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New evidence for late Eocene-early Oligocene uplift of Aves Ridge and paleogeography of GAARlandia

Manuel A. Iturralde-Vinent[1] and **Ross D.E. MacPhee**[2]

[1]**Cuban Academy of Sciences**
Cuba 360, La Habana Vieja, La Habana, Cuba. E-mail: maivcu@gmail.com

[2]**American Museum of Natural History**
200 Central Park West, New York, NY 10024, USA. E-mail: macphee@amnh.org

ABSTRACT

The GAARlandia hypothesis has produced vigorous debate among biologists regarding whether now-submerged landforms that existed in the Caribbean region during the late Paleogene might have acted as a barrier for marine organisms and as a bridge for terrestrial biotas migrating from South America into the Greater Antilles. This concept derived from the hypothesized emergence history of the Aves Ridge. In the quarter century since GAARlandia was first proposed, new paleontological, geological and geophysical information has greatly extended the database available. Here we reaffirm that GAARlandia was a positive topographic feature from middle Eocene, and was exposed above sea level between late Eocene and early Oligocene when it facilitated biotic colonization of the northern Greater Antilles and their satellite islands, whether as a series of closely spaced islands or as a continuous peninsula projecting from northeastern South America along the crown of the rise.

KEYWORDS **GAARlandia. Aves Ridge. Eocene-Oligocene. Paleogeography. Biogeography. Caribbean.**

INTRODUCTION

GAARlandia (Greater Antilles Rise-Aves Ridge) was originally proposed as a late Eocene-early Oligocene peninsular extension of northeastern South America (Fig. 1; Iturralde-Vinent and MacPhee, 1999). The basic hypothesis posits that widespread uplift in the Caribbean Basin ca. 35-32Ma resulted in a transient subaerial connection ("landspan") between South America and the northern Greater Antilles, extending as far as Central Cuba. This event may, in turn, have provided a pathway for dispersing terrestrial organisms, allowing them to successfully enter the evolving Greater Antilles (Iturralde-Vinent and MacPhee, 1999; MacPhee and Iturralde-Vinent, 1995). These, however, are quite separate issues: whether GAARlandia actually had the biogeographical role presumed for it, as discussed pro and con in a wide array of papers (*e.g.* Ali and Hedges, 2021; Cala-Riquelme *et al.*, 2022; Chamberland *et al.*, 2018; Presslee *et al.*, 2019; Vélez-Juarbe *et al.*, 2014), is independent of the facts relating to its geological history, a distinction which is not always made in the literature. This is understandable to the degree that relatively few papers have considered the geological aspects of this hypothesis (but see Ali, 2012; Ali and Hedges, 2021; Cerpa *et al.*, 2021; Garrocq *et al.*, 2021; Hedges 2001, 2006; Padron *et al.*, 2021; Phillipon *et al.*, 2021).

The purpose of this paper is to review the paleogeographic side of this controversy in light of new work on the Aves

FIGURE 1. Eastern Caribbean map with locations mentioned in the text.

Ridge and other relevant structures in the eastern Caribbean Sea. Several points that were earlier in contention have now been resolved, thanks to new explorations of the Saba Bank (Church and Allison, 2004), La Blanquilla High (Clark *et al.*, 2008) and the Aves Ridge (Cerpa *et al.*, 2021; Escalona and Mann, 2011; Garrocq *et al.*, 2021; Padron *et al.*, 2021; Philippon *et al.*, 2020; Sawyer and Mann, 2004). In this review we evaluate their impact on efforts to reconstruct the history of the Aves Ridge, the geological arguments against GAARlandia raised by Ali (2012) and Ali and Hedges (2021), and our present understanding of GAARlandia as a paleogeographic concept.

Aves Ridge

The Aves Ridge (Fig. 1) is a N-S trending, positive submarine longitudinal structure located in the eastern Caribbean Sea. An axial ridgecrest running along its western half exhibits an irregular, undulating topography featuring shallow banks, local ridges, topographic highs and seamounts. Only two small islands, Aves and La Blanquilla, exist along the ridgecrest at present. The northern half of the ridge, denominated the Saba Bank, is separated from the Greater Antilles by the Anegada Trough. This bank is part of a complex submarine topography of highs and lows that extends eastward to the northern Lesser Antilles. To the south, the Aves Ridge continues into La Blanquilla High and the Leeward Antilles on the continental margin of South America. Toward the west, the ridge faces the Venezuela Basin, while on the southeast it gently slopes into the deep marine Grenada Basin.

It is uncontroversial that the Aves Ridge is underlain by a Cretaceous-Eocene? remnant volcanic arc basement draped by Eocene to Recent sedimentary rocks (Bouysse *et al.*, 1985; Escalona and Mann, 2011; Fox *et al.*, 1971; Neill *et al.*, 2011; Pinet *et al.*, 1985; Tomblin, 1975; see also summaries by Gallocq *et al.*, 2021; Iturralde-Vinent and MacPhee, 1999). It is likewise uncontroversial that the Aves Ridge began to rapidly subside during the early middle Miocene, as indicated by abundant evidence for middle Miocene and younger marine deposits in wells (GA28A, DSDP 30, DSDP 148; Edgar *et al.*, 1973) and dredge hauls (Bock, 1972; Bouysse *et al.*, 1985; Garrocq *et al.*, 2021; Nagle, 1972) taken along the ridge. The division of opinion in the literature concerns how much land was exposed, where and for how long. For example, Cerpa *et al.* (2021), Philippon *et al.* (2020) and Vélez-Juarbe *et al.* (2014) reported evidence of Virgin Islands-northern Aves Ridge emergence during the Eocene-Oligocene transition. By contrast, Garrocq *et al.* (2021) proposed that subsidence began at least as early as the middle Eocene, with the Ridge's entire southern half being persistently submarine throughout the Tertiary. As both interpretations cannot be correct, it is imperative to resolve this disagreement.

Seismostratigraphy

Recent seismic reflection analyses along portions of the Aves Ridge and Grenada and Venezuela basins (Garrocq *et al.*, 2021; Padron *et al.*, 2021) provide a basis for distinguishing six relevant seismic units and five unconformities (Fig. 2).

Seismic unit U2a is of critical importance for paleogeographic interpretation of the ridge during the late Eocene-Oligocene. According to seismic reflection profiles (Figs. 3,4), this unit is mainly characterized by weak, parallel and continuous reflectors with interval velocity ranges from 4.0 to 4.75km/s. This signature correlates with presence of Late Eocene to Oligocene basin floor turbidites according to Garrocq *et al.* (2021, their figure 3). The unit apparently mostly occurs on the southern part of the ridge top, as north of 14°N its thickness drastically decreases, to less than 1km. Below unit U2a there is a marked unconformity which extends to mainland South America. It is associated with a late Eocene-early Oligocene erosional hiatus in the Caracolito and Carupano basins and Leeward Antilles, which was subsequently followed by a major subsidence in the late Oligocene-Neogene (Escalona and Mann, 2011; Macsotay and Feraza, 2005; Schneider *et al.*, 2012). This hiatus is consistent with the brief episode of ridge uplift and erosion stipulated in the original GAARlandia hypothesis (Ituralde-Vinent and MacPhee, 1999).

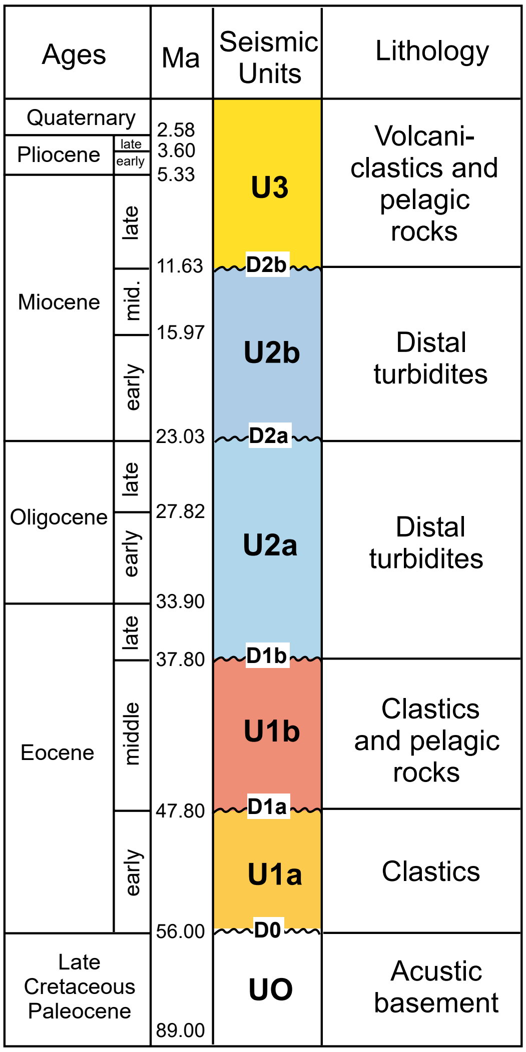

FIGURE 2. Seismostratigraphic units identified by Garrocq *et al.* (2021) within the Venezuela Basin, Aves Ridge and Grenada Basin. In the seismic profiles, alphanumeric strings beginning with U are seismic units; those with D are unconformities (redrawn and modified from Garrocq *et al.*, 2021).

Seismic reflection profiles GA21, GA34, GA02 and GA29 show the wedging-out of unit U2a from the Grenada Basin to the ridge slope (Garrocq *et al.*, 2021, their figures 3 and 5). Segments of lines GA35, GA32, GA02, GA25AB, GA31, GA04 and GA34 atop the ridge lack unit U2a (Garrocq *et al.*, 2021, their figures 7 and 8). Unit U2a is also generally missing along the ridgecrest and slope margins, with a questionable unique exception in the ridge's southern area (Fig. 4).

According to the interpretation presented by Garrocq *et al.* (2021, their figure 6d), unit U2a within the Aves Ridge is restricted to small, isolated structural depressions and does not exceed 1km in thickness (Fig. 3). The early to middle Miocene seismic unit U2b lies over unit U2a within the Venezuela and Grenada basins, except along the ridge margins where it rests on the basement (Garrocq *et al.*, 2021, their figure 5).

At present, only a single NW-SE seismic line (BOL30) is available that transects the Venezuela Basin, Aves Ridge and Grenada Basin. In the Venezuela Basin the entire set of seismostratigraphic units is present (Fig. 2), but toward the ridge axis units U2a and U2b are missing, and only Miocene unit U3 is found above the basement (Fig. 4). In the Grenada Basin an almost-complete section occurs, in which units U1, U2a, U2b and U3 reach their greatest thicknesses. Northwestward, toward the ridge slope, seismostratigraphic units U1, U2a and U2b wedge out and only unit U3 rests upon the slope (Garrocq *et al.*, 2021, their figure 5). According to Garrocq *et al.* (2021, their figure 6d), a unit attributable to U2a occurs above the ridge: but only in shallow, non-contiguous depressions (Fig. 4).

A basic question is whether the available evidence is sufficient to establish that unit U2a actually fills structural depressions in Aves Ridge, for two related reasons. First, there is no seismostratigraphic continuity between unit U2a as identified in the basins and the alleged U2a unit identified on the ridge summit (*i.e.* it cannot be traced laterally from

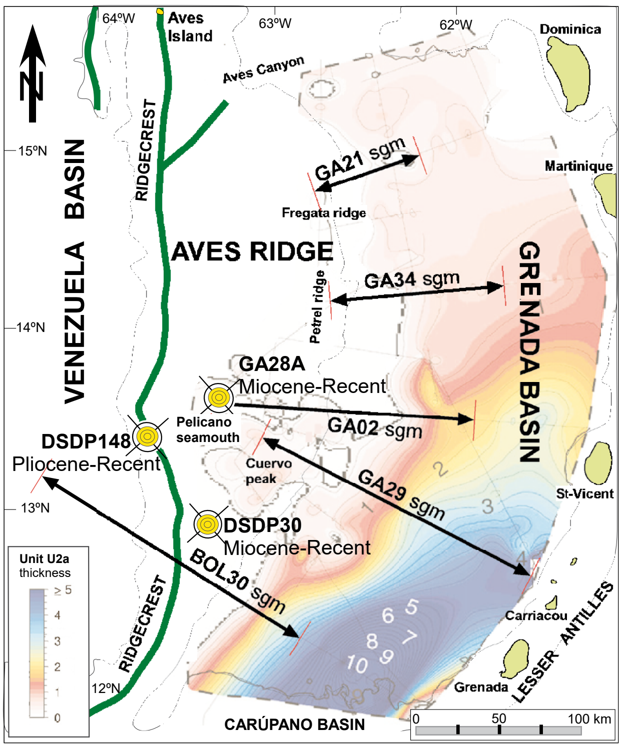

FIGURE 3. Southeastern Caribbean map depicting the thickness of the Late Eocene to Oligocene U2a seismic unit, location of selected wells, relevant seismic lines, and trace of the ridgecrest (modified and redrawn from Garrocq *et al.*, 2021).

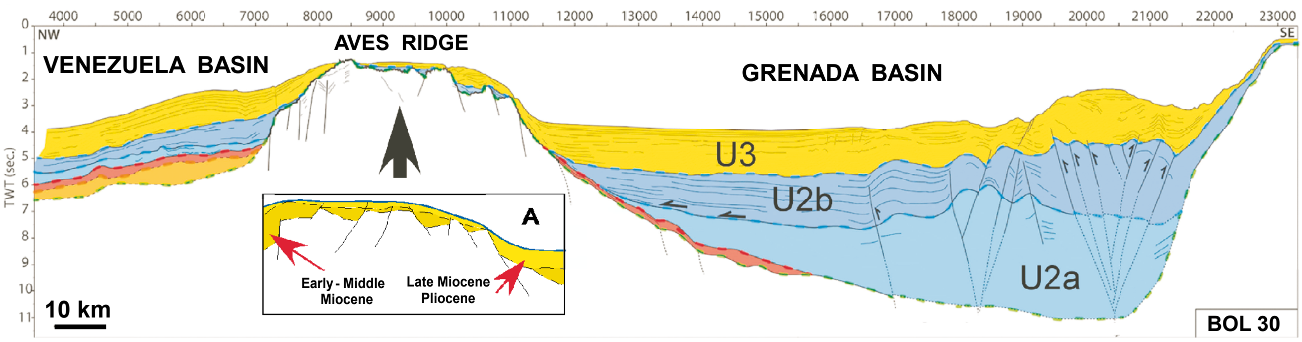

FIGURE 4. Seismic reflection profile BOL30, shot along the southern part of the Aves Ridge; location given in Figure 3. Note the presence of the questionable seismic unit U2a in the axial part of the ridge filling small local depressions, overlain by a thin layer of Unit U3; and (Insert A) alternative interpretation by Escalona and Mann (2011) (redrawn and modified from Sawyer and Mann, 2004; Escalona and Mann, 2011 and Garrocq *et al.*, 2021).

basin to ridge). Secondly, according to Garrocq *et al.* (2021, Fs8 in their Table U2), seismic facies are the same in unit U2b and U2a, and both units are interpretable as basin floor turbidites. U2a differs in that it displays slightly higher amplitudes in the uppermost part of the unit, with interval velocity ranges from 3 to 4km/s (Garrocq *et al.*, 2021, their figure 3). Yet it is surely problematic to characterize and differentiate these units on seismic grounds alone, given the low instrumental resolution (ca. 50 meters) and the reduced thickness and local distribution of "unit U2a" over the Aves Ridge. Even if it were meaningfully possible to trace unit U2a onto the ridge, describing it compositionally as a deep-water turbidite goes beyond the evidence. This is a critical issue, because there is no dispute that the Aves Ridge was a topographic high for a significant part of the Tertiary (Tomblin, 1975).

Here it is relevant to point to an alternative interpretation of the BOL30 seismic line developed by Escalona and Mann (2011, their figure 12B and C), which distinguishes two units overlying the acoustic basement above the Aves Ridge. The first is a "lower middle Miocene" section that fills small local depressions; the second, of "late Miocene-Pliocene" age, drapes the whole ridge. This interpretation is supported by DSDP148 and DSDP30 drilled on the ridge (Fig. 3). Surprisingly, Garrocq *et al.* (2021, their figure 3) show exactly the same succession at the ridge's Pelicano seamount of Aves Ridge, where Miocene to Recent deposits overlie the basement (Fig. 3; GA28A).

In addition to seismic stratigraphy and drilling, rock composition can be inferred from dredge-haul samples from Aves Ridge. These mostly consist of Eocene to lower Miocene conglomerates and limestones of shallow water to middle ramp environments (Bouysse *et al.*, 1985; Fox *et al.*, 1971; Marlowe,1971; Nagle, 1972; Neill *et al.*, 2021; Nemec, 1980), which obviously do not represent distal turbidites as defined by Garrocq *et al.* (2021) for units U2a and U2b. However, their presence is fully consistent with positive relief (submarine and/or subaerial) on the Aves Ridge during this time interval. Some of these samples show evidences of short phases of emersion (Garrocq *et al.*, 2021). It therefore cannot be excluded that the seismic unit developed in the isolated depressions and located between basement and unit U3 is neither U2a nor U2b, but instead, an entirely different unit of Miocene age.

Additional data challenging the interpretation of the Aves Ridge as a completely submarine feature sensu Garrocq *et al.* (2021) during late Eocene-Oligocene times come from the geology of the Saba Bank and La Blanquilla High, representing the northernmost and southernmost ends of the Aves Ridge (Fig. 1). According to the geological and geophysical data compiled by Church and Allison (2004), the northwestern half of the Saba Bank represents an elevated basement, consistent with the presence of a hiatus between Cretaceous and Pliocene sections (Fig. 5; Church and Allison 2004, their figures 4 and 27). East and southeast of this structural high, facing the Grenada Basin, there is a neritic to bathyal Oligocene and early Miocene fluvio-deltaic sequence, containing significant quantities of volcanoclastic material derived from the uplifted western part of Saba Bank and adjacent areas. La Blanquilla High consists of Cretaceous metamorphic and igneous basement covered by middle Miocene and younger deposits (Clark *et al.* 2008, their figure 4, North A7 line).

Overall, the geological and geophysical evidence is fully consistent with the view that much of the Aves Ridge, especially its ridgecrest, was emergent during latest Eocene-early Oligocene times, after the termination of magmatism in a remnant arc environment, and at the same time as an uplift was taking place in the Greater Antilles, Virgin Islands and northern South America (Cerpa *et al.*, 2021; Church and Allison, 2004; Clark *et al.*, 2008; Escalona and Mann, 2011; Iturralde-Vinent and MacPhee, 1999;

MacPhee and Iturralde-Vinent, 1995, 2005; Macsotay and Feraza, 2005; Vélez-Juarbe *et al.*, 2014).

With regard to the uplift/subsidence calculations made by Garrocq *et al.* (2021), they note that their approach "…does not allow us to calculate amounts of uplift [within the Aves Ridge], since we cannot estimate the amount of material that would have emerged and been eroded." The subsidence and subsidence rates calculated at different sites by Garrocq *et al.* (2021) suggest that "…from early Eocene to the end of middle Eocene (~56-38Ma), all the sites subside uniformly and the differences between them are within the error range", a statement which conflicts with the lack of a depositional record on the ridgecrest. Furthermore, they stipulate that from "late Eocene to Oligocene (~38-23Ma), the subsidence rate decreases at all sites from 0.02-0.03 to 0.01mm/yr". This decrease of the "subsidence rate", which is probably valid only for the ridge´s eastern slope where calculations were made. In fact correlates with the time of accelerated uplift and emergence of the Aves Ridge axis as suggested by the wide range of observations discussed above.

Geological arguments against GAARlandia

Arguments against the geological tenets of the GAARlandia hypothesis were first raised by Hedges (2001, 2006). These were addressed by MacPhee and Iturralde-Vinent (2000, 2005) and Iturralde-Vinent (2006; pages 812, 819-820). In regard to the Aves Ridge, Hedges (2001) stated that "…the difference between an island chain and a continuous land bridge is fundamental for biogeography [but] geological support for a continuous land bridge vs. a chain of islands does not exist." Iturralde-Vinent and MacPhee (1999) did not rule out the possibility that GAARlandia may have consisted of a chain of closely-spaced islands separated by shallow shelves. In fact, either scenario provides a mostly-terrestrial Eo-Oligocene route for dispersion of land taxa, as confirmed by the expanding Antillean fossil record (MacPhee *et al.*, 2003; MacPhee and Iturralde-Vinent, 2005; Marivaux *et al.*, 2020; Tejada *et al.*, in press; Vélez-Juarbe *et al.*, 2014). Whatever the fine details of its subaerial history, Aves Ridge operated as a filter, not as a wide-open corridor for the unimpeded dispersion of land biota of all kinds (Iturralde-Vinent, 2006, page 812; MacPhee and Iturralde-Vinent, 2000).

More recently, Ali (2012) and Ali and Hedges (2021) have challenged the GAARlandia hypothesis on various geological and oceanographic grounds, but do not provide any new data on stratigraphy, rock dating or tectonic reconstruction. One argument that need not be considered further, as it has already been addressed above, is their contention that GAARlandia, as a continuous landspan or landbridge, fails because "the southern and central Aves Ridge was submerged during the Eocene-Oligocene boundary". This assertion is contrary to the results of the new investigations referenced here.

Ali (2012) has noted that the "lack of ocean-floor drilling data demonstrating the extent to which Aves was sub-aerial in the mid-Cenozoic" is a problem. We agree; but we also contend that the information provided by new sample dredging and drilling (Church and Allison, 2004; Clark *et al.*, 2008; Garrocq *et al.*, 2021; and see DSDP30, DSDP148 and GA28A, Fig. 3) is a good basis for establishing environmental conditions, and should not be ignored. Ali (2012) has also maintained that "Insights can, however, be gleaned from active island arcs around the globe, *e.g.* Marianas-Bonin (western Pacific), Scotia (South Atlantic), Kermadec-Tonga (South-West Pacific), Sangihe (Molucca Sea), Luzon (western Philippine Sea), as well as the Lesser Antilles. Cursory inspection of these archipelagos renders it highly improbable that the Aves volcano chain ever formed an unbroken land bridge between South America and the Greater Antilles." Quite so, but such a selective list is hardly conclusive because counter-examples, such as Kamchatka, Panama-Central America, Baja California and the Alaskan Peninsula, can be cited just as easily. More importantly, in trying to understand the fate of GAARlandia it is critical to appreciate that, by the middle Eocene, the Aves Ridge was no longer an active arc. It was only at this stage, after the end of magmatic activity, that the post-volcanic ridge would have undergone a phase of uplift and emergence, as has been recorded for other volcanic arcs (Gough, 1973; Iturralde-Vinent and MacPhee, 1999).

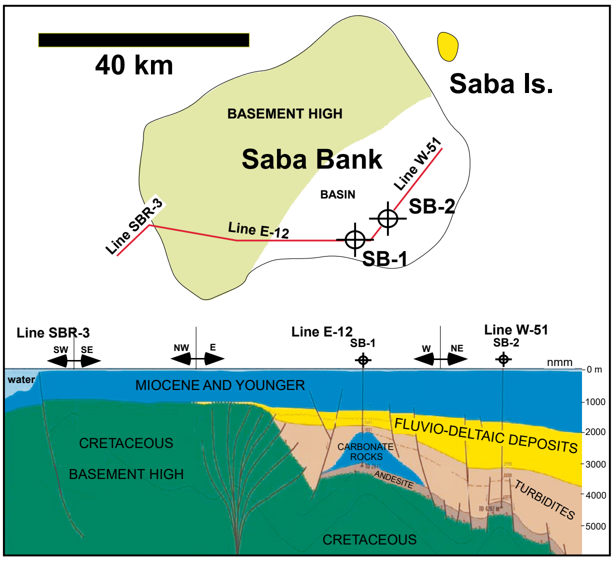

FIGURE 5. Basement high on the Saba Bank, northern Aves Ridge. Location map and combined seismic lines (redrawn from Church and Allison, 2004).

Not relevant for a different reason is Ali's (2012) contention, based on Escalona and Mann (2011), that the southern tail of the Aves Ridge-Lesser Antilles complex (within the Caribbean plate) slid along the Venezuelan margin (South American plate) between the middle Eocene and the middle Oligocene. As this model agrees with the tectonic reconstructions utilized by Iturralde-Vinent and MacPhee (1999), it stands as an endorsement rather than a disagreement with the GAARlandia hypothesis (see also Clark *et al.* 2008; Locke and Garver, 2005; Pindell and Kennan, 2009).

Finally, Ali (2012) disagrees with Iturralde-Vinent and MacPhee's (1999) interpretation of GAARlandia as a barrier for marine water circulation between the Central Atlantic and the main Caribbean because we "failed to incorporate computer-based palaeoceanographical simulations to the ocean current analysis"; and because "ocean-atmosphere modelling for various points in the Cenozoic, invariably shows currents flowing from northern South America to the Greater Antilles (Huber and Caballero, 2003)". This last statement is generally correct because of the pervasive effects of Coriolis forces, but it should be noted that the Huber and Caballero (2003) model is focused on the Eocene (55 to 35Ma) "El Niño" events centred in the Pacific Ocean, and does not cover the latest Eocene-early Oligocene time interval (35 to 32Ma) within the Caribbean. By contrast, our modelling of marine currents was based on a digest of published data concerning historic migratory patterns of marine biota, present-day patterns of circulation, ocean water geochemistry, submarine topography, and real-time experimental investigations utilizing tracking buoys (see summaries in Iturralde-Vinent, 2003, 2006; Ivany and Nesbitt, 2003; MacPhee and Iturralde-Vinent, 2005; Prothero *et al.*, 2003).

Paleogeography of GAARlandia: A New Synthesis

This synthesis takes into account relevant paleontological, geological and geophysical literature appearing since the original statement of the GAARlandia hypothesis (Iturralde-Vinent and MacPhee, 1999), organized by sectors from northwest to southeast.

Northwestern GAARlandia

Commenting on the biogeographical history of certain bat and insectivoran taxa, Agnolin *et al.* (2019, their figures 1 and 2) suggested that GAARlandia might have extended all the way to North America in the early Miocene, thereby facilitating a biotic exchange between that continent and westernmost Cuba. This northwestward extension of the GAARlandia landspan is contradicted by geological and geophysical data collected along the Strait of Yucatan, which indicates that a deep water channel has intervened between Cuba and the mainland at least since the Oligocene (Iturralde-Vinent and MacPhee 1999, their figure 14). Furthermore, a fairly deep-water channel existed between western and central Cuba during Oligocene and Miocene times, in the present area of La Habana and Matanzas provinces (Fig. 6B; Iturralde-Vinent and MacPhee, 1999).

Agnolin *et al.* (2019) also argued that, during latest Eocene-early Miocene times, the Greater Antillean rise was a close-packed array, either constituting a single large island or a series of islands separated by very narrow water gaps from each other and from North and Central America. Thus, dispersal between the Antilles and proximate mainland may have been easier at that time than it would be today (Agnolin *et al.*, 2019). But this scenario fails to consider two important facts: i) During late Oligocene and early Miocene, a general transgression affected the land areas of the Greater Antilles, southern North America and northern South America, reducing subaerial exposure and actually increasing rather than decreasing over-water distances between these land masses (Iturralde-Vinent and MacPhee, 1999, their figures 4, 7, 8, 15, 18, 20, 21 and 22). ii) Since the Miocene, tectonic extension along the Caribbean-North American plate boundary has opened and/or enlarged several deepening marine channels (Cayman Trench, Anegada Trough), interrupting the continuity of GAARlandia (Iturralde-Vinent and MacPhee 1999, their figures 7, 8), again increasing rather than decreasing distances between land areas.

Puerto Rico-Virgin Islands

Vélez-Juarbe *et al.* (2014), Phillipon *et al.* (2021), Cerpa *et al.* (2021) and Marivaux *et al.* (2021) report a regional late Eocene-early Oligocene hiatus in the sedimentary record, related to tectonic uplift. The existence of this subaerial element represents a potential connection to the Aves Ridge before the opening of the Anegada Trough. This, together with fossils indicating the occurrence of a land biota at that time, supports the existence of a Greater Antilles-Northern Lesser Antilles landmass, subsequently reduced after the mid Oligocene-early Miocene transgression. Both the fossil record (MacPhee *et al.*, 2003; Marivaux *et al.*, 2020; Vélez-Juarbe *et al.*, 2014) and inferences from molecular biology (Cala-Riquelme *et al.*, 2022; Chamberland *et al.*, 2018) demonstrate that complex terrestrial ecosystems were already present in the Greater Antilles in the late Paleogene.

Aves Ridge, Saba Bank and La Blanquilla High

In their original description of GAARlandia, Iturralde-Vinent and MacPhee (1999, page 31) noted that the exposed ridgecrest of the north-south trending Aves Ridge created, for a short time ca. 33-35Ma, "a series of large, closely spaced islands or possibly a continuous peninsula stretching from northern South America to the Puerto

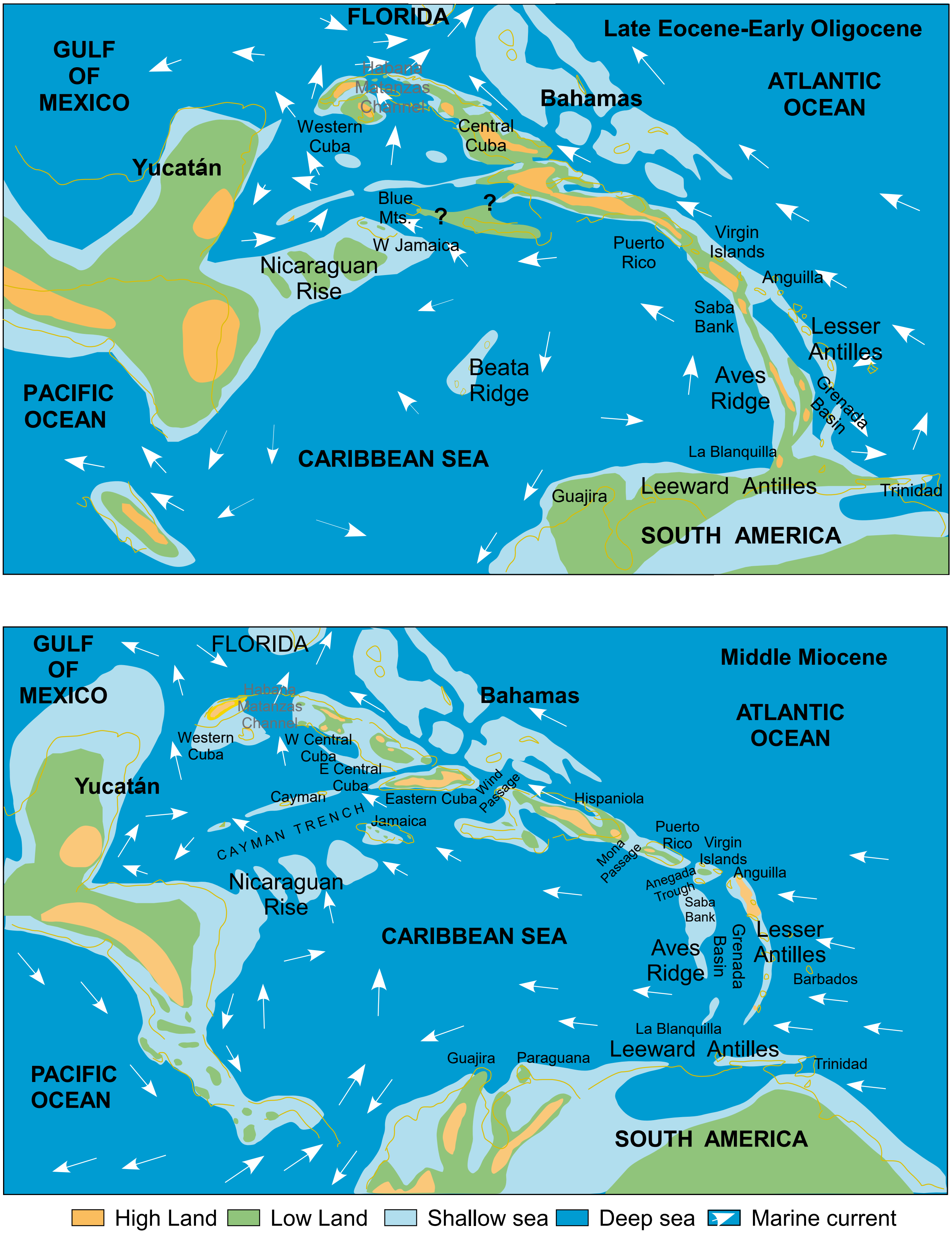

FIGURE 6. Paleogeographic maps with hypothetical ocean currents for the A) late Eocene-early Oligocene (35-32Ma) and B) middle Miocene (14-12Ma). Updated from Iturralde-Vinent and MacPhee, 1999; Iturralde-Vinent, 2006 and references therein.

Rico-Virgin Island Block". Our reinterpretation of the data provided by Patron *et al.* (2021) and Garrocq *et al.* (2021) augments this analysis by strongly suggesting that the Aves ridgecrest, including the Saba Bank and La Blanquilla High, was a structural high, and most probably land, during middle Eocene-early Miocene times. All pertinent data reaffirm our conception of the termination of GAARlandia as a subaerial entity due to Miocene subsidence, when the Aves Ridge became a shallow-water carbonate platform that has persisted as such until the present (Church and Allison, 2004; Clark *et al.* 2008, their fig. 4, North A7 line; Iturralde-Vinent and MacPhee, 1999).

Northern South America

The final riddle to solve is the nature of the linkage between GAARlandia and northern South America, which would have taken place while the Caribbean plate was sliding along the South American plate, but after extinction and uplift of the Aves remnant magmatic arc (Clark *et al.* 2008; Escalona and Mann, 2011; Locke and Garver, 2005; Pindell and Kennan, 2009; Sawyer and Mann, 2004). The possibility of subaerial continuity between Aves Ridge and mainland during the interval 35-33Ma was contemplated by Iturralde-Vinent and MacPhee (1999), and new research has strongly affirmed this by identifying the occurrence of a major unconformity and depositional hiatus between the upper Eocene and the lower Oligocene in several stratigraphic sections along the northern South American periphery, including the Cordillera de la Costa, Leeward islands, La Blanquilla High, and the Caracolito and Carupano basins (Clark *et al.*, 2008; Locke and Garver, 2005; Macsotay and Feraza, 2005; Schneider *et al.*, 2012).

Lesser Antilles

Searching for an alternative to the GAARlandia landspan, Cornée *et al.* (2021, 2023) recently proposed that the appearance of large archipelagos in the Lesser Antilles during the early middle Miocene and the latest Miocene, may have facilitated dispersals between South America and the Greater Antilles by decreasing interisland distances within the Lesser Antilles. This interesting idea is partly confounded by countervailing evidence for general subsidence and transgression, beginning in the late Oligocene-early Miocene, during which time the distances between all land areas in the Caribbean Sea and its surroundings would have increased (Fig. 6B). It is plausible that middle Miocene uplift in the Lesser Antilles would have increased the dimensions and proximity of some local landmasses. However, widening water gaps in other parts of the Caribbean Sea, due to Miocene extension (*e.g.* Cayman Trench, Windward Passage, Mona Passage, Anegada Trough, Saba Bank, Grenada Basin, Carupano Basin, Caracolito Basin) as well as subsidence, would have had the opposite effect (Fig. 6B). These considerations tend to showcase not only the possibilities, but also the problems, inherent in overwater dispersal in the Caribbean Sea (Iturralde-Vinent and MacPhee, 1999; MacPhee and Iturralde-Vinent, 2004). Clearly, the last word on the fascinating biogeographical issues connected with this region have yet to be written.

CONCLUSION

New paleontological, geological and seismic information obtained from the eastern Caribbean (Puerto Rico, Virgin Islands, Aves Ridge, Saba Bank, Grenada Basin, Lesser Antilles, La Blanquilla High, Leeward Antilles and northern South America) supports the conclusion that the ridgecrest of the Aves Ridge was a positive topographic feature from the middle Eocene to the early Miocene. Furthermore, the bulk of the available evidence continues to favor the interpretation that GAARlandia was emergent, at least during the late Eocene-early Oligocene transition, between 35 and 32Ma. Whatever the fine details of its subaerial history, Aves Ridge operated as a filter, not as a wide-open corridor for the unimpeded dispersion of land biota of all kinds from South America into the Greater Antilles.

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