THE PETROGRAPHY OF SOME ANTARCTIC ROCKS*

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INTRODUCTION

There are 294 specimens in the Antarctic rock and mineral collections at the University of Michigan. Dr. Laurence M. Gould, geologist of the Byrd Antarctic Expedition, collected 103 of these specimens in South Victoria, Marie Byrd, and King Edward VII Lands. The remainder represents duplicate material collected by the National Antarctic, *Terra Nova*, Australasian Antarctic, Scottish Antarctic (1902–04), German South Polar (1901–03), French Antarctic (1903–05), and Swedish Antarctic Expeditions obtained in exchange by the University. Of the 178 specimens studied 152 thin sections have been examined qualitatively. Ninety-four thin sections have had their mineral constituents determined quantitatively by means of the recording micrometer. Fourteen new chemical analyses are added to the 158 previously recorded analyses of rocks from the Antarctic Continent and the Antarctic Archipelago. Analyses *f*, *i*, *m*, *q*, *s*, and *t* in Tables I and II have been previously recorded.

Gould (3) has published a map of that portion of the Queen Maud Mountains of South Victoria and Marie Byrd Lands which was surveyed by his party. Gourdon (4) has described petrographically specimens 7, 9, and 13, and Stillwell (8) has made a thorough study of specimens 18, 19, and 20 (Table III).

GENERAL STATEMENTS

In many petrographical papers published in the United States and abroad the qualitative microscopic determinations of the minerals found in a thin section are accompanied by the standard mineral compositions which have been computed from the chemical analyses of the rock specimens The standard mineral composition represents the norm of the rock which is the basis of the well-known C.I.P.W. classification of igneous rocks (1). Finlay (2) gives a brief description of this classification, and lists numerous

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This article is a preliminary paper on the geology and petrography of the Antarctic Continent which is in part completed and which will be published later in full.

examples of calculated analyses to aid the beginner in obtaining command of the formulated method of calculation. Johannsen (7) (pp. 83–99) has recently reviewed this chemical method for the classification of igneous rocks.

The quantitative determinations of the percentages of the actual mineral constituents present in thin sections may readily be calculated by the use of the improved Wentworth recording micrometer described by Hunt (6). The quantitative classification of Johannsen (7) (pp. 140–158) has been used in selecting the names of the igneous rock types. Although the C.I.P.W. system treats only of igneous rocks other types will also be considered in the following discussion in that the chemical-mineralogical calculations of sedimentary and metamorphic rocks will be compared with the data obtained with the recording micrometer.

ACCURACY OF THE MICROMETER METHOD

An aggregate distance of some 39,000 units was measured in traversing each thin section, an average of 15 times with the recording micrometer. The following are examples of the accuracy obtained by the use of the micrometer:

(1) The percentages of the mineral constituents of two thin sections of the same rock—a tonalite from Mount Betty, Queen Maud Mountains, South Victoria Land, Antarctica.

	(a)	(b)
Quartz	43.48	39.41
Oligoclase	40.88	42.61
Biotite	14.58	15.73
Muscovite	0.74	1.46
Magnetite	0.32	0.55
Other accessories	—	0.26
	100.00	100.00

(2) The percentages of the mineral constituents of two thin sections of the same rock—a diabase from Mount Fridtjof Nansen, Queen Maud Mountains, South Victoria Land, Antarctica.

	(a)	(b)
Quartz	0.95	1.91
Micrographic intergrowth	7.86	7.13
Labradorite	50.37	49.65
Mafites	40.03	40.70
Iron "ores"	0.80	0.61
	100.01	100.00

(3) The percentages of the mineral constituents of one thin section taking two complete sets of readings—a biotite schist from midway between Stations 1 and 2, Queen Maud Mountains, South Victoria Land, Antarctica. The readings were made parallel to the schistosity.

	(a)	(b)
Quartz	19.74	19.38
Feldspar	0.70	0.75
Biotite	67.61	67.34
Muscovite	11.77	12.37
Auxillaries	0.18	0.18
	100.00	100.02

(4) The percentages of the mineral constituents of one thin section taking two complete sets of readings—a granite gneiss from Great Mackellar Island, Adelie Land, Antarctica.

	(a)	(b)
Quartz	26.47	26.63
Feldspar	62.58	63.37
Biotite, chlorite	5.90	5.84
Muscovite	2.68	2.44
Accessories	2.36	1.72
	99.99	100.00

(5) Comparison of the mineral percentages of one thin section as determined with the recording micrometer with the data obtained from another thin section of the same rock as determined by the Rosiwal method. A plagioclase-pyroxene gneiss from Madigan Nunatak, Adelie Land, Antarctica. [See Stillwell (8) (p. 129).]

	Stewart	Stillwell (Rosiwal)	Difference
Feldspar, quartz	49.01	42.50	6.51
Pyroxene	43.02	45.50	2.48
Hornblende, biotite	3.19	3.60	0.41
Iron "ores"	4.68	8.40	3.72
Apatite	0.11	—	0.11
	100.01	100.00	

CHEMICAL ANALYSES OF THE ROCKS

In Tables I and II are the chemical analyses of the rock specimens that have been examined quantitatively with the micrometer. From these 20 analyses the volumetric norms have been calculated for comparison with the quantitative microscopical data. Analyses *f*, *i*, *m*, *q*, *s*, and *t* have been previously recorded.

TABLE I. CHEMICAL ANALYSES OF ROCKS EXAMINED PETROGRAPHICALLY.

	a	*b*	*c*	*d*	*e*	*f*	*g*
SiO_2	77.83	75.89	75.37	75.13	72.78	71.10	70.36
Al_2O_3	11.71	13.36	12.94	14.15	14.70	14.50	14.00
Fe_2O_3	0.11	0.89	0.06	0.07	0.27	0.31	0.77
FeO	1.24	0.18	1.48	0.89	1.18	3.10	3.32
MgO	tr	0.06	0.07	0.07	0.42	1.17	1.29
CaO	0.63	0.27	0.73	0.35	0.99	2.59	2.09
Na_2O	3.11	4.78	3.23	4.07	3.01	3.25	2.98
K_2O	4.19	3.71	5.13	4.27	5.77	4.02	3.05
H_2O	0.56	0.54	0.44	0.44	0.46	0.25	0.71
H_2O-	0.09	0.11	0.07	0.10	0.04	—	0.06
TiO_2	0.10	0.04	0.10	0.02	0.21	0.46	0.89
P_2O_5	0.06	0.08	0.02	0.09	0.20	0.03	0.21
MnO	0.02	0.01	0.02	0.02	0.03	n.d.	0.08
F	0.15	n.d.	0.15	0.15	n.d.	n.d.	n.d.
$O=F$	0.06	—	0.06	0.06	—	—	—
	99.74	99.92	99.75	99.76	100.06	100.78	99.81

	h	*i*	*j*	*k*	*l*	*m*	*n*
SiO_2	64.57	59.85	53.64	52.67	52.41	36.70	78.54
Al_2O_3	16.92	16.90	14.56	13.17	15.53	11.00	10.81
Fe_2O_3	1.30	1.92	1.81	0.74	1.79	14.21	0.35
FeO	2.14	5.22	8.12	6.75	6.64	12.24	1.42
MgO	1.71	3.12	6.14	11.81	8.03	7.55	0.80
CaO	4.09	6.63	10.39	12.01	10.74	11.90	0.73
Na_2O	4.52	3.45	1.87	1.03	1.64	0.95	3.32
K_2O	2.01	1.28	0.50	0.39	0.62	0.20	2.08
H_2O	1.62	0.87	1.65	0.57	1.36	1.36	0.95
H_2O-	0.13	—	0.41	0.25	0.65	—	0.09
TiO_2	0.53	0.84	0.82	0.43	0.55	3.85	0.65
P_2O_5	0.17	0.06	0.15	0.12	0.07	n.d.	0.15
MnO	0.05	n.d.	0.17	0.17	0.14	n.d.	0.06
	99.76	100.14	100.23	100.11	100.17	99.98	99.95

(*a*) Monzogranite (specimen 1). Rockefeller Mountains, King Edward VII Land, Antarctica. Ellestad, analyst.

(*b*) Leucogranitic aplite (specimen 4). *Ibid.*

(*c*) Porphyritic leucomonzogranite (specimen 2). *Ibid.*

(*d*) Alaskite (specimen 5). Rockefeller Mountains, King Edward VII Land, Antarctica. Kameda, analyst.

(*e*) Leucogranite (specimen 6). One half way between Stations 1 and 2, Queen Maud Mountains, South Victoria Land, Antarctica. Kameda, analyst.

(*f*) Granodiorite (specimen 7). Wandel Island, Antarctic Archipelago, Antarctica. Pisani, analyst.

(*g*) Tonalite (specimen 3). Mount Betty, Queen Maud Mountains, South Victoria Land, Antarctica. Ellestad, analyst.

(*h*) Granodiorite (specimen 8). Mount Fridtjof Nansen, Queen Maud Mountains, South Victoria Land, Antarctica. Ellestad, analyst.

(*i*) Tonalite (specimen 9). Wandel Island, Antarctic Archipelago, Antarctica. Pisani, analyst.

(*j*) Diabase (specimen 10). Mount Fridtjof Nansen, Queen Maud Mountains, South Victoria Land, Antarctica. Kameda, analyst.

(*k*) Gabbro (specimen 12). Mount Fridtjof Nansen, Queen Maud Mountains, South Victoria Land, Antarctica. Ellestad, analyst.

(*l*) Melabasalt (specimen 11). Mount Fridtjof Nansen, Queen Maud Mountains South Victoria Land, Antarctica. Ellestad, analyst.

(*m*) Melagabbro (specimen 13). Cape Tuxen, Graham Land, Antarctica. Pisani, analyst.

(*n*) Arkose (specimen 14). Mount Fridtjof Nansen, Queen Maud Mountains, South Victoria Land, Antarctica. Ellestad, analyst.

TABLE II. CHEMICAL ANALYSES OF ROCKS EXAMINED PETROGRAPHICALLY.

	o	*p*	*q*	*r*	*s*	*t*
SiO_2	69.89	69.76	67.10	64.51	50.62	48.74
Al_2O_3	13.14	15.15	14.87	16.87	11.43	13.64
Fe_2O_3	0.43	0.87	1.14	1.33	4.43	3.31
FeO	5.61	2.51	3.76	4.06	11.11	9.98
MgO	2.82	1.25	1.80	2.58	6.87	7.12
CaO	0.37	3.20	3.47	0.94	10.90	10.34
Na_2O	1.81	3.53	2.56	1.35	1.75	1.96
K_2O	3.21	2.42	3.50	5.17	0.24	0.83
H_2O	1.31	0.59	0.68	1.75	0.62	1.95
H_2O-	0.04	0.05	0.11	0.03	0.19	0.11
TiO_2	0.68	0.38	0.68	0.82	1.42	1.26
P_2O_5	0.10	0.14	0.20	0.22	0.08	0.14
MnO	0.43	0.07	tr	0.07	0.28	0.35
CO_2			nil			tr
SO_3			nil		nil	nil
S						0.06
Cl			0.05		tr	
ZrO_2						nil
Cr_2O_3						0.05
NiO, CoO			tr		0.03	0.01
CoO			nil		tr	tr
BaO						nil
Li_2O			tr		tr	tr
O=Cl						0.01
O=S						0.02
	99.84	99.92	99.92	99.70	99.97	99.86

(*o*) Biotite schist (specimen 15). Supporting Party Mountain, Queen Maud Mountains, Marie Byrd Land, Antarctica. Ellestad, analyst.
(*p*) Oligoclase-biotite gneiss (specimen 16). O'Brien Peak, Queen Maud Mountains, South Victoria Land, Antarctica. Ellestad, analyst.
(*q*) Granodiorite gneiss (specimen 18). Cape Denison, Adelie Land, Antarctica. Watson, analyst.
(*r*) Muscovite-biotite schist (specimen 17). Southeast of Station 1, Queen Maud Mountains, South Victoria Land, Antarctica. Ellestad, analyst.
(*s*) Plagioclase-pyroxene gneiss (pyroxene granulite) (specimen 19). Madigan Nunatak, Adelie Land, Antarctica. Hall, analyst.
(*t*) Amphibolite (specimen 20). Cape Denison, Adelie Land, Antarctica. Hall, analyst.

Chemical-Mineralogical Calculations and the Mode

The authors of the C.I.P.W. classification (1) (pp. 147–152) state that the rocks of Classes I and II, rocks high in the standard minerals, have norms that show almost complete accord with the modes. Due to the presence of alferric minerals the norms and modes of rocks of Classes III and IV show less accord, although those of Class V again exhibit a rather close correspondence.

The following is a typical example of (1) norm of the rock, (2) the volumetric chemical-mineralogical determinations derived from the norm taking into consideration the specific gravities of the minerals, and (3) the data obtained with the recording micrometer. The rock is a leucogranite (specimen 6, chemical analysis *b*).

		(1)	(2)	(3)
Quartz		30.00	29.78	30.6
Orthoclase		34.47	35.56	45.4
Albite		25.15	25.26	16.5
Anorthite		4.17	3.97	
Corundum		1.94	1.29	2.6 (muscovite)
Hypersthene	$FeO \cdot SiO_2$	1.58	2.04	4.8 (biotite)
	$MgO \cdot SiO_2$	1.10		
Ilmenite		0.46	0.26	
Magnetite		0.46	0.24	
Apatite		0.34	0.28	0.1 (apatite, zircon)
H_2O		0.50	1.32	
		100.17	100.00	100.0

It will be seen that the percentages of the feldspars of the chemical-mineralogical and quantitative microscopical determinations are not in close agreement. This indicates that the rocks high in the standard minerals do not *always* have norms that show almost complete accord with the modes. This variation is due to the fact that pure orthoclase is of rare occurrence in nature.

Harker (5) (pp. 245–246) makes the following statement:

> "Orthoclase crystals contain an admixture of Ab (and An) up to a limit of about 28 *per cent*, and plagioclase crystals may contain Or up to about 12 *per cent.*"

Inasmuch as the feldspars contain varying amounts of the K, Na, and Ca molecules they should be grouped in both the norm and the mode. When this is done the correspondence between the totals is rather striking. In like manner, due to the variability of the compositions of the alferric minerals they, too, should be grouped in both the norm and the mode.

In the above table the excess of Al_2O_3 is calculated as corundum in the chemical-mineralogical determinations whereas this mineral is absent in the mode. It is practically impossible to calculate from the chemical composition accurate amounts of such minerals as muscovite and biotite, which frequently occur as important constituents in the rock. For example the muscovite present in specimen 15 (Table III), must be reported as feldspar although feldspar is really a minor constituent. If the rock contains a high percentage of Na- or K-minerals the entire amount of the Na and K are calculated as orthoclase or albite in the norm, instead of the Na- or K-mineral that actually occurs in the rock.

Table III shows the grouped chemical-mineralogical calculations and the correspondingly grouped quantitative microscopical determinations. An average of the mineral constituents of two thin sections was used in computing the data of specimens 3, 14, 15, 16, and 17. Under the term *mafites* in the chemical-mineralogical analyses the minerals considered include hypersthene, diopside, olivine, and iron "ores," while in the quantitative microscopical measurements the minerals actually present are hornblende, augite, biotite (chlorite), and the iron "ores." Under the heading *other constituents* the norm includes apatite, fluorite, and water. The microscopical determinations include auxillary minerals.

TABLE III. COMPARISONS OF THE GROUPED MINERALS OF VOLUMETRIC NORMS AND MODES.

	Quartz	Feldspars	Corundum	Mafites	Other Constituents
1.	41.54*	53.17	1.01	1.80	2.49
	34.42**	59.54	—	5.48	0.62
2.	34.63	60.75	0.74	2.27	1.60
	35.37	61.29	—	3.03	0.34
3.	33.88	54.98	1.46	7.29	2.37
	41.445	41.745	—	15.630	0.130
4.	33.34	63.05	0.88	0.75	1.98
	37.67	57.42	—	4.87	—
5.	33.16	61.39	1.77	1.48	2.22
	32.44	61.14	—	4.06	2.32
6.	29.78	64.79	1.29	2.54	1.60
	30.60	61.90	—	4.80	2.70
7.	27.26	65.48	—	6.55	0.67
	37.86	53.84	—	8.10	0.19
8.	18.82	69.90	0.14	6.20	4.92
	23.67	67.22	—	9.11	—
9.	14.91	66.44	—	16.24	2.42
	19.04	53.05	—	27.32	0.59
10.	9.14	52.44	—	32.12	6.29
	1.91	56.78	—	41.31	—
11.	5.71	52.88	—	34.92	6.07
	2.06	41.95	—	55.98	—
12.	3.41	45.62	—	47.18	2.79
	—	66.47	—	33.54	—
13.	—	41.46	—	54.08	4.45
	—	40.88	—	59.12	—

* Volumetric chemical-mineralogical
** Quantitative microscopical

TABLE III (*Continued*).

	Quartz	Feldspars	Corundum	Mafites	Other Constituents
14.	48.63	43.27	1.43	3.59	3.04
	48.675	48.605	—	2.715	0.115
15.	30.64	47.93	5.31	11.01	5.11
	33.97	41.29[a]	—	23.53	0.21
16.	30.89	60.02	0.91	6.16	1.98
	30.44	60.66	—	8.67	0.26
17.	30.90	51.71	0.13	13.69	3.83
	50.11	1.47	—	42.03	6.41
18.	27.72	60.24	0.63	8.94	2.43
	42.80	42.47	—	14.72	
19.	1.21	49.54	—	42.79	6.46
	25.53		—	74.47	
20.	7.26	43.69	—	46.24	2.80
	49.01		—	51.00	

[a] Muscovite

1. Monzogranite. Rockefeller Mountains, King Edward VII Land, Antarctica.
2. Porphyritic leucomonzogranite. *Ibid.*
3. Tonalite. Mount Betty, Queen Maud Mountains, South Victoria Land, Antarctica.
4. Leucogranitic aplite. Rockefeller Mountains, King Edward VII Land, Antarctica.
5. Alaskite. *Ibid.*
6. Leucogranite. One half way between Stations 1 and 2, Queen Maud Mountains, South Victoria Land, Antarctica.
7. Granodiorite. Wandel Island, Antarctic Archipelago, Antarctica.
8. Granodiorite. Mount Fridtjof Nansen, Queen Maud Mountains, South Victoria Land, Antarctica.
9. Tonalite. Wandel Island, Antarctic Archipelago, Antarctica.
10. Diabase. Mount Fridtjof Nansen, Queen Maud Mountains, South Victoria Land, Antarctica.
11. Melabasalt. *Ibid.*
12. Gabbro. *Ibid.*
13. Melagabbro. Cape Tuxen, Graham Land, Antarctica.
14. Arkose. Mount Fridtjof Nansen, Queen Maud Mountains, South Victoria Land, Antarctica.

15. Biotite schist. Supporting Party Mountain, Queen Maud Mountains, Marie Byrd Land, Antarctica.
16. Oligoclase-biotite gneiss. O'Brien Peak, Queen Maud Mountains, South Victoria Land, Antarctica.
17. Muscovite-biotite schist. Southeast of Station 1, Queen Maud Mountains, South Victoria Land, Antarctica.
18. Granodiorite gneiss. Cape Denison, Adelie Land, Antarctica.
19. Plagioclase-pyroxene gneiss (pyroxene granulite). Madigan Nunatak, Adelie Land, Antarctica.
20. Amphibolite. Cape Denison, Adelie Land, Antarctica.

Considering the rocks as a whole, those igneous types that are acid in character exhibit good accord between the percentages of the *grouped minerals* of the volumetric norm and the *grouped minerals* of the mode. The acid rocks high in alferric minerals show groupings that have less agreement as noted in specimen 3, a tonalite. In this instance the rock contains over 15 per cent biotite. Aside from specimen 13, a melagabbro, the grouped minerals of the more basic rocks examined—diabase, melabasalt, gabbro—show limited correspondence. Hence, we may conclude that of the rocks examined the majority high in alferric minerals exhibit little accord between the grouped minerals of the volumetric norms and modes. The one sediment, an arkose, shows good accord between the grouped minerals of the norm and mode. Metamorphic rocks show variability in accord between the groups, although the correspondence is closer in the more acid types, as may be noted in the oligoclase-biotite gneiss (specimen 16).

THE AB AN RATIO OF THE NORM AND THE MODE

Of considerable interest is the comparison of the Ab An ratios of the plagioclase determined microscopically and as calculated from the chemical composition of the igneous rock. In the acid rocks the correspondence between the Ab An ratio of the norm and the mode is very striking. In general it may be stated that the Ab of the norm is slightly higher than that of the mode in acid rocks, and tends to be the reverse in the more basic types studied. The following are a few typical examples:

Alaskite (specimen 5)
Mode $Ab_{97}An_3$
Norm $Ab_{100}An_0$
Monzogranite (specimen 1)
Mode $Ab_{93}An_7$
Norm $Ab_{95}An_5$

Diabase (specimen 10)
Mode $Ab_{50}An_{50}$
Norm $Ab_{35}An_{65}$
Melagabbro (specimen 13)
Mode $Ab_{45}An_{55}$
Norm $Ab_{25}An_{75}$

RÉSUMÉ

Comparisons are made between the quantitative microscopical and volumetric chemical-mineralogical determinations of 20 rock specimens. Fourteen new chemical analyses of rocks from the Antarctic Continent are listed. It may be noted that the minerals of the volumetric norm and mode correspond in some cases, although in the majority of instances it is necessary to group such constituents, as feldspars, in order to obtain an agreement. In general, the Ab of the norm is slightly higher than that of the mode in acid rocks, and tends to be the reverse in the more basic types studied.

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