Geochemistry of the Mabujina Complex, Central Cuba: Implications on the Cuban Cretaceous Arc Rocks

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ABSTRACT

The margins of the Caribbean plate are marked by Cretaceous island-arc basalts associated with accreted fragments of the Cretaceous Colombian Caribbean oceanic plateau. In Cuba, the Cretaceous volcanic island-arc rocks are in fault contact with the Mabujina complex, interpreted as an oceanic Jurassic to Early Cretaceous arc basement with local island-arc rocks. The Cuban Cretaceous island arc consists of Early to Late Cretaceous volcanic series associated with limestones. While the pre-Albian arc rocks consist of tholeiitic basalts and rhyolites, the post-Albian volcanic series is characterized by calc-alkaline andesites. The Cretaceous lavas have Sr and Nd isotopic compositions similar to the intraoceanic arcs, and the Pb isotopic initial ratios are close to the East Pacific Rise mid-ocean ridge basalt field. According to our data, the Mabujina arc rocks are tholeiites and calc-alkaline basalts, developed in a Jurassic and/or Early Cretaceous intraoceanic island arc. Their Nd, Sr, and Pb isotopic compositions indicate that they derive from a depleted mantle source contaminated by sediments. This subduction magmatism is not related to the classic Early Cretaceous Caribbean tholeiitic series but is similar to the Late Jurassic to Early Cretaceous Guerrero arc terrane from Mexico and may represent its southernmost extension. Thus, the different tectonic units of central Cuba cannot be easily correlated with those of Hispaniola. Our data also indicate that two different island arcs were tectonically juxtaposed in central Cuba: the classical Lower and Upper Cretaceous suites of the Greater Antilles arc and a Jurassic to Early Cretaceous island-arc suite with a Pacific provenance.

Introduction

The northern and eastern margins of the Caribbean plate are marked by the presence of numerous occurences of subduction-related lavas that belong to the Lesser and Greater Antillean arcs. The Eocene to Recent Lesser Antillean arc stretches from the continental margin of South America (eastern Venezuela) up to the Anegada Passage, on the eastern margin of the Caribbean plate. The Cretaceous to early Eocene Greater Antillean arc is discontinuous from Jamaica (the Greater Antilles) to northern South America and forms locally the basement of the Lesser Antilles arc rocks. The Greater Antillean arc consists of Early to Late Cretaceous volcanic suites associated with intercalated limestones. The pre-Albian rocks consist mainly of basalt and rhyolite that form the Primitive Island-Arc suite (PIA of Donnelly and Rogers 1980; Donnelly et al. 1990; Lebrón and Perfit 1993), whereas that of post-Albian age consist predominantly of calc-alkaline andesites that are locally associated with shoshonitic suites (Donnelly et al. 1990).

Recently, geochemical investigations have discovered that Late Cretaceous oceanic crustal sequences, exposed in Costa Rica (fig. 1*A*; Girard et al. 1982; Frisch et al. 1992; Sinton et al. 1997, 1998), in western Colombia including Gorgona island (fig. 1*A*; Aitken and Echeverria 1984; Millward et al. 1984; Nivia 1996; Arndt et al. 1997; Kerr et al.

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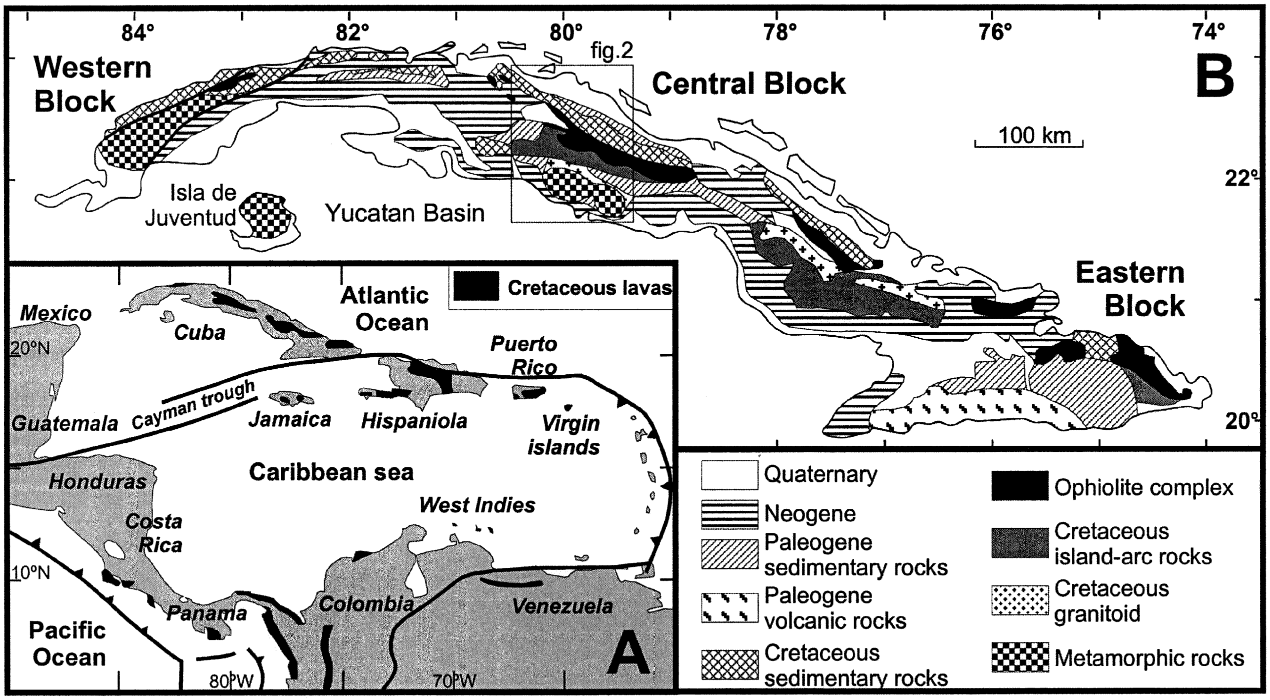

Figure 1. *A*, Synthetic map of the Central America and Caribbean sea; in black Cretaceous lavas (after Donnelly et al. 1990). *B*, Simplified geological map of Cuba showing the main lithological units exposed in the text (after Iturralde-Vinent 1994).

1996*a*, 1996*b*, 1997*a*, 1997*b*), in Venezuela (fig. 1*A*; Kerr et al. 1997*a*), in Dutch Antilles (fig. 1*A*; Beets et al. 1984; Kerr et al. 1997*a*), and in Hispaniola (fig. 1*A*; Dumisseau Formation, Sen et al. 1988; Duarte Unit, Kerr et al. 1997*a*; Lapierre et al. 1997, 2000) displayed oceanic plateau affinities, some of which belong to the so-called Caribbean–Colombian Oceanic plateau. Locally, in Hispaniola, or in the Dutch Antilles (Aruba, Curaçao, and Bonaire), the Early and Late Cretaceous arc suites of the Greater Antilles are in close spatial association with the Caribbean–Colombian Oceanic plateau. However, the nature of the relationship between the arc rocks and the accreted fragments of the Caribbean–Colombian oceanic plateau still remains unclear. In Hispaniola, Mann et al. (1991) and Draper and Lewis (1991) proposed that the Late Cretaceous arc volcanic rocks of the Tireo Group were built on the Duarte complex, considered Late Jurassic to Early Cretaceous in age. In contrast, Pindell and Barrett (1990) and Lapierre et al. (2000) suggested that the Early Cretaceous arc collided with the buoyant Caribbean–Colombian oceanic plateau. Lebrón and Perfit (1993) suggested that the transition from Early to Late Cretaceous island-arc volcanism was caused by the partial subduction of the Caribbean–Colombian plateau choking the subduction zone.

In the island of Cuba, the presence of remnants of the Caribbean–Colombian oceanic plateau has not been documented. The geology of Cuba is represented by post-Jurassic accreted terranes of both continental and oceanic material (Iturralde-Vinent 1994). Early and Late Cretaceous volcanic and plutonic rocks have tholeiitic to calc-alkaline affinities corresponding to an island-arc setting (Iturralde-Vinent 1994; Kerr et al. 1999). The basement of the Cretaceous arc, the Mabujina complex, is composed of the Mabujina amphibolites that have an oceanic affinity, and the Porvenir formation (Somin and Millán 1981; Millán 1996; Iturralde-Vinent 1989, 1994). Kerr et al. (1999) suggested that the Mabujina amphibolites are probably PIA rocks. According to a palynological study (Dublan et al. 1988), the possible age of the Mabujina protolith is Jurassic to Early Cretaceous.

In 1998, in the Mabujina formation, we collected petrographic facies that are interpreted as PIA rocks. In this article, we present new data on the major, trace element chemistry and Nd, Sr, and Pb isotope compositions of the Jurassic to Early Cretaceous Mabujina rocks from central Cuba. These data will allow us to better constrain the nature of the Mabujina unit, the geodynamic setting of the Cuban Cretaceous igneous rocks, and the Greater Antilles during the Cretaceous.

Geological Setting

Meyerhoff and Hatten (1968) divided Cuba into three major blocks: the western block, characterized by Jurassic sediments correlated with Jurassic continental beds in Central America and Jurassic sediments in the Gulf of Mexico; the central block, characterized by Cretaceous island-arc rocks; and the eastern block, which may represent an uplifted part of the Cayman Rise (Perfit and Heezen 1978) (fig. 1*B*). In Central Cuba, the geology consists of a series of accreted terranes of continental and oceanic affinity that strike parallel to the axis of the island (Iturralde-Vinent 1994): the Jurassic to Eocene sedimentary rocks, the ophiolite complex, the Cretaceous island-arc rocks, and the metamorphic rocks.

Along the northern half of the island of Cuba, the Jurassic to Eocene sedimentary rocks are folded and appear in a set of northward thrust units called the Northern Cuban fold belt. To the south, these rocks are in thrust contact with the ophiolite complex and the Cretaceous island arc and are deposited on a Jurassic–Cretaceous passive margin and a Paleocene to Eocene foreland basin (fig. 2). In general, the northernmost units are typical of the Bahama, whereas those to the south represent the continental slope and the old Carribean sections. Detailed descriptions of these sections were given in Khudolev (1967), Meyerhoff and Hatten (1974), Pardo (1975), and Iturralde-Vinent (1994).

The Ophiolite complex (fig. 2; Iturralde-Vinent 1994) is an allochthonous belt composed of ultramafic to mafic igneous rocks associated with marine sedimentary rocks. These mafic igneous and sedimentary sections have been interpreted as being formed within a marginal back-arc environment (Iturralde-Vinent 1989, 1994, 1996*a*) or within a supra-subduction fore-arc setting (Andó et al. 1996). The ophiolite complex has been thrusted north on the foreland basins of the Northern Cuban fold belt and tectonically juxtaposed by a sinistral strike-slip fault to the south against a thick sequence of Cretaceous volcanic-arc and sedimentary rocks.

The Cretaceous island arc is in tectonic contact with the ophiolite complex, the Mabujina complex, and the Escambray massif (fig. 2). Iturralde-Vinent (1994) has divided the Cretaceous island arc into three formations: Los Pasos, Matagua, and Provincial. The Los Pasos Formation is pre-Albian and is made up of basalts and rhyolites, of which one sample was collected (CU49; fig. 2). The Albian to Cenomanian Matagua Formation, composed of basalts and andesites and intercalated with reefal limestones, overlay the Los Pasos formation. Finally, the Santonian to Campanian Provincial formation consists of andesites and rhyodacitic ignimbrite flows with isolated beds of conglomerates. An erosional unconformity separates the Los Pasos and Matagua formations from the overlying Provincial formation. One sample of andesite was collected in the Provincial formation (CU50; fig. 2).

To the south, the Cretaceous island arc is in tectonic contact with the Mabujina complex—high-temperature metamorphosed volcanic and sedimentary rocks. On the basis of their metamorphic grade, Dublan and Alvarez (1986) distinguished two formations, Mabujina and Porvenir, in the Mabujina complex. The rocks of the Mabujina formation, folded and metamorphosed to the epidote-amphibolite-facies, are represented mainly by amphibolites, but more-felsic rocks such as meta-plagiogranites and meta-tonalites also occur. Serpentinized ultramafic rocks occur between steeply dipping fault zones. Five samples of amphibolites and meta-diorites have been collected (CU28, CU37, CU38, CU40, CU41, CU44; fig. 2). Locally, late- to postorogenic granodiorites and associated pegmatites cross-cut these metamorphosed island-arc rocks. These granodiorites have a K–Ar age of 85 ± 4 Ma (Somin and Millán 1981). These granitoid intrusives may be correlated with the alkaline and late-orogenic series of the Cretaceous island-arc best developed in the region of Camagüey (Stanek 1996). The Porvenir formation is predominated by basalts (CU47), pyroclastics, and gabbros (CU45 and CU46) affected by a light greenschist facies (fig. 2).

In south-central and western Cuba (figs. 1, 2), the metamorphic rocks (Iturralde-Vinent 1994), such as the Escambray massif, exposed Jurassic to Cretaceous sedimentary sections. These rocks are strongly deformed and display varying degrees of metamorphism. The Escambray massif is composed of carbonate, terrigeneous, and metabasic rocks with high-P/low-T assemblages (blueschists and eclogites). These rocks form two structural domes connected by a narrow bridge beneath a Paleogene cover (Millan and Somin 1985).

Petrography of Analyzed Samples

The two fresh samples were collected from the Cretaceous arc: a rhyolite (CU49) of the lower Creta-

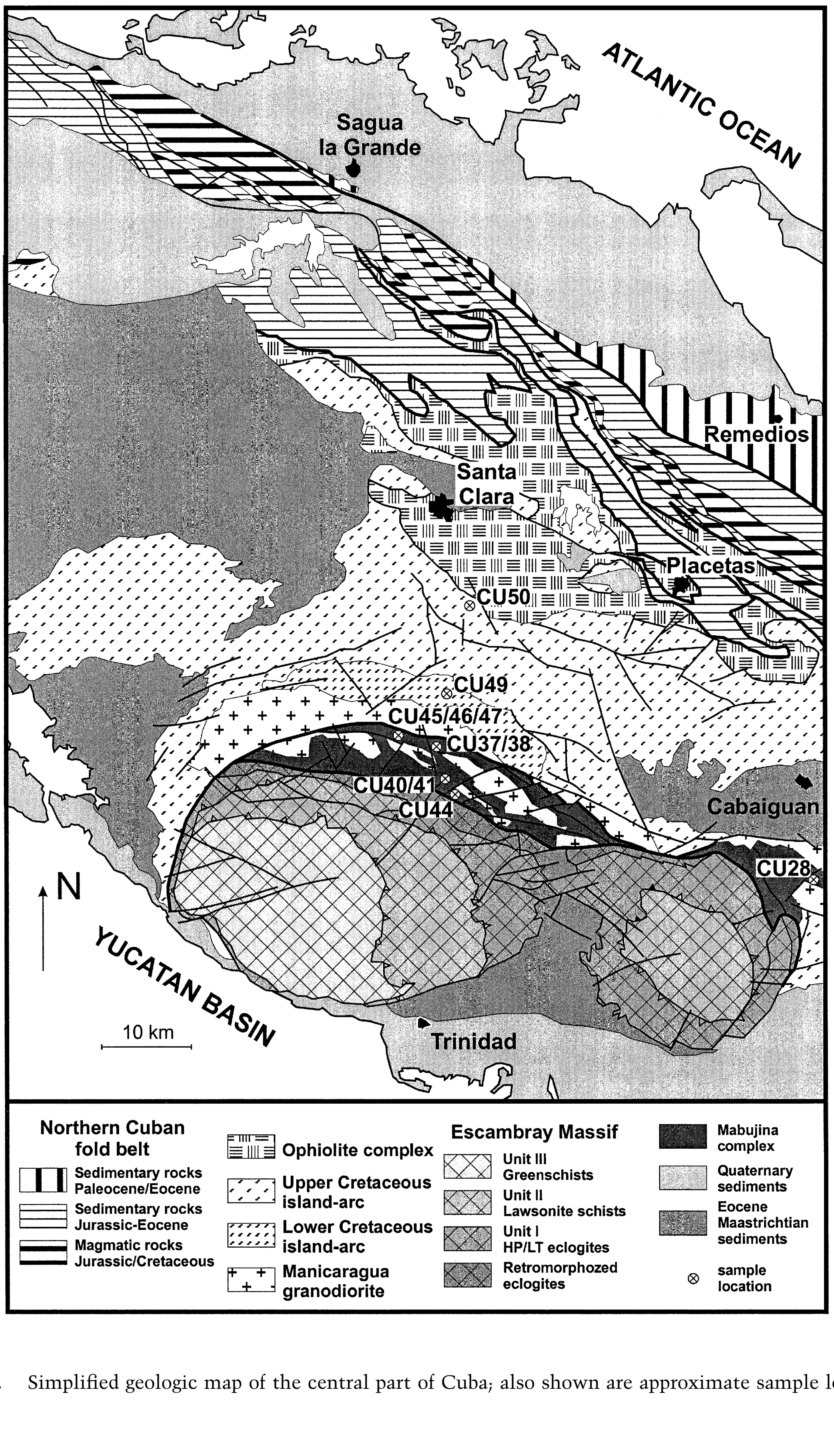

Figure 2. Simplified geologic map of the central part of Cuba; also shown are approximate sample locations

ceous Los Pasos Formation and a upper Cretaceous andesite (CU50) of the Provincial Formation. CU49 is characterized by an aphanitic texture with alkali feldspar phenocrysts and microliths of plagioclase, quartz, and oxides. CU50 is formed of large plagioclase, alkali feldspar, quartz, green hornblende, and biotite phenocrysts. Fe-Ti oxides are included in the feldspars, hornblende, and biotite phenocrysts and may represent early crystallizing minerals.

The samples collected in the Mabujina and Porvenir formations are amphibolites, gabbros, and basalt. The Mabujina amphibolites exhibit two main facies: clinopyroxene-phyric meta-basalt (CU28, CU40, CU41) and fine-grained meta-dolerite (CU37, CU38, CU44). The Porvenir gabbros display cumulate (CU45) or pegmatitic textures (CU46) and are cross cut by dolerite dikes (CU47). Relations between the Porvenir gabbros and the Mabujina amphibolites have not been observed.

Phenocryst compositions have been determined using a Camebax electron microprobe operating at 15 kV (12 nÅ)$^{-1}$ 10 s^{-1} at the UMR 6524, University of Clermont-Ferrand (France). Major oxides analyses for the gabbro CU45 and the meta-basalt CU40 are given in tables 1 and 2 (tables 1, 2, and 3 are available form the *Journal of Geology*'s Data Depository on request).

The clinopyroxene-phyric meta-basalt is composed of clinopyroxene porphyroblasts associated with millimeter-scale andesine laths embedded within pleochroic green hornblende and few oxides. Clinopyroxene phenocrysts have a diopsidic core ($Wo_{47–48}$, $En_{40–43}$, $Fs_{9–13}$; table 1; Morimoto 1988) and are rimmed by pleochroic green actinolitic hornblende. The fine-grained dolerites are composed of millimeter-scale andesine laths embedded within brown and green hornblende and few oxides.

The cumulate olivine gabbro is composed of olivine (65%), clinopyroxene (30%), and oxides (5%). Olivine is partly altered to iddingsite, and its composition ranges from Fo_{80} to Fo_{77} (table 2). Clinopyroxene has a diopsidic composition ($Wo_{47–49}$, $En_{40–43}$, $Fs_{8–12}$; table 1; Morimoto 1988). The pegmatitic gabbro is composed of clinopyroxene (50%), plagioclase (45%), olivine (5%), and oxides. The dolerite is composed of clinopyroxene porphyroblasts with millimeter-scale plagioclase laths embedded within pleochroic green hornblende.

Analytical Procedures

Major and four trace elements (V, Cr, Ni, and Co) were analyzed by ICP-AES at the CRPG in Nancy, France. Detection limits are 0.05 wt% for major elements and 5 ppm for minor elements (Govindaraju and Mevelle 1987). Trace elements, including rare earth elements (REE), were analyzed by ICP-MS using acid dissolution of a 100–150-mg sample at the Laboratoire de Géodynamique des Chaînes Alpines of the Université Joseph Fourier in Grenoble, France, following the procedures of Barrat et al. (1996).

For Sr and Nd isotopic analyses, samples were leached twice in 2 N HCl-0.1 HF mixture. Nd and Sr isotopic compositions were determined on a Finnigan MAT 261 multicollector mass spectrometer at the Laboratoire de Géochimie isotopique of the Université Paul Sabatier in Toulouse, France, using the analytical procedures described by Lapierre et al. (1997).

For Pb isotope determinations, whole rocks were successively leached in hot 2 N HCl for 20 min in an ultrasonic bath, rinsed with tridistilled water, leached in cold 1 N HNO_3 for 20 min, and rinsed with tridistilled water in an ultrasonic bath during 15 min. $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ isotopic ratios were measured by plasma source mass spectrometry on the Plasma 54 instrument of VG Elemental at ENS Lyon France using the analytical procedures of Manhes et al. (1978).

Geochemical Results

The Los Pasos and Provincial Formations. The Early Cretaceous Los Pasos rhyolite (CU49) is felsic in composition ($SiO_2 > 70$ wt%), with high Al_2O_3 (13.8 wt%), and low MgO (0.95 wt%), CaO (3 wt%), K_2O (0.84 wt%) and TiO_2 contents (0.36 wt%) (table 3). Its chondrite-normalized REE pattern is flat ($[La/Yb]_N = 0.83$) with a slight depletion in light rare earth elements (LREE; $[La/Sm]_N = 0.8$; fig. 3*A*). Relative to Primitive mantle (fig. 4*A*), this facies displays: (i) low Nb, Ta and Ti abundances; and (ii) a slight enrichment in LILE and Pb. Its La/Nb ratio is higher than 2, the lower limit value proposed by Gill (1981) for orogenic suites (table 3). With a Th/Yb ratio lower than 0.2, the rhyolite is typical of tholeiitic suites related to oceanic island arcs (Pearce 1983).

The Late Cretaceous Provincial quartz-andesite (CU50) has high SiO_2 (61.6 wt%), Al_2O_3 (17.6 wt%), Na_2O (4 wt%), K_2O (3 wt%) and low TiO_2 content (0.46 wt%) (table 3). Its chondrite-normalized REE pattern is enriched in LREE relative to heavy rare earth elements (HREE; $[La/Yb]_N = 7.2$; fig. 3*A*). Relative to the Primitive mantle (fig. 4*A*), this andesite displays: (i) significant enrichments in LILE, Pb and Sr; and (ii) low Nb, Ta and Ti abundances. The La/Nb ratio is higher than 2 (La/Nb = 3.4, table 3),

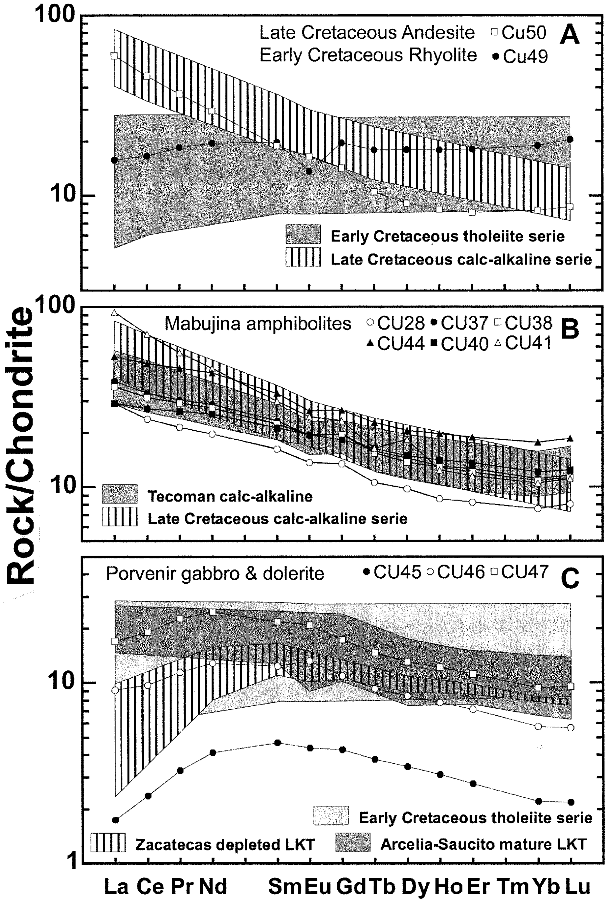

Figure 3. Chondrite-normalized (Sun and McDonough 1989) rare earth elements patterns: *A*, Cretaceous island-arc rocks; *B*, Mabujina amphibolites; *C*, Porvenir oceanic gabbros and associated lava. The fields of the Early and Late Cretaceous island-arc rocks (Donnelly et al. 1990; Lebrón and Perfit 1993; Kerr et al. 1999), the Mexican Tecoman, Arcelia-Saucito, and the Zacatecas island-arc series (Tardy et al. 1994) are shown for comparaison.

and the Th/Yb higher than 1, and typical of calc-alkaline suites (Pearce 1983).

Isotopic ratios measured on the rhyolite (CU49) and the andesite (CU50) have been corrected for in situ decay with an age of 95 and 135 Ma, respectively. The ϵNd_i and ϵSr_i values of the rhyolite and andesite are +7.2 and +6.3, and −18.7 and −15.8, respectively (table 4). These ϵNd_i values are similar to those observed for the intraoceanic arcs such as Mariana, New Britain, Aleutians or South Sandwich (fig. 5; Wilson 1989). Thus, their Pb/Pb isotopic ratios are close to the East Pacific rise (EPR) mid-ocean ridge basalt (MORB) field that is characterized by a depleted signature (fig. 6). The Early Cretaceous rhyolite has high ϵNd_i and low $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios, that suggest derivation from a source similar to that of the Depleted MORB Mantle (DMM) reservoir, slightly contaminated by subducted sediments. The Late Cretaceous andesite exhibits lower ϵNd_i (fig. 5), and higher Pb isotopic ratios (fig. 6), suggesting contamination of a DMM reservoir by subducted sediments or arc basement.

The Mabujina Complex. The Mabujina meta-basalts and meta-dolerites (CU28, CU37, CU38, CU40, CU41, CU44) are mafic to intermediate in composition, with SiO_2 from 46.1 wt% to 56.4 wt%, high Al_2O_3 (14.9 wt% ± 2.2 wt%) CaO (11.2 wt% ± 2.5 wt%), moderate K_2O (1.1 wt% ± 0.5 wt%), and low TiO_2 (0.84 wt% ± 0.12 wt%) content. MgO, Cr and Ni contents are highly variable (table 3). This suggests an evolution from mafic to fractionated facies. The major element contents indicate that the protoliths of the Mabujina amphibolites are volcanic rocks, clinopyroxene-phyric basalts and dolerites. All these igneous

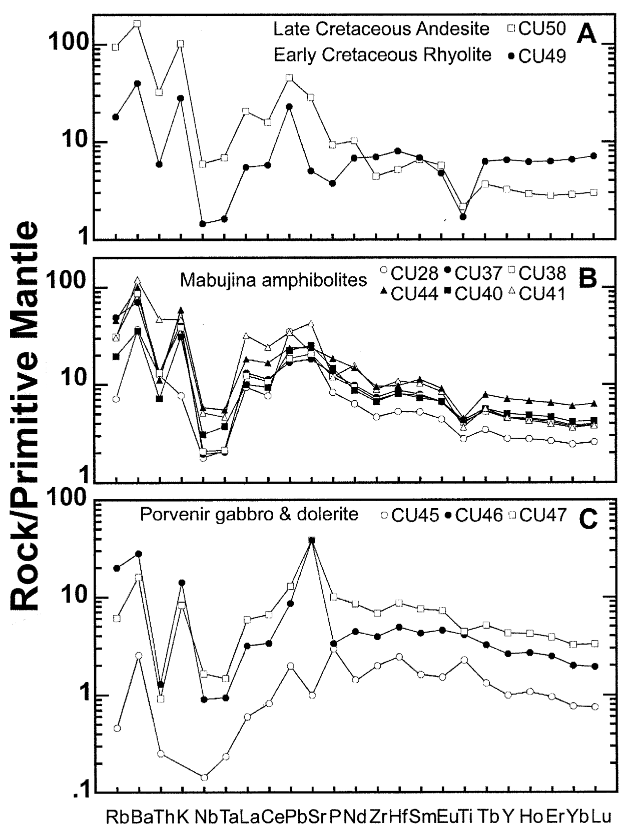

Figure 4. Primitive mantle-normalized (Sun and McDonough 1989) spidergrams: *A*, Cretaceous island-arc rocks; *B*, Mabujina amphibolites; *C*, Porvenir oceanic gabbros and associated lava.

Table 4. $^{143}Nd/^{144}Nd$, $^{87}Sr/^{86}Sr$, $^{208}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{206}Pb/^{204}Pb$ Isotopes Ratios of the Igneous Rocks of the Cretaceous Island Arc and Early Cretaceous Amphibolites for the Mabujina Complex

	Mabujina Complex									
	Mabujina Formation							Porvenir Formation	Los Pasos	Provincial
	CU28	CU38	CU41	CU44	CU40	CU40	CU40	CU46	CU49	CU50
Rock type	Basalt	Basalt	Basalt	Basalt	Basalt	Amphibole	Plagioclase	Basalt	Rhyolite	Andesite
Age (Ma)	145	145	145	145	145	145	145	145	135	95
Sm	2.30	3.37	4.54	5.00	3.21	1.49	.416	1.80	3.00	2.87
Nd	8.56	12.61	21.12	19.84	11.69	4.55	1.33	5.76	9.02	13.65
$^{143}Nd/^{144}Nd$	.512915 ± 5	.512950 ± 5	.512929 ± 5	.512983 ± 5	.513060 ± 6	.513103 ± 13	.513168 ± 12	.513002 ± 7	.513011 ± 6	.512917 ± 8
$^{147}Sm/^{144}Nd$	.16245	.16158	.12997	.15237	.16602	.19800	.18912	.18894	.20109	.12712
$(^{143}Nd/^{144}Nd)_i$	.512761	.512797	.512806	.512838	.512902	.512915	.512989	.512823	.512833	.512838
ϵNd_i	6.0	6.7	6.9	7.6	8.8	9.0	10.5	7.2	7.2	6.3
Rb	4.5	19.5	19.2	28.8	12.3	5.4	…	12.2	11.3	59.2
Sr	450	433	901	501	533	70	…	780	104	600
$^{87}Sr/^{86}Sr$	.704710 ± 8	.704033 ± 8	.703474 ± 9	.703426 ± 9	.703393 ± 8	.703539 ±8	…	.703332 ± 10	.703521 ± 9	0.703661 ± 9
$^{87}Rb/^{86}Sr$	.0289240	.1302495	.0616286	.1662488	.0667391	.2231024	…	.0452340	.3142000	.2853541
$(^{87}Sr/^{86}Sr)_i$	.70465	.70376	.70335	.70308	.70326	.70308	…	.70324	.703061065476442	.70328
ϵSr_i	4.6	−8.0	−14.0	−17.7	−15.3	−17.8	…	−15.5	−18.7	−15.8
$(^{206}Pb/^{204}Pb)_i$	…	18.878	18.936	18.653	18.874	…	18.856	18.620	18.429	18.547
$(^{207}Pb/^{204}Pb)_i$	…	15.540	15.569	15.553	15.568	…	15.555	15.503	15.525	15.536
$(^{208}Pb/^{204}Pb)_i$	…	38.569	38.592	38.268	38.687	…	38.451	38.193	38.056	38.202

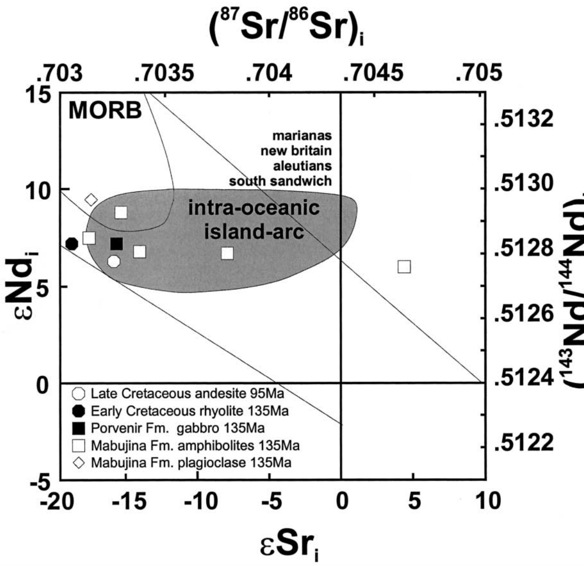

Figure 5. ϵNd_i versus ϵSr_i diagram for the Cretaceous island-arc rocks and igneous rocks of the Mabujina Complex. The fields of the MORB and the intraoceanic Marianas, New Britain, Aleutians, and South Sandwich (after Wilson 1989) are also shown.

rocks have low TiO_2 contents suggesting an island-arc setting.

The Porvenir gabbros (CU45, CU46) and clinopyroxene-phyric dolerite (CU47) are mafic in composition, with SiO_2 lower than 40 wt%. The olivine gabbro displays high MgO (26.6 wt%), and low Al_2O_3 (2.3 wt%), CaO (7.1 wt%), K_2O (0.1 wt%), and TiO_2 contents (0.46 wt%) (table 3). Such major element composition likely reflects olivine accumulation. By contrast, the pegmatic gabbro and the clinopyroxene-phyric dolerite have similar major element concentrations, with high Al_2O_3 (>20 wt%), MgO (>6 wt%), CaO (>15 wt%), and low K_2O (<0.4 wt%) and TiO_2 contents (<0.92 wt%).

The chondrite-normalized REE patterns of the Mabujina arc rocks are enriched in LREE relative to HREE ($[La/Yb]_N = 4.2$; fig. 3*B*). The Porvenir gabbros and associated dolerite have REE patterns depleted in both LREE ($0.37 < [La/Sm]_N < 0.78$; fig. 3*C*) and HREE ($[Gd/Yb]_N = 1.9$). The low REE concentrations of olivine gabbro clearly demonstrated that it is a cumulative rock. Relative to the primitive mantle (fig. 4*B*, 4*C*), their patterns are characteristic of subduction related suites with: (i) an enrichment in LILE, Pb and Sr; and (ii) low Nb, Ta and Ti abundances. Their La/Nb ratios are higher than 2. Mabujina meta-basalts and meta-dolerites have Th/Yb ratios higher than 1 typical of calc-alkaline island arcs (Pearce 1983), whereas Porvenir gabbros and dolerite Th/Yb ratios are lower than 0.2 typical, of tholeiitic island arcs (Pearce 1983).

Isotopic data on the Mabujina igneous rocks have been corrected for in situ decay with an age of 145 Ma (Hatten et al. 1989). The ϵNd_i and ϵSr_i values of the meta-basalts and meta-dolerites range from +6.0 to +8.8 and from −17.7 to +4.6, respectively (table 4; fig. 5). The ϵNd_i values of the plagioclase and amphibole separates from the basalt CU40 are +10.5 and + 9.1, respectively. These values are slightly higher than that of the whole rock (+8.7) (table 4). Finally, the ϵNd_i and ϵSr_i values of the pegmatic gabbro of +7.2 and −15.5, respectively (table 4) are similar to those of the Mabujina arc rocks. This suggest that the gabbro, meta-basalts and meta-dolerites were derived from similar sources. The relatively homogeneous ϵNd_i of the Mabujina arc rocks fall in the range of most intra-oceanic arcs such as Mariana, New Britain, Aleutians or South Sandwich (fig. 5). Thus, the Nd isotopic compositions of the Mabujina and Porvenir arc rocks reflect the restricted range of available magma source materials from which these rocks derived. These sources are likely N-MORB type mantle and subducted sediments.

Initial lead isotopic compositions of gabbros, dolerites, basalts and mineral separates from sample CU40 define a domain characterized by $^{206}Pb/^{204}Pb > 18.6$, $^{207}Pb/^{204}Pb > 15.5$ and $^{208}Pb/^{204}Pb > 38.2$ (table 4). These rocks and minerals cluster in the upper limit of the MORB field, and fall in the field defined by the Aleutians island-arc lavas (fig. 6). This suggests a mixing between a MORB-type mantle source and a component characterized by $^{206}Pb/^{204}Pb$ ratios similar to that of MORB but with higher $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios.

Discussion

The Los Pasos and Provincial Formations. The Los Pasos rhyolite CU49, with a tholeiitic affinity, flat REE patterns, high ϵNd_i (+7.2), and low lead isotopic ratios, indicating a depleted mantle source, shares similarities with the Cuban Early Cretaceous arc, characterized by a basalt-rhyolite tholeiite serie (Villalvilla et al. 1998; Kerr et al. 1999). In contrast, the Late Cretaceous Provincial andesite is calc-alkaline, with an enrichment in LREE, a lower ϵNd_i value (+6), and higher lead isotope compositions than that of the lower Cretaceous rhyolite. These geochemical data on the Cuban Cretaceous arc lavas show that these rocks are similar

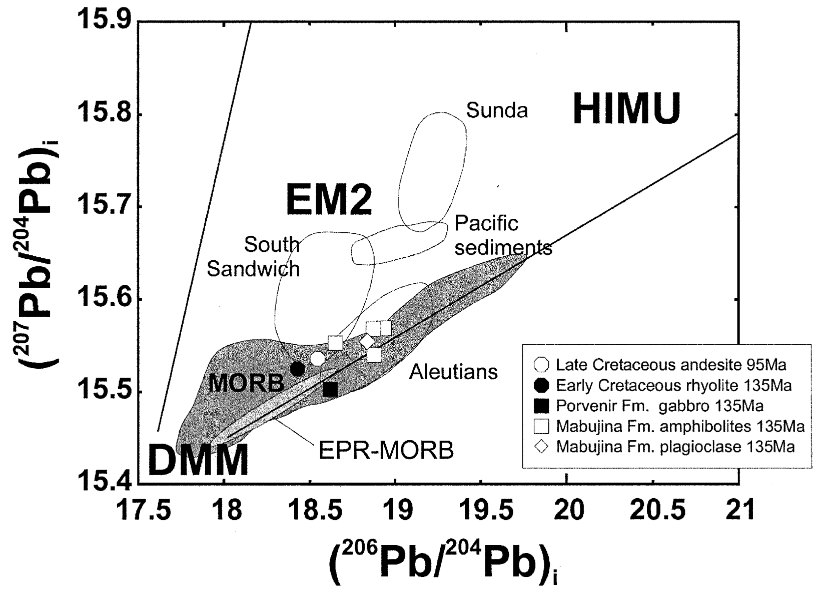

Figure 6. $(^{207}Pb/^{204}Pb)_i$ versus $(^{206}Pb/^{204}Pb)_i$ correlation diagram for for the Cretaceous island-arc rocks and igneous rocks of the Mabujina Complex. The Northern Hemisphere Reference Line (*NHRL*) and variors reservoirs (*DMM*, *EM1*, *EM2*, *HIMU*) are shown after Zindler and Hart (1986). Fields for South Sandwich and Aleuntians arc are from White and Dupré (1986); Sunda arc data are from Whitford and Jezek (1982).

to the Cretaceous lavas exposed elsewhere in the Greater Antilles (Donnelly et al. 1990).

In the Greater Antilles, the Cretaceous island-arc assemblages consist of a primitive island-arc suite (PIA of Donnelly and Rogers 1980; Donnelly et al. 1990; Lebrón and Perfit 1993) that is the oldest island-arc occurrence. The PIA is composed of Early Cretaceous basalts and rhyolites with flat REE patterns and followed by Late Cretaceous calc-alkaline series, locally occuring together with shoshonitic suites (Donnelly et al. 1990).

The Mabujina Complex. The rocks collected in the Mabujina complex evolved from mature tholeiites (Porvenir formation) to calc-alkaline (Mabujina formation) suites characterized by an enrichment in LILE and low Ti, Nb and Ta contents relative to REE. Both suites have positive ϵNd_i values (+8.8 to +6.0), and their initial Pb isotopic compositions indicate that they derived from a depleted mantle source contamination by subducted sediments or arc basement. Thus, the rocks of the Mabujina complex likely developed in an island-arc setting. The Porvenir gabbros and dolerite with a tholeiitic affinity may represent the earlier Mabujina island-arc activity before the calc-alkaline suite.

Somin and Millán (1981), Millán (1996), and Iturralde-Vinent (1994) considered the Mabujina complex to represent the pre-Albian oceanic basement of the Cretaceous arc, with local island-arc volcanic rocks. Kerr et al. (1999) suggested that these island-arc rocks are probably Early Cretaceous PIA rocks. Our data preclude a correlation between the Mabujina complex and an oceanic basement or the Early Cretaceous PIA rocks. The Mabujina rocks have an island-arc affinity and not MORB; however, they differ strikingly from PIA rocks characterized by flat REE patterns with $[La/Sm]_N$, $[Gd/Yb]_N$, and $[La/Yb]_N$ ratios lower than 1 (Donnelly and Rogers 1980; Donnelly et al. 1990; Lebrón and Perfit 1993). The protoliths of the Mabujina amphibolites are calc-alkaline lavas characterized by a fractionation of LREE ($[La/Yb]_N = 4.2$; fig. 3*B*). The Porvenir rocks, like PIA rocks, have a tholeiitic affinity; however, they are characterized by fractionated HREE with $[Gd/Yb]_N$ ratios higher than unity ($[Gd/Yb]_N = 1.8 \pm 0.2$), higher Ce/Pb ratios ($Ce/Pb = 4.9 \pm 1.5$), and higher Pb isotopic ratios ($[^{206}Pb/^{204}Pb]_i > 18.6$ and $[^{208}Pb/^{204}Pb]_i > 38.2$). According to our data, the Jurassic and/or Early Cretaceous Mabujina complex is characterized by island-arc rocks with tholeiitic and calc-alkaline affinities but does not represent a metamorphosed lower Cretaceous PIA, as suggested by Kerr et al. (1999) with only one sample.

During Late Cretaceous, island-arc granitoid intruded the Mabujina complex. If these plutonic rocks represent the end of the Cuban Cretaceous island-arc activity, then the Mabujina complex was part of the Cuban island-arc basement during Late Cretaceous time. This suggests a juxtaposition between the Mabujina complex and the Cretaceous Cuban island-arc in late–Early Cretaceous or early–Late Cretaceous times.

Kerr et al. (1999) suggested the presence of a second Early Cretaceous arc in Cuba. The sparse evidence for this arc occurs in the form of volcanic, plutonic, and metamorphic rocks of arc affinities, found as pebbles in mid–late Albian conglomerates in several localities of western and central Cuba (Iturralde-Vinent 1996*b*). Because these arc-derived conglomerates overlie the Lower Cretaceous rocks of the island-arc tholeiite series within the Cretaceous arc, it is suggested that the source of these conglomerates was located elsewhere. This second Early Cretaceous arc may be represent by the island-arc rocks of the Mabujina complex.

Geodynamic Implications. As an other Jurassic and/or Early Cretaceous island arc is still unknown in the Caribbean region; we looked farther west, in Mexico, to see whether similar formations are exposed. The accreted terranes of the Mexican Cordillera are characterized by the presence of a Late Jurassic to Early Cretaceous island arc, the Guerrero terrane (Centeño-Garcia et al. 1993; Tardy et al. 1994; Freydier et al. 1997). This terrane forms scattered outcrops in central-western Mexico under the Cenozoic volcanic cover; it was accreted to nuclear Mexico at the end of the Early Cretaceous (Tardy et al. 1994). It encompasses a complex of continental and oceanic lithospheric fragments collectively constituting an intraoceanic setting, active for about 40 Ma (Centeño-Garcia et al. 1993; Tardy et al. 1994). The sequences were built on continental crust, or oceanic lithosphere thickened by continental-derived sediments (Playa Azul; Freydier et al. 1997). They consist of tholeiites and calc-alkaline suites derived from a depleted mantle source with large involvement of contamination by subducted sediments or crustal basement. The ϵNd_i range from +9 for the tholeiitic olivine-phyric basalt to +2 for the calc-alkaline basalt in the Playa Azul sequence. In contrast, the arc sequences built on oceanic crust began with the development of depleted low-K mafic suites (Zacatecas; fig. 3*C*) followed first by mature tholeiitic basalts (Arcelia; fig. 3*C*) and then by calc-alkaline olivine basalts of Early Cretaceous age (Tecoman; fig. 3*B*). Their high ϵNd_i (+10 to +6) values express a depleted mantle source in intraoceanic arc setting.

The Mabujina island-arc rocks share similarities with the intraoceanic arc sequences of the Guerrero terrane (fig. 3*B*, 3*C*). Both suites show similar evolution with time from LREE-depleted low-K tholeiitic to calc-alkaline suites (fig. 3*B*, 3*C*), and most of the arc rocks have similar positive ϵNd_i values. The Mabujina island-arc rocks may represent the southernmost extension of the Guerrero terrane and then could be of Pacific provenance. At the end of the Early Cretaceous, the Guerrero arc terrane was accreted to nuclear Mexico (Tardy et al. 1994), but not the Mabujina arc. In a southern position, the Mabujina arc moves in the widening ocean basin between North and South America and accreted to the Early Cretaceous PIA during late Early Cretaceous or early Late Cretaceous. Consequently, the Mabujina complex may represent a junction between the Mexican Late Jurassic to Early Cretaceous and the Early to Late Cretaceous Carribean island arcs. The major implication of this is that the Mabujina complex, and therefore probably the metamorphic rocks like the Escambray, is of Pacific provenance.

In the circum-Caribbean terranes (i.e., the Greater Antilles arc), central America (Costa Rica, Panama, Guatemala), and the northern margin of South America (Venezuela, Colombia), Cretaceous island-arc rocks are tectonically associated with at least three types of oceanic fragments: Late Jurassic oceanic crust, Early Cretaceous island arc, and 90–80-Ma remnants of the Caribbean–Colombian oceanic plateau. However, the distribution of these three types of oceanic fragments within the peri-Caribbean realm differs with respect to the present-day geographic location of the different islands that form the Greater Antilles arc, and perhaps also the different segments of the central American Cordillera. Two main associations can be distinguished based on the available geochemical data (see for review Donnelly et al. 1990; Kerr et al. 1997*a*, 1997*b*; Lapierre et al. 2000). The first association (type I), which appears to be the best documented, consists of the 90–80-Ma remnants of the Caribbean–Colombian oceanic plateau tectonically imbricated with Cretaceous island-arc rocks and locally with Upper Jurassic N-MORB type basalts and/or cherts (e.g., Costa Rica, Hispaniola, and perhaps eastern Guatemala). The second association (type II) is formed predominantly of Upper Jurassic to Upper Cretaceous island-arc suites that are tectonically associated with Jurassic metamorphosed oceanic crust.

The present-day geographic distribution of these two associations can be roughly drawn as follows: type I association is exposed south of a SSW–NNE boundary, marked by the transform faults that bound the Cayman trough and extend from Honduras to the south of Cuba, north of Puerto Rico, and the Virgin islands (fig. 1*A*). The area south of this boundary corresponds to the southern Caribbean that encompasses the southernmost islands of the Greater Antilles arc: Honduras, Costa Rica, and Panama in central America; West Indies; Venezuela; and Colombia (fig. 1*A*). Conversely, Type II association is restricted to the northern Caribbean (Cuba and Guatemala) (fig. 1*A*). If this distinction is confirmed by new tectonic, stratigraphic, and geochemical investigations on the pre-Cretaceous metamorphosed or nonoceanic terranes from the Greater Antilles arc (particularly the Cuban Escambray massif) and Central America, this implies that the pre-Tertiary geodynamic evolution of Cuba is linked to the tectonic history of the North American Pacific margin, whereas that of the other islands from the Greater Antilles is related to the Cordilleras of northern South America (Pindell and Barret 1990; Pindell et al. 1988; Stéphan et al. 1990).

Conclusions

New geochemical data on the meta-igneous rocks of the Mabujina complex from central Cuba shed light on the pre-Tertiary geodynamic evolution of the northern segment of the Greater Antilles arc. Some Mabujina rocks clearly exhibit an island-arc affinity and may show an evolution from mafic tholeiites to calc-alkaline suites. The Nd, Sr, and Pb isotopic compositions of the Mabujina arc rocks indicate that they derive from a depleted mantle source contaminated by subducted sediments or arc basement, developed in an intraoceanic setting. They are distinct from the Early Cretaceous intraoceanic island arc known in Cuba but share similar geochemical features with the Guerrero island-arc terrane from central-western Mexico.

The Mabujina arc rocks could represent the southernmost extension of the Guerrero terrane, and they are not genetically related to the Greater Antilles island arc from the Early Cretaceous. During late Early Cretaceous, the Mabujina arc accreted to the Early Cretaceous Greater Antilles island arc and then composed the basement of the Late Cretaceous island arc. This implies that the pre-Tertiary geodynamic evolution of Cuba is more likely linked to the Pacific history of the North American Cordillera than to that of the Caribbean oceanic realm.

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