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1 **Structure, age, and origin of the Caribbean Plate unraveled**

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5

6 **ABSTRACT**

7 Our compilation of marine magnetics of the Caribbean Plate allows us to identify magnetic
8 anomalies from the Cretaceous Normal Superchron (CNS) in the Colombia and Venezuela
9 basins, from which we propose a model for the age and origin of the Caribbean Plate and its
10 Large Igneous Province (CLIP). The comparison of selected marine magnetic profiles across
11 these basins with high resolution profiles from other areas across the CNS indicates that the
12 Colombia Basin formed 73-92 million years ago (Ma) and the Venezuela Basin 92-108 Ma. The
13 two basins and the older part of the CLIP formed at a ridge axis in the Pacific Ocean, near the
14 Central American Seaway. These results strongly constrain regional plate tectonic models for
15 America and the Pacific Ocean.

16

17 **INTRODUCTION**

18 The Caribbean plate is a small tectonic plate trapped between two major continental plates, the
19 North and South American plates, and two major subduction zones. The oceanic lithosphere of
20 the Atlantic and Pacific oceans subducts beneath the Caribbean plate at its eastern and western
21 ends, respectively. At its northern and southern ends, the Caribbean plate is bounded by two
22 large transform systems which accommodate its eastward motion with respect to the North and
23 South American plates. Its core is made of the Caribbean Large Igneous Province (CLIP)

24 resulting from extensive volcanism in the Cretaceous. Fragments of the CLIP are found all
25 around the Caribbean islands. The CLIP includes the thickened oceanic crust of the Colombia
26 Basin and most of the Venezuela Basin (e.g., Diebold et al., 1981).

27 Different models have been proposed for the origin of the Caribbean plate, either formed in situ
28 (e.g., Meschede and Frisch, 1998) or transferred from the Pacific Ocean to its present location
29 (e.g., Pindell, 1990). Therefore, many questions remain on the structure and age of the plate. The
30 main reason for these uncertainties is that no clear magnetic anomaly is observed in most of the
31 Caribbean plate. This is partly because the plate is located at low latitude, but also because it was
32 probably formed during the Cretaceous Normal Superchron (CNS). The CNS is a 35 to 40
33 million years-long episode of stable normal geomagnetic polarity between 83 and ~120 Ma: the
34 lack of geomagnetic reversals results in the absence of the typical lineated seafloor spreading
35 anomalies used to date the seafloor. The sequence of anomalies 18 to 1 (46-0 Ma) has been
36 identified on both flanks of the Cayman Ridge, the only active spreading center bounding the
37 Caribbean plate (Leroy et al., 2000). The oceanic crust of the Colombia and Venezuela basins
38 display set of anomalies interpreted as anomalies 27-33 (70-83 Ma) in the central and southern
39 Colombia Basin (Christofferson, 1973). Several attempts to recognize lineated anomalies in the
40 Venezuela Basin led to contradictory interpretations due to the low amplitude of the signal and
41 the paucity of data (Donnelly, 1973; Ghosh et al., 1984; Orihuela et al., 2013).

42 Here we take advantage of our new marine magnetic anomaly map of the Caribbean Plate
43 (Garcia-Reyes, 2018) together with recent results obtained from the detailed analysis of the CNS
44 in other oceanic basins to reinvestigate the structure, age, and origin of the Caribbean plate.

45

46 **METHODS**

47 We gathered total marine magnetic field measurements from the National Centers for
48 Environmental Information (NCEI) and French Research Institute for Exploitation of the Sea
49 (IFREMER). After removing spurious data, excluding noisy tracks and performing quality
50 control over navigation and acquisition time along marine tracks, we subtracted models of the
51 internal geomagnetic field (CM4, Sabaka et al., 2004 for the period 1960-2002.5; IGRF-11,
52 Thébault et al., 2015 for other periods) to obtain magnetic anomalies. Internal and external cross-
53 over correction allowed to significantly reduce the misfit (see details in García-Reyes, 2018). We
54 removed wavelengths shorter than 3 km. The resulting magnetic anomaly map of the Caribbean
55 Plate is presented in Figure 1b.

56 Several factors result in low magnetic anomaly amplitudes, of the order of ± 50 nT, in the
57 Caribbean Plate area:

58 (1) Magnetic anomalies created and/or observed at low latitude are usually weak, depending on
59 the direction of their causative source body. For instance, elongated bodies (such as prisms of
60 given geomagnetic polarity created at a spreading center) trending toward the geomagnetic pole
61 show no anomaly at the magnetic equator, because the ambient geomagnetic field vector is
62 aligned to the source body.

63 (2) The lineated magnetic anomaly pattern of the oceanic crust may also be blurred in areas
64 where extensive volcanics (and their strong and complex three-dimensional anomalies) overlay
65 and possibly demagnetize such pre-existing oceanic crust. Coherent linear magnetic anomalies
66 are only observed on a Large Igneous Province (LIP) when the LIP is formed at a ridge axis and
67 displays a thicker but otherwise similar oceanic crust, as in Iceland (Jónsson et al., 1991), the
68 Azores Plateau (Gente et al., 2003), and the Shatsky Rise (Sager et al., 2019).

69 (3) Last but not least, the lack of geomagnetic reversals during the CNS may also explain the
70 absence of prominent seafloor spreading magnetic anomaly pattern on the Caribbean Plate, if the
71 plate was actually formed during this period. However, Granot et al. (2012) have used selected
72 magnetic anomaly profiles from different oceans to show that three main periods, with different
73 geomagnetic fluctuation patterns, can be distinguished within the CNS, separated by two
74 ubiquitous anomalies named Q1 and Q2, tentatively dated ~92 and ~108 Ma. The older period,
75 between Anomaly M0 (~120 Ma) and Q2, displays moderate fluctuations; the intermediate
76 period, between Q2 and Q1, shows strong and rapid variations; and the younger period, between
77 Q1 and Anomaly 34 (84 Ma), is characterized by a very smooth field, almost devoid of short
78 wavelength variations. These observations opened the way for magnetic anomaly identifications
79 in areas formed during the CNS (e.g., Granot and Dymant, 2015).

80 We extracted a set of representative magnetic profiles in the Colombia and Venezuela basins
81 from the map. These profiles were drawn, as much as possible, across areas displaying linear
82 anomalies (for instance the strong linear anomalies in the Colombia Basin) and avoided three-
83 dimensional anomalies characterizing off-axis volcanism. We also selected measured marine
84 magnetic anomaly profiles with similar orientation, where available. We compared the profiles
85 with the CNS magnetic patterns and recognized anomalies 33-34, the characteristic second and
86 third periods of the CNS as well as marker Q1 (Granot et al., 2012). By this approach, we derive
87 the structure and age of the Colombia and Venezuela basins. The identification of these
88 anomalies confirms that this part of the CLIP was formed at a ridge axis, most likely in the
89 Pacific Ocean. We finally propose a possible evolution model for the Caribbean Plate that takes
90 into account these new observations.

91

92 **RESULTS: SEAFLOOR SPREADING MAGNETIC ANOMALIES IN THE**
93 **CARIBBEAN PLATE**

94 The main magnetic anomalies displayed in Figure 1b are related to major structural features such
95 as the Hess Escarpment separating the Lower Nicaragua Rise and the Colombia Basin, the
96 western flank of Beata Ridge, the basement of the Greater Antilles from Hispaniola to Puerto
97 Rico, and the Lesser Antilles volcanic arc, to cite only the most prominent. A complex,
98 hummocky magnetic pattern is observed on the Lower Nicaragua Rise, Aves Ridge, and to a
99 lesser extent Beata Ridge. This pattern likely marks late off axis volcanics overlying the
100 thickened oceanic crust. Finally, only three areas qualify to investigate seafloor spreading
101 anomalies: (1) the Cayman Trough, where anomalies 18 to 1 (46-0 Ma) have been identified
102 (Leroy et al., 2000) – we do not further consider this area; (2) the Colombia Basin north of 13°N
103 in a narrowing sector flanked by the Hess Escarpment and Beata Rise and abutting the southern
104 tip of Hispaniola; and (3) the entire Venezuela Basin.

105

106 **Magnetic anomalies in the Colombia Basin**

107 Among the magnetic anomalies interpreted by Christofferson (1973) as Chrons 27 to 33 in the
108 southern and central Colombia Basin, only two prominent East-West trending anomalies
109 observed between 11.5 and 14°N appear to be linear enough to reflect seafloor spreading. The
110 amplitude of these anomalies varies between ± 200 nT, making them the strongest anomalies in
111 the area. Further West and South, the complex hummocky magnetic pattern previously
112 mentioned on the Lower Nicaragua Rise overlaps the Hess Escarpment and partially covers the
113 Colombia Basin, interrupting and masking any preexisting linear magnetic anomalies. This
114 pattern marks volcanics obviously erupted in a later stage, long after the formation of the

115 thickened oceanic crust of the Colombia Basin (Sigurdsson et al., 1996; Durkefalden et al.,
116 2019). Further Northeast, no major boundary separates the Colombia Basin *sensu stricto* and an
117 elongated triangle pinched between the Hess Escarpment to the west and Beata Ridge to the east,
118 as confirmed by the Vertical Gradient of Gravity (VGG; Sandwell et al., 2014; Figure 1a),
119 suggesting that both belong to the same oceanic basin.

120 We extracted a 700 km-long profile running through the whole basin, first cutting across the
121 prominent East-West anomalies of the central Colombia Basin then bisecting the elongated
122 triangular basin northeastward, pinched between the Lower Nicaragua Rise on the west and the
123 Beata Ridge on the east. The profile location and magnetic anomaly are displayed on Figures 1c
124 and 2a, respectively.

125 The profile shows clear magnetic anomalies of high amplitude between 11.5 and 14°N and a
126 magnetically smooth area with anomalies of short wavelength and low amplitude further
127 northeast. We try to identify this sequence of magnetic anomalies – including the smooth part –
128 by comparing it with profiles derived from the Geomagnetic Polarity Time Scale and consider
129 that the smooth pattern marks the younger part of the CNS, i.e., the smooth third period of
130 Granot et al. (2012). The strong anomalies in the central Colombia Basin would therefore be
131 anomalies 33-34 (73 -83 Ma). The VGG map (Figure 1a) reveals a linear structure parallel to the
132 magnetic anomalies which probably marks the location of an extinct spreading center, suggesting
133 the presence of a local ridge jump and duplicated anomalies 33-34 in this basin (Figure 1c).
134 Further South, the thick sediments of the North Panama deformed belt and of the Magdalena Fan
135 make the anomalies difficult to identify due to larger distance to and possible thermal
136 demagnetization of the magnetic basement (e.g., Granot and Dymant, 2019).

137 The Colombia Basin show a sequence of magnetic anomalies extending from the third period of
138 the CNS to anomaly 33, representing ages of (less than) 92 Ma to 73 Ma.

139

140 **Magnetic anomalies in the Venezuela Basin**

141 The Venezuela Basin shows a prominent N-S structure on its eastern side on the VGG map
142 (Figure 1a), associated with a marked low on the magnetic anomaly map (Figure 1b). We
143 interpret these anomalies as reflecting a major fracture zone. Other weaker N-S trending
144 magnetic anomalies in the center of the basin may correspond to secondary fracture zones. A
145 band of dominantly positive magnetic anomalies extends along a general NE-SW direction,
146 parallel to the anomalies tentatively recognized by Ghosh et al. (1984); the northwestern corner
147 of the basin shows negative magnetic anomalies, and the southeastern corner presents smooth
148 low amplitude anomalies. At a local scale however, the anomalies trend E-W and are left-
149 laterally offset by the secondary N-S fracture zones, resulting in the general NE-SW direction.
150 We extracted two N-S, ~450 km-long magnetic profiles across the Venezuela Basin (Figure 1c).
151 The two profiles show similarities that confirm that the observed anomalies record geomagnetic
152 signal. However, they do not present the character of classical marine magnetic anomalies
153 associated to polarity reversals as recorded by seafloor spreading. We suggest that they record
154 the strong geomagnetic intensity variations observed within the second period of the CNS. The
155 magnetically smooth area bounding them to the south is similar to the one observed north of the
156 Colombia Basin. We interpret it as reflecting the third period of the CNS, as in the northern
157 Colombia Basin, its northern limit corresponding to marker Q1 (Figure 2a). Alternative
158 explanations for the smooth area include (1) thermal demagnetization of the extrusive basalt
159 under sediments that are twice thicker in this area than in the other parts of the Venezuela Basin

160 (Straume et al., 2019) as suggested by Granot and Dymant (2019), and (2) crustal thickness
161 variation as this area displays a normal oceanic crust in contrast to the thick oceanic plateau
162 seismically imaged in the other parts of the basin (Diebold et al., 1981).

163 The Venezuela Basin therefore shows a sequence of magnetic anomalies extending from the
164 second to third periods of the CNS, including Q1 at 92 Ma and extending at most from Q2
165 (108 Ma) to C34 (83 Ma) (Figure 2b). Comparing the tiny wiggles of our profiles across the
166 Venezuela Basin to the profiles presented by Granot et al. (2012) suggests a more likely age
167 interval of about 100-90 Ma (Figure 2c), although the correlation among individual “tiny
168 wiggles” is faint and questionable.

169

170 **DISCUSSION: AGE AND ORIGIN OF THE CARIBBEAN PLATE**

171 **A plateau formed at a spreading center**

172 The observation of identifiable magnetic anomalies 33-34 and Q1 as well as the second and third
173 periods of the CNS in the Colombia and Venezuela basins has an important implication. It means
174 that the part of the CLIP making these basins was formed at a spreading center. Although quite a
175 difficult exercise considering the paucity of constraints, we attempted to estimate spreading rates
176 from the identified anomalies. The clear anomaly 33r in the Colombia Basin leads to spreading
177 rate values of 35 km/Myr in the West, where this anomaly is well developed, to 25 km/Myr in
178 the East where it shows a significant narrowing. The third CNS period in the Colombia Basin
179 suggests a spreading rate much faster than 63 km/Myr, the period being uncomplete as marker
180 Q1 is not observed south of Hispaniola. Conversely, the uncomplete second and third CNS
181 periods in the Venezuela Basin predict a minimum spreading rate value of 22 km/Myr if the
182 whole second and third periods are considered. A spreading rate of ~55 km/Myr is obtained if

183 our tentative ages of 100-90 Ma are adopted. If so, fast to intermediate spreading rates would be
184 prevalent on the Caribbean Plate. The magmatic oceanic lithosphere formed at these rates is a
185 much better recorder of tiny magnetic variations such as those of the CNS than lithosphere
186 formed at slow spreading rates. Fast to intermediate spreading rates, similar to those observed on
187 the Pacific plate, are therefore in better agreement with a Pacific origin than an *in situ* origin. The
188 oceanic lithosphere of the northern Pacific plate recorded an important reorganization of the
189 Pacific-Farallón spreading center at the time of anomaly 33r, resulting in a change of the
190 transform fault direction and the development of multiple splays and intermediate ridge segments
191 (Granot et al., 2009). The different widths of anomaly 33r in the Colombia Basin may result
192 from such ridge jump.

193

194 **Age of the Caribbean Plate**

195 Summarizing the ages given by magnetic anomalies in the Colombia and Venezuela basins gives
196 a maximum range interval of 108 to 73 Ma at most for the part of the CLIP formed at a spreading
197 center. Several authors suggest that the Venezuela Basin may be of Early Cretaceous age
198 (Diebold et al., 1999; Fox and Heezen, 1975; Officer et al., 1957), a bit older but not inconsistent
199 with the second CNS period (108-92 Ma). Based on an extensive collection of samples from
200 many locations of the Caribbean Plate, Whattam and Stern (2015) proposed that the CLIP
201 formed in three magmatic pulses at 124-112 Ma, 92-88 Ma and 76-72 Ma, respectively. Our
202 results support the two later pulses but the formation of most of the Caribbean plate at a
203 spreading center suggests a more progressive building of the CLIP. The hummocky magnetic
204 pattern observed on the Lower Nicaragua Rise and the western part of the Colombia Basin may

205 represent an evidence for the latest proposed pulse, contemporaneous with the youngest
206 magnetic anomaly 33 and the inferred fossil spreading center.

207

208 **Reconciling constraints from geology, marine magnetics, and plate kinematics**

209 Three principal sets of constraints should be reconciled in any model describing the Caribbean
210 Plate and the CLIP evolution: (1) the CLIP was mainly formed at a spreading center, although
211 additional off-axis volcanism was also produced, and (2) it was formed between 120 and 73 Ma,
212 as emphasized above; and (3) the CLIP reached its present position between North and South
213 America between 73 and 45 Ma, as proven by numerous geological studies in the Caribbean
214 Islands, the Central American Isthmus, and the north of South America (e.g., Burke et al., 1978;
215 Duncan and Hargraves, 1984; Pindell and Barrett, 1990; among many others). These constraints
216 should be accommodated within the known motion of the main plates including the opening of
217 the Atlantic Ocean, the spreading reorganizations of the Pacific Ocean, and the consumption of
218 the latter in the subduction zone bounding the Americas to the West. A major difficulty is that
219 most plate tectonic reconstruction models do not predict a spreading center where the CLIP is
220 supposed to have been at 73 Ma, just before entering between North and South America. The
221 available models predict that the Pacific-Farallón spreading center was located more than 4000
222 km further west, too far from the required location if reasonable spreading rates and asymmetry
223 are considered. We therefore examined alternative options while honoring the incomplete
224 knowledge of the Pacific Plate evolution in the Cretaceous. A first observation is that magnetic
225 anomalies 33r and 34 are not observed between Clarion and Marquesas fracture zones, over a
226 distance of more than 2700 km along the inferred Pacific-Farallón spreading center, although
227 anomalies more recent than anomaly 33 young (73 Ma) are depicted at the same latitudes (e.g.,

228 Seton et al., 2012). This suggests that the Pacific-Farallón spreading center may have been
229 relocated to the position predicted by the plate reconstructions by a westward ridge jump at 73
230 Ma. Our first option is therefore assuming that the Pacific-Farallón spreading center was located
231 further East with respect to its predicted location during the formation of the CLIP up to 73 Ma.
232 A second observation is, before 85 Ma the inferred Farallón-Chazca spreading center was cutting
233 across the Pacific Ocean from the Pacific Plate to the subduction zone bounding the Americas to
234 the West on plate reconstruction models (e.g., Matthews et al., 2016). The lack of magnetic
235 anomalies 33r and 34 between Clarion and Marquesas fracture zones does not allow to identify
236 any kink (also called “magnetic bight”) marking the possible trace of a triple junction and the
237 continuation of the Farallón-Chazca spreading center beyond 85 Ma. Our second option is
238 therefore assuming that the Farallón-Chazca spreading center was active until 73 Ma and the
239 CLIP was emplaced on this spreading center. A third alternative option would be to consider an
240 independent Caribbean plate as early as 134 Ma, as proposed by Matthews et al. (2016).
241 However, we see no clear reason which would have led to such an individualization.
242 Furthermore, recent paleomagnetic evidences suggest that the Caribbean Plate was not
243 independent from the Farallón plate before 100 Ma (Boschman et al., 2019). We therefore do not
244 consider this option anymore.

245

246 **A plate tectonic evolution model for the CLIP and Caribbean Plate**

247 In Figure 3 we are gathering the constraints obtained from our marine magnetic anomaly
248 analysis, previous geological studies, and available plate kinematics in a series of eight sketches
249 that summarize the possible evolution of the Caribbean Plate since the initiation of the CLIP at
250 120 Ma. We assumed South America as fixed and built the evolution of the surrounding plates

251 and continents from finite rotations taken from the compilation of Matthews et al. (2016). For
252 120 Ma, we included the angular correction suggested by Torsvik et al. (2019) for the Pacific
253 Plate and other plates underlying the Pacific Ocean. It should be noted, however, that the
254 concepts illustrated by these sketches are generally compatible with most plate reconstruction
255 models of the area. During the period considered, the Gulf of Mexico was fully open, and the
256 Yucatan Block was in its present position with respect to North America. In the initial phases
257 (Figure 3, at 120, 83 and 73 Ma) we attached the Chortis Block to North America along the
258 southwestern shore of today's Mexico (Rogers et al., 2005) and let it drift eastward together with
259 the Caribbean Plate after 45 Ma, as proposed by previous authors (Gose, 1985; Pindell et al.,
260 1988).

261 At 120 Ma (Figure 3), active spreading centers in the Central Atlantic and (inferred) Proto-
262 Caribbean oceans were separating Laurasia (here North America and the Chortis and Yucatan
263 blocks) from Gondwana (here Africa and South America). The Pacific Plate was exclusively
264 surrounded by spreading centers and therefore expanding. Among them, the Pacific-Farallón and
265 Pacific-Chazca spreading centers formed the most recent Hawaiian and Phoenix M-series
266 magnetic anomalies and converged at a triple junction which third arm, the (inferred) Farallón-
267 Chazca spreading center, tentatively drawn up to the major subduction zone bounding North and
268 South America to the west. We infer that the Caribbean Plateau initiated at this triple junction
269 (called the Tongareva Triple Junction by Hochmuth et al., 2015), as observed for other oceanic
270 plateaus such as the Mozambique and Agulhas Plateaus (e.g., Gohl et al., 2012) or the Shatsky
271 Rise (e.g., Sager et al., 2019). It was probably coincident with the Galapagos hotspot, as
272 suggested by geochemical studies (Hauff et al., 1997; Kerr et al., 2003; Geldmacher et al., 2003;
273 Thompson et al., 2004) and geodynamic modelling (Nerlich et al., 2014). At that time, this triple

274 junction was about 1500 km away from the major plateau formed at ~120 Ma and constituted by
275 the present-day Ontong Java, Manihiki, and Hikurangi plateaus (Taylor, 2006; this plateau lies
276 just beyond the southwestern corner of Figure 3, 120 Ma).

277 As previously explained, two options for plate reconstructions are considered at 83 and 73 Ma.
278 We first discuss what is common to both options, then examine them successively for both times.
279 At 83 Ma, spreading was taking place all along the Mid-Atlantic Ridge (MAR) in the Central,
280 Equatorial and South Atlantic oceans (since 105 Ma; Granot and Dymant, 2015), between Africa
281 and both North and South America, whereas motion decreased considerably in the Proto-
282 Caribbean domain, between North and South America. The spreading center separating North
283 and South America was connected at a triple junction to the Central and Equatorial MAR. Plates
284 of the Pacific Ocean were subducting beneath North America, the Proto-Caribbean domain, and
285 South America. Our Option A considers a large Farallón Plate, subducting beneath the Americas
286 to the East and bounded by the Pacific-Farallón spreading center to the West, as in most plate
287 reconstruction models. The only difference with these models is that our Option A places the
288 spreading center between Clarion and Marquesas fracture zones further East. We speculate that
289 this part of the ridge drifted eastward through asymmetric spreading to remain in close vicinity
290 of the Galapagos hotspot, allowing the progressive construction of the CLIP on the spreading
291 center, as observed in other areas affected by ridge-hotspot interactions (e.g., Dymant, 1998;
292 Müller et al., 1998). Conversely, our Option B considers two plates, Farallón to the North and
293 Chazca to the South, subducting beneath the Americas to the East and bounded by spreading
294 centers to the West. The Farallón-Chazca spreading center extended from a RRR triple junction
295 with the Pacific Plate to the subduction zone eastward. Again, we speculate that this ridge

296 remained in the close vicinity of the Galapagos hotspot, allowing the progressive construction of
297 the CLIP on the spreading center.

298 At 73 Ma (Figure 3), the Atlantic Ocean continued opening between Africa and both North and
299 South America and is still doing so at present – we will not mention it again in further sections.
300 The proto-Caribbean domain was encountering slow convergence between North and South
301 America, that we symbolized with a subduction feature South of the Florida Block and Bahamas
302 Platform. The detailed history of this complex episode is beyond the scope of this paper. The
303 linearity of the Belize-Yucatan margin suggests a transform margin that is necessarily older than
304 the Cayman Trough system and may therefore have been active at this period. Motion along this
305 transform fault would have split the so-called Caribeana terrane and transported its western part
306 to the North, to be later accreted to the Greater Antilles (Garcia-Gasco et al., 2008). The CLIP
307 reached the subduction zone bounding the Americas to the West and collided with the Chortis
308 Block, later to detach from North America and join the Caribbean Plate in its eastward journey
309 (Rogers et al., 2007; Sanchez et al., 2016). Further East, the buoyancy of the thick and light
310 CLIP prevented it to enter into subduction, which resulted in inverting the subduction polarity
311 (Hoernle and Hauff, 2007). After this event, the Proto-Caribbean lithosphere was going to
312 subduct westward beneath the CLIP (e.g., Pindell et al., 2001). In the Pacific Ocean, seafloor
313 spreading ceased on the section of the Pacific-Farallón spreading center between Clarion and
314 Marquesas fracture zones (Option A) or the Farallón-Chazca spreading center (Option B),
315 leaving behind a fossil spreading center on the CLIP (now located in the Colombia Basin). At
316 that time, the CLIP had reached its maximal extension. A westward ridge jump (Option A) or the
317 attachment of the Chazca Plate to the Farallón Plate (Option B) resulted in the plate

318 configuration predicted by the reconstruction models (e.g., Matthews et al., 2016) in the Pacific
319 Ocean, as in the next evolution stages which we will not describe further.

320 At 45 Ma (Figure 3), the Caribbean Plate, including the CLIP and the Chortis Block, exists as an
321 independent plate in a configuration similar to the present one. The older subduction separating it
322 from South America retreated eastward and consumed the whole Proto-Caribbean lithosphere.

323 To the West, a new subduction zone initiated to accommodate the faster eastward motion of the
324 Farallón Plate with respect to that of the Caribbean Plate, with the former subducting under the
325 latter. Since that time, the Caribbean Plate has been bracketed by these two subductions. Two
326 major transform fault systems separate the Caribbean Plate from North and South America,
327 respectively. The Cayman Trough, a short spreading center part of the northern transform
328 system, started to open shortly before 45 Ma (Leroy et al., 2000). Significant parts of the CLIP
329 probably accreted to the Equatorial Andes during this period (Jaillard et al., 2009).

330 Since 45 Ma (Figure 3, 45, 25 and 0 Ma), the CLIP was subject to strong deformation due to the
331 convergence between the North and South American continents. As a result, it split into at least
332 two main blocks, roughly representing the Colombia and Venezuela Basin, separated by a
333 convergent boundary, the reactivated Beata Ridge. Both blocks probably rotated, the sense and
334 magnitude of the rotation depending on which model does apply. For Option A (Pacific-Farallón
335 spreading center), a full counterclockwise rotation of 45° is required, whereas for Option B
336 (Farallón-Chazca spreading center), a full clockwise rotation of 20° is sufficient to explain an
337 East-West fossil spreading center in the Colombia Basin (e.g., Burmester et al., 1996).

338 Paleomagnetic investigations on undeformed parts of the Colombia and Venezuela basins would
339 help to test these hypotheses. The Caribbean Plate has shortened, with incipient subductions at
340 Muertos Trough south of Puerto Rico and the South American Deformed Belt off Colombia.

341 Both Options A and B succeed in taking into account the major constraints derived from both our
342 new magnetic anomaly interpretation, i.e., the CLIP being formed at a spreading center between
343 120 and 73 Ma, and from many previous geological studies, i.e., the CLIP being emplaced
344 between North and South America between 73 and 45 Ma. Although some elements constituting
345 the complex geological history proposed above have been already suggested by previous works,
346 the peculiarity of this work is to investigate the possibilities of a spreading center lying in the
347 close vicinity of the Central American Seaway, either through a large but local jump of the
348 Pacific-Farallón spreading center at 73 Ma (Option A) or through the Farallon-Chazca activity
349 being extended by 12 Ma, until 73 Ma (Option B).

350

351 **CONCLUSION**

352 In the Colombia Basin, we identify a sequence of strong magnetic anomalies in the South and a
353 smooth magnetic zone extending to the North that we interpret as Chrons 33-34 and the youngest
354 part of the Cretaceous Normal Superchron (CNS), respectively. In the Venezuela Basin, we
355 identify a major N-S fracture zone on both the gravity and magnetic data; a consistent pattern of
356 magnetic anomalies in the central part of the basin is interpreted as the intermediate part of the
357 CNS, whereas a smooth area in the southern part of the basin may correspond to its younger part.
358 The observation of recognizable magnetic anomalies in the Caribbean Large Igneous Province
359 (CLIP) means that the CLIP was mostly formed at the axis of a spreading center, although
360 secondary volcanics also overlie preexisting structures such as the Lower Nicaragua Rise and the
361 Beata Ridge where they generate disordered magnetic anomaly patterns. Our magnetic anomaly
362 identifications suggest that the CLIP was formed between 108 and 73 Ma, in good agreement
363 with published ages measured on samples from all over the Caribbean Plate (Sinton et al., 1998;

364 Kerr et al., 2003). We propose a model in which the CLIP was formed at a spreading center in
365 the Pacific Ocean located in the vicinity of the present Central America.

366

367 **Data availability:** A low-resolution version of the magnetic anomalies supporting the findings of
368 this study will be incorporated in the WDMAM version 2.1. The full resolution version is
369 available from the corresponding author upon request.

370 We downloaded marine total magnetic field measurements from the National Center for
371 Environmental Information (formerly National Geophysical Data Center;
372 www.ngdc.noaa.gov/mgg/geodas/trackline.html). Magnetic anomalies on land are from the
373 World Digital Magnetic Anomaly Map (wdmam.org). Vertical gradients of gravity are available
374 from the Scripps Institution of Oceanography, University of California in San Diego
375 (topex.ucsd.edu).

376

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385

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536

537 **FIGURE CAPTIONS**

538 **Figure 1.** Potential field anomalies and interpretation in the Caribbean plate. **(a)** Vertical
539 gradient of gravity (Sandwell et al., 2014), **(b)** marine magnetic anomaly (Garcia-Reyes, 2018),
540 and interpretation **(c)** at the scale of the plate and **(d)** the Colombia Basin (CB) and Venezuela
541 Basin (VB). Transparent polygons mark the Lower Nicaragua Rise (LNR), Beata Ridge (BR)
542 and Aves Ridge (AR), formed by volcanic episodes post-dating the main emplacement of the
543 Caribbean Large Igneous Province. Solid blue lines mark the front of accretionary prisms at,
544 from North to South, Los Muertos Trough, South Caribbean Deformed Belt, and Panama
545 Deformed Belt; dashed blue line delineates the Hess Escarpment; thick solid red lines represent
546 conjugate magnetic anomalies 34 and 33 in the CB, and magnetic feature Q1 of the Cretaceous
547 Normal Superchron (CNS) in the VB; dashed red lines underline other magnetic features of the

548 dynamic mid-CNS in the VB; dotted thick red line underline the fossil spreading center in the
549 CB; thin red lines mark fracture zones in the VB; thick black lines identify the magnetic profiles
550 1-3 extracted from the magnetic map and thin black lines measured magnetic profiles displayed
551 in Figure 2.

552

553 **Figure 2.** Interpretation of magnetic anomalies in the Colombia and Venezuela basins. Magnetic
554 anomalies were extracted from the computed grid in the Colombia Basin (CB) and Venezuela
555 Basin (VB) along Profiles 1, 2 and 3 (see location on Figure 1c). Other measured magnetic
556 anomalies are also displayed where available along proper direction. These profiles are
557 compared to selected magnetic anomaly profiles across the Cretaceous Normal Superchron
558 (CNS). **(a)** In the CB, Profile 1 displays conjugate magnetic anomalies 33 and 34 on both sides
559 of a fossil spreading center (FR) clearly depicted on the gravity data (Figure 1a); the smooth
560 magnetic anomaly further Northeast correspond to the quiet more recent part of the CNS
561 underlined by red boxes on (a) and (c). **(b)** In the VB, Profiles 2 and 3 show smooth magnetic
562 anomalies in their southern side and more dynamic anomalies in their northern side, separated by
563 a clear anomaly; they encompass the youngest and medium parts of the CNS, respectively,
564 underlined by blue boxes on (b) and (c), the clear anomaly being identified with marker Q1
565 (Granot et al., 2012). **(c)** Sea surface anomaly profiles from different ocean basins showing
566 consistent magnetic intensity variations within the CNS (after Granot et al., 2012). Magnetic
567 anomaly profiles have been visually deskewed in the CB and on the reference CNS profiles from
568 Granot et al. (2012) to restore the typical boxcar shape of anomaly 33r. This cannot be achieved
569 in the VB, where the original anomalies are displayed. See text for additional information.

570

571 **Figure 3.** Plate tectonic evolution model for the Caribbean Large Igneous Province (CLIP) and
572 Caribbean Plate at 120, 83, 73, 45, 25 and 0 Ma. At **120 Ma**, the Caribbean Plateau initiated at
573 the Tongareva triple junction, whereas the Proto-Caribbean Ocean was opening between North
574 and South America. Two options are proposed at **83** and **73 Ma** for the formation of the CLIP at
575 a mid-ocean ridge in the vicinity of the future Central America: in **Option A**, the CLIP formed at
576 the Pacific-Farallon spreading center, later affected by a major westward ridge jump; in **Option**

577 **B**, the CLIP formed at the Farallón-Chazca spreading center. At **73 Ma**, the CLIP collided with
578 the Chortis Block and the nearby subduction zone, which reversed its polarity and started to
579 consume the Proto-Caribbean lithosphere. At **45 Ma**, the Central American subduction zone
580 formed west of the CLIP and Chortis Block, which therefore constitute the new Caribbean Plate.
581 The slow convergence between North and South America and the eastward motion of the
582 Caribbean plate result, at **25** and **0 Ma**, in compression on Beata Ridge and rotation of the CB
583 and VB. See text for additional information. The “computed” Galapagos hotspot location is
584 computed from Matthews et al. (2016), whereas the “proposed” one is modified to better agree
585 with a plateau formed by the hotspot at a spreading center from 120 to 73 Ma as proposed in our
586 model.





