1984/70. Petrology of Tertiary olivine-bearing tholeiitic basalt from Barnes Road, St Marys Quadrangle

J.L. Everard

Abstract

        Quartz normative tholeiitic basalt occurring 16 km WNW of St Marys consists mainly of resorbed olivine (Fo$_{74-77}$), augite, plagioclase and black glass, and belongs to the intergranular-insertal Bridgewater textural type. Chemically the basalt is similar to other Tasmanian Tertiary tholeiites, but is more strongly differentiated with lower MgO and higher SiO$_2$. The basalt probably evolved from an original parental olivine tholeiite, formed by 20-25% partial melting of mantle, by low pressure (<5 kb) fractionation of olivine, clinopyroxene and plagioclase.

INTRODUCTION

        C.R. Calver mapped Tertiary basalt along Barnes Road between St Marys and Mathinna, north-eastern Tasmania, in the extreme north-western corner of the St Marys Quadrangle. A sample of fresh float, field number M366, was collected from EQ848044. A thin section was prepared from this sample, reconnaissance electron microprobe work undertaken on it, and a whole-rock chemical analysis (831451) obtained from the Department of Mines Laboratories at Launceston.

        This is the only Tertiary basalt occurrence in the St Marys Quadrangle. Basalts occurring around St Marys and Germantown are Triassic in age (Calver and Castleden, 1981).

PETROGRAPHY

        The rock is massive, moderately dense, medium-grained and grey-green in colour. Equant, pale greenish ferromagnesian minerals up to one milli-metre diameter are visible against a grey groundmass in hand specimen.

        In thin section, the rock displays an intergranular to insertal texture, and consists of plagioclase (about 45%), augite and olivine (about 15%) and black to sometimes brown glass (about 40%). There is no flow lamination or oriented fabric.

        Plagioclase, the most abundant mineral, occurs typically as dis-oriented, narrow, multiply twinned laths, mostly 200-700 µm long and 30-100 µm across. The plagioclase is optically positive with fairly large extinction angles, in agreement with a microprobe analysis (Table 1) of An$_{60}$ (labradorite).

        Olivine phenocrysts vary from a few hundred micrometres to rarely two millimetres across. The phenocrysts are generally polygonal subhedra, sometimes with plagioclase inclusions, but some are embayed by black glass and a few are very corroded. The mineral is biaxial negative with a large 2V (so Fo<87) and two probe analyses (Table 1) show compositions of Fo$_{77}$ and Fo$_{74}$ (chrysolite).

        Augite occurs as equant subhedral crystals, sometimes 700 µm across, but typically 40-100 µm and smaller than most olivine grains. Augite lies in interstices between plagioclase laths, and is sometimes clumped as glomerocrysts. Small crystals are often difficult to distinguish from

olivine, except by the positive optic sign. A probe analysis (Table 1) shows, after subtracting feldspar contaminant, a rather iron-rich composition.

The black glassy groundmass contains incipient augite granules and skeletal plagioclase laths. Abundant fine (<5 μm) opaque scales and blebs, probably magnetite and ilmenite, are associated with the glass. Also present in the groundmass are minor patches of clearer greenish-brown glass, and irregular patches of off-white carbonate, probably calcite.

Despite the normative composition (Table 3), quartz, potash feldspar and calcium-poor pyroxene are apparently absent. Cooling and solidification was probably too rapid to allow quartz and potash feldspar to crystallise; this is supported by the composition of the glass (Table 1), which is slightly richer in SiO_2 and K_2O than the bulk rock (Table 2). On the other hand, normative hy is represented by resorbed olivine, which is common in saturated Tasmanian Tertiary basalts (e.g. Edwards, 1950).

The rock is petrographically similar to the "basalts with black glass" described by Edwards (1950) and, in particular, the mineralogy, texture and glass content is similar to Edward's Bridgewater Type. This variety, which is widespread in Tasmania, is intermediate in texture between the more glassy Ouse Type and the almost holocrystalline Midlands Type. Chemical analyses (Table 2) support this comparison.

GEOCHEMISTRY

The Barnes Road basalt is chemically a tholeiite (Table 2). Distinctive geochemical features are the presence of normative hy and absence of ne; the relatively low total alkali (Na_2O+K_2O) content, which plots well below the alkalic field in the alkali-silica diagram of Macdonald and Katsura (1964); and $Y/Nb>1$. Petrographically, the presence of olivine as corroded phenocrysts only, and its absence from the groundmass, is also typical of tholeiites.

Only a handful of analyses of Tasmanian Tertiary tholeiites have been published, and few include trace element data. For comparative purposes, five analyses are quoted in Tables 2 and 3. In addition, at least three of the four analysed Tertiary basalts from the Arm River region (Spry, 1958) appear to be tholeiites.

The Barnes Hill basalt is comparable to the other tholeiites, particularly the quartz normative ones collected by Edwards (1950) from Ouse, Bridgewater and Vineys Sugarloaf (near Nile). However, the MgO content is considerably lower, and SiO_2 slightly higher (in fact, higher than any previously published analysis of Tasmanian Tertiary basalt).

Frey et al. (1978) proposed three criteria for the identification of primary magmas (i.e. partial melts of mantle peridotite, unmodified by crystal fractionation or contamination). The first, the presence of spinel lherzolite xenoliths, can be disregarded here as these xenoliths are nearly always absent from tholeiitic magmas (e.g. Green, 1976). On the basis of the other two criteria; an Mg number (100 $Mg/Mg+Fe^{II}$) of 68-72 to be in equilibrium with mantle olivine of Fo_{88-90}, and high compatible trace elements (particularly Ni>320 ppm); the Barnes Road basalt, and indeed the other tholeiites, are not primary magmas. In the case of the quartz-normative tholeiites, this is not unexpected as it would be impossible to directly derive them by partial melting of mantle peridotite.

The simplest petrogenetic model is the low pressure (<12-13 kb) fractionation of olivine from an olivine tholeiite magma just below its liquidus. Re-iterative calculations (cf. Frey et al., 1978) indicate that addition of about 28% olivine in equilibrium with the magma, assuming a distribution coefficient $K_{Dol/Liq}^{Fe/Mg}$ = 0.3 is required to increase the Mg

number to about 70 (i.e. about 22% loss of olivine by crystal fractionation from this hypothetical primary magma would produce the Barnes Road basalt). As the most evolved basalt studied by Frey et al. (1978) required equilibrium addition of only 25% olivine to produce a "primitive" composition, this indicates that the Barnes Road basalt is one of the most strongly frac-tionated of the Tasmanian Tertiary basalts.

However, several features suggest that fractionation of phases other than olivine has also occurred. The Ni content of 210 ppm is less depleted than expected for olivine fractionation alone. Basalts and basanites identified as unmodified primary melts by Frey et al. (1978) have about 350 ppm Ni. Although the mineral/liquid partition coefficient of Ni is very temperature dependent an average value of about ten seems likley (e.g. Frey et al., 1978; Cox et al., 1979). Therefore 22% olivine fractiona-tion (F = 0.78) requires a nearly ten-fold decrease in Ni to about 37 ppm (C_L = C_0F^{D-1}). The Al_2O_3/CaO ratio of 1.57 is considerably greater than the mantle value, inferred from chondrites of 1.20 which should be reflected in tholeiites if they are derived by high degrees of partial melting (Frey et al., 1978), regardless of any olivine fractionation.

Fractionation of calcic clinopyroxene in addition to olivine would tend to increase Al_2O_3/CaO. However, the extreme Al_2O_3 enrichment (to >17%) characteristic of high-alumina basalts has not occurred and some fractionation of calcic plagioclase is also likely.

Differentiation of olivine tholeiites by low pressure fractionation of olivine, pyroxenes and plagioclase is well documented, for example, at Mauna Loa, Hawaii (Wright, 1971). Experimental work on Hawaiian olivine tholeiite (Green and Ringwood, 1967; Green, 1976) indicates that olivine is the liquidus phase below 12-13 kb, and at low pressures (>5 kb) clino-pyroxene and plagioclase also appear together below the liquidus (fig. 1). Low pressure (>5 kb) fractionation of olivine, clinopyroxene and plagioclase from a parental olivine tholeiite will produce a quartz-normative tholeiite. However, there are insufficient constraints to quantitatively model this process for the Barnes Road basalt

Using a pyrolite model mantle composition (Green and Ringwood, 1967), Frey et al. (1978) estimated that the primary tholeiites of Tasmania and Victoria were produced by 20-25% partial melting. It is likely that the primary magma parental to the Barnes Road basalt had a similar origin.

REFERENCES

CALVER, C.R.; CASTLEDEN, R.H. 1981. Triassic basalts from Tasmania. Search 12:40-41.

COX, K.G.; BELL, J.D.; PANKHURST, R.J. 1979. The interpretation of igneous rocks. George Allen & Unwin : London.

EDWARDS, A.B. 1950. The petrology of the Cainozoic rocks of Tasmania. Proc.R.Soc.Vict. 62:97-120.

EVERARD, J.L. 1984. Petrography of Tertiary basalt, altered dolerite and tuff samples, in GULLINE, A.B. Geological atlas 1:50 000 series. Sheet 83(8412N). Sorell. *Explan.Rep.geol.Surv.Tasm.*

FREY, F.A.; GREEN, D.H.; ROY, S.D. 1978. Integrated models of basalt petrogenesis : a study of quartz tholeiites to olivine melilitites from south eastern Australia utilizing geochemical and experimental petrological data. *J.Petrology* 19:463-513.

GREEN, D.H. 1976. Experimental petrology in Australia - a review. *Earth Sci.Reviews* 12:99-138.

GREEN, D.H.; RINGWOOD, A.E. 1967. The genesis of basaltic magmas. *Contrib. Mineral.Petrology* 15:103-190.

MACDONALD, G.R.; KATSURA, T. 1964. Chemical composition of Hawaiian lavas. *J.Petrology.* 5:82-133.

SPRY, A.H. 1958. The Precambrian rocks of Tasmania. Part III. Mersey-Forth area. *Pap.Proc.R.Soc.Tasm.* 92:117-138.

SUTHERLAND, F.L. 1974. High pressure inclusions in tholeiitic basalt and the range of lherzolite-bearing magmas in the Tasmanian volcanic province. *Earth Planet.Sci.Lett.* 24:317-325.

WRIGHT, T.L. 1971. Chemistry of Kilauea and Mauna Loa lava in space and time. *Prof.Pap.U.S.geol.Surv.* 735.
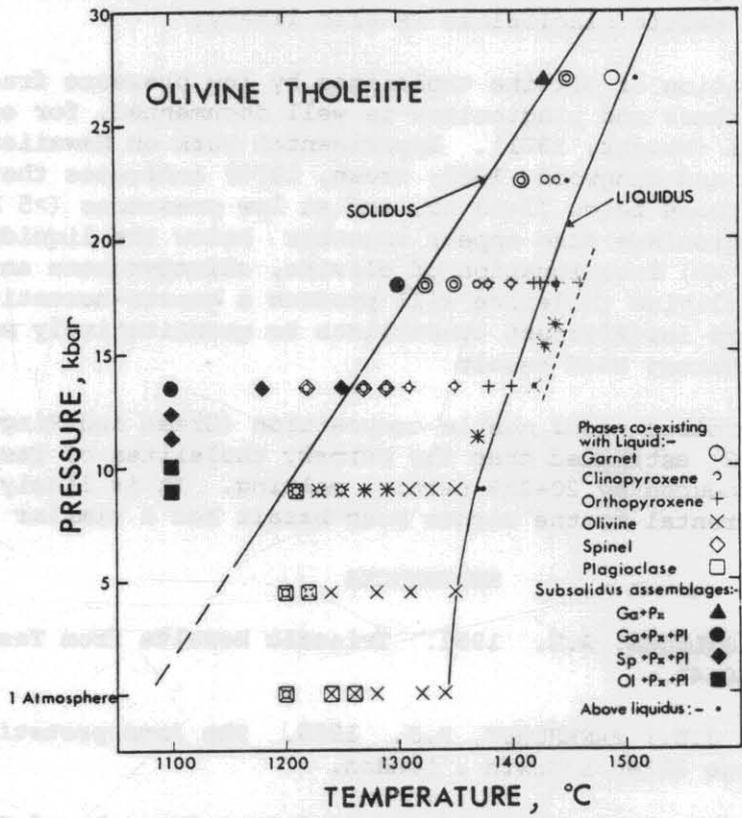
[30 October 1984]

Figure 1. *Experimental crystallisation of Hawaiian olivine tholeiite showing nature of phases between liquidus and solidus as functions of pressure and temperature. The data points using dotted symbols refer to an olivine-enriched tholeiite prepared by addition of 5% olivine (Mg90) to the original olivine tholeiite (from Green, 1976).*

5 cm
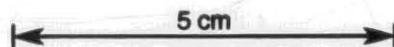
Table 1. *ELECTRON MICROPROBE ANALYSES OF MINERALS AND GLASS*

	Plagioclase	Augite (+ feldspar)	Olivine		Glass
SiO_2	54.56	51.66	38.29	37.76	56.31
TiO_2	-	1.73	-	-	1.82
Al_2O_3	27.67	6.50	-	-	11.53
Σ FeO	0.47	12.55	21.43	23.88	9.82
MgO	-	8.55	40.32	37.96	3.60
CaO	11.56	15.94	0.18	0.14	9.17
Na_2O	4.24	1.15	-	-	2.84
K_2O	0.14	0.34	-	-	0.64
P_2O_5	-	0.28	-	-	0.21
Total	98.64	98.70	100.22	99.74	95.94

No. of ions calculated on basis of oxygen number

	(O) = 8	(O) = 6	(O) = 4	
Si	2.500	1.977	0.990	0.992
Ti	-	0.066	-	-
Al	1.494	-	-	-
Fe		0.537	0.463	0.525
Mg	-	0.651	1.553	1.487
Ca	0.567	0.725	0.005	0.004
Na	0.377	-	-	-
K	0.008	-	-	-
Cation total	4.946	3.956	3.011	3.008
Fe/Fe+Mg	-	0.452	0.230	0.261
or	0.9			
an	59.6			
ab	39.6			

Cr_2O_3, MnO, V_2O_3, SO_3, Cl sought but not detected.

Plagioclase calculated after subtracting Fe (as magnetite or hematite)

Augite calculated after subtracting stoichiometric apatite, orthoclase, and sufficient plagioclase (An_{53}) to remove Al_2O_3 and Na_2O. Inferred augite composition approximate only.

Table 2. ANALYSIS OF BASALT, AND COMPARISON WITH OTHER TASMANIAN TERTIARY
THOLEIITIC ROCKS

	831451	-	830814	Mc25	Mc10	Md79
	Barnes Rd	Andover	Marion Bay	Ouse	Bridgewater	Midlands (Vineys Sugarloaf)
SiO_2	52.53	49.69	48.05	51.48	51.48	50.04
TiO_2	1.54	1.92	1.08	1.45	1.60	1.55
Al_2O_3	14.27	13.33	14.41	14.32	14.18	14.47
Fe_2O_3	2.19	1.74	2.81	2.17	1.56	4.26
FeO	9.69	9.51	8.63	8.98	9.61	7.69
MnO	0.19	0.18	0.16	0.14	0.15	0.17
MgO	5.99	8.36	9.49	8.02	8.18	7.89
CaO	9.08	9.79	9.16	8.33	8.95	9.35
Na_2O	2.71	2.85	2.67	2.48	2.61	2.47
K_2O	0.50	0.53	0.40	0.61	0.82	0.26
P_2O_5	0.19	0.35	0.32	0.21	0.29	0.23
H_2O^+	0.68	)	1.48	0.58	1.00	1.43
H_2O^-	0.32	)1.22 (LOI)	0.66	1.54	0.24	0.52
CO_2	0.43	)	0.08	0.05	tr	tr
SO_3	0.06	)	0.07	-	tr	tr
Traces as oxides	0.19	0.20	0.22	nd	nd	nd
Total	100.56	99.67	99.69	100.36	100.67	100.33
Sc	23	26	23			
V	145	142	165			
Cr	290	312	390			
Co	48	59	48			
Ni	210	103	240			
Cu	52	61	59			
Zn	125	118	92			
Ga	20	nd	nd			
Rb	21	9	16			
Sr	230	373	300			
Y	22	27	23			
Zr	145	146	82			
Nb	12	nd	13			
Ba	110	125	200			
Pb	<4	nd	<4			
Na_2O/K_2O	5.42	5.38	6.68	4.07	3.18	9.50
Al_2O_3/CaO	1.57	1.36	1.57	1.72	1.58	1.55
K/Rb	198	489	208	-	-	-
Zr/Y	6.6	5.4	3.6	-	-	-
Ti/Zr	63.7	78.8	79.0	-	-	-
Y/Nb	1.8	-	1.8	-	-	-
$\dfrac{100\ Mg}{Mg + Fe^{II}}$	52.4	61.0	66.2	61.4	60.3	64.7

831451 : new data
Andover basalt analysis from Sutherland (1974)
830814 from Everard (1984)
Mc25, Mc10, Md79 from Edwards (1950)

Table 3. CIPW NORMS OF THOLEIITIC BASALTS

	Barnes Rd	Andover	Marion Bay	Ouse	Bridgewater	Midlands
Q	5.29	-	-	2.9	0.1	3.4
Or	2.96	3.13	2.36	3.6	4.8	1.6
Ab	22.93	24.12	22.59	21.0	22.1	20.9
An	25.31	22.01	26.16	26.1	24.6	27.6
Di	13.11	19.78	13.96	11.0	14.9	14.1
Hy	22.20	16.50	15.62	27.1	27.1	21.2
Ol	-	5.73	9.59	-	-	-
Mt	3.18	2.52	4.07	3.1	2.3	6.2
Il	2.92	3.65	2.05	2.8	3.0	2.9
Ap (OH)	0.45	0.83	0.76	0.5	0.6	0.5
Cm (Fe)	0.06	-	0.09	-	-	-
Z	0.03	-	0.01	-	-	-
Py	0.04	-	-	-	-	-
Cc	0.98	-	-	0.1	-	-
H_2O, traces etc.	1.09	1.41	2.41	2.1	1.2	1.9
Total	100.55	99.68	99.67	100.3	100.7	100.3
mol%An, plag.	51.0	46.2	52.2	54.0	51.2	55.5
(Fe/Fe+Mg) px	0.41	0.33	0.28	0.32	0.36	0.24