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Analysis of the compositional variations of biotite in pelitic hornfelses from northeastern Minnesota

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Abstract

Biotite from pelitic hornfelses, northeastern Minnesota, shows a wide compositional range, from Mg/(Mg + Fe) = 0.35 to 0.95. Strong correlations among Mg, Fe, Ti, ^{VI}Al, and ^{IV}Al are observed, and the technique of principal components analyses is used to extract independent biotite components. The dependence of composition on assemblage is exemplified by biotite from the assemblage quartz + muscovite + biotite + cordierite + K-feldspar + ilmenite with compositions that contain more dioctahedral component and less Ti than biotite from a similar, but muscovite-free assemblage. Principal components analysis shows that 98% of the total variance in compositions of biotite from the muscovite-bearing assemblage can be ascribed to two substitutions with *phlogopite:* the substitution $^{IV}Al_{0.45} + Fe_{2.29} + {}^{VI}Al_{0.21} + Ti_{0.31} + {}^{VI}\square_{0.19} \rightleftharpoons Si_{0.45} + Mg_{3.0}$, and the substitution $Ti_{1.5} + {}^{IV}\square_{0.5} \rightleftharpoons {}^{VI}Al_2$. The analysis indicates that although biotite is rigorously a six- or more-component mineral, three components are sufficient to describe the bulk of its compositional range. These three components are used to calculate the possible range in biotite compositions for the muscovite-bearing assemblage using ideal-mixing activity models. The calculated range is very similar to the observed range; however, the absolute value of K_D (Mg/Fe, Cord/bio) is underestimated. In addition, the amounts of octahedral Al, Ti, and vacancies are poorly estimated, especially for Mg-rich biotite. These faults are probably the result of treating biotite as a three-component rather than a six-component phase. The observed cation correlations are believed to result from crystal chemical constraints on the volume of the biotite unit cell. It is proposed that biotite compositions from a particular assemblage might be sensitive indicators of the thermal gradient.

Introduction

Biotite occurs in a great variety of rock types and has a structure that can accommodate most of the abundant elements. The large range in composition of natural biotite makes it a valuable source of information regarding equilibrium conditions. The composition of biotite depends principally on the bulk composition and the extents of the various continuous reactions among the minerals in the rock. The latter dependence can be used to deduce the prevailing conditions during equilibration of the mineral assemblage. For example, the partitioning of Fe and Mg between biotite and garnet can be used to determine temperature (Goldman and Albee, 1977, Ferry and Spear, 1978), and the Fe/(Fe+Mg) value of biotite coexisting with magnetite and sanadine can be used to determine the value of fH_2O/fO_2 (Wones and Eugster, 1965). The composition of biotite in these examples is governed by the progress of the continuous reactions that involve biotite end-members like phlogopite and annite. In order to obtain the values of the desired intensive parameters, the activities of the end-member components must be determined. Previous workers have expressed the activity of the end-member component using the ionic model of Kerrick and Darken (1975). For example, Ghent *et al.* (1979) expressed the activity of *phlogopite* as $(X_K)(X_{Mg})^3(X_{OH})^2$ in which X refers to the mol fraction of the cation or anion in the appropriate crystallographic site. Thompson (1976) used the activity model $(X_K)(X_{Fe})^3$ for *annite* in his calculations of continuous and discontinuous mineral equilibria during progressive metamorphism of pelitic schists. In this type of model cations and anions are presumed to substitute on their respective sites independently.

Holdaway (1980) addressed the problem of picking end-member biotite compositions to use in thermodynamic calculations involving natural or experimental systems. Holdaway determined an iron end-member composition for biotite from pelitic schists by linear regression of the various cations or groups of similar cations like $^{VI}(Al+Cr)$ against Ti. The end-member biotite is given by Holdaway as the composition at Ti = 0, determined by the regression coefficients.

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APPENDIX II: Biotite analyses from muscovite + Kfeldspar - bearing assemblages

ANALYSIS	039A1BIO 102	039A1BIO 201	039A2BIO 101	039A2BIO 301	039A2BIO 401	039A2BI1 401	035F2BIO 201	035F2BIO 301	035F2BIO 401	035F1BIO 101
SEQ #	5	6	7	9	10	11	23	24	25	34
REF #	0	0	0	0	0	0	0	0	0	0
SIO2	35.71	36.85	38.71	38.54	38.16	37.34	36.22	35.60	36.47	35.62
AL2O3	19.60	17.46	18.37	18.36	17.93	17.61	18.10	18.44	18.84	18.63
FEO	18.72	18.68	18.57	18.58	19.10	18.88	21.90	21.80	21.60	22.34
FE2O3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
MGO	10.47	9.18	9.45	9.24	9.33	9.14	6.34	6.68	6.59	6.96
MNO	.02	.02	.04	.05	.03	.00	.03	.04	.03	.03
TIO2	1.62	4.29	2.96	3.54	3.84	3.99	3.92	3.91	3.49	3.79
CR2O3	.03	.44	.34	.42	.47	.43	.23	.27	.22	.29
CAO	.02	.04	.06	.03	.04	.04	.03	.03	.02	.05
NA2O	.00	.00	.20	.00	.00	.00	.00	.00	.00	.00
K2O	8.92	9.23	8.96	9.27	9.14	9.47	9.63	10.25	10.05	9.84
SUM	95.11	96.19	97.66	98.03	98.04	96.90	96.40	97.02	97.31	97.55
FEO	18.72	18.68	18.57	18.58	19.10	18.88	21.90	21.80	21.60	22.34
FE2O3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
SI	2.70	2.76	2.83	2.81	2.80	2.78	2.76	2.70	2.75	2.69
AL	1.75	1.54	1.58	1.58	1.55	1.55	1.62	1.65	1.67	1.66
FE2+	1.18	1.17	1.14	1.13	1.17	1.17	1.39	1.39	1.36	1.41
FE3+	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
MG	1.18	1.03	1.03	1.00	1.02	1.01	.72	.76	.74	.78
MN	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
TI	.09	.24	.16	.19	.21	.22	.22	.22	.20	.21
CR	.00	.03	.02	.02	.03	.02	.01	.02	.01	.02
CA	.00	.00	.01	.00	.00	.00	.00	.00	.00	.00
NA	.00	.00	.03	.00	.00	.00	.00	.00	.00	.00
K	.86	.88	.84	.86	.85	.90	.94	.99	.97	.95

	035F1BIO 201	035F1BIO 301	035Q1BIO 401	035Q1BIO 501	035Q1BIO 601	039C1BIO 201	039C1BIO 301	039C1BIO 401	039B1BIO 401	039B1BIO 501
SEQ #	35	36	45	46	47	48	49	50	51	52
REF #	0	0	0	0	0	0	0	0	0	0
SIO2	35.57	35.81	35.45	35.26	34.76	36.21	36.45	36.12	35.80	35.51
AL2O3	18.55	18.96	21.50	18.98	19.01	18.20	18.06	18.08	19.49	19.23
FEO	22.52	22.32	18.63	21.12	21.08	18.33	18.39	18.42	18.64	17.78
FE2O3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
MGO	6.67	6.66	10.00	7.51	7.39	9.28	9.05	8.65	10.09	10.36
MNO	.02	.03	.04	.03	.05	.00	.04	.00	.04	.06
TIO2	3.83	3.80	.07	3.93	4.02	3.44	3.51	3.62	1.76	1.60
CR2O3	.33	.29	.04	.29	.25	.36	.36	.29	.06	.00
CAO	.05	.05	.02	.01	.04	.01	.02	.02	.08	.01
NA2O	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
K2O	9.94	9.70	9.54	9.46	9.53	9.50	9.64	9.52	9.09	9.39
SUM	97.48	97.62	95.29	96.59	96.13	95.33	95.52	94.72	95.05	93.94
FEO	22.52	22.32	18.63	21.12	21.08	18.33	18.39	18.42	18.64	17.78
FE2O3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
SI	2.69	2.70	2.68	2.67	2.65	2.74	2.75	2.75	2.71	2.72
AL	1.66	1.68	1.91	1.69	1.71	1.62	1.61	1.62	1.74	1.73
FE2+	1.43	1.41	1.18	1.34	1.34	1.16	1.16	1.17	1.18	1.14
FE3+	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
MG	.75	.75	1.12	.85	.84	1.05	1.02	.98	1.14	1.18
MN	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
TI	.22	.21	.00	.22	.23	.20	.20	.21	.10	.09
CR	.02	.02	.00	.02	.02	.02	.02	.02	.00	.00
CA	.00	.00	.00	.00	.00	.00	.00	.00	.01	.00
NA	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
K	.96	.93	.92	.91	.93	.92	.93	.92	.88	.92

ANALYSIS	039B1BIO 601	039R1BIO 101	039R1BIO 201	039R1BI1 101	048F1BIO 201	048F1BIO 301	048F1BIO 701	048F1BIO 801	048F2BIO 201	048F2BIO 501
SEQ #	53	41	42	43	57	58	59	60	61	62
REF #	0	0	0	0	0	0	0	0	0	0
SIO2	36.31	35.98	35.90	36.14	41.38	41.50	41.00	41.26	40.71	40.97
AL2O3	19.74	20.01	19.70	19.89	15.80	15.43	16.05	15.92	16.14	16.71
FEO	17.31	19.38	18.65	19.13	3.03	2.85	2.96	2.84	3.07	3.23
FE2O3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
MGO	10.47	8.90	8.98	9.44	22.51	22.68	22.64	22.80	21.71	22.16
MNO	.04	.02	.05	.03	.00	.01	.00	.00	.00	.00
TIO2	1.47	2.50	2.70	2.34	.64	.71	.70	.76	.77	.85
CR2O3	.01	.29	.30	.24	.09	.06	.11	.10	.20	.16
CAO	.01	.03	.01	.03	.00	.00	.00	.00	.02	.00
NA2O	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
K2O	9.36	9.41	9.31	9.38	9.84	10.11	10.16	9.95	9.51	9.88
SUM	94.72	96.52	95.60	96.62	93.29	93.35	93.62	93.63	92.13	93.96
FEO	17.31	19.38	18.65	19.13	3.03	2.85	2.96	2.84	3.07	3.23
FE2O3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
SI	2.74	2.69	2.70	2.70	2.95	2.96	2.92	2.94	2.94	2.91
AL	1.75	1.77	1.75	1.75	1.33	1.30	1.35	1.33	1.37	1.40
FE2+	1.09	1.21	1.17	1.19	.18	.17	.18	.17	.19	.19
FE3+	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
MG	1.18	.99	1.01	1.05	2.39	2.41	2.41	2.42	2.34	2.34
MN	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
TI	.08	.14	.15	.13	.03	.04	.04	.04	.04	.04
CR	.00	.02	.02	.01	.01	.00	.01	.01	.01	.01
CA	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
NA	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
K	.90	.90	.90	.89	.90	.92	.92	.90	.88	.90

ANALYSIS	048F2BI1 101	039D0BIO 201	039D0BIO 301	039D1BIO 301	018A1BIO 101	018A1BIO 201	018A1BIO 301	022A1BIO 201	022A1BIO 301	022A1BIO 401
SEQ #	63	70	71	72	90	91	92	78	79	80
REF #	0	0	0	0	0	0	0	0	0	0
SIO2	40.79	36.03	36.68	36.37	34.45	34.40	34.73	35.04	35.23	35.22
AL2O3	16.36	18.33	18.89	18.60	18.61	18.96	19.66	19.40	19.14	19.79
FEO	3.22	17.51	17.98	17.98	21.87	22.03	21.28	16.27	16.61	16.11
FE2O3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
MGO	22.09	9.30	9.10	8.58	6.87	6.76	6.68	9.53	9.75	10.06
MNO	.00	.03	.03	.03	.01	.00	.00	.03	.02	.07
TIO2	.90	3.15	3.06	3.29	3.91	3.74	3.51	2.40	1.92	2.07
CR2O3	.31	.23	.31	.34	.16	.16	.22	.16	.14	.11
CAO	.01	.00	.03	.03	.02	.01	.00	.03	.02	.04
NA2O	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
K2O	9.82	8.92	9.15	9.72	9.42	9.46	9.11	9.47	9.33	9.30
SUM	93.50	93.50	95.23	94.94	95.32	95.52	95.19	92.33	92.16	92.77
FEO	3.22	17.51	17.98	17.98	21.87	22.03	21.28	16.27	16.61	16.11
FE2O3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
SI	2.91	2.76	2.76	2.76	2.66	2.65	2.66	2.71	2.73	2.71
AL	1.38	1.65	1.67	1.66	1.69	1.72	1.78	1.77	1.75	1.79
FE2+	.19	1.12	1.13	1.14	1.41	1.42	1.37	1.05	1.08	1.03
FE3+	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
MG	2.35	1.06	1.02	.97	.79	.78	.76	1.10	1.13	1.15
MN	.00	.00	.00	.00	.00	.00	.00	.00	.00	.01
TI	.05	.18	.17	.19	.23	.22	.20	.14	.11	.12
CR	.02	.01	.02	.02	.01	.01	.01	.01	.01	.01
CA	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
NA	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
K	.89	.87	.88	.94	.93	.93	.89	.94	.92	.91

ANALYSIS	041E0BI1 001	043D0BI0 601	043D0BI0 701	0032BI02 01	0032BI03 01	0031BI06 01
SEQ #	56	84	85	13	14	18
REF #	0	0	0	0	0	0
SIO2	35.48	34.59	36.10	35.90	35.90	37.87
AL2O3	18.85	18.27	18.19	19.10	19.28	20.63
FEO	20.55	17.74	18.27	17.28	17.06	16.60
FE2O3	.00	.00	.00	.00	.00	.00
MGO	7.95	9.97	9.49	9.77	9.68	10.63
MNO	.03	.11	.11	.09	.11	.07
TIO2	1.57	2.23	1.97	1.53	1.53	1.57
CR2O3	.17	.03	.03	.11	.12	.06
CAO	.05	.16	.07	.06	.03	.04
NA2O	.00	.00	.00	.00	.00	.00
K2O	9.43	8.14	8.81	8.53	9.20	8.47
SUM	94.08	91.24	93.04	92.37	92.91	95.94
FEO	20.55	17.74	18.27	17.28	17.06	16.60
FE2O3	.00	.00	.00	.00	.00	.00
SI	2.75	2.72	2.78	2.77	2.76	2.78
AL	1.72	1.69	1.65	1.74	1.75	1.78
FE2+	1.33	1.17	1.18	1.11	1.10	1.02
FE3+	.00	.00	.00	.00	.00	.00
MG	.92	1.17	1.09	1.12	1.11	1.16
MN	.00	.01	.01	.01	.01	.00
TI	.09	.13	.11	.09	.09	.09
CR	.01	.00	.00	.01	.01	.00
CA	.00	.01	.01	.01	.00	.00
NA	.00	.00	.00	.00	.00	.00
K	.93	.82	.87	.84	.90	.79

Biotite analyses from muscovite - absent assemblages

ANALYSIS	016B3BIO 201	016B3BIO 301	016B3BIO 401	016B3BIO 501	016J1BIO 101	016J1BIO 201	016J1BIO 301	016J0BIO 201	018E1BIO 101	018E1BIO 201
SEQ #	1	2	3	4	73	74	75	76	86	87
REF #	0	0	0	0	0	0	0	0	0	0
SIO2	36.69	36.78	36.99	37.41	39.43	38.46	38.92	39.08	41.60	40.88
AL2O3	15.35	15.31	14.67	15.08	14.52	14.49	14.27	14.49	13.43	13.77
FEO	16.05	16.32	10.30	15.94	13.07	13.63	13.12	12.73	13.43	13.77
FE2O3	.00	.00	.00	.00	.00	.00	.00	.00	1.12	1.10
MGO	13.19	13.38	12.80	12.76	16.57	15.62	16.57	17.00	.00	.00
MNO	.04	.02	.02	.03	.05	.04	.03	.00	25.50	24.66
TIO2	4.91	5.07	5.14	5.08	3.54	4.07	3.64	4.52	.01	.02
CR2O3	.35	.31	.24	.35	.09	.18	.13	.07	2.33	2.16
CAO	.00	.00	.00	.02	.14	.08	.12	.06	.15	.26
NA2O	.05	.03	.07	.09	.00	.00	.00	.00	.04	.03
K2O	9.33	9.24	9.38	9.36	9.43	9.65	9.54	10.10	.00	.00
SUM	96.16	96.46	89.61	96.12	96.84	96.22	96.34	98.05	9.82	9.42
FEO	16.05	16.32	10.30	15.94	13.07	13.63	13.12	12.73	94.00	92.30
FE2O3	.00	.00	.00	.00	.00	.00	.00	.00	1.12	1.10
SI	2.73	2.73	2.87	2.78	2.86	2.82	2.84	2.81	.00	.00
AL	1.36	1.34	1.34	1.32	1.24	1.25	1.23	1.23	2.94	2.93
FE2+	1.00	1.01	.67	.99	.79	.84	.80	.77	1.12	1.16
FE3+	.00	.00	.00	.00	.00	.00	.00	.00	.07	.07
MG	1.46	1.48	1.48	1.41	1.79	1.71	1.80	1.82	.00	.00
MN	.00	.00	.00	.00	.00	.00	.00	.00	2.68	2.63
TI	.27	.28	.30	.28	.19	.22	.20	.24	.00	.00
CR	.02	.02	.02	.02	.01	.01	.01	.00	.12	.12
CA	.00	.00	.00	.00	.01	.01	.01	.00	.01	.02
NA	.01	.00	.01	.01	.01	.01	.01	.01	.00	.00
K	.89	.88	.93	.89	.87	.90	.89	.92	.88	.86

ANALYSIS	022B1BIO 301	043F3BIO 101	043F3BIO 201	043F1BIO 201	043F1BIO 501	043F3BIO 102
SEQ #	83	64	65	66	68	69
REF #	0	0	0	0	0	0
SIO2	36.34	41.05	39.97	35.95	36.72	39.27
AL2O3	14.52	12.69	14.83	16.57	15.56	13.73
FEO	23.39	11.88	12.22	16.09	16.27	12.11
FE2O3	.00	.00	.00	.00	.00	.00
MGO	9.80	19.03	18.18	14.69	13.61	18.58
MNO	.06	.13	.18	.17	.12	.13
TIO2	2.71	.59	.75	1.30	1.83	.53
CR2O3	.11	.03	.00	.03	.03	.00
CAO	.30	.09	.07	.19	.23	.05
NA2O	.00	.00	.00	.06	.00	.00
K2O	8.17	9.38	9.28	8.15	9.51	9.61
SUM	95.40	94.87	95.48	93.20	93.88	94.01
FEO	23.39	11.88	12.22	16.09	16.27	12.11
FE2O3	.00	.00	.00	.00	.00	.00
SI	2.81	3.01	2.92	2.74	2.80	2.92
AL	1.32	1.10	1.28	1.49	1.40	1.20
FE2+	1.51	.73	.75	1.03	1.04	.75
FE3+	.00	.00	.00	.00	.00	.00
MG	1.13	2.08	1.98	1.67	1.55	2.06
MN	.00	.01	.01	.01	.01	.01
TI	.16	.03	.04	.08	.11	.03
CR	.01	.00	.00	.00	.00	.00
CA	.02	.01	.01	.02	.02	.00
NA	.00	.00	.00	.01	.00	.00
K	.81	.88	.86	.79	.93	.91

ANALYSIS	018E1BIO 401	018BOBIO 301	016I1BIO 301	016I1BIO 401	039M3BIO 101	039IOBIO 201	039IOBIO 401	039I1BIO 101	039I1BIO 201	039I1BIO 301
SEQ #	88	89	94	95	12	13	14	15	16	17
REF #	0	0	0	0	0	0	0	0	0	0
SIO2	41.39	36.83	39.31	39.23	37.87	36.14	36.62	36.44	36.18	35.83
AL2O3	14.74	14.83	14.94	14.90	16.11	15.93	16.10	16.22	15.95	16.18
FEO	2.73	16.22	10.04	10.01	17.69	18.78	19.43	19.17	18.61	18.78
FE2O3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
MGO	23.96	14.22	17.53	17.85	13.85	11.07	11.57	11.23	11.36	11.51
MNO	.02	.04	.12	.12	.02	.02	.06	.08	.00	.05
TIO2	2.22	3.59	3.35	3.26	2.51	3.25	3.54	3.26	2.93	2.66
CR2O3	.15	.14	.04	.01	.12	.10	.12	.16	.11	.12
CAO	.04	.09	.02	.00	.14	.12	.10	.10	.07	.11
NA2O	.00	.00	.00	.00	.09	.07	.04	.05	.05	.03
K2O	9.56	8.67	8.82	8.92	8.24	9.28	9.04	8.92	8.78	8.70
SUM	94.81	94.63	94.17	94.30	96.64	94.76	96.62	95.63	94.04	93.97
FEO	2.73	16.22	10.04	10.01	17.69	18.78	19.43	19.17	18.61	18.78
FE2O3	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
SI	2.91	2.78	2.87	2.87	2.79	2.76	2.75	2.76	2.78	2.76
AL	1.22	1.32	1.29	1.28	1.40	1.44	1.42	1.45	1.44	1.47
FE2+	.16	1.02	.61	.61	1.09	1.20	1.22	1.21	1.19	1.21
FE3+	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
MG	2.51	1.60	1.91	1.94	1.52	1.26	1.29	1.27	1.30	1.32
MN	.00	.00	.01	.01	.00	.00	.00	.01	.00	.00
TI	.12	.20	.18	.18	.14	.19	.20	.19	.17	.15
CR	.01	.01	.00	.00	.01	.01	.01	.01	.01	.01
CA	.00	.01	.00	.00	.01	.01	.01	.01	.01	.01
NA	.00	.00	.00	.00	.01	.01	.01	.01	.01	.00
K	.86	.83	.82	.83	.78	.91	.87	.86	.86	.85

ANALYSIS	039I1BIO 401	039M2BIO 201	039M2BIO 301	039M2BIO 401	039M2BIO 501	035A2BIO 501	035A2BIO 601	035A2BIO 701	022B1BIO 101	022B1BIO 201
SEQ #	18	19	20	21	22	31	32	33	81	82
REF #	0	0	0	0	0	0	0	0	0	0
SIO2	36.26	36.98	38.08	38.28	37.99	34.40	34.55	35.53	35.98	35.78
AL203	16.14	16.80	16.48	16.60	16.22	16.00	14.79	15.60	14.93	14.53
FEO	19.16	17.33	16.72	15.57	16.23	25.63	24.02	24.28	22.97	23.24
FE203	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
MGO	11.25	14.23	14.89	13.52	14.61	8.25	8.24	8.60	9.64	9.40
MNO	.04	.03	.04	.02	.00	.11	.08	.10	.09	.08
TIO2	3.39	1.82	2.45	2.19	2.28	3.25	3.59	3.83	2.73	2.75
CR203	.09	.11	.09	.09	.11	.00	.02	.03	.11	.09
CAO	.10	.20	.15	1.61	.16	.44	.66	.13	.11	.16
NA20	.04	.04	.06	.04	.03	.00	.00	.00	.00	.00
K20	8.87	8.22	7.51	8.13	8.20	9.10	8.90	9.26	8.70	8.51
SUM	95.34	95.76	96.47	96.05	95.83	97.18	94.85	97.36	95.26	94.54
FEO	19.16	17.33	16.72	15.57	16.23	25.63	24.02	24.28	22.97	23.24
FE203	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
SI	2.75	2.75	2.79	2.82	2.81	2.66	2.72	2.72	2.79	2.80
AL	1.44	1.47	1.42	1.44	1.41	1.46	1.37	1.41	1.36	1.34
FE2+	1.22	1.08	1.02	.96	1.00	1.66	1.58	1.55	1.49	1.52
FE3+	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
MG	1.27	1.58	1.62	1.48	1.61	.95	.97	.98	1.11	1.10
MN	.00	.00	.00	.00	.00	.01	.01	.01	.01	.01
TI	.19	.10	.13	.12	.13	.19	.21	.22	.16	.16
CR	.01	.01	.01	.01	.01	.00	.00	.00	.01	.01
CA	.01	.02	.01	.13	.01	.04	.06	.01	.01	.01
NA	.01	.01	.01	.01	.00	.00	.00	.00	.00	.00
K	.86	.78	.70	.76	.77	.90	.90	.90	.86	.85