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THE ANORTHOSITE-CHARNOCKITE SUITE OF ROCKS OF ROARING BROOK VALLEY IN THE EASTERN ADIRONDACKS (MARCY MASSIF)

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ABSTRACT

Within the bounds of the Marcy anorthosite massif, fresh and extensive rock exposures in the valley of Roaring Brook display a great variety of rock types ranging from hypersthenite and anorthosite to charnockite and leptynite. With the exception of xenolithic metasediments all rocks are considered members of one differentiation series. Consanguinity is indicated by transitional field relations between rock types, and by the complete modal and chemical gradation between members of the suite.

Transgressive relationships demonstrate that anorthosite and hypersthenite are the older, and the K-feldspar and quartz-rich rocks the younger members of the series. Textures indicate that hypersthenite, anorthosite, and leuconorite are orthocumulates. Orthopyroxene in hypersthenite, and plagioclase in anorthosite and leuconorite are the principal cumulus minerals. Igneous lamination is a common structure in leuconorite; rhythmic layering is observed in jotunite. Hypersthenite, which occurs in a dike intersecting the igneous lamination, apparently intruded leuconorite when both rocks were in the state of a crystal mush.

Although all rocks have undergone orogenic deformation and granulite-facies metamorphism, the rocks poor in K-feldspar and quartz are little affected. Foliation developed only in part of the area, in jotunitic, farsunditic and charnockitic rocks. The development of garnet and metamorphic recrystallization occurred in rocks with an Fe:Mg ratio above a value of about 1.3.

INTRODUCTION

On the 29th of June 1963 heavy rains caused large-scale slides in the cirque of Giant Mountain, and muddy torrents swept through the valley of the Roaring Brook. The freshly exposed rock in the valley floor and on the slides are a petrologist's paradise. Located well within the bounds of the Marcy anorthosite massif (Fig. 1), the outcropping rocks are surprisingly varied in composition and texture. Although all rocks have undergone metamorphism and many are recrystallized, few are deformed, and magmatic textures and transgressive relationships can be observed in detail.

Since 1963 the writer and his students have studied outcrops and rock samples of the valley as a research project in petrography courses. The accumulated petrographic knowledge is summarized here so that it may serve as a guide for petrologic fieldtrips in the Roaring Brook valley.

LITHOLOGIES

The rock section exposed in the valley is 3.5 km long, and runs from the base of the cascade at 1400 ft altitude to the top of Giant Mountain

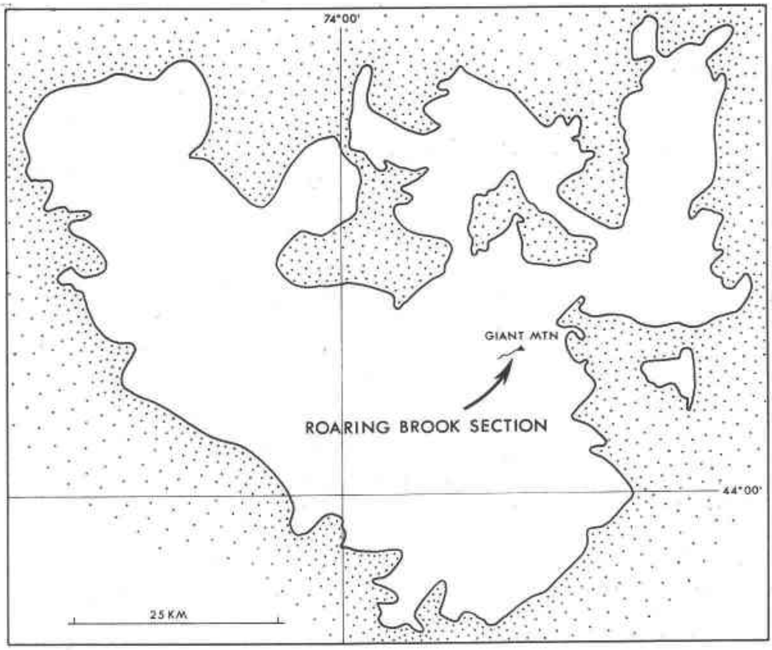

FIG. 1. Outline of the Marcy anorthosite massif after the Geologic Map of New York State (Broughton *et al*, 1962), showing the location of the Roaring Brook section.

at 4627 ft (Fig. 2 and 3). The section can be roughly divided into three lithologically different parts. The western part, between 1400 and 2000 ft, is composed of coarse to medium-grained rocks of anorthositic and leuconoritic[1] composition. Textures vary; the mafic constituents may be dispersed between plagioclase crystals, or form poikilitic clots in plagioclase rock, or they may increase in amount to form an ophitic texture. Locally, xenolithic masses of anorthosite occur in the leuconorite. Elsewhere, the two rock types appear to grade into each other. One important feature in this part of the valley is a dike of hypersthenite, which is followed by the brook between 1600 and 1900 ft. It is at least 875 m long and between 1 and 2 m wide, with offshoots and veins paralleling it.

At about 2000 ft there is an abrupt change in lithologies: beyond a well-exposed sharp contact the rock is medium to fine grained, contains between 10 and 40 percent mafic minerals, and K feldspar and quartz are invariably present, but in variable amounts. This part of the valley, be-

[1] The term leuconorite is used here as an abbreviation of leucocratic norite, which is a norite containing between 5 and 25 percent mafic minerals, too much to be called anorthosite. See Figure 5 for rock terms and classification.

tween 2000 and about 2700 ft, is characterized by the occurrence of jotunite, farsundite, and charnockite. All of these rocks are metamorphosed and garnet bearing. Some are foliated, but many are granulites without distinct orientation. Locally, and especially between 2000 and 2200 ft, xenoliths of various size and composition occur. The inclusions consist of fine-grained, finely layered diopside-microperthite metasediment (first reported by Kemp, 1921, 35), and of anorthositic and leuconoritic rocks represented in the western part of the valley. The xenoliths are embedded in a mafic granulite of jotunitic composition in which relict magmatic textures and structures can be recognized. Between 2250 and 2450 ft the rocks are foliated, and compositions range from jotunite with plagioclase augen to charnockite with K-feldspar augen.

A third set of lithologies is encountered in the eastern part of the valley, from about 2700 ft (unfortunately, outcrops are scarce here) to the top of Giant Mountain. The rocks are predominantly coarse to medium-grained anorthosite and leuconorite, similar to the rocks in the western part of the valley, but here dikes and bodies of jotunite, farsundite, and charnockite cut across the anorthositic and leuconoritic rocks. The number of dikes varies locally; more were encountered on the Bottle Slide than on the Tulip Slide. The upper portion of the Bottle Slide displays block structure of leuconorite with the usual anorthositic parts and masses, intersected by dikes of garnet-bearing charnockite. The top of Giant Mountain consists of a crosscutting body of farsundite. As in the middle part of the valley, these transgressive rocks are now metamorphic rocks of granulitic texture and composition. The most acidic type, leptynite, contains garnet as virtually the only mafic mineral.

The Rock Suite

With the exception of the xenolithic metasediments all rocks of Roaring Brook valley are considered more or less metamorphosed and deformed members of a differentiation series. A close genetic relationship is indicated by the gradual transitions observed between rock types in the field. The order of differentiation is considered to be largely reflected by the sequence of rocks in Table 1. The table shows modal and chemical compositions of 16 rock samples which are representative for the variation among the rocks occurring in the valley. The sample locations are shown in Figure 2. Sample numbers reflect altitude in feet.

The rocks in the table are arranged in order of decreasing value of the molecular normative ratio (Ab+An)/(Q+Or+Ab+An). The sequence shows a general increase in K-feldspar and quartz content of the rock, and a general decrease of the An percentage of plagioclase and the En percentage of orthopyroxene. Trends in the series expressed by cation

TABLE 1. CHEMICAL AND MODAL ANALYSES OF ROCKS OF THE ANORTHOSITE-CHARNOCKITE SUITE OF THE ROARING BROOK VALLEY (MARCY MASSIF)

	1740-1[e]	2040S	2060N-3	1960S	1400-1	2900S	3050T	2950N	2060N-1	4627	2630S	2250S-3	2540S	3400T	4250N	3100N
Chemical analysis (wt. %)[a]																
SiO_2	50.88	53.27	52.19	52.16	53.83	47.25	47.15	56.24	46.84	56.77	56.45	62.70	65.35	61.76	68.56	68.12
TiO_2	1.08	0.37	0.55	0.37	0.27	2.91	3.32	1.10	2.75	1.76	1.50	0.44	0.79	1.06	0.79	0.73
Al_2O_3	4.40	23.46	22.30	23.96	25.67	15.39	15.61	20.32	13.58	15.84	15.88	18.41	14.37	17.06	14.23	14.61
Fe_2O_3	2.30	0.88	1.73	1.93	1.33	2.95	3.36	1.96	4.43	3.24	2.60	0.63	2.19	1.08	1.18	1.26
FeO	14.17	3.73	3.73	2.13	1.42	11.06	10.92	5.18	13.84	9.05	8.13	2.37	4.10	4.98	4.52	4.43
MnO	0.29	0.06	0.08	0.05	0.04	0.17	0.16	0.09	0.25	0.17	0.17	0.05	0.10	0.08	0.07	0.07
MgO	17.37	4.25	4.68	2.69	1.16	3.10	2.82	1.25	2.92	1.26	1.06	0.40	0.64	0.57	0.54	0.55
CaO	8.03	10.02	8.63	10.12	9.27	9.52	10.37	7.23	8.58	4.91	4.39	2.49	2.45	2.68	2.63	2.07
Na_2O	0.87	3.70	4.30	4.16	5.12	3.43	2.96	4.36	3.30	3.23	3.56	3.85	3.87	2.09	1.88	1.82
K_2O	0.03	0.62	0.72	0.81	0.97	1.26	1.50	2.38	2.00	3.85	5.50	7.59	5.45	7.15	5.26	5.87
P_2O_5	0.16	0.03	0.06	0.10	0.01	2.29	1.85	0.33	1.03	0.62	0.38	0.15	0.26	0.25	0.23	0.20
total	99.58	100.39	98.97	98.48	99.09	99.33	100.02	100.44	99.52	100.70	99.62	99.08	99.57	98.76	99.89	99.73
Molecular norm (ionic %)																
Q	—	—	—	—	—	—	0.6	3.3	—	7.7	1.6	4.2	14.5	12.7	27.6	26.4
Or	0.2	3.6	4.2	4.8	5.5	7.7	9.2	14.0	12.3	23.2	33.2	44.9	32.7	43.5	32.0	35.7
Ab	7.9	32.6	38.3	37.3	45.0	31.9	27.5	39.0	30.9	29.6	32.6	34.6	35.3	19.4	17.4	16.9
An	8.1	44.7	39.1	44.3	44.0	23.7	25.7	28.8	17.0	17.7	11.4	10.6	5.9	12.0	11.9	9.2
C	—	—	—	—	—	—	—	—	—	—	—	—	—	1.8	1.3	2.2
Di	24.8	3.1	2.4	4.2	0.8	7.8	12.0	3.9	16.2	2.4	6.7	0.6	3.8	—	—	—
Hy	52.7	14.6	7.2	6.2	0.2	16.1	12.6	6.8	3.0	12.1	8.8	3.5	3.8	7.4	6.9	6.8
Ol	2.1	—	6.2	0.5	2.7	0.4	—	—	9.6	—	—	—	—	—	—	—
Mt	2.4	0.9	1.8	2.0	1.4	3.2	3.6	1.5	4.8	3.5	2.8	0.7	2.3	1.2	1.3	1.4
Il	1.5	0.5	0.7	0.5	0.4	4.2	4.8	2.0	4.0	2.5	2.1	0.6	1.1	1.5	1.1	1.0
Ap	0.3	—	0.1	0.2	—	5.0	4.0	0.7	2.2	1.3	0.8	0.3	0.6	0.5	0.5	0.4
An/Ab+An	50.6	57.8	50.5	54.3	49.4	42.6	48.4	42.4	35.5	37.4	25.8	23.4	14.2	38.3	40.6	35.4
Mg/Mg+ ΣFe+Mn	65.2	62.3	60.8	55.0	43.8	28.5	26.3	24.1	22.4	15.6	15.1	19.3	15.6	14.4	14.6	14.8
femic %	83.8	19.1	18.4	13.6	5.5	36.7	37.0	14.9	39.8	21.8	21.2	5.7	11.6	10.6	9.8	9.6

TABLE 1—(*Continued*)

	1740-1	2040S	2060N-3	1960S	1400-1	2900S	3050T	2950N	2060N-1	4627	2630S	2250S-3	2540S	3400T	4250N	3100N
								Modal analysis (vol. %)								
quartz	0.3	—	—	—	0.3	1.1	1.8	3.6	1.2	11.8	7.6	6.1	20.5	16.3	28.2	32.2
K feldspar	0.1	—	—	1.7	2.6	6.6	12.6	14.8	14.8	31.0	46.2	52.6	52.8	49.8	41.7	44.0
plagioclase	8.1[g]	71.1	81.5	74.3	93.0	53.3	45.6	61.6	37.0	34.9	23.3	35.2	16.0	19.7	15.6	11.7
biotite	0.7	1.5	1.1	—	—	—	—	—	—	—	—	—	—	—	—	—
hornblende	2.0	4.0	10.3	2.7	0.3	0.3	2.3	1.0	—	0.5	0.1	0.1	0.2	—	0.7	—
clinopyroxene	8.7	1.1	1.3	17.6	3.0	11.9	19.1	10.4	19.9	7.4	9.6	2.4	3.7	0.4	0.4	0.5
orthopyroxene	78.1	21.2	5.3	2.5	—	9.5	0.2	—	10.0	3.7	3.2	1.2	2.3	—	—	—
garnet	—	—	—	—	0.7	10.1	7.2	5.5	15.5	6.8	5.7	1.2	2.0	12.4	10.8	10.1
ore & accessories	2.0	1.1	0.5	1.2	0.1	7.2	11.2	3.1	1.6	3.9	4.3	1.2	2.5	1.4	2.6	1.5
An %[b]	55–50[f]	58–50	50–42	50–47	50–42	52–32	47–30	48–33	36–23	30–25	25–20	27–22	30–20	38–35	35–32	36–33
En %[c]	70	67	63	60	—	38	34	—	30	23	17	20	18	—	—	—
mafic %	91.5	28.9	18.5	24.0	4.1	39.0	40.0	20.0	47.0	22.3	22.9	6.1	10.7	14.2	14.5	12.1
texture[d]	P	P	P	P	Pc	pC	pC	pC	pC	C	C	Cf	CF	C	C	C
name	hypers-thnite	leuco-norite	leuco-norite	leuco-norite	anortho-site	jotunite	jotunite	jotunite	jotunite	farsun-dite	char-nockite	farsun-dite	char-nockite	leptynite	leptynite	leptynite

[a] Analyses by Japan Analytical Chemistry Research Institute, Tokyo.
[b] Determined by universal stage method (Slemmons, 1962) and Tsuboi method (Morse, 1968).
[c] Based upon conoscopic universal stage determination of $2V$ and dispersion, and on refractive index determination (Deer, Howie, & Zussman, 1963).
[d] Textures: P (p), primary texture well (poorly) preserved; C (c), crystalloblastesis strongly (weakly) developed; F (f), foliation strongly (weakly) developed.
[e] Sample numbers reflect altitude in feet of sample location on valley floor; N indicates north side and S south side of valley, and T refers to the Tulip Slide.
[f] Range in An percentage indicates compositional zoning from core of large crystals to rim and small grains. Zoning is primary in rocks with igneous texture, and partly or completely metamorphic in all others.
[g] Includes 0.5% scapolite.

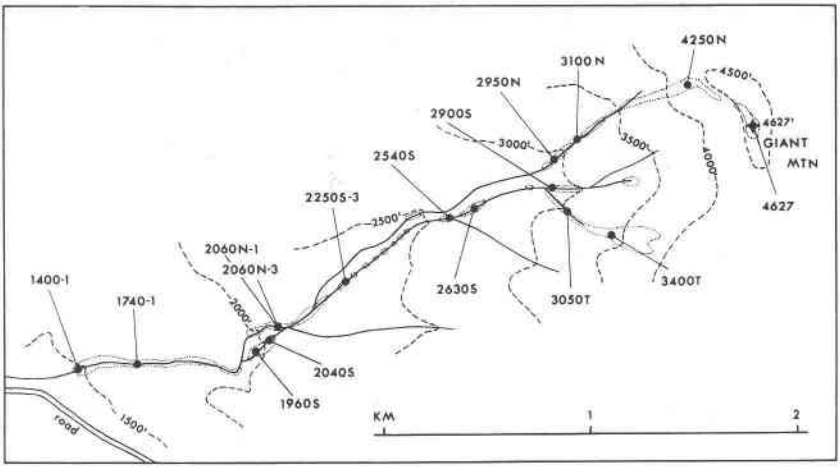

FIG. 2. Map of the Roaring Brook Valley showing sample locations and the extent of rock exposure on the valley floor (stippled). The Bottle Slide is west of sample location 4250N, and the Tulip Slide is east of location 3400T. Topography based upon U.S. Geological Survey topographic 15 minute quadrangle maps, sheets Mount Marcy, N. Y., and Elizabethtown, N.Y.

ratios are further demonstrated in variation diagram Figure 4 in which the samples are arranged in the same order. Crosscutting contacts observed in the valley between the members of the suite indicate that a relationship of decreasing age exists, which is largely correlative with the order shown in the table.

The different behavior of the members of the rock suite to metamorphism and deformation hampers the use of a consistent rock terminology. Some of the rocks are not affected by these processes, and they may be termed as igneous cumulates. Other members of the rock suite are foliated and completely recrystallized. In this paper, as in previous ones (de Waard, 1969; de Waard and Romey, 1969a, b), use is made of the terms jotunite, farsundite and charnockite, which refer to orthopyroxene-bearing magmatic or metamorphic rocks, chemically the equivalents of monzodiorite, adamellite and granite, respectively. The classification of these rocks is shown in Figure 5, which also demonstrates the serial nature of the rock suite as a function of the proportions of leucocratic minerals. Part of the rocks having granitic bulk composition are free of orthopyroxene and therefore cannot be called charnockite. They are here named leptynite a term used for a felsic granulite essentially consisting of quartz, feldspars and garnet.

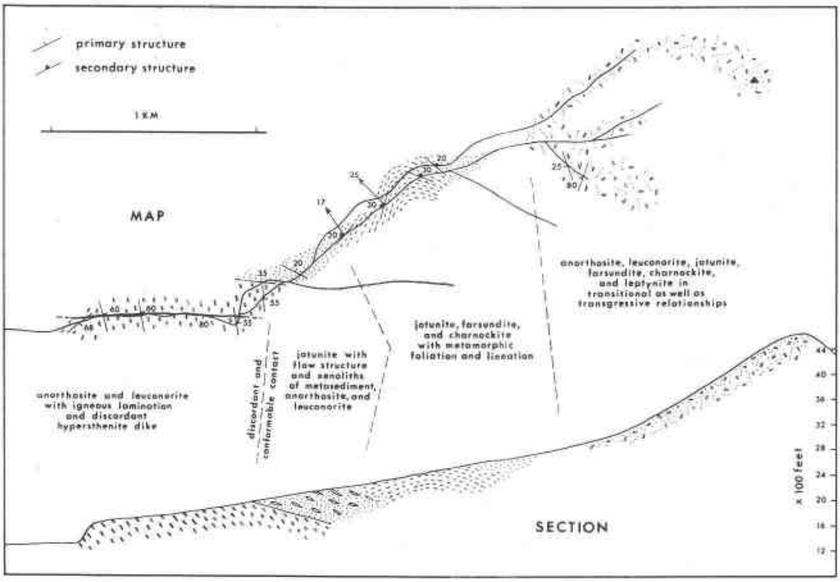

FIG. 3. Geologic map and section of Roaring Brook valley.

TEXTURES

Three groups of textures can be distinguished in the rocks of the Roaring Brook valley: igneous textures, unoriented metamorphic textures, and oriented metamorphic textures.

The igneous textures are not deformed because the rock reacted rigidly to orogenic stress, and the rock is not recrystallized because the mineral assemblage was stable under metamorphic conditions. Most of the igneous textures are those of orthocumulates or mesocumulates, containing pore material amd strongly zoned plagioclase. The hypersthenite is an orthopyroxene orthocumulate with pore material consisting of zoned labradorite, quartz, K-feldspar, biotite, hornblende, clinopyroxene, apatite, and ore. Part of the plagioclase is scapolitized, presumably by the trapped residual liquid.

The sequence of crystallization is reversed in anorthosite and leuconorite, where plagioclase is the cumulus mineral and pyroxenes the principal pore material. The large, commonly subparallel plagioclase crystals are compositionally zoned (see Table 1). The less calcic rim matches in composition that of the smaller, surrounding plagioclase grains. Deformation in the rock is evidenced by the bent and broken nature of the large plagioclase crystals. The undeformed pore material demonstrates, however, that crushing and granulation of plagioclase occurred before

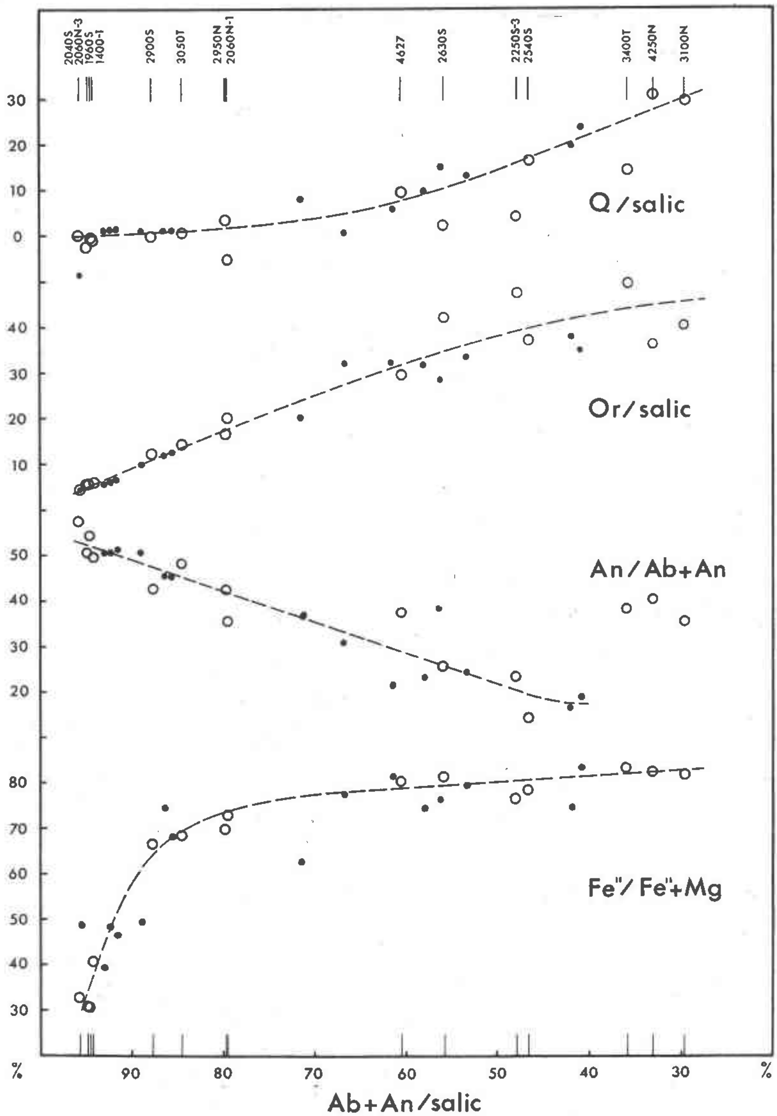

FIG. 4. Variation diagram for rocks of the anorthosite-charnockite suite of Roaring Brook valley (circles) showing trends in the variation of characteristic cation ratios plotted against the molecular normative ratios (Ab+An)/(Q+Or+Ab+An). Ratios of published rock analyses from about 30 km further to the northwest in the Marcy massif (Saranac Lake area) have been added (dots) for comparison (Buddington, 1953, Table 3, no. 1, 2, 3, 4, 5, 6, 8, Table 5, no. 1, 2, 3, 4, 6, 7, 8; Buddington, 1939, Table 32, no. 114).

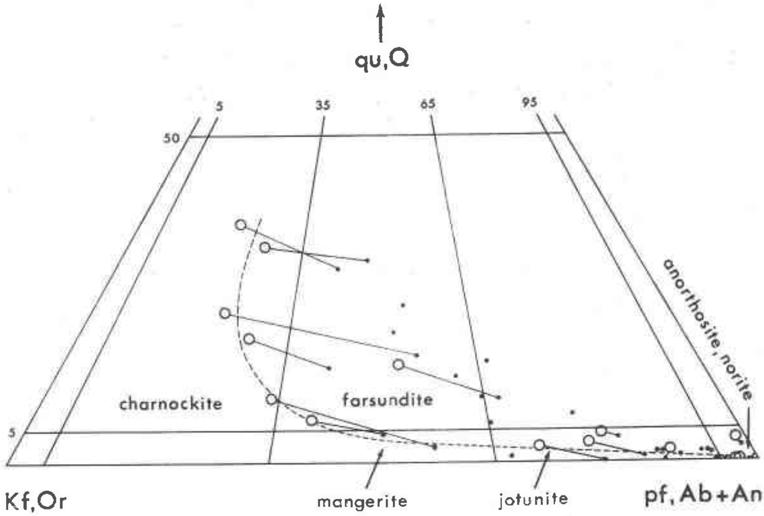

FIG. 5. Volumetric modal ratios of quartz, K feldspar, and plagioclase (circles), and the molecular normative ratios of Q, Or, and Ab+An (dots) of the analyzed rocks of Roaring Brook valley. The molecular normative ratios of rocks of the Saranac Lake area have been added for comparison. The terminology used (de Waard, 1969) is based on the subdivision of the triangular quartz–K-feldspar–plagioclase field of modal compositions. Amounts of perthite components have been estimated and treated as K-feldspar and plagioclase in the classification.

complete consolidation, *i.e.*, in the state of a crystal mush. The texture of the pyroxenes is poikilitic, interstitial poikilitic, or sub-poikilitic. Also hornblende, K feldspar, and quartz occur as sub-poikilitic pore material in the plagioclase orthocumulates.

Unoriented metamorphic textures occur in rocks in which the igneous mineral assemblage was in disequilibrium during metamorphism, and the rock recrystallized to a stable assemblage. No foliation developed, either because the rock reacted rigidly to orogenic stress, or because it was situated in a sheltered position during orogenesis. Texturally and compositionally, most of these rocks are granulites.

The transformation of the igneous mineral assemblage to a metamorphic assemblage involves the production of garnet, clinopyroxene, and quartz at the expense of orthopyroxene and the anorthite component of plagioclase (de Waard, 1965a, b). The reaction appears controlled by the Fe-Mg ratio of the rock, occurring only when this exceeds a value of about 1.3. Corona textures in some of the rocks attest to equilibration on a local scale. In other rocks recrystallization produced an equigranular mosaic of the stable assemblage. Jotunitic rocks commonly contain relict igneous plagioclase crystals, in which garnet developed in the rim, producing intense compositional zoning in the plagioclase (see Table 1). The more acidic rocks tend to be more thoroughly recrystallized to equigranular granulites such as the leptynite.

Oriented metamorphic textures have developed in rocks of the middle part of the valley. Here, orogenesis caused planar and linear textures in granulitic rock types which appear unaffected by deformation elsewhere in the valley. Lenses and thin layers of granulated mafic and felsic minerals define the foliation, as does the orientation of plagioclase and K-feldspar augen which presumably are igneous relicts.

Structures

Most of the structures in the Roaring Brook valley are of pre-orogenic, igneous origin; in part of the valley the early structures are blurred or obliterated by orogenic deformation and recrystallization. Igneous structures include igneous lamination, rhythmic layering, flow structure, conformable and discordant contacts, xenoliths, block structure, and dikes.

Igneous lamination is well developed in the leuconorite and anorthosite of the western part of the valley. Tabular plagioclase crystals, about 5 cm long, have parallel or subparallel orientation, forming a planar structure which dips steeply to the east. Rhythmic layering is observed particularly in jotunite, *e.g.*, at location 3050T. At this location there are about 20 layers exposed, 5 to 30 cm thick, dipping 25° to the west. Each layer shows a gradual decrease in the proportion of mafic minerals upward, as in density-graded bedding. Sample 3050T in Table 1 is taken from the leucocratic portion of a layer; the lower part of the layer is an almost ultramafic, garnet-clinopyroxene rock.

Between 1500 and 1900 ft the hypersthenite dike cuts across the igneous lamination of the leuconorite and anorthosite, seemingly demonstrating that hypersthenite is the younger rock. Cation ratios in Table 1 and Figure 4 indicate that both the hypersthenite and the plagioclase rock are early crystallization products in the anorthosite-charnockite series. Along the borders of the dike some mixing appears to have taken place between the two rock types. Here pyroxene and plagioclase occur in all proportions. In places the hypersthenite dike appears broken and intruded in its turn by plagioclase-rich material. These phenomena seem to indicate that both the intruding and the intruded rock were crystal mush, solid enough for the plagioclase mush to break along an almost straight surface, and plastic enough for the hypersthene mush to intrude the fissure.

At 2000 ft the igneous lamination of the plagioclase cumulates is interrupted by a discordant contact with jotunite which apparently intruded anorthosite and leuconorite as a magma. A flow structure, conformable with the contact plane, is indicated by schlieren of mafic minerals in the jotunite and by parallelism of platy metasedimentary xenoliths.

Xenoliths of various sizes and compositions are common in places where the rock has not been affected by orogenic deformation. Anorthosite blocks and masses, with sharp contacts and commonly with a mafic border, occur in many places in leuconorite. Blocks of anorthosite and of leuconorite (*e.g.*, sample 2060N3) are found in jotunite. Dikes and intrusive masses of jotunite occur in anorthosite and leuconorite. Farsundite, charnockite and leptynite form dikes and intrusive bodies in anorthosite, leuconorite and jotunite. In some places abundant dikes form a reticulate structure of the intruding, and a block structure of the intruded rock type.

Foliation and lineation are locally superimposed on the pre-orogenic structures, which are gradually obliterated between 2190 and 2230 ft. Metasedimentary xenoliths are still faintly visible at 2230 ft. Between 2200 and 2900 ft the foliation forms an arch with low-angle dips. The lineation, which is in the foliation plane and plunges about 20° to the northwest, parallels the fold axis of the arch.

Conclusions

The problem, whether the variation in rock types of Roaring Brook valley is the result of a single occurrence of magmatic differentiation as advocated by Bowen (1917), Balk (1931), Buddington (1931), Crosby (1968), and de Waard and Romey (1969), or is the result of two magmatic events, separated in time, as proposed by Buddington (1936, 1939, and 1969), cannot be solved conclusively from the observations in the field. However, the mutual relationships between the rock types, the complete gradation of members within the rock suite, and the consistent chemical trends shown in variation diagrams, speak for a differentiation process involving only one magmatic event. If all rocks belong to one rock suite, then there are three end members in the differentiation series; plagioclase cumulate and hypersthene cumulate are the two early products, and charnockite or granite is the final product of differentiation.

A hypersthene dike is a very unusual phenomenon in anorthosite massifs. Ultramafic rocks are not known to occur associated with anorthosite bodies, though they do occur locally as clots of mafic minerals in anorthosite or leuconorite. Models for the formation of anorthosite massifs from a basaltic parent magma require an ultramafic differentiate. The absence of masses of ultramafic rocks in or below anorthosite massifs, which was confirmed in the Adirondacks by geophysical data, indicates a possible dioritic or granodioritic parent magma, or a basaltic magma altered in composition by assimilation or anatexis. The presence of the hypersthenite dike in the valley indicates that ultramafics are indeed an early differentiation product during the formation of anorthosite bodies, but the rarity of such occurrences makes it unlikely that the quantity of ultramafic rock produced was very large. There are no indications as to whether the hypersthenite cumulate was formed above, below, or as a layer in the plagioclase cumulate before intrusion.

If, in conclusion, a tentative evolution of the anorthosite massif needs to be given in order to generate discussions on the outcrops of Roaring Brook valley, the following sequence of events appears consistent with the observations. From a parent magma a little hypersthene cumulate differentiated on the floor and much plagioclase cumulate near the roof of the magma chamber. Both cumulates contained interstitial liquid of granitic composition, and ultimate consolidation of the cumulates could only take place after a sufficient drop in temperature. The two cumulates were separated by magma whose composition was changing, with decreasing density, as crystallization progressed. Finally the density became less than that of the plagioclase cumulate, which settled in large chunks. The igneous lamination became tilted, and a fissure developed in which the bottom deposit of hypersthene penetrated as a crystal mush. While the plagioclase cumulate sank, the residual magma rose, intruded in and above the plagioclase cumulate, and incorporated, as it flowed, xenoliths of anorthosite, leuconorite, and metasedimentary rock from the roof of the magma chamber. This short and simplified development of an anorthosite massif is essentially the same as the one proposed by Morse (1969).

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