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Mesozoic dolerites from Whichaway Nunataks

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Abstract: The southernmost exposures of Mesozoic dolerites in Coats Land, the Omega dolerites, occur at Whichaway Nunataks. The dolerites are geochemically indistinguishable from the Theron Mountains' dolerites. In both regions high- and low-Ti compositions occur with trace element signatures more akin to island-arc magmas than within-plate tholeiites. From a preliminary Sr isotopic study the Omega dolerites can be classified as Ferrar type. The existence of Ferrar type material in these nunataks suggests that the boundary between the Ferrar and Weddell Sea sub-provinces occurs within the Theron Mountains.

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Key words: Coats Land, Ferrar, magmatic provinces.

Introduction

Whichaway Nunataks lie south of Recovery Glacier in Coats Land (Fig. 1). These nunataks have a maximum elevation of *c.* 1350 m with outcrop relief up to 370 m (Marsh 1985). Whichaway Nunataks were first visited by the Commonwealth Trans-Antarctic Expedition 1955–58 (Fuchs 1982) and all of the specimens reported herein are those described by Stephenson (1966). Subsequent visits were made by the 22nd and 23rd Soviet Antarctic Expeditions in 1976–77 and 1977–78 and a sample of dolerite was dated at 195 ± 20 Ma by the K-Ar method (Hofmann *et al.* 1980). Whichaway Nunataks form small conical hills composed of flat-lying sedimentary rocks (Whichaway Formation) and/or dolerite sills (Omega dolerites; Stephenson 1966). The sedimentary rocks are predominantly sandstones, and plant remains within a shale intercalation indicate a 'Lower Gondwana age' (Plumstead 1962). The Whichaway Formation was thus described as part of the Beacon Supergroup (Gunn & Warren 1962). The Omega dolerites are predominantly sills of unknown maximum thickness but the scarp-capping sill at Hopalong Nunatak is more than 45 m thick (Stephenson 1966). A single 0.3-m thick dyke has been reported, which, because of its similar palaeomagnetic orientation, is correlated with the sills (Blundell *in* Stephenson 1966). The Omega dolerites have K-Ar ages of 195 ± 20 Ma (Hofmann *et al.* 1980) which is slightly older than the reported range for the Theron Mountains' dolerites (169 ± 6 – 154 ± 6, Rex 1972). Petrological and geochemical data for the Omega dolerites are presented here and they are compared to the Theron Mountains' dolerites.

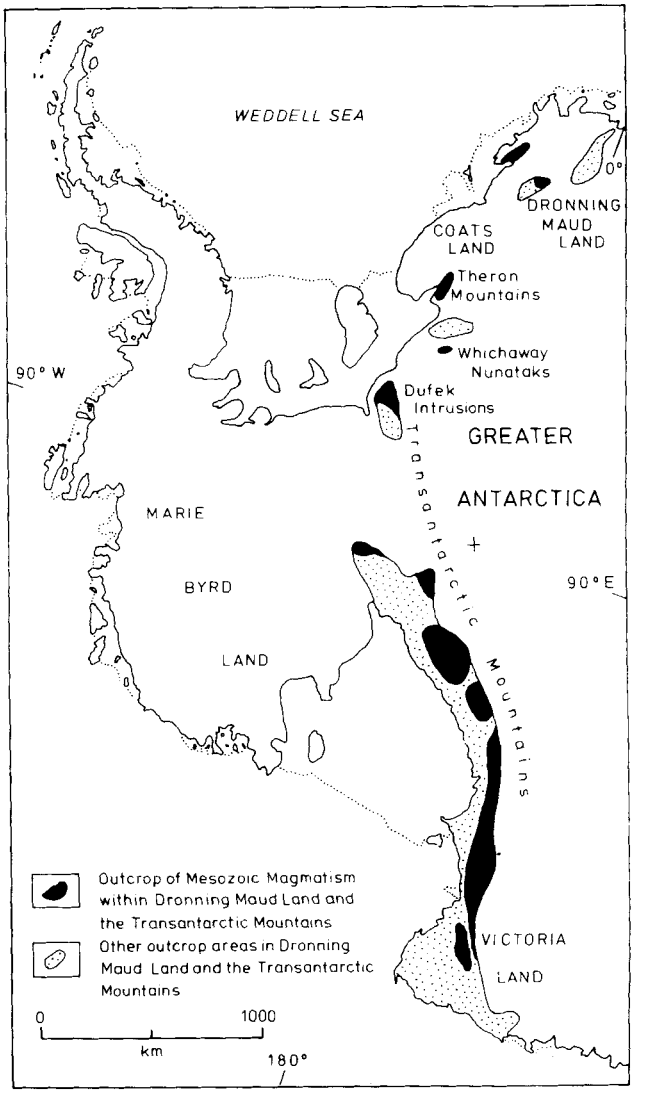


Fig. 1. The distribution of outcrops along the Transantarctic Mountains.

Petrography

The sills are composed predominantly of either holocrystalline or hypocrystalline mosaics of clinopyroxene and plagioclase, which display either ophitic or granophyric textures (Table

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Table I. The petrography of the Omega dolerites.

	Sample	Mineralogy
High-Ti	TAE.301/1, 304/2 TAE.304/6, 304/7	Pale pink augite, plagioclase, opaque minerals, interstitial glass and granophyric quartz and K-feldspar intergrowths. Textures: ophitic and granophyric. Alteration: minor serpentinization of augite.
Low-Ti	TAE.302/5	Augite, normally zoned plagioclase, opaque minerals and granophyric quartz and K-feldspar intergrowths. Textures: seriate, granophyric, mymerkitic intergrowths of augite and plagioclase.
Dyke	TAE.305/1	Very fine-grained intergrowths of plagioclase microlites and augite with interstitial glass. Amygdales filled with quartz and calcite.

I). The most marked mineralogical variations are in the compositions of the pyroxene and the proportion of granophyric intergrowths (Table I). The dyke is hypocrystalline and is composed of radiating microlites of feldspar and clinopyroxene and interstitial glass (Table I). Within the dyke there are also many small amygdales composed of either quartz and/or calcite (Table I).

Geochemistry

Six samples (Table II; five sills, one dyke) have been analysed by X-ray fluorescence spectrometry for 10 major and 18 trace elements, following the methods of Harvey & Atkin (1982). All of the samples are tholeiites with sub-alkaline affinities and are quartz-normative. In the total-alkali–silica diagram (cf. Le Maitre 1984) all of the samples plot in the basaltic andesite field. On the basis of the TiO_2 content the samples can be divided into low-Ti and high-Ti

Table II. Major and trace element analyses of the Omega dolerites, sample TAE.305/1 is a dyke, all of the remaining samples are sills. The trace elements are in ppm, LOI is loss on ignition at 1000°C.

Sample	TAE.301/1	TAE.302/5	TAE.304/2	TAE.304/6	TAE.304/7	TAE.305/1
SiO_2	52.58	56.56	53.31	55.87	55.69	53.91
Al_2O_3	12.06	13.36	12.67	11.87	11.91	14.48
TiO_2	2.23	0.82	1.87	1.88	1.89	0.92
Fe_2O_3	17.18	11.18	15.92	15.77	15.68	12.43
MgO	3.11	4.73	3.63	2.45	2.33	5.40
CaO	7.94	8.68	7.70	6.91	6.77	7.19
Na_2O	2.24	2.17	2.29	2.50	2.63	2.04
K_2O	1.29	1.16	1.24	1.63	1.68	0.26
MnO	0.19	0.17	0.20	0.19	0.19	0.13
P_2O_5	0.21	0.12	0.19	0.27	0.29	0.13
LOI	0.71	0.82	0.67	0.40	0.60	2.79
Total	99.74	99.77	99.69	99.74	99.66	99.68
Ba	347	313	332	424	422	297
Ce	54	33	62	85	82	47
Co	47	41	48	41	43	46
Cr	22	45	67	27	24	51
Cu	152	107	158	201	195	127
Ga	23	19	24	20	23	21
Ni	13	39	31	21	18	47
Nb	8	9	9	11	12	9
Pb	17	15	11	13	18	11
Rb	56	42	52	69	70	6
Sr	162	147	160	142	155	221
Th	2	9	1	6	8	2
U	3	2	1	2	2	2
V	464	193	458	331	303	240
Y	46	31	40	55	55	34
Zn	98	83	98	130	118	115
Zr	162	147	157	222	209	156

Measured isotope ratios for TAE.301/1 are $^{143}Nd/^{144}Nd = 0.512402 \pm 12$ and $^{87}Sr/^{86}Sr = 0.71291 \pm 3$.

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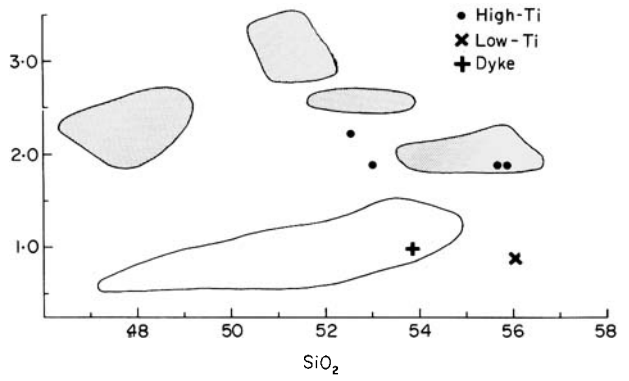


Fig. 2. Subdivision of the Omega dolerites based on Ti content. High-Ti (stippled) and low-Ti (blank) fields from the Theron Mountains after Brewer & Brook (in press).

compositions (Fig. 2), which are identical to the subdivisions used for the Theron Mountains' dolerites (Brewer & Brook, in press).

The high-Ti samples have higher Fe_2O_3, P_2O_5, Ba, Ce, La, Rb, V, Y, Zn and Zr and lower MgO and Cr concentrations than the low-Ti sample (Table II). The high-Ti samples all have relatively high SiO_2 values (Fig. 2) and are therefore similar to other high-Ti samples described from Antarctica (Siders & Elliot 1985, Brewer & Brook, in press). The extremely high SiO_2 value (56.26%) of the low-Ti sample reflects the abundance of granophyric quartz-K-feldspar intergrowths in this sample. The most striking features of the trace elements are their calc-alkaline signatures and high Ba/Nb and Ce/Nb ratios (Fig. 3) which are more similar to island-arc rocks. The Ba/Nb and Ce/Nb ratios are unrelated to the Ti content and do not seem related to the SiO_2 or MgO contents.

All of the samples are light rare-earth element (LREE) enriched and have flat heavy rare-earth element (HREE) profiles (Fig. 4, Table III). The high- and low-Ti compositions have sub-parallel profiles with negative Eu anomalies, although the high-Ti compositions have higher rare-earth element concentrations (Fig. 4). The basic dyke differs from the sills in having a smaller Eu anomaly.

A single high-Ti sample (TAE.301/1) has been analysed for Sr and Nd isotopes at the Open University, following the procedures of Fraser *et al.* (1985/86). This sample has a high initial $^{87}Sr/^{86}Sr$ ratio (0.71064) and an ε_{Nd} of –3.5, and it plots in the enriched mantle domain of Fig. 5. The trace element and isotopic results are indicative of magmas derived from an enriched source or those contaminated by crustal material. It is not possible from the present study to determine whether these characteristics were derived solely from the source region or were modified by some degrees of crustal contamination.

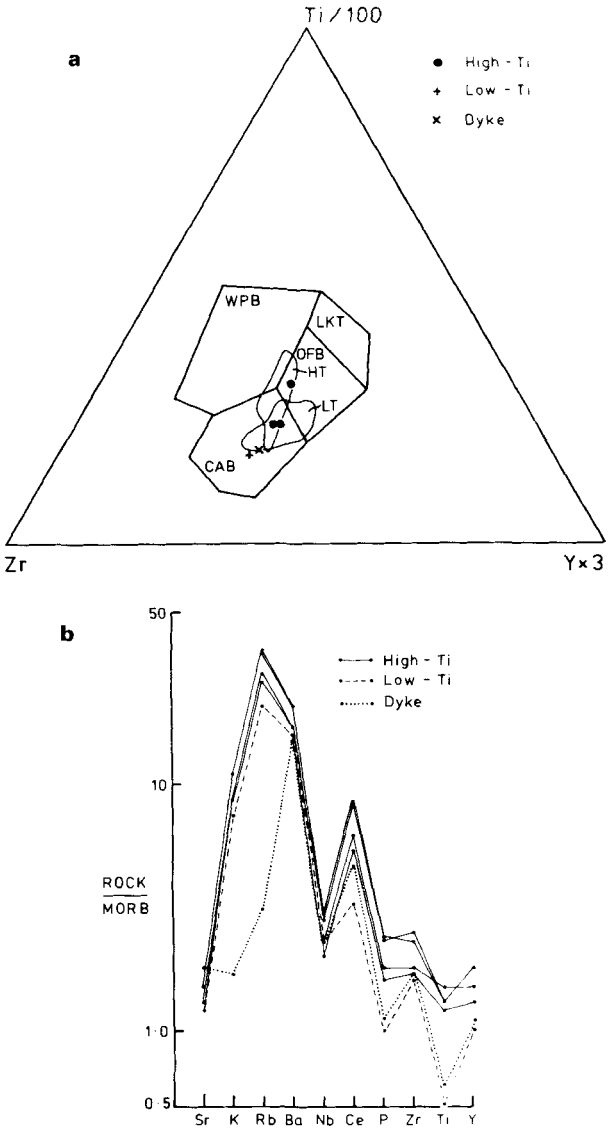


Fig. 3. Trace element characteristics of the Omega dolerites. **a.** The discrimination fields in the Ti-Y-Zr diagram are from Pearce & Cann (1973); WPB = within-plate basalt, LKT = low-K tholeiite, OFB = ocean floor basalt, CAB = calc-alkali basalt. **b.** MORB-normalized diagram constructed using values from Pearce (1980).

Conclusions

The Omega dolerites are geochemically indistinguishable from the Theron Mountains' dolerites. The origin of the low- and high-Ti compositions is problematic because of the small data set. However, Siders & Elliot (1985) have argued that the high-Ti compositions in the Transantarctic Mountains were probably derived by fractional crystallization from low-Ti tholeiites. In contrast Brewer & Brook (in

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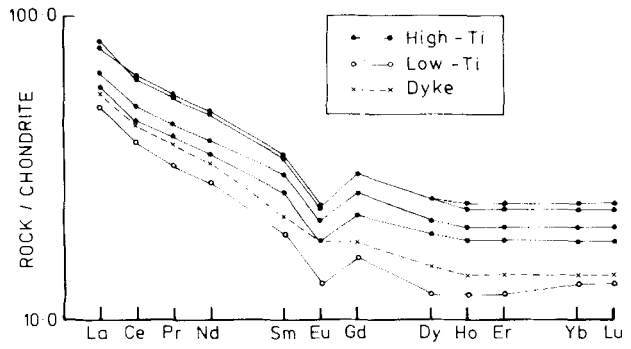


Fig. 4. Chondrite-normalized (values from Nakamura 1974) rare-earth elements were determined using the method of Walsh *et al.* (1981).

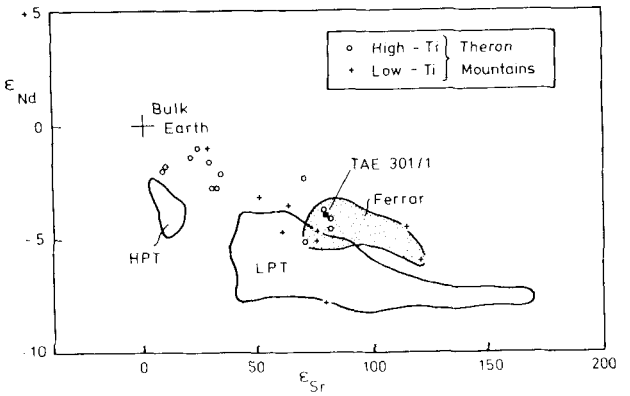


Fig. 5. ε_{Sr}–ε_{Nd} diagram of Mesozoic tholeiites from Antarctica and South America. Ferrar data from Pankhurst *et al.* (1986); Parana data (HPT = High P-Ti, LPT = low P-Ti groups) Hawkesworth *et al.* (1986); Theron Mountains data from Brewer & Clarkson (in press). For consistency with the Theron Mountains data the diagram was calculated assuming an age of 160 Ma.

press) have argued that the low- and high-Ti tholeiites from the Theron Mountains cannot be related by fractional crystallization and were probably derived from different sources. The geochemical similarity of the Omega dolerites to the Theron dolerites probably suggests that Ti bimodality is a primary feature and unrelated to fractional crystallization.

Previous studies of the Antarctic Mesozoic tholeiites have demonstrated that they can be geochemically subdivided into the Transantarctic Mountains or Ferrar (TMS) and the Weddell Sea (WSS) sub-provinces (Faure *et al.* 1972, 1974, 1979, 1982, Ford & Kistler 1980). The TMS is characterized by high SiO_2 and $^{87}Sr/^{86}Sr$ (> 0.709, Kyle *et al.* 1983) and low MgO, CaO, Sr, Ni and K/Rb relative to the WSS (Compston *et al.* 1968, Faure *et al.* 1972, 1974, 1979, 1982, Juckes 1972, Ford & Kistler 1980). The boundary between the two sub-provinces was postulated as lying somewhere between the Theron Mountains and the Pensacola Mountains (Ford & Kistler 1980). Recent work by Brewer & Brook (in press) has indicated that geochemically both sub-provinces are found within the Theron Mountains. It is also now apparent that both high- and low-Ti tholeiites occur in both sub-provinces (Siders & Elliot 1985, Brewer & Brook, in press) and the geochemical signature which characterizes the individual sub-provinces is the $^{87}Sr/^{86}Sr$ ratio. Thus the TMS (Ferrar; Faure *et al.* 1979) are distinguished by $^{87}Sr/^{86}Sr$ ratios greater than 0.709 (Kyle *et al.* 1983), whereas, the WSS has $^{87}Sr/^{86}Sr$ ratios in the range 0.7018–0.7076 (Faure *et al.* 1972).

Using the previous nomenclature, the Omega dolerites contain TMS signatures. These data would suggest that the boundary between the two sub-provinces is located in Coats Land and rather than being a distinct line it is represented by the intermixing of the two geochemical types in the Theron Mountains.

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Table III. Rare-earth element concentrations for the Omega dolerites, using the method of Walsh *et al.* (1981).

Sample	TAE.301/1	TAE.302/5	TAE.304/2	TAE.304/6	TAE.304.7	TAE.305/1
La	21.3	16.5	19.0	25.8	27.3	18.5
Ce	43.4	33.2	39.2	54.8	53.8	38.0
Pr	5.3	3.9	4.8	6.7	6.6	4.6
Nd	24.9	17.8	22.3	30.9	30.4	20.6
Sm	6.0	3.9	5.2	7.1	6.9	4.4
Eu	1.7	1.0	1.4	1.8	1.8	1.4
Gd	7.1	4.4	6.1	8.3	8.2	5.1
Dy	7.3	4.6	6.5	8.7	8.5	5.2
Ho	1.6	1.0	1.4	1.9	1.8	1.1
Er	4.6	2.6	4.1	5.3	5.2	3.1
Yb	4.4	2.8	3.9	5.2	5.1	3.1
Lu	0.7	0.4	0.6	0.8	0.8	0.5

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References

Brewer, T.S. & Brook, D. In press. The geochemistry of Mesozoic tholeiites from Coats Land and Dronning Maud Land. *In* Thomson, M.R.A., Crame, J.A. & Thomson, J.W., *eds. Geological evolution of Antarctica.* Cambridge: Cambridge University Press.

Brewer, T.S. & Clarkson, P.D. In press. Mesozoic magmatism in Greater Antarctica: implications for Precambrian plate tectonics. *In* Thomson, M.R.A., Crame, J.A. & Thomson, J.W., *eds. Geological evolution of Antarctica.* Cambridge: Cambridge University Press.

Compston, W., McDougall, I. & Heier, K.S. 1968. Geochemical comparison of the Mesozoic basaltic rocks of Antarctica, South Africa, South America and Tasmania. *Geochimica et Cosmochimica Acta,* **32**, 129–149.

Faure, G., Bowman, J.R. & Elliot, D.H. 1979. The initial $^{87}Sr/^{86}Sr$ ratios of the Kirwan volcanics of Dronning Maud Land: comparison with the Kirkpatrick Basalt, Transantarctic Mountains. *Chemical Geology,* **26**, 77–90.

Faure, G., Pace, K.K. & Elliot, D.H. 1982. Systematic variations of $^{87}Sr/^{86}Sr$ ratios and major element concentrations in the Kirkpatrick Basalt of Mount Falla, Queen Alexandra Range, Transantarctic Mountains. *In* Craddock, C., *ed. Antarctic geoscience.* Madison: University of Wisconsin Press, 715–723.

Faure, G., Bowman, J.R., Elliot, D.H. & Jones, L.M. 1974. Strontium isotope composition of the Kirkpatrick Basalt, Queen Alexandra Range, Antarctica. *Contributions to Mineralogy and Petrology,* **48**, 153–169.

Faure, G., Hill, R.I., Jones, L.M. & Elliot, D.H. 1972. Isotope composition of strontium and silica content of Mesozoic basalt and dolerite from Antarctica. *In* Adie, R.J., *ed. Antarctic geology and geophysics.* Oslo: Universitetsforlaget, 617–624.

Ford, A.B. & Kistler, R.W. 1980. K-Ar age, composition, and origin of Mesozoic mafic rocks related to Ferrar Group, Pensacola Mountains, Antarctica. *New Zealand Journal of Geology and Geophysics,* **23**, 371–390.

Fraser, K.J., Hawkesworth, C.J., Erlank, A.J., Mitchell, R.H. & Scott-Smith, B.H. 1985/86. Sr, Nd and Pb isotope and minor element geochemistry of lamproites and kimberlites. *Earth and Planetary Science Letters,* **76**, 57–70.

Fuchs, V.E. 1982. Synopsis of results. *Trans-Antarctic Expedition Scientific Reports,* No. 1, 14 pp.

Gunn, B.M. & Warren, G. 1962. Geology: 4. Geology of Victoria Land between the Mawson and Mulock glaciers, Antarctica. *Trans-Antarctic Expedition Scientific Reports,* No. 11, 157 pp.

Harvey, P.K. & Atkin, B.P. 1982. Automated X-ray fluorescence analysis. *In* Denyer, J.E. *Sampling and analysis for the minerals industry.* London: Institution of Mining and Metallurgy, 17–26.

Hawkesworth, C.J., Mantovani, M.S.M., Taylor, P.N. & Palacz, Z. 1986. Evidence from Parana of south Brazil for a continental contribution to Dupal basalts. *Nature,* **322**, 356–359.

Hoffmann, J., Kaiser, G., Klemm, W. & Paech, H.-J. 1980. K/Ar-Alter von Doleriten und Metamorphiten der Shackleton Range und der Whichaway-Nunataks, Ost-und Sudostumrandung des Filchner-Eisschelfs (Antarktis). *Zeitschrift für Geologische Wissenschaften Berlin,* **8**, 1227–1232.

Juckes, L.M. 1972. The geology of north-eastern Heimefrontfjella, Dronning Maud Land. *British Antarctic Survey Scientific Reports,* No. 65, 64 pp.

Kyle, P.R., Pankhurst, R.J. & Bowman, J.R. 1983. Isotopic and chemical variations in Kirkpatrick Basalt Group rocks from southern Victoria Land. *In* Oliver, R.L., James, P.R. & Jago, J.B., *eds. Antarctic earth science.* Canberra: Australian Academy of Science & Cambridge: Cambridge University Press, 234–237.

Le Maitre, R.W. 1984. A proposal by the IUGS Subcommission on the systematics of igneous rocks for a chemical classification of volcanic rocks based on the total alkali silica (TAS) diagram. *Australian Journal of Earth Sciences,* **31**, 243–255.

Marsh, P.D. 1985. Ice surface and bedrock topography in Coats Land and part of Dronning Maud Land, Antarctica, from satellite imagery. *British Antarctic Survey Bulletin,* No. 68, 19–36.

Nakamura, N. 1974. Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites. *Geochimica et Cosmochimica Acta,* **44**, 287–308.

Pankhurst, R.J., Millar, I.L., McGibbon, F., Menzies, M., Hawkesworth, C.J. & Kyle, P.R. 1986. Evidence for the enriched source of the Jurassic Ferrar magmas of Antarctica. *Terra Cognita,* **6**, 204.

Pearce, J.A. 1980. Geochemical evidence for the genesis and eruptive setting of lavas from Tethyan ophiolites. *In* Panayiotou, A., *ed. Ophiolites.* Cyprus: Ministry of Agriculture and Natural Resources, Geological Survey Department, 261–272.

Pearce, J.A. & Cann, J.R. 1973. Tectonic setting of basic volcanic rocks determined using trace element analyses. *Earth and Planetary Science Letters,* **19**, 290–300.

Plumstead, E.P. 1962. Geology: 2. Fossil floras of Antarctica (with an Appendix on Antarctic fossil wood by R. Kräusel). *Trans-Antarctic Expedition Scientific Reports,* No. 9, 154 pp.

Rex, D. 1972. 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, 133–136.

Siders, M.A. & Elliot, D.H. 1985. Major and trace element geochemistry of the Kirkpatrick Basalt, Mesa Range, Antarctica. *Earth and Planetary Science Letters,* **72**, 54–64.

Stephenson, P.J. 1966. Geology: 1. Theron Mountains, Shackleton Range and Whichaway Nunataks (with a section on palaeomagnetism of the dolerite intrusions by D.J. Blundell). *Trans-Antarctic Expedition Scientific Reports.* No. 8, 79 pp.

Walsh, J.N., Buckley, F. & Barker, J. 1981. The simultaneous determination of the rare-earth elements in rocks using inductively coupled plasma spectrometry. *Chemical Geology,* **33**, 141–153.

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