49. A Pb, Sr, AND Nd ISOTOPIC STUDY OF BASALTIC ROCKS FROM THE SEA OF JAPAN, LEGS 127/128

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ABSTRACT

The western Pacific includes many volcanic island arc and backarc complexes, yet multi-isotopic studies of them are rare. Basement rocks of the Sea of Japan backarc basin were encountered at Sites 794, 795, and 797, and consisted of basaltic sills and lava flows. These rocks exhibit a broad range in isotopic composition, broader than that seen in any other western Pacific arc or backarc system: 87Sr/86Sr = 0.70369 to 0.70499, 143Nd/144Nd = 0.51267 to 0.51317, 206Pb/204Pb = 17.64 to 18.36. The samples form highly correlated arrays between very depleted mid-ocean ridge basalt (MORB) and the Pacific pelagic sediment fields on Pb-Pb plots. Similarly, on plots of Sr-Pb and Nd-Pb, the Sea of Japan samples lie on mixing curves between depleted mantle and enriched mantle ("EM II"), which is interpreted to be of average crustal or pelagic sediment composition. The source of these backarc rocks appears to be a MORB-like mantle source, contaminated by pelagic sediments. Unlike the Mariana and Izu arc/backarc systems, Japanese arc and backarc rocks are indistinguishable from each other in a Sr-Nd isotope plot, and have similar trends in Pb-Pb plots. Thus, sediment contamination of the mantle wedge appears to control the isotopic compositions of both the arc and backarc magmas. Two-component mixing calculations suggest that the percentage of sediments in the magma source varies from 0.5% to 2.5%.

INTRODUCTION

A controversial problem in the understanding of the dynamics of arc systems has been the source and origin of backarc volcanism. The radiogenic isotope geochemistry of volcanic arc and backarc lavas is an important tool in discriminating processes that may occur in subduction zones. Such processes include melting of the subducting slab and subsequent metasomatism of the overlying mantle wedge, recycling of pelagic sediments into the mantle, partial melting of the slab as it undergoes metamorphism, partial melting of variably depleted mantle peridotite, and crustal assimilation (e.g., Arculus and Powell, 1986; Elam and Hawkesworth, 1988). Correlations between Sr, Nd, and Pb isotopic systems have allowed geochemists to identify different chemical "components" in the mantle (e.g., Zindler and Hart, 1986), which may include altered ancient oceanic crust, pelagic sediments, continental crust and lithosphere, and "depleted" mantle (the source of MORB).

The western Pacific includes many volcanic island arc and backarc complexes, yet comprehensive isotopic studies of them are rare. In this paper, we present the results of a high-precision isotopic study of backarc basaltic rocks from the Sea of Japan, drilled during Ocean Drilling Program (ODP) Legs 127 and 128 (Fig. 1), and examine the implications of these rocks for the composition of the mantle beneath the Sea of Japan. The goals of Legs 127/128 in the Sea of Japan were (1) to determine the age and nature of the basement, (2) measure the direction and magnitude of the present stress field, and (3) to characterize the sedimentation, subsidence, and oceanographic evolution of the area. Our goal is to use coupled trace element and isotopic studies to determine the components that are present in the mantle beneath the Sea of Japan and to infer the nature of subduction processes acting in this area.

PREVIOUS WORK

Isotopic data from western Pacific island arc and back-arc basalts are sparse compared to those available for mid-ocean ridge basalts (MORB) or ocean island basalts. Much of the previous work has been on rocks from the Mariana arc (Meijer, 1976; Stern and Ito, 1983; Hole et al., 1984; Woodhead and Fraser, 1985; Hawkins and Melchior, 1985; Woodhead et al., 1987), but some samples from the Tonga-Kermadec arc (Oversby and Ewart, 1972; Ewart and Hawkesworth, 1987), the Philippine Sea (Meijer, 1973), the Philippine Island arc (Defant et al., 1989), the Japanese volcanic arc (Tatsumoto, 1969; Nohda and Wasserburg, 1981; Notsu, 1983; Nohda and Wasserburg, 1986; Tatsumi et al., 1988), eastern China (Zhou and Armstrong, 1982; Peng et al., 1986) and the Sea of Japan (Kaneoka et al., 1988) have been analyzed. Isotopic and trace-element differences between island arc lavas and MORB have been interpreted in terms of two models, one in which most western Pacific arc lavas have a depleted, MORB-like source that has been contaminated by subduction of Pelagic sediments, and the other in which MORB-like primary magmas have been contaminated by continental crust/lithosphere. Sediment contamination of the mantle source is best documented in the Sunda arc (Whitford and Jezek, 1979) and has also been proposed for the Mariana and Izu/Bonin arcs, where there is no continental crust exposed in the arc (Meijer, 1976; White and Patchett, 1984; Hole et al., 1984; Woodhead et al., 1987). Trace-element and isotopic data suggest that the percentage of the sediment component in the arc source is between 0.5% and 1%. Their 87Sr/86Sr ratios are higher than MORB (0.7034-0.7038), and Mariana lavas are displaced above the NHRL in Pb-Pb isotope plots. Arc lavas from both northeastern and central Japan form linear trends on Pb-Pb plots from moderately depleted MORB toward the sediment field. 87Sr/86Sr ratios range from 0.7032 to >0.7055, and in northeastern Japan 87Sr/86Sr ratios decrease from the arc front to the backarc region.

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RESULTS OF ISOTOPIC ANALYSES OF LEG 127 BASALTS

Analytical Methods

Basement rocks were encountered at Sites 794, 795, and 797. Samples for isotopic analysis were taken from unit cores adjacent to samples analyzed for major-element, trace-element, and petrographic analysis (Tamaki, Pisciotto, Allan, et al., 1990; Ingle, Suyehiro, von Breymann, et al., 1990; Allan and Gorton, this volume). Basement rocks in Hole 794C were interpreted to be tholeiitic sills intruded into soft, water-rich sediments, as were lower units cored in Hole 794D (Tamaki, Pisciotto, Allan, et al., 1990; Ingle, Suyehiro, von Breymann, et al., 1990). The sampled rocks ranged from fine-grained, aphyric basalt to relatively coarse-grained aphyric to plagioclase phryic dolerite. Units 1 to 5 are mildly LREE enriched, while Units 6 to 9 are less enriched (Allan and Gorton, this volume). Most rock units at Site 797 were also interpreted to be tholeiitic sills or dikes intruded into soft, water-rich sediments (Tamaki, Pisciotto, Allan, et al., 1990). Unit 2 at this Site is a lava flow. Units 1 to 9 (upper complex) have significantly lower concentrations of incompatible major and trace elements than Units 10-21 (lower complex; Tamaki, Pisciotto, Allan, et al., 1990; Allan and Gorton, this volume). Samples analyzed for isotopes from this site consisted of fine to medium grain basalt from both compositional groups. In contrast, samples from Site 795 were taken from massive to brecciated lava flows of calc-alkaline basalt to basaltic andesite composition.

All sampled igneous rocks from Legs 127/128 were altered by hydrothermal and diagenetic processes, with alteration often being quite severe especially along the sill margins. Twelve samples from the interiors of the freshest units were chosen for Sr, Nd, and Pb isotopic analysis on a Finnigan MAT 261 multicollector mass spectrometer at the University of California, Santa Barbara. Concentrations of Rb, Sr, Sm, Nd, U, Th, and Pb were determined by isotope dilution mass spectrometry. Analytical procedures are those of Cousens et al. (1990). $^{87}$Sr/$^{86}$Sr ratios were normalized to $^{87}$Sr/$^{86}$Sr = 0.1194. The average value obtained for NBS 987 was 0.71022 ± 1, and all samples were further normalized to NBS 987 = 0.71025. So normalized, four analyses of the E&A SrCO$_3$ yielded an average value of 0.70802 ± 2. $^{143}$Nd/$^{144}$Nd were normalized to $^{146}$Nd/$^{144}$Nd = 0.7219. The average $^{143}$Nd/$^{144}$Nd ratio measured for the La Jolla standard was 0.51189 ± 2, and five runs of BCR-1 yielded an average of 0.51263 ± 2. A mass fractionation factor of 0.08%/amu was applied to Pb ratios using NBS 981 as a standard (Todt et al., 1984).

Because samples analyzed for isotopes contained between 10% and 60% secondary minerals (mixed-layer clays, sulfides, carbonate), all samples were acid-leached for 24 hr in 6N HCl at 120°C to remove alteration products containing seawater Sr. $^{87}$Sr/$^{86}$Sr ratios were significantly lower in leached splits than in unleached splits (Table 1). The Nd and Pb isotopic compositions of leached and unleached splits were identical, indicating that the leaching process had no effect on Nd or Pb isotope ratios. $^{87}$Sr/$^{86}$Sr ratios correlate well with $^{143}$Nd/$^{144}$Nd and Pb isotopic ratios, suggesting that the acid leaching was successful in removing most of the alteration. Sr, Nd, and Pb initial ratios were calculated from Rb/Sr, Sm/Nd, U/Pb, and Th/Pb ratios determined on unleached sample splits, assuming basement ages of 16, 15, and 19 Ma for Sites 794, 795, and 797, respectively, as derived from paleontological data (Tamaki, Pisciotto, Allan, et al., 1990).
isotope ratios discussed in the text are calculated initial ratios based on analyses of leached samples.

### Isotopic Compositions

The basaltic rocks exhibit a broad range in isotopic composition, broader than that seen in any other northwestern Pacific arc or backarc system; $\varepsilon^{143}\text{Nd}$/Nd $= 0.70369-0.70494$, $143\text{Nd}/144\text{Nd}$ $= 0.51267-0.51317$, $206\text{Pb}/204\text{Pb} = 17.64-18.36$, $207\text{Pb}/206\text{Pb} = 15.42-15.55$, and $208\text{Pb}/206\text{Pb} = 37.36-38.35$. On plots of $208\text{Pb}/204\text{Pb}$ vs. $206\text{Pb}/204\text{Pb}$ and $207\text{Pb}/204\text{Pb}$ vs. $206\text{Pb}/204\text{Pb}$, the samples define highly linear arrays between very depleted MORB and the field of Pacific pelagic sediments (Fig. 2). Samples from both the upper depleted (La/Smn < 1) complex and the lower enriched (La/Smn > 1) complex at Site 797 fall on the regression line, although these complexes have different trace-element patterns (Allan and Gorton, this volume). The basaltic rocks from Hole 794 plot slightly above the best-fit line through Site 797 lavas, but also define an array with the same slope as the Site 797 array. Leg 127/128 basaltic rocks are displaced to higher $\varepsilon^{143}\text{Nd}$/Nd ratios as Izu-arc rocks, but are displaced to lower $\varepsilon^{143}\text{Nd}$/Nd ratios as a Sr-Nd isotopic plot (Hochstaeder et al., 1990). Basaltic rocks from other western Pacific and Indonesian arcs generally have much lower $143\text{Nd}/144\text{Nd}$ at a given $\varepsilon^{143}\text{Nd}$/Nd ratio, and plot below the mantle array (Defant et al., 1989).

In plots of $\varepsilon^{143}\text{Sr}$/Sr vs. $208\text{Pb}/204\text{Pb}$ and $143\text{Nd}/144\text{Nd}$ vs. $208\text{Pb}/204\text{Pb}$ (Fig. 4), the Sea of Japan samples have higher $\varepsilon^{143}\text{Sr}$/Sr and lower $143\text{Nd}/144\text{Nd}$ ratios than Pacific MORB and both the Mariana and Izu arc/back-arc rocks. As noted in other plots, the data points from Leg 127/128 basalts form an array trending from a highly depleted mantle composition toward the field of Pacific pelagic sediments.

Lavas from Site 797 exhibit a correlation between isotope ratios and trace-element composition (Table 1; Fig. 5). In Figures 2 through 5, it is apparent that basalts from both the upper depleted and lower enriched complexes form correlated arrays, suggesting that lavas from the two complexes are related. Neither fractional crystallization nor variable partial melting of a homogeneous source can be the cause of this correlation. Basalts from Site 794 do not show as good a correlation between isotope ratios and La/Smn (normalized to chondritic abundances). This implies that the petrogenetic relationships between the basaltic sills drilled at Site 794 are more complex than at Site 797.

### DISCUSSION

The data from Leg 127 and 128 samples indicate that Sea of Japan backarc basaltic lavas are isotopically similar to Japanese island-arc lavas, but are different from both MORB and most backarc basalts from the northwestern Pacific. Basalts from the Mariana Trough and Sumisu Rift backarc basins are interpreted to be derived from a predominantly DM source that has been variably contaminated with an enriched "arc component" (Volpe et al., 1990; Stern et al., 1990; Hochstaeder et al., 1990). Similarly, Leg 127/128 basalts appear to have a highly depleted, MORB-like mantle source (DM), and either the source itself or primary melts from the source have been contaminated by "enriched" material (EM). This EM contaminant could be subducted pelagic sediment, slab-derived fluids, subcontinental lithosphere, continental crust, or a combination of any of these materials.
Figure 2. Pb-Pb plots of arc volcanic rocks from (A) the Japan, Mariana, and Tonga arcs, backarc basalts from the Philippine Sea, Mariana Trough, and Sumisu Rift; and (B) Leg 127 basalts from the Sea of Japan. On both plots, Pb ratios in samples from Site 797 are highly correlated, lying on a line with a steeper slope than the NHRL (Hart, 1984). The best-fit lines (dashed) shown are for Site 797 basalts only. The lines trend from a depleted MORB-like composition toward Pacific pelagic sediments. Most Pacific arc and backarc basalts also plot above the NHRL, displaced toward the sediment field. (Data sources: Tatsumoto, 1969; Meijer, 1973, 1976; Oversby and Ewart, 1972; Nakamura et al., 1985; Ewart and Hawkesworth, 1987; Othman et al., 1989; Stern et al., 1990; Volpe et al., 1990; Hochstaedter et al., 1990.)
Slab-derived Fluids

H$_2$O-rich fluids driven from the subducting slab are a potential source of large ion lithophile (LIL) elements to the overlying mantle wedge (e.g., Perfit et al., 1980; Gill, 1981; Davidson, 1987). Because seawater Sr is incorporated into altered oceanic crust, slab-derived fluids should have 87Sr/86Sr ratios greater than typical MORB. However, seawater has a very low Nd concentration, and thus seawater does not affect 143Nd/144Nd in altered oceanic crust except under very high water/rock ratios (Eggle, 1987; Ludien and Thompson, 1979). Experimental data (e.g., Tsutsumi et al., 1986) suggest that slab-derived fluids have low Nd/Sr ratios, so the contribution of these fluids to the Nd concentration and isotopic composition of the mantle wedge is very small (Ellam and Hawkesworth, 1988). The relatively high 87Sr/86Sr values measured in Leg 127/128 basalts at a given 143Nd/144Nd ratio (Fig. 3) may reflect either post-emplacement alteration (incomplete removal of seawater Sr by acid-leaching) or excess slab-derived Sr in the mantle wedge. Leg 127/128 basalts, and western Pacific arc and backarc lavas in general, have both higher 87Sr/86Sr and lower 143Nd/144Nd ratios than depleted MORB, suggesting that slab-derived fluids cannot be the sole “enriched” material in the source.

Crustal Contamination

Previous studies of Japanese-arc volcanics found that there are systematic changes in Sr and Nd isotopic ratios in Quaternary volcanic rocks in transects both across and along the arc (Notsu, 1983; Nohda and Wasserburg, 1981, 1986). 87Sr/86Sr ratios decrease, and 143Nd/144Nd ratios increase, from the arc front to the backarc side of the arc in northeastern Japan (Fig. 5). Quantitative modeling of contamination of an “original magma” (an Izu-arc tholeiitic basalt) by a Cretaceous granite or pre-Silurian gneiss suggests that 10%-20% of the Sr and Nd in the Quaternary arc lavas is from the contaminant (Nohda and Wasserburg, 1981). It was also found that there is a secular decrease in 87Sr/86Sr and increase in 143Nd/144Nd over the last 27 Ma in volcanic rocks from northeastern Japan (Nohda and Wasserburg, 1986). These results were interpreted to reflect a high level of crustal contamination prior to and during the initial opening of the backarc. Subsequently, the degree of contamination dropped as the continental crust was thinned during the opening of the Sea of Japan. Quaternary arc magmas suffer more contamination at the arc front, where the continental crust is thickest, and become progressively less contaminated to the west where the continental crust is thinner (Nohda and Wasserburg, 1981). This model predicts that Sea of Japan basalts should be relatively uncontaminated, and thus MORB-like isotopically. Yet, they are nearly indistinguishable from Japan arc lavas (see also Kaneoka et al., 1990).

The isotopic data from Leg 127/128 rocks could be interpreted to reflect variable degrees of crustal contamination of basaltic magmas. The crust beneath the Yamato Basin is anomalously thick for purely oceanic crust (12–16 km; Tamaki, 1988; K. Suyehiro, pers. comm., 1990). The seismic velocities of the middle crustal section are consistent with either a thick sill-sediment complex, such as that drilled in Holes 794 and 797, or continental crust that has been thinned and intruded by basaltic magmas. Also, rafts of continental material are found in the Sea of Japan, including the large Yamato Block. Granites of the Yamato Block appear to be approximately 60 Ma in age, and reported 87Sr/86Sr ratios range from 0.7046–0.7067 (Ueno et al., 1974). However, the Mg numbers of Sea of Japan basalts recovered during Legs 127 and 128 are between 0.58 and 0.70, indicating that they have probably not interacted to an appreciable extent with silicic crust. Interaction between mantle-derived magmas and silicic crust by assimilation/fractional crystallization in small magma chambers,
conduits, or soft sediments, would likely produce a larger scatter on Pb-Pb plots, because of the variable composition of continental crust. The isotopic compositions of Leg 127/128 lavas are also inconsistent with the intuitively reasonable continental contamination model of Nohda and Wasserburg (1986) outlined above. For these reasons, we prefer a model whereby the enriched component is located in the mantle source.

Figure 4. Covariations of $^{206}\text{Pb}^{204}\text{Pb}$ with (A) $^{143}\text{Nd}^{144}\text{Nd}$ and (B) $^{87}\text{Sr}^{86}\text{Sr}$ in basalts from Leg 127/128; the Philippine Sea; the Mariana arc, the Izu arc, the Tonga arc, and their backarc basins. Note the trend from MORB-like depleted mantle toward Pacific pelagic sediments. Best-fit line is for Site 797 basalts only. Data sources as in Figures 2 and 3.

Lithospheric Contamination

A recent reappraisal of the chemistry of Tertiary to Quaternary arc lavas from northeast Japan has concluded that their isotopic and trace-element characteristics are best explained by contamination of primary magmas with subcontinental lithosphere, rather than with continental crust (Tatsumi et al., 1988; Nohda et al., 1988). This
modification to the Nohda and Wasserburg (1986) model is largely a result of geophysical data that indicate that the continental crust beneath northeast Japan is not thinner than that beneath the volcanic arc (Tatsumi et al., 1988). Nohda et al. (1988) propose that the opening of the Sea of Japan was the result of asthenospheric injection of depleted mantle beneath the backarc region. Subsequent thinning of subcontinental lithosphere during and after opening of the Sea of Japan would result in lesser degrees of contamination of subsequent primary arc magmas going from the arc front to the backarc region, just as thinning of the continental crust would do. This model, like the Nohda and Wasserburg model discussed in the previous section, predicts that Sea of Japan lavas should be isotopically MORB-like, which is not the case.

The composition of subcontinental lithosphere can be extremely variable (e.g., Menzies, 1989), and as noted by Kaneoka (1990), Nohda et al. (1988) do not present any data that shed light on the composition of the subcontinental lithosphere in the Japan region. Prior to opening of the Sea of Japan, Japan was attached to eastern China, and it is reasonable to assume that Japan and eastern China shared a common subcontinental lithosphere. Clues as to the composition of the subcontinental lithosphere beneath Japan may therefore be found in isotopic data from Neogene to Cenozoic volcanic rocks in eastern China (Zhou and Armstrong, 1982; Peng et al., 1986; Zhi et al., 1990; Song et al., 1990). Unlike northeastern Japan, there is no secular variation in $^{87}$Sr/$^{86}$Sr in volcanic rocks from easternmost China. From combined incompatible element and isotopic data, Zhou and Armstrong (1982) concluded that tholeiitic volcanic rocks from eastern China are partial melts of subcontinental lithosphere, while alkalic rocks are partial melts from a deeper source which have been recently enriched in incompatible elements. Peng et al. (1986) determined that there was an east to west isotopic transition from arc-like volcanics to lavas with evidence of a late Archean subcontinental lithosphere component: $^{143}$Nd/$^{144}$Nd ratios increase and $^{206}$Pb/$^{204}$Pb ratios decrease with decreasing $^{206}$Pb/$^{204}$Pb, typical of lavas that are interpreted to have interacted with subcontinental lithosphere (EM I component of Zindler and Hart, 1986; Menzies, 1989; Hawkesworth et al., 1990). The Hannuoba basalts (west of Beijing and west of the Tan-lu Fault) show the same range and trends in isotopic composition as other Cenozoic basalts west of the Tan-lu Fault, providing further evidence that an EM I component is present beneath eastern China (Zhi et al., 1990; Song et al., 1990). Song et al. (1990) conclude that the EM I component could be either mixed in the convecting mantle or trapped within the subcontinental lithosphere.

Sr and Nd isotopic data for Japan arc and Cenozoic eastern China lavas are compared in Figure 6. Note that for arc rocks from northeastern Japan, it is difficult to determine what the enriched component is, EM I, EM II, or some other component intermediate between the two, because the data all fall within the mantle fan and do not curve appreciably toward any enriched end member. Miocene arc rocks from Japan clearly curve toward EM II, while the China basalts appear to be displaced toward EM I at the end of the mantle fan. In a plot of Pb-Pb, lavas from eastern China plot above the NHRL and trend toward EM I (Fig. 7A). This trend from MORB to EM I is clearer on plots of Sr-Pb or Nd-Pb (Fig. 7B). Thus the trends interpreted to be
produced by subcontinental lithospheric contamination of basaltic magmas in eastern China are opposite to those seen in Japanese arc lavas and Hole 797.

Alternatively, the subcontinental lithosphere beneath Japan may have developed subsequent to the initiation of arc volcanism during the Cretaceous. The subcontinental lithosphere would then be composed of the residue of partial melting events in the mantle wedge, and would be isotopically similar to the arc crust above it. It would then be impossible to distinguish the two as potential contaminants on purely isotopic grounds.

**Subducted Sediments**

The correlation of the three isotope systems puts some constraints on the composition of the two components in Sea of Japan backarc basalts. The correlation between $^{206}\text{Pb}/^{204}\text{Pb}$ ratios and $\text{I}/[\text{Pb}]$ is good, especially in Hole 797, supporting two-component mixing (Fig. 8A). The isotopic composition of a composite of Pacific pelagic sediments is a good candidate for the non-MORB component (Table 2). However, similar plots of $^{87}\text{Sr}/^{86}\text{Sr}$ vs. $\text{I}/[\text{Sr}]$ or $^{143}\text{Nd}/^{144}\text{Nd}$ vs. $\text{I}/[\text{Nd}]$ indicate that Japanese continental crust, including older granites and gneisses, is less likely to be this component, because their $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are generally too high (0.707–0.715) and $^{143}\text{Nd}/^{144}\text{Nd}$ ratios are too low (Nohda and Wasserburg, 1981; Arakawa, 1990a, 1990b).

Dredged lavas from the Yamato seamount chain (central Yamato Basin) have $^{87}\text{Sr}/^{86}\text{Sr}$ ratios between 0.70375 and 0.70388, falling at the low end of the range observed in Hole 797 (Kaneoka et al., 1990). The seamounts appear to have formed after the major phase of opening of the Yamato Basin (Kaneoka et al., 1990) and are not part of a hotspot chain, so the most likely source of the seamount lavas was the mantle wedge. The low $^{87}\text{Sr}/^{86}\text{Sr}$ ratios suggest that either (a) the sedimentary component was volumetrically smaller in the source, perhaps because it was depleted during the major phase of spreading in the Sea of Japan, or (b) basaltic magmas were more effectively insulated from continental blocks trapped within the Sea of Japan such that crustal contamination was minimized, even though many of the Yamato Seamount lavas are quite evolved. Of course, $^{87}\text{Sr}/^{86}\text{Sr}$ ratios are still higher than MORB, so there is still an "enriched" component in these rocks.

If the enriched component is Pacific pelagic sediments, the proportions of the two components in the magmas can be estimated. The sediment and depleted MORB source compositions assumed for the mixing calculations are listed in Table 2, and the results are plotted in Figure 8B. The percentage of sediments inferred to be in the mantle source varies from 0.5% to 2.0%, which is greater than that estimated to be in Mariana arc magmas. Lavas from the Tonga arc (Oversby and Ewart, 1972) may have as much as 3% of a sedimentary component in the source, based on Pb isotopes. Note that the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio assumed for the depleted source is much higher than that normally attributed to depleted MORB mantle. If the mantle wedge is indeed composed largely of depleted, MORB-like mantle, it may have already been enriched in $^{87}\text{Sr}$, perhaps as a result of incorporation of fluids driven from the subducting slab. The assumed Sr concentration in the sedimentary component is fairly low, only 240 ppm, compared to the Pacific authigenic weighted mean sediment (PAWMS) composition derived by Hole et al. (1984). However, PAWMS contains a high proportion of nanofossil ooze with a high Sr content, which is not representative of sediment being incorporated into the Japan...
Figure 7. Pb-Pb (A) and Nd-Pb (B) isotope plots comparing Leg 127 backarc, Japanese arc, and eastern Chinese Cenozoic intraplate basalts. While the backarc and arc rocks lie on trends between depleted mantle and EM II (pelagic sediments), the Chinese lavas lie between an enriched MORB composition and EM I, which is interpreted to be subcontinental lithosphere (Zindler and Hart, 1986; Hawkesworth et al., 1990). (Data sources: Peng et al., 1990; Song et al., 1990; Japan arc data from Figs. 2 and 3)
Figure 8. Two-component mixing plots between depleted mantle (DM) and pelagic sediments (PS) for Leg 127 basalts. A. The $^{206}\text{Pb}^{204}\text{Pb}$ vs. $1/\text{Pb}$ plot suggests that the spread in isotopic composition is due to mixing between depleted mantle and pelagic sediments. Leg 127/128 basalts fall to the right of the mixing line, possibly due to the effect of fractional crystallization. Mixing lines between DM and PS are shown, assuming Pb compositions listed in Table 2. Squares on the line are for 0%, 1%, 2%, 3%, 4%, 5%, 10%, and 100% PS in the mix. B. $^{143}\text{Nd}^{144}\text{Nd}$ vs. $^{206}\text{Pb}^{204}\text{Pb}$ mixing curve for Leg 127/128 basalts. Squares on the curves are shown at 0%, 1% (marked), 2%, 3%, 4%, 5% (marked), 10%, 20%, 60% and 100% PS in the mix. End-member compositions are defined in Table 2. The most enriched basalts have a maximum of 2% pelagic sediment component.
produces a more realistic Sr/Sr86 plex lavas are enriched in LIL and light rare-earth elements compared to their lower component. Trace-element analysis shows that the lower complex contain a much larger contribution from the sedimentary melt, or as bulk fragments of the sedimentary column, is an important component added to their mantle source (e.g. Davidson, 1987).

Two Sr concentration in subducted sediments mixing with a MORB source produces a more realistic Sr/Sr86 Sr in the source of Mariana arc lavas than does the 1140- ppm Sr value for PAWMS (Hole et al., 1984).

Samples from the upper and lower complexes in Hole 797 have distinct major- element, trace-element, and isotopic compositions. However, all samples from Hole 797 lie on the highly correlated Pb-Pb regression lines in Figure 2, with the samples from the lower complex plotting at the high 206Pb/204Pb end. This suggests that the two magmatic groups may be related by mixing, in that rocks in the lower complex contain a much larger contribution from the sedimentary component. Trace-element analysis shows that the lower complex are enriched in LIL and light rare-earth elements compared to upper complex basalts (Tamaki, Pisciotta, Allan, et al., 1990; Allan and Gorton, this volume) and isotopic and incompatible element ratios are correlated (Fig. 5), as would be expected if they contained a larger sedimentary component. In what form the sedimentary component is introduced to the mantle wedge, as an aqueous fluid, a partial melt, or as bulk fragments of the sedimentary column, is an important question. The degree of alteration of these basalts, resulting in mobilization of critical LILE and Sr, makes it difficult to be quantitative when attempting to answer this question.

An aqueous fluid from sediments should have high LILE/REE, LILE/HfPSE, Sr/Nd, and Sr/Sr8686 Sr ratios, as does an aqueous fluid derived from oceanic crust (e.g., Tatsumi et al., 1986). Ba/La ratios in the lower complex at Site 797 range between 15 and 17, higher than the lower complex at Site 797 enriched in pelagic sediments mixing with a MORB end. This suggests that the processes that control the isotopic composition of these rocks is mixing of subducted pelagic sediments with depleted MORB mantle in the mantle wedge. The proportion of the sedimentary component in the source varies from 0.5% to 2.5%.

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Figure 9. REE mixing model showing the effect of mixing of pelagic sediment into depleted mantle. The depleted mantle pattern is calculated from the composition of Unit 3 depleted tholeiite, and the sediment is a composite of modern Pacific sediments whose REE patterns are shown in the upper part of the diagram. A 10%–13% partial melt of a mixed (97% mantle, 3% sediment) source yields an REE pattern similar to enriched tholeiite from Unit 13. Data sources are listed in the text.