Crustal structure of the Lesser and Leeward Antilles forearcs inferred from satellite Vertical Gravity Gradients

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1. Introduction

The **characterization of the crustal structure** of the plates involved in a subduction system is a crucial step towards the **understanding of potentially associated geohazards**. In regions where the seismic records do not extend far back in time, or where large earthquakes are infrequent, **alternative indirect methods for delimiting seismogenic zones may be applied**. In those cases, it would be valuable to **characterize in detail**, for example, **the regional continental-oceanic transition** and **the backstop edge location**.

Taking advantage of the high spatial resolution and homogeneous coverage of satellite gravity and altimetry data, **we propose a new methodology for characterizing the oceanic crust, using Vertical Gravity Gradients (VGG).**

The **VGG** are especially **sensitive to shallow density variations** [20],[21].

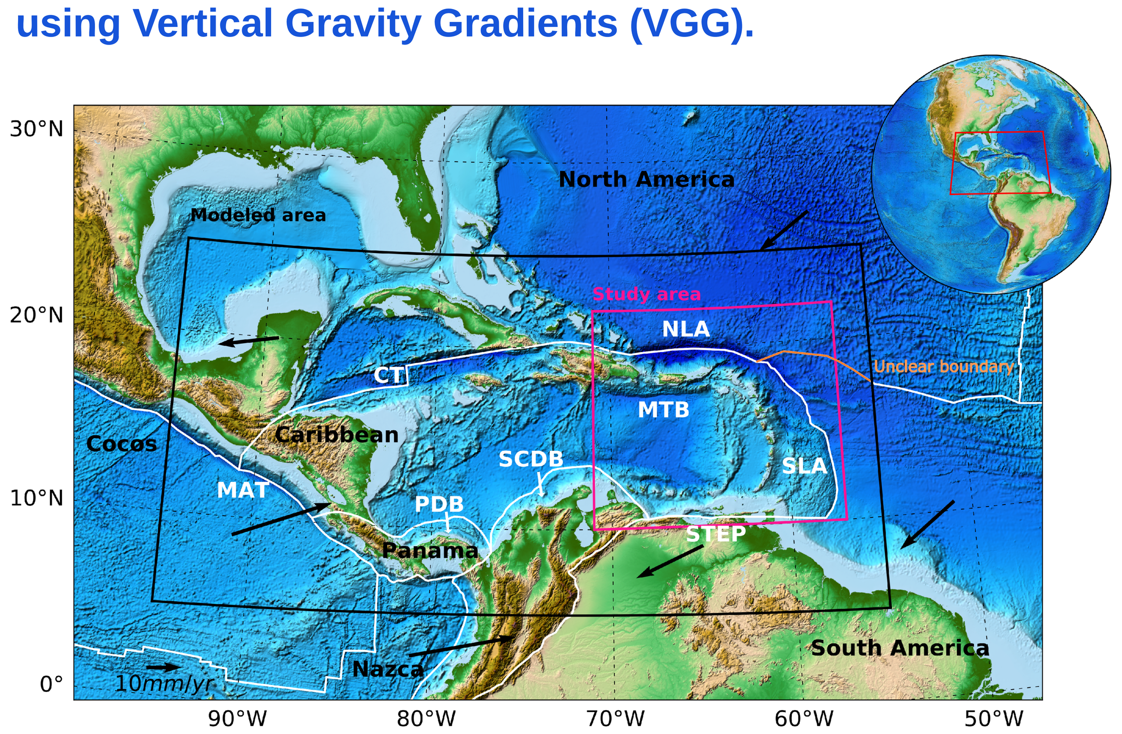
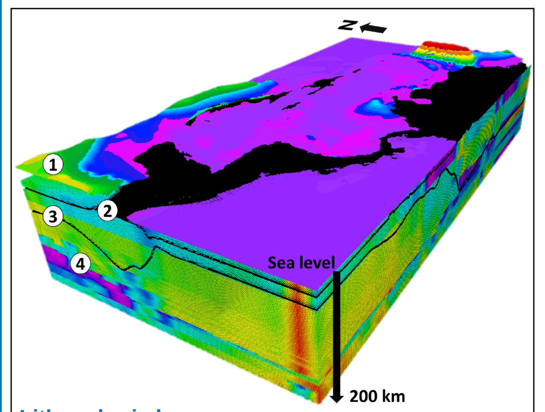


Fig. 1. Shaded relief image of the Caribbean region including the modelled area, the study area, and the main tectonic boundaries [1]. Plate velocities represented by black arrows [2][3]. CT = Cayman Trough, MAT = Middle American Trench, MTB = Muertos Thrust Belt, NLA = North Lesser Antilles, PDB = Panama deformed belt, SCDB = South Caribbean Deformed Belt, SLA = South Lesser Antilles, and STEP = Subduction Transform Edge Propagator fault system.

2. Modelling approach (spherical coordinates)

Starting 3D lithospheric model → **Density solutions for lithospheric layers** → **Modelling of VGG**



Lithospheric layers:
1. **Sediment thickness:** NOAA, 5arcmin [4].
2. **Bathymetry**: GEBCO - 30arcmin [5].
3. **Moho:** GEMMA - 0.5deg [6].
4. **Tomography**: SL2013 - Swave model [7].

Density solutions for lithospheric layers

- **Water: 3D solution** [8]

$$\rho(D,\varphi) = 1000 + \alpha(\varphi) \times \left\{\mu(\varphi) + \frac{1-\mu(\varphi)}{2} \times [1+\xi(D)]\right\} + \beta(\varphi) D^{\upsilon(\varphi)}$$

(Latitudinal contribution; Picnocline correction; Pressure)

- **Sediments: 3D solution** [9]

$$\rho_s(d_s, D) = 1.66 - 5.1 * 10^{-5} D + 0.0037\, d_s^{0.766}$$

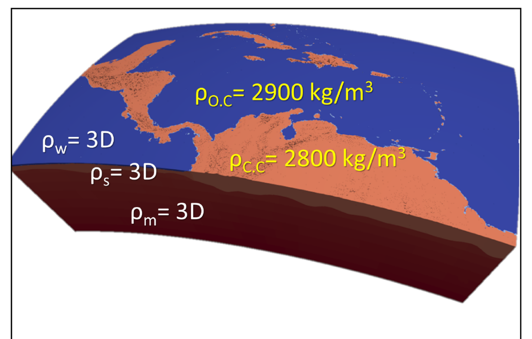
(Lateral density variation; Compaction)

- **Crystalline crust:**
  Continental crust: 2800 kg m^{-3}
  Oceanic crust: 2900 kg m^{-3}

- **Mantle: 3D solution** [10], [11]

Swave velocity anomalies → Mantle composition → **Mantle densities**

Modelling of VGG



Calculate the gravity response - **in spherical coordinates**- using the software **Tesseroids** [12].

High-pass Gaussian filter [13]

Spherical harmonic solution of EIGEN6C4 (N_{max} = 2190):

$$\lambda_{min} = 2\pi R / N_{max} \cong 18 \text{ km}$$

VGG residuals

EIGEN6C4 - Modelled VGG

Hypothesis: Residuals of VGG **contain information** about the structure and density heterogeneities at crustal level.

Novel approach: 3D modelling of VGG in spherical coordinates

Results

Tectonic boundaries	Crystalline crust density	Final lithospheric density model
Analysis of VGG residuals with respect to previously proposed and/or unknown tectonic boundaries	**Forward modelling** of VGG to infer the **average crustal density**	**3D density solutions:** water, sediments, and mantle. **Average density of the cystalline crust.**

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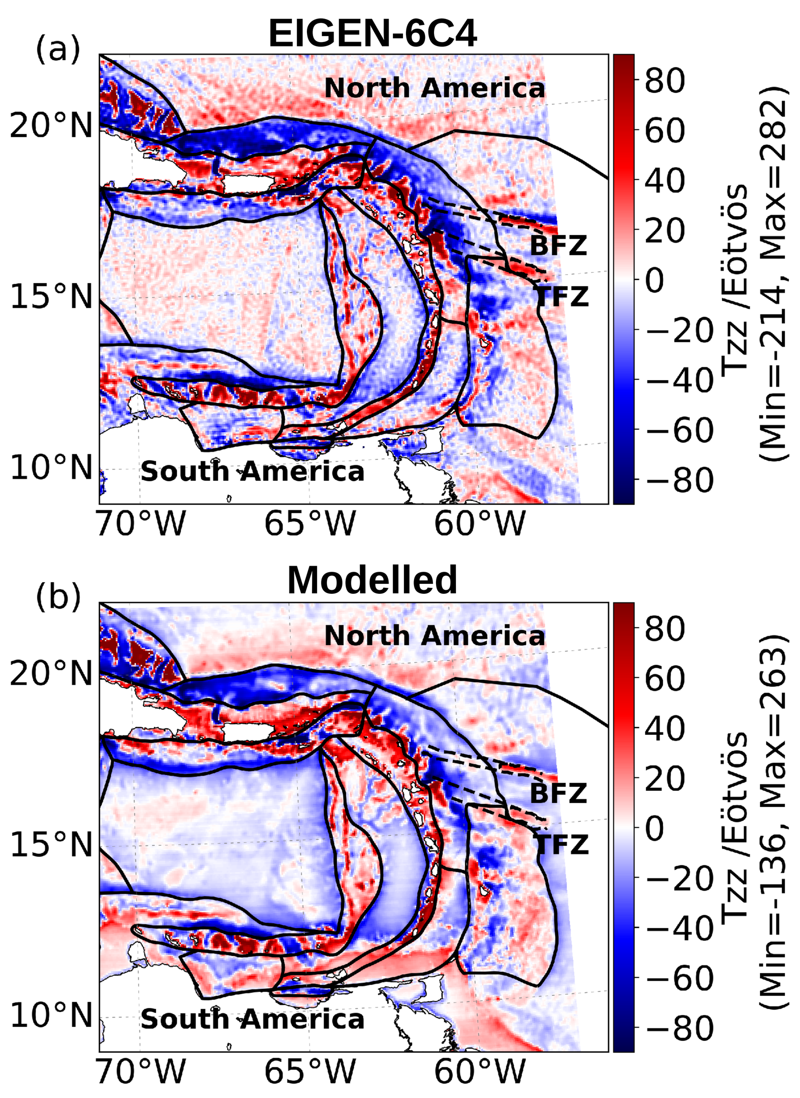
3. VGG residuals and identification of tectonic boundaries



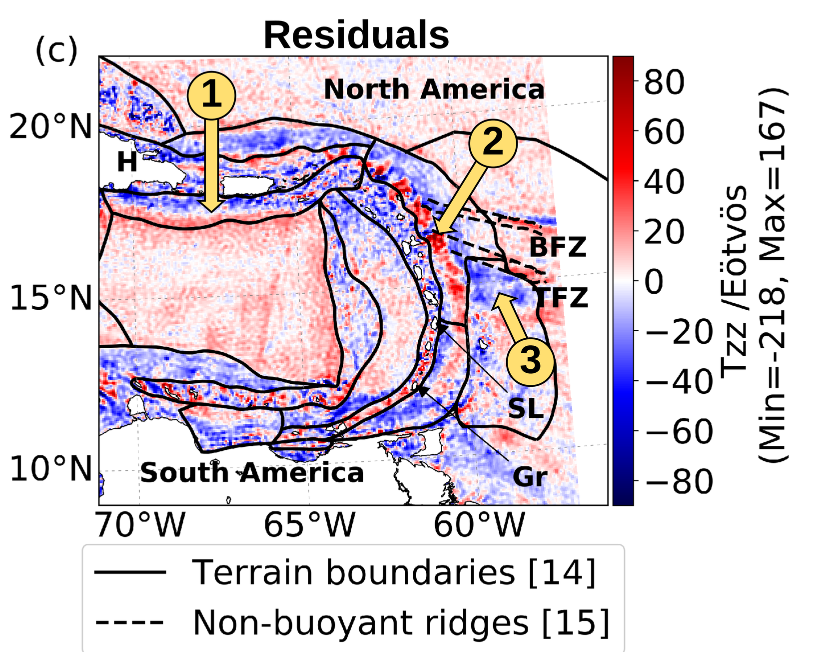


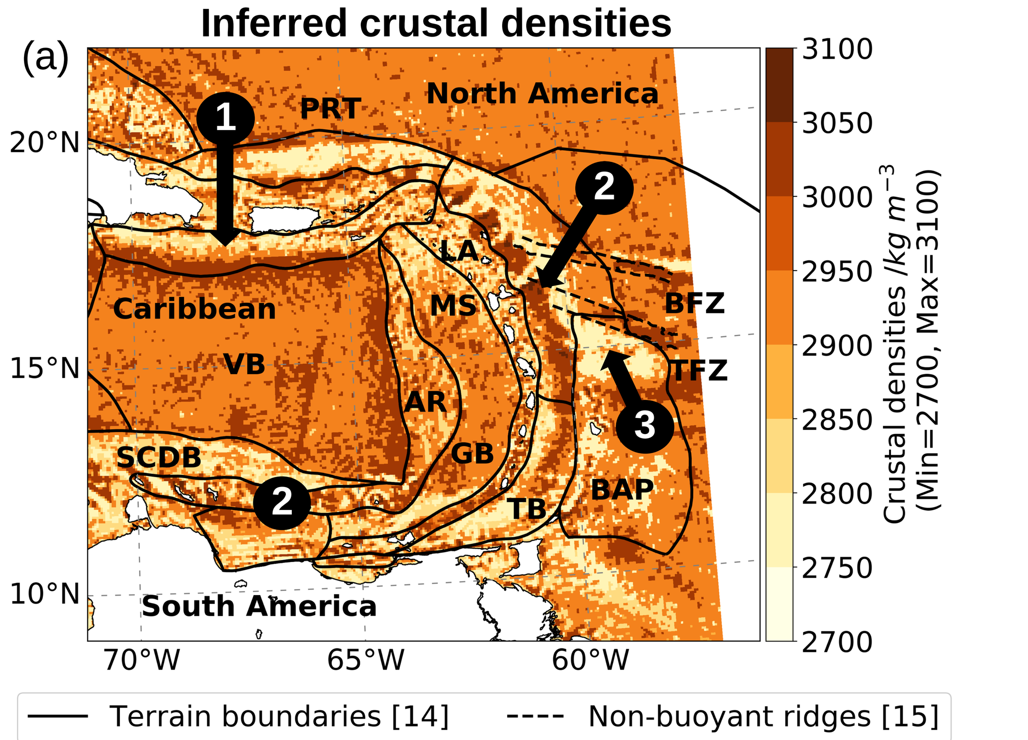
Fig. 2. VGG from: (a) EIGEN-6C4 database [16]. (b) Modelled and filtered. (c) Residuals. Gr = Grenada, H = Hispaniola, and SL = St. Lucia Islands. BFZ and TFZ = Barracuda and Tiburon Fault Zones.

Interpretation of VGG residuals:
Positive: Deficit in modelled crustal density.
Negative: Excess in modelled crustal density.

1. **Continental - Oceanic Transition.**
2. **Along-arc stripes** (+ and − residuals).
3. **Anomalous crustal fragment** (− residuals).

4. Inferred density of the crystalline crust

1. **Continental - Oceanic Transition**: light island arc (2700 kg m^{-3}) and denser oceanic crust (3050 kg m^{-3}).
2. **Along-arc stripes**: high-density inner and low-density outer forearc domains.
3. **Anomalous crustal fragment:** volcanic arc? (2700 kg m^{-3}).



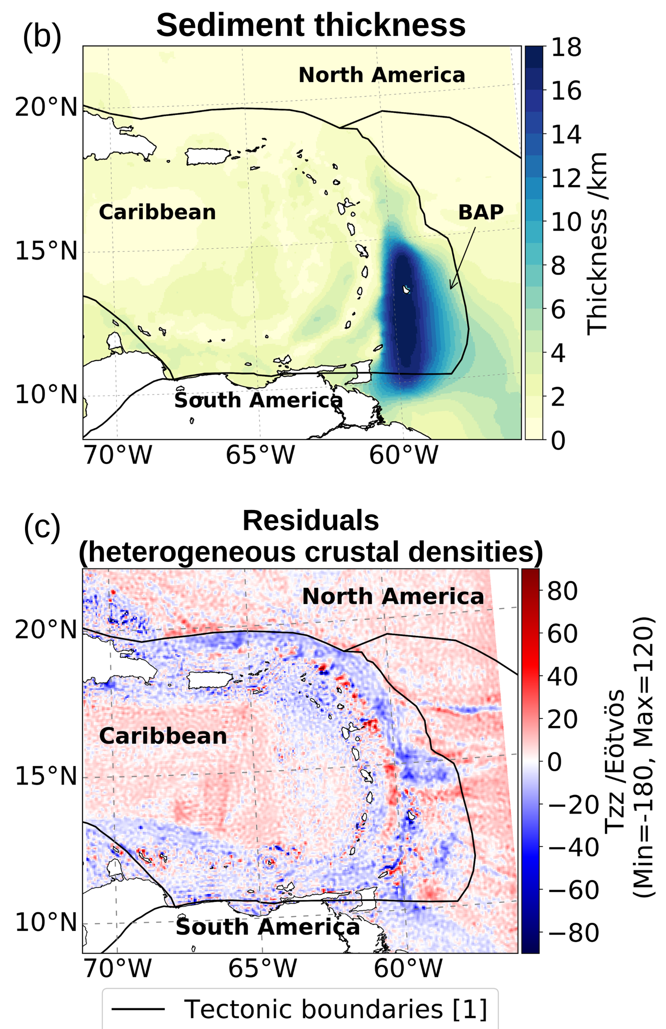


Fig. 3. (a) Average crustal densities inferred from the forward modelling of the VGG. AR = Aves Ridge, BAP = Barbados Accretionary Prism, GB = Grenada Basin, LA = Lesser Antilles, MS = Modified Saba crust, PRT = Puerto Rico Trench, SCDB = South Caribbean Deformed Belt, TB = Tobago Basin. VB = Venezuelan Basin. BFZ and TFZ = Barracuda and Tiburon Fault Zones. (b) Thick sediments of BAP are overlying the low density crustal body. (c) VGG residuals are minimized when the heterogeneous crystalline crust showed in (a) is considered in the starting model.

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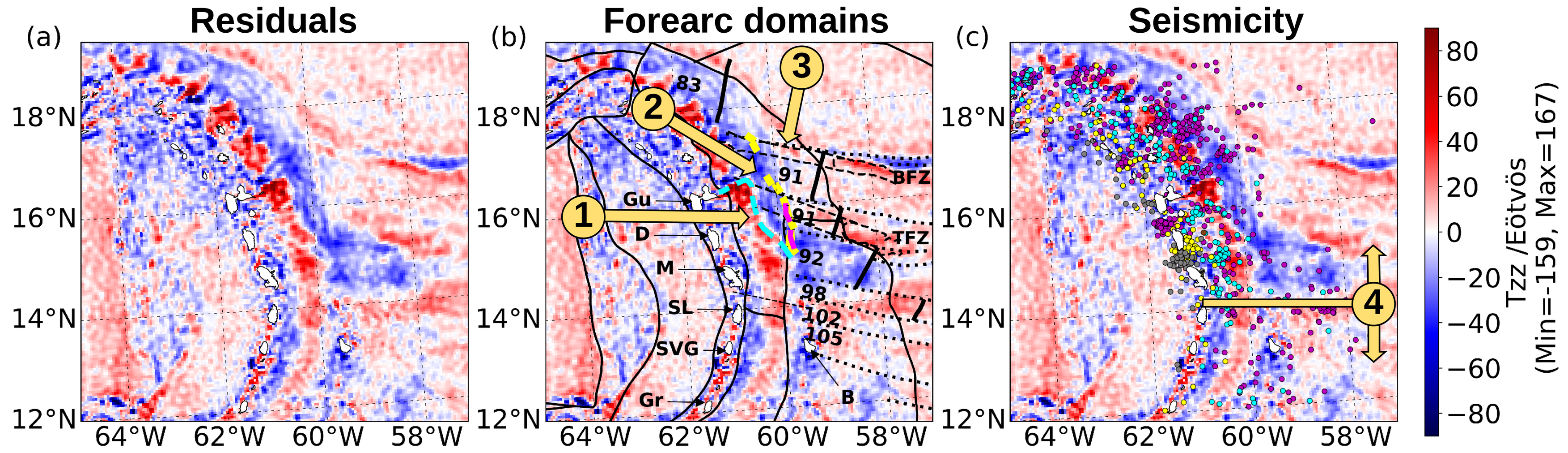
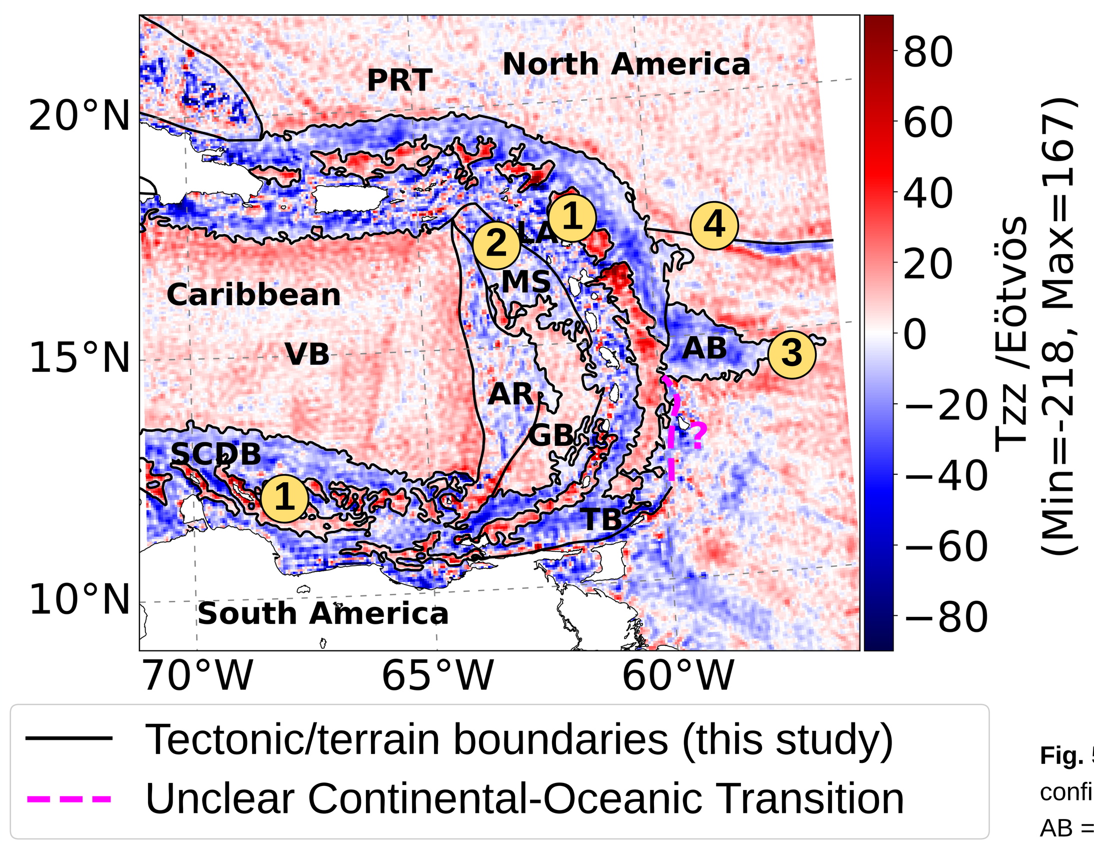
5. Tectonic implications



The residuals highlight different crustal domains in the Lesser Antilles:
1. **Inner** forearc (+ residuals).
2. **Outer** forearc (− residuals).
3. **8 Ma "jump"** in crustal ages.
4. **Anomalous body delimits two clusters of seismicity**.

Fig. 4. (a) Residuals. (b) Forearc domains from seismic data (see legend). B = Barbados Island. D = La Desirade Island, Gr = Grenada Island, Gu = Guadeloupe Island, M = Martinique Island, SL = St. Lucia Island, SVG = St. Vicent and the Grenadines Islands. BFZ and TFZ = Barracuda and Tiburon Fault Zones. Numbers indicate the ages of the subducting oceanic crust (Myr) [18]. (c) Earthquakes recorded from 1980 to 2017 [19].

6. Updated crustal domains



1. **Inner/outer forearcs** of the Lesser and Leeward Antilles.
2. **Boundary** of the **Modified Saba** crust (Grenada Basin).
3. **Anomalous buoyant body** (≈ 31x10^3 km^2). **Buried** under the Barbados Accretionary Prism.
4. **Boundary** between the **North** and **South American** plates (?).

Fig. 5. Tectonic and terrain boundaries refined, proposed or confirmed in this study. Acronyms as defined in Fig. 3. AB = Anomalous Bouyant body.

7. Outlook

- **With our novel approach**, based on the VGG residuals, we **refine, propose and/or confirm** tectonic (or terrain) boundaries in the Caribbean oceanic region (Section 6).
- Using 3D lithospheric models, we forward modelled these gradients to **infer the average density structure of the crystalline crust** (Section 4).
- Thanks to the global coverage of the combined gravity dataset, our **new methodology could be used in other marine or continental environments**, where direct measurements are limited.
- **Future work:** Our up-to-date density model of the Caribbean can be used to study the thermal properties of the lithosphere. In turn, this may **delineate seismogenic zones, or possible gas hydrates accumulation regions** within the sediments.

Contact me!

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