AM-82-183

American Mineralogist, Volume 67, pages 14–27, 1982

Mineralogy of mafic and Fe–Ti oxide-rich differentiates of the Marcy anorthosite massif, Adirondacks, New York

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Abstract

Rocks enriched in mafic silicates, Fe–Ti oxides and apatite form a minor but ubiquitous facies of nearly all Proterozoic massif-type anorthosite complexes. In the Marcy massif of the Adirondack highlands, New York, the mafic rocks have two modes of occurrence: 1) as conformable segregations interpreted as cumulate layers in the border zones, and 2) as dikes throughout the massif, interpreted as having crystallized from residual liquids extracted at varying stages during differentiation. Primary mineral compositions in these rocks are commonly preserved, despite the effects of subsolidus recrystallization in the high pressure granulite facies. In the mafic rock suite, primary compositions of mafic silicates reveal an iron enrichment trend which is broadly similar to that of basic layered intrusions, but suggestive of somewhat higher crystallization temperatures. Textural relationships suggest the following crystallization sequence: plagioclase, pigeonite + augite, hemo-ilmenite + magnetite, apatite. Fe-rich olivine replaced pigeonite in the latest-stage residual liquids. The mineralogy and field relationships of these mafic rocks are consistent with their origin as differentiates from the same melts which produced the anorthosites. This conclusion agrees with recent geochemical data that suggest an independent origin for the spatially associated mangerite–charnockite suite.

Introduction

For the past several decades, the controversy over the origin of massif-type anorthosites has centered around the question of the consanguinity of anorthositic rocks and spatially associated suites of orthopyroxene-bearing granitic rocks (charnockite–mangerite series). Recent trace element geochemical studies focusing on, but not limited to, rare earth elements (REE) (Philpotts *et al.*, 1966; Green *et al.*, 1969, 1972; Seifert *et al.*, 1977; Seifert, 1978; Simmons and Hanson, 1978; Ashwal and Seifert, 1980) demonstrate that the acidic rocks do not represent differentiates from the melts which produced the anorthosites. This was recognized as early as 1939 by A. F. Buddington on the basis of field relationships (summarized by Buddington, 1969).

In addition to huge volumes of pure anorthosite, the typical massif anorthosite *suite* contains minor facies with larger proportions of mafic silicates, Fe–Ti oxides and apatite. Extreme concentrations of these minerals give rise to minor ultramafic rocks, as well as the ilmenite–magnetite ore deposits whose association with anorthosite massifs is well known (Rose, 1969). It is these mafic rocks, and not the mangerite–charnockites, which complement the anorthosites, as demonstrated by REE geochemical relationships (Ashwal and Seifert, 1980). The purpose of this paper is to describe the field relationships and mineralogical characteristics of mafic rocks associated with the Marcy anorthosite massif in the Adirondack highlands of northern New York State, and to emphasize the importance of these rocks in understanding the fractionation histories of this and other massif-type anorthosite complexes.

Field relations of mafic facies of anorthosite

In the Marcy massif, the most felsic anorthosites are found in the central regions, and more mafic varieties occur near the margins. Because of the domical form of the massif, the mafic border facies overlies the anorthositic core zone (Buddington, 1939, 1960, 1969). In some places there is a systematic increase in mafic silicates and oxide minerals from coarse, core zone anorthosite (Marcy facies) structurally upwards to finer-grained, border zone

0003–004X/82/0102–0014$02.00

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TABLE 3. REPRESENTATIVE MICROPROBE ANALYSES OF PYROXENES AND OLIVINES

	MM-8		SA-3D				SA-3A				SA-5			
	primary opx.	primary cpx.	meta. opx.	meta. cpx.	primary pig.[2]	primary cpx.	meta. opx.	meta. cpx.	primary pig.[2]	primary cpx.	meta. opx.	meta. cpx.	primary pig.[2]	primary cpx.
SiO_2	52.96	52.14	52.53	52.16	52.45	52.07	51.84	51.79	51.83	51.32	50.87	50.44	50.77	50.84
TiO_2	0.07	0.26	0.12	0.40	0.18	0.28	0.06	0.30	0.11	0.29	0.07	0.38	0.11	0.26
Al_2O_3	1.68	2.45	2.30	3.14	2.46	2.81	1.97	2.83	2.16	2.48	1.96	3.66	2.34	3.18
Cr_2O_3	0.05	0.09	0.00	0.00	0.00	0.02	0.01	0.03	0.01	0.04	0.05	0.04	0.05	0.02
FeO[1]	21.28	10.68	22.45	9.90	19.70	12.09	25.82	10.35	22.36	13.71	27.82	11.46	24.13	15.03
MnO	0.38	0.22	0.42	0.21	0.37	0.28	0.32	0.16	0.29	0.21	0.30	0.15	0.27	0.19
MgO	22.34	15.42	22.23	13.31	20.28	14.68	20.43	12.40	18.63	13.94	18.56	11.75	17.03	13.14
CaO	1.35	17.94	0.68	20.71	5.07	17.15	0.49	20.90	5.06	16.60	0.46	21.03	5.10	16.75
Na_2O	0.06	0.47	0.00	0.74	0.16	0.63	0.02	0.93	0.22	0.70	0.00	0.66	0.15	0.45
	100.17	99.67	100.73	100.58	100.69	100.01	100.96	99.71	100.67	99.79	100.09	99.57	99.95	99.86
Formulas based on 6 oxygens (pyroxenes) or 4 oxygens (olivines)														
Si	1.962	1.944	1.942	1.936	1.941	1.943	1.942	1.946	1.944	1.950	1.943	1.911	1.937	1.925
Al	0.038	0.056	0.058	0.064	0.059	0.057	0.058	0.054	0.056	0.050	0.057	0.089	0.063	0.075
	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Al	0.035	0.052	0.042	0.073	0.049	0.067	0.029	0.072	0.040	0.061	0.032	0.074	0.042	0.067
Ti	0.002	0.007	0.003	0.011	0.005	0.008	0.002	0.009	0.003	0.008	0.002	0.011	0.003	0.007
Cr	0.001	0.002	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.001	0.002	0.001	0.002	0.001
Fe[1]	0.659	0.333	0.694	0.307	0.610	0.377	0.809	0.325	0.701	0.431	0.889	0.363	0.770	0.476
Mn	0.012	0.007	0.013	0.007	0.012	0.009	0.010	0.006	0.007	0.007	0.010	0.005	0.009	0.006
Mg	1.233	0.857	1.225	0.736	1.118	0.817	1.141	0.695	1.041	0.782	1.057	0.663	0.968	0.742
Ca	0.054	0.717	0.027	0.823	0.201	0.686	0.020	0.841	0.203	0.669	0.019	0.854	0.208	0.680
Na	0.004	0.034	0.000	0.053	0.012	0.046	0.001	0.068	0.016	0.051	0.000	0.048	0.011	0.033
	2.000	2.009	2.004	2.010	2.007	2.011	2.012	2.017	2.011	2.010	2.011	2.019	2.013	2.012
Wo	2.7	37.6	1.4	44.1	10.4	36.5	1.0	45.2	10.5	35.6	1.0	45.4	10.7	35.8
En (Fo)	63.4	44.9	62.9	39.4	58.0	43.4	57.9	37.3	53.5	41.5	53.8	35.3	49.7	39.1
Fs (Fa)	33.9	17.5	35.7	16.5	31.6	20.1	41.4	17.5	36.0	22.9	45.2	19.3	39.6	25.1

[1] Total Fe as FeO

[2] Composition of primary inverted pigeonite calculated by combining analyses of host and lamella in proportions given by broad beam energy dispersive analysis

[3] Energy dispersive analysis normalized to 100% for comparison with wavelength dispersive analysis

5683d							MM-6			SR-9		
meta. opx.	meta. opx.[3]	meta. cpx.	meta. cpx.[3]	primary pig.[2]	primary cpx.	olivine	meta. cpx.	primary cpx.	olivine	meta. cpx.	primary cpx.	olivine
51.03	50.63	50.92	51.85	51.00	51.18	32.53	51.09	50.67	31.95	50.51	49.55	30.84
0.11		0.34		0.17	0.27		0.26	0.26		0.21	0.29	
1.38	2.64	3.06	4.24	1.81	2.80	0.00	2.56	2.30	0.09	2.00	2.49	0.00
0.05		0.00		0.04	0.00		0.00	0.00		0.00	0.00	
30.59	29.46	13.79	13.19	26.27	17.29	52.50	14.93	20.08	56.97	17.59	20.01	59.88
0.45	0.64	0.21	0.06	0.39	0.28	0.44	0.23	0.33	0.50	0.32	0.38	0.78
16.73	16.00	11.01	11.31	15.26	11.98	14.96	9.74	10.25	10.84	8.77	8.75	7.71
0.55	0.63	19.84	19.35	5.51	16.12	0.01	19.79	15.49	0.02	19.86	17.10	0.03
0.00		0.77		0.20	0.77		1.16	0.85		0.87	0.83	
100.89	100.00	99.94	100.00	100.65	100.69	100.44	99.77	100.23	100.37	100.13	99.40	99.24
1.960	1.952	1.935	1.946	1.953	1.940	0.988	1.957	1.954	0.996	1.954	1.941	0.995
0.040	0.048	0.065	0.054	0.047	0.060	0.000	0.043	0.046	0.003	0.046	0.059	0.000
2.000	2.000	2.000	2.000	2.000	2.000	0.998	2.000	2.000	0.999	2.000	2.000	0.995
0.022	0.072	0.072	0.134	0.035	0.065		0.072	0.059		0.046	0.056	
0.003		0.010		0.005	0.008		0.007	0.007		0.006	0.008	
0.002		0.000		0.001	0.000		0.000	0.000		0.000	0.000	
0.983	0.950	0.438	0.414	0.841	0.548	1.334	0.478	0.648	1.485	0.569	0.655	1.616
0.015	0.021	0.007	0.002	0.013	0.009	0.011	0.008	0.011	0.013	0.011	0.013	0.021
0.958	0.919	0.624	0.633	0.871	0.677	0.678	0.556	0.589	0.504	0.506	0.511	0.371
0.023	0.026	0.808	0.778	0.226	0.655	0.000	0.812	0.640	0.001	0.823	0.717	0.001
0.000		0.057		0.015	0.057		0.086	0.064		0.065	0.063	
2.006	1.988	2.016	1.961	2.007	2.019	2.023	2.019	2.018	2.003	2.026	2.023	2.009
1.2	1.4	43.2	42.6	11.7	34.8		44.0	34.1		43.4	38.1	
48.8	48.5	33.4	34.7	45.0	36.0	(33.7)	30.1	31.4	(25.3)	26.6	27.1	(18.7)
50.0	50.1	23.4	22.7	43.3	29.2	(66.3)	25.9	34.5	(74.7)	30.0	34.8	(81.3)