near contact zone of intrusion breccia and anorthosite, Roaring Brook, elevation 2050'(625m), Giant Mt. at Elizabethtown-Mt. Marcy quadrangle boundary.

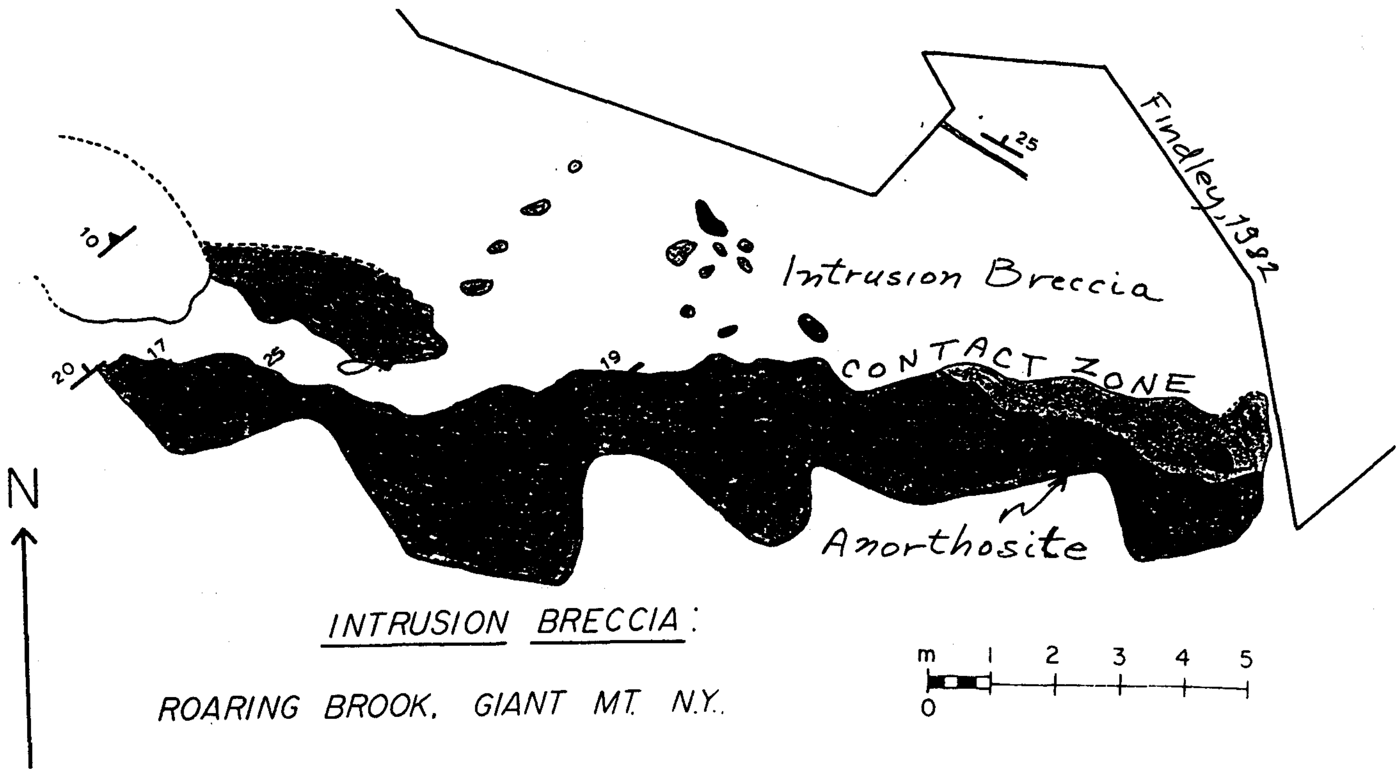


Figure 27. Contact zone of Roaring Brook intrusion breccia with a large block of felsic andesine anorthosite near the 2000'(610m) elevation, Roaring Brook, Giant Mt., Mt. Marcy quadrangle.

pigeonite, now eulite, Fs_{70-75}, rimmed by recrystallized augite, all in a matrix of sodic andesine, An_{27-30}, ilmenite, minor magnetite and apatite, and variable amounts of microperthite(Table 8). Although the pink-weathering mesocratic outcrop surfaces suggest a mafic syenite, the host rock is generally low in alkali feldspar, and the color is caused by the decomposition of the iron-rich pyroxenes. The microscopic texture is metamorphic and granoblastic, dominated by abraded calcic andesine megacrysts extensively replaced by chains and microporphyroblasts of euhedral garnet, and ferroaugite containing copious amounts of metamorphic "100" and "001" pigeonite exsolution lamellae. The microfabric, thus, in no way exhibits the magmatic texture anticipated from the outcrop appearance.

A very detailed geologic map on a scale of 1:76 made by John Findley in the summer of 1982(U. Mass. Dep't. of Geol. & Geog. Senior Honors Thesis(1983) in preparation), shows xenoliths as small as about 15 cm (6") length(Figs. 24,25). The detailed mapping shows that xenoliths make up a much greater volume of the outcrops than would be estimated from cursory examination, and reveal a complex history. There was polyphase deformation of supracrustal rocks, intrusion of felsic andesine anorthosite with associated contact metamorphism, brecciation accompanying the intrusion of anorthositic norite, partial anatexis and chemical exchange between supracrustal material and magma, and regional metamorphism converting the anorthositic norite intrusive into a garnetiferous anorthositic ferrogabbro. The conversion of anorthositic norite to garnet-augite-rich anorthositic metagabbro would use up much of the hypersthene, ilmenite, and anorthite components of the former.

Many of the xenoliths lie in parallel orientation, and dip gently northward, possibly in their pre-intrusion orientation; others have been rotated during brecciation accompanying intrusion. A very important result of the geological mapping by the authors reveals that supracrustal layering is persistently subhorizontal(gently north- gently south-dipping) over 3400'(1037 m) of section, ranging from Putnam Brook migmatitic outcrops at 1300'(396 m) through the Roaring Brook intrusion breccia at 2250'(636 m) in the gabbroic anorthosite of the Ridge Trail, and on the summit of Giant Mt. itself where a layered ferromonzonite granulite dips 12^{o}N to 10^{o}S. This pervasive subhorizontal trend of supracrustals stands in marked contrast to the equally pervasive steeply dipping foliation of the anorthositic rocks. We interpret this to mean that the anorthosite has discordantly intruded the supracrustals.

Anorther interesting feature of the Roaring Brook supracrustal xenoliths is their texture. They most commonly occur as fine-grained, 0.1-0.3 mm, granulites, often layered but seldom gneissic. Such texture may be a relic of contact metamorphism during which hornfelses were formed. Many of the xenoliths contain magnesian pyroxenes and biotite accompanied by sodic plagioclase and microperthite, whereas the anorthositic ferrogabbro intrusive host carries ferroan pyroxenes, more calcic plagioclase, and little potassium feldspar. Common reaction borders of ferroaugite on xenoliths, and dikes and tongues of syenitic material, suggest that evolution of anatectic felsic melts and assimilation of iron and potassium by the invading anorthositic melts were important processes.

As we descend the brook, occasional xenoliths of felsic andesine anorthosite appear in the company of the pyroxene granulite xenoliths (Fig. 26) and the former become larger and more abundant until a contact zone between felsic anorthosite and the intrusion breccia(Fig. 27) is reached at an elevation close to 2000'(610 m) in the easternmost part of the Mt. Marcy quadrangle. The contact is irregular and the felsic anorthosite xenoliths in the intrusion breccia are interpreted to be remnants of the earlier anorthosite intrusion, brecciated and caught up in the later noritic-gabbroic anorthosite magma; they are block structure remnants. De Waard classed the invading rock as jotunite (hypersthene monzodiorite), Kemp(1921) called it anorthosite, and we prefer the name anorthositic ferrogabbro. Although the plagioclase now shows $An_{27-48.5}$, the An content has been considerably reduced because of the copious metamorphic growth of garnet and augite. Thus, anorthositic ferrogabbro or ferrodiorite are equally appropriate.

We will return to the top of the intrusion breccia for lunch and discussion. Descent to the parking area will take about forty minutes. Time permitting, we will make a final stop of three hour duration to the "Chicken Fold" of Rooster Comb Mt. with those who have time to remain.

Notes:

Stop 12. THE CHICKEN FOLD OF ROOSTER COMB MOUNTAIN, RC-1

Drive north on Route 73 past the village of St. Huberts and park just north of the Ausable River bridge on either side of the road. On the west side of Route 73, walk up a private road, bearing left around the curve at the top of the first hill, past a house on the left, and find a trail west into the woods, where the road curves right. Follow this trail west about 3/4 mile (1.2 km) almost to a waterfall, where a trail to Snow Mt. bears right(north). Further along, the trail to Snow Mt. summit will again bear right. Avoid it and continue straight ahead (approximately northwest) to the intersection of the Flume Brook trail to Rooster Comb. Turn left(west) and climb another 1/4 mile(0.4 km) to a large outcrop about 500 feet (152 m) NW of trail.

In this spectacular outcrop, which forms a small knob about 500 x 1500' (152 x 456 m) with its long axis SSW-NNE just east of and below the summit of Rooster Comb Mt., a gray, lineated and foliated percalcic anorthosite is intimately infolded with pink alaskite and buff-weathering scapolite gneiss(Table 9). Quartz in the alaskite is strongly elongated and bent into micro-folds. The deep green clinopyroxene is iron-rich, 100Fe/(Fe+Mg) = 60, contains abundant inclusions of sphene, and is partially retrograded to hornblende. The hedenbergitic clinopyroxene with sphene inclusions is inherited Grenville calc-silicate.

The fold axis is parallel to a strong augite+hornblende lineation in a recline fold section is N 22-40 E 13-18^{o} and the overall foliation strikes N 50-78 W and dips 12-40 NE. Over the 75' section, beds differ in thickness from fractions of inches (cm) to several feet (m). There has been a great deal of "bedding plane" slip, as it is difficult to trace a layer from one fold into another(Fig. 28). Higher up in the outcrop, the interlayered alaskite and anorthosite are thicker.

A severely brecciated layer of anorthosite lies on top of the knob. This brecciation is later than the folding although at one end of the knob, small scale folds in the anorthosite are quite unlike the larger folds below, and are perhaps related to the brecciation. An alternative and not necessarily contradictory hypothesis is that these are isoclinal recumbent folds that have simply been refolded during later faulting similar to the Baxter fold at Beede ledge. Their dissimilarity to the larger folds below could be explained by a difference in rock type or thickness of original beds.

Whatever the origin of the folds, they are significant because here the anorthosite is clearly involved in the east-west isoclinal recumbent folding we have seen wherever the Grenville beds have not been disrupted by faulting. The scapolite gneiss and the alaskite were contact-metamorphosed by an early intrusion of anorthosite, probably as sills or lit-par-lit; the whole package was then isoclinally and recumbently folded along an east-west axis, and subsequently faulted and sheared, probably repeatedly.

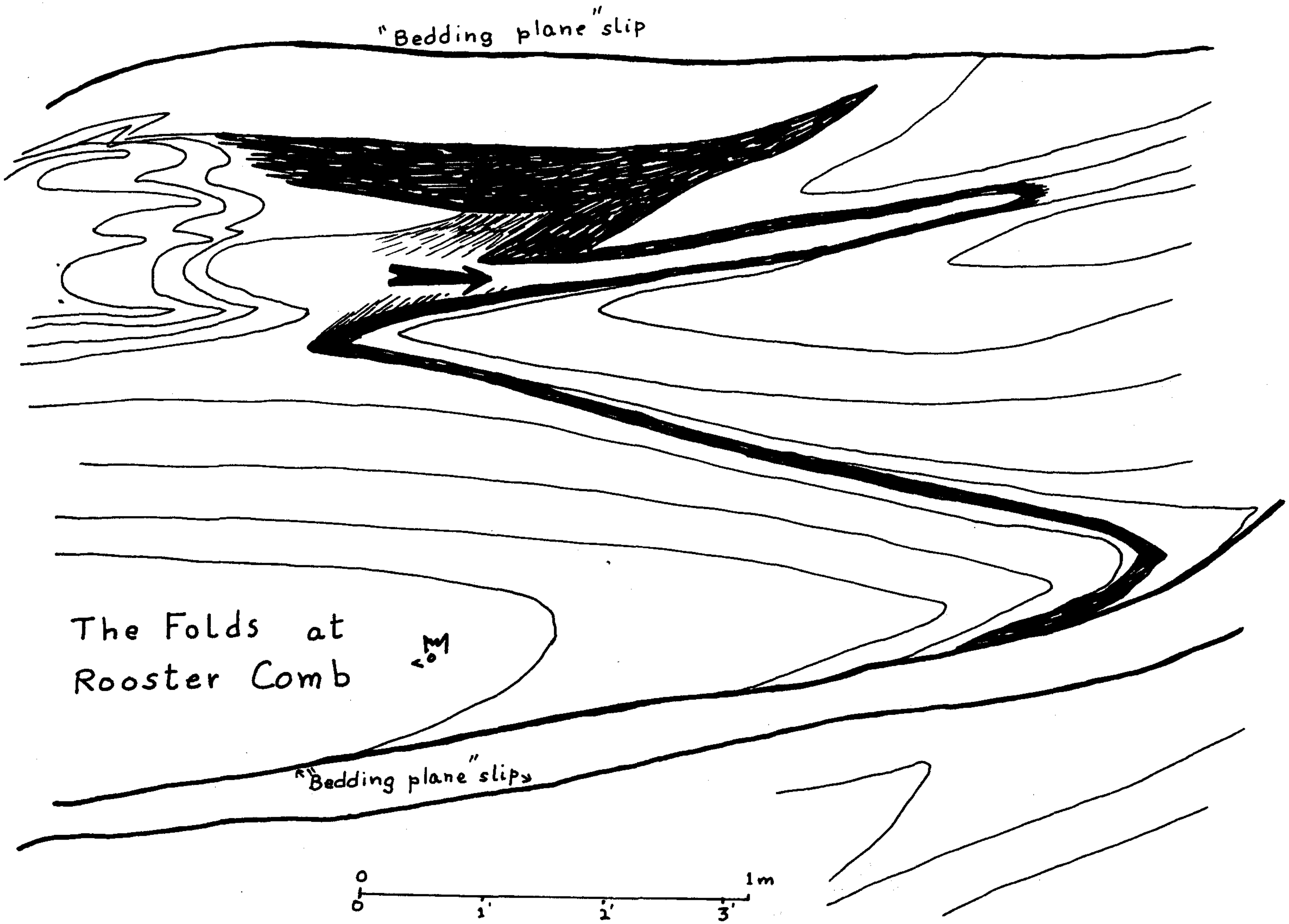


Figure 28. Complex recumbent folding of intercalated percalcic anorthosite, alaskite, and scapolite gneiss in the Chicken Fold of Rooster Comb Mt., Mt. Marcy quadrangle.

Table 9. Modes of percalcic anorthosite, alaskite, and scapolite gneiss from the Chicken Fold on Rooster Comb Mt.

	Percalcic Anorthosite Gn RC-1-a	Alaskite Gn RC-1-g	Scapolite Gn RC-1-s
Quartz	0	34.5	
Microcline	0	56.5	
Albite		9.0	
Andesine	84.3		40
Scapolite	3.5		57
Clinopyroxene	7.0		
Hornblende	4.0	tr	
Pyrite	0		3
Sphene	1.2		
Total	100.0	100.0	100.0
C.I.	16	<0.5	3

Plagioclase:

Megacrysts - $An_{48.5}$

Matrix $An_{44.5}$

Clinopyroxene-Fs_{60}

Alkali feldspar: unmixed microperthite

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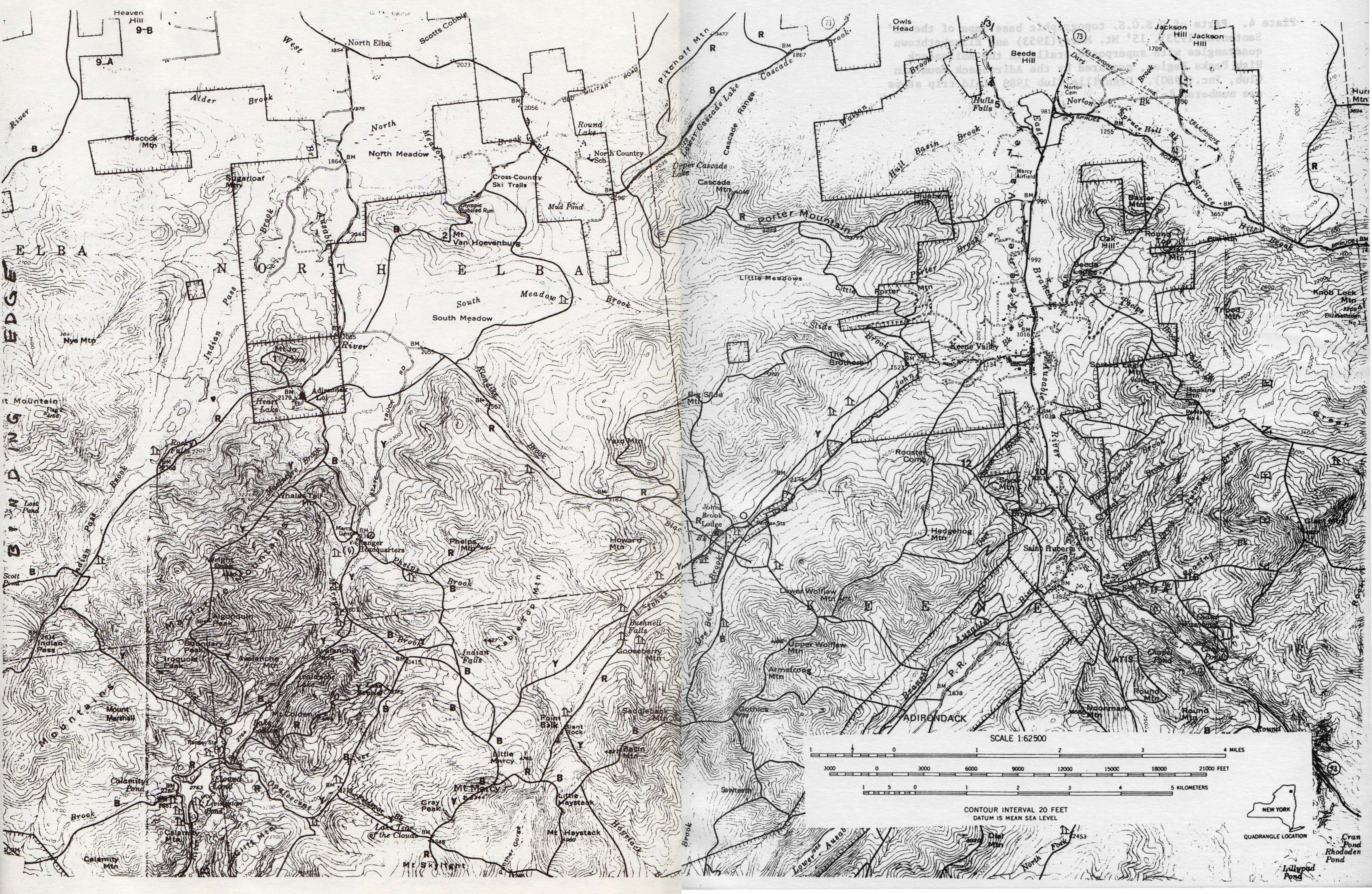
Heaven Hill
9-B
9-A
North Elba
Scotts Cobble
Alder Brook
Peacock Mtn
North Meadow
Round Lakes
North Country Sch
Cross-Country Ski Trails
Olympic Bobsled Run
Mud Pond
Sugarloaf Mtn
Mt Van Hoevenberg
N O R T H E L B A
South Meadow
Indian Pass
Nye Mtn
Mt Jo
Heart Lake
Adirondak Loj
Marcy Dam
Ranger Headquarters
Phelps Mtn
Phelps Brook
Yard Mtn
Howard Mtn
Whales Tail Mtn
Wright Peak
Algonquin Peak
Indian Pass
Iroquois Peak
Boundary Peak
Avalanche Pass
Avalanche Lake
Mt Colden
Mount Marshall
Calamity Pond
Calamity Mtn
Indian Falls
Table Top Mtn
Bushnell Falls
Gooseberry Mtn
Point Balk
Saddleback Mtn
Basin Mtn
Little Marcy
Mt Marcy
Gray Peak
Lake Tear of the Clouds
Little Haystack
Mt Haystack
Mt Skylight
Panther Gorge
Pitchoff Mtn
Owls Head
Beede Hill
Hulls Falls
Jackson Hill
Norton Cem
Spruce Hill
Cascade Lakes
Cascade Mtn
Porter Mountain
Blueberry Mtn
Marcy Airfield
Baxter Mtn
Oak Hill
Round Top Mtn
Beede Ledge
Little Meadows
Porter Mtn
Slide Brook
The Brothers
Keene Valley
Big Slide Mtn
Tripod Mtn
Knob Lock Mtn
Spread Eagle Mtn
Hopkins Mtn
Rooster Comb
Johns Brook Lodge
Hedgehog Mtn
Saint Huberts
Giant Mtn
Lower Wolfjaw Mtn
Upper Wolfjaw Mtn
Armstrong Mtn
Gothics
Chapel Pond
Round Mtn
Noonmark Mtn
ADIRONDACK
Sawteeth
Dial Mtn
Lower Ausable Lake
North Fork
Cran Pond
Rhododen Pond
Lillypad Pond
SCALE 1:62500
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL
NEW YORK
QUADRANGLE LOCATION

Plate 4. Parts of U.S.G.S. topographic base maps of the 15' Santanoni (1953), 15' Mt. Marcy (1953) and Elizabethtown quadrangles with superposed trails in the Adirondack High Peaks Region, prepared by the Adirondack Mountain Club, Inc. (1980). Grenville Club 1983 field trip stops are numbered 1-12.