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# Isotopic and trace-element profiles across the New Britain island arc, Papua New Guinea

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**Abstract.** New Pb-, Sr-, and Nd-isotopic data have been obtained for the rocks of volcanoes overlying a wide range of depths (100–580 km) to the Wadati-Benioff Zone (WBZ) in the New Britain island arc, Papua New Guinea. Well-defined trends consistent with two-component mixing are observed in combined Pb-isotope/trace-element plots. One of the components is believed to represent a slab contribution whose isotopic signature, unlike those noted for several other arcs, appears to be dominated by subducted, altered, oceanic crust rather than by sediment. This conclusion is consistent with the results of a recent Be-B study of New Britain rocks. The influence of the slab component is considered to decrease as depth to the WBZ increases. Higher abundances of high-field-strength elements correlate with increasing depths to the WBZ, and may be indicative of smaller degrees of partial melting of the mantle wedge as WBZ depths increase. Abundances of other incompatible elements appear to reflect a complex interplay between the slab-derived flux and melting process.

## Introduction

Both mantle-wedge and subducted oceanic-crust/sediment assemblages are likely to be involved in different degrees in arc-magma genesis (e.g. Gill 1981). However, debate continues on the precise role of the mantle wedge (e.g. Tatsumi 1989; McKenzie and O'Nions 1991) and on the nature of the mass-transfer process between slab and wedge – in particular, whether simple partial melt, hydrous fluid, or bulk assimilation is dominant (e.g. Kay 1980; Gill 1981; Davidson 1987; Woodhead 1989). Furthermore, dehydration reactions within the slab are known from experimental studies to be multi-stage, depth-related phenomena (e.g. Tatsumi 1989), and therefore the slab/wedge interface is likely to be a site of considerable complexity. This possibility highlights a problem encountered in the interpretation of geochemical data from subduction-related settings: arc volcanism commonly takes place in narrow, trench-parallel zones at the surface, and therefore generally only a two-dimensional "snapshot" is available of what is clearly a three-dimensional process.

Individual volcanoes in many arcs may lie up to 50 km behind the volcanic front (e.g. Gill 1981). However, the New Britain arc in Papua New Guinea (Fig. 1) affords an outstanding opportunity to study transverse processes in arc-magma genesis, because active volcanism takes place over an especially wide depth-range to the Wadati-Benioff Zone (WBZ) – from about 100 km in the south down to almost 600 km in the north beneath the Witu Islands. New isotopic data presented here for New Britain rocks are combined with previously published (and some unpublished) trace- and major-element analyses to produce geochemical profiles across the island arc. The data are used to test current models of arc petrogenesis from this rather different perspective.

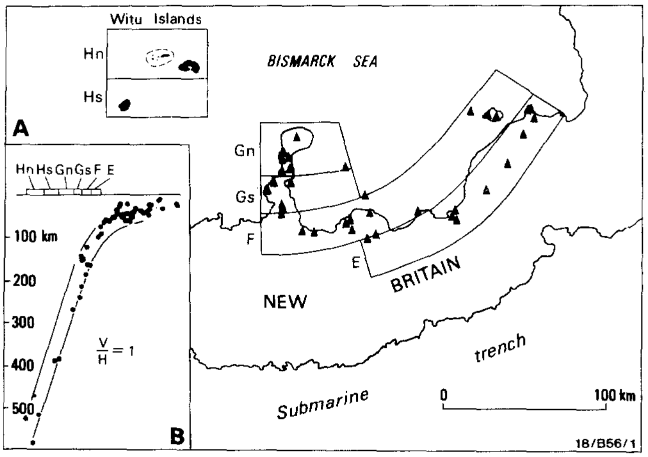

**Fig. 1. A** Distribution of Quaternary volcanoes, *filled triangles*, in the New Britain island arc divided into zones E to H. The submarine trench marks the descent of the Solomon Sea floor beneath New Britain. **B** New Britain Wadati-Benioff Zone in cross section. Adapted from Johnson (1977) and Johnson and Arculus (1978)

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## Geological setting and previous interpretations

The volcanoes of the New Britain island arc have been divided into four, main, trench-parallel zones E, F, G, and H[1], which overlie progressively deeper parts of the WBZ (Johnson 1977; Fig. 1). Zone E runs along the central north coast of New Britain and represents the "volcanic front" of the Quaternary arc – that is, the clearly defined row of volcanoes closest to the submarine trench. Zone F is immediately behind zone E, extending westwards to the southern end of Willaumez Peninsula, a remarkable, 60 km-long chain of mainly zone-G volcanoes running northwards perpendicular to the volcanic front (Fig. 1). Volcanoes of the Witu Islands to the northwest of Willaumez Peninsula constitute zone H and overlie the WBZ at depths of up to 580 km. Both zones G and H can be divided further into southern and northern parts – Gs and Gn, Hs and Hn (Fig. 1).

The volcanic rocks of the Witu Islands have a wide range of compositions. They are mainly of island-arc type, but include rocks of back-arc-basin affinity as well (Johnson and Arculus 1978). However, the Witu Islands cannot be considered to be distinct from the remainder of the New Britain arc (see, for example, Gill 1981). Rather, they are an integral component, and their rocks are part of the geochemical continuum across the WBZ (see below).

Previous petrogenetic interpretations of the across-arc range of chemical compositions have focused on the nature and extent of

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[1] Zones A to D refer to the western Bismarck arc which stretches from Langila in western New Britain to Vokeo Island, north of the New Guinea mainland (Johnson 1977). Zones A to D and E to H correspond to subduction of the Indo-Australian and Solomon Sea plates respectively, and therefore must be considered as separate arcs

**Table 1.** Major- and trace-element analyses of selected New Britain rocks (trace elements, in ppm: Ba–Ga by XRF, Cs–Hf by SSMS)

| Sample<br>Volcano | E2/1<br>Sulu | E5/11<br>Ulawun | F5/2<br>Wulai | F7/2<br>Lolobau | Gs2/1<br>Bangum | Gs3/1<br>Garua | Gn1/4<br>Dakataua | Gn2/1<br>Kimbe | Hs1/1<br>Unea |
|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 53.10 | 52.32 | 52.50 | 53.50 | 50.90 | 57.10 | 53.50 | 49.20 | 50.40 |
| $TiO_2$ | 0.30 | 0.76 | 0.49 | 0.59 | 0.52 | 0.50 | 0.71 | 0.52 | 0.80 |
| $Al_2O_3$ | 14.70 | 18.66 | 17.90 | 17.10 | 15.60 | 13.20 | 15.80 | 15.30 | 19.50 |
| $Fe_2O_3$ | 1.91 | 3.22 | 4.05 | 2.70 | 5.20 | 3.50 | 3.55 | 2.55 | 2.70 |
| FeO | 6.90 | 6.05 | 5.45 | 6.65 | 4.85 | 3.85 | 5.80 | 6.70 | 6.60 |
| MnO | 0.16 | 0.17 | 0.16 | 0.17 | 0.18 | 0.14 | 0.18 | 0.18 | 0.16 |
| MgO | 9.20 | 4.69 | 5.60 | 5.75 | 6.90 | 7.35 | 6.05 | 10.10 | 4.45 |
| CaO | 10.90 | 10.60 | 10.20 | 10.60 | 11.70 | 9.05 | 10.80 | 13.00 | 11.20 |
| $Na_2O$ | 1.58 | 2.48 | 2.15 | 2.05 | 1.69 | 2.35 | 2.40 | 1.51 | 2.65 |
| $K_2O$ | 0.28 | 0.32 | 0.48 | 0.37 | 0.62 | 1.26 | 0.51 | 0.19 | 0.59 |
| $P_2O_5$ | 0.03 | 0.08 | 0.08 | 0.06 | 0.11 | 0.11 | 0.14 | 0.06 | 0.15 |
| $H_2O^+$ | 0.30 | 0.33 | 0.41 | 0.35 | 0.82 | 0.45 | 0.34 | 0.60 | 0.54 |
| $H_2O^-$ | 0.22 | 0.07 | 0.16 | 0.14 | 0.48 | 0.79 | 0.17 | 0.23 | 0.18 |
| Total | 99.58 | 99.75 | 99.58 | 99.98 | 99.57 | 99.65 | 99.95 | 100.0 | 99.92 |
| Ba (XRF) | 30 | 75 | 75 | 100 | 130 | 215 | 100 | 30 | 80 |
| Rb | 2.6 | 4.6 | 4.2 | 4.8 | 8.6 | 17.4 | 5.2 | 1.2 | 8.6 |
| Sr | 167 | 297 | 403 | 259 | 560 | 394 | 446 | 228 | 520 |
| Zr | 14 | 21 | 24 | 25 | 31 | 54 | 31 | 21 | 48 |
| Nb | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | < 1 | 2 |
| Y | 6 | 13 | 10 | 12 | 13 | 16 | 15 | 13 | 18 |
| Sc | 42 | 33 | 35 | 35 | 42 | 32 | 35 | 42 | 25 |
| V | 188 | 290 | 266 | 256 | 269 | 185 | 285 | 258 | 241 |
| Cr | 283 |  | 59 | 85 | 69 | 387 | 55 | 386 | 15 |
| Ni | 88 | 21 | 30 | 25 | 34 | 83 | 38 | 119 | 18 |
| Cu | 97 | 81 | 159 | 114 | 68 | 74 | 140 | 127 | 77 |
| Zn | 68 | 81 | 70 | 68 | 67 | 63 | 75 | 65 | 70 |
| Ga | 11 | 17 | 15.5 | 14.5 | 13.5 | 11.5 | 14.5 | 12.5 | 17 |
| Cs (SSMS) | 0.07 | 0.30 | 0.09 | 0.10 | 0.16 | 0.60 | 0.10 |  | 0.18 |
| Pb | 2.6 | 3.3 | 1.9 | 1.9 | 3.4 | 4.4 | 3.4 | 1.4 | 3.1 |
| La | 0.74 | 1.4 | 2.1 | 1.8 | 4.8 | 6.8 | 3.5 | 1.6 | 6[a] |
| Ce | 2.1 | 3.7 | 5.4 | 4.2 | 12 | 17 | 9.6 | 4.5 | 14 |
| Pr | 0.31 | 0.55 | 0.73 | 0.68 | 1.6 | 2 | 1.4 | 0.68 | 1.8 |
| Nd | 1.7 | 3.1 | 3.8 | 3.7 | 7.6 | 8.6 | 6.9 | 3.7 | 9 |
| Sm | 0.6 | 1.1 | 1.2 | 1.2 | 2 | 2.1 | 2 | 1.2 | 2.5 |
| Eu | 0.26 | 0.5 | 0.46 | 0.5 | 0.71 | 0.64 | 0.73 | 0.53 | 0.85 |
| Gd | 0.86 | 1.5 | 1.4 | 1.6 | 2.3 | 2.5 | 2.2 | 1.7 | 2.6 |
| Tb | 0.16 | 0.28 | 0.24 | 0.33 | 0.34 | 0.41 | 0.40 | 0.32 | 0.47 |
| Dy | 1 | 1.8 | 1.6 | 2.3 | 2.1 | 2.5 | 2.4 | 2 | 3.1 |
| Ho | 0.24 | 0.42 | 0.33 | 0.51 | 0.45 | 0.50 | 0.56 | 0.47 | 0.70 |
| Er | 0.73 | 1.3 | 1.1 | 1.5 | 1.3 | 1.4 | 1.6 | 1.4 | 2.1 |
| Yb | 0.74 | 1.2 | 1 | 1.4 | 1.3 | 1.4 | 1.6 | 1.4 | 2.1 |
| Th | 0.07 | 0.11 | 0.20 | 0.20 | 0.35 | 0.82 | 0.39 | 0.13 | 0.52 |
| U | 0.07 |  | 0.15 | 0.16 | 0.22 | 0.49 | 0.20 | 0.07 | 0.32 |
| Hf | 0.50 | 0.61 | 0.67 | 0.85 | 0.80 | 1.30 | 0.86 | 0.50 | 1.40 |

[a] XRF values

Table 1 (continued)

| Hs1/3 Unea | Hn2/3 Garove | Hn2/7 Garove | Hn3/3 Undaka | Hn3/7 Mundua |
|---|---|---|---|---|
| 53.70 | 52.60 | 55.40 | 49.20 | 51.70 |
| 0.58 | 1.43 | 1.38 | 1.15 | 0.99 |
| 15.30 | 16.30 | 16.40 | 14.40 | 16.90 |
| 2.35 | 1.80 | 3.00 | 1.40 | 2.95 |
| 6.00 | 8.45 | 6.10 | 8.10 | 5.75 |
| 0.15 | 0.20 | 0.20 | 0.18 | 0.18 |
| 6.95 | 5.30 | 4.35 | 10.80 | 6.45 |
| 10.20 | 9.80 | 8.10 | 11.40 | 10.90 |
| 2.75 | 3.00 | 3.80 | 2.15 | 2.50 |
| 1.12 | 0.41 | 0.53 | 0.19 | 0.75 |
| 0.17 | 0.16 | 0.17 | 0.11 | 0.18 |
| 0.30 | 0.04 | < 0.01 | 0.28 | 0.35 |
| 0.02 | 0.20 | 0.16 | 0.20 | 0.15 |
| 99.54 | 99.69 | 99.59 | 99.56 | 99.75 |
| 115 | 55 | 95 | 30 | 90 |
| 17.6 | 6.2 | 7.6 | 2.4 | 12.6 |
| 406 | 213 | 210 | 187 | 346 |
| 76 | 98 | 130 | 69 | 71 |
| 2 | 4 | 4 | 3 | 3 |
| 19 | 30 | 37 | 21 | 21 |
| 28 | 32 | 24 | 33 | 31 |
| 198 | 294 | 194 | 230 | 246 |
| 194 | 38 | 22 | 535 | 59 |
| 57 | 24 | 18 | 196 | 50 |
| 76 | 50 | 25 | 86 | 128 |
| 61 | 89 | 87 | 71 | 66 |
| 14.5 | 17.5 | 18.5 | 15.5 | 15.5 |
| 0.20 | 0.16 | 0.11 |  | 0.16 |
| 3.7 | 2.5 | 2 | 1.9 | 3.2 |
| 9[a] | 5.3 | 9[a] | 4 | 5.2 |
| 22 | 15 | 22 | 12 | 13 |
| 2.7 | 2.3 | 3.2 | 1.9 | 1.9 |
| 12 | 12 | 16 | 9.3 | 9.7 |
| 2.8 | 3.8 | 4.9 | 2.7 | 2.6 |
| 0.86 | 1.4 | 1.6 | 0.98 | 0.9 |
| 2.9 | 4.6 | 5.7 | 3.2 | 3 |
| 0.51 | 0.81 | 1.00 | 0.59 | 0.53 |
| 3.2 | 5.3 | 6.7 | 3.9 | 3.5 |
| 0.75 | 1.20 | 1.60 | 0.84 | 0.78 |
| 2.2 | 3.6 | 4.8 | 2.4 | 2.3 |
| 2.2 | 3.5 | 4.5 | 2.2 | 2.2 |
| 1.20 | 0.59 | 0.80 | 0.29 | 0.71 |
| 0.58 | 0.27 | 0.39 | 0.11 | 0.35 |
| 1.90 | 2.40 | 3.60 | 1.80 | 1.80 |

involvement of fluids derived from the downgoing Solomon Sea slab. Johnson (1977) proposed that the volcanism of zones E and F derived from the sub-solidus breakdown of amphibole in subducted oceanic crust and from the release of water into overlying peridotite, whereas the volcanism in at least the southern part of zone G resulted from melting of the downgoing slab and reactions of slab melt with the overlying mantle wedge. He proposed that the influence of slab fluids decreased northwards such that a slab influence is barely detectable, if at all, in some rocks of zone H (Witu Islands).

DePaolo and Johnson (1979) examined the Sr- and Nd-isotopic compositions of eight rocks from zones E-to-H. They discovered no systematic isotopic changes across the WBZ, but pointed out that elemental Sr/Nd values decreased progressively northwards, suggesting that a closer-to-trench slab component accounted for the higher Sr/Nd magmas. However, the Sr- and Nd-isotopic values deviate only slightly from the Sr-Nd mantle array. DePaolo and Johnson (1979) therefore suggested that the subducted oceanic crust from which any fluids were derived must have been relatively less affected by elemental exchange with seawater than would appear to be the case for some other island arcs.

No Sr- and Nd-isotopic evidence was found for the influence of oceanic sediments with continent-like high $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$ values. Arculus and Johnson (1981) noted that there is no positive correlation between Sr/Nd and $^{87}Sr/^{86}Sr$ in the most mafic analysed rocks of the arc, and suggested, alternatively, that the Sr anomalies may derive from the lower crust in the arc and that the northwards decrease in Sr/Nd relates to decreasing crustal thickness between zone E and zone H.

Morris et al. (1990) analysed a suite of zone E-H samples for $^{10}Be$ and B, both of which are effective tracers of sediment recycling through subduction zones. They confirmed the significantly high values for near-trench volcanoes, providing the strongest evidence yet (in the absence of an acceptable alternative interpretation) for a subduction component in these rocks. These studies were extended by J.B. Gill, J.D. Morris, R.W. Johnson (submitted) who obtained U-Th-Po disequilibria data on the same samples, and concluded that the slab-derived components in the mantle wedge had had a residence time of several hundred thousand years before contributing to arc melts, because the fluids ascended into a more rapidly convecting mantle wedge (compared to, say, the Chilean arc).

## Sample selection

The samples used in this study were selected from a suite of more than 200 rocks analysed mainly by X-ray fluorescence (XRF) spectrometry for major and trace elements (Johnson and Chappell 1979). These data are used below in determining average element values at 55 wt% $SiO_2$.

The 14 samples selected for isotopic analysis were chosen from a subset of New Britain samples that has been analysed also for rare-earth elements (REE) and other trace elements by spark-source mass spectrography (SSMS). This larger dataset, together with the additional XRF data, form the basis of a paper on New Britain petrogenesis that will integrate the wide range of geochemical and petrological data now available for New Britain and will extend the discussion provided below (R.W. Johnson and B.W. Chappell, in preparation). The 14 samples selected for the current study consist of two each from zones E, F, Gs, Gn, and Hs, and four from zone Hn (Table 1).

## Analytical methods

Sr, Nd, and Pb were separated from crushed, hand-picked rock chips by conventional ion-exchange techniques using, on average, 50 mg of sample. Procedural blanks are in all cases negligible (150 pg total in the case of Pb). All samples were run for Sr, Nd, and Pb isotopes on a Finnigan MAT261 mass spectrometer operated in static multicollector mode. The $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ values were normalised to $^{86}Sr/^{88}Sr = 0.1194$ and $^{144}Nd/^{146}Nd = 0.7219$, respectively. Multiple analyses of the NBS 987 Sr and La Jolla Nd standards provided mean values of $0.710219 \pm 4$ ($2\sigma_{mean}$ for 79 analyses) and $0.511872 \pm 2$ ($2\sigma_{mean}$ for 85 analyses) respectively.

Pb-isotope determinations were corrected routinely for mass fractionation by the use of a $^{207}Pb$-$^{204}Pb$ double-spike, in a manner similar to that documented by Hamelin et al. (1985). Samples were split for spiking immediately prior to filament loading and mass spectrometry, thus avoiding any problem of variable blank composition in spiked and unspiked aliquots. This technique yields consistently high-quality data (giving an improvement in both precision and accuracy over conventional correction procedures) and is considered particularly suitable for the "new generation" of multiple-sample, multicollector, mass spectrometers.

Major- and most trace-element analyses are by standard XRF and spark-source mass spectrography techniques (see Chappell 1991, and Taylor and Gorton 1977, for details).

## Data presentation

The method of data presentation used here follows that of previous authors who have studied so-called "K-h" variations (e.g. Dickinson 1975). More than 200 rock analyses are available for the New Britain arc permitting element-versus-$SiO_2$ covariation plots to be constructed for each zone in the arc ($SiO_2$ is used as an index of differentiation rather than, for example MgO, because the resulting trends are approximately linear and have higher correlation coefficients). These trends are linear for all the elements considered here, and presumably are caused to a large extent by fractional crystallisation. The major- and trace-element differences between zones E-H can be generalised by means of simple regressions for a constant $SiO_2$ value (a typical data set is shown in Fig. 2, in this case for $K_2O$, from which the $K_2O$ means in Table 2 were determined). The full major- and trace-element analyses for the subset of twelve samples selected for isotopic study are provided in Table 1.

Particular effort has been directed towards the estimation of errors, which are quoted at 95-percent confidence at the $SiO_2$ value of interest - in this case 55 weight percent. These errors reflect not only the quality of "fit" in the data, but also: (1) the number of samples involved in each plot (ranging from $n = 84$ in the case of major elements for zone E, to $n = 3$ in the case of La in zone Gn); (2) the proximity of the sample mean, $X$, to 55 weight-percent $SiO_2$ (the choice of 55 wt% $SiO_2$ was, in part, chosen to minimise the error). Clearly, this approach has inherent assumptions - most importantly, that the fractionation "extract" (presumably gabbroic) is of reasonably constant composition across the arc. No primary magmas (those likely to have been in equilibrium with upper-mantle peridotite) have been identified in the New Britain data, but rocks containing around 55 percent $SiO_2$ are common and, although clearly fractionated, are nevertheless considered to be a reflection of the relative differences in composition between the primary magmas (and therefore sources) of each zone.

"Error bars" in Figs. 3, 4, and 8 on the WBZ-depth axes define the maximum and minimum depths to the top of the WBZ established for each of the zones E to H (Johnson 1977).

## Role of melting in the mantle wedge: high-field-strength and major-element constraints

The nature and origin of the generally low high-field-strength (high charge/ionic-radius) element (HFSE) content of subduction-related volcanic rocks remains a matter of considerable debate. Some investigators have asserted that depletion of HFSE in arcs is caused through retention by residual titanate phases in, or close to, the subducting slab (e.g. Green 1981; Saunders et al. 1980). Others cast doubt on the potential stability of such miner-

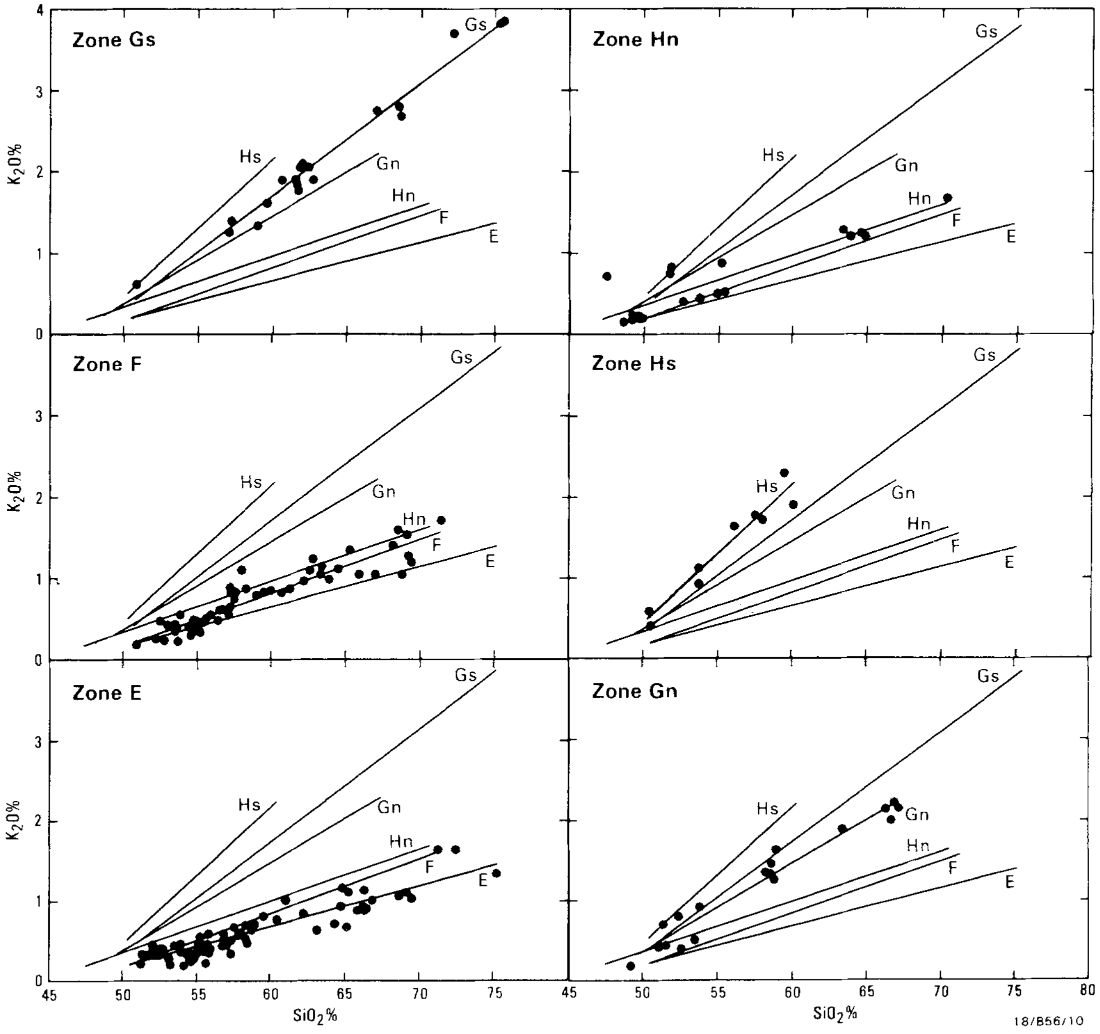

**Fig. 2.** $K_2O$ versus $SiO_2$ diagrams for each of the six zones shown in Fig. 1. Means used in Figs. 3, 4, and 8 were determined in this way, using regression lines in these and other plots not shown here

**Table 2.** Mean values, with errors, for selected oxide and trace-element abundances in each of the zones (E–H) of the New Britain WBZ, at 55 wt% SiO2 (number of analyses used in the calculation of each value shown in brackets)

| Zone | E | F | Gs | Gn | Hs | Hn |
|---|---|---|---|---|---|---|
| Depth to top of WBZ (km) | ~70–95 | ~95–130 | ~130–185 | ~185–295 | ~295–415 | ~415–540 |
| CaO | 9.53 ± 0.13 (84) | 9.21 ± 0.15 (58) | 9.27 ± 0.33 (19) | 9.18 ± 0.32 (20) | 8.64 ± 0.61 (9) | 8.60 ± 0.38 (20) |
| $Al_2O_3$ | 17.44 ± 0.31 (84) | 17.34 ± 0.33 (58) | 16.07 ± 0.72 (19) | 16.22 ± 0.55 (20) | 16.39 ± 1.04 (9) | 15.62 ± 0.41 (20) |
| FeO | 8.57 ± 0.21 (84) | 8.41 ± 0.25 (58) | 8.25 ± 0.37 (19) | 8.67 ± 0.45 (20) | 8.26 ± 0.67 (9) | 8.69 ± 1.03 (20) |
| MgO | 4.69 ± 0.31 (84) | 4.80 ± 0.21 (58) | 5.31 ± 0.64 (19) | 5.11 ± 0.53 (20) | 4.71 ± 1.15 (9) | 4.80 ± 0.54 (17) |
| $Na_2O$ | 2.51 ± 0.07 (84) | 2.49 ± 0.09 (58) | 2.35 ± 0.16 (19) | 2.90 ± 0.14 (20) | 3.21 ± 0.20 (9) | 3.45 ± 0.15 (20) |
| $K_2O$ | 0.43 ± 0.06 (84) | 0.50 ± 0.03 (56) | 1.01 ± 0.12 (19) | 0.91 ± 0.08 (19) | 1.29 ± 0.13 (9) | 0.67 ± 0.09 (20) |
| Zr | 31 ± 2 (77) | 34 ± 4 (56) | 45 ± 7 (19) | 50 ± 4 (20) | 94 ± 11 (9) | 138 ± 12 (20) |
| Hf | 0.9 ± 0.3 (7) | 1.1 ± 0.3 (10) | 1.2 ± 0.3 (6) | 1.3 ± 1.7 (3) | 1.9 ± 0.4 (3) | 3.3 ± 0.5 (9) |
| Sc | 31 ± 1 (79) | 31 ± 2 (56) | 31 ± 3 (17) | 31 ± 1 (11) | 28 ± 4 (9) | 28 ± 2 (20) |
| V | 249 ± 11 (79) | 245 ± 11 (56) | 217 ± 14 (19) | 247 ± 17 (20) | 220 ± 37 (9) | 212 ± 28 (20) |
| La | 1.41 ± 0.29 (7) | 2.85 ± 0.49 (10) | 5.82 ± 0.89 (6) | 5.02 ± 5.19 (3) | 10.25 ± 0.36 (3) | 7.53 ± 0.78 (8) |
| Nd | 3.26 ± 1.12 (7) | 5.33 ± 1.07 (10) | 8.24 ± 0.69 (6) | 9.01 ± 6.02 (3) | 12.16 ± 5.66 (3) | 14.48 ± 2.68 (8) |
| Yb | 1.23 ± 0.35 (7) | 1.53 ± 0.57 (10) | 1.44 ± 0.21 (6) | 2.11 ± 2.66 (3) | 2.31 ± 0.41 (3) | 3.84 ± 0.70 (8) |
| Rb | 5.9 ± 0.5 (77) | 6.2 ± 0.9 (56) | 11.1 ± 1.4 (19) | 10.7 ± 1.6 (19) | 19.5 ± 2.1 (9) | 9.6 ± 1.5 (20) |
| Ba | 92 ± 7 (77) | 110 ± 8 (56) | 179 ± 41 (19) | 185 ± 34 (19) | 143 ± 14 (9) | 90 ± 9 (20) |

als (e.g. Ryerson and Watson 1987) and have suggested that depletions must be inherent to the mantle source or related to processes taking place in the mantle wedge (e.g. Kelemen et al. 1990). Still others argue for caution and suggest that, on the basis of available data, HFSE depletions may not be significant relative to concentrations observed in mid-ocean ridge basalt (MORB; e.g. Hildreth and Moorbath 1988; Davidson and Wolff 1989; Vukadinovich and Nicholls 1989). The HFSE are important in the context of this study in that most authors suggest or imply minimal HFSE flux from the slab. These elements therefore provide a unique insight into melting phenomena in the wedge, independent of effects related to slab fluxes that may complicate the interpretation of variation in other incompatible elements (e.g. Rb, Ba).

Zr and Hf are used here as representatives of the HFSE group, as Nb is notoriously difficult to analyse at the levels commonly encountered in arcs, a problem that still confounds progress on the HFSE issue. Both Zr and Hf have a slightly lower field strength compared to Nb, but far more good-quality data are available by XRF (for Zr) and SSMS (for Hf). Note, however, that the same qualitative trends are shown by the Nb data (XRF) as for Zr and Hf.

A clear increase in Zr and Hf concentrations with increasing depth to the WBZ is shown in Fig. 3, providing enrichment factors (e.f.) relative to zone E of up to 4.5 and 3.7 respectively. Titanium also increases in similar fashion (Johnson 1977) and, by inference, all the HFSE. There is more than one possible explanation for this increase – including a gradual breakdown of a titanate residual phase, as suggested by Ringwood (1990), for example. However, there is no systematic change in Zr/Sm or Hf/Sm values across the arc. Both Zr and Hf have a similar incompatibility to Sm (Sun and McDonough 1989) but should behave very differently in the presence of a residual titanate phase, although the extent to which such a signature from the slab may be diluted by mantle-wedge effects is not clear. In addition, similar trends are shown also by many non-HFSE such as the heavy rare-earth elements. The Na (Fig. 4A) and P contents also increase as depth to the WBZ increases (Johnson 1977). The gradual decomposition of a residual phase therefore seems unlikely to be responsible for the range of HFSE abundances.

Green (1972, 1973) concluded that changes in the conditions of partial melting of a homogeneous mantle source would result in considerable variations in major-element abundances. In particular, magmas would become more alkaline and mafic in terms of (FeO + MgO) and ($Na_2O$ + $K_2O$) relative to $SiO_2$, with increasing pressure and decreasing degrees of melting. New Britain has clear parallels with the Sunda arc (Whitford et al. 1979) in that both of the aforementioned parameters increase progressively as depth to the WBZ increases, whereas $Al_2O_3$ decreases (Fig. 4B). In addition Ti/Zr values decline steadily as HFSE contents increase across the arc. Mean concentrations of compatible trace elements such as Sc and V do not change with increasing depth to the WBZ (Fig. 3C, D). All of these features therefore may reflect decreasing degrees of partial melting in deeper parts of the mantle wedge as depth to the WBZ increases. The HFSE data in particular lend themselves to this interpretation.

Alternatively, the similar compatible-element abundances, concomitant with a gradual increase in incompatible-element concentrations, could be indicative of a process similar to zone refining. True zone refining, as described by Harris (1957), is analogous to the industrial process for removing impurities from metals, and involves total fusion in front of an advancing magma and deposition of crystalline cumulates behind it. It is identical in geological terms to an assimilation/fractional-crystallisation (AFC) process where the ratio of assimilation to crystallisation is unity. Incompatible-element enrichment

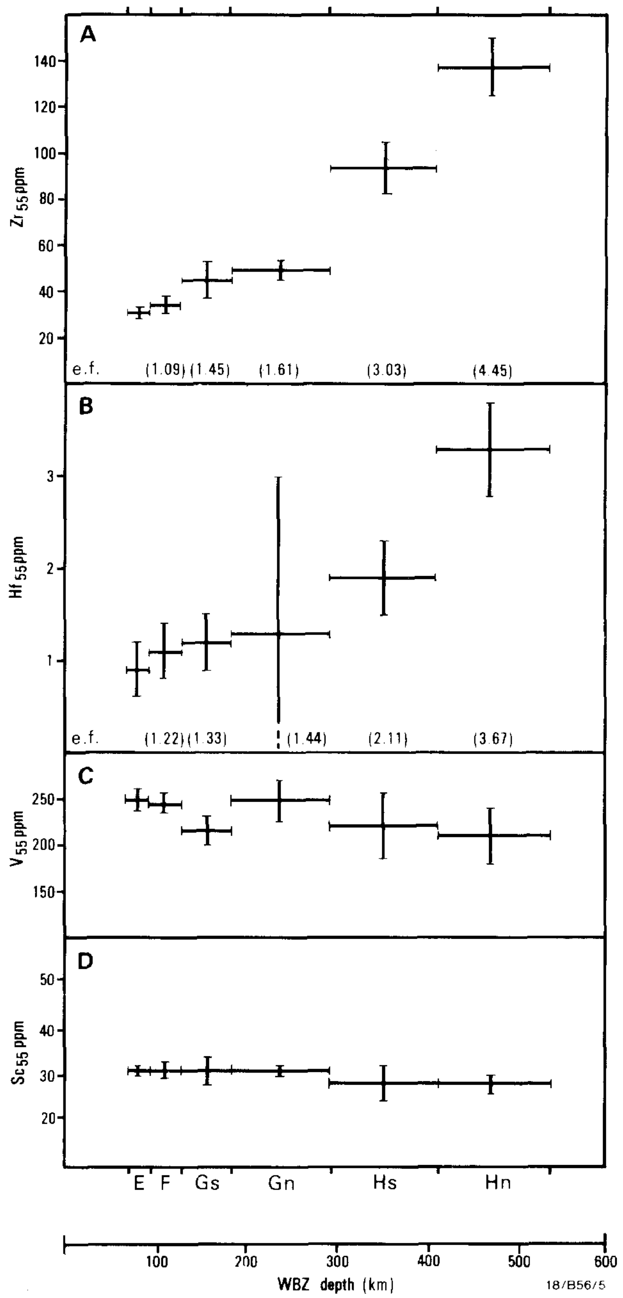

**Fig. 3A–D.** HFSE (Zr, Hf) and compatible trace-element (V, Sc) changes across the New Britain arc. e.f. values in parentheses represent enrichment factors relative to zone E. Data from Table 2

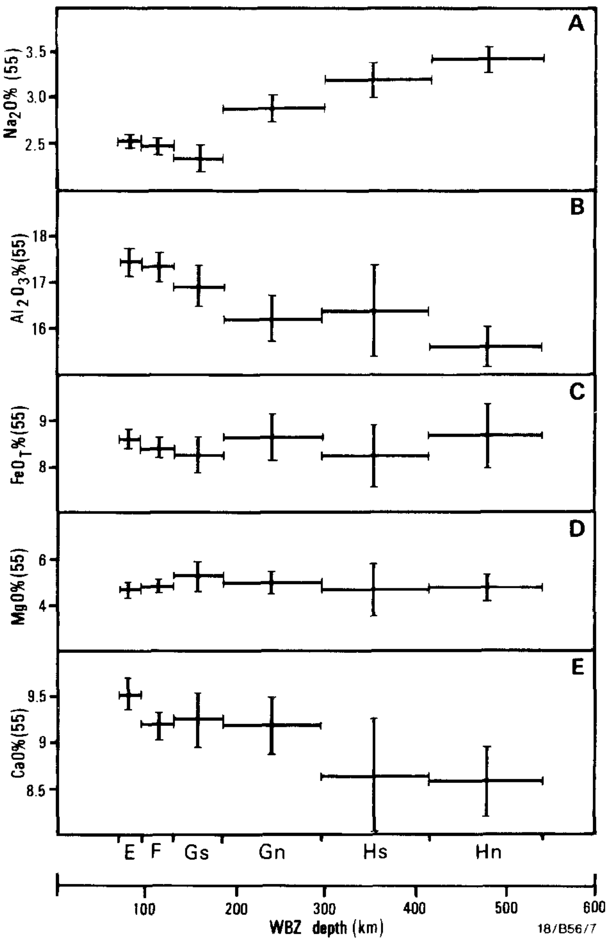

**Fig. 4A–E.** Averages of selected major-oxides versus WBZ depth

depends upon distribution coefficient and number of "zone lengths" traversed, whereas compatible elements remain unaffected, and elemental abundances therefore are controlled largely by mantle/melt interaction. Considerable superheat is required for a magma to ascend by this method, and therefore the geological significance of zone refining remains uncertain (e.g. Cox et al. 1979). However, Wilson (1989) pointed out the difficulty in envisaging magmas traversing the mantle without some form of interaction. Also, Marsh (1982) in his study of igneous diapirism provided a method by which such melts may reach the surface without solidification (the first few bodies of magma provide a hot passageway which thermally insulates successive magma bodies allowing them to ascend to higher levels). The pattern of incompatible-element enrichment observed in Figs. 3 and 8 may thus reflect a complex mantle/melt interaction process (see also Ryerson and Watson 1987).

Both models readily account for the decrease in Zr/Nb and Hf/Nb with increasing depth to the WBZ (Gill 1981) and the inverse correlation commonly observed between Zr/Nb and large-ion-lithophile element (LILE) enrichment (indeed, they may be complementary). This is because Nb, being more incompatible than Zr and Hf, has a greater rate of concentration increase.

These observations have important implications for two recent studies. Plank and Langmuir (1988) in an evaluation of the major-element chemistry of arc basalts, noted a correlation between Na and Ca contents (at a constant fractionation index) and crustal thickness, and suggested that shorter mantle columns (thick crust) would lead to smaller degrees of melting in the mantle and hence higher Na and lower Ca. Our conclusions are similar in that they are strongly indicative of melting control, but our data define exactly the opposite trends to those obtained by Plank and Langmuir (1988) – that is, longer mantle columns produce lower Ca and higher Na. We conclude, therefore, that although differences in the height of the mantle-melting column between arcs may correlate with degree of melting, differences in degree of melting within *individual* arcs correlate with height of the mantle column in an opposite sense – that is, the greater the depth, the lower the degree of melting.

Kelemen et al. (1990) modelled a mantle-melt interaction process using experimental element-partitioning data, concluding that extensive assimilation of mantle "wall-rock" by ascending magmas would lead to HFSE depletion in such liquids. However, concentrations of HFSE and HREE in the New Britain lavas increase with longer "mantle columns", contrary to these conclusions. Thus, variations in the concentrations of these predominantly wedge-sourced elements in the New Britain magmas more likely are controlled primarily by different degrees of partial melting and there is little or no overprint from mantle-melt interaction processes.

## Source parameters and the nature of the slab-derived component: isotope and trace element constraints

Sr-isotope ratios for the New Britain rocks (Table 3; $^{87}Sr/^{86}Sr$ 0.703204 to 0.703559) agree well with previous determinations (Page and Johnson 1974; DePaolo and Johnson 1979; BVSP 1981) and are typical of intraoceanic arcs worldwide (e.g. Mariana, Aleutian, and South Sandwich islands), extending to values slightly more radiogenic than N-type MORB. The data set is rather homogeneous and there are no apparent systematic differences across the arc. Nd-isotope ratios (Table 3) also compare well with the few existing determinations (DePaolo and Johnson 1979) and, again, there are no systematic cross-arc trends. The ratios are exceptionally homogenous ($^{143}Nd/^{144}Nd$ 0.513020 to 0.513089), plotting entirely within the range of known Nd-isotope values for Pacific N-type MORB (Fig. 5).

These first-order observations are consistent with minimal involvement of slab-derived sedimentary material which is expected to have high $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$. However, they are compatible with an input from altered oceanic crust which is characterised by high $^{87}Sr/^{86}Sr$ but MORB-like $^{143}Nd/^{144}Nd$ (a consequence of the relative insensitivity of Nd isotopes to seawater-alteration processes) or, possibly, carbonate material with very high Sr/Nd values. The former conclusion is consistent with one of two models presented by Morris et al. (1990) who undertook a detailed study of Be-B systematics in arc rocks. The presence of $^{10}Be$ in arc lavas requires a contribution from subducted sediments, but the low $^{10}Be/Be$ and high B/Be character of the New Britain rocks, relative to other arcs, may be interpreted in terms of a subducted component dominated (90–99%) by altered oceanic crust, rather than by sediment.

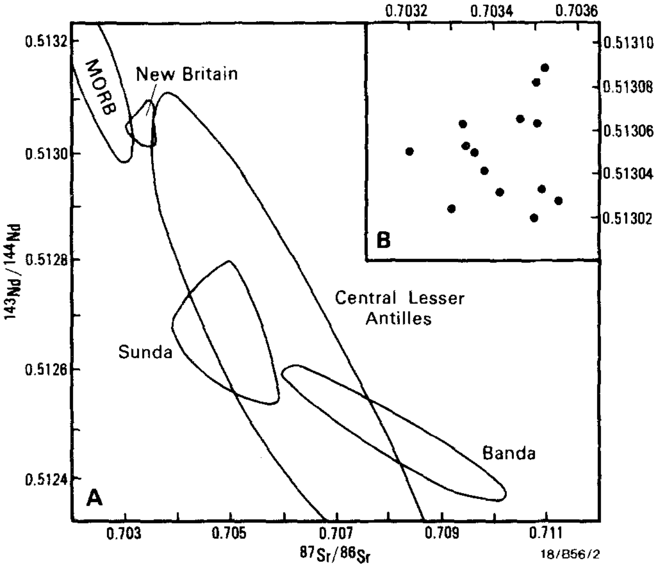

**Fig. 5A, B.** $^{87}Sr/^{86}Sr$ versus $^{143}Nd/^{144}Nd$ relationships for selected intra-oceanic island-arc rocks. The New Britain data (individual data points shown in **B**) fall within the "isotopically coherent" group of arcs, as defined by White and Patchett (1984), in contrast to the more extreme ranges noted, for example, in the Sunda, Banda, and central Antilles arcs. Note that the Nd-isotopic compositions of the New Britain samples plot entirely within the range of known Pacific MORB values. Data sources: Pacific MORB, White et al. (1987); Sunda and Banda, Whitford et al. (1981); Antilles, Davidson (1987)

**Table 3.** Sr-, Nd-, and Pb-isotope compositions of New Britain rocks (duplicates represent separate dissolutions)

| Sample | $^{87}Sr/^{86}Sr$ | $^{143}Nd/^{144}Nd$ | $^{206}Pb/^{204}Pb$ | $^{207}Pb/^{204}Pb$ | $^{208}Pb/^{204}Pb$ |
|---|---|---|---|---|---|
| E2/1 | 0.703360 ± 14 | 0.513050 ± 10 | 18.724 | 15.539 | 38.379 |
| Duplicate | 0.703386 ± 11 | | | | |
| E5/11 | 0.703305 ± 13 | 0.513024 ± 12 | 18.776 | 15.542 | 38.381 |
| F5/2 | 0.703500 ± 11 | 0.513020 ± 9 | 18.723 | 15.533 | 38.349 |
| Duplicate | 0.703505 ± 10 | | | | |
| F7/2 | 0.703507 ± 11 | 0.513064 ± 8 | 18.782 | 15.538 | 38.380 |
| Duplicate | 0.703507 ± 13 | | | | |
| Gs2/1 | 0.703433 ± 12 | 0.513031 ± 8 | 18.725 | 15.534 | 38.344 |
| Gs3/1 | 0.703559 ± 13 | 0.513027 ± 6 | 18.735 | 15.541 | 38.378 |
| H1/1 | 0.703382 ± 10 | 0.513041 ± 6 | 18.658 | 15.530 | 38.319 |
| H1/3 | 0.703204 ± 11 | 0.513051 ± 9 | 18.658 | 15.537 | 38.333 |
| H2/3 | 0.703464 ± 13 | 0.513065 ± 18 | 18.532 | 15.527 | 38.275 |
| Duplicate | 0.703464 ± 10 | | | | |
| H2/7 | 0.703523 ± 16 | 0.513089 ± 10 | 18.520 | 15.508 | 38.221 |
| H3/3 | 0.703323 ± 9 | 0.513063 ± 9 | 18.461 | 15.505 | 38.242 |
| H3/7 | 0.703345 ± 9 | 0.513053 ± 7 | 18.617 | 15.528 | 38.306 |

The high-precision Pb-isotope data provide clear, systematic trends for the New Britain samples. Arrays (Fig. 6) are defined in Pb-Pb space suggesting two-component mixing, and there is a distinct shift from relatively radiogenic values in zones E and F to less radiogenic compositions away from the trench. Pb-isotopic data for many oceanic arcs form characteristically steep arrays in Pb-Pb diagrams (e.g. Woodhead 1989, Fig. 4). These have been interpreted in terms of mixing between depleted mantle and sedimentary components having elevated $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ values. The relatively low-angle trend for the New Britain data does not suggest the involvement of any significant quantity of sedimentary Pb, but – consistent with the Sr and Nd data – does not preclude mixing with a slab-derived component dominated by altered oceanic crust having a MORB-like isotopic composition. The Pb-Pb plots in Fig. 6 therefore are analagous to the $^{10}Be$-B plot of Morris et al. (1990, Fig. 3b). The New Britain data points define well-developed linear trends of low angle in both Fig. 6A and B. This is indicative that: (1) any slab-derived components must be well mixed, approximating the composition of a single "contaminant"; (2) a considerable proportion of the B (data of Morris et al. 1990), Sr, Pb, and possibly Nd budgets of the New Britain lavas is derived from altered oceanic crust rather than subducted sedimentary material.

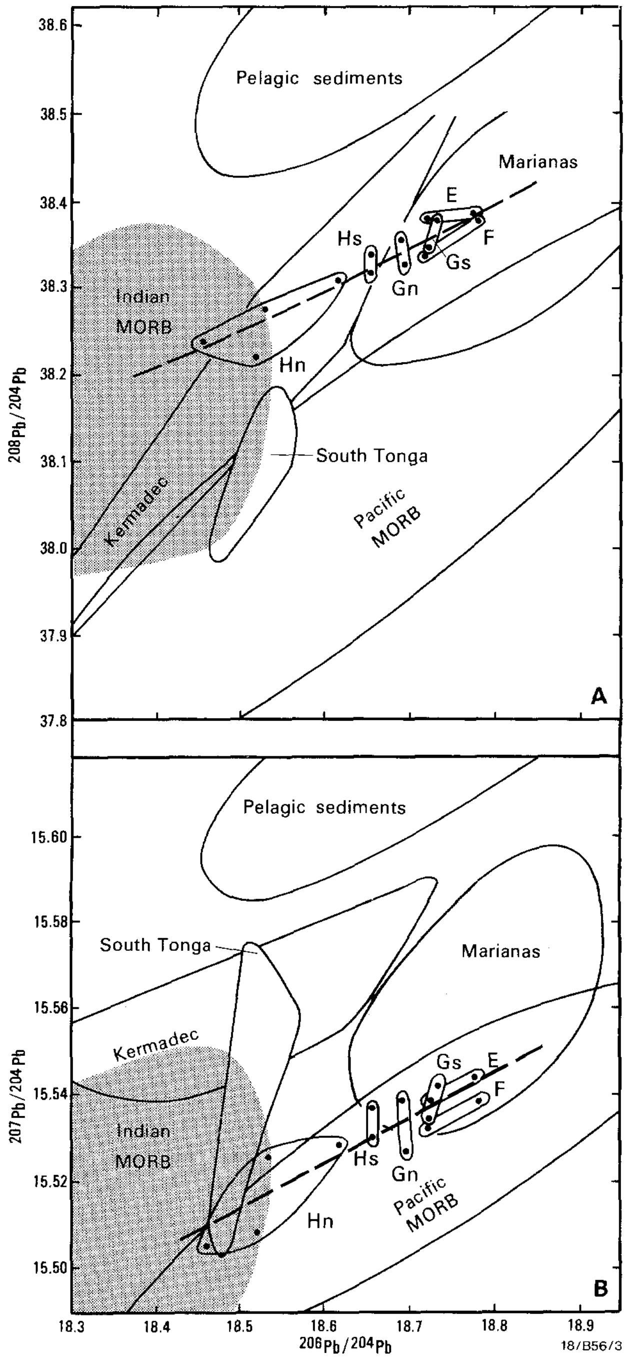

**Fig. 6A, B.** Pb-isotopic compositions for New Britain samples. Note the well-defined linear arrays, *dashed lines*, consistent with two-component mixing and the shift to more radiogenic values from zone H (Witu Islands) to zones F and E (volcanic front). Sample identifiers refer to prefixes in Tables 1 and 3. Data for other intra-oceanic arcs such as the Marianas, South Tonga, and Kermadec are characterised by steeper arrays in contrast to the New Britain suite. Data sources: Pacific MORB, White et al. (1987); Marianas, Woodhead 1989; Tonga and Kermadec, Ewart and Hawkesworth (1987). Zone Hn is thought to define the composition of the mantle source, before modification by slab-derived components – note the high $^{208}Pb/^{204}Pb$ ratios, similar to Indian Ocean MORB sources

We note also the relatively high $^{208}Pb/^{204}Pb$ of the unradiogenic end member, which is very similar to a component seen in many southwest Pacific island arcs and back-arc basins – for example, New Georgia (J.D. Woodhead, R.W. Johnson, P.N. Dunkley, submitted), Vanuatu (S. Eggins, personal communication 1992) and Lau Basin (J.M. Hergt and C.J. Hawkesworth, submitted). The source of Indian Ocean MORB has been shown to be quite distinct from that of the North Atlantic and East Pacific ridges, characterised by relatively high $^{208}Pb/^{204}Pb$ and $^{87}Sr/^{86}Sr$ (e.g. Hamelin et al. 1985/86). In addition, a relatively sharp boundary has been shown to exist between the Indian and Pacific mantle domains on the Southeast Indian ridge south of Australia (Klein et al. 1988). We suggest, based upon available data, that the Indian MORB domain may well extend beneath much of the southwest Pacific region, producing distinctive isotopic signatures in a number of arc and back-arc settings, including New Britain.

Some authors have proposed an important role for ocean-island-basalt (OIB) sources beneath island arcs (e.g. Morris and Hart 1983; Gill 1984). This conclusion is based primarily on the isotopic similarities observed between arcs and some OIB. The similarities are seen also in the New Britain Pb-isotope data that plot sub-parallel to the MORB array and which, lacking any clear evidence for sediment mixing, could be interpreted in terms of the addition of an enriched OIB-source component. However, the radiogenic Pb end-member also has high Ba/La, high Sr/Nd, and high U/Th – far outside the range of known OIB, as shown clearly in Fig. 7.

Trends such as those shown in Fig. 7 are critical to an understanding of arc geochemistry. Not only are they inconsistent with the involvement of OIB-type sources, but they also preclude bulk addition of sedimentary material into the arc source and direct melting of the slab. This is because a slab melt would be expected to have, for example, a low U/Th value (Th generally is considered to be more incompatible than U; e.g. Condomines 1988). The

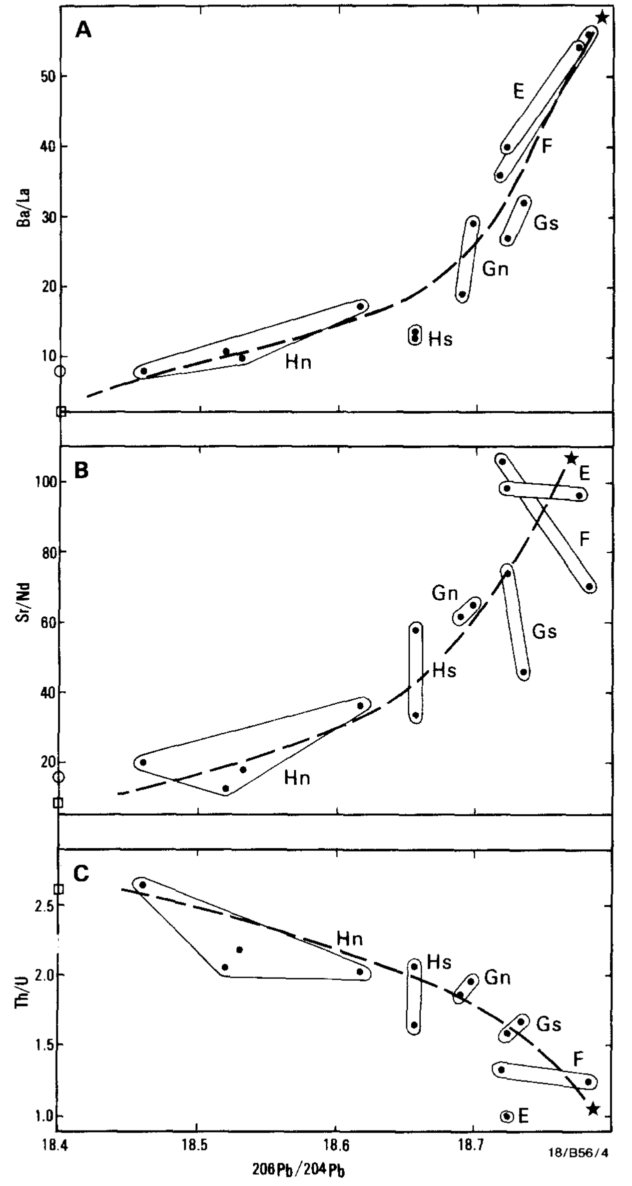

**Fig. 7A–C.** Selected incompatible-element ratios versus $^{206}Pb/^{204}Pb$ for New Britain samples. Sample identifiers refer to prefixes in Tables 1 and 3. Note the well-defined trends consistent with two-component mixing and the progressive shift in composition across the arc. The "enriched" component must have high Ba/La (greater than 55), high Sr/Nd (greater than 100), and low Th/U (1.0 or less). *Open circles* and *open squares* on *left-hand* vertical axis represent OIB and MORB average values, respectively, for elemental ratios (data from Sun and McDonough 1989). *Stars* at *right-hand* end of generalised trends, *dashed lines*, represent "enriched" component (schematic only). Th/U value for OIB is off-axis at 3.9

only reasonable way to produce elevated U/Th, Sr/Nd, and Ba/La is by hydrous-fluid transport in which elemental partitioning is controlled by ionic potential ("field strength") or complexing behaviour, or both, and not the more familiar solid/melt equilibria. Therefore a model involving mixing with slab-derived fluids, rather than sources having affinities with OIB, is favoured.

## Extent of slab influence: large-ion lithophile elements

Concentration versus WBZ-depth profiles for four LILE that may be sourced in part from the subducting slab, are shown in Fig. 8. The trends are slightly different for each element but, in direct contrast to the HFSE and HREE, all have a maximum in either zone Gn or Hs. These differences can be presumed to reflect a combination of a slab-derived flux with variable partial melting as described in the preceding section. Figure 9 represents an attempt to quantify this interaction. A simple batch-melting model is assumed, with HFSE derived solely from the mantle wedge [D(Zr) = 0.025; data from Kelemen et al. 1990]. The Zr data can be used to provide estimates of the relative degree of melting beneath each zone in the

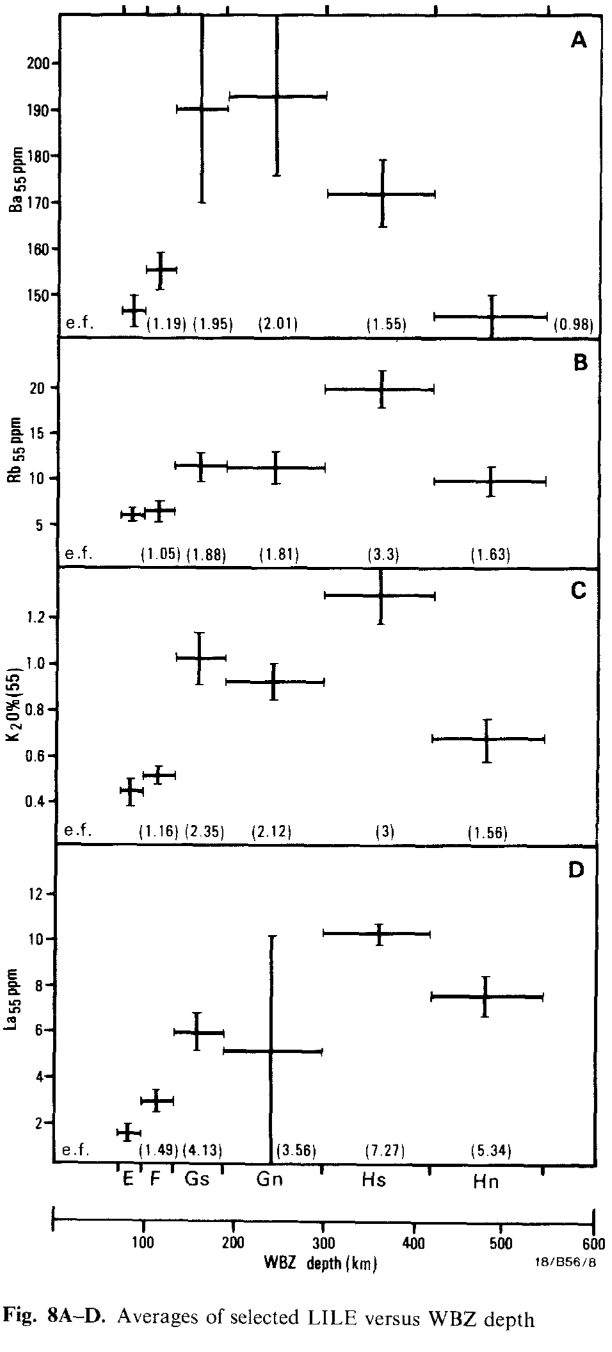

**Fig. 8A–D.** Averages of selected LILE versus WBZ depth

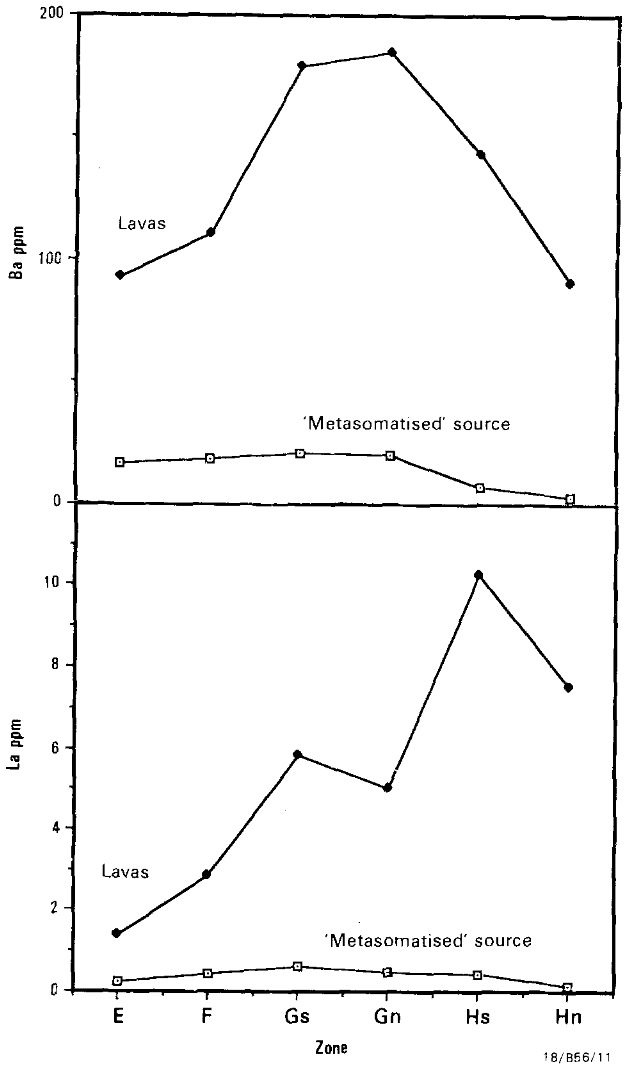

**Fig. 9.** Removal of the melting effect, defined by variations in Zr abundance, from some of the data in Fig. 8, to produce pre-melting, "metasomatised source" profiles across the New Britain arc. See text for details of the procedure used in this calculation

arc. For example, melting beneath zone Hn is set at 2 percent, and the following values obtained: E 17%, F 15%, Gs 11%, Gn 10%, Hs 4%. The LILE profiles of Fig. 8 then can be corrected for the effects of variable melting/wedge effects, and therefore the unmelted source values 'back-calculated' [using D (La) from Kelemen et al. 1990 and D (Ba) from Ewart and Hawkesworth 1987]. This modelling is necessarily simplistic, but the resulting profiles may be taken to represent the "metasomatised" mantle source prior to the onset of melting, together with a peak in the assumed slab flux at around 150 km depth. Individual source profiles and melting behaviour for different elements therefore may be responsible for producing subtle differences in the resulting geochemical profiles at a constant fractionation index (Fig. 8). Note also that these changes appear to be systematic. In particular, there is a progressive shift from the Ba profile (maximum in zone Gn), to Rb-K-La (maxima in zone Hs), to Zr-Hf in Fig. 3 (maxima in zone H). This is close to the empirically derived ordering of slab-fluid enrichment factors for arcs described recently by McCulloch and Gamble (1991).

Sediment involvement in New Britain arc magmas is thought to be somewhat less than in many other arcs, as discussed above. The extent to which the LILE are sourced in altered oceanic crust or sediment may well affect the extent to which these LILE profiles are applicable to other mantle-wedge locations.

Discussion on so-called "K-h" profiles has been exhaustive, but relatively few studies have been extended to other incompatible elements (see however Gill 1981). Jakeš and White (1972), Gill and Gorton (1973), and Whitford et al. (1979) demonstrated that the incompatible elements K, Rb, La, Th, and U increase with increasing WBZ depth, as do the ratios La/Yb and Rb/Sr. Levels of P, F, Sr, Ba, and Zr also commonly increase. In contrast, major- and compatible trace-element abundances for the Sunda arc (Whitford et al. 1979) correlate little, if at all, with WBZ depth. Much of these data have not been corrected for the effects of low-pressure fractionation processes, as we have attempted to do here, but the parallels with this study are clear.

The distinction between, and quantification of, the contrasting slab effect versus mantle-melting process must be a major goal for future studies of arc petrogenesis. Such distinctions may allow a ready explanation for many apparently contradictory features of arc volcanism, such as decreasing $^{87}Sr/^{86}Sr$ values, despite increasing Rb/Sr as depth to the WBZ increases, beneath northern Honshu, Japan (Hedge and Knight 1969), New Zealand (Stipp 1968), Sulawesi, Indonesia (Jezek et al. 1979), and the eastern Aleutian arc (Morris and Hart 1980). Decreasing $^{87}Sr/^{86}Sr$, in an analogous manner to $^{206}Pb/^{204}Pb$ in New Britain, may reflect a decreasing slab contribution as WBZ depth increases, whereas the increasing Rb/Sr may be a mantle effect reflecting the greater incompatibility of Rb compared to Sr.

## Current perceptions of slab/wedge interaction: towards a general model?

Tatsumi (1989) presented a model for petrogenesis in island-arc systems, based upon an analysis of dehydration reactions within the downgoing lithosphere, coupled with experimental data on the partitioning of elements into a hydrous fluid phase. Water is released from the dehydrating slab beneath the forearc and reacts with the forearc wedge forming hydrous minerals including serpentine, chlorite, amphibole and phlogopite. This hydrated peridotite then is carried downwards by convective mantle flow, whereupon amphibole and phlogopite dehydrate at about 90 and 200 km respectively, inducing melting in the overlying wedge peridotites. A key tenet is that transfer of mobile components from the slab takes place at shallow levels, concomitant with dewatering. Furthermore, the model provides a ready explanation for the location of the volcanic front predominantly at around 100 km above the

WBZ (amphibole breakdown), and less abundant volcanism at deeper levels towards the back-arc (phlogopite breakdown). Note also that the existence of serpentinite diapirs on the Mariana forearc (Fryer et al. 1985) may be a direct consequence of such slab-dewatering processes.

McKenzie and O'Nions (1991) took a somewhat different approach by combining the melt-streamline analysis of Spiegelman and McKenzie (1987) with a "chromatographic column" analogy for the mantle wedge, originally proposed by Navon and Stolper (1987). The effective transport velocity of a given element in this model is critical in determining whether it could traverse the wedge to the site of magmagenesis, or would be swept downwards and away by convective mantle flow. The model has the considerable advantage of explaining some of the apparent conflicts of arc geochemistry (for example, LILE enrichments from the slab without large isotopic shifts towards slab signatures), but it has two main flaws: (1) it provides no simple explanation for the location of the volcanic front because melts in the Spiegelman and McKenzie (1987) analysis are focused into what is essentially the forearc; (2) it requires melting of the slab at considerably greater depths than the volcanic front, in conflict with the findings of Tatsumi (1989) and Peacock (1990), for example.

These studies have led to a range of "minimal slab involvement" models in which LILE enrichments are seen as being sourced predominantly by the mantle wedge and perhaps concentrated by a metasomatic, slab-derived fluid phase carrying little, if any, elements from the slab (e.g. Stern et al. 1991; Hawkesworth et al. 1991a, b). A necessary proviso in these models appears to be that the mantle wedge has an isotopic composition similar to Icelandic-type OIB, because radiogenic components cannot be supplied by the slab and yet all arcs analysed to date are non-MORB-like in isotopic composition. These models also encounter problems: (1) OIB-type mantle material must be spread homogeneously throughout the mantle wedge over considerable distances (thousands of km), even though such material cannot be detected in corresponding back-arc environments (in addition, many trace-element features of arc magmas preclude the involvement of OIB-type material – see discussion above); (2) they require a slab-derived fluid capable of scavenging and concentrating elements from the wedge, yet free from elements derived from the slab itself. Additionally, if much of the slab-derived element flux is carried away by mantle flow, how can the same elements, scavenged from the wedge, also avoid being swept away?

An acceptable general model may include the advantages of these models. Thus, dehydration and transfer of many slab-derived elements takes place beneath the forearc region. This metasomatised wedge material is carried downwards by mantle flow, and dehydration reactions result in melting of wedge peridotites. The mantle melt at this point may have a somewhat extreme isotopic character inherited from the slab (although it is important to note that the *bulk* slab component may be considerably less radiogenic than sedimentary material alone) and trace-element ratios appropriate to hydrous-fluid transit. However, subsequent interaction with the convecting mantle and operation of the chromatographic effect detailed by Navon and Stolper (1987) would result in a series of elemental fronts traversing the mantle wedge, each with its own characteristic rate and form, dependent upon its transport velocity relative to mantle-wedge convection rate. Less mobile elements may be carried away by mantle flow, while highly mobile ones quickly would traverse the wedge producing the enrichments commonly seen in arcs. The extent to which such "fronts" could infiltrate pervasively large volumes of the wedge is unclear but note that new isotope and trace-element data for volcanic rocks of the New Georgia Group, Solomon Islands, are indicative that slab signatures can be stored in the mantle wedge for periods of millions of years (J.D. Woodhead, R.W. Johnson, P.N. Dunkley, submitted). The fact that many elements such as Sr and Nd, of intermediate incompatibility, may behave complexly between these extremes could hold clues to many of the conflicts between estimates of the slab-flux derived from isotope systematics and those derived from trace-element concentration considerations. Thus, large proportions of radiogenic Sr may emanate from the slab, but most may be carried away, with a much smaller component, diluted by mantle wedge Sr, eventually finding its way to the surface. Highly mobile elements such as Rb, Ba, Pb, and U are sourced heavily by the dehydrating slab but, as elements become less mobile, the wedge influence becomes greater.

Geochemical characteristics of individual arcs therefore may result from a complex interplay of critical parameters such as age of the subducting slab and subduction rate, which would control slab dewatering and mantle convection rates.

## Conclusions

The New Britain arc represents a rare opportunity to assess the nature and cause of geochemical changes across a wide depth to the Wadati-Benioff Zone and thus provides new insight into subduction-zone processes.

The concentration of HFSE and HREE in derivative lavas, at a given fractionation level, is proportional to the depth to the WBZ. Models involving decreasing degrees of partial melting with depth are favoured to account for these trends.

Radiogenic-isotope data, in particular Pb, are consistent with the interpretation that New Britain magmas contain a slab-derived component which, in contrast to many other arcs, is dominated by altered oceanic crust rather than by sediment. This conclusion is consistent with the findings of a previously published Be-B study. There is a distinct shift in Pb-isotopic composition across the arc, effectively delineating the extent of slab influence for Pb.

Well-defined trends consistent with two-component mixing are shown by combined Pb-isotope/trace-element plots. Characteristic trace-element ratios appear to rule out any involvement of material with affinities to OIB but require a fluid-transport mechanism both to change these ratios and homogenise the slab component.

Concentrations of the LILE reflect a complex interplay between a slab-derived flux and the melting process described above, a conclusion that appears to be applicable to other arcs.

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