ISOTOPE AND LIL ELEMENT GEOCHEMISTRY OF THE GALAPAGOS ISLANDS

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The Galapagos archipelago consists of 15 volcanic islands and numerous smaller islets which emerge from a shallow plateau in the eastern equatorial Pacific. The archipelago is bounded on the north by the Galapagos Ridge, an active spreading center, which extends from the East Pacific Rise to the Peru-Chile trench and forms the boundary between the Cocos and Nazca plates. The Galapagos have been interpreted as the surface manifestation of a deep mantle plume (Morgan, 1971) on the basis of structural, geophysical, and geochemical evidence (for example, Johnson and others, 1976; Case and others, 1973; Schilling and others, 1976). There have been several petrological studies of the Galapagos since Darwin first visited the islands, the most complete of which is cBirney and Williams (1969). Of particular interest to us is the fact that these islands are among the relatively few oceanic islands with abundant tholeiites as well as alkali basalts.

In an attempt to test geochemical models for the origin of oceanic islands and mid-ocean ridges, we have so far determined $^{87}Sr/^{86}Sr$ ratios and K, Rb, Cs, Sr, Ba, and Ni abundances in 23 samples from 9 islands. In seven samples we have also determined rare-earth abundances. Most of the samples were kindly provided by A. R. McBirney, and major-element analyses and petrographic descriptions of these samples are given in McBirney and Williams (1969). We used isotope dilution analysis for all element abundances except Sr and Ni, which were determined by X-ray fluorescence. $^{87}Sr/^{86}Sr$ ratios were normalized to $^{86}Sr/^{88}Sr$ = 0.11940 and are reported relative to a value of 0.70800 for the E&A standard. Precision is ±0.00007 (±2 sigma) or better.

Figure 1 shows the average $^{87}Sr/^{86}Sr$ ratio of each island. In contrast with some other oceanic islands or island groups, the isotope ratios are surprisingly variable. Individual values from the island of Santa Cruz range from 0.70263 to 0.70399. This is also the maximum

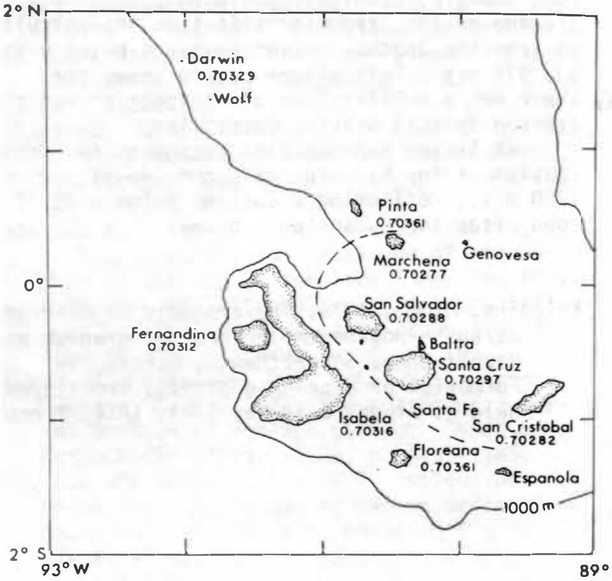

Figure 1.--Map of the Galapagos Islands. 1000-meter bathymetric contour outlines the Galapagos Plateau. Average $^{87}Sr/^{86}Sr$ for each island is given below island name. Dashed line separates islands with average $^{87}Sr/^{86}Sr$ ratios greater than 0.7030 from islands with average ratios less than 0.7030.

range for the entire Galapagos group. Nevertheless, such extreme local variation is the exception rather than the rule. For example, four of the five Santa Cruz samples have $^{87}Sr/^{86}Sr$ ratios between 0.70263 and 0.70289, and three of the four tholeiites from Isabela range from 0.70327 to 0.70331 (the fourth sample has a ratio of 0.70278). We do not know whether these local consistencies reflect an unknown sampling bias, but the geographical pattern of the average isotopic ratios shown in figure 1 indicates that the consistencies may be real. The four islands with $^{87}Sr/^{86}Sr$ averages less than 0.7030 may be separated geographically from the five islands with averages greater than 0.7030 by a simple contour line. Significantly, the islands with low $^{87}Sr/^{86}Sr$ ratios all occur in the east-central portion of the archipelago, while the islands with higher ratios occur on the western, northern, and southern edges of the archipelago.

The large-ion-lithophile (LIL) element abundances of the Galapagos basalts are low when compared to most other oceanic islands. Especially striking are the low LIL element abundances in most of the alkali basalts (thus defined if nepheline normative). For example, an alkali basalt from San Salvador (E-24) has 1190 ppm K, 1.39 ppm Rb, 0.010 ppm Cs, 242 ppm Sr, and 25 ppm Ba. Except for Sr, these concentrations are within the mid-ocean ridge basalt range. When the effects of fractional crystallization are taken into consideration, alkali basalts do appear to have slightly higher LIL element concentrations than tholeiites, but the difference is surprisingly small. There is no systematic difference in $^{87}Sr/^{86}Sr$ ratios between the two rock types. The concentration ranges (mean values in parentheses) for all samples are:

K -------	690 - 8940 (3920)
Cs ------	0.007 - 0.230 (0.066)
Ba ------	13 - 620 (126)
K/Rb ----	350 - 2130 (508)
[Ce/Yb]EF	1.21 - 3.69 (2.68)
Rb ------	0.61 - 21.0 (7.7)
Sr ------	192 - 505 (317)
Ni ------	51 - 323 (124)
Rb/Sr ---	0.004 - 0.055 (0.023)

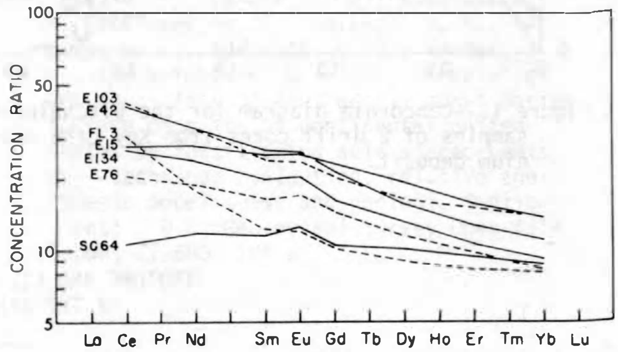

Figure 2.--Chondrite-normalized rare-earth abundance patterns of Galapagos Islands basalts. Solid lines, tholeiites; dashed lines, alkali basalts. Sample numbers beginning with 'E' are described by McBirney and Williams (1969). Samples SC-64 and FL-3 are from the islands of Santa Cruz and Floreana, respectively.

Rare-earth abundance patterns are shown in figure 2. Most of the samples have a modest light rare earth enrichment, again with little difference between tholeiites and alkali basalts. Sample SC-64 (tholeiite from Santa Cruz) has a rare-earth pattern similar to that of mid-ocean ridge basalts. This sample also has other LIL element characteristics of mid-ocean ridge basalts (690 ppm K, 0.61 ppm Rb, 0.010 ppm Cs, 236 ppm Sr, 13.6 ppm Ba, K/Rb = 1138, $^{87}Sr/^{86}Sr$ = 0.70289). All samples show a slight positive Eu anomaly, a feature also characteristic of basalts from the Azores Islands (White, 1977). The Eu anomaly could reflect source chemistry or peculiarities of magma genesis in the area.

The variability of the trace-element abundances and Sr isotope ratios clearly indicates that the mantle source of these magmas is inhomogeneous. On the average, the magma sources are more depleted in character than are those of most other oceanic islands, and some are indistinguishable from typical mid-ocean ridge sources. None show the high enrichment common among oceanic island basalts. A relatively large characteristic length of source heterogeneity is suggested by the geographical pattern of isotopic compositions, but smaller scale, intra-island variations are also present.

The results are consistent with a mantle plume model, if the magma source consists of poorly mixed depleted asthenosphere and enriched plume components. The presence of basalts with low $^{87}Sr/^{86}Sr$ ratios may be due to a relatively small ratio of plume material to depleted asthenosphere material available for magma production. This may be due to the relatively high asthenosphere upwelling rates implied by high spreading rates in the region (3 cm yr^{-1} half rate for the Galapagos Ridge) compared to the northern part of the Mid-Atlantic Ridge. A model of partial mixing is also consistent with the positive correlation of $^{87}Sr/^{86}Sr$ with Rb/Sr, corresponding to a local pseudo-isochron with an age of about 500 m.y. It should be noted, however, that the geographical pattern observed for the $^{87}Sr/^{86}Sr$ ratios is not consistent with Schilling's (1976) simple model of plume-asthenosphere mixing based on the variation of La/Sm ratios along the Galapagos Ridge, because the apparent center of the plume contains a large proportion of depleted asthenosphere component.

The average $^{87}Sr/^{86}Sr$ and Rb/Sr ratios of all 12 tholeiites analyzed fall within the field of oceanic tholeiites defining the 1.6 b.y. mantle isochron described by Brooks and others (1976). In this respect, the Galapagos are similar to Samoa and Kerguelen in that although they fit the 1.6 b.y. oceanic mantle isochron, the data also define a much younger local isochron. We consider the present data to be a test of the world-wide nature of that oceanic mantle isochron, because the plot shown by Brooks and others (1976) contained no data from the Galapagos Islands.

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