

## GEOLOGY OF THE SHACKLETON RANGE: IV. THE DOLERITE DYKES

By PETER D. CLARKSON

**ABSTRACT.** The dolerite dykes are the youngest known rocks in the Shackleton Range; their field relations and petrology are described. 25 new chemical analyses are given and these indicate that at least one dyke has close chemical affinities to the Mesozoic dolerites of western Dronning Maud Land and the Transantarctic Mountains. The chemistry of the other dykes shows considerable variation and, although geochronological studies suggest the presence of two suites, they cannot be simply distinguished and do not appear to correlate with similar rocks in western Dronning Maud Land.

The Shackleton Range (lat.  $80^{\circ} 07' - 80^{\circ} 50' S$ , long.  $31^{\circ} - 19^{\circ} W$ ) lies east of the Filchner Ice Shelf at the head of the Weddell Sea. The greater part of the range is formed of basement rocks of the Shackleton Range Metamorphic Complex (Clarkson, 1981*a*) unconformably overlain by the slates and quartzites of the Turnpike Bluff Group in the south (Clarkson, 1981*b*) and by the Cambro-Ordovician sandstones of the Blaiklock Glacier Group in the north-west (Clarkson and Wyeth, 1981).

### DISTRIBUTION

Dolerite dykes occur in the northern parts of the Shackleton Range from the Haskard Highlands to eastern Pioneers Escarpment (Clarkson, 1972). They are dark grey, usually fine-grained rocks weathering to a red colour. All the dykes intrude schists and gneisses of the Shackleton Range Metamorphic Complex (Fig. 1) except the dyke at The Dragons Back which intrudes sandstones of the Blaiklock Glacier Group. The dykes are narrow, rarely exceeding 3 m in width; most of them crop out for short distances only and their exposure is poor but one dyke,



Fig. 1. A dolerite dyke cutting schists of the Shackleton Range Metamorphic Complex at Shaler Cliffs, Herbert Mountains.

on the northern flanks of Charpentier Pyramid, can be traced for 2–3 km. There is no general trend of intrusion (Fig. 2) and all the dykes appear to be petrographically similar, except for slight variations in grain-size, but two generations of intrusion have been recognized by radiometric K-Ar dating. The dyke at The Dragons Back (Z.736) gives a date of  $297 \pm 12$  Ma and a dyke at Lundström Knoll (Z.628) gives a date of  $457 \pm 18$  Ma (Rex, 1971). These periods of intrusion, during the Upper Carboniferous and the Ordovician, correlate with other radiometrically dated events in Dronning Maud Land (Picciotto and Coppez, 1964; Picciotto and others, 1964; Ravich and Krylov, 1964; Craddock, 1970) but none of these determinations was made on dolerites. The Ordovician event may be correlated with the folding of the Blaiklock Glacier Group during the Ross orogeny in the Shackleton Range but at present the Upper Carboniferous event has no known local equivalent.

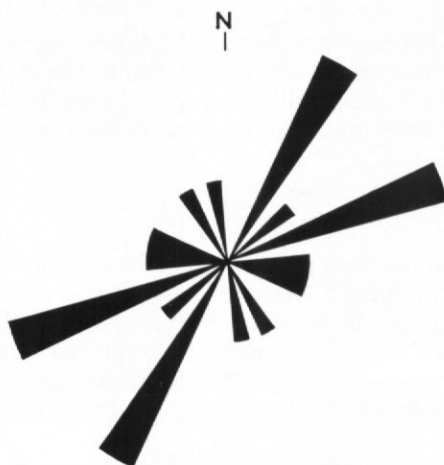


Fig. 2. A rose diagram of dolerite dyke trends in the Shackleton Range; all the dykes are either vertical or near-vertical.

#### PETROGRAPHY

In the hand specimen, all these dykes appear to be similarly fine-grained except specimens Z.1036.12 and 13 which are coarser. Exposure of this particular dyke is very poor but in the field it appeared to bifurcate and the differing textures may represent different phases of cooling or intrusion. Chilled margins were not generally observed, probably due to the narrowness of most of the intrusions.

In thin section, these rocks comprise pyroxene, plagioclase, biotite and ore minerals and the are altered to some degree (Fig. 3a). The main difference between the dykes is their grain-size.

The pyroxene is augite, although the pale pink crystals in some of the thin sections may be titaniferous augite. Almost all the pyroxene is partly altered, either to a pale green chlorite or uraltite or, very commonly, to a brown micaceous mineral (see below). Augite occurs as equant crystals up to 0.7 mm in diameter or as anhedral laths up to 1.2 mm long. Some of the thin sections show a sub-ophitic texture but none is ophitic. The groundmass of these rocks may contain pigeonite but it has not yet been proved.

The plagioclase laths are generally up to 3 mm long in the coarser rocks, although the thin section of specimen Z.726.6 from Mount Beney contains plagioclase phenocrysts up to 5 mm long in a microcrystalline groundmass. All laths are twinned, often as a combination of Carlsbad and albite twins, but compositional determinations are not always possible. All crystals which could be determined are labradorite with a compositional range of  $An_{52-65}$ . The extent of sericitization varies and the finer-grained feldspars appear to be more severely affected.



TABLE I. CHEMICAL ANALYSES OF SPECIMENS FROM DOLERITE DYKES IN THE SHACKLETON RANGE																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	ANALYSES (wt %)																								
SiO <sub>2</sub>	50.12	51.57	51.44	48.94	48.87	48.72	48.97	48.64	51.29	51.36	47.93	48.35	49.32	49.19	49.18	48.81	49.07	48.98	47.48	47.69	47.76	47.74	47.53	50.88	51.51
TiO <sub>2</sub>	3.39	3.22	3.25	3.47	3.48	3.52	3.62	3.82	3.01	3.08	4.13	4.10	2.75	2.62	2.43	2.44	2.49	2.51	2.76	2.83	2.79	2.73	2.78	0.93	0.89
Al <sub>2</sub> O <sub>3</sub>	12.18	12.70	12.72	10.22	10.12	9.79	10.38	9.46	11.20	11.21	9.98	10.45	13.09	12.97	13.07	12.97	12.94	12.88	12.00	13.03	12.77	12.90	12.11	14.81	15.55
Fe <sub>2</sub> O <sub>3</sub>	8.99	4.84	5.06	7.04	7.00	6.84	6.04	6.79	5.46	5.98	7.57	5.37	6.52	6.27	6.41	6.66	6.35	6.36	5.26	5.59	4.59	4.33	5.34	5.26	4.92
FeO	6.30	8.87	8.92	9.60	9.60	9.94	10.39	9.91	7.64	7.30	8.20	10.14	6.40	6.62	6.34	6.22	6.65	6.66	10.22	9.98	10.68	10.83	10.19	6.83	6.61
MnO	0.28	0.22	0.23	0.28	0.28	0.28	0.27	0.27	0.21	0.22	0.25	0.27	0.25	0.25	0.23	0.23	0.26	0.26	0.27	0.28	0.28	0.28	0.28	0.25	0.22
MgO	4.36	4.39	4.50	4.71	4.65	4.79	4.88	4.88	5.11	5.01	6.44	6.22	5.76	5.59	5.85	5.80	6.38	6.46	8.46	7.61	7.47	7.55	8.31	6.42	6.30
CaO	7.22	7.57	7.50	7.22	7.18	7.33	7.15	7.46	7.01	7.46	8.00	8.06	7.80	7.56	7.92	7.92	7.53	7.61	8.55	8.89	8.60	8.47	8.51	10.35	10.37
Na <sub>2</sub> O	2.62	2.23	2.21	1.97	1.95	1.87	1.96	1.81	2.05	1.83	1.61	1.75	3.04	3.54	3.04	2.89	3.62	3.57	2.20	2.50	2.55	2.60	2.22	2.08	2.33
K <sub>2</sub> O	2.97	2.38	2.39	2.88	2.86	2.76	2.73	2.61	2.68	2.68	1.89	1.85	1.85	1.95	2.17	2.19	1.09	1.07	0.88	0.92	0.90	0.92	0.85	0.74	0.78
P <sub>2</sub> O <sub>5</sub>	1.11	1.45	1.45	1.75	1.75	1.76	1.66	1.63	1.33	1.33	0.93	0.94	1.06	0.97	0.99	0.99	1.05	1.07	0.51	0.43	0.48	0.50	0.46	0.14	0.15
H <sub>2</sub> O+	0.92	0.80	0.89	1.20	1.20	1.97	1.07	1.12	1.41	1.05	1.22	1.36	1.37	1.71	1.83	1.72	1.95	1.90	1.57	0.98	1.04	0.77	1.11	0.56	0.73
H <sub>2</sub> O–	0.48	0.54	0.62	1.30	1.30	1.30	1.08	1.22	0.84	0.88	1.40	1.10	0.36	0.32	0.40	0.36	0.36	0.30	0.34	0.42	0.32	0.38	0.42	0.48	0.46
TOTAL	100.94	100.78	101.18	100.58	100.24	100.87	100.20	99.62	99.24	99.39	99.55	99.96	99.57	99.56	99.86	99.20	99.74	99.63	100.50	101.15	100.23	100.00	100.11	99.73	100.82

ANALYSES RECALCULATED TO 100% ANHYDROUS

SiO <sub>2</sub>	50.35	51.86	51.61	49.90	50.00	49.92	49.85	50.00	52.88	52.70	49.45	49.59	50.41	50.44	50.37	50.26	50.36	50.27	48.16	47.81	48.31	48.30	48.21	51.56	51.70
TiO <sub>2</sub>	3.41	3.24	3.26	3.54	3.56	3.61	3.70	3.93	3.10	3.16	4.26	4.21	2.81	2.69	2.49	2.51	2.56	2.58	2.80	2.84	2.82	2.76	2.82	0.94	0.89
Al <sub>2</sub> O <sub>3</sub>	12.24	12.77	12.76	10.42	10.35	10.03	10.61	9.72	11.55	11.50	10.30	10.72	13.38	13.30	13.39	13.35	13.28	13.22	12.17	13.06	12.92	13.05	12.28	15.01	15.61
Fe <sub>2</sub> O <sub>3</sub>	9.03	4.87	5.08	7.18	7.16	7.01	6.17	6.98	5.63	6.14	7.81	5.51	6.66	6.43	6.57	6.86	6.52	6.53	5.34	5.60	4.64	4.38	5.43	5.33	4.94
FeO	6.33	8.92	8.95	9.79	9.82	10.18	10.62	10.19	7.88	7.49	8.46	10.40	6.54	6.79	6.49	6.40	6.83	6.84	10.37	10.01	10.80	10.96	10.34	6.92	6.63
MnO	0.28	0.22	0.23	0.29	0.29	0.29	0.28	0.28	0.22	0.23	0.26	0.28	0.26	0.26	0.24	0.24	0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.25	0.22
MgO	4.38	4.41	4.51	4.80	4.76	4.91	4.99	5.02	5.27	5.14	6.64	6.38	5.89	5.73	5.99	5.97	6.55	6.63	8.58	7.63	7.56	7.64	8.43	6.51	6.32
CaO	7.25	7.61	7.52	7.36	7.35	7.51	7.31	7.67	7.23	7.65	8.25	8.27	7.97	7.75	8.11	8.15	7.73	7.81	8.67	8.91	8.70	8.57	8.63	10.49	10.41
Na <sub>2</sub> O	2.63	2.24	2.22	2.01	2.00	1.92	2.00	1.86	2.11	1.88	1.66	1.79	3.11	3.63	3.11	2.98	3.72	3.66	2.23	2.51	2.58	2.63	2.25	2.11	2.34
K <sub>2</sub> O	2.98	2.39	2.40	2.94	2.93	2.83	2.79	2.68	2.76	2.75	1.95	1.90	1.89	2.00	2.22	2.25	1.12	1.10	0.89	0.92	0.91	0.93	0.86	0.75	0.78
P <sub>2</sub> O <sub>5</sub>	1.12	1.46	1.45	1.78	1.79	1.80	1.70	1.68	1.37	1.36	0.96	0.96	1.08	0.99	1.01	1.02	1.08	1.10	0.52	0.43	0.49	0.51	0.47	0.14	0.15

C.I.P.W. NORMS

Q	7.97	9.63	9.49	8.89	9.20	9.30	7.96	10.02	10.89	12.19	10.44	7.69	4.42	1.58	2.68	3.34	2.70	2.78	1.13	0.30	0.00	0.00	1.38	6.06	5.07
zc	0.15	0.08	0.08	0.15	0.15	0.15	0.13	0.13	0.10	0.10	0.10	0.10	0.05	0.05	0.04	0.04	0.04	0.05	0.04	0.04	0.04	0.04	0.04	0.02	0.02
or	17.59	14.11	14.14	17.30	17.24	16.66	16.44	15.81	16.29	16.21	11.50	11.19	11.15	11.79	13.11	13.30	6.60	6.47	5.27	5.44	5.37	5.49	5.09	4.43	4.62
ab	22.21	18.93	18.72	16.94	16.83	16.16	16.90	15.70	17.84	15.85	14.03	15.16	26.23	30.65	26.29	25.13	31.36	30.93	18.36	21.18	21.80	22.23	19.03	17.82	19.77
an	12.73	17.67	17.75	10.71	10.62	10.39	11.68	10.23	13.83	14.80	14.85	15.55	16.94	14.06	15.96	16.39	16.22	16.34	20.53	21.64	20.95	21.03	20.84	29.25	29.75
di	12.75	8.96	8.55	11.84	11.82	12.62	11.36	14.01	10.80	11.69	15.92	15.78	12.75	14.66	14.41	14.17	12.52	12.64	15.61	16.14	15.66	14.98	15.47	17.68	16.91
hy	4.97	13.99	14.31	12.88	12.81	13.50	15.60	12.60	12.98	11.06	11.53	16.31	10.94	10.47	10.90	10.54	13.75	13.87	24.27	20.71	22.77	21.56	23.83	14.87	14.60
ol																					0.17	1.86			
mt	11.42	7.04	7.34	10.38	10.35	10.13	8.92	10.09	8.14	8.88	11.30	7.97	9.64	9.30	9.50	9.92	9.43	9.44	7.73	8.12	6.72	6.34	7.85	7.72	7.15
il	6.45	6.14	6.18	6.70	6.74	6.83	7.01	7.44	5.88	5.99	8.08	7.97	5.33	5.09	4.72	4.76	4.84	4.88	5.31	5.38	5.35	5.24	5.35	1.79	1.70
hm	1.13																								
ap	2.63	3.44	3.44	4.21	4.23	4.26	4.00	3.96	3.24	3.22	2.27	2.28	2.56	2.35	2.40	2.41	2.54	2.59	1.22	1.02	1.15	1.20	1.10	0.34	0.36
Plagioclase composition	An <sub>36</sub>	An <sub>48</sub>	An <sub>49</sub>	An <sub>39</sub>	An <sub>39</sub>	An <sub>39</sub>	An <sub>41</sub>	An <sub>39</sub>	An <sub>44</sub>	An <sub>48</sub>	An <sub>51</sub>	An <sub>51</sub>	An <sub>39</sub>	An <sub>31</sub>	An <sub>38</sub>	An <sub>39</sub>	An <sub>34</sub>	An <sub>35</sub>	An <sub>52</sub>	An <sub>51</sub>	An <sub>49</sub>	An <sub>49</sub>	An <sub>52</sub>	An <sub>62</sub>	An <sub>60</sub>
or	34	28	28	38	38	39	36	38	34	35	28	27	21	21	24	24	12	12	12	11	11	11	11	8	8
ab	42	37	37	38	38	37	38	38	37	34	35	36	48	54	47	46	58	58	42	44	45	46	42	35	37
an	24	35	35	24	24	24	26	24	29	31	37	37	31	25	29	30	30	30	46	45	44	43	47	57	55

ELEMENT WEIGHT PERCENTAGES, ANHYDROUS

Si <sup>4+</sup>	23.54	24.24	24.13	23.33	23.37	23.34	23.31	23.38	24.72	24.64	23.12	23.18	23.57	23.58	23.55	23.50	23.55	23.50	22.51	22.35	22.58	22.58	22.54	24.10	24.17
Ti <sup>4+</sup>	2.04	1.94	1.95	2.12	2.13	2.16	2.22	2.35	1.86	1.89	2.55	2.52	1.69	1.61	1.49	1.51	1.53	1.54	1.68	1.70	1.69	1.66	1.69	0.56	0.54
Al <sup>3+</sup>	6.48	6.76	6.75	5.51	5.48	5.31	5.61	5.15	6.11	6.09	5.45	5.67	7.08	7.04	7.08	7.07	7.03	7.00	6.44	6.91	6.84	6.91	6.50	7.94	8.26
Fe <sup>3+</sup>	6.32	3.40	3.55	5.02	5.01	4.90	4.32	4.88	3.94	4.29	5.46	3.85	4.66	4.50	4.59	4.80	4.56	4.57	3.73	3.92	3.25	3.06	3.79	3.73	3.45
Fe <sup>2+</sup>	4.92	6.93	6.96	7.61	7.63	7.92	8.25	7.92	6.12	5.82	6.58	8.08	5.08	5.28	5.05	4.98	5.31	5.31	8.06	7.78	8.40	8.52	8.03	5.38	5.16
Mn <sup>2+</sup>	0.22	0.17	0.18	0.22	0.22	0.22	0.21	0.21	0.17	0.17	0.20	0.21	0.20	0.20	0.18	0.18	0.21	0.21	0.21	0.22	0.22	0.22	0.22	0.20	0.17
Mg <sup>2+</sup>	2.64	2.66	2.72	2.90	2.87	2.96	3.01	3.03	3.18	3.10	4.01	3.85	3.55	3.46	3.61	3.60	3.95	4.00	5.18	4.60	4.56	4.61	5.08	3.92	3.81
Ca <sup>2+</sup>	5.18	5.44	5.38	5.26	5.25	5.37	5.22	5.48	5.17	5.47	5.90	5.91	5.70	5.54	5.80	5.83	5.52	5.58	6.20	6.37	6.22	6.12	6.17	7.50	7.44
Na <sup>+</sup>	1.95	1.66	1.65	1.49	1.48	1.42	1.49	1.38	1.57	1.39	1.23	1.33	2.31	2.69	2.31	2.21	2.76	2.72	1.66	1.86	1.91	1.95	1.67	1.56	1.74
K <sup>+</sup>	2.48	1.99	1.99	2.44	2.43	2.35	2.32	2.23	2.29	2.28	1.62	1.58	1.57	1.66	1.85	1.87	0.93	0.91	0.74	0.77	0.76	0.77	0.72	0.62	0.65
p <sup>5+</sup>	0.49	0.64	0.64	0.78	0.78	0.79	0.74	0.73	0.60	0.60	0.42	0.42	0.47	0.43	0.44	0.45	0.47	0.48	0.23	0.19	0.21	0.22	0.20	0.06	0.07
O <sup>2-</sup>	43.75	44.16	44.11	43.32	43.33	43.27	43.31	43.26	44.27	44.25	43.47	43.39	44.13	44.02	44.04	44.02	44.19	44.18	43.37	43.34	43.37	44.39	44.38	44.42	44.55

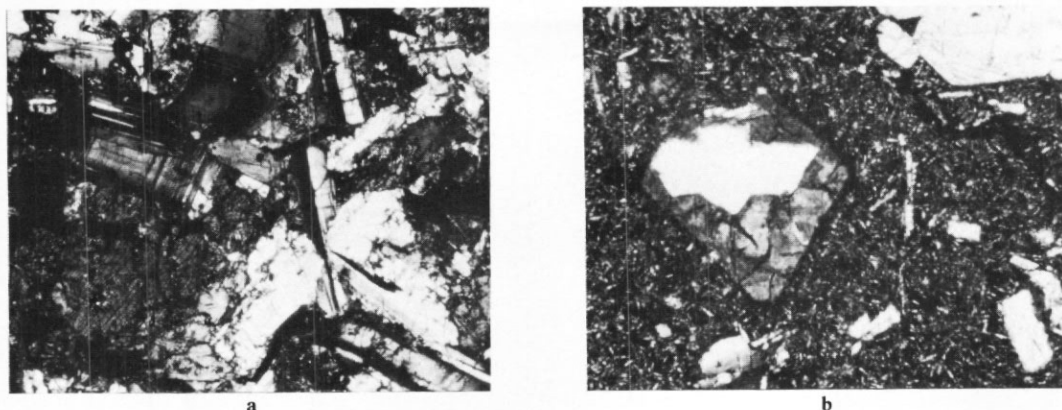


Fig. 3. a. Labradorite laths and altered augite with ilmenite in a dolerite (Z.955.3; X-nicols;  $\times 25$ ).  
b. A pyroxene phenocryst replaced by (?) stilpnomelane in a fine-grained dolerite (Z.726.6; ordinary light;  $\times 25$ ).

Biotite occurs as an interstitial mineral in some of the thin sections but a slightly pleochroic, golden brown micaceous mineral is commoner. It is interstitial in most thin sections and replaces pyroxene in some, notably in specimen Z.726.6 (Fig. 3b). It is usually cryptocrystalline or fibrous but rare crystals give a negative biaxial interference figure with a very small optic axial angle. Its properties match those of stilpnomelane and its presence as a veinlet in specimen Z.726.6 suggests hydrothermal introduction but its identification is not certain.

The accessory minerals include quartz and calcite, chlorite as an alteration product, pyrite, ilmenite and haematite.

#### GEOCHEMISTRY

The two dolerite dykes dated by Rex (1971) suggested that at least two suites of dykes are present in the Shackleton Range and, as none of the dykes has a distinctive petrography, chemical analysis was undertaken to distinguish the two suites. Where possible, two specimens from each dyke have been analysed (with the exception of specimen Z.628.1 which was dated at  $457 \pm 18$  Ma) and most specimens were of sufficient bulk, relative to grain-size, to ensure a representative analysis. Chemical analyses and norms are given in Table I and the data are plotted graphically against a modified Larsen index (Nockolds and Allen, 1953) in Figs 4 and 5; other graphs and triangular diagrams (Figs 6–11) are used to interpret these data.

#### Discussion of the analyses

The general term "dolerite", implying an intrusive rock of basaltic composition, has been used to describe these dykes but in some cases the analyses depart from the oxide limits of the chemical screen (Manson, 1967) for basaltic rocks, e.g. low alumina and high ferric oxide, phosphorus pentoxide and total. However, these departures are generally small and inconsistent within any grouping so that the rocks have all been treated as dolerites.

Silica content shows fairly little variation (47.4–51.6%) but normative quartz values vary from 0 to 12.2%. Alumina values are generally low and some fall below the minimum of 10.5% for basalts (Manson, 1967). With one exception, FeO exceeds  $\text{Fe}_2\text{O}_3$  and in some rocks  $\text{Fe}_2\text{O}_3$  exceeds the maximum of 6.0% for basalts (Manson, 1967). Potash values are relatively high in most of the rocks and this is further demonstrated by the plot of the normative feldspar components on the or-an-ab diagram (Fig. 6). This diagram indicates the presence of two feldspars, e.g. labradorite and anorthoclase, although the latter has not been recognized in thin section. Many of the rocks also give normative plagioclase compositions in the andesine range, which

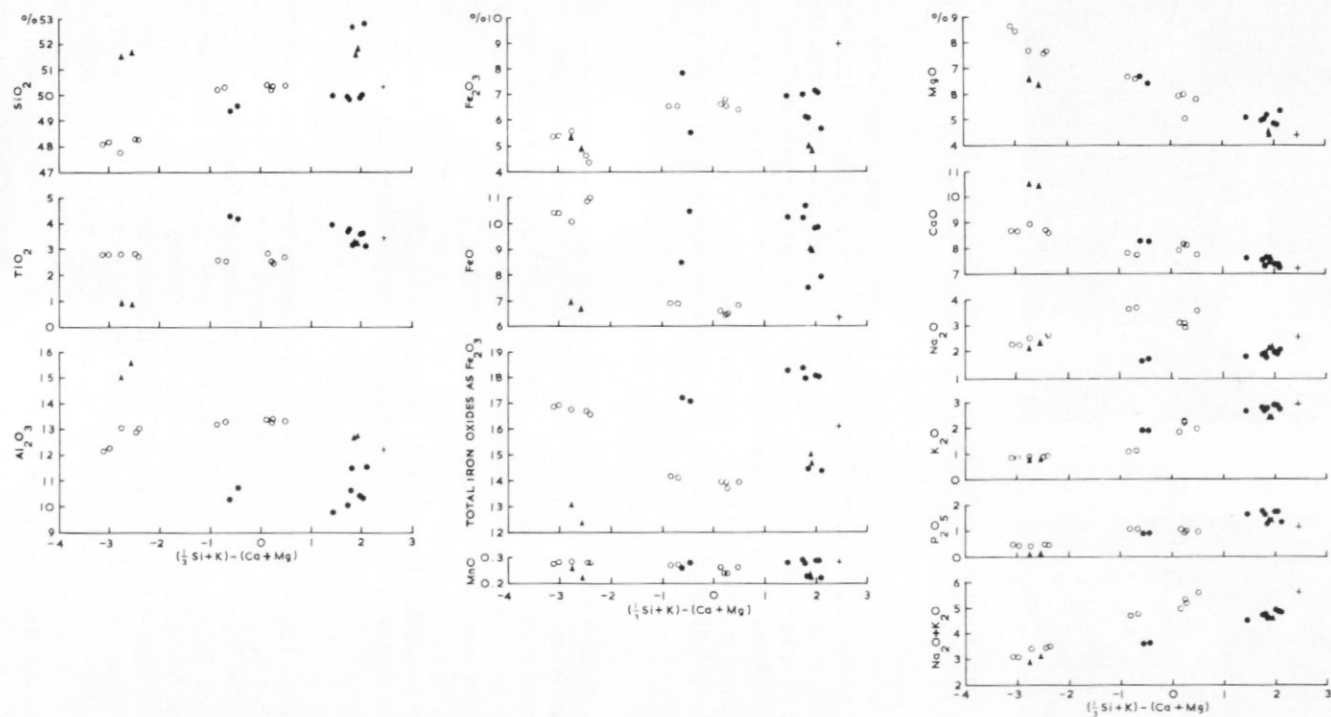


Fig. 4. Plots of major oxides (recalculated to 100% anhydrous) of dolerite dykes against the modified Larsen index  $(\frac{1}{2} \text{Si} + \text{K}) - (\text{Ca} + \text{Mg})$ .

Symbols for Figs 4-11:

+ Lundström Knoll.

● Herbert Mountains.

▲ Mount Beney and The Dragons Back, Lagrange Nunataks.

○ Haskard Highlands.



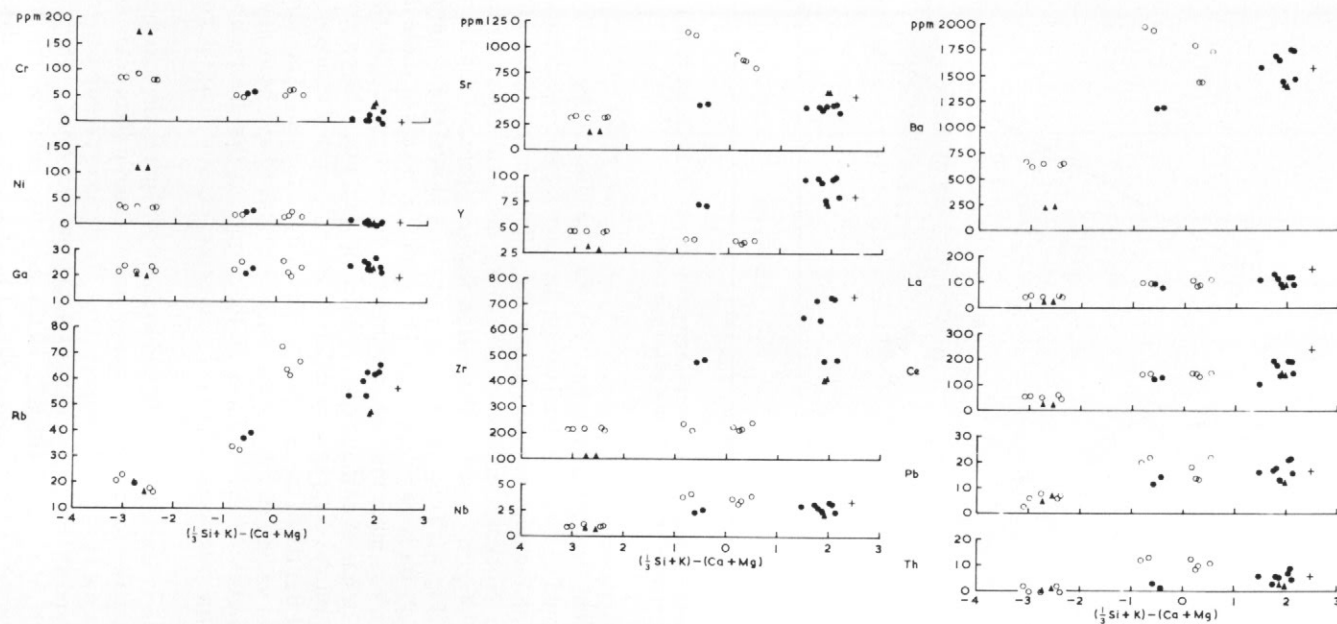


Fig. 5. Plots of trace elements (ppm) of dolerite dykes against the modified Larsen index  $(\frac{1}{2} \text{Si} + \text{K}) - (\text{Ca} + \text{Mg})$ ; symbols as in Fig. 4.

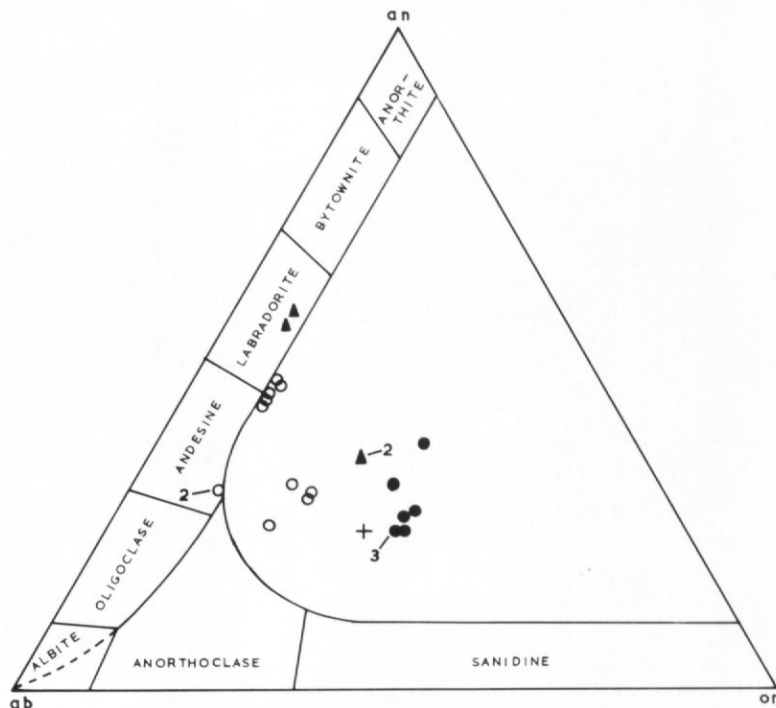


Fig. 6. Triangular diagram on the coordinates an-or-ab (normative values). Symbols are as in Fig. 4; figures beside symbols indicate the number of analyses plotting as a single point.

contrasts with the optical determinations but this may be due to the relatively few optical determinations which could be made, particularly on the finer-grained specimens.

The trends of the major oxides plotted against the differentiation index follow broadly the trends demonstrated by Nockolds and Allen (1954) for the alkali-basalt to trachyte series of Scotland, Hawaii and Polynesia, but the Shackleton Range specimens represent only the more basic end of the trends (Fig. 4). Trace-element data similarly plotted (Fig. 5) also broadly follow the same trends, although Ba is generally high. The spread of points in these diagrams (Figs 4 and 5) implies that there was more than one magma source, as suggested by the dates, and it is possible to see different minor or partial trends in different diagrams. The geographical locations of the dykes are shown on the diagrams by different symbols so that regional groups or trends can be readily identified but these are not always internally consistent. The number of dykes in the Shackleton Range is small (16 are known) and 13 of them have been analysed, but all of them are too narrow to expect much variation in their width so that the number of analyses is insufficient to resolve the variations observed. Consequently, the natural complexity of the problem is increased.

The triangular variation diagrams (Fig. 7a and b) show groupings close to the basic end of the alkali-basalt to trachyte series for Scotland, Hawaii and Polynesia (Nockolds and Allen, 1954), although the dykes from the Herbert Mountains show Na depletion relative to these trends. Also shown are the main trend of Karroo dolerites (Nockolds and Allen, 1956), the trend of the dolerites of the Theron Mountains (Brook, 1972) and the fields of the hypersthene- and pigeonite-tholeiites of Victoria Land (Gunn, 1966). The Shackleton Range dykes form a group rather than a trend, so that sub-division is difficult and unreliable.

The plot of mafic index against felsic index shows one trend through the dyke at Mount Beney

and those in the Haskard Highlands, and a second trend through the dykes of the Herbert Mountains, The Dragons Back and Lundström Knoll, with one dyke from the Herbert Mountains plotting between the two trends (Fig. 8). The graph of total alkalis against silica (Fig. 9) shows a group, a trend and one isolated dyke. The group lies within the alkali-basalt field, whereas the trend follows the boundary between the alkali- and tholeiitic basalt fields (Macdonald and Katsura, 1964) and comprises specimens from each major geographical area. The isolated dyke from Mount Beney is most interesting as it lies well within the tholeiitic field and at the intersection of the Mesozoic tholeiite trend in the Heimefrontfjella area (Jukes, 1972) and the Ferrar-Tasmanian trend observed in the Theron Mountains (Brook, 1972). This suggests a relationship between the dyke at Mount Beney and the Mesozoic tholeiites of Dronning Maud Land and the Transantarctic Mountains. This relationship appears to be confirmed by the position of this dyke on the plot of Sr against Rb (Fig. 10), in which a group of five analyses from the dykes in the north-eastern part of the Haskard Highlands plots at the edge of the Dronning Maud Land field, also suggesting a relationship to the Mesozoic dolerites. In Fig. 10 these dykes are, paradoxically, chemically most distant from their geographically closest equivalents in the Haskard Highlands.

The plot of Ca against Y (Fig. 11) again shows the Mount Beney dyke lying within the Mesozoic trend (Table II; Brook, 1972; Jukes, 1972), to which are aligned both groups in the Haskard Highlands. Although Taylor (1965) has queried the value of the Ca/Y ratio as an indicator of differentiation, other workers have used it and it is used here only to distinguish between groups of analyses.

### Conclusions

It is not possible to draw any certain conclusions from the chemistry of these dykes but the data suggest several possibilities:

TABLE II. Ca/Y RATIOS FOR SOME MESOZOIC DOLERITES IN THE THERON MOUNTAINS AND WESTERN DRONNING MAUD LAND  
*Mean analyses of groups of Jurassic dolerites in the Theron Mountains (Brook, 1972, table XVIII)*

	1	2	3	4	5	6	7	8
CaO	7.31	10.18	9.18	8.21	10.98	8.71	8.13	9.08
Ca	5.22	7.28	6.56	5.87	7.85	6.22	5.81	6.49
Y	32	25	32	49	17	24	29	34
Ca/Y	1 633	2 910	2 050	1 198	4 616	2 594	2 004	1 909

1. Scarp-capping sill.

2. First-phase intrusion, Marø Cliffs.

3. Third-phase intrusion, Marø Cliffs.

4. Basal sill, Lenton Bluff.

5. Younger sills and dykes, Lenton Bluff.

6. Layered sill, Jeffries Glacier and Marø Cliffs.

7. Middle sill, Coalseam Cliffs.

8. Basal sill, Coalseam Cliffs.

*Basalt and dolerite analyses from Heimefrontfjella (Jukes, 1972, table VI)*

	1	2	3	4	5	6	7	8	9
Ca	7.28	8.56	7.25	7.62	7.65	8.23	7.99	8.10	7.25
Y	19	13	25	25	26	23	22	18	32
Ca/Y	3 832	6 585	2 900	3 048	2 942	3 578	3 632	4 500	2 266

1. Z.308.4 Coarse basalt lava, Bjørnnutane.

2. Z.310.2 Coarse basalt lava, Bjørnnutane.

3. Z.349.1 Fine-grained basalt lava, Sembberget.

4. Z.350.1 Coarse basalt lava, Sembberget.

5. Z.350.2 Fine-grained basalt lava, Sembberget.

(CaO and Ca as weight percentage; Y as ppm.)

6. Z.370.1 Coarse basalt lava, western Bjørnnutane.

7. Z.371.7 Basal lava, west of Bjørnnutane.

8. Z.372.1 Coarse basalt, western Bjørnnutane.

9. Z.353.7 Fine-grained dolerite sill, Schivestolen.



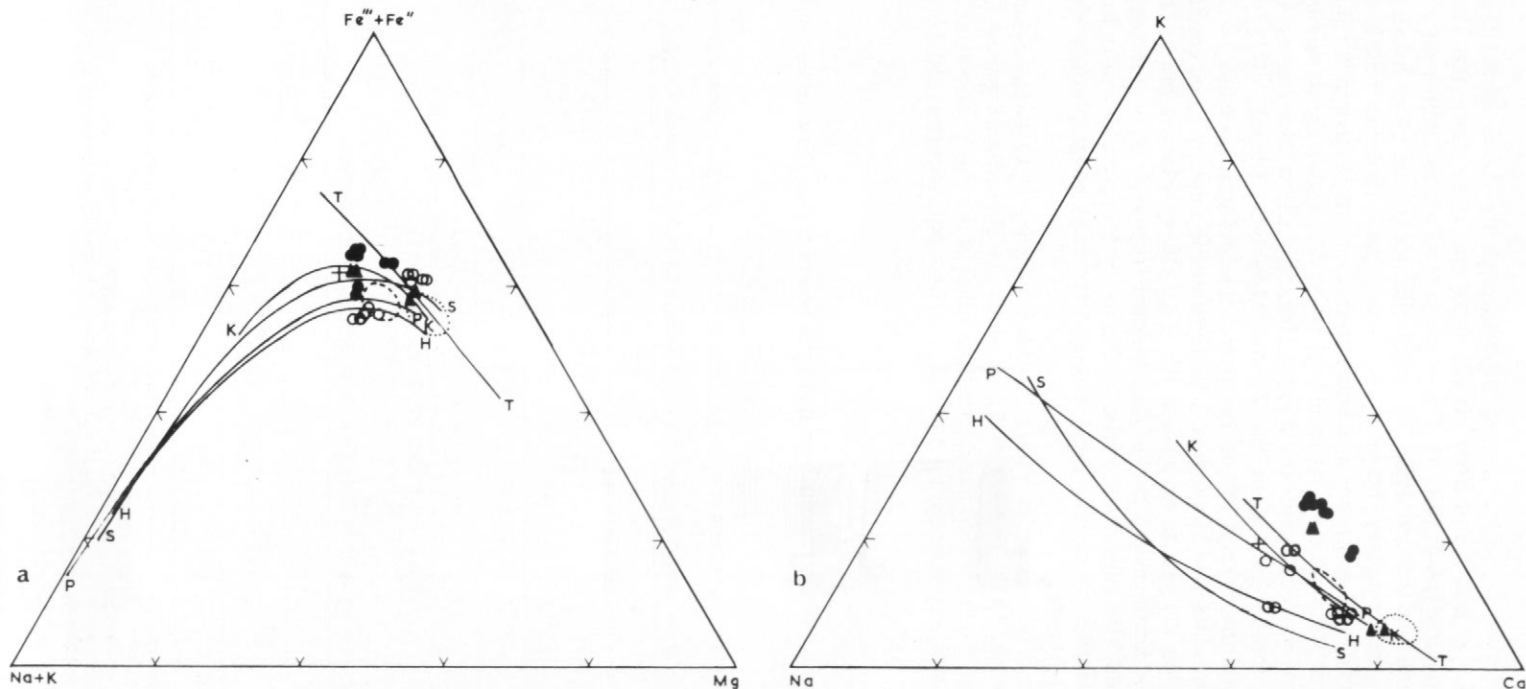


Fig. 7. Triangular variation diagrams on the coordinates:

a.  $(\text{Fe}^{+++} + \text{Fe}^{++})\text{-Mg-(Na + K)}$  (wt %).

b.  $\text{K-Ca-Na}$  (wt %).

Symbols are as in Fig. 4.

Differentiation trends for the alkali-basalt to trachyte series in Scotland (S), Hawaii (H) and Polynesia (P) after Nockolds and Allen (1954); differentiation trend for Karroo tholeiites (K) (main trend) after Nockolds and Allen (1956); differentiation trend for tholeiites in the Theron Mountains (T) after Brook (1972); pigeonite-tholeiite (pecked boundary) and hypersthene-tholeiite (dotted boundary) fields for Victoria Land after Gunn (1966).

- i. The dyke at Mount Beney (Z.726) is related to the Mesozoic dolerites of western Dronning Maud Land and the Transantarctic Mountains.
- ii. The dykes in north-eastern Haskard Highlands (Z.1043 and 1044) may be related to the dykes of western Dronning Maud Land.
- iii. a. The dykes in north-western Haskard Highlands (Z.1036 and 1039) may form a separate group, or  
b. They may be related to the dykes in north-eastern Haskard Highlands.

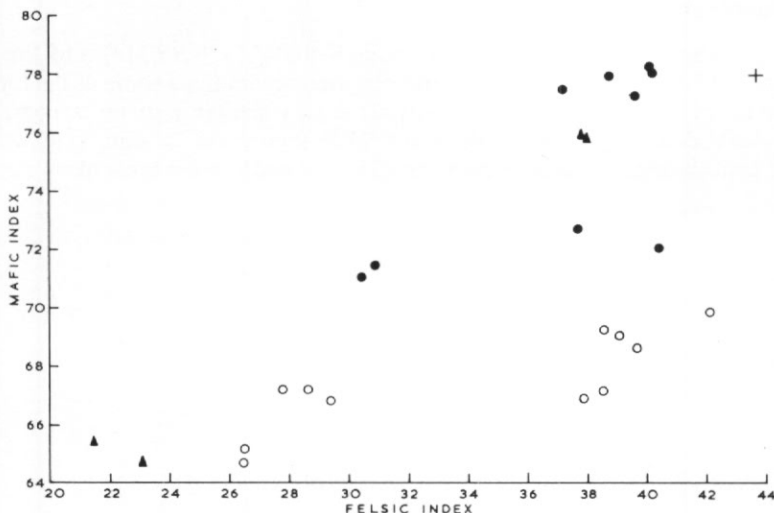


Fig. 8. Plot of mafic index ( $100 (\text{FeO} + \text{Fe}_2\text{O}_3) / (\text{FeO} + \text{Fe}_2\text{O}_3 + \text{MgO})$ ) against felsic index ( $100 (\text{Na}_2\text{O} + \text{K}_2\text{O}) / (\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{CaO})$ ) for dolerite dykes. Symbols as in Fig. 4.

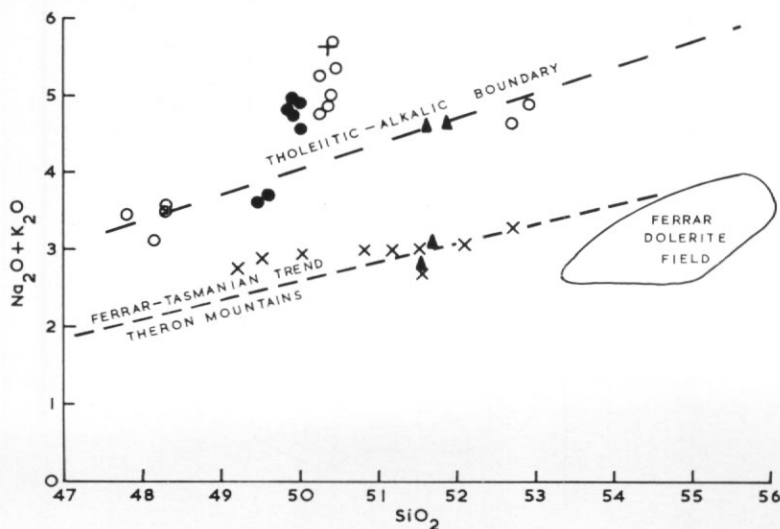


Fig. 9. Plot of  $(\text{Na}_2\text{O} + \text{K}_2\text{O})$  against  $\text{SiO}_2$  (wt %) for some Antarctic dolerites. Solid symbols represent dykes from the Shackleton Range (as in Fig. 4); x dolerite analyses from Heimefrontfjella (Jukes, 1972). Ferrar dolerite field after Gunn (1962, fig. 22); tholeiitic-alkalic boundary after Macdonald and Katsura (1964, fig. 1); Ferrar-Tasmanian trend from the Theron Mountains after Brook (1972).

- iv. The dykes of the Herbert Mountains (Z.912, 914, 916 and 942), the dyke at Lundström Knoll (Z.628) and possibly the dyke at The Dragons Back (Z.736) may form a single group.
- v. The dykes of north-eastern Haskard Highlands (Z.1043 and 1044), The Dragons Back (Z.736) and two dykes from the Herbert Mountains (Z.916 and 942) may form a single group.
- vi. The dykes of north-western Haskard Highlands (Z.1036 and 1039) with two dykes from the Herbert Mountains (Z.912 and 914) and the dyke at Lundström Knoll (Z.628) may form a single group.

The radiometric ages of the dyke at Lundström Knoll ( $457 \pm 18$  Ma) and the dyke at The Dragons Back ( $297 \pm 12$  Ma) (Rex, 1971) may be used to eliminate some of the foregoing possibilities, although the chemistry of these two dykes is very similar in many respects and they frequently plot very close together despite their wide separation in time (160 Ma) and space (150 km). By considering the dates, possibilities i, iii.a, v and vi seem most likely but, if the  $297 \pm$

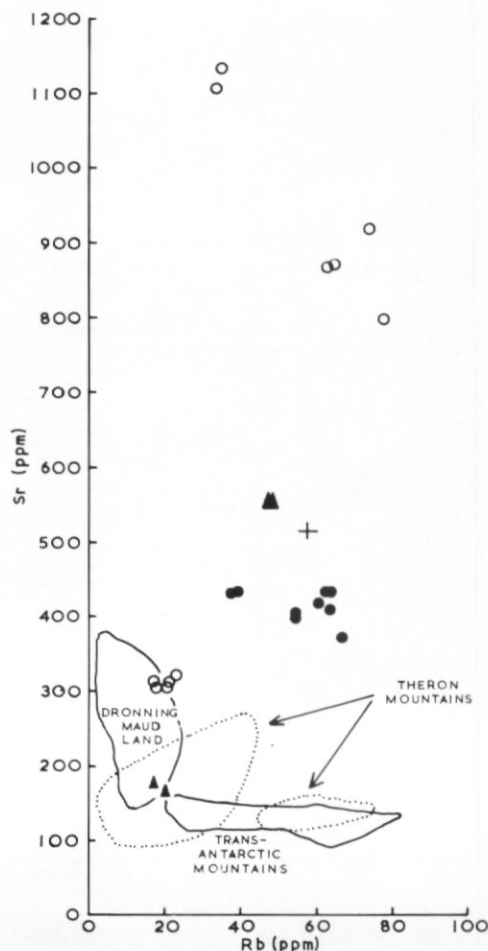


Fig. 10. Plot of Sr against Rb (ppm); symbols as in Fig. 4. Dronning Maud Land and Transantarctic Mountains fields after Faure and Elliot (1971, fig. 2); Theron Mountains fields after Brook (1972).

12 Ma date is unreliable and there is no other evidence of a Carboniferous event in the Shackleton Range, then possibilities i, ii, iii.a and iv seem most likely.

Dolerite dykes and sills in Mannefallknausane dated at  $259 \pm 10$ ,  $256 \pm 10$  and  $547 \pm 100$ ,  $580 \pm 100$  Ma (Rex, 1971), for which chemical data are available (Juckes, 1968, 1969), bear no relation to either of the dated dykes in the Shackleton Range. Similarly, the Precambrian and Palaeozoic–Mesozoic dolerite intrusions from Ahlmannryggen (Neethling, 1971) differ markedly from the dykes considered here, except in the Mesozoic similarities of the Mount Beney dyke, and the basaltic rocks described by von Brunn (1964) are all considered to be Mesozoic.

The dolerite dykes of the Shackleton Range are difficult either to group within themselves or to correlate with basaltic rocks from other areas, except in the case of the dyke at Mount Beney which shows definite affinities with the Mesozoic intrusions of western Dronning Maud Land and the Transantarctic Mountains. The remaining dykes have a varied chemistry and the present paucity of data creates ambiguities. From the radiometric evidence, there are undoubtedly some Ordovician dykes and these are almost certainly related to events during the Ross orogeny which folded the Blaiklock Glacier Group. Although a relationship between the Upper Carboniferous dyke at The Dragons Back and the Permian dyke in Mannefallknausane might be expected, its presence may well be due to the lack of data.

Further sampling and analysis of the dykes will, hopefully, clarify the apparent anomalies revealed by the present study.

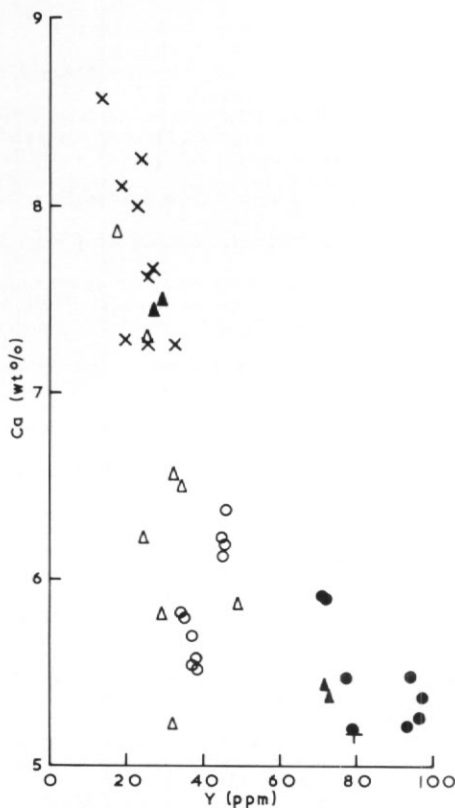


Fig. 11. Plot of Ca (wt %) against Y (ppm) (Table II). Solid symbols represent dykes from the Shackleton Range (as in Fig. 4); x dolerite analyses from Heimfrontfjella (Juckes, 1972);  $\Delta$  mean dolerite analyses from the Theron Mountains (Brook, 1972, table XVIII).



## ACKNOWLEDGEMENTS

I wish to thank Professors F. W. Shotton and A. Williams for providing facilities in the Department of Geological Sciences, University of Birmingham, Drs G. L. Hendry, S. D. Weaver, A. D. Saunders and D. Millward for much help with the geochemical analyses, and Dr R. J. Adie for advice during the preparation of this paper. I am indebted to R. B. Wyeth for permission to use his rock collections and field data which contributed greatly to the work and to P. H. Noble, who collected the Ordovician specimens. I am grateful to all my field companions and, above all, to the US Navy squadron VXE-6 without whose transport facilities this work would not have been done.

MS received 22 February 1977

## REFERENCES

- BROOK, D. 1972. *Geology of the Theron Mountains, Antarctica*. Ph.D. thesis, University of Birmingham, 267 pp. [Unpublished.]
- CLARKSON, P. D. 1972. Geology of the Shackleton Range: a preliminary report. *British Antarctic Survey Bulletin*, No. 31, 1-15.
- . 1981a. Geology of the Shackleton Range: I. The Shackleton Range Metamorphic Complex. *British Antarctic Survey Bulletin*, No. 51, 257-83.
- . 1981b. Geology of the Shackleton Range: II. The Turnpike Bluff Group. *British Antarctic Survey Bulletin*, No. 52, 109-24.
- and R. B. WYETH. 1981. Geology of the Shackleton Range: III. The Blaiklock Glacier Group. *British Antarctic Survey Bulletin*, No. 52.
- CRADDOCK, C. 1970. Radiometric age map of Antarctica. (In BUSHNELL, V. C. and C. CRADDOCK, ed. *Geologic maps of Antarctica. Antarct. Map Folio Ser.*, Folio 12, Pl. XIX.)
- FAURE, G. and D. H. ELLIOT. 1971. Isotope composition of strontium in Mesozoic basalt and dolerite from Dronning Maud Land. *British Antarctic Survey Bulletin*, No. 25, 23-27.
- GUNN, B. M. 1962. Differentiation in Ferrar dolerites, Antarctica. *N.Z. J. Geol. Geophys.*, 5, No. 5, 820-63.
- . 1966. Modal and element variation in Antarctic tholeiites. *Geochim. cosmochim. Acta*, 30, No. 9, 881-920.
- JUCKES, L. M. 1968. The geology of Mannefallknausane and part of Vestfjella, Dronning Maud Land. *British Antarctic Survey Bulletin*, No. 18, 65-78.
- . 1969. Trace-element values for dolerites from western Dronning Maud Land. *British Antarctic Survey Bulletin*, No. 22, 95-96.
- . 1972. The geology of north-eastern Heimfrontfjella, Dronning Maud Land. *British Antarctic Survey Scientific Reports*, No. 65, 44 pp.
- MACDONALD, G. A. and T. KATSURA. 1964. Chemical composition of Hawaiian lavas. *J. Petrology*, 5, Pt. 1, 82-133.
- MANSON, V. 1967. Geochemistry of basaltic rocks: major elements. (In HESS, H. H. and A. POLDERVAART, ed. *Basalts. The Poldervaart treatise on rocks of basaltic composition. Vol. 1*. New York, John Wiley and Sons, Inc., 215-70.)
- NEETHLING, D. C. 1971. Comparative geochemistry of Proterozoic and Palaeo-Mesozoic tholeiites of western Dronning Maud Land. (In ADIE, R. J., ed. *Antarctic geology and geophysics*. Oslo, Universitetsforlaget, 603-16.)
- NOCKOLDS, S. R. and R. ALLEN. 1953. The geochemistry of some igneous rock series. *Geochim. cosmochim. Acta*, 4, No. 3, 105-42.
- and —. 1954. The geochemistry of some igneous rock series: Part II. *Geochim. cosmochim. Acta*, 5, No. 6, 245-85.
- and —. 1956. The geochemistry of some igneous rock series—III. *Geochim. cosmochim. Acta*, 9, Nos. 34-77.
- PICCIOTTO, E. and A. COPPEZ. 1964. Bibliography of absolute age determinations in Antarctica (addendum). (In ADIE, R. J., ed. *Antarctic geology*. Amsterdam, North-Holland Publishing Company, 563-69.)
- , DEUTSCH, S. and P. PASTEELS. 1964. Isotopic ages from the Sor-Rondane mountains, Dronning Maud Land. (In ADIE, R. J., ed. *Antarctic geology*. Amsterdam, North-Holland Publishing Company, 570-78.)
- RAVICH, M. G. and A. J. KRYLOV. 1964. Absolute ages of rocks from east Antarctica. (In ADIE, R. J., ed. *Antarctic geology*. Amsterdam, North-Holland Publishing Company, 579-89.)
- REX, D. C. 1971. K-Ar age determinations on volcanic and associated rocks from the Antarctic Peninsula and Dronning Maud Land. (In ADIE, R. J., ed. *Antarctic geology and geophysics*. Oslo, Universitetsforlaget, 133-36.)
- TAYLOR, S. R. 1965. The application of trace element data to problems in petrology. (In AHRENS, L. H., PRESS, F., RUNCORN, S. K. and H. C. UREY, ed. *Physics and chemistry of the Earth*, 6, Oxford, London, Edinburgh, New York, Paris, Frankfurt, Pergamon Press, 133-213.)
- VON BRUNN, V. 1964. Note on some basic rocks in western Dronning Maud Land. (In ADIE, R. J., ed. *Antarctic geology*. Amsterdam, North-Holland Publishing Company, 415-18.)