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Kingsley Ezenwaka, Boris Marcaillou, Mireille Laigle, Frauke Klingelhofer,  
Jean-Frédéric Lebrun, Michele Paulatto, Youssef Biari, Frédérique Rolandone,  
Francis Lucazeau, Arnauld Heuret, et al.

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# 1 Thermally-constrained fluid circulation and seismicity in the 2 Lesser Antilles Subduction Zone

3 Ezenwaka, K.<sup>a</sup>, Marcaillou, B.<sup>a</sup>, Laigle, M.<sup>a</sup>, Klingelhoefer, F.<sup>b</sup>, Lebrun, J.-F.<sup>c</sup>, Paulatto, M.<sup>d</sup>, Biari,  
4 Y.<sup>a,e</sup>, Rolandone, F.<sup>f</sup>, Lucazeau, F.<sup>g</sup>, Heuret, A.<sup>h</sup>, Pichot, T.<sup>b,i</sup>, Bouquerel H.<sup>g</sup>

5 <sup>a</sup> Université Côte d'Azur, CNRS, Observatoire de la Côte d'Azur, IRD, Géoazur, Valbonne, France.

6 <sup>b</sup> Geo-Ocean, Univ Brest, CNRS, Ifremer, UMR6538, F-29280 Plouzane, France.

7 <sup>c</sup> Géosciences Montpellier, Université de Montpellier, CNRS, Université des Antilles, Pointe à Pitre,  
8 Guadeloupe (FWI), France.

9 <sup>d</sup> Imperial College London, Department of Earth Science and Engineering, Prince Consort Road, UK.

10 <sup>e</sup> Capgemini – Oil & Gas Centre of Excellence, Technopole Hélioparc Bâtiment Newton, 4 Rue Jules Ferry,  
11 64000, Pau, France.

12 <sup>f</sup> Sorbonne Université, CNRS, Institut des Sciences de la Terre de Paris, IStEP UMR 7193, Paris, France.

13 <sup>g</sup> Université de Paris, Institut de physique du globe de Paris, CNRS, Paris, France.

14 <sup>h</sup> Université de Guyane, Géosciences Montpellier (UMR 5243), Cayenne, 97300, France.

15 <sup>i</sup> Beicip-Franlab, 232 avenue Napoleon Bonaparte Rueil-Malmaison, Paris 92500, France.

## 16 **Abstract**

17 At subduction zones, fluid circulation and elevated pore pressure are key factors controlling the  
18 seismogenic behavior along the plate interface by reducing absolute fault strength, increasing the time  
19 return of high magnitude co-seismic rupture and favoring aseismic slip. The Lesser Antilles is an end-  
20 member subduction zone where the slow subduction of numerous trans-oceanic fracture zones and  
21 patches of pervasively fractured, hydrated and serpentized exhumed mantle rocks increase the water  
22 input. Heat-flow variations measured in the trench and the forearc during the Antithesis 1 cruise reveal  
23 heat advection by fluid circulation and shed a new light onto the thermal control of seismicity location  
24 in the subduction zone.

25 In the Northern Lesser Antilles, heat-flow anomalies, negative in the trench and positive in the  
26 forearc, reveal a ventilated fluid circulation with downward percolation of cold fluids at the sediment-  
27 starved, pervasively fractured trench and upward discharge of warm fluids through the Tintamarre Fault  
28 Zone in the forearc. In contrast, in the Central Lesser Antilles, a positive heat-flow anomaly at the trench  
29 and the accretionary wedge is typical of an insulated fluid circulation where warm fluids invade the plate  
30 interface flowing updip from the subduction depths up to the trench.

31 The investigated margin segments correspond with a very low number of interplate thrust  
32 earthquakes, illustrating the frequent statement that fluids in subduction zones tend to reduce the  
33 interplate coupling, favor slow to aseismic slip behavior, and increase the time return of large seismic  
34 events. Moreover, the location of intraslab, and supraslab earthquakes at depth beneath the Central  
35 Lesser Antilles suggest a close relation to temperature-related dehydration reactions.

36

37        **Keywords**

38        Thermal modelling, Heat-flow, Lesser Antilles, Subduction zone, Seismogenic zone, Serpentinite  
39        dehydration reaction

40        **1. Introduction**

41        In subduction zones, complex temperature–fluid interactions control predominantly the seismogenic  
42        behavior of the megathrust, which hosts most of the large ( $M_w > 7$ ) to great ( $M_w > 8$ ) subduction  
43        earthquakes in the world. The temperature increases with depth and the transition from shallow stable  
44        (aseismic) to deeper stick-slip (seismogenic) behavior along the interplate contact depends on  
45        mechanical and chemical processes promoting gouge consolidation at temperature of 60–150°C (Moore  
46        & Saffer, 2001, Vrolijk, 1990). At greater depth, the onset of deep stable sliding for a “normal type”  
47        oceanic crust is generally associated with temperatures of 350–450°C (Tse & Rice, 1986) and/or the  
48        interaction of the interplate with the serpentinized mantle wedge of the upper plate (Hyndman et al.,  
49        1997). However, subduction of exhumed ultramafic rocks of slow-spreading oceanic crust and deep  
50        fluid circulation may affect thermally and mechanically this evolution of the interplate sliding behavior.  
51        Pore fluid overpressure possibly correlates with patches of low interseismic coupling (e.g. Moreno et  
52        al., 2014) and promotes aseismic creep, slow-slip and very-low frequency earthquakes (SSE and VLFE)  
53        rather than large co-seismic ruptures (Saffer & Wallace, 2015, and Kodaira et al., 2004). Moreover, fluid  
54        circulation at depth partly controls earthquake recurrence (Byerlee, 1993, Sibson, 2013, Saffer & Tobin,  
55        2011).

56        Fluids enter subduction zones through different processes at work before the trench. These processes  
57        includes fluids trapped in the subduction channel sediments (e.g. Calahorrano et al., 2008), or  
58        hydrothermal flow in the oceanic upper crustal aquifer (e.g. Fisher & Becker, 2000), or trapped at greater  
59        depth in hydrous minerals down to the lithospheric mantle through different types of structure such as  
60        trans-oceanic fracture zones (Cooper et al., 2020), large-scale detachments at slow-spread oceanic ridges  
61        (Marcaillou et al., 2021), crustal-scale folded ridge (Kodaira et al., 2004), or outer rise slab-bending  
62        faults (e.g. Ranero et al., 2003). Circulating fluids advect heat which may drastically change the oceanic  
63        plate geotherm prior to subduction, modulate temperatures along the plate interface and change the heat  
64        flow at the surface and the margin thermal structure with respect to that estimated from the model of a  
65        conductively cooling plate (Kummer & Spinelli, 2008; Harris et al., 2010; Harris et al., 2017; Harris et  
66        al., 2020; Spinelli et al., 2018). The effect of hydrothermal fluids on thermal structure depends on the  
67        mode of circulation. Thick, continuous and undeformed sediments in the trench prevent fluid exchange  
68        between the ocean and the crust and favor insulated hydrothermal circulation (Harris et al., 2017). In  
69        this context, warm fluids flowing from subduction depth updip along the basement aquifer may generate  
70        heat-flow values higher than that predicted by conductive heat transfer models in the accretionary wedge  
71        and at the trench (e.g., Nankai ; Spinelli & Wang, 2008). In contrast, fractured oceanic crust with a thin

72 sediment cover in the trench, and/or a deeply fractured forearc crust favor fluid-driven heat advection to  
73 and/or from the ocean, generating the so-called ventilated hydrothermal circulation (Harris et al., 2017).  
74 As a result, downward percolation of cold fluids in the trench may generate significantly lower heat-  
75 flow values than that predicted by conductive heat transfer models (e.g., Costa Rica; Harris & Wang,  
76 2002). Moreover, in a deeply and pervasively fractured forearc, fluid upward migration along fault  
77 planes and expulsion at the seafloor can generate elevated heat flow (Pecher et al., 2017). Hence,  
78 measured heat-flow values significantly different from those expected for conductive heat transfer  
79 provide indirect constraint on fluids circulation at depth.

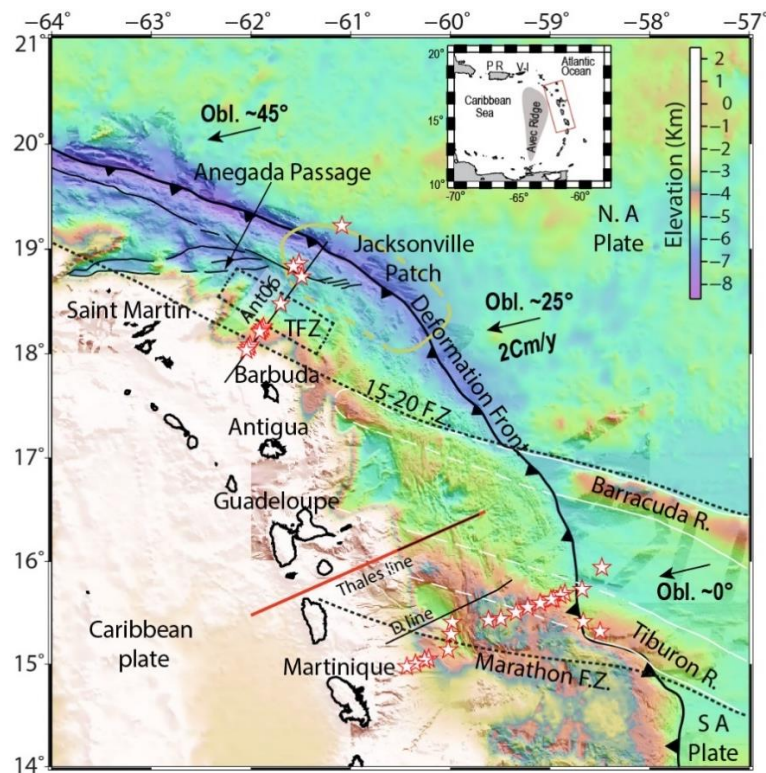
80 The Lesser Antilles is an end-member subduction zone, which undergoes the subduction of a slow-  
81 spreading oceanic lithosphere, partly made of exhumed, hydrated, serpentinized peridotite patches  
82 within the slab crust (Paulatto et al., 2017), fractured with pervasive detachment faults (Marcaillou et  
83 al., 2021) and/or highly hydrated trans-oceanic fracture zones (Cooper et al., 2020). Moreover, the  
84 Lesser Antilles seismicity is heterogeneous, with along-strike variations in b-value (Schlaphorst et al.,  
85 2016) and isolated nests of thrust-faulting earthquakes (Hayes et al., 2013). This subduction zone is thus  
86 a promising study area to investigate the influence of along-strike variations in deep hydrothermal  
87 circulation onto the interplate seismic activity. During cruises Antithesis 1 and 3, we acquired a grid of  
88 multichannel seismic (MCS), four trench-normal Wide-Angle Seismic (WAS) profiles, and heat-flow  
89 measurements along two trench-normal profiles at the Lesser Antilles Subduction zone (Marcaillou &  
90 Klingelhoefer, 2013a, 2013b, 2016). These measurements offshore of Martinique and Saint Martin  
91 islands respectively (Figure 1) aim at investigating heat-flow variations related to fluid circulation at  
92 depth. Drastic mismatches between measurements of heat flow and predictions assuming conductive  
93 cooling highlight the strong influence of fluid-driven heat advection on the heat-flow at the surface. We  
94 analyze pathways for fluid charge and discharge, the impact of this hydrothermal circulation on the  
95 regional heat-flow and the temperature along the interplate contact, and discuss the relation to the  
96 seismicity location in the Lesser Antilles Subduction Zone (LASZ).

## 97 **2. Regional setting**

### 98 *2.1 Geodynamical and structural background*

99 The Caribbean plate overthrusts the North and South American Plates in a N76° direction with a 2  
100 cm/yr convergence rate (DeMets et al, 2000). In the study area, the calculated age of the subducting  
101 oceanic plate at the trench from the nearby magnetic anomaly C34 of the North American Plate ranges  
102 from 83 Ma east of Barbuda island to 98 Ma east of southern Martinique island (Carpentier et al., 2008).  
103 A dense geophysical dataset - including bathymetric, multichannel seismic and wide-angle seismic data  
104 - constrain the along-strike variations in structure of the LASZ (Kopp et al., 2011, Pichot et al., 2012,  
105 Laigle et al., 2013b, Evain et al., 2013, Paulatto et al., 2017, Laurencin et al., 2017, 2018, 2019, and  
106 Boucard et al., 2021).

107 The nature and structure of the Atlantic subducting crust is expected to vary both in the north-south  
 108 and east-west directions. At slow-spreading mid-ocean ridges, magmatically-robust segments promote  
 109 typical layer 2/3 “Penrose” structure (e.g. White et al., 1992), while tectonically-dominated segments  
 110 generate stretched and thinned crust frequently hosting large bodies of exhumed, hydrated and  
 111 serpentinized upper mantle peridotites (e.g. Cannat et al., 2006, Escartín et al., 2008). Numerous  
 112 occurrences of tectonically-dominated basement have been observed near the Mid-Atlantic Ridge,  
 113 where Oceanic Core-Complexes and Megamullions outcrop (e.g. Tucholke et al., 1998, Ildefonse et al.,  
 114 2007, Sztikar et al., 2019), between the Mid-Atlantic Ridge and the Lesser Antilles Subduction Zone  
 115 about 300 km from the trench (Davy et al., 2020), and at the Jacksonville Patch in the trench offshore  
 116 of Barbuda island (Marcaillou et al., 2021). Moreover, numerous trans-oceanic fracture zones deeply  
 117 hydrate the oceanic crust and mantle. The subducting Vema, Marathon, Mercurius and Doldrums  
 118 Fracture zones of the South American Plate generate vigorous dewatering beneath the Central Lesser  
 119 Antilles Arc (Cooper et al., 2020). The 15-20 Fracture Zone in the North American Plate (Braszus et al.,  
 120 2021) located beneath the Northern Lesser Antilles forearc is likely to favor fluids circulation at depth  
 121 (Marcaillou et al., 2021).



122  
 123 *Figure 1: Bathymetric map of the Northern Lesser Antilles based on data recorded during cruises Antithesis*  
 124 *I, III (Marcaillou & Klingelhofer, 2013a, 2013b, 2016), Sismantilles II (Laigle et al., 2013a, b). The map shows*  
 125 *the location for heat-flow measurements recorded during Antithesis cruise (plain stars), Multichannel and Wide-*  
 126 *Angle seismic lines (black and red lines respectively) Ant06 (Laurencin et al., 2017, Boucard et al., 2021), Thales*  
 127 *line (Kopp et al., 2011), D line (Laigle et al., 2013a, b). The black dotted line shows the projection onto the seafloor*  
 128 *of the 15-20 and Marathon Fracture Zones, which deeply incise the subducting oceanic plate, and the dotted frame*  
 129 *shows the 60-km-wide Tintamarre Fault Zone (TFZ) in the forearc. N A – North American, S A – South American,*  
 130 *PR – Puerto Rico, VI – Virgin Islands.*

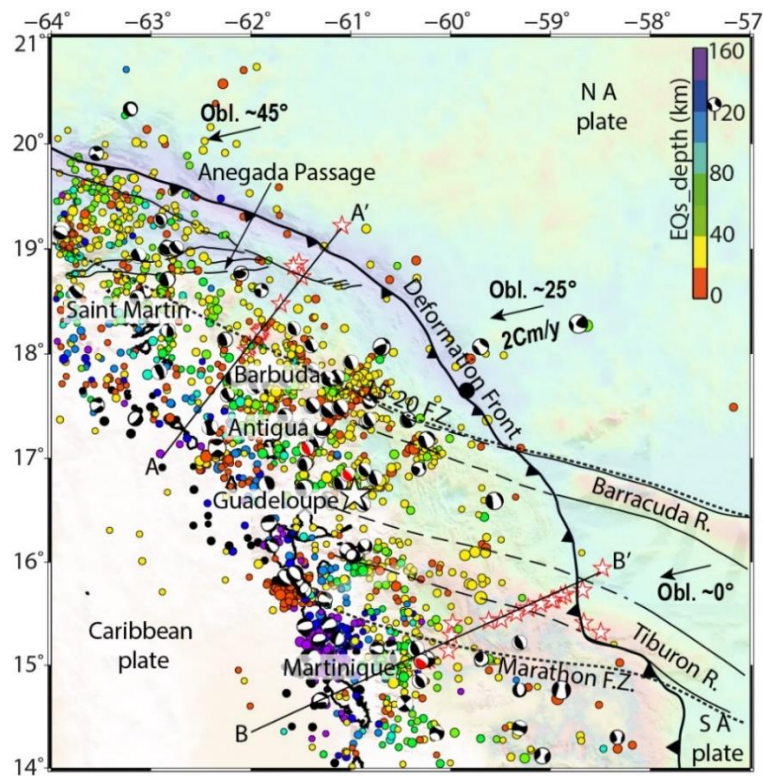
131 The sediment thickness in the trench decreases northward from approximately ~3 km south of  
132 Tiburon Rise (Pichot et al., 2012) offshore of Martinique, to ~0.5 km north of Barracuda Ridge offshore  
133 of Saint Martin (Laurencin et al., 2019). The width of the accretionary prism also decreases from 110 to  
134 30 km (Laurencin et al., 2019, Laigle et al., 2013b). Seismic lines in the Northern Lesser Antilles  
135 (Laurencin et al., 2017, Boucard et al., 2021) and in the Central Lesser Antilles (De Min et al., 2015,  
136 Laigle et al., 2013a, 2013b) show that the overall thickness of the forearc sedimentary layer and the  
137 margin basement is similar along-strike. In the forearc domain offshore of Antigua-Barbuda, the >100-  
138 km-long and 60-km-wide N120° trending Tintamarre Fault Zone deeply and pervasively fractures the  
139 margin (Figure 1) (Boucard et al., 2021). The slab dip angle shows apparent along-strike variation at the  
140 shallower part, when observed as a function of the distance from the trench. For instance, the slab dip is  
141 ~10° at 30 km and 110 km distance offshore of Saint Martin and Martinique islands respectively  
142 (Laurencin et al., 2019, Boucard et al., 2021, Kopp et al., 2011, Laigle et al., 2013b). This difference  
143 corresponds to the along-strike variation in accretionary wedge size. In contrast, the landward increase  
144 in slab dip angle is similar on the two profiles when observed as a function of interplate depth. At large  
145 depth, the slab dip angle is up to 51° at 280 km distance from the trench and shows no significant along-  
146 strike variation up to Guadeloupe (Paulatto et al., 2017), and Saint Martin when projected from Wide  
147 angle model of Klingelhoefer et al., (2018). The mantle wedge of the upper plate intersects the slab at  
148 24 km and 28 km depth (~100 km and ~160 km from the deformation front) offshore of Saint Martin  
149 and Martinique islands respectively (Laurencin et al., 2018, Kopp et al., 2011).

## 150 *2.2 Seismicity and seismogenic zone*

151 A recent re-interpretation of the available campaign and continuous GPS measurements in the  
152 Caribbean resulted in a re-evaluated plate velocity field (van Rijsingen et al., 2021). These authors  
153 propose that the plate coupling along the Puerto-Rico and Lesser Antilles subduction interface is very  
154 low. Consistently, the seismicity catalogue record only a few hundred earthquakes per year in the Lesser  
155 Antilles (Figure 2). However, investigations on some coral micro-atolls suggest that vertical  
156 deformation are possibly related to a local increase in interseismic coupling at great depth (Philibosian  
157 et al., 2022). A more recent study (van Rijsingen et al., 2022) has however, presented vertical velocities  
158 for the Lesser Antilles Islands and examine the link between the short and long-term vertical motions  
159 and their underlying processes. Based on their elastic dislocation models, they show that a locked or  
160 partially locked interplate up to 60 km depth would produce uplift of the island arcs, which is opposite  
161 to the observations of microatolls and GNSS data. Thus, suggesting low coupling for this subduction  
162 zone.

163 During the historical period, only few earthquakes among damaging events occurred on the plate  
164 interface, including the largest 1843 event with an intensity-based magnitude possibly ranging between  
165 7.0 (Bernard & Lambert, 1988) and 8.4 (Feuillet et al., 2011; Hough, 2013). The CMT catalog  
166 (Dziewonski et al., 1981; Ekström et al., 2012) indicate that only about 46 earthquakes along ~800-km-

167 long segment, with  $M_w > 5$  and focal mechanisms consistent with a co-seismic rupture along the  
 168 subduction interface, have been recorded teleseismically since 1973 (Figure 2). This scarce interplate  
 169 seismicity is mainly aggregated in two clusters: one from Montserrat to Barbuda and the other from the  
 170 Anegada Passage to the Virgin Islands. Between these regions and to the south of Guadeloupe,  
 171 subduction earthquakes are very rare in the instrumental period, and small earthquakes ( $M_w < 5$ )  
 172 dominate (Schlaphorst et al., 2016). The scarcity of subduction earthquakes raises the question of  
 173 seismic gaps in the Lesser Antilles, particularly between Barbuda and the Anegada Passage (Marcaillou  
 174 et al., 2021).  
 175



176  
 177 *Figure 2: Seismicity distribution along the Lesser Antilles margin. The colored circles are the earthquakes*  
 178 *from the USGS catalogue ( $M_w > 3.5$  from 1900 to 2022), with size and color representing magnitude and*  
 179 *epicentral depth, respectively. The black star represents the epicenter of the 1843 earthquakes. Black focal*  
 180 *mechanisms are thrust-type earthquakes recorded teleseismically (from the gCMT catalogue 1976 – 2021). Red*  
 181 *focal mechanisms are relocated flat thrust earthquakes based on OBS deployment (Laigle et al., 2013a). Black*  
 182 *lines AA' and BB' show the location of the thermal models and the earthquake profiles shown in Figure 8.*

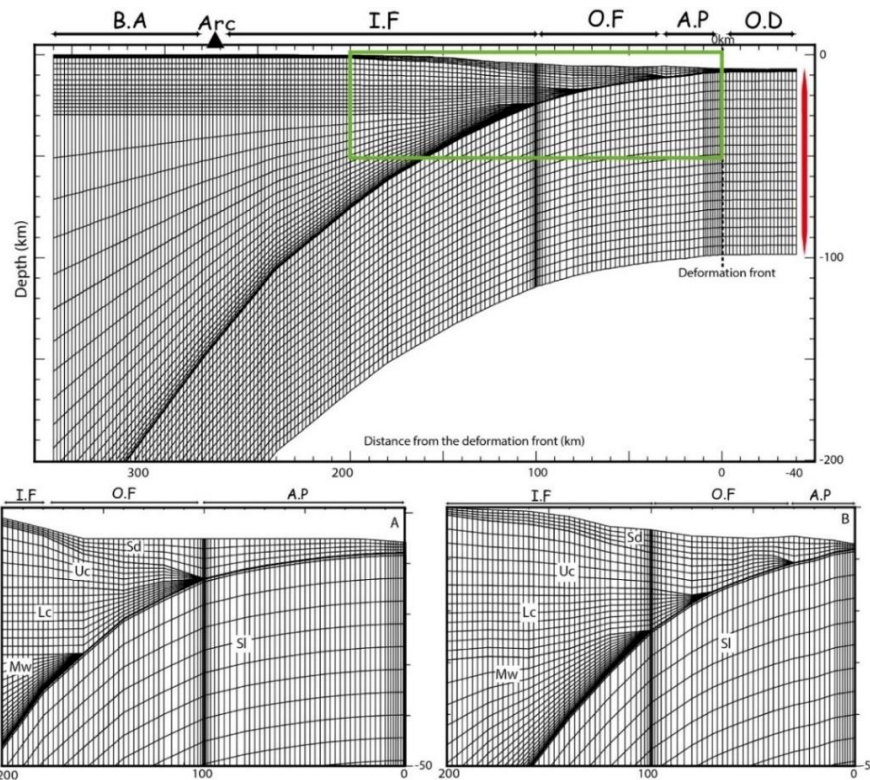
### 183 **2.3 Thermal regime**

184 Prior to the Antithesis cruises, old, scarce and highly scattered heat-flow measurements existed in  
 185 the Lesser Antilles forearc and the trench. More recent data were acquired in the Grenada backarc basin  
 186 and Island arcs (Manga et al., 2012). Gutscher et al. (2013) proposed first thermal models at various  
 187 latitudes along the Lesser Antilles. In their study, lines AA' and CC' approximately correspond to the  
 188 Saint Martin and Martinique heat-flow profiles in the current study. However, along these two lines, the  
 189 modelling resulted in a poorly constrained thermal structure. Offshore of Antigua, only one heat-flow

190 measurement ( $82 \text{ mW/m}^2$ ) in the forearc constrain the model, and offshore of Martinique, old heat flow  
 191 measurements scattered between  $30$  and  $90 \text{ mW/m}^2$ . Thus, the margin thermal structure needs to be re-  
 192 evaluated in the Northern and Central Lesser Antilles.

### 193 3 Methods

194 During the Antithesis 1 cruise (Dec 2013 - Jan 2014), we acquired 39 heat-flow measurements using  
 195 a microprocessor-controlled heat-flow (MCHF) instrument (see the Supplementary Material for  
 196 description). We model the thermal structure of the subduction zone along two trench-normal profiles,  
 197 one located between Barbuda and Saint Martin islands and crossing the volcanic arc at St Kitts island  
 198 (hereafter named ‘Saint Martin’ profile), and the other crossing Martinique island forearc and active  
 199 volcanic arc (hereafter named ‘Martinique’ profile) (Figure 1). The 2-D finite-element steady-state  
 200 modelling method (Wang et al., 1997), the mesh geometry (Figure 3), the input parameters and the  
 201 thermal boundary conditions are described in details in the supplementary material.  
 202



203  
 204 *Figure 3 : Geometry of the finite element mesh used for the 2D steady-state thermal modelling. The green*  
 205 *frame indicates projected regions for (A) Martinique profile and (B) Saint Martin profile. The red line indicates*  
 206 *the location of the calculated oceanic geotherm. [O.D – Oceanic domain, A.P – Accretionary prism, O.F – Outer*  
 207 *forearc, I.N – Inner forearc, B.A – Backarc, Sd – Sediment, Sl – Slab, Uc – Upper crust, Lc – Lower crust, Mw –*  
 208 *Mantle wedge]*

209 For conductive models, the geotherm at the oceanic boundary is calculated using a model of a  
 210 conductive half-space cooling lithosphere based on a 1-D approach (Hutchison, 1985) and detailed by  
 211 Marcaillou et al., (2008). However, fluid circulation within the incoming oceanic crust can cause



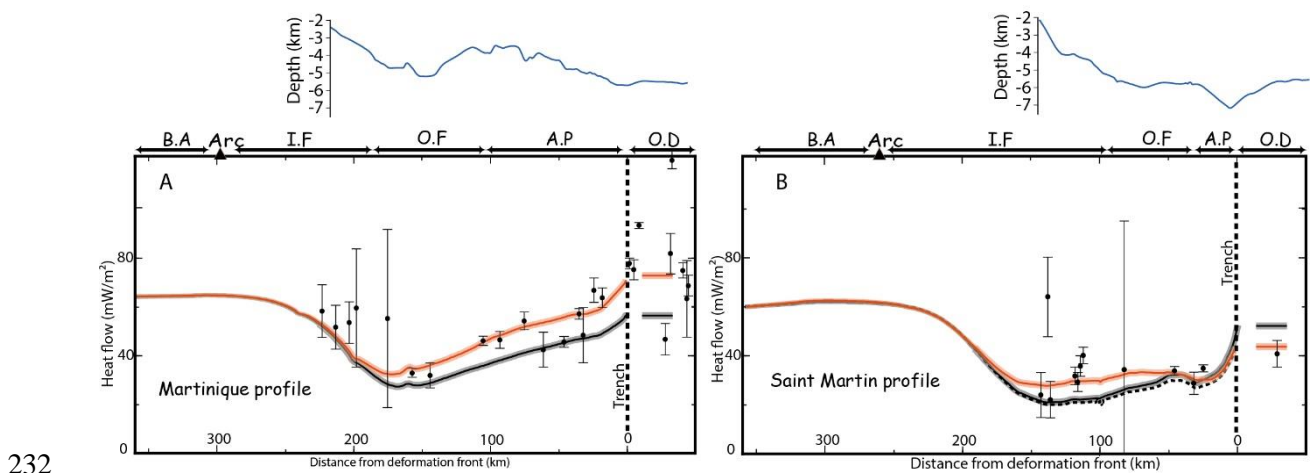
212 hydrothermal warming (e.g. Spinelli & Wang, 2008) or cooling (e.g. Harris & Wang, 2002) in the trench,  
 213 and modify the heat flow at the surface, the oceanic geotherm and the temperature along the subduction  
 214 interface. We use the methods by (Spinelli & Wang, 2008, Harris & Wang, 2002) to calculate the oceanic  
 215 geotherm where anomalous heat flow (i.e. heat-flow different from conductive value) indicate  
 216 significant heat advection. This approach requires the use of Nusselt number (Nu) as a proxy to model  
 217 heat advection due to hydrothermal circulation (See the Supplementary material).

## 218 4 Regional heat-flow and fluid-driven heat advection

219 In the following, we describe the measured and calculated heat-flow values based on conductively  
 220 cooling modelling and heat advection in order to discuss the influence of fluid circulation.

### 221 4.1 Measurements

222 We recorded 13 and 26 heat-flow measurements, at depth greater than 2400m, from 30-50 km before  
 223 the trench up to the inner forearc, at the latitude of Saint Martin and Martinique respectively (Figure 1).  
 224 Water depths for heat-flow measurements are indicated in Figure 4. Along the Martinique profile, the  
 225 heat flow decreases progressively from  $\sim 78\text{mW/m}^2$  in the trench to  $35\text{-}45\text{mW/m}^2$  at 100-150 km from  
 226 the deformation front in the outer forearc and increases to  $\sim 60\text{mW/m}^2$  towards the arc (Figure 4A). In  
 227 contrast, along the Saint Martin profile, the heat flow does not significantly vary from the trench,  
 228  $\sim 42\text{mW/m}^2$ , to the forearc, where values range from 30 to  $42\text{mW/m}^2$  between 45 and 120 km from the  
 229 deformation front (Figure 4B). The two profiles differ in two key ways. First, the heat flow is 53%  
 230 higher in the trench offshore of Martinique than of Saint Martin. Moreover, the heat flow decreases from  
 231 the trench to the outer forearc along the former but remains constant along the latter.



233 *Figure 4: Measured and calculated heat-flow along Martinique profile (A) and Saint Martin profile (B). The*  
 234 *figures show the heat-flow measurements (black dots), the calculated heat-flow for conductive models (black line)*  
 235 *and for models including fluid thermal convection (red line) with 10% uncertainty (shaded area). In the oceanic*  
 236 *domain, the horizontal lines are 1D calculated values. The dash line represent model without fluid expulsion in*  
 237 *the forearc. The blue lines are the shapes of the bathymetry along the collected heat-flow data for the both profiles.*  
 238 *[O.D – Oceanic domain, A.P – Accretionary prism, O.F – Outer forearc, I.N – Inner forearc, B.A – Backarc]*

239 **4.2 Calculated conductive heat flow**

240 Conductive thermal modelling predicts a heat flow profile which decreases from the oceanic domain  
241 to the forearc, from 56 to 26 mW/m<sup>2</sup> along the Martinique Profile and from 52 to 22 mW/m<sup>2</sup> along the  
242 Saint Martin Profile (black lines in Figure 4A and Figure 4B). The calculated heat flow at the trench is  
243 consistent with the expected value for an 80-Myr-old oceanic plate (Stein & Stein, 1994; Lucazeau,  
244 2019). Along both profiles, the calculated conductive heat flow poorly fits the measurements. Offshore  
245 of Martinique, the calculated heat flow is ~30% lower than the measurements in the trench and decreases  
246 westward similarly as the measurements, thus remaining significantly lower along the outer forearc. In  
247 other words, the heat-flow mismatch at the trench and the accretionary prism indicates a positive thermal  
248 anomaly compared to the conductive model at the margin front. In contrast, on Saint Martin profile, the  
249 calculated conductive heat-flow is ~23% higher than the measurement in the oceanic Jacksonville Patch  
250 (Figure 1). Moreover, the calculated heat-flow decreases westward, along the forearc and is lower than  
251 the measurements between 60 and 140 km from the deformation front. Thus, compared to the conductive  
252 model, this result indicates contrasting thermal anomalies: one negative near the trench and at the  
253 accretionary prism, the other positive at the forearc.

254 **4.3 Sensitivity tests for the calculated conductive heat-flow**

255 We performed sensitivity tests for the key-parameters of the conductively cooling model to check  
256 whether heat conduction can possibly account for the measured heat-flow variations, or if these  
257 variations are necessarily related to fluid-driven thermal advection.

258 In the frame of a conductively cooling oceanic lithosphere, the northward decrease in measured heat-  
259 flow from 78 to 42mW/m<sup>2</sup> in the trench is possibly related to two parameters: the incoming plate age  
260 and the oceanic sedimentation rate (Hyndman & Wang, 1993; Marcaillou et al., 2008). However, this  
261 decrease would require an increase in the oceanic plate age from 40 Myr to >120 Myr, which is highly  
262 unreasonable at the Lesser Antilles, where the age of the ~80-Myr-old American Plate does not vary  
263 significantly along-strike (Müller et al., 2019). Moreover, a sedimentation rate in the trench, offshore of  
264 Saint Martin, high enough to reduce the heat-flow by 23% is inconsistent with the <500-m-thick trench  
265 fill (Laurencin et al., 2019). Offshore of Martinique, the trench fill is up to 3 km thick (Pichot et al.,  
266 2012), but even a theoretical model with zero sedimentation rate results in calculated heat-flow that  
267 remains ~30% lower than the measurements. As a result, in the trench, heat conduction cannot generate  
268 the high heat-flow along the Martinique profile and low heat-flow along the Saint Martin profile without  
269 a key-contribution by heat advection.

270 Along the Saint Martin profile, measurements indicate an intriguingly stable heat-flow from the  
271 trench to the inner forearc, while typically at subduction zone, the heat-flow decreases as the oceanic  
272 plate deepens beneath the margin (Wang et al., 1995). In the conductively cooling model, the slab-  
273 dipping angle and the upper plate thermal conductivity are the key parameters that control the landward

274 decrease of the calculated heat-flow (Figure 4). Fitting the measurements by varying the slab-dipping  
275 angle is obtained when involving flat slabs geometries in the models (slab dip angle  $< 2^\circ$ ). However,  
276 offshore of Saint Martin, wide-angle models (Laurencin et al., 2018) and MCS data (Laurencin et al.,  
277 2019) show that the slab dip is up to  $\sim 25^\circ$  beneath the forearc. In addition, fitting the measurements by  
278 varying the thermal conductivity in the upper-plate and the sediments would require values greater than  
279  $10 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$ , which is unrealistic for these lithologies (Beardsmore & Cull, 2010).

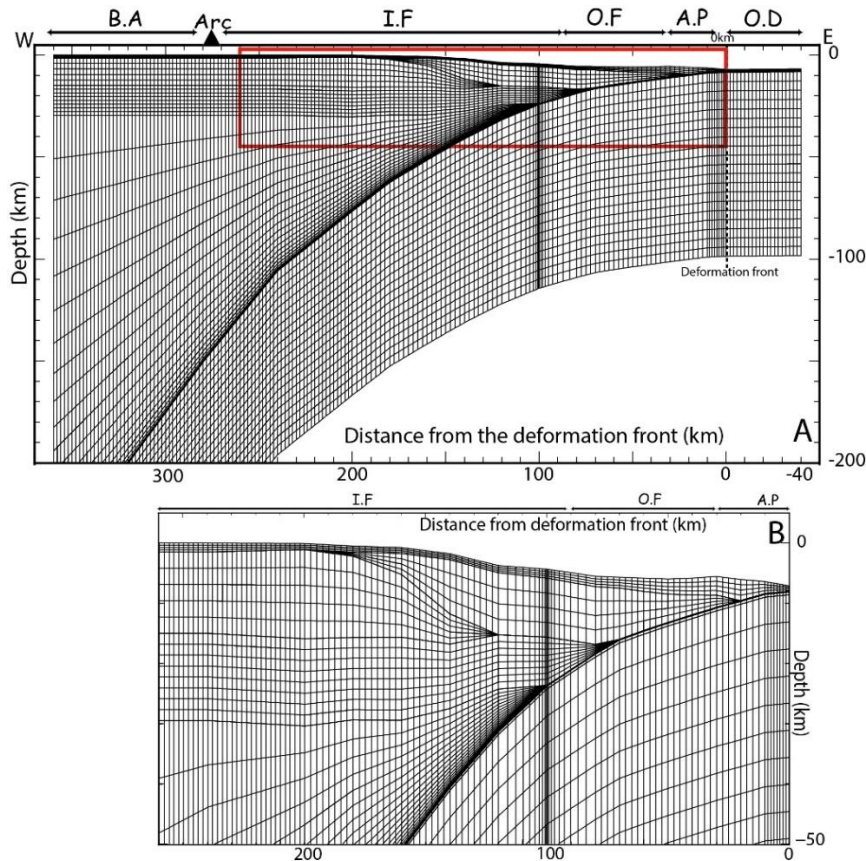
280 These tests thus indicate that conductively cooling models cannot satisfactorily account for 1) the  
281 heat-flow in the trench, which is too high offshore of Martinique and too low offshore of Saint Martin  
282 and 2) the high heat-flow at 60-140 km from the deformation front at the forearc of Saint Martin.

#### 283 *4.4 Calculated heat advection*

284 Offshore of Martinique, anomalously high heat flow in the trench and at the deformation front is  
285 typical of the hydrothermal warming related to insulated circulation: warm fluids flow updip along the  
286 oceanic basement aquifer to the trench, where thick and poorly faulted sedimentary fill reduces  
287 exchanges with seawater (Spinelli & Wang, 2008, Harris et al., 2010). A similar insulated system has  
288 been observed and modelled in the Nankai subduction zone (Spinelli & Wang, 2008). We applied the  
289 methodological approach used by these authors to model heat advection (See the Supplementary  
290 material). In this approach, increasing the Nusselt Number (Nu) in a mesh layer that represent the crustal  
291 aquifer simulates fluid flow along this region. Using Nu of 1000, consistent with previous modelling in  
292 other subduction zones (e.g. Harris et al., 2020), results in higher calculated heat-flow of  $76 \text{ mW}/\text{m}^2$  in  
293 the trench and at the deformation front, which is consistent with the measurements. The addition of fluid  
294 advection results in a landward decreasing calculated heat-flow that fits the measurements from the  
295 trench to the inner forearc (red line in Figure 4A).

296 Offshore of Saint Martin, anomalously low heat-flow in the poorly sedimented and pervasively  
297 fractured trench is typical of ventilated hydrothermal systems where cold seawater percolates through  
298 oceanic basement faults (e.g. Harris & Wang, 2002). In Costa-Rica, these authors successfully modelled  
299 hydrothermal cooling by reducing the oceanic geotherm of the incoming plate. In our model, reducing  
300 the oceanic geotherm at the seaward boundary results in lowering the calculated heat-flow to  $45 \text{ mW}/\text{m}^2$ ,  
301 in the trench and at the margin deformation front (black dotted line in Figure 4B) which is consistent  
302 with the measurements. Hydrothermal cooling in the trench reduces the calculated heat-flow along the  
303 accretionary wedge where it fits the measurements, but does not significantly change the calculated  
304 value beneath the forearc (60-140 km from the deformation front) where it remains much lower than the  
305 measurements. This positive thermal anomaly in the forearc corresponds to the location of the  
306 Tintamarre Fault Zone suggesting warm fluid upward migration to the seafloor as consistently proposed  
307 by previous studies based on tectonic observations (Boucard et al., 2021), wide-angle derived velocity  
308 anomaly (Klingelhoefer et al., 2018) and discussion from geochemical data (Cooper et al., 2020). We  
309 model this heat migration, using a Nusselt Number of 3.5 at the forearc area where the Tintamarre Fault

310 Zone (TFZ) deeply fracture the margin (Figure 5). The TFZ covers ~100 km wide and ~6km depth  
 311 (second layer in the close up in Figure 5B), and is in line with the extent of the faults zone as  
 312 imaged in seismic and bathymetric data (Boucard et al., 2021). This value of Nu accounts for the  
 313 thermal effects of heat transfer by fluid circulation in this unit. This modelling generates heat-flow of  
 314 34 mW/m<sup>2</sup> at the surface, which fits the measurements (Figure 4b) and thus approximate the upward  
 315 heat migration in the Tintamarre Fault Zone.

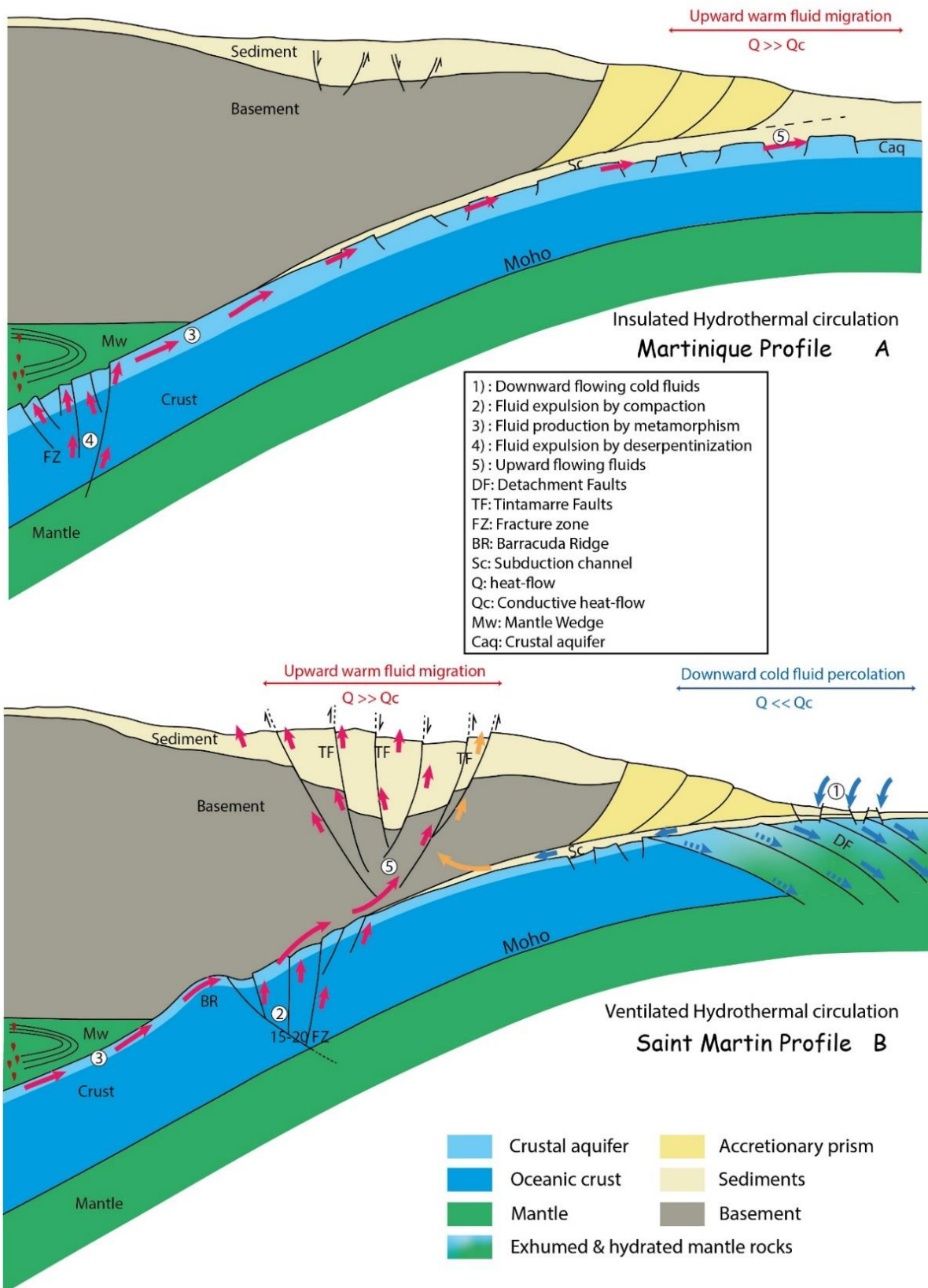


316

317 *Figure 5: Global view (A) and close up (B) of the modified 2D mesh grid for the Saint Martin. The mesh*  
 318 *includes a theoretical layer, which corresponds with the forearc area where the Tintamarre Fault Zone deeply*  
 319 *and pervasively fractures the margin. Increasing the Nusselt Number in this layer (see supplementary material)*  
 320 *accounts for the high heat-flow measured in surface, inconsistent with conductive modelling and thus likely related*  
 321 *with upward fluid-driven heat-flow along the Tintamarre Fault planes.*

## 322 5 Hydrothermal circulation within the Lesser Antilles subduction zone

323 Measurements provide unexpected heat-flow values in the trench, at the deformation front and in the  
 324 forearc of the Lesser Antilles Subduction Zone. Conductively cooling modelling cannot predict heat-  
 325 flow values which satisfactorily fit the measurements indicating that fluid-driven heat advection strongly  
 326 influences the heat transfer in the margin segments. This result is consistent with an increasing number  
 327 of recent studies, which conclude that the LASZ is extremely hydrated (e.g. Schlaphorst et al., 2016,  
 328 Paulatto et al., 2017, Cooper et al., 2020, Marcaillou et al., 2021). Moreover, the measurements and  
 329 models indicate that the fluid circulation varies along-strike, as discussed below.



330

331 *Figure 6: Interpretative sketches of the fluid circulation in the subduction for (A) an insulated hydrothermal*  
 332 *system in the Central Lesser Antilles, offshore of Martinique and (B) a ventilated hydrothermal system in the*  
 333 *Northern Lesser Antilles, offshore of Saint Martin. The structures are based on MCS profiles and Wide Angle*  
 334 *interpretations of (Laigle et al., 2013b, Kopp et al., 2011) for the Martinique profile, and (Boucard et al., 2021,*  
 335 *Marcaillou et al., 2021, Laurencin et al., 2018) for the Saint Martin profile (See section 2 for details).*

336 **5.1 Central Lesser Antilles, offshore of Martinique**

337 Along the Martinique profile, the heat flow is significantly higher than the conductive value in the  
338 trench, decreasing regularly landward beneath the forearc. This behavior is typical of shallow  
339 hydrothermal warming related to insulated circulation, as described for instance in Nankai (Spinelli &  
340 Wang, 2008, Harris et al., 2017). In the Central Lesser Antilles, Boron isotope ratio indicates excess  
341 dehydration, i.e. high rate of water released from the slab, at great depth beneath the volcanic arc (Cooper  
342 et al., 2020). These authors thus confirm previous geophysical studies, which highlighted the strong  
343 hydration of this subduction segment (Schlaphorst et al., 2016, Paulatto et al., 2017). They indicate that  
344 the subduction of numerous deep large-scale oceanic transform fault zones and potentially exhumed  
345 mantle rocks related to the slow-spreading Mid-Atlantic Ridge have the potential to supply substantial  
346 volumes of fluid to the subduction. We propose that warm fluids, released at shallow depths by sediment  
347 compaction and at greater depths by metamorphic dehydration and/or deserpentinization of exhumed  
348 mantle rocks along major fracture zones (e.g. Marathon F.Z.), collected within the oceanic basement  
349 aquifer and the interplate fault zone, migrate updip along the subduction interface and the shallow crustal  
350 aquifer toward the trench, as exemplified in Chile by Moreno et al. (2014) and in Nankai by Spinelli &  
351 Wang, (2008). The 2-to-3-km thick poorly-faulted sedimentary trench fill to the South of the Barracuda  
352 Ridge, impedes cold seawater downward percolation into the trench, insulating the downgoing oceanic  
353 plate. As a result, fluids updip migration warms up the subduction interface beneath the shallow portion  
354 of the accretionary prism, the deformation front and the trench, increasing the heat-flow at the seafloor  
355 (Figure 6A).

356 **5.2 Northern Lesser Antilles, offshore of Saint Martin**

357 Along the Saint Martin profile, the measured heat flow is significantly lower than the conductive  
358 value in the trench and at the accretionary wedge. This behavior is typical in the presence of shallow  
359 hydrothermal cooling and ventilated circulation, as described for instance in Costa-Rica (Harris &  
360 Wang, 2002, Harris et al., 2010). In the trench, the subducting oceanic basement within the Jacksonville  
361 patch consists of exhumed and hydrated mantle rocks deeply and pervasively fractured by widespread  
362 detachment faults overlain with a fractured <500-m-thin sedimentary layers (Marcaillou et al., 2021).  
363 These detachment faults, likely reactivated by plate bending, and the thin fractured sedimentary layers  
364 favor downward cold seawater percolation and hydrothermal cooling in the trench. Outside the  
365 Jacksonville patch, within the oceanic domain, a second heat-flow measurement (55mW/m<sup>2</sup>) is  
366 consistent with an expected conductive heat-flow value. However, this region shows no evidence of  
367 highly faulted sediment and oceanic basement as observed in the patch (Marcaillou et al., 2021). Thus,  
368 it is likely that hydrothermal cooling maybe restricted to the extent of the Jacksonville patch in the  
369 oceanic domain. However, this is based only on the 2 heat-flow values acquired inside and outside of  
370 the patch respectively. In the forearc, the Tintamarre Fault deeply fractures the basement, while the 15-  
371 20 Fracture Zone deeply fractures the subducting oceanic plate at greater depth beneath the forearc. The

372 slab dehydration at depth, by sediment compaction, metamorphic reactions and deserpentinization of  
 373 basement and/or mantle rocks probably releases large amount of fluids into the interplate fault damaged  
 374 zone. We propose that the >100-km-long and 60-km-wide Tintamarre Fault Zone associated to intense  
 375 basal erosion (Boucard et al., 2021) offers efficient pathways for fluid upward migration up to the  
 376 seafloor where they create numerous possible pockmarks (Klingelhoefer et al., 2018). As a result,  
 377 downward percolation of cold seawater through reactivated detachment faults in the trench, and warm  
 378 fluid upward migration through major fault zones in the forearc are consistent with heat-flow  
 379 measurements respectively lower and higher than conductive value in this ventilated hydrothermal  
 380 system (Figure 6B).

## 381 6 Thermal structure and potential seismogenesis

382 The thermal structures for the Saint Martin and Martinique profile models, with and without heat  
 383 advection, show small variations in the location of the 100, 150, 350 and 450°C isotherms often  
 384 interpreted to be associated with the updip and downdip limit of seismogenic zones when located at  
 385 shallower depth than hydrated mantle wedge (e.g. Hyndman et al., 1995) (

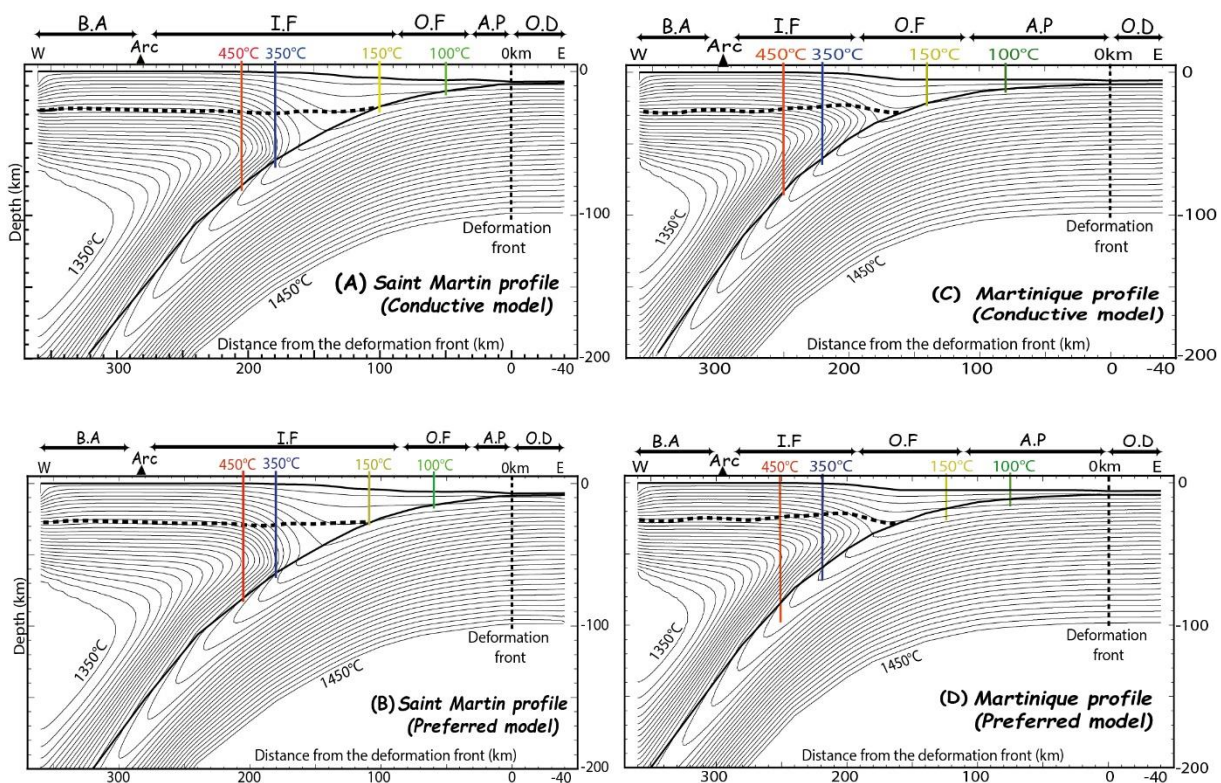
<b>(A) Martinique model</b>		<b>Conductive Model</b>		<b>Insulated Model</b>	
Isotherm	Distance from deformation front (km)	Depth (km)	Distance from deformation front (km)	Depth (km)	
100°C	80	12	75	10	
150°C	140	22	124	20	
350°C	220	60	220	60	
450°C	250	85	250	85	
<b>(B) Saint Martin model</b>		<b>Conductive Model</b>		<b>Insulated Model</b>	
Isotherm	Distance from deformation front (km)	Depth (km)	Distance from deformation front (km)	Depth (km)	
100°C	50	12	60	15	
150°C	100	23	110	25	
350°C	180	62	180	65	
450°C	205	80	205	80	

386 Table 1 and Figure 7).

387 When comparing the effect of advection vs conduction, offshore of Martinique, fluid updip migration  
 388 warms up a shallow section of the interplate contact, from 190 km to the trench, shifting the 150°C  
 389 isotherms seaward by 15 km. In contrast, this heat advection has no effect on the thermal structure of  
 390 the deepest part of the interplate contact, which is mostly controlled by the mantle wedge. Along the  
 391 Saint Martin profile, cold fluid downward percolation in the Jacksonville Patch cools down the  
 392 temperature of the frontal segment of the interplate contact and this cooling effect rapidly decreases  
 393 landward. As a result, the 100 and 150°C isotherms are shifted by 10 km by this hydrothermal cooling,  
 394 which has no impact on the location of the 350 and 450°C isotherms. The moderate effect of this

395 hydrothermal circulation onto the thermal structure is likely related to the old age of the oceanic plate  
 396 and the slow convergence rate. The age and convergence rate of the oceanic plate in the LA typically  
 397 generate cold subduction zone and thus reduce the influence of hydrothermal circulation onto the  
 398 thermal structure.

399 What is noteworthy are the significant distances from the trench of the 150°C and 350°C  
 400 temperatures on the interplate fault : they are both located beneath the inner forearc for the Saint Martin  
 401 profile and beneath the outer forearc for the Martinique profile. The distance between the 150°C and  
 402 350°C, often referred to as the minimum width of the thermally defined seismogenic zone, varies from  
 403 80 to 94 km for the Martinique profile, and from 80 to 72 km for the Saint Martin profile from the  
 404 conductive to the advective models.



405  
 406 *Figure 7: Thermal structure of the Lesser Antilles Margin at the latitude of Saint Martin (A, B) and Martinique*  
 407 *(C, D) predicted by the conductive models and the advective models (preferred models). The location of the 100,*  
 408 *150, 350 and 450°C isotherms are marked with vertical lines.*

409

(A) Martinique model	Conductive Model		Insulated Model	
	Distance from deformation front (km)	Depth (km)	Distance from deformation front (km)	Depth (km)
100°C	80	12	75	10
150°C	140	22	124	20
350°C	220	60	220	60
450°C	250	85	250	85



(B) Saint Martin model	Conductive Model		Insulated Model	
	Distance from deformation front (km)	Depth (km)	Distance from deformation front (km)	Depth (km)
100°C	50	12	60	15
150°C	100	23	110	25
350°C	180	62	180	65
450°C	205	80	205	80

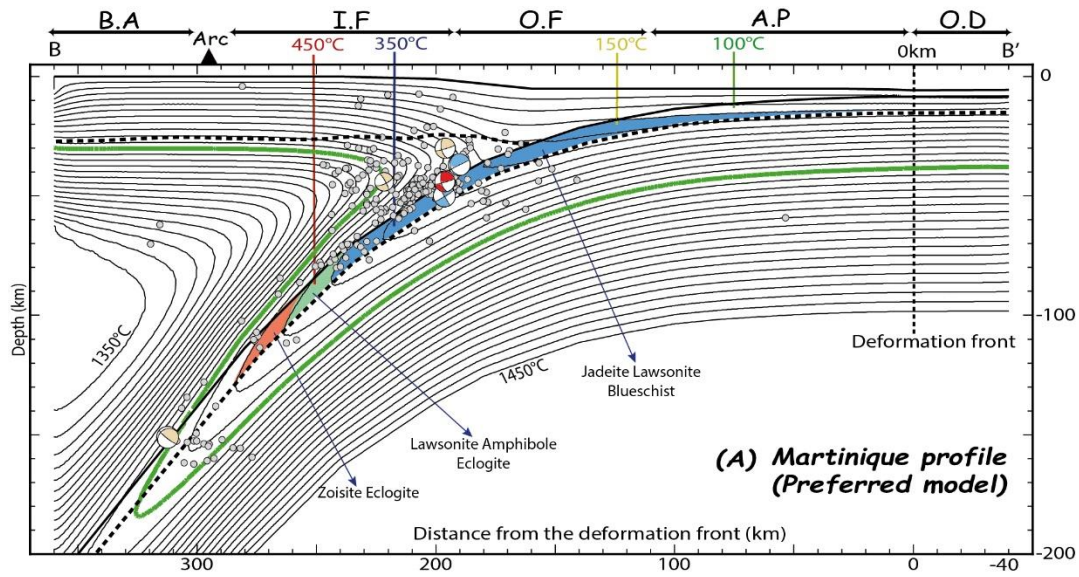
410 *Table 1: Calculated depth and distance from the deformation front for isotherms 100°C, 150°C, 350°C and*  
411 *450°C for the Martinique (A) and Saint Martin (B) models. These isotherms are commonly associated with the*  
412 *updip and downdip limits for the thermally-defined seismogenic zone.*

413 Along the Martinique profile, temperatures of 150°C and 350°C reach depths of 20 km and 60 km  
414 respectively on the interplate fault. The forearc Moho located at a shallower depth (28 km) than 350°C  
415 would thus become the downdip limit of the potential seismogenic portion (Hyndman et al., 1997), with  
416 a sharp reduction of the width to 36 km. On the Saint Martin Profile, a greater depth of 25 km for the  
417 150°C marking the updip limit, and a shallower Moho (25 km) appear to further reduce the potential  
418 width of the seismogenic portion, making it potentially almost non-existent. In case of subducting  
419 exhumed mantle patches within the slab's crust outcropping along the plate interface, seismogenic width  
420 will be even more reduced due to their expected serpentinization at those low temperatures. However,  
421 we can still not quantify the degree of serpentinization of these mantle materials (wedge and slab's crust)  
422 along the interplate contact, and these new measurements and models of thermal structure provide up-  
423 to-date estimations of temperatures along the megathrust fault. Moreover, up to Mw ~5 flat-thrust events  
424 have been recorded at the depth of 40-45 km (Laigle et al., 2013), and up to 51 km (Bie et al., 2019) in  
425 the Central Lesser Antilles, offshore Martinique. These events highlight a deep seismogenic zone which  
426 appears to extend (or resume) beyond the intersection between the forearc Moho and the interplate, but  
427 raises question as to the nature of the subducting crust and/or the forearc mantle materials.

## 428 **7 Relationship between temperature, fluids, and seismicity**

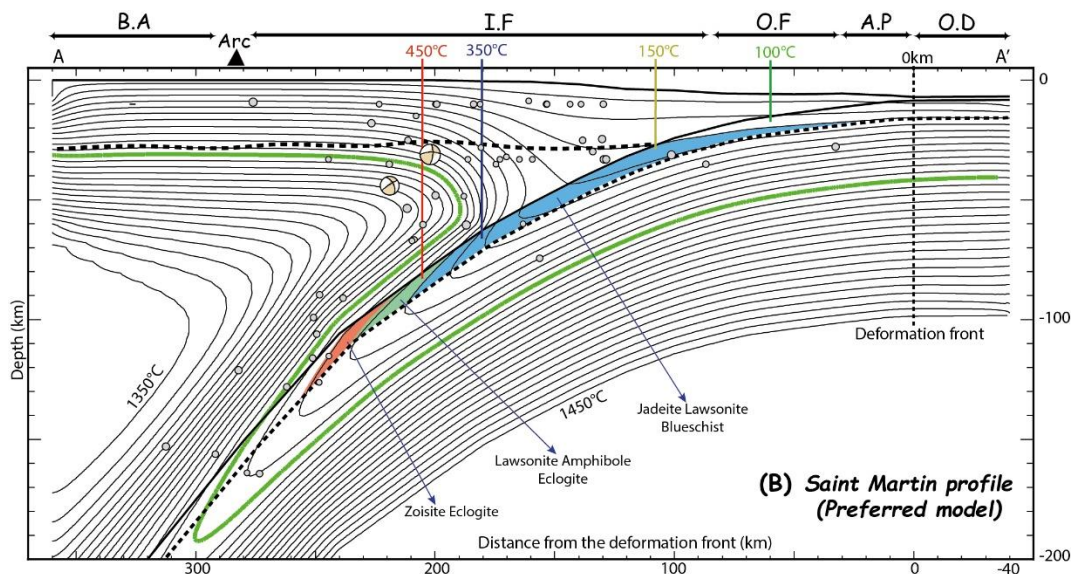
429 We investigate the relationship between the thermal structure of the margin, fluid release, and the  
430 location of intraslab, supraslab, and interplate seismicity (Figure 8). We put a particular emphasis on the  
431 Martinique profile (Figure 8A) where 5.5-years-long OBS deployments provide us with numerous and  
432 accurately relocated earthquakes (Laigle et al., 2013a). In contrast, the seismicity in the vicinity of the  
433 Saint Martin profile is sparse and poorly located (Figure 8B).

434



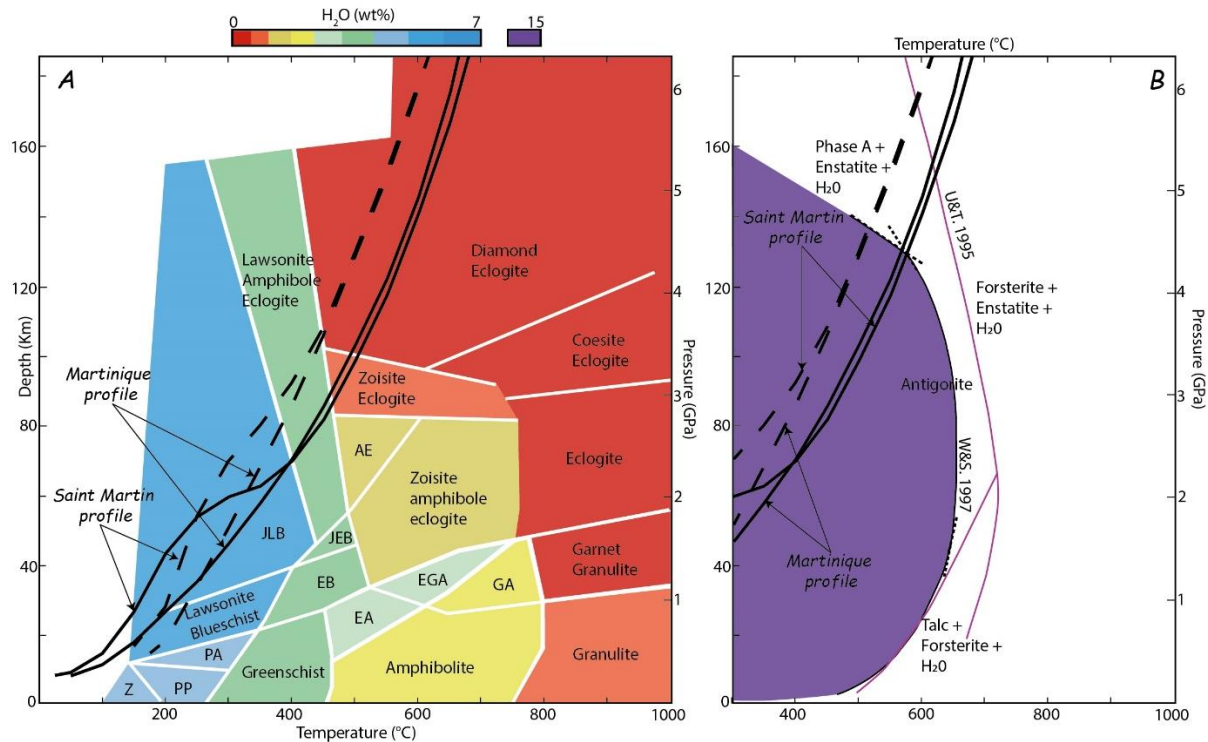
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436



437

438 *Figure 8: Thermal structure of the LASZ with cross-sections of the hypocenters for earthquakes located*  
 439 *within 25 km on each side of the Martinique (A) and Saint Martin (B) profiles (see figure 2). The gray circles are*  
 440 *relocated earthquakes from OBS deployment (Laigle et al., 2013a) for the Martinique profile, and earthquakes*  
 441 *from USGS catalogue for Saint Martin profile. The blue focal mechanisms are thrust faults, and the red is a*  
 442 *relocated flat thrust event, while the yellow represents other focal mechanism from CMT catalogue. The black*  
 443 *thick line represent the top of the subducting slab, while the black dotted lines represent the Moho. The green*  
 444 *contour line marks the 600 °C isotherm usually considered as an averaged temperature for antigorite dehydration.*



445

446 *Figure 9: Phase diagram and maximum H<sub>2</sub>O content for (A) metamorphosed MORB modified from Hacker,*  
 447 *et al., (2003) and (B) hydrated mantle modified from (Wunder & Schreyer, 1997 and Ulmer & Trommsdorff, 1995),*  
 448 *showing the Pressure-Temperature (PT) path for the slab tops (thick black lines), and moho (dash lines) offshore*  
 449 *of Martinique and Saint Martin in the LASZ. (Z – Zeolite, PP – Prehnite pumpellyite, PA – Prehnite actinolite,*  
 450 *JLB – Jadeite lawsonite blueschist, EB – Epidote blueschist, EA – Epidote amphibolite, JEB – Jadeite epidote*  
 451 *blueschist, AE – Amphibole eclogite, EGA – Epidote garnet amphibolite, GA – Garnet amphibolite).*

### 452 **7.1 Intraslab seismicity**

453 At depth in subduction zones, the location of intraslab seismicity is mainly controlled by the  
 454 combined influence of pressure, temperature, slab bending stresses, and fluid release related to  
 455 dehydration reactions, in particular, crust eclogitisation and mantle deserpentinization (Kirby et al.,  
 456 1996; Hacker et al., 2003; Ferrand, 2019). Intraslab seismicity in the LASZ is distributed both within  
 457 the crust and the mantle of the slab. At the LASZ, numerous fracture zones and detachment faults deeply  
 458 incise the basement of the incoming oceanic plate, down to the mantle, likely favoring deep hydration  
 459 and serpentinization of mantle rocks before the trench (Cooper et al., 2020; Marcaillou et al., 2021).  
 460 These hydrated rocks are more stable at shallow depths and transport volatiles to dehydrate at greater  
 461 depths during deserpentinization reaction at temperatures greater than 450°C (Ulmer & Trommsdorff,  
 462 1995 and Van Keken et al., 2011; Ferrand, 2019; Bie et al., 2022). Since the composition of the  
 463 subducting oceanic crust of the slow-spreading mid-Atlantic ridge can vary from mid-oceanic basalt up  
 464 to serpentinized exhumed mantle, we report the slab's top and moho on a phase diagram for  
 465 metamorphosed mid-oceanic ridge basalt (MORB) (e.g. Hacker, et al., 2003) and for hydrated mantle  
 466 materials (e.g. Wunder & Schreyer, 1997; Ulmer & Trommsdorff, 1995) (Figure 9A & B). We also  
 467 report on the thermal structure and seismicity cross-section (Figure 8A) the main metamorphic facies of

468 the MORB phase diagram, as well as the 600 °C isotherm which could be used as a proxy of the  
469 maximum temperature for antigorite stability (650°C).

470 Slab's intracrustal seismicity in the LASZ is distributed between 35 and 165 km depth, which  
471 corresponds to calculated temperature's range of 240-625°C (Figure 8A). According to the *PT* path of  
472 the slab's top and moho, slab's intracrustal seismicity at 70-80 km depth at 400-450°C could result from  
473 dehydration reaction at the Blueschist-Eclogite transition. This depth is consistent with the downdip  
474 extent of the low-*V<sub>p</sub>* anomaly in the slab crust and the transition towards higher *V<sub>p</sub>* interpreted to be the  
475 result of crustal eclogitization (Paulatto et al., 2017). Fluids generated by dehydration reactions could  
476 migrate upward into the mantle wedge and updip through the slab, driven by gradients in tectonic  
477 stresses related to slab bending/unbending and densification (Faccenda et al., 2012; Paulatto et al.,  
478 2017), induce hydrofracturing, and trigger earthquakes within the shallow slab crust at 35-70 km depth.  
479 The oceanic crustal portions made of exhumed serpentinized peridotites is expected to dehydrate at  
480 depths >130 km above 550°C, and also be responsible for fluids upward migration and associated  
481 seismicity by dehydration embrittlement at these depths.

482 Within the slab mantle, the seismicity is aggregated in two main zones within a ~25-km-thick band  
483 beneath the slab top, at 35-80 km and 140–165 km depths, which correspond to calculated intraslab  
484 temperature's range of 250-450°C and 550-800°C respectively (Figure 8A). According to *PT* path of  
485 the slab's moho reported on the hydrated mantle phase diagram (Figure 9B), antigorite is expected to be  
486 unstable from 140 km at 520°C and up to ~620°C within the slab mantle along the depth of 160 km.  
487 Thus, we propose that the deeper intraslab seismicity zone located at 140–165 km depth, within the  
488 antigorite destabilization zone, is related to dehydration of serpentinized peridotite. This is consistent  
489 with elevated *V<sub>p</sub>*/*V<sub>s</sub>* ratio observed at similar depth which is interpreted to correspond to peak water  
490 release (Bie et al., 2022). For the shallower active zone within the slab mantle at 35-80 km depth, the  
491 deepest events below the slab top close to the isotherms of >450-520°C could be associated to antigorite  
492 destabilization process-related temperatures as proposed by Laigle et al., (2013a). The shallower events  
493 within the 20 km thick mantle band below the slab top may be linked to other processes similar to the  
494 reactivated faults of this slow-spreading oceanic lithosphere. The origin of the seismic activity located  
495 in the footwall of the deep-rooted detachments faults at the Mid-Atlantic ridge down to ~10 km depth  
496 (e.g. Parnell-Turner et al., 2017) is not yet really understood. However, their seismogenic potential might  
497 persist even at those depths of 50 km, thanks to the still preserved thermal structure of the lithospheric  
498 mantle.

## 499 **7.2 Supraslab seismicity**

500 Supraslab earthquakes, offshore of Martinique are aggregated in a cluster located at 30-60 km depth  
501 in the mantle wedge, and extending up to 80 km arcward of the contact between the interplate and the  
502 upper plate moho (Figure 1Figure 8A). The seismicity occurring above the slab at depths greater than  
503 100 km may be interplate or slab crust/mantle events, and could be related to uncertainties of seismicity

504 location/ or slab geometry. The supraslab seismicity zone is distributed over isotherms between 200°C  
505 and 800°C. At temperature below 450°C, antigorite is expected to be stable, and mantle rocks to undergo  
506 serpentinization in the presence of fluid. Existing hypothesis for supraslab seismicity in the LASZ  
507 suggests heterogeneous mantle wedge and upward fluid migration (Laigle et al., 2013a; Paulatto et al.,  
508 2017). Our predicted temperature and depth of crustal eclogitization and fluid production at 70-80 km  
509 supports this hypothesis for the earthquakes occurring at least ~50 km arcward of the mantle wedge  
510 corner, at temperatures lower than 500°C. Beyond the 50 km distance, and between 500-800°C, we  
511 propose that supraslab seismicity in this subduction zone could be related to dehydration embrittlement  
512 due to deserpentinization reaction in the serpentinized mantle wedge, as invoked beneath northeast New  
513 Zealand (e.g. Davey & Ristau, 2011).

### 514 *7.3 Interplate seismicity*

515 Interplate seismicity is located at depth greater than 25 km, and distance greater than 160 km from  
516 the deformation front (Figure 8A), and includes deep moderate size flat-thrust earthquakes between 40-  
517 50 km depth and 190-200 km distance from the deformation front. This seismicity corresponds to  
518 calculated temperatures ranging from 200°C and 450°C at the slab top, while the upper-plate Moho  
519 intersects the subduction interface at ~28 km depth and temperature of ~210°C. The interplate  
520 seismogenic zone thus extends downdip of the upper-plate Moho, consistently with other cold  
521 subduction zones, e.g. Tohoku, where flat-thrust earthquakes are observed at similar depth in the Mantle  
522 (Uchida & Matsuzawa, 2011). Thermal models predict a cold forearc mantle above the location of the  
523 Mw 5 flat-thrust event (Figure 8A), and downdip slab dehydration, with updip fluid migration into the  
524 mantle wedge, favourable for serpentinization reaction to occur. This result suggests that dry peridotite  
525 in the mantle is unlikely, rather, tilts towards existing hypothesis of chemical heterogeneity of the mantle  
526 corner (Laigle et al., 2013a) as mechanism for this “deep flat-thrust” earthquakes. The interplate contact  
527 beneath the forearc, from the trench to 110-125 km distance westward (Table 1), corresponds to  
528 temperatures lower than 150°C, frequently considered as poorly, or conditionally favorable to stick-slip  
529 behavior. Hence, temperatures lower than 100°C below the accretionary prism make seismic rupture up  
530 to the trench very unlikely. Thus, the thermal models highlight a deep “thermally-defined seismogenic  
531 zone” (i.e. 150° - 350°C temperature range), typical of cold subduction zones, associated with intense  
532 fluid circulation from the subduction depth to the trench.

533 These features shed light on the mechanical conditions and the sliding behavior along the interplate  
534 contact at the Lesser Antilles. Geodetic modelling predict very low interplate coupling (van Rijsingen  
535 et al., 2021) consistent with scarce interplate thrust earthquakes mostly aggregated in two local clusters  
536 (Hayes et al., 2013) (see details in §2.2). Intense fluid circulation, as suggested by the thermal models,  
537 is able to increase the pore-fluid pressure, reducing the effective stress along the interplate contact  
538 (Moreno et al., 2014). A heterogeneous reduction of this effective stress may generate an interplate  
539 patchiness of contrasting frictional properties. Moreover, the rheology of low-temperature species of

540 serpentine minerals results in substantial weakening of serpentine-bearing faults and crustal rocks  
541 formed and altered at tectonically-dominated slow-spreading segments ridges (eg. Escartin et al., 1997).  
542 The ongoing subduction of tectonically-dominated oceanic patches, such as the Jacksonville patch  
543 identified at the trench (Marcaillou et al., 2021), may also favor this heterogeneity in interplate frictional  
544 properties. In subduction zones, the patchiness of contrasting frictional properties may impede large-  
545 scale zones of full interplate coupling (Hirauchi et al., 2010), instead favoring a mix of stable and  
546 unstable behaviors prone to triggering moderate-sized-Mw, slow-slip and/or very-low frequency  
547 earthquakes (Saffer & Wallace, 2015), and increasing time return of large co-seismic rupture.

#### 548 **Conclusion**

549 Thermal models of the Lesser Antilles Subduction Zone, based on heat-flow data recorded during  
550 Antithesis 1 cruise (2013), show that fluid-driven heat advection strongly influences the heat transfer  
551 across the margin. Moreover, variations in heat-flow anomalies, compared to the regional conductive  
552 heat-flow, highlight the varying fluid flow pattern from ventilated to insulated circulation systems.

553 In the Central Lesser Antilles, offshore of Martinique, warm fluids released at depths in the  
554 subduction zone migrate updip along the subduction interface generating hydrothermal warming in the  
555 trench and at the margin front. The low level of fluid exchange with the water column is typical of  
556 insulated systems. Contrastingly, in the Northern Lesser Antilles, offshore of Saint Martin, downward  
557 percolation of cold fluids through crustal detachment faults in the trench triggers hydrothermal cooling  
558 at the margin front, while warm fluid upward migration through major fault zones in the forearc  
559 generates hydrothermal warming in the margin. These interpreted vigorous fluid exchanges with the  
560 water column are typical of ventilated systems.

561 Based on the model offshore Martinique, we show that intraslab, supraslab, and interplate seismicity  
562 distribution has a close relationship with temperature-related dehydration reactions at depth in the  
563 subduction. It is noteworthy that typical temperature and depth of eclogitisation and deserpentinisation  
564 reactions correspond to intraslab and supraslab seismicity clusters. Consistently with previous tectonic  
565 investigations, these thermal models confirm that the Northern Lesser Antilles is an end member  
566 subduction zone where the subduction of oceanic transform fault zones and oceanic patches partly made  
567 of exhumed and serpentinised mantle rocks deeply hydrate the subduction zone at depth. This “hyper-  
568 hydration” likely explains the very low interplate coupling and the scarce large co-seismic ruptures,  
569 possibly favoring alternate mode of sliding behavior, such as low velocity earthquakes, which are yet to  
570 be investigated.

#### 571 **CRedit authorship contribution statement**

572 **K.E.** wrote the manuscript. **K.E.**, and **Y.B.** performed the thermal modelling supervised by **B.M.** and  
573 **M.L.** **B.M.**, **F.K.**, **J.-F.L.**, **F.R.**, **A.H.**, **T.P.**, **F.L.**, **M.P.**, **M.L.** and **B.H.** were onboard RVs “l’Atalante”  
574 and “Pourquoi Pas?” during the ANTITHESIS cruise and acquired the heat-flow data. All authors  
575 discussed the scientific issues and commented on the manuscript.

576 **Declaration of Competing Interest**

577 The authors declare that they have no known competing financial interests or personal relationships  
578 that could have appeared to influence the work reported in this paper.

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