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CHEMICAL AND PETROLOGIC TRENDS IN THE ANORTHOSITE-CHARNOCKITE SERIES OF THE SNOWY MOUNTAIN MASSIF, ADIRONDACK HIGHLANDS

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ABSTRACT

Anorthosite in the core of Snowy Mountain massif is closely associated with, and partly transitional into, rocks that form a shell around the anorthosite core. These rocks range from leucocratic norite near the core to charnockite near the margin of the massif. Modal analyses show a gradual increase in K feldspar and quartz from core to margin. Chemical analyses further show a gradual decrease in the normative anorthite percentage and an increase in Fe-Mg ionic proportion.

The completely gradual compositional sequence of members of the anorthosite-charnockite series favors an origin by differentiation from one magma, or formation of part of the magma by anatexis, rather than an origin involving two magmatic events.

INTRODUCTION

The core of Snowy Mountain dome in the south-central Adirondack highlands consists of coarse, leucocratic anorthosite. The anorthosite is closely associated with, and partly transitional into, the overlying suite of rocks that forms a shell around the anorthosite core, and which varies in composition from leucocratic norite near the core to charnockite near the margin of the massif. No boundaries between members of this gradational series have been observed. Foliation, considered to have been formed during a period of deformation and high-grade metamorphism that came after anorthosite formation, is weakly developed in the anorthosite core, becomes more prominent in the surrounding rocks of noritic and jotunitic composition, and is strongly developed in the farsunditic and charnockitic rocks of the outer shell.[1] Relict magmatic textures are present in anorthosite, norite, and jotunite, but in the outermost far-farsunditic and charnockitic rocks they are entirely lacking. The existence of metamorphic conditions at some time after the formation of the anorthosite and associated rocks is also indicated by the general presence of garnet in all members of the anorthosite-charnockite suite.

Details of geologic and petrologic relationships in the Snowy Mountain massif have been described in previous papers (de Waard and Romey, 1963, 1969; Romey and de Waard, 1964, 1966); in this note the results are presented of 14 chemical analyses of rocks of the anorthosite-

[1] The rock names jotunite, mangerite, farsundite, and charnockite refer to orthopyroxene-bearing magmatic or metamorphic rocks, chemically the equivalents of monzodiorite, monzonite, adamellite, and granite, respectively (see also Fig. 4).

charnockite suite. The chemical analyses and field work in the Snowy Mountain area have been made possible because of financial support of the National Science Foundation.

Rock Compositions

It was shown by mapping in the field and by petrographic examination of the samples that there is a gradual change in rock composition from the center to the periphery of the Snowy Mountain dome. In the core of the massif rocks consist predominantly of intermediate plagioclase and pyroxene in varying proportions, giving rise to anorthosite in the center and to leucocratic norite surrounding it. Potash feldspar and quartz, being absent in the anorthosite and norite, are found in increasing amounts in rocks towards the periphery of the massif. The gradual increase in K feldspar and quartz is shown in Figure 1 by isopleths indicating zones of less than 5, 5 to 35, 35 to 65, and more than 65 percent K feldspar of total feldspar, and of less and more than 5 percent quartz, of quartz and feldspar, in the rock.

The variation in composition is further illustrated by the group of 14 analyzed rocks in Table 1, and Figures 2, 3, and 4. The group is representative of the common rock types of the anorthosite-charnockite series in the Snowy Mountain massif.

The rocks in the table are arranged in order of decreasing value of the molecular normative ratio Ab+An/Q+Or+Ab+An. This order is correlative with the relative position of the samples, from the center of the complex outward, and is reflected in the modes of the rocks by decreasing plagioclase, and increasing quartz and K-feldspar contents. This order also reflects a relationship of decreasing age between members of the anorthosite-charnockite suite as evidenced by transgressive relationships observed in the Adirondacks and elsewhere. The same order has been adopted for purposes of plotting the variation diagrams of the series.

The variation diagram given in Figure 2 shows the gradual increase in Si and K, and decrease in Ca and Mg throughout the series. The femic content in this group of rock samples decreases generally, though there is a distinct increase in the middle of the series. The number of samples is too small, however, to establish the detail of this trend as characteristic for the Snowy Mountain massif. Most of the variation curves in Figure 2, particularly those of Fe^{2+}, Al, and Si are noticeably affected by the higher femic content in the middle of the series. The variation diagram given in Figure 3 demonstrates trends in the series expressed by cation ratios.

Figure 4 further illustrates the serial nature of the rock suite of Snowy Mountain massif, and also shows the correlation between normative and modal ratios of the leucocratic components in the rocks. The difference

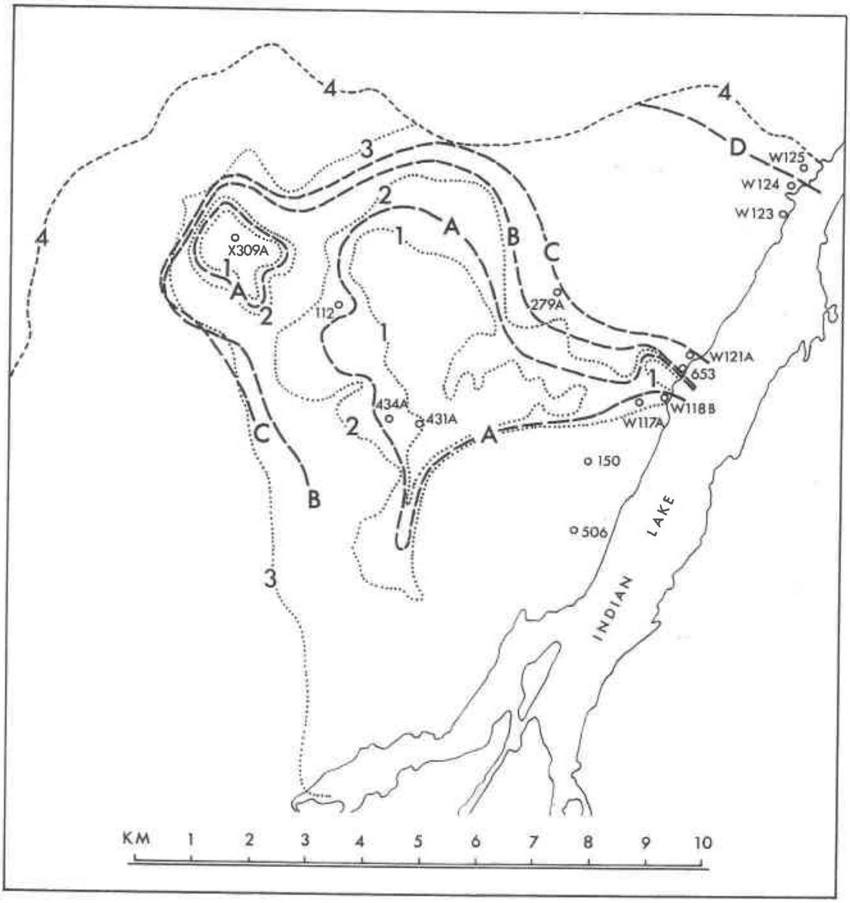

FIG. 1. Outline map of Snowy Mountain dome, south-central Adirondack highlands, New York, showing locations of analyzed rock samples, gradational textural boundaries, and the approximate and simplified trend of K-feldspar and quartz isopleths. Based on rock textures are the following: 1. approximate boundary between predominantly coarse-grained anorthositic rock and finer-grained rocks with recognizable magmatic textures, 2. approximate limit of well-developed foliation, 3. approximate limit of the occurrence of relict plagioclase augen, and 4. boundary of the anorthosite-charnockite complex. Based on modal rock compositions are the following isopleths; A: 5% K feldspar of total feldspars, B: 35% K feldspar of total feldspars, C: 5% quartz of quartz and feldspars, and D: 65% K feldspar of total feldspars. These limits are the same as those used to define the rock terms in Figure 4. Hence, within isopleth A rocks termed anorthosite and norite predominate, between isopleths A and B, there is jotunite, between B and C: mangerite, between C and D: farsundite, and outside D: charnockite.

TABLE 1. CHEMICAL AND MODAL ANALYSES OF ROCKS OF THE ANORTHOSITE-CHARNOCKITE SUITE OF THE SNOWY MOUNTAIN MASSIF

		434-A	431-A	W-117-A	X-309-A	W-118-B	112	150
chemical analysis (wt. %)	SiO_2	43.44	47.61	48.51	53.74	51.95	56.24	56.74
	TiO_2	4.46	3.09	2.79	1.04	2.45	1.15	1.28
	Al_2O_3	14.81	16.74	16.45	21.13	17.95	20.88	18.47
	Fe_2O_3	7.56	4.06	3.66	3.53	3.12	2.76	2.13
	FeO	11.36	8.27	8.36	2.77	4.56	2.29	4.48
	MnO	0.24	0.20	0.17	0.12	0.12	0.05	0.12
	MgO	4.24	3.28	3.25	1.24	2.21	0.96	1.59
	CaO	8.69	9.24	9.09	8.54	8.37	7.57	5.73
	Na_2O	2.69	3.59	3.69	4.24	4.36	4.23	4.76
	K_2O	0.83	1.38	1.51	1.98	1.80	2.70	3.27
	P_2O_5	0.57	1.62	1.66	0.55	1.37	0.53	0.57
	total	98.89	99.08	99.14	98.88	98.26	99.37	99.14
	analyst[a]	S.I.	S.I.	T.A.	T.A.	T.A.	T.A.	S.I.
molecular norm (ionic %)	Q	0.6	0.2	0.2	3.6	3.3	4.0	2.5
	Or	5.5	8.5	9.0	12.0	11.0	19.0	19.5
	Ab	25.5	33.0	34.0	38.5	40.0	38.0	43.0
	An	27.3	26.3	24.8	33.0	24.5	28.3	19.5
	Di	11.2	8.0	8.4	5.2	7.2	4.4	4.4
	Hy	13.8	11.8	12.2	1.4	4.2	0.8	6.0
	Mt	8.2	4.3	3.9	3.8	3.3	2.8	2.2
	Il	6.6	4.4	4.0	1.4	3.6	1.6	1.8
	Ap	1.3	3.5	3.5	1.1	2.9	1.1	1.1
	An/Ab+An	51.7	44.4	42.2	46.2	38.0	42.7	31.2
	Mg/Mg+ΣFe+Mn	29.1	32.5	32.9	26.7	34.5	26.1	30.3
	femic %	41.1	32.0	32.0	12.9	21.2	10.7	15.5
modal analysis (vol. %)	quartz	tr	tr	0.5	1.0	tr	3.0	1.3
	K feldspar	0.5	4.7	4.3	5.3	9.6	14.9	19.8
	plagioclase	66.4	62.6	63.3	80.4	66.7	70.0	61.3
	biotite	—	—	—	—	—	tr	—
	hornblende	2.5	3.2	1.3	1.3	0.9	3.5	3.2
	clinopyroxene	9.2	8.5	8.5	2.3	6.4	6.0	4.4
	orthopyroxene	9.0[b]	9.9[b]	10.2	1.3	4.6	1.5	4.9
	garnet	2.8	1.6	1.5	3.1	—	0.2	0.3
	ore	7.7	6.8	6.5	5.3	5.2	0.9	3.3
	accessories	1.9	2.7	3.9	tr	6.6	tr	1.5
	An %[c]	43	35	45–35	43	34	40	29
	En %[d]	42	38	40	40	40	40	33
	mafic %	33.1	32.7	31.9	13.3	23.7	12.1	17.6
	relict texture (R)	R	R	R	R	R	R	—
	name	norite	jotunite	jotunite	jotunite	jotunite	jotunite	jotunite

[a] Analysts: S. I., Shiro Imai; T. A., Tadashi Asari; both of Japan Analytical Chemistry Research Institute in Tokyo.
[b] Bushveld-type lamellae.
[c] Universal stage determinations.
[d] Based upon universal stage determinations of 2V and dispersion.

TABLE 1—(*Continued*)

		W-123	506	279-A	653	W-121-A	W-124	W 125
chemical analysis (wt. %)	SiO_2	55.74	55.16	53.47	57.86	58.94	60.85	66.67
	TiO_2	1.40	1.92	2.06	1.10	1.27	1.22	0.89
	Al_2O_3	17.06	15.72	15.12	15.52	15.73	15.65	13.96
	Fe_2O_3	3.33	3.42	5.21	2.74	2.25	2.38	2.57
	FeO	4.64	6.63	6.84	5.80	6.51	4.22	2.99
	MnO	0.17	0.19	0.22	0.16	0.18	0.13	0.09
	MgO	1.69	1.80	1.72	1.18	0.91	1.07	0.50
	CaO	5.15	5.58	5.51	4.29	3.66	3.58	2.43
	Na_2O	4.65	4.43	4.36	4.44	4.40	4.57	3.75
	K_2O	3.73	3.52	3.65	4.63	4.82	4.76	4.84
	P_2O_5	0.83	0.94	0.78	0.62	0.47	0.48	0.21
	total	98.39	99.31	98.94	98.34	99.14	98.91	98.90
	analyst[a]	T.A.	T.A.	S.I.	T.A.	T.A.	T.A.	T.A.
molecular norm (ionic %)	Q	2.7	2.6	1.8	3.4	4.3	7.6	20.0
	Or	22.5	21.0	22.5	28.0	29.0	28.5	29.5
	Ab	42.5	40.5	40.0	41.0	40.0	41.5	34.5
	An	15.0	13.0	11.2	9.0	9.3	8.3	7.0
	Di	4.0	7.6	9.6	7.2	5.2	4.8	2.4
	Hy	5.8	7.0	4.8	5.6	7.2	4.0	2.2
	Mt	3.6	3.6	5.5	2.9	2.4	2.6	2.7
	Il	2.0	2.8	3.0	1.6	1.8	1.6	1.2
	Ap	1.9	1.9	1.6	1.3	0.8	1.1	0.5
	An/Ab+An	26.1	24.3	21.9	18.0	18.9	16.7	16.9
	Mg/Mg+ΣFe+Mn	27.8	24.5	20.7	20.0	15.7	22.7	14.2
	femic %	17.3	22.9	24.5	18.6	17.4	14.1	9.0
modal analysis (vol. %)	quartz	5.8	1.3	1.0	2.0	3.7	12.0	15.4
	K feldspar	30.0	22.5	30.2	38.1	43.6	40.3	47.4
	plagioclase	38.1	47.8	44.2	38.5	31.7	30.2	14.9
	biotite	—	tr	—	—	—	0.2	—
	hornblende	6.1	6.4	—	4.0	4.6	12.0	6.4
	clinopyroxene	6.1	9.3	9.7	4.1	5.9	1.2	8.0
	o thopyroxene	5.3	5.9	5.8	6.9[b]	6.4[b]	2.2	5.3
	garnet	0.1	0.2	—	—	—	0.1	—
	ore	7.1	3.9	7.8	3.3	2.7	1.2	1.8
	accessories	1.4	2.7	1.3	3.1	1.4	0.6	0.8
	An %[c]	21	25	21	22	20	21	23
	En %[d]	40	28	25	20	17	25	16
	mafic %	26.1	28.4	24.6	21.4	21.0	17.5	22.3
	relict texture (R)	—	—	—	—	—	—	—
	name	farsundite	jotunite	mangerite	mangerite	mangerite	farsundite	charnockite

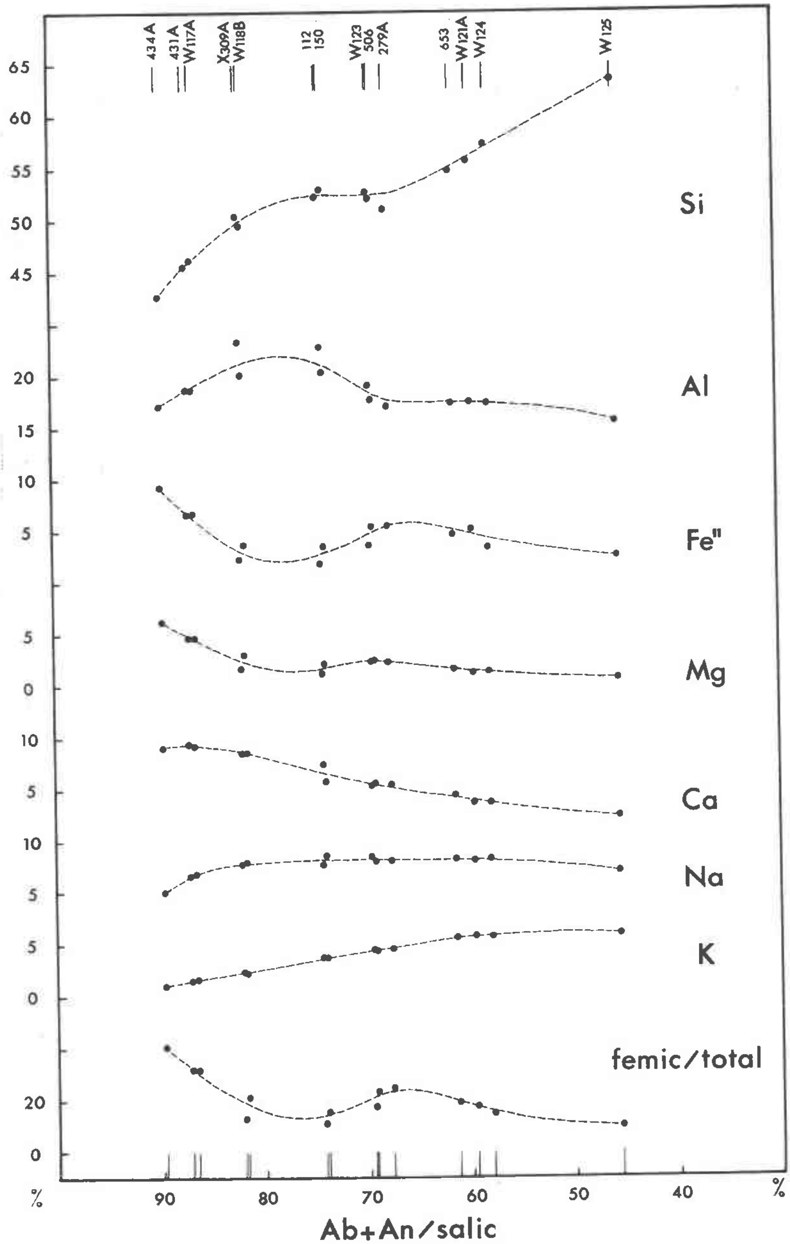

FIG. 2. Variation diagram for rocks of the anorthosite-charnockite suite of the Snowy Mountain massif showing trends in the variation of percentages of the principal cations plotted against the molecular normative ratios (Ab+An)/(Q+Or+Ab+An).

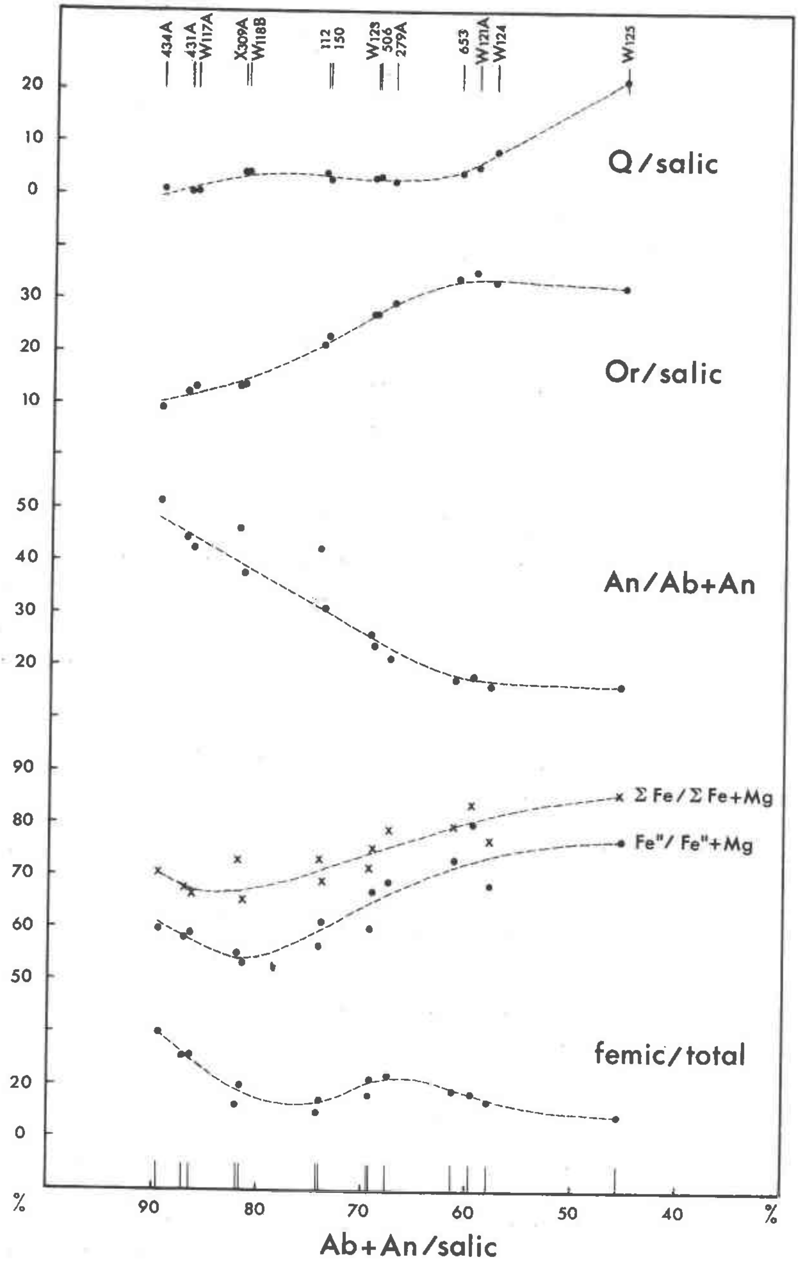

FIG. 3. Variation diagram for rocks of the anorthosite-charnockite suite of the Snowy Mountain massif showing trends in the variation of characteristic cation ratios plotted against the molecular normative ratios (Ab+An)/(Q+Or+Ab+An).

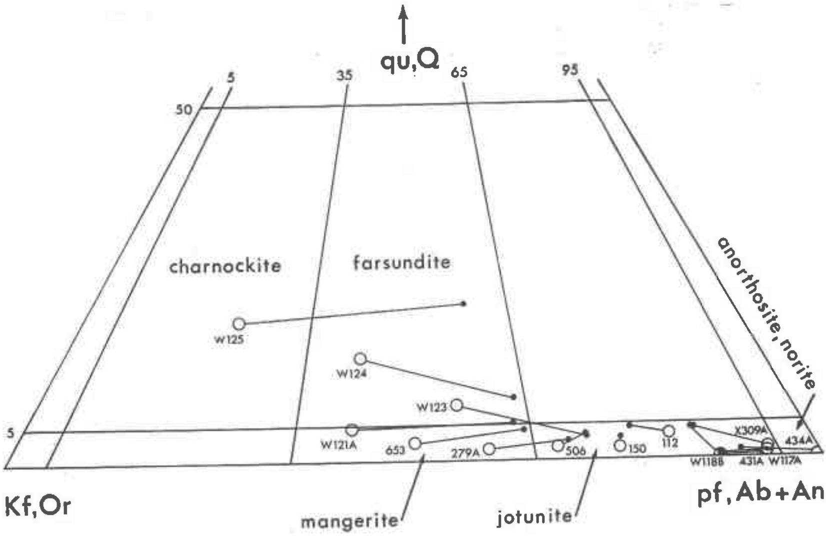

FIG. 4. Volumetric modal ratios of quartz, K feldspar, and plagioclase (circles), and the molecular normative ratios of Q, Or, and Ab+An (dots) of the analyzed rocks of the anorthosite-charnockite suite. The terminology used (de Waard, 1969) is based on the subdivision of the triangular quartz-K feldspar-plagioclase field of modal compositions. Amounts of perthite components have been estimated and treated as K feldspar and plagioclase in the classification.

between the two ratios for a rock was demonstrated in an earlier paper (de Waard, 1969), and was attributed to solid solution of feldspars resulting in higher modal values for the dominant feldspar, and to the presence of hydrous ferromagnesian minerals in the mode which are calculated as pyroxenes and feldspars in the norm. Tie lines between normative and modal plots appear to rotate about a fulcrum located at about 25 percent K feldspar of total feldspars, and between 5 and 15 percent quartz, depending on the anorthosite massif from which the rocks have been taken. Figure 4 also shows the terminology used for the rocks of the series and their classification which is based on volumetric modal percentages.

CONCLUSIONS

Anorthosite bodies, in the Adirondacks and elsewhere, are generally closely associated with masses of predominantly gray-green-colored rocks, commonly containing perthitic feldspars and orthopyroxene, and varying in composition from leucocratic norite to granite. They are known in the Adirondacks as syenites and quartz syenites; here they are called jotunites, mangerites, farsundites, and charnockites.

Because of the close association of these rocks with anorthosite masses they have been interpreted as products of the process of anorthosite formation. Bowen (1917), Balk (1931), and Buddington (1931) interpreted the rocks of the anorthosite-charnockite suite in the Adirondacks as differentiation products of a gabbroic or dioritic magma. Later, Buddington (1936, 1939, 1961) advocated the involvement of two different magma series, a gabbroic-anorthosite magma which produced the anorthositic and noritic rocks, and a quartz-syenite magma which gave rise to a differentiation series of its own. The quartz-syenite magma is believed to have been intruded distinctly later, and to have formed transitional rocks by injection and assimilation of anorthosite.

Besides possible origins of the anorthosite-charnockite suite by means of one or two magmas, a third possible origin was first proposed for the Allard Lake anorthosite massif in Quebec by Hargraves (1962). He postulated that intrusion of hydrous gabbroic-anorthosite magma in a katazonal environment of predominantly salic gneisses would cause anatexis of the surrounding rocks. Reciprocal reaction between the crystallizing anorthosite mass and the anatectic magma would thus produce the intermediate members of the anorthosite-charnockite suite.

Considering these three possibilities for the origin of the rock suite, neither the concentric distribution of the associated rocks around an anorthositic core, nor the variation diagrams showing a completely gradual compositional sequence of members of the series, appear to favor an origin involving two magmas of distinctly different age. An origin of the suite by differentiation from one magma, or the formation of part of the magma by anatexis appear to be possibilities which agree with the chemical, modal, and field data of the Snowy Mountain massif.

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