21. ISOTOPE GEOCHEMISTRY OF LEG 129 BASALTS: IMPLICATIONS FOR THE ORIGIN OF THE WIDESPREAD CRETACEOUS VOLCANIC EVENT IN THE PACIFIC

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ABSTRACT

Basaltic rocks recovered from three drill sites in the western Pacific during Ocean Drilling Program Leg 129 have fairly distinct Sr, Nd, and Pb isotopic compositions. The Cretaceous alkali olivine dolerites from Site 800 in the northern part of Piafetta Basin have fairly low 87Sr/86Sr (0.70202-0.70320) and 143Nd/144Nd (0.51277-0.51281) and high present-day Pb isotopic ratios (206Pb/204Pb = 20.53-21.45, 207Pb/204Pb = 15.70-15.77, 208Pb/204Pb = 37.56-38.18). The Middle Jurassic theolites from Site 801 in the southern part of the basin have low 87Sr/86Sr (0.70237-0.70248), high 143Nd/144Nd (0.51298-0.51322), and moderate present-day Pb isotopic ratios (206Pb/204Pb = 18.20-19.12, 207Pb/204Pb = 15.47-15.60, 208Pb/204Pb = 37.56-38.18); isotopic compositions of the alkali olivine basalts overlying the theolites fall between those of the theolites and Site 800 dolerites. The Cretaceous theolites from Site 802 in the East Mariana Basin have high 87Sr/86Sr (0.70360-0.70372), fairly low 143Nd/144Nd (0.51277-0.51280), and fairly low and homogenous present-day Pb isotopic ratios (206Pb/204Pb = 18.37-18.39, 207Pb/204Pb = 15.49-15.51, 208Pb/204Pb = 38.24-38.35). Isotopic compositions of Site 801 theolites are indistinguishable from those of modern mid-ocean ridge basalts, consistent with the proposal that these theolites are a part of the oldest Pacific crust. The diverse isotopic compositions of the younger basalts appear to be the result of Jurassic Pacific plate migration over the geologically anomalous south-central Pacific region, wherein they acquired their distinct isotopic compositions. The anomalous region was volcanically more active during the Cretaceous than at present.

INTRODUCTION

During Leg 129 of the Ocean Drilling Program (ODP) we drilled three sites (800, 801, and 802) in the western Pacific (Fig. 1) to sample the Jurassic sedimentary section and underlying basaltic basement in that region (Lancelot, Larson, et al., 1990). The three drill sites bottomed in basaltic rocks, but only Site 801 in the southern Piafetta Basin reached Jurassic crust. An upper sequence of ~60 m of alkali olivine basalt flows and a lower sequence of ~60 m of theolite basalt flows and pillow units separated by a hydrothermal Fe-oxhydroxide deposit were penetrated beneath Jurassic sediments at Site 801. The alkali basalts have a radiometric age of 157 Ma whereas the theolites underlie the hydrothermal deposit and have a radiometric age of ~167 Ma (Pringle, this volume). Leg 129 drilling at Site 800 in the northern part of the basin penetrated ~100 m of intrusive dolerite sills underneath Upper Cretaceous sediments. The dolerites have a radiometric age of 126 Ma. At Site 802 in the East Mariana Basin, ~50 m of theolite basalt pillow lavas were drilled below Cretaceous sediments. The Site 802 theolites are ~52 m.y. younger, at 115 Ma, than the Jurassic theolites at Site 801.

In this paper, we present the Sr, Nd, and Pb isotopic compositions of the basaltic rocks recovered from Leg 129 drill sites in the western Pacific. These isotopic data are then combined with information on petrology and possible geologic occurrence of these basals presented in detail elsewhere in this volume (Floyd and Castillo, Floyd et al.). The main objectives of our study were to determine the interseis as well as intrusive compositional variability of the Leg 129 basaltic rocks and to identify their respective mantle sources. Finally, we propose a crustal evolution model of the western Pacific that bears on the origin of the so-called widespread volcanic "event" that occurred in the Pacific Basin during the Cretaceous (e.g., Larson, Schlanger, et al., 1981; Moberly, Schlanger, et al., 1986).

As a secondary objective, we attempted to determine the crystallization ages of two alkali dolerites (Samples 129-800A-5R-2, 52-60 cm, and 129-801C-1R-1, 109-114 cm) using both the Rh-Sr and Sm-Nd isotopic methods of dating. We analyzed the Sr and Nd isotopic compositions and Rh, Sr, Sm, and Nd elemental concentrations in coexisting mineral phases from these samples. To test the validity of our results, both of these samples were also dated by Pringle (this volume) using the 40Ar/39Ar single-crystal dating method.

BACKGROUND AND METHODOLOGY

In general, basaltic rocks from the three Leg 129 drill sites have distinct petrologic characteristics (Lancelot, Larson, et al., 1990; Floyd et al., this volume; Floyd and Castillo, this volume). The Site 800 samples are all alkali olivine dolerites. These are aphyric in texture and consist chiefly of plagioclase and olivine and minor amounts of iron oxides and hydroxides, biotite, apatite, spinel, and alkali feldspar, hornblende, and pyrite; they are moderately to highly (20%-55%) altered. The dolerites are enriched in incompatible elements such as Ba, Sr, La, and Ce relative to mid-ocean ridge basalts (MORB), which is typical of many ocean island basalts (OIB). The upper sequence alkali olivine basalts at Site 801 have a similar but not identical mineralogy with the Site 800 alkali dolerites. These alkali basalts are also enriched in incompatible elements, but to a lesser degree in comparison to the dolerites. Specifically, the trace element signature of Site 801 alkalic basalts belongs to the mildly alkaline oceanic island group typified by St. Helena and Réunion (Floyd and Castillo, this volume). Site 801 alkaline basalts are variably (20%-80%) altered. The lower sequence theolite basalts at Site 801 are composed mainly of plagioclase, augite, olivine (always pseudomorphed by secondary clays), and minor amounts of spinel, titanomagnetite, biotite, and apatite. The Site 801 theolites are depleted in incompatible elements, which is typical of modern normal-MORB. These theolites show the widest range of alteration among the basalts recovered from all sites, from slight (10%) to very highly altered (100%), and with the samples directly beneath the hydrothermal deposit showing the greatest alteration. On the average, however, the alteration of Site 801 theolites is moderate and directly comparable to that of younger (<10 Ma) oceanic rocks from other
Rb, Sr, Sm, and Nd elemental determinations of the whole-rock samples analyzed for isotopic compositions were done by inductively coupled plasma atomic emission spectrometry (ICP-AES) at the Centre de Recherches Pétrographiques et Géochimiques, using the procedure described by Goudarzi and Mavelli (1987). Rb concentrations of the incompatible-element-depleted Site 802 basalts were done by atomic absorption spectrophotometry (AA) at Scripps (C. Macdougal, analyst) because their concentrations are below the detection limit of the ICP-AES method.

Mineral separation of the two coarse-grained samples analyzed for dating purposes was done at the United States Geological Survey (USGS) in Menlo Park and the procedure used is described in detail by Pringle (this volume). In addition to the mineral purification done at the USGS, all the mineral separates were leached in ultraclean 2.5 N HCl for ~1 hr under constant agitation in an ultrasonic bath; clinopyroxene separates were further leached in 10% HNO₃ for ~2 min also under constant agitation. Finally, the separates were rinsed several times with ultraclean water and dried overnight in an oven at 105°C. All trace element concentration measurements of the rocks and minerals analyzed for dating purposes were done by the isotope dilution method. The accuracy, precision, and isotopic measurement corrections of all the analyses are listed beneath Table 1.

**RESULTS AND COMPARISON WITH OTHER OCEANIC BASALTS**

The isotopic compositions of Leg 129 basalts and mineral separates are listed in Table 1 and shown graphically in Figures 2 through 6. A detailed description of the results is presented as follows. First, we discuss the effects of seawater alteration on the isotopic compositions of the samples, then the results of age determination, and finally the isotopic analyses of samples from the three sites. As a whole, basalts from the sites can be separated into four isotopic groups, with Site 801 having two groups. Each group shows a limited to moderate degree of variation but by and large, intragroup variation is small relative to intergroup variation. These isotopic groupings agree well with the petrologic differences observed among the basaltic rocks. In the presentation of the analyses for each site, the isotopic values are generally described relative to the proposed hypothetical end-member mantle components: (1) depleted MORB mantle (DMM), (2) enriched mantle I and II (EM I and EM II), and (3) high U/Pb mantle (HUM) (Figs. 3 through 5; nomenclature is after Zindler and Hart, 1986). The DUPAL isotope anomaly proposed by Hart (1984) is related to the EM components, particularly to EM I.

**Alteration Effects**

A major concern in this study is the effects of seawater alteration on the Sr, Nd, and Pb isotopic compositions of old (>100 m.y.) basalts that are variably altered by seawater. The best examples are the Site 801 tholeiites directly underneath the hydrothermal deposit. Megascopic, petrographic, physical properties, and chemical evidence (Lancelot, Larson et al., 1990; Floyd and Castillo, this volume; Alt et al., this volume; Bush et al., this volume) clearly showed that these are the most altered igneous rocks recovered during Leg 129.

To investigate seawater alteration effects, leached and un-leached powders from the interior of two Site 801 tholeiitic cooling units (Samples 129-801 C-SR-3, 38–43 cm, and 129-801 C-SR-2, 78–80 cm) were analyzed for Sr, Nd, and Pb isotopic compositions. The cooling unit that contains Sample 129-801 C-SR-3, 38–43 cm, is directly beneath the hydrothermal deposit and is the most altered at Site 801 (Alt et al., this volume; Bush et al., this volume). Leached-unleached pairs of two comparatively less altered alkaline Samples 129-801 C-1R, 109–114 cm, and 129-800A-61R-1, 17–24 cm, were also analyzed for their Sr and Nd isotopic contents for comparison.

As expected, there is a large difference between the present-day or measured and initial Sr isotopic values in all pairs (Table 1). Many investigators have shown that the difference is due to the isotopic
Table 1. Strontium, Nd, and Pb isotope compositions of Leg 129 basalts.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Interval (cm)</th>
<th>Type</th>
<th>Sr isotopic compositions</th>
<th>Nd isotopic compositions</th>
<th>Pb isotopic compositions</th>
</tr>
</thead>
<tbody>
<tr>
<td>129-93DA-1</td>
<td>L</td>
<td>0.70323</td>
<td>0.152878</td>
<td>7</td>
<td>25</td>
</tr>
<tr>
<td>129-93DA-2</td>
<td>L</td>
<td>0.70379</td>
<td>0.152879</td>
<td>33</td>
<td>21</td>
</tr>
<tr>
<td>129-93DA-3</td>
<td>L</td>
<td>0.70321</td>
<td>0.152879</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>129-93DA-4</td>
<td>L</td>
<td>0.70321</td>
<td>0.152879</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>129-93DA-5</td>
<td>L</td>
<td>0.70321</td>
<td>0.152879</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>129-93DA-6</td>
<td>L</td>
<td>0.70321</td>
<td>0.152879</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>129-93DA-7</td>
<td>L</td>
<td>0.70321</td>
<td>0.152879</td>
<td>7</td>
<td>16</td>
</tr>
</tbody>
</table>

Notes: All concentration data are reported in ppm. — not determined. Analytical uncertainty on 206Pb/204Pb measurements is ±0.00002 and for Sr is ±0.00002 ppm. Sr isotopic compositions were determined by mass spectrometry using a VG sector mass spectrometer and by microPIXE (Vacca et al., 1990). Sr isotopic compositions of the basalts are average ±2σ of all points. Nd isotopic compositions are based on measurements of 143Nd/144Nd and 148Sm/144Nd and Nd isotopic compositions are based on measurements of 143Nd/144Nd and 146Sm/144Nd and determined by ion microprobe (Vacca et al., 1990). Pb isotopic compositions are average ±2σ of all points. Pb isotopic compositions of the basalts are average ±2σ of all points.

*U = unlit; L = leached; e.g., specific gravity.

Isotope data for mineral separates from Samples 129-801C-1R-1, 109-114 cm and 129-800A-5R-2, 52–60 cm, form linear arrays in both the Rb-Sr and Sr-Nd isochron diagrams (Fig. 2). However, the two "isochrons" in the Sm-Nd system are defined by data points that are not well correlated (both R² = 0.92); these give imprecise "dates" of 136 ± 40 Ma for Sample 129-801C-1R-1, 109–114 cm, and 167 ± 59 Ma for Sample 129-800A-5R-2, 52–60 cm. The case is even worse in the Rb-Sr system (both R² < 0.80); the dates given by the isochrons are 171 ± 76 Ma for Sample 129-801C-1R-1, 109–114 cm, and 77±50 Ma for Sample 129-800A-5R-2, 52–60 cm. Moreover, the mineral phases and whole rock from each sample do not have the same initial Sr and Nd isotopic values (Table 1) and these data indicate that there seems to be isotopic disequilibrium in the samples analyzed. For comparison, crystallization age determined by the 40Ar/39Ar single-crystal method on the plagioclases and a small amount of biotite from Sample 129-801C-1R-1, 109–119 cm, is 126.9 ± 0.4 Ma, whereas on the K-feldspar from Sample 129-800A-5R-2, 52–60 cm, is 125.2 ± 0.4 Ma.
129-800A-58R-2, 52–60 cm, is 126.1 ± 0.9 Ma (Pringle, this volume). These 40Ar/39Ar crystallization ages are consistent with the biotratigraphically determined ages of the sediments overlying these igneous samples (Matsuoka, this volume; Erba and Covington, this volume).

Results of previous studies have shown that the Rb-Sr isotope systematics is sensitive to seawater alteration (e.g., McCulloch et al., 1980; Faure, 1986) and, thus, it is not surprising that we failed to get reliable Rb-Sr dates. An attempt to date the sill and flow complex in the nearby Nauru Basin using different size fractions of igneous samples by the Rb-Sr method was also not successful (Notsu et al., 1986). The Rb-Sr dating method, however, has been employed quite successfully in dating celadonite veins in oceanic crust (e.g., Staudigel et al., 1981; Hart and Staudigel, 1986). For example, the celadonite veins in the same Nauru sills and flows studied by Notsu et al. (1986) yield an age of 105.1 ± 2.8 Ma (Hart and Staudigel, 1986), which is well within the age of formation of the complex determined by the 40Ar/39Ar method and the biotratigraphy of the interbedded sediments (Moberly, Schilinger, et al., 1986). It is important to note that these ages of celadonite veins determined by this method, though, are commonly younger than the crystallization age of the host oceanic crust because they are sensitive to the history of hydrothermal activity in the host oceanic crust.

An analogue of our Sm-Nd age determination study is that by McCulloch et al. (1980), who determined the crystallization age of the Samail ophiolite complex in Oman. The complex is an exceptionally well preserved and exposed cross section of oceanic crust and, unlike many Leg 129 samples, some of its rocks have not experienced intense
interaction with seawater. Coexisting clinopyroxene and plagioclase in four oceanic gabbros from Samail differ greatly in their $^{147}$Sm/$^{144}$Nd ratios (0.129–0.377). These mineral fractions define two excellent internal isochrons (both $R^2 = 1.0$) that give crystallization ages of 130 ± 12 Ma and 100 ± 20 Ma, which were interpreted as the time of formation of two portions of the complex. In the present study, the range of $^{147}$Sm/$^{144}$Nd (0.058–0.176) is more than a factor of 2 less than that of the Samail samples and, coupled with seawater alteration, gives larger age uncertainties.

Site 800 Dolerites

These dolerites have the highest measured Pb isotopic ratios among the samples analyzed here (Fig. 3) or, for that matter, ever reported for any oceanic igneous rocks drilled by ODP or the earlier Deep Sea Drilling Project (DSDP). Although the Site 800 dolerites have high Pb isotopic values, these have relatively low Sr and intermediate Nd isotopic compositions (Fig. 4). Site 800 dolerites plot below the so-called mantle array or the linear trend defined by the majority of oceanic lavas in Nd and Sr isotopic space; they belong to the "LoNd" array with Tubuai Island and Walvis Ridge as end points in Sr-Nd-Pb isotopic space (Gerlach et al., 1986). More accurately, the isotopic compositions of the dolerites almost overlap with those of Mangaia, which has even more extreme Pb isotopic compositions than Tubuai. Magmas from Tubuai and Mangaia, as well as St. Helena in the Atlantic, were proposed to be the closest representatives of the hypothetical HIMU end-member component in the mantle. Mantle component with HIMU characteristics has a high $^{238}$U/$^{204}$Pb ratio ($\mu$) that is needed to explain the high $^{206}$Pb/$^{204}$Pb (e.g., White, 1985; Zindler and Hart, 1986; Hart, 1988).

Major and trace element data indicate an OIB mantle source for Site 800 dolerites (Floyd et al., this volume), but it is difficult to relate these dolerites to a particular type of island or island group using chemical data alone. The distinct isotopic signature of the dolerites is similar to those of basalts from St. Helena in the Atlantic or from islands in the Cook-Australis in the southern Pacific, such as Runutu, Mangaia, and Tubuai (Figs. 3 through 5). The Site 800 dolerites and OIB from these islands were derived from mantle sources with a HIMU isotopic signature. Recently, Staudigel et al. (1991; see also Smith et al., 1989) have shown that some Cretaceous volcancoces from the Magellan, Marshall, and Wake seamount groups also have HIMU isotopic characteristics. Of particular importance in this study is the isotopic similarity between Site 800 dolerites and Hiim and Golden Dragon Seamount alkalic rocks because it places important constraints on the mode of emplacement of the dolerites. Hiim Seamount is only ~80 km to the southwest of Site 800 and is only 6 m.y. younger than the dolerites (Smith et al., 1989). Although Golden Dragon is located ~160 km southeast of the site and is 25 m.y. younger than the dolerites, its origin is identical to that of Hiim Seamount (Smith et al., 1989; Staudigel et al., 1991). The origin of the seamounts and its relationship to the emplacement of Site 800 dolerites will be discussed in more detail in the following section.

Site 801 Alkaline and Tholeitic Basalts

The Jurassic tholeiites in the southern Pigafetta Basin have low $^{87}$Sr/$^{86}$Sr and moderately high, though variable, $^{143}$Nd/$^{144}$Nd compared to other oceanic basalts (Fig. 4). A couple of Site 801 tholeiites have high Nd and low Sr isotopic compositions that are near the high $^{143}$Nd/$^{144}$Nd and low $^{87}$Sr/$^{86}$Sr end of the mantle array. This indicates that they came from a mantle source that has a long time-integrated depletion in Rb with respect to Sr and Nd with respect to Sm. Such a mantle source is similar to the hypothetical DMM end-member component, which is widely believed to constitute the bulk of the uppermost suboceanic mantle; it is also regarded as the main component in the mantle source of MORB (White, 1985; Zindler and Hart, 1986). Site 801 tholeiites have a moderately wide range of Pb isotopic compositions, but as a whole, they resemble the Pb isotopic signature of Pacific and Atlantic MORB more than any other group of oceanic lavas (Fig. 3).

The Site 801 tholeiites are the oldest oceanic basalts recovered in situ in the western Pacific and their radiometric age (~167 Ma; Pringle, this volume) is very close to the predicted Jurassic age of the seafloor based on magnetic lineations (Larson, 1976; Handschumacher et al., 1988). Most important, all their lithologic and geo-
Another distinctive feature of these theolettes is their high $^{208}\text{Pb}/^{206}\text{Pb}$ for given $^{208}\text{Pb}/^{204}\text{Pb}$, which, together with the high $^{87}\text{Sr}/^{86}\text{Sr}$ values, forms some of the characteristic features of oceanic lavas that have the DULAP isotopic signature (Hart, 1984). These oceanic basalt samples must have come from mantle sources that have a long-term (>1 Ga) history of incompatible element enrichment and, thus, must have been isolated in the mantle for a long period of time (Hart, 1984).

The Site 802 theolettes have petrographic and bulk chemical characteristics typical of oceanic basalt from mid-ocean ridges (Floyd et al., this volume). Specifically, these are hypersthene-normative basalts that are depleted in incompatible trace elements. However, East Mariana basalts are neither as incompatible element depleted as normal-MORB nor as incompatible element enriched as those erupted near hotspots or plume-MORB. For example, some of their trace element ratios that indicate the degree of incompatible element depletion such as La/Sr (0.98 [ave. ±0.24 [std. dev.]), La/Yb (1.57 ±0.58), and Zr/Nb (1.54 ±1.8) are in between the values of normal- and plume-MORB. Site 802 theolettes are directly comparable to those of transitional MORB from certain sections of the ocean ridge such as the Reykjanes Ridge and the Costa Rica Rift. In these regards, Site 802 theolettes are geochemically similar to the theolette basalts recovered at DSDP Site 452 in the Nauru Basin (Larson, Schlanger, et al., 1981; Meiby, Schlanger, et al., 1986; Floyd, 1989; Castillo et al., 1986, 1991). The similarity is even more striking because of their identical Sr and Nd isotopic compositions (Fig. 4). Site 802 and Site 462 Pb isotopic compositions strictly speaking do not overlap, but the field for the entire ~640 m of the Nauru complex (Castillo et al., 1991) trends toward the limited field for the glass ~19 m top of the pillow lavas drilled in the East Mariana Basin (Fig. 3). In addition, new $^{40}\text{Ar}/^{39}\text{Ar}$ age data for the Site 462 theolettes (M. Pringle, unpubl. data, 1992) suggest that the East Mariana Basin and Nauru Basin theolettes were emplaced contemporaneously. Altogether, these data bear on the origin of both igneous bodies and this will be discussed in more detail in the following section.

Similar to the Nauru theolettes, the isotopic compositions of Site 802 theolettes overlap both with some OIB and MORB (Figs. 3 through 5). The Site 802 theolettes overlap with MORB from the South Atlantic and Indian Ocean, which have some attributes of the DULAP isotopic signature (Dupre and Allègre, 1983; Hart, 1984; Castillo, 1988; Mahoney et al., 1989). These theolettes do not overlap with modern MORB from the Pacific. The isotopic compositions of Site 462 and 802 theolettes also overlap with those of OIB from oceanic islands such as the Marquesas, San Felix, Juan Fernandez, and Hawaii in the Pacific. More importantly, the isotopic compositions of Site 802 theolettes are very similar to the Ontong Java and Manus Plateaus (Mahoney, 1987; Mahoney and Spencer, 1991), which were formed contemporaneously with the eruption of Site 462 and 802 theolettes (e.g., Pringle, this volume; Tarduno et al., 1991). These plateau basalts have an EM I and/or DUPLA isotopic signature (Mahoney, 1987; Mahoney and Spencer, 1991).

**DISCUSSION**

The preceding presentation shows that the origin of Site 802 alkalic and Site 802 theolette magmas can be traced back, respectively, to the proposed hypothetical HIMU and DMM end-member components in the mantle. The mantle source of Site 802 alkalic magma is most probably a mixture of these two components. The Site 802 magma resulted from mixing DMM and EM1, most probably in the source, due to their fairly limited isotopic and geochemical variations. Very similar isotopic compositions are known to have persisted for a long period of time (>10 m.y.) and over a large area in the nearby Site 462 theolettes, and hence, most probably is an inherent feature of the mantle source (Castillo et al, 1991). The important problem that will be addressed here is the relationship between the distinct isotopic signatures of Leg 129 basaltic magmas and the tectonic evolution of the western Pacific. Based on the available
information, we propose a model to explain the origin of the widespread volcanic event that occurred in the western Pacific during the Cretaceous (e.g., Larson, Schlanger, et al., 1981; Moberly, Schlanger, et al., 1986).

The recovery of the lower sequence tholeiites at Site 801 in the southern part of Pigafetta Basin verifies the presence of the oldest Pacific crust in that region as predicted by plate reconstruction models based on seafloor magnetic lineations (e.g., Larson, 1976; Hambach, 1986). All available data indicate that the tholeiites were erupted along a mid-ocean ridge system. This system most probably is a Middle Jurassic boundary of the oldest Pacific plate though it is impossible to trace whether this is the Pacific-Farallon, Pacific-Phoenix, or Pacific-Izanagi plate boundary because of a lack of correlatable magnetic lineation patterns near the site (e.g., Hambach, 1986). An important point is that the bulk compositions of the old samples and modern MORB erupted along the eastern boundaries of the Pacific plate (e.g., White, 1987; Ito et al., 1987; Macdougall and Lugmair, 1986) are similar and must have come from the incompatible element-depleted upper mantle. In other words, the isotopic data imply that the ridge that formed Site 801 tholeiites was away from hotspots and/or isotopically anomalous regions in the mantle (e.g., Allègre et al., 1984; Hanan et al., 1986; Castillo, 1988). The presence of alkali olivine basalts at Site 801 on top of the hydrothermal deposit, therefore, is interesting because of their fairly homogenously, but mixed OIB and MORB isotopic signature. One possible explanation is that Site 801 was actually above a transition zone between a "normal" ocean ridge and an anomalous mantle such that the off-axis volcanism that produced the alkali basalts tapped a mixed mantle source. For example, isolated seamount lavas from such a zone tend to magnify the isotopic differences that are present in the mantle but are subdued in MORB by magmatic plumbing processes along the ridge (e.g., Castillo and Battia, 1983). Alternatively, the Jurassic tholeiitic basement moved toward an isotopically diverse and volcanically active off-ridge region at ~157 Ma. This would explain not only the isotopic composition of the alkali basalts but also the possible cause of volcanism that formed the basalts and drove the hydrothermal system beneath these basalts. In either case, there is a need for a mantle source (i.e., one that is dominated by a HIMU component) to explain the formation of the upper alkali basalt sequence. Interestingly, Site 800 dolerites in the northern part of Pigafetta Basin originated directly from such a mantle source ~30 m.y. later.

The isotopic compositions of Site 800 dolerites consistently overlap with those of the Cretaceous Himu and Golden Dragon seamounts (Figs. 3 through 5). Site 800 is also geographically close to these Cretaceous seamounts (Fig. 1) and, thus, it is reasonable to assume that the formation of Site 800 dolerites and seamount magmas are closely related. Smith et al. (1989; see also, Staudigel et al., 1991) showed that the Cretaceous Himu and Golden Dragon seamounts can be "backtracked" to the Rurutu hotspot in French Polynesia (south central Pacific) at zero age using a plate reconstruction model based on a hotspot frame of reference (Henderson, 1985; Duncan and Clague, 1985). They also emphasized the presence of HIMU and EM II (EM I is only minor) components as well as a thermal anomaly in the upper mantle beneath French Polynesia since ~120 Ma. They called this isotopically and thermally "anomalous" region SODPTA, which is approximately the same area that was termed the south Pacific "supersewswell" by McNutt and Fisher (1987). If this is the case, then the Site 800 dolerites most probably were emplaced when their underlying Jurassic lithosphere moved close to or directly over the anomalous region at ~126 Ma.

The emplacement of Site 802 and Site 462 MORB-like tholeiites most probably is also connected to the presence of the anomalous region in south central Pacific. Earlier, we have proposed that the Site 462 tholeiites in the Naunu Basin were erupted along an ocean ridge system that propagated into or was formed in the preexisting Jurassic basement when this basement drifted near the intensely volcanically active south central Pacific region during the Cretaceous (Castilli et al., 1986, 1991). The intense volcanism in this region, in turn, may be related to the large-scale mantle convection (e.g., Hart, 1984, 1988; Castillo, 1988). We believe that the Site 802 tholeiites were produced by a similar process and in fact, their morphologic features as pillow lavas that presently lie beneath ~6000 m of water (Lancelot, Larson, et al., 1990) make them better suited for the proposed ocean ridge origin. It is important to note that the main arguments against Site 462 tholeiites being MORB, besides the fact that they are younger than the predicted age of the crust in the Nauru Basin, are that the upper part of the complex consists of intrusive sills and that the whole complex is anomalously shallow for a Jurassic-age crust.

An alternative and widely believed origin of the Site 462 tholeiites is that these are intraplate volcanic lavas that were erupted off-axis, ~15 m.y. after the formation of the underlying Jurassic crust (Larson, Schlanger, et al., 1981; Moberly, Schlanger, et al., 1986; Floyd, 1989; Renkin and Schlater, 1988). Of course, the Site 802 tholeiites could have been emplaced in a similar fashion. A third plausible explanation for the origin of the Site 802 tholeiites is that these are products of fracturing and extensional melting in the lithosphere proximal to the anomalous region (e.g., Castillo and Pringle, 1991). However, although the Site 802 tholeiites could have been produced by this process because it may only be a thin cap of the Jurassic basement (cf. Clague et al., 1990), this may not be true for the thick (>640 m) Site 462 tholeiites. In any event, the volcanism that produced these Cretaceous MORB-like tholeiites most probably were connected to the anomalous region since both Sites 802 and 462 were in the southern hemisphere in the Pacific during the Cretaceous (Wallick and Steiner, this volume).

The similarity of the isotopic compositions of the Sites 802 and 462 tholeiites and those of the Ontong Java Plateau also bears directly on the origin of these tholeiites. The plateau forms the western boundary of the Nauru Basin and the southern boundary of the East Mariana Basin prior to the formation of the Caroline Islands from the Miocene to Recent (Fig. 1). Recent models for the formation of the Ontong Java Plateau call for a mantle plume somewhere between ~34°S to far south as the present location of the Louisville hotspot at ~5°W. Clague et al., 1991; Mahowney and Spencer, 1991; Richards et al., 1991). Although these locations lie to the south of French Polynesia, the plume that produced the Ontong Java Plateau (~30 x 10⁶ km²) must have been robust, especially if the plateau was emplaced in a short period of time (a few million years; Tarduno et al., 1991). Moreover, the strong EM I signature of the voluminous plateau lavas (Mahowney and Spencer, 1991) and the somewhat less pronounced EM I characteristics of the Site 462 igneous complex (Castilli et al., 1991) and Site 802 tholeiites (Figs. 3 through 5) are volumetrically minor in modern French Polynesia basalts (e.g., Staudigel et al., 1991; Mahowney and Spencer, 1991). These data are consistent with the idea that a mantle source dominated by an EM I component was active in the South Pacific during the Cretaceous but is no longer there at present. Altogether, the data suggest that the anomalous region may have been larger during the Cretaceous than at present (Larson; 1991) and that a ridge system could have been easily associated with the Ontong Java hotspot (Mahowney and Spencer, 1991), one which formed the Site 462 and 802 tholeiites.

**CONCLUSIONS**

Leg 129 drilled the northern (Site 800) and southern (Site 801) parts of the Pigafetta Basin and the central (Site 802) East Mariana Basin to sample the oldest oceanic crust in the western Pacific. Basaltic rocks were recovered from the bottom of the three sites. Results of our isotopic investigations of these basaltic rocks are as follows:

1. An attempt to determine the crystallization ages of the basaltic rocks by the Rb/Sr and Sm/Nd isotope methods of dating was not successful. This is mainly due to seawater alteration and small range of parent/daughter elemental ratios, but may also be due to the
presence of xenocrystic phases in the samples (Pringle and Castillo, work in progress).

2. Isotopic compositions of the Middle Jurassic tholeiites from Site 801 resemble those of modern normal-MORB. These tholeiites are the oldest oceanic crust recovered in situ in the Pacific and must have been produced along an accreting boundary of the oldest Pacific plate.

3. Isotopic compositions of the alkaline olivine basalts overlying the tholeiites at Site 801 fall between those of the tholeiites and Site 800 dolerites. The volcanism that produced these basalts must have tapped a mantle source produced by mixing the hypothetical DMM and HIMU end-member components.

4. The Cretaceous alkalic lavas from Site 800 in the northern part of the Pigafetta Basin and those of the nearby Himu and Golden Dragon seamounts must have come from the same mantle source with HIMU isotopic characteristics.

5. The Cretaceous MORB-like tholeiites from Site 802 in the East Mariana Basin and from Site 462 in the adjacent Nauru Basin are isotopically very similar. These tholeiites were emplaced contemporaneously and their emplacement may have been initiated by the intense plume activity that formed the Ontong Java Plateau.

6. A simple model of the crustal evolution of the western Pacific can be constructed based on the results of our isotopic investigations combined with other recently available data. The oldest Pacific crust was formed during the Jurassic along a section of a normal ocean ridge similar to those elsewhere in the eastern Pacific today. The Jurassic crust moved toward the south central Pacific region, which may be geologically anomalous since about 157 Ma to the present, and the Site 801 alkalic olivine basalts were emplaced. Volcanism became more intense in the south central Pacific region during the Cretaceous due to the possible occurrence of numerous, voluminous hotspot magmatism (e.g., Larson, 1991; Pringle, 1991) and/or impingement of a large mantle plume on the oceanic lithosphere that formed the Ontong Java Plateau (Richards et al., 1991). The basaltic rocks at Sites 800, 802 and 462 were emplaced during this period. Since then, the Pacific crust has moved to the northwest, and volcanism in south central Pacific has been reduced to the current level of intensity.

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