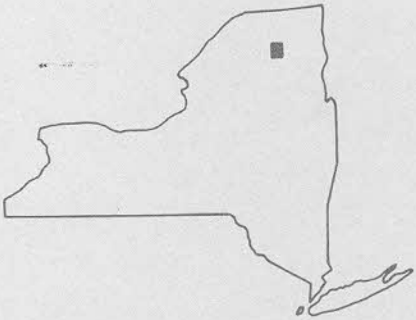

Bedrock Geology of the St. Regis Quadrangle, New York

Brian T. C. Davis

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Preface

This publication is a condensation of the original doctoral dissertation by Brian T. C. Davis, and was accepted at Princeton University in November 1962 for the Ph.D. degree. Dr. Davis died in 1966, before he was able to revise the manuscript.

Brian T. C. Davis was a young scientist of great promise, as exemplified by his experimental research at the Geophysical Laboratory in Washington and the Graduate Research Center of the Southwest at Dallas, and by the critical data and reasoning he has presented in this report bearing on the origin of the Adirondack anorthosite and quartz syenitic series.

This writer prepared the present, considerably abridged version of the original manuscript with the least revision and editing necessary.

A. F. BUDDINGTON

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Bedrock Geology of the St. Regis Quadrangle, New York[1]

by Brian T. C. Davis

ABSTRACT

The St. Regis quadrangle lies in the northern Adirondack mountains of New York. It is underlain preponderantly (about 160 square miles) by rocks of an anorthositic suite that form the northwest part of the great Adirondack anorthositic massif (the Marcy massif). The outer and upper part of the anorthositic mass is largely granulated and recrystallized with the development of a metamorphic foliation. The foliation of the border dips outward beneath a sheet of overlying differentiated quartz syenitic gneiss.

Metamorphosed anorthosite, with less than 10 percent mafic minerals by volume, forms the major member of the anorthositic suite. It grades upward into gabbroic anorthosite with 10 to 25 percent mafics. Small pyroxene-rich and oxide mineral-rich segregations locally form a late stage facies.

Remnants of magmatic structure, predominantly lineation of plagioclase, may be seen in portions of the anorthosite which are only slightly granulated, and in inclusions of anorthosite within gabbroic anorthosite.

Systematic variations in mineral abundance roughly parallel the foliation in the anorthosite. Gabbroic rocks occur structurally high in the mass, and extremely leucocratic rocks form the base of the exposed section. The exposed anorthosite is best described as part of a layered sheet or lens with the more mafic portions at the top. These simple relationships are complicated by gentle folding and differential erosion which have left leucocratic anticlinal areas as topographic highs. The mafic top is preserved within the mass as synclinal topographic lows. The true structural relationship of upward increase in mafic content may be seen on a few hills.

The composition of the plagioclase has effectively the same range (An_{40-48}) throughout all the facies of the anorthositic suite. Both the ortho- and clinopyroxenes of this series, however, show a systematic increase in Fe / Mg ratio with increase in abundance of mafic minerals. Metamorphic garnet in small amounts forms an almost ubiquitous constituent, occurring in small accessory amounts.

The quartz syenitic series occurs in the form of a sheet and has the general composition of a quartz syenite of charnockitic character, but varies from a mafic syenite or mangerite in the basal portion to a granitic or charnockitic facies at the top. In complete contrast to the anorthositic rocks, the quartz syenitic sheet shows a gradational decrease upward in mafic content with a concomitant increase in quartz. In addition, both the ortho- and clinopyroxenes become systematically more iron-rich with decrease of mafic content upward. These features are consistent with fractional crystallization and differentiation of a magma under the influence of gravity.

The quartz syenitic series has been inferred by some to be cogenetic with the anorthositic series as differentiates from a common magma. The evidence from the St. Regis quadrangle, however, is in favor of origin from two independent magmas.

The quartz syenite sheet is intrusive into the rocks of the anorthositic series. On a large scale, the base of the syenite cuts across and transgresses anorthositic layers of different composition, so that syenite may be in contact with leucocratic anorthosite on antiforms and with mafic gabbroic anorthosite where crossing synforms. In the latter situation there may locally be an appearance of gradation. Dikes of syenite occur in the anorthositic series, and may include blocks of the latter. Locally, discontinuous screens of pyroxene-plagioclase granulite occur between the syenite gneiss and the anorthositic rocks, and inclusions of the granulite occur in both series. At most contacts there are sharp compositional breaks in plagioclases and in the ortho- and clinopyroxenes. Rocks that might be called transitional exist, but they are

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of exceedingly small volume and are confined to contacts between mafic syenite gneiss and gabbroic anorthosite gneiss. The contacts of mafic syenite and leucocratic anorthosite are knife sharp. A "transition" type rock with andesine xenocrysts occurs locally above contacts with anorthositic rocks. The composition of pyroxenes of the "transition" rocks is erratic and the result of inhomogeneous incorporation of material from rocks of the anorthositic suite. These observations indicate that the "transition" rock is not a cogenetic differentiate with the anorthosite suite.

The anorthositic suite of rocks is interpreted as a differentiation series from a magma of gabbroic anorthosite composition.

Younger intrusives consist of a few hypersthene metadiabase dikes and still younger unmetamorphosed basaltic diabase dikes. A period of metamorphism occurring between the emplacement of the last two rock types is tentatively assigned to the Grenville episode terminating roughly one thousand million years ago. The principal result of this metamorphism was intense plastic flowage and recrystallization in the syenite and to a lesser extent in the coarse-grained anorthosite, and the development of corona and porphyroblastic garnet in both rock types.

Post-basaltic diabase history is recorded in this area only as erosion and Pleistocene glaciation, neither of which were studied.

Introduction

LOCATION, TOPOGRAPHY, AND CULTURE

The St. Regis 15′ quadrangle is situated in the northern portion of the Adirondack mountains of New York State, between latitudes 44°15′ and 44°30′ N. and longitudes 74°15′ and 74°30′ W. The quadrangle lies wholly within Franklin County.

The area lies on the western edge of the high Adirondacks. The highest point in the quadrangle is St. Regis Mountain, 2,873 feet. The St. Regis River leaves the quadrangle at the lowest point, 1,520 feet.

The many lakes of the quadrangle occupy about 13 percent of the area, and an approximately equal area is occupied by sphagnum muskegs. Only one small river, the St. Regis, flows through the area, and the drainage is poorly organized. A major drainage divide crosses the area, the northwestern part of the quadrangle draining into the St. Lawrence via the St. Regis River, and the southeastern part draining via the Saranac River into Lake Champlain and thence into the St. Lawrence. This divide, rather obscure topographically, passes from 1 mile north of Lake Clear westward to the center of the quadrangle and then south, leaving the map area south of Deer Pond.

The forests of the area, formerly mixed conifers and northern hardwoods, were extensively cut in the late 19th and early 20th centuries. Most of the uplands now consist of young second-growth hardwoods while the lower forested areas are dominated by balsam-spruce-tamarack bogs. Considerable burned areas in the northern part of the quadrangle support a mixture of birch, blueberries, and bracken.

Large game is represented solely by deer and black bear, both quite abundant; bobcat, red and gray foxes are common. Among the commercially interesting furbearers, mink, otter, fisher, and muskrat are plentiful, and some beaver and marten persist, despite intensive trapping. Varying hares, porcupines, raccoons, and small rodents round out the mammalian population. A rich avifauna inhabits the area; during two summers' casual observation, the author counted approximately 135 summer-resident species.

A major highway runs along the east edge of the map area, and most of the sparse human population is centered along this route. Two small roads provide access to the western portions of the quadrangle, but much of the area is most conveniently reached by backpacking or boat.

Settlement throughout the quadrangle is light; logging, formerly important, is currently minor. Farming is negligible. There are no large settlements in the area, and the principal employment of the residenst is in connection with recreational facilities.

PREVIOUS GEOLOGICAL WORK

The first publications of significance dealing with the geology of the St. Regis area are those of H. P. Cushing. His "Preliminary Report on the Geology of Franklin County" (1899), and "Geology of the Northern Adirondack Region" (1905) provide good introductory descriptions of the regional geology. The Pleistocene history of the area is adequately and readably discussed in Alling's "Geology of the Lake Clear Region" (1919).

New York State Museum reports on quadrangles adjacent to the St. Regis include Long Lake (Cushing, 1907), Santa Clara (Buddington, 1937), and Saranac (Buddington, 1953). In addition, there are U.S. Geological Survey maps for two areas tangential to the St. Regis quadrangle: Nicholville (Postel et al, 1959) and Loon Lake (Balsley, Postel et al, 1956). Finally, two works have been published which deal with this map area only as parts of major regional studies, but which present so many interesting and applicable ideas that they must be considered part of the background against which the present study was undertaken. These are Balk's (1931) epochal study of the structure of the Adirondack anorthosite, and Buddington's "Adirondack Igneous Rocks and Their Metamorphism." (1939)

PRESENT STUDY AND ACKNOWLEDGEMENTS

The St. Regis quadrangle was chosen for intensive study because it was known that the bedrock included a large area of the main Adirondack anorthositic complex, a substantial body of rocks of an adjoining quartz syenitic complex, and a long boundary between them along which contacts might be seen.

It was hoped that a detailed field study of the geology complemented by laboratory investigation of the mineralogy might contribute to the relationships and origin of the two series.

A total of 9 months was spent in the field during the summers of 1960 and 1961.

My thanks are due to Professors A. F. Buddington, R. B. Hargraves, H. H. Hess, and H. D. Holland of Princeton University for their advice and unflagging interest in the problem, and to my fellow graduate students A. T. Anderson and R. L. Chase for their constructive criticism. During the summer of 1961, capable assistance in the field was given by Thomas Wellman, an undergraduate at Hamilton College. Research funds were provided by graduate fellowships from the National Science Foundation and by a summer research expense grant from the New York State Geological Survey.

Pyroxenic Granulites

The oldest rock exposed in the St. Regis quadrangle consists of pyroxenic granulites of variable composition. They have two principal modes of occurrence—as inclusions in the anorthositic and syenitic masses, and as a thin discontinuous screen between them.

Inclusions of granulite in the anorthositic complex are generally restricted to the gabbroic uppermost portion, *i.e.*, near the edge boundary of the complex in plan. Two localities serve to characterize the occurrences. On the east side of Upper Saranac Lake, along the south side of Gull Pt., a 3 to 6 meter thick sheet of granulite concordant to the foliation of the anorthosite may be traced for 200 meters. A thin pyroxene selvage is developed at the contact. The anorthosite within 30 meters of the inclusions is irregularly more mafic than that of the general region and appears to have incorporated some of the granulite. The inclusion consists of layers of anhedral clinopyroxene and plagioclase with minor garnet. Grains range from 0.5 to 1 mm in diameter. On the northeast slope of the hill immediately south of Fish Creek Bay of Upper Saranac Lake, numerous sheets of granulite, in all stages of disintegration, occur in gabbroic anorthosite of variable composition. On the east side of route 30, 2.4 miles north of the southern boundary of the quadrangle, exposures in a small quarry consist of phlogopite-clinopyroxene granulite intimately involved with anorthosite. Much of the granulite is quite pyritic. This quarry exposure probably represents an inclusion in the anorthosite mass.

In the south-central part of the quadrangle, particularly near Deer Pond, a clinopyroxene-plagioclase granulite, locally bearing hornblende, occurs as a screen between the anorthosite and the syenite. The thickness of the screen varies from zero to roughly 30 meters.

A large number of granulite inclusions of extremely varied composition may be observed in the large syenite dikes on the crest of Jenkins Mountain and along route 30, 2.6 miles southeast of the northern boundary of the quadrangle. Foliations of the blocks are intensely distorted (especially so at the roadcut on route 30) and are randomly oriented. Blocks vary in mineralogy from wholly clinopyroxene through clinopyroxene-plagioclase assemblages to perthite-clinopyroxene. Hornblende and garnet are present in some assemblages.

A granulite layer included in pink granite gneiss occurs near the top of Iron Mountain, near the western border of the quadrangle. It is unique in possessing masses of black garnet which are easily confused at first glance with magnetite. Local concentrations of magnetite, none of commercial interest, also occur associated with this skarn layer.

The foregoing granulites have been interpreted by previous workers as metamorphosed calcareous sediments.

Amphibolite and Pyroxene-Plagioclase Granulite

Layers of amphibolite and pyroxene-plagioclase granulite occur on Brandon Hill, on Buck Mountain, and in several outcrops near Long Pond. They are much dismembered by pink granite, and may once have been parts of a continuous sheet of gabbro. The mixed rocks occur in a synclinal structure overlying quartz syenitic gneiss.

The rocks near Long Pond are coarse grained (2-5 mm) granulites consisting of variable amounts of plagioclase, orthopyroxene, and clinopyroxene with several percent of iron-titanium oxide minerals. Similar bands occur in the pink granite of Brandon Hill and Buck Mountain, but the rock here may also vary to amphibolite.

Anorthositic Series

CLASSIFICATION

The term anorthositic suite or series is here used to describe a group of rocks consisting preponderantly of anorthosite and gabbroic anorthosite, but having minor amounts of associated gabbroic rocks that grade into pyroxenitic or feldspathic pyroxenitic facies rich in iron-titanium oxide minerals. All are thought to be genetically related.

The following nomenclature of Buddington (1939, p. 19) is used herein: anorthosite, less than 10 percent mafic minerals; gabbroic anorthosite, 10 to 22.5 percent mafics; anorthositic gabbro, 22.5 to 35 percent mafics, and gabbro, more than 35 percent mafics. The term mafic as used here includes the iron-titanium oxide minerals. The plagioclase is calcic andesine and the rocks could be called a diorite suite. However, long usage justifies the terms gabbroic and anorthositic. Where oxide minerals account for more than 10 percent by volume, the modifier "oxide mineral-rich" is used. If orthopyroxene is more abundant than clinopyroxene, the prefix "noritic" is substituted for "gabbroic." Garnet, hornblende, biotite, K-feldspar, and quartz may also be present locally in minor amounts.

Very coarse grained pods, with crystals measuring 10-25 cm in longest dimension and 0-15 percent mafics occur locally. These have been termed pegmatite in other reports, and the term is accordingly used here, but without genetic implications. Such patches grade into the surrounding anorthosite.

FIELD OCCURRENCE AND WEATHERING

Rocks of the anorthositic suite crop out over about two-thirds of the St. Regis quadrangle (plate 1). Small outlying domes occur near the northern boundary along the St. Regis River and south and west of River Pond in the west-central portion of the quadrangle.

Weathering in the more leucocratic varieties is seldom more than superficial, and it generally accentuates the appearance of internal structure, texture, and mafic content. Mafic-rich varieties do not crop out well, and appraisal of their field relations is consequently difficult.

Topographically high areas are leucocratic and anticlinal. Topographically low areas are underlain by more mafic facies and are synclinal.

GRANULATION

The anorthositic rocks show all degrees of granulation. Most commonly the rock consists of 25 to 50 percent of rounded and pervasively fractured plagioclase crystals 1 to 4 cm in longest dimension, surrounded by a matrix of comminuted plagioclase and mafics grading in size down to 1 mm. Some of the larger pyroxenes remain in interstitial relation to coarse plagioclase. With the onset of granulation, garnet appears as thin coronas around pyroxenes and oxide-minerals, and with increasing granulation as small porphyroblasts of garnet. Rarely, the anorthosite is totally mylonitized to a cherty white rock with bands of altered mafics.

Granulation shows neither systematic spatial distribution nor consistent relationship to shear zones or intersections of shears. One is struck by abrupt changes in grain size and fabric in traversing a large outcrop. Gradation dies out as sharply in depth as laterally, and attempts to trace it into the third dimension proved abortive. The overall impression is that of highly irregular crushing, often with only slight total displacement.

STRUCTURAL FEATURES

Foliation and Lineation

Structures within the anorthositic rocks include both foliation and lineation. Foliation consists of the parallel orientation of lenses and streaks of mafic minerals and relict plagioclase augen. It is best developed in fine- to medium-grained rocks which have at least several percent mafics and show in thin section evidence of bending, strain, and intense granulation. Such deformation is most common in the gabbroic anorthosite border facies, but is also prominent well within the mass in the area around Boot Bay

Mt. with orientations appropriate to an anticline. Hints of similar anticlinal structures are found on all the higher hills from East Pond and Floodwood Mountains to Jenkins and St. Regis Mountains. All the hilltops are also leucocratic.

Lineation is formed by oriented coarse tablets of plagioclase in ungranulated to slightly granulated rocks. It is largely restricted to the crestal area of the Jenkins Mt.-St. Regis Mt.-East Pond Mt. anticlinal zone. Several lines of evidence indicate that the lineation is a primary structure which antedates foliation. A glance at lineation-foliation relations in the northeast corner of the geologic map, for example, shows conflicting structures which cannot be reconciled with the idea of simultaneous metamorphic development of foliation on the limbs and lineation on the crests and troughs of folds as suggested by Buddington (1956). The preservation of lineation is fortuitous. Its preservation in the above-mentioned anticlinal zone is due to its orientation coinciding with the axial direction of the later folding. In contrast, primary lineation in areas that coincidentally became flanks of later folds, and lineation that had orientations not parallel to later fold axes was destroyed.

Block structure (Balk, 1931, p. 357; Buddington, 1939, p. 27) is common locally in the more mafic border facies. It is represented by inclusions of anorthosite in gabbroic anorthosite. Polygonal blocks, ranging from a few cm to 2 m in diameter, are everywhere more leucocratic than their host. Within any one exposure the inclusions vary widely in texture, composition, and degree of development of fabric. Foliation in the host rock commonly swirls around the inclusions. Plagioclase crystals within the blocks are generally lineated rather than foliated, and orientations are totally random with respect to adjacent blocks and the host rock. Clearly this is a relict magmatic lineation.

If one assigns fold axes on the basis of orientations of foliation and compositional variation, lineation is seen to be roughly parallel to fold axes. However, in several places near Mountain Pond lineation may be seen to plunge more steeply than the dip of the foliation in an adjacent outcrop. Such conflicts have, in several examples, been repeatedly recorded at the same series of outcrops by the same observer or by more than one observer on different visits, and they appear to be highly systematic. Lineation and foliation almost never occur in the same outcrop, and in this area as elsewhere, foliation occurs in the more severely granulated outcrops. Clearly the foliation is superposed on the lineation.

The foliation and the border of the anorthositic mass everywhere dips under adjacent syenite gneiss. The anorthosite is inferred to be a domical sheet or lens with a series of open folds in the upper surface. These have northeasterly axes that plunge northeast in the eastern part of the quadrangle and southwest in the western part.

If anticlinal axes obtained from compositional variation and foliation are projected southwestward, they line up perfectly in each case with anticlinal axes in the overlying syenite gneiss as determined from prominent foliation. Along anticlines, the anorthosite forms projections into the syenite gneiss in plan. Similar projection of anticlines northeastward into the Saranac quadrangle yields equally good correlations between structures in anorthosite and syenite gneiss, as was tentatively noted by Buddington (1953, pp. 74-77). The structures of the anorthosite and syenite appear to form one unit. The folds in both are quite open, with dips seldom exceeding 30°. Local reversals of axial plunge near the syenite-anorthosite contact south of Floodwood have led one previous worker (Balk, 1931, p. 325) to conclude that the syenite gneiss locally dips under the anorthosite. The true relations were determined by Buddington (1939, p. 203) and confirmed in the present study.

The extent to which premetamorphic foliation was developed is indeterminable because of the superposition of later structure.

Most previous students have agreed that regional structure was developed in the Adirondack anorthosite and in the syenite bodies during magmatic as well as metamorphic episodes, but have differed in the relative emphasis placed on either mode of origin.

The views of the present writer and those of Buddington (1939) are in substantial agreement on the origin of structure in the anorthosite and syenites of the Adirondack highlands.

The anorthosite, at least, possessed a magmatic lineation in general, which has been preserved whereever granulation and recrystallization have not been too intense. Adjacent to inclusions and contacts this probably gave way to foliation. Both structures are formed by crude orientation of plagioclase crystals. Around the northwest margin of the anorthosite, the syenite is generally intrusive into the anorthosite and therefore at least slightly younger. A foliation in the syenite is accentuated by compositional layering. Foliation parallel to this occurs in the anorthosite, but dies out towards the coarser, more leucocratic lower portions of the anorthosite. This foliation is clearly metamorphic, and the difference in quality of development in the two rock types may be attributed to the greater rigidity of the anorthosite mass.

Lineation is commonly observed in syenite gneiss in the axial zones of folds where it is formed by aligned mafic prisms and rods of quartz which are commonly several centimeters long. In zones of intense deformation, the lineation is pervasive and is consistently oriented down dip, indicating strong movement perpendicular to fold axes.

Anorthositic Mass an Extensive Slab

The generally open structures in this quadrangle are consistent with the hypothesis that the anorthositic massif has acted as a buttress. The open structures that characterize the syenite gneiss even several miles distant from the nearest anorthosite exposure were considered by Buddington (1956, p. 103) to reflect the presence of a thick anorthosite mass at relatively shallow depth. The gravity data of Simmons (1964) confirm this interpretation and suggest that a 3-km thick extension of the anorthosite slab continues beneath the syenitic gneiss for several km west of the western outcrop boundary of the anorthosite.

DISTRIBUTION AND SYSTEMATIC RELATIONS OF MAJOR ROCK TYPES

Introduction

The content of mafic minerals in the anorthositic series is variable and gives rise to different rock types. The major rock types have systematic relationships to each other. In general, the structurally lower facies are leucocratic and become increasingly more mafic up-section. This results in the border facies being generally more mafic than the core. The general relations are complicated by nonsystematic variations on the scale of outcrops and hand specimens. In most places the magnitude of the small-scale variation is well below that of the systematic regional change. Compositional trends may, therefore, be drawn from data collected by averaging the total mafic content of each outcrop separately. The variation pattern thus obtained is consistent with the regional structure. Variations in mafic content become most extreme in the gabbroic zone where pods averaging up to 50 percent pyroxenes may occur in hypersthene-gabbroic anorthosite containing only 10 percent mafics. Compositional figures for the gabbroic top of the sheet are consequently less meaningful than those for the leucocratic portions.

Estimation of Percent Mafic Minerals

A necessary adjunct to a discussion of the anorthositic series is the problem of estimating volume percentages in coarse-grained, nonhomogeneous rocks. Grains of typical ungranulated parts of the anorthositic rocks commonly range between 2 to 5 cm in longest dimension, and occasionally attain lengths up to 30 cm. Granulated portions of the anorthosite contain many grains in the .01-1 cm range, but uncrushed relics approaching the original grain size generally constitute 25 to 50 percent of the rock.

Complicating the problem is nonhomogeneity on several scales. Mafic minerals tend to occur in pods unequally distributed through the rock. It was found necessary to rely on visual estimates made on weathered surfaces, comparing these frequently with the estimates of other workers on the same outcrop. From the average value obtained in this fashion a typical sample was selected, with a conscious effort to avoid selecting the most accessible sample. At a date enough later to blur one's memory of the outcrop, the hand specimen was described without referring to the outcrop description. The two descriptions were then compared and differences noted. It was satisfying to notice that no systematic differences emerged from these comparisons. Deviation of the percent mafics in hand specimen from that in outcrop was generally ±2 percent in the 5 to 10 percent range, increasing to ±5 percent in the 20 to 25 percent range—about the same as the worker-to-worker variation. As a further check on the method, bulk densities were determined on 200 selected specimens. The densities were then plotted against the estimated mafic content (fig. 1). The scatter in values of density for samples having similar estimated mafic content was ±2 percent in the 5 to 10 percent range, ±4 percent at 20 percent, and probably not in excess of ±8 percent at 50 percent. The values could be explained as a mixture of andesine of density 2.68 and pyroxenes of average density 3.45, with oxide minerals tending to give a bias toward higher density values. The average uncertainty in estimates of mafic content of anorthosite by visual inspection as compared with measured density values is about 20 percent.

An areal map showing the range of variation in content of mafic minerals in the anorthositic mass is given in Plate 1.

DENSITIES AND COMPOSITION OF COEXISTING MINERALS ON ROCKS OF THE ANORTHOSITIC SERIES

The densities of 25 samples of the anorthositic series are shown in table 1, together with compositions of pyroxenes and plagioclase in the same rock. The pyroxene compositions, as determined from optical data, are probably slightly different from what would be found by chemical analysis, but they are believed to be sufficiently accurate for some qualitative conclusions. Details on the minerals are given in the following section.

TABLE 1

Densities and compositions of coexisting minerals of rocks of the anorthositic series

Sample number[1]	Density	Plagioclase	Orthopyroxene	Clinopyroxene
		Anorthosite		
Sr-15	2.76	An_{44}	Mg_{61}	Ca_{45} Mg_{36} Fe_{19}
Sr-20	2.75	An_{45}	Mg_{61}	Ca_{45} Mg_{36} Fe_{19}
Sr-33	2.75	An_{46}	Mg_{62}	Ca_{45} Mg_{36} Fe_{20}
Sr-105	2.71	An_{45}	Mg_{60}	Ca_{45} Mg_{36} Fe_{19}
Sr-153-B	2.73	An_{43}	Mg_{60}	Ca_{45} Mg_{34} Fe_{22}
Sr-190	2.69	An_{47}	Mg_{61}	Ca_{45} Mg_{36} Fe_{19}
Sr-194	2.73	An_{45}	Mg_{62}	Ca_{45} Mg_{34} Fe_{21}
Sr-200	2.74	An_{43}	Mg_{62}	Ca_{45} Mg_{36} Fe_{19}
Sr-206	2.75	An_{43}	Mg_{61}	Ca_{45} Mg_{36} Fe_{19}
Sr-207	2.73	An_{44}	Mg_{62}	Ca_{45} Mg_{35} Fe_{20}
Sr-250	2.72	An_{45}	Mg_{61}	Ca_{45} Mg_{37} Fe_{18}
Sr-276	2.77	An_{45}	Mg_{58}	Ca_{45} Mg_{34} Fe_{21}
Sr-177	2.79	An_{48}	Mg_{58}	Ca_{45} Mg_{34} Fe_{21}
Sr-181	2.77	An_{42}	Mg_{59}	Ca_{45} Mg_{35} Fe_{20}
		Gabbroic anorthosite		
Sr-127	2.83	An_{45}	Mg_{57}	Ca_{45} Mg_{34} Fe_{21}
Sr-143	2.92	An_{45}	Mg_{48}	Ca_{44} Mg_{32} Fe_{24}
Sr-151	2.85	An_{43}	Mg_{62}	Ca_{45} Mg_{36} Fe_{19}
Sr-315	2.84	An_{40}	Mg_{54}	Ca_{45} Mg_{33} Fe_{22}
		Anorthositic norite		
5718	2.98	An_{44}	Mg_{46}	
Sr-239	2.93	An_{43}	Mg_{49}	Ca_{44} Mg_{31} Fe_{25}
Sr-328	2.98	An_{45}	Mg_{42}	Ca_{44} Mg_{25} Fe_{31}
		Norite and hypersthene gabbro		
Sr-292	3.04	An_{29}	Mg_{34}	Ca_{43} Mg_{21} Fe_{36}
Sr-163-A	3.05	An_{31}	Mg_{43}	Ca_{48} Mg_{25} Fe_{27}
Sr-171-A	3.07	An_{44}	Mg_{54}	Ca_{44} Mg_{33} Fe_{23}
		Garnetiferous feldspathic oxide mineral-rich pyroxenite		
Sr-289	3.37	An_{30}	Mg_{36}	Ca_{43} Mg_{22} Fe_{35}
Sr-305	3.49	An_{37}	Mg_{35}	Ca_{43} Mg_{21} Fe_{36}

[1]For information concerning locations see Plate 1

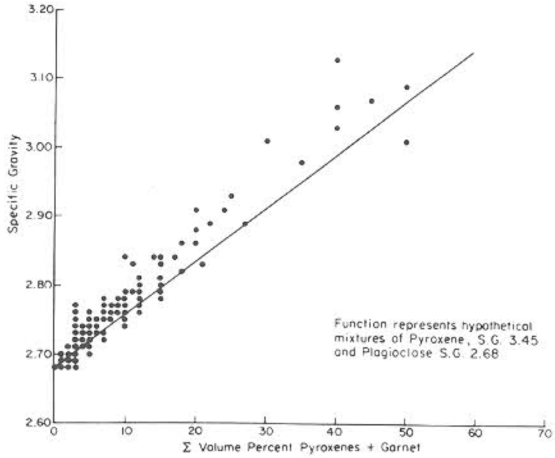


FIGURE 1 — Relationship between volume percent of mafic minerals and specific gravity for members of the anorthosite series.

PLAGIOCLASE

The plagioclase in thin section commonly shows extreme strain and fracturing. Polysynthetic twinning of the type in which lamellae are of uneven thickness (the thickness depending on intensity of strain at a given point in the grain) is well developed in the more intensely strained grains. Such twins have been shown to be of postcrystallization origin on the basis of their lensoid nature, termination against fractures, and relations between their thickness and the local intensity of bending (Vance, 1962, p. 1108).

Inclusions and possible exsolution phenomena of several types are well nigh universal in the plagioclase grains. Scattered spindles of K-feldspar occur in the plagioclases of very leucocratic anorthosites, and the more gabbroic facies, most plagioclase is strongly antiperthitic. K-feldspar spindles are everywhere localized along secondary twin planes, suggesting that their exsolution is strain dependent. To test whether the K/Na ratio of plagioclase varies with mafic content, Na and K contents were made of 12 plagioclases, using a Coleman flame photometer. Recalculation to mole percent K-feldspar showed a range of 4.5 to 6.4 with an average of 5 ± 0.5. No significant variation could be substantiated despite apparent variation in the abundance of K-feldspar spindles. This is not surprising in view of the constant An values.

Small (0.1 mm) euhedral clinopyroxene and apatite commonly occur in the plagioclase of anorthosite and gabbroic anorthosite. These are generally preferentially located on sides of plagioclases adjacent to large grains of pyroxene and apatite.

Minute rods of opaque minerals are ubiquitous in the plagioclases and probably account in large part for their dusky color. In polished section these are seen to be hematite-ilmenite intergrowths. The origin of these rods is uncertain. If they are taken to be inclusions, it is hard to explain why they do not show the characteristic tabular habit of these oxide minerals. They may be due to exsolution.

Another noticeable feature of the plagioclases of the Adirondack anorthosite is the lack of compositional zoning. Only in garnetiferous gabbroic anorthosite and gabbro is zoning at all common, and even here it never amounts to more than 6 or 7 percent An as determined from measurement of refractive indices. The extreme homogeneity was confirmed by determination of the X-ray parameter $\wedge$ $1\bar{3}1$-131 on 13 typical plagioclases.

Although the great homogeneity of anorthosite plagioclases has been noted by numerous workers there have been no detailed studies of the extent of compositional variation within the plagioclases of an entire anorthosite mass. Consequently it seemed worthwhile to examine a large number of samples from all varieties of the anorthosite.

Accordingly, the alpha indices of refraction of 56 plagioclases were determined in powder on the universal stage according to the method of J. R. Smith (Hess, 1960, pp. 200-202). A summary of the results follows. In all anorthosites, gabbros, and feldspathic oxide mineral-rich pyroxenites, the plagioclase averages $An_{45\pm2}$, 48 values of the 59 measured falling within this range. Four are An_{48} and two An_{41}. The remaining 5 plagioclases are from garnet-rich gabbros, norites, and oxide mineral-rich feldspathic pyroxenites. Zoning of plagioclase is absent from all rocks except the garnet-rich facies in which cores range from An_{42-45} and margins from An_{36-40}. It thus appears that there is no systematic variation in the composition of the plagioclase of the Adirondack anorthositic series except where a metamorphic reaction effect has been superimposed.

The plagioclases were further studied by X-ray diffractiometer. Delta values for $\wedge$ $1\bar{3}1$-131 of 12 samples ranged between 1.74 and 1.79, all consistent with low-temperature structure for plagioclase of this composition. All peaks measured were well defined and narrow. There can, therefore, be little or no zoning of either composition or structure.

The origin of giant (occasionally up to 40 cm.) plagioclase crystals totally free of zoning and of constant composition throughout the mass poses a problem. Two alternative explanations are possible. Either through some peculiarity of the anorthositic system the gap between solids and liquids is very small, or else there has been postcrystallization equilibrium on an enormous scale.

On the basis of presently known experimental data, it does not seem likely that crystallization paths in the system diopside-albite-anorthite-water (the model for anorthosite crystallization) should always be such that plagioclase would crystallize isocompositionally regardless of the bulk composition. This is especially unlikely in view of the similarity of the plagioclase systems at one atmosphere and at 5 kilobars water pressure (Yoder, 1956, p. 192). Such a singular crystallization path is not true of the anhydrous system diopside-albite-anorthite either. Available data indicate that plagioclase of early crystallization should be much more calcic than that at successively lower temperatures and some zoning might be expected.

Equilibration within a crystal is difficult principally because substitution of a Na for Ca requires the simultaneous exchange of an Si for an Al. This in turn necessitates the breaking of the strong Si-O and Al-O bonds, a statistical process whose rate is quite slow even at high grade metamorphic temperatures. Thus the persistence of compositional zoning in plagioclases of magmatic rocks is almost universal.

The alternative of large-scale postcrystallization equilibration is next considered. Long distance equilibration in a magma poses no great problems. The extent of equilibration will be increased by slow crystallization, the presence of large quantities of volatiles, and maintenance of high temperatures during the course of crystallization. Any mechanism whereby the plagioclases might be held at temperatures on the order of 1000°C for long periods after crystallization would also promote the destruction of zoning.

PYROXENES

General

Pyroxenes are next to plagioclases in importance among the minerals in the Adirondack anorthosite. In all portions of the anorthosite both orthorhombic and monoclinic species are present, monoclinic generally being slightly more abundant. Although no systematic survey was undertaken because of the difficulty of making precise modal analyses, no large systematic variation in the ratio of orthorhombic to monoclinic types as a function of mafic content or position in the intrusion was noted.

In portions of the anorthosite which are only slightly granulated, large (average 1 cm) anhedral grains of both pyroxenes occur clumped with oxide minerals and apatite in interstitial relation to plagioclase. Orthopyroxenes are crowded with oriented oxide mineral inclusions, and mutual exsolution relations between orthorhombic and monoclinic phases are common.

With increasing granulation, well formed exsolution intergrowths no longer appear, but in their place are anhedral "inclusions" of one species in another. With intense granulation, no large grains are preserved, and granules of the exsolved species rim the former host. Buddington (1939, p. 33) described granular augite rims around hypersthene and thought they were the product of reaction with plagioclase. However, it is tempting to attribute such rims on hypersthene to completion of exsolution as a function of the degree of recrystallization.

Exsolution

Three types of exsolution were noted in the pyroxenes of the uncrushed anorthosite. Universal are fine lamellae of clinopyroxene parallel to (100) of an orthorhombic host. Universal too are somewhat coarser and more irregular lamellae of orthopyroxene parallel to (100) of clinopyroxene.

A third type is much less common but has been noted in several thin sections (fig. 2). It consists of coarse, irregular lamellae of clinopyroxene with their poles rotated about 15° from *c* toward *a* of the orthorhombic host.

Poldervaart and Hess (1951) discuss all three types of exsolution. From their work it is clear that exsolved intergrowths of clinopyroxene parallel to (100) of an orthorhombic host and exsolved intergrowths of orthopyroxene parallel to (100) of a monoclinic host are common to plutonic and hypabyssal intrusives. Similar exsolved intergrowths are to be expected in deepseated metamorphism. They are the result of the decreased mutual miscibility of the two pyroxenes with decrease in temperature, and have no quantitative thermometric significance.

However, exsolution of clinopyroxene at about 15° to (001) of the orthohombric host appears to be inconsistent with the lattice symmetry of orthopyroxene but perfectly consistent with that of the monoclinic clino-polymorph. Exsolved intergrowths of identical orientation are observed in natural monoclinic Mg-Fe pyroxenes (pigeonites). The restriction of the exsolution on "monoclinic (001)" of an orthorhombic host to hypabyssal and plutonic rocks of the

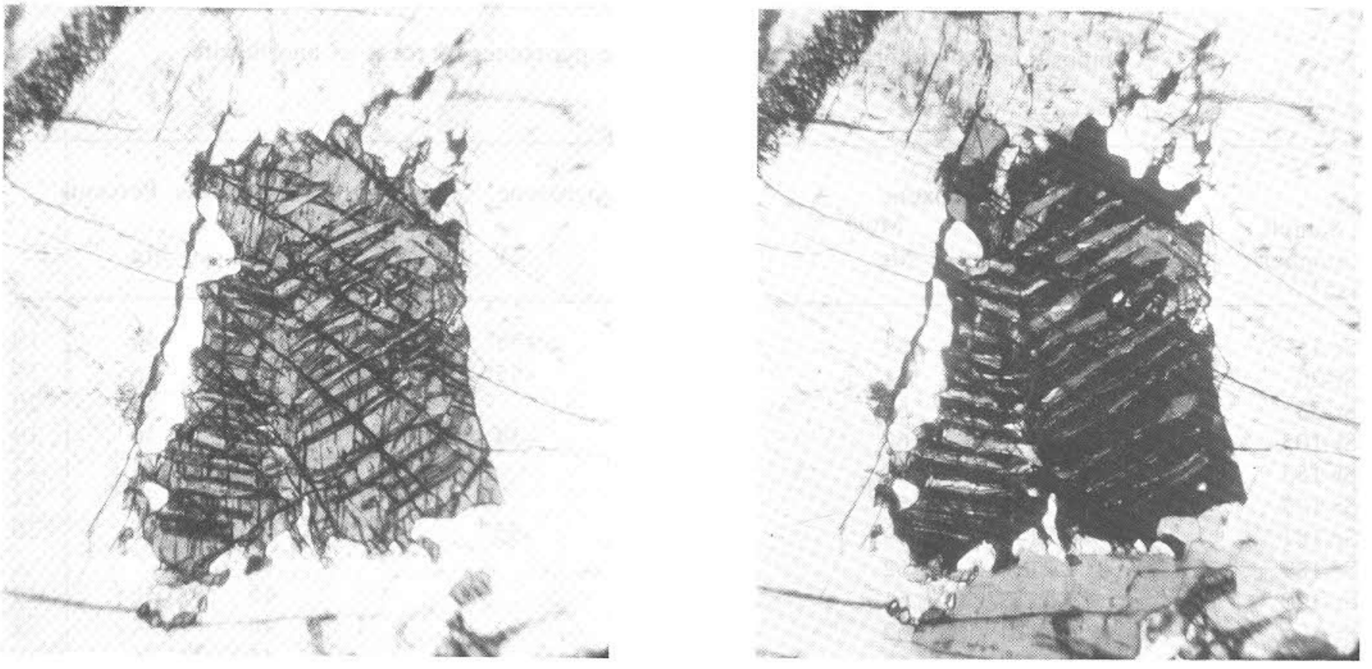


FIGURE 2 — Stillwater-type " monoclinic (001) " exsolution lamellae in hypersthene from Adirondack anorthosite; in plane and polarized light, 45x

gabbro clan has been well demonstrated. This is commonly taken as evidence of crystallization of such rocks at temperatures above that at which clinopyroxene inverts to the orthorhombic phase. Although the temperatures of this inversion at high pressures cannot be assigned quantitatively, it nonetheless seems a safe criterion of magnatic temperatures on the basis of its absence from metamorphic rocks.

Orthopyroxenes

The orthopyroxenes are brownish-green megascopically, and are strongly pleochroic in thin sections, with X=pink, Y=pale yellow, Z=pale green. Cleavages on (210) are prominent; partings on (100) and (010) are common and on (001) less common. The optic plane is (100), with X=*a*, Y=*b*, Z=*c*. The crystals are length slow and extinction is always parallel. The optic angles are universally negative, from 45 to 60 degreees.

Twenty-three orthopyroxenes were separated on the Frantz Isodynamic separator from powders ground to 120 to 200 mesh. The value nZ was determined on (210) cleavage fragments; precision is believed to be ±.001 corresponding to ±1 mole percent $MgSiO_3$. Compositions were determined from the curve of Hess (1960, p. 27). The data are shown in table 2.

A systematic increase in mole percent $FeSiO_3$ occurs with increasing specific gravity of the rock (tables 1 and 2, fig. 3); *i.e.* with increased mafic content. Orthopyroxene compositions for members of the anorthosite series are: for anorthosite, Mg_{58-62}; for hypersthene gabbroic anorthosite, Mg_{48-58}; for hypersthene gabbro, Mg_{34-54}; and for feldspathic oxide mineral-rich pyroxenite, Mg_{35-36}. A pyroxenite from the eastern Adirondacks has an orthopyroxene as low in magnesium as Mg_{27} (Buddington, 1952, p. 47). Sample S-171-A has an anomalously high percentage of ilmenite and magnetite. The trend towards an increase in iron content of orthopyroxenes with increasing mafic content should provoke some thought, for it is opposite to that seen in normal calc-alkaline differentiation, and bears no relation to trends in stratified sheets.

Clinopyroxenes

The clinopyroxenes are pale green, almost nonpleochroic. Cleavages along (110) are common, and partings on (100) and (001) are frequently seen. Pair twins are uncommon. The clinopyroxenes are optically positive, with 2V ranging from 54½ to 56½ degrees. The N_y varies from 1.6950 to 1.7135. Other indices and $C \wedge Z$ were not measured. Maximum interference colors in thin sections cut to 0.09 mm

TABLE 2

Compositions of orthorhombic and monoclinic pyroxenes of rocks of anorthositic series

Sample number[1]	Orthopyroxene nZ	Orthopyroxene Mole % Mg	Clinopyroxene nY	Clinopyroxene 2V	Mole Percent Ca	Mole Percent Mg	Mole Percent Fe
			Anorthosite				
Sr-15	1.7129	61	1.6985	+55°	45	36	19
Sr-20	1.7126	61	1.6965	+55°	45	36	19
Sr-33	1.7118	62	1.6973		45	35	20
Sr-105	1.7139	60	1.6985	+54 ½°	45	36	19
Sr-153	1.7136	60	1.7001		44	34	22
Sr-177	1.7148	58	1.6970		45	34	21
Sr-181	1.7140	59	1.6982	+55°	45	35	20
Sr-189	1.7120	62	1.6947				
Sr-190	1.7127	61	1.6990		45	36	19
Sr-194	1.7124	62	1.6960		45	34	21
Sr-200	1.7123	62	1.6958		45	36	19
Sr-206	1.7127	61	1.6985		45	36	19
Sr-207	1.7123	62	1.6972		45	35	20
Sr-250	1.7134	61	1.6950		45	37	18
Sr-276	1.7166	58	1.6975		45	34	21
			Gabbroic anorthosite				
Sr-127	1.7174	57	1.6972		45	34	21
Sr-143	1.7275	50	1.7014		44	32	24
Sr-151	1.7120	62	1.6961		45	36	19
Sr-315	1.7214	54	1.6995		45	33	22
			Anorthositic norite and anorthositic gabbro				
5718		46					
Sr-239	1.7280	49	1.7030	+55 ½°	44	31	25
Sr-328	1.7373	42	1.7095	+56°	44	25	31
			Norite and hypersthene gabbro				
Sr-292	1.7465	34	1.7140		43	21	36
Sr-163-A	1.7365	43	1.7070	+58°	48	25	27
Sr-171-A	1.7207	54	1.7005	+54 ½°	44	33	23
			Garnetiferous feldspathic oxide mineral-rich pyroxenite				
Sr-289	1.7439	36	1.713		43	22	35
Sr-305	1.7398	35	1.713		43	21	36

[1]For information concerning locations see Plate 1

thickness range in the second order from blue to yellow. Compositions of 25 clinopyroxenes (table 2) were determined from 2V and Ny using the curve of Hess (1960, p. 11). Principle sources of error appear to be variable amounts of Fe_2O_3, Al_2O_3, and TiO_2 not taken into consideration in the curve. The use of this curve, however, is appropriate since four chemically analyzed pyroxenes from Adirondack anorthosite were used in establishing it. 2V was determined on the five-axis universal stage by standard

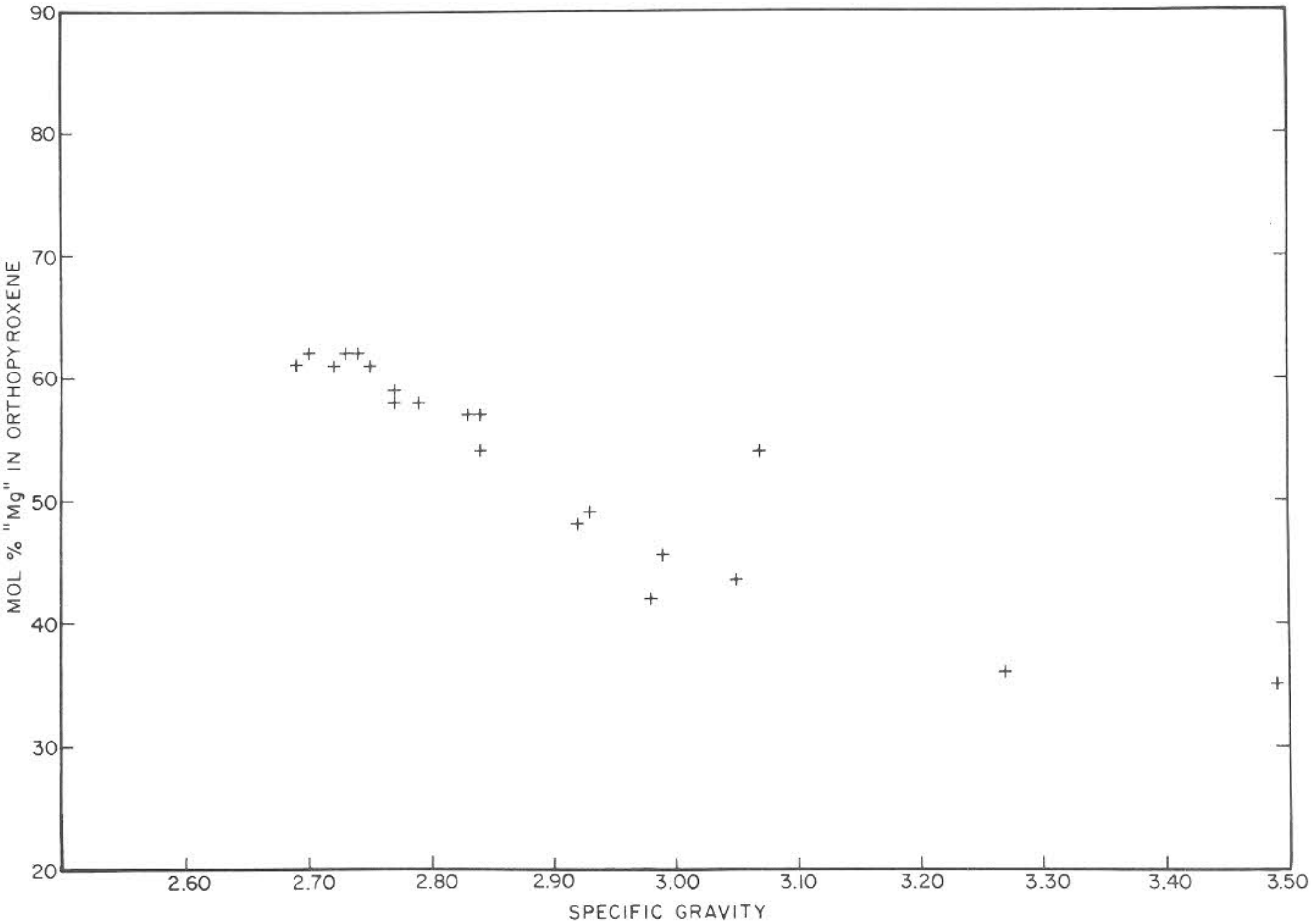


FIGURE 3 — Composition of orthopyroxenes of the anorthosite series as a function of specific gravity of host rock

methods (Emmons, 1943) and the indices of refraction by oil immersion method. Like the orthopyroxenes, the clinopyroxenes become richer in FeO as the percent of mafics increases. The range (table 2) is $Ca_{45}Mg_{37}Fe_{18}$ to $Ca_{45}Mg_{34}Fe_{21}$ in anorthosite, $Ca_{45}Mg_{36}Fe_{19}$ to $Ca_{44}Mg_{32}Fe_{24}$ in gabbroic anorthosite, $Ca_{44}Mg_{31}Fe_{25}$ to $Ca_{44}Mg_{25}Fe_{31}$ in anorthositic gabbro, $Ca_{48}Mg_{25}Fe_{27}$ to $Ca_{43}Mg_{21}Fe_{36}$ in hypersthene gabbro, and $Ca_{43}Mg_{21}Fe_{36}$ in feldspathic oxide mineral-rich pyroxenite.

IRON – TITANIUM OXIDE MINERALS

Fourteen polished surfaces of various rock types of the anorthositic series were examined to determine the nature of the oxide minerals. Oxide mineral assemblages in all members of the suite contain hemo-ilmenite. This mineral is invariably accompanied by ilmeno-magnetite, with coarse irregular lamellae of ilmenite oriented parallel to (111) of the magnetite host. In three anorthosite specimens, ilmeno-hematite was observed in trace amounts. This intergrowth consists of ilmenite exsolved from a hematite host (0001) on a somewhat coarser scale than the hemo-ilmenite intergrowth. Small amounts of medium gray isotropic pleonaste were also noted as ubiquitous exsolution intergrowths on (100) of the magnetite. Some of the hemo-ilmenite in the anorthosite is partly altered to meta-ilmenite, a fine intergrowth of ilmenite, hematite, anatase, and rutile.

Rod-like inclusions observed in plagioclases in thin section were proven in reflected light to be hemo-ilmenite identical to that forming larger separate grains, except in morphology. Oxide mineral inclusions which produce a schiller in clinopyroxenes are also hemo-ilmenite.

With increasing mafic content, fewer and smaller hematite lamellae were observed in the ilmenite, and in some of the mafic gabbro and pyroxenite the mineral is entirely ilmenite. Though lamellae of hematite in ilmenite appear to be more sparsely distributed in garnetiferous anorthosite, no diminution in the lamellae toward grain boundaries with garnet was noted.

Coexistent ilmeno-magnetite and ilmenite were separated from two feldspathic oxide mineral-rich pyroxenites and partially analyzed and recomputed to mole percent (table 3). The curve used for estimating the approximate temperature of equilibration and the f_{O_2} is that given by Buddington and Lindsley (1964, p. 316). Sample Sr-153 has only meagre garnet and is a massive rock, whereas Sr-289 has undergone a greater amount of metamorphic reconstitution with the development of considerable garnet. The temperature indicated for Sr-153 could be that of the last stage of its magmatic crystallization; that of Sr-289 must have undergone some equilibration at subsolidus temperatures. It is not, however, thoroughly recrystallized at the general range of temperature for regional metamorphism which is around 650 C and is exemplified by Sr-181. The latter has a granoblastic mortar texture. Samples Sr-153 and 289 contain about twice as much MnO in ilmenite as in magnetite. This is appropriate for gabbroic rocks (Buddington and Lindsley, 1964, p. 353). In Sr-181, the MnO in the ilmenite is many times that in the magnetite. This is approximate for high grade metamorphic rocks.

GARNET

Garnet in small amounts forms an almost ubiquitous constituent of the anorthosite and gabbroic anorthosite. It is texturally related to the mafic silicates and oxide minerals, and its abundance varies with both total mafic content and degree of granulation. It is commonly as abundant as oxides but seldom amounts to more than one-fifth of the total mafic silicate assemblage. With incipient granulation, small garnet coronas rimming pyroxenes and oxide minerals become noticeable. In more granulated specimens these coronas increase in thickness at the expense of other mafics, but never are pyroxenes or oxide minerals totally destroyed by the garnet. In extremely granulated specimens garnet porphyroblasts, occasionally up to 1 cm in diameter coexist with two pyroxenes, hemo-ilmenite and ilmeno-magnetite.

In thin section, the coronas are seen to consist of granular garnet and vermicular quartz, with garnet greatly preponderant. Orthopyroxenes are destroyed preferentially to clinopyroxenes, though both participate in the reaction. (Buddington, 1965, believes garnet is the product of reaction of hypersthene and anorthite molecule of plagioclase to yield clinopyroxene.) Minor compositional zoning occurs in plagioclase adjacent to garnet, but no zoning was noted in pyroxene.

TABLE 3

Compositions of ilmeno-magnetite and ilmenite in rocks of the anorthosite series

	Ilmeno-magnetite			Ilmenite	Estimated values		
	Wt.% TiO_2	Wt. % MnO	Equivalent Mole % Fe_2TiO_4	Mole % Fe_2O_3	Wt. % MnO	T.° C ± 50	log f_{O_2} (atm.) ± 1.0
Sr-153	11.2	.30	31.9	9.4	.57	810°	—13.6
Sr-289	8.7	.20	24.0	8.1	.45	730°	—13.8
Sr-181	4.1	.02	11.0	12.9	.20	635°	—17.1

Sr-153 Feldspathic oxide mineral-rich pyroxenite with sparse garnet. One-half mile west of Derrick, St. Regis quadrangle (Plate 1).

Sr-289 Feldspathic oxide mineral-rich pyroxenite with considerable garnet. South center of St. Regis quadrangle.

Sr-181 Garnetiferous gabbroic anorthosite gneiss, 0.5 mile south of Wabeek, Saranac quadrangle (Plate 1).

ACCESSORY MINERALS

Apatite, in small (< 2 mm) anhedral grains forms a constant accessory associated with the pyroxenes and oxide minerals. It seldom exceeds 1 percent except in oxide mineral-rich feldspathic pyroxenites where it may reach 15 percent.

Zircon occurs rarely as an accessory in oxide mineral-rich norites and feldspathic pyroxenites where it forms embayed anhedral grains from 1 to 3 mm in diameter. Despite the anomalous morphology, the optical properites are typical.

Quartz, which has commonly been reported as an accessory mineral in anorthosite, was found only as vermicular intergrowths with garnet in coronas, and rarely in trace amounts in gabbroic facies adjacent to the syenite gneiss.

ALTERATION

Scapolite, as an alteration product in the form of vermicular masses on the margins of plagioclase and in the groundmass, locally replaces plagioclase. It is colorless, uniaxial (—), with interference colors of the upper first order (yellow or blue) and shows no relief against plagioclase. Accompanying scapolitization in a few specimens is the marginal development of sphene on the oxide minerals. This mineral occurs as yellowish-brown embayments in oxides and is biaxial (+) with 2V about 40°, and high positive relief against plagioclase. Prominent pleochroism from yellow to brown is characteristic, as is polysynthetic twinning.

Both ortho- and clinopyroxenes are commonly altered marginally and along cleavages to a greenish, fibrous to scaly material of uncertain identity. Usually this material has interference colors in the first order and is pleochroic in greens and yellows. In several cases it is accompanied by carbonate. It is tentatively identified as a chlorite.

In gabbroic anorthosites near the syenite contact a rim of granoblastic green hornblende on pyroxenes is quite common.

Saussuritization, frequently described from the Whiteface facies anorthosite of the eastern Adirondacks, was not noted in the St. Regis quadrangle.

Tupper-Saranac Sheet of Quartz Syenite Gneiss

FIELD DESCRIPTION AND PETROGRAPHY

The Tupper-Saranac sheet of quartz syenitic gneiss was initially described as such by Buddington (1939, pp. 116-126) and later (1952, p. 58) referred to as charnockitic in order to emphasize the occurrence of hypersthene. Part of this sheet extends across the St. Regis quadrangle overlying the anorthositic massif. On the St. Regis quadrangle the bulk composition has a quartz content between 10 and 15 percent. Portions carry as much as 25 percent quartz and by definition would be granite gneiss. The lower facies is syenitic.

The gneiss is prominently foliated and compositionally banded, and exhibits systematic variations from a mafic-rich base to a leucocratic top which apparently passes gradationally upward into pink granite gneiss. Compositional variation is roughly normal to the foliation and the body is interpreted as an intrusive sheet. The syenite portion of the sheet, containing less than 10 percent quartz, is between 270 and 360 m thick. Close parallelism of foliation in the syenite gneiss and the underlying anorthosite is universal.

Weathered outcrops are generally deep yellow-brown in color. Fresh rock is dark green.

In hand specimen the compositional banding is seen to consist of alternating laminae of fine (<5 mm) subsequent mafic silicates and oxide minerals with subordinate feldspar and coarser (0.5 mm to 1 cm) subsequent feldspars and quartz with subordinate mafic minerals. Fractured whitish feldspar augen, surrounded by mortar, are common in the felsic bands.

Thin section shows the syenite gneiss to be composed of variable amounts of mesoperthite, oligoclase, quartz, clinopyroxene, orthopyroxene, hornblende, and garnet. Ubiquitous accessories are ilmenite, ilmenomagnetite, zircon, apatite and biotite. Textures are metamorphic, ranging from incipiently crushed to largely crushed and moderately recrystallized.

In the mafic-rich bands, coronas of garnet and quartz may rim all mafics indiscriminately, but in no case is any phase totally destroyed by the garnet; more commonly, garnet, two pyroxenes, hornblende, and two oxide minerals coexist with no evidence of replacement. Texturally, it seems reasonable to conclude that all four mafic silicates were stable in the metamorphic assemblage and that the coronas merely indicate the relatively late development of garnet in equilibrium with the other mafics. However, partitioning coefficients (from compositions based on optical data) of magnesium between pyroxene pairs indicate that magmatic equilibria are still preserved, at least in part. This casts considerable doubt on the validity of drawing conclusions concerning the degree of attainment of equilibrium in metamorphic rocks from textural studies alone.

Another ubiquitous feature of the mafic bands is the intimate intergrowth of two pyroxenes. A single crystal unit consists of clino- and orthopyroxene in approximately equal proportions intergrown in plates parallel to (100) as determined from optic orientations of the two phases. Although complete solid solution is not now believed to exist between magnesian orthopyroxenes and clinopyroxenes, such is believed the case for iron-rich compositions (F. R. Boyd, 1962, personal communication), and the observed intergrowth of iron-rich syenite pyroxene pairs is probably a reflection of that relationship, with a solvus somewhere below the solidus, on the join hypersthene-salite.

SYENITE DIKES

Rocks of composition similar to that of the main sheet of quartz syenite gneiss form several dikes in the anorthosite, and locally in the adjoining Long Lake quadrangle to the south, such dikes may be seen to be continuous with the main mass of the syenite gneiss (Cushing, 1907, p. 481). Some dikes of syenite in the anorthosite contain blocks of the anorthosite. Xenocrysts of calcic andesine occur universally in the dikes. Grain size generally varies with the thickness of the dike but true chilled margins were nowhere observed.

A mafic syenite dike of great extent was previously described by Buddington (1939, pp. 23-124) as the "Jenkins Mountain polymict breccia dike." On the ridges of Jenkins Mountain a large dike trending N 55°E and dipping 70°S cuts leucocratic anorthosite (plate 1). It pinches out on the west end of Jenkins Mountain, but increases in width eastward to 15-30 m on the main crest of the hill. The dike disappears under cover north of the crest of the east ridge, and the next outcrops east are entirely anorthosite.

A dike, identical in texture and composition to the above, emerges from cover about 200 m west of the main N-S highway, fully one quarter mile south of the projected position of the dike on Jenkins Mountain. This dike may be seen in a roadcut 2.3 miles south of the north boundary of the quadrangle. It is not possible to determine from exposures whether this is a fault displaced continuation of the dike on Jenkins Mountain or an en echelon relative. East of the roadcut, the dike may be traced up the hill south of Mountain Pond until it is finally lost under cover 0.7 mile northeast of the highway.

The dike rock is distinctly finer grained (1-3 mm) than most syenite, and quite inhomogeneous. No marginal chilling is observable. Large irregular blocks of pyroxene-plagioclase granulite with randomly oriented foliation are well exposed in several places. Large inclusions are common on the crest of Jenkins Mountain. On the hillside immediately east of the highway, areas up to 30 m^2 are composed of up to 80 percent granular clinopyroxene. Blocks of anorthosite 2 cm to 1 m in diameter occur in the dike of Jenkins Mountain. Angular xenocrysta of blue-gray plagioclase up to 2 cm in diameter are ubiquitous. These crystals are andesine with cores of composition An^{24} and contain the hemo-ilmenite rods so characteristic of the plagioclase of the anorthosite. The cores are gradationally rimmed by a more sodic antiperthite and finally by mesoperthite.

The groundmass of the dike is predominantly mesoperthite (65-70 volume percent). Orthopyroxene and clinopyroxene, in parallel intergrowth, account for 15 to 20 percent of the rock, and hornblende and granular garnet form most of the rest. Quartz and minor amounts of oxide minerals are present. A chemical analysis of a sample has been published by Buddington (1939, table 32, No. 114) who describes it as medium grained granoblastic.

Syenite dikes cited by Cushing (1907) as evidence for magmatic origin of the syenite may be seen 3.1 miles east of the center of Tupper Lake village in a small quarry just north of New York highway No. 3 and in adjacent outcrops. These are identical in texture and composition to the Jenkins Mountain dike but lack inclusions of granulite. Large inclusions of anorthosite, however, are visible here. Although it is difficult to discriminate in hand specimen between the feldspars of the groundmass of the anorthosite and those of the dikes, microscopic examination allows no confusion. Mesoperthite preponderates in the syenite, with only 5 percent oligoclase present. Plagioclase of the anorthosite inclusions contains sparse antiperthite, and separate potassic feldspar grains are absent. Identical dikes are found in several localities along the western edge of the anorthosite.

POTASSIC FELDSPARS

The most abundant mineral in all varieties of the syenite is potassic feldspar. In the portions of the mass which are only slightly granulated, this feldspar occurs in the form termed mesoperthite by Michot (1939); *i.e.* fine sinusoidal hairs of K-feldspar and sodic plagioclase intergrown in about equal proportions.

More commonly, the feldspars of the syenite are largely recrystallized to form a more coarse-textured microperthite and separate grains of oligoclase. Rarely, the quadrille twinning of microcline is observable. In one area on the south slope of hill 1940, 2 miles southwest of Floodwood, the syenite consists mainly of coarse subhedral crystals of microperthite up to 5 cm in maximum dimension. It would appear from this and the presence of augen surrounded by finer anhedra of oligoclase and nonperthitic K-feldspar that the present fabric of the syenite results from the crushing and partial recrystallization of a coarser-grained rock.

In some extremely recrystallized syenites, bands of almost pure potassic feldspar occur. These are apparently the products of metamorphic segregation.

PLAGIOCLASES

Exclusive of the xenocrysts of andesine so common near the base of the syenite gneiss sheet, plagioclase in the slightly granulated portions of the syenite is restricted almost wholly to the mesoperthite. In the more granulated and recrystallized syenite gneiss, separate grains of plagioclase account for 5 to 20 volume percent of the rock.

In order to determine whether complete gradation occurs between plagioclases of the syenite and those of the anorthosite, and to judge the range of composition of plagioclase within the syenite proper, 27 plagioclases from the granitic top, syenitic middle, and mafic base of the syenite were separated and examined optically. Compositions were read from the curve of J. R. Smith (Hess, 1960, plate 12). Plagioclase compositions (plotted in fig. 4) in mafic syenite, syenite and granite gneiss range from An_{19} to An_{35} with no obvious relation to the mafic content of the rock. Two mafic syenite gneisses, each with 20±5 percent mafic silicates, have plagioclase compositions of An_{21} and An_{35}, respectively, and two hornblende alaskite granite gneisses have plagioclases of An_{25} and An_{32}, respectively. Nevertheless, in general and on the average, the mafic syenite and syenite gneisses have a more calcic plagioclase than quartz syenitic and granitic gneisses, and pink hornblende and biotite granites have a more sodic plagioclase than the pyroxene quartz syenitic series (Cf. Buddington and Leonard 1962, p. 57 and 76).

Anomalous variations in the composition of the plagioclases may arise from local contamination with incorporated older rocks or by the metamorphic development of garnet and/or hornblende partly at the expense of anorthite.

PYROXENES

Two pyroxenes occur ubiquitously in all green facies of the Tupper-Saranac sheet from mafic syenite to gran-

TABLE 4

Compositions of coexisting minerals of transition rock, mafic syenite, and syenite of the Tupper-Saranac sheet, St. Regis quadrangle

Sample number[1]	Density	Plagioclase	Orthopyroxene	Clinopyroxene
		Granite		
Sr-302	nd	An_{27}	Mg_{20}	Ca_{43} Mg_{14} Fe_{43}
		Syenite		
Sr-237-A	2.75	An_{27}	Mg_{39}	Ca_{45} Mg_{24} Fe_{31}
Sr-257	2.82	An_{23}	Mg_{16}	Ca_{44} Mg_{12} Fe_{44}
Sr-255	2.84	An_{30}	Mg_{21}	Ca_{43} Mg_{14} Fe_{43}
Sr-242	2.87	An_{20}	Mg_{22}	Ca_{43} Mg_{14} Fe_{43}
Sr-309	nd	An_{29}	Mg_{20}	Ca_{43} Mg_{14} Fe_{43}
		Mafic Syenite		
Sr-77	2.80	An_{21}	Mg_{22}	Ca_{44} Mg_{15} Fe_{41}
Sr-81	2.84	An_{22}	Mg_{20}	Ca_{44} Mg_{14} Fe_{42}
Sr-82	2.86	An_{19}	Mg_{17}	Ca_{44} Mg_{12} Fe_{44}
Sr-233	2.92	An_{22}	Mg_{35}	Ca_{43} Mg_{21} Fe_{35}
Sr-260	2.91	An_{27}	Mg_{27}	Ca_{45} Mg_{17} Fe_{39}
Sr-317	nd	nd	Mg_{28}	Ca_{44} Mg_{19} Fe_{37}
Sr-319	nd	nd	Mg_{25}	Ca_{44} Mg_{16} Fe_{40}
Sr-327	nd	An_{35}	Mg_{32}	Ca_{43} Mg_{20} Fe_{37}
Sr-329	nd	An_{28}	Mg_{27}	Ca_{44} Mg_{17} Fe_{39}
Sl- 1	nd	An_{26}	Mg_{30}	Ca_{44} Mg_{18} Fe_{38}
		Transition Rock		
Sr-230	nd	An_{32}	Mg_{40}	Ca_{43} Mg_{23} Fe_{32}
Sr-293	2.92	An_{34}	Mg_{27}	Ca_{43} Mg_{19} Fe_{38}
Sr-304	nd	An_{31}	Mg_{33}	Ca_{44} Mg_{21} Fe_{35}
Sr-306	nd	An_{37}	Mg_{36}	Ca_{44} Mg_{22} Fe_{34}
Sr-318	nd	An_{27}	Mg_{34}	Ca_{44} Mg_{23} Fe_{34}
Sr-330	nd	An_{37}	Mg_{38}	Ca_{45} Mg_{23} Fe_{32}
Sr-331	nd	An_{25}	Mg_{20}	Ca_{42} Mg_{15} Fe_{41}

[1]For information concerning locations see Plate 1

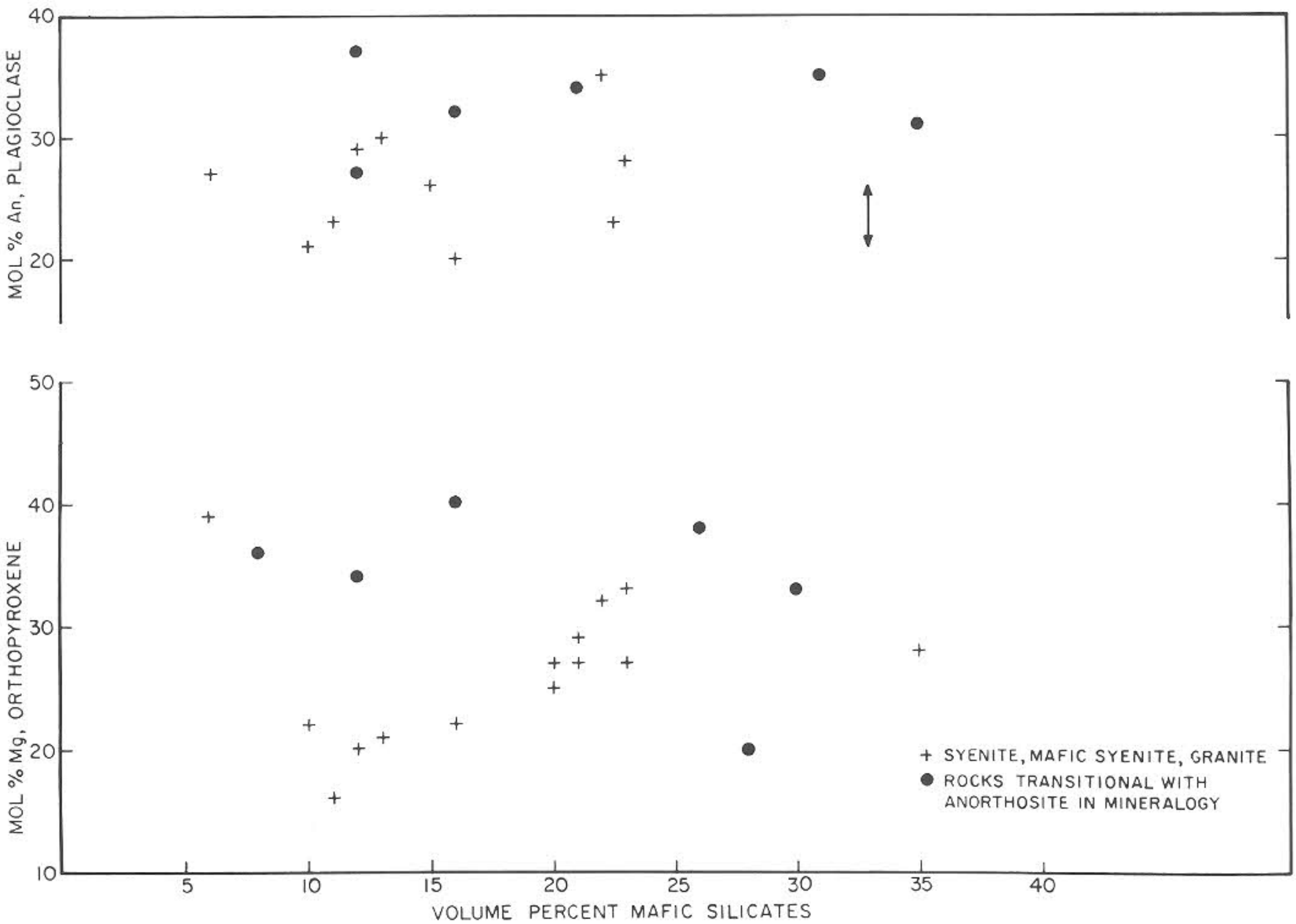


FIGURE 4 — Compositions of plagioclase and orthopyroxene as functions of mafic content of host rock, Tupper-Saranac sheet

ite. In general they occur as subhedral to anhedral grains 0.1 to 0.5 mm in longest dimension. Most commonly the two pyroxenes form a parallel intergrowth with (100) in common. This relationship is believed to result from unmixing in the solid state in a system where the solvus is below the liquidus. Exsolution of clinopyroxenes on " monoclinic (001) " of orthopyroxenes was nowhere observed in the syenite gneisses. This could reflect their lower temperature of formation as compared to the anorthositic rocks, or to more complete recrystallization. In intensely recrystallized syenite gneiss, parallel intergrowths of pyroxenes is less obvious.

Compositions of coexisting plagioclase, orthopyroxenes and clinopyroxenes from 23 samples of rocks of the complex as determined by optical methods are given in table 4. The same curves were used for determining mineral compositions as were used for the anorthositic rocks. If transition rocks (fig. 4, circled) are ignored, a fair correlation between mafic content of the rock and Mg content of the enclosed orthopyroxene is obvious. A large part of the apparent scatter is believed to result from poor correlation between estimated and true mafic content.

It is concluded that the Mg content of orthopyroxene in the complex decreases with decreasing mafic content from Mg_{33} to Mg_{16} and that transition rocks at the base of this sheet immediately above the anorthosite do not show any such relation.

Clinopyroxenes of the syenites show the expected compositional relationship to coexisting orthopyroxenes. Compositions vary from $Ca_{43}Mg_{21}Fe_{35}$ in the most mafic syenite to $Ca_{44}Mg_{12}Fe_{44}$ in the most leucocratic quartz-syenite examined.

HORNBLENDE

Hornblende, in unaltered subhedral grains from 0.1 to 2.5 mm in diameter, is a very common but not ubiquitous constituent of the gneisses of the Tupper-Saranac sheet. Hornblende is found in even the least metamorphosed rock, and is probably, in large part, a primary mineral.

QUARTZ

Bluish quartz, in trace amounts, is locally present in the basal mafic portion of the syenite gneiss sheet. Higher in the body where mafics do not exceed 15 percent, quartz increases in abundance with diminution of mafics, attaining 25 percent in the pink granite gneiss at the top of the sheet. Locally, in axial zones of folds, aggregates of quartz form pencil-like lineation parallel to the fold axes.

ACCESSORY MINERALS

Garnet is a very common, but not ubiquitous, constituent of the mafic syenites and syenites. It occurs as granoblastic grains 0.1 to 0.5 mm in diameter, and less commonly as coronas around mafic aggregates in the less granulated rocks.

The two oxide minerals ilmenite and ilmeno-magnetite are found in all portions of the Tupper-Saranac sheet. Usually, they occur mainly in the mafic laminae where they either form simple subhedral to anhedral grains or are rimmed by garnet coronas. In 12 polished sections, no exsolved hematite was seen in the ilmenite, even at magnifications of 450X. Thick exsolved intergrowths of spinel were occasionally observed in meagre amounts on the cubic planes of the magnetite.

Biotite, zircon, and apatite are additional accessory minerals. Zircon and apatite are ubiquitous. Sphene is restricted to the pink granite gneiss.

PINK GRANITE GNEISS

Pink granite gneiss containing included layers of amphibolite occupies the trough of a complex synclinal structure in the northwestern part of the quadrangle. Similar pink granite gneiss with interlayered amphibolite also occurs within a complex synclinal structure overlying the Tupper-Saranac sheet on the Saranac quadrangle (Buddington, 1953, pp. 85-86). The granite thus occupies a similar structural position in both areas and for this reason could be considered an upper facies of the quartz syenitic sheet, although no actual contacts have been seen.

On the other hand, Buddington and Leonard (1962, p. 103) report that to the southwest (on the Tupper Lake quadrangle) the syenite gneiss underlying the pink granite is more thoroughly granulated and recrystallized than the associated hornblende granite, that a local screen of metasediment occurs between the syenite gneiss and the overlying granite, and that granite apparently underlies as well as overlies the syenitic gneiss. They interpret the granite as a younger intrusion. Furthermore, Buddington (1953, p. 86) states that where garnetiferous amphibolites have been intruded or included and modified by the granite, the garnet has been reconstituted to other minerals suggesting that it was produced by a metamorphic episode that preceded granite emplacement. The garnet of both the amphibolite and the syenite gneiss is assumed to have been formed during this same metamorphism. Granite masses occur also in metasedimentary rocks on the Stark quadrangle independent of any associated quartz syenite. Sphene occurs in the pink granite gneiss but not in the green granite facies of the quartz syenitic sheet.

The foregoing arguments cannot be easily refuted, but detailed examination along the contact between syenite and granite in the St. Regis area has failed to reveal a megascopically visible contact or any evidence of granite intruding syenite. The granite is therefore assigned to the syenite sheet.

TRANSITION ROCK

Distribution

A type of rock transitional in some respects between the anorthositic and syenitic rocks was first described by Cushing (1900, pp. 43-44) from the Tupper-Saranac quartz syenitic gneiss sheet. Megascopically, such rocks are crudely banded and contain 15 to 35 percent mafic silicates. Because it is generally easier to draw an arbitrary boundary between transition rocks and anorthosite than between transition rocks and syenite, all have been mapped with the syenite gneiss.

Transition rocks are confined to irregular areas between mafic syenite and gabbroic anorthosite, particularly to a belt ½ to 1 mile wide between Rollins Pond and Deer Pond Marsh.

Xenocrysts

Almost invariably conspicuous blue-gray augen of plagioclase are present in the transition rock. Angular

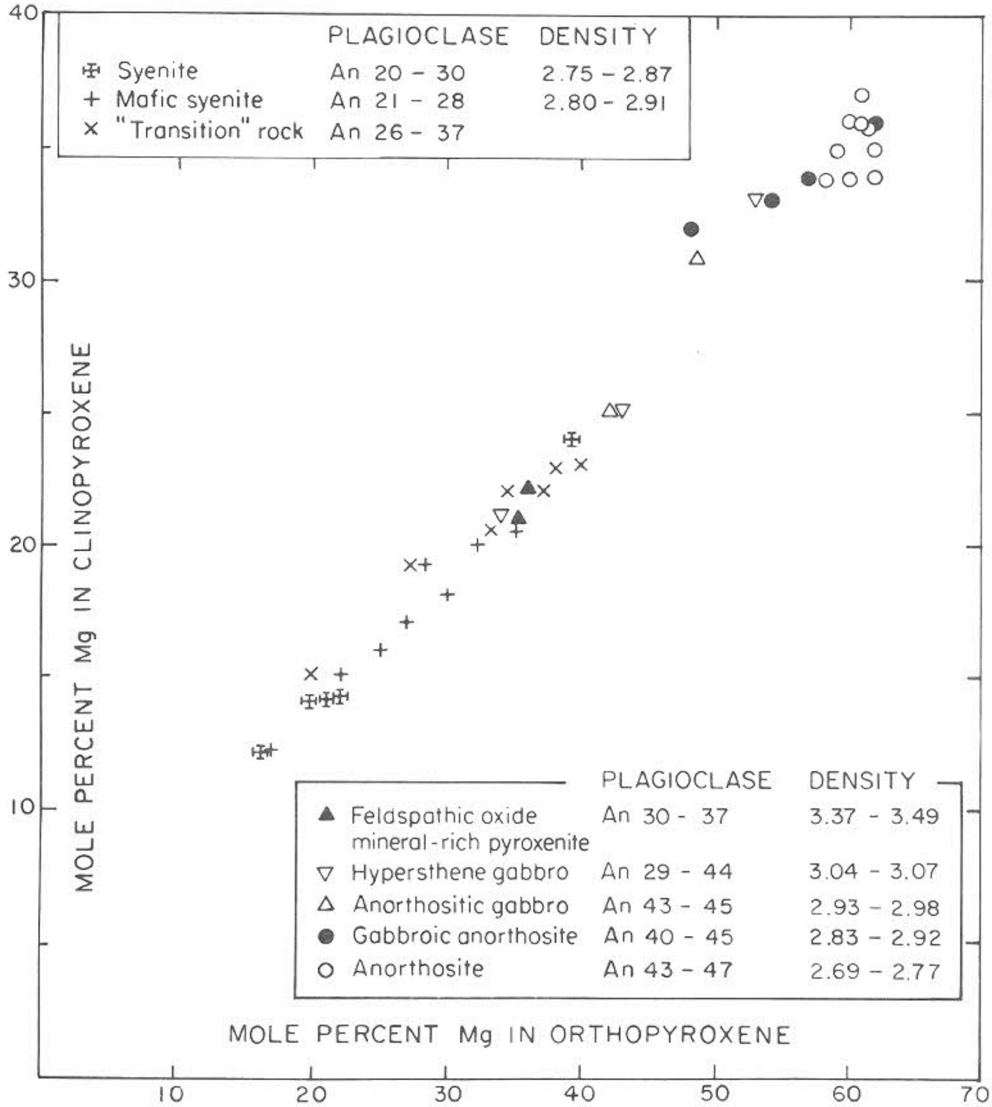


FIGURE 5 — Composition of coexistant pyroxenes of syenitic, transitional, and anorthositic rocks

crystals (xenocrysts) of andesine are conspicuous not only in syenite dikes, but in all portions of the syenite within 30 m of the anorthosite. Their characteristics are everywhere the same. Core compostions are invariably in the range An_{40-45}. These crystals are linked with the anorthosite by restricted area of occurrence, composition, and minute inclusions of hemo-ilmenite.

Mineralogy

In thin section, these coarse plagioclase grains show concentric zoning, with antiperthitic sodic andesine cores, more sodic intermediate zones, and mesoperthite borders. The matrix feldspar is from 15 to 65 percent mesoperthite occurring as subhedral to anhedral grains 0.1 to 3 m in diameter. Two pyroxenes, in part as parallel intergrowths and in part as separate grains, are invariably present. Hemo-ilmenite, ilmeno-magnetite, and garnet are other minerals of the assemblage. Quartz is not common as an accessory.

The plagioclase of the groundmass of the transition rocks generally ranges from An_{30} to An_{35}, and the rims of the xenocrysts from An_{22} to An_{35}.

Pyroxenes compositions (fig. 5) plot directly between those of the anorthositic series and those of the syenite. In contrast to pyroxenes of the anorthositic series, however, they show no relation to mafic content of the host rock (fig. 4).

Origin of Adirondack Anorthositic and Quartz Syenitic Series

PREVIOUS HYPOTHESES

Various hypotheses have been presented for the origin of the Adirondack anorthositic and quartz syenitic series. Bowen (1917) proposed that both the quartz syenitic and anorthositic series were differentiated under the influence of gravity from a common magma. Balk (1931) proposed a parent magma of dioritic composition, from which gabbros segregated by frictional clumping of mafics with little gravitative differentiation leaving a residuum of plagioclase crystals in a monzonitic " mother liquor." Filter pressing (differentiation by deformation) later separated the residuum into anorthosite crystal aggregate and syenitic liquid. Miller (1918) presented evidence that the quartz syenitic and anorthositic series were formed from independent magmas. Buddington (1934) also attributed the two series to different intrusions. He suggested that the anorthositic series formed from an intrusive magma equivalent in composition to a gabbroic anorthosite. Later (1959, p. 100) on the basis of Yoder's data for the system H_2O-anorthite-diopside he proposed that the gabbroic anorthosite magma had a relatively high percent of H_2O compared with normal gabbroic magmas and still later (1961) he developed this idea further. Ramberg (1948) presented a hypothesis that all great anorthosite massifs originate by metamorphic differentiation, the migration of light and heavy elements under the influence of heat, and the earth's gravitational field. The net effect of this process over a long period of time would be to concentrate anorthositic massifs as a more or less continuous anorthositic shell below a certain depth in the crust and to squeeze out oxygen, silicon, potassium, and some sodium from the solid rocks to accumulate at higher levels. De Waard and Romey (1963, p. 263) concluded that there are two possible explanations for the concomitant mineralogical and textural gradation from the metanorite of the anorthositic series to charnockite: the transition may be (a) primary or (b) secondary, caused by metasomatism during the development of foliation whereby charnockite formed by metasomatism of the norite.

Other explanations have been offered for the origin of anorthositic and associated siliceous alkalic rocks elsewhere in the world.

P. Michot (1939, 1955a, 1955b, 1960) studied the anorthositic rocks of Norway and called upon large-scale assimilation of pelitic sediments by basaltic magma to explain the highly aluminous gabbroic anorthosite magma which he considered the source of the intrusions. Crystallization of such a magma with concomitant expulsion of residual liquid (enriched in ferro-magnesian constituents), or later anatexis with removal of a leuconoritic liquid, would yield a residual anorthosite. Associated alkalic siliceous rocks are ascribed to later arrival to K, Na, and Si which effected transformations of a noritic-anorthositic series.

Hargraves (1959) described the Allard Lake mass of Quebec. He adopted a magmatic differentiation scheme similar to that of Buddington for the anorthositic series. He described the anorthosite and adjacent syenitic rocks as everywhere intergradational, with the mafic contents of the two rocks varying sympathetically. The contact relations are ascribed by him to interaction of a largely crystalline gabbroic anorthosite magma with quartzo-feldspathic gneissic country rocks. He reasoned that a wet anorthositic magma at roughly gabbroic temperatures should induce considerable ionic interchange between the feldspars of the anorthosite and those of the country rock through the medium of the escaping fluids. Where sufficiently high water pressure and temperature were attained, local partial melting of the country rock adjacent to the intrusion might be expected to occur. Because the melting range of the anorthosite lies largely above that of the syenite or granite minimum melt from the country rock, melting might continue after the anorthosite was largely crystalline, giving rise to intrusive relations.

CONTACT RELATIONS BETWEEN SYENITIC GNEISS AND ANORTHOSITIC SERIES

Contacts between syenite gneiss and the anorthositic rocks of the St. Regis quadrangle are best exposed in the southwest corner, between Derrick and the southern boundary. An overall transgression of the syenite upon the compositional contours of the anorthositic rocks may be seen in plate 2. Such a relationship was noted qualitatively by Cushing (1907,

p. 473 and map) in the Long Lake quadrangle immediately to the south.

Examples of abrupt contacts between syenite gneiss and anorthosite crop out well 2 miles southwest of Floodwood on hill 1940 and on the hillocks just to the west. Approaching the contact from the anorthosite, texture and grain size remain constant for more than 400 m, and mafic content varies only within the range 8 to 12 percent. Abruptly, 10 meters from the last anorthosite outcrop, mafic syenite gneiss is encountered. In contrast to the predominant 3 to 5 cm feldspars of the adjacent anorthosite, the syenite gneiss has grains from 2 to 5 mm. Foliation in the gneiss is well developed in contrast to the anorthosite. Mafics approach 35 percent. Continuing downhill to the south, mafic content decreases gradually to 10 to 15 percent at the base of the hill. Quartz is visible in hand specimen. Coarser feldspars of the syenite gneiss are whitish pearly augen not easily confused with plagioclase of the anorthosite. Xenocrysts of the latter are present locally.

Microscopic examination confirms the differences. The basal syenite gneiss is seen to have mesoperthite as the predominant feldspar. Hornblende is present in the syenite but not in the anorthosite, except at several contacts immediately adjacent to the syenite where it occurs as rims on the pyroxenes.

In places the syenite rests directly on the anorthosite, but commonly the two are separated by a thin discontinuously outcropping screen of pyroxene-plagioclase granulite, lenses of which occur in many places in the adjacent anorthosite and syenite.

Contacts that show more gradational characteristics are the rule where both rocks are quite mafic adjacent to the contact. Such is the case in the synclinal reentrant upon the anorthosite northeast of Deer Pond Marsh. Outcrops are not nearly so continuous as in the areas of discordance. Approaching a contact from either direction in the field, the observer is unable to locate any sharp discontinuity. Away from the contact on one side is undoubted gabbroic anorthosite, and away from the contact on the other a medium to coarse grained syenite gneiss with 10 to 15 percent mafics. Between is apparently a complete gradation, and repeated field traverses across such zones confirm the appearance of transition. In plan, the gradation occurs over a distance of as much as a mile. However, because of the extremely shallow dip (less than 10 degrees) and frequent reversal of the foliation, it is unlikely that as much as 70 meters of section are involved. In this part of the contact zone, not only is the mafic content gradational but so are the compositions of the plagioclase and pyroxenes. Plagioclases vary in composition through the calcic oligoclase range, and orthopyroxenes from Mg_{45} to Mg_{32}. Seen alone, these graditional relationships could well be taken to indicate comagmatic origin of the entire suite from anorthosite through gabbroic anorthosite to syenite. It must be emphasized, however, that these apparent gradational relations occur only between gabbroic anorthosite and syenite, in one area, and through a very thin zone compared to the thickness of the adjacent syenite and anorthositic bodies. The occurrence of mafic syenite dikes in the anorthosite must also be taken into account in discussing the significance of the gradation and the discontinuous increase in K-feldspar.

THE PROBLEM OF MINERALOGICAL GRADATION BETWEEN ANORTHOSITIC AND QUARTZ ANORTHOSITIC AND QUARTZ SYENITIC SERIES

A plot of the compositions of pyroxenes for the anorthositic and quartz syenitic series (fig. 5) appears to suggest a gradation from one series to the other. However, it may be noted (figs. 1 and 3) that the orthopyroxenes of the anorthositic series show an orderly increase in the Fe/Mg ratio with increasing specific gravity (= *increasing* mafic content) whereas those of the quartz syenitic series (fig. 4) show an orderly increase in this ratio with *decreasing* percent mafics. Furthermore, pyroxene compositions in the " transition rock " (fig. 4) show a disorderly relationship to percent mafics. This last relationship is consistent with the model of an intruding magma which becomes inhomogeneously contaminated by the host rock. The xenocrysts of plagioclase in the " transition rock " are thought to be of similar origin. The " transition rock " is thus interpreted as a product of contamination rather than of simple differentiation from a parent magma common with the anorthositic series.

PARTITIONING COEFFICIENT FOR MG BETWEEN COEXISTENT PYROXENES

Partitioning coefficients for Mg between coexistent pairs of pyroxene in the anorthositic and quartz syenitic series of rocks were determined from the compositions calculated from optical data.

The distribution coefficient for 14 pairs of pyroxenes of the anorthositic series averaged $0.8 \pm .06$ and the same for an equal number of the quartz syenitic series. This is in close agreement with the values determined by Kretz (1961, table 1) for gabbros and ferrogabbros (which average 0.73±.04), and greatly different from his value of 54±.04 for high grade metamorphic rocks. In a later paper Kretz (1963, p. 773) states that in 25 high grade metamorphic rocks the coefficient ranges from 0.51 to 0.65, and in 14 rocks known or presumed to have crystallized from silicate melt from 0.65 to 0.86. The foregoing data would *appear* to imply that the pyroxenes of both series were formed at temperature equivalent to those of magmas. If this were so, reequilibration must not have occurred during the regional metamorphism and recrystallization. Lack of equilibration is also indicated by 1) the persistence of ungranulated augen of mesoperthite and of zircons with elongation ratios approaching 10:1 in many specimens, and by 2) the fact that a relatively massive, slightly garnetiferous feldspathic oxide mineral rich pyroxenite gave a temperature of 810 C by the magnetite-ilmenite geothermometer, whereas thoroughly recrystallized gneisses gave temperatures around 650 C (Buddington and Lindsley, 1964, pp. 335-337). The incompleteness of reequilibration to metamorphic conditions is also indicated by the general retention of oxide mineral schiller and exsolution intergrowths, and the not uncommon preservation of magmatic fabric. There is thus the possibility that magmatic equilibria of the pyroxenes has been preserved.

[It should be noted that the pyroxene compositions used by Kretz for determination of the distribution coefficient were based on chemical analyses, whereas those used in Davis' report are calculated from optical data and are therefore only approximations. As an example, the distribution coefficients calculated from the compositions based on optical data and those based on chemical analyses for pairs of pyroxenes given by Philpotts (1966, table 2) are quite different from each other. It will therefore be necessary to have chemical analyses of a series of coexistent pyroxenes in Adirondack rocks before valid conclusions can be drawn. A.F.B.]

ORIGIN OF ANORTHOSITE

The following features support the interpretation of a magmatic origin of the anorthositic series:

1) the interstitial texture of unmetamorphosed anorthosite,
2) inclusions of anorthosite randomly oriented in gabbroic anorthosite,
3) the occurrence of local inclusions of pyroxene-plagioclase granulite,
4) gradation between anorthosite, gabbroic anorthosite, gabbro, and feldspathic, oxide mineral-rich pyroxenite,
5) the presence of orthopyroxenes showing exsolved intergrowths of a type indicating an inversion from a monoclinic form,
6) a systematic increase in the Fe / Mg ratio of pyroxenes with increase of mafic content of rock,
7) temperature of certain late stage unmetamorphosed facies of 810°±50° C.

The magma is inferred to have had a gabbroic anorthosite composition. Plagioclase must have crystallized alone during a large part of the crystallization period. A plagioclase-rich melt can exist under very high water pressures as shown by Yoder (1954). Prolonged crystallization in the primary phase field for plagioclase will result if separation of plagioclase starts quite near a plagioclase-pyroxene boundary curve and if the boundary curve retreats towards pyroxene as plagioclase crystallizes. This will occur if crystallization results principally from loss of water. The lack of zoning in the plagioclase can also be best explained in terms of prolonged crystallization in a water-rich environment at high temperatures.

The problems of generating such a water-rich and plagioclase-rich magma, however, are considerably greater than those involved in crystallization of the magma to yield the anorthositic series. All known anorthosites of the Adirondack type are of Precambrian age. Two possible explanations suggest themselves: 1) anorthosite masses crystallize at such great depths that only certain Precambrian terranes have been deeply enough exhumed to expose them, 2) assuming that anorthosite magmas could originate only from the coincidence of mafic or ultramafic rocks with an abundant source of water, the chance for such coincidence decreased as devolatilization of the mantle proceeded, becoming negligible by late Precambrian time.

The hypothesis of deep exhumation is inconsistent with the absence of anorthosite in great Paleozoic mountain chains where presently exposed rocks were once buried at depths of at least 6 to 12 kilometers. If anorthositic magmas were common in the Paleozoic, some trace of their emplacement should be preserved. There is little evidence to suggest that presently exposed anorthositic terranes have been more deeply eroded than the foregoing since their emplacement. Also, seismologists infer that basaltic magmas are currently being generated at depths of 60 to 200 kilometers, yet in no young basalts or andesites do we find great quantities of suspended coarse plagioclase crystals or included blocks of anorthosite. The restriction of Adirondack-type anorthosites to Precambrian age appears most easily related to the process of devolatilization of the mantle. The effect of water would be to lower the temperature of melting and permit the development of a liquid of gabbroic anorthosite composition at temperatures normal for gabbroic magmas.

It appears probable that the Adirondack anorthosite originated as a magma of gabbroic anorthosite composition on or near the pyroxene-plagioclase boundary curve at a water pressure approaching 5 kilobars. It appears necessary to postulate that enormous volumes of plagioclase crystallized before any other phase joined it on the liquidus. This is most easily accomplished if crystallization is initiated by loss of water pressure. This would shift the plagioclase-pyroxene boundary toward pyroxene, leaving the melt still in the field where plagioclase is the primary phase. Continuation of this process through a large part of the crystallization history would allow the crystallization of plagioclase alone until most of the melt had been used up. For example, starting with a melt of 85 percent plagioclase An_{45} and 15 percent diopside approximately on the boundary curve at 5 kilobars water pressure, crystallization entirely by loss of water pressure of roughly two-thirds of the melt might leave a residuum containing 40 percent diopside. This is very close to the composition of the least porphyritic gabbroic facies of the mass. Once water pressure became sufficiently low so that the rate of decline in water pressure was small compared to the rate of cooling, the plagioclase-diopside boundary curve might be reached causing both phases to crystallize simultaneously. However, such a model, involving crystallization solely by loss of water pressure, is a flagrant oversimplification inasmuch as it gives no consideration to the rate of cooling. In general, it will not be possible to define the crystallization path of a liquid having as independent variables both water pressure and temperature, without some knowledge of the interrelationships of temperature, permeability, and conductivity of the host rock.

The plagioclase crystals are inferred to have been heavier than the melt and to have settled in it. The melt would become relatively rich in normative pyroxenes and oxide minerals as the dissolved H_2O was lost, and these would form a moderate concentration towards the top of the mass. The uniform composition of plagioclases is ascribed to formation under conditions of high water pressure and high temperature. The pyroxenes, crystallizing under lower water pressure, would be sensitive to the effects of fractionation; their compositions would be controlled by the variation of the boundary curve with loss of water. This would explain the way in which their compositions vary with the amount of mafics in the rock.

ORIGIN OF THE TUPPER-SARANAC QUARTZ SYENITIC SHEET

The author (Davis) believes that the Tupper-Saranac sheet originated as a magma at least slightly younger than the anorthosite. An origin comagmatic with the anorthosite is rejected because of the absence of syenite pods within the anorthosite, the *local* nature of the gradations between anorthositic and syenitic rocks, and especially because of the overall transgression of the syenitic series on the compositional contours of the anorthositic complex. Xenocrysts of andesine in all stages of reaction from angular crystals to ovids mantled with more sodic feldspar and mesoperthite abound in the first 70 meters of syenite gneiss above the anorthosite. If these be taken to represent unreplaced residuals, it is very strange that some should remain totally unaltered while the groundmass feldspars were completely replaced by mesoperthite. If they be called phenocrysts of a syenitic magma, their coincidence in compositions and inclusions (hemo-ilmenite rodlets) with feldspars of the anorthosite is remarkable.

It appears quite significant that most of the inclusions of apparent anorthositic material in the syenite gneiss occur as xenocrysts rather than as blocks (xenoliths). Such relations are hard to visualize if the anorthosite were totally crystalline when intruded by the syenite. If, however, the last fluids of the anorthositic rocks were still molten and charged with plagioclase phenocrysts, the dissemination of the crystals in the hybridized magma at the contact would be understandable.

The highly variable relations between mafic content of transition rocks and the composition of their pyroxenes, in contrast to the orderly relations in adjacent gabbroic anorthosite and mafic syenites, are also most understandable in terms of local interaction.

Lastly, the greatest weaknesses of the metasomatic hypothesis appears to be lack of gradation between the syenitic sheet and the adjoining quartzfeldspathic paragneisses. Within the St. Regis quadrangle, the mafic syenite gneiss grades upwards into a granitic facies by a decrease in mafics and a concomitant increase in quartz. It is difficult to believe that diffusion of cations through the gneiss would have occurred in just the right amount to alter the aluminosilicates to feldspars without leaving any evidence. The only relics of metasedimentary gneisses actually found in association with the sheet are pyroxene-plagioclase granulites, and no evidence has been found to suggest their metasomatic conversion to quartz syenitic rocks.

Buddington and Leonard (1962, p. 58) have suggested that the Tupper quartz syenite complex has an average modal composition of about 10 volume percent quartz, 70 percent feldspar, and 18 percent mafics. If this is representative of the mean composition of the sheet, the parent magma would lie far on the quartz-poor side of the low melting trough as experimentally determined for the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2 for any appropriate water pressure (Tuttle and Bowen, 1958). The generation of such a magma directly by partial or total melting would require a temperature of perhaps 100° C more than that for the onset of melting. This implies rapid localized heating because, in general, the addition of heat beyond that necessary to initiate melting merely increases the volume of minimum melting fraction rather than raising the temperature of the melt. The above reasoning suggests that the Tupper-Saranac sheet did not originate from a melt of its present bulk composition but rather from one having an initial composition near that of the minimum melt in the quartz-alkali feldspar system, at unspecified physical conditions. Wholesale incorporation of pyroxene and plagioclase from country rocks could have produced the present bulk composition. Gravitative differentiation plus local reaction with the last fluids of the underlying anorthosite would complete the model.

Metadiabase

Dikes of metadiabase 3 to 13 meters in width occur in at least two localities in the St. Regis quadrangle: on the southwest slope of hill 1940, 2 miles southwest of Floodwood, and on hill 1880, immediately north of Gilpin Bay, Upper Saranac Lake. In both localities the rock is granulitic with anhedra 0.1 to 0.4 mm in diameter and a faint foliation caused by minor differences in abundance of mafics. No chilling was observed against the host anorthosite, but the trend of each dike is strongly discordant to the foliation of the anorthosite in the vicinity. The dike on hill 1940 strikes N50°W and dips 55°N and may be followed for about 300 meters before being lost at each end. The dike of hill 1880 strikes N20°W and dips 75°E, and may be traced from the base of the hill in a small dry stream to the crest and thence about 10 meters vertically down the north slope of the hill. A few scattered angular crystals of andesine (unzoned An_{34}) occur in this dike.

Mineralogically, the metadiabase differs significally from the older pyroxene-plagioclase granulites which occur as inclusions in the anorthosite in the vicinity of the second-mentioned dike. Plagioclase forms 35 to 45 volume percent of the rock, oxide minerals approach 5 percent, and the remainder is divided equally among orthopyroxene, clinopyroxene, and hornblende. In the first-mentioned dike, biotite occurs in trace amounts marginal to the orthopyroxene.

Basaltic Diabase

At 23 localities within the anorthosite and one in the syenitic gneisses, small dikes of basaltic diabase were found. Because of their small dimensions, none are shown on the geologic map. Most commonly this diabase is exposed as slabs about 1 m^2 and 15 to 60 cm thick, clinging to the edge of an anorthosite outcrop; in about one-third of the exposures, both dike walls were observed, however. The dikes are localized along vertical joints striking N50°-65°E. No dike wider than 3 1/3 m was observed, and most were 1/3-1 m in width.

The diabase weathers more rapidly than the anorthosite, and its surface is commonly 60 cm below that of the enclosing anorthosite. One dike on the bare crest of St. Regis mountain could be followed for about 450 m. This rock type is doubtless far more abundant than the recorded outcrops would indicate.

All dikes wider than 30 cm have a diabasic interior with grains 0.5 to 1 mm in diameter, and a chilled wall zone lacking megascopically observable grains. Several dikes show flow alignment of plagioclase phenocrysts.

The diabase portions consist of 20 to 35 percent euhedral plagioclase laths, strongly zoned, 10 percent spongy gridworks of oxide minerals, and highly variable amounts of clinopyroxene and chlorite. Either moderately serpentinized olivine, or orthopyroxene largely replaced by carbonate, is present, but not both. The basaltic wall zones consist mainly of cloudy, brownish-green chloritic masses which probably represent replaced glass, and small numbers of phenocrysts of olivine or plagioclase.

Basaltic diabase dikes are extremely abundant in the eastern Adirondacks but decrease towards the west. Their age has been variously assigned to the Precambrian and Paleozoic. No evidence bearing on this question has been found in the St. Regis quadrangle.

Regional Metamorphism

Evidence of a period of regional metamorphism between the emplacement of the earlier diabase (now metadiabase) dikes and the intrusion of the basaltic diabase is well known from mineralogical and textural relations in the Adirondacks as a whole and from similar relations in the St. Regis quadrangle. Buddington (1953, pp. 89-90) and Buddington and Leonard (1962, pp. 97-106) concluded from studies in the adjacent Saranac and Tupper Lake quadrangles respectively, that a period of profound high grade regional metamorphism preceded a period of large-scale emplacement of pink granite and that a second period of deformation followed, which converted much of the granite to gneiss. The exposed rocks in the St. Regis quadrangle do not afford conclusive evidence for the younger age of the pink granite gneiss.

Changes attributable to regional metamorphism of rocks of the St. Regis quadrangle are the following:

a. Development of garnet in coronas around oxide minerals and mafic silicates in moderately granulated rocks.
b. Development of garnet porphyroblasts in intensely granulated rocks.
c. Recrystallization of mesoperthite to microperthite plus oligoclase in gneissic syenitic and granite rocks.
d. Development of granulitic fabric in the metadiabase.
e. Local segregation of coarse, anhedral microperthite parallel to foliation in the syenite gneiss.
f. Development of foliation of plagioclase augen and streaks of crushed mafics in gabbroic anorthosite. This last may in part be only an intensification of preexisting magmatic foliation.

Garnets were separated from 10 samples of rock chosen to represent the major range of compositions of members of the anorthositic and syenitic series. They were subjected to chemical analysis for total iron, the index of refraction measurements, and A_0 was calculated from the average of five 2θ values for each of three carefully indexed peaks of the Phillips X-ray diffractometer. The results suggest a very slight increase in almandite content of the garnet, going successively from anorthosite through anorthositic gabbro and mafic syenite to syenite. This corresponds to the increase in Fe/Mg ratio of the pyroxenes of the rocks.

Only meagre evidence is available concerning the temperature and pressure at which regional metamorphism took place. Even in the most recrystallized syenite gneiss, the predominant feldspar is microperthite. For this to form during metamorphism, the period of prolonged heating could not have been far below the solvus for the system albite-potassium feldspar-anorthite. It appears unlikely on the basis of experimental data, that the temperature of metamorphism could have been appreciably less than 600 C. Buddington and Lindsley (1964, p. 337) obtained a value averaging 650°±50° C based on the magnetite-ilmenite geothermometer for the development of gneisses of adjacent quadrangles.

Recrystallization is not as extensive in the anorthosite as in the syenitic gneisses, probably because of coarser grain size and other inherent properties of the rock. However, over large areas coarse plagioclase crystals are reduced to augen surrounded by a matrix of comminuted and more or less recrystallized plagioclase. Garnet rims on pyroxenes are developed at the expense of pyroxene and plagioclase. Garnet may also rim the oxide minerals. Primary structure was obliterated throughout large areas, and northeast trending folds were formed or accentuated. These secondary structures are defined in the anorthosite by subparallel alignment of plagioclase augen and mafic streaks, and in the syenite gneiss by crude planar orientation of mafics and perthite augen.

Faulting

High angle faults are characteristic of the northeastern Adirondacks (Buddington, 1939, p. 246) but decrease rapidly in abundance to the west. The St. Regis quadrangle lies to the west of the zone of intense faulting. Compelling evidence for the presence of faults of significant magnitude of displacement in this quadrangle is lacking. However, in two places faulting is a distinct possibility.

On the western border of the anorthosite near the abandoned village of Derrick (Plate 1), the syenite-anorthosite contact is displaced sharply westward south of a line roughly from Derrick to East Pond. The displacement lies along a linear topographic depression; outcrops are poor, however, and no direct evidence of faulting is exposed.

A second possible fault would account for the lack of continuity of the dike on the east end of Jenkins Mountain, but there is no evidence for an offset. An alternative explanation is that the dikes are en echelon intrusions.

References

Alling, H. L.
1919. Geology of the Lake Clear Region. N. Y. State Mus. Bull. 207-208: 111-145.

Balk, Robert
1930. Structural survey of the Adirondack anorthosite. Jour. Geol. 38: 289-302.

____
1931. Structural geology of the Adirondack anorthosite. Min. Pet. Mitt. 41: 308-434.

Balsley, J. R., Postel, A. W., & others
1959. Aeromagnetic and geologic map of the Loon Lake quadrangle, Franklin County, New York. U.S. Geol. Survey, Geophys. Investigations, Map G.P. 191.

Bowen, N. L.
1917. The problem of the anorthosites. Jour. Geol. 25: 209-243.

Buddington, A. F.
1937. Geology of the Santa Clara quadrangle. N. Y. State Mus. Bull. 309, 56 pp.

____
1939. Adirondack igneous rocks and their metamorphism. Geol. Soc. Amer. Mem. 7, 354 pp.

____
1952. Chemical petrology of some metamorphosed gabbroic, syenitic and quartz syenitic rocks. Amer. Jour. Sci., Bowen volume: 37-84.

____
1953. Geology of the Saranac quadrangle. N. Y. State Mus. Bull. 346, 100 pp.

____
1956. Correlation of rigid units, types of folds, and lineation in a Grenville belt. The Grenville Problem, J. E. Thomson, editor; Roy. Soc. Canada Special Publ. 1: 99-118.

____
1957. Interrelated Precambrian granitic rocks, Northwest Adirondacks, New York. Geol. Soc. Amer. Bull. 68: 291-306.

____
1961. The origin of anorthosite re-evaluated. Rec. Geol. Survey India, 86: 421-432.

____
1965. The origin of three garnet isograds in Adirondack gneisses. Mineral. Mag. 34: 71-81.

__________ & Leonard, B. F.
1962. Regional geology of the St. Lawrence County magnetite district, northwest Adirondacks, New York. U.S. Geol. Survey, Prof. Paper 376, 145 pp.

__________ & Lindsley, D. H.
1964. Iron-titanium oxide minerals and synthetic equivalents. Jour. Petrology, 5: 310-357.

Cushing, H. P.
1899. Preliminary report on the geology of Franklin County, New York. N. Y. State Mus. Ann. Rept. 52, 2: 73-128.

____
1905. Geology of the Northern Adirondack region. N. Y. State Mus. Bull. 95.

____
1907. Geology of the Long Lake quadrangle. N. Y. State Mus. Bull. 115.

Davis, Brian T. C.
1963. Geology of the St. Regis quadrangle, New York. Unpub. Ph.D. thesis, Princeton University.

De Waard, D., & Romey, W. D.
1963. Boundary relationships of the Snowy Mountain anorthosite in the Adirondack mountains. Proc. Koninkl. Nederl. Akademie van Wetenschappen, Ser. B, 66: 251-264.

Emmons, R. C.
1943. The universal stage. Geol. Soc. Am. Mem. 8, 205 pp.

Hess, H. H.
1949. Chemical composition and optical properties of common clinopyroxenes. Am. Mineral. 34: 621-666.

____
1960. Stillwater igneous complex, Montana. Geol. Soc. Amer. Mem. 80, 230 pp.

Kretz, R. S.
1961. Some applications of thermodynamics to coexisting minerals of variable composition—Ex-

amples, orthopyroxene-clinopyroxene and orthopyroxene-garnet: Jour. Geol. 69: 361-387.

———

1963. Distribution of magnesium and iron between orthopyroxene and calcic pyroxene in natural mineral assemblages. Jour. Geol. 71: 773-785.

Michot, P.
1939. La serie rubanee noritogranituque de massif d'Egersund (Norvege). Ann. Soc. Geol. Belgium LXII: 532-546.

———

1955a. Anorthosites et anorthosites. Bull. de Belgique (Classe des Sciences): 275-294.

———

1955b. L'anatexie leuconortique. Bull. del'Academie Roy. de Belgique (Classe des Sciences): 374-384.

———

1960. Le probleme des intrusions marginales. Geol. Rundschau; Bd. 50: 94-105.

Miller, W. J.
1918. Adirondack anorthosite. Geol. Soc. Amer. Bull. 29: 399-462.

Philpotts, A. R.
1966. Origin of anorthosite-mangerite rocks in southern Quebec. Jour. Petrology, 7: 1-64.

Postel, A. Williams, Nelson, A. E., & Wiesnet, D. R.
1959. Geology of the Nicholville quadrangle, New York. U.S. Geol. Survey, Geol. quadrangle maps, G.Q.-123.

Poldervaart, A., & Hess, H. H.
1951. Pyroxenes in the crystallization of basaltic magma. Jour. Geol. 59: 472-489.

Ramberg, H.
1948. Titanic iron ores formed by dissociation of silicates in granulite facies. Econ. Geol. 43: 553-570.

Simmons, G.
1961. Gravity survey and geological interpretation, Northern New York. Geol. Soc. Am. Bull. 75: 81-98.

Vance, J. A.
1961. Polysynthetic twinning in plagioclase. Amer. Mineral. 46: 1097-1119.

Yoder, H. S., Jr.
1954. The system diopside—anorthite-water. Ann. Rept.: Director Geophys. Lab., Washington, D.C.: 106-107.

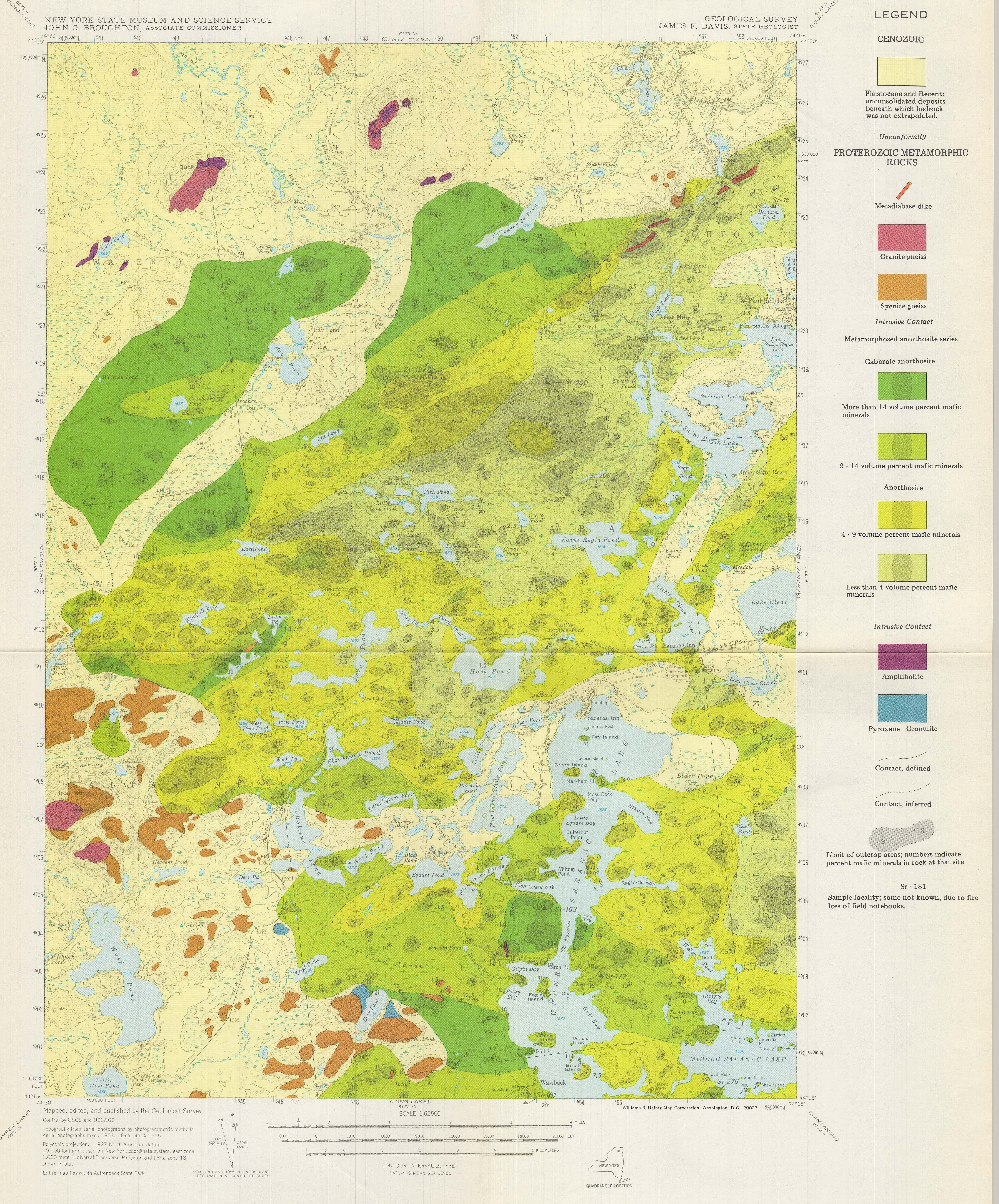


PLATE 1

BEDROCK GEOLOGY OF THE ST. REGIS QUADRANGLE, NEW YORK

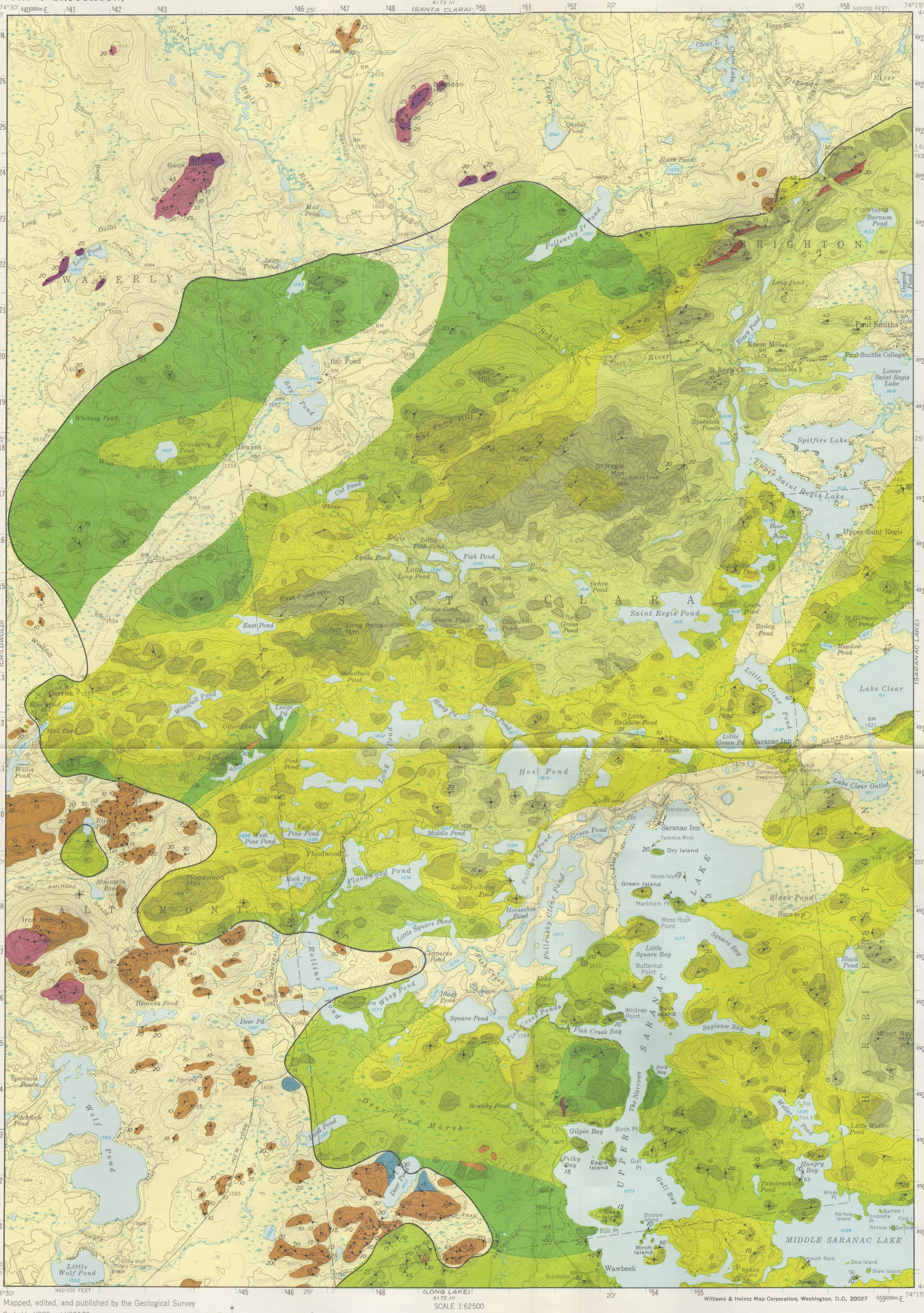
Brian T. C. Davis

1971

MAP AND CHART SERIES NO.16

NEW YORK STATE MUSEUM AND SCIENCE SERVICE
JOHN G. BROUGHTON, ASSOCIATE COMMISSIONER

GEOLOGICAL SURVEY
JAMES F. DAVIS, STATE GEOLOGIST



Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Topography from aerial photographs by photogrammetric methods
Aerial photographs taken 1953. Field check 1955
Polyconic projection. 1927 North American datum
10,000-foot grid based on New York coordinate system, east zone
1,000-meter Universal Transverse Mercator grid ticks, zone 18, shown in blue
Entire map lies within Adirondack State Park

UTM GRID AND 1955 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:62500

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

Williams & Heintz Map Corporation, Washington, D.C. 20027

QUADRANGLE LOCATION

LEGEND

CENOZOIC

Pleistocene and Recent: unconsolidated deposits beneath which bedrock was not extrapolated.

Unconformity

PROTEROZOIC METAMORPHIC ROCKS

Metadiabase dike

Granite gneiss

Syenite gneiss

Intrusive Contact

Metamorphosed anorthosite series

Gabbroic anorthosite

More than 14 volume percent mafic minerals

9 - 14 volume percent mafic minerals

Anorthosite

4 - 9 volume percent mafic minerals

Less than 4 volume percent mafic minerals

Intrusive Contact

Amphibolite

Pyroxene Granulite

Contact, defined

Contact, inferred

Limit of outcrop areas.

Sr - 181
Sample locality; some not known, due to fire loss of field notebooks.

Strike and dip of Foliation

Horizontal Foliation

Bearing and plunge of Lineation

Bearing of horizontal Lineation

Metanorthosite Contact

PLATE 2 STRUCTURAL GEOLOGY OF THE ST. REGIS QUADRANGLE, NEW YORK

Brian T. C. Davis
1971

MAP AND CHART SERIES NO.16