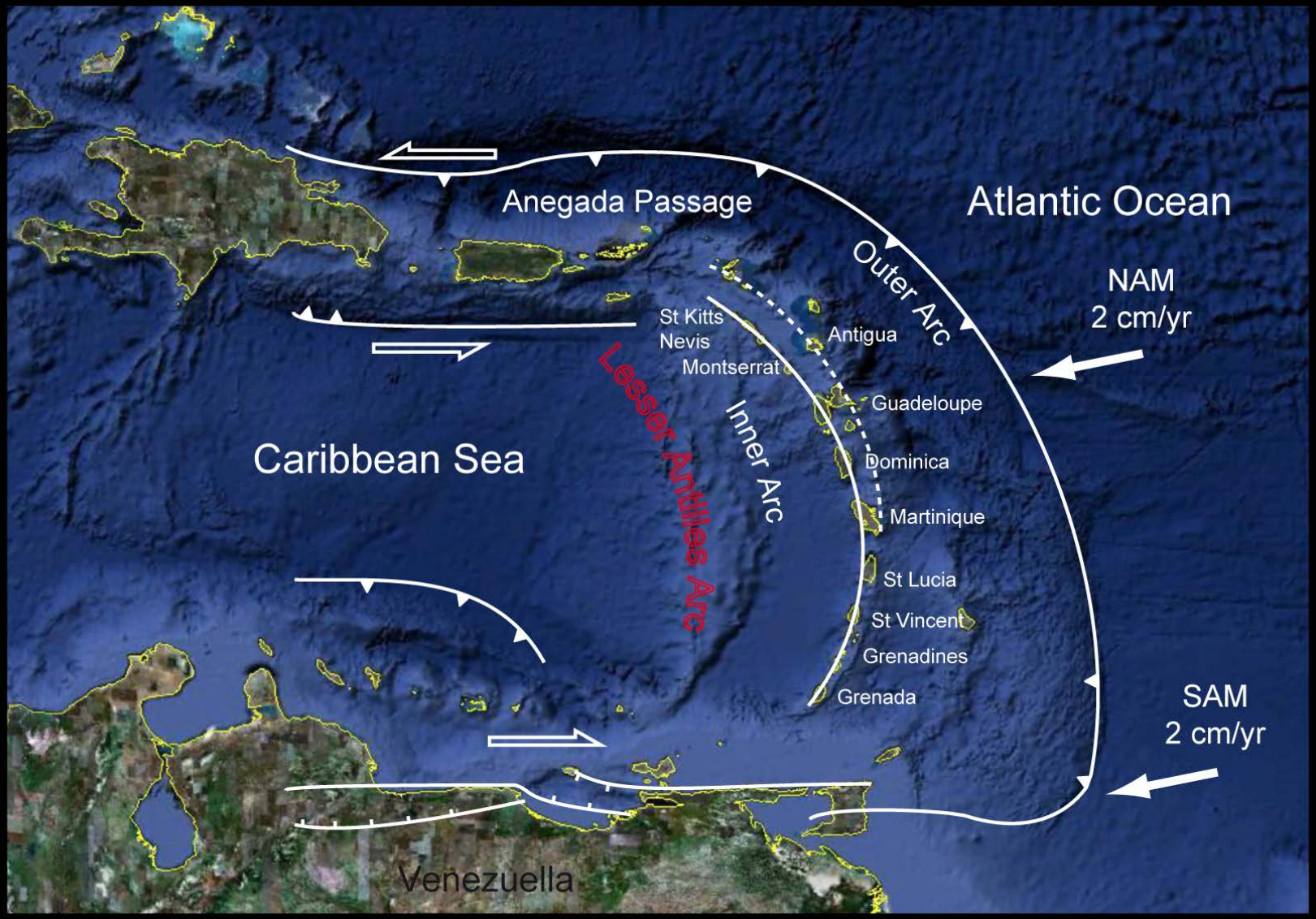
Crustal structure of the Lesser Antilles Arc and Guadeloupe Islands :

A new gravity and magnetic synthesis

Gailler L., Martelet G., Thinon I., Bouchot V., Lebrun J.-F., Munch P.

Geodynamic Context



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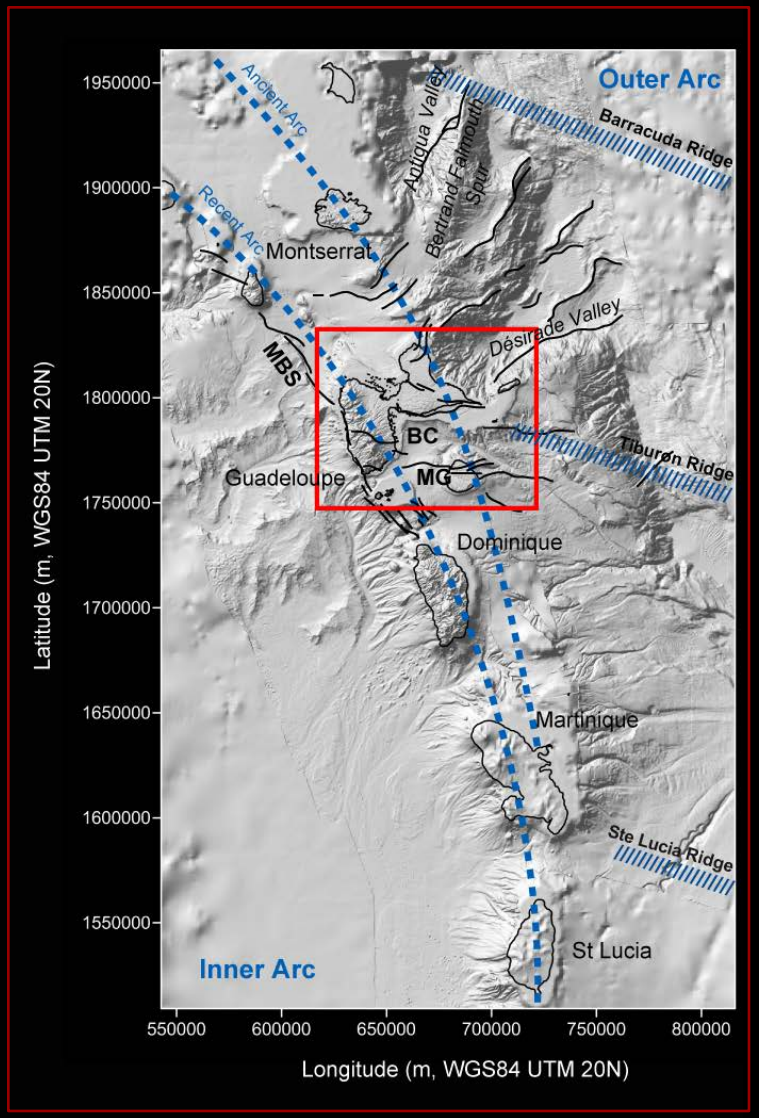


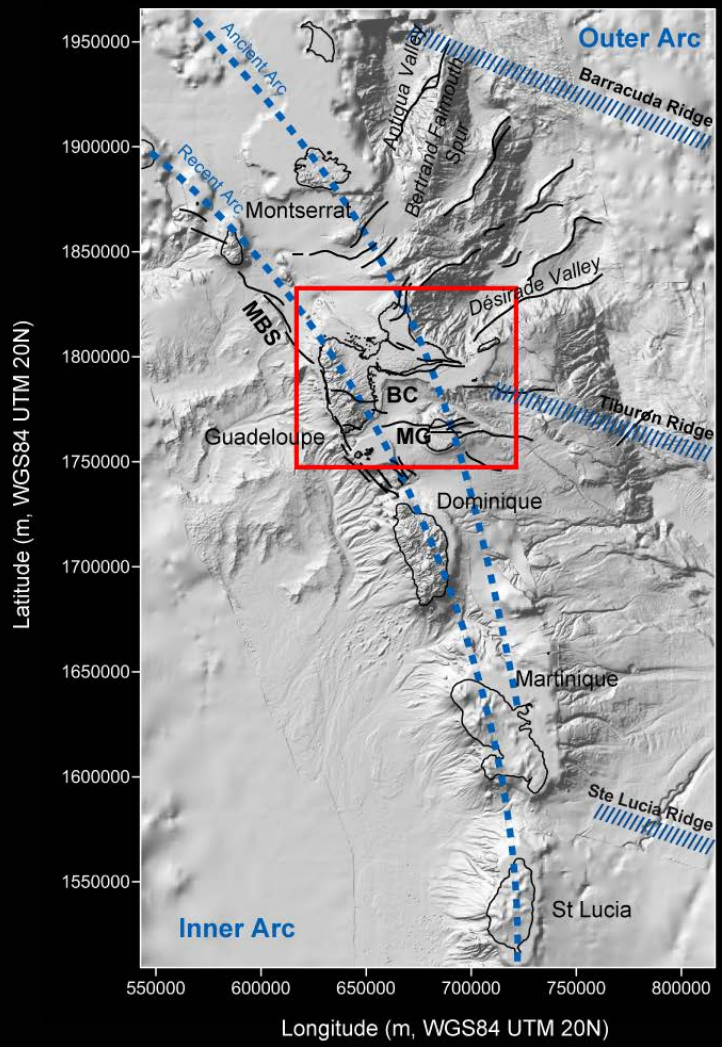
- Lesser Antilles arc (850 km) divides in 2 sub-arcs: Outer and Inner northern arcs

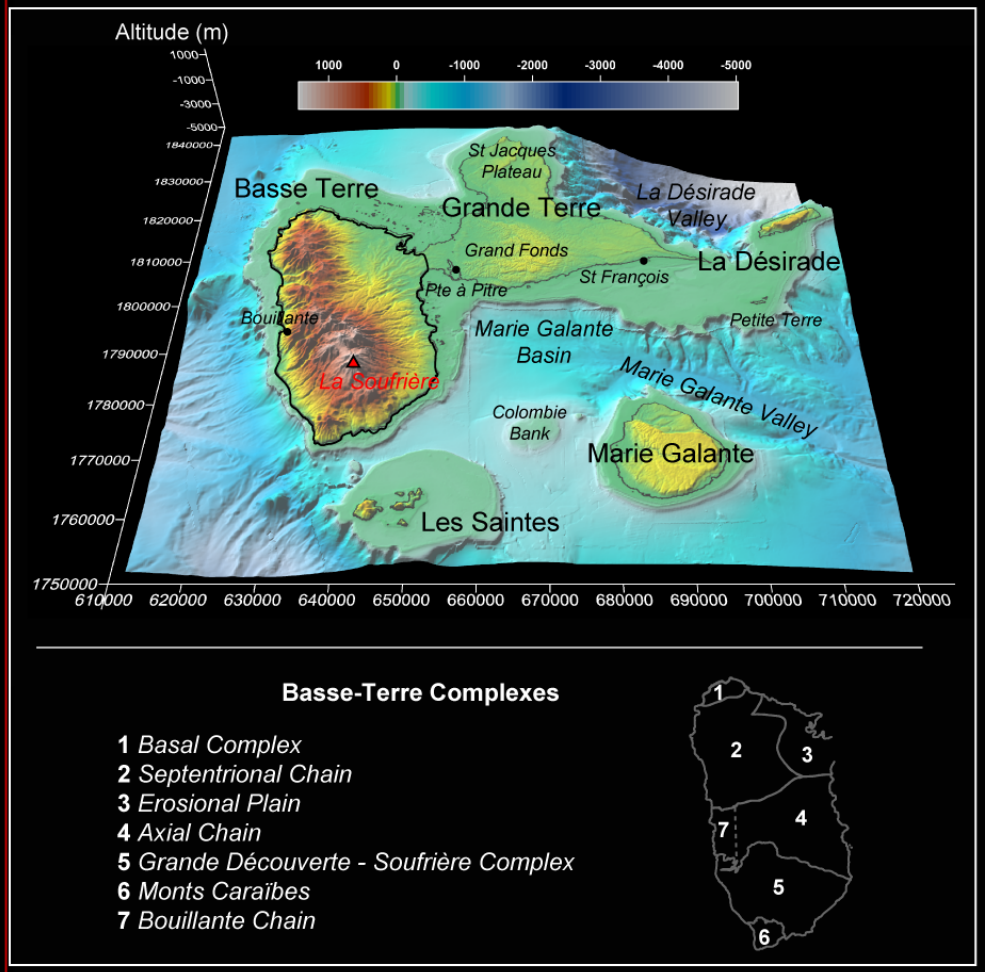
- Eastern of the accretion prism:
  - ⇨ Highly fractured Atlantic oceanic plate
  - ⇨ N130°E ridges :
    - *Barracuda*
    - *Tiburon*
    - *Ste Lucia*

- Complex tectonic system:
  - ⇨ Fan-shaped orientation
  - ⇨ MBS fault sinistral system

- Guadeloupe Islands : part of both sub-arcs

Geodynamic Context





Geodynamic Context

➢ **East :**

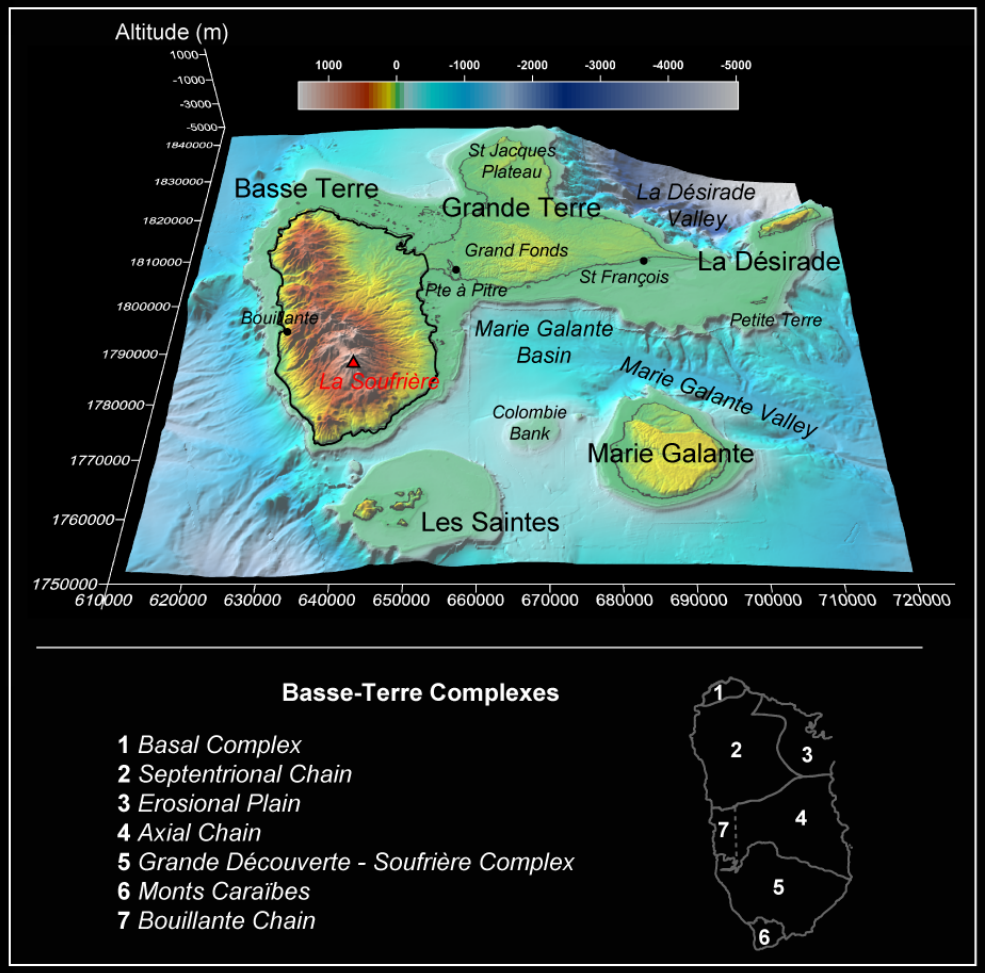
- *Grande-Terre*
- *Désirade*
- *Petite-Terre*
- *Marie Galante*

⇨ ***Limestone reliefs of the early pre-Miocene Outer Arc***

➢ **East :**

- *Basse-Terre*
- *Les Saintes*

⇨ ***Recent volcanic Inner Arc***



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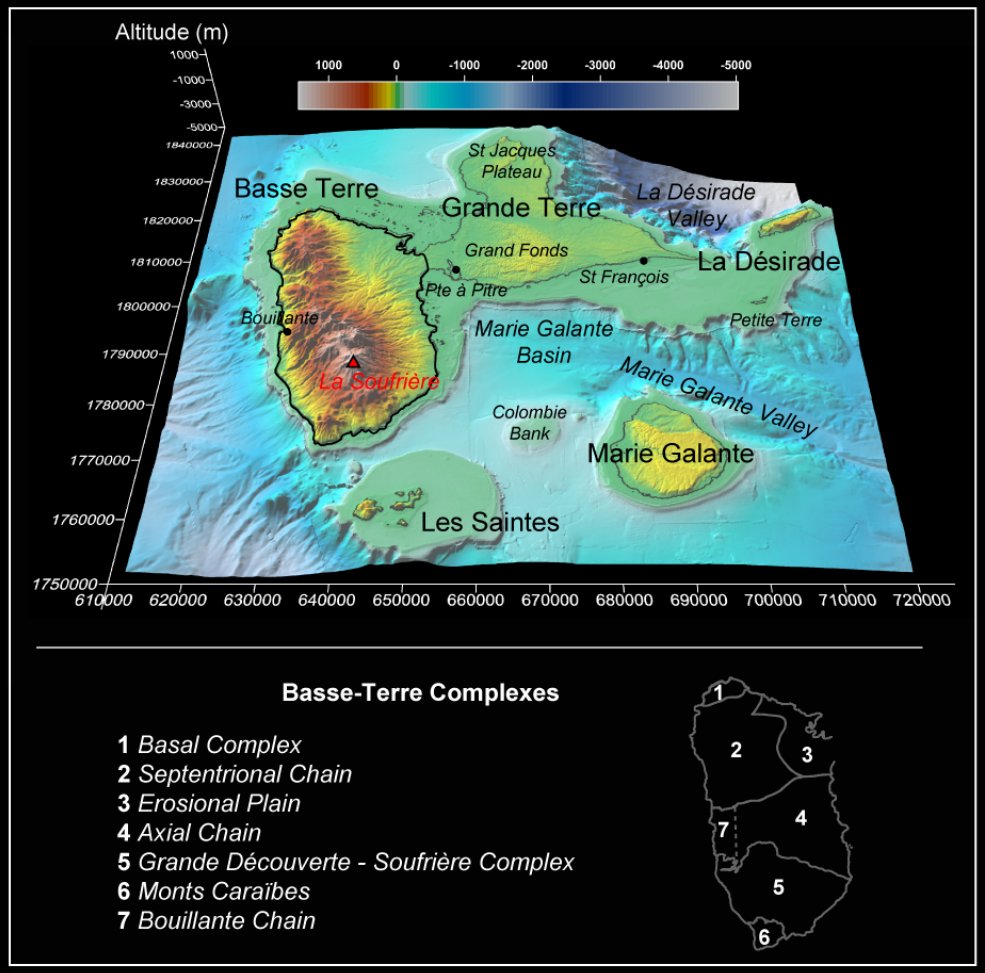


Geodynamic Context

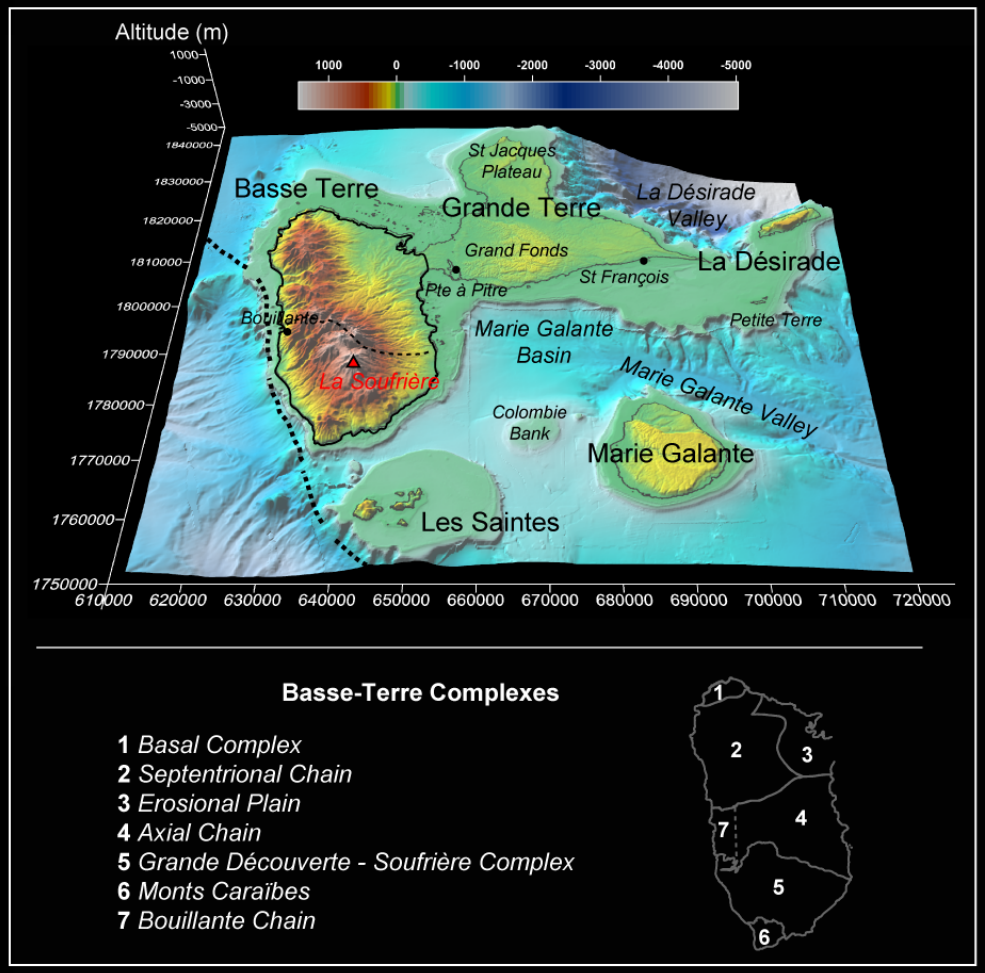
- **East :**

⇨ ***Limestone reliefs of the early pre-Miocene Outer Arc***

- **East :**

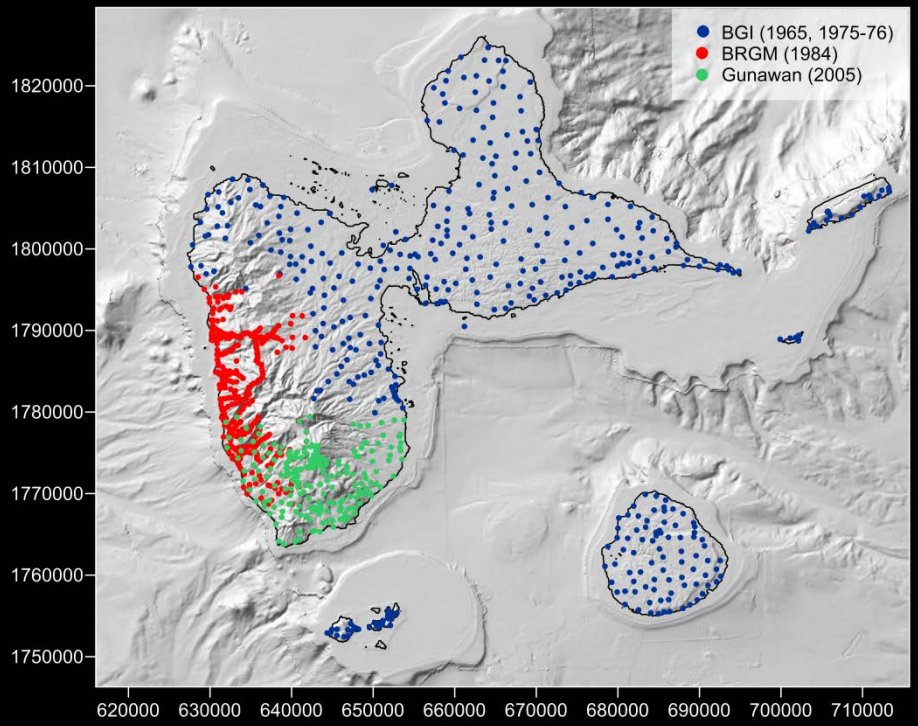
- Basse-Terre

⇨ Assemblage of composite volcanoes developed in an active sinistral transtensional fault zone : the **Montserrat-Bouillante-Les Saintes fault**

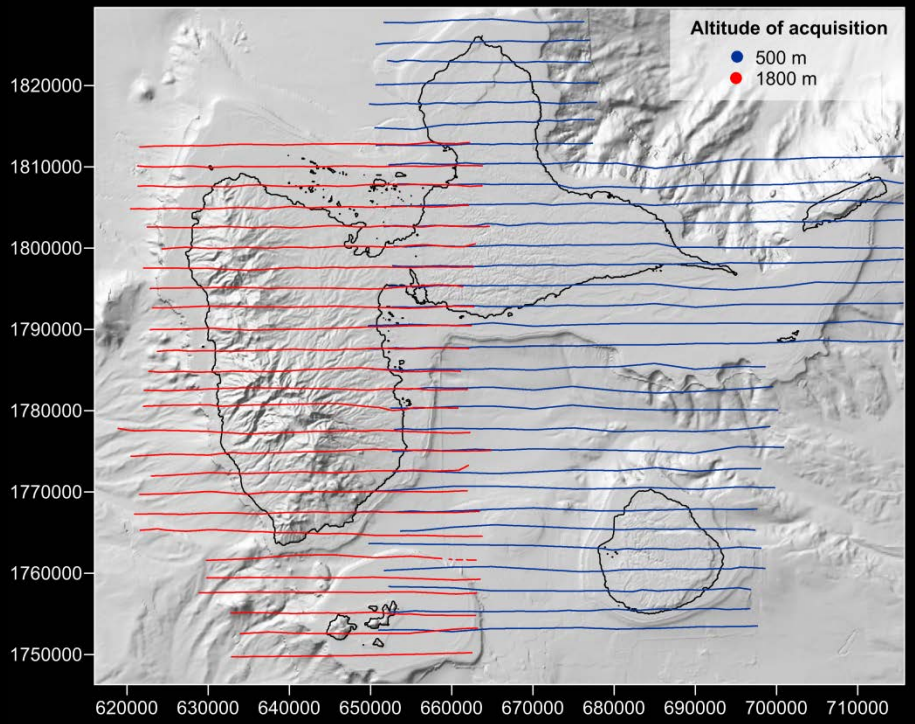


Geophysical Methods and Data

Gravity



Magnetism



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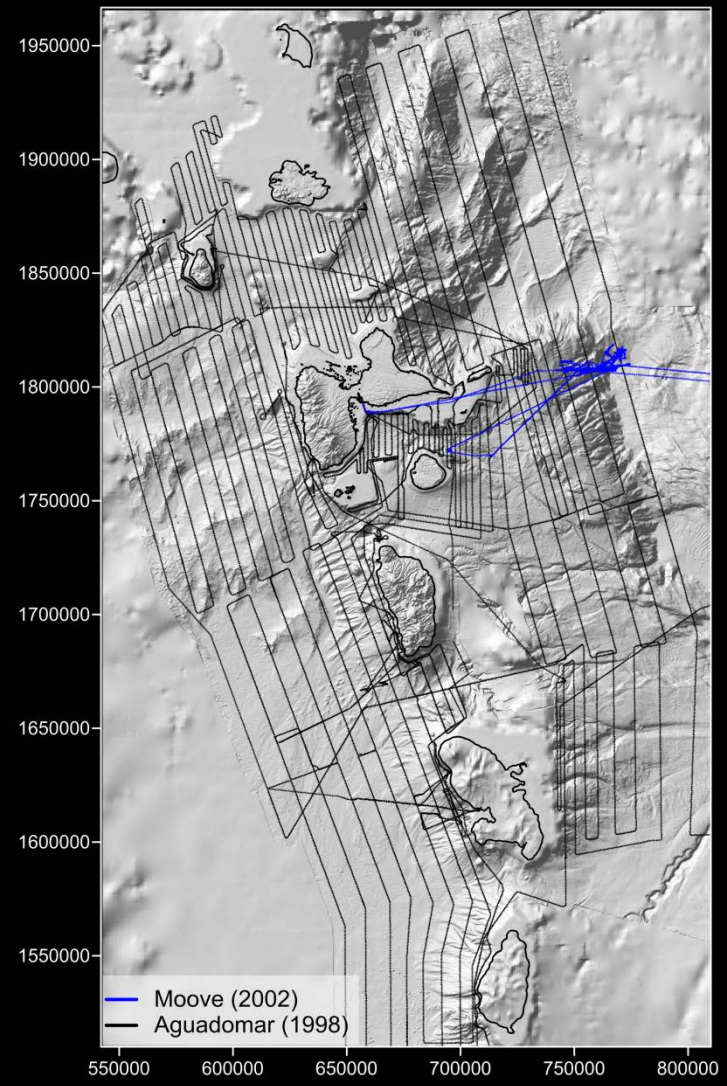

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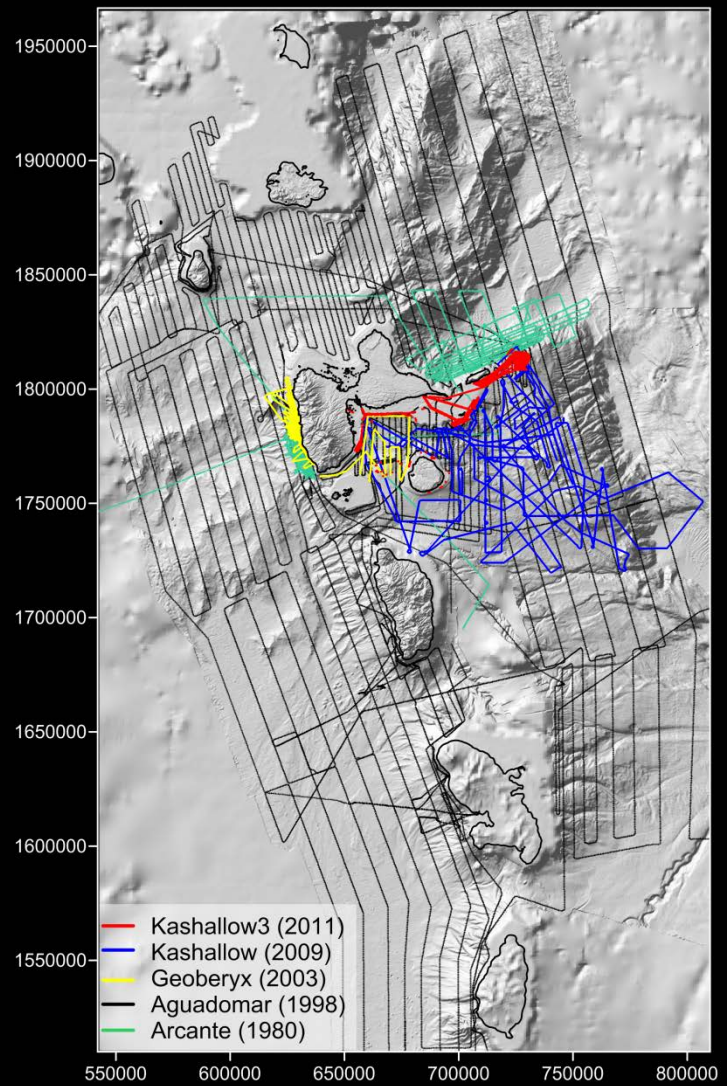
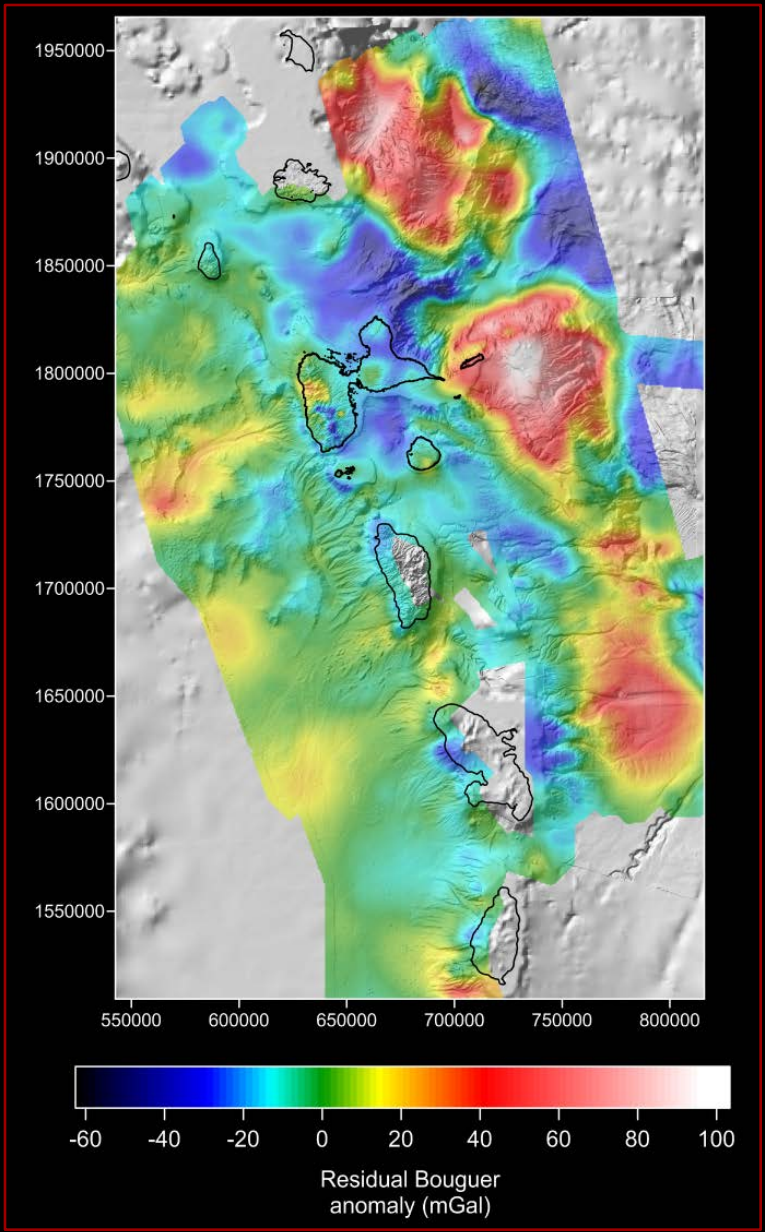


Qualitative Intepretation - *Gravity*

Regional scale

- **Residual Bouguer anomaly map (short λ) :**
  - ⇨ Density correction 2.67
  - ⇨ Better resolution of the local structure and fault system



Qualitative Intepretation - *Gravity*

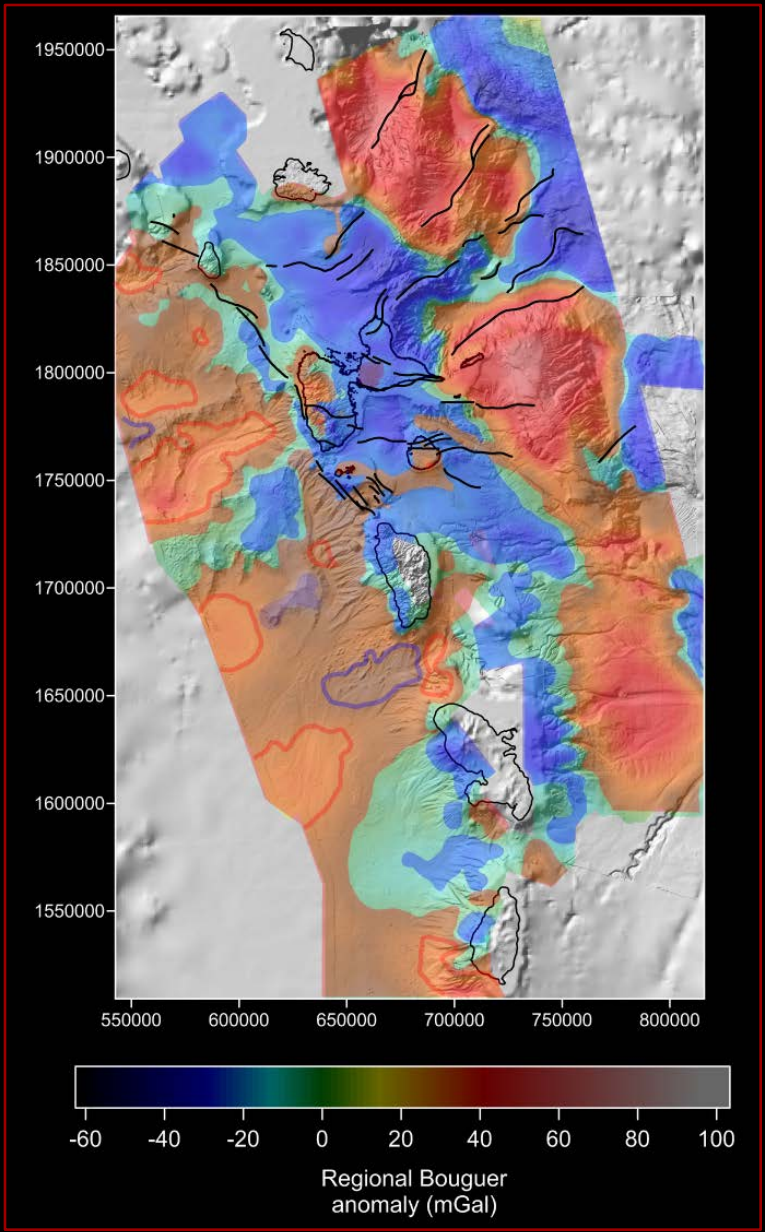
Regional scale

- **3 main areas ~ oriented N160°**

⇨ **Eastern domain** along the Outer Arc & superimposed to the accretion prism (Karukera) + oceanic crust and ridges

⇨ **Western domain** associated with the Inner Arc & limited to the E by the MBS

⇨ **Central area** associated with the emerged relief between the ancient and recent volcanic arc systems



Qualitative Intepretation - *Gravity*

- Eastern domain :

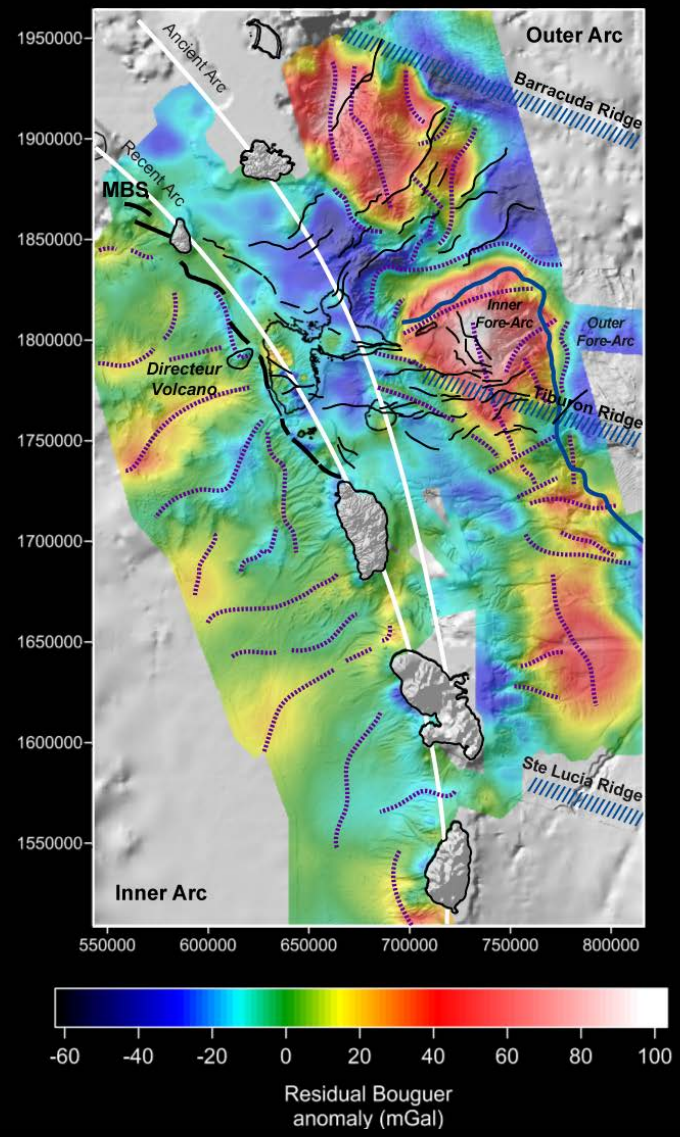
  3 main > 0 anomalies

⇨ **Karukera Spur:**
OC thickened by deep magmatic processes & underplating *(Diebold et al., 2009)*

- Western domain :

  Smoother with N60°E trends

⇨ **Basse-Terre coast :**
elongated < 0 anomaly striking the N140°-N160°E along the MBS



Structures known from previous studies

- Trace of the ancient and recent volcanic arcs [from *Bouysse et al.*, 1988]
- Montserrat-Bouillante-Les Saintes (MBS) fault system [from *Feuillet et al.*, 2010; *Calcagno et al.*, 2011]
- Main regional tectonic features [from *Feuillet et al.*, 2010]
- Barracuda, Tiburon and Ste Lucia Ridges [from *Andreieff et al.*, 1989]
- Limit between an Inner Fore-Arc and an Outer Fore-Arc from 3D seismic refraction tomography [from *Evain et al.*, 2011]

Structures inferred from the geophysical anomalies interpretation [this study]

- Main gravity lineaments

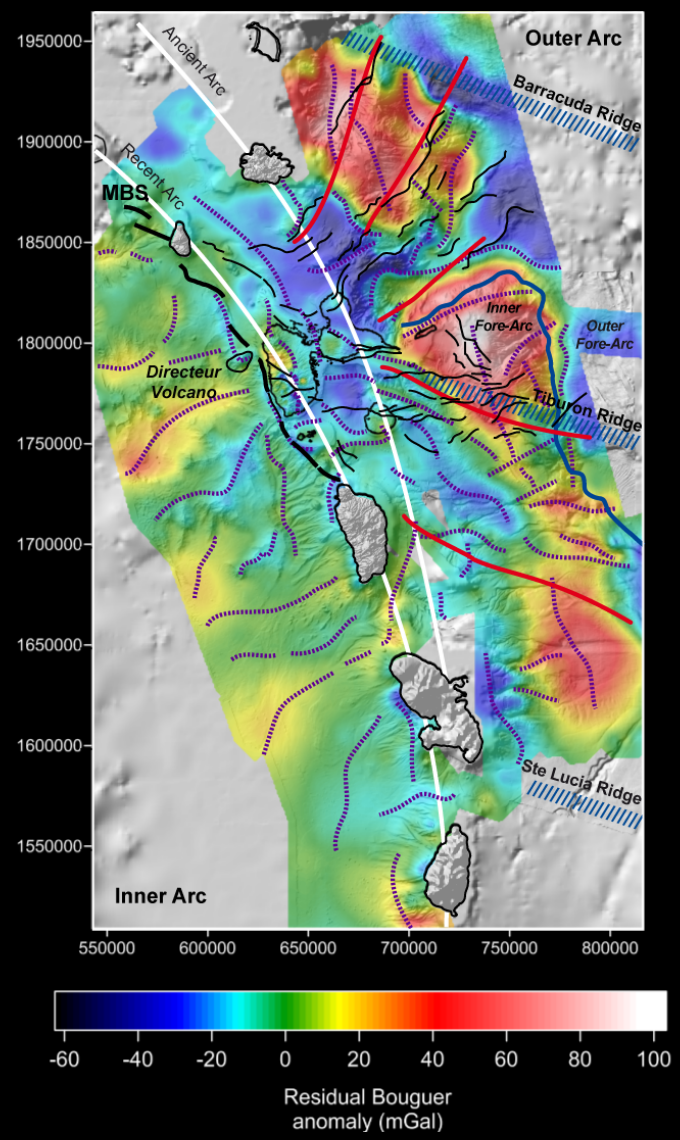
Qualitative Intepretation - *Gravity*

➢ Central area :

⇨ Continuity with the E trends

⇨ Range of orientations from N20 to ~ N130°E

⇨ Coherent with the fault system and the fan-shaped folding



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Structures inferred from the geophysical anomalies interpretation [this study]

- Main gravity lineaments
- Main gravity axis associated with a rupture in the Bouguer lineaments

Qualitative Intepretation - *Gravity*

➢ Central area :

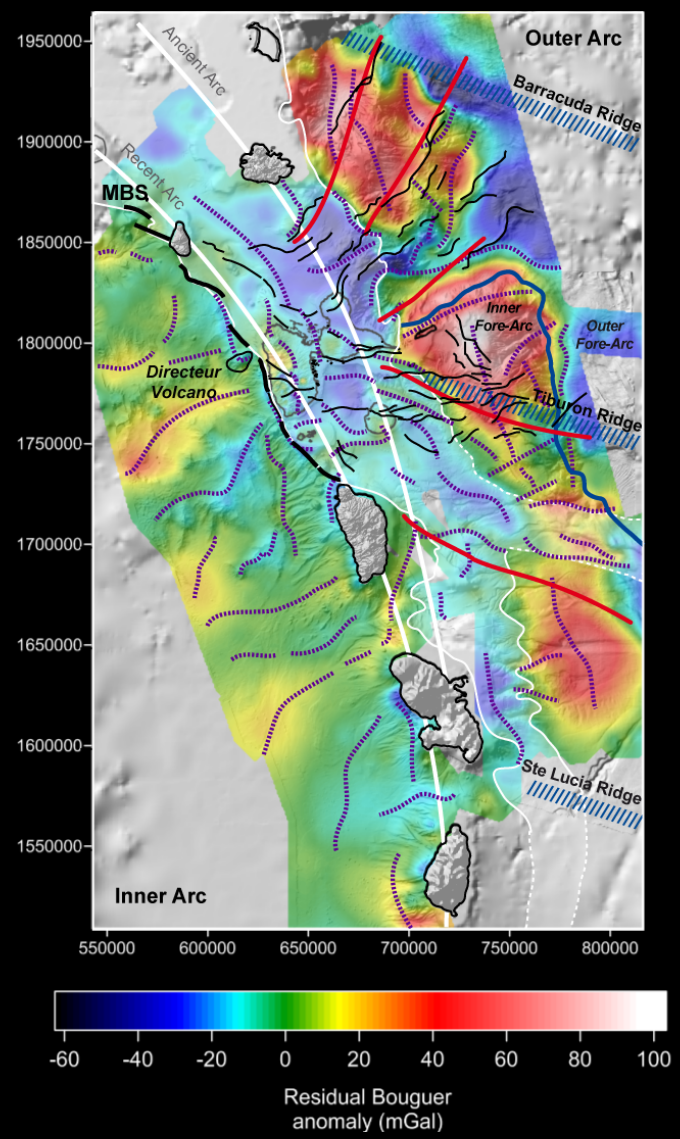
① *Negative trend*

⇨ **Border to the N by the MBS** (N160°E)

⇨ **Strong < 0 anomalies** (valleys and basins)

② **Distinct < 0 trend** // to the oceanic ridges E of La Dominique

⇨ Curvilinear < 0 area cross-cuts and structures the S > 0 block of the E domain



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Structures inferred from the geophysical anomalies interpretation [this study]

- Main gravity lineaments
- Main gravity axis associated with a rupture in the Bouguer lineaments
- Main area associated with negative anomalies

Qualitative Intepretation - *Gravity*

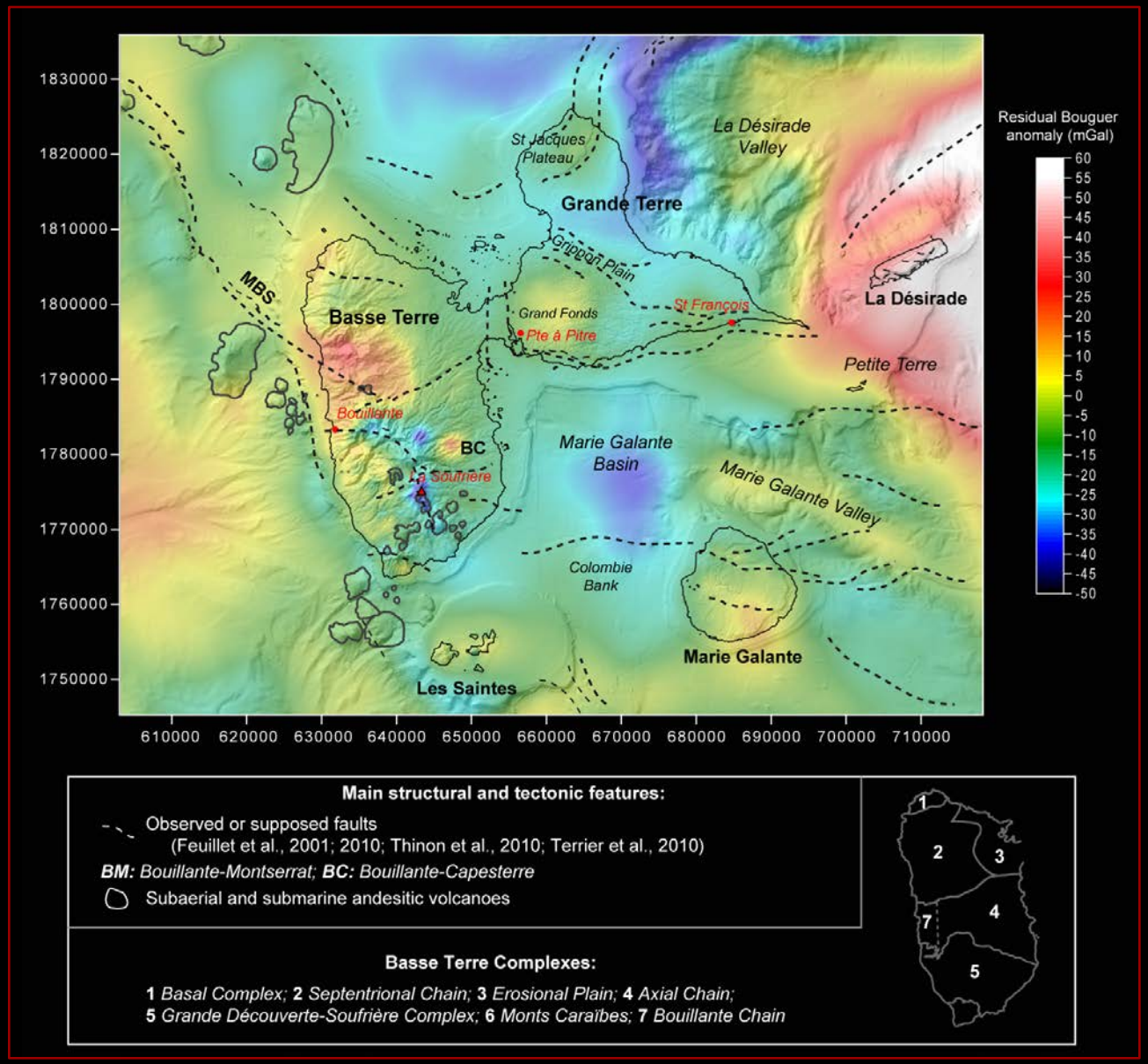
Guadeloupe Islands

- Marie-Galante > 0 : NS gradation related to the relief and the fault system

- La Désirade > 0 :
  ⇨Oldest rocks of the Lesser Antilles Arc *(Corsini et al., 2011)*

- Grande-Terre : 3 > 0 areas
  - Grands Fonds
  - St Jacques
  - St François

⇨ **Up-rise of the underlying volcanic basement**



Qualitative Intepretation - *Gravity*

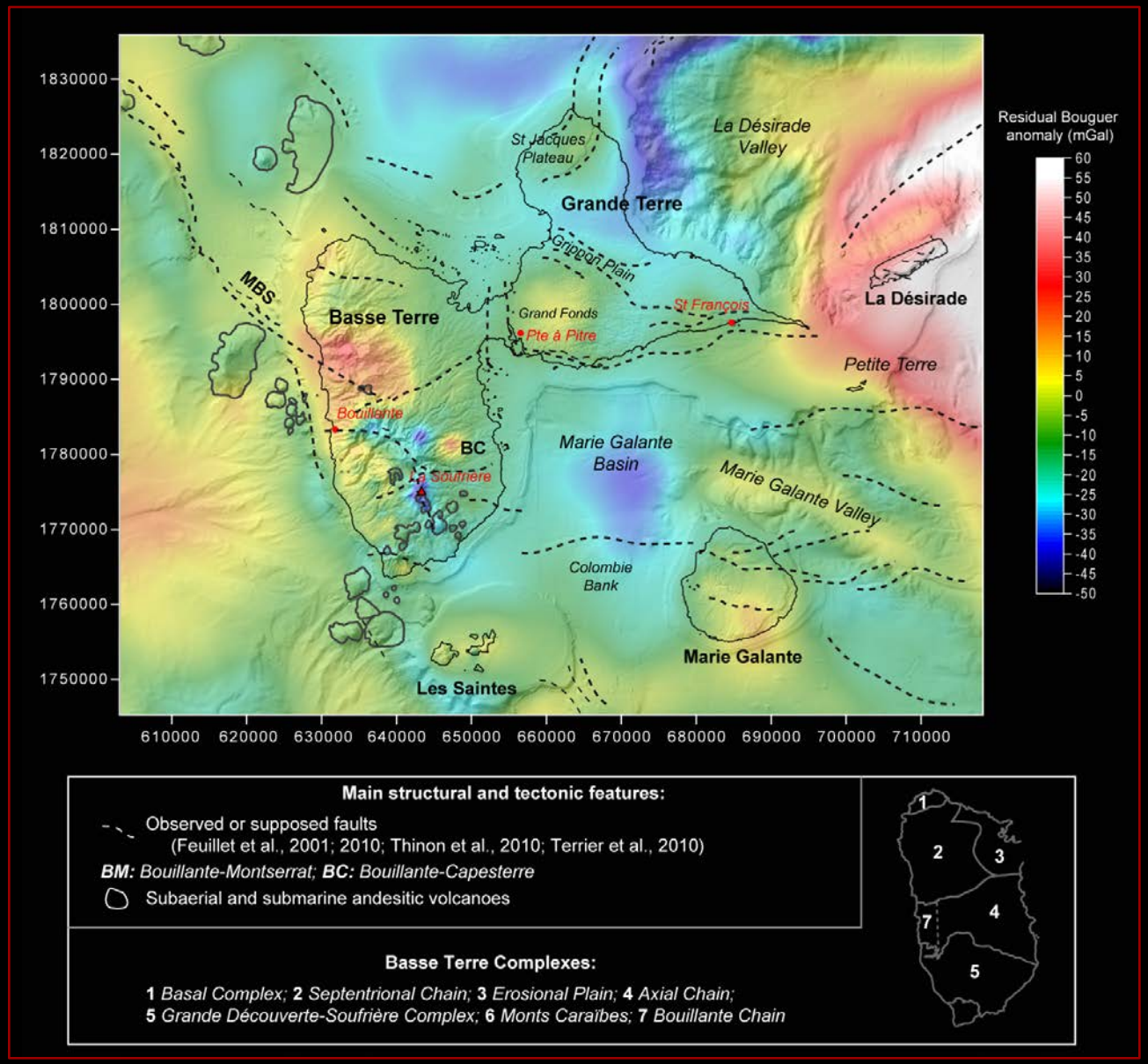
Guadeloupe Islands

➢ Basse-Terre :

- **Septentrional Chain > 0**
⇨ andesitic lava flows

- **Soufrière Volcano < 0**

- **BT – GT transition :** no particular signal *(NS faults reported - Terrier et al., 2010)*



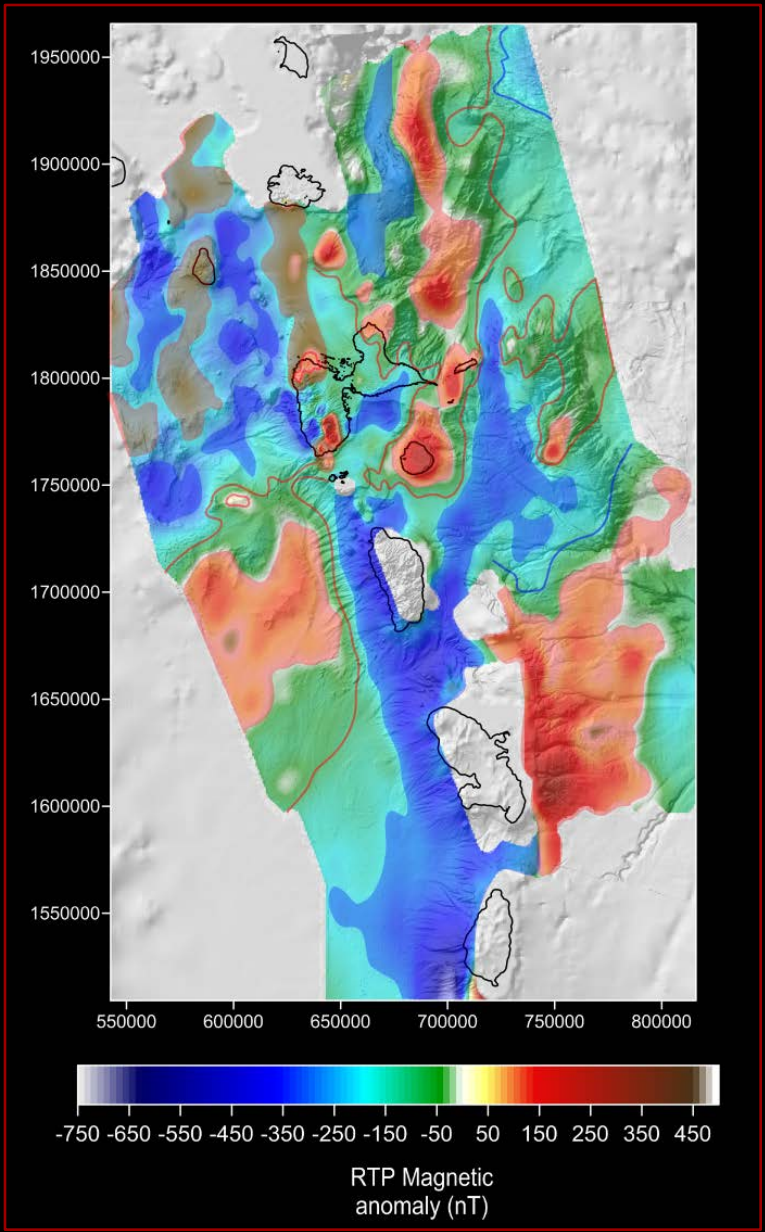
Qualitative Intepretation - *Magnetism*

Regional scale

- Negative and positive high amplitude anomalies
  - ⇨ Several magnetic domains

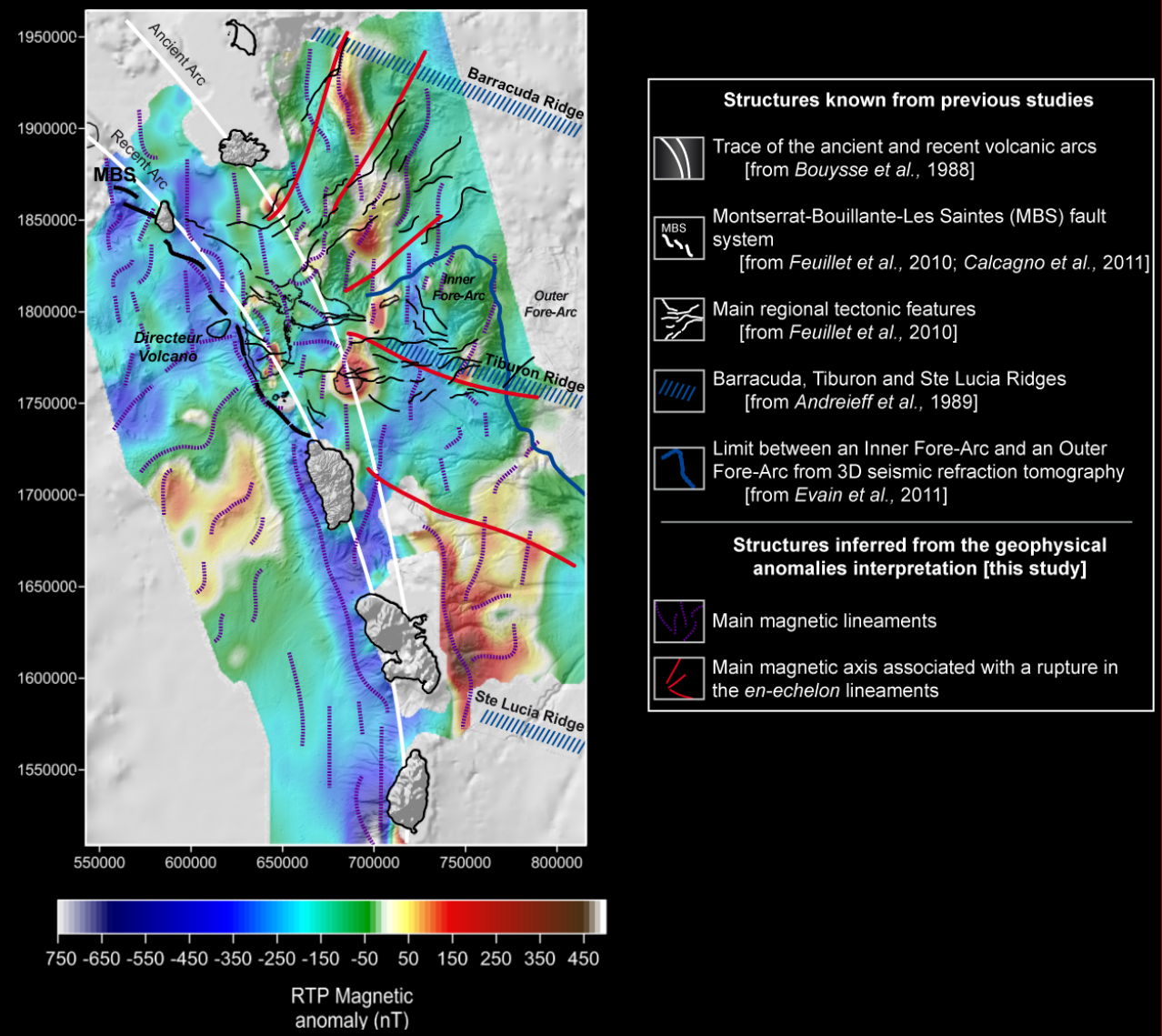
- Northern area dominated by the juxtaposition of > 0 and < 0 *en-echelon* trends

- Southern areas: long wavelength > 0 anomalies to the W of Dominique Island and to the E of Martinique Island
  - ⇨ *deep origin*



Qualitative Intepretation - *Magnetism*

- Deformation of the plate along 5main structural axes ranging from ~N20° to N130°E
- Fan-shaped structures consistent with the seabed morphology of the Outer Arc mapped by *Feuillet et al. (2010)*

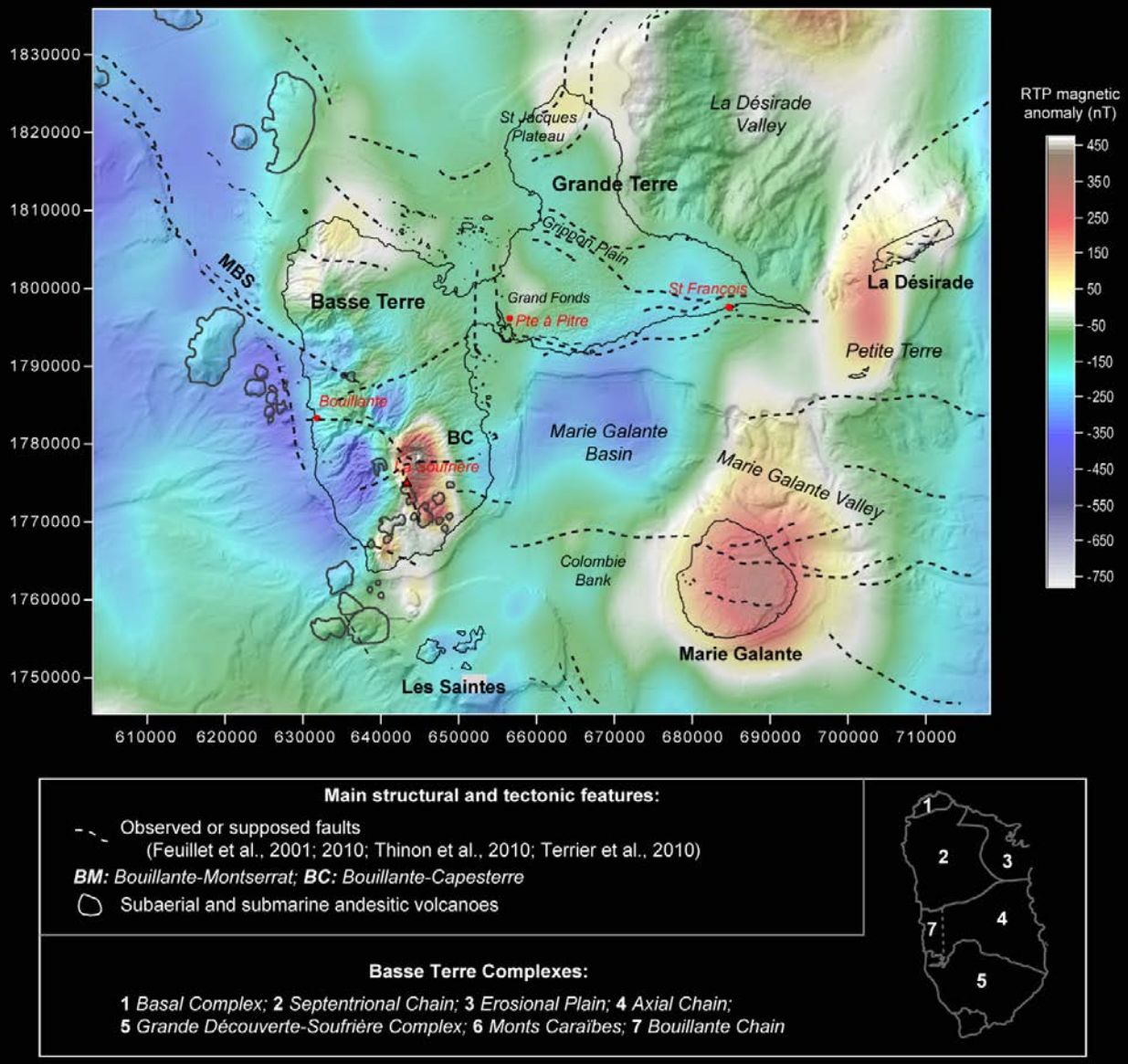


Qualitative Intepretation - *Magnetism*

Guadeloupe Islands

- Marie Galante Island : > 0
- La Désirade : 2 // > 0 trends NS
- Grande-Terre : 2 main > 0 anomalies
  - Saint Jacques Plateau
  - Grands Fonds

⇨ **Up-rise of the volcanic basement**
(Bouysse and Garrabé, 1984)



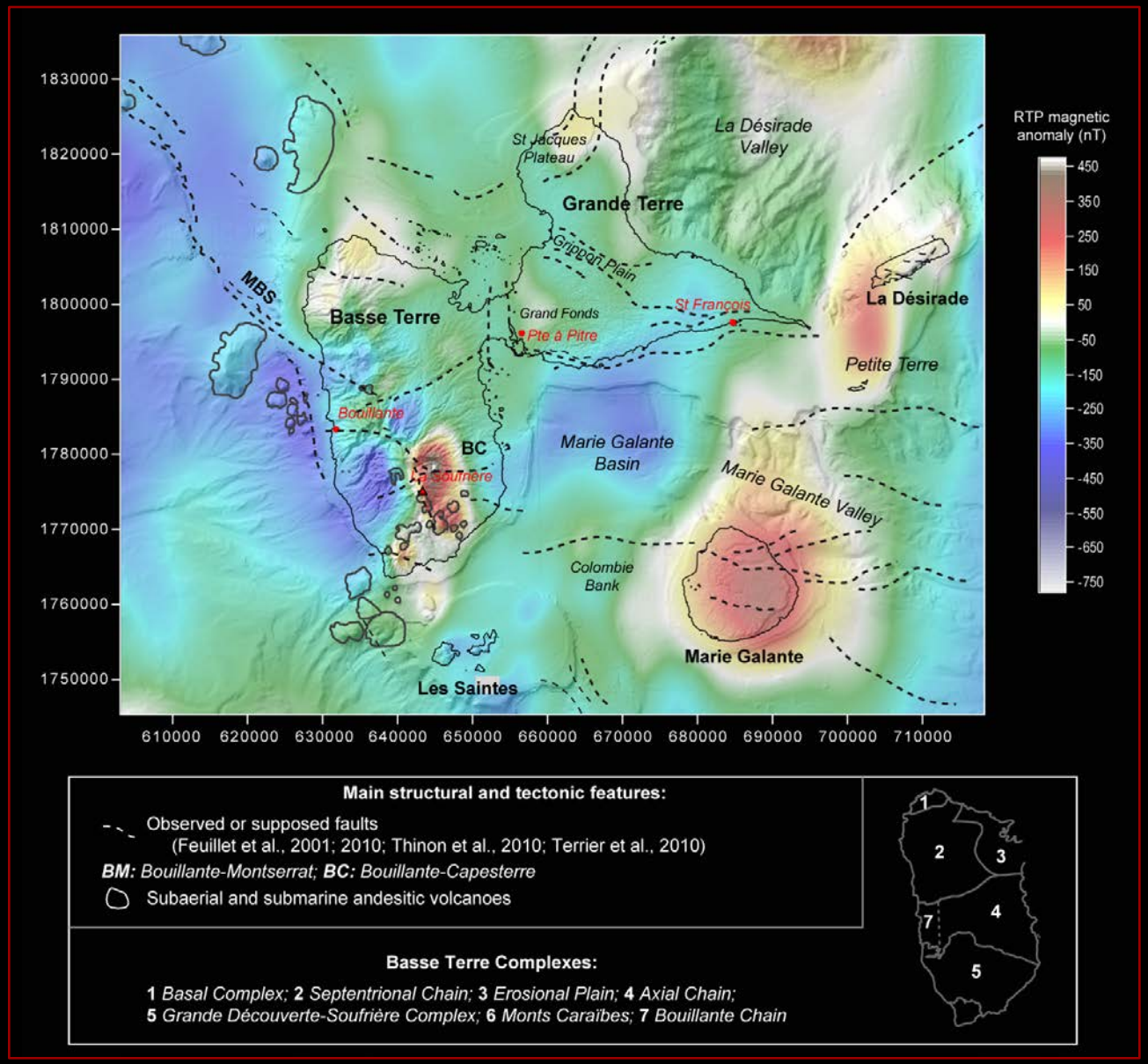
Qualitative Intepretation - *Magnetism*

Guadeloupe Islands

➢ Basse-Terre :

- Consistent with the age of the associated formations *(Samper et al., 2007)*

- S of the BC fault : two main domains associated with la Soufrière Volcano



Modeling and constraints

Modeling Approach

- Different modeling approaches to define the gravity (and magnetic) structure of the area of interest

- 2D, 2D 1/2 , 2D ¾ gravity (and magnetic) modeling *(GMSYS - Oasis Montaj, Geosoft)*

  ⇨ Detailed models with more geological and geophysical constraints

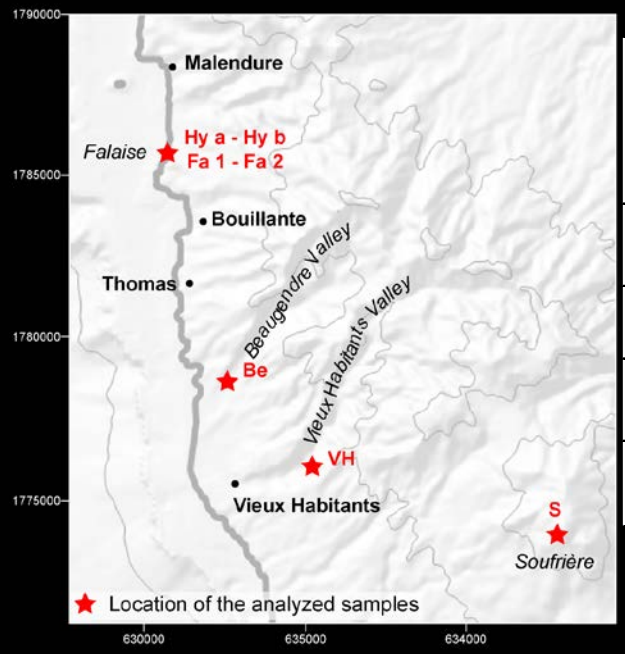
- Non-uniqueness of the models

  ⇨ Constraints to restrain the field of solutions

Modeling and constraints

Geological Constraints - *Density*

- Homogeneous reduction density : 2.67 10^3 kg m^{-3} ⇨ Average density of the volcanic system
- Large range of densities among the rocks of Guadeloupe Island ⇨ $1.6 < \rho < 3.0$ 10^3 kg m^{-3}

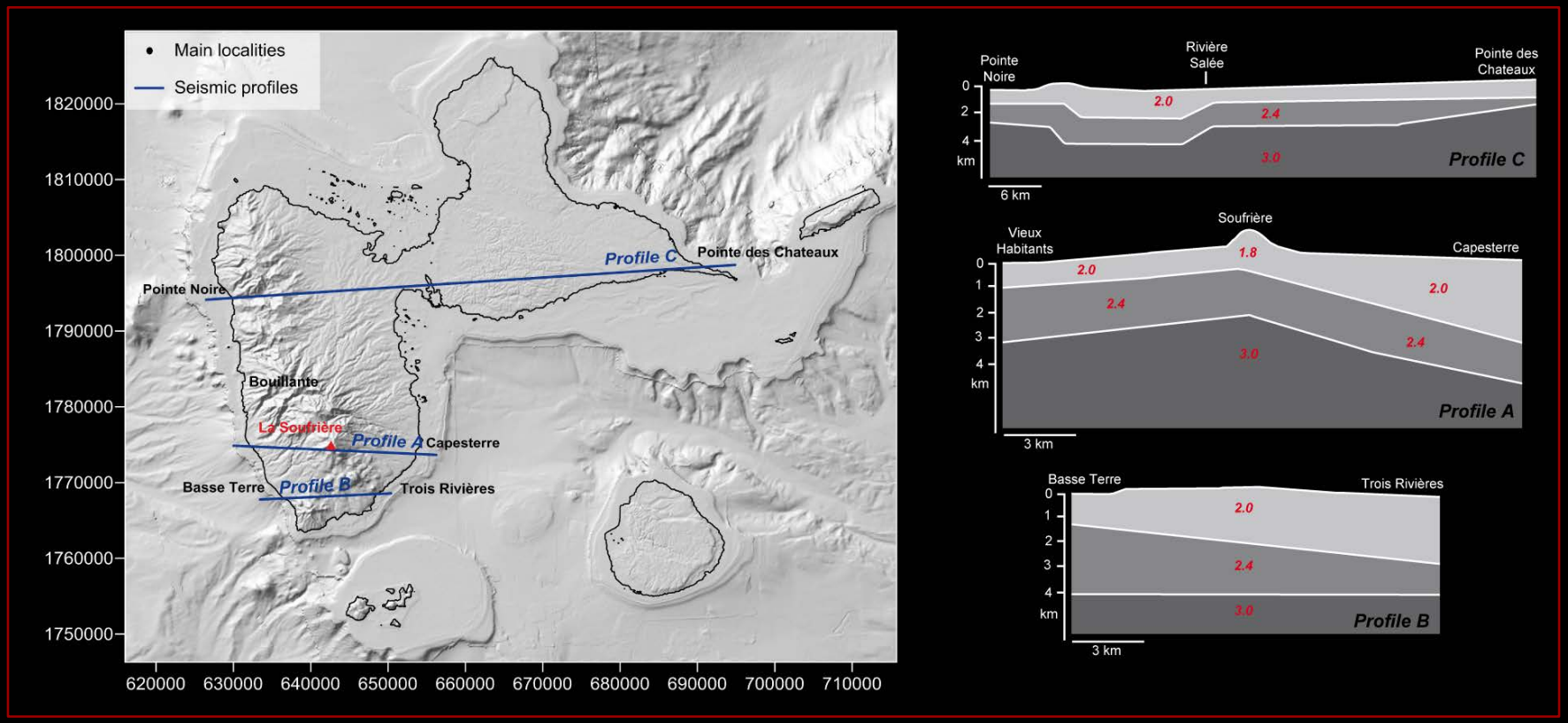


Sample reference	Description	Bulk density (g / cm^3)	True density (g / cm^3)	Porosity (%)
Falaise (Fa 1 & 2)	*Massive lava flow*	2.33 - 2.61	2.57 - 2.65	1.58 - 10.23
Beaugendre (Be)	*Massive lava flow*	2,75	2,78	0,91
Vieux Habitants (VH)	*Altered lava flow*	1.97 - 2.18	2.17 - 2.50	9.0 - 12.9
Soufrière (S)	*Vesiculated lava*	1.31 - 1.44	2.13 / 2.16	32.13 - 39.28
Hyaloclastite (Hy 1 & 2)	*Various blocks in matrix*	1.58 - 1.84	2.54 - 2.61	29.5 - 37.8

Measurements on various samples from the Bouillante geothermal Province and La Soufrière Volcano (Gailler et al., in prep)

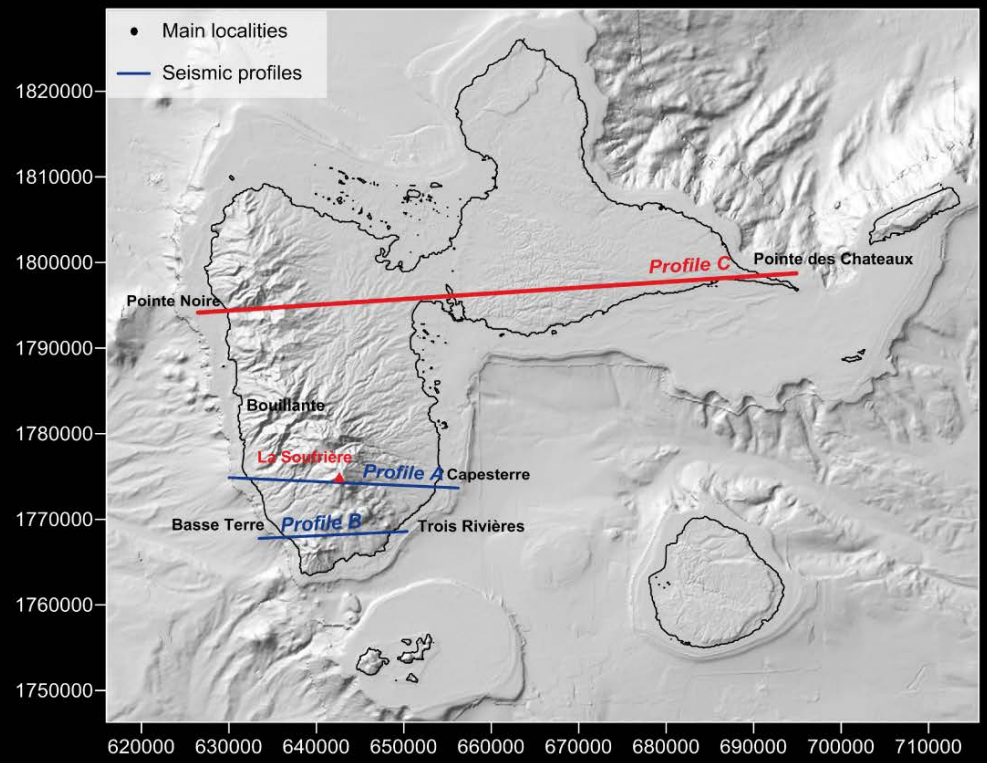
Modeling and constraints

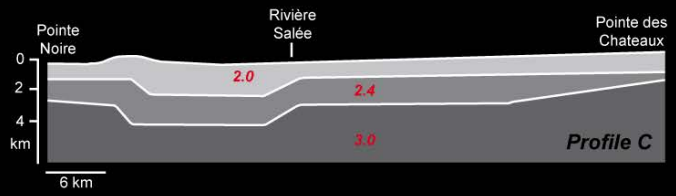
Geophysical Constraints – *Dorel et al. (1979)*



- **Shallow layer:** non- or semi-consolidated materials (sediments, pyroclastic, detritic products)
- **Intermediate layer:** range of rocks (consolidated sediments, volcanic, metamorphic rocks)
- **Deep layer:** Oceanic crust

Quantitative Intepretation





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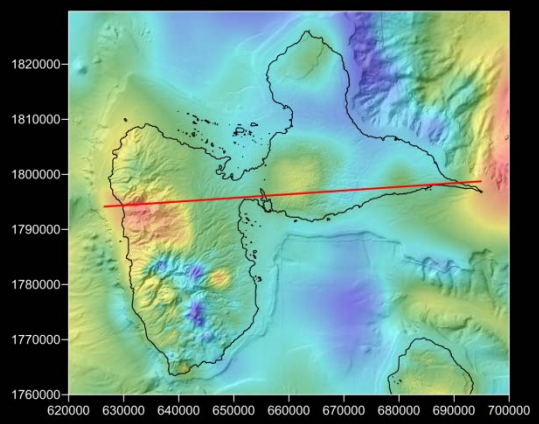
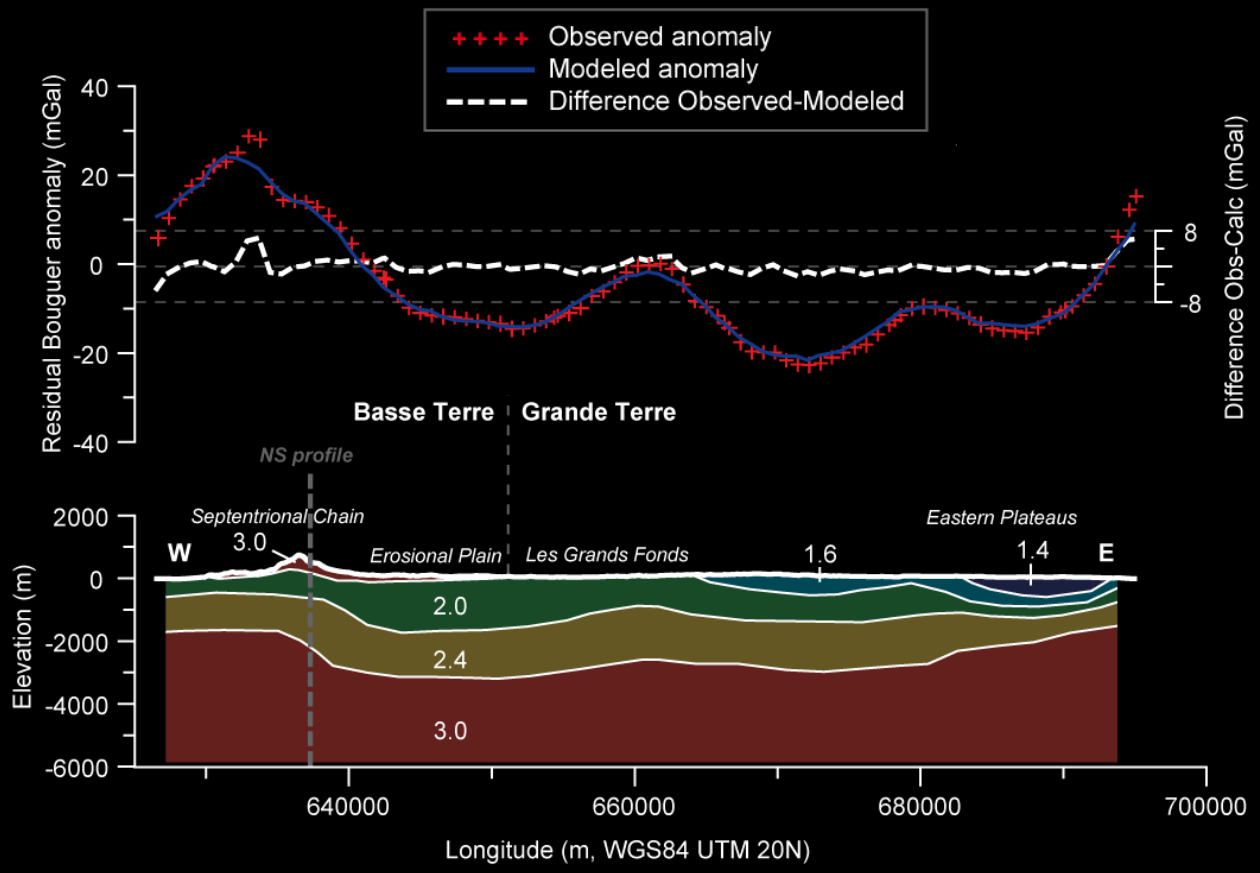
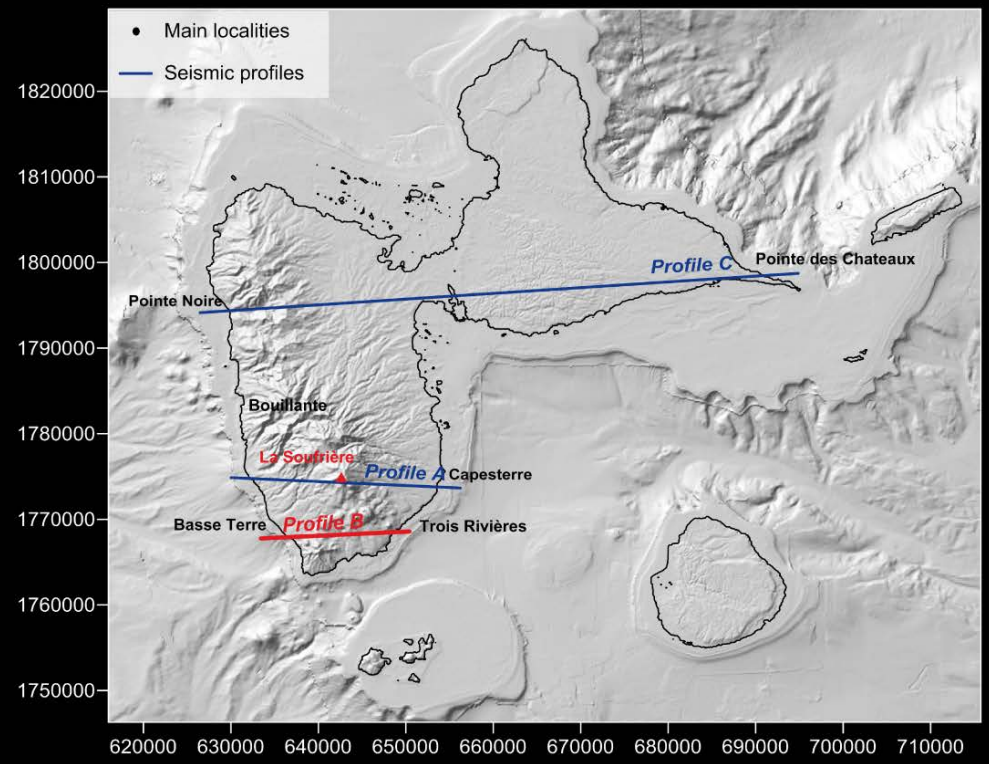
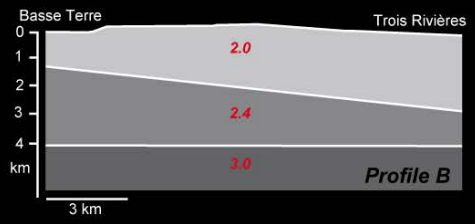




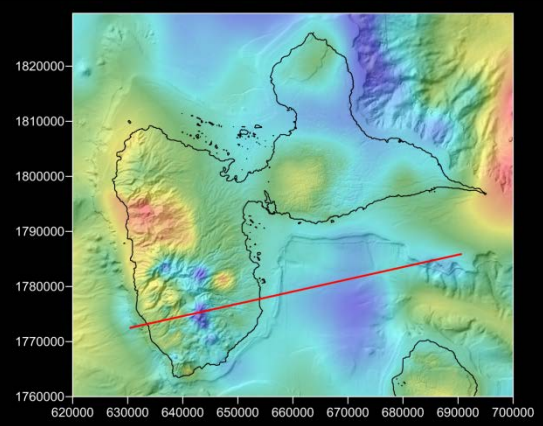
- Long λ gravity signal well reproduced by the simple three layers derived from the seismic refraction model (Dorel et al., 1979)
- Short λ gravity signal fitted by introducing geologically realistic shallow contrast

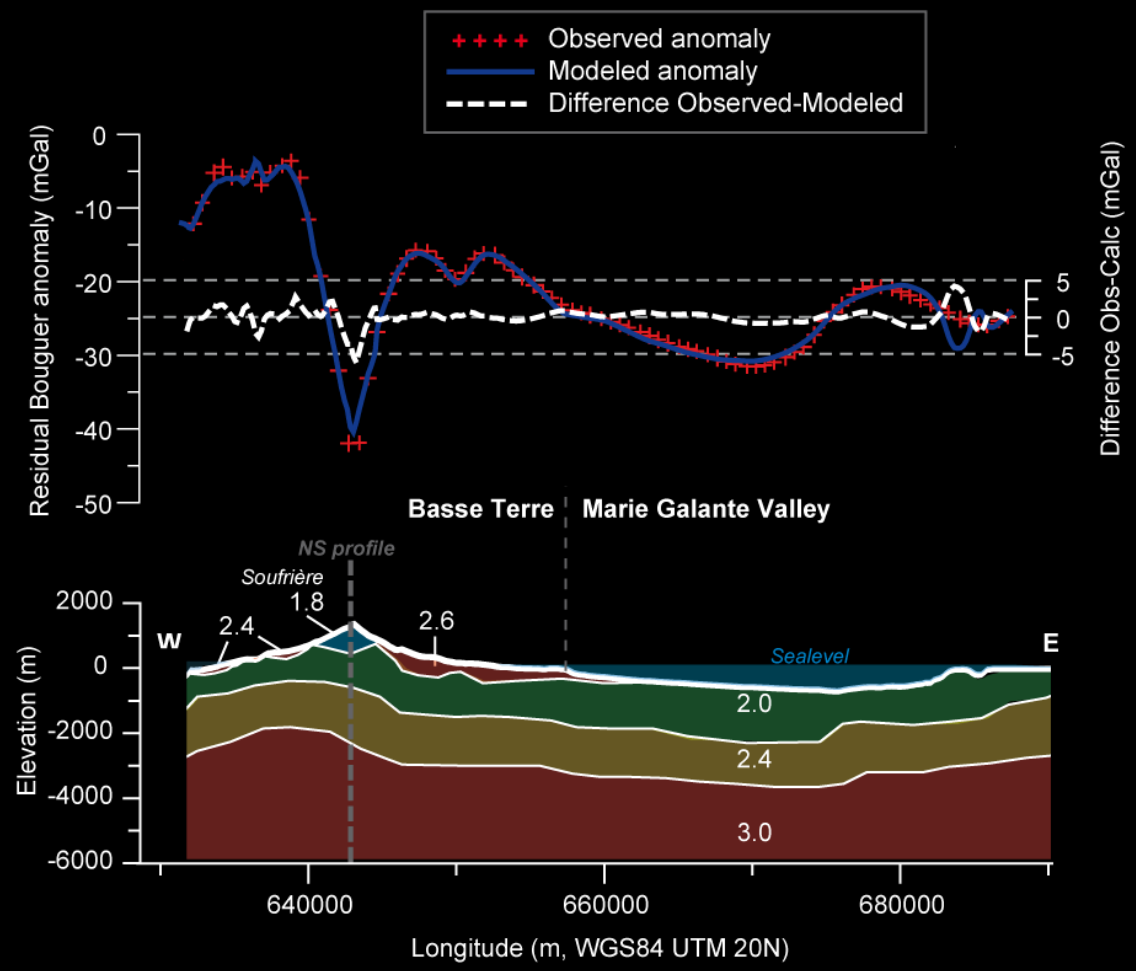
Quantitative Intepretation





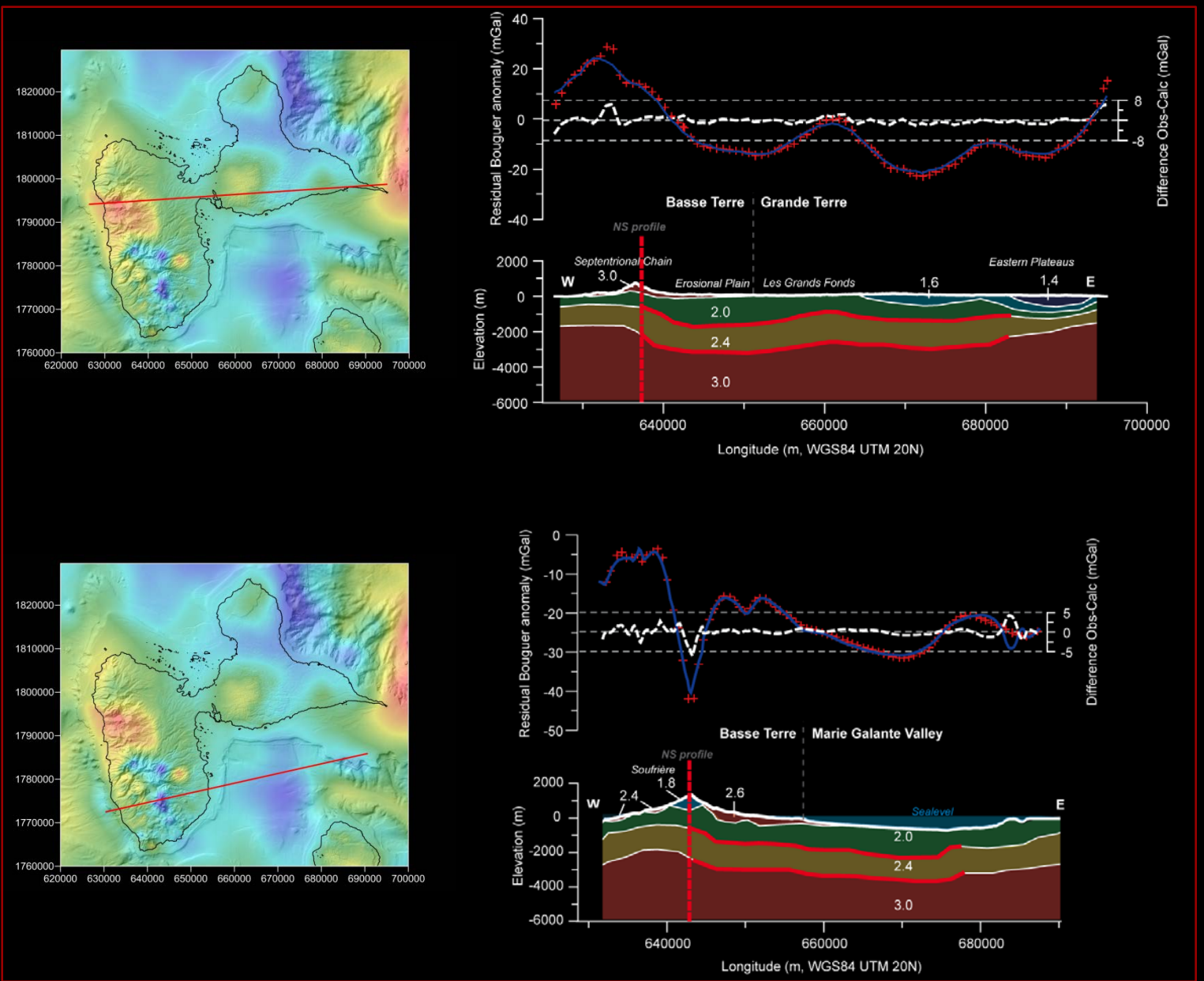
Quantitative Intepretation





➢ Active volcano modeled as a low dense & demagnetized structure (0 A m^{-1}) reliable to the volcanic activity and the presence of the hydrothermal system

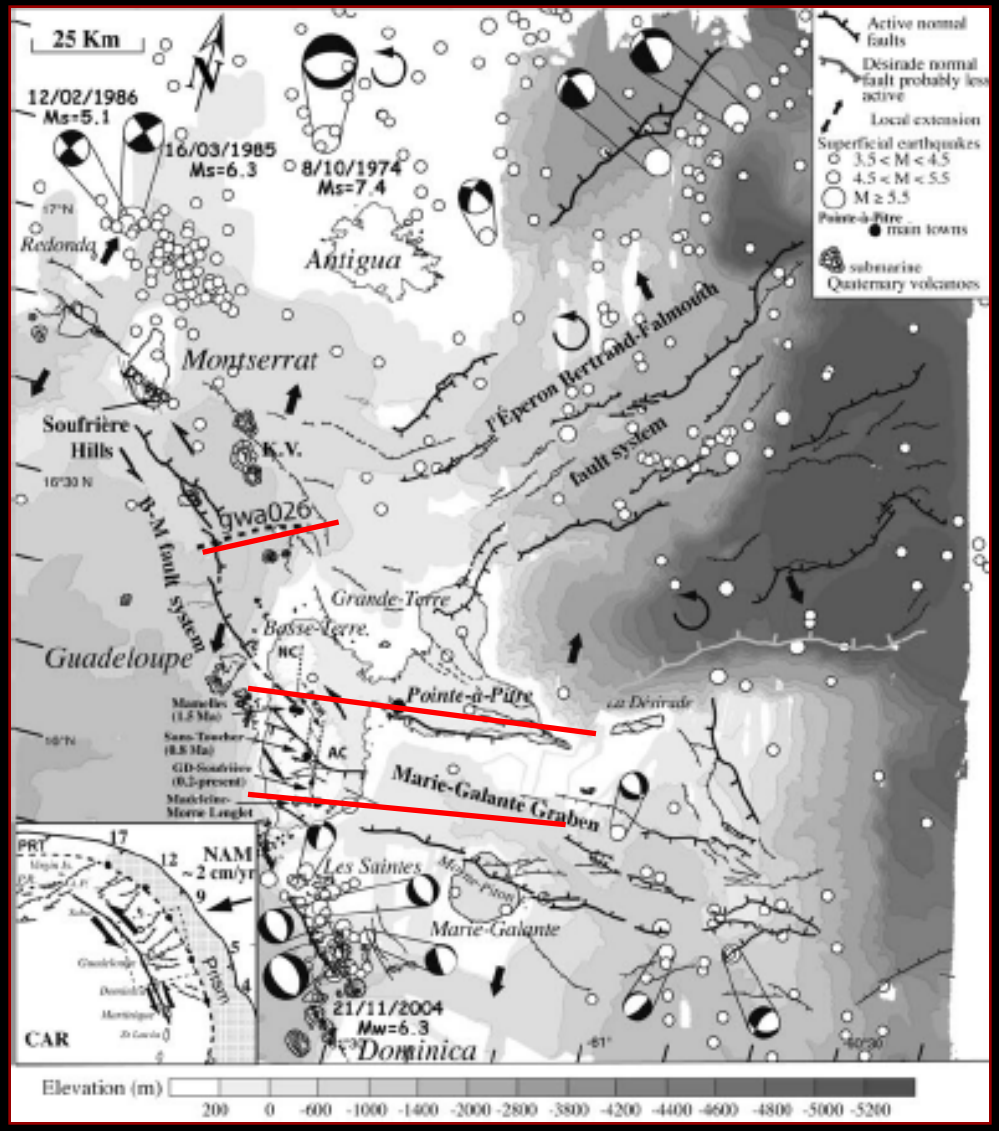
Quantitative Intepretation



Quantitative Intepretation

- Depressed structure at the base of the island (gravity, magnetism, seismic data)

- Similar depressed structure to the N according to bathymetric and seismic studies *(Feuillet et al., 2010)*



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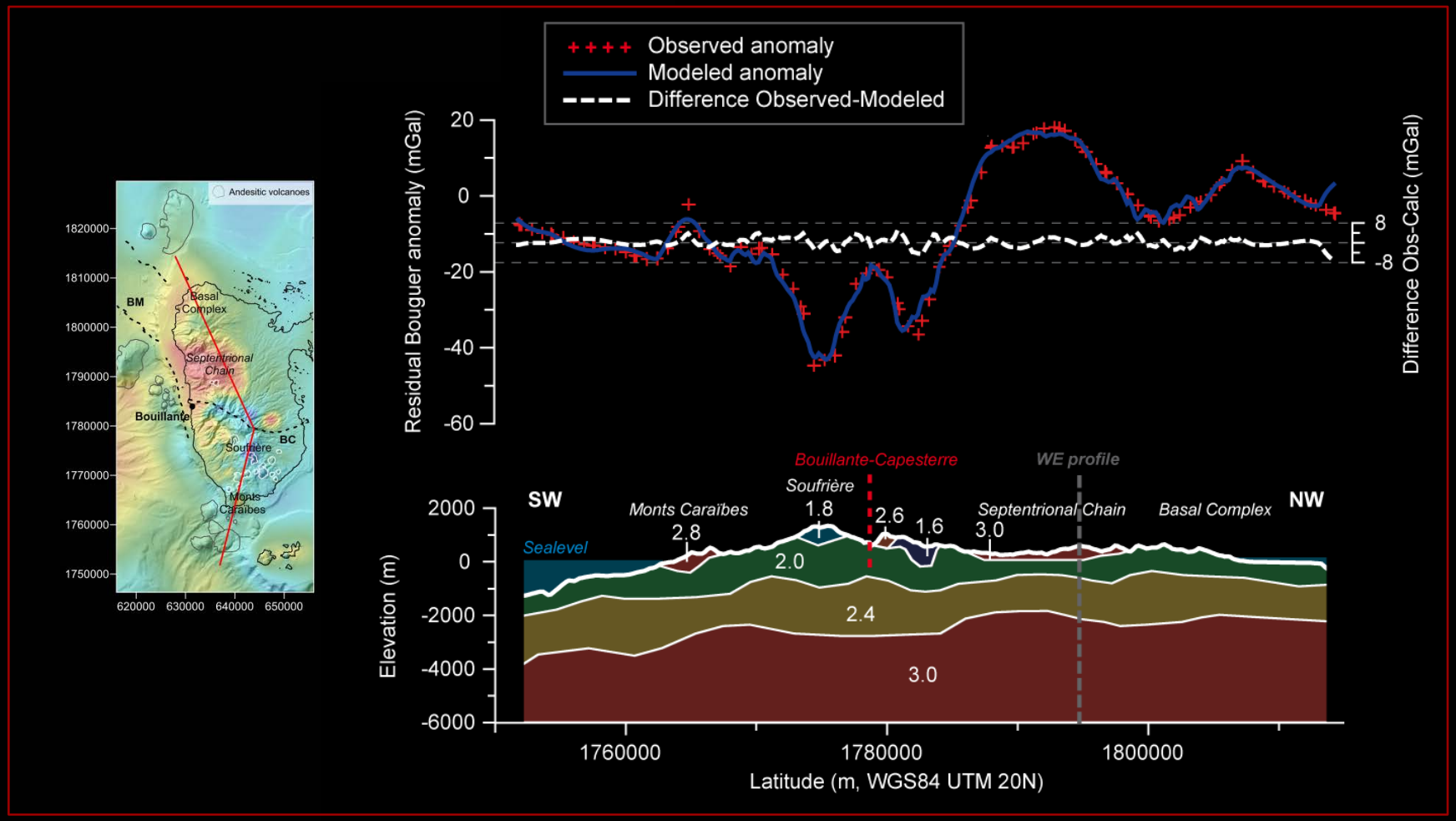


- Long λ gravity signal fairly consistent with the overall geometry of the seismic refraction model where the model cross-cuts the 2 seismic lines *(Dorel et al., 1979)*
- Shallow density contrasts : geological formations recognized in surface

Synthesis and Conclusions

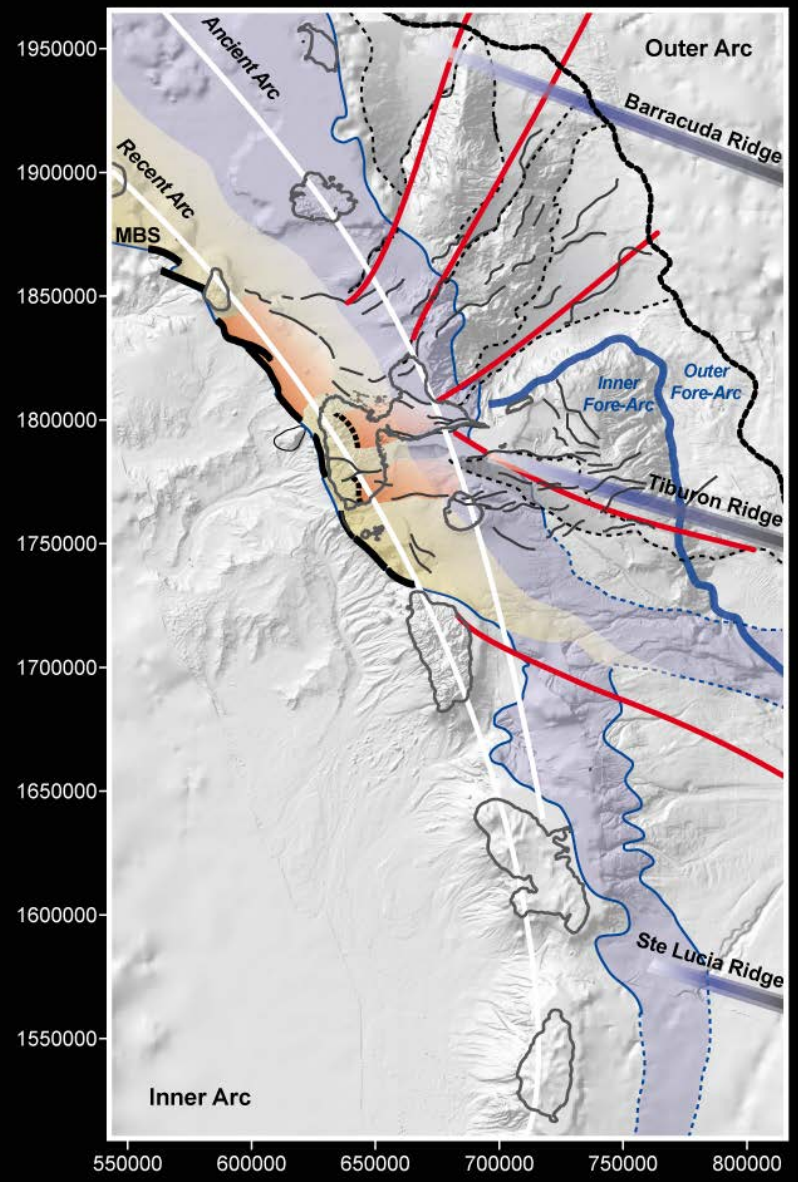
Synthesis

- **Imbricate dual two scale analysis of the main gravity and magnetic anomalies :**

  ⇨ General structural scheme of the Lesser Antilles Arc

  ⇨ More locally of Guadeloupe Island

Synthesis



Structures known from previous studies

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- Montserrat-Bouillante-Les Saintes (MBS) fault system [from *Feuillet et al.*, 2010; *Calcagno et al.*, 2011]
- Main regional tectonic features [from *Feuillet et al.*, 2001; 2010]
- Fracturation evidenced in bathymetric and seismic studies, coherent with gravity and magnetic anomalies [from *Feuillet et al.*, 2001; 2010, and this study]
- Limit between an Inner Fore-Arc and an Outer Fore-Arc from 3D seismic refraction tomography [from *Evain et al.*, 2011]
- Barracuda, Tiburon and Ste Lucia Ridges [from *Andreieff et al.*, 1989]

Structures inferred from the geophysical anomalies interpretation [this study]

- Fracturation and deformation affecting primarily the upper plate, coherently inferred from gravity and magnetic qualitative interpretation
- Eastern limit of the fan-shaped deformation of the upper plate
- Main area of subsidence of the upper plate including:
  - an central arc-parallel component (N160°E)
  - an abnormal transverse component (N130°E) to the ESE
- Present-day active front of deformation inferred from :
  - gravity modelling
  - bathymetric and seismic studies [from *Feuillet et al.*, 2010]
- Front of deformation within the Caribbean plate, outlined by the MBS to the north and parallel to the Atlantic oceanic ridges to the SE

Conclusions

- **Large scale geophysical approach**
  - An unique dataset to address the structure and evolution of the arc as a whole
  - New additional constrains to understand this complex volcano-tectonic system
    - ⇨ *No unambiguous interpretations of the volcano-tectonic features*
    - ⇨ *Complexity of the arc, especially at the scale of Guadeloupe Archipelago*

Conclusions

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    - ⇨ *Complexity of the arc, especially at the scale of Guadeloupe Archipelago*

- **Regional image of the structure of the Lesser Antilles Arc**
  - Consistent with a more local assessment of the internal structure of Guadeloupe Island
  - New hypothesis concerning the tectonics and deep structure of the arc
    - ⇨ *Inheritance of the lithospheric structure in the island evolution?*
    - ⇨ *Role of the main bathymetric ridges within the subduction ?*

Conclusions

- **Large scale geophysical approach**
  - An unique dataset to address the structure and evolution of the arc as a whole
  - New additional constrains to understand this complex volcano-tectonic system
    - ⇨ *No unambiguous interpretations of the volcano-tectonic features*
    - ⇨ *Complexity of the arc, especially at the scale of Guadeloupe Archipelago*

- **Regional image of the structure of the Lesser Antilles Arc**
  - Consistent with a more local assessment of the internal structure of Guadeloupe Island
  - New hypothesis concerning the tectonics and deep structure of the arc
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    - ⇨ *Role of the main bathymetric ridges within the subduction ?*

- **Guadeloupe Island:**
  - Detailed analysis of each area of interest
  - Ascertain the origin and the nature of the different formations at depth

Thank you for your attention