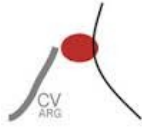


<sup>1</sup>Dublin Institute for Advanced Studies

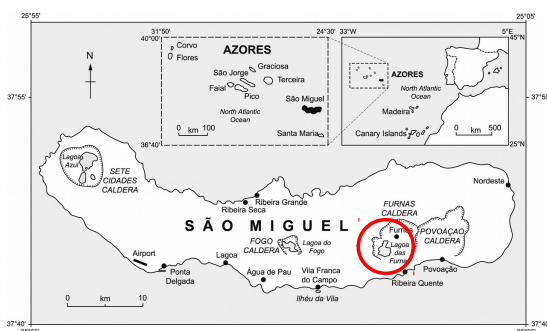
<sup>2</sup>ISterre, Université Savoie Mont Blanc, Chambéry, France

<sup>3</sup>Centro de Vulcanologia e Avaliação de Riscos Geológicos da Universidade dos Açores, Complexo Científico

<sup>4</sup>Centro de Informação e Vigilância Sismovulcânica dos Açores, Complexo Científico



## Azores Archipelago...a brief introduction



### Azores Archipelago:

- 9 volcanic islands
- Triple junction where the Eurasian, the North American, and the Nubian Plates meet!

### São Miguel Island

- 3 volcanic centres:
- Sete Cidades, Fogo and Furnas

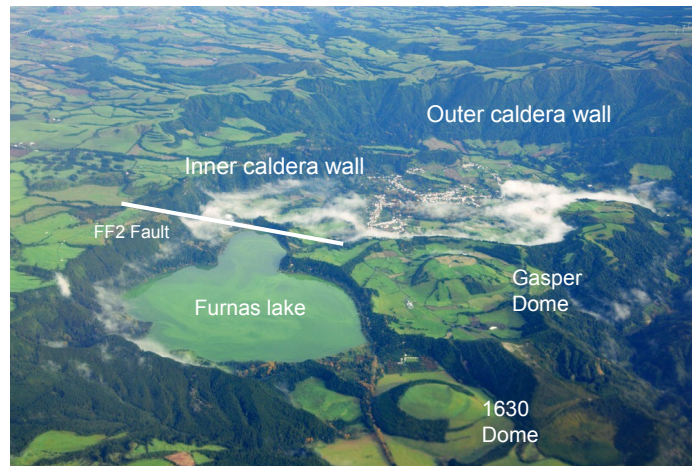
## Furnas Caldera, São Miguel Island

Caldera complex.

Outer caldera 8 x 5 km, and Inner caldera 6 x 3.5 km

WNW-ESE trending dip-slip faulting crosses the volcanic edifice (FF2)

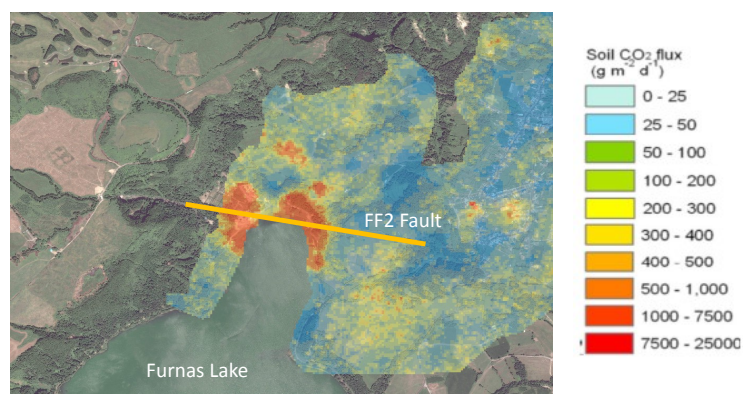
- Two recent big eruptions 1439-43 AD, and 1630 AD produced volcanic domes.



## Furnas Caldera, São Miguel Island

Intensive CO<sub>2</sub> / Radon outgassing.

Geometry and character of the hydrothermal system unknown



(modified after Viveiros *et al.* 2010)

## Scientific Questions...

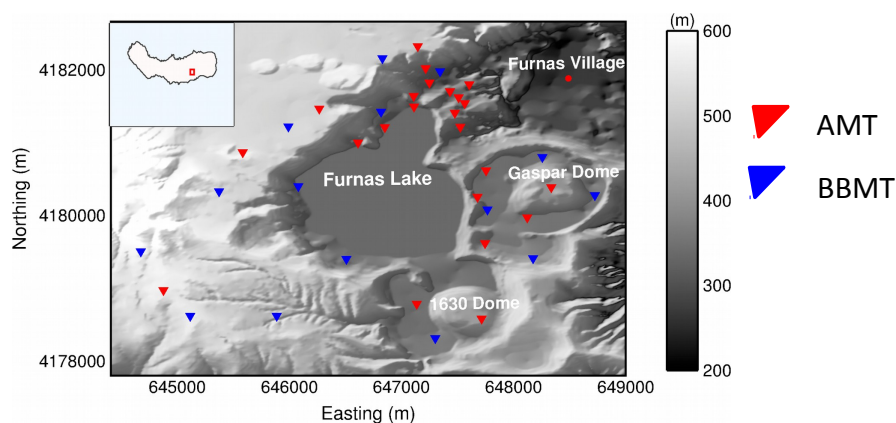
Characterisation of the 3-D geo-electrical structure of the volcano

Investigate the relationship between fault systems and gas/fluid (CO<sub>2</sub> and Radon gas) concentrations / pathways

Roles of fluids and clay material within the volcano-hydrothermal system

Ambitious: An estimate of the depth of the magma source...proposed at 3-6km depth through geochemistry, magnetic data and seismic tomography...

## MT Fieldwork, 2015/16



**39 AMT** (10kHz -1Hz), **15 BBMT** (10kHz – 1000s) sites

Full Tensor MT data and vertical magnetic field data recorded at all sites



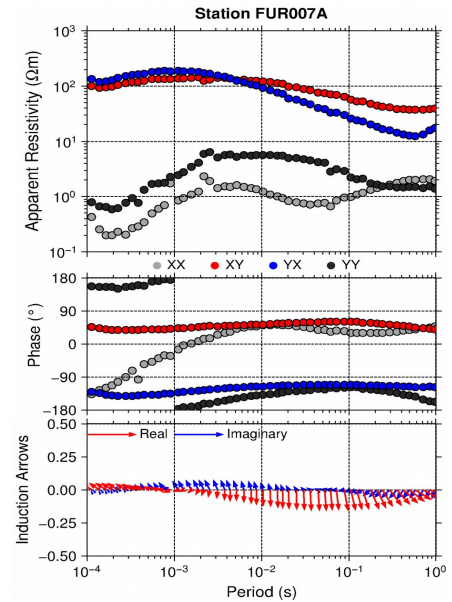
# Furnas AMT Dataset – data processing

Sample Apparent Resistivity and Phase Curve

Excellent data quality

Remote reference processing

Phoenix Geophysics commercial processing

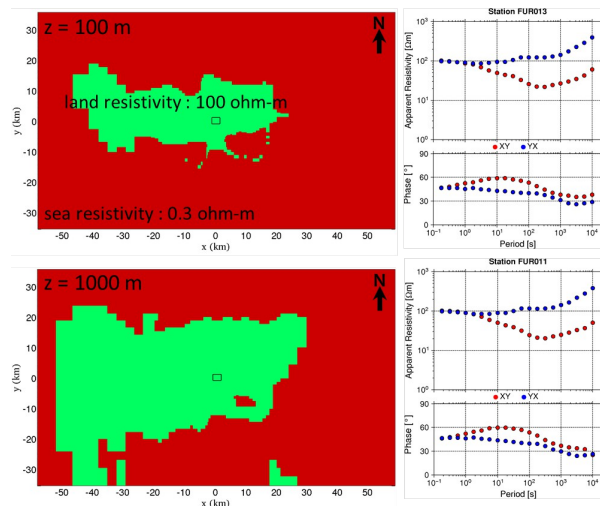


## Ocean Effect on the MT Data

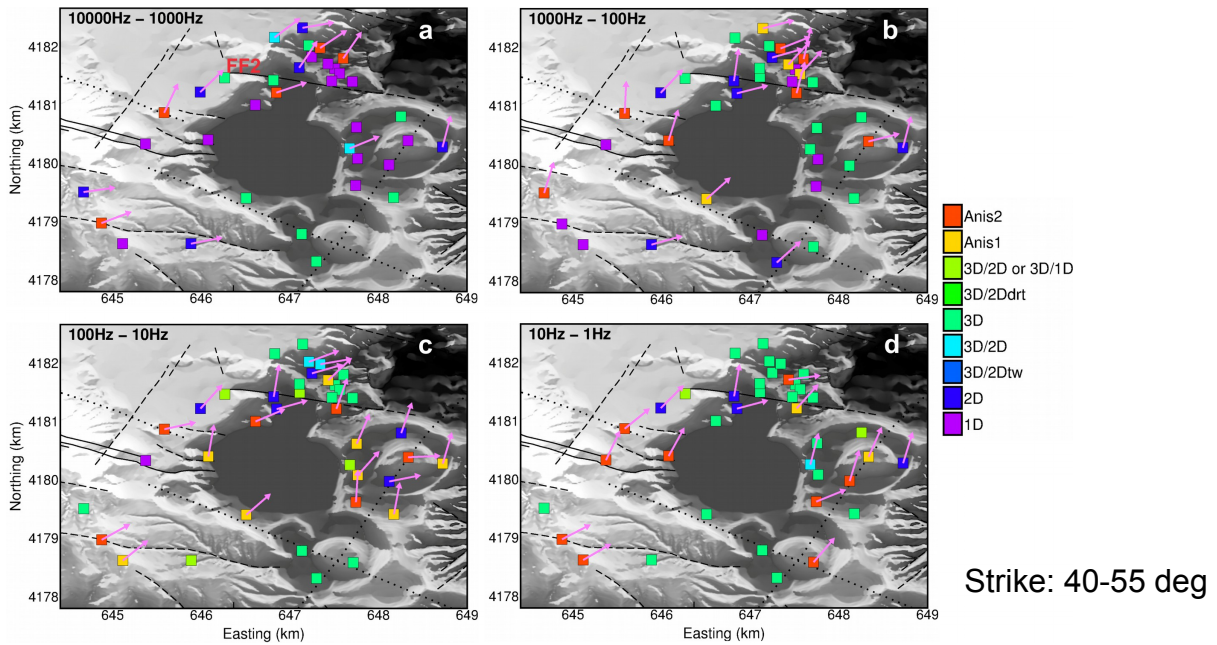
3-D Forward Modelling (WinGlink)

Sites 4km from Atlantic Ocean

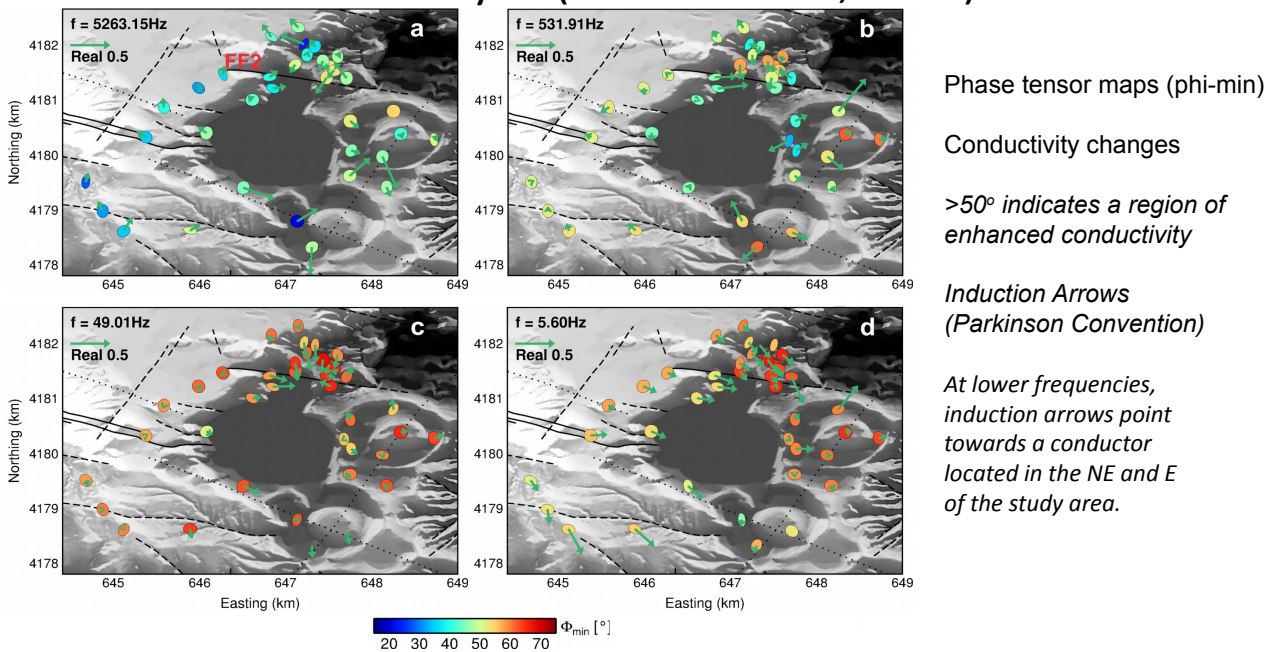
The influence of the ocean can not be neglected beyond periods  $> 1$  s.



### MT data analysis – WALDIM (Marti, 2009)



### Phase Tensor analysis (Caldwell et al, 2004)



## 3-D modelling...

3-D MT Inversion Code, ModEM (Egbert and Kelbert, 2012; Kelbert et al. 2014, Meqbel, 2009)

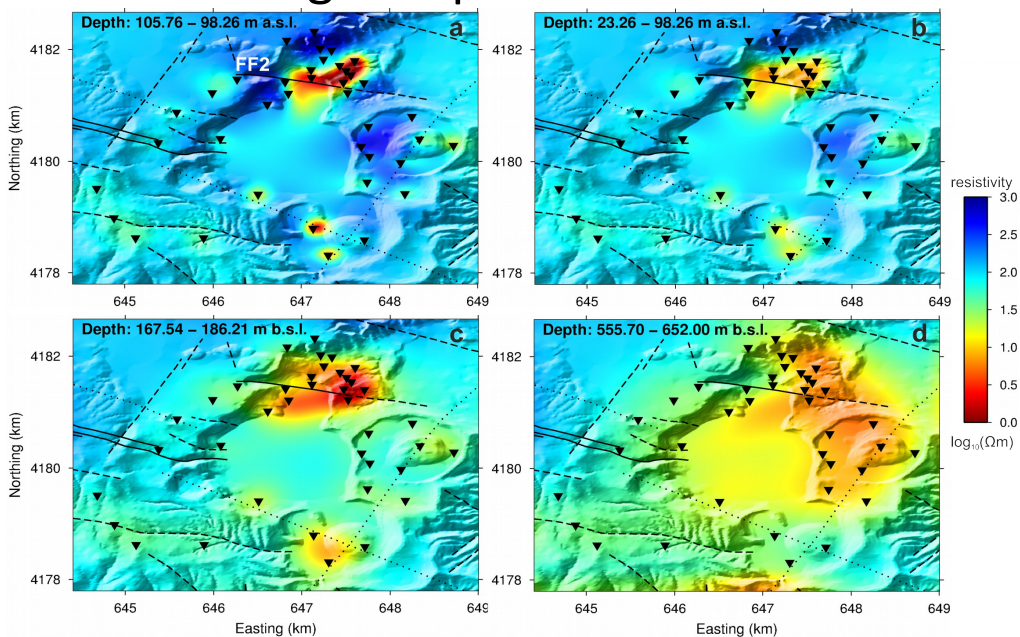
### 3-D mesh set-up:

- 119 (N-S) x 119 (E-W) x 149 (vertical) (plus 10 air layers)
- horizontal cell size 50m x 50m
- thickness of the first layer is 7.5m
- high-resolution topography data
- starting model resistivity of 100 ohm-m with Furnas lake resistivity of - 63 ohm-m (Andrade et al., 2016), which is kept fixed during the inversion

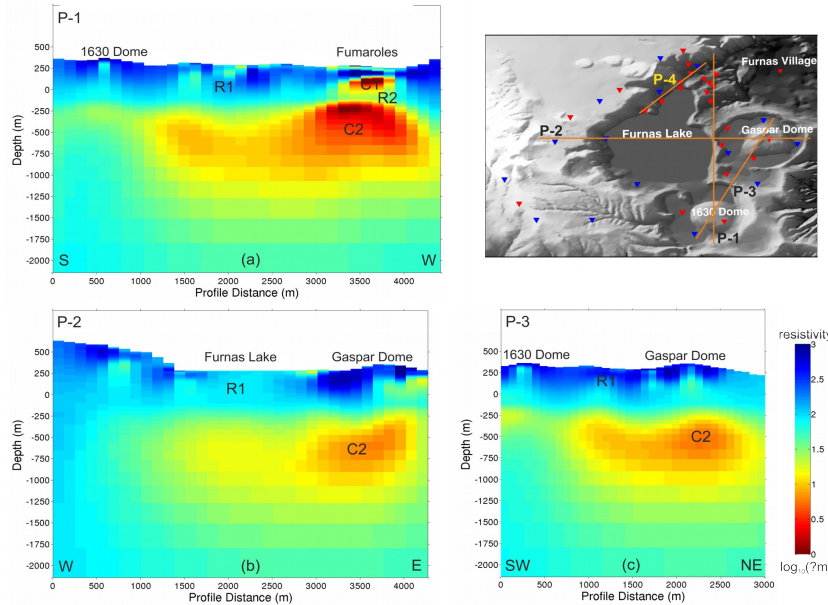
### Input Data:

- full impedance tensor data in the frequency range of 10,000Hz – 1Hz
- 39 AMT sites, and 17 frequencies per site were used
- error floors were set as an absolute value of 3% of  $(|Z_{xy} \times Z_{yx}|^{1/2})$  for Zxx, Zxy, Zyx, and Zyy; for vertical transfer functions, a constant error of 0.015 was used.

## 3D modelling – Depth Slices

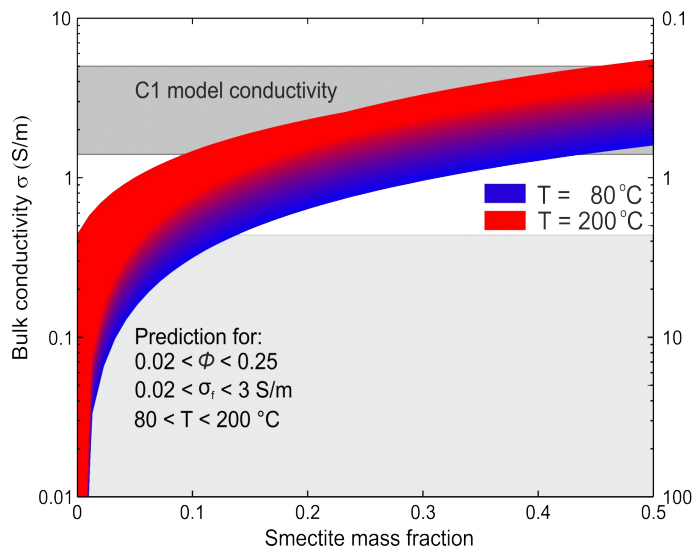


## 3D modelling – Cross Sections



R1: 100-1000 ohm-m  
 C1: 0.5 – 10 ohm-m at a depth of approx 100m  
 R2: Thin. More resistive  
 C2: main conductive zone throughout the region

### Conductivity of shallow conductor, C1.



No borehole data...

Water cannot cause the conductivity of C1 conductor Woticheck (2017).  
 meteoric in origin > 10ohm-m

...petrophysics...surface conductivity of smectite using Waxman & Smits (1968), Revil et al (1998) and Flovenz (2005).

20% smectite is required.

Comparable depth fom adjacent volcano

## Temperature?

Smectite 50-200 deg C

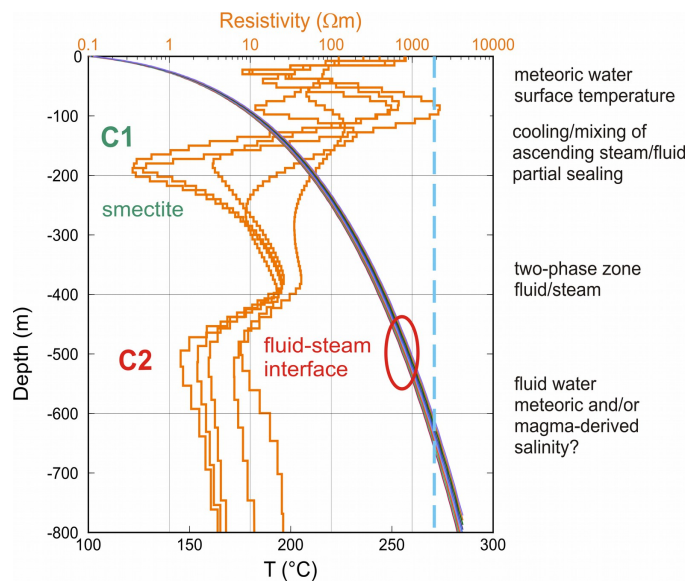
Arnason (2008) documents that low Temp' zeolites disappear 220-250 deg C

Smectite -> Chlorite (mixed clay zone)

Chlorite is dominant after 250 deg C.

Caliro et al (2015), temp of waters feeding fumaroles at 275 deg C

...derived from lower conductor, C2



## Summary: Overall picture of Furnas...

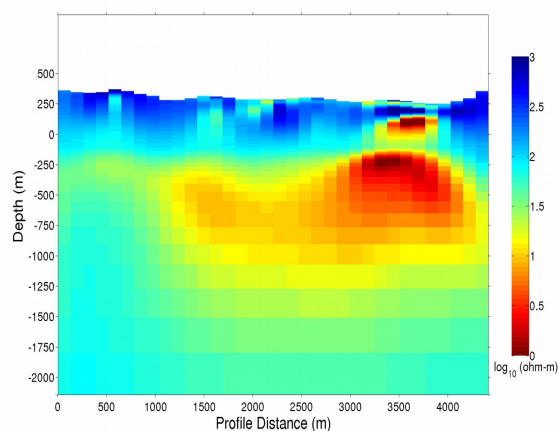
Complex system overlaid by caldera infill (R1)

C1: 20% smectite and low salinity meteoric water. Temp up to 200 deg C

R2: Mixed clay zone?

C2: Clays (Chlorite), possible temp' of around 250 deg C.

Recent thermobarometry (Caliro 2015) Inferred the temp to be 275 deg C





## On-going and future work

- This work has been submitted to Geophysical Journal International
- 3-D inverse modelling of broad-band magnetotelluric (BBMT) responses with bathymetry and high-resolution topography data
  - (Kiyani et al., *in prep*)
- Furnas Lake Time-domain EM (TDEM) measurements have been completed (University of Cologne, DIAS, and the University of Azores). Please check out Mira's poster tomorrow!
- Comparison of COMSOL and MODEM in terms of topography??
- Fogo and beyond...

