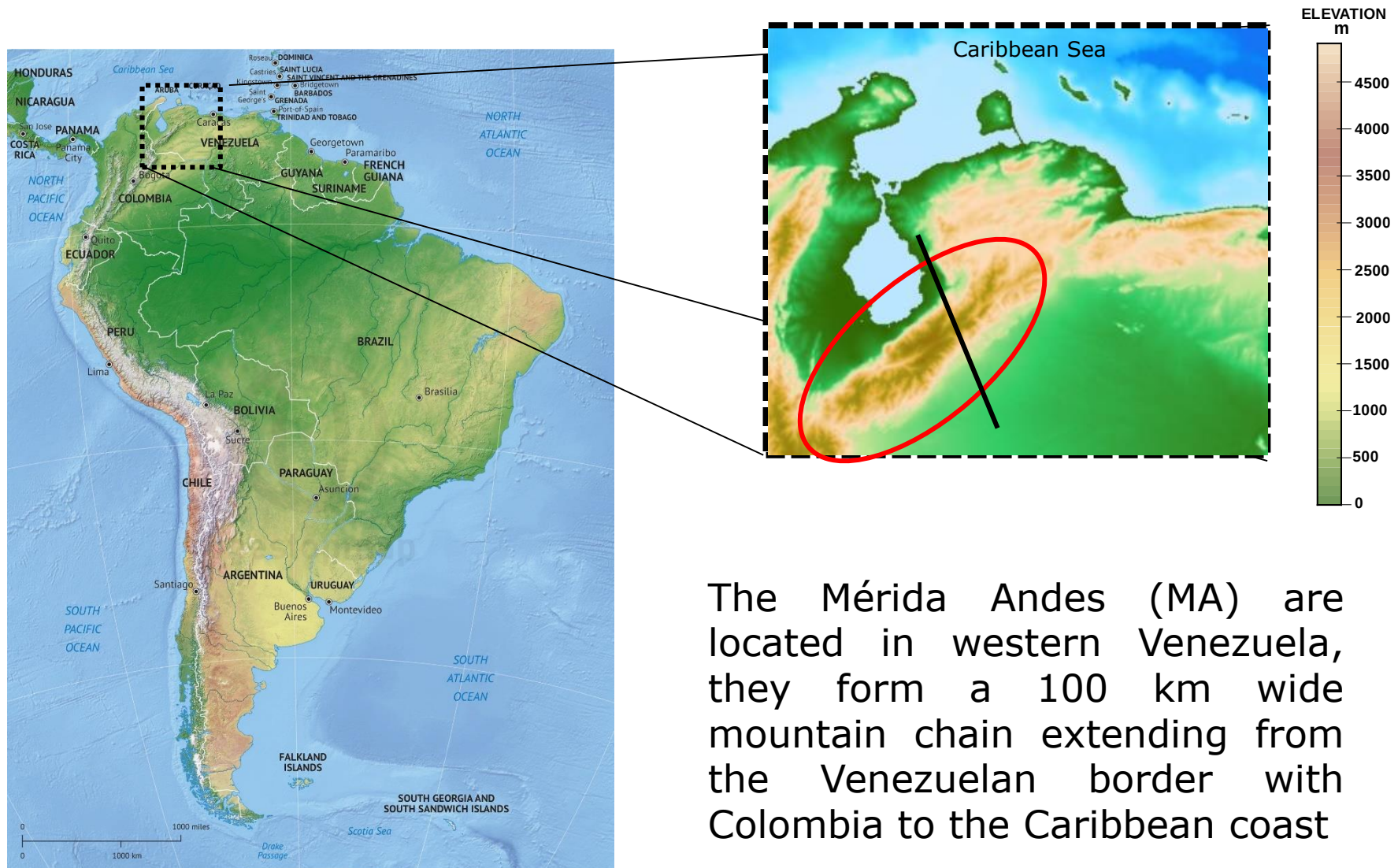


Conductive anomalies related to the Mérida Andes derived from the 3D inversion of a magnetotelluric profile

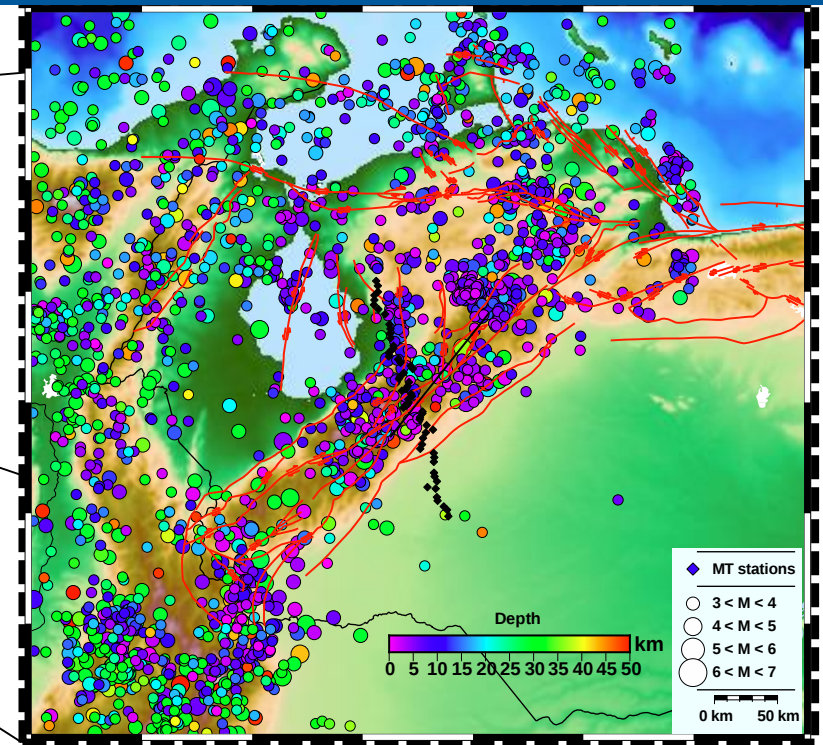
J. Cruces-Zabala ^{1,2,3}, O. Ritter ^{1,3}, U. Weckmann ^{1,4}, K. Tietze ^{1,3}
and M. Schmitz ²

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2. FUNVISIS Venezuelan Foundation for seismological Research, Caracas, Venezuela
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4. Institute of Earth and Environmental Science, University of Potsdam, Potsdam, Germany



The Mérida Andes (MA) are located in western Venezuela, they form a 100 km wide mountain chain extending from the Venezuelan border with Colombia to the Caribbean coast

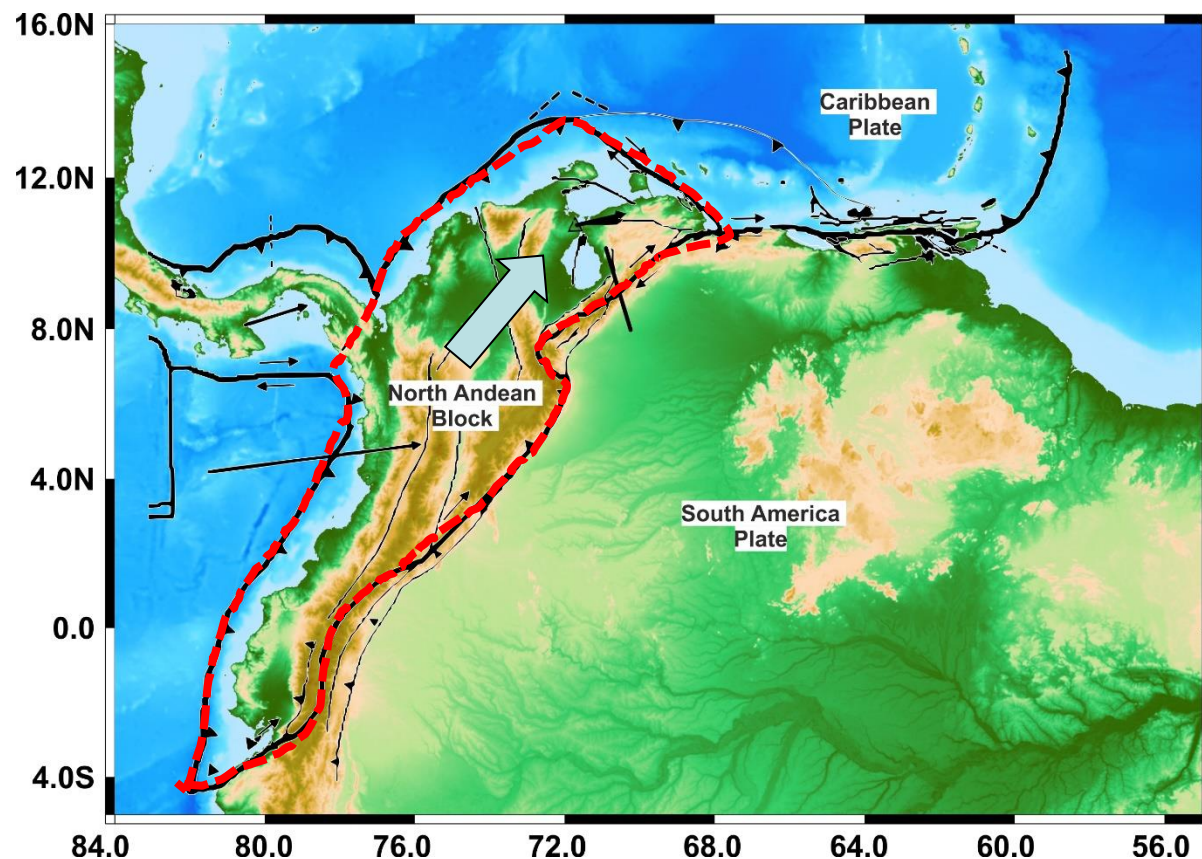
- Black line indicates the position of our profile
- Red ellipse marks the location of the Mérida Andes



The MA are in one of the most sismogenically active zones in Venezuela. Most earthquakes' hypocenters are crustal. Yet, deep structures under the MA have not been imaged by geophysical methods, and the tectonic processes controlling the geodynamics are still in dispute

- Map of shallow earthquakes (above 50 km depth) in western Venezuela. Red lines indicate the location of the Quaternary fault systems (after Audemard, 2000). Earthquakes from 1970 to present (database FUNVISIS, personal comm.).

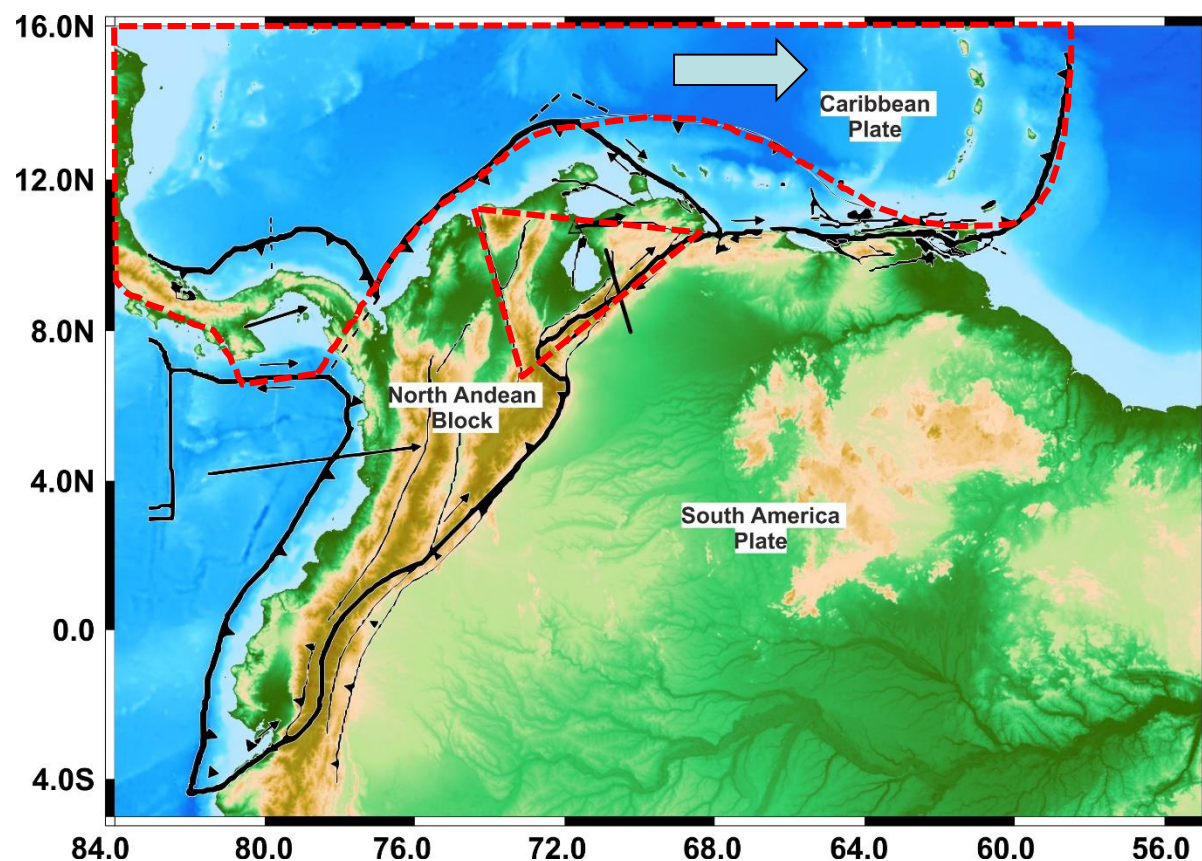
Tectonic settings



- The geodynamics in western Venezuela are dominated by the interaction of the different blocks controlled by the eastward movement of the Caribbean plate and the escape of the North Andean Block (NAB) and the South American plate

Black lines represent structure boundaries after Perez et al. (2018)

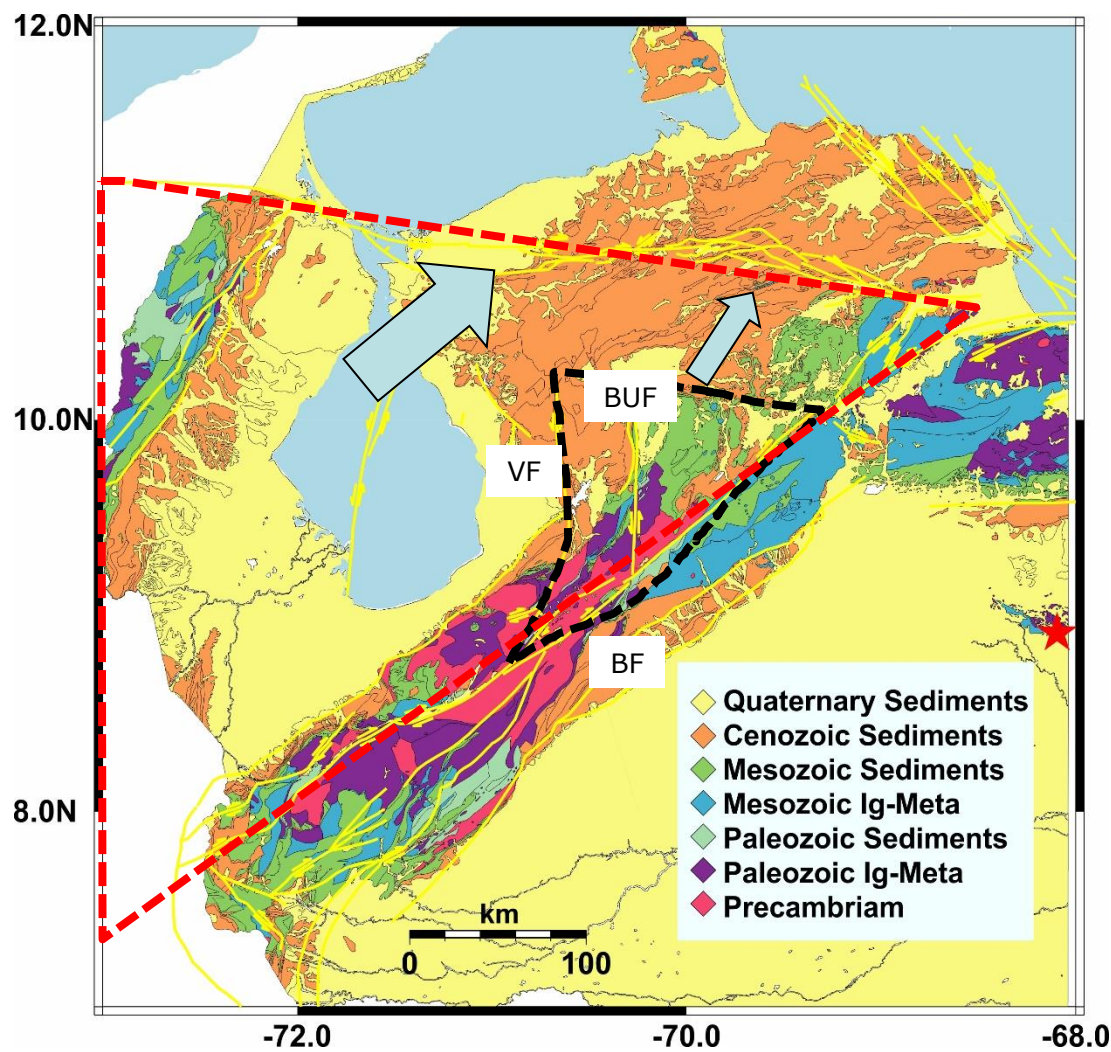
Tectonic settings



- The interaction of these major plates fosters the partition of the NAB into several sub-blocks. Among them The Maracaibo Block (red triangle) has played a key role in the uplift of the MA
- These tectonic processes caused the formation of several strike-slip deep reaching fault systems

Black lines represent structure boundaries after Perez et al. (2018)

Geological settings

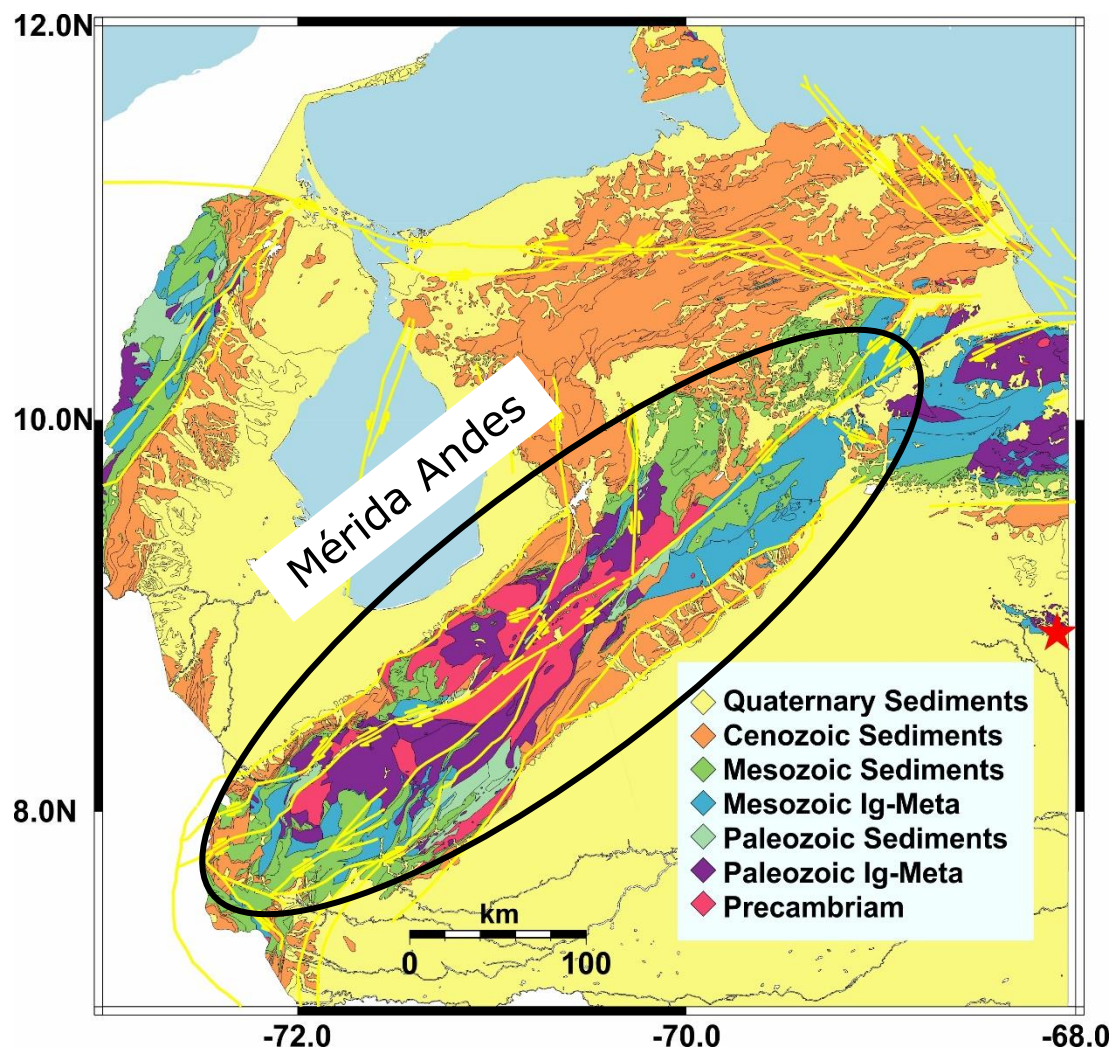


- The different fault systems in the area resulted in the partition of the Maracaibo Block along the Valera and Boconó Fault systems, producing the Trujillo block, among others.
- The tectonic escape of the Trujillo block may create the space for deep fluids, related to the subduction of the Caribbean plate, to rise to the upper crust and flow along the deep reaching faults of the MA

- VF – Valera fault
- BF – Boconó fault
- BUF – Burbusay fault

Yellow lines indicate location of fault systems (after Audemard et al., 2000);
Geology map edited from Hackley et al. (2006) and Urbani (2017)

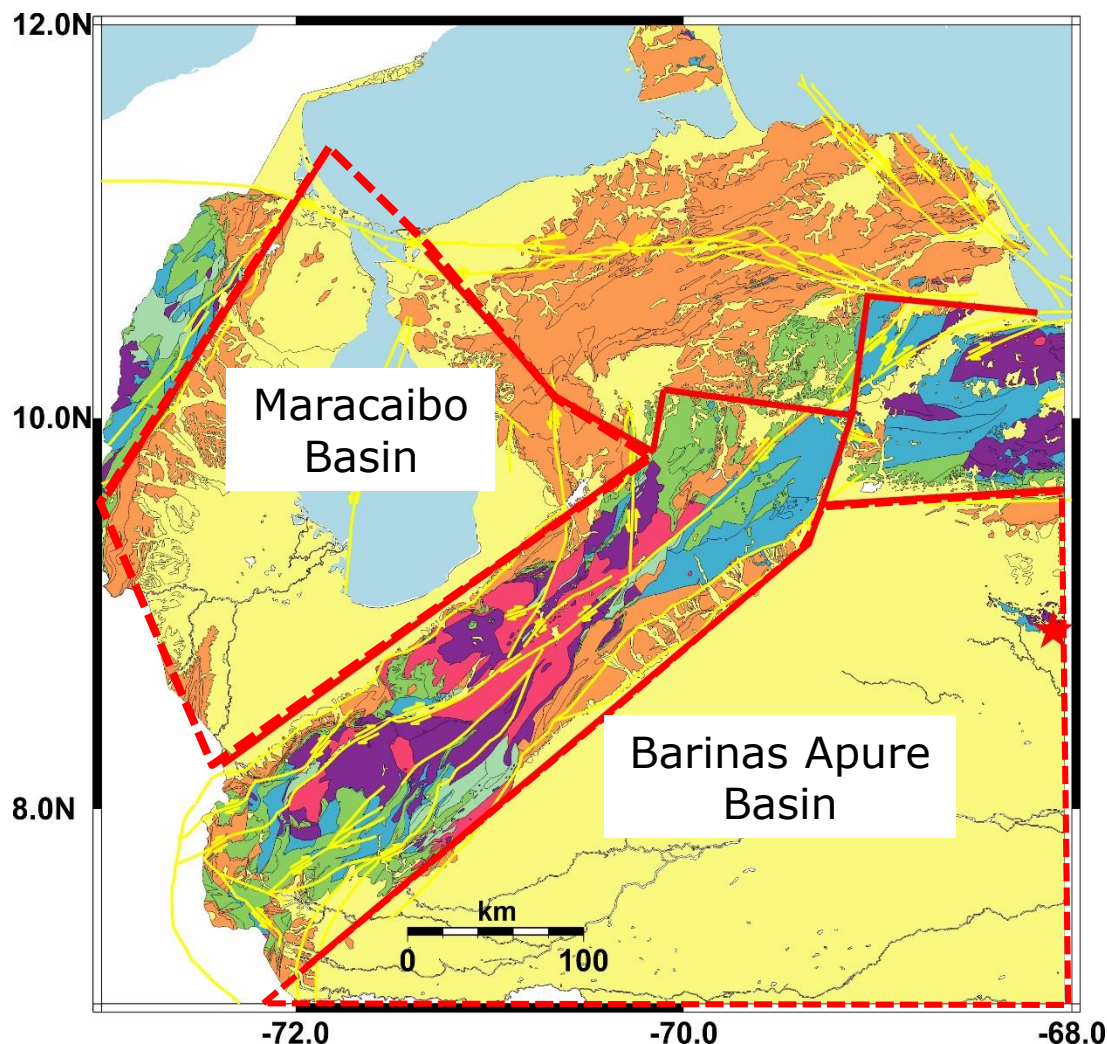
Geological settings



- The MA are the most important orogeny in western Venezuela. Uplift of the MA commenced in the Late Miocene and accelerated during the Plio-Quaternary, exposing crystalline and metamorphic rocks of Precambrian to Paleozoic age in the central part of the MA

Yellow lines indicate location of fault systems (after Audemard et al., 2000);
Geology map edited from Hackley et al. (2006) and Urbani (2017)

Geological settings

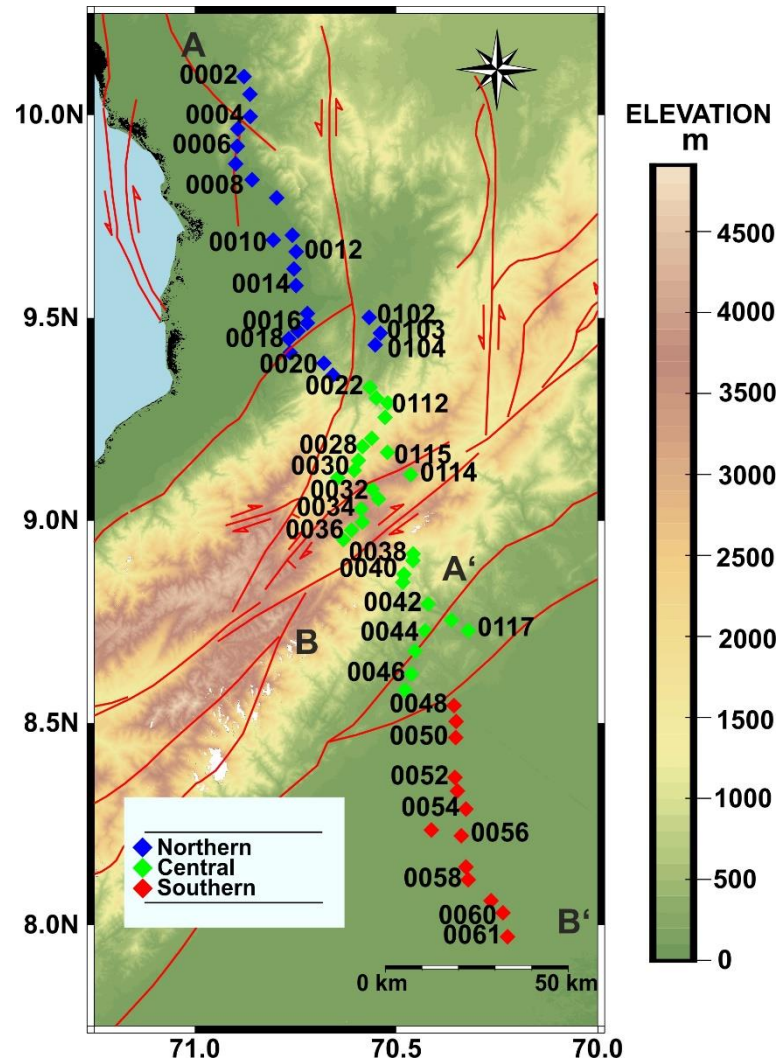


- Uplift of the MA, separated the Maracaibo (MB) and Barinas-Apure (BAB) basins, and subsequent erosion filled them with Neogene to Quaternary sediments.
- The MB is an asymmetric trough that contains up to 12 km of carbonates and shale of late Cretaceous to Eocene age (De Toni & Kellogg, 1993).
- The stratigraphic section of the BAB basin comprises as much as 5 km of Aptian through Pleistocene sediments (Callejón & von der Dick, 2002).

Yellow lines indicate location of fault systems (after Audemard et al., 2000); ,
Red lines mark the boundaries of surface structures (after Urbani, 2017)

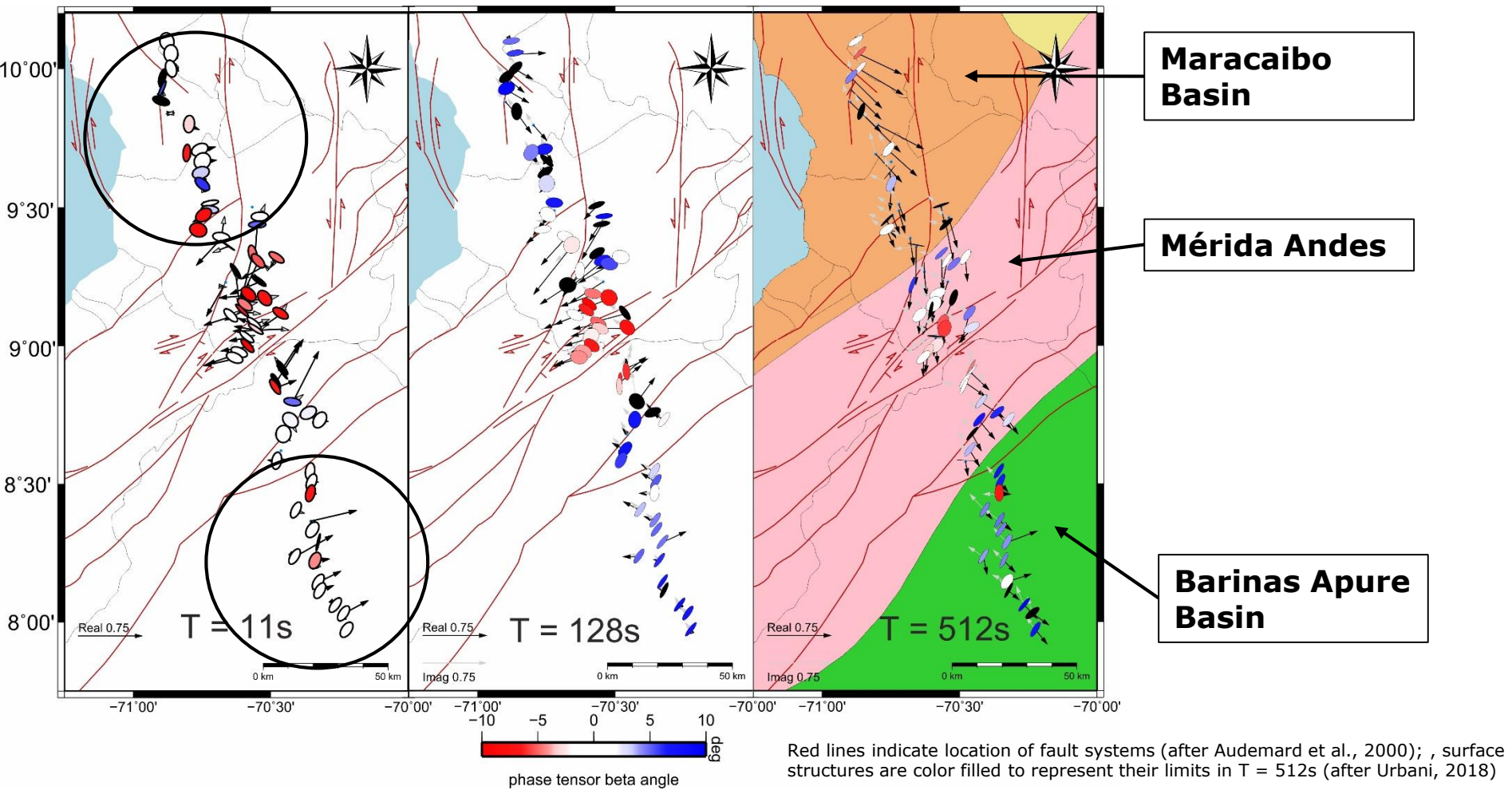
The Venezuelan MT dataset

- 72 MT stations along a 240 km-long profile
- 5 component MT data stations with 3 to 5 km spacing
- 3 days per site and sampling rates of 25 kHz (10 min/day) – 1250 Hz (10 min/2h) -50 Hz (continuous), using S.P.A.M. Mk IV instruments of the Geophysical Instrument Pool Potsdam.
- RR located 300 km east of the profile
- The MT transfer functions were estimated using robust single site and remote reference processing routines of the EMERALD software package (Ritter et al., 1998; Weckmann et al., 2005; Krings, 2007)
- Data quality could be further improved by using a frequency domain selection scheme (Weckmann et al., 2005) and a novel statistical approach for data pre-selection employing the concept of the Mahalanobis distance and the magnetic polarization direction to remove outliers and EM noise (Platz & Weckmann, 2019).



Dimensionality analysis

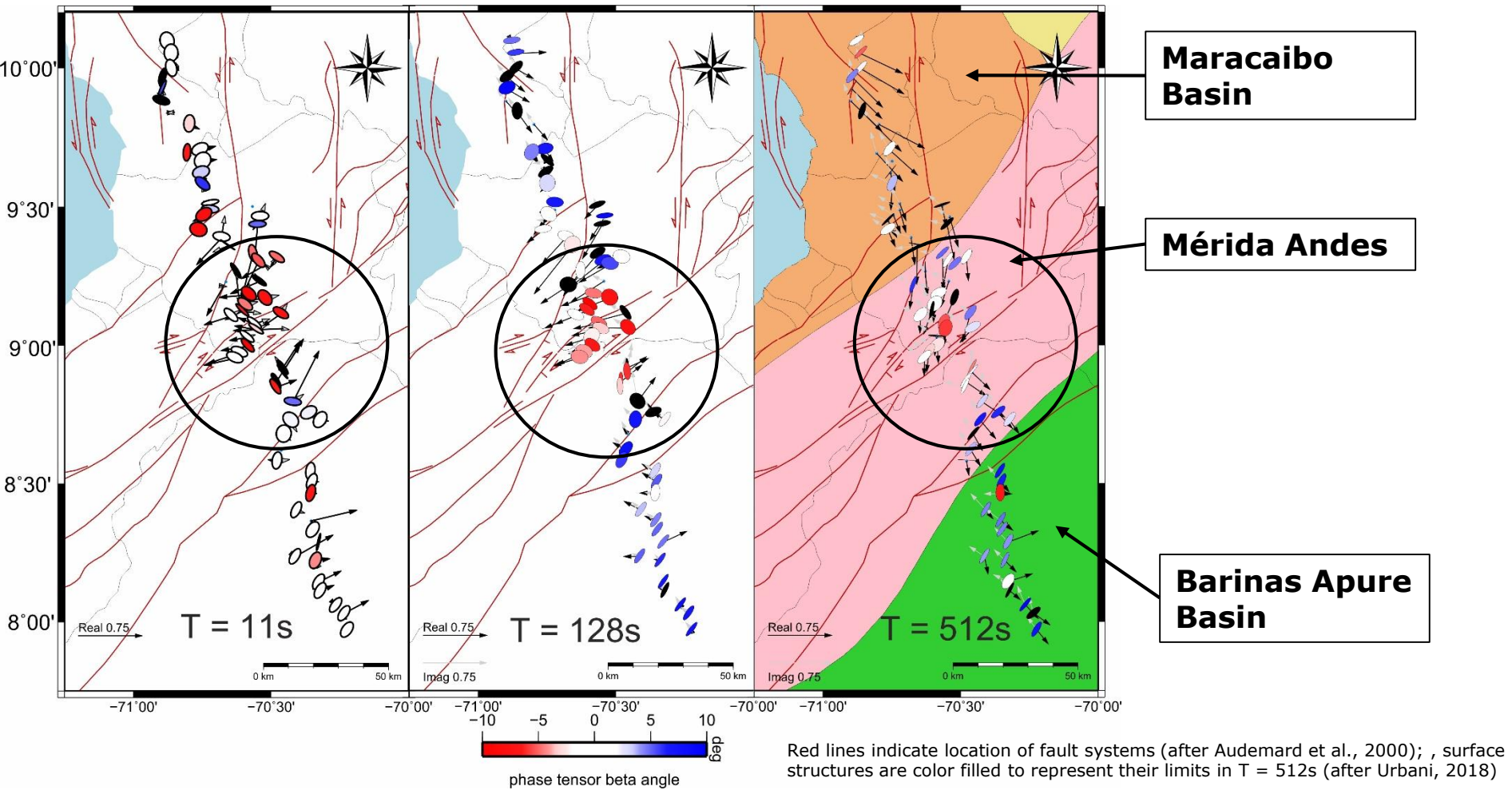
Phase tensor (Caldwell et al, 2004. Skew values above 3° are considered 3D) and Induction vectors in Wiese convention (pointing away from conductors)



Phase tensor skew angles show that at low periods data is still 2D on the northern and southern part of the profile above the sedimentary basins. They are accompanied by small induction vectors. The complexity of the data increase with period.

Dimensionality analysis

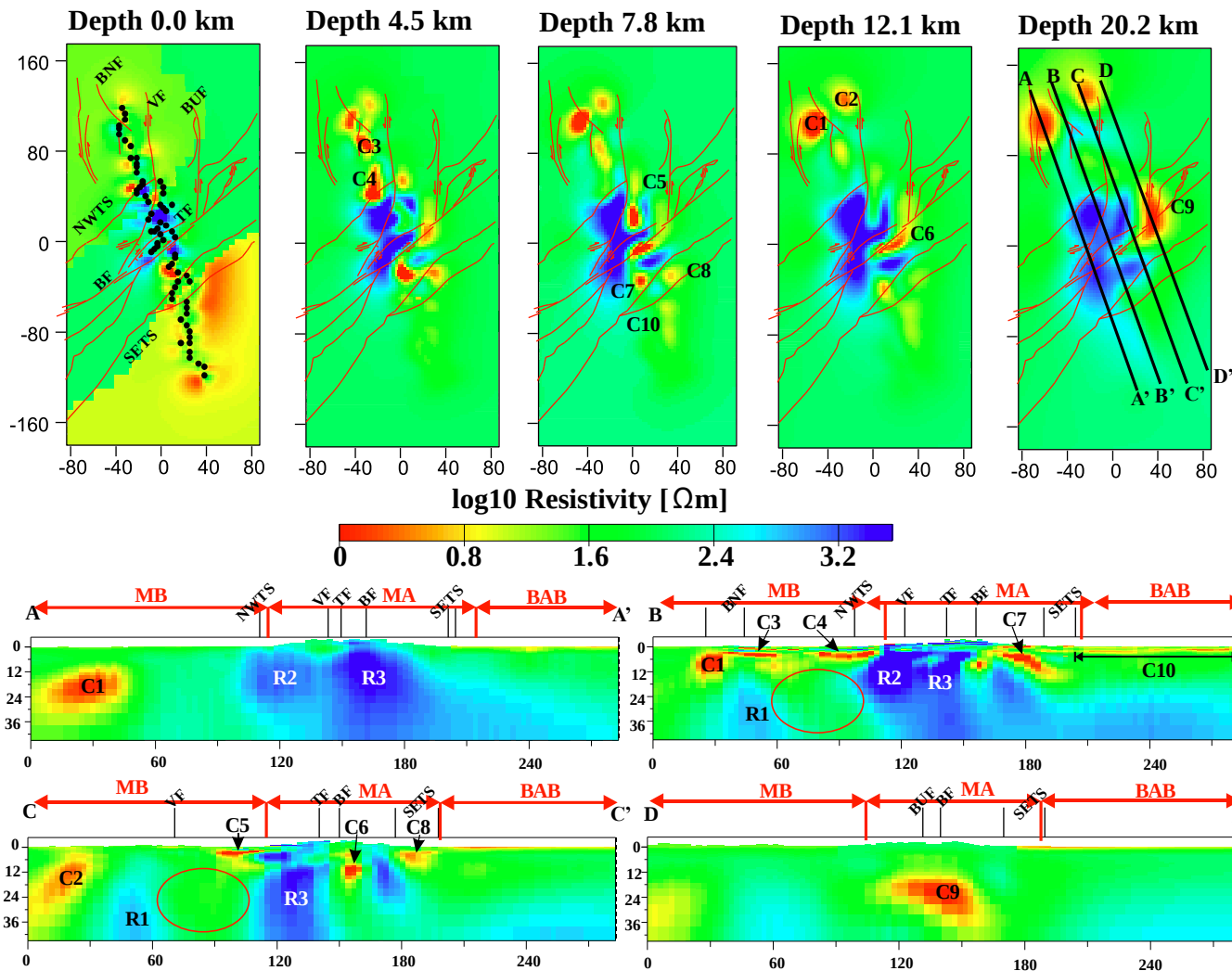
Phase tensor (Caldwell et al, 2004. Skew values above 3° are considered 3D) and Induction vectors in Wiese convention (pointing away from conductors)



Red lines indicate location of fault systems (after Audemard et al., 2000); , surface structures are color filled to represent their limits in $T = 512s$ (after Urbani, 2018)

- Phase tensors show 3D dimensionality for the central part of the profile. Induction vectors in this area locate an off profile conductor east to the profile.
- Dimensionality analysis reveal that sections of the data can be 2D approximated, yet there are structures that can only be interpreted by 3D inversion approach.

3D inversion



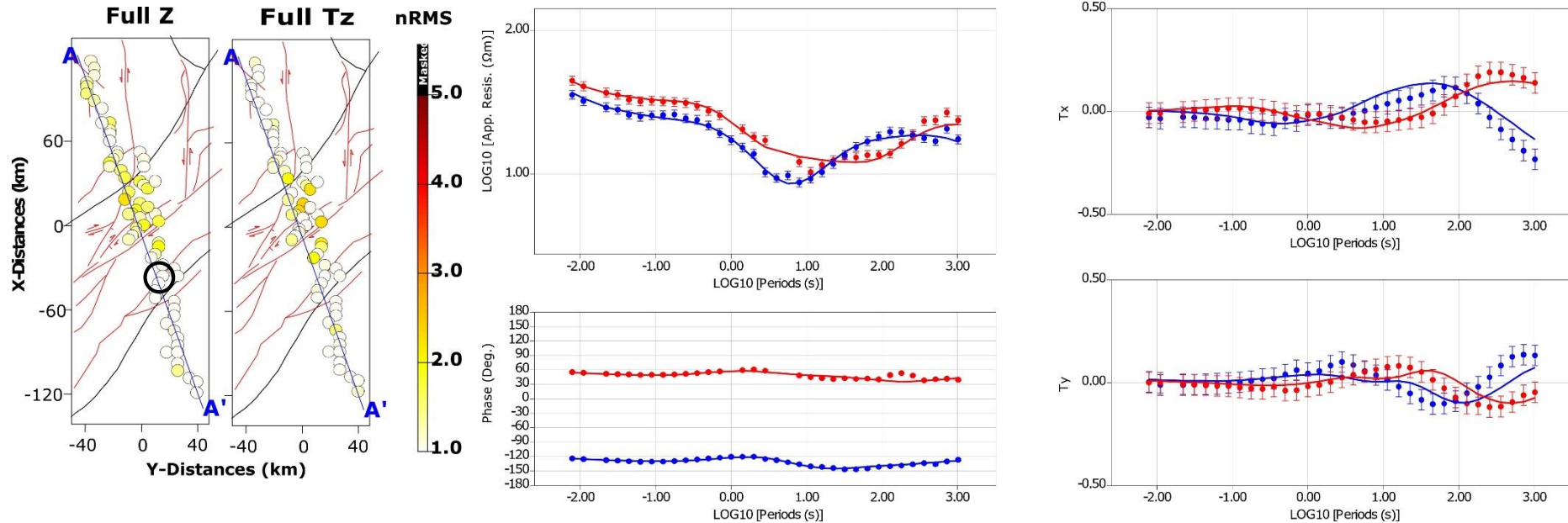
The constrained model

- The initial model for the inversion included known surface structures, and their resistivities were taken from the average of the apparent resistivity of the station above them. Resulting on 25 Ωm and thickness of 10 km for the Maracaibo basin and 15 Ωm and 5 km thickness for the Barinas-Apure basin. The Background resistivity was 120 Ωm , and included the Mérida Andes.

Red lines indicate location of fault systems, black lines the boundaries of the surface structures (after Audemard et al., 2000; Urbani, 2018)

3D inversion

Station 43



- Total RMS = 1.24
- Total Z = 1.26
- Total T = 1.19
- 91 iterations
- Initial RMS 11.76

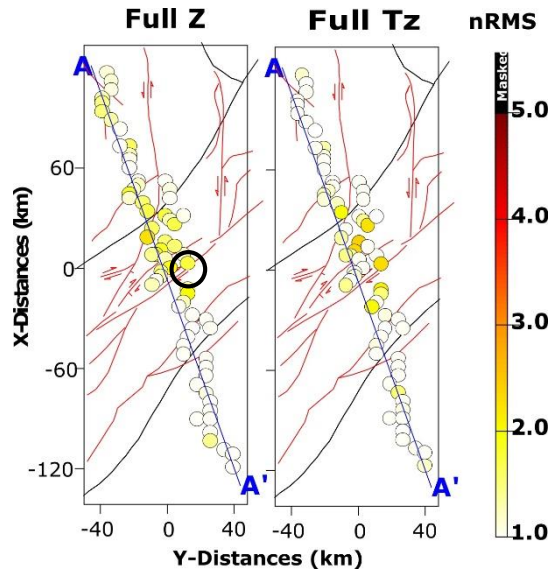
- Total RMS = 0.77
- Total Z = 0.78
- Total T = 0.77

• measured
— predicted

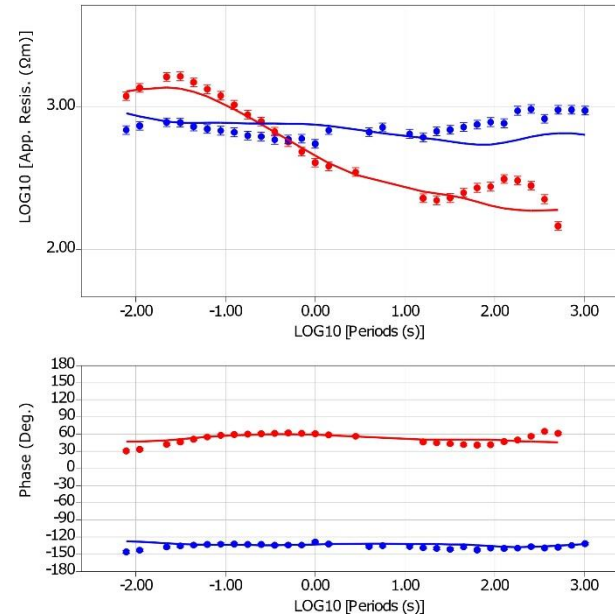
Zxy Zyx
Im Re

3D inversion

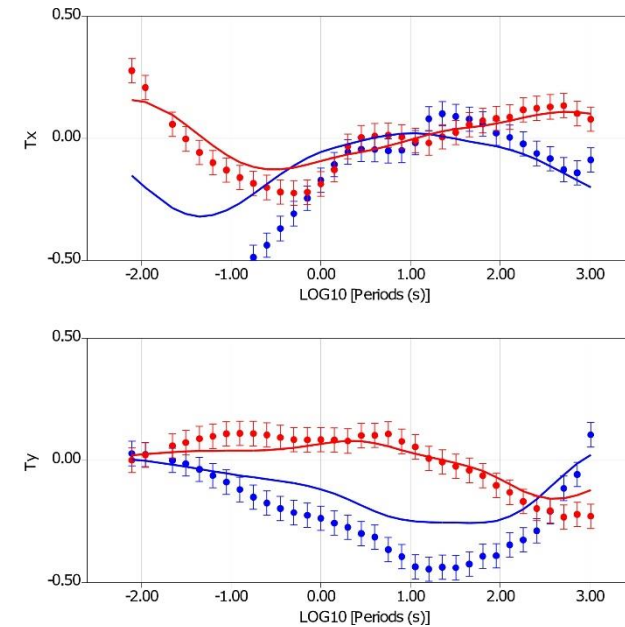
Station 116



- Total RMS = 1.24
- Total Z = 1.26
- Total T = 1.19
- 91 iterations
- Initial RMS 11.76



- Total RMS = 2.00
- Total Z = 1.75
- Total T = 2.34

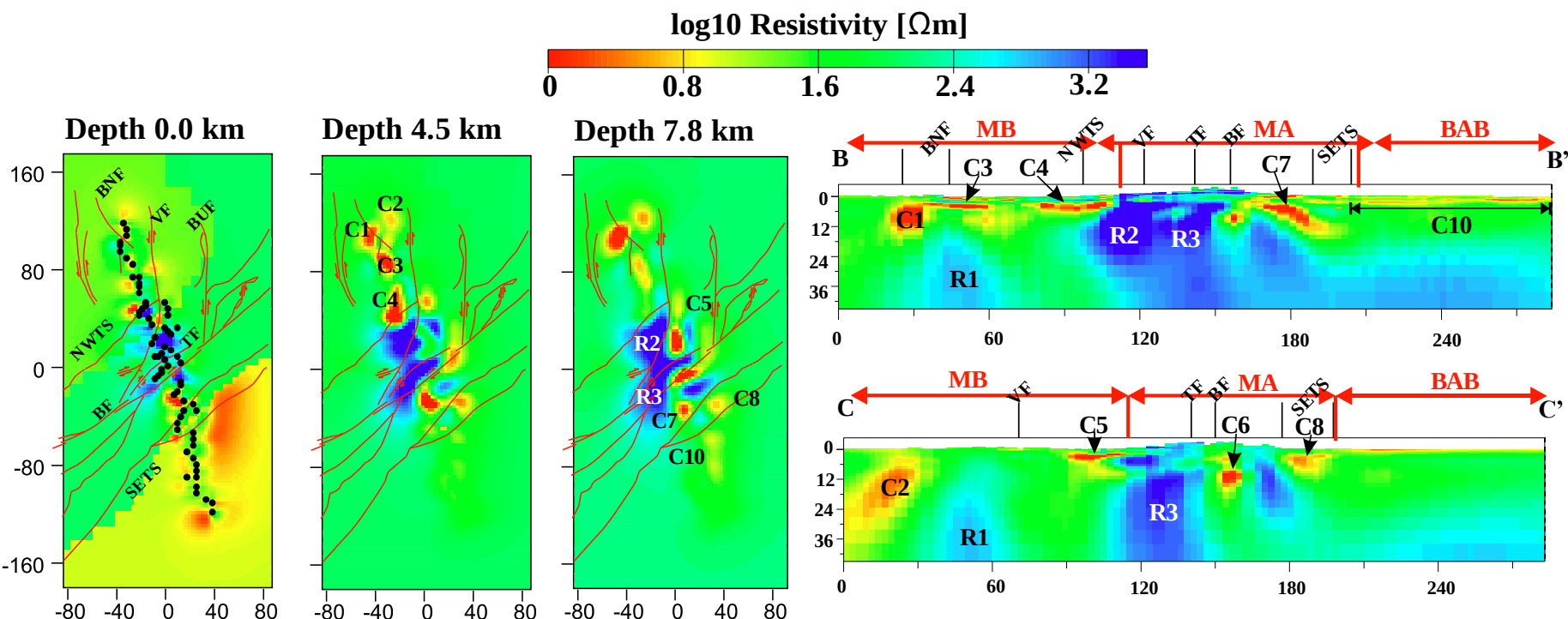


- measured
- predicted

Zxy Zyx

Im Re

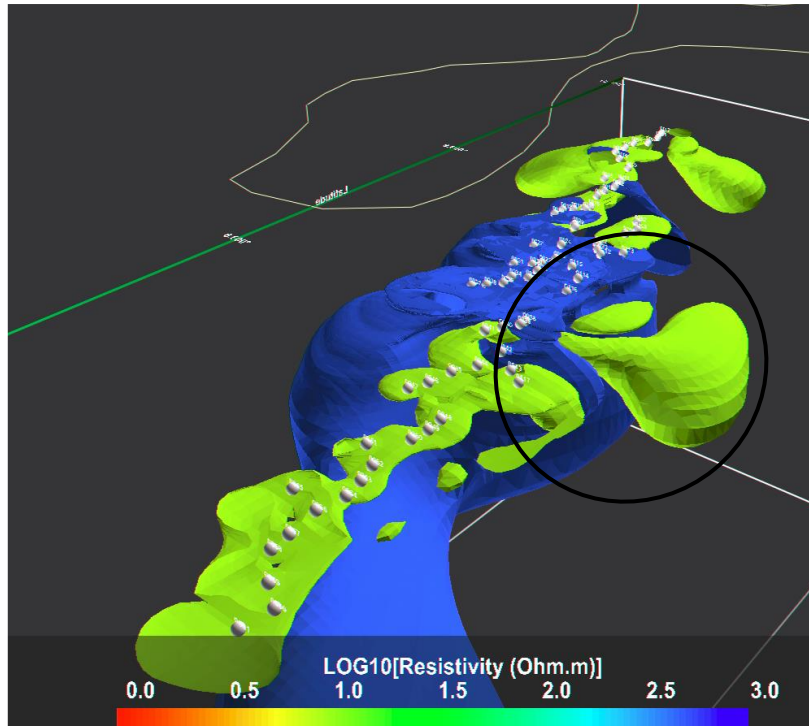
Surface structures



- The MB seems to be represented by conductors C1-C4, with their deeper extent corresponding with the location of several fault systems in surface (e.g. C1 – BNF, C4 – NWTs). The resistivity of the conductors is in the range of sedimentary rocks and the maximum depth of the basin (10 km) is consistent with its reported depth (Escalona & Mann, 2003, 2006a).
- The MA is recovered as two big resistors (R2 and R3) extending laterally to west, these resistor are limited to the east by the VF (C5) and split by the BF (C6).
- The conductive anomalies C7 and C8, south to the BF, correspond to the SETs and its associated piggy-back basins filled with Late Miocene - Quaternary molassic deposits, respectively.
- The BAB correlates in surface with the C10 with a maximum depth of 5 km.
- The low resistivity values observed in the conductive anomalies could also indicate that the fault systems may act as pathways for groundwater. Also, drainage and alluvial deposits are reported along the strike of the BF by Audemard & Audemard (2002).

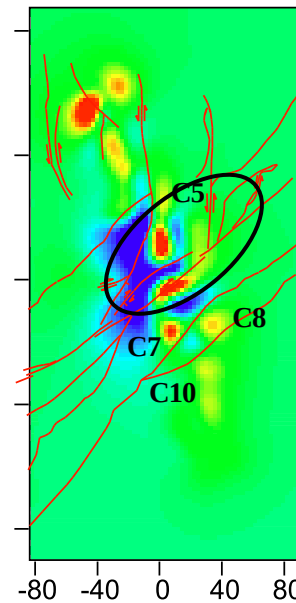
Off-profile conductor

3D resistivity iso-surface at $10\Omega\text{m}$ (green) and $500\Omega\text{m}$ (blue)

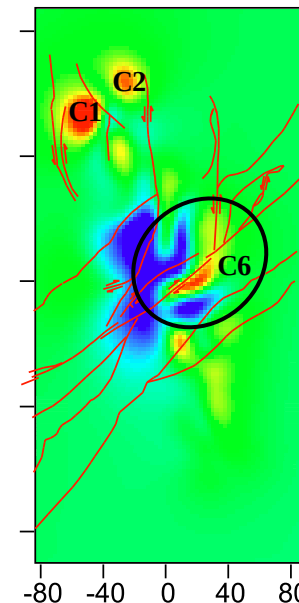


3D inversion depth slices

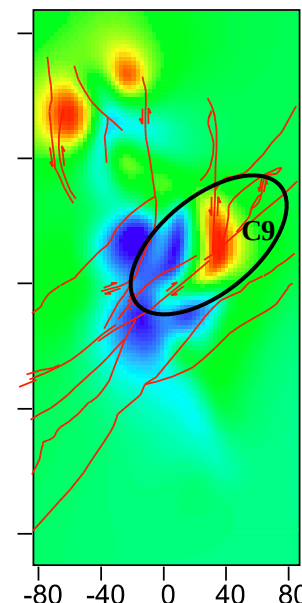
Depth 7.8 km



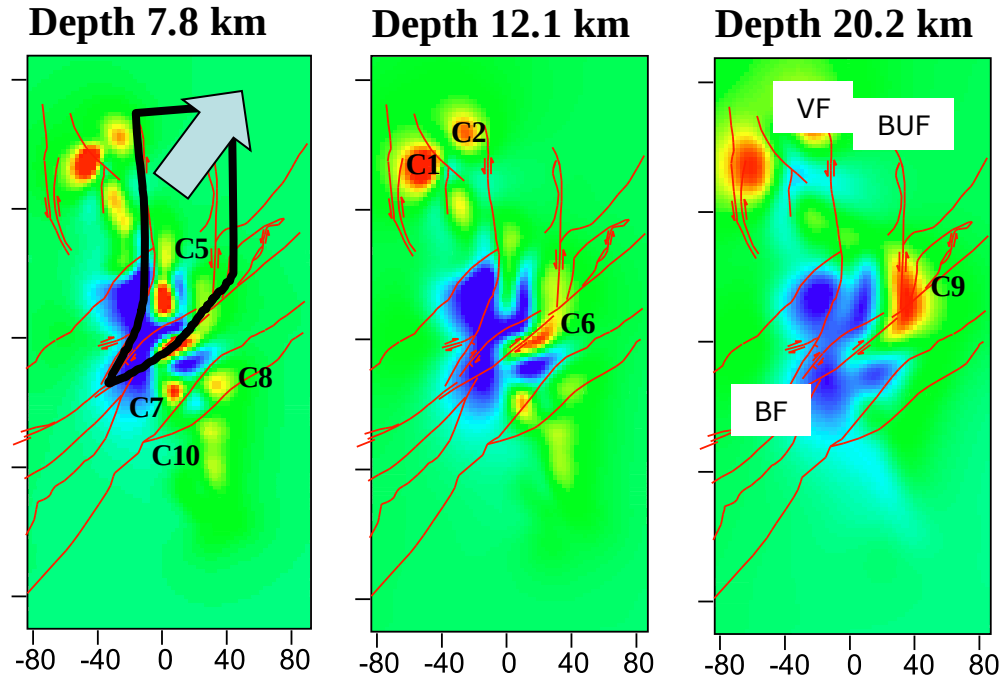
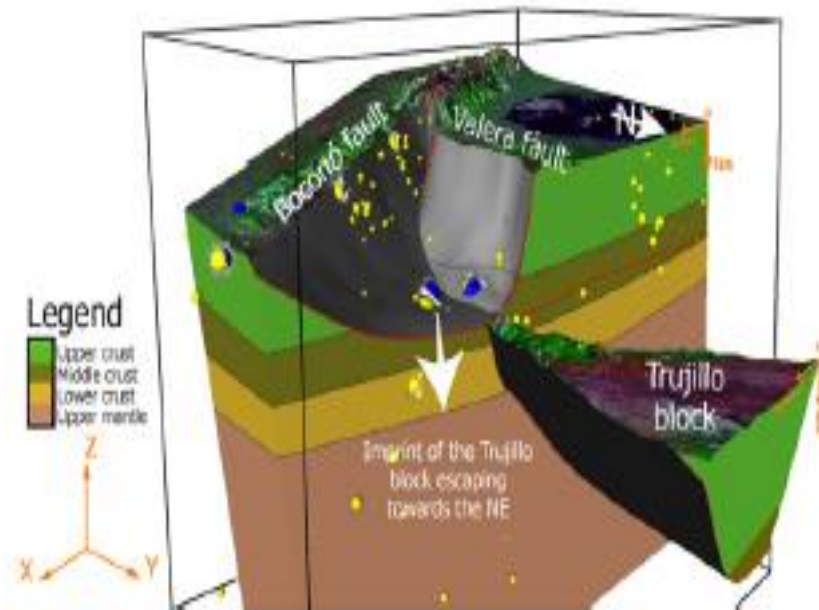
Depth 12.1 km



Depth 20.2 km



Off-profile conductor



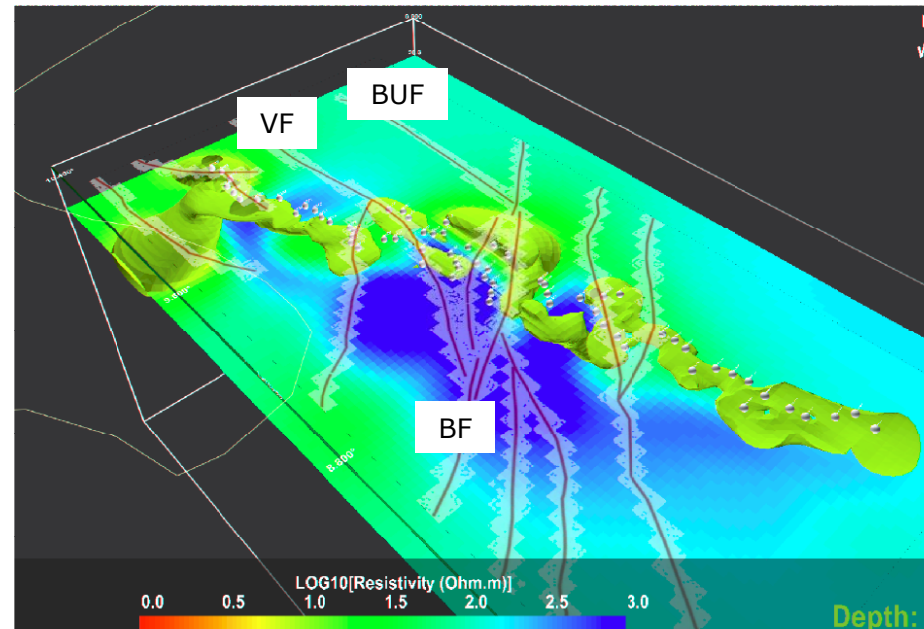
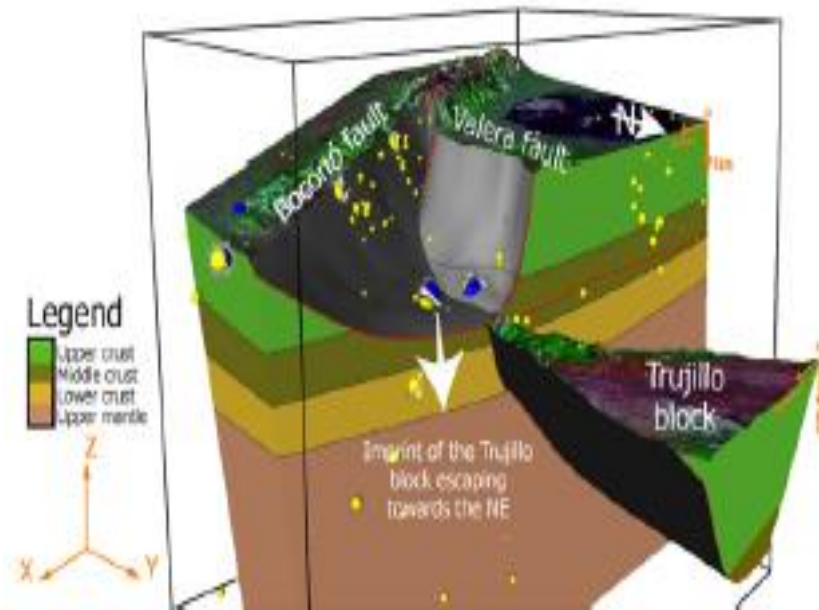
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- VF – Valera fault
- BF – Boconó Fault
- BUF – Burbusay Fault

- This structure is interpreted as the detachment surface of the Trujillo block. Geodynamic modelling place this block between the Valera and Boconó fault systems with a detachment surface at 15 km depth (Dhont et al, 2012).

Off-profile conductor

3D resistivity iso-surface at $10\Omega\text{m}$ (green) against a depth slice at 20 km



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- VF – Valera fault
- BF – Boconó Fault
- BUF – Burbusay Fault

- High conductivity crustal anomalies are often associated to the presence of fluids. The detachment of the Trujillo block could provide a pathway for fluids, which may originate from re-mineralization processes associated with the subduction of the Caribbean plate. Deep reaching fault systems of the area (e.g. the VF and the BF) may even provide pathways for such fluids towards surface.

Thank you for your time



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