Geological architecture and history of the Antigua volcano and carbonate platform: Was there an Oligo–Miocene lull in Lesser Antilles arc magmatism?

Leny Montheil, Mélody Philippon, Jean-Jacques Cornée, Marcelle Boudagher-Fadel, Douwe J.J. van Hinsbergen, Pierre Camps, Marco Maffione, Franck Audemard, Brechtje Brons, Koen J.R. van der Looij, et al.

Geological architecture and history of the Antigua volcano and carbonate platform: was there an Oligo-Miocene lull in Lesser Antilles arc magmatism?

Leny Montheil[1], Mélody Philippon[2], Jean-Jacques Cornée[2], Marcelle Boudagher-Fadel[3], Douwe J.J. van Hinsbergen[4], Pierre Camps[1], Marco Maffione[6], Franck Audemard[5], Brechtje Brons[4], Koen J.R. Van der Looij[4], Philippe Münch[1]

[1] *Géosciences Montpellier, Université de Montpellier-CNRS-Université des Antilles), 34095 Montpellier Cedex 05, France. leny.montheil92@gmail.com; pierre.camps@umontpellier.fr; philippe.munch@umontpellier.fr*

[2] *Géosciences Montpellier (Université de Montpellier-CNRS-Université des Antilles), 97159 Pointe-à-Pitre, France. melody.philippon@univ-antilles.fr; jean-jacques.cornee@umontpellier.fr*

[3] *Office of the Vice-Provost (Research), University College London, 2 Taviton Street, London WC1H 0BT, UK. m.fadel@ucl.ac.uk*

[4] *Department of Earth Sciences, Utrecht University, Princetonlaan 8A, 3584 CB Utrecht, the Netherlands. D.J.J.vanHinsbergen@uu.nl; b.brons@students.uu.nl; k.j.r.vanderlooij@students.uu.nl*

[5] *FUNVISIS, Caracas, Venezuela. faudemard@gmail.com*

[6] *School of Geography, Earth and Environmental Sciences, University of Birmingham, B15 2TT, UK. M.Maffiane@bham.ac.uk*

Keywords: Lesser Antilles subduction, arc, magmatic lull and flareup, Antigua, tectonics, radiochronology, biostratigraphy.

Corresponding author : Leny Montheil, leny.montheil92@gmail.com

ABSTRACT

Since the acceptance of plate tectonics, the presence of calc-alkaline magmatic rocks is recognized as evidence of subduction. But under specific geodynamic circumstances, subduction may occur without generating magmas. Here, we investigate the Cenozoic northern Lesser Antilles arc where, from sparsely exposed magmatic records, Eocene-Oligocene and Pliocene magmatic flare-ups and a Miocene lull were postulated. Nevertheless, most of the arc is submarine, so it is challenging to discern lulls and flare-ups from sampling bias. We make a review of the magmatic evidences exposed onshore in the Lesser Antilles and investigate in detail the island of Antigua that exposes an Eocene to Miocene volcanic sequence and platform carbonate series that coincide with the postulated lull. By combining, lithostratigraphic analysis, structural mapping, $^{40}Ar/^{39}Ar$ geochronology, and biostratigraphy we refine the magmatic history of the island and date the arrest of extensive arc magmatism at 35 Ma, with minor activity until 27 Ma. No magmatic products are interleaved with the platform sequence until the latest Oligocene, confirming a lull in northern Lesser Antilles arc magmatism, that may have lasted ~ 20 Ma. We propose that the magmatic activity contributed to the paleo-(bio-)geographical evolution of the Eastern Caribbean region with crustal thickening during flareup favouring the rise of terrestrial pathways and thermal subsidence during lull responsible for its demise.

Fault kinematic analysis together with anisotropy of magnetic susceptibility suggests that magmatic arrest is not associated with a change in stress field during Oligocene. We speculate that slab flattening triggered by progressive curvature played a role in the temporal shut-down of the northern Lesser Antilles arc.

INTRODUCTION

Active volcanic arcs and associated calc-alkaline magmatic rocks are recognized as closely associated with, and being the result of, modern subduction zones (e.g., Tatsumi et al., 1983; Davies and Stevenson, 1992; Pearce and Peate, 1995). Based on that observation, geological records of volcanic arcs have become widely used as argument to date and reconstruct contemporaneous paleo-subduction zones (e.g., Li et al., 2008; Merdith et al., 2021; Cawood et al., 2009). But is the reverse also true ? Is absence of arc magmatism evidence against subduction?

Worldwide, spatial and temporal lulls in magmatism are identified with the absence of calc-alkaline magmas in the rock record. Such gaps are observed in the trans-Mexican belt (Ferrari et al., 2001, 2012), the Andes (Kay and Coira, 2006; Gutscher et al, 2000; Rosenbaum et al., 2021), the archetypal Cascade arc of the western USA (Glazner, 2004), the Nankai trough near Japan (Cross and Pilger, 1982; McGeary et al, 1985), Taiwan (Yang et al., 1996), Sumatra (Zhang et al., 2019), and in Tibet (Ma et al., 2022). In the western European Alps, subduction of the Tethys ocean did not produce long-lasting magmatic activity (e.g., McCarthy et al., 2020). Such paucity of magmatic evidence is typically explained by specific variations in geodynamical parameters that may affect the downgoing plate and the upper-plate, such as flat-slab subduction (McGeary et al, 1985, van Hunen et al., 2002, Martinod et al, 2013, Zhang et al., 2019; Ma et al., 2022), subduction of hyperextended, dry mantle (McCarthy et al., 2020), or changes in convergence rates (Cross and Pilger, 1982), but not as an absence of subduction.

In the Eastern Caribbean, the Lesser Antilles region host an arc for which magmatic flare-ups and lulls has been postulated (Briden et al., 1978; Bouysse and Westercamp, 1990). At first-look, the Lesser Antilles arc is a textbook example of ocean-ocean

subduction (e.g., MacDonald et al., 2000). The N-S trending Lesser Antilles trench accommodate 2 cm/year of westward motion of North and South America relative to the overriding Caribbean plate (Pindell and Dewey, 1982; Boschman et al., 2014, Symithe et al., 2016) (Fig. 1). Marine magnetic anomalies in the Cayman Trough, that forms a pull-apart basin on the Caribbean-North American plate boundary, documented constant and stable westward plate motion since 50 Ma (Leroy et al., 2000). This subduction is associated with a currently active, well-developed modern volcanic arc that consists of 17 active volcanoes forming islands spread over ~800 km. Nevertheless, the arc rocks exposed on these islands are mainly recent (Pliocene to Present-day) and the magmatic record shows significant breaks in volcanism along sections of the arc during both the Late Paleogene and Miocene, especially in the northern part of the arc (Brown et al., 1977; Briden et al. 1979; Bouysse and Westercamp, 1990; MacDonald et al., 2000; Legendre et al. 2018; Noury et al., 2021). In the northern Lesser Antilles, older arc rocks are confined to the islands of the 'Limestone Caribbees', that are located in the forearc of the modern arc (Fig. 1, Fig. 2, Table 1). The Limestone Caribbees contain well-developed Eocene (~45 Ma) to early Oligocene (~28 Ma) volcanic records, overlain by platform carbonates. From the period between 28 Ma to 20 Ma, only sparse records of magmatic activity have been reported from the northeastern branch of the Lesser Antilles arc (Briden et al., 1978, Legendre et al., 2018, Cornée et al., 2021, Noury et al., 2022) (Fig. 2, Table 1). From 20 Ma to 4 Ma, no record of magmatic activity is reported in the Northern Lesser Antilles (Fig. 2, Table. 1). This interval could represent a lull in magmatism or simply be a sampling bias as exposure are sparsely dispersed on islands. Miocene volcanic record could also be buried below younger volcanoes or located offshore.

103 An answer to these questions may come from Antigua, that displays a
104 magmatic unit whose age was previously estimated from Oligocene to Miocene based
105 on K-Ar whole rock analysis (Nagle et al., 1976; Briden et al., 1978) and where the
106 only complete Oligocene to Miocene sedimentary sequence of the Limestone
107 Caribbees is preserved.

108 Uncertainties on the K-Ar ages, that are partly rejuvenated by a hydrothermal
109 event (Gunn and Roobol, 1976; Briden et al., 1978), on the age and thickness of the
110 sedimentary sequence (Mascle and Westercamp, 1983; Multer et al., 1986; Weiss,
111 1994) and the absence of structural data and of a description of the tectonic
112 architecture of the island lead to uncertainties on the timing of the geological events
113 that affected the island and consequently on the age of the arrest of the northern
114 Paleogene Lesser Antilles arc (even questioning the existence of its arrest).

115 In that perspective, we constrain the magmatic and stratigraphic architecture
116 and evolution of the island, by developing (1) the detailed lithostratigraphy record of
117 the island, in which we analysed the temporal and spatial relationships between the
118 previously identified lithological units; (2) a first mapping and analysis of the tectonic
119 structures deforming the lithological units; (3) an updated geological map according
120 to our lithostratigraphy and structural analysis. We aim to refine the duration of
121 magmatism and the duration and depositional setting of sedimentary rocks (which
122 may or may not overlap) by establishing (4) age estimates of key volcanic and
123 intrusive units using $^{40}Ar/^{39}Ar$ geochronology and (5) an updated facies analysis and
124 foraminiferal biostratigraphy of the marine units. To estimate whether changes in
125 magmatism correlate with tectonic changes, we perform on the scale of Antigua (6) a
126 kinematic analysis using small-scale syn- and post- depositional faults; and (7) an
127 anisotropy of the magnetic susceptibility (AMS) study to complement the structural

analysis and estimate the stress field, and changes therein, that existed during sedimentation. Finally, we aim at putting our results in most recent regional structural, stratigraphic and paleo-geographic frameworks (Philippon et al., 2020a; Marivaux et al., 2020; Cornée et al., 2021) by providing land-sea correlations using seismic lines to the west and south of Antigua acquired during the Antilles IV oceanographic cruise (Bouysse and Mascle, 1994). We will use our results to evaluate the presence and duration of a lull in Lesser Antilles magmatism and discuss our results in terms of possible geodynamic triggers for anomalous magmatism.

GEOLOGICAL SETTINGS

Regional setting

The Lesser Antilles arc developed above a west-dipping subduction zone that accommodates the convergence between the Caribbean upper plate and the downgoing North and South America plates. The plate boundary between the North and South American plates is diffuse, as relative motion between the two is minor (e.g., Pindell and Kennan, 2009; Fig. 1). To the north and south, the Caribbean plate boundary changes to E-W trending transforms, sinistral in the north and dextral in the south (Pindell and Kennan, 2009; Fig. 1). The transition is abrupt in the south and accommodated by a slab tear but gradual in the north along a curved plate boundary overlying a curved, amphitheater-shaped slab with a north(west)ward increase in subduction obliquity (Govers and Wortel, 2005; van Benthem et al., 2013; 2014) (Fig. 1). This plate configuration developed around 60-40 Ma ago when the Caribbean plate motion relative to the Americas changed from NE-ward to E-ward (Boschman et al., 2014; Montes et al., 2019). Before that, the Eastern Caribbean plate boundary consisted of an oblique subduction at the origin of the Great Caribbean Arc that

extended from Cuba to the south of the Aves Ridge (Fox et al., 1971; Bouysse et al., 1985; Christeson et al., 2008; Neill et al., 2011, Allen et al., 2019, Padron et al., 2021, Fig. 1). After the kink, the subduction became orthogonal and the arc jumped eastward toward the Limestones Caribbees.

At regional scale, a north-south morpho-structural dichotomy is observed along the curved Lesser Antilles trench: the southern back-arc region hosts the Eocene Grenada basin with a flat bathymetry and a mean depth of 2800 m and thin oceanic crust (Garrocq et al. 2021, Padron et al., 2021). To the north, the seafloor is rough, mean bathymetry is 1400 m, and the arc crust is thicker (Schlaphorst et al., 2018). The Northern Lesser Antilles region, hosts a middle to late Eocene fold and thrust belt (Philippon et al., 2020a) in which subsequently, the trench-parallel Kalinago extensional basin opened in the late Eocene to early Oligocene (Bouysse et al., 1990; Legendre et al., 2018; Philippon et al., 2020a; Cornée et al., 2021; Fig. 1). From the late Oligocene to middle Miocene, the Northern Lesser Antilles forearc became deformed by V-shaped extensional, perpendicular to the trench basins that opened from late Oligocene to middle Miocene time (Fig. 1). That may suggest intensification of the trench curvature (Philippon et al., 2020b; Boucard et al., 2021). These basins are crosscut by trench-parallel normal faults since middle Miocene that accommodate fore-arc subsidence (Boucard et al., 2021).

Offshore investigations in the southern Kalinago basin and its extension south of Antigua island (Willoughby sub-basin) showed that the sedimentary infilling was composed of three megasequences (MS) separated by regional unconformities (Sequence Boundaries, SB) : a late Oligocene to early Miocene megasequence (MS4) resting above a deformed basement and topped by the early- middle Miocene major erosional surface (SB4) indicative of a regional uplift; middle to present day

177 megasequences (MS5 to MS 6-7) representative of a subsidence of the Kalinago and
178 Willoughby basins (Cornée et al., 2021; Fig. 11, Appendix 3). No conic structures or
179 chimneys, that could have been representative of a fossil volcanic activity were found
180 on seismic lines.

181 The present-day Lesser Antilles magmatic arc consists primarily of calc-
182 alkaline volcanoes forming islands from Grenada in the south to Saba in the north
183 (Macdonald, 2000) (Fig. 1). These islands span a trench-parallel arc, with a north-
184 westward kink at the latitude of Martinique (Fig. 1).

185 To the south, the Pliocene to present-day arc is superimposed on older arc
186 rocks. In Grenada and the Grenadines, these rocks are upper Eocene to Miocene calc-
187 alkaline dykes, volcanic arc rocks and volcaniclastic deposits (Briden et al., 1979;
188 Westercamp et al., 1985; Andréïeff et al., 1987; Speed et al., 1993; Donovan et al.,
189 2003; Rojas-Agramonte et al., 2017; White et al., 2017) (Fig. 2, Table 1). In
190 Dominica, Martinique, and Sainte-Lucia, older arc rocks consist of well-developed
191 latest Oligocene to Miocene volcanics (Le Guen de Kerneizon et al., 1983,
192 Westercamp et al., 1985, Briden et al., 1979, Germa et al., 2011, Smith et al., 2013)
193 (Fig. 2, Table 1).

194 In the north, the onset of recent arc volcanoes occurred during the
195 Pliocene to present-day on Saba, St-Eustatius, St-Kitts and Nevis, Monserrat, and
196 Guadeloupe (Baker, 1984; Defant et al., 2001; Samper et al., 2007; Hatter et al., 2018;
197 Favier et al., 2019). These eruptive centers are located on the western shoulder of the
198 Kalinago basin, 50 to 20 km westward from the older eruptive centers preserved in
199 the NW-trending ‘Limestones Caribbees’ islands (St-Martin, St-Barthélemy, Antigua)
200 on the eastern shoulder of the Kalinago basin (Fig. 1).

The Limestone Caribbees host platform carbonates overlying extinct volcanoes, that are preserved in flat bathymetric high (Anguilla and Antigua Banks). These banks are bounded to the east by V-shaped basins (Fig. 1). On St-Martin, arc volcanism developed an Eocene volcaniclastic series (Dagain et al., 1989) intruded by a 29 Ma granodioritic pluton and associated dykes and sills (Noury et al., 2021), and last magmatic activity is represented by a submarine volcanic breccia of 24.4 Ma (Cornée et al., 2021, Fig. 2, Table 1). In St-Barthélemy, magmatic rocks consist of submarine tholeiitic and calk-alkaline lavas (45 to 39 Ma), granodioritic plutons (33.5 to 30 Ma) and local tholeiitic lavas (24.5 Ma, Legendre et al., 2018; Philippon et al., 2020a; Fig.1, Table 1). On Antigua, current dating (K-Ar whole rock analysis, Nagle et al., 1976; Briden et al., 1979) supports arc magmatism from the Late Eocene to Miocene and comprises plutonic and volcanic calc-alkaline rocks (Basal Volcanic Suite) and an Oligocene volcaniclastic series (Central Plain Group, Gunn and Roobol, 1976; Briden et al., 1979; Mascle and Westercamp, 1983) (Fig. 2, Table 1).

Geology of Antigua

The first geological study of the lithologies of Antigua by Vaughan (1919) described coral associations and larger benthic foraminifera. Martin-Kaye (1959) subdivided the island in three NW-SE trending geological units, the Basal Volcanic Suite (BVS), the Central Plain Group (CPG) and the Antigua Formation (Fig. 3).

The Basal Volcanic Suite is a mountainous region exposed on the west side of the island, which includes the island's highest point (Mont Obama, 402 m). The suite consists of lava flows and pyroclastic rocks, dykes, and domes of predominantly basaltic, andesitic, and dacitic compositions and with island-arc type geochemical signature (Christman, 1973; Gunn and Roobol, 1976; Fig. 3). Basaltic dykes are also found crosscutting the topmost stratigraphic units (CPG and Antigua Fm.) and are

thus considered as the last magmatic pulses exposed on the island (Martin-Kayes, 1959, 1969; Fig.2). Whole rock K-Ar analyses for volcanic rocks of the BVS gave ages ranging between 38.5 ± 2 Ma (middle Eocene) and 20 Ma ? (minimum age, early Miocene) (Nagle et al., 1976; Briden et al., 1979).

The Central Plain Group is described as a ~1500m of terrestrial volcaniclastic rocks (conglomerates, sandstones, mudrocks, tuffites) derived from volcanism and the erosion of the Basal Volcanic Suite (Mascle and Westercamp, 1983; Multer et al., 1986; Weiss, 1994). These volcaniclastic rocks are interbedded with lacustrine limestones, which contain petrified wood, charophytes, ostracods, and freshwater gastropods (Brown and Pilsbry, 1914; Trechman, 1941; Martin-Kayes, 1959, 1969; Mascle and Westercamp, 1983; Weiss, 1994; Donovan et al., 2014, Fig. 3). Thomas (1942) and Martin-Kayes (1959, 1969) also suggested that there may be patches of marine carbonates interbedded with the CPG (e.g., the Seaforth limestone, Fig. 3) that they interpreted as episodic marine invasions.

The Antigua Fm. is composed of carbonate deposits overlying the CPG, in which volcanic deposits have not been recognized. It comprises numerous coral patches and associated bioclastic carbonate deposits, upward and laterally changing into deeper marine carbonate deposits in the east (e.g., Martin-Kayes, 1959, 1969; Persad, 1969; Mascle and Westercamp, 1983; Multer et al., 1986; Weiss, 1994). The estimated thickness of the Antigua Fm is 350 to 550 m (Mascle and Westercamp, 1983). Based on the study of larger benthic foraminifera, planktonic foraminifera, ostracods, and calcareous nannofossils, the age of the Antigua Fm has been estimated as Late Oligocene (Chattian) (Vaughan, 1919; Van den Bold, 1966; Martin- Kaye, 1959, 1969; Persad, 1969; Mascle and Westercamp, 1983), consistent with five strontium isotope ages ranging from 26 to 28 Ma (Robinson et al., 2017, Fig. 3) and with recent

preliminary age determinations of Cornée et al. (2021). Previous geological studies did not investigate the tectonic architecture or structural history of Antigua.

The three units composing the island are affected by sub-greenschist hydrothermal alteration that could be responsible for rejuvenation of K-Ar ages (Briden et al. 1978). Gunn and Roobol, (1976) observed albitised plagioclases and chloritised orthopyroxenes and groundmass in the Basal Volcanic Suite. In the Central Plain Group, bright green chloritised tuffites were described by Martin-Kaye (1959, 1969) and Jackson et al. (2013). In the Antigua Fm, this alteration phase is found in the form of silicified limestones (Strang et al., 2018).

METHODS

Field investigation

Three field campaigns (2018, 2019, and 2020) were conducted to investigate the tectono-magmatic history of Antigua. Exposure within the interior of the island is poor due to thick alluvial, colluvium, or vegetation cover. Exposure is most abundant along the coast, even though numerous private properties hampered a full remapping of some coastal portions. Nevertheless, we updated the geological map by mapping the first-order lithostratigraphic units and regional structures (unconformities, faults, dykes), and investigating the relations between units (Fig. 3).

Because the Antigua formation outcrops are isolated, we coupled microfacies and biostratigraphy with lithostratigraphy to reconstruct the general sedimentary organization (Fig. 4, Appendix 1) and paleo-environments (Fig. 10). We logged eight sedimentary sections in the Central Plain Group (CPG) and ten in the Antigua Fm. (Fig. 4, Appendix 1) and used dated isolated exposures from road cuts or along the

seashore (e.g., Galleon, Military Camp, Marble Hill, Fort James, Nelson Dockyard, Piggots, Willoughby Bay), continuous cross-sections along the shoreline (e.g., Half Moon Bay, Devil's Bridge, Pigeon Beach) and quarries (Burma, Newfield, Pares, Parnham) (Fig. 3, Fig. 4). We collected some 400 structural measurements (bedding orientations, faults, striaes) and reported these on the map (Fig. 3, Appendix 4).

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

For $^{40}Ar/^{39}Ar$ geochronology, we collected samples from volcanic and igneous rocks of the BVS (Fig. 3). To understand the magmatic evolution of the island, we collected all types of magmatic material that were recognized in the island, targeting the least altered outcrops. Samples consist on an andesitic lava (ANT 20.4, Fig. 5C) crosscut by a rhyolitic dyke (DWB-B, Fig. 5C), a dacitic dome (ANT 6.8, Sugar Hill) a quartz-dioritic pluton (ANT 20.8, Old Road) and two mafic dykes, one crosscuting the CPG (ANT 20.12, Fig. 3, Fig. 5B) and the other that pierce the base of the Antigua Fm (ANT 20.6, Fig. 3). $^{40}Ar/^{39}Ar$ step-heating analyses were performed at Géosciences Montpellier (France, detailed methodology in Appendix 5). Raw data of each step and blank were processed and ages were calculated using the ArArCALC software (Koppers, 2002). Ages are statistically analyzed in two ways: ^{39}Ar released spectra and inverse isochrones. Plateau ages are calculated from at least three consecutive ^{39}Ar release steps comprising up to 50% of total $^{39}Ar_K$ released and overlapping at the 2σ-confidence level (Fleck et al., 1977). Isochrone ages are accepted when mean square weighted deviation (MSWD) is close to 1 and the $^{40}Ar/^{36}Ar$ intercept close to the $(^{40}Ar/^{36}Ar)_{atm}$ value. All results are given at the 2σ uncertainty.

299 **Microfacies and biostratigraphy**

300 For microfacies and fossil content determination, 35 thin sections were
301 analyzed from the carbonate rocks of the Antigua Fm. and ten from volcaniclastic
302 rocks and lacustrine limestones of the CPG, collected from the 18 logged sections
303 (Fig. 4, Appendix 1). The microfacies were associated to a depositional environment
304 following the classification of Wright and Burchette (1996) and Flügel (2010),
305 supplemented by the larger benthic foraminiferal content (BouDagher-Fadel, 2018a)
306 (Fig. 10, Appendix 2). The biostratigraphic analyses were only carried out for the
307 marine Antigua Formation (the CPG only contains undatable freshwater gastropods),
308 and were based on a complete inventory of larger benthic and planktonic foraminifera
309 taxa identified in the thin sections. We used the zonal calibrations of BouDagher-
310 Fadel (2015, 2018b) for the foraminifera, calibrated against the time scale of
311 Gradstein et al. (2012).

312 **Fault analysis**

313 We employed the right dihedron methods to inverse fault kinematics and interpret the
314 paleo-stress tensor using WinTensor software (Angelier, 1979; Delvaux and Sperner,
315 2003). WinTensor allows the rotational optimization of the obtained tensor by
316 performing iterative tests of tensors to minimize a misfit function. We perform these
317 inversions with sets of data consisting of fault strike, dip, plunge of the striations and
318 beddings offsets (Appendix 4). The quality of inversion is given by QRw (world
319 stress map quality criteria) ranging from A (good) to E (poor) depending of the
320 amount of data used for the inversion (n), the ratio between the amount of data used
321 for the inversion over the amount of input data (n/nt), deviation between observed and
322 theoretical slip direction (α_w), the sense of slip confidence level (Cl_w) and the type of
323 structure (fault, fracture, shear zone).

Anisotropy of the magnetic susceptibility (AMS)

To supplement fault kinematics analysis, we used anisotropy of the magnetic susceptibility (AMS) to determine the petrofabric of samples of the CPG and of the Antigua Fm. and determine the direction of tectonic paleo-strain. We drilled 71 paleomagnetic cores of fine-grained rocks over 8 sites (Fig. 9A). Samples were collected with a petrol-powered, water-cooled drill and oriented with a magnetic compass. The local magnetic declination (14° W in January 2020) was corrected on all samples. Non-demagnetized standard specimens were measured using an AGICO KLY-3S Kappabridge at the Geosciences Montpellier palaeomagnetic laboratory. AMS is defined by an ellipsoid with the principal axes $k_{max} > k_{int} > k_{min}$ used as strain indicator (Jelinek, 1978; Parés et al., 1999; Maffione et al., 2015). Undeformed sediments display a so-called sedimentary fabric where k_{max} and k_{int} are dispersed within the plane of magnetic foliation (F), which is parallel to the sedimentary stratification, and K_{min} is the pole to the bedding plane. A tectonic fabric can overprint the sedimentary one, and produce a magnetic lineation (L) by aligning the k_{max} axes parallel to the maximum axis of stretching (σ_3). In this study we have used the magnetic lineation as a paleo-strain proxy to determine the nature and direction of the tectonic strain. The AMS parameters were evaluated using ANISOFT 5.1 software according to Jelinek statistics (Jelinek, 1978; Chadima et al., 2020).

RESULTS

$^{40}Ar/^{39}Ar$ geochronology of the BVS

The Basal Volcanic Suite (BVS) crops out in the southwest of the island and is mainly composed of andesitic lavas and pyroclastic deposits. These are crosscut by rhyolitic dykes (Fig. 5C) and intruded by a dacitic dome at Sugar Hill and at Seaforth

Bay (Fig. 3). At the site of Old Road, a small stock of quartzitic diorite, previously described by Christmann (1973) is intruded by ENE-WSW rhyolitic dykes similar in appearance with the one crosscutting the andesitic lavas (Fig. 5C, 5D). To the south-east, at Nelson Dockyard, mafic dykes intrudes the CPG. To the northeast and southeast (Devil's Bridge) similar dyke are found intruding the Antigua Fm. (Fig.3, Fig. 5A, 5B). No consistent bedding dip is apparent in the BVS; the pyroclastic rocks have bedding that vary between 0 to 30° around local eruptive centers (Fig. 3).

The andesitic lava (sample ANT20.4) yields a plateau age of 18.57 ± 1.26 Ma with 82.07 % of Ar released (Fig.8, Table 2). Individual steps show large errors, especially for low temperature degassing steps, resulting from high atmospheric contamination. Consequently, all data cluster along the ordinate axis of the inverse isochron diagram. The inverse isochron calculations for the steps corresponding to the plateau yielded a concordant age of 19.74 ± 2.46 Ma with MSWD = 1.52 for an initial $^{40}Ar/^{36}Ar$ ratio of 297.8 ± 1.5 indicating that the trapped $^{40}Ar/^{36}Ar$ is indistinguishable from atmospheric $^{40}Ar/^{36}Ar$.

The rhyolitic dyke (sample DWB-B) that crosscuts the andesite lava flow (sample ANT20.4) yields a hump-shaped spectrum with a mini-plateau age (cumulative ^{39}Ar released ~40 %) of 35.32 ± 0.16 Ma. The inverse isochron calculations for the steps corresponding to the mini-plateaus yielded concordant ages of 35.06 ± 0.61 Ma (MSWD = 1.93, initial $^{40}Ar/^{36}Ar$ ratio of 301.9 ± 7.3) with the trapped $^{40}Ar/^{36}Ar$ indistinguishable from atmospheric $^{40}Ar/^{36}Ar$. The low and high temperature degassing steps yield younger ages between 10 and 15 Ma and exhibit compositions poorer in ^{40}Ar and richer in ^{38}Ar than the central part, indicating that they correspond to a secondary phase (Fig. 8, Table 2).

Plagioclase populations from the dacitic dome of Sugar Hill, previously dated

with K-Ar geochronology at 20.8 Ma (Nagle et al., 1976, Fig. 3), yield a plateau age of 29.76 ± 0.22 Ma for the central part of the spectra corresponding to 68.59% of the ^{39}Ar released. The inverse isochron age of 29.74 ± 0.62 Ma is concordant with an MSWD = 2.03 and an initial ^{40}Ar/^{36}Ar ratio of 298.9 ± 9.4, indicating that the trapped ^{40}Ar/^{36}Ar is indistinguishable from atmospheric ^{40}Ar/^{36}Ar (Fig. 8, Table 2).

Analysis of the plagioclase population of the quartz diorite (ANT 20.8) yields a staircase spectrum without a plateau ranging from 10 Ma for low temperature degassing steps to 28 Ma at high temperature. The total fusion age is 22.88 ± 0.29 Ma. To aid interpretation of the measured spectra and the thermal history, we performed an inverse modelling of the ^{40}Ar/^{39}Ar spectra of the plagioclase population from the dioritic pluton with QTQt software (Gallagher, 2012). The inverse QTQt model for the plagioclase ^{40}Ar/^{39}Ar spectrum suggests that the diorite sample underwent a steady cooling at a rate of ~5°/Ma since ~25 Ma (Fig. 8).

Despite a large error on individual steps related to atmospheric contamination, analysis of the groundmass of the basaltic andesite dyke crosscutting the Central Plain Group (ANT20.12) yields a plateau age of 27.03 ± 1.89 Ma corresponding to 90.99 % of the ^{39}Ar released (Fig. 8, Table 2). The inverse isochron yields a concordant age of 27.73 ± 2.94 Ma with an MSWD = 0.48 and an initial ^{40}Ar/^{36}Ar ratio of 297.3 ± 3.2 indistinguishable from atmospheric ratio. Low-temperature individual degassing steps show larger errors and yield younger ages (10 to 20 Ma).

For the basaltic andesite dyke intruding the Antigua Fm (ANT 20.6) we analyzed both plagioclase and groundmass populations. The plagioclase analysis yields a plateau age of 30.50 ± 0.70 Ma with a large error on degassing steps corresponding to 97.98 % of the ^{39}Ar released (Fig. 8, Table 2). Calculated inverse isochron show indistinguishable trapped and atmospheric ^{40}Ar/^{36}Ar and an age of

399 30.57 ± 0.81 Ma with MSWD = 0.74 for an initial $^{40}Ar/^{36}Ar$ ratio of 297.7 ± 5.4.
400 Analysis on the groundmass population did not yield a plateau and a hump-shaped
401 spectrum with younger low and high temperature individual steps (~15 Ma) with a
402 poorer ^{40}Ar and richer ^{38}Ar composition. However, the total fusion age obtained on
403 groundmass (30.54 ± 0.27 Ma) is concordant with the plateau age obtained from
404 plagioclase population analysis.
405

406 **Lithostratigraphy, microfacies and biostratigraphy**

407 Central Plain Group

408 The CPG comprises various terrestrial clastic rocks, lacustrine limestones,
409 volcaniclastic mud and debris flows and conglomerates interpreted as alluvial fan
410 deposits, volcaniclastic clay-rich deposits, tuffites, and lapilli-rich beds. These are
411 well exposed at St-John, Corbison, to the NW, and at the site of All Saints, in the
412 central part of the island (Fig. 3; Fig. 4, Appendix 1). To the SE, the volcaniclastic
413 deposits of the CPG are topped by the lacustrine limestones of Christian Hill that
414 contain feldspar and quartzitic debris (Fig. 3; Fig. 4). We interpret the volcaniclastic
415 series as deposited in an alluvial plain system with lakes (where the limestones
416 formed) and ephemeral braided alluvial fans (cf. Nemec and Steel, 1984) that was
417 located at the foot of a volcanic edifice located to the SW and corresponding
418 nowadays to the Basal Volcanic Suite. Volcanic activity during deposition of the CPG
419 was ongoing, as recorded by tuffites and lapilli-rich deposits. We mapped
420 discontinuous exposures of a tuffite member that is bright green in color and easy to
421 recognize in the field, which we use as a marker in our cross section (Fig. 3; Fig. 4,
422 Appendix 1). The CPG is overall a monoclinal succession striking ~ NW-SE and

dipping 10° toward the NE (Fig. 3). In the vicinity of normal faults, dips vary and may be up to 30° (Fig. 3).

Previous maps (Martin-Kaye, 1969; Christman, 1973) suggested that the CPG is overlying the BVS, but we carefully studied the contacts and did not find this relationship: rather, the CPG is interfingering with the BVS, as a syn-magmatic sedimentary sequence adjacent to the main volcanic edifice. This is supported by the presence of volcaniclastic deposits within the CPG at Willoughby, Pigeon beach and Galleon (Fig. 3, Fig. 4). At Nelson Dockyard, the volcaniclastic and green tuffite layers of the CPG are intruded by mafic dykes (Fig. 5A) that follow a NW-SE trending normal fault (Fig. 5B). From the NE-SW cross-section (Fig. 3), we estimate a minimum thickness of 200 m for the CPG, but the true thickness may be much thicker as the base of the sequence is not exposed.

Antigua Formation

At Galleon, Pigeon Beach, Five Island, Fort James, and Seaforth, patches of few meter-thick, reefal limestones are observed resting either above the CPG or the BVS (Fig. 3, Fig. 4). Previous authors (e.g., Thomas, 1942, Martin-Kaye, 1969, Bouysse and Westercamp, 1983) interpreted these as interbedded in the CPG, but our observations rather show that these patches are always unconformably overlying the CPG and preserved in the hanging walls of normal faults. From microfacies analyses, we dated these marine limestones from Zones P20 (Rupelian, 30.3-29.2 Ma) to P21b-P22 (Chattian, 28.1-23 Ma).

The Antigua Fm. is exposed in the east of the island, upon the CPG. Local observations (St-John, Fig. 6A) and the regional shallower monoclinal orientation striking N140° and dipping 5° toward NE indicate an angular unconformity between

the CPG and the Antigua Fm (Fig. 3). The minimum thickness of the Antigua formation is 80m and is estimated from section logging in Burma Quarry (Fig.4, Appendix 1). From the cross-section (Fig. 3), we re-evaluate its thickness to 160m. Centimeter-size sub-horizontal stylolite are observed within the top beds of the Antigua Fm. (Fig. 3, Fig. 6B and 6C, Fig. 8) showing that the thickness of the Antigua Fm. must have been perhaps some several hundred meters thicker, but the overburden was later removed.

In the northwestern part of the island, the formation comprises: ~10 m- thick coarse-grained cross bedded siliciclastic carbonates; 18 m-thick foraminiferal packstones dated from Zones P18-P21a (Rupelian, 33.9-28.1 Ma) to P21b (Chattian, 28.1-26.8 Ma); 45 m thick coral biostromes (Fig. 6E) and foraminiferal wackestones to packstones, dated to Zones P21 to P22 (upper Rupelian-Chattian) in their lowermost part (Fig. 4, Fig. 10, Appendix 1 and 2). In the central part of the island the Antigua Fm. comprises, from bottom to top: ~10 m-thick coarse grained mixed carbonate and volcaniclastic grainstone with corals, dating from zones P18 to P21a (Rupelian, 33.9-28.1Ma); 8m- thick foraminiferal wackestones and coral beds dating from zones P21b to P22 (upper Rupelian-Chattian, 29.2-23 Ma); 5.5 m- thick planktonic foraminiferal wackestones dating from zones P21b – P22 (Chattian) to P22b-N4 (upper Chattian-Aquitanian, 24-21 Ma) in the uppermost part (Fig. 4, Fig. 10, Appendix 2 and 3). The southeastern part of the Antigua Fm is made of few meter-thick foraminiferal wackestones dated to Zones P18-P21a (Rupelian, 33.9-29.2 Ma) (Half Moon Bay) or Zones P22-N4 (upper Chattian-Aquitanian, 26.8-21 Ma) (Devil's Bridge) (Fig. 3, Fig. 4, Fig. 10, Appendix 1 and 2). The presence of several interbedded mixed volcaniclastic-carbonate rocks indicates occasional mass flow deposition.

The Antigua Fm was deposited in low angle reefal carbonate ramp setting above the BVS and the CPG (Fig. 10). The sequence is composed of inner ramp coral biostromal beds (Fig. 6E) changing southeastwards into planktonic foraminifera-rich wackestones. An upward deepening trend is also recorded from reefal deposits in the lower part of the formation to muddy, mid to outer ramp deposits in its uppermost part. Our biostratigraphic constrains show that the Antigua Fm was deposited from the late Rupelian (Zone P20, 30.3-29.2 Ma) to the late Chattian-Aquitanian (Zones P22-N4, 26.8-21 Ma) (Fig. 10, Appendix 2).

The Antigua Fm includes reworked and weathered volcaniclastic beds that we interpreted as turbidites or tempestites (Fig.4, Appendix 1) but nowhere did we find volcanic ash or pumice deposits interbedded in the Antigua formation.

Structure and kinematics of Antigua

Mapped and outcrop-scale faults are normal faults that may be roughly subdivided into three clusters: ~N020° (±020°), N090° and ~N140° (±020°). The fault planes dips on average about 60° and show dip-slip slickenslides and displacements up to tens of meters (Fig. 7). The N020° and N090° faults are observed in the three units of Antigua but the N140° faults are absent in the Antigua Fm. The CPG and Antigua Fm strike parallel to the N140° faults suggesting that these faults are responsible for the main orientation of the island's stratigraphy. The trend of Antiguan coastlines is controlled by each of these three fault populations: the northweastern and south-eastern shores are trending NE-SW, the southern shore is E-W trending and the northeastern and southwestern shore display a series of NW-SE trending deep and narrow bays and capes. Although no direct crosscutting evidence has been found in the field, at map scale the N20° faults seem to intersect the N90°

and N140° faults, especially to the north of Liberta Hill and Christian Hill and on the southeastern and northwestern coasts (Fig. 3). The N090° and N140° faults are well visible in the CPG where they shape the landscape with the footwall consisting of 100- 200 m high hills that trend NW-SE (Christian Hill, All Saint Hill, Fig. 3).

At site scale, paleo-stress tensors indicate pure to radial extension with the direction of stretching varying from NNW-SSE to E-W. Strike-slip faults were observed only at one site (Old Road, Fig. 9A). Some sites display slightly oblique-slip normal faulting (Fig. 9A). Evidence for syn-sedimentary activity was observed for N090° faults at Fort James (injectites, Fig. 7A) and at Newfield (abrupt facies changes and reworked reefal blocks across the fault, Fig. 6B). At Nelson Dockyard, a N140° trending fault was intruded by a mafic dyke that we dated to 27.03 ± 1.89 (ANT20.12), giving a minimum fault age.

As the N020° and N090° faults are observed in the three units of Antigua but the N140° faults are absent in the Antigua Fm, we assume that N20° and N90° faults postdate N140° faults. Moreover, there is no clear cross cutting relationships between N020° and N090° fault suggesting that they might be synchronous, therefore while performing the kinematics inversion, we split our dataset separating N140° trending faults from the N020°-N090° dataset, according to our filed constraints and observations. For the N140° faults set, we obtained a paleo-tensor with σ_1 = N255°/80°, σ_2 = N120°/0°, σ_3 = N020°/10°, indicating that these faults accommodated a NNE-SSW stretching (Fig. 9C). The paleo-tensors obtained for the E-W and N-S trending faults show a subvertical σ_1, a sub-horizontal N130°-trending σ_2, and a sub-horizontal, N030° trending σ_3 indicating NNE-SSW stretching (Fig. 9C). Due to the limited number of observed faults and lack of kinematics indicators on fault planes, the quality of the tensors is poor (i.e., class D). Nonetheless, the

obtained tensors provide no evidence for major changes in the stress field during deposition of the Antigua Fm: strain is minor, and characterized by a NNE-SSW stretching direction that did not vary much during the Oligocene (Fig. 9C).

Anisotropy of the magnetic susceptibility (AMS)

Site mean susceptibility (k_m) of sites in the CPG (31.31-76.55 x 10^{-4} SI) and in Antigua Fm (0.052-25.59 x 10^{-4}) are indicative of a significantly high concentration of ferromagnetic minerals. Corrected anisotropy degrees are low (P' < 1.06) with values ranging from 1.014 to 1.058, suggesting a relatively weak tectonic overprint (Table 3). The shape of AMS ellipsoid varies from oblate (T > 0, F > L) to triaxial (T ≈ 0, F ≈ L) with a dominance of oblate ellipsoids, indicating that the tectonic fabric has only partially overprinted the original sedimentary fabric (Borradaile and Jackson, 2004) (Table 3). Pure sedimentary fabrics are recognized at sites CH, TU1, CO and PA, where k_{int} and k_{max} are randomly distributed within a plane sub-parallel to the stratification (Fig. 9B). Tectonic fabrics are recognized at sites TU2, FJ, FI and DB, where a well-defined (i.e., e_{12} < 30°) magnetic lineation is observed (Fig. 9B, Table 3). This magnetic lineation is sub-horizontal to shallowly plunging towards NNE to NE (Fig. 9B). This direction is sub-parallel to the regional NNE-SSW stretching direction estimated from the fault kinematic analysis from the Basal Volcanic Suite, the Central Plain Group and the Antigua Fm. (Fig.9C).

DISCUSSION

Geological evolution of Antigua

Late Eocene - early Oligocene magmatic activity

With a combination of field observations, lithostratigraphy, biostratigraphy, and $^{40}Ar/^{39}Ar$ dating we establish the duration of magmatic activity in Antigua and subsequent sedimentation. The lithostratigraphy of Antigua shows that magmatism formed the Basal Volcanic Suite, and was active during the deposition of the volcaniclastic Central Plain Group, but not during the deposition of the Antigua Fm (Fig. 3). The stratigraphically lowest (tuffites) and highest (lacustrine limestones with volcanic debris) units of the CPG that we observed in the field contain evidence of explosive volcanism (Appendix 1). In the Antigua Fm. all volcanic elements are reworked as clastic sediment but no evidence for explosive (ash deposits or pumice) or effusive volcanism (intercalated lavas) was observed (Fig. 8B, Appendix 1). Our field observations corroborate seismic interpretations of lines offshore Antigua, where in megasequences interpreted to reflect the Oligocene and Neogene deposits, no magmatic features (conic shaped bumps) were identified (Cornée et al., 2021; Fig. 11, Appendix 3).

From our $^{40}Ar/^{39}Ar$ ages of a rhyolitic dyke (sample DWB-B) and a dacitic dome (sample ANT 6.8) crosscutting the andesite-pyroclastic suite (35.32 ± 0.16 Ma and 29.76 ± 0.22 Ma, respectively; Fig.7, Table 2), and the K/Ar age of Nagle et al. (1976) of an andesitic lava (38.5 ± 2 Ma, Fig. 1, Table 1), we infer that the bulk andesitic and explosive volcanism of the Basal Volcanic Suite occurred in the late Eocene.

We discarded our age of 18.57 ± 1.26 Ma for the andesite from the BVS (sample ANT 20.4) because it is inconsistent with the one of the rhyolitic dyke that crosscut it. We assume that this sample was fully reset during a late (post-magmatic) hydrothermal event as exemplified by the very high atmospheric contamination within it. This is supported by the occurrence of various degrees of sub-greenschist

572 hydrothermal alteration within the Basal Volcanic Suite (albitized plagioclases,
573 chloritized orthopyroxenes and groundmass; Gunn and Roobol, 1976), the Central
574 Plain Group (chloritised tuffites; Jackson et al., 2013) and the Antigua Fm (silicified
575 limestones; Strang et al., 2018). Such pervasive subgreenschist hydrothermal
576 metamorphism has been described within the recent arc in the Guadeloupe and may
577 take place at 1 to 3-4 km depth (Favier et al., 2019).

578 Late volcanic activity occurred in Antigua at the transition between early and
579 late Oligocene and is exemplified by the emplacement of a dacitic dome through the
580 BVS and basaltic andesite dykes through the CPG and the Antigua Fm. The dacitic
581 dome yields a late Rupelian age of 29.76 ± 0.22 Ma (ANT 6.8, Sugar Hill). The mafic
582 dykes intruding the base of the Antigua Fm gives an age of 30.50 ± 0.70 Ma (ANT
583 20.6) that is consistent with the biostratigraphic dating to the late Rupelian (Zone P20,
584 30.3-29.2 Ma). As the CPG is synchronous with magmatic activity of the BVS and
585 capped by the Antigua Fm its age must range from at least 38 to 30 Ma (late
586 Bartonian to late Rupelian). The 27.03 ± 1.89 Ma age of a dyke crosscutting the CPG
587 is the youngest evidence for magmatic activity on Antigua (Fig. 5A, 5B).
588 The quartz diorite stock, now exposed at Old Road, gives only a minimum age of 28
589 Ma, and could represent a late-stage intrusion (ANT 20.8, Fig. 7, Table 2).
590
591 *Late Oligocene – early Miocene carbonate platform*
592 Following the end of magmatic activity, we observe a change from terrestrial
593 (CPG) to marine environment (Antigua Fm.) during the Rupelian-Chattian transition.
594 The depositional environment of the Antigua Fm. varies both geographically from
595 inner ramp coral biostromal beds (Fig. 6E) to the north-west to planktonic
596 foraminifera-rich wackestones to the south-east and temporally with reefal deposits in

the lower Rupelian part of the sequence to muddy, mid to outer ramp deposits in its uppermost part (late Chattian to Aquitanian). We reinterpreted the marine carbonates deposits, previously described as interbedded within the CPG (Mascle and Westercamp, 1983), as residual exposures of the Rupelian lower part of the Antigua Fm, preserved in grabens. This indicates that the Antigua Fm was entirely covering the CPG and, consequently, that a transgressive event occurred in Antigua during the P20 Zone (30.3-29.2 Ma, Rupelian). The late Rupelian-Chattian global sea level variations (tens of meters; Miller et al., 2020) are smaller than those of the depositional environment of the Antigua Fm (tens to hundreds of meters). Consequently, we infer that the Island subsided during the late Rupelian–Chattian interval. Thermal subsidence upon cooling after magmatic activity could have played a role (Moore, 1970; Tallarico et al. 2003).

To account for the presence of centimetres long, subvertical pressure-dissolution stylolitic peaks (Fig. 6C, 6D) the Antigua Fm must has undergone vertical compaction related to a post-Aquitanian sedimentary pile that was later eroded. In the neighbouring volcanic area, this erosional event and associated exhumation is supported by the outcropping of sub-greenschist facies units, that are thought to be originated from 1 to 3-4 km depth (Favier et al., 2019). In the offshore domain, the megasequence 4 (MS4, Oligocene to Early Middle Miocene in Cornée et al., 2021), that can be correlated to CPG and Antigua Fm, is topped by a major erosive Sequence Boundary (SB5) dated as early middle- Miocene (Fig. 11, Appendix 3) and recognized regionally (Cornée et al., 2021; Boucard et al., 2021). We thus suggest that erosion occurred during early–middle Miocene time. After this period, the island likely remained above sea-level as no post-Aquitanian sediments (aside from Quaternary alluvium) can be observed. Meanwhile, the Willoughby Basin subsided

along the N090° faults bounding the Antigua bank to the South (Fig. 11). This stable position appears consistent with the slow cooling estimated with QTQt modelling of $^{40}Ar/^{39}Ar$ spectrum of plagioclase from the quartz diorite (~5° per Ma; sample ANT 20.8, Fig. 8) since 25 Ma at least – a similar cooling rate was recently reported from the granodioritic plutons of St Martin island (Noury et al., 2021).

A 20 Ma long magmatic lull

The geological history we unraveled from Antigua thus includes (1) a main magmatic pulse occurred in Antigua during the late Eocene (continuing to at least 35 Ma), (2) magmatic activity continued mainly during the early Oligocene in the form of late-stage dykes and plugs (30.5 to 27 Ma), (3) magmatic activity ceased during the late Oligocene synchronously with a regional transgressive event and a subsidence of the island leading to the development of a carbonate platform completely devoid of evidence of volcanism; (4) an early–middle Miocene exhumation and uplift event responsible for the removal of a part of the volcanic and sedimentary series after which Antigua stayed emerged and stable.

From our new age model, we find that, in the northern Lesser Antilles, the main activity of the Paleogene arc occurred between the late Eocene and the early Oligocene and show that magmatism – previously supposed to possibly continue into the Miocene based on K-Ar ages (Nagle et al., 1976; Briden et al., 1979) – waned and came to an arrest by ~27 Ma in Antigua. Small-volume, late-stage magmatism on nearby islands St-Martin (24.4 Ma; Cornée et al., 2021) and St-Barthélemy (24.5 Ma; Legendre et al., 2018) continued slightly longer. The recent arc, located further west in the island of Saba, St-Kitts, Monserrat and Guadeloupe, is active since the Pliocene. Our analysis thus supports a long magmatic lull in the northern Lesser

Antilles arc despite ongoing subduction at more or less constant rates (Leroy et al., 2000; Boschman et al., 2014). With our new age model that includes $^{40}Ar/^{39}Ar$ dates and lithostratigraphy, we more accurately constraining it to a *ca* 20 Ma period lasting from the early late Oligocene to the Pliocene. As magmatic flareup contribute to crustal thickening (Ma et al., 2022), the Paleogene activity of the Lesser Antilles arc should have participated to the building of the GrANoLA land (Philippon et al., 2020a), an emerged area that was spread out through the Northern Lesser Antilles to Puerto Rico and favoured terrestrial fauna dispersal from South America to Greater Antilles (e.g. Marivaux et al., 2020). The end of magmatic activity and subsequent thermal and tectonic subsidence could have participated to the removal of this pathway during late Oligocene. This is showing the importance of the understanding of the magmatic history of the Lesser Antilles arc in the frame of paleo-(bio-)geographical history of the Eastern Caribbean region.

A correlation between end of magmatism and tectonic changes ?

In the Northern Lesser Antilles, a correlation between tectonics and magmatism is suggested by the NW-SE orientation of the Paleogene arc that aligns with the eastern flank of the NW-SE oriented Kalinago basin. This basin opened from the Eocene to the late Oligocene, synchronously with magmatic activity (Cornée et al., 2021).

At the scale of Antigua, we found evidences for syn-magmatic and syn-sedimentary tectonic activity. Within the CPG, we estimate a pre- or Rupelian age for the activity of a normal fault at Nelson Dockyard as it is intruded by a dyke dated at 27 Ma (this study). Furthermore, the presence of injectites at Fort James (Fig. 7A), of abrupt facies changes and reworked reefal blocks in Newfield (Fig. 6B) and the NE

orientation of the magnetic lineation obtained from sites of the CPG and of the Antigua Fm, that are consistent with the NE-SW stretching orientation obtained from paleotensor, strongly suggest syn-sedimentary tectonic activity.

Synchronously with the arrest of magmatism, we observe a marine transgression and a tilt of the Central Plain Group resulting in a 5° difference of the mean dip beddings between the CPG and the Antigua Fm. This strongly suggests that the late Rupelian-Chattian transgression reflects tectonic subsidence although thermal subsidence could also have played a role. The gentle northeastward 5° dip of the Antigua Fm and a general deepening of the paleo-environment toward the uppermost part of the sequence indicate that the subsidence is active until at least early Miocene.

Our structural observations and AMS measurement does not show a clear change in deformation behavior or directions during Oligocene. Both paleostress tensors indicate a NNE-SSW directed stretching, which remained consistent over time. In the BVS and CPG, this stress field is accommodated by dominant N140° faults and N090° and N020° normal faults. In the Antigua Fm, N140° faults are not recognized and the stress is accommodated by N090° and N020° faults. The absence of N140° faults could be indicative of a lowering of the intensity of the deformation. AMS results show that magnetic lineations acquired during syn-tectonic deposition are consistent with the NNE-SSW stretching direction estimated by paleotensors. This confirms that this stretching direction was dominant in Antigua from the early Oligocene to the early Miocene even though different families of faults accommodate it.

With our field and kinematic investigations, we did not see (1) significant deformation in the Antigua Fm and (2) a change in stress field during the Oligocene. The decrease or change in tectonic activity on the island is subtle and only outlined by

the absence of N140° faults in the Antigua Fm. Thus it is unlikely to correlate the end of magmatism to a change in tectonic activity on Antigua.

On the island of St-Martin and St-Barthélemy, a switch from pure orthogonal-to-the-trench to radial extension is recognized during the early Miocene (Legendre et al., 2018; Noury et al., 2021). In the northern Lesser Antilles region, a change in upper-plate deformation style from back arc rifting (Kalinago basin; Cornée et al. 2021) to fore-arc dissecation (V-shape basin, Boucard et al., 2021) as well as drastic vertical motion (Cornée et al., 2021; Boucard et al., 2021) is observed during the Oligocene. Together with the arrest of magmatism, these changes in upper-plate deformation and vertical motion are certainly controlled by subduction related processes and slab parameters variations.

What controls Lesser Antilles magmatic flare-ups and lull?

The oldest volcanic rocks of the Lesser Antilles arc are ~42 Ma (Philippon et al., 2020a), some 10 Ma younger than the NE-SW to E-W change in Caribbean-North America plate motion that led to the to the formation of the modern day N-S trending Lesser Antilles subduction zone (Briden et al., 1979; Boschmann et al , 2014).

Such a delay is often seen between the onset of subduction and the development of a mature arc (e.g., Stern et al., 2012). During ~ 15 Ma (late Eocene to late Oligocene), volcanic edifices developed on the eastern flank of the Kalinago basin, and in this period, the arc-trench distance, and by inference, the slab angle, remained more or less constant. But by the end of the Oligocene, magmatism ceased in the Northern Lesser Antilles.

Several hypotheses have been proposed to explain this arrest. Bouysse and Westercamp (1990) speculated that slab break-off occurred following the subduction

of a postulated buoyant, thick oceanic crust. But seismic tomographic images reveal a continuous, non-broken slab reaching the mantle transition zone without evidence for breaks (van Benthem et al., 2013; van der Meer et al., 2018; Braszus et al., 2021), and the subduction rate has not changed (Boschmann et al., 2014). If a slab breakoff had occurred, a new slab would have had to quickly formed to re-instate the arc as observed.

Boucard et al., (2021) suggested that subduction erosion occurred during middle Miocene time. Subduction erosion could push an arc towards the hinterland, but the timing of this event (post-middle Miocene) cannot explain the late Oligocene onset of the magmatic lull, and subduction erosion would migrate an arc, rather than stop its activity.

Slab flattening is then a third option. Subduction of buoyant features (oceanic aseismic ridges, oceanic plateaus, or seamount chains) is commonly thought to possible trigger flat slab subduction at mantle-stationary trenches (Yang et al., 1996, Gutscher et al., 2000; Gerya et al., 2009; Martinod et al., 2013, Ma et al., 2022). In the Lesser Antilles region, McCann and Sykes (1984) were the first to propose that a former anomalously thick aseismic ridge connecting the Barracuda ridge and the Main Rise (Fig.1) and/or that fragments of the Bahamas platform interacted with the subduction and could have triggered slab flattening and westward migration of the volcanic center. To the North, the thin continental margin below the Bahamas bank diachronously subducted and entered the Greater Antilles subduction zone Antilles in the late Eocene after which subduction on Cuba ceased (Erikson et al., 1990; Mann et al., 2002; Iturralde-Vinent et al., 2008; Granja-Bruna et al., 2010; Cruz-Orosa et al., 2012; Lao-Davila et al., 2014). The eastern, ocean-ward end of the Bahamas bank already interacted with the NE Caribbean margin during the Caribbean plate motion

change of the mid-Eocene and there is no clear reason to infer that this interaction allowed for an arc in the late Eocene and early Oligocene, but not in the 20 Ma that followed.

So while slab flattening may be a viable reason to explain the magmatic lull, the obvious solutions inferring the arrival of buoyant features do not seem straightforward solutions.

As showed by recent reconstructions of the Caribbean region, a change in the age of the oceanic lithosphere subducted, from a young Proto-Caribbean oceanic crust to an old America's oceanic crust is observed in the eastern Caribbean subduction zone during the end of Oligocene (Braszus et al., 2021). Nevertheless, variation of the age of the subducted oceanic lithosphere might not be by itself sufficient to change the slab dip (Cruciani et al., 2005).

Schepers et al. (2017) showed for the Andean subduction zone that flat slabs may also arise when roll-back of a subducted slab is locally impeded, and sub-slab mantle starts to support a flat slab. But the Lesser Antilles trench can be considered more or less stable relative to the mantle since 50 Ma following the kinematic reconstructions of Boschmann et al. (2014) and roll-back was short-lived and restricted to the southern portion of the trench, where the Grenada-Tobago Basin opened in the Eocene (Aitken et al., 2011), before the magmatic lull. So the scenario for the Andes does not apply to the Lesser Antilles arc.

We suggest that slab flattening in the northeastern corner of the Caribbean plate may have originated from the progressive formation of the spoon-shaped, curved slab (Laurencin et al., 2013; van Benthem et al., 2013; Braszus et al., 2021). The westward motion of North America relative to the nearly mantle-stationary Caribbean plate (Boschmann et al., 2014) and Lesser Antilles trench must be associated with

westward dragging of the south-dipping Puerto Rico part of the slab (Spakman et al., 2018; van de Lagemaat et al., 2018; Parsons et al., 2021). With ongoing absolute westward motion of North America, the E-W segment of the Puerto Rico segment becomes longer (Boschmann et al., 2014), and in the curved area, the slab folds and may flatten (Fig. 12). This curvature and flattening could have been minimal in the Eocene, allowing for a regular volcanic arc, but became progressively more intense, which may explain the long magmatic lull (Cerpa et al., 2021). We speculate that the recent reinstatement of arc magmatism in the northern Lesser Antilles may relate to a recently seismically imaged gap in the slab in the bend area (Meighan et al., 2013) that may have allowed for the slab to steepen (Fig. 12).

Evaluating whether this may explain the Pliocene magmatic flareup requires further dynamic and magmatic analysis and is beyond the scope of this paper. We note, however, that if the magmatic lull is caused by slab flattening, the Pliocene flareup may provide a proxy for reorganization in slab dynamics in the northeastern Caribbean region. A detailed kinematic reconstruction of the northeastern Caribbean plate boundary zone back to the onset of magmatism would be helpful to establish the temporal and spatial relationships between subduction and the length of the E-W trench segment east of Puerto Rico, and magmatism.

CONCLUSION

In this study, we revise the geological architecture and history of Antigua and integrate our findings within the regional frame of both the Lesser Antilles arc evolution and of the Caribbean upper plate strain pattern.

With lithostratigraphy, structural mapping, $^{40}Ar/^{39}Ar$ dating and biostratigraphy, we revised the geological map of the island and provide a new age

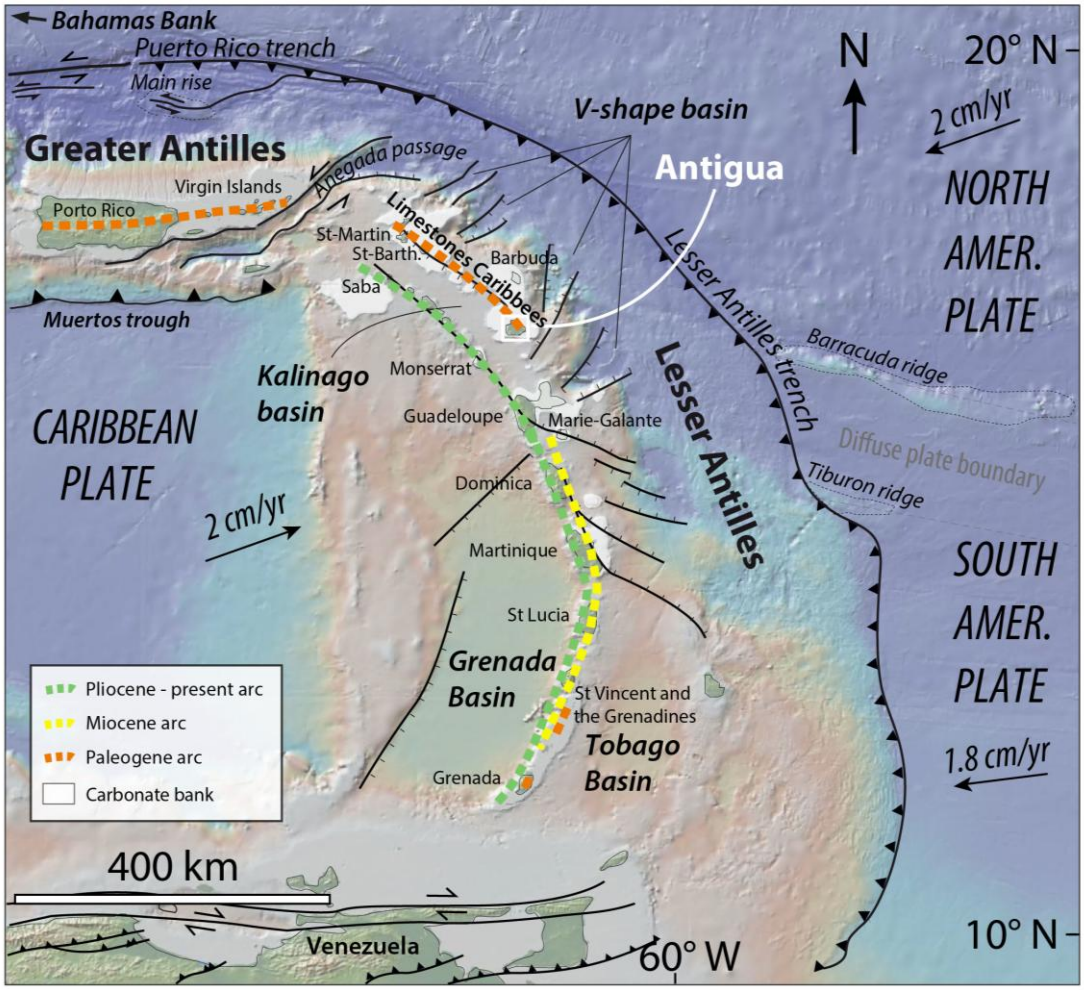
model for magmatism and sedimentation of the island. The climax of magmatic activity and concomitant volcaniclastic deposition emplaced during late Eocene and continued until early Oligocene in the form of late-stage domes and dykes. From the early Oligocene to, at least, the early Miocene, the island subsided along NW-SE fault, resulting in subsequent transgression and deposition of a carbonate platform. The island was then uplifted and partially eroded during the early-middle Miocene and since that time, the island stayed emerged and stable. With a kinematic analysis coupling paleontensors and anisotropy of the magnetic susceptibility (AMS), we show that minor normal faulting accommodates NE-SW stretching and that, at island-scale, there is not a clear change in deformation style that accompanies the end of magmatism during Oligocene.

This integrative geological study of Antigua restricts the period of magmatic activity on this island and definitively confirms the existence of a 20 Ma-long magmatic lull in the northern Lesser Antilles. The Paleogene arc that is also recognized in St-Martin and St-Barthélemy was emplaced along the eastern flank Kalinago basin, synchronously with its rifting. The concordance in the period of magmatic activity and of the occurrence of a large emerged area in the Lesser Antilles (GrANoLA land) suggests that the magmatic evolution of the Lesser Antilles arc could have participated to terrestrial pathways building and demise with crustal thickening during flareups and thermal subsidence during lull.

During the Oligocene, magmatism ceased contemporaneously with a change in upper-plate deformation from back-arc, perpendicular to the trench stretching (Kalinago basin) to fore-arc, parallel to the trench stretching (V-shaped basins). This episode is followed by regional uplift during early-middle Miocene. We postulate that the end of magmatic activity, the change in upper-plate deformation style and vertical

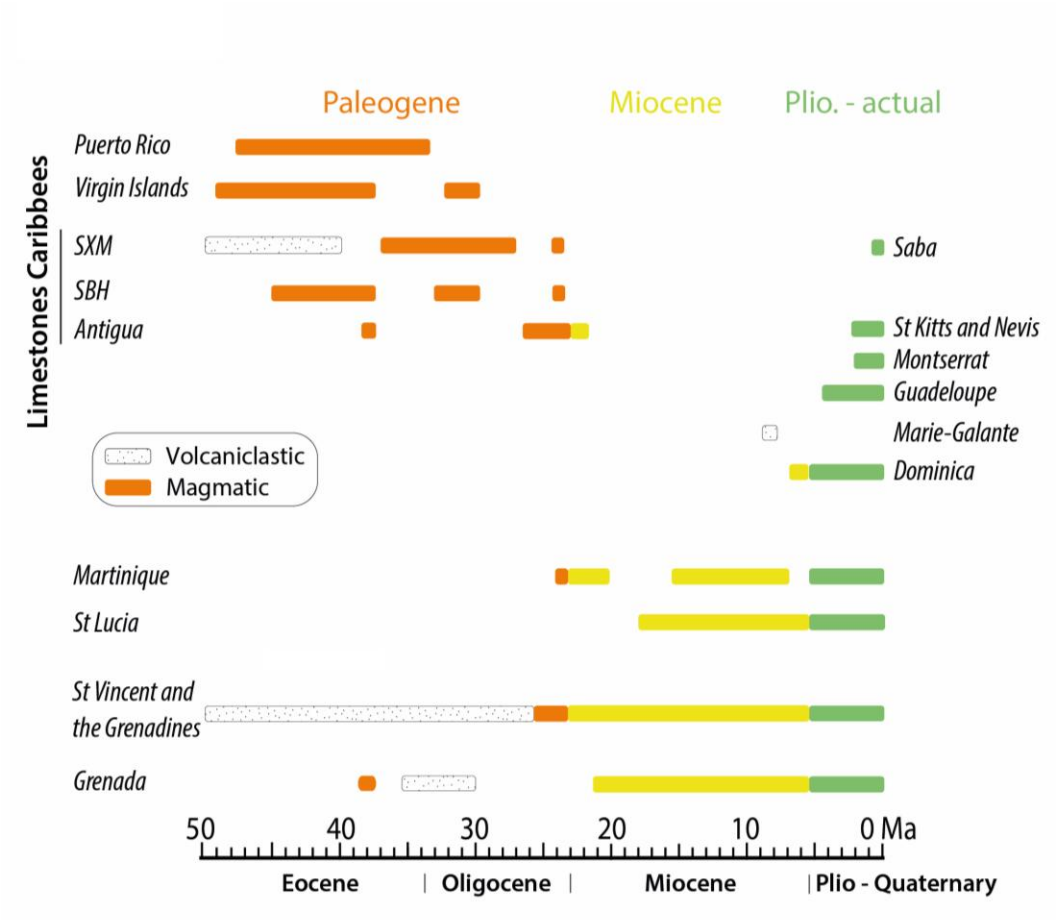
822 motion may have been triggered by slab flattening originated from the progressive
823 formation of the spoon-shaped, curved slab. Nevertheless, this is still hypothetical and
824 further constrains on the kinematic evolution of the northeastern Caribbean plate
825 boundary back to Eocene are needed to understand the relation between magmatism,
826 upper-plate deformation and subduction.
827
828 **ACKNOWLEDGMENTS**
829 The authors would like to warmly thank Arthur Iemmolo of the University of
830 Montpellier for its precious help in $^{40}Ar/^{39}Ar$ analyses and and Fabienne Zami of the
831 University of Antilles and Christophe Nevado of the University of Montpellier for the
832 thin sections. A special thank to the National park of Antigua and especially to Dr.
833 Reg Murphy and to Chris Waters that allowed us the access to special sites and
834 accompagnied us in the field. This work was supported by the GAARAnti project
835 (ANR-17-31 CE-0009) and by the INSU TelluS-SYSTER grant call 2017-2019.
836 DJJvH acknowledges Netherlands Organization for Scientific Research (NWO) Vici
837 grant 865.17.001.
838
839
840
841
842
843
844
845
846

847 **FIGURE**



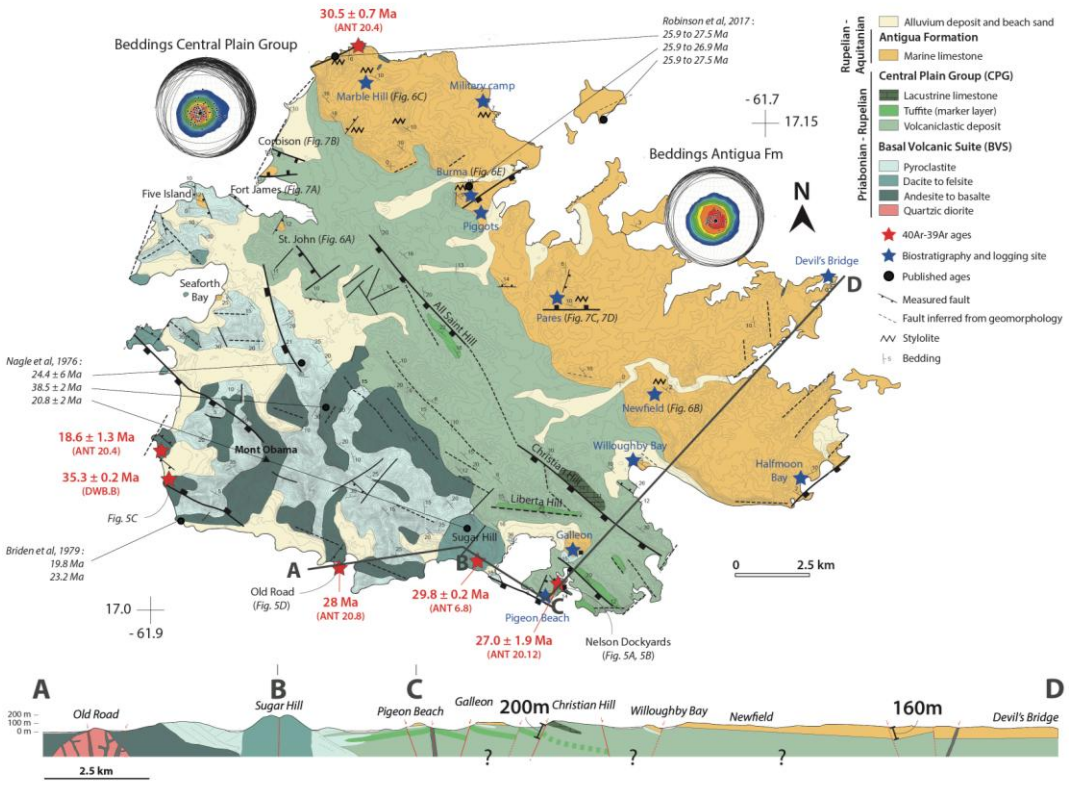
848

849 Figure 1. Bathymetric map, tectonic and volcanic settings of the Lesser Antilles
850 subduction zone. The main faults are drawn from Cornée et al. (2021). The study area
851 (Antigua) is outlined by the white square. Velocity vectors of the Caribbean and
852 North and South Americas plates are from Symithe et al., 2015.



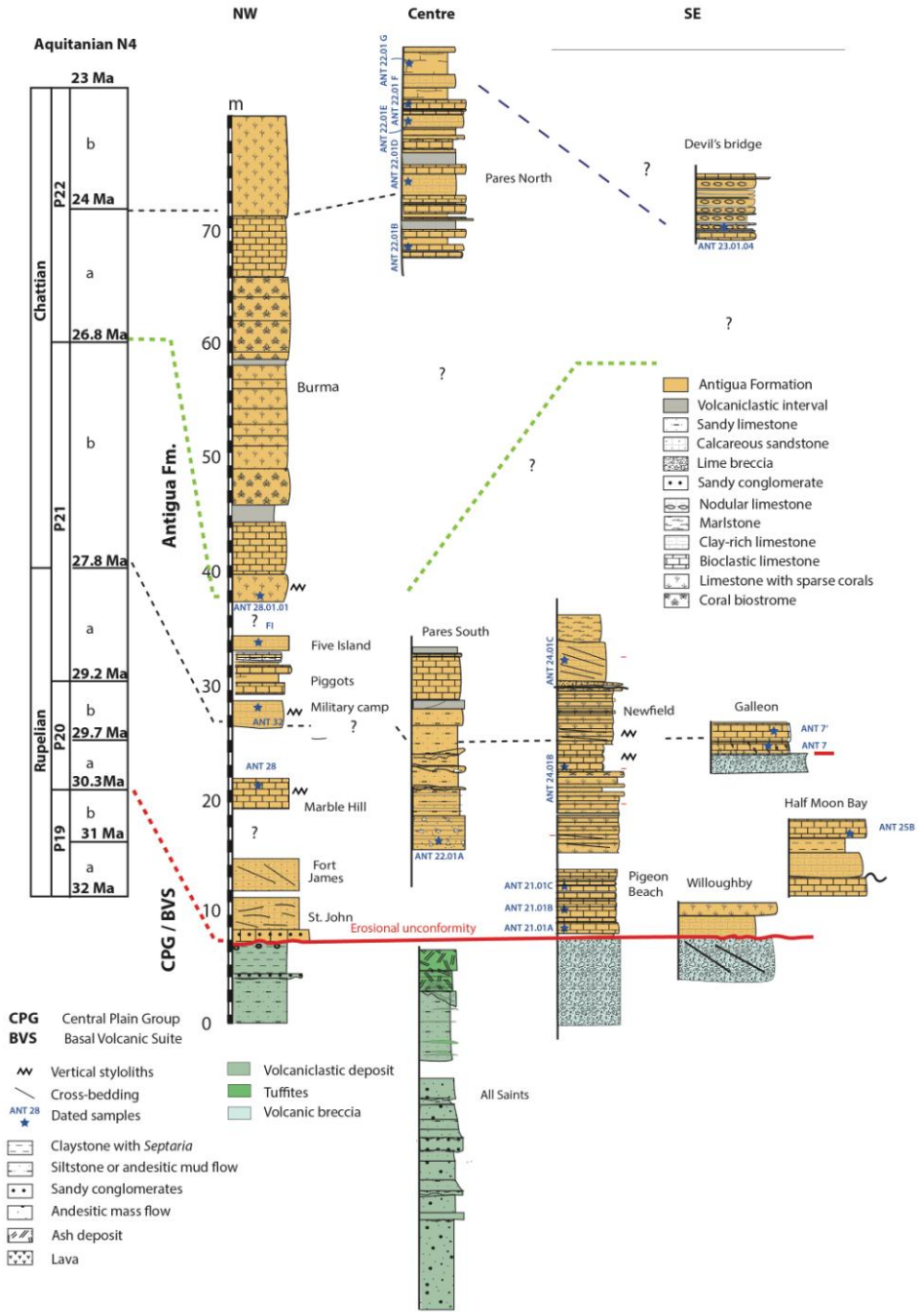
853

854 Figure 2. Schematic representation of the dated magmatic and volcaniclastic onshore
855 evidences of the Lesser Antilles arc, from Eocene to present. The references used for
856 the construction of this sketch are presented in Table 1.



857

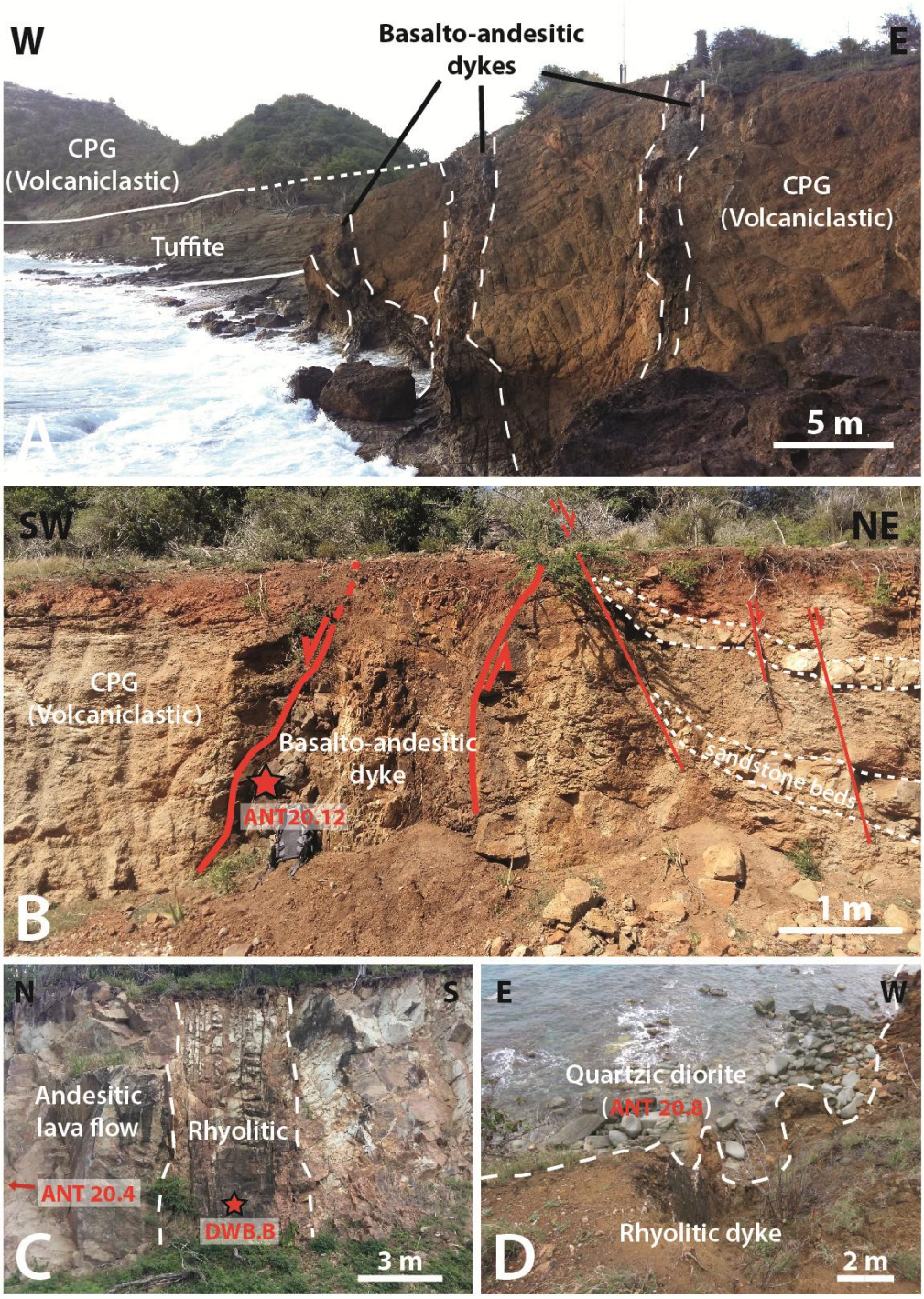
858 Figure 3: Revised geological map and synthetic cross-section of Antigua. The map
859 was constructed based on the map of Martin-Kaye (1959, 1969) and Christman
860 (1973), and completed and updated with fieldwork observations, lithostratigraphy and
861 structural measurements. The cross-section is located by a grey line on the map. The
862 tuffite layer (light green) was used as a marker layer in the construction of the cross-
863 section. Beddings are plotted on lower hemisphere. The K-Ar ages (Nagle et al.,
864 1976; Briden et al., 1979) and the Sr-Sr ages (Robinson et al., 2017) are represented
865 in italic.



866

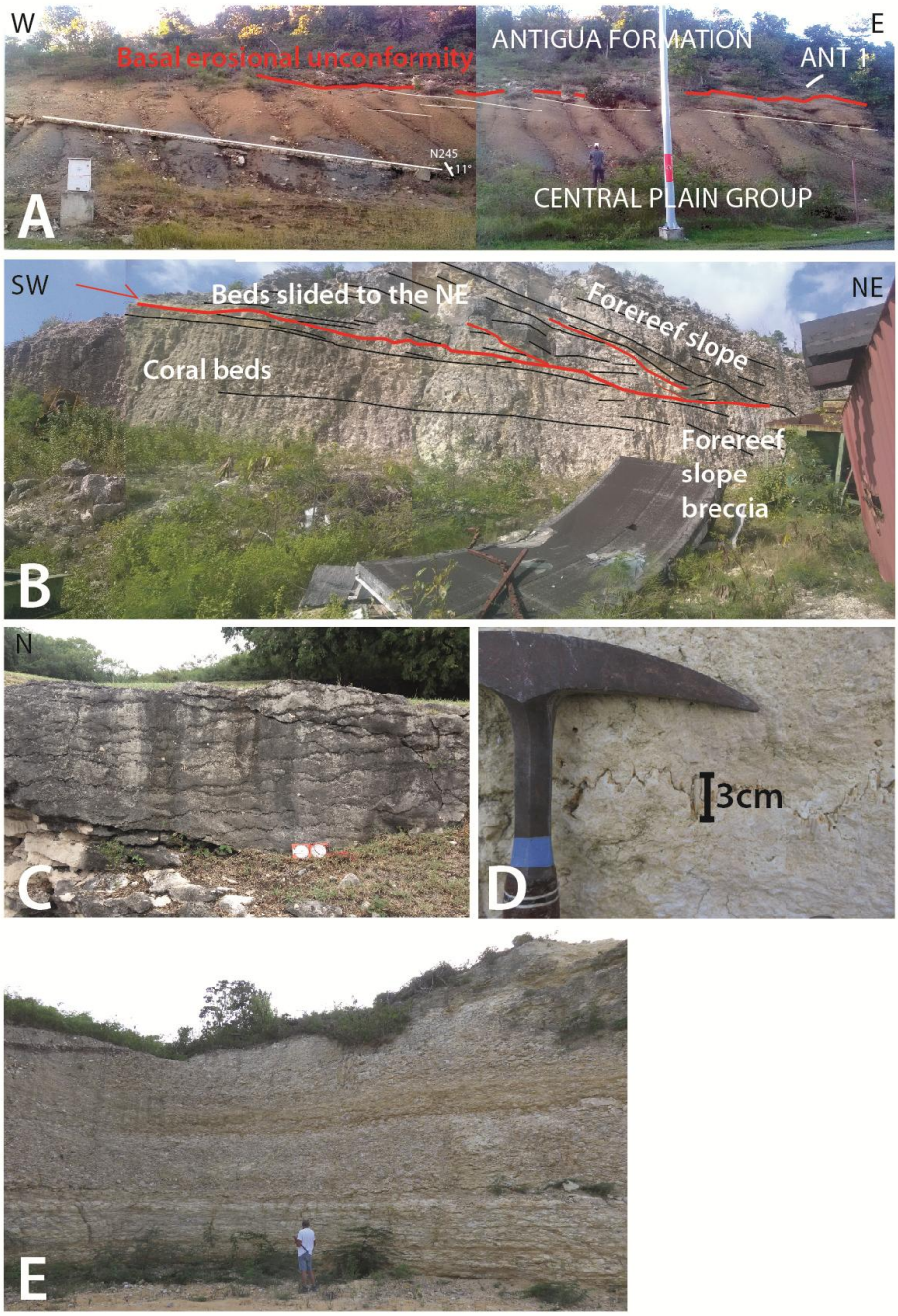
867 Figure 4. Stratigraphic synthesis and lithological successions of the Antiguan units.
868 The locations of the sections are presented in Fig.3. See Appendix 1 for a detailed
869 description of each sections.

870



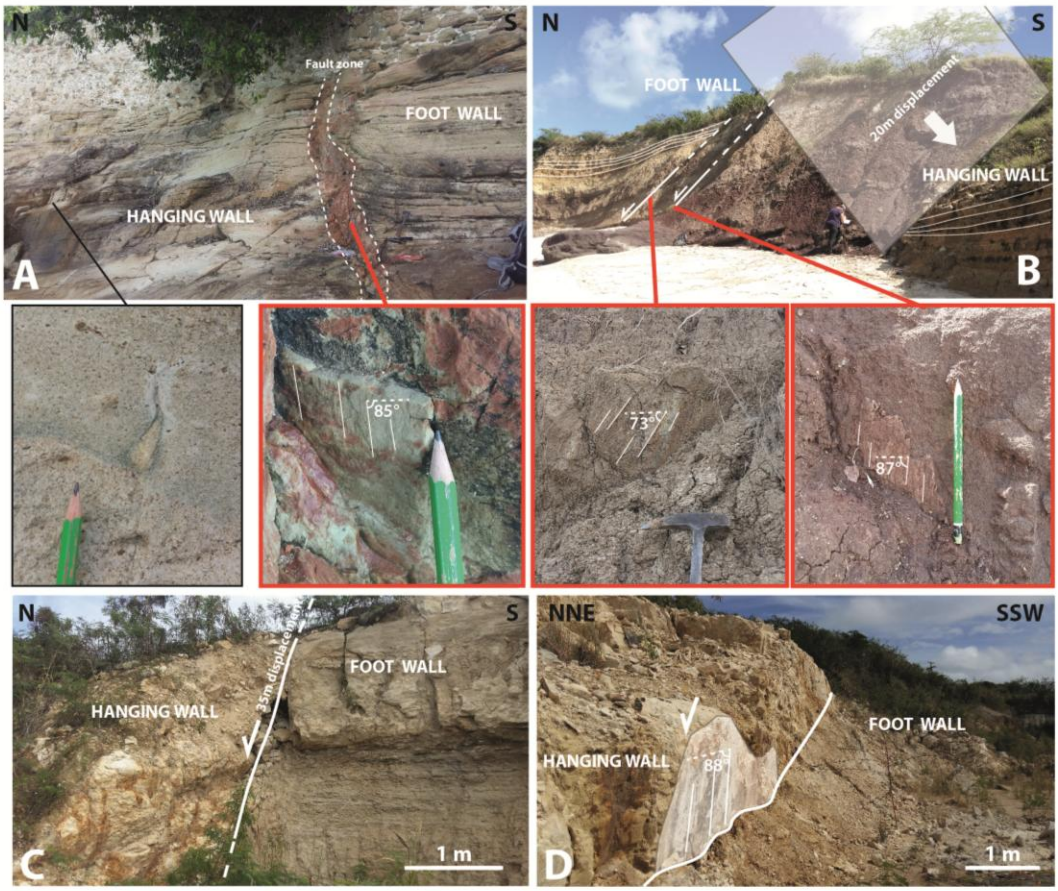
871

872 Figure 5. Field photography of the Basal Volcanic Suite and of the Central Plain
873 Group. **A**: basaltic andesite dykes crosscutting the volcaniclastic deposits of the
874 Central Plain Group; **B**: basaltic andesite dyke intruding a NW-SE trending normal
875 faults and crosscutting the Central Plain Group; **C**: 35 Ma- old rhyolitic dyke (Sample
876 DWB-B) crosscutting an andesite lava flow; **D**: quartzitic diorite stock crosscut by a
877 rhyolitic dyke.



878

879 Figure 6. Field photography of the sedimentary units of Antigua. **A**: Unconformity
880 between the Central Plain Group and the lower part of the Antigua Fm, observed at
881 Saint-John. Cross-bedded conglomeratic limestones rest above tilted and eroded silty
882 claystones of the CPG; **B**: abrupt change from reef platform to forereef slope at
883 Newfield Quarry. Note the presence of blocks slided towards the NE; **C**: wavy
884 subhorizontal stylolitic surfaces in foraminiferal wackestones, Marble Hill. **D**: vertical
885 stylolites at Burma Quarry; **E**: coral beds with diverse massive and platy coral
886 colonies (upper part of the Burma Quarry). For location, see Fig.3.



887

888 Figure 7. Field photography of normal faults and associated high-angle striation at (**A**)
889 Fort James, (**B**) Corbison beach and (**C**) and (**D**) Pares Quarry. Note the presence of
890 injectites (sediment injection during earthquakes), representative of syn-sedimentary
891 deformation at Fort James.

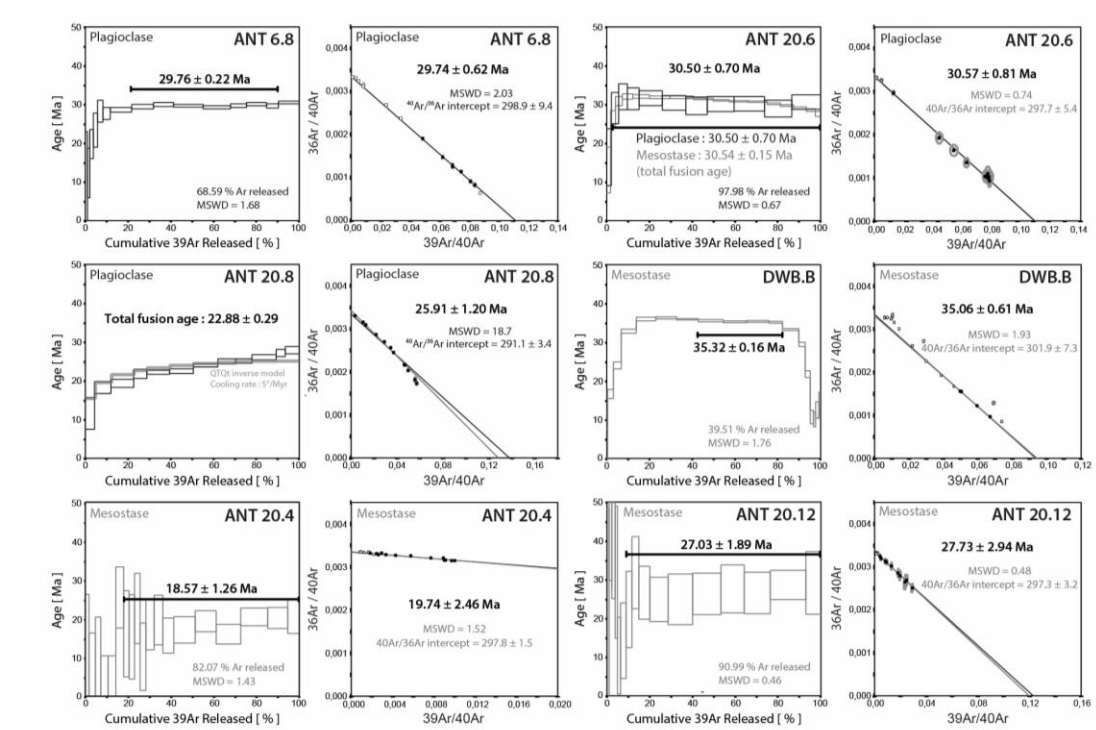


Figure 8 *:* $^{40}Ar/^{39}Ar$ spectra and inverse isochron for the samples from Antigua. MSWD = mean square weighted deviation. The thick grey line in the spectra of ANT 20.8 corresponds to the spectrum modeled using QTQt software (Gallagher, 2012).

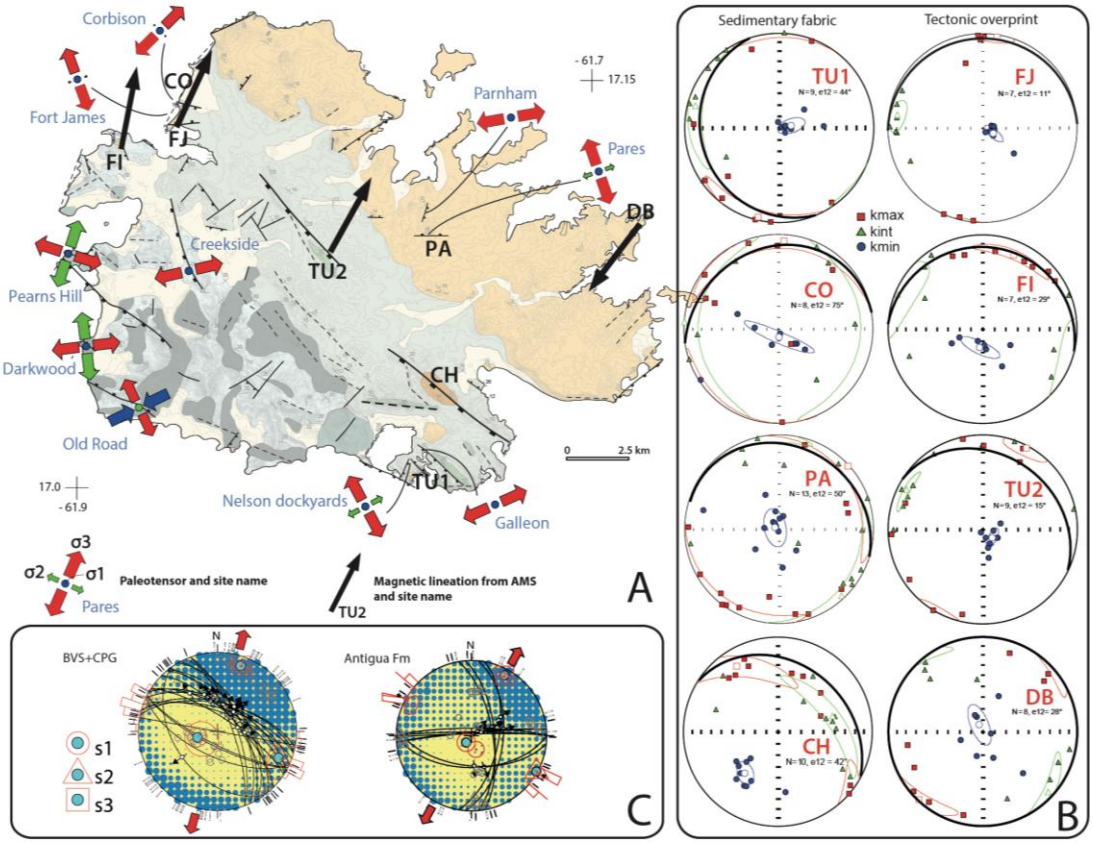


Figure 9 : **A**: Kinematic map of Antigua with paleotensors estimated per faults and magnetic lineation estimated from Anisotropy of the magnetic susceptibility (AMS) analysis; **B**: Schmidt equal area projections of the AMS ellipsoid principal axis for all sampled sites in geographic coordinates. 95% confidences ellipses and associated mean values for each axis are represented by coloured line and empty symbols respectively. Bold black arc represents the mean bedding plane of the site; **C**: Paleostress tensor obtained from the field data (faults with kinematic criteria and fractures) for the NW-SE trending faults within the Basal Volcanic Suite and the Central Plain Group (to the left) and for the E-W and N-S trending faults of the Antigua Formation (to the right).

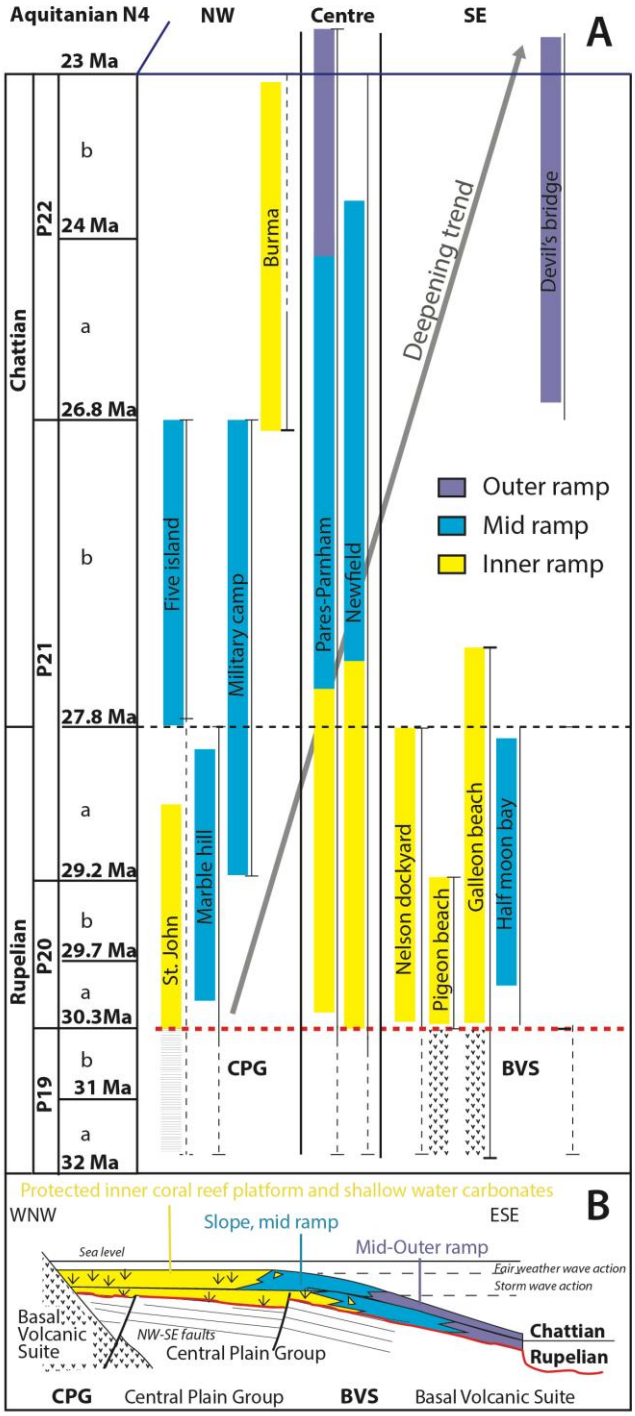


Figure 10. **A**: Depositional settings of the Antigua Fm. with ages from the biostratigraphic investigations (Appendix 1 and 2); **B**: Synthetic sedimentary organization during the late Rupelian and the Chattian. The Antigua Fm was deposited on a northeastward, low-angle dipping ramp. The underlying Central Plain Group was previously faulted and tilted by NW-SE normal faults. For sites location, see Fig.3.

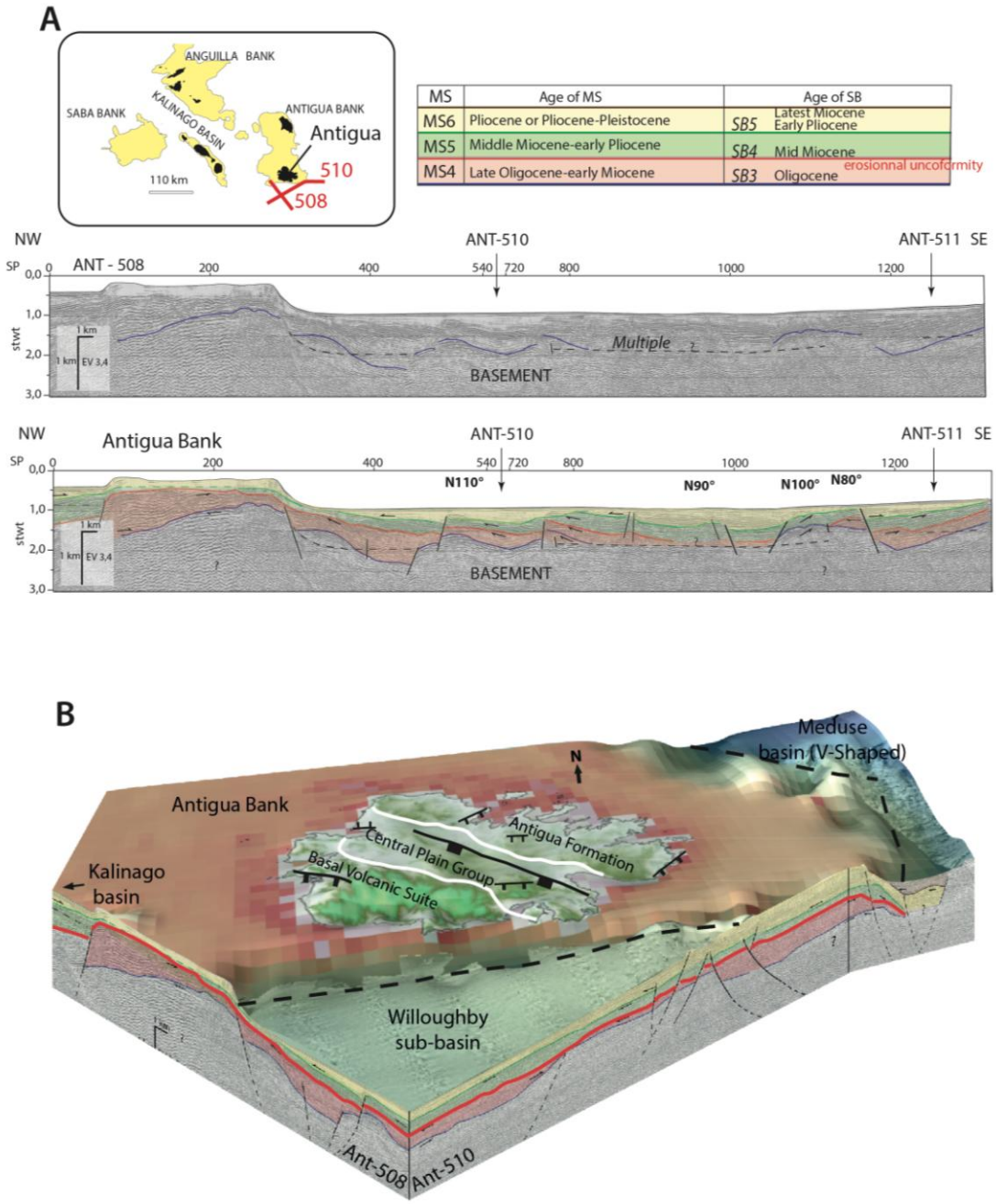
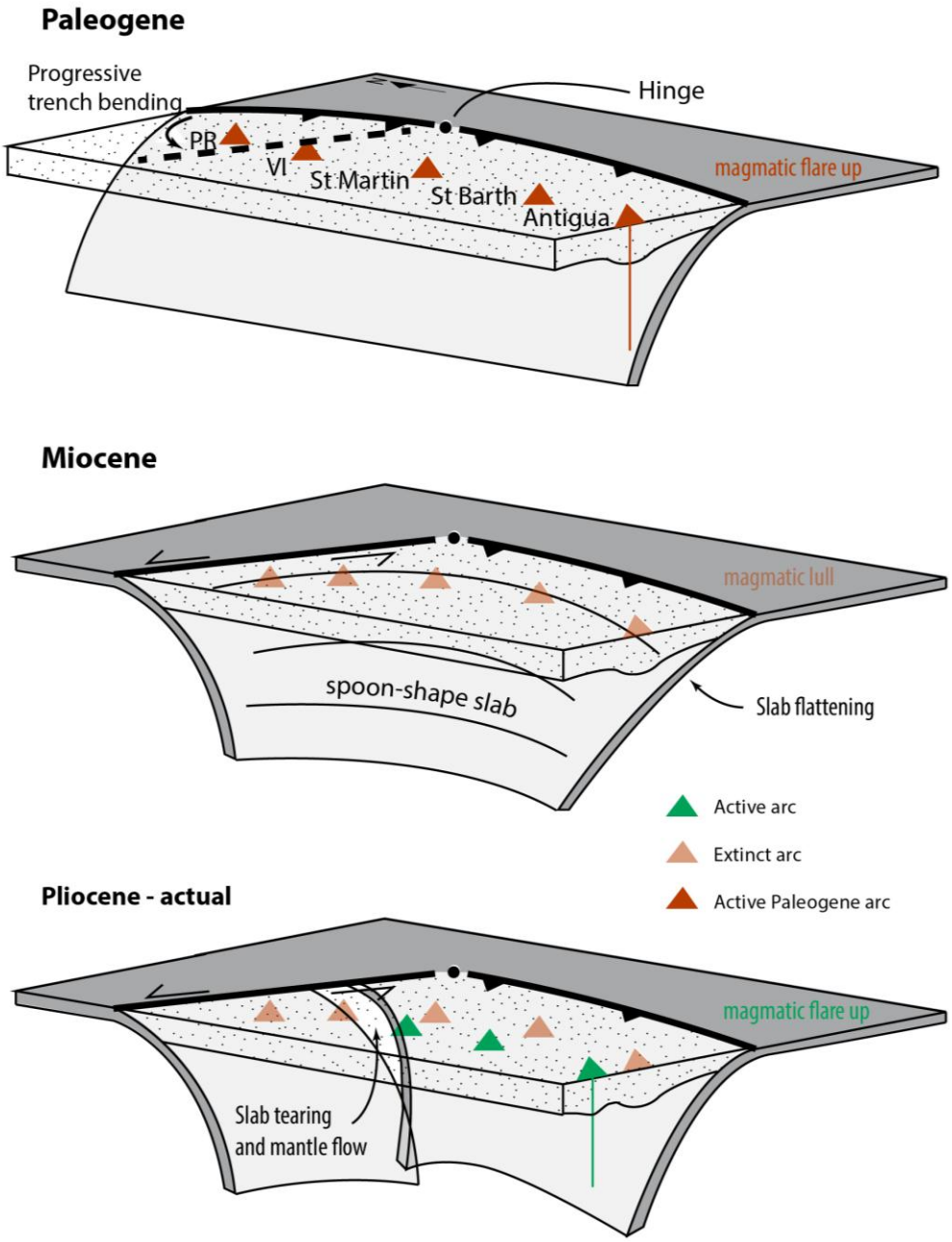


Figure 11. **A** : Time calibrated seismic stratigraphy analysis of the seismic profiles CPEM 508 and 510 (ARCANTE 3 Cruise, Bouysse et al., 1985a, 1985b; Bouysse and Mascle, 1994) from Cornée et al., 2021. Top: non interpreted; below : interpreted. The definition and time calibration follow the seismic stratigraphy chart defined by Cornée al. (2021) in the northeastern Lesser Antilles. MS: MegaSequence; SB: Sequence Boundary; **B** : 3D block with seismic profiles 508 and 510 showing the onshore and offshore structures in Antigua, Willoughby basin and the V-shaped Meduse basin. Note the erosional character of the SB4 unconformity that seals prior faults affecting MS4.



925

926 Figure 12 : Schematic 3D sketch of the progressive curvature of the Lesser Antilles
927 slab from Eocene to present and its impact on slab dip variation and magmatism
928 location.

929

930

931

932

REFERENCES CITED

Aitken, T., Mann, P., Escalona, A., & Christeson, G. L., 2011. Evolution of the Grenada and Tobago basins and implications for arc migration. *Marine and Petroleum Geology*, *28*, 235-258. https://doi.org/10.1016/j.marpetgeo.2009.10.003

Alminas, H. V., Foord, E. E., Tucker, R. E., 1994, Geochemistry, mineralogy, and geochronology of the US Virgin Islands, v. 2057. US Government Printing Office.

Andréïeff, P., Bouysse, P., Westercamp, D., 1987, Géologie de l'arc insulaire des Petites Antilles, et évolution géodynamique de l'Est-Caraïbe, (PhD thesis), Université de Bordeaux I..

Angelier, J. ,1979, Determination of the mean principal directions of stresses for a given fault population. Tectonophysics, v.56, no.3-4, p.17-26.

Baker, P. E., 1984,, Geochemical evolution of St Kitts and Montserrat, Lesser Antilles. Journal of the Geological Society, v.*141*, no.3, p.401-411

Blake, D.B., Donovan, S.K., Christopher L. Mah, C.L., Dixon, H.L., 2015, Asteroid (Echinodermata) skeletal elements from upper Oligocene deposits of Jamaica and Antigua. Geological Magazine, v.152, p. 1043–1056. doi:10.1017/S0016756815000096

Barabas, A.H., 1982, Potassium-argon dating of magmatic events and hydrothermal activity associated with porphyry copper mineralization in west central Puerto Rico. Economic Geology, v. 77, p. 109–126. https://doi.org/10.2113/gsecongeo.77.1.109

Borradaile, G.J., Jackson, M., 2004, Anisotropy of magnetic susceptibility (AMS): magnetic petrofabrics of deformed rocks. Geological Society, London, Special Publications , v. 238, p. 299–360. https://doi.org/10.1144/GSL.SP.2004.238.01.18

Boschman, L.M., van Hinsbergen, D.J.J., Torsvik, T.H., Spakman, W., Pindell, J.L., 2014, Kinematic reconstruction of the Caribbean region since the Early Jurassic. Earth-Science Reviews, v.138, p. 102–136. https://doi.org/10.1016/j.earscirev.2014.08.007

Boucard, M., Marcaillou, B., Lebrun, J. ‐ F., Laurencin, M., Klingelhoefer, F., Laigle, M.,

Lallemand, S., Schenini, L., Graindorge, D., Cornée, J. ‐J., Münch, P., Philippon, M., the ANTITHESIS and GARANTI Scientif, 2021, Paleogene V ‐Shaped Basins and Neogene Subsidence of the Northern Lesser Antilles Forearc. Tectonics, v.40. https://doi.org/10.1029/2020TC006524

BouDagher-Fadel, M. K. , 2015, Biostratigraphic and Geological Significance of Planktonic Foraminifera (Updated 2nd Edition) London: UCL Press. doi:10.14324/111.9781910634257

BouDagher-Fadel, M. K., 2018a, Evolution and Geological Significance of Larger Benthic Foraminifera. London, UK: UCL Press. doi:10.14324/111.9781911576938

BouDagher-Fadel, M. K., 2018b, Revised diagnostic first and last occurrences of Mesozoic and Cenozoic planktonic foraminifera. UCL Office of the Vice-Provost Research, Professional Papers Series, p. 1-5.

Bouysse, P., Andréïeff, P., Richard, M., Baubron, J. C., Mascle, A.,1985, Aves Swell and northern Lesser Antilles Ridge: rock-dredging results from ARCANTE 3 cruise. In : Symposium géodynamique des Caraïbes, p. 65-76, Technip Ed.

Bouysse, P., Westercamp, D., 1990, Subduction of Atlantic aseismic ridges and Late Cenozoic evolution of the Lesser Antilles island arc. Tectonophysics, v 175, p. 349–380. https://doi.org/10.1016/0040-1951(90)90180-G

Bouysse, P., Mascle, A., 1994, Sedimentary basins and petroleum plays around the French Antilles. In Hydrocarbon and Petroleum Geology of France, p. 431-443. Springer, Berlin, Heidelberg.

Braszus, B., Goes, S., Allen, R., Rietbrock, A., Collier, J., Harmon, N., Henstock, T., Hicks, S., Rychert, C.A., Maunder, B., van Hunen, J., Bie, L., Blundy, J., Cooper, G., Davy, R., Kendall, J.M., Macpherson, C., Wilkinson, J., Wilson, M., 2021, Subduction history of the Caribbean from upper-mantle seismic imaging and plate reconstruction. Nat. Commun, v. 12, no. 4211. https://doi.org/10.1038/s41467-021-24413-0

Briden, J.C., Rex, D.C., Faller, A.M., Tomblin, J.F., 1979, K-Ar Geochronology and

Palaeomagnetism of Volcanic Rocks in the Lesser Antilles Island Arc. Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences, v. 291, p. 485–528.

Brown, A.P., Pilsbry, H.A., 1914, Fresh-water mollusks of the Oligocene of Antigua. Proceedings of the Academy of Natural Sciences of Philadelphia v. 66, p. 209-213.

Brown, G.M., Holland, J.G., Sigurdsson, H., Tomblin, J.F., Arculus, R.J., 1977, Geochemistry of the Lesser Antilles volcanic island arc. Geochimica et Cosmochimica Acta v. 41, p. 785–801. https://doi.org/10.1016/0016-7037(77)90049-7

Cawood, P.A., Kröner, A., Collins, W.J., Kusky, T.M., Mooney, W.D., Windley, B.F., 2009, Accretionary orogens through Earth history. Geological Society, London, Special Publications, v.318, p. 1–36. https://doi.org/10.1144/SP318.1

Cerpa, N.G., Hassani, R., Arcay, D., Lallemand, S., Garrocq, C., Philippon, M., Cornée, J. ‐ J., Münch, P., Garel, F., Marcaillou, B., Mercier de Lépinay, B., Lebrun, J. ‐ F., 2021. Caribbean Plate Boundaries Control on the Tectonic Duality in the Back- Arc of the Lesser Antilles Subduction Zone During the Eocene. Tectonics 40. https://doi.org/10.1029/2021TC006885

Chadima, M., Hrouda, F., & Jelínek, V., 2020, Anisoft5. AGICO: Brno, Czech Republic.

Miller et al, Cenozoic sea-level and cryospheric evolution from deep-sea geochemical and continental margin records, 2020. SCIENCE ADVANCES 16.

Christman, R.A., 1973, Volcanic geology of southwestern Antigua, B.W.I. Geological Society of America Memoir, v.132, p. 439-448.

Christeson, G.L., Mann, P., Escalona, A., and Aitken, T.J., 2008, Crustal structure of the Caribbean–northeastern South America arc-continent collision zone: Journal of Geophysical Research–Solid Earth, v. 113, no. B8, B08104, https://doi .org/10.1029/2007jb005373.

Cruciani, C., Carminati, E., Doglioni, C., 2005. Slab dip vs. lithosphere age: No direct

1013 function. Earth and Planetary Science Letters 238, 298–310.
1014 https://doi.org/10.1016/j.epsl.2005.07.025
1015 Cornée, J.-J., Münch, P., Philippon, M., BouDagher-Fadel, M., Quillévéré, F., Melinte-
1016 Dobrinescu, M., Lebrun, J.-F., Gay, A., Meyer, S., Montheil, L., Lallemand, S.,
1017 Marcaillou, B., Laurencin, M., Legendre, L., Garrocq, C., Boucard, M., Beslier, M.-
1018 O., Laigle, M., Schenini, L., Fabre, P.-H., Antoine, P.-O., Marivaux, L., 2021, Lost
1019 islands in the northern Lesser Antilles: possible milestones in the Cenozoic dispersal
1020 of terrestrial organisms between South-America and the Greater Antilles. Earth-
1021 Science Reviews, v.217, no. 103617. https://doi.org/10.1016/j.earscirev.2021.103617
1022 Cross, T.A., Pilger, R.H., 1982, Controls of subduction geometry, location of magmatic arcs,
1023 and tectonics of arc and back-arc regions. Geological Society of America Bulletin
1024 v.93, no.545. https://doi.org/10.1130/0016-7606(1982)93<545:COSGLO>2.0.CO;2
1025 Cruz-Orosa, I., Sàbat, F., Ramos, E., Vázquez-Taset, Y.M., 2012, Synorogenic basins of
1026 central Cuba and collision between the Caribbean and North American plates.
1027 International Geology Review, v.54, p.876–906.
1028 https://doi.org/10.1080/00206814.2011.585031
1029 Dagain, J., Andréïff, P., Westercamp, D., Bouysse, P., Garrabe, F., 1989, Notice et carte
1030 géologique de Saint-Martin 1/50 000, Antilles Françaises, Département de la
1031 Guadeloupe, v. 3). BRGM.
1032 Davidson, J. P., Boghossian, N. D., Wilson, M.,1993, The geochemistry of the igneous rock
1033 suite of St Martin, northern Lesser Antilles. Journal of Petrology, v.34, no.5, p.839-
1034 866
1035 Davies, J.H., Stevenson, D.J., 1992, Physical model of source region of subduction zone
1036 volcanics. Journal of. Geophysical Research, v.97, p.2037–2070.
1037 https://doi.org/10.1029/91JB02571
1038 Defant, M.J., Sherman, S., Maury, R.C., Bellon, H., de Boer, J., Davidson, J., Kepezhinskas,

1039 P., 2001, The geology, petrology, and petrogenesis of Saba Island, Lesser Antilles.
1040 Journal of Volcanology and Geothermal Research, v.107, p.87–111.
1041 https://doi.org/10.1016/S0377-0273(00)00268-7
1042 Delvaux, D., Sperner, B., 2003, New aspects of tectonic stress inversion with reference to the
1043 TENSOR program. Geological Society, London, Special Publications, v.212, p.75–
1044 100. https://doi.org/10.1144/GSL.SP.2003.212.01.06
1045 Donovan, S., Pickerill, R., Portell, R., Jackson, T., Harper, D., 2003. The Miocene
1046 palaeobathymetry and palaeoenvironments of Carriacou, the Grenadines, Lesser
1047 Antilles. Lethaia, v.36, p.255–272. https://doi.org/10.1080/00241160310004666
1048 Donovan, S. K., Jackson, T. A., Harper, D. A., Portell, R. W., and Renema W., 2014, The
1049 upper Oligocene of Antigua: the volcanic to limestone transition in a limestone
1050 Caribbee. Geology Today, v.30, p.151-158.
1051 Donovan, S.K., Harper, D.A.T., Portell, R.W. 2015, In deep water: a crinoid-brachiopod
1052 association in the Upper Oligocene of Antigua, West Indies. Lethaia 48, 291-298.
1053 Donovan, S.K., David A.T., Harper, D.A.T, Portell, R.W., Toomey, J.K., 2017, Echinoids as
1054 hard substrates: varied examples from the Oligocene of Antigua, Lesser Antilles
1055 Proceedings of the Geologists' Association, v.128, p.326–331.
1056 Erikson, J.P., Pindell, J.L., Larue, D.K., 1990, Mid-Eocene-Early Oligocene Sinistral
1057 Transcurrent Faulting in Puerto Rico Associated with Formation of the Northern
1058 Caribbean Plate Boundary Zone. The Journal of Geology, v.98, p.365–384.
1059 https://doi.org/10.1086/629410
1060 Favier, A., Lardeaux, J.-M., Legendre, L., Verati, C., Philippon, M., Corsini, M., Münch, P.,
1061 Ventalon, S., 2019, Tectono-metamorphic evolution of shallow crustal levels within
1062 active volcanic arcs. Insights from the exhumed Basal Complex of Basse-Terre
1063 (Guadeloupe, French West Indies). Bulletin de la Société Géologique de France,
1064 v.190, no.10. https://doi.org/10.1051/bsgf/2019011
1065 Ferrari, L., Petrone, C.M., Francalanci, L., 2001, Generation of oceanic-island basalt–type

volcanism in the western Trans-Mexican volcanic belt by slab rollback, asthenosphere infiltration, and variable flux melting. Geology v.29, no.6, p.507-510. https://doi.org/10.1130/0091-7613(2001)029<0507:GOOIBT>2.0.CO;2

Ferrari, L., Orozco-Esquivel, T., Manea, V., Manea, M., 2012, The dynamic history of the Trans-Mexican Volcanic Belt and the Mexico subduction zone. Tectonophysics, p. 522–523, 122–149. https://doi.org/10.1016/j.tecto.2011.09.018

Fleck, R. J., Sutter, J. F., & Elliot, D. H., 1977, Interpretation of discordant 40Ar/39Ar age-spectra of Mesozoic tholeiites from Antarctica. Geochimica et Cosmochimica Acta, v.41, no.1, p.15-32.

Frost, S.H., Weiss, M.P., 1979, Patch reef communities and succession in the Oligocene of Antigua, West Indies. Geol. Soc. Amer. Bull.,v. 90, p.1094-1141.

Fox, P. J., Schreiber, E., & Heezen, B. C.,1971. The geology of the Caribbean crust: Tertiary sediments, granitic and basic rocks from the Aves Ridge. Tectonophysics, vol.*12*, *no.*2, p.89-109

Gallagher, K., 2012, Transdimensional inverse thermal history modeling for quantitative thermochronology. Journal of Geophysical Research : Solid Earth, v.117(B2). https://doi.org/10.1029/2011JB008825

Garrocq, C., Lallemand, S., Marcaillou, B., Lebrun, J. F., Padron, C., Klingelhoefer, F., ... & GARANTI Cruise Team., 2021, Genetic relations between the Aves Ridge and the Grenada back- arc Basin, East Caribbean Sea. Journal of Geophysical Research: Solid Earth, v.126, no.2, e2020JB020466.

Germa, A., Quidelleur, X., Labanieh, S., Chauvel, C., Lahitte, P., 2011, The volcanic evolution of Martinique Island: Insights from K–Ar dating into the Lesser Antilles arc migration since the Oligocene. Journal of Volcanology and Geothermal Research v.208, p.122–135. https://doi.org/10.1016/j.jvolgeores.2011.09.007

Gerya, T.V., Fossati, D., Cantieni, C., Seward, D., 2009, Dynamic effects of aseismic ridge subduction: numerical modelling. European Journal of Mineralogy, v.21, p.649–661. https://doi.org/10.1127/0935-1221/2009/0021-1931

1094 Glazner, A. F., Walker, J. D., Farmer, G. L., & Bowers, T. D., 2004, The curious
1095 decoupling of magmatism and plate tectonics during the Cenozoic in western North
1096 America: Insight from the Navdat database. In AGU Fall Meeting Abstracts, v.2004,
1097 pp. SF32A-04.
1098 Govers, R., Wortel, M.J.R., 2005, Lithosphere tearing at STEP faults: response to edges of
1099 subduction zones. Earth and Planetary Science Letters, v.236, p.505–523.
1100 https://doi.org/10.1016/j.epsl.2005.03.022
1101 Gradstein, F.M., Ogg, J.G., Hilgen, F.J., 2012, On The Geologic Time Scale. No. 45, p.171–
1102 188. https://doi.org/10.1127/0078-0421/2012/0020
1103 Granja Bruña, J.L., Muñoz-Martín, A., ten Brink, U.S., Carbó-Gorosabel, A., Llanes Estrada,
1104 P., Martín-Dávila, J., Córdoba-Barba, D., Catalán Morollón, M., 2010, Gravity
1105 modeling of the Muertos Trough and tectonic implications (north-eastern Caribbean).
1106 Marine Geophysical Research, v.31, p.263–283. https://doi.org/10.1007/s11001-010-
1107 9107-8
1108 Gunn, B.M., Roobol, M.J., 1976, Metasomatic alteration of the predominantly island arc
1109 igneous suite of the Limestone Caribbees (E. Caribbean). Geologische Rundschau,
1110 v.65, p.1078–1108. https://doi.org/10.1007/BF01808512
1111 Gutscher, M.-A., Spakman, W., Bijwaard, H., Engdahl, E.R., 2000, Geodynamics of flat
1112 subduction: Seismicity and tomographic constraints from the Andean margin.
1113 Tectonics, v.19, p.814–833. https://doi.org/10.1029/1999TC001152
1114 Harford, C. L., Pringle, M. S., Sparks, R. S. J., and Young, S. R., 2002, The volcanic
1115 evolution of Montserrat using 40Ar/39Ar geochronology: Geological Society,
1116 London, Memoirs, v. 21, no.1, p. 93- 113, doi:10.1144/gsl.mem.2002.021.01.05.
1117 Hatter, S.J., Palmer, M.R., Gernon, T.M., Taylor, R.N., Cole, P.D., Barfod, D.N., Coussens,
1118 M., 2018, The Evolution of the Silver Hills Volcanic Center, and Revised 40Ar/ 39Ar
1119 Geochronology of Montserrat, Lesser Antilles, With Implications for Island Arc
1120 Volcanism:. Geochemistry, Geophysics, Geosystems, v.19, p.427–452.
1121 https://doi.org/10.1002/2017GC007053

1122 Hutton, C. O., and Nockolds, S. R., 1978, The petrology of Nevis, Leeward Islands, West
1123 Indies: Overseas Geology and Mineral Resources, no. 52, p. 1- 31.
1124 Iturralde-Vinent, M., & MacPhee, R. D., 1999, Paleogeography of the Caribbean region:
1125 implications for Cenozoic biogeography. Bulletin of the AMNH: no. 238.
1126 Iturralde-Vinent, M., Díaz Otero, C., García-Casco, A. and van Hinsbergen, D.J.J., 2008,
1127 Paleogene Foredeep Basin Deposits of North-Central Cuba: A Record of Arc-
1128 Continent Collision between the Caribbean and North American Plates. International
1129 Geology Review, v.40, p.1-22.
1130 Jackson, T.A., 2013, A review of volcanic island evolution and magma production rate: an
1131 example from a Cenozoic island arc in the Caribbean. Journal of the Geological
1132 Society 170, 547–556. https://doi.org/10.1144/jgs2011-166
1133 Jelínek, V., & Kropáček, V., 1978, Statistical processing of anisotropy of magnetic
1134 susceptibility measured on groups of specimens. Studia geophysica et geodaetica, v.
1135 22, p. 50-62.
1136 Jolly, W., Lidiak, E., Schellekens, J., and Santos, H., 1998, Volcanism, tectonics, and
1137 stratigraphic correlations in Puerto Rico, Special Paper 322: Tectonics and
1138 geochemistry of the Northeastern Caribbean, Geological Society of America, p.
1139 1- 34.
1140 Kay, S.M., Coira, B.L., 2009, Shallowing and steepening subduction zones, continental
1141 lithospheric loss, magmatism, and crustal flow under the Central Andean Altiplano-
1142 Puna Plateau, in: Backbone of the Americas: Shallow Subduction, Plateau Uplift, and
1143 Ridge and Terrane Collision. Geological Society of America, v.204, p.229
1144 https://doi.org/10.1130/2009.1204(11)
1145 Koppers, A.A.P., 2002, ArArCALCF software for 40Ar/39Ar age calculations, Computers
1146 and Geosciences, v.28, no.5, p.605-619.
1147 Laó-Dávila, D.A., 2014, Collisional zones in Puerto Rico and the northern Caribbean. Journal
1148 of South American Earth Sciences, v.54, p.1–19.
1149 https://doi.org/10.1016/j.jsames.2014.04.009

1150 Laurencin, M., Marcaillou, B., Graindorge, D., Klingelhoefer, F., Lallemand, S., Laigle, M.,
1151 Lebrun, J.-F., 2017, The polyphased tectonic evolution of the Anegada Passage in the
1152 northern Lesser Antilles subduction zone. Tectonics, v.36, p.945–961.
1153 https://doi.org/10.1002/2017TC004511
1154 Lee, S. H., Iza, F., & Lee, J. K., 2006, Particle-in-cell Monte Carlo and fluid simulations of
1155 argon-oxygen plasma: Comparisons with experiments and validations. *Physics of*
1156 *plasmas*, v.*13*, no.5, p.57-102.
1157 Legendre, L., Philippon, M., Münch, Ph., Leticée, J.L., Noury, M., Maincent, G., Cornée, J.J.,
1158 Caravati, A., Lebrun, J.F., Mazabraud, Y., 2018, Trench Bending Initiation: Upper
1159 Plate Strain Pattern and Volcanism. Insights From the Lesser Antilles Arc, St.
1160 Barthelemy Island, French West Indies. Tectonics, v.37, p.2777–2797.
1161 https://doi.org/10.1029/2017TC004921
1162 Le Guen de Kerneizon, M., Bellon, H., Carron, J.-P., Maury, R., 1983, L'ile de Sainte Lucie
1163 (Petites Antilles): distinction des principales séries magmatiques à partir des données
1164 pétrochimiques et géochronologiques. Bulletin de la Société Géologique de France 7
1165 (XXV, no 6), p.845–853.
1166 Leroy, S., Mauffret, A., Patriat, P., Mercier de Lepinay, B., 2000, An alternative
1167 interpretation of the Cayman trough evolution from a reidentification of magnetic
1168 anomalies. Geophysical Journal International, v.141, p.539–557.
1169 https://doi.org/10.1046/j.1365-246x.2000.00059.x
1170 Li, Z.X., Bogdanova, S.V., Collins, A.S., Davidson, A., De Waele, B., Ernst, R.E.,
1171 Fitzsimons, I.C.W., Fuck, R.A., Gladkochub, D.P., Jacobs, J., Karlstrom, K.E., Lu,
1172 S., Natapov, L.M., Pease, V., Pisarevsky, S.A., Thrane, K., Vernikovsky, V., 2008,
1173 Assembly, configuration, and break-up history of Rodinia: A synthesis. Precambrian
1174 Research, v.160, p.179–210. https://doi.org/10.1016/j.precamres.2007.04.021
1175 Lindsay, J.M., Trumbull, R.B., Schmitt, A.K., Stockli, D.F., Shane, P.A., Howe, T.M., 2013.

1176 Volcanic stratigraphy and geochemistry of the Soufrière Volcanic Centre, Saint Lucia
1177 with implications for volcanic hazards. Journal of Volcanology and Geothermal
1178 Research 258, 126–142. https://doi.org/10.1016/j.jvolgeores.2013.04.011
1179 Ma, X., Attia, S., Cawood, T., Cao, W., Xu, Z., & Li, H., 2022, Arc Tempos of the Gangdese
1180 Batholith, Southern Tibet. Journal of Geodynamics, 101897 (in press).
1181 Macdonald, R., Hawkesworth, C.J., Heath, E., 2000, The Lesser Antilles volcanic chain: a
1182 study in arc magmatism. Earth-Science Reviews, v.49, p.1–76.
1183 https://doi.org/10.1016/S0012-8252(99)00069-0
1184 Maffione, M., Hernandez-Moreno, C., Ghiglione, M.C., Speranza, F., van Hinsbergen, D.J.J.,
1185 Lodolo, E., 2015, Constraints on deformation of the Southern Andes since the
1186 Cretaceous from anisotropy of magnetic susceptibility. Tectonophysics, v.665,
1187 p.236–250. https://doi.org/10.1016/j.tecto.2015.10.008
1188 Mann, P., Calais, E., Ruegg, J.-C., DeMets, C., Jansma, P.E., Mattioli, G.S., 2002, Oblique
1189 collision in the northeastern Caribbean from GPS measurements and geological
1190 observations,. Tectonics, v.21, p.1–26. https://doi.org/10.1029/2001TC001304
1191 Marivaux, L., Vélez-Juarbe, J., Merzeraud, G., Pujos, F., Vinola Lopez, L. W., Boivin, M.,
1192 Santos-Mercado, H., Cruz, E.J., Grajales A., Padilla J., Vélez-Rosado, K.I.,
1193 Philippon, M., Léticée, J.L., Münch, P.,, Antoine, P.O., 2020, Early Oligocene
1194 chinchilloid caviomorphs from Puerto Rico and the initial rodent colonization of the
1195 West Indies. Proceedings of the Royal Society Bulletin, v.287, no.1920,.
1196 Martinod, J., Guillaume, B., Espurt, N., Faccenna, C., Funiciello, F., Regard, V., 2013, Effect
1197 of aseismic ridge subduction on slab geometry and overriding plate deformation:
1198 Insights from analogue modeling. Tectonophysics, v. 588, p.39–55.
1199 https://doi.org/10.1016/j.tecto.2012.12.010
1200 Martin-Kaye, P.H.A., 1959, Reports on the geology of the Leeward and British Virgin
1201 Islands. Voice Publishing Co., Ltd., St. Lucia, W.I., p.117.
1202 Martin-Kaye, P.H.A., 1969, A summary of the geology of the Lesser Antilles. Overseas
1203 Geology and Mineral Resources , v.10, p.172-206.

1204 Mascle, A., Westercamp, D., 1983, Geologie d'Antigua, Petites Antilles. Bulletin de la
1205 Société Géologique de France S7-XXV, p.855–866.
1206 https://doi.org/10.2113/gssgfbull.S7-XXV.6.855
1207 Multer, H.G., Weiss, M.P., Nicholson, D.V., 1986, Antigua; reefs, rocks and highroads of
1208 history. Leeward Island Science Associates, St John's, Antigua, Contrib., v.1, p.116
1209 McCann, W.R., Sykes, L.R., 1984, Subduction of aseismic ridges beneath the Caribbean
1210 Plate: Implications for the tectonics and seismic potential of the northeastern
1211 Caribbean. Journal of Geophysical Research, v..89, p.4493–4519.
1212 https://doi.org/10.1029/JB089iB06p04493
1213 McCarthy, A., Tugend, J., Mohn, G., Candioti, L., Chelle-Michou, C., Arculus, R.,
1214 Schmalholz, S.M., Müntener, O., 2020, A case of Ampferer-type subduction and
1215 consequences for the Alps and the Pyrenees. American Journal of Sciences, v.320,
1216 p.313–372. https://doi.org/10.2475/04.2020.01
1217 McGeary, S., Nur, A., Ben-Avraham, Z., 1985, Spatial gaps in arc volcanism: The effect of
1218 collision or subduction of oceanic plateaus. Tectonophysics, v.119, p.195–221.
1219 https://doi.org/10.1016/0040-1951(85)90039-3
1220 Meighan, H. E., Pulliam, J., ten Brink, U., & López- Venegas, A. M., 2013, Seismic
1221 evidence
1222 for a slab tear at the Puerto Rico Trench. Journal of Geophysical Research: Solid
1223 Earth, v.118, no.6, p.2915-2923.
1224 Merdith, A.S., Williams, S.E., Collins, A.S., Tetley, M.G., Mulder, J.A., Blades, M.L.,
1225 Young, A., Armistead, S.E., Cannon, J., Zahirovic, S., Müller, R.D., 2021, Extending
1226 full-plate tectonic models into deep time: Linking the Neoproterozoic and the
1227 Phanerozoic. Earth-Science Reviews, v.214, no.103477.
1228 https://doi.org/10.1016/j.earscirev.2020.103477
1229 Miller, K. G., Browning, J. V., Schmelz, W. J., Kopp, R. E., Mountain, G. S., & Wright, J. D.,

2020, Cenozoic sea-level and cryospheric evolution from deep-sea geochemical and continental margin records. Science advances, v.6, no.20.

Mohn, G., Karner, G.D., Manatschal, G., Johnson, C.A., 2015, Structural and stratigraphic evolution of the Iberia–Newfoundland hyper-extended rifted margin: a quantitative modelling approach. Geological Society of London, Special Publications, v.413, p.53–89. https://doi.org/10.1144/SP413.9

Montes, C., Rodriguez-Corcho, A.F., Bayona, G., Hoyos, N., Zapata, S. and Cardona, A., 2019. Continental margin response to multiple arc-continent collisions: The northern Andes-Caribbean margin. Earth-Science Reviews, no.102903.

Moore, J.G., 1970, Relationship between subsidence and volcanic load, Hawaii: Bulletin Volcanologique, v. 34, no. 2, p. 562–576, https:// doi .org /10 .1007 /BF02596771

Multer, H.G., Weiss, M.P., Nicholson, D.V., 1986, Antigua; reefs, rocks and highroads of history. Leeward Island Science Associates, St John's, Antigua, Contrib. v.1, p.116

Münch, P., Lebrun, J.-Frédéric., Cornée, J.-J., Thinon, I., Guennoc, P., Marcaillou, B.J., Begot, J., Bertrand, G., De Berc, S.B., Biscarrat, K., Claud, C., De Min, L., Fournier, F., Gailler, L., Graindorge, D., Léticée, J.-L., Marie, L., Mazabraud, Y., Melinte-Dobrinescu, M., Moissette, P., Quillévéré, F., Verati, C., Randrianasolo, A., 2013, Pliocene to Pleistocene carbonate systems of the Guadeloupe archipelago, French Lesser Antilles: a land and sea study (the KaShallow project). Bulletin de la Société Géologique de France, v.184, p.99–110. https://doi.org/10.2113/gssgfbull.184.1-2.99

Nagle, F., Stipp, J.J., Fisher, D.E., 1976, K-Ar geochronology of the Limestone Caribbees and Martinique, Lesser Antilles, West Indies. Earth and Planetary Science Letters, v.29, p.401–412. https://doi.org/10.1016/0012-821X(76)90145-X

Nemec, W., Steel, R. J.,1984, Alluvial and coastal conglomerates: their significant features and some comments on gravelly mass-flow deposits. In: Koster, E.H., Steel, R.J. (Eds.), Sedimentology of Gravels and Conglomerates. Mem. Can. Soc. Petrol. Geol., v.10.

Noury, M., Philippon, M., Cornée, J., Bernet, M., Bruguier, O., Montheil, L., Legendre, L.,

1258 Dugamin, E., Bonno, M., Münch, P., 2021, Evolution of a Shallow Volcanic Arc
1259 Pluton During Arc Migration: A Tectono‐Thermal Integrated Study of the St.
1260 Martin Granodiorites (Northern Lesser Antilles). Geochemistry, Geophysics,
1261 Geosystems, v.22. https://doi.org/10.1029/2020GC009627
1262 Padron, C., Klingelhoefer, F., Marcaillou, B., Lebrun, J. F., Lallemand, S., Garrocq, C., Laigle,
1263 M., Roest, W.R., Beslier, M.O., Schenini, L., Graindorge, D., Gay, A., Audemard, F.,
1264 Münch, P., 2021, Deep structure of the Grenada Basin from wide-angle seismic,
1265 bathymetric and gravity data. Journal Of Geophysical Research : Solid Earth,
1266 v.126, no.2.
1267 Parés, J.M., van der Pluijm, B.A., Dinarès-Turell, J., 1999, Evolution of magnetic fabrics
1268 during incipient deformation of mudrocks (Pyrenees, northern Spain).
1269 Tectonophysics, v.307, p.1–14. https://doi.org/10.1016/S0040-1951(99)00115-8
1270 Parsons, A.J., Sigloch, K., Hosseini, K., 2021, Australian Plate Subduction is Responsible for
1271 Northward Motion of the India‐Asia Collision Zone and ~1,000 km Lateral
1272 Migration of the Indian Slab. Geophysical Research Letters, v.48.
1273 https://doi.org/10.1029/2021GL094904
1274 Pearce, J. A., Peate, D. W., 1995, Tectonic implications of the composition of volcanic arc
1275 magmas. Annual review of Earth and planetary sciences, v.23, no.1, p.251-285
1276 Persad, K.M., 1969, Stratigraphy, paleontology and paleoecology of the Antigua Formation.
1277 Unpublished, University of the West Indies Ph.D. dissertation, 222 p., Kingston,
1278 Jamaica.
1279 Philippon, M., Cornée, J.-J., Münch, P., van Hinsbergen, D.J.J., BouDagher-Fadel, M.,
1280 Gailler, L., Boschman, L.M., Quillevere, F., Montheil, L., Gay, A., Lebrun, J.F.,
1281 Lallemand, S., Marivaux, L., Antoine, P.-O., with the GARANTI Team, 2020a,
1282 Eocene intra-plate shortening responsible for the rise of a faunal pathway in the
1283 northeastern Caribbean realm. PLoS ONE, v.15, no.0241000.
1284 https://doi.org/10.1371/journal.pone.0241000

1285 Philippon, M., van Hinsbergen, D.J.J., Boschman, L.M., Gossink, L.A.W., Cornée, J.-J.,
1286 BouDagher-Fadel, M., Léticée, J.-L., Lebrun, J.-F., Munch, P., 2020b, Caribbean
1287 intra-plate deformation: Paleomagnetic evidence from St. Barthélemy Island for post-
1288 Oligocene rotation in the Lesser Antilles forearc. Tectonophysics, v.777, no.228323.
1289 https://doi.org/10.1016/j.tecto.2020.228323
1290 Pindell, J., Dewey, J.F., 1982, Permo-Triassic reconstruction of western Pangea and the
1291 evolution of the Gulf of Mexico/Caribbean region. Tectonics, v.1, p.179–211.
1292 https://doi.org/10.1029/TC001i002p00179
1293 Pindell, J.L., Kennan, L., 2009, Tectonic evolution of the Gulf of Mexico, Caribbean and
1294 northern South America in the mantle reference frame: an update. Geological
1295 Society, London, Special Publications, v.328, p.1–55.
1296 https://doi.org/10.1144/SP328.1
1297 Rankin, D. W., 2002, Geology of St. John, US Virgin Islands, US Geological Survey, U.S.
1298 Geological 531 Survey Professional Paper.
1299 Renne, P.R., Balco, G., Ludwig, K.R., Mundil, R., Min, K., 2011, Response to the comment
1300 by W.H. Schwarz et al. on "Joint determination of 40K decay constants and
1301 40Ar∗/40K for the Fish Canyon sanidine standard, and improved accuracy for
1302 40Ar/39Ar geochronology" by P.R. Renne et al. (2010). Geochimica et
1303 Cosmochimica Acta, v.75, p.5097–5100. https://doi.org/10.1016/j.gca.2011.06.021
1304 Robinson, E., Paytan, A., Chein, C.-T., 2017, Strontium isotope dates for the Oligocene
1305 Antigua Formation, Antigua, W. I. Caribbean Journal of Earth Science 50, 11-18.
1306 Rojas-Agramonte, Y., Williams, I.S., Arculus, R., Kröner, A., García-Casco, A., Lázaro, C.,
1307 Buhre, S., Wong, J., Geng, H., Echeverría, C.M., Jeffries, T., Xie, H., Mertz-Kraus,
1308 R., 2017, Ancient xenocrystic zircon in young volcanic rocks of the southern Lesser
1309 Antilles island arc. Lithos, v.290–291, p.228–252.
1310 https://doi.org/10.1016/j.lithos.2017.08.002
1311 Rosenbaum, G., Caulfield, J.T., Ubide, T., Ward, J.F., Sandiford, D., Sandiford, M., 2021,

1312 Spatially and Geochemically Anomalous Arc Magmatism: Insights From the Andean
1313 Arc. Geochemistry, Geophysics, Geosystems, v.22.
1314 https://doi.org/10.1029/2021GC009688
1315 Samper, A., Quidelleur, X., Lahitte, P., Mollex, D., 2007, Timing of effusive volcanism and
1316 collapse events within an oceanic arc island: Basse-Terre, Guadeloupe archipelago
1317 (Lesser Antilles Arc). Earth and Planetary Science Letters, v.258, p.175–191.
1318 https://doi.org/10.1016/j.epsl.2007.03.030
1319 Schepers, G., van Hinsbergen, D.J.J., Spakman, W., Kosters, M.E., Boschman, L.M. and
1320 McQuarrie, N., 2017,. South-American plate advance and forced Andean trench
1321 retreat as drivers for transient flat subduction episodes. Nature communications, v.8,
1322 no.15249.
1323 Schlaphorst, D., Melekhova, E., Kendall, J. M., Blundy, J., & Latchman, J. L., 2018, Probing
1324 layered arc crust in the Lesser Antilles using receiver functions. Royal Society open
1325 science, v.5, no.11.
1326 Schrecengost, K. L., 2010,. Geochemistry and uranium/lead zircon geochronology of the
1327 Virgin Islands batholith, British Virgin Islands (PhD thesis), The University of North
1328 Carolina at Chapel Hill.
1329 Smith, A. L., Roobol, M. J., Mattioli, G. S., Fryxell, J. E., Daly, G. E., & Fernandez, L. A.
1330 2013, The volcanic geology of the mid-arc Island of Dominica, Geological Society of
1331 America, v.496.
1332 Spakman, W., Chertova, M.V., van den Berg, Arie., van Hinsbergen, D.J.J., 2018, Puzzling
1333 features of western Mediterranean tectonics explainedby slab dragging. Nature
1334 Geoscience, v.11, p.211–216. https://doi.org/10.1038/s41561-018-0066-z
1335 Speed, R. C., Smith-Horowitz, P. L., Perch-Nielsen, K. V. S., & Sanfilippo, A. B., 1993,
1336 Southern Lesser Antilles Arc Platform: pre-late Miocene stratigraphy, structure, and
1337 tectonic evolution , Geological Society of America, v.277.
1338 Stern, R.J., Reagan, M., Ishizuka, O., Ohara, Y. and Whattam, S., 2012, To understand

1339 subduction initiation, study forearc crust: To understand forearc crust, study
1340 ophiolites. Lithosphere, v.4, no.6, p.469-483.
1341 Strang, K.M., Harper, D.A.T., Donovan, S.K., 2018, Silicification of low-magnesium mollusc
1342 shells from the Upper Oligocene of Antigua, Lesser Antilles. Caribbean Journal of
1343 Earth Science, v.50, p.37-43.
1344 Symithe, S., Calais, E., de Chabalier, J.B., Robertson, R., Higgins, M., 2015. Current block
1345 motions and strain accumulation on active faults in the Caribbean: CURRENT
1346 CARIBBEAN KINEMATICS. Journal of Geophysical Research. Solid Earth 120,
1347 3748–3774. https://doi.org/10.1002/2014JB011779
1348 Tallarico, A., Dragoni, M., Anzidei, M., and Esposito, A., 2003, Modeling long-term ground
1349 deformation due to the cooling of a magma chamber: Case of Basiluzzo island,
1350 Aeolian Islands, Italy: Journal of Geophysical Research. Solid Earth, v. 108, no. B12,
1351 https:// doi .org /10 .1029 /2002JB002376.
1352 Tatsumi, Y., Sakuyama, M., Fukuyama, H., Kushiro, I., 1983, Generation of arc basalt
1353 magmas and thermal structure of the mantle wedge in subduction zones. Journal of
1354 Geophysical Research, v.88, p.5815–5825. https://doi.org/10.1029/JB088iB07p05815
1355 Thomas, H.D., 1942, On fossils from Antigua, and the age of the Seaforth Limestone.
1356 Geological Magazine, v.79, p.49-61. doi.org/10.1017/S0016756800073490
1357 Trechmann, C.T., 1933, The Uplift of Barbados. Geological Magazine, v.70, p.19–47.
1358 https://doi.org/10.1017/S0016756800091214
1359 Trechmann, C.T., 1941, Some observations on the geology of Antigua, West Indies.
1360 Geological Magazine v.78, p.113-124.
1361 van Benthem, S., Govers, R., Spakman, W., Wortel, R., 2013. Tectonic evolution and mantle
1362 structure of the Caribbean, Journal of Geophysical Research : Solid Earth, v.118,
1363 p.3019–3036. https://doi.org/10.1002/jgrb.50235
1364 van Benthem, S., Govers, R. and Wortel, R., 2014, What drives microplate motion and
1365 deformation in the northeastern Caribbean plate boundary region? Tectonics, v.33,
1366 no.5, p.850-873.

van den Bold, W.A., 1966, Ostracoda from the Antigua Formation (Oligocene, Lesser Antilles). Journal of Paleontology, v.40, p.1233-1236.

van de Lagemaat, S.H.A., van Hinsbergen, D.J.J., Boschman, L.M., Kamp, P.J.J., Spakman, W., 2018, Southwest Pacific Absolute Plate Kinematic Reconstruction Reveals Major Cenozoic Tonga-Kermadec Slab Dragging. Tectonics, v.37, p.2647–2674. https://doi.org/10.1029/2017TC004901

van Hunen, J., van den Berg, A.P., Vlaar, N.J., 2002, On the role of subducting oceanic plateaus in the development of shallow flat subduction. Tectonophysics, v.352, p.317–333. https://doi.org/10.1016/S0040-1951(02)00263-9

Vaughan, T.W., 1919, Fossil corals from Central America, Cuba, and Puerto Rico with an account of the American Tertiary, Pleistocene, and Recent coral reefs. U.S. National Museum Bulletin, v.103, p.189-524.

Weiss, M.P., 1994, Oligocene limestones of Antigua, West Indies: Neptune succeeds Vulcan. Caribbean Journal of Earth Sciences, v.30, p.1-29.

White, W., Copeland, P., Gravatt, D.R., Devine, J.D., 2017, Geochemistry and geochronology of Grenada and Union islands, Lesser Antilles: The case for mixing between two magma series generated from distinct sources. Geosphere, v.13, p.1359–1391. https://doi.org/10.1130/GES01414.1

Yang, T.F., Lee, T., Chen, C.-H., Cheng, S.-N., Knittel, U., Punongbayan, R.S., Rasdas, A.R., 1996, A double island arc between Taiwan and Luzon: consequence of ridge subduction. Tectonophysics, v.258, p.85–101. https://doi.org/10.1016/0040-1951(95)00180-8

Zami, F., Quidelleur, X., Ricci, J., Lebrun, J.-F., Samper, A., 2014, Initial sub-aerial volcanic activity along the central Lesser Antilles inner arc: New K–Ar ages from Les Saintes volcanoes. Journal of Volcanology and Geothermal Research, v.287, p.12–21. https://doi.org/10.1016/j.jvolgeores.2014.09.011

Zhang, X., Chung, S.-L., Lai, Y.-M., Ghani, A.A., Murtadha, S., Lee, H.-Y., Hsu, C.-C.,

2019, A 6000-km-long Neo-Tethyan arc system with coherent magmatic flare-ups and lulls in South Asia. Geology, v.47, p.573–576. https://doi.org/10.1130/G46172.1

APPENDIX

Appendix 1 : DESCRIPTION OF THE SECTIONS, AGES AND DEPOSITIONAL SETTINGS;

Appendix 2 : MICROFACIES AND LARGER BENTHIC FORAMINIFERA CONTENT;

Appendix 3 : DESCRIPTION OF THE SEISMIC PROFILES 508 AND 510

Appendix 4 : STRUCTURAL MEASURMENTS.

Table of the structural measurements collected in the field. Strikes are expressed from 0 to 360° following the right hand rule.

Appendix 5 : $^{40}Ar/^{39}Ar$ methodology

[1]GSA Data Repository item 201Xxxx, [Appendix 1 : DESCRIPTION OF THE SECTIONS, AGES AND DEPOSITIONAL SETTINGS; Appendix 2 : MICROFACIES AND LARGER BENTHIC FORAMINIFERA CONTENT; Appendix 3 : DESCRIPTION OF THE SEISMIC PROFILES 508 AND 510], is available online at www.geosociety.org/pubs/ft20XX.htm, or on request from editing@geosociety.org.