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VOLCANIC ROCKS OF CAPE ADARE AND ERRATICS FROM TERRA NOVA BAY REGION, ETC.

BY

W. CAMPBELL SMITH

WITH ONE FIGURE IN THE TEXT AND ONE PLATE

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I. CHEMICAL COMPOSITION OF VOLCANIC ROCKS OF CAPE ADARE

Chemical analyses have been made of seven of the rocks from Cape Adare described in the previous number of these reports. Three are of basalts, three of phonolites, and one of a sanidinite from the boulder-bearing agglomerate on the northern face of the cliff at Cape Adare. These analyses have been made by Mr. D. I. Bothwell in the Department of Mineralogy, British Museum (Natural History). They were not available when the petrographical descriptions of the rocks were written, and, in the light of the results of the analyses, some comments on and amendments to those descriptions are now called for. The analyses are tabulated in columns, 33 to 40 of Tables VIII and IX, and X and subsequent tables give the C.I.P.W. norms, the cation per cent composition, and 'basis' of Niggli and Burri in conformity with the tables in No. 1 of this volume in which the volcanic rocks of the Ross Archipelago are described. The 'Niggli values' are tabulated in Table XII (p.165).

Olivine-Basalts

On the basis of their characters as seen in hand-specimens and thin sections the Cape Adare basalts were divided into three types: A. Black, glassy, aphanitic olivine-basalt; B. Dark grey, holocrystalline olivine-basalt; and C. Porphyritic olivine-basalt with insets of augite and olivine.

The first point that emerges from a consideration of the analyses of the three olivine-basalts is the close similarity in composition between Types A and C (Nos. 432 and 245). The two types were distinguished mainly on account of the differences in fabric, Type A (p. 115) being compact and aphanitic, with a partly glassy groundmass, and Type C (p. 118) being porphyritic, with insets of augite and olivine, and occasional xenocrysts of brown hornblende, in a dense, black groundmass with glassy lustre. The analyses show that in chemical composition these two types are very similar. The normative composition also is very similar. The percentage of femic minerals is a little higher in Type C. The normative plagioclase in Type A (432) is An_{54}, in Type C (245) An_{56}, *or* and *ne* are both slightly higher in Type A than in Type C.

Compared with chemical analyses of other South Victoria Land basalts the closest match is presented by a basalt from Sulphur Cones, Hut Point Peninsula, described by Prior as "hornblende-basalt" [B.M. 87171, 385] and re-described in the preceding number of this volume (p. 79). In fact the two rocks are not closely alike in mineral composition, and the closest matches among the Ross Island basalts for the Cape Adare Types A and C seem to be the basalts of Cape Barne, described in the first place by Jensen from specimens collected on the British Antarctic Expedition, 1907–9, and re-described (p. 86) with an analysis by D. I. Bothwell (p. 99, No. 26a) from material collected by Frank Debenham on the Terra Nova Expedition.

The analysis of the Type B basalt (No. 392) shows slightly lower alkalies than Types A and C but the more striking differences are a high content of H_2O lost above 110°C. and the reversal of the Fe_2O_3:FeO relations, the Fe_2O_3 being in excess of FeO. This and the lower alkali-content induce notable differences in the calculated norms (Table VIII*a*), but in the 'Niggli values' the principal differences are the much higher *si*, compared with the *si* for Types A and C.

Plotted on the diagram based on variation of 'Niggli values' with *si* (this volume No. 1, Fig. 5, p. 92) one finds Type B at *si* 110·5 coming very close to a Cape Barne basalt [D24R] while types A and C at *si* 102 and 97 respectively fall on either side of the position of Jensen's basalt from Cape Barne [J4] (except for the *fm* value), and equally close to Prior's 'hornblende-basalt' from Sulphur Cones referred to above. As has been remarked already this 'hornblende-basalt' does not resemble, either in hand-specimen or thin section, the Type A and C basalts, but, contrariwise, there is a fairly good resemblance between the groundmass of Prior's 'hornblende-basalt' and that of the Type B olivine-basalt. It may be that the siliceous sedimentary xenoliths which the Type B basalt has partially digested has given the rock an abnormally high silica content and perhaps the high $H_2O+110°$ and the oxidation of such a high proportion of the ferrous iron in this basalt may be other effects of the same cause. A similar suggestion was made to account for the unusual composition of the Mount Cis 'trachyte' (this volume, No. 1, p. 93).

A description by Edgeworth David, Smeeth and Schofield of a pebble of a porphyritic olivine-basalt collected by C. S. Borchgrevink from the beach at Cape Adare in 1895 makes it probable that this specimen, though evidently much weathered, is of a rock similar to the olivine-basalt Type C (see No. 2, p. 120). However, the analyses (op. cit. p. 121, col. 1) of Borchgrevink's specimens shows very much higher MgO and CaO and much lower alkalies than in either the Type C or the Types A and B analyses.

TABLE VIII. CHEMICAL ANALYSES, NORMS, ETC. OF OLIVINE-BASALTS

33. Olivine-basalt, A. "III.6".4.4. 100 yards N. of northern limit of snow drift on Cape Adare. D. I. Bothwell, anal. [432=B.M. 1953, 91, 4]
34. Olivine-basalt, B. II (III).5"."3.4. Bluff near the end of upper beach platform, Cape Adare. D.I.Bothwell, anal. [392=B.M. 1953, 91, 40a].
35. Porphyritic Olivine-basalt, C. III.6.2(3).4. Cliff not far from Borchgrevink's Depot, Cape Adare. D. I. Bothwell, anal. [245=B.M. 1953, 91, 151].

TABLE VIII

a

CHEMICAL ANALYSES

	33	34	35
SiO_2	44·1	44·5	43·2
TiO_2	3·3	3·2	3·8
Al_2O_3	16·7	15·8	15·7
Fe_2O_3	4·0	7·3	4·4
FeO	7·9	4·8	8·1
MnO	0·2	0·2	0·2
MgO	4·2	4·1	5·3
CaO	9·7	9·3	10·2
Na_2O	5·5	4·4	4·9
K_2O	2·4	1·6	2·0
H_2O+	1·0	2·0	0·9
H_2O-	0·1	0·9	0·1
P_2O_5	1·2	1·3	1·2
CO_2	—	—	—
ZrO_2	—	—	—
SO_3	—	—	—
SrO	—	—	—
TOTALS	100·3	99·4	100·0

b

C.I.P.W. NORMS

	33	34	35
or	14·46	9·45	11·68
ab	10·48	27·25	11·53
an	13·62	18·63	15·01
ne	19·60	5·40	16·19
di	22·13	14·90	22·80
ol	4·32	2·38	5·41
mt	5·80	6·96	6·50
il	6·23	6·08	7·30
hm	—	2·56	—
ap	2·69	3·02	2·69

c

CATION PER CENT

	33	34	35
SiO_2	41	43·2	40·5
TiO_2	2·3	2·3	2·7
$\frac{1}{2}Al_2O_3$	18·2	18·0	17·7
$\frac{1}{2}Fe_2O_3$	2·8	5·4	3·1
FeO MnO	6·3	4·1	6·5
MgO	5·9	5·9	7·5
CaO	9·6	9·7	10·2
$\frac{1}{2}Na_2O$	10·0	8·3	8·9
$\frac{1}{2}K_2O$	2·9	2·0	2·4
H_2O+	—	—	—
H_2O-	—	—	—
$\frac{1}{2}P_2O_5$	0·9	1·0	0·9
TOTALS	100·0	99·9	100·4

d

'BASIS'

	33	34	35
Cp	2·2	2·6	2·2
Ru	2·3	2·3	2·7
Kp	8·7	6	7·1
Ne	29·6	24·8	26·7
Cal	8·2	11·7	9·1
Cs	8·4	6·3	8·6
Fo	8·8	8·9	11·1
Fa	9·5	6·1	9·8
Fs	4·2	8	4·7
Q	17·9	23·2	17·8
Q	19	24	19
L	49	45	45
M	32	31	36
π	0·18	0·27	0·21
γ	0·27	0·21	0·25

In the π-k diagram (No. 1, fig. 7, p. 95) the points corresponding to Types A, C, and B (cols. 33, 35, and 34), fall (in that order) between No. 6, the trachytoid phonolite from Observation Hill, Ross Island, and No. 31 an olivine-basalt [D2F] from 'Black Hill' in the Ferrar Glacier region on the mainland.

The new analyses fill a gap in the series in this diagram and lie smoothly on a curve between the two points at its ends.

Phonolite and Trachytoid Phonolites

The analysis given in column 36, Table IX, is of the remarkable phonolite with the 'variolitic structure' found at 900 feet above sea-level at Cape Adare [227]. This finds its nearest match among the analyses of volcanic rocks from South Victoria Land in the trachytoid phonolite [188] from Cape Crozier, analysed by G. T. Prior (No. 1, col. 3, Table I*a*). Comparison of the two rocks shows, however, that they bear no resemblance to each other in mineral composition. Nothing comparable to this compact phonolite from Cape Adare has been described among the Ross Island volcanics, so for the present it stands alone.

The analysed specimen of the trachytoid phonolite [584] is an erratic from the plateau above Cape Adare. It is a rock of the same kind as one [231] collected at 900 feet above sea-level on the Cape and described in this volume (No. 2, p. 125). Its chemical analysis, given in column 37, Table IX, finds a tolerably close match in an analysis by Prior of a 'phonolitic trachyte' from Scott Island [B.M. 87171, 973] quoted in column 4, Table Ia (No. 1, p. 37).

By comparison the analysis of the Cape Adare trachytoid phonolite shows lower Al_2O_3 and FeO, but higher Fe_2O_3 and more H_2O lost above 110°C. The differences in the 'Niggli values' are in the same sense, that is lower *al* and *fm* for the trachytoid phonolite but also it has higher *alk*, 32·5 as against 30.[1]

In thin section the Scott Island rock and the Cape Adare trachytoid phonolite appear to be roughly similar in mineral composition. Comparison suggests that there are more feldspar micro-insets in the Cape Adare rock, while in the Scott Island 'phonolitic trachyte' of Prior there is more brown hornblende and perhaps more magnetite (?), which occurs as occasional micro-insets as well as in the groundmass.

---

[1] The 'Niggli values', and also the other values, except the analysis and the C.I.P.W. norms given for the Scott Island phonolitic trachyte given in col. 4 of Tables Ic–f are incorrect. The correctly calculated Niggli values are given in Table XII and corrections have also been supplied on a sheet of Errata for No. 1. of this volume.

The Scott Island rock in hand-specimen is compact, fine-grained, deep olive-grey[1] in colour, and it breaks with an undulating platy fracture. The thin section shows frequent micro-insets of simply twinned alkali-feldspar and faintly purplish, green-rimmed pyroxene prisms, as well as a few brown amphiboles and magnetites (as already mentioned). These micro-insets lie in a groundmass consisting of laths and plates of alkali-feldspar, with granules of a nearly colourless, or faintly yellow pyroxene and also plates of a pale green pyroxene, very small crystals of magnetite (?) and small areas of a colourless birefringent base that may be feldspathoid.

It is difficult to understand why H. S. Washington classified this analysis as 'trachydolerite' (1917, p. 573, No. 40),[2] but he had only the analysis to go on as Prior had not published any detailed description of the rock. It is to remedy this position that the above brief description of the rock is included here.

The third analysis (No. 670, col. 38) is of one of the boulders of sodalite-trachyte from the 'agglomerate' on the northern face of Cape Adare, described in the preceding number of this volume (pp. 127–8). The analysed specimen is representative of the rocks there described, except that olivine, recorded as an occasional constituent in these rocks (p. 128), is very rare in the thin sections of the analysed specimen. Also it is evident from the low Cl′ that sodalite forms only a small percentage of the mineral composition.

None of the analysed phonolitic trachytes from South Victoria Land are at all near this sodalite-trachyte in composition. In the variation diagram based on the 'Niggli values' it falls, owing to its *si* value, near the two analysed Mt. Cis 'trachytes', but its other values do not fit in at all well with these. Comparing thin sections of the two rocks one notes that the Mount Cis trachyte contains fewer insets, its green pyroxene is relatively poorly developed, and the feldspar laths of the groundmass are much more slender and more closely packed. However, I have recorded probable sodalite, both as small colourless cubes (p. 24) and as interstitial material between the feldspars (p. 23) in the Mount Cis 'trachyte' which is another point of resemblance with the sodalite-trachytes. As remarked above (p. 25 and p. 93) the Mount Cis 'trachyte' analyses may have unusual composition owing to partial assimilation of so many inclusions of Beacon Sandstone in the 'trachyte', so that the *si* values may be relatively high.

It is of interest to note a rather remarkably close similarity between the chemical analysis of the sodalite-trachyte [670] and that of the hedrumite from between Sundet and Delingsdal on Lake Åsrum, east of Lougenthal, Hedrum,

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(1) Names used for colours are based on 'Color standards and color nomenclature'. By R. Ridgway. Washington, 1912.

(2) References given by date and page in parentheses refer to the list on p.149 of No. 2 of this volume.

in the Oslo region, described by W. C. Brøgger[1]. The modal mineral composition of the two rocks is also very similar but they differ notably in texture, the hedrumite, a dyke, being a medium- to coarse-grained rock with trachytic structure, whereas the sodalite-trachyte is fine-grained and porphyritic. This contains more nepheline than some hedrumites described by Brøgger. The mode calculated by Brøgger shows 7·3 per cent nepheline, and according to Johanssen 'the pyroxene is predominantly aegirite with subordinate aegirite-augite';[2] also the brown mica, lepidomelane, the predominant coloured mineral in the Skirstad and Ostö hedrumites is very subordinate (3%) to the pyroxene.

TABLE IX. CHEMICAL ANALYSES, NORMS, ETC. OF PHONOLITES

36. Phonolite. 'II.6.1.4.
900 feet above sea-level, Cape Adare.
D. I. Bothwell, anal. [227=B.M. 1953, 91, 316].

37. Trachytoid phonolite. "II."6.1.4.
Erratic from plateau on the top of Cape Adare.
D. I. Bothwell, anal. [584=B.M. 1953, 90, 57].

38. Sodalite-trachyte. II'.(5)6.1'.4.
Boulder from the 'agglomerate' on northern face of cliff, Cape Adare.
D. I. Bothwell, anal. [670=B.M. 1953, 90, 82].

TABLE IX

a

CHEMICAL ANALYSES

	36	37	38
SiO_2	56·2	55·5	59·2
TiO_2	0·2	0·6	0·2
Al_2O_3	18·7	18·2	17·5
Fe_2O_3	3·0	3·9	3·9
FeO	1·8	3·0	2·1
MnO	0·2	0·2	0·2
MgO	0·3	0·9	0·4
CaO	1·6	3·6	1·6
Na_2O	9·4	8·1	8·2
K_2O	5·3	3·9	5·6
H_2O+	2·7	1·2	0·6
H_2O-	0·3	0·3	0·1
P_2O_5	0·1	0·2	0·1
Cl'	—	—	0·3
TOTALS	99·8	99·6	100·0

b

C.I.P.W. NORMS

	36	37	38
Q	—	—	—
or	31·14	22·80	33·36
ab	26·86	40·87	37·20
an	—	1·67	—
ne	21·51	15·05	11·64
hl	—	—	0·47
ac	8·78	—	7·39
ns	0·73	—	—
di	6·5	7·98	6·18
wo	—	2·78	—
ol	0·51	—	0·35
mt	—	5·57	1·86
il	0·46	1·22	0·46
ap	0·23	0·50	0·34

(1) Brøgger (W. C.). Die Eruptivgesteine des Kristianiagebietes. III. Das Ganggefolge des Laurdalits. 1898, pp. 185–6, and p. 192.

(2) Johannsen (A.). A descriptive petrography of the igneous rocks. Vol. 4 (1938), p. 26.

TABLE IX (continued)

c

CATION PER CENT

	36	37	38
SiO_2	51·2	51	53·7
TiO_2	0·16	0·44	0·2
$\frac{1}{2}Al_2O_3$	20	19·6	18·7
$\frac{1}{2}Fe_2O_3$	2·1	2·7	2·6
FeO			
MnO	1·5	2·5	1·74
MgO	0·4	1·25	0·05
CaO	1·6	3·6	1·6
$\frac{1}{2}Na_2O$	16·7	14·4	14·35
$\frac{1}{2}K_2O$	6·1	4·5	6·5
H_2O+	—	—	—
H_2O-	—	—	—
$\frac{1}{2}P_2O_5$	0·08	0·16	0·1
TOTALS	99·8	100·15	99·5

d

'BASIS'

	36	37	38
Cp	0·17	0·4	0·3
Ru	0·16	0·4	0·2
Kp	18·4	13·5	19·6
Ne	41·8	43·3	36·5
Ns	4·1	—	3·3
Cal	—	1	—
Cs	2·25	4·5	2·15
Fo	0·6	1·8	0·8
Fa	2·3	3·7	2·6
Fs	3·1	4·0	3·9
Q	27·0	27·4	30·4
Q	27·1	27·6	30·6
L	60·5	58·5	56·5
M	12·4	14·1	12·85
π	0	0·02	0
γ	0·27	0·32	0·22

TRACHYTE AND SANIDINITE

Two further analyses enable one to extend the variation diagram (this vol., No. 1, fig. 5) beyond the *si* values of the 'sodalite-trachyte' and the Mount Cis phonolitic trachyte. These are analyses of one of the sanidinite blocks from the agglomerate on the north face of the cliff at Cape Adare described in the previous number of this volume (pp. 130–132), and a 'trachyte' collected at Cape Adare [from the beach?] by C. E. Borchgrevink in 1895 and described and analysed by Edgeworth David, Smeeth and Schofield (1896, pp. 473–4). The analyses of these two rocks are given in Table X and their calculated 'Niggli values' at the top of Table XII.

The description by Edgeworth David, Smeeth, and Schofield of the 'trachyte' is as follows:—

Trachyte (*Nos.* 1 *and* 2)

"Compact, greenish-grey in colour, somewhat fissile. Sp. gr. 2.49. Under the microscope the rock is seen to be composed principally of sanidine microlites. There is a small proportion of lath-shaped triclinic microlites and of crypto-crystalline interstitial material. The sanidines are apparently all tabular in form, some slices showing nothing but tabular sections while others yield only lath-shaped ones.

The ferromagnesian constituent is represented by an aegirine which is present in considerable quantity (probably nearly 25% of the whole bulk). It exhibits brownish-green to bluish-green pleochroism with a small extinction angle. It is uniformly distributed in minute angular patches moulded on the feldspars with here and there a tendency to an elongated prismatic habit. In places it shows ophitic structure on a small scale. The only porphyritic constituents are a few rounded grains of this same aegirine and a few large grains of magnetite.

As accessory constituents there are a number of minute flakes of a brown biotite, some needles of apatite included in the feldspars, a few zircons and a little magnetite."

Among the many pebbles collected from Ridley Beach (this volume, No. 2, p. 138) are two of phonolitic trachytes [355, 369] whose mineral composition and structure agrees fairly well with the above description of Borchgrevink's specimen, probably also a pebble picked up on the shore (op. cit. 1896, p. 468), but the high SiO_2 in the chemical analysis implies that in this case the rock is 'saturated' and nepheline is absent from the norm.

TABLE X. CHEMICAL ANALYSES, NORMS, ETC. OF SANIDINITE AND TRACHYTE

39. Sanidinite. (I)II.5.1.(3)4.
Boulder from the 'agglomerate' on northern face of cliff, Cape Adare. D. I. Bothwell, anal. [686=B.M. 1953, 90(95)].

40. Trachyte, Edgeworth David, Smeeth and Schofield, 1896. Washington, 1917, p. 430.
Pebble collected by C. E. Borchgrevink, 1895, from the beach at Cape Adare. J. A. Schofield, anal.

TABLE X

a
CHEMICAL ANALYSES

	39	40
SiO_2	60·6	61·01
TiO_2	0·5	—
Al_2O_3	17·3	16·62
Fe_2O_3	1·9	3·55
FeO	4·3	2·81
MnO	0·2	0·55
MgO	0·4	0·06
CaO	2·5	3·27
Na_2O	6·7	5·92
K_2O	5·4	5·22
H_2O+110	0·3	1·13
H_2O-	0·2	—
P_2O_5	0·1	tr.
Cl	0·03	tr.
less O for Cl		
TOTAL	100·1	100·14

b
C.I.P.W. NORMS

	39	40
Q	—	0·84
or	31·9	31·14
ab	46·56	49·78
an	1·12	3·34
ne	5·57	—
di	9·20*	6·63
wo	—	2·20
hy	—	—
en	—	—
ol	1·74*	—
mt	2·76	5·10
il	0·9	—
hm	—	—
ap	0·27	—

The *di* has $CaSiO_3$ 4·43 and $MgSiO_3$ 1·0: *the *ol* is fayalite, Fe_2SiO_4.

TABLE X (continued)

c

CATION PER CENT

	39	40
SiO_2	55·3	56·5
TiO_2	0·33	n.d.
$\frac{1}{2}Al_2O_3$	18·58	18·15
$\frac{1}{2}Fe_2O_3$	1·35	2·45
FeO	3·24	2·17
MnO	0·15	0·44
MgO	0·54	0·11
CaO	2·45	3·23
$\frac{1}{2}Na_2O$	11·85	10·6
$\frac{1}{2}K_2O$	6·28	6·25
H_2O+	—	—
H_2O-	—	—
$\frac{1}{2}P_2O_5$	0·07	n.d.
TOTAL	100·14	99·90

d

'BASIS'

	39	40
Cp	0·2	—
Ru	0·3	—
Kp	18·9	19·8
Ne	35·5	32
Hl	0·1	—
Cal	0·7	2
Cs	3·3	3·9
Fo	0·8	0·02
Fa	4·9	3·3
Fs	2·0	3·7
Q	33·4	36·2
TOTAL	100·1	100·02
Q	33·4	36
L	55·1	53
M	11·5	11
π	0·013	0·04
γ	0·3	0·36

The sanidinite [686], as remarked above, was described in the previous number of this volume, a chemical analysis of its feldspar was given (p. 131) and its composition and optical properties were there discussed. The accompanying minerals recorded were: "brown amphibole, green pyroxene, biotite, and some opaque 'ore' "; and unidentified minerals perhaps representing altered cancrinite appearing in some small interstitial area (footnote, p. 133). Since the publication of that description of the minerals further determinations of optical properties of the biotite and of the brown amphibole have been attempted with the following results. The biotite is biaxial with 2V at least 20°. The refractive index, γ is near 1·67. Comparable high values for γ are recorded for siderophyllite and also for several biotites with high FeO and low MgO. Larsen and Berman[(1)] quote one with $FeO+Fe_2O_3$ 38·4% having γ=1·677, while G. Schauberger[(2)] quotes an analysis for a mica, said to be from Brevik, as having γ 1·697, the FeO being 24·36% and Fe_2O_3 16·48 with MgO 1·08.

(1) Larsen (Esper S.) and Berman (Harry). 1934. The microscopic determination of the non-opaque minerals. U.S. Geol. Surv. Bulletin 848, 1934, p. 238.

(2) Schauberger (G.). 1927. Biotit in tertiären Eruptivgesteinen Böhmens. Centr. f. Min., Abt. A., 1927, p. 103.

In the calculation of mineral composition from the bulk analysis below the mica is taken as almost pure annite which corresponds to the Fe-Biotite of Burri's conventional mica in the equivalent norm calculations.

The amphibole was found to have α' just above 1·716 and below 1·717 and γ' near 1·737 with extinction angle $c=\gamma$ 14°. The pleochroism is intense; α' cinnamon buff, γ' dusky olive-green. Owing to the high absorption a satisfactory measurement of the refractive index γ' is difficult to obtain. These properties indicate that the amphibole is probably referable to hastingsite and the high refractive indices point to its being near the ferrohastingsite end of this series as interpreted by Winchell.

A good example of a hastingsite with high refractive indices and high iron content quoted by Winchell [1] is a ferrohastingsite from rapakivigranite at Uuksunjoki, Salmi area, Finland: for which $a=1 \cdot 702$, $c\text{-}\gamma=12°$, 2V very small, and pleochroism, α pale greenish brown, β dark greenish brown, γ bluish green. The analysis of this amphibole shows Fe_2O_3 5·0, FeO 26·64, MgO 1·07. (Sahama, [2]). It is noteworthy that in the same rock the biotite has a and γ near 1·730 with 2V=22°.

For the composition of the feldspar we have the analysis by Mr. D. I. Bothwell referred to above. The sample was slightly impure and after allowing for this the composition arrived at was Or:Ab:An=36:62·6:1·4.

A further, rather rough, guide to the mineral composition of the sanidinite is provided by the relative proportions of feldspar to two fractions of magnetic coloured minerals as obtained in the magnetic separation used in preparing the feldspar sample for analysis. The separation was not originally made on a quantitative basis but the separate fractions were weighed later and showed:—

Non-magnetic; feldspar, 79·3%
moderately magnetic; amphibole and biotite, 17·2
most magnetic; magnetite, etc., 3·5

On calculating the 'basis' components from the analysis of the feldspar it was found that the ratio of Ne:Kp was 1·85. This is very close to the same ratio Ne:Kp for the sanidinite (Table X, col. 39) which is 1·88.

On starting to calculate the mineral composition from the 'basis' of the sanidinite it was decided to keep this Ne:Kp ratio as close as practicable to near 1·85–1·88, and this controlled the relative proportions of Ne to be allotted to the amphibole and pyroxene and of Kp to the biotite. The pyroxene was known to be aegirine-augite (p. 132). The biotite is to be calculated on Burri's formula

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[1] Winchell (A. N.). Elements of optical mineralogy, Part II, 4th ed., 1951, p. 435.
[2] Sahama (Th. G.). Rapakivi amphibole from Uuksunjoki, Salmi area. Bull. Com. Geol. Finlande, 1947, No. 140, pp. 159–162.

for Fe–Biotite, $6SiO_2.Al_2O_3.6(Fe,Mg)O.K_2O.2H_2O$; and the amphibole as ferrohastingsite according to the formula: $NaCa_2(Fe,Mg)_4Al_3Si_6O_{22}(OH)_2$ which can be written:

$$12SiO_2.3Al_2O_3.8(Fe,Mg)O.4CaO.Na_2O.2H_2O.$$

The Fe–Biotite is derived from Kp according to the equation:

$$6Kp+9(Fe,Mg)O+1Q(+2W)=16\ Fe\text{-}Bi.$$

The Na_2O for the amphibole must be derived from Ne, and, in addition Na_2O for acmite must also be found, as no Ns is available. This can be provided according to the equation:

(1) $6Ne+3Fs+1Q=8Ac+2C$, or

(1′) $12Ne+6Fs+2Q=16Ac+4C$.

The ferrohastingsite is made up according to the equation:

(2) $6Ne+6Cs+12(Fa,Fo)+4Q(+2W)=32Fe\text{-}Ha.$[1]

Combining equation 1′ and 2 to eliminate 4C on both sides of the equation we have:

(3) $18Ne+6Fs+6Cs+12(Fa,Fo)+6Q(+2W)=32\ Fe\text{-}Ha+16Ac.$

The fact that the units of Ne in this combined equation number 18 made it easy to keep the Ne taken for amphibole and pyroxene at near 1·8 times the Kp used for biotite. In fact the ratio was only disturbed by the need to take 0·3 Fa to combine with 0·2 of the Ru for ilmenite.[2]

The calculation of the mineral composition follows the methods given by C. Burri (1959, p. 121 *et seq*).[3] The final results obtained, shown in detail in the adjoining table, are:

Or	Ab	An	Ne	Sod	Wo	Ac	Fe-Bi	Fe-Ha†	Mt	Il	Tit	Cp	Total
28·5	49·5	1·2	1·3	1	2·6	3·2	4·8	6·4	0·8	0·4	0·3	0·2	100·2

In the feldspars and feldspathoids the final ratio Ne/Kp is 1·86. Feldspar constitutes 79·2% of the whole rock, and its percentage composition in terms of Or:Ab:An=35·9:62·5:1·6, which, is in very close agreement with the composition deduced from feldspar analysis, *viz*: 36:62·6:1·4.

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(1) Fe–Ha=ferrohastingstite.

(2) See footnote to Table XI.

(3) Burri (C.). Petrochemische Berechnungsmethoden auf Äquivalenter Grundlage. 1959, p. 121, *et seq.*

TABLE XI

CALCULATED COMPOSITION OF THE SANDINITE

Mineral composition derived from Basis	Kp	Ne	Hl	Cal	Cs	Fs	Fo Fa	Cp	Ru	Q	Totals
	18·9	35·5	0·1	0·7	3·3	2·0	0·8 4·9	0·2	0·3	33·4	100·1
6·4 *Fe*-Ha+3·2 Ac	–	3·6	–	–	1·2	1·2	2·4	–	–	1·2	9·6
4·8 *Fe*-Bi	1·8	–	–	–	–	–	2·7	–	–	0·3	4·8
1 Sodalite	–	0·9	0·1	–	–	–	–	–	–	–	1·0
0·4 Ilm [+0·1 Q]	–	–	–	–	–	–	0·3*	–	0·2	–	0·5
0·8 Mt [+0·4 Q]	–	–	–	–	–	0·8	0·4	–	–	–	1·2
2·6 Wo+0·3 Tit	–	–	–	–	2·1	–	–	–	0·1	0·7	2·9
1·2 An	–	–	–	0·7	–	–	–	–	–	0·5	1·2
28·5 Or	17·1	–	–	–	–	–	–	–	–	11·4	28·5
49·5 Ab	–	29·7	–	–	–	–	–	–	–	19·8	49·5
1·3 Ne	–	1·3	–	–	–	–	–	–	–	–	1·3
0·2 Cp	–	–	–	–	–	–	–	0·2	–	–	0·2
100·2+0·5 Q	–	–	–	–	–	–	–	–	–	–	–
—0·5 Q	–	–	–	–	–	–	–	–	–	—0·5	–
	18·9	35·5	0·1	0·7	3·3	2·0	5·8	0·2	0·3	33·4	100·2*

* 0·1 Fa in excess of the 4·9 available was added to avoid awkward arithmetic in calculating the hornblende, magnetite and ilmenite.

The Niggli values of all the analyses of the volcanic rocks from both Cape Adare and the Ross Archipelago are set out in Table XII in order of decreasing ***si***. It will be noticed that *qz* values differ from those given for analyses of Ross Archipelago volcanics in Tables I–VI in No. 1 of this volume. Those values were calculated incorrectly. The correct values are as now given in the last column but two of Table XII.

The collected analyses have been studied afresh using the variation diagram, the Q–L–M diagram and others illustrated in Figures 5–8 of the report on the Ross Island volcanics. In addition use has been made of a method employed by C. Burri in his recent study of the petrochemistry of the rocks of the Cape Verde Islands. This method introduced by A. Rittmann in 1933 plots on rectangular co-ordinates the 'Silicification-grade' (Si°) against the 'Acidity-grade' (Az°). These quantities, as defined by Rittmann, are calculated from the equations:

$$\mathrm{Si}^\circ = \frac{si}{100+4alk} \text{ if } al > alk; \text{ or } \mathrm{Si}^\circ = \frac{si}{100+3al+alk} \text{ if } al < alk$$

$$\mathrm{Az}^\circ = \frac{si}{si+al+fm+c+alk} = \frac{si}{si+100}$$

TABLE XII. 'NIGGLI VALUES' OF VOLCANIC ROCKS OF SOUTH VICTORIA LAND

	'Anal.'*	si	al	fm	c	alk	k	mg	ti	p.	c/fm	qz,	Si°	Az°
40. Sanidinite, C. Adare	D.I.B.	233	36·3	18·6	9·8	35·2	0·345	–	1·4	0·2	0·525	–8	0·97	0·70
39. 'Trachyte', C. Adare	J.A.S.	218	35	20	12·5	32·5	0·37	0·02	n.d.	n.d.	0·625	–12	0·95	0·69
2. Phonolite trachytic, Mt. Cis	H.	205	33·3	28·7	7·9	30·2	0·38	0·19	3·7	0·83	0·275	–15·8	0·93	0·67
38. 'Sodalite-trachyte', C. Adare	D.I.B.	204	35·5	18·6	6·0	39·75	0·313	0·11	0·62	0·2	0·32	–42	0·83	0·67
1. Phonolitic trachyte, Mt. Cis	D.I.B.	203	33	27	8·5	31·5	0·41	0·15	3·3	0·2	0·315	–23	0·90	0·67
5. Phonolitic trachyte, Brown I.	G.T.P.	200	45	6	5	43·5	0·33	0·13	0·8	–	0·83	–74	0·73	0·67
3. Trachytoid phonolite, C. Crozier	G.T.P.	192·8	40	14	6·5	39·5	0·32	0·1	1·0	0·1	0·465	–65	0·75	0·66
36. Phonolite, C. Adare	D.I.B.	190	37·2	14·8	5·9	42·2	0·27	0·095	0·6	0·2	0·4	–63·8	0·75	0·655
15. Kenyte (Jensen), C. Evans	H.	180	36·3	21·1	9·3	33·2	0·29	0·27	3·2	–	0·44	–52·8	0·77	0·64
16. 'Leucite-Kenyte' (Prior), C. Royds	G.T.P.	180	39	20	11	30	0·26	0·31	–	–	0·54	–40	0·82	0·64
14. Vitrophyric Kenyte, C. Evans	H	178·5	36	22	11	31·5	0·29	0·23	3·3	–	0·47	–47·5	0·79	0·64
37. Trachytoid phonolite, C. Adare	D.I.B.	175	33·6	21·8	12·1	32·5	0·24	0·225	1·5	0·2	0·55	–55	0·76	0·64
4. 'Phonolitic trachyte' (Prior), Scott I.	G.T.P.	172	35·3	23	11·6	30	0·24	0·1	1·5	0·17	0·5	–48	0·78	0·63
13. Kenyte, C. Evans	D.I.B.	172	36	20	11·8	32	0·29	0·25	–	–	0·59	–56	0·755	0·63
6. Trachytoid phonolite, Hut Pt.	G.T.P.	169	37	18	11	34	0·28	0·36	3·1	0·04	0·61	–67	0·72	0·63
17. Kenyte-pumice, Mt. Erebus	J.D.E.	158	34	24·2	8·5	33·2	0·24	0·21	–	–	0·35	–74·8	0·68	0·61
7. Trachytoid phonolite, C. Bird	B. & W.	148	32·5	27	14	26·5	0·25	0·3	3·0	0·34	0·52	–58	0·72	0·60
23. Plagioclase-Kenyte, Turk's Hd.	H.	126	29	31	22	18	0·26	0·57	5·2	0·1	0·74	–46	0·73	0·56
22. 'Kulaitic Basalt', C. Bird	B. & W.	122	33·4	30	23·4	13·2	0·25	0·47	1·7	tr.	0·78	–31	0·80	0·55
24a. Basalt, Little Razorback I.	D.I.B.	118	24	38	22·5	14·5	0·21	0·39	0·55	1·65	0·59	–40	0·75	0·54
24. Hornblende-basalt (Prior), Mt. Terror	G.T.P.	116	29·5	32·5	20	18	0·24	0·34	1·2	0·88	0·61	–56	0·675	0·54
34. Olivine-basalt B., C. Adare	D.I.B.	110·5	23·1	39·1	24·7	13·1	0·19	0·4	5·9	1·3	0·71	–41·6	0·73	0·525
26a. Basalt, Cape Barne	D.I.B.	110	24	38	24	14	0·22	0·385	0·56	1·7	0·63	–46	0·705	0·52
33. Olivine-basalt A, C. Adare	D.I.B.	102	22·75	37·2	24	16	0·23	0·38	5·7	1·1	0·64	–62	0·62	0·505
27. Hornblende-basalt, Hut Pt. Pen.	G.T.P.	100	23·2	40·5	23·2	13·2	0·23	0·41	0·18	0·02	0·57	–52·8	0·65	0·50
26. Basalt, C. Barne	H.	100	21·6	46·2	21·75	10·4	0·23	0·48	0·86	0·01	0·47	–41·6	0·70	0·50
35. Olivine-basalt, C., C. Adare	D.I.B.	97	20·7	41	24·5	13·5	0·21	0·44	6·5	1·08	0·60	–57	0·63	0·49
30. Olivine-basalt, Cheyenne Crater	N.E.B. / D.I.B.	91	19	48	25	8	0·21	0·48	0·6	–	0·51	–41	0·69	0·47
32. 'Leucite-tephrite' (Jensen), Hut Pt. Pen.	H.	89·3	17·4	51	25·8	6·3	0·30	0·55	0·73	0·08	0·51	–35·9	0·71	0·47
31. Olivine-basalt, Taylor Valley	D.I.B.	89·1	18	50	23	8·7	0·25	0·46	0·84	0·05	0·46	–45·7	0·72	0·47
29. Olivine-basalt, Hut Pt. Pen.	G.T.P.	87	18	49·5	23·5	9	0·27	0·55	0·8	0·05	0·475	–49	0·64	0·46
25. 'Limburgite' (Jensen), Mt. Erebus	B. & W.	87	11·7	57·5	26·4	4·6	0·19	0·75	0·34	0·03	0·46	–31·4	0·73	0·46
28. Olivine-basalt, Hut Pt. Pen.	G.T.P.	86	18	50	23	9	0·26	0·57	0·75	0·04	0·46	–50	0·63	0·46

* Abbreviations of analysts' names:—

B. & W. = Burrows and Walkom.
D.I.B. = D. I. Bothwell.
G.T.P. = G. T. Prior
H. = Hogarth.
J.D.E. = J. D. Easton.
N.E.B. = N. E. Butcher.

Plotting the analyses on this Si°–Az° diagram shows that apart from the first five analyses in Table XII all the analyses can be regarded as belonging to a single series.

The sanidinite from the agglomerate at Cape Adare, the analysis of the 'trachyte' described by Edgeworth David and others, and the two analyses of the 'Mount Cis' phonolitic trachyte are rather widely separated from the rest. The peculiar composition of these Mount Cis rocks with their xenoliths of partly digested sediments has been commented on earlier (this volume, p. 25 and p. 93). The analysis of the sodalite-trachyte (38), which is also from the agglomerate at Cape Adare, also has slightly high Si° and Az° relative to the main body of the volcanics.

Otherwise only two other analyses lie a little apart owing to their slightly high Si°. These are a 'Kulaitic basalt' (22) described by Jensen, and Prior's type 'leucite-kenyte' (16).

Apart from this slight divergence nothing new has been observed to indicate that any real significance should be attached to the author's suggestion that the lavas of Mount Erebus itself do not fall in the same differentiation series as the "Hut Point Peninsula–Cape Bird lavas" (this vol., p. 93). It appears rather that the Ross Archipelago lavas and the Cape Adare lavas can be treated together as one series.

The Si°–Az° diagram brings out another point that may be of interest. Burri in his study of the petrochemistry of the Cape Verde Islands was led to distinguish: a series (III) of extremely undersaturated and often melilite-bearing rocks; a series (II) of feldspathoid-rich rocks; and two series (Ia and Ib) of basaltic-trachytic and basaltic-phonolitic rocks. The Si°–Az° diagram for the South Victoria Land volcanics shows a distribution of points comparable with the series Ib, basaltic-phonolitic series, of the Cape Verde Islands. Following up this suggestion by plotting the Niggli values for this series on the variation diagram for the Ross Archipelago volcanics (this vol., fig. 5) one finds a good general agreement between the two. The agreement is better than that between the variation diagrams for the Ross Archipelago and the Tristan da Cunha volcanics plotted by Burri and Niggli as a representative of an assemblage of Atlantic type, which as previously remarked (this volume No. 1, p. 93) show a general similarity.

Rocks of these different series which have similar Niggli values have not been found, on examination of their thin sections, to resemble each other closely in mineral composition and texture but, in spite of that, the above comparisons as regards the petrochemistry do add to the evidence that the South Victoria Land volcanics belong to the 'Atlantic type'. It would be very interesting to make similar comparisons with volcanic rocks from Mount Kenya and Mount Kilimanjaro in particular and from the Rift Valley in general whenever sufficient analyses of rocks from these areas are available.

II. THOLEIITES FROM THE PRIESTLEY GLACIER, TERRA NOVA BAY REGION

Among the erratics collected by Priestley from the outer moraines of the Priestley Glacier are some fine-grained greyish olive to brownish drab rocks with abundant amygdules or vesicles filled with white zeolites.

These rocks look so much like old volcanic rocks that they were not described along with the hypabyssal rocks of the Terra Nova Bay region although, as will appear, they are very closely akin to the quartz-dolerites many erratics of which occur also in the Priestley Glacier outer moraine.[1]

So far as this author is aware 'vesicular' rocks similar to these have not been recorded elsewhere in South Victoria Land by any of the later Antarctic expeditions. It seems worth while therefore to describe Priestley's specimens in some detail.

A. Vesicular fine-grained to medium grained basalts related to the quartz-dolerites.

Nos. 1620, 1831, 1710, 1785, 1945=B.M. 1953, 89 (18, 19, 20 and 21, 40 and 41).

A group of these erratics very similar in texture to quartz-dolerites but containing many irregular druses or small vesicles and a few amygdules filled with zeolites. They are light greyish olive to hair brown in colour, medium-grained, and aphyric. They consist of stout laths of plagioclase, laths of colourless pyroxene, a few small magnetite cubes, and much interstitial dark mesostasis. The pyroxene occurs as plates between or partly enclosing the feldspar, so that the texture is partly micro-ophitic (pl. 1, fig. 1).

The plagioclase is labradorite. The laths show albite and Carlsbad twinning and maximum symmetrical extinction angles measured on the universal stage indicate compositions ranging from An_{63-70}. The pyroxene, nearly colourless in thin section, has 2V 50° to 60°, and $c{:}\gamma$ 43°–45°.

The interstitial mesostasis in 1710 is very dark, frequently opaque, but translucent where the section is very thin and it can then be seen to be turbid glass with swarms of globulites, short black rods, and very slender colourless feldspars. The two other specimens of this group (1620, 1831) have interstitial glass transparent and faintly buff coloured in 1620 and ochraceous buff to ochraceous tawny in 1831.

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(1) Smith (W. Campbell). 'The plutonic and hypabyssal rocks of South Victoria Land'. Brit. Ant. ("Terra Nova"). Exp. 1910. Nat. Hist. Rep. Geology, Vol. 1, No. 6, 1924, p. 214, and map, fig. 1, in vol. 1, No. 5b, p. 146.

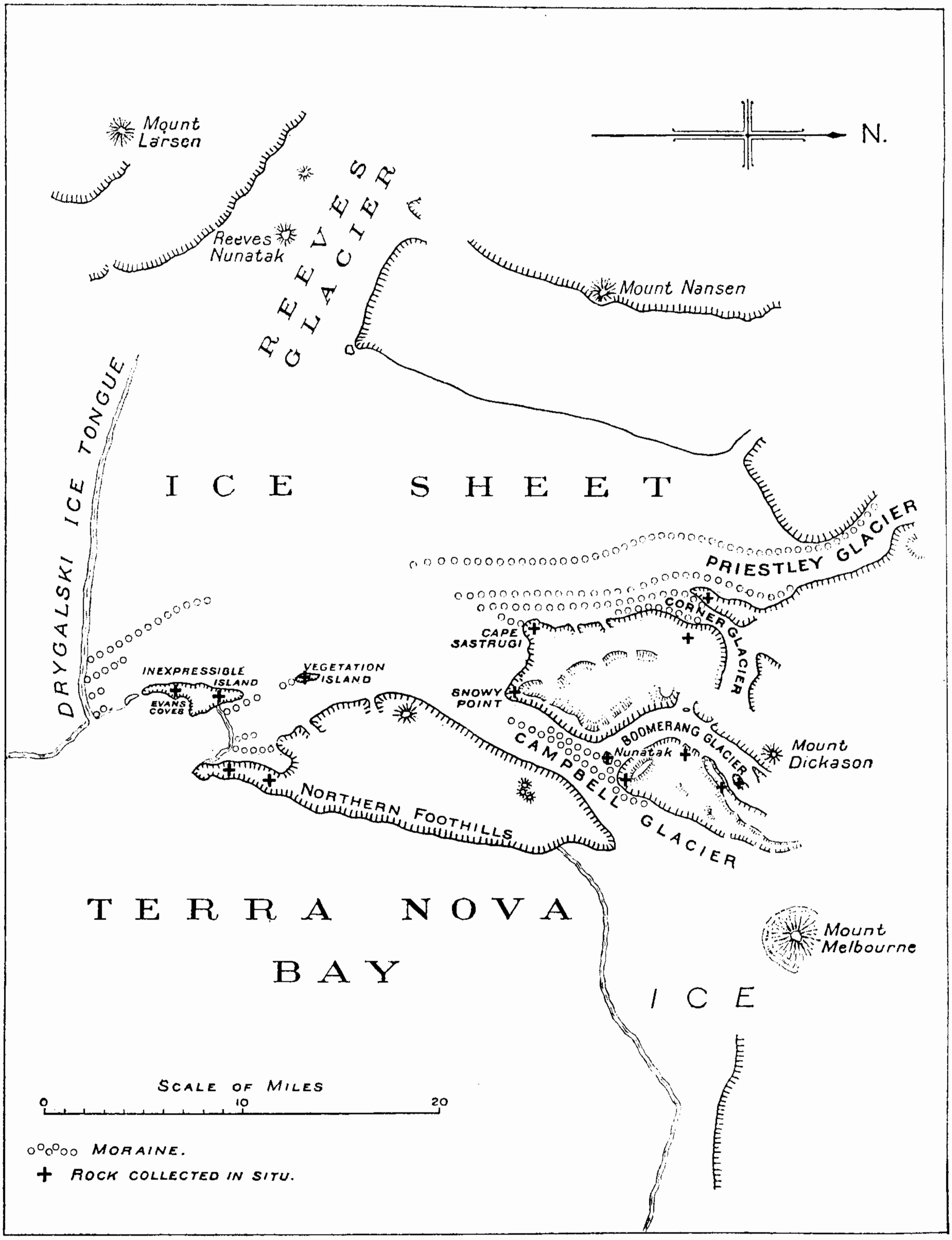

Fig. 1. Map of Terra Nova Bay Region.

A remarkably fresh and compact specimen (1945) is probably related to these. It is olivaceous black to iron-grey in colour. Its texture is ophitic and the mesostasis, which occurs in numerous small patches, is a cinnamon-buff glass with abundant hair-like crystallites.

Other related but finer grained, compact, specimens (1711, 1807, 1895, 1896), several with a very thin platy fracture, have the dark mesostasis gathered in numerous irregular patches occasionally up to 7 mm. across. This mesostasis has crystallized out yielding abundant slender curved feldspars and fern-like skeletal growths of magnetite in a cryptocrystalline perhaps partly quartzose base. Within the patches of mesostasis there are often also slender skeletal plagioclase laths and very long slender augite prisms (1896).

B. In contrast to this group with very few vesicles and a close approach to dolerite in texture there are several specimens of a fine-grained aphanitic basalt, greyish olive in colour which show numerous large vesicles filled by white zeolites and in one case as much as 7 cm. in length. [Nos. 1254, 1798, 1831, 1830]. In thin section these rocks are seen to consist of laths of plagioclase, augite, and some coloured interstitial mesostasis. The feldspar laths form a mesh or framework within which lie platy crystals and grains of pyroxene. There are numerous small, rounded vesicles in addition to the large ones so conspicuous in the hand-specimens (pl. 1, fig. 3).

The plagioclase shows albite and Carlsbad twins with symmetrical extinction angles of 30° to 35° indicating labradorite about An_{57-63}. The pyroxene is augite with moderate 2V and $c{:}\gamma$ 39°. In one specimen [1830] augite occurs as microinsets as well as in the groundmass. The mesostasis, vinaceous fawn to russet vinaceous in colour gives weak aggregate polarisation and contains inclusions of small rods or lines of cubes of magnetite (?). Presumably this is devitrified glass. The fieldspars in these specimens are partly replaced by zeolites.

C. Closely resembling this group in mineral composition and texture are specimens of fine-grained basalts with numerous sub-rounded vesicles and amygdules partly filled with zeolites. The colour of this group is dark vinaceous drab to deep brownish drab. The plagioclase and augite are similar to those in the group just described, but in some of the specimens the feldspars are partly replaced by a colourless isotropic zeolite, probably analcime (?). Small amounts of fine-grained magnetite (?) occur usually near the margins of the area of mesostasis. The mesostasis varies much in amount from one specimen to another. It is pale brown in colour, is weakly birefringent, and contains opaque granules and crystallites, and occasionally also very long, slender feldspars. The feldspars and pyroxene seem to be similar to those in the paler coloured vesicular basalts described above. Extinction angles in the plagioclase laths indicate labradorite near An_{63}. The augite has 2V about 52° and $c{:}\gamma$ 43°. It occurs in prismatic (columnar) crystals rather than as plates and grains and though frequently penetrated by feldspar laths, the two minerals are fairly evenly distributed and both are immersed in, or wrapped around by, the coloured mesostasis. Specimen No. 1817 is similar to this.

Another example [1783] is a fine-grained aphyric basalt, iron-grey to olivaceous black in colour and has frequent roughly spherical vesicles of which the majority appear to be empty, while some very small 'druses' are filled by green chloritic material. The thin section shows a few small insets of a colourless pyroxene and some micro-insets of plagioclase. The pyroxene is enstatite with optic axial angle near 90°, indicating about 20% $FeSiO_3$. The plagioclase of some of the micro-insets is bytownite near An_{85}, but the feldspar laths of the groundmass are labradorite-bytownite with a range from An_{63} to An_{75} to judge from extinction angles measured on the universal stage.

In this rock the plagioclase laths are very sharply defined. They penetrate and are partly enclosed by the colourless augite crystals of the groundmass. Interstices are filled by dark 'glass' which, in very thin section, has a brownish drab colour and is crowded with minute opaque globules and a few black rod-like bodies. Very noticeable in the section of this specimen are circular areas filled with black 'glass' like that of the interstitial mesostasis and in these have crystallized slender, sometimes curved, laths of feldspar, and similarly slender and skeletal, augite prisms. Small vesicles within these spherical bodies are filled by pale green chlorite. A typical example of one of these spherical mesostasis-filled vesicles measures 1·5 mm. in diameter. (Pl. 1, fig. 4). Other examples filled by a lighter coloured mesostasis occur also in No. 1823. Similar mesostasis-filled amygdules have been described from the tholeiite of the Coley Hill dike, nr. Newcastle, Northumberland.(1)

Another specimen to be mentioned is a fine-grained, deep greyish-olive basalt with some very small 'druses' filled by white zeolitic material but not otherwise vesicular. Green material resembling celadonite coats one part of the specimen [1836].

There are rare micro-insets of plagioclase and a few small insets of pyroxene. The pyroxene insets are of two kinds. Many are augite, with $c{:}\gamma$ 41° and 2V 70° to 75°; the others, less frequent, are nearly uniaxial pigeonite. Both pyroxenes are colourless in thin section. The texture of the groundmass is intersertal (pl. 1, fig. 2). It consists of small laths of labradorite (about An_{63}), granular pyroxene, frequent very small grains of magnetite (?) and a mesostasis of birefringent material, which may be cryptocrystalline quartz-feldspar aggregate. Its

(1) Holmes (A.), and Harwood (H. F.). The tholeiite dikes of the North of England. Min. Mag., 1929, Vol. 22, pl. 2, fig. 4, and p. 31.

effective refractive index is below that of canada balsam. Occasionally the mesostasis shows traces of radial structure. The augite grains in the groundmass are slightly altered and darkened at their edges, and there is also present some green chloritic material which occasionally invades the larger feldspar laths.

D. Specimens of greyish olive aphanitic basalt [1454, 1618A, 1947, 1972], some of which have a glassy, tachylytic, selvage along one face, probably represent a marginal facies of rocks like those described above [1254, 1798, 1830, etc.] (p. 169). They have elongated, irregularly shaped vesicles filled with fibrous zeolites.

Under the microscope it is seen that there are frequent micro-insets of labradorite and rare, colourless micro-insets of an orthorhombic pyroxene. This is enstatite with 2V very near 90°. The whole of the groundmass is microspherulitic. In very thin parts of the sections it can be seen that many of the spherulitic growths have formed about a skeletal prism of clino-pyroxene, and that from this radiate fine fibres and beautiful feathery growths of feldspar. The fibres in the spherulites are extremely slender and the general effect in thin section is to give a prevailing turbid brownish colour to the groundmass.[1]

All the rocks here described are more or less vesicular. In several specimens the vesicles are up to 7 cm. in length and filled by fibrous zeolites in others they are smaller, rounded and only partially filled. In most cases there are very narrow linings of a chlorite-like mineral, and in some specimens green material of this kind completely fills small vesicles or druses. Preliminary identifications of the zeolites occupying the vesicles in these rocks were made by Mr. M. J. Canham while working in the Department of Mineralogy as a vacation student in the summer of 1960.

The rather large, conspicuous, vesicles described above in one group of these rocks (p. 169) are filled mainly by stilbite, which occurs in long prismatic groups sometimes completely filling the rather flattened vesicles. The dominant zeolite in the smaller, rounded vesicles in No. 1830 is heulandite,[2] associated with analcime and very finely fibrous natrolite or thomsonite:

Little vesicles in the rather fine-grained tholeiites in the first group described (p. 167) are sometimes completely filled by single plates of stilbite and others have a fibrous zeolite, thomsonite or scolecite, in a matrix of analcime. Occasionally the centre is filled by quartz.

Small vesicles in the brownish drab tholeiites (p. 169) are occupied by stilbite associated with some heulandite, and the same two zeolites are found in the

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(1) This structure resembles those described in some spherulitic tachylytes, e.g. in some of the tholeiites of Mull. Mem. Geol. Survey Scotland, 1924, Tertiary . . . geology of Mull . . . p. 285.

(2) Heulandite in No. 1830 was confirmed by X-ray powder photograph (X. 8968).

vesicles of the greyish-olive microspherulitic specimens (D. p. 171). In this last group apophyllite also is present, and is readily recognized by the pearly cleavage surfaces displayed. It is associated also with fibrous natrolite.

The above description shows that these fine-grained vesicular rocks have much in common as regards both mineral composition and texture. It seems probable that they are closely related to one another and are probably all derived from the same rock formation.

Petrographically they are similar to tholeiites. Comparison with thin sections of typical tholeiites from well known localities confirms this. For instance there is a striking resemblance between the fine-grained, greyish-olive 'basalt' 1836] (p. 170) and a specimen of tholeiite from the Acklington dike at Debdon near Rothbury, Northumberland. A further point of resemblance with the tholeiites of the north of England is the presence in the fine-grained 'basalt' [1783] of spherical vesicles filled with the dark mesostasis described above (p. 170). Precisely similar spherical vesicles were described from the Tynemouth dike by Sir J. J. H. Teall in 1889,[1], and, more recently, they have been recorded and figured by Holmes and Harwood in the Coley Hill dike, a tholeiite of Acklington type.[2] Teall noted the spherical form and also the fact that the plagioclase laths lie tangentially to the surface of the spheres and he gave the explanation of these structures. They are bubbles formed after the crystallization of the insets and feldspar laths and before the consolidation of the groundmass. The mesostasis oozed into some of the bubbles completely filling some and partially filling others. In the Antarctic counterpart [1783] some of the bubbles contain no mesostasis. These are lined with chlorite but may be otherwise empty.

Another point that calls for special remark is the identification of small insets of pigeonite together with insets of augite in specimen 1836, and of small insets of orthopyroxene near enstatite in specimens 1783 and 1785 and in the microspherulitic 'basalts' (D. p. 171).

The early formation of enstatite or hypersthene in tholeiites is well known. Holmes and Harwood (op. cit. p. 29 and p. 31) have recorded it as 'rare stumpy prisms' in the Acklington dike referred to above, and the Coley Hill dike is a similar type. On the other hand the presence of insets of pigeonite in effusive rocks is exceptionally rare as noted by Hess.[3] H. Kuno[4] described it as insets in the pyroxene-andesites of the Hakone volcano, Honshu, Japan, where its pre-

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(1) Teall (J. J. H.). On the amygdaloids of the Tynemouth dyke. Geol. Mag., 1889, dec. 3, Vol. 6, pp. 481–3, pl. 14.

(2) Holmes (A.) and Harwood (H. F.). Min. Mag., 1929, Vol. 22, p. 31 and pl. 2, fig. 4.

(3) Hess (H. H.). Pyroxenes of common mafic magmas. Amer. Min., 1941, Vol. 26, p. 533.

(4) Kuno (H.). Preliminary note on the occurrence of pigeonite as phenocrysts in some pyroxene-andesites from Hakone volcano. Journ. Geol. Soc. Japan (Tokyo), 1935, Vol. 42, pp. 39–44.

sence has been explained by supposing that the pigeonite began to crystallize in depth and the magma containing it was suddenly extruded.[1]

In Mull A. L. Hallimond recorded uniaxial augite (pigeonite) as rounded insets in an inninmorite intrusive sheet at Pennygael[2]. Also under the name of enstatite-augite it is recorded in Mull[3] as small rounded insets in craignurite, and in the form of pseudomorphs in rocks ranging from granophyre to quartz-dolerite, but all these are intrusive rocks. It seems most likely that our erratic [1836] containing pigeonite is itself an intrusive rock.

The same conclusion as to their probable intrusive character, may be drawn from the petrography of many of the other rocks here described as tholeiites. All the tholeiites of the north of England described by Holmes and Harwood are dike-rocks, and the tholeiites of Mull and Ardnamuchan are either cone-sheets or dikes. Most of the European tholeiites are intrusive rocks.

It seems very likely then that except perhaps for the most highly vesicular examples these tholeiite erratics are derived from small intrusions and not from lava flows. As such they will represent a fine-grained variation of the quartz-dolerites and these in turn presumably belong to the great dolerite sills intruding the Beacon Sandstone which is abundantly represented among the erratics of the Priestley Glacier. The highly vesicular specimens may indeed be derived from effusive rocks and if so they are the only evidence of a volcanic phase of the Ferrar Dolerite[4] so far recorded.

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(1) Hess (H. H.), op. cit. supra, p. 581.

(2) Hallimond (A. L.). Optically uniaxial augite from Mull. Min. Mag., 1914, Vol. 17, p. 97.

(3) Bailey (E. B.) and others. Tertiary and Post-Tertiary Geology of Mull . . . Mem. Geol. Surv. Scotland, 1924.

(4) Harrington (H. J.). Nomenclature of rock units in the Ross Sea Region, Antarctica. Nature, 1958, Vol. 182, p. 290.

III. VOLCANIC ROCKS FOUND AS ERRATICS IN THE TERRA NOVA BAY REGION

Several small erratics of volcanic rocks were found by Priestley in the moraines of the Boomerang and Campbell Glaciers. Some were collected at Camp 7 on 19th Jan. 1912, a few at the nunatak at the entrance of the Boomerang Glacier, and a few more further out near Inexpressible Island (*see* map, fig. 1). The Campbell Glacier commences 'on the neck between Mount Dickason and Mount Melbourne'[1] Priestley found a granite ridge covered with erratics among which olivine-basalt was very common, and a nunatak up the glacier was found to consist 'of red and black basalt, being quite clearly the southernmost outlier in this region of the volcanic series' [of Mount Melbourne].

The Boomerang Glacier is a tributary of the Campbell Glacier coming in on its westward side with walls of granite and schist but in its upper course it bends north-east and is probably fed by ice which comes from between Mount Dickason and Mount Melbourne as in the case of the Campbell Glacier (op. cit. p. 61).

Distant observations by Ferrar and others have indicated that Mount Melbourne consists of volcanic rocks[2] but it has never been reached. Specimens collected on the Southern Cross Expedition labelled 'Newnes Land' were thought to have come from Mount Melbourne, presumably coastal cliffs, but the specimens arrived in London unlabelled and their localities were only guessed at by Lieutenant Colbeck and L. Bernacchi by comparisons with their own specimens and from memory. Such material cannot be regarded as trustworthy samples. The erratics from the Boomerang-Campbell moraines collected by Priestley thus provide the first reliable samples of the rocks of the Mount Melbourne volcanic centre.

Seven of the erratics collected are basalts. One (1496), hematite-red in colour, is fine-grained, and slightly scoriaceous and contains some inclusions consisting of granular quartz. These resemble fragments of Beacon Sandstone. A fresher example probably of the same kind of basalt is from the nunatak at the entrance of Boomerang Glacier (1500 J). This is a very fine-grained, slightly vesicular black basalt. It has abundant micro-insets of plagioclase, olivine, and augite in a black, extremely fine-grained base of feldspar microliths, grains of magnetite, and pyroxene and some doubtful interstitial glass.

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[1] Priestley (R. E.). Physiography (Robertson Bay and Terra Nova Bay Regions). Brit. (Terra Nova) Ant. Exp. 1910-1913, 1923, p. 59.

[2] See this volume, footnote, p. 111.

Similar to this but with the insets of plagioclase, augite and olivine all better developed is 1357 T. The plagioclase is labradorite near An_{62}. [The augite, very pale buff, has 2V near 60°]. The groundmass is extremely fine-grained and very dense. A small inclusion seen in the thin section of this basalt consists of granular quartz.

Two of the basalts contain insets of olivine up to 1 cm. across in a fine-grained base iron-grey in the hand-specimen. This groundmass consists of abundant laths of labradorite, augite and small cubes of magnetite with an interstitial colourless base. In one of the specimens (1304) this is crowded with minute rods of ilmenite or magnetite, but in the other (1503) some of it appears to be alkali-feldspar containing minute flakes (biotite ?) and needles of apatite (?).

The remaining two basalts (1499, 1502) are similar in the hand-specimen to the last described (1503) but, in addition to the large olivine insets, they have large black insets of augite as well. The groundmass is very fine-grained and iron-grey in colour. It consists of abundant laths of labradorite (An_{55}), crystals of augite and cubes of magnetite (?) and occasional olivines, with small amounts of a colourless base. This colourless base contains abundant little hair-like and rod-like crystallites arranged in parallel groups like skeletal crystals.

These basalts with insets of augite and olivine resemble tolerably well type C from Cape Adare (p. 118) except that brown hornblende is not found in the erratics from the Boomerang–Campbell moraines. The three basalts with insets or micro-insets of plagioclase, augite, and olivine are less confidently compared with the black glassy olivine-basalts, type A (p. 115). These two varieties of basalt, as has been shown in an earlier chapter (p. 151), are very similar in composition though slightly different in the habit and distribution of the minerals. It must be noted also that basalts like the Cape Adare, type C, with augite and olivine insets are represented among erratics on the plateau above the Cape (p. 138). Also one of the second group (1496) matches tolerably well some pebbles from Ridley Beach (343 and 430), and one erratic from the Newnes Glacier (GN 962).

The middle group (1304, 1503) with insets of olivine up to 1 cm. across find no exact match among the Cape Adare specimens, but there are similar basalts in the Hut Point Peninsula, e.g. D25H and D20H from Harbour Heights (p. 77), and also among the basalts from the recent craters on the mainland in the Ferrar Glacier region (D2F, p. 89).

One of the basalts with large augites and olivine (1500) also can be matched by specimens from these recent craters (D13K and D16F).

It is interesting also to note that inclusions of sandstone and of dolerite were detected in the basalts of Cheyenne Crater and from the lava flow on the opposite side of the Taylor Valley as they are in some of the erratics from the Boomerang–Campbell moraine.

One of the basalts of the Boomerang–Campbell moraine (Camp 7, 19/1/12) is a trachybasalt, perhaps comparable to mugearite (1511). It is fine-grained, aphanitic, and slate-olive in colour. This contains some micro-insets of plagioclase and augite, and small magnetites in a very fine-grained groundmass of short laths of oligoclase (An_{25}), small magnetites, many bright, colourless, little crystals of olivine and augite, abundant small cubes of magnetite and a colourless interstitial base of alkali-feldspar.

There is one other specimen like this among the erratics from the Priestley Glacier.

Similar rocks are found among the pebbles on Ridley Beach (332, 333). One of these is described (p. 139) as 'either trachybasalt or tephrite'. It has a better developed trachytic texture. Another rather similar pebble but definitely more basic was described as an aphanitic basalt 'perhaps near to the trachybasalts' (372, p. 139).

Some of the basalt erratics described above (1304, 1503) were compared with basalts from Hut Point Peninsula.

Another close similarity between specimens from the Hut Point Peninsula and erratics from the Boomerang-Campbell moraines is found in a specimen of basalt-tuff (1290, 1334). This is very similar to a tuff from 'Boulder Cones' (D28H), p. 15. Similar tuffs were also found by Priestley in the moraines of the Murray Glacier and have been fully described (p. 145). The specimen from the Boomerang–Campbell moraine contain precisely similar lapilli of yellow-glass and basalt lapilli with a very fine-grained groundmass but they do not contain the variety of lapilli found in the Murray Glacier tuffs. The glassy lapilli consist of buff yellow to maize-yellow glass crowded with small spherical vesicles, and also spheres of slightly darker yellow 'glass' showing a black cross between crossed nicols. In addition there are frequent crystals of plagioclase and of colourless olivine. Some of the spherical vesicles contain tufts of a colourless mineral with positive elongation and refractive index less than balsam, probably a zeolite.

Besides the erratics of olivine-basalts Priestley found a few of alkali-trachytes. One of these (1500 H) was collected at the nunatak at the entrance to the Boomerang Glacier. The others were found among erratics on Inexpressible Island.

The specimen from the nunatak is a rounded pebble, deep olive-grey on a freshly broken surface, and very slightly vesicular. It consists of small laths and plates of alkali-feldspar with frequent small grains and prisms of pale green pyroxene and very small magnetites. Some of the pyroxene is interstitial to the feldspar laths, but there is also some rather turbid interstitial material and some which is colourless and isotropie and so may be sodalite. The only micro-insets are of a greenish-grey pyroxene as crystals, 0·05 mm., across and somewhat larger crystals of nearly colourless olivine and of magnetite. These average 0·18 mm. in diameter.

The other alkali-trachytes, from Inexpressible Island, came no doubt down the Campbell or Boomerang Glacier. They are very small fragments, tea-green in colour and showing on the broken surfaces glistening feldspar cleavage faces. In thin section they are seen to have a fine-grained groundmass consisting mainly of slender laths of alkali-feldspar, like that of the specimen just described, but they have also frequent insets of alkali-feldspar, and micro-insets of a green pyroxene and of magnetite. No olivine micro-insets were seen. The pyroxene is pleochroic from deep grape-green to honey-yellow. The feldspar insets are simple Carlsbad twins and have extinction angles of 10° to 15°.

Alkali-trachytes rather similar to these are known among the pebbles on Ridley Beach (668, 579, 584, p. 135), and they occur also as erratics on the plateau on the top of Cape Adare (p. 136) and as boulders in the agglomerate in the face of the cliff at the north end of the Cape (p. 129).

The erratics on the plateau may have been carried by ice from the Mount Melbourne–Mount Dickason volcanic centres (*see* Priestley, op. cit. 1923, p. 10), and the pebbles on Ridley Beach may be derived either from erratics fallen from the plateau, or from material carried up the coast from further south, but the alkali-trachyte boulders in the agglomerate cannot be accounted for in either of these ways. Either they must be erratics like the 'quartzite' and dolerite and other igneous rocks described by Priestley, or they must be volcanic rocks thrown up or brought into the agglomerate of a volcanic vent, as the sanidinite 'bombs' must have been (this volume, p. 135). In either case they would be among the earliest volcanic rocks of the Cape Adare centre. (Priestley, op. cit. 1923, p. 11).

No volcanic rocks of this kind were found associated with basalts of Hut Point Peninsula, but somewhat similar rocks are recorded from the neighbourhood of Mount Terror and Cape Crozier, and on the Dellbridge Islands in the McMurdo Sound Region as well as from a debris heap on Minna Bluff (p. 147).

That they are available at some places down the coast between Cape Adare and Newnes Bay is indicated by the presence of phonolitic trachytes and trachytoid phonolites in material dredged off Cape Adare and west of Coulman Island (p. 147), and Lieutenant Colbeck on the Southern Cross Expedition found a fragment of alkali-trachyte or phonolitic trachyte on an ice-floe in Wood Bay.[1]

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[1] Prior (G. T.), Report on the rock-specimens collected by the 'Southern Cross' Antarctic Expedition. *In* Report on the collections of Natural History made in the Antarctic Regions . . . London, 1903, p. 330.

It is more fine-grained than any of the Ridley Beach alkali-trachyte pebbles examined, but clearly related to them.

An erratic of kenyte (1312) found at Evans Coves is of considerable interest.

Numerous erratics of this readily recognizable porphyritic lava were recorded by Edgeworth David and Priestley during the Shackleton Expedition on Cape Roberts south of the entrance of Granite Harbour at about 20 to 30 feet above sea-level. Their presence there was attributed to transport by floating ice from Ross Island[(1)].

Priestley found two kenyte boulders on the raised beach at Evans Coves of which the specimen now described is one. It measures 20 × 14 × 6 cm., is roughly elliptical in outline, and one side is discoloured as if it had lain in one position for a long time. The other specimen was the size of a man's head. The two blocks of kenyte lay, the one at 80 and the other about 50 feet above sea-level. At this level local erratics were almost wanting. Also nothing approaching kenyte in composition or appearance was seen amongst the erratics found on the foothills or on the moraines of the glaciers.[(2)] Priestley concludes that the two boulders of kenyte 'came from the south in the neighbourhood of McMurdo Sound, probably from one of the spurs of Mount Erebus itself, on a piece of floe ice or a small berg which stranded on the beach before the recent elevation [of the beach] had commenced'. (Priestley, op. cit. 1923, p. 56). This is an important piece of evidence in support of Priestley's opinion that the raised beach at Evans Coves is very recent.

The identification of the boulder (1312) with kenytes described from Ross Island is amply confirmed by the petrographical examination of the specimen.

A cut surface on the specimen shows abundant typical lozenge-shaped insets of 'anorthoclase' up to 2 cm. in cross-section in a black, slightly vesicular, glassy base. The crystals have not weathered out much on the surface. In thin section the glass is near cinnamon buff to pale pinkish buff. In addition to the anorthoclase there are some pyroxene insets accompanied by small magnetites and apatites and occasional small olivine crystals. In all these respects the boulder closely resembles several of the glassy kenytes described from Ross Island.

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(1) David (T. W. E.) and Priestley (R. E.), Brit. Ant. Exp. 1907–9, Geology, vol. 1, 1914, p. 82.

(2) The only other specimen with anorthoclase insets that has been found in the Terra Nova Bay or Cape Adare Region is one collected on the Southern Cross Expedition at Cape Adare [B.M. 85752, 24]. This was described by Prior (op. cit. 1903, p. 329) and re-described on p. 137 of this volume, where it is noted that its feldspars, both in size and habit, are quite unlike those in the Mount Erebus kenytes. Nor are they like the feldspars in the boulder from Evans Coves.

IV. VOLCANIC ROCKS FOUND AS ERRATICS AT GRANITE HARBOUR

Debenham's collection of rocks from Granite Harbour includes four specimens of volcanic rocks. These are erratics, numbered D52G and listed as: 'Lavas, erratic at Granite Harbour'. They are of considerable interest as, apart from some boulders of kenyte reported on Cape Roberts by Edgeworth David and Priestley on the Shackleton Expedition, no volcanic rocks, erratic or in situ, are known in the Granite Harbour district.

One of the specimens (B.M. 1953, 89(65)) is very fine-grained, iron-grey in colour, and riddled with small, glass-lined vesicles 0·5 to 1 mm. in diameter. Very small insets can be seen with a hand-lens. These prove to be olivine, colourless in thin section, idiomorphic, and up to 0·75 mm. in length. They are frequent but not abundant. The groundmass consists of abundant, small prisms of pale buff augite and cubic crystals of magnetite in a turbid, dusky drab glass. The pyroxene prisms average about 0·05 mm. in thickness. The only feldspar is very rare and is seen only as elongated plates of plagioclase of later crystallization than the pyroxene and magnetite.

This rock is a limburgite.

No similar rock has been described from Ross Island or elsewhere in South Victoria Land but a limburgite from Franklin Island described by Prior is a good match. The Franklin Island specimens collected by both the Southern Cross and the Discovery expeditions are, however, not vesicular and they seem to contain rather less magnetite and the glass of the groundmass is lighter coloured. These are trivial distinctions but of course similar limburgite may easily occur in Victoria Land itself.

The rocks described by Jensen as limburgites are not well named and the lava from Fortress Rocks on Hut Point Peninsula described in this volume (p. 78) contains a few thin laths of labradorite so feldspar is more in evidence than in the limburgite now described.

A second specimen [B.M. 1953, 89(64)] is a porphyritic olivine-basalt. It is dark olive-grey in colour, with many near-spherical vesicles up to 5 mm. across. Under the microscope it is seen to consist of colourless insets of olivine up to 3 mm. in length, abundant in a medium-grained groundmass of plagioclase laths and allotriomorphic augite with frequent small magnetites. The plagioclase laths average about 0·03 mm. in thickness. There is only a small proportion of interstitial material. Some of this contains rods and skeletal growths of ilmenite or magnetite and may be glass, but other parts seem to be birefringent.

The two other specimens (1953, 86 (63, 66)) are both of the same kind of rock. They are vesicular, dark olive-grey rocks crowded with insets and groups of insets of black augite and slightly smaller olive-yellow or browner stained olivines. White specks in the medium-grained groundmass are due to small feldspars. In thin section the olivines are colourless and up to 1 mm. in length, the augites pale greyish vinaceous in colour range up to 5 mm. across. Both are idiomorphic. The augite often occurs in groups of several crystals. The groundmass is medium-grained and coarser grained than for most basalts. It consists of laths of plagioclase with granular augite and frequent small magnetites. This augite is unusual for its deep colour, near vinaceous purple. Interstitial material is very small in amount and consists of still finer-grained feldspar, augite and dusty opaque magnetite or ilmenite. In some parts of this interstitial material the little pyroxenes occur as closely packed prisms in parallel position in the birefringent base. The augites and the feldspars of the groundmass average 0·06 mm. in thickness, but there are many feldspars, perhaps to be described as micro-insets, that are up to 0·15 mm. across.

These two erratics must be very near in mineral composition to the rocks described by A. Lacroix from Madagascar as ankaramite but the groundmass of the erratics is coarser in grain-size. The rock described by C. Gagel from Madeira as madeirite is also similar but it also has the finer-grained groundmass. With this proviso on the grain-size of groundmass the two erratics may be described provisionally as ankaramite.[1]

Nothing like these rocks has been described from Ross Island or elsewhere in South Victoria Land. That is, of course, not to say that such rocks do not occur but in view of the records of kenyte erratics that indicate possible centres of vulcanicity on the mainland (p. 196) one must regard a mainland source as also possible for the erratics at Granite Harbour.

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[1] A rather similar rock from S. Vicente, Cape Verde Islands has been described and figured by G. M. Part.

Part (G. M.). Volcanic rocks from the Cape Verde Islands. Bull. Brit. Mus. (Nat. Hist.) Min., 1950, vol. 1, no. 2, p. 60.

V. PEBBLES DREDGED FROM THE SEA-FLOOR IN THE BAY OF WHALES

The Bay of Whales, as it was then called, was visited by the *Terra Nova* in February, 1911. The intention was to land a party under Commander V. L. A. Campbell with the object of exploring King Edward Land. When the ship arrived they found anchored in the 'bay' Roald Amundsen's ship, the *Fram*, and Amundsen preparing to race Scott to the Pole. The plan to make a base near the Bay of Whales had to be abandoned. Sir Raymond Priestley has given an account of this historic meeting and records that after an exchange of visits between the Norwegian and British parties, to quote: "The *Terra Nova* loosed her anchor and we steamed slowly out the bay trawling as we went".[1]

The dredge brought up a surprising quantity of stones along with mud and bottom fauna, and indeed supplied samples of the rocks of the mainland far exceeding in bulk and in variety the rocks collected by Amundsen's party on their journeys on land.

The position of the Bay of Whales is approximately 78° S., 166° W., about 140 miles from Cape Colbeck. In the list of collecting stations it is No. 191 and the depth is given as 194–250 fathoms (355–457 m.) and the date, February 4, 1911.[2]

Priestley examined the pebbles on board and records in his diary, February 5, 1911: "I have 20 or 30 pounds of varied rock material through this haul and it alone was well worth the trouble and the wasted steam". After the expedition returned he made thin sections of many of the pebbles and re-examined them. He regards the material as moraine, glacier borne from King Edward Land, and perhaps from a not very distant source.

A few more specimens have now been sliced and altogether some forty thin sections have been examined out of a total of about three hundred pebbles. These range in size from quite small stones up to small cobbles. The heaviest weighs 530 grams and measures $10 \times 8 \times 4$ cm. However, there are only four approaching these dimensions and the average volume is probably 4–5 cm^3.

Detailed descriptions of the sectioned specimens have been written and these will be filed for future reference. The following report gives a brief account of

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(1) Priestley (R. E.). Antarctic Adventure. Scott's Northern Party. 1914, p. 40.

(2) Harmer (S. F.) and Lillie (D. G.). List of collecting stations. Brit. Ant. ("Terra Nova") Exp., 1910. Natural History Reports. Zoology, 1914, vol. 2, p. 7.

the kinds of rock represented with fuller descriptions of a few of the more interesting ones.

Various collections of rocks outcropping above the ice in Marie Byrd Land have now been made by parties operating during Admiral Byrd's Expeditions and later under the U.S.A. Antarctic I.G.Y. Project, 1957–1959.

One account of the petrography of these rocks has already appeared[1] and others are expected in the near future. The rock exposures so far described are all at great distances from the Bay of Whales. The nearest outcrops of which the rocks have been described are Scott's Nunataks (77° 13′ S., 153° 20′ W.) where specimens of granites, granite-pegmatite, amphibolites and fine-grained gneisses were collected by Amundsen's party, and described by J. Schetelig in 1915.[2]

The most prevalent kinds of rock among the pebbles are fine-grained quartzites and quartz-schists with muscovite developed in the matrix between the grains. Many of these are greenish-grey, deep olive-grey to storm grey, in colour and show some slight degree of foliation. This sometimes results in a lenticular disposition of fine-grained material around the larger (0·3 mm.) grains of quartz. Great quantities of smaller quartz grains, with feldspar among them, and abundant small but definite muscovite flakes make up the matrix (102). Others of these greenish-grey quartzites contain a little biotite in addition to muscovite. Occasionally quartz grains are over 1 mm. in diameter, but the average in different specimens ranges from 0·15–0·5 mm.

A few pebbles of a cream-coloured, fine-grained quartz-schist with small flakes of muscovite have patches of calcite developed intermittently along parallel planes (1983).

Rocks of a somewhat lower grade of metamorphism are represented by greenish-grey pebbles showing varying degrees of fissility. One of these (122) consists of very fine-grained quartz with an abundant development of small flakes of green chlorite and perhaps also muscovite. The grain-size of the quartz averages about 0·02 mm. This appears to be a metamorphosed siltstone. The more fissile of this group can be classified as phyllites.

Almost as frequent as the greenish-grey quartzite and quartz-schists are very fine-grained olive-grey to brownish-drab quartzose rocks. Some of these may be quartzites but those examined in thin sections appear to be metamorphosed impure sandstones or siltstones. They are foliated and both biotite and muscovite

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[1] Anderson (V. H.). The petrography of some rocks from Marie Byrd Land, Antarctica. Ohio State University Research Foundation Report. 825-2-Part 8, 1960.

[2] Schetelig (J.). Report on rock-specimens collected on Roald Amundsen's South Pole Expedition. Videnskaps. Skrifter, Christiania, I.Mat. naturv. Kl., 1915, No. 4.

are developed between the quartz-grains, biotite often being dominant. Quartz-grains are of all sizes up to 1 mm. across though few attain this size (164).

A rock of this kind, deep slaty brown in colour is a "spotted schist" in a fairly high grade of metamorphism (1984). This consists of a very fine-grained aggregate of biotite with muscovite (?) and some quartz, and occasional grains of sphene and magnetite. In this matrix are many oval patches consisting of a flakey mineral with low birefringence, negative elongation, and straight extinction: perhaps an optically positive chlorite. These are probably pseudo-morphs and they resemble in shape the oval patches in a schist (D2K) from the moraines of the Koettlitz Glacier (vol. 1, p. 140). These are thought to be pseudo-morphs after andalusite but they consist mainly of muscovite, not chlorite.

There are a few pebbles of fissile biotite-quartz-schists, dark brownish drab in colour; also a few of well foliated biotite-gneiss, one with small garnets in some biotite-rich bands (177). There is also one pebble of a pink hornblendic granite-gneiss with coral-pink feldspars, and with mylonite veins between the quartz and feldspar fragments (142).

Two or three pebbles are quartz-syenites in composition. One of these has very much the appearance and texture of a charnockite. A mineral in this pebble appears to be allotriomorphic corundum. It is colourless in thin section, uniaxial negative, and has rather high birefringence (131).

Remarkably frequent among the pebbles are quartz-feldspar-porphyries with abundant black quartz insets, with smaller insets of white or cream-coloured feldspar (orthoclase?), in an olive-buff to light greyish-olive groundmass. The quartz insets are occasionally as much as 4 mm. across but they average something less than half this. These porphyry pebbles are almost as abundant as the greenish-grey quartzites and quartz-schists: 20 as compared with 25 per cent as estimated on a count of over 300 pebbles.[1] A thin section (167) shows, in addition to the quartz and feldspar insets, small clots of deep greyish-olive biotite in a fine-grained groundmass consisting of rounded crystals of clear quartz in a base of feldspar of low refractive index (orthoclase?).

There are a few pebbles of biotite-feldspar-porphyry with a cryptocrystalline groundmass (175) cream to buff-brown in colour in the hand-specimen.

Related to these quartz-porphyries are several pebbles with an aphanitic groundmass, olivaceous black streaked with iron-grey, and shown on examination of thin sections to be partly glassy and partly devitrified glass (184). The glass is near light brownish-drab in colour, and shows well-marked flow structure. This rock may be described as a porphyritic rhyolite, or perhaps as a rhyolitic-tuff, as much of the quartz and some of the feldspar occurs as broken crystals.

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[1] It was the constant recurrence of this quartz-feldspar-porphyry in the samples that led Priestley to the conclusion that the source of this rock was not far distant.

Another pebble which contains fragments of glass with flow structure like that just described contains also abundant "lapilli" of an opaque vesicular "glass", with angular fragments of quartz, some feldspar and an occasional pyroxene. The hand-specimen, buffy-brown in colour, has the appearance of a detrital rock but the abundance of glassy material seems to indicate that it is probably a tuff. A remarkably constituent, however, is glauconite. This is present only as a few rounded grains. Hitherto it has been recorded in South Victoria Land only from the Beacon Sandstone.(1) This pebble (1982) was the second largest pebble in the dredge. It measures $7 \times 5 \times 4$ cm. and weighs 387 gms.

There is evidence in some of the pebbles that the quartz-porphyries just described have, in places, been involved in metamorphism of rather low grade. There are two pebbles which seem to indicate this. One of them (179), shows in thin section idiomorphic and hypidiomorphic quartz and plagioclase, altered orthoclase, and frequent flakes of tawny-olive biotite in a groundmass resembling that of the quartz-porphyries, but with ragged flakes of 'new' biotite enclosing the rounded quartz-grains of the groundmass and there developing sieve structure. The other (141), perhaps in a further stage of metamorphism, shows turbid feldspars with sieve structure and some altered insets of biotite occasionally enclosing epidote while the groundmass though still showing the same fabric as the quartz-porphyries has its feldspar now represented by flakes of muscovite.

This evidence indicates that the quartz-feldspar-porphyries belong to an early period in the history of this part of Antarctica probably earlier than the Beacon Sandstone and perhaps as old as the more recent members of the Ross System in South Victoria Land (i.e. Lower Palaeozoic).

Volcanic rocks such as might be similar in age to the volcanic rocks of Ross Island and Cape Adare are very scarce in the dredged specimens: only seven pebbles were found among over three hundred examined. One of these is an olivine-free andesine-basalt (100); one may be mugearite (140); and a third (133) is a hornblendic 'trachyte' with insets of sanidine and plagioclase, and occasional dark brown hornblendes. It somewhat resembles some of trachytoid phonolites of Inaccessible Island or of Great Razorback but contains less of the dark minerals and none of the pyroxene insets that occur in these rocks (this volume, pp. 28 and 29).

The rock (100) provisionally named andesine-basalt has micro-insets of augite and andesine in a turbid, brownish-black glassy groundmass crowded with laths of plagioclase with low extinction angles indicating oligoclase-andesine.

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(1) Stewart (D.). The petrography of the Beacon Sandstone of South Victoria Land. Amer. Min. 1934, Vol. 19, p. 353.

Pebbles of sedimentary rocks are almost as scarce in the dredge as the volcanic rocks. They are fine-grained compact sandstones. A few are buff coloured on broken surfaces but the majority are white and contain occasional pebbles of white vein-quartz (178). These resemble the Beacon Sandstone.

One pebble of sandstone with a dark purple-drab sandy matrix contains abundant angular fragments of a greenish-grey quartzite (?). Only one pebble of this kind was seen (197).

The only other sedimentary 'rocks' represented appear to be of relatively recent formation. These are pebbles of consolidated calcareous mud often containing aggregates of small, highly polished pebbles in a crystalline calcite cement. Many of the pebbles are similar to some of the slightly metamorphosed dark, fine-grained, quartzose rocks so frequent among the pebbles of the dredge. Dr. J. D. H. Wiseman, who kindly examined the calcareous mud, found no benthonic or planktonic organisms present apart from rare minute sponge-spicules. The carbonate material in the mud is extremely fine-grained. In these respects it resembles the "clay" mentioned by Debenham as having been obtained in one haul off the edge of the Barrier and described as pieces of hard clay interspersed with grit and small pebbles. (Vol. 1, no. 3, p. 99). Indeed Debenham may be here describing the actual specimens from the Bay of Whales. He regards it as 'Boulder Clay' formed from the fine-grained material carried in the base of the glaciers.

VI. SUMMARY OF THE REPORTS ON THE GEOLOGY OF SOUTH VICTORIA LAND

So many years have elapsed since the first reports on the geological results of the Terra Nova Expedition were published that it seems worth while, in this concluding report, to present a summary of the whole series.

When the Terra Nova Expedition sailed in 1910 the main geological formations, their apparent succession, and some idea of the structure of South Victoria Land had been established as a result mainly of the two earlier expeditions of Scott in the *Discovery*, 1901–4, and of Shackleton in the *Nimrod*, 1907–9.

The story of the geological exploration of South Victoria Land actually begins with the voyages of Sir James Clark Ross, who sighted the mainland of South Victoria Land in 1841 and observed the two volcanic peaks on Ross Island and named them, after his two ships, Mounts Erebus and Terror. Mt. Erebus was active at the time of this discovery.

The surgeon in *Erebus*, [Sir] Robert McCormick was also one of the two naturalists on Ross's expedition, and he recorded the rock-specimens collected from the islands on which landings were made, from dredges, and, more unusual, from the stomachs of seals and penguins which he dissected.

McCormick noted that many of these pebbles were of 'granite', and a block of grey granite was dredged up in over 270 fathoms in lat. 72° 31′ S., long. 173° 39′ E., on 19th January, 1841. This, as Ross realized, had probably been carried by an iceberg and indicated the proximity of a continental land-mass.

The collection of pebbles from the penguins' and seals' stomachs were not further examined by any geologist until G. T. Prior described them in 1898, listing them as: granite, epidiorite, basalt, rhyolite and rhyolite-breccia, and a micaceous quartz-grit. This additional information was, of course, of interest but by 1898 the first man had landed on the Antarctic Continent and sampled the rocks for himself.

The Norwegian whaler *Antarctic*, Captain Lars Kristensen, had reached Cape Adare in 1894. Carstens Borchgrevink, one of the crew, had landed with others and collected a few fragments of rocks and pebbles. These were described by T. W. Edgeworth David, W. F. Smeeth and J. A. Schofield in 1896. Borchgrevink returned to Cape Adare in the *Southern Cross* and wintered there, 1898–9, and the rocks collected on this expedition were described by G. T. Prior who recorded volcanic rocks, mostly basalts, and also pale green slates and quartz-grits.

Twentieth century exploration of South Victoria Land opened with the Discovery Expedition of 1901–4, led by Captain Robert Falcon Scott, accompanied by [Sir] Ernest Shackleton, with Dr. E. A. Wilson as doctor and naturalist and H. T. Ferrar as geologist. This expedition and the two that followed it were based on Ross Island in McMurdo Sound. Ferrar collected volcanic rocks from Mount Erebus and other parts of Ross Island, and on the mainland he established the existence of metamorphic rocks including crystalline limestones, of two distinct granites, and of a very extensive sandstone formation named from Beacon Heights in the Ferrar Glacier region, the Beacon Sandstone. He described great sills of quartz-dolerites, the Ferrar Dolerites as they are now called, penetrating the sandstone, and he also discovered in the sandstone thin carbonaceous bands in which he sought without success to find recognizable plant remains.

The report on Ferrar's collection of rocks was written by G. T. Prior. He gave a description of the quartz-dolerites, of the Beacon Sandstone and of the plutonic and volcanic rocks. Prior showed that the remarkable lavas of Mount Erebus with large crystals of feldspar were similar to rocks from Kilimanjaro, named 'Rhombenporphyr' by Finckh, and to the lavas from Mt. Kenya to which J. W. Gregory had given the name 'Kenyte'.

In reporting on the volcanic rocks of Cape Adare in 1902 Prior had pointed out their general resemblance to the East African volcanics which by that date had become known from collections made by J. W. Gregory and Sir Harry Johnston in British East Africa and by the German explorers. His examination of the volcanic rocks of Ross Island added further evidence to support this comparison.

The Discovery Expedition was followed by Shackleton's British Antarctic Expedition in 1907–9 in the *Nimrod.* He took with him as geologists [Sir] T. W. Edgeworth David, Professor of Geology in the University of Sydney, [Sir] Douglas Mawson, and [Sir] Raymond Priestley, then an undergraduate of Bristol. They extended Ferrar's observations, made a successful ascent of Mount Erebus, and carried their exploration along the coast and into the Granite Harbour region north of Ross Island. In their reports published in 1914 they drew the main lines of the structural geology and they showed how the volcanic centres are related to a main north and south fault from Ross Island to Cape Adare. This added still further to the interest of Priors' comparison of the volcanic rocks of South Victoria Land with those of the African Rift Valley. Shackleton's Polar Party on the ascent of the Beardmore Glacier made two discoveries of fossils of very great interest. Near the entrance of the glacier they found among moraine material a dolomitized limestone-breccia containing remains of *Archaeocyathus,* definitely referred to Cambrian in age[1]; and at Buckley Island they found coal seams and fossil wood. This was identified by Professor Goddard as possibly a gymnospermous plant indicating perhaps Lower Carboniferous or Upper Devonian age. This established for the first time the existence of an arborescent plant on the Antarctic Continent.

The above is a brief account of the extent to which the geology of South Victoria Land was known when Captain Scott's Expedition in the *Terra Nova* set sail in 1910. Scott had a strong scientific staff with Dr. E. A. Wilson as scientific director, S. C. Wright as physicist, and three geologists, Raymond Priestley who had already served with Shackleton's expedition, Griffith Taylor, and Frank Debenham. The results of their work, apart from important memoirs on Glaciology and on the Physiography of the region, are described in these reports on the Geology. It was originally planned that both Priestley and Debenham would have time and opportunity to work out the results and to report on their collections and with that end in view on the return of the Expedition both went as post-graduate students to Cambridge, working in the Department of Geology there. This excellent arrangement was soon to be upset for within a few months the first World War had broken out and both Priestley and Debenham were in the Army almost at once. However arrangements had been made for specialists to undertake the description of some parts of the collections. Sir Arthur Smith-Woodward, Keeper of Geology in the British Museum (Natural History), had agreed to describe the fish scales and plates discovered by Debenham, and Professor A. C. Seward the fossil plants. Both were acknowledged authorities on their subjects. Professor Seward's report on 'Antarctic Fossil Plants' was the first to be completed and was issued on 24th October, 1914. No further reports on geology were published until after the War, in 1921.

Terra Nova Expedition, 1910 (Geology). Vol. 1, No. 1.

Seward had available Priestley's specimens of fossil wood from the Beacon Sandstone and Wilson's specimens from Buckley Island collected with great patience and endurance on the way back from the Pole. The fossil trees from the Priestley Glacier were described and named *Antarcticoxylon Priestleyi*,[2] and

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(1) Limestones containing fossils belonging to several genera of Archaeocyathus have now been found *in situ* near the Nimrod Glacier in the Holyoake Range (approx. 82° S., 160° E.). The rocks are believed to form part of the Ross System. A distant view of Mount Hunt showed almost vertical limestone overlain by horizontal Beacon Sandstone.

Laird (M.) and Waterhouse (J. B.). Archaeocyathine Limestones of Antarctica. Nature, 1962, Vol. 194, pp. 860–1

(2) J. Walton re-examined the fossils and showed that the *Antarcticoxylon* can be referred to the genus *Rhexoxylon*, Bancroft, species of which were discovered in South Africa from beds of the Stormberg Series corresponding in age to the Trias in Europe.

Walton (J.). On *Rhexoxylon*, Bancroft — . . . Phil. Trans. Roy. Soc. London, 1923, ser. B., Vol. 212, pp. 79–109.

Seward also discovered in the specimens a winged spore which he named *Pityosporites antarcticus*. *Antarcticoxylon* he regarded as a distinct type of Gymnospermous plant not affording any very satisfactory evidence of geological horizon. The spore he considered afforded some evidence of the existence in Antarctica of an Abietineous conifer, possibly in lower Mesozoic, e.g. Rhaetic times. He added, however: 'on geographical grounds it would seem more probable that the spores belonged to some plant allied to *Podocarpus*, *Dacrydium*, or *Microcachrys*, genera [Coniferal] possessing winged pollen and at the present day characteristic of the southern hemisphere' (Vol. 1, p. 24).[1]

Seward's conclusion as to the age of the part of the Beacon Sandstone in which the fossil stems and the spore were found is as follows: "So far as *Pityosporites* is concerned there is obviously no reason why the rock should not be of any age, from, say the latter part of the Trias upwards. There is, moreover, not sufficient reason for asserting that *Antarcticoxylon* could not have come from beds higher than the Jurassic" (p. 24). These discoveries were interesting enough in themselves but still greater interest attaches to Seward's studies of the plant remains collected from the moraines between Mount Darwin and Buckley Island on the Beardmore Glacier. Seward identified and described *Glossopteris indica*, a variety of this, var. *Wilsoni*, and other fragments of Glossopteris flora. This was the first indication of the existence of Glossopteris in Antarctica and it opened up problems of distribution and of climate of very great geological interest. As regards age Seward noted that

" . . . the genus ranges from the Upper Carboniferous or Lower Permian rocks to the Rhaetic period. It is, however, not improbable that *Glossopteris* appeared on the Antarctic continent earlier than in other parts of the southern province . . . the probability is that the beds are Permo-Carboniferous in age: . . ."

Vol. 1, No. 2. On a moraine of the Mackay Glacier off Granite Harbour Debenham found dermal plates and scales of fish "in pieces of shale and shaly sandstone which are identical in outward appearance with the bands of shale that are found in the lower layers of the Beacon Sandstone, both in Granite Harbour . . . and in the Depot Nunatak on the Ferrar Glacier" (p. 110). They were described and figured by Smith-Woodward (vol. 1, no. 2) who named two new species of ostracoderm from plates and a ribbed spine, and also a new species of *Holoptychius* from several somewhat imperfect scales. Although these remains were so fragmentary that few of them could be definitely named he considered that they were sufficient to prove an Upper Devonian age for the shale fragments in which they were found (p. 60).

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[1] This second suggestion of Seward's is the one favoured by S. Manum who has recently re-examined the type specimen, re-described it, and given a new definition of *Pityosporites*.

Manum (S.). On the genus Pityosporites Seward 1914 with a new description of *Pityosporites antarcticus* Seward. Nytt. Magasin Botanik, 1960, vol. 8, pp. 11–15.

The two palaeontological reports suggested an extensive time-range for the Beacon Sandstone Group, from Upper Devonian to Permo-Carboniferous, possibly Rhaetic.

Vol. 1, No. 4a. The lithology and distribution of the Beacon Sandstone was described by Debenham. He noted its immense extent and great thickness. In the Terra Nova region he noted the presence of coarse tuffs containing charred fragments of stems, and both here and at Granite Harbour sandstones with bituminous cement. Bands of coal were confirmed in the Granite Harbour region, as well as at Buckley Island on the Beardmore Glacier, while in the Granite Harbour district ripple-marks and sun-cracks gave evidence of 'a sandy waste with occasional pools of shallow water' (p. 107). On the Beardmore the moraine from Mount Darwin shows a preponderance of calcareous sandstone, and at Buckley Island a good proportion of the specimens collected by Wilson, are impure grey limestone. The limestone-breccia in which the *Archaeocyathus* was found by Shackleton's Expedition in the western moraine of the Beardmore is thought to come 'from the very base of the sediments as seen in Mount Bell'. This is in line with Edgeworth David's suggestion that the breccia is at the base of the Beacon Sandstone, the fragments being derived from strata in another locality not now exposed (p. 118).[1]

Vol. 1, No. 4b. The Northern Party of the Terra Nova Expedition under Commander V. L. A. Campbell was the first party to make a thorough examination of the green slaty rocks first discovered at Cape Adare by the Southern Cross Expedition (1898–9). Priestley assisted by the other members of the party collected from outcrops wherever they could be reached along the west coast of Robertson Bay. The rocks have been described by R. H. Rastall and Priestley (vol. 7, No. 4b). The Slate-Greywacke Formation, as it was named, consists of green-grey slates with some gritty and some small pebbly bands. Interesting variations are described. Some of the greywackes contain carbonates, usually siderite but sometimes calcite, and often aggregated into spots. Some of the finer grained rocks are chloritic and rather calcareous mudstones. At several localities pyrite cubes are frequent, and it was mainly specimens of this type that were collected by Borchgrevink and Louis Bernacchi on the Southern Cross Expedition. No fossils have been found in the Slate-Greywacke Formation of Robertson Bay. With regard to their age Rastall wrote: "The general appearance of the rocks with their prevailing grey and green colours, suggest a considerable age: in fact they present the characteristics usually associated with Palaeozoic or Algonkian sediments. Among British formations their nearest analogue is to be found in the Ingletonian series, to which indeed they show a strong resemblance" (p. 128).

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[1] See footnote [1] page 188.

The Metamorphic Rocks that form the Basement of the Antarctic Horst are exposed at many points *in situ* in the Kukri Hills and south of New Harbour in the McMurdo Sound Region, and boulders are found on Ross Island, along the coast in the direction of Granite Harbour, and many erratics of metamorphic rocks were found in the moraines of glaciers coming down towards Terra Nova Bay. They are described in vol. 1, No. 5.

Vol. 1, No. 5a. In the McMurdo Sound Region they comprise a considerable thickness of schists, with some crystalline limestones. Probably associated with these are green para-pyroxene-granulites that are found only as erratics or as inclusions in intrusive granites. The crystalline schists include garnet-sillimanite-gneiss, cordierite-bearing garnet-gneiss, and biotite-schist with abundant pseudomorphs after andalusite. These, with the pyroxene-granulites and limestones, represent highly metamorphosed argillaceous, calcareous and dolomitic sediments probably of Precambrian age. Fairly closely associated with some of these rocks is a biotite-hornblende-gneiss and some amphibolites and hornblende-schists. The gneiss may have been intrusive into the crystalline schists but contacts were not seen.

Edgeworth David and Priestley regarded these metamorphic rocks as Precambrian and the report on the Terra Nova collections endorses this view. Attention was drawn to very similar associations in the Precambrian of Burma, Ceylon, Madagascar, and East Africa, and in South Australia. Very close comparisons can be made with the Precambrian rocks of the Hutchison Series in Southern Eyre Peninsula described by C. E. Tilley in 1920 (p. 144).

Vol. 1, No. 5b. Metamorphic rocks were found *in situ* at five localities in the Terra Nova Bay region between the Priestley and the Campbell Glaciers. These are garnetiferous biotite-gneiss, a sillimanite-bearing muscovite-biotite-schist, and several pieces of a pyroxene-pegmatite similar to some 'intrusions' in the crystalline limestones enclosed by grey granite in the Granite Harbour region. At one place, Cape Sastrugi, the rocks were quartz-schists, more or less micaceous, and some of them of more gneissic texture. A tourmaline-bearing pegmatite was prominent at this locality. A few miles to the north of Cape Sastrugi the rocks *in situ* are fine-grained well-foliated gneiss grading into biotite-schist and succeeded to the north by a porphyritic biotite-orthoclase-gneiss.

Four glaciers were discovered coming down from the mountains to the north of the ice sheet at Terra Nova Bay: the Campbell Glacier from the direction of Mount Melbourne with a tributary, the Boomerang, coming in on its western side; and, further to the west the Priestley Glacier with a tributary, the Corner Glacier, joining it on its eastern side (fig. 7, p. 146).

The erratics collected from the moraines of these glaciers yielded a great assortment of rocks among which metamorphic rocks and fragments of Beacon

Sandstone were the most abundant. Priestley collected 770 specimens (exclusive of the erratics of sedimentary formations). The metamorphic rocks among the erratics are classified as biotite-gneiss, garnetiferous biotite-gneisses with sillimanite and/or cordierite, muscovite-biotite-schists, again sillimanite-bearing, various quartz-granulites of sedimentary origin, and numerous examples of the pyroxene-granulites already mentioned from the McMurdo Sound Region. Except for a chondrodite-limestone, crystalline limestones are almost unrepresented but it will be realized readily that granular rocks as friable as weathered crystalline limestones are hardly likely to survive as erratics under Antarctic conditions.

This assemblage is similar to the metamorphic rocks of the McMurdo Sound Region, and one can probably assume tentatively that they represent the same formation, but there are in addition erratics of fine-grained *graphitic mica-schists* believed to represent slates or shales altered by thermal metamorphism. Some contain ovoid aggregates of biotite, one carries well-developed chiastolite, and another, a "spotted schist", has spots consisting in part of muscovite probably pseudomorphing andalusite or cordierite. In one specimen pale yellow garnets have formed in 'eyes' of quartz and biotite round nuclei of pyrrhotite. The garnets are similar to some described in contact metamorphosed rocks from Bastogne in the Belgian Ardennes (p. 162).

By listing and tabulating all the specimens collected from these moraines an attempt was made to get some idea of the regions occupied by the different groups of metamorphic rocks (p. 163). What emerged was that the biotite-gneiss and the garnet and cordierite-biotite-gneisses were well represented in the Campbell and Boomerang moraines and in the moraines of the Corner Glacier but were scarce in the western (or outer) moraine of the Priestley. The quartz-granulites and the few specimens of crystalline limestones occurred in the eastern moraine of the Corner Glacier, while the outer, western moraine of the Priestley Glacier contained few biotite-gneisses, more quartz-granulites, all the para-pyroxene-granulites, and all the graphitic mica-schists. It was this western moraine of the Priestley Glacier that yielded also abundant erratics of Beacon Sandstone, and the specimens of fossil wood.

Vol. 1, No. 6. The Plutonic and Hypabyssal rocks were described in 1924. In the region extending from the Ferrar Glacier and the Kukri Hills to Granite Harbour two distinct granites have been recognized, an older, grey, hornblende-free granodiorite with associated aplitic dikes, and a younger pink hornblendic biotite-granite. The same two granites had been recognized by Ferrar and they had been distinguished by Mawson on Shackleton's Expedition, as the grey granite of Mount Larsen type, and the pink granite of Cape Irizar. Much additional information on these granites was obtained by Debenham and recorded on his own plane-table maps. It seems possible that the grey granite (Granite Harbour type) may form part of a great intrusive mass of which the edge is exposed along or near the coast. Observations of the exposed upper surface at the outcrops in the Ferrar Glacier region, and perhaps also in Granite Harbour, indicate a remarkably level surface. In the Ferrar Glacier region the grey granite is often separated from the overlying Beacon Sandstone by a quartz-dolerite sill. The granite contains very numerous xenoliths of gneisses, pyroxene-granulites and limestones. These are supposed to represent fragments of the foundered roof of the granite intrusion. At the Flatiron in Granite Harbour Debenham's mapping showed a very interesting and close relation between the distribution of para-pyroxene-granulite xenoliths and the development of a hornblendic facies of the granite with large hornblende insets and occasional growth of orbicular structures in the granite.

Marble Dike and Marble Outcrop are large masses of white crystalline limestones enclosed by the grey granite, and interesting metamorphic effects were observed at contacts where these are intruded by aplite dikes. One result is the formation of veins containing large green diopside crystals with orthoclase, quartz, and abundant sphene. Rocks similar to these diopside-orthoclase rocks were found by A. F. Zealley associated with masses of limestone in Donegal, and another possibly similar occurrence has been described by A. Lacroix from St. Brévin (Brittany). At other places acid dikes cutting the inclusions of crystalline limestone and pyroxene-granulite have produced a garnet-actinolite-idocrase-calcite assemblage with wollastonite at the actual junction (p. 182).

The younger of the two granites in the McMurdo Sound Region is a pink hornblendic biotite-granite. This is recorded from Granite Harbour, Cape Gregory, Cape Irizar (described by Mawson), and from Prior Island (near the Davis Glacier).

A similar granite occurs in the Kukri Hills. Ferrar believed it was younger than the dolerite sills that cut the Beacon Sandstone but the geologists of Shackleton's expedition of 1907–9 took the opposite view, and Debenham's observations [and a re-examination of some of the specimens on which Ferrar's opinion partly depended] confirms it is older than the Quartz-dolerite (p. 185). At a section which Ferrar interpreted as showing granite penetrating dolerite Debenham found that triangular masses of granite were hoisted up and enclosed within the quartz-dolerite sill (fig. 5, p. 184).

An interesting series of dikes: quartz-orthoclase-porphyries, orthoclase-porphyries, and lamprophyres (sometimes as composite dikes) is associated with this younger granite. In the Terra Nova Bay region investigated by the Northern Party erratics from Evans Beach include various specimens comparable with the grey biotite-granite from Mount Larsen and also dikes of aplite, pegmatite and the lamprophyres, vogesite and spessartite. Two boulders of enstatite-peridotite were the only representatives of ultra-basic rocks collected on this Expedition.

Rocks *in situ* near Evans Coves, in the Northern Foothills, Vegetation Island and the northern part of Inexpressible Island, comprise a biotite-granite and a diorite (Northern Foothills type). The diorite is intricately penetrated by microgranite as well as by aplite and pegmatite veinlets. These rocks were described (in 1924) on the assumption that the diorite and the microgranite were separate intrusions. It was noted that the diorite has features recalling those of some so-called 'basic patches' occurring in certain granites, such as that of Newry, County Down. They were also compared to segregations of dioritic rocks in some granites of northern New South Wales (p. 209). In the light of recent work on similar assemblages of dioritic and granitic rocks elsewhere, such as for instance that described by A. K. Wells and S. W. Wooldridge in 1931 at Ronez and Sorel Point in Jersey, it is probable that the diorites of the Northern Foothills would re-pay re-examination.

Erratics high upon Cape Adare include rocks resembling some of those from the Terra Nova Bay region, and others resembling some of the granites and dike rocks from Granite Harbour (p. 214).

The source of these erratics is unlikely to be so far south as Terra Nova Bay or Granite Harbour. Between Mount Melbourne and Robertson Bay (and Cape Adare) is 200 miles of still unknown country and it is Priestley's opinion that somewhere in this area, possibly in the Admiralty Range, e.g. in the region of Mount Sabine, are outcrops of granitic rocks similar to those we know in Terra Nova Bay, Granite Harbour and the Ferrar Glacier region.

There are a few plutonic types among the erratics in the Murray Glacier moraines. These are dioritic rocks ranging from granodiorite to olivine-bearing types. Some of them are similar to the dioritic rocks of Terra Nova Bay but they are not identical (pp. 217–8).

The Beardmore Glacier yielded only fragments of granite in the moraine near The Cloudmaker. These may be similar to the grey granite (Granite Harbour type). No outcrop was seen so it is possible that the two small fragments collected are from a pebbly band in the sedimentary formation (p. 226).

The extensive sills intruding the Beacon Sandstone in the McMurdo Sound region found, first by H. T. Ferrar, are quartz-dolerites. They are now to be known as the Ferrar Dolerites.[1] They have been found by the geologists of the Terra Nova Expedition also in the Granite Harbour region, in the western moraine of the Priestley Glacier, and on the Beardmore Glacier. These rocks have been described by G. T. Prior and by W. N. Benson in the reports of the earlier expeditions. Both authors have drawn attention to the close similarity

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[1] Harrington (H. J.). Nature, 1958, vol. 182, p. 290.

between them and widespread intrusions of late Mesozoic and probably Cretaceous age in Natal, Brazil, British Guiana, and particularly in Tasmania. The resemblance with the Tasmanian dolerites is so close that Benson suggested a similar, Cretaceous, age for the dolerites of South Victoria Land (p. 198). All the specimens of quartz-dolerites collected by the Polar party were carefully examined and it was established that nearly all of them are typical of the quartz-dolerites of the McMurdo Sound region. A few of them are exceedingly fine-grained varieties and one shows small round vesicles filled with zeolites (p. 222). Similar fine-grained rocks with many large zeolite-filled vesicles were associated with typical quartz-dolerites and with Beacon Sandstone, in the western moraine of the Priestley Glacier. These have been shown to be tholeiites (vol. 2, no. 3, p. 172) and it is possible, judging from their vesicular habit, that they are effusive equivalents of the intrusive quartz-dolerites. The only other indication of vulcanicity associated with the Beacon Sandstone formation in South Victoria Land is the record of 'dark-brown grits with much volcanic debris as well as the almost universal fragments of stems' from morainic material in the Terra Nova Bay region (p. 111).

Vol. 2, No. 1.

Thirty years elapsed between the publication of the report on the plutonic and hypabyssal rocks and that on the Volcanic rocks of the Ross Archipelago, which are reported on in No. 1 of this volume (pp. 1–107).

The notes on the distribution of the volcanic rocks were compiled chiefly from "The Physiography of the Ross Archipelago" by Frank Debenham (1923) and from field-catalogues and labels. A brief summary listing the main groups of the volcanic rocks encountered concludes this introductory part of the chapter and the detailed petrography and chemistry of each group follows (p. 19).

At Mount Erebus the kenytes are the most recent lavas; phonolitic trachytes and porphyritic basalts are among the earlier ones. Considerable interest attaches to the 'anorthoclase' phenocrysts of the kenytes, which are found not only in the lavas but loose on the sides of the crater. They were analysed by E. D. Mountain in 1925, and classified by him as potash-oligoclase.

At 'Mount Cis', a parasitic cone on Erebus, there are many inclusions some of which are identifiable as having been sandstone. This fact, first recorded by Edgeworth David and Priestley (1914), is evidence that the Beacon Sandstone, faulted down to a considerable depth, lies beneath the volcanic pile on Ross Island (p. 26).

In the chapter on the basalts four different areas are treated separately, viz.: Mount Erebus and the Dellbridge Islands (p. 68): Hut Point Peninsula (p. 76); Cape Barne (p. 86); and the Mainland opposite Ross Island. The likelihood of recent basalts being found on the mainland was realized by G. T. Prior as Ferrar's collection contained a specimen of basalt found on the Ferrar Glacier.

The geologists of the Terra Nova Expedition located two distinct areas of small scale, recent volcanic activity, one in the Koettlitz Glacier Valley, and the other in the Taylor Valley (p. 18). At this latter locality the basalts contain inclusions of Beacon Sandstone and of quartz-dolerite. In composition these 'mainland' basalts resemble those of Hut Point Peninsula, where the basalts appear to be the most recent of the lavas. Priestley[1] has drawn attention to the records of erratics of kenytes lavas on the mainland in the neighbourhood of the Koettlitz Glacier and in the Taylor Valley, and, revising his earlier opinion in the light of additional evidence, he considers there is a pretty good indication that separate centres of eruption, supplying kenyte lavas, occur in the neighbourhood of Mount Discovery, a 9,090 ft. conical mountain between the Koettlitz Glacier and Minna Bluff. He also considers that the kenyte erratics recorded both by himself and Edgeworth David[2] and by Griffith Taylor[3] in the Taylor Valley may have their origin in the upper reaches of the "South-West Arm" of the Ferrar Glacier.

Vol. 2, No. 2. The volcanic rocks from Cape Adare were collected by Priestley with the Northern Party which landed there on 18th February 1911. He collected rocks *in situ* from the cliffs, erratics from a high plateau on the top of the Cape, pebbles from the beach, and erratics from the Newnes and Murray Glaciers. With the exception of a phonolite and trachytoid phonolite all the lavas are basalts. Their chemical composition is discussed in this, the final, number (No. 3) of these reports. One of the basalts *in situ* at Cape Adare contains large numbers of partly digested xenoliths of sedimentary rocks. It is thought that these are derived from the slate-greywacke formation which outcrops in Robertson Bay (p. 122). Particular interest attaches to a boulder-bearing agglomerate on the cliff face. Priestley found in it erratics of green 'quartzite' and what appeared to be dolerite as well as boulders of igneous rocks. Some of the latter prove to be sanidinite, others are alkali-trachytes related to some of the rocks found as erratics on the plateau on the top of Cape Adare (p. 135) and as pebbles on Ridley Beach, and well-crystallized sodalite-trachytes. The matrix of the agglomerate is volcanic tuff. The agglomerate is probably the product of a volcanic vent which in some way

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[1] Priestley (R. E.). Physiography (Robertson Bay and Terra Nova Bay Regions). Brit. (Terra Nova) Ant. Exp., 1910–1913. 1923, p. 55.

[2] David (T. W. E.) and Priestley (R. E.), Brit. Ant. Exp., 1907–9. Geology, vol. 1, 1914, p. 95.

A footnote on this page records that "The Western Party of the Scott Expedition 1910–13 have since examined this district in detail, and Debenham found kenyte and basalt *in situ* in the upper reaches of the glacier". The only specimens in the collection from this site are basalts; they are described on pp. 88–90 of this volume. A view of the recent craters on the mainland in 'Dry Valley' is shown in Debenham's report on the recent and local deposits (Vol. 1, No. 3, p. 71).

[3] Taylor (Griffith). The physiography of the McMurdo Sound and Granite Harbour Region. Brit. Ant. (Terra Nova) Exp. 1910–1913, 1922, p. 100.

has involved blocks of quartzite and dolerite erratics brought within its reach by very early glaciation.

In the report on Recent and Local deposits (Vol. 1, no. 3, 1921) Debenham in describing the small craters on the mainland remarked that one at least was active after the maximum extension of the ice (p. 89) and in the crater of Crater Hill in the Hut Point Peninsula he recorded small erratics of granites, granulites, porphyries and sandstones but these are all small and have been carried into the Crater by wind not by ice (p. 82).

From Cape Adare the Northern Party moved by ship to Evans Coves in Terra Nova Bay. In this region a few erratics of volcanic rocks were found in the moraines of the Boomerang and Campbell Glaciers. These are basalts and alkali-trachytes allied to those of Cape Adare. It seems likely that they come from the neighbourhood of Mount Melbourne (p. 174), of which no authentic specimens had ever been obtained.

Priestley (1923, p. 49) has suggested that the main flow of the Priestley Glacier "is also derived . . . from some local ice-sheet, banked up in rear of Mount Melbourne", but, apart from the tholeiites, the only erratics of volcanic rocks from the Priestley Glacier are a mugearite and a fine-grained olivine-free basalt that may be related to the tholeiites rather than to the younger volcanic rocks.

The only other possibly volcanic rocks from the Terra Nova Region are the tholeiites with zeolite-filled vesicles from the Priestley Glacier mentioned above (p. 173).

Two boulders of kenyte were found on the beach at Evans Coves. They are thought to have been transported on ice-floes from Ross Island and their present position affords evidence of recent elevation of the beach. In Granite Harbour four erratics of other volcanic rocks were collected by Debenham. They are of porphyritic ankaramitic basalt and limburgite, unlike any of the volcanic rocks described from Ross Island.

The last chapter (V) describes the pebbles dredged in the Bay of Whales at depths of 355–457 metres on 4th February, 1911. These represent morainic material probably derived from King Edward Land and parts of Marie Byrd Land. Quartzites, schists, gneisses, a few sandstones, and vein-quartz are all represented. Quartz-feldspar-porphyries and rhyolite, or rhyolitic tuff, are frequent but otherwise volcanic rocks are very rare, less than one per cent of the haul.

In conclusion the author of this volume wishes to record his thanks to the many members, past and present, of the Department of Mineralogy of the British Museum (Natural History) who in various ways have helped him with the work, and to Dr. G. F. Claringbull, Keeper of Minerals, who has given the author facilities to continue working in the Department. In particular he wishes to record

his great indebtedness to Sir Raymond Priestley and Professor Frank Debenham, geologists on the Terra Nova Expedition. At intervals during many years, as successive stages of the work of describing their collections were reached, they came again and again to his help. Much of the geology of South Victoria Land is now known, and this is owed to the men who initiated and directed the extensive scientific programme of the Expedition, Captain Robert Falcon Scott and Dr. Edward A. Wilson, and to the geologists who with great patience and endurance collected, carried and man-hauled on sledges a great collection of geological material and, in the comparative comfort of the base huts, catalogued and labelled it all.

Duplicate specimens from this collection have been given to the Geological or Mineralogical Departments of many Universities and in the Department of Mineralogy of the British Museum there are over 1,500 registered specimens. These have now all been described.

EXPLANATION OF PLATE

PLATE I

THOLEIITE ERRATICS FROM THE OUTER MORAINE OF THE PRIESTLEY GLACIER

Fig. 1. A medium-grained 'basalt' related to the quartz-dolerites. Laths of labradorite are partially enclosed by plates of pyroxene. Dark 'glass' fills the interstices. The large vesicle is occupied by a single crystal of stilbite. B.M. 1953, 89 (20a) = 1710. × 14·5, p. 167.

Fig. 2. Micro-insets of pyroxene occur occasionally in a fine-grained groundmass of laths of labradorite, granular pyroxene and a light mesostasis, perhaps a cryptocrystalline quartz-feldspar aggregate. B.M. 1953, 89 (15) = 1836. × 36, p. 169.

Fig. 3. Laths of labradorite form a mesh within which lie platy crystals and grains of pyroxene and dark mesostasis. The vesicles are filled by zeolites. B.M. 1953, 89 (1) = 1254. × 36, p. 170.

Fig. 4. Spherical vesicle filled by black glass in which have crystallized slender laths of feldspar and prisms of augite. Small vesicles, within the larger one, are filled with chlorite (bottom right). The rock consists of plagioclase laths which penetrate and are partly enclosed by augite. Interstices are filled by dark glass. B.M. 1953, 89 (17) = 1783. × 36, p. 170.

Fig. 1.

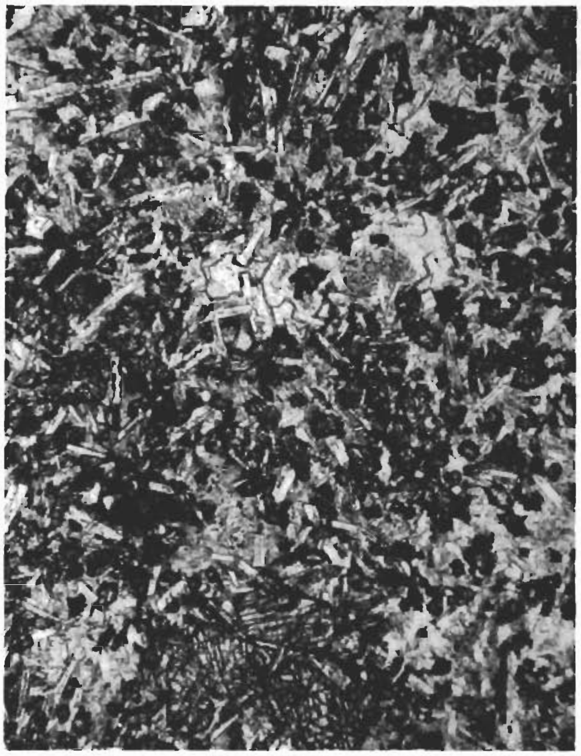

Fig. 2.

Fig. 3.

Fig. 4.

D. L. Williams, B.M. (Nat. Hist.), photo.

THOLEIITES FROM THE PRIESTLEY GLACIER

BRITISH ANTARCTIC ("TERRA NOVA") EXPEDITION, 1910
NATURAL HISTORY REPORTS

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