15. PRELIMINARY PETROLOGY OF LEG 34 BASALTS FROM THE NAZCA PLATE

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INTRODUCTION

Leg 34 of the Deep Sea Drilling Project cored basaltic basement at three locations within the Nazca plate. Site 319 within the Bauer Deep lies westward of the extinct Galapagos Rise and eastward of the presently active East Pacific Rise. Estimates of basement age are about 15 m.y. (Hart et al., 1974). Sites 320 and 321 lie between the Galapagos Rise and Peru-Chile Trench; Site 320 north and Site 321 south of the Mendaña Fracture Zone. Basement ages at both sites are estimated at 40-45 m.y.

Basement samples have been analyzed from Holes 319, 319A, and 320B, and Site 321. Data are reported for Ti, Zr, Y, Sr, Rb, together with petrographic and phase chemistry data for samples taken at intervals down each core. Distribution of analyzed samples is shown in Table 1, and a crude estimate of the relationship of samples to proposed cooling units is shown in Figure 1. Petrographic descriptions of analyzed samples are given in Table 2.

TABLE 1

Distribution of Analyzed Samples

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Hole</th>
<th>Core</th>
<th>Section</th>
<th>Depth Within Section (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>319</td>
<td>13</td>
<td>1</td>
<td>77-80 (PTS a 75-78)</td>
</tr>
<tr>
<td>2</td>
<td>319A</td>
<td>1</td>
<td>1</td>
<td>48-51</td>
</tr>
<tr>
<td>3</td>
<td>319A</td>
<td>2</td>
<td>1</td>
<td>111-114</td>
</tr>
<tr>
<td>4</td>
<td>319A</td>
<td>3</td>
<td>1</td>
<td>78-81</td>
</tr>
<tr>
<td>5</td>
<td>319A</td>
<td>3</td>
<td>5</td>
<td>75-78</td>
</tr>
<tr>
<td>6</td>
<td>319A</td>
<td>5</td>
<td>1</td>
<td>20-22</td>
</tr>
<tr>
<td>7</td>
<td>319A</td>
<td>6</td>
<td>1</td>
<td>93-98</td>
</tr>
<tr>
<td>8</td>
<td>319A</td>
<td>7</td>
<td>1</td>
<td>121-124</td>
</tr>
<tr>
<td>9</td>
<td>320B</td>
<td>3</td>
<td>1</td>
<td>54-57</td>
</tr>
<tr>
<td>10</td>
<td>320B</td>
<td>bit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>321</td>
<td>14</td>
<td>1</td>
<td>42-45 (PTS 52-55)</td>
</tr>
<tr>
<td>12</td>
<td>321</td>
<td>14</td>
<td>2</td>
<td>9-12</td>
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<tr>
<td>13</td>
<td>321</td>
<td>14</td>
<td>3</td>
<td>4-7</td>
</tr>
<tr>
<td>14</td>
<td>321</td>
<td>14</td>
<td>4</td>
<td>7-10</td>
</tr>
</tbody>
</table>

aPTS = depth at which polished thin sections were taken when different from powdered samples.

CHEMISTRY

Data for Ti, Zr, Y, Sr, and Rb are shown in Table 3. Ti, Zr, and Y are relatively unaffected by subsolidus alteration (Pearce and Cann, 1971) and probably represent initial magmatic concentrations (Figure 2). Since the basalts studied here generally show only minor alteration, Rb and Sr values may also be initial values. There is a close coherence between Ti and Zr and a weaker correlation between Zr and Y. Ti/Zr ratios remain fairly constant between 120 and 150; however, individual holes can be recognized on the basis of their trace element abundances. Site 321 has higher Ti, Zr, slightly higher Y, and lower Sr compared to other holes.

Figure 1. Location of analyzed samples relative to surmised cooling units (irregular lines) as described in core log. At Hole 319A a tentative flow boundary has been drawn (straight line). Thickness of units are approximate accumulate thicknesses of recovered basalt, spacers, and voids.
Hole 319 and the topmost sample from Hole 319A are relatively depleted in Ti, Zr, and Y. In Figure 1 these samples are compared to distinct basalt types characterized by Pearce and Cann (1971). Only samples from Hole 320B fall in the range of typical abyssal tholeiites. A sample from Hole 319 and the topmost sample from Hole 319A are similar to abyssal tholeiites, but are slightly depleted in Zr. Basalts from Hole 319A and Site 321 are enriched in Ti, Zr (and Y) relative to abyssal tholeiites, and are clearly of a more alkalic nature, particularly samples from Site 321.

### TABLE 2

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Hole</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>319</td>
<td>Very fine grained, aphyric; acicular plagioclase and pyroxene, intergranular titanomagnetite and rare ilmenite laths</td>
</tr>
<tr>
<td>2</td>
<td>319A</td>
<td>Medium grained, occasional plagioclase microphenocrysts; intimately intergrown rosettes of plagioclase and pyroxene; intergranular titanomagnetite; Secondary iddingsite after anhedral olivine</td>
</tr>
<tr>
<td>3</td>
<td>319A</td>
<td>Fine grained with occasional plagioclase phenocrysts, showing strong optical zoning; groundmass texture similar to Sample No. 2; Chlorite fills interstitial areas and lines vesicles</td>
</tr>
<tr>
<td>4</td>
<td>319A</td>
<td>Essentially similar to Sample No. 3, but coarser grained, except for the lack of vesicles; yellowish-brown smectite replacing interstitial glass?</td>
</tr>
<tr>
<td>5</td>
<td>319A</td>
<td>Medium grained; phenocrysts of zoned, anhedral plagioclase and rarer pseudomorphs after olivine; brown, interstitial smectite</td>
</tr>
<tr>
<td>6</td>
<td>319A</td>
<td>Medium grained, massive, with occasional large plagioclase phenocrystals; interstitial yellow-brown smectite extensive; equigranular groundmass of lathy plagioclase, anhedral pyroxene, and intergranular titanomagnete</td>
</tr>
<tr>
<td>7</td>
<td>319A</td>
<td>Very fine grained, occasional plagioclase phenocrystals, and greenish-yellow smectite pseudomorphing olivine; acicular groundmass plagioclase and pyroxene; no opaques</td>
</tr>
<tr>
<td>8</td>
<td>319A</td>
<td>Essentially similar to Sample No. 7</td>
</tr>
<tr>
<td>9</td>
<td>320B</td>
<td>Very fine grained; common phenocrysts of zoned plagioclase; no visible opaques; Common iron oxide staining</td>
</tr>
<tr>
<td>10</td>
<td>320B</td>
<td>Similar to Sample No. 9, except for a few irregular vesicles partly filled with yellow smectite</td>
</tr>
<tr>
<td>11</td>
<td>321</td>
<td>Fine grained, rare plagioclase phenocrysts and very rare microphenocrysts of pyroxene; equigranular groundmass and interstitial dark brown glass; occasional irregular veins of iron sulphide</td>
</tr>
<tr>
<td>12</td>
<td>321</td>
<td>Fine grained, abundant vesicles filled with calcite; otherwise similar to Sample No. 11</td>
</tr>
<tr>
<td>13,14</td>
<td>321</td>
<td>Fine grained, vesicles filled with calcite and brown smectite; abundant interstitial titanomagnetite and rarer ilmenite laths; intimately intergrown acicular plagioclase and pyroxene</td>
</tr>
</tbody>
</table>

**TABLE 3**

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Ti (%)</th>
<th>Zr (ppm)</th>
<th>Y (ppm)</th>
<th>Sr (ppm)</th>
<th>Rb (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hole 319</td>
<td>1</td>
<td>0.90</td>
<td>60</td>
<td>31</td>
<td>120</td>
</tr>
<tr>
<td>Hole 319A</td>
<td>2</td>
<td>0.85</td>
<td>60</td>
<td>29</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1.52</td>
<td>110</td>
<td>45</td>
<td>128</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.60</td>
<td>113</td>
<td>42</td>
<td>128</td>
</tr>
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<tr>
<td></td>
<td>6</td>
<td>1.40</td>
<td>112</td>
<td>40</td>
<td>136</td>
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<td></td>
<td>7</td>
<td>1.32</td>
<td>113</td>
<td>43</td>
<td>120</td>
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<td></td>
<td>8</td>
<td>1.32</td>
<td>115</td>
<td>40</td>
<td>112</td>
</tr>
<tr>
<td>Hole 320B</td>
<td>9</td>
<td>0.99</td>
<td>96</td>
<td>38</td>
<td>132</td>
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<tr>
<td></td>
<td>10</td>
<td>1.28</td>
<td>98</td>
<td>46</td>
<td>145</td>
</tr>
<tr>
<td>Site 321</td>
<td>11</td>
<td>1.90</td>
<td>150</td>
<td>53</td>
<td>100</td>
</tr>
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<td></td>
<td>12</td>
<td>1.64</td>
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<td></td>
<td>13</td>
<td>1.93</td>
<td>154</td>
<td>48</td>
<td>97</td>
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<tr>
<td></td>
<td>14</td>
<td>1.73</td>
<td>113</td>
<td>48</td>
<td>95</td>
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<td>W-1</td>
<td>95</td>
<td>24</td>
<td>194</td>
<td>24</td>
<td></td>
</tr>
</tbody>
</table>

aData collected by X-ray fluorescence techniques, as described by Pearce and Cann (1971).

Figure 2. Plot of alteration-resistant pair Ti-Zr. Fields are Hawaiian tholeiites (1), abyssal tholeiites (2), Japanese tholeiites (3), derived from Pearce and Cann (1971).

**PHASE CHEMISTRY**

Microprobe data have been collected for pyroxenes, oxides, and plagioclases in representative basalts from each hole. Except for some plagioclases, all minerals are essentially fine-grained, groundmass grains. Titano-
magnetite is ubiquitous, frequently associated with
minor ilmenite. Subsolidus oxidation is rare, reflecting
the overall freshness of these samples. Coexisting
ilmenite-titanomagnetite pairs in Hole 319A and Site
321 give temperatures of 1050°C and 1080°C, respectively
(Table 4) using the curves of Buddington and Lindsley
(1954). From the general aphyric textures, these values
are assumed to be close to liquidus temperatures upon
eruption.

Representative pyroxene analyses are shown in Table
5 and Figure 3. Pyroxene trends in individual crystals
are shown in Figure 4. Two trends are evident, one in-
volving iron enrichment at relatively constant calcium
content, and a second representing little iron enrich-
ment, but significant calcium depletion. The former
probably represents the closest approach to equilibrium
crystallization; the latter is a metastable, quench trend
reflecting rapid cooling and crystallization. Overall, the
concentrations of minor elements TiO₂ and Al₂O₃ are
high, compared, say, to Icelandic tholeiites (Car-
michael, 1967) or Hawaiian tholeiites. With iron enrich-
ment, TiO₂ and Al₂O₃ decrease and MnO and Na₂O in-
crease slightly. No correlation exists between bulk TiO₂
content and TiO₂ in pyroxenes, i.e., Site 321 pyroxenes
actually contain slightly lower Al₂O₃ and TiO₂ com-
pared to the other holes. Al₂O₃ contents, and conse-
quently Tiθ₂, in pyroxenes are controlled largely by
silica activity (assuming CaTiAl₂O₆ is the major mole-
cule; Carmichael et al., 1974). We might surmise that
silica activity may be slightly higher in 321 basalts (more
fractionated?) than the others, but all basalts
have silica activities lying between Icelandic tholeiites
and alkali basalts.

Data for plagioclases which point out that some
grains are strongly zoned, are shown in Figure 5. Enrichment in the orthoclase molecule is noticeable but
of minor significance, reflecting the overall low potash
contents of the bulk systems. Although more precise
data are required, it would appear that plagioclases in
Hole 319 have lower orthoclase contents than in other
samples. This may provide a good correlation with bulk
K content (Ridley et al., 1974) and be useful in recogniz-
ing either different degrees of alkalinity in fresh basalts
or secondary potash enrichment. Generally, increasing
orthoclase is accompanied by increasing iron enrich-
ment, although the trend is by no means well defined.
This trend also corresponds to an increasing divergence
from simple Si-Al stoichiometry, suggesting iron sub-
stitution as Fe₂O₃.

CONCLUSIONS

1. The chemical data suggest that at least two flows
have been penetrated in Hole 319A. The topmost flow
corresponds closely in trace element composition to
basement penetrated in Hole 319, hence we might sur-
mise both holes initially penetrated the same flow.
Deeper penetration in Hole 319A located a more alkalic
(or more fractionated) flow of several chemically similar
flow units.

2. Although Hole 320B and Site 321 are relatively
close together, the basement is chemically different. The
alkalic or more fractionated flow at Site 321 may repre-
sent off-ridge volcanism and be a thin sill injected along
the basalt-sediment interface. The higher TiO₂ content
compared to ridge tholeiites probably cannot be a con-
sequence of small amounts of fractional crystallization
from a ridge tholeiite parent magma. Site 321 magma
was probably slightly different from ridge tholeiites at
the source region either as a consequence of partial
melting differences or source composition differences.

3. Only samples from Hole 319, the topmost flow at
Hole 319A, and Hole 320B are typical ridge tholeiites.
Their origin is somewhat equivocal for Site 319 samples
since both the East Pacific Rise and the Galapagos Rise

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**TABLE 4**

Analyses of Ilmenite and Titanomagnetite

<table>
<thead>
<tr>
<th></th>
<th>Hole 319A</th>
<th></th>
<th>Site 321</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample 4</td>
<td>Sample 6</td>
<td>Sample 7</td>
<td>Sample 13</td>
</tr>
<tr>
<td></td>
<td>Ilmenite</td>
<td>Magnetite</td>
<td>Ilmenite</td>
<td>Magnetite</td>
</tr>
<tr>
<td>TiO₂</td>
<td>48.81</td>
<td>22.50</td>
<td>48.72</td>
<td>47.23</td>
</tr>
<tr>
<td></td>
<td>47.23</td>
<td>22.51</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>0.12</td>
<td>3.05</td>
<td>0.14</td>
<td>1.71</td>
</tr>
<tr>
<td></td>
<td>0.14</td>
<td>1.71</td>
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<tr>
<td>Cr₂O₃</td>
<td>0.03</td>
<td>0.05</td>
<td>0.02</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>0.02</td>
<td>0.05</td>
<td></td>
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<tr>
<td>FeO</td>
<td>44.34</td>
<td>69.13</td>
<td>46.03</td>
<td>46.54</td>
</tr>
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<td></td>
<td>46.03</td>
<td>46.54</td>
<td>68.80</td>
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<td>0.57</td>
<td>0.99</td>
<td>0.65</td>
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<tr>
<td></td>
<td>0.99</td>
<td>0.65</td>
<td>0.60</td>
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</tr>
<tr>
<td>MgO</td>
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<td>0.71</td>
<td>0.47</td>
<td>0.63</td>
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<td>0.47</td>
<td>0.63</td>
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<td>Fe₂O₃</td>
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<td>22.08</td>
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<td>5.96</td>
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<td>21.12</td>
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<tr>
<td>FeO</td>
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<td>50.40</td>
<td>42.84</td>
<td>41.47</td>
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<tr>
<td></td>
<td>42.84</td>
<td>41.47</td>
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<td>Total</td>
<td>95.99</td>
<td>99.36</td>
<td>99.18</td>
<td>97.07</td>
</tr>
<tr>
<td></td>
<td>99.18</td>
<td>97.07</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

% Ulv  | 67.1      | 6.0        | 7.8      | 68.0       |
|        |           |            |          | 9.2        |
| % Ilm  | 3.1       | 6.0        | 7.8      | 68.0       |
|        | 6.0       | 7.8        |          | 9.2        |
| T°C    | 1050      | 10-10.2    | 1080     | 10-10.0    |
|        | 1050      | 10-10.2    | 1080     | 10-10.0    |
| Fo₂    |           |            |          |            |
|        |           |            |          |            |

Note: Low totals reflect small grain size of opaque phases.
were actively spreading at this time (Herron, 1972). The more evolved nature of the majority of the basalt cored at Hole 319A suggests this may also be the product of off-ridge volcanism. The freshness of basalt cored at Hole 320B and Site 321 seems inconsistent with an age again we may be dealing with later, off-ridge volcanism which in the case of Hole 320B produced basalt similar to ridge tholeiite.

4. Magma erupted with few or no phenocrysts and cooled quickly. This resulted in some mineral zoning and preservation of metastable compositional trends. Eruption temperatures were above 1050°C and fO2 about 10^-10 bars.

ACKNOWLEDGMENTS

Ti data were obtained by M. Perfit. We are grateful to Stan Hart and the Deep Sea Drilling Project (NSF) for access to Leg 34 samples. This work was supported by National Science Foundation Grant GX 39231 (IDOE).

REFERENCES

Figure 3. Composition of all pyroxenes in terms of enstatite (EN)-diopside (DI)-hedenbergite (HD)-ferrosilite (FS).

Figure 4. Composition trends in individual pyroxenes. Inset trends are for Holes 319, 320B, and Site 321.


Figure 5. Compositional trends in plagioclases. (a) Anorthite (AN) and orthoclase (OR) variations. Lines indicate zoning trends in individual grains. (b) Anorthite and molecular iron variations.