

PEGMATITE VEINS AND THE SURROUNDING ROCKS VI.

Re-interpretation of the genesis of pegmatite veins in olivine gabbro, Risør, Norway

PAUL H. REITAN

Reitan, Paul H.: Pegmatite veins and the surrounding rocks VI. Re-interpretation of the genesis of pegmatite veins in olivine gabbro, Risør, Norway. *Norsk Geologisk Tidsskrift*. Vol. 50, pp. 289–300. Oslo 1970.

New data on the composition variation of the olivine gabbro near pegmatite veins, Risør, Norway, obtained by spectrochemical analysis, fail to confirm data published earlier (Reitan, 1958) which were computed from modal analyses. The computed composition from modal analyses of a new set of samples correlate very poorly with the spectrochemically determined compositions of the same samples. The coronated olivine gabbro and its amphibolitized variant adjacent to the veins are not well suited to the method of estimating composition from modes. The new data lead to a new interpretation of the genesis of these veins, namely by introduction of material from a source outside the observable system. There was some metasomatic alteration of the host rock close to the veins by material which migrated into the rock from the veins.

Paul H. Reitan, Department of Geological Sciences, State University of New York at Buffalo, Buffalo, New York, 14214 U.S.A.

Introduction

In 1958, I published the results of a study of the variations in the olivine gabbro surrounding small pegmatite veins near Risør (Reitan, 1958). The study was based on a series of samples from points at different distances from the veins. Thin sections of the samples were examined and from modal analyses the approximate chemical compositions were computed. The validity of the computed compositional changes in the olivine gabbro was substantiated by comparison of the computed compositions with the compositions of three samples as determined by standard wet chemical analysis. Significant variations of the computed compositions appeared to be a function of distance from the veins.

For several years I was satisfied that the compositional differences indicated by the computations based on the modal analyses truly reflected real variations. Despite the possibility of a systematic error, I believed there to be no relative error or lack of precision approaching the differences indicated. However, as I became more aware of the necessity to be able to evaluate the precision of any attempts at quantitative analyses and of the various sources of error that could cause deviation of computed composition from true compositions, I became convinced of the need to re-evaluate the compositional variations of the olivine gabbro near the pegmatite veins.

Re-investigation

In 1963 I collected two series of samples of the olivine gabbro from between the pegmatite veins. The sampling scheme, though not ideal as a coring drill was not available, was an improvement over the earlier sampling scheme. The number of samples and sample density over the outcrop were increased. One series of samples was a set taken along a straight line at road level; the second series consisted of nearly randomly selected samples from various places and at different heights on the rock wall of the roadcut (Fig. 1).

When funds became available the samples of these series were analyzed chemically by spectrochemical methods by N. H. Suhr of the Pennsylvania State University. The precision of the analyses is better than $\pm 5\%$ for most elements (see O'Neil & Suhr, 1960; Ingamells & Suhr, 1963; Suhr & Ingamells, 1966). Na_2O and K_2O values are by flame photometry, and the others are by emission spectrometry. The results of these analyses and cation percentages calculated from them are given in Table 1 and are displayed in Fig. 2a (weight percents as oxides) and Fig. 2b (cation percents). The concentrations of Cr, V, Zr, and Ni were present in such small quantities ($<0.05\%$) that they were not determined.

These samples were also analyzed by microscopic point-count determination of the modes (Table 2); the mineralogical modes were recalculated to

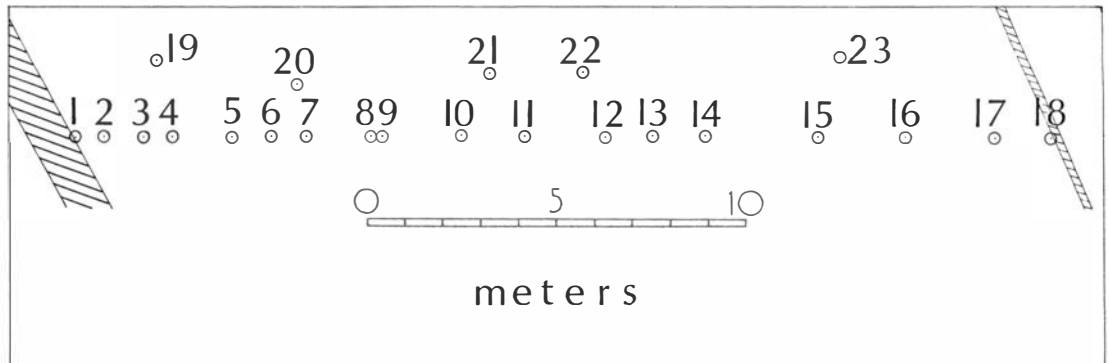


Fig. 1. Schematic diagram showing pegmatite veins (hatched) and sample localities. Samples 24 and 25 were taken 15 and 25 meters, respectively, to the left of the larger pegmatite vein.

Fig. 2. The ordinates show (a) percent of oxides by weight of the metals as labeled as determined by spectrochemical analyses, (b) percent cations as calculated from the spectrochemical analyses, and (c) percent cations as calculated from microscopic point-count modal analyses. The abscissas, the same in (a), (b), (c), show positions of the samples between the pegmatite veins plotted as a function of distance from the veins measured perpendicular to the veins.

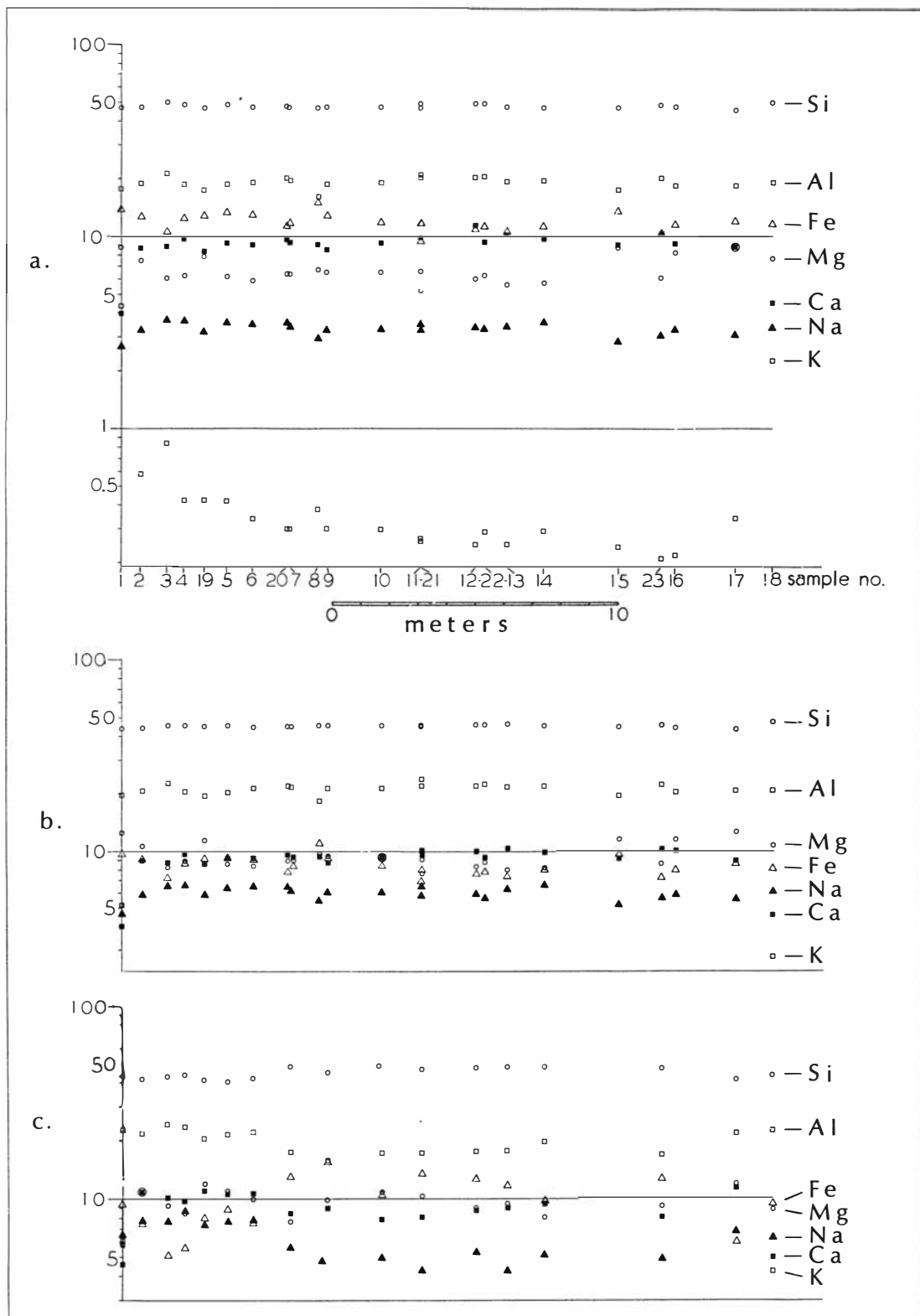


Table 1. Weight percent oxides : instrumental analysis†

Sample No.	1	2	3	4	5	6	7
SiO ₂	46.5	47.2	50.0	48.4	48.6	47.0	47.0
TiO ₂	1.31	1.33	1.05	1.34	1.67	1.79	1.30
Al ₂ O ₃	17.7	18.9	21.1	18.6	18.6	19.1	19.6
Fe ₂ O ₃ *	13.85	12.70	10.55	12.35	13.20	12.75	11.85
MgO	8.75	7.55	6.01	6.22	6.19	5.83	6.38
MnO	0.126	0.208	0.155	0.215	0.252	0.207	0.158
CaO	3.98	8.70	8.88	9.68	9.31	9.08	9.30
SrO	0.023	0.036	0.045	0.034	0.030	0.037	0.037
BaO	0.062	0.020	0.026	0.003	0.008	0.011	0.006
Na ₂ O	2.56	3.23	3.65	3.60	3.55	3.50	3.36
K ₂ O	4.33	0.58	0.84	0.42	0.42	0.34	0.30
SUM	99.19	99.94	102.29	100.87	101.84	99.66	99.29
Cation percent of major components							
Si	43.61	43.82	45.29	44.86	44.80	44.26	44.16
Al	19.53	20.60	22.51	20.23	20.13	21.14	21.66
Fe	9.74	8.85	7.18	8.56	9.13	8.99	8.35
Mg	12.32	10.52	8.16	8.67	8.57	8.25	9.02
Ca	3.99	8.63	8.65	9.62	9.18	9.16	9.36
Na	4.61	5.79	6.42	6.45	6.30	6.39	6.09
K	5.18	0.67	0.98	0.50	0.50	0.39	0.34
SUM	98.98	98.88	99.19	98.89	98.61	98.58	98.98

Table 1 cont.

Sample No.	8	9	10	11	12	13	14
SiO ₂	47.0	47.2	47.5	49.5	49.3	47.7	47.1
TiO ₂	2.17	1.33	1.28	1.34	1.51	1.21	1.27
Al ₂ O ₃	16.1	18.9	19.1	20.3	20.3	19.2	19.7
Fe ₂ O ₃ *	15.00	12.70	11.85	11.55	10.95	10.30	11.10
MgO	6.70	6.48	6.52	6.61	6.00	5.57	5.76
MnO	0.210	0.180	0.165	0.165	0.154	0.154	0.168
CaO	9.10	8.52	9.20	9.74	10.23	10.11	9.74
SrO	0.031	0.037	0.038	0.041	0.041	0.040	0.042
BaO	0.010	0.010	0.008	0.009	0.010	0.009	0.011
Na ₂ O	2.96	3.23	3.28	3.25	3.33	3.38	3.57
K ₂ O	0.38	0.30	0.30	0.27	0.25	0.25	0.29
SUM	99.66	98.90	99.25	102.79	102.09	97.93	98.76
Cation percent of major components							
Si	44.74	44.72	44.72	44.93	45.09	45.40	44.42
Al	18.06	21.02	21.12	21.68	21.83	21.47	21.84
Fe	10.74	9.03	8.36	7.84	7.51	7.37	7.87
Mg	9.60	9.20	9.20	8.99	8.23	7.97	8.15
Ca	9.26	8.64	9.26	9.48	10.04	10.34	9.85
Na	5.43	5.91	5.98	5.72	5.87	6.22	6.51
K	0.46	0.34	0.34	0.33	0.27	0.28	0.34
SUM	98.29	98.86	98.98	98.97	98.84	99.95	98.98

Table 1 cont.

Sample No.	15	16	17	18	19	20	21
SiO ₂	46.8	47.5	46.0	50.0	47.0	47.5	46.2
TiO ₂	1.24	0.87	0.84	0.98	1.37	1.19	0.98
Al ₂ O ₃	17.5	18.5	18.6	19.0	17.5	20.0	20.7
Fe ₂ O ₃ *	13.40	11.45	12.05	11.45	12.80	11.15	9.45
MgO	8.80	8.20	8.87	7.67	7.96	6.39	5.20
MnO	0.186	0.162	0.186	0.128	0.192	0.174	0.128
CaO	9.10	9.22	8.87	4.58	8.40	9.62	9.78
SrO	0.035	0.040	0.038	0.032	0.037	0.038	0.043
BaO	0.006	0.009	0.011	0.041	0.010	0.010	0.009
Na ₂ O	2.81	3.25	3.05	3.39	3.15	3.52	3.50
K ₂ O	0.24	0.22	0.34	2.29	0.42	0.30	0.26
SUM	99.41	99.22	98.87	99.56	98.85	99.90	96.26
Cation percent of major components							
Si	44.09	43.83	43.09	46.43	44.34	44.20	44.46
Al	19.39	20.09	20.45	20.73	19.42	21.87	23.44
Fe	9.44	7.91	8.48	7.97	9.06	7.76	6.81
Mg	11.42	11.34	12.47	10.70	11.27	8.93	7.50
Ca	9.16	10.02	8.88	4.57	8.49	9.60	10.10
Na	5.14	5.81	5.50	6.07	5.77	6.36	6.52
K	0.28	0.28	0.39	2.73	0.51	0.33	0.35
SUM	98.92	99.28	99.26	99.20	98.86	99.05	99.18

Table 1 cont.

Sample No.	22	23	24	25
SiO ₂	49.0	48.5	46.0	46.5
TiO ₂	0.96	1.06	1.65	1.27
Al ₂ O ₃	20.4	20.1	16.1	18.4
Fe ₂ O ₃ *	11.20	10.25	14.80	13.20
MgO	6.27	6.13	9.17	7.62
MnO	0.155	0.141	0.196	0.190
CaO	9.42	10.22	8.51	8.72
SrO	0.042	0.039	0.031	0.036
BaO	0.010	0.005	0.007	0.012
Na ₂ O	3.14	3.07	2.75	2.98
K ₂ O	0.29	0.21	0.26	0.29
SUM	100.89	99.73	99.46	99.22
Cation percent of major components				
Si	45.31	45.29	43.38	43.86
Al	22.18	22.08	17.87	20.37
Fe	7.76	7.17	10.46	9.34
Mg	8.71	8.58	12.95	10.75
Ca	9.32	10.26	8.60	8.83
Na	5.60	5.55	5.03	5.43
K	0.33	0.22	0.34	0.34
SUM	99.21	99.15	98.63	98.92

† Determinations by emission spectrometry except for Na₂O and K₂O values obtained by flame photometry. Analyst: Norman H. Suhr

* Total iron reported as Fe₂O₃ equivalent

Table 2. Modal analyses†

Sample No.	1	2	3	4	5	6	7	9	10
Plagioclase	50.0	39.2	51.2	54.8	37.3	44.7	60.0	52.9	56.2
(An)	(36)	(45)	(48)	(42)	(43)	(44)	(52)	(52)	(53)
Olivine							2.4	1.2	0.1
Clinopyroxene	6.0	1.3				0.6	10.2	16.5	10.2
Orthopyroxene							4.4	6.7	8.4
Clinoamphibole		55.5	41.4	38.6	57.4	51.3	10.8	7.3	5.4
Orthoamphibole	0.7						8.1	6.2	14.3
Opagues	0.4	1.9	0.4	1.3	3.2	2.5	3.3	6.3	1.2
Garnet			1.5	1.0		0.2	0.2	1.8	3.9
Biotite	41.4	1.3	5.4	3.7	1.6			0.3	
Muscovite									
Chlorite				0.3					
Apatite	1.5	0.7	0.1	0.5	0.6	0.6	0.4	0.7	0.4
SUM	100.0	99.9	100.0	100.2	100.1	99.9	99.8	99.9	100.1
Total Points Counted	1919	2149	1781	1777	1769	1878	1640	1960	1887

Table 2 cont.

Sample No.	11	12	13	14	17	18	19	23	25
Plagioclase	54.3	57.6	57.7	54.5	35.6	54.4	35.1	57.0	60.1
(An)	(58)	(52)	(61)	(59)	(52)	(38)	(42)	(55)	(59)
Olivine		1.6						1.3	9.5
Clinopyroxene	9.3	12.1	10.9	0.9	4.0	9.2	3.9	6.9	6.8
Orthopyroxene	10.1	4.5	8.5	9.0				8.8	9.4
Clinoamphibole	5.2	9.8	9.1	14.2	55.7		57.0	6.5	4.0
Orthoamphibole	13.0	6.7	11.1	18.4				15.8	7.1
Opagues	2.8	3.7	1.7	1.4	0.4	0.7	2.3	2.2	1.8
Garnet	4.3	3.2	0.3						
Biotite	0.5				4.0	30.4	1.5		0.8
Muscovite				1.3				1.2	
Chlorite						3.3			
Apatite	0.5	0.9	0.6	0.2	0.3	1.9	0.2	0.4	0.4
SUM	100.0	100.1	99.9	99.9	100.0	99.9	100.0	100.1	99.9
Total Points Counted	1911	1984	2020	1940	1780	1834	1688	1789	1915

† Analyst: Gerald G. Millard

cation percents (Table 3 and Fig. 2c). In order to insure against any possible bias, the point-count analyses were done by G. G. Millard of the State University of New York at Buffalo. The thin sections were counted in arbitrary order in the absence of knowledge of the significance of original sample numbers. The correlation of the cation percents calculated from mineralogical modes and the cation percents calculated from spectrochemical analyses are shown for each of the major element components in Fig. 3.

Table 3. Cation percent, major components, computed from modes

Sample No.	1	2	3	4	5	6	7	9	10
Si	42.3	41.5	43.2	43.9	40.6	42.0	48.2	45.3	48.6
Al	22.6	21.6	24.1	23.5	21.3	22.0	17.4	15.5	17.1
Fe	9.3	7.3	5.0	5.5	8.7	7.3	12.8	15.3	10.6
Mg	5.8	10.9	9.1	8.3	10.8	9.9	7.5	9.8	10.7
Ca	4.6	10.9	10.1	9.7	10.7	10.7	8.3	8.9	7.8
Na	6.5	7.5	7.6	8.4	7.5	7.6	5.5	4.7	4.9
K	6.0	0.4	0.9	0.8	0.4	0.2	0.3	0.3	0.2
SUM	97.1	100.1	100.0	100.1	100.0	99.7	100.0	99.8	99.9

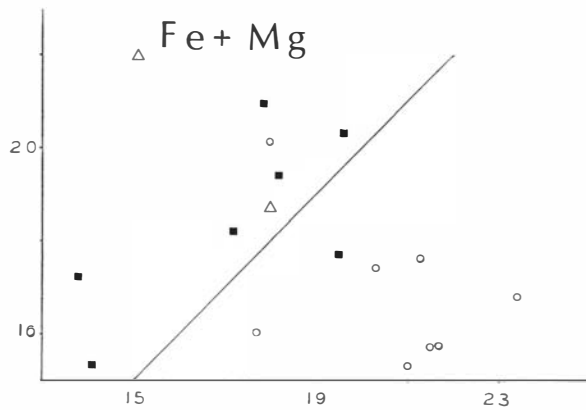
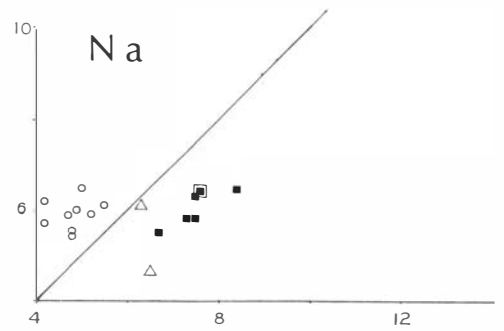
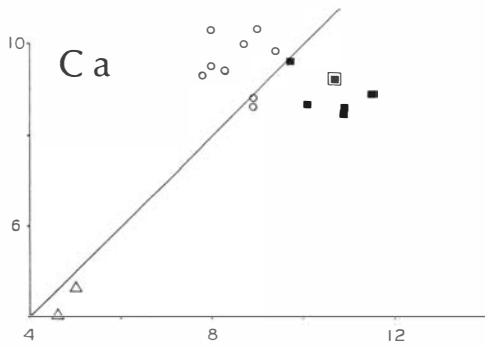
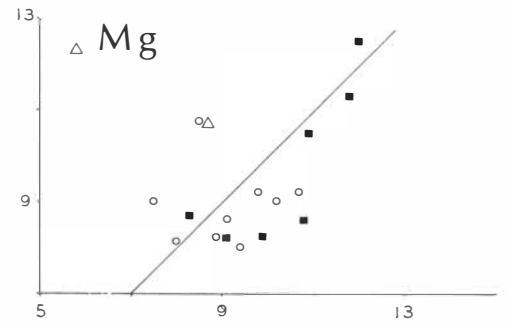
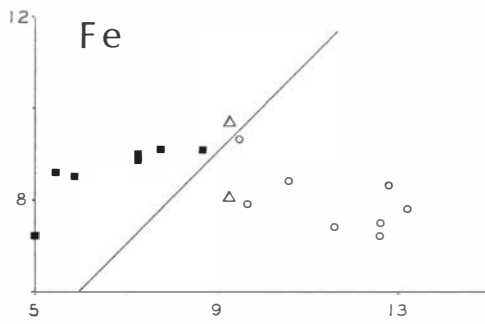
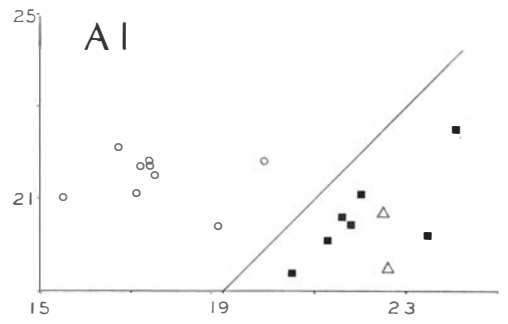
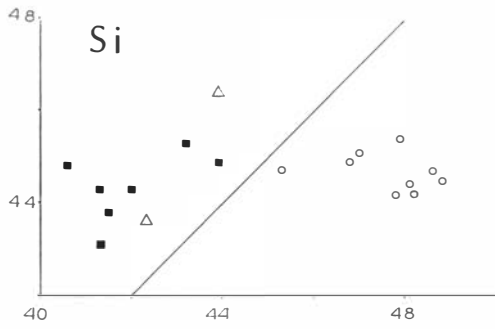
Table 3 cont.

Sample No.	11	12	13	14	17	18	19	23	25
Si	46.8	47.0	47.9	48.1	41.3	43.9	41.3	47.8	48.8
Al	17.2	17.4	17.5	19.9	21.8	22.5	20.5	16.7	18.9
Fe	13.2	12.6	11.6	9.7	5.9	9.3	7.8	12.6	9.5
Mg	10.2	8.9	9.4	8.0	12.0	8.7	11.8	9.1	8.5
Ca	8.0	8.7	9.0	9.4	11.5	5.0	10.9	8.0	8.9
Na	4.2	5.2	4.2	5.0	6.7	6.3	7.3	4.8	4.8
K	0.3	0.3	0.2	0.2	0.6	4.2	0.4	0.2	0.3
SUM	99.9	100.1	99.8	100.3	99.8	99.9	100.0	99.2	99.7

The cation percents calculated from modes are those derived from the first point-count of each section (i.e., comparable to the method used by me in 1958). The point-counting was done as a part of a study of the usefulness of the technique when applied to several different kinds of rocks, both the precision of the point-counting method of determining mineralogical modes of different rocks and the reliability of the point-count modes to provide an estimate of the chemical composition of rocks. The results of this study will be reported elsewhere (Millard, in preparation).

From the data given in Tables 1 and 3 and displayed in Figs. 2b, 2c, and 3, it is clear that the methods used by me in preparing the report published in 1958 are quite apt to lead to erroneous results. Specifically, more reliable methods of determining the character of the variations in chemical composition of the olivine gabbro between the pegmatite veins do not support the conclusions drawn in 1958 as to the nature of the variation of composition as a function of distance from the pegmatites.

The extent to which the results reported by me in 1958 were fortuitous or were influenced by unconscious bias is impossible to determine. However, it may be worthwhile to note that the *form* of the variation of composition with distance from the veins as reported in 1958 was not foreseen as a possibility.



The olivine gabbro with its complex coronas, its transformation to amphibolite near the veins, and the marked increase in biotite content immediately adjacent to the veins, appears to be particularly poorly suited to the method of estimating bulk chemical composition by calculation from modal analyses (for comparison see, e.g., Friedman, 1960, and Heier, 1961). Illustrative of this is the graphical correlation of cation concentrations as determined from spectro-chemical analysis and from modal analysis and the nearly complete separation of the points representing coronated and amphibolitized rock (Fig. 3).

Re-interpretation

In light of the new data it is appropriate for me to re-interpret the formation of the plagioclase rich pegmatite veins in the olivine gabbro near Risør.

Most of the elements show either no significant variation or variation which, while analytically significant, bears no discernible systematic relationship to any other parameter. To this statement there are a few exceptions. They are: 1) in the immediate vicinity of the veins the cation percentage of Ca decreases from its typical level of concentration; 2) in the immediate vicinity of the veins the cation percentages of K and Ba increase above their typical level of concentration; 3) within 3 to 5 meters of the veins the Mg content in the rocks may be significantly elevated above its typical level of concentration; and 4) the sum of alkalis ($\Sigma \text{Na} + \text{K}$) is apparently systematically higher relative to the sum of Mg plus Fe ($\Sigma \text{Mg} + \text{Fe}$) in the amphibolitized rock near the veins. Although the chemical analyses did not determine the amount of chemically bound water (as hydroxyl ion), it is probably safe to conclude from inspection of the modal analyses that H_2O^+ is increased near the veins.

The data presented in 1958 were interpreted as signifying that the material constituting the pegmatite veins was derived from the immediately adjacent rock by a process of lateral metamorphic differentiation in response to pressure gradients in the olivine gabbro resulting from tensile failure. The new data do not support this interpretation.

The presently available data seem to indicate that the material which constitutes the pegmatites was derived from outside the observable system. However, the data do not permit one to characterize the nature of the material from which the pegmatite crystallized, i.e., whether a condensed liquid, a fluidized gas-solid system, or a diffuse phase (i.e., gaseous or supercritical solution).

Fig. 3. The percent of the cations as calculated from the spectrochemical analyses are plotted on the ordinates; the percents of the cations as calculated from modal analyses are plotted on the abscissas. Coronated olivine gabbro is represented by open circles; amphibolitized rock is represented by filled squares; biotite-rich rock adjacent to the veins is shown by triangles. Each diagonal line shows the locus of points representing perfect agreement of the two methods of evaluating cation percentages.

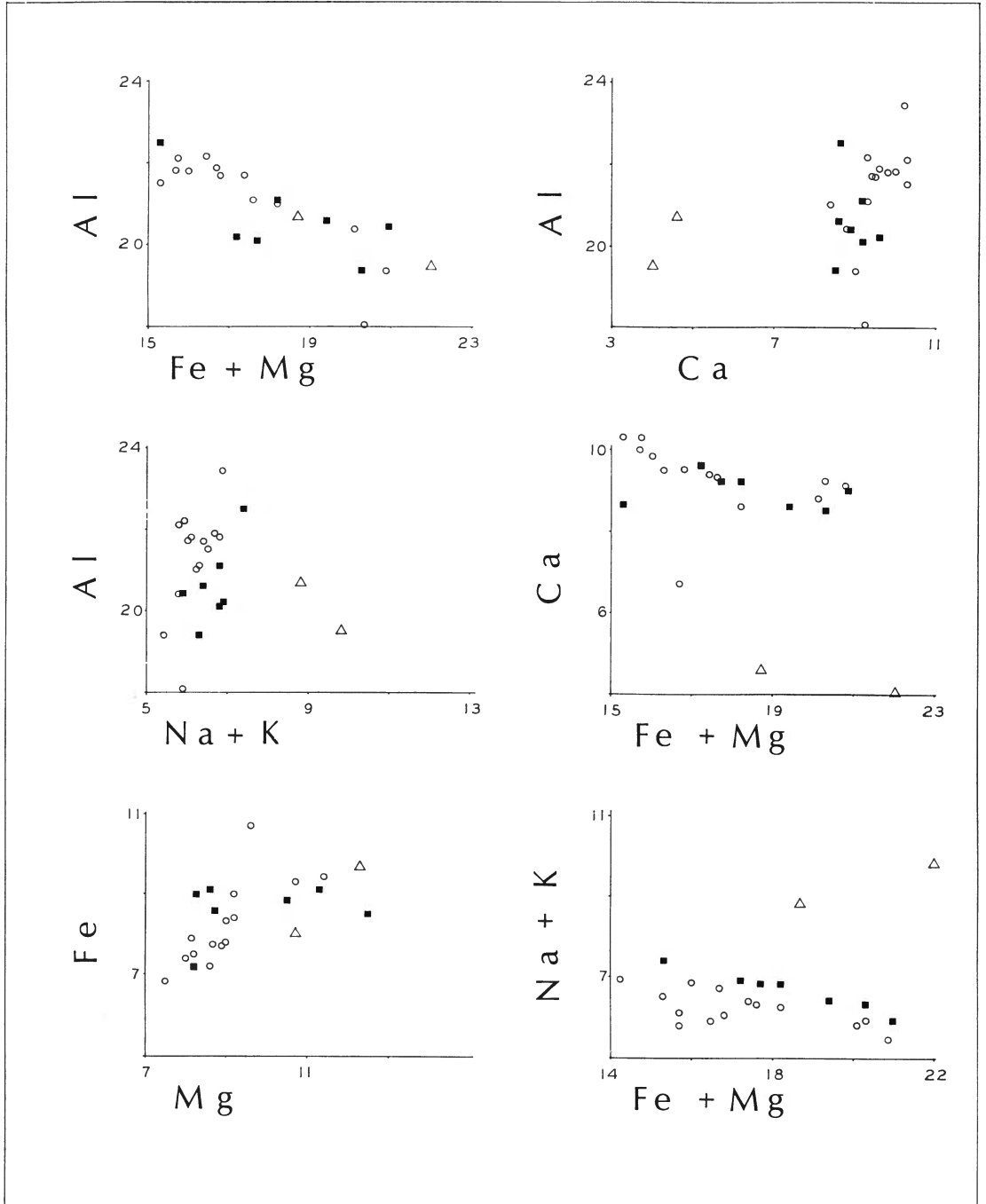


Fig. 4. Correlations of cations or cation groups (percentages as calculated from spectrochemical analyses). Open circles represent coronated olivine gabbro; filled squares represent amphibolitized rock; triangles represent biotite-rich rock adjacent to veins. Depletion of Ca and enrichment of Σ Na + K in the biotite-rich rocks is evident. Slight relative enrichment of Σ Na + K associated with amphibolitization seems to be indicated.

The data suggest that the most mobile components, K_2O , BaO , and most probably also H_2O (no data are available on other mobile components such as F, Cl, etc.), after introduction into the sites of the pegmatite veins migrated from there outward into the surrounding amphibolitized rock a limited distance. The decrease in Ca content immediately adjacent to the veins suggests that there may have been some reverse migration of Ca into the veins, possibly in response to a partial equilibration of plagioclase in the veins and in the surrounding rock. (An alternative explanation of decrease in Ca content near the veins by a dilution caused by addition of other components is discarded because an equivalent dilution of other components whose concentration in material derived from the vein would be expected to be low – particularly Mg and Fe – is not detected.) The apparent slight systematic increase of Mg and evidently appreciable increase in chemically bound H_2O (as [OH] near the veins) suggest the possibility of migration of these components into the surrounding rock with the formation of hydrated minerals (biotite and hornblende), largely with only reconstitution of the mafic components already there.

The correlation of the concentrations of elements with one another (Fig. 4) shows, at best, only weak negative correlations (e.g. Al vs. Σ Mg + Fe). With one exception these graphs reveal no significant separation of points representing coronated and amphibolitized rock. The exception is Σ Na + K vs. Σ Mg + Fe. Over the range of values of Σ Mg + Fe the value of Σ Na + K is higher in amphibolitized rock than in coronated rock. From this it appears that amphibolitization of the olivine gabbro – a process clearly associated with the formation of the pegmatite veins – resulted in a distinct increase in the concentration of the alkalis with respect to the sum of Mg plus Fe. This also indicates limited contact metasomatism involving addition of alkalis, presumably derived from the material emplaced in the pegmatite dikes, to the surrounding rocks.

As the strike of the veins is nearly perpendicular to the regional foliation and the elongation of the olivine gabbro body (Hofseth, 1942; Bugge, 1943; Reitan, 1956, 1958; Starmer, 1969) it seems not unreasonable to postulate a tensile failure of the olivine gabbro. Into the fracture produced the material now constituting the pegmatites was emplaced. The mechanism is similar to that proposed to account for the origin of a discordant K-feldspar-rich pegmatite in the banded gneiss on the island St. Hansholmen (Reitan, 1959), and it has also been suggested by Frodesen (1968), in his study of the chemical variations in a gabbroic body, to account for the emplacement of the pegmatites in it and the rather minor variations in host rock composition spatially associated with them. A problem remaining unresolved, however, is that of accounting for the great mineralogical and chemical differences between pegmatites in close geographical proximity – Risør area (Reitan, 1959; Starmer, 1969), and possibly Hiåsen (Frodesen, 1968) – to which we attribute essentially the same mode of formation. Despite the fact that the pegmatites appear to have formed from material

derived from outside the observable system, the compositions of the pegmatite veins seem closely related to composition of the host rock – i.e., plagioclase-rich in mafic host rock and K-feldspar-rich in intermediate to felsic host rock. The relationship is apparently too strong for an appeal to coincidence to be satisfactory, but attributing the material in the pegmatites to unknown sources outside the observable system contributes nothing positive to the solution of this problem.

February 1970

ACKNOWLEDGEMENTS. The spectrochemical analyses necessary for this study were paid for by an award from the National Science Foundation Institutional Grant #050-8600 supervised by the Research Foundation of the State University of New York.

REFERENCES

- Bugge, J.A.W. 1943: Geological and petrological investigations in the Kongsberg-Bamble formation. *Norges Geol. Unders.* 160, 150 pp.
- Friedman, G. M. 1960: Chemical analyses of rocks with the petrographic microscope. *Amer. Mineral.* 45, 69-78.
- Frodesen, S. 1968: Petrographical and chemical investigations of a Precambrian gabbro intrusion, Hiåsen, Bamble area, South Norway. *Norsk Geol. Tidsskr.* 48, 281-306.
- Heier, K. S. 1961: Estimation of chemical composition of rocks. *Amer. Mineral.* 46, 728-733.
- Hofseth, B. 1942: Geologiske undersøkelser ved Kragerø, i Holleia og Troms. *Norges Geol. Unders.* 157, 89 pp.
- Ingamells, C. O. & Suhr, N. H. 1963: Chemical and spectrochemical analysis of standard silicate samples. *Geochim. et Cosmochim. Acta* 27, 897-910.
- O'Neil, R. L. & Suhr, N. H. 1960: Determination of trace elements in lignite ashes. *Appl. Spectrosc.* 14, 45-50.
- Reitan, P. H. 1956: Pegmatite veins and the surrounding rocks. I. Petrography and structure. *Norsk Geol. Tidsskr.* 36, 213-239.
- Reitan, P. H. 1958: Pegmatite veins and the surrounding rocks II. Changes in the olivine gabbro surrounding three pegmatite veins, Risør, Norway. *Norsk Geol. Tidsskr.* 38, 279-311.
- Reitan, P. H. 1959: Pegmatite veins and the surrounding rocks IV. Genesis of a discordant pegmatite vein, St. Hansholmen, Risør, Norway. *Norsk Geol. Tidsskr.* 39, 197-229.
- Starmer, I. C. 1969: The migmatite complex of the Risør area, Aust-Agder, Norway. *Norsk Geol. Tidsskr.* 49, 33-56.
- Suhr, N. H. & Ingamells, C. O. 1966: Solution technique for analysis of silicates. *Anal. Chem.* 38, 730-734.