Huchon, P., Taylor, B., and Klaus, A. (Eds.)
Proceedings of the Ocean Drilling Program, Scientific Results Volume 180

1. AFFINITY OF THE LEG 180 DOLERITES OF THE WOODLARK BASIN: GEOCHEMISTRY AND AGE[1]

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ABSTRACT

New trace element analyses are presented for Leg 180 dolerites, basalts from the Papuan Ultramafic Belt (PUB), and basement rocks of Woodlark Island. The Leg 180 dolerites are similar to those from Woodlark Island in being derived from an enriched source but differ from the PUB, which came from a source similar to normal mid-ocean ridge basalts.

A reliable ^{40}Ar/^{39}Ar age of 54.0 ± 1.0 Ma has been obtained by step heating of a whole-rock sample from Site 1109, and a similar but less reliable age was obtained for a sample from Site 1118. Plagioclase from Site 1109 did not give a meaningful age. This age is broadly similar to ages from the Dabi volcanics of the nearby Cape Vogel and for the PUB.

INTRODUCTION

During Ocean Drilling Program (ODP) Leg 180 drilling, we encountered dolerite in a number of holes (at Sites 1109, 1114, and 1118) and a gabbro at Site 1117 (Taylor, Huchon, Klaus, et al., 1999). This contribution seeks to illuminate the possible affinities of these dolerites with respect to the regional geology using new geochemical and age data. Metadolerites were also recovered at Sites 1110, 1111, 1112, and 1113, but these are tectonized to some degree and exhibit considerable metamorphic alteration. These have not been considered further here. The almost ubiquitous presence of dolerite and gabbro in Leg 180 holes shows the importance of this rock type in the regional context and sug-

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[1] Brooks, K., and Tegner, C., 2001. Affinity of the Leg 180 dolerites of the Woodlark Basin: geochemistry and age. *In* Huchon, P., Taylor, B., and Klaus, A. (Eds.), *Proc. ODP, Sci. Results,* 180, 1–18 [Online]. Available from World Wide Web: <http://www-odp.tamu.edu/publications/180_SR/VOLUME/CHAPTERS/155.PDF>. [Cited YYYY-MM-DD]

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Initial receipt: 19 December 2000
Acceptance: 18 June 2001
Web publication: 6 September 2001
Ms 180SR-155

gests that the basement may be of ophiolitic character. The nature of the basement is relevant to the rheological properties of the lithosphere and thus to the nature of rifting.

Sites 1109 and 1118 are on the hanging wall of the Moresby Seamount detachment, where the dolerite, which is interpreted as basement, has subsided to considerable depths (773 and 869 meters below sea floor [mbsf], respectively) (see Taylor, Huchon, Klaus et al., 1999, for subsidence history). The two other sites are on the footwall and have experienced net uplift; the dolerite at Site 1114 was encountered at 295 mbsf, whereas the gabbro at Site 1117 at ~85 mbsf was found to underlie a fault gouge that passes gradually downward into fresh quartz gabbro.

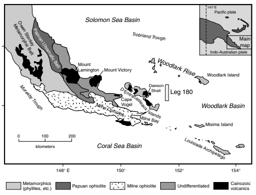
These dolerites are olivine- to quartz-normative with low contents of K_2O and high levels of incompatible elements. They are similar to basalts reported from Woodlark Island (the Luluai Formation), which were designated "ocean-floor" basalts by Ashley and Flood (1981). They show relatively little variation from differentiation processes as judged by their relatively constant FeO/MgO ratios and contents of compatible elements (Ni and Cr).

Taylor, Huchon, Klaus, et al. (1999) concluded that of the doleritic/gabbroic material recovered, the material from Site 1109 was the freshest (i.e., least altered by processes of hydrothermal alteration, weathering, or possible igneous differentiation, unlike material from the other sites). This conclusion is based on petrographic observations (largely fresh primary mineralogy) and the generally undisturbed pattern of its incompatible element chemistry relative to pristine mid-ocean-ridge basalt (MORB). Basalts from all other sites showed erratic behavior of elements known to be mobile under conditions of weathering and/or hydrothermal alteration and/or low-grade metamorphism (e.g., K, Rb, and Ba). Site 1118 dolerite was seen to be weathered; the core material has pervasive red iron oxides. This conclusion was supported by its increased K_2O, Rb, and Ba, possibly indicating seafloor weathering (Bednarz and Schmincke, 1990). Site 1117 contains a quartz gabbro, whose composition is quite variable and has probably been affected both by hydrothermal activity as a result of its proximity to the Moresby Seamount detachment fault and by variable degrees of differentiation (its contents of Ni and Cr are lower and its FeO/MgO ratio markedly higher than in the dolerites). It was concluded that it resembled gabbros from typical ophiolites in having low TiO_2 and K_2O contents. In light of these considerations, we have concentrated on samples from Sites 1109 and the fresher samples from Site 1118.

POSSIBLE ONSHORE EQUIVALENTS TO THE LEG 180 DOLERITES

Eastern Papua and the islands of Milne Bay Province (Fig. F1) have widespread ophiolite complexes and fragments of such. Best known is the Papuan Ultramafic Belt (PUB), a classic ophiolite consisting of ultramafic rocks of mantle origin, gabbros, and cumulate ultramafics, sheeted dike swarms, and pillow basalts. It is interpreted as a northeasterly dipping sliver of oceanic lithosphere emplaced during Cretaceous to Eocene subduction by thrusting over the Owen Stanley metamorphics, an uplifted accretionary complex (Davies, 1971; Davies and Smith, 1971; Davies and Jaques, 1984; Davies et al., 1984; Rogerson et

F1. Map of the Papuan Peninsula and the western Woodlark Basin, p. 10.



al. 1987, 1993) This huge thrust sheet extends over ~400 km from south of Collingwood Bay (~149°E) to the Huon Gulf (~147°E) and reaches thicknesses of up to 18 km. It is thought to have been formed by normal seafloor spreading in the Cretaceous.

The geological map (Fig. **F1**) shows an extensive area of volcanic rocks in the Milne Bay area known as the Milne Basic Complex (Smith, 1982) or the Milne Ophiolite (Hamilton, 1979), although the basis for this being an ophiolite is somewhat unclear as mantle rocks have not been reported. Smith (1982) reported that it consists largely of basalt (70%), microgabbro (25%), minor gabbro, and sediments. The submarine basalts of the Milne Bay area (Fig. **F1**) are discussed in Smith and Davies (1976) and in the relevant 1:250,000 series geological maps and explanatory notes under the name Kutu Volcanics. These authors report two sets of micropaleontological ages: Late Cretaceous (Maastrichtian) and middle Eocene. Analyses of basalts published by Smith (1982) show that it contains tholeiitic basalts of oceanic character, and Milsom and Smith (1975) interpret it as oceanic crust formed during opening of the Coral Sea in the Eocene, thickened by underplating in middle Miocene when it was uplifted and intruded by shoshonites.

In addition, ophiolitic fragments are found throughout the Milne Bay Islands, including tectonically emplaced mantle rocks in the D'Entrecasteaux islands (emplaced along the margins of metamorphic core complexes of Owen Stanley metamorphics) (Davies and Warren, 1988; Baldwin et al., 1993) and the basement rocks of Woodlark Island. The basement rocks of Woodlark Island consist of oceanic floor–type tholeiites (the Luluai volcanics) overlain by younger volcanics of shoshonitic character (Okiduse volcanics). It may be the extension of the Milne Basic Complex (Ashley and Flood, 1971). Similarly, late Paleocene volcanics were encountered at the base of the Nubiam-1 well (Stewart et al. 1986) west of the Trobriand Islands.

Previous workers, enumerated above, have concluded, based on the geological associations and geochemistry, that the PUB, Milne Basic Complex, and basement rocks of Woodlark Island all represent ocean floor fragments. A compilation of published analyses of basalts from these units shows them all to be similar in composition: low-potassium tholeiites. These earlier studies, carried out in the 1970s, relied on X-ray fluorescence (XRF) determinations of major and selected trace elements. Since that time, analytical methods have improved greatly and it is now possible to routinely determine a great many more trace elements to a higher precision. Similarly, our understanding of such rocks, specifically their genesis and tectonic affiliations, have made a quantum leap. It should now be possible to refine our conclusions. For example, "oceanic basalt" covers normal mid-ocean-ridge basalt (N-MORB), backarc basin basalts, and enriched MORB (E-MORB), as found at hotspots, such as Iceland, or at oceanic plateaus, such as the Ontong Java Plateau.

We obtained previously analyzed samples from the volcanics of the PUB (courtesy of A.L. Jaques) and from the basement rocks of Woodlark Island (courtesy of R.H. Flood) and reanalyzed them, along with Leg 180 material, by inductively coupled plasma–mass spectrometer (ICP-MS) techniques. Unfortunately, samples from the Milne Basic Complex were not forthcoming in time and could not be included. Earlier analyses were made on this material in the 1970s using XRF techniques. We use the new analyses in an attempt to better characterize their tectonic setting and to suggest their affinities.

In addition, we have conducted $^{40}Ar/^{39}Ar$ analyses of selected material from Leg 180 to determine its age as accurately as possible for purposes of correlation.

GEOCHEMICAL RESULTS

The following conclusions were drawn from shipboard studies (Taylor, Huchon, Klaus, et al., 1999):

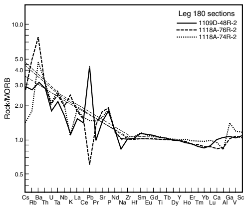
1. Site 1109 dolerites are apparently little altered.
2. Site 1118 dolerites are relatively fresh but have suffered some alteration at low temperatures (weathering), which has affected mobile elements such as K, Rb, and Ba.
3. Other dolerites (i.e., from Sites 1110–1114) and the gabbro at Site 1117 exhibit varying degrees of hydrothermal alteration.
4. The Leg 180 dolerites are closely related to N-MORB; low levels of Ba, even when enhanced by alteration, show no evidence of subduction zone processes, which might otherwise be expected from the presence in the area of Tertiary compressional tectonics manifested by the emplacement of the PUB. Volcanoes of typical calc-alkaline character, such as Mount Lamington, suggest compressional tectonics persists to the present.

The new ICP-MS results for Leg 180, Woodlark Island, and the PUB are shown in Table **T1.** They are plotted on multielement diagrams in Figures **F2, F3,** and **F4** (using the values of Pearce and Parkinson, 1993, as normalizing factors). These data were acquired partly at Durham University and partly at the Geological Survey of Denmark and Greenland in Copenhagen, by J. Kystol (using the method described by Turner et al., 1999). Analyses from the two laboratories are generally within experimental error, and the same standards were used. New analyses of major elements from the Leg 180 samples analyzed here for trace elements were determined by largely by XRF using the methods of Kystol and Larsen (1999) and are shown in Table **T2.**

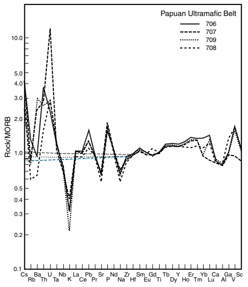
The multielement diagrams for three Leg 180 cores shown in Figure **F2** reveal alteration effects in their spikiness. All samples show moderate positive Ba peaks and minor Na troughs; one shows a moderate K peak, one shows a pronounced positive Pb peak, and all show a possible minor P peak. Surprisingly, the sample with the pronounced Pb enrichment is from Site 1109, thought to be the least altered sample. Two samples show a negative K peak, and one shows a negative Pb peak. Nevertheless, some elements are little modified by weathering and low-temperature alteration ("conservative elements") (e.g., Nb, Ta, Zr, Hf, Ti, and the heavy rare earth elements). If we draw baselines through these elements in a similar manner to that done by Pearce and Parkinson (1993), who were trying to eliminate the effects of circulating fluids in subduction zones, we see that this baseline rises to the left (most incompatible end) of the diagram. We can conclude that the source region for the dolerite magmas was markedly enriched in these most incompatible elements relative to that for MORB. It was perhaps similar to the source of the alkali basalt from Grenada used as an example by Pearce and Parkinson (1993), although the alkaline character of their sample probably derives from the very high levels of slab-derived large ion lithophile elements.

T1. Major element analyses, p. 16.

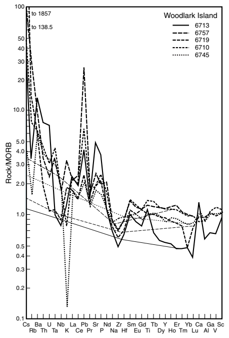
F2. MORB-normalized multielement diagram for dolerites, p. 11.



F3. MORB-normalized multielement diagram for PUB basalts, p. 12.



F4. MORB-normalized multielement diagram for Luluai Formation basalts, p. 13.



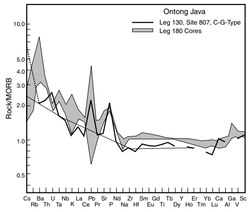
T2. Trace element analyses, p. 17.

In contrast, samples of Jaques and Chappell (1980) from the PUB (Fig. F3) show essentially flat patterns of conservative elements, indicating their source was very similar to MORB. This in itself is an important observation, as although ophiolites have been regarded as fragments of normal oceanic lithosphere, a long-standing discussion has gone on as to whether they are normal ocean crust, subduction influenced, or possibly anomalous in some way (e.g., parts of oceanic plateaus), thus accounting for the fact that they have been obducted rather than subducted. Although the PUB rocks are clearly derived from a source almost identical to that of MORB, they also show marked alteration patterns. Thus, all samples are markedly enriched in U, Th, Pb, and P and are strongly depleted in K, Na, and Sr.

Figure F4 shows results from five samples from Woodlark Island. These samples show a very marked spikiness indicative of advanced alteration as might be expected from the description of Ashley and Flood (1981): "Metamorphism to lower greenschist assemblages is common, and a metasomatic-contact metamorphic event ... has produced diopside, grossular ...etc." in the interbedded limestones. The alterations are similar to those already observed and include loss of K (generally), increase in Pb, Sr, and P (all samples), but, perhaps surprisingly, no notable alteration of Na. The conservative elements allow us to conclude that these volcanics originated from an enriched source region similar to that of the Leg 180 dolerites.

In Figure F5 we also show an abundance pattern for a sample from the Ontong Java Plateau (Neale et al., 1997) for comparison. This shows a very similar enrichment pattern for conservative elements and enrichments of Pb and Na to those observed in Leg 180 dolerites and the Woodlark Island basement but quite different from the PUB.

F5. Comparison between oceanic plateau Leg 180 cores, p. 14.



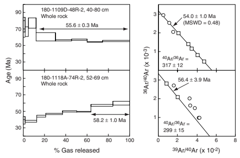
AGE OF THE LEG 180 DOLERITES

Three samples have been analyzed by ^{40}Ar/^{39}Ar analysis using incremental step heating experiments at Oregon State University as described by Sinton and Duncan (1998) and Tegner et al. (1998). The results are reported in Table T3 and Figure F6; errors are given as one standard deviation.

T3. Incremental heating ages, p. 18.

The age spectrum for whole-rock Sample 180-1109D-48R-2, 40–80 cm, defines a five-step plateau at 55.6 ± 0.3 Ma. The isochron age for these same steps is slightly younger, at 54.0 ± 1.0 Ma with ^{40}Ar/^{36}Ar intercept close to air and low mean squared weighted deviates (MSWD) (= 0.48). We regard this value as being the most reliable age and interpret it as a cooling age for the dolerite. We also analyzed a plagioclase separate (not shown) from this sample, but it failed to produce either a plateau or an isochron age, seemingly due to argon loss. The age spectrum for a whole-rock sample from Hole 1118A (Sample 180-1118A-74R-2, 5–69 cm) steps up from ~40 Ma at low temperature to 58.2 ± 1.0 Ma in a short plateau (37% gas) in the two highest temperature steps (Fig. F6). This staircase pattern indicates argon loss, but the high-temperature steps are likely to represent the original cooling age. A regression line for these two steps (56.4 ± 3.9 Ma) on an isochron diagram is concordant with the plateau age. Altogether, our data indicate the dolerites of the Woodlark Basin formed at 58–54 Ma (probably close to the lower value). This age range spans the Paleocene/Eocene boundary.

F6. Age spectra and inverse isochron correlation diagrams, p. 15.



INTERPRETATION

All samples studied here show considerable alteration, as seen in their volatile contents, high Fe_2O_3/FeO ratios (as reported by Jaques and Chappell, 1980, and Ashley and Flood, 1981), and elemental abundance anomalies in the multielement diagrams. Because of the level of alteration and lacking fresher material, it is necessary to use immobile elements, as we have done here.

We conclude from the geochemical observations that the basement at Leg 180 sites, as represented by the almost ubiquitous dolerites and gabbros, consists of material derived by partial melting of enriched mantle, possibly similar to that of the Ontong Java Large Igneous Province. However, Ontong Java is situated well to the east and is at present on the opposite side of the Solomon Trench, so there is no direct connection. This work clearly shows the marked difference in geochemical character to the Papuan Ophiolite Belt, and we consider it unlikely that the ophiolite extends into the drilled area. Instead, the basement at the Leg 180 sites may be identical to the Luluai volcanics, which form the basement rocks of Woodlark Island, ~120 km to the northeast, and are overlain by the high-K (shoshonitic) Okiduse volcanics, whose age is late middle Miocene (Ashley and Flood, 1981). High-K clasts were also found in Leg 180 material (Sample 180-1111A-4R-CC, 3–5 cm) (see Taylor, Huchon, Klaus, et al., 1999), suggesting that the Okiduse volcanics may also be represented in this area. Indeed, they may be the equivalents of the shoshonitic intrusives described by Smith (1972) from eastern Papua, which give variable K-Ar ages, preferred values being Miocene. These high-K rocks are all subduction-related, whereas the dolerites described here and the ophiolites in surrounding areas were formed in an extensional environment. We note that subduction at the Trobriand Trough began by the early Miocene (Hamilton, 1979; Smith and Milsom, 1984). The Milne Basic Complex, whose age has been determined using biostratigraphic methods (see above) may be identical to the basement of Woodlark Island, but we have been unable to confirm this because of lack of samples or precise age information.

We regard the best age for the Leg 180 dolerites to be that of Section 180-1109D-48R-2 whole rock, which is 54.0 ± 1.0 Ma, although we are unsure how to interpret this result. It is clearly younger than the accepted ages for the PUB, which is thought to have been emplaced in the Paleocene, although formed in the Cretaceous (Rogerson et al., 1993). There are no radiometric ages for the Woodlark Island basement (Luluai volcanics), although they are stratigraphically constrained to pre-early Miocene (Ashley and Flood, 1981). They are thought to be possibly equivalent to the Lokanu volcanics of southeast Papua, although these are also considered to be Paleocene (Stewart et al., 1986).

In the light of present knowledge of the various ophiolite-like complexes in the Woodlark Basin area, it seems that the rocks dated here were contemporaneous with similar events in the area. Thus, Walker and McDougall (1982) reported ages of 58.93 ± 1.09, 58.85 ± 0.70, and 53.70 ± 1.02 Ma (all 1-σ uncertainties) for tholeiitic rocks and boninites from Cape Vogel (Fig. F1), whereas Duncan (pers. comm., 2001) has obtained hornblende ages of 55.5 and 58.4 Ma from pegmatitic gabbros from the PUB. Neither the Kutu volcanics (Milne Bay) nor the basement of Woodlark Island have been dated by radiometric techniques, but we expect them to have similar ages.

CONCLUSIONS

We conclude that the ophiolite-like basement encountered during Leg 180 drilling is not equivalent to the PUB (although of similar age) but might be similar to the basement of Woodlark Island (Luluai volcanics), which it shares in being derived from an enriched source (in the sense of having higher incompatible elements than the MORB source). The source of the Leg 180 dolerites and Luluai volcanics is similar to, for example, the Ontong Java Plateau. Possibly, the Kutu volcanics of the Milne Basic Complex may belong to the same group, but we do not have any modern information on these rocks. In contrast, the PUB has been derived from a depleted source, similar to that for N-MORB.

We cannot completely achieve the aims set out above because of several factors. First, we lack material from the adjacent Milne Basic Complex for comparative purposes. Second, information on the other areas discussed is insufficient or lacking; there are no reliable dates for these areas, and much of the investigated material seems to be highly altered. After a burst of activity in the 1970s, which achieved praiseworthy results, little has been done in recent years in spite of the fact that techniques and understanding have greatly advanced. We urge a renewed effort in researching the geology of this fascinating area. Studies of rift propagation into continental crust will not be completely understood until the precise nature of this crust is known.

ACKNOWLEDGMENTS

This research used samples and/or data provided by the Ocean Drilling Program (ODP). ODP is sponsored by the U.S. National Science Foundation (NSF) and participating countries under management of Joint Oceanographic Institutions (JOI), Inc. Funding for this research was provided to C.K.B. by the Danish Natural Sciences Research Foundation.

This study was made possible by the donation of described material by A.L. Jaques, Canberra, Australia, and R.H. Flood, Sydney, Australia, to whom we are grateful.

We are also indebted to Bob Duncan and Lew Hogan for help and access to the argon facility at Oregon State University through funding from the U.S. National Science Foundation. J. Kystol, Geological Survey of Denmark and Greenland in Copenhagen, is thanked for his high-quality analytical results, both for major and trace elements.

We are further indebted to the two reviewers, Bob Duncan and Hugh Davies, who both made valuable input.

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Figure F1. Simplified geological map of the Papuan Peninsula and the western Woodlark Basin, based on the 1:2,500,000 map, Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia. The approximate area of operation of ODP Leg 180 is shown in the labeled box.

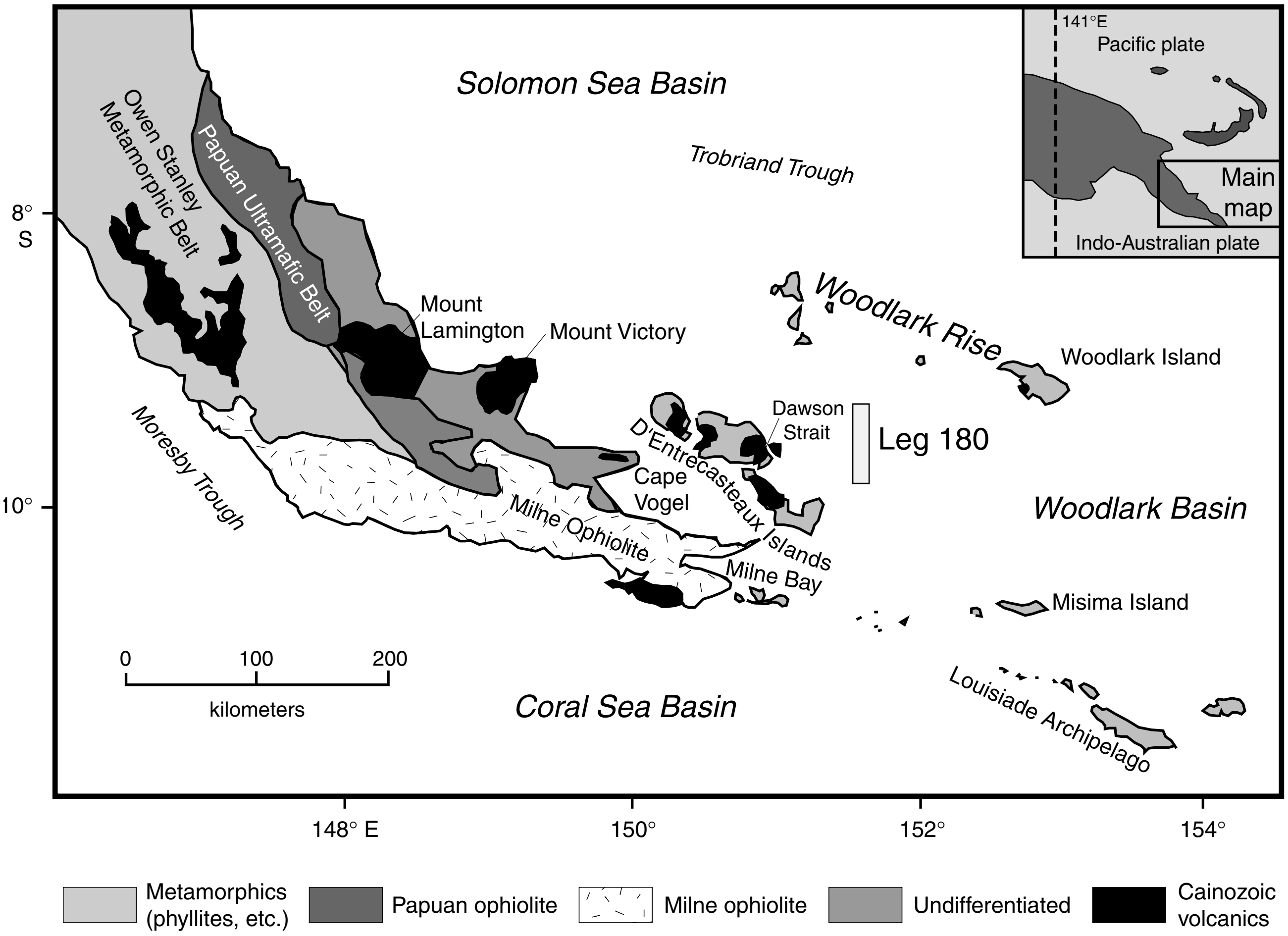

Figure F2. MORB-normalized multielement diagram for Leg 180 dolerites. The lighter dashed lines are baselines, as explained in "Geochemical Results," p. 4.

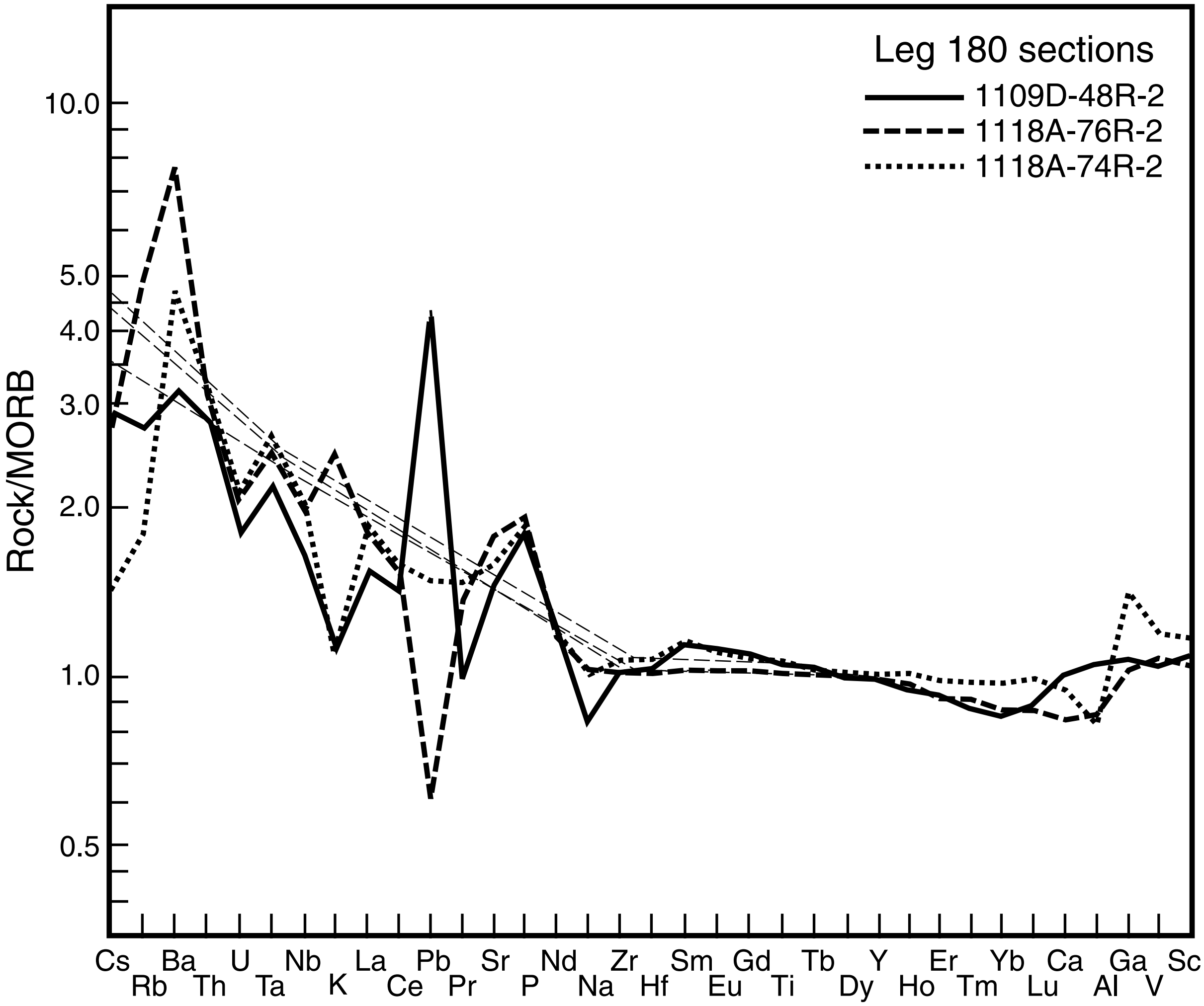

Figure F3. MORB-normalized multielement diagram for the samples of Jaques and Chappell (1980) from the basalts of the PUB. The lighter lines are baselines, as explained in "Geochemical Results," p. 4.

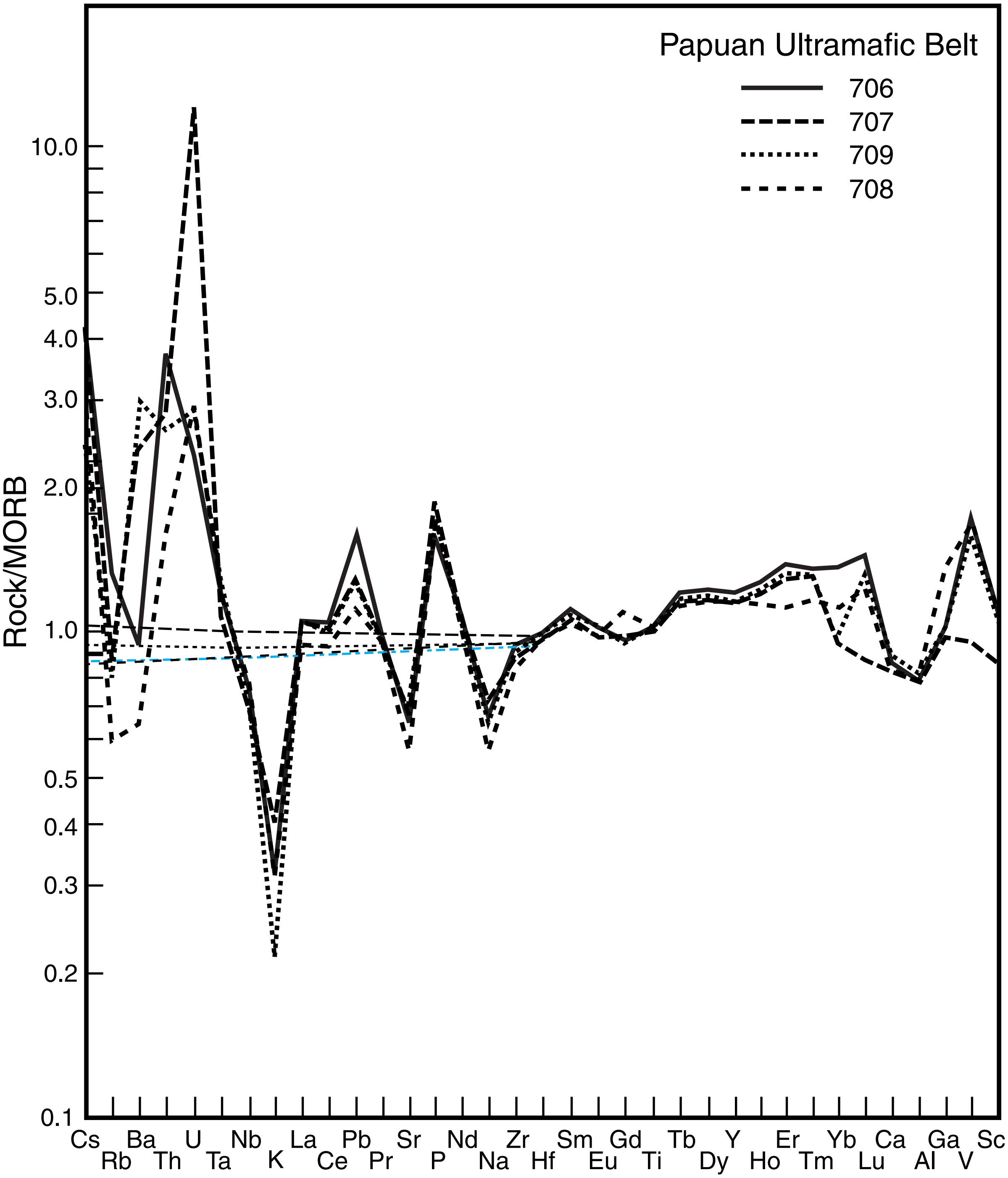

Figure F4. MORB-normalized multielement diagram for the samples of Ashley and Flood (1981) from the basalts of the Luluai Formation, Woodlark Island. The lighter lines are baselines, as explained in "Geochemical Results," p. 4.

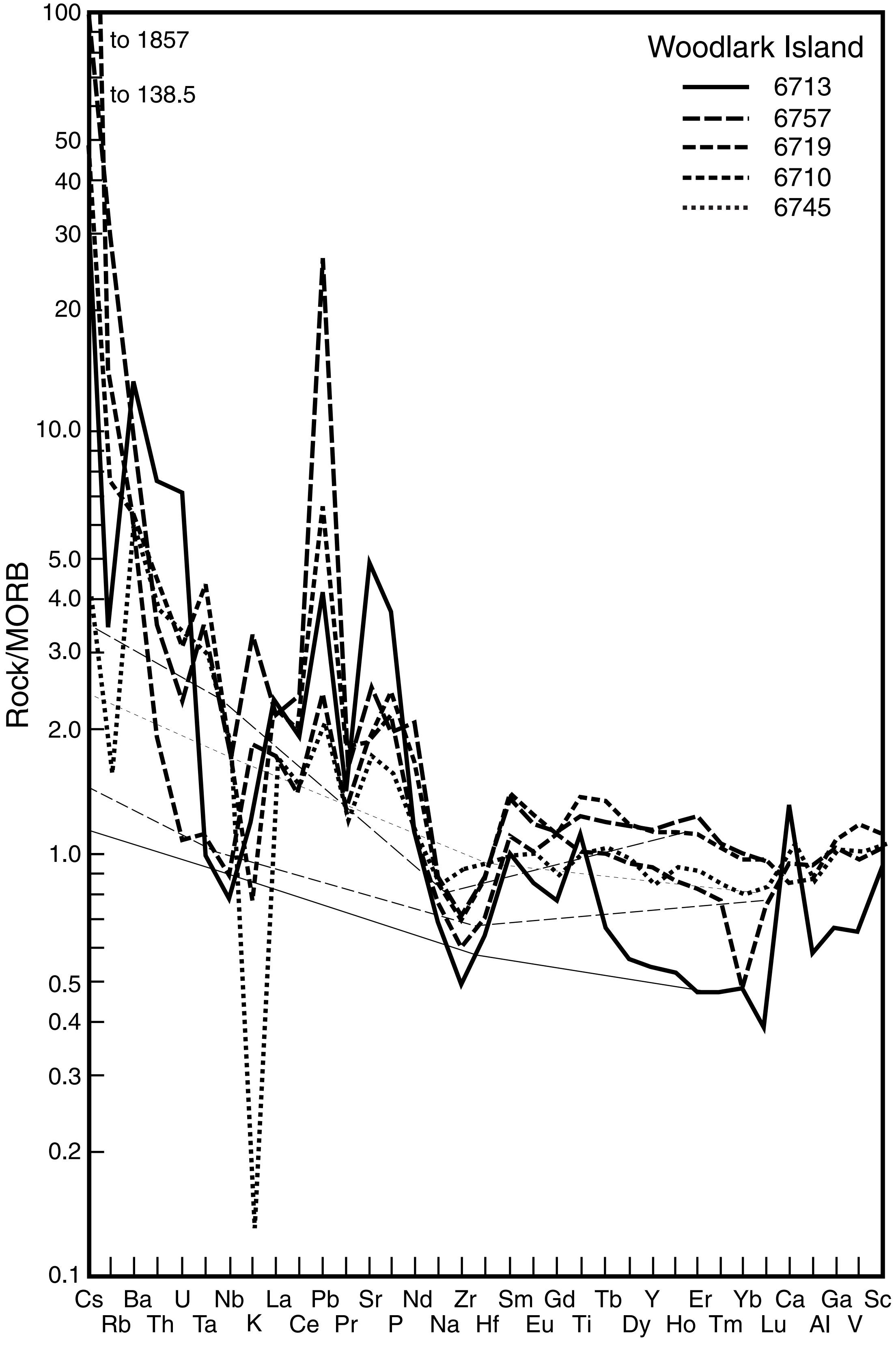

Figure F5. Comparison between a typical oceanic plateau sample (from the Ontong Java Plateau from Neal et al. [1997]) and the Leg 180 cores. Lighter lines are baselines, explained in **"Geochemical Results,"** p. 4.

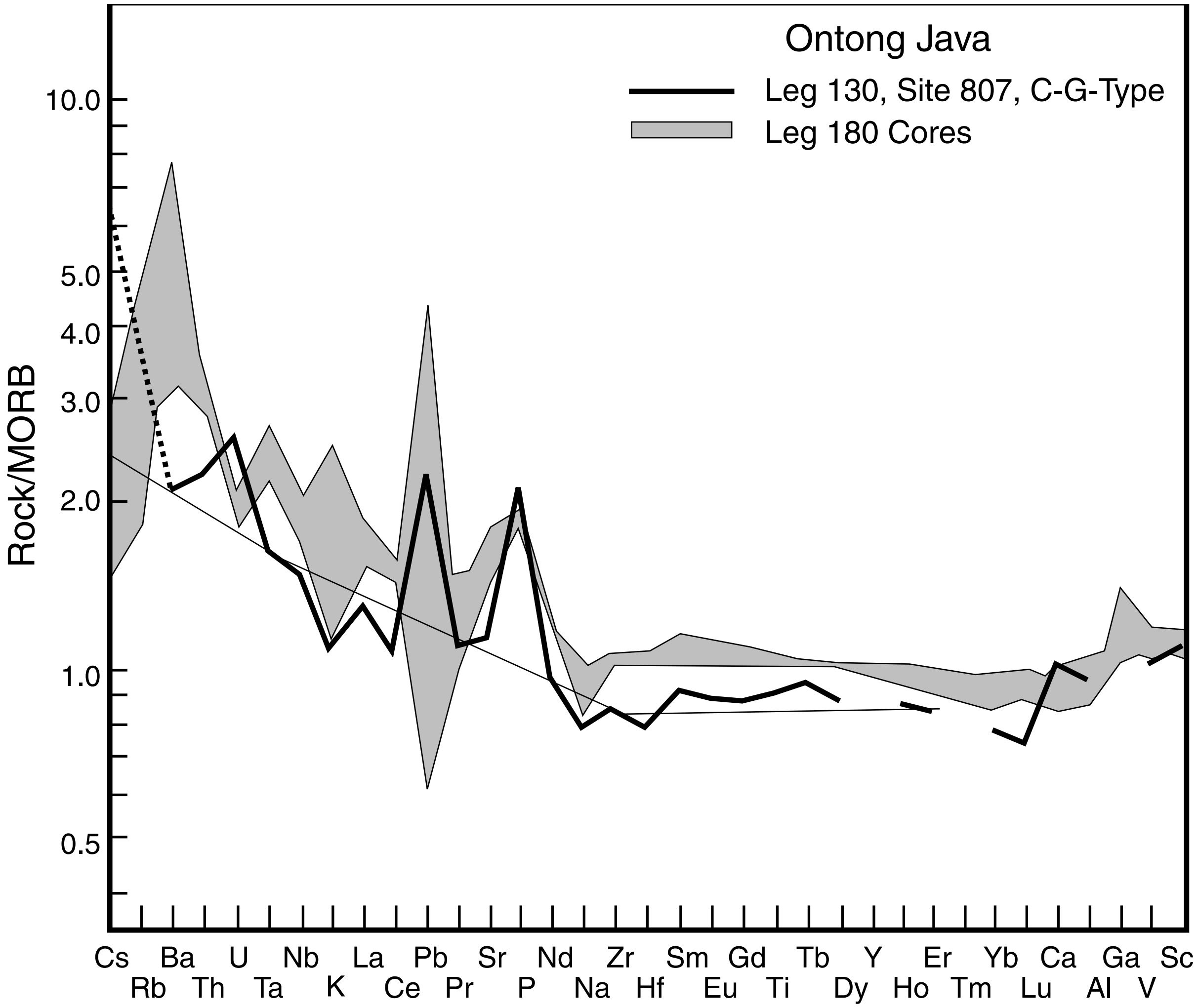

Figure F6. Results of $^{40}Ar/^{39}Ar$ incremental heating experiments showing age spectra and inverse isochron correlation diagrams. Squares = regressed steps on the isochron diagrams, open circles = other steps. MSWD = mean squares of weighted deviations.

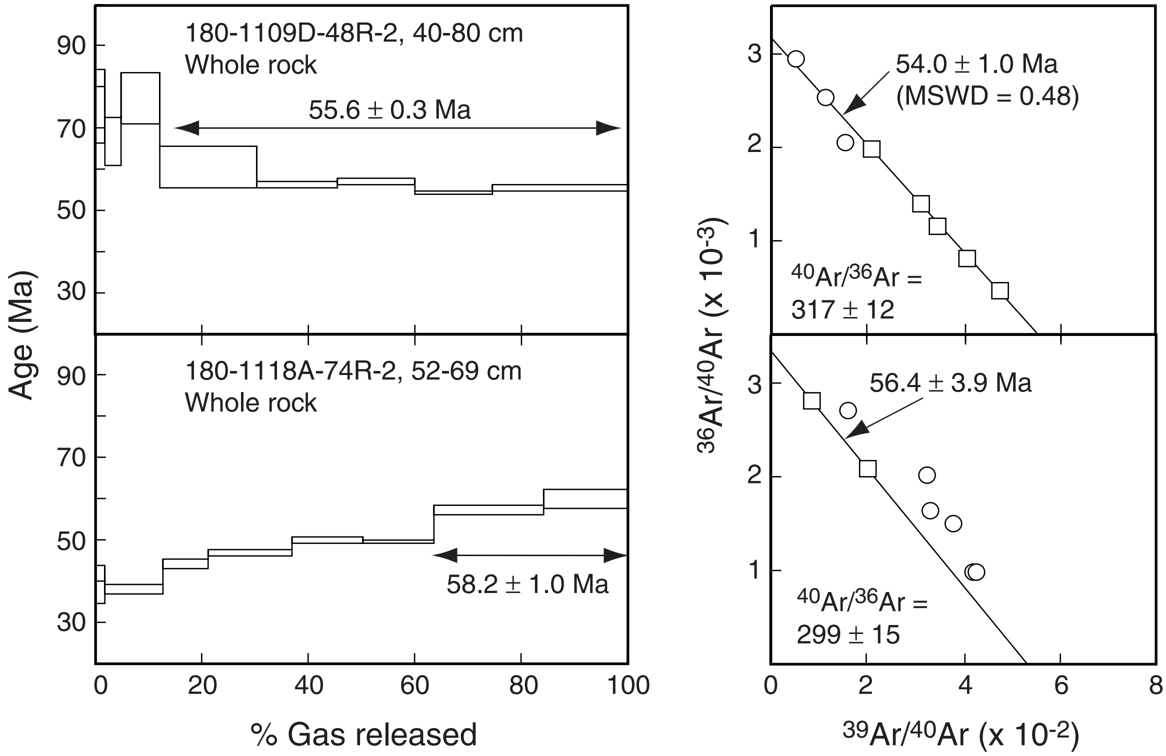

Table T1. ICP-MS analyses of Leg 180 dolerites and basalts from Woodlark Island (Luluai Formation) and the Papuan Ultramafic Belt.

	180-1109D-48R-2,	180-1118A-76R-2,	180-1118A-74R-2,	Woodlark Island*					Papuan Ultramafic Belt†			
Sample:	40–80 cm	45–53 cm	51–69 cm	MU6713	MU6719	MU6710	MU6745	MU6757	708	706	707	709
Trace element:												
Cs	0.022	0.020	0.005	0.214	1.3	0.331	0.028	0.969	0.017	0.030	0.028	0.015
Rb	1.5	2.6	1.0	2.0	8.1	2.2	0.89	14.5	0.33	0.70	0.49	0.45
Ba	20.0	48.7	29.7	103.8	40.5	40.28	38.5	56.6	3.99	5.91	14.57	19.05
Th	0.323	0.375	0.388	0.932	0.227	0.48	0.46	0.38	0.19	0.45	0.33	0.32
U	0.082	0.098	0.100	0.285	0.046	0.148	0.160	0.10	0.142	0.127	0.579	0.141
Ta	0.282	0.321	0.344	0.127	0.146	0.567	0.386	0.419	0.144	0.16	0.149	0.16
Nb	3.74	4.53	4.68	1.82	2.10	4.37	3.11	3.63	2.04	1.76	1.60	1.63
K_2O	0.14	0.32	0.14	0.17	0.23	0.1	0.07	0.39	0.04	0.04	0.04	0.03
La	3.92	4.37	4,.50	5.82	4.03	5.83	4.29	4.81	2.34	2.68	2.71	2.55
Ce	10.63	11.60	12.13	13.51	10.74	15.03	11.22	12.85	6.94	7.89	7.59	7.53
Pb	1.32	0.19	0.44	1.26	0.72	2.03	0.625	7.20	0.34	0.504	0.394	0.39
Pr	1.71	1.81	1.91	1.93	1.71	2.24	1.69	1.92	1.28	1.30	1.27	1.26
Sr	133	154	141	440	162	160	156	214	50	56	61	62
P_2O_5	0.12	0.13	0.13	0.26	0.15	0.17	0.11	0.13	0.12	0.11	0.13	0.12
Nd	8.81	9.28	9.77	8.92	8.78	11.81	8.92	10.36	7.47	7.78	7.42	7.66
Na_2O	2.27	3.13	2.93	1.90	2.12	2.32	2.38	2.20	1.58	1.73	2.03	1.85
Zr	75.9	78.0	81.5	36.5	44.3	52.0	67.8	47.5	63.2	68.7	64.5	67.0
Hf	2.10	2.13	2.23	1.32	1.44	1.80	1.98	1.64	2.05	2.05	1.95	2.06
Sm	3.00	3.08	3.25	2.62	2.88	3.74	2.78	3.36	2.75	2.89	2.72	2.79
Eu	1.18	1.17	1.20	0.86	1.04	1.34	1.08	1.19	1.01	1.05	0.99	1.04
Gd	4.12	4.23	4.20	2.91	3.89	4.40	3.31	4.08	4.28	3.55	3.63	3.53
TiO_2	1.32	1.42	1.51	1.48	1.29	1.82	1.37	1.64	1.30	1.29	1.30	1.32
Tb	0.70	0.71	0.75	0.45	0.67	0.94	0.70	0.82	0.82	0.87	0.84	0.83
Dy	4.47	4.62	4.81	2.57	4.26	5.71	4.45	5.21	5.45	5.86	5.43	5.65
Y	27.5	27.8	29.6	15.0	26.1	30.14	24.09	29.16	35.6	34.97	32.49	34.20
Ho	0.947	0.975	1.031	0.518	0.884	1.187	0.951	1.111	1.242	1.328	1.273	1.331
Er	2.69	2.72	2.87	1.37	2.44	3.38	2.70	3.07	3.56	4.09	3.74	3.97
Tm	0.400	0.419	0.444	0.196	0.364	0.467	0.392	0.437	0.586	0.625	0.566	0.586
Yb	2.56	2.66	2.81	1.23	2.27	2.99	2.47	2.79	3.81	4.19	3.88	4.03
Lu	0.40	.40	0.46	0.18	0.35	0.45	0.39	0.40	0.62	0.67	0.59	0.65
CaO	12.30	10.13	10.13	16.64	11.37	10.05	12.87	12.93	9.98	10.30	9.84	10.46
Al_2O_3	14.19	13.72	13.36	9.47	14.76	14.10	15.41	14.26	12.75	12.68	12.79	12.89
Ga	17.3	17.1	22.5	10.7	17.0	18.1	16.2	17.73	22.46	16.7	15.7	16.5
V	308	347	368	198	293	378	304	351	497	518	497	501
Sc	45.5	44.9	49.1	37.6	40.3	45.4	44.2	45.8	47.0	49.5	47.3	47.5
Mn	0.19	0.21	0.25	0.21	0.17	0.174	0.12	0.14	0.20	0.17	0.15	0.17
Fe_2O_3	10.92	11.40	12.04	8.13	10.65	13.78	11.17	11.84	14.03	16.05	15.37	16.35
Co	49	51	52	57	58	71	57	58	53	57	57	54
MgO	7.58	7.45	7.07	10.20	8.16	7.54	6.49	6.39	7.01	6.48	6.80	6.63
Cr	371	203	110	1107	367	93.7	308	103.6	80.8	71.7	68.4	65.8
Ni	83	85	75	192	105	65.4	66.7	58.6	65.9	70.6	80.6	68.0

Notes: All results are reported in parts per million, except oxides which are in percent normalizing factors after Pearce and Peate (1995). * = low-K tholeiite, Woodlark Island (Ashley and Flood, 1981). † = basalts from the Papuan Ultramafic Belt (Jaques and Chappell, 1980).

Table T2. New major element analyses for the Leg 180 samples whose trace element compositions are reported in Table T1, p. 16.

Sample:	180-1109D-48R-2, 40–80 cm	180-1118A-76R-2, 51–69 cm	180-1118A-76R-2, 44–55 cm
Major element:			
SiO_2	49.07	48.24	48.72
TiO_2	1.32	1.51	1.42
Al_2O_3	14.19	13.36	13.72
Fe_2O_3	3.94	3.62	3.03
FeO	7.37	8.78	8.67
MnO	0.19	0.24	0.21
MgO	7.58	7.07	7.45
CaO	11.94	11.22	10.13
Na_2O	2.27	2.93	3.13
K_2O	0.14	0.14	0.32
P_2O_5	0.12	0.13	0.13
LOI	1.33	2.31	2.70
Total:	99.46	99.55	99.62
CIPW weight norms:			
q	1.49	—	—
or	0.83	0.83	1.89
ab	19.21	24.79	26.49
an	28.12	22.89	22.44
di	24.49	26.02	21.97
hy	15.51	9.71	9.92
ol	—	4.58	6.84
mt	5.71	5.25	4.39
il	2.51	2.87	2.70
ap	0.28	0.30	0.30

Notes: LOI = loss on ignition. CIPW norms: q = quartz, or = orthoclase, ab = albite, an = anorthite, di = diopside, hy = hyperthene, ol = olivine, mt = magnetite, il = ilmenite, ap = apatite.

Table T3. ^{40}Ar-^{39}Ar incremental heating ages for Leg 180 dolerites and a separated plagioclase.

Core, section, interval (cm)	Apparent Plateau			Inverse isochron				
	Matrix	Age ± 1 σ (Ma)	*N*	^{39}Ar (%)	Age ± 1 σ (Ma)	*N*	^{40}Ar/^{36}Ar$_i$ ± 1 σ	MSWD
180-								
1109D-48R-2, 40–80	Whole rock	55.6 ± 0.3	5	88	54.0 ± 1.0	5	317 ± 12	0.48
1118A-74R-2, 52–69	Whole rock	58.2 ± 1.0	2	37	56.4 ± 3.9	2	299 ± 15	—
1109D-48R-2, 40–80	Plagioclase	Plateau not developed			Isochron not developed			

Notes: Ages are reported relative to biotite monitor FCT-3 (27.84 ± 0.12 Ma), which in turn is calibrated against hornblende Mmhb-1 (520.4, Samson and Alexander, 1987). Calculations use the following decay and reactor interference constants: $\lambda_e = 0.581 \times 10^{-10}$ yr^{-1}, $\lambda_b = 4.963 \times 10^{-10}$ yr^{-1}; $(^{36}Ar/^{37}Ar)_{Ca} = 0.000673$, $(^{40}Ar/^{39}Ar)_{Ca} = 0.01$. MSWD = mean squares of weighted deviations.