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METABASITES FROM THE NORTHERN SERPENTINITE BELT (CUBA) AND A METAMORPHIC PERSPECTIVE OF THE PLATE TECTONIC MODELS FOR THE CARIBBEAN REGION

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ABSTRACT

The analysis of metamorphosed magmatic rocks along the northern serpentinite belt (Cuba) suggest a variety of tectonic settings of formation and metamorphism. Slightly deformed coherent bodies of metabasites from Cajálbana (western Cuba) and Iguará-Perea (central Cuba) underwent ocean-floor type metamorphism at low-pressure (<3 kbar) amphibolite (locally granulite) facies conditions. ^{40}Ar/^{39}Ar plateau ages on amphiboles have yielded 88.0 +/- 3.2 (Iguará-Perea) and 129.8 +/- 1.9 Ma (Cajálbana). These rocks have tholeiitic (Cajálbana) and calc-alkaline (Iguará-Perea) signatures and evidence of formation in suprasubduction environments (Th, Nb and Sr anomalies). Based on geochemical similarities with the arc-related metamorphic Mabujina complex (central Cuba), it is hypothesized that the Iguará-Perea complex may represent the roots of an embryonary or abandoned arc. Indeed, arc-related (instead of mid-ocean ridge) thermal focuses for metamorphism are favored because of the consistent relationships between the age of metamorphism and geochemistry of the protoliths and the age and geochemistry of the Lower and Upper Cretaceous volcanic arc suites of Cuba. The Güira de Jauco amphibolites (eastern Cuba) have N-MORB and E-MORB basaltic to picritic composition that suggest an Upper Cretaceous plateau basalt origin of the protolith. These rocks were strongly deformed and metamorphosed to intermediate pressure (6-8 kbar) amphibolite facies conditions, indicating collision-related metamorphism. The documented Cretaceous formation of suprasubduction and intraplate oceanic complexes must be added to the inferred event of formation of oceanic lithosphere at Upper Jurassic to Lower Cretaceous times in ocean-ridge environments, and put important constraints to models of plate tectonic evolution of the Caribbean region.

This is a contribution of the IGCP Project 433.

Introduction

Ophiolitic rocks constitute one of the main Mesozoic geological features of Cuba, and deciphering their geologic history is fundamental to achieve reliable plate-tectonic reconstructions of the northern branch of the Caribbean plate margin during Mesozoic times. In Cuba, the largest bodies of ophiolitic rocks crop out to the north of the island, forming the "northern serpentinite belt" that constitutes one of the largest (> 1000 km in length) ophiolitic belts in the Caribbean. The northern serpentinite belt represents fragments of oceanic lithosphere accreted to the North America/Yucatan margin during the late Mesozoic-Paleogene convergence of the Caribbean and North America plates. Different plate-tectonic models for the Caribbean region envisage the origin of this oceanic lithosphere as formed essentially at mid-ocean ridges associated to the break up of Pangea and the North America-South America drift in Jurassic-Lower Cretaceous times, either in Pacific/Caribbean or Proto-Caribeean realms. However, geochemical studies of the ophiolitic assemblage in different parts of the belt indicate formation at suprasubduction environments (e.g., Andó et al., 1996; Proenza et al., 1999). In this paper we present petrological, geochemical, and geochronological data of the metamorphic products of the crustal magmatic sections of the ophiolitic bodies (i.e., gabbros, diabases and basalts) that consistently indicate formation of the protoliths at the neighborhood of arcs during the Lower and Upper Cretaceous. Additionally, we also document metamorphosed ophiolitic rocks whose protoliths probably formed in intraplate environments during the Upper Cretaceous. All these type of ophiolitic rocks must be added to old (Jurassic-Lower Cretaceous) oceanic lithosphere formed at mid ocean ridges, fragments of which subducted at pre-Aptian times (García-Casco et al., 2002). As will be shown, our data and interpretations militate in favor of considering the northern serpentinite belt as a polygenetic oceanic lithosphere which records a protracted geologic history since the Upper Jurassic-Lower Cretaceous (Iturralde-Vinent, 1996).

Samples and analytical methods

We have focused our study in metabasites from coherent metamorphic complexes present in the northern serpentinite belt from western (Cajálbana ophiolite), central (Iguará-Perea complex) and eastern (Güira de Jauco complex) Cuba (Somin & Millán, 1981; Millán, 1996). The samples from the Cajálbana ophiolite were taken from cm- to m-sized blocky bodies of metabasite metamorphosed to the amphibolite facies close to the village of Bahía Honda. Some of these bodies being roughly parallel to the main foliation of the enclosing serpentinites have a faint foliation (SRO2A and SRO2B), which is not so evident in isometric (SRO3) and dike-like bodies (SRO2C, SRO2D). The samples from the Iguará-Perea complex were taken from massive bodies of metadiabase (LV37, LV37A and LV39A) and metagabbro (LV38, LV38AI and LV38AII) metamorphosed to the amphibolite and upper amphibolite to granulite facies, respectively. All samples are slightly to non-deformed. The samples from eastern Cuba were taken from the Guira de Jauco massive body of amphibolites (GJ8, GJ9, GJ10, GJ11, GJ12, GJ13) and from concordant cm-sized layers of amphibolite-facies rocks (GJ1A, GJ1B, GJ2, GJ4, GJ4, GJ7) intercalated within adjacent bodies of serpentinized harzburgite that may form part of the Moa-Baracoa ophiolite. All rocks in the Güira de Jauco amphibolite body and the layers within the serpentinites appear strongly foliated. As shown below, the latter type of samples are similar in geochemical, petrological, and structural features to those of the samples from Güira de Jauco massive body, suggesting that this body may not be a distinct tectonic unit but an integral part of the Moa-Baracoa ophiolite. Structural recognizance suggest that the Güira de Jauco complex is located at the base of this ophiolite, suggesting that the protholiths of the amphibolites may represent magmas intruded at the base of the ophiolitic lithosphere.

Whole-rock major and trace element determinations were done at the university of Granada (Spain) by means of XRF and ICP-MS. The analyses of the minerals were obtained at the University of Granada through WDX and EDS microanalysis using a CAMECA SX-50 and a ZEISS DSM 950. Isotope analyses ($^{40}Ar/^{39}Ar$) of amphibole were determined at the Servicio Nacional de Geología y Minería (SERNAGEOMIN, Chile).

Whole-rock composition

Within the framework of the IUGS classification scheme, the samples from the Cajálbana and Iguará-Perea complexes have a subalkaline low-K basaltic composition, except for the subalkaline medium-K basaltic andesite composition of LV37 from Iguará-Perea (Fig. 1). The composition of amphibolites from Güira de Jauco includes subalkaline low-K basaltic, pricrobasaltic and picritic compositions (Fig. 1), the latter being present in the amphibolitic body s.s, but more abundant in the adjacent bodies of serpentinite.

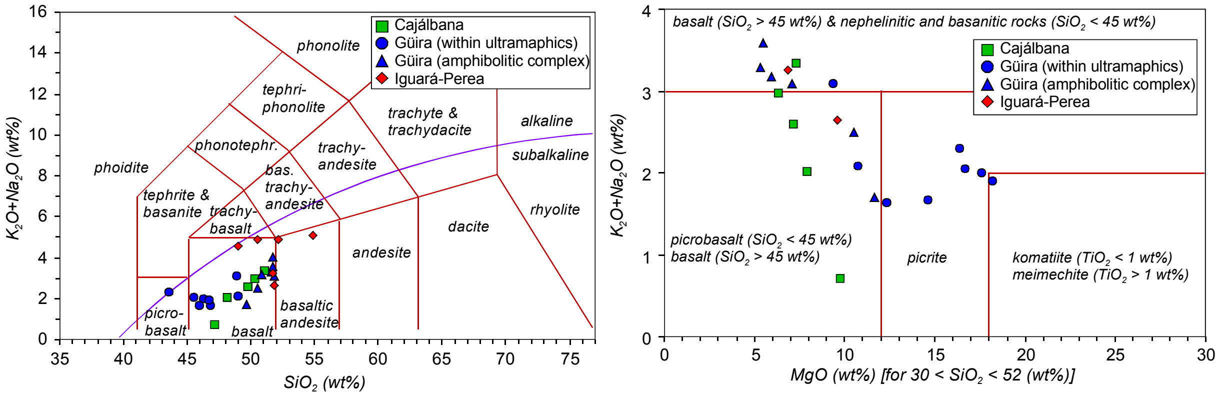

Figure 1: IUGS classification of the studied samples.

Cajálbana. The samples have a tholeiitic character in the AFM diagram (Fig. 2). Their chondrite-normalized REE patterns are homogeneous, and conform with a N-MORB pattern having distinctive LREE depletion (Fig. 2). However, their primitive mantle-normalized element patterns and other chemical features (e.g., Th/Yb-Ta/Yb relations) compare well with island-arc tholeiitic (IAT) basalts, showing distinctive Nb and Th depletion and Sr enrichment relative to MORB typical of basalts from supra-subduction zone environments (Fig. 3).

Iguará-Perea. At divergence with the Cajálbana metabasites, all samples have a calc-alkaline character in the AFM diagram (Fig. 2). The chondrite- and primitive mantle-normalized element patterns are varied (Figs. 2 and 3), though the metadiabases show distinctive Nb and Th depletion and Sr enrichment typical of supra-subduction origin. To some extent, these metabasites are comparable to calc-alkaline metabasites from the Mabujina complex (Fig. 2).

Güira de Jauco. All samples have a tholeiitic character in the AFM diagram (Fig. 2). The chondrite-normalized REE patterns are heterogeneous, conforming with N-MORB, depleted N-MORB, and E-MORB (Fig. 2). The primitive mantle-normalized element patterns (Fig. 3) and other geochemical diagrams indicate similarities with intraplate basaltic rocks of the Upper Cretaceous Caribbean Large Igneous Province, suggesting a similar origin for the protoliths of this complex.

Mineral composition and assemblages

The extent of metamorphic recrystallization in all samples is considerable to complete, with formation of metamorphic assemblages of the amphibolite facies and, locally, of the upper amphibolite to granulite facies (Iguará-Perea). All samples except the granulites have low- to very low-grade retrograde overprints made of albite, chlorite, prehnite and pumpellyite that replace the earlier amphibolite-facies matrix assemblages and fill veins.

Cajálbana. The samples bear amphibolite facies assemblages made of plagioclase (andesine-oligoclase), amphibole (magnesiohornblende, locally edenite and actinolite), titanite, epidote, and apatite. When present, relict igneous labradorite and augite are replaced by metamorphic andesine-oligoclase and calcic amphibole, respectively. The non-deformed samples retain diabasic texture defined by laths of pseudomorphosed igneous plagioclase and inter-grain blastic amphibole formed after clinopyroxene.

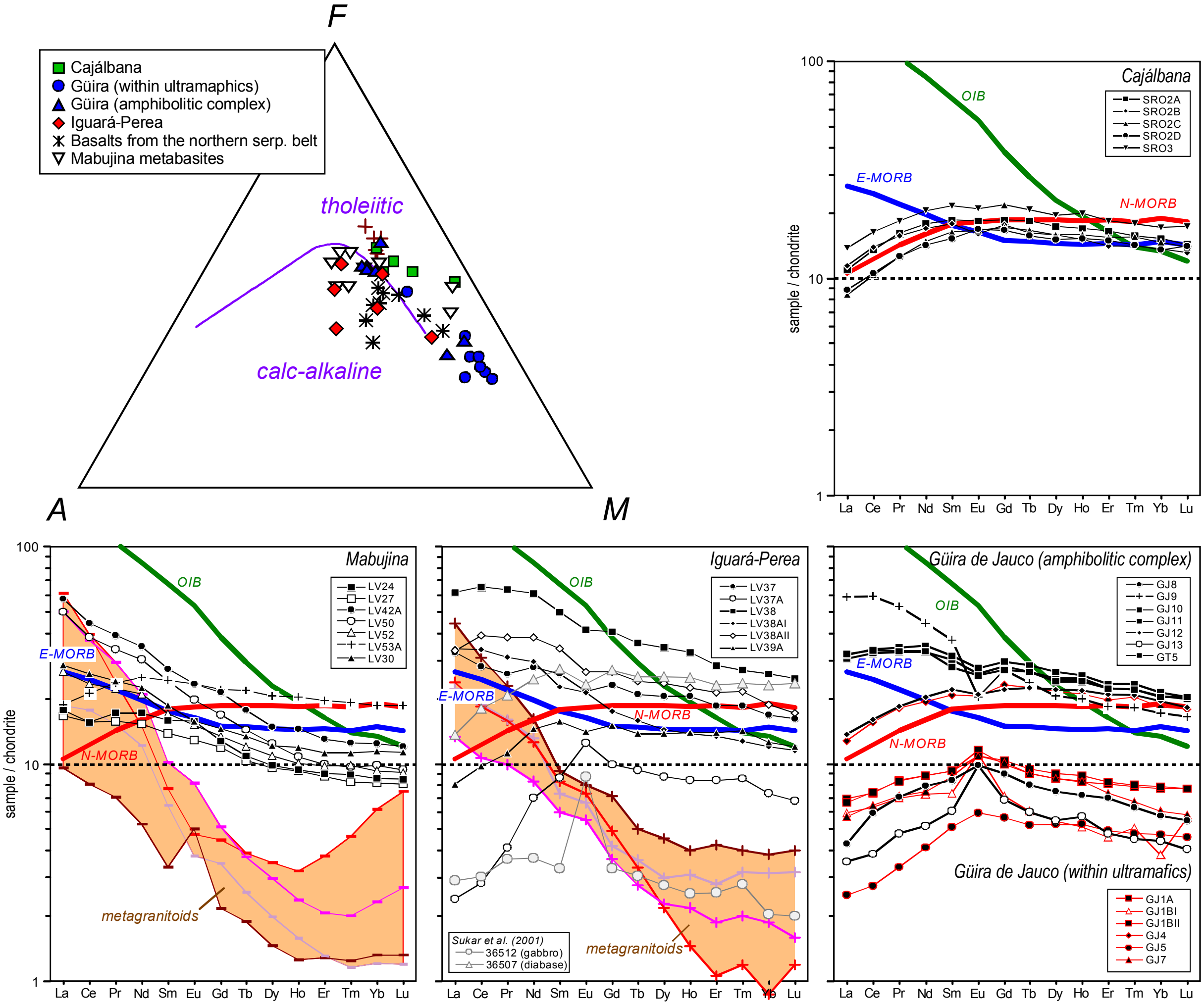

Figure 2. AFM and chondrite-normalized REE diagrams of the studied samples, non metamorphic volcanic rocks of the northern serpentinite belt (Kerr et al., 1999), metagranites from Iguará-Perea (K. Sukar), and metabasites and metagranites from Mabujina (unpublished data).

Iguará-Perea. The metadiabases retain relict diabasic texture and bear amphibolite-facies metamorphic assemblages formed by calcic amphibole (magnesiohornblende), plagioclase (andesine; relict igneous labradorite in found in the cores of andesine grains), titanite, epidote, apatite and, locally, quartz and diopside. These assemblages are similar to those of the metadiabases from Cajálbana. The metagabbros do not preserve relict igneous textures or minerals, displaying granoblastic texture with abundant triple-point junctions among all types of mineral grains. The assemblage is formed by plagioclase (andesine), clinopyroxene (diopside-augite), amphibole (pargasite-kaersuitite), magnetite, ilmenite and apatite. This is a high-grade assemblage which, however, is not diagnostic of the metamorphic facies as it can be attributed either to the upper amphibolite or the granulitie facies. Temperature estimates (see below) conform with granulite facies conditions.

Güira de Jauco. The samples of basaltic composition are amphibolites formed by calcic amphibole (pargasite-edenite-magnesiohornblende), plagioclase (andesite-oligoclase), epidote, titanite, and apatite (±quartz). The samples of picritic composition are amphibolitites that bear a high-variance non-diagnostic assemblage made almost exclusively of Mg-rich calcic amphibole (pargasite-tschermakite-magnesiohornblende-actinolite) with minor titanite and epidote. However, this assemblage must have formed within the amphibolite-facies because of the amphibolite-facies assemblages present in adjacent non-picritic rocks. All type of samples are strongly deformed and foliated, have no trace of relict igneous textures and minerals. The deformation of the rocks occurred during the formation of the peak amphibolite facies assemblages, but termination of deformation at (near) peak metamorphic conditions is indicated by recrystallization and formation of triple-point junctions among grains of amphibole.

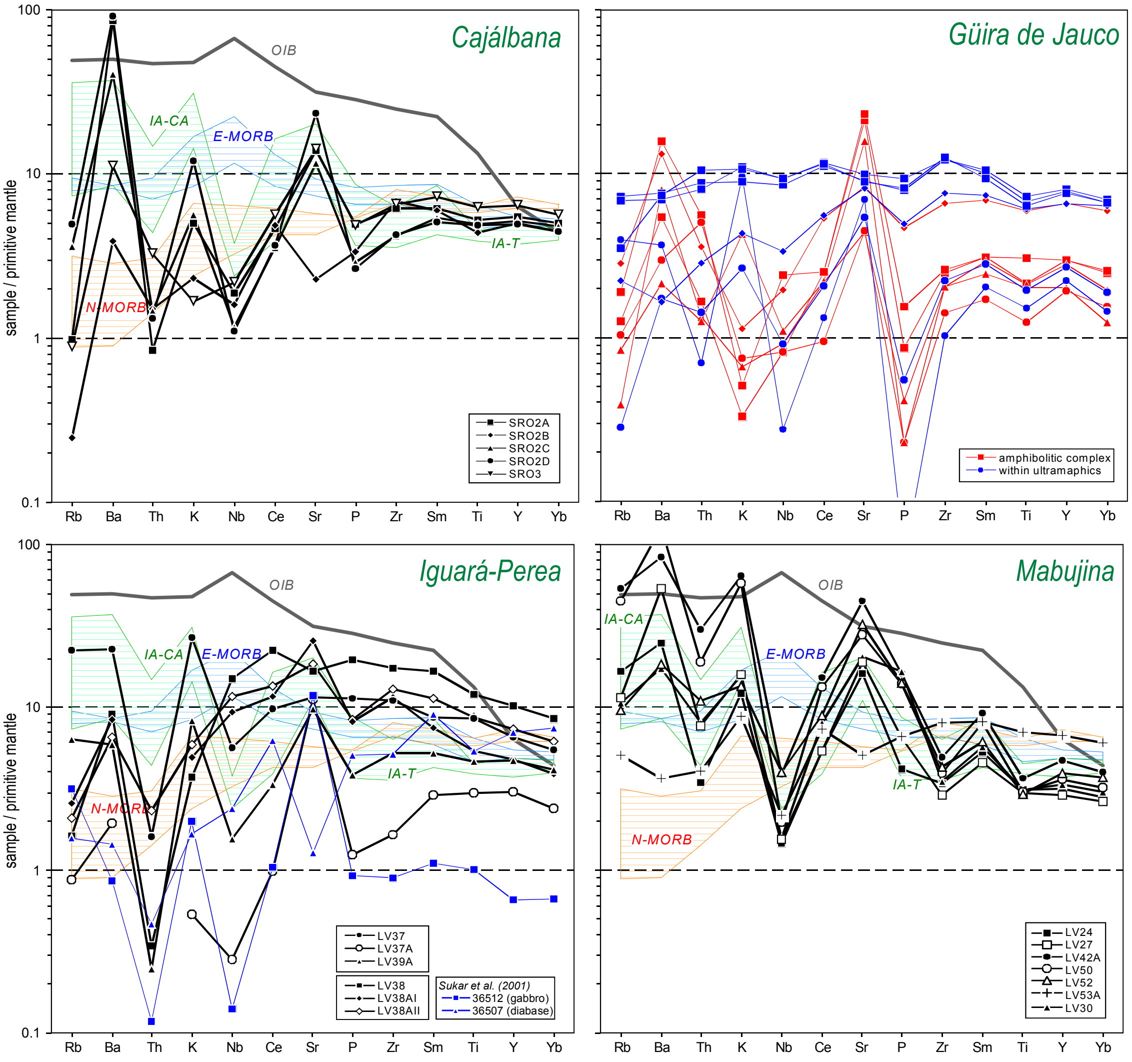

Figure 3. Primitive mantle-normalized element patterns of the studied samples and metabasites and metagranites from Mabujina (unpublished data).

P-t conditions, age and origin of metamorphism

Thermobarometric estimates (Fig. 4) in the Cajálbana and Iguará-Perea complexes indicate maximum pressures lower than 3 kbar and temperatures of 600-650 ºC (Cajálbana), 650-800 ºC (Iguará-Perea metadiabases) and 900-1100 ºC (Iguará-Perea (granulites). Because of the poorly known thermodynamic properties of amphibole solid solutions, the more conservative lower bounds of these temperature ranges are preferred. ^{40}Ar/^{39}Ar plateau ages have yielded 88.0 +/- 3.2 (LV38, granulite of Igará-Perea) and 129.8 +/- 1.9 Ma (SRO2A, deformed metadiabase of Cajálbana). Both dates are interpreted as cooling ages since the temperature attained were in excess of 600 ºC and the blocking temperatures of the isotopic system is 500-600 ºC. That is, the samples abandoned their respective thermal focuses (i.e., cooled below 500 ºC) by ca. 130 and 90 Ma. Such difference in the age of cooling is considered to reflect local, rather than regional, thermal focuses for metamorphism. This, and the coherent Ar-release spectra of the sample from Iguará-Perea, suggests that the age of this sample may not be the result of the resetting of the isotopic system at the Upper Cretaceous. Work is in progress to confirm/reject this hypothesis.

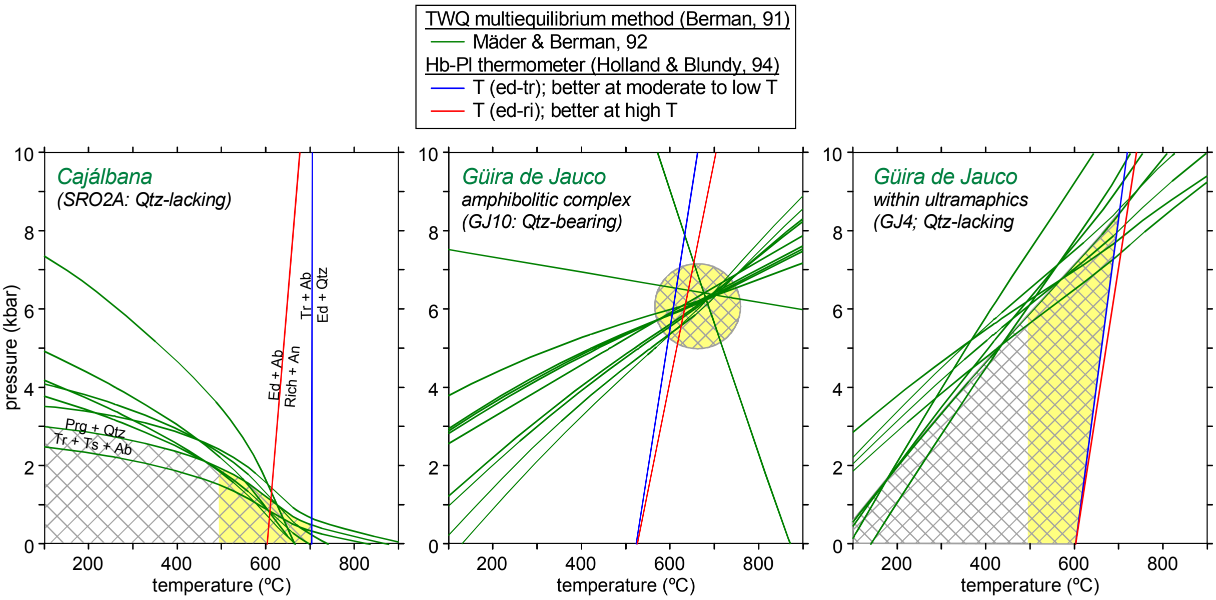

Figure 4. P-T estimates of representative samples of amphibolites from Cajálbana and Güira de Jauco. In the quartz-lacking samples the pressure estimates are maximum.

The low pressure of metamorphism and the general lack of deformation in all types of rock from both regions suggest ocean-floor type of metamorphism. This is strengthened by the composition of amphibole and apatite from the metadiabases, which are rich in Cl and comparable to amphiboles from samples dragged in present-day oceanic environments. Additionally, amphibole grains from the metadiabases show cores with lower Si and Mg and higher Al(T), Al(C), Ti, and Na+K(A) contents, and rims with higher Si and Mg and lower Al(T), Al(C), Ti, Fe, and Na+K (A) contents. Na(B) is systematically low (< 0.14 atoms per 22 O, 2(OH,F,Cl)) and does not change significantly from core to rim. This type of zoning indicate cooling during amphibole growth at constant low-pressure, in agreement with expectations of ocean-floor metamorphic recrystallization. Interestingly, however, some grains show oscillatory zoning that indicate the occurrence of events of re-heating in the general course of amphibole growth during cooling, perhaps due to the input of magma batches in the neighborhood. However, the probable Lower and Upper Cretaceous age of formation of the protoliths and of metamorphism in Cajálbana and Iguará-Perea, respectively, and the likely formation of both complexes at suprasubduction environments, are better explained by arc-related rather than true mid-ocean ridges thermal focuses. We suggest arc environments either at embryonary stages of development or abandoned (i.e., short-lived) in favor of other locations where the arcs copiously developed (i.e., to the south, in the case of Iguará-Perea). This interpretation is strengthened by the existing correlation between the age of metamorphism and the geochemical nature of the protoliths, that mirror relationships between the age and type of igneous suite of the Cretaceous arcs of Cuba. Thus, the protoliths of the metabasites from Cajálbana formed in the Lower Cretaceous (pre-Hauterivian) and have an island-arc tholeiitic signature similar to the Lower Cretaceous (pre-Aptian) primitive island arc. The protoliths of the metabasites from Iguará-Perea, on the other hand, probably formed in the Upper Cretaceous (pre-Turonian) and have an island-arc calc-alkaline signature similar to the Upper Cretaceous (post-Albian) island arc. In this respect, it is worth mention that not only age and chemical signature of the basic rocks conform with these relationships, but also other features such as the presence of Upper Cretaceous calc-alkaline granitoids in the Iguará-Perea complex similar to Upper Cretaceous calc-alkaline granitoids of the Mabujina complex that underlies the volcanic arc in southern central Cuba (Fig. 2).

Thermobarometric estimates in the Güira de Jauco complex yield conditions of 600-700 ºC and 6-8 kbar (Fig. 4). This pressure and the strong syn-metamorphic deformation indicate collision-related metamorphism. Research is currently in progress to obtain the age of this collision event. Late Upper Cretaceous age is indicated by the available K-Ar ages (75-58 Ma; Iturralde-Vinent et al., 1996), though it is uncertain whether these ages represent the age of collision-related metamorphism or resetting of the isotopic system during the Upper Cretaceous collision of the calc-alkaline arc and adjacent oceanic lithosphere with the North America margin indicated by the structural pile of the region (i.e., Purial volcanics, Sª del Convento serpentinite melange, Moa-Baracoa ophiolite, Güira de Jauco, and Asunción metasediments). The basalt-picrite association in this complex and its geochemical signatures, on the other hand, suggest an Upper Cretaceous (ca. 90-80 Ma?) intraplate magmatism similar to that of the Caribbean Large Igneous Province. Still, magmatic under-plating at the base of an oceanic lithosphere (represented by the serpentinites containing amphibolitic layers) is hypothesized here because of the location of the Güira de Jauco complex at the base of the Moa-Baracoa ophiolite.

Tectonic implications

Our data confirm a protracted geologic history of the oceanic lithosphere represented by northern serpentinite belt previous to its accretion to the North-America/Yucatan margin during the uppermost Cretaceous-Paleogene. The formation of the oceanic lithosphere in the northern serpentinite belt is diachronous and involved a number of environments including Lower and Upper Cretaceous arc and Upper Cretaceous(?) intraplate settings. These episodes must be added up to the inferred major episode of formation of oceanic lithosphere that took place at mid-ocean ridges during the Upper-Jurassic to Lower-Cretaceous drift of North and South America. Though these data cannot, by themselves, solve the plate tectonic configuration of the northern margin of the Caribbean plate during the Mesozoic, they put important constraints to available models. For example, in the model of Pindell and co-workers (e.g. Pindell & Barrett, 1990; Pindell, 1996), that incorporates a pre-Aptian NE-dipping subduction of the Pacific plate below the Proto-Caribbean (Atlantic Caribbean) lithosphere, the Cajálbana ophiolite should fit with a fragment of the Proto-Caribbean because of its suprasubduction nature at the Lower Cretaceous. After the Aptian-Albian polarity flip of subduction predicted by this model, this part of the Proto-Caribbean should not have entered the SW-dipping subduction zone, as it does not appear metamorphosed to high pressure. That is, the Cajálbana ophiolites should represent a fragment of the pre-Aptian Proto-Caribbean plate incorporated to the Caribbean plate during the Aptian-Albian, and consequently located at the fore-arc of the Great Arc of the Caribbean during the Upper Cretaceous. On the contrary, the Iguará-Perea complex should correspond with a fragment of the Caribbean plate (or pre-Aptian Pacific in this model) because of its suprasubduction nature and probable Upper Cretaceous age, when the model predicts SW-dipping subduction of the Proto-Caribbean below the Caribbean plate. In this model, the most likely position of the lithosphere represented by the Iguará-Perea complex would be the fore-arc of the Great Arc of the Caribbean. Finally, the Güira de Jauco-Moa-Baracoa ophiolite may represent Upper Cretaceous Caribbean lithosphere but, at divergence with the Iguará-Perea complex, located well within the interior of the plate because of its proposed intraplate origin. To be noted, however, is that the Güira de Jauco-Moa-Baracoa ophiolite may also represent Proto-Caribbean lithosphere in this model, as long as a large plateau basalt region is located to the SE prolongation of the Florida-Bahamas block. These configurations have profound impact in the predicted provenance of the ophiolitic bodies. Thus, the position of the Cajálbana and Iguará-Perea ophiolites at the fore-arc of the Great Arc of the Caribbean in Upper Cretaceous times implies that the arc overrode the fore-arc during the late Upper Cretaceous to Paleogene collision of the arc with the North America/Yucatan margin, in accordance with common views of the structure of the Cuban orogenic belt (Iturralde-Vinent, 1996), but the intraplate position of the Güira de Jauco-Moa-Baracoa ophiolite would imply that the arc was overridden by the northern serpentinites (if the body belongs the Pacific plate) or that the arc overrode the ophiolite (if the latter belongs to the Proto-Caribbean). On the other hand, the Cajálbana and Iguará-Perea ophiolitic bodies can be conceptualized in the model of Iturralde-Vinent and co-workers (e.g. Iturralde-Vinent, 1996; Kerr et al., 1999) as fragments of the Proto-Caribbean during Lower and Upper Cretaceous times, since the model predicts NE-dipping subduction of the Caribbean below the Proto-Caribbean at his time. The most likely position of the lithosphere represented by these ophiolitic bodies would be to the back-arc of the Great Arc of the Caribbean, latter overridden by the Great Arc and emplaced on top of the North America/Yucatan margin during the Upper Cretaceous to Paleogene arc-continent collision. As in Pindell's model, the Güira de Jauco-Moa-Baracoa ophiolite may be of Caribbean or Proto-Caribbean origin and, consequently, may have been overridden by the arc (if the ophiolite belongs to the Pacific plate) or the arc may have overrode the ophiolite (if the latter belongs to the Pacific plate). Clearly, more field, petrological and geochronological work in the northern serpentinite belt is needed before the problems addressed here are solved.

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