Late Jurassic Oceanic Crust and Upper Cretaceous Caribbean Plateau Picritic Basalts Exposed in the Duarte Igneous Complex, Hispaniola

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ABSTRACT

Four distinct rock units have been recognized near El Aguacate, in the Janico-Juncalito-La Vega area of the Duarte complex [Dominican Republic]: [1] serpentinites crosscut by numerous diabasic dikes, [2] basalts interbedded with Late Jurassic ribbon cherts, [3] picrites and ankaramites relatively enriched in incompatible trace elements, and [4] amphibolites and gneissic amphibolites chemically similar to Oceanic Plateau Basalts. Similar Ar-Ar ages of late magmatic amphibole from a picrite, and hornblende from an amphibolite [86.1 ± 1.3 Ma and 86.7 ± 1.6 Ma, respectively], suggest that the Duarte picrites are contemporaneous with the Deep Sea Drilling Program Leg 15 and Ocean Drilling Program Leg 126 basalts drilled from the Caribbean oceanic plateau. These basalts are associated with sediments containing Late Cretaceous faunas. Sr, Nd, and Pb data show that enriched picrites and amphibolites are isotopically similar to mafic lavas from previously described Caribbean plateau and Galápagos hotspot basalts. Major element, trace element, and lead isotopic features of Late Jurassic basalts and diabases are consistent with those of normal oceanic crust basalt. However, these basalts differ from typical N-MORB because they have lower εNd ratios that plot within the range of Ocean Island Basalts. These rocks appear to represent remnants of the Caribbean Jurassic oceanic crust formed from an oceanic ridge possibly close to a hotspot. Later, they were tectonically juxtaposed with Late Cretaceous slices of the Caribbean-Colombian plateau.

Introduction

Oceanic plateaus represent some of the largest geological features on earth [Coffin and Eldholm 1994]. Their structure and composition are still poorly understood, however, because only their uppermost levels have been drilled during Deep Sea Drilling Program/Ocean Drilling Program [DSDP/ODP] investigations [Saunders et al. 1996]. In particular, the oceanic crust on which the oceanic plateaus rest has never been studied directly, and available ages are only estimated from magnetic anomaly data. It has been suggested that most of oceanic plateaus were emplaced over young oceanic crust and, consequently, formed as a result of near-ridge hotspot activity [Floyd 1989].

The Caribbean-Colombian Oceanic Plateau [CCOP] offers a unique opportunity to study the deep levels of an oceanic plateau and the associated oceanic crust. Magmatic units considered part of this 800,000-km² structure have been drilled from the Caribbean Sea [DSDP Leg 15, Donnelly et al. 1973; ODP Leg 126, Sigurdsson et al. 1997]. They consist of pillowed or massive basalt flows and shallow sills of basalt/diabase [Donnelly et al. 1973]

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with Late Cretaceous ages (Turonian-Campanian faunas, 93.5 ± 0.5 to 71.3 ± 0.5 Ma, according to Gradstein et al. 1994, whole-rock \(^{39}Ar/^{39}Ar\), 95.7 ± 6.2 to 85.9 ± 4.5 Ma, Sinton et al. 1998). In addition, parts of the CCOP have been obducted onto the margins of both South and North America and are now exposed in southern Haiti, Curaçao, and western Colombia, where they include the depleted komatites and enriched basalts from Gorgona (Arndt et al. 1996; Kerr et al. 1996, 1997). On the basis of new petrological and geochemical data, Lapierre et al. (1997) suggested that the enriched mafic tholeiites from the Duarte complex (Hispaniola) could be part of the CCOP.

The purpose of this article is (1) to report new ages on the picritic basalts and amphibolites of the Duarte complex that support the hypothesis of Lapierre et al. (1997) and (2) to show that the El Aguacate pillow basalts, stratigraphically interbedded with uppermost Jurassic ribbon cherts (Montgomery et al. 1994), represent remnants of the Caribbean oceanic crust, tectonically imbricated with slices of serpentinitized peridotites and their diabase dikes.

**Geological Data**

The Duarte complex consists of basaltic to ultramafic rocks metamorphosed to greenschist and amphibolite facies, intruded by subduction-related Late Cretaceous to Late Eocene plutons [Kesler et al. 1991]. Bowin (1975) and Palmer (1979) proposed that this complex could represent a fragment of oceanic crust, while Draper and Lewis (1991), Lewis and Jiménez (1991), and Donnelly et al. (1990) considered it to be an ocean island or seamount.

The age of the Duarte complex remains poorly constrained. On the basis of K/Ar data from an undeformed hornblende dike within a foliated tonalite [west of Piedra Blanca; fig. 1], the Duarte complex is assumed to be Early Cretaceous in age [127 ± 5 Ma; Bowin 1966]. A Late Jurassic age has also been proposed for the Duarte complex because of the presence of tectonic slices of ribbon cherts exposed near the village of Aguacate [fig. 1a]. These cherts yield Upper Jurassic radiolarians [Montgomery et al. 1994]. Ages of undeformed hornblende tonalites that intrude the Early complex range between 92 and 56 Ma [Draper and Lewis 1991]. Older ages, of 123–148 Ma, have been reported from gabbroic rocks belonging to the Loma de Cabrera batholith [near the Haiti-Dominican Republic frontier; Cribb et al. 1989; Draper and Lewis 1991], which intrudes the Duarte complex. However, the older ages are questionable because of the inherent uncertainties of argon loss and argon excess with the K/Ar method.

New field data allow us to distinguish four units in the Juncalito–Janico–La Vega area [fig. 1]: (1) serpentinitized peridotites crosscut by diabasic dikes; (2) basaltic flows stratigraphically interbedded with Upper Jurassic ribbon cherts [Montgomery et al. 1994]; (3) a thick pile [≈1500 m] of picritic and ankaramitic basaltic flows [Lapierre et al. 1997]; and, finally, (4) mafic amphibolites and amphibole-epidote gneisses tectonically overlain or underlain by the picrites/ankaramites. The contacts between these four units are faulted.

Near El Aguacate village, the Upper Jurassic basalts and sediments are thrust on the serpentinitized peridotites. The latter contain large orthopyroxenes that show kink band deformations. This suggests that the serpentinitized peridotites could represent remnants of depleted upper mantle. Pillow basalts display quenched textures, whereas massive basalts and diabases show interstitial to ophitic textures. Basalts and diabases are almost devoid of secondary minerals. Glass is partly recrystallized in smectites. Plagioclase is sometimes replaced by albite.

Picritic and ankaramitic basalts are generally strongly deformed, especially along the recent NW–SE transcurrent faults that cut out the Central Belt. This deformation develops irregular cleavages, marked by the elongation of clinopyroxene phenocrysts replaced by smectites or actinolite, and mesoscopic phacoidal fabrics in a lower greenschist facies [Draper and Lewis 1991].

However, between these high-strain corridors, picrites and ankaramites are devoid of any deformation. Igneous textures of the rocks are preserved, and local stratigraphic succession may be observed. These rocks form massive flows, <2 m thick, interbedded with lapilli and crystal tuffs. At their base, the flows show accumulation of olivine and/or clinopyroxene crystals [picrite or ankaramite], while the tops of the flows are highly vesicular. The rocks are weakly altered and contain fresh clinopyroxene, plagioclase, and amphibole, while olivine is systematically altered in serpentine and/or chlorite.

Amphibolites and gneissic amphibolites are composed of green hornblende ± Ca-rich plagioclase, epidote, and sphene. Preliminary geochemical data indicate that these metamorphic rocks also display enriched tholeitic affinities with flat chondritenormalized REE patterns very similar to those of unmetamorphosed Upper Cretaceous basalts from Curaçao and Haiti [fig. 5b; Dupuis et al. 1997].

At the southeastern extremity of the Central
Cordillera, the amphibolites of the Duarte complex are tectonically overlain by the unmetamorphosed pillow basalts from the Siete Cabezas Formation (fig. 1). The pillow basalts of the Siete Cabezas Formation are interbedded with cherts that yield Cenomanian to Santonian radiolarians (99–83 Ma; de Wever in Mercier de Lépinay 1987; Donnelly et al. 1990). According to Sinton et al. (1998), though, the age of the Siete Cabezas Formation is slightly younger, i.e., Campanian to Maastrichtian (69.0 ± 0.7 and 68.5 ± 0.5 Ma; Sinton et al. 1998). The basalts of Siete Cabezas Formation show features of oceanic plateau basalts with flat chondrite-normalized REE patterns similar to those of the amphibolites [see fig. 5b, V. Dupuis, unpub. data].

Figure 1. Geologic map of the Janico–Juncalito–LaVega area showing the four types of igneous/metamorphic units defined in the Duarte complex. Inset at lower right, SSW-NNE cross section of El Aguacate area showing the tectonic relationships between the Jurassic basalts and associated ribbon cherts and the serpentinized peridotite slices.

Petrology and Geochemistry of the Cumulitic Picrite

A cumulitic picrite [96VD126; table 1] has been sampled along the Duarte Autopista, north of Santo Domingo [18°36′04″N, 70°08′03″W]. This rock forms, in association with other olivine and/or clinopyroxene cumulitic facies, a plug intercalated with massive Mg-rich flows and crystal tuffs. It is composed of olivine pseudomorphs, clinopyroxene rimmed by pleochroic brown magnesio-hastingsite (fig. 2), and late-crystallizing interstitial plagioclase.

Preserved clinopyroxene has a diopsidic core [Wo45-46; En40-45; Fs8-14] rimmed successively by au-
<table>
<thead>
<tr>
<th>Sample</th>
<th>Location</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Texture</th>
<th>Mineralogy</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>96VD126</td>
<td>Villa Altagracia, Autopista, Santo Domingo</td>
<td>18°36'04&quot;N</td>
<td>70°08'03&quot;W</td>
<td>Cumulus-enriched</td>
<td>Olivine pseudomorphs, cpx, large phenocrysts rimmed by Mg-rich Hastingite, skeletal cpx crystals, interstitial glass presently recrystallized in smectites</td>
<td>Picrite</td>
</tr>
<tr>
<td>96VD48</td>
<td>Piedra Blanca</td>
<td>18°51'14&quot;N</td>
<td>70°20'04&quot;W</td>
<td>Foliated</td>
<td>Tschermakitic hornblende oligoclase</td>
<td>Gneissic amphibolite</td>
</tr>
<tr>
<td>96VD33</td>
<td>Jarabacoa–La Vega, intrusive in serpentinites</td>
<td>19°12'55&quot;N</td>
<td>70°35'12&quot;W</td>
<td>Ophitic</td>
<td>Anhedral cpx rimmed with pale green or brown hornblende, euhedral Ca-rich plagioclase, late-crystallizing Fe-Ti oxides</td>
<td>Diabase</td>
</tr>
<tr>
<td>96VD35</td>
<td>Jarabacoa–La Vega, intrusive in serpentinites</td>
<td>19°12'55&quot;N</td>
<td>70°35'12&quot;W</td>
<td>Ophitic</td>
<td>Anhedral cpx rimmed with pale green or brown hornblende, euhedral Ca-rich plagioclase, late-crystallizing Fe-Ti oxides</td>
<td>Diabase</td>
</tr>
<tr>
<td>96VD39</td>
<td>Jarabacoa–La Vega, intrusive in serpentinites</td>
<td>19°13'05&quot;N</td>
<td>70°35'08&quot;W</td>
<td>Ophitic</td>
<td>Anhedral cpx rimmed with pale green or brown hornblende, euhedral Ca-rich plagioclase, late-crystallizing Fe-Ti oxides</td>
<td>Diabase</td>
</tr>
<tr>
<td>97VD14</td>
<td>El Aguacate; intrusive in serpentinites</td>
<td>19°13'53&quot;N</td>
<td>70°40'43&quot;W</td>
<td>Ophitic</td>
<td>Anhedral cpx rimmed with pale green or brown hornblende, euhedral plagioclase replaced by albite, late-crystallizing Fe-Ti oxides partly altered in titanite</td>
<td>Diabase</td>
</tr>
<tr>
<td>97VD07</td>
<td>El Aguacate; pillow basalt associated with Upper Jurassic cherts</td>
<td>19°14'08&quot;N</td>
<td>70°41'24&quot;W</td>
<td>Phryic and quenched</td>
<td>Olivine phenocrysts replaced by smectites, quenched cpx, abundant glassy groundmass recrystallized in smectites</td>
<td>Basalt</td>
</tr>
<tr>
<td>97VD08C</td>
<td>El Aguacate; pillow basalt associated with Upper Jurassic cherts</td>
<td>19°14'05&quot;N</td>
<td>70°41'17&quot;W</td>
<td>Intersertal</td>
<td>Plagioclase laths, anhedral cpx, glassy pods crystallized in smectites</td>
<td>Basalt</td>
</tr>
<tr>
<td>97VD09</td>
<td>El Aguacate; pillow basalt associated with Upper Jurassic cherts</td>
<td>19°13'53&quot;N</td>
<td>70°41'01&quot;W</td>
<td>Intersertal</td>
<td>Plagioclase laths, anhedral cpx, glassy pods crystallized in smectites</td>
<td>Basalt</td>
</tr>
<tr>
<td>97VD15</td>
<td>El Aguacate; massive flow associated with Upper Jurassic cherts</td>
<td>19°13'53&quot;N</td>
<td>70°40'51&quot;W</td>
<td>Aphyric</td>
<td>Microphenocrystals and microlites of cpx, interstitial groundmass with tiny quenched plagioclase needles</td>
<td>Basalt</td>
</tr>
</tbody>
</table>
Figure 2. Microphotos of thin sections of the cumulitic picrite 96VD126 showing the clinopyroxene rimmed by the late magmatic magnesio-hastingsite.
gite (Wo$_{40-45}$ En$_{45-51}$ Fs$_{12-12}$) and Fe-rich augite (Wo$_{39-42}$ En$_{38-45}$ Fs$_{14-23}$). Locally, this clinopyroxene
is rimmed by magnesio-hastingsite (fig. 3a).

Sample 96VD126 is light REE [LREE] enriched ([La/Yb]$_{n}$ = 4.31; table 2; fig. 3b) relative to heavy
REE [HREE] with low REE contents (around 10 times chondritic values), similar to the other
Duarte picrites and anakramites [Lewis and Jiménez 1991; Lapierre et al. 1997]. Clinopyroxene
[cpp] separates have moderate LREE depletion ([La/Yb]$_{n}$ = 0.62), while the igneous amphibole
[amph] separates have rather flat REE patterns ([La/Yb]$_{n}$ = 1.48). The LREE enrichment of
the whole rock with respect to cpp and amph is consistent with the preferential partitioning of REE
into the melt. The host rock is more HREE depleted than cpp within it (fig. 3b). Cpx and amph separates,
and their host rock, have similar [87Sr/86Sr] ratios (0.70315 < [87Sr/86Sr] < 0.70320). Moreover, the cpp and
its host rock exhibit similar eNd ratios (+8.34 and 8.53, respectively), while that of the amphibole
is slightly lower (eNd = 7.7; Lapierre et al. 1999) (fig. 3c).

On the basis of the major element, trace element,
and isotopic compositions of the clinopyroxene,
amphibole, and host rock, we assume that [1] no metamorphic process has affected the Nd and Sr
isotopic compositions of 96VD126 clinopyroxene,
magnesio-hastingsite, and host rock, and [2] the magnesio-hastingsite developed during a late magmatic
cooling stage of the host picrite.

$^{40}$Ar/$^{39}$Ar Data

One cumulitic picrite 96VD126; table 1) and one
amphibolite (96VD48; table 1) from the southern
part of the Duarte complex have been dated using the
$^{40}$Ar/$^{39}$Ar laser probe technique of Monié et
al. [1997]. Step-heating experiments were performed either on a single amphibole grain
(96VD48, 500 µm) or on a group of small amphiboles (96VD126, 20–50 µm) using a very defocused laser beam to ensure simultaneous degassing of all grains. The data are portrayed as age spectra and isochron plots in figure 4. Ca/K and
Cl/K ratios have been estimated according to the relations: Ca/K = 1.83±0.08 × $^{40}$Ar/$^{39}$Ar, Cl/K =
0.22±0.04 × $^{38}$Ar/$^{39}$Ar [Onstott et al. 1991].

Late magmatic amphibole 96VD126 has a flat age spectrum for a large percentage of argon released,
with a corresponding plateau date of 85.4 ± 1.7 Ma
(fig. 4). The isochron diagram yields an intercept age of 86.1 ± 1.3 Ma with an initial $^{40}$Ar/$^{39}$Ar ratio
close to the present-day atmospheric ratio. The
Ca/K ratio is relatively constant for the main por-
tion of the spectrum (~33), with variable ratios ob-
served in the lower temperature steps, and a higher
Ca/K ratio in the last experiment. Cl/K ratios range
from 0.03 to 0.06 for the main portion of the spectrum.
Calcic hornblende from amphibolite sample
96VD48 (table 1) gives an irregular age spectrum
with an integrated total fusion age of 86.4 ± 2.0 Ma
(fig. 4b). Approximately 65% of the gas released at
high experimental temperatures yielded a plateau
date of 88.6 ± 2.4 Ma, which corresponds to con-
stant Ca/K (~73) and Cl/K (~0.03) ratios, and an
isochron age of 86.7 ± 1.6 Ma. Compared to the
plateau date, the age spectrum displays evidence of
excess argon, then argon loss at a low experimental
temperature, coupled with lower Ca/K and Cl/K
ratios. These features are thought to reflect the thermal influence of the granites (fig. 1a) that intruded
the Duarte complex during Late Cretaceous–Paleogene
time.

Since no assumption was made on the composi-
tion of initial argon, the ages derived from the
isochron plots are considered to represent the best
age estimates for closure of both amphiboles. Late magmatic and metamorphic amphiboles yield sta-

tistically similar ages of 86.1 ± 1.3 and 86.7 ± 1.6
Ma, recording cooling of picrites and amphibolites at
about 500°C. These dates have several possible
interpretations. It could be assumed that the 86–87
Ma age records only the thermal effects of granite intrusions in the Duarte complex; however, it was
demonstrated geochemically that the granite intru-
sion did not affect the 96VD126 cumulitic picrite.
Alternatively, these dates suggest that the amphibolites and picrites cooled down simultaneously during
emplacement of the Caribbean oceanic plateau over the Late Jurassic oceanic crust. This conclu-
sion conflicts with the previously proposed Late Jurassic age for the Duarte complex based on question-
able radiometric and stratigraphic age constraints.

Geochemical Results

The major element chemistry of basalts from El
Aguaicate and diabase dikes crosscutting serpentines
from La Vega and El Aguaicate does not depart
significantly from that of fresh MORB (table 2). Loss on ignition ranges from 1.8 to 4 wt %, and
K₂O content remains very low. According to their
MgO, Ni, and Cr contents, these rocks are mostly
evolved MORBs; the only exception is sample
97VD09, which is relatively Mg-rich (9.8 wt %; table 2). Relative to enriched oceanic plateau thol-
ite, these basalts are depleted in the most in-
compatible trace elements. Despite obvious alteration effects, most of their Rb, Nb, Ta, Th, and U concentrations do not exceed those of N-MORB and are much lower than those of the Duarte enriched picrites [Lapierre et al. 1997]. Corresponding REE data have been plotted in figure 5a. All the samples are LREE depleted, a characteristic typical of N-MORB but also found in some oceanic plateau basalts [Arndt et al. 1996]. Again, their patterns contrast with those of Duarte picrites and ankaramites, which are consistently LREE enriched [Lapierre et al. 1997]. The basalts display either slight positive or negative Eu anomalies, indicative of minor plagioclase accumulation or removal. Some basalts are more depleted than the dikes, suggesting that either they formed as a result of higher degrees of partial melting or are derived from a more residual source than the dikes.

Initial Sr, Nd, and Pb isotopic ratios of the picrites and ankaramites of the Duarte complex have been calculated with a model age of 86 Ma. Isotopic data of diabases and basalts have been corrected for in situ decay with an age of 150 Ma on the basis of the radiolarian faunas in the ribbon cherts (table 2).

The $\varepsilon$Nd and $\varepsilon$Sr values of the diabase dikes, from Jarabacoa-La Vega and El Aguacate, range from +7.0 to +9.3 and from −18.7 to −9.8, respectively. An $\varepsilon$Nd-$\varepsilon$Sr correlation diagram [fig. 6a] shows that the initial isotopic composition of these diabases plots within or close to the field of depleted mantle, suggesting an N-MORB affinity for these rocks. The
diabase Pb/Pb isotopic ratios define a limited domain located on or close to the EPR-MORB and MAR-MORB fields, except sample 96VD35, which displays particularly depleted signatures (fig. 6b, c).

These rocks are characterized by low \(^{206}\text{Pb}/^{204}\text{Pb}\) and \(^{207}\text{Pb}/^{204}\text{Pb}\) ratios that suggest derivation from a relatively primary source similar to the Depleted MORB Mantle (DMM) reservoir. Compared to di-
abase dikes, the Upper Jurassic pillow basalts from El Aguacate display lower εNd ranging from +6.8 to +7.7 and significantly higher εSr evolving from −9.6 to −10.2, likely linked to oceanic hydrothermal alteration processes. In the Nd-Sr diagram (fig. 6a), these basalts plot within a restricted field, distinct from the diabase dikes domain and located within or close to the Ocean Island Basalts (OIB) field. This suggests that the El Aguacate basalts were derived from a significantly enriched source, similar to that of the 86-Ma picrites and ankaramites of the Duarte complex (Lapierre et al. 1997), and reflects the contribution of an HIMU-like enriched component. Nevertheless, on the Pb/Pb diagrams, the Pb/Pb initial isotopic ratios of the Upper Jurassic basalts (fig. 6b, c) plot close to those of the diabases (fig. 6b, c) and away from the 86-Ma picrites and ankaramites field. No indication of a noticeable contribution of an enriched component has been detected in the Upper Jurassic basalts on the basis of Pb isotopic data.

**Discussion**

The chemical features, based on the trace element and Nd, Sr, and Pb isotopic compositions of the Duarte picrites/ankaramites and amphibolites, are indicative of their affinity with the previously described oceanic plateau occurrences in the CCOP, e.g., the Leg 15 and Leg 126 basalts; the Curaçao, Haiti, Gorgona, and Colombia basalts (Kerr et al. 1997); and the recent Galápagos hotspot basalt (fig. 6). The newly determined ca. 87–86 Ma ages for the picrites and amphibolites are also consistent with the Turonian-Campanian (93–71 Ma) biostratigraphic ages of Leg 15, Leg 126, and Aruba basalts, as well as with other recent Ar-Ar dates grouping around 90–87 Ma for basalts from Isla Gorgona,
Figure 5. Chondrite-normalized [Sun and McDonough 1989] REE patterns of the Jurassic basalts and diabase dikes from El Aguacate. The fields of the picrite/ankaramite [Lapierre et al. 1997] and diabase dikes [a] of the Jarabacoa-La Vega area and the basalts of the Siete Cabezas and the amphibolites of the Duarte complex [b] [Dupuis et al. 1997; V. Dupuis, unpub. data] are shown for comparison.


The isotopic data, especially the $^{143}$Nd/$^{144}$Nd and $^{207}$Pb/$^{206}$Pb, $^{208}$Pb/$^{206}$Pb, and $^{208}$Pb/$^{204}$Pb initial ratios of the picrites/ankaramites and amphibolites of the Duarte complex are similar to those of the Gorgona, Curacao, and Nicoya peninsula basalts, the LREE-enriched Dumisseau Formation basalts, and some of the young Galapagos lavas. This indicates that all these rocks were likely to have been derived from an enriched plume-like source, similar to that of the Galapagos plume.

These results allow us to constrain the geodynamic models proposed by Draper and Lewis [1991] and Draper et al. [1996] for the tectonic evolution of Hispaniola during the Cretaceous. On the basis of structural data in the Central Cordillera [Draper et al. 1996] and the presence of local unconformities and conglomerates in the Cretaceous volcanic pile from the Eastern Cordillera, Draper and Lewis [1991] and Draper et al. [1996] suggested that a collision occurred at the end of the Early Cretaceous [pre-Hatillo limestone; i.e., Albian times, $\sim$100 Ma]. This collision occurred between the Duarte complex and the Early Cretaceous arc [Amina-Maimon schists, tholeiitic and calc-alkaline lavas, and arc-sediments of the Los Ranchos Formation; primitive island arc [PIA] of Donnelly and Rogers 1978, 1980; Donnelly et al. 1990; Lapierre et al. 1997]. According to this model, the collision initiated a change in the subduction polarity that provoked the end of the south-facing Early Cretaceous arc growth. The subduction vergence changed from northeast to southwest, leading to the development of the Late Cretaceous arc.

Taking into account that the Duarte complex was likely formed during the early Late Cretaceous, we suggest that the collision between the Duarte complex and the Early Cretaceous arc took place after the Albian times, possibly around 86 Ma, the age of the amphibolite facies metamorphism. The latter likely developed while the uppermost levels of the oceanic plateau [the mafic amphibolites] began to subduct. Soon after, when the deepest levels of the oceanic plateau reached the trench [as they...
Figure 6.  

a, εNd versus εSr diagram for the Upper Jurassic diabases and basalts from Janico-Juncalito-LaVega area. Plots of Upper Cretaceous picrites/ankaramites and amphibolites of the Duarte complex are given for comparison. OIB and N-MORB fields are from DePaolo [1988]. b, $^{206}\text{Pb}/^{204}\text{Pb} - {\text{Pb}}/^{206}\text{Pb}$) correlation diagram for the Upper Jurassic diabases and basalts (this article) and Upper Cretaceous picrites/ankaramites of the Duarte complex (Lapierre et al. 1999). c, $^{207}\text{Pb}/^{204}\text{Pb} - {\text{Pb}}/^{206}\text{Pb}$) correlation diagram for Upper Jurassic diabases and basalts and Upper Cretaceous picrites/ankaramites of the Duarte complex. The Galápagos lavas field and MAR and EPR-MORB domains are reported from White [1993] and White et al. [1987, 1993]. The Northern Hemisphere Reference Line (NHRL) and various reservoirs [DMM, EM1, EM2, HIMU] are shown after Zindler and Hart [1986].
Figure 7. Map of the Caribbean oceanic floor showing the thickness variations of the Caribbean oceanic crust. The Upper Jurassic basalts and diabases could represent the remnants of the Caribbean oceanic crust whose thickness does not exceed 10 km. Data are after Houtz and Ludwig [1977], Diebold et al. [1981], Case et al. [1990], and Mauffret and Leroy [1997].

were more or less unsubductable, they blocked the subduction process; this blockage finally led to the collision of the oceanic plateau (i.e., the Duarte complex), with the Early Cretaceous arc mentioned in Draper et al. [1996].

There remains, however, the problem of the age of the Tireo arc rocks and the structural and/or geodynamic relations of these arc rocks to the Albian collisional event. The 81.4 ± 0.8 Ma 40Ar/39Ar age of a dacite [Lewis and Jiménez 1991] of the Tireo Group fits with such a model. But, according to paleontological ages, the age of the Tireo Group ranges from Cenomanian to Turonian [93–89 Ma]; thus the Tireo arc rocks are slightly older or contemporaneous with the 90–86-Ma oceanic plateau picrites and basalts. This suggests that either the oceanic plateau collided with the oldest segments (Early Cretaceous) of the arc while the youngest (Late Cretaceous) were still developing or that the arc polarity reversal occurred at the end of the Late Cretaceous arc growth, sometime during the Late Cretaceous or Early Eocene.

The structural layout of the Duarte complex, which consists of imbricated tectonic slices of picrites/ankaramites, amphibolites, serpentinites, and Upper Jurassic basalts, could have been formed during this collisional process. During the collision, parts of thickened oceanic-plateau-like crust or unthickened normal oceanic crust were thrust on the Lower Cretaceous arc rocks, uplifted, and exhumed.

Thus, the juxtaposition of tectonic slices of the CCOP with slices of Upper Jurassic N-MORB basalts and of serpentinites containing N-MORB dikes strongly suggests that the latter could represent fragments of oceanic crust originating from the Caribbean domain. Although the Caribbean ocean crust has never been studied in situ, there are several lines of evidence that suggest it could be at least partly Jurassic. Indeed, Jurassic ophiol-
ites have been dated from radiolarian faunas in cherts exposed in Puerto Rico and La Désirade [Montgomery et al. 1992]. Remnants of Upper Jurassic oceanic crust have been described in Costa Rica, where N-MORB type basalts [Meschede et al. 1988; Meschede and Frisch 1994] are associated with Late Jurassic radiolarian cherts [Gursky 1994]. Moreover, these radiolarians likely derived from the subducting Farallon plate [Mattsson and Pes- sagno 1979; Montgomery et al. 1994].

Seismic refraction data [Maffret and Leroy 1997] indicate that the present-day Caribbean plate crust is not uniformly thick. The thickness of the crust of the southern Venezuelan and Colombian basins and the basin south of Haiti is not greater than that of normal oceanic crust (<10 km), whereas elsewhere this thickness may reach 20 km [Fig. 7]. The top of the igneous basement of the thickened crust is defined seismically by a smooth reflector horizon [termed B'; Duncan and Hargraves 1984], while in the areas of normal thickness [i.e., Venezuelan and Colombian basins and basin south of Haiti], B' reflector is topographically rougher [similar to oceanic crust] and is found at greater depths than the smooth B' basement [Ludwig et al. 1975; Diebold et al. 1981; Bowland and Rosencrantz 1988]. Rough B' has been interpreted to be that of normal, older oceanic crust that locally, where the crust thickness reaches 20 km, was overlain by younger oceanic plateau flows and sills [smooth B' basement]. The Upper Jurassic basalts from Aguacate could represent accreted remnants of this Caribbean "normal oceanic crust" [rough B' basement] before they were tectonically juxtaposed with the picrites-anakaramites and amphibolites of the Duarte complex during the oceanic plateau Early Cretaceous arc collision. Indeed, these basalts do not show any high-grade metamorphism. If they represent the remnants from the overthickened Caribbean oceanic crust, over and through which the CCOP magmas were emplaced, these basalts would have experienced amphibolite and/or high-grade greenschist facies due to the overload and/or intrusion of hot plume–generated magmas.

The εNd ratios of the Upper Jurassic N-MORB type basalts from El Aguacate are lower than those of N-MORB and plot within the range of OIB. This feature suggests that an OIB component has been involved in the genesis of these Upper Jurassic basalts. The most likely explanation is that these basalts originated from an oceanic ridge located near a hotspot. Indeed, it is currently suggested that most of the oceanic plateaus were formed as a result of near-ridge hotspot activity [Floyd 1989], which supports the case for the El Aguacate Upper Jurassic basalts.

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