

GEOTERMIA NOS AÇORES

da Produção de Electricidade aos Usos Directos

*João Carlos Nunes**

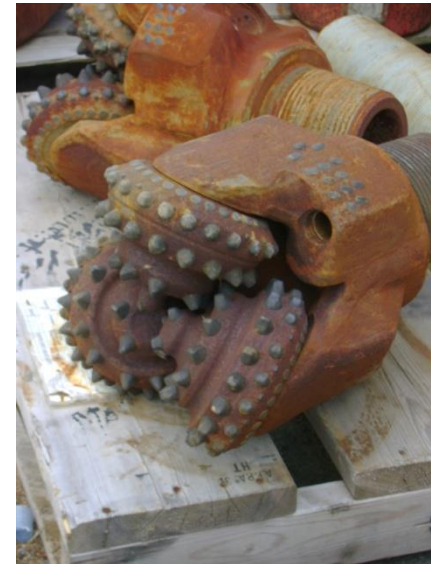
Dep. Geologia, Fac. Ciências, Univ. Lisboa – 04.MAI.2020

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EDA Renováveis Consultant
[jcnunes@inovacores.pt; jcnunes@uac.pt]**

Geothermal exploration studies started in mid-70's years in S. Miguel Island and in 80's in Terceira Island...

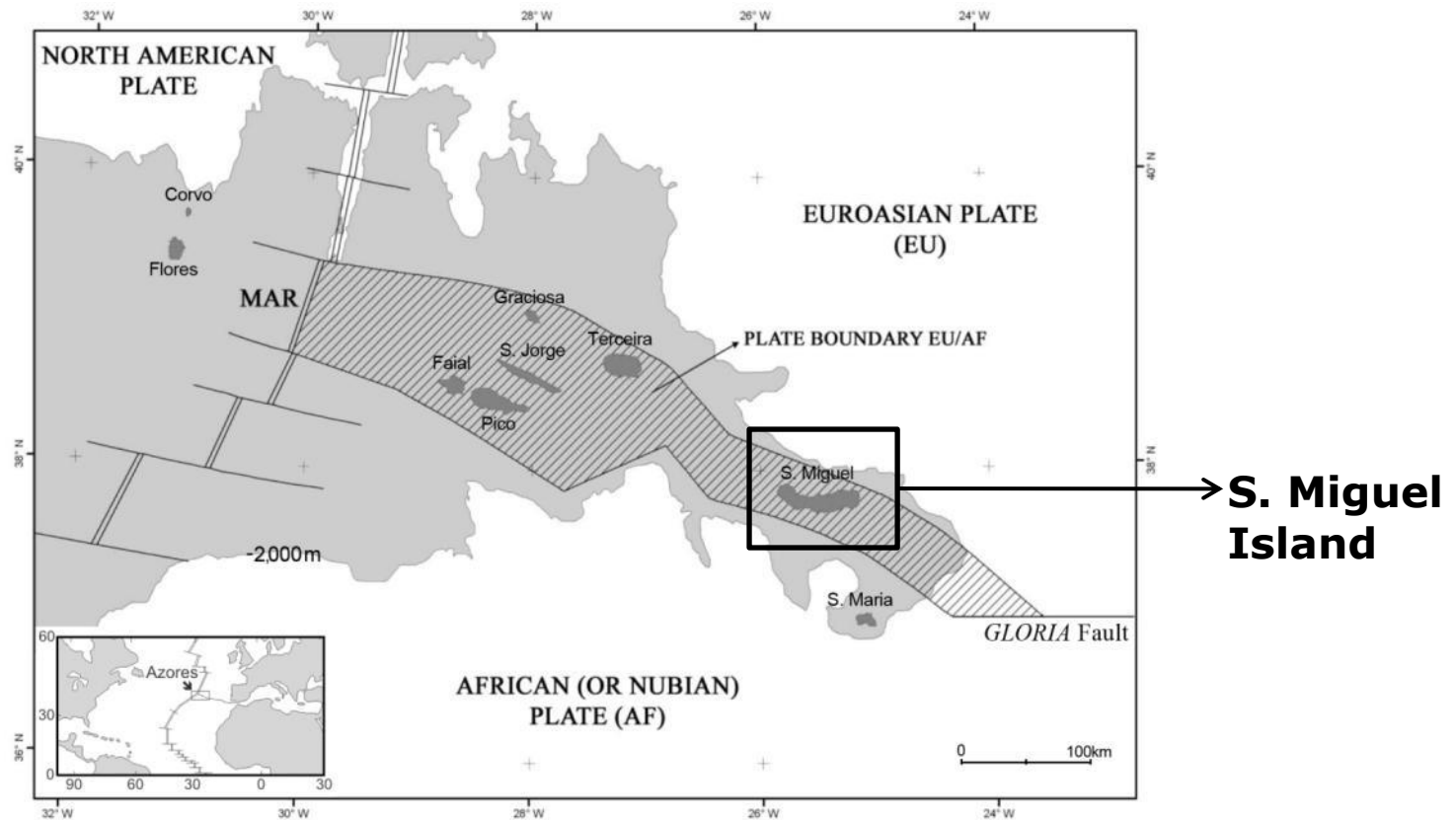


...leading to the geothermal energy production as a “pilot scale” from 1980 until 1994!

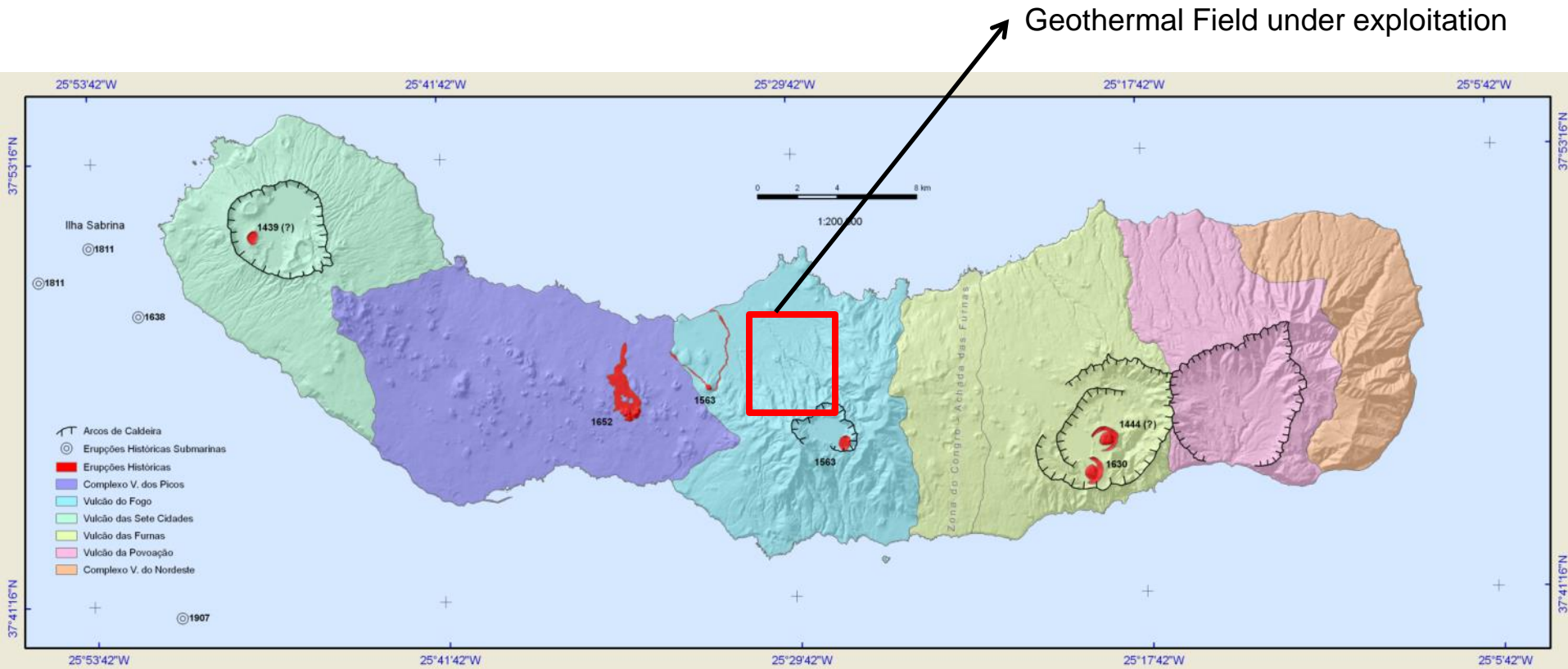


AZORES GEOTHERMAL PROJECT

S. Miguel Island



SÃO MIGUEL GEOTHERMAL PROJECT



Volcanological map of São Miguel (Nunes, 2004)

SÃO MIGUEL GEOTHERMAL PROJECT

Fogo Volcano & Ribeira Grande *graben*

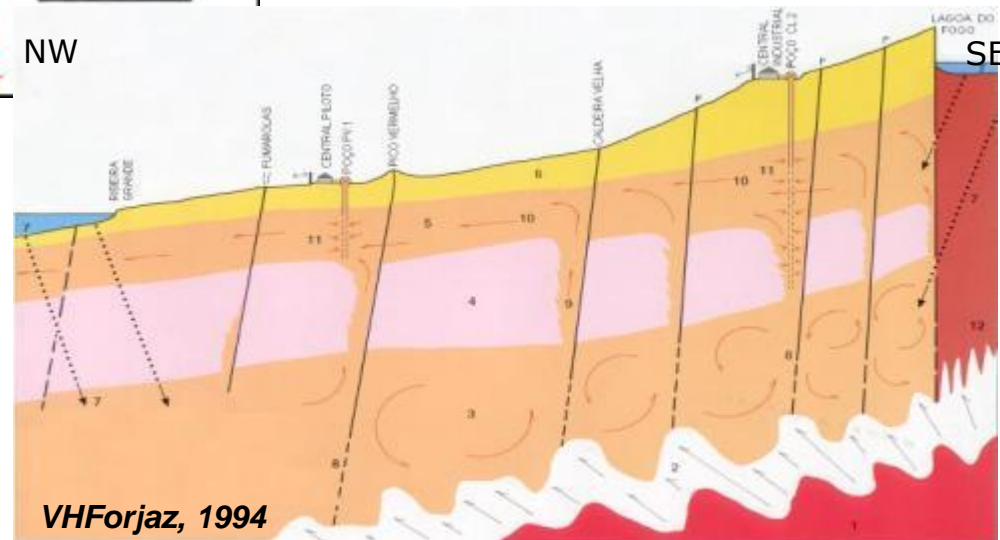
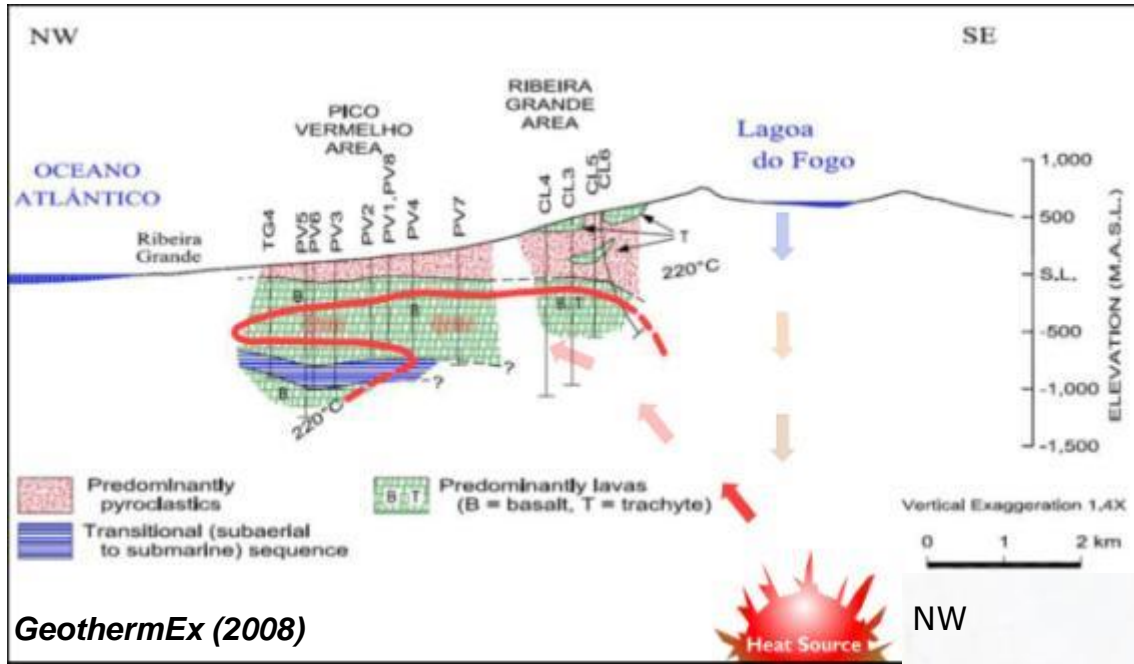


JCNunes, 1991



SÃO MIGUEL GEOTHERMAL PROJECT

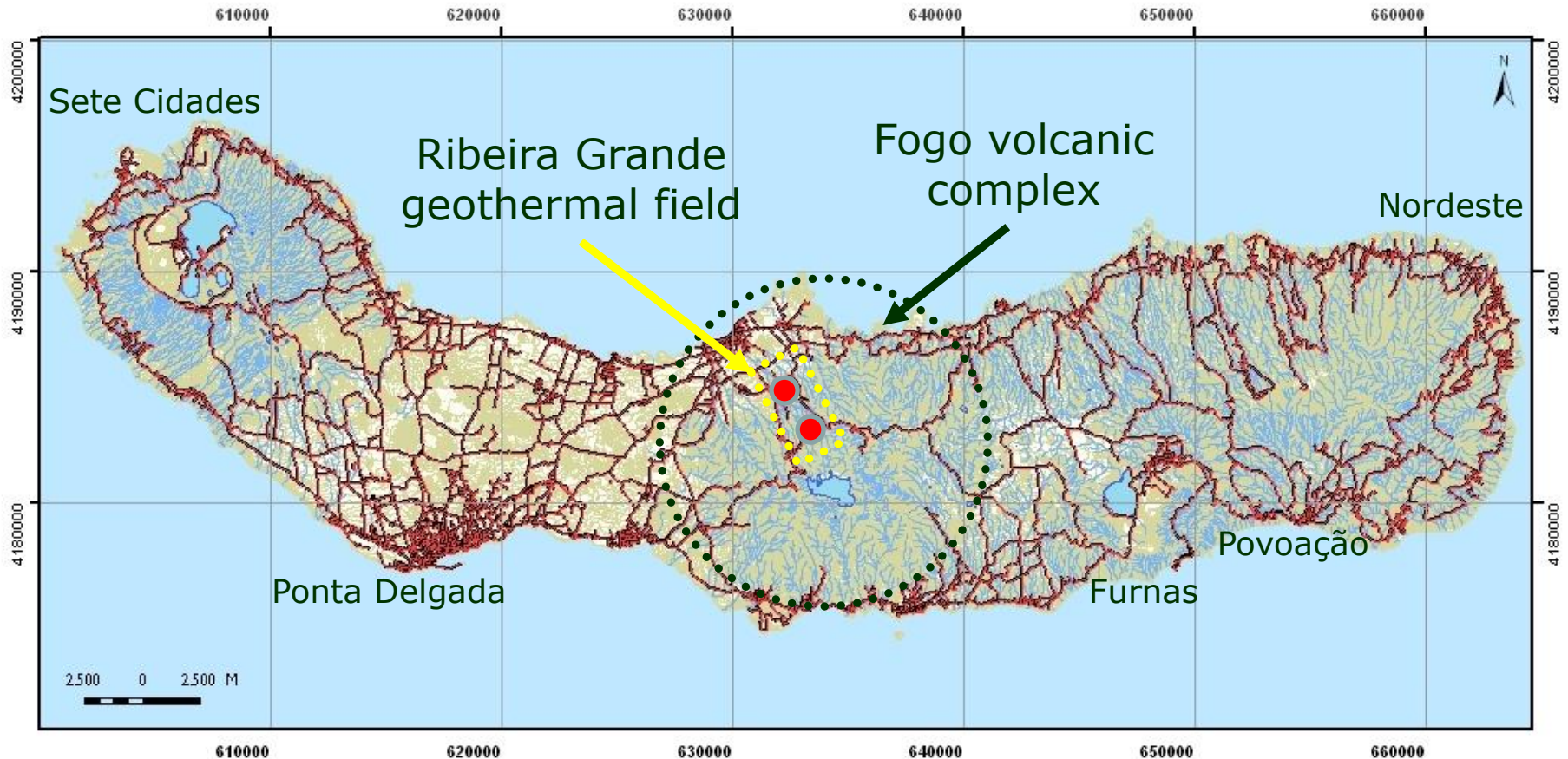
Ribeira Grande Geothermal Field conceptual model



SÃO MIGUEL GEOTHERMAL PROJECT

Ribeira Grande Geothermal Field

Two geothermal power plants



...a total installed capacity of 27,8 MW ... and power of 23,2 MWe.

SÃO MIGUEL GEOTHERMAL PROJECT

Pico Vermelho Pilot Plant

1973-1980: Surface exploration and exploratory drilling of the Ribeira Grande Geothermal Field

1980-2005: Exploitation of the pilot plant

Manufacturer: Mitsubishi

Nominal capacity: 3 MW (...usually 0,8-1MW production!)

Steam consumption: 56 t/h @ 5,1 bar.a

Operating results: 84 GWh in 136 khours
(...no re-injection!)

Pico Vermelho power plant was operated for 25 years and served as a valuable training school for the technical staff in the operation and maintenance of the geothermal field and generation equipment

SÃO MIGUEL GEOTHERMAL PROJECT

Pico Vermelho Pilot Plant

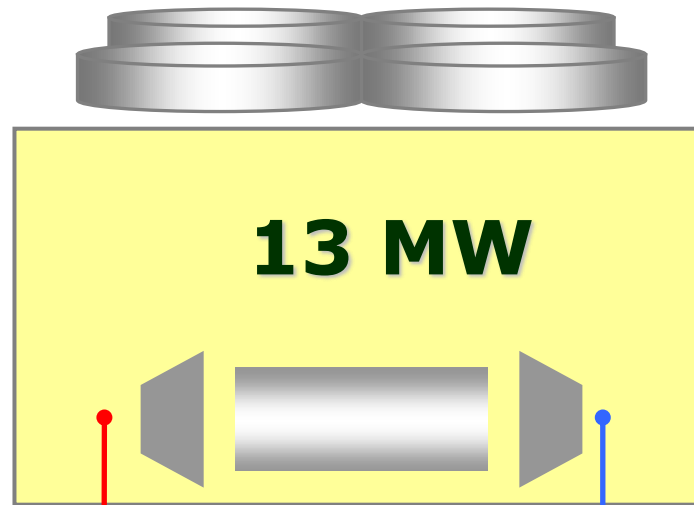


SÃO MIGUEL GEOTHERMAL PROJECT

New Pico Vermelho Plant

One generation unit,
binary cycle, air-cooled
condensing system

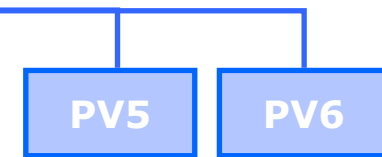
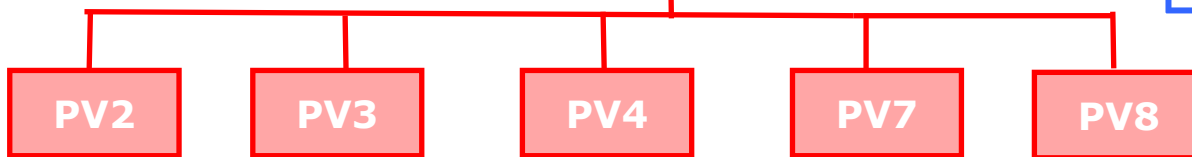
(2006-2017)



Geothermal fluid
provided by five
production wells

Re-injection in two
geothermal wells
(until 2014)

AFTER
2014



Today's TOTAL installed capacity = 13 MW ((12,5 MWe power))

SÃO MIGUEL GEOTHERMAL PROJECT

New Pico Vermelho Plant



ORMAT (Israel)

SÃO MIGUEL GEOTHERMAL PROJECT

Ribeira Grande Plant

(1994-2017)

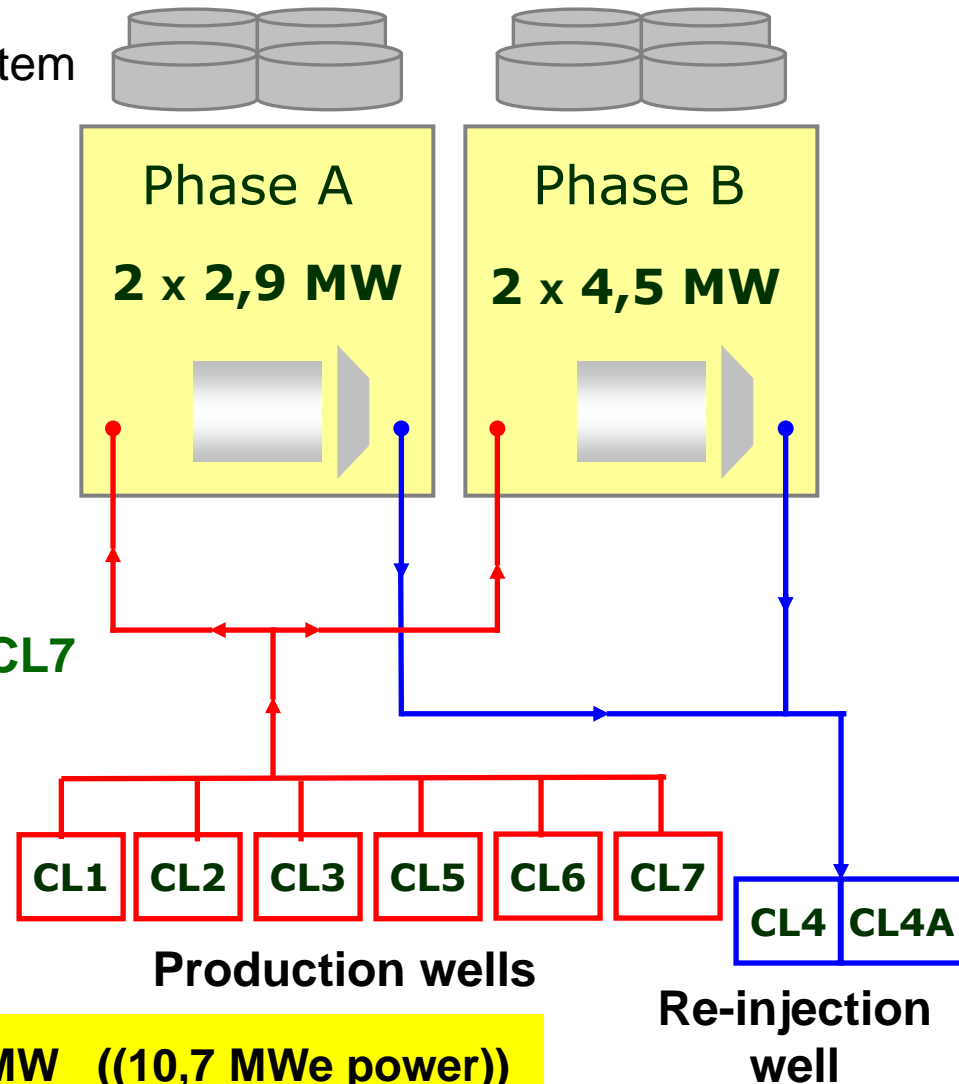
ORC binary system

Phase A (1994)

- Installed capacity 2 x 2,9 MW
- Geothermal wells CL1 and CL2

Phase B (1998-2017)

- New installed capacity 2 x 4,5 MW
- Wells CL1, CL2, CL3, CL5, CL6 and CL7
- Re-injection of effluent in well CL4



Today's TOTAL installed capacity = 14,8 MW ((10,7 MWe power))

SÃO MIGUEL GEOTHERMAL PROJECT

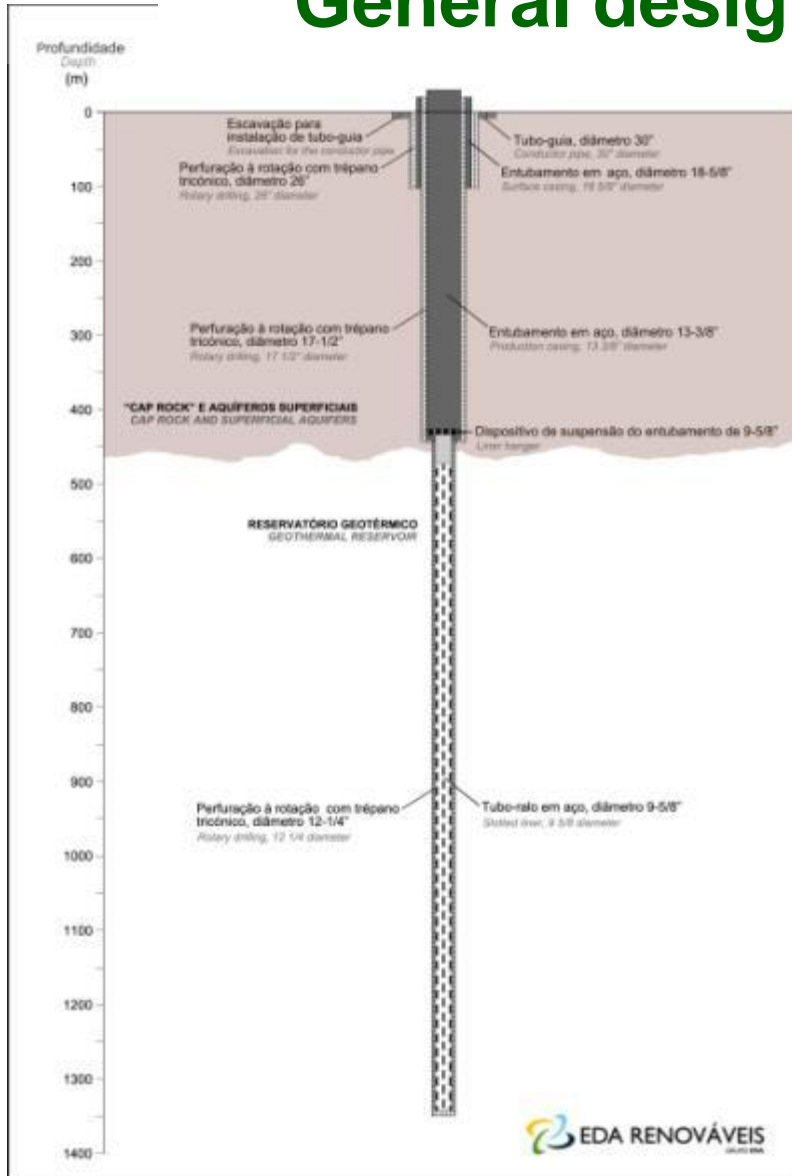
Ribeira Grande Plant



ORMAT (Israel)

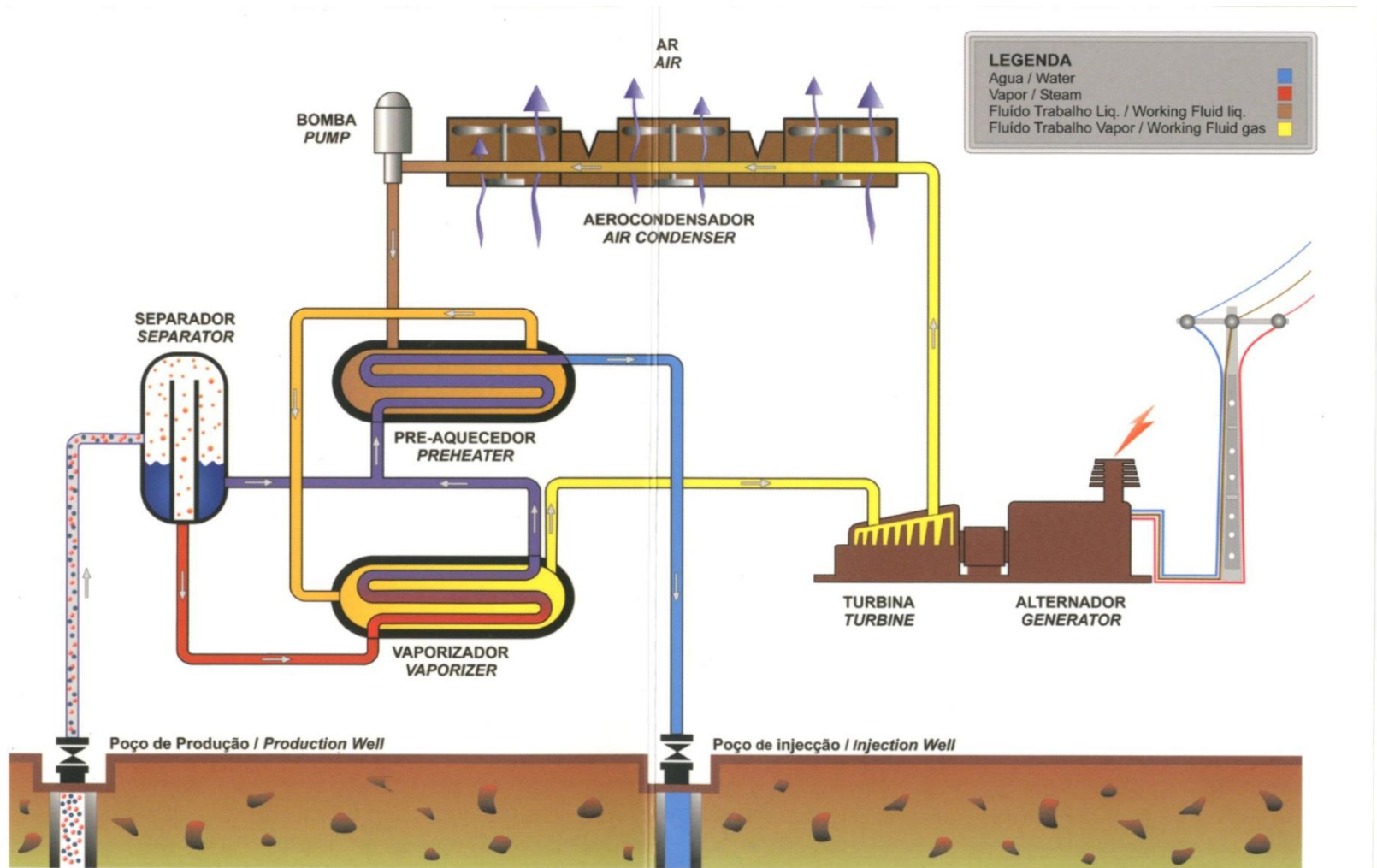
SÃO MIGUEL GEOTHERMAL PROJECT

General design of geothermal wells



SÃO MIGUEL GEOTHERMAL PROJECT

The ORC binary system geothermal power plants



SÃO MIGUEL GEOTHERMAL PROJECT

Ribeira Grande Geothermal Field - Summary

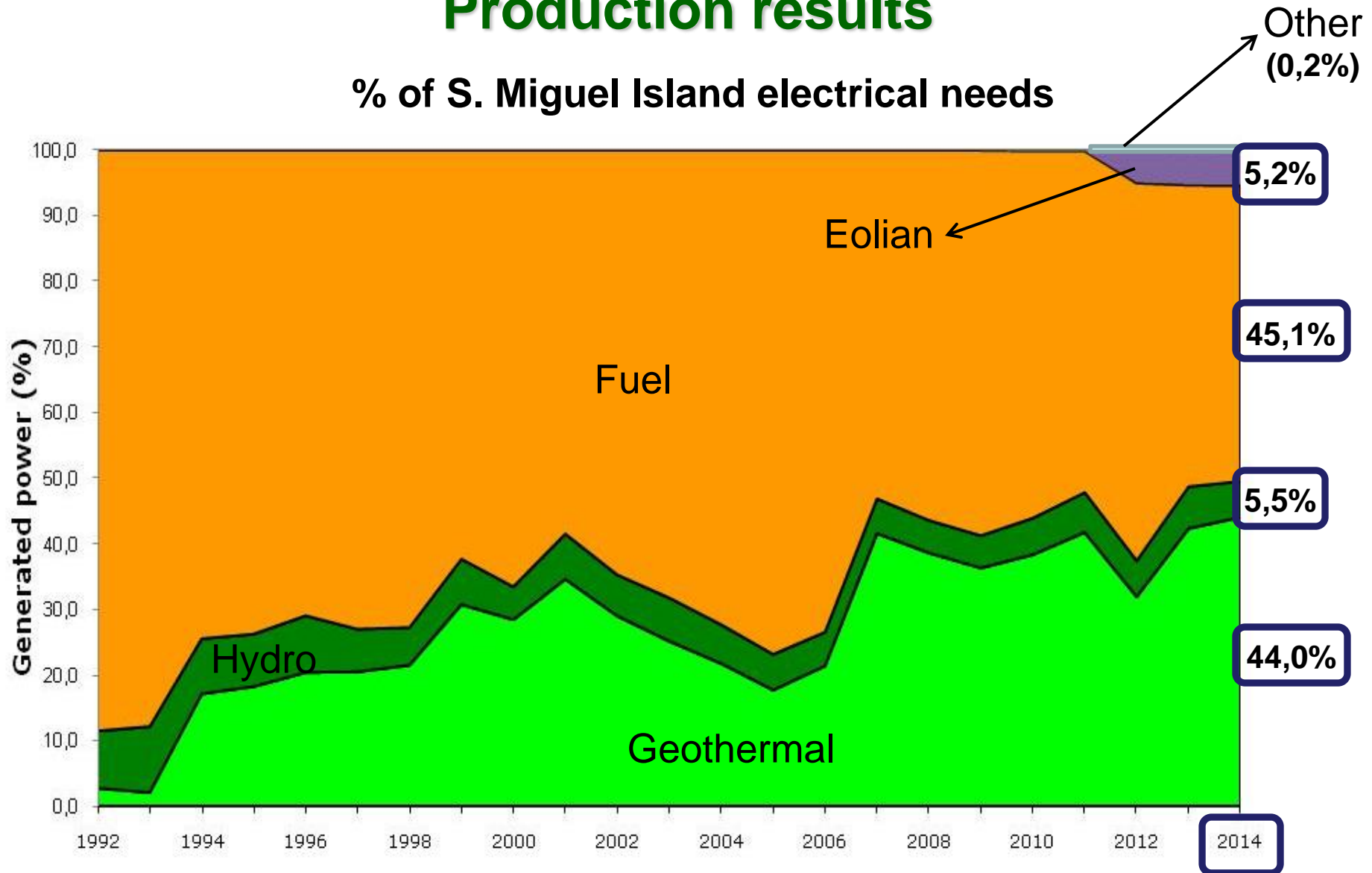
- Extensive single NW-SE elongated geothermal reservoir;
- Maximum measured temperature: 245°C;
- Liquid-dominated field;
- Fluid moving laterally northwestward;
- Permeable formations from 700 to 1300 m depth in CL sector and from 450 to 900 m in PV sector;
- Boundaries controlled by NW-SE faulting (cf. Ribeira Grande *graben*);
- Sodium-chloride brine with TDS of 6-7 g/l;
- Estimated capacity: 60 to 90 MW.

...production of 183,6 GWh (2018) ...~42% São Miguel Island / ~23% Azores Archipelago

SÃO MIGUEL GEOTHERMAL PROJECT

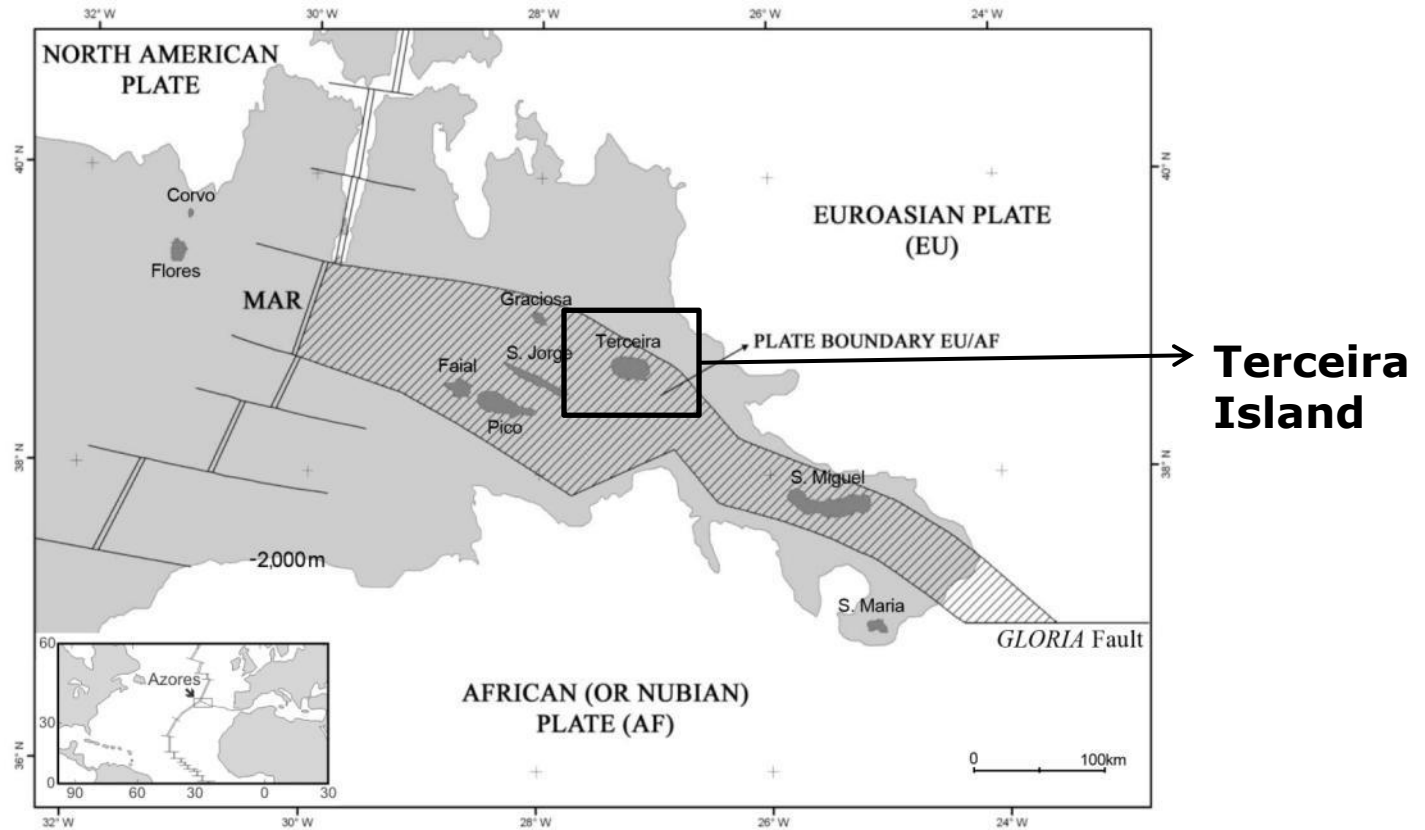
Production results

% of S. Miguel Island electrical needs



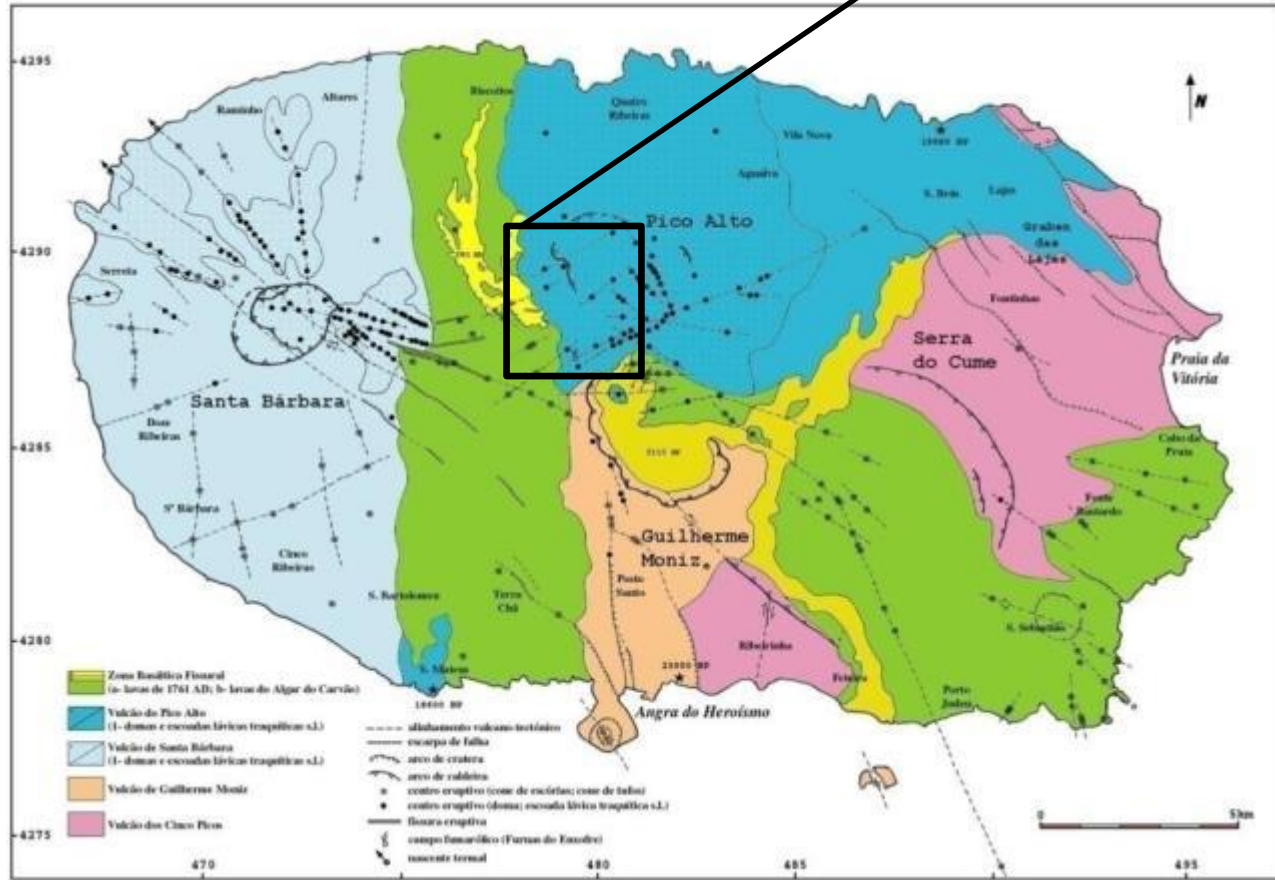
AZORES GEOTHERMAL PROJECT

Terceira Island



TERCEIRA GEOTHERMAL PROJECT

Pico Alto Geothermal Field



Production wells



Volcanologic map of the island of Terceira (Nunes, 2000)

TERCEIRA GEOTHERMAL PROJECT

Pico Alto Geothermal Field



TERCEIRA GEOTHERMAL PROJECT

General Overview

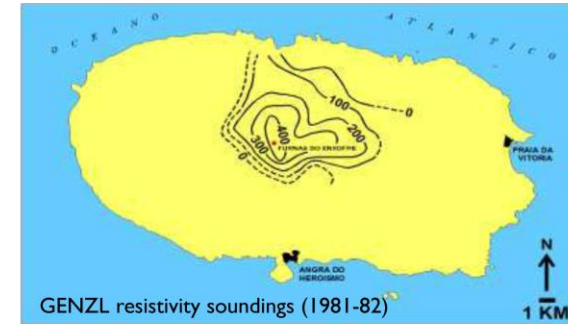
...”Phase I” (initial!), in years 80’s with general studies (e.g. /island scale!

I – Exploration phase

- ⇒ Geoelectric survey
- ⇒ Environmental studies and licensing
- ⇒ Thermo-gradient drilling holes
- ⇒ ...and “incipient” geological survey (e.g. island scale!)

II – Feasibility phase

- ⇒ Drilling of 5 evaluation wells
- ⇒ Testing of evaluation wells (phase 1)
- ⇒ Testing of evaluation wells (phase 2)
- ⇒ Detailed Geological & Geophysical Studies



2000

2000/02

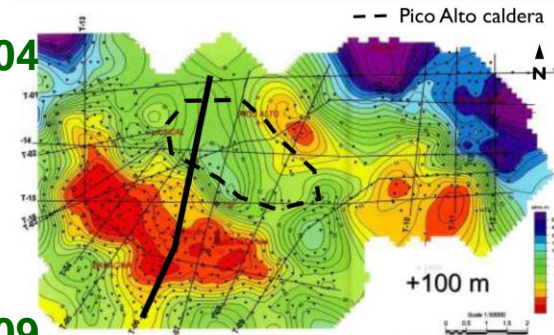
2003/04

2006/09

2009/10

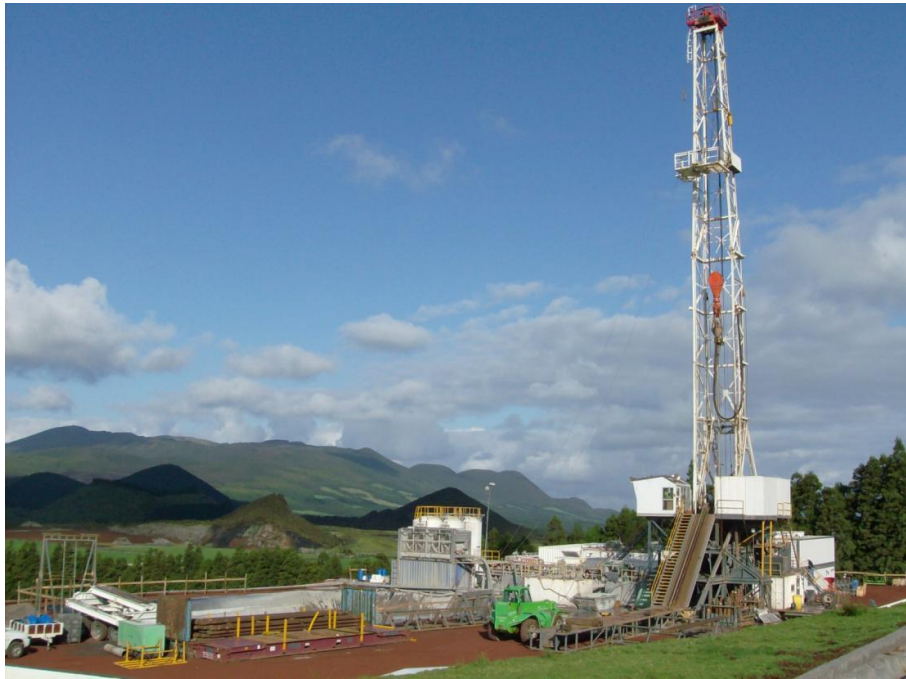
2013/14

2013-2015



TERCEIRA GEOTHERMAL PROJECT

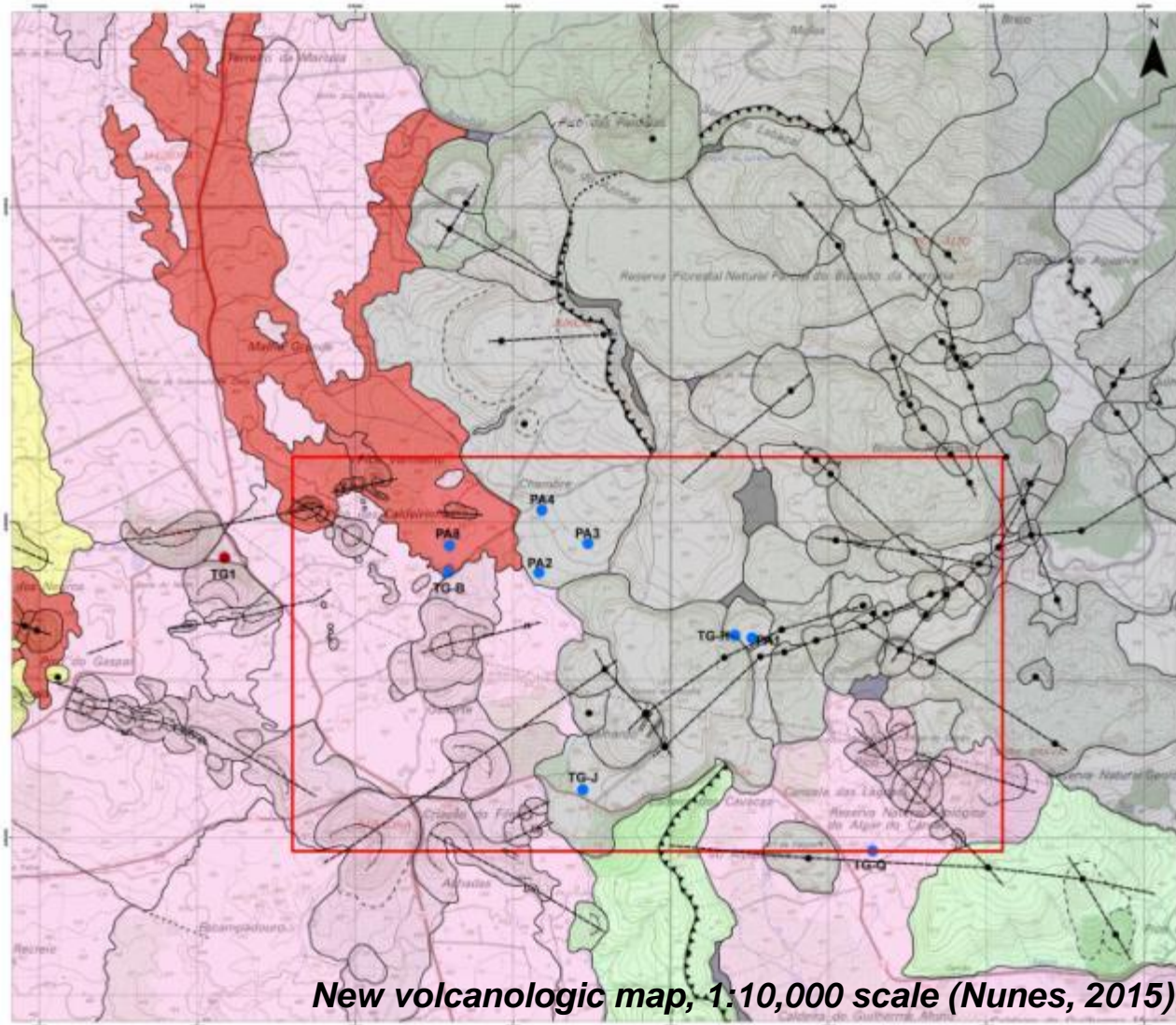
Deep Drilling & Well Testing



2006-2014

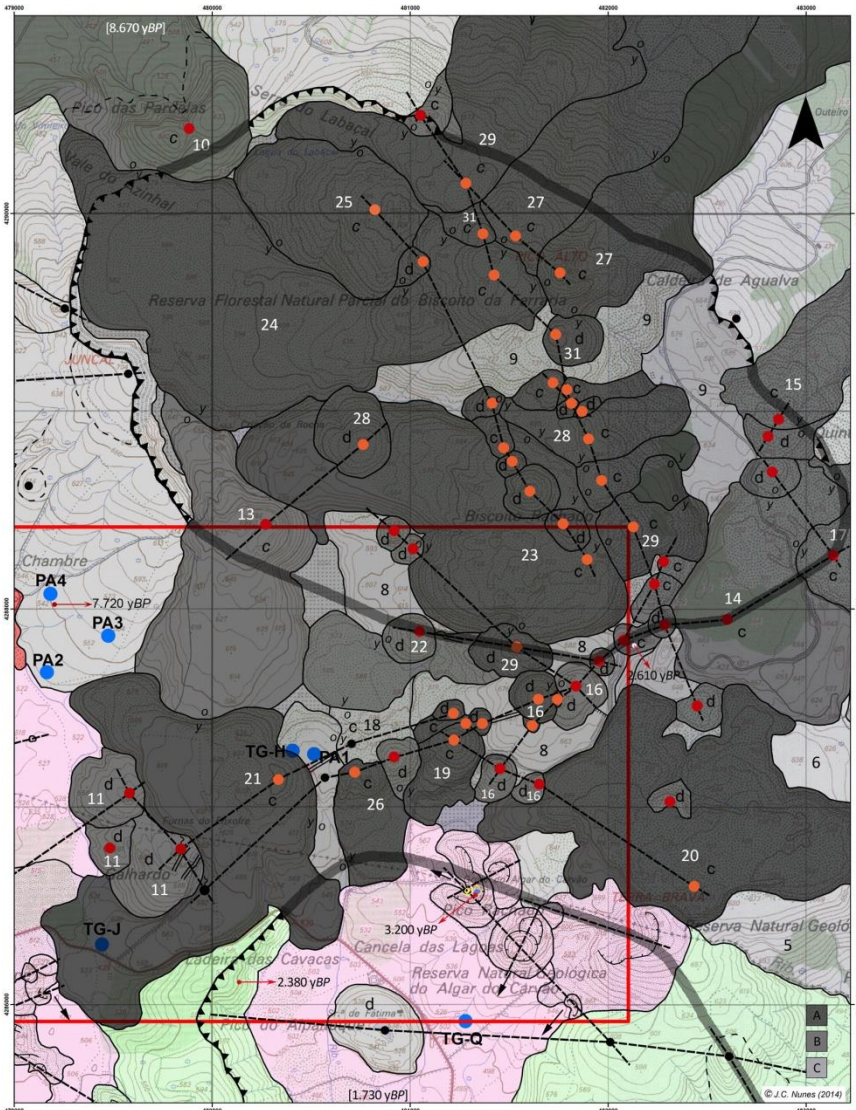
TERCEIRA GEOTHERMAL PROJECT

Geological Exploration



TERCEIRA GEOTHERMAL PROJECT

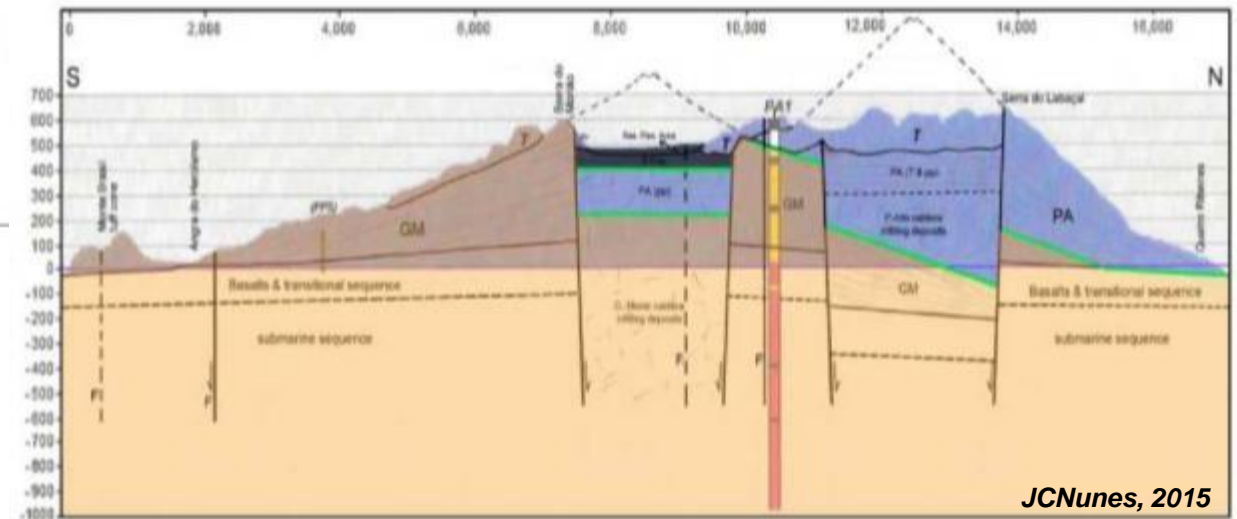
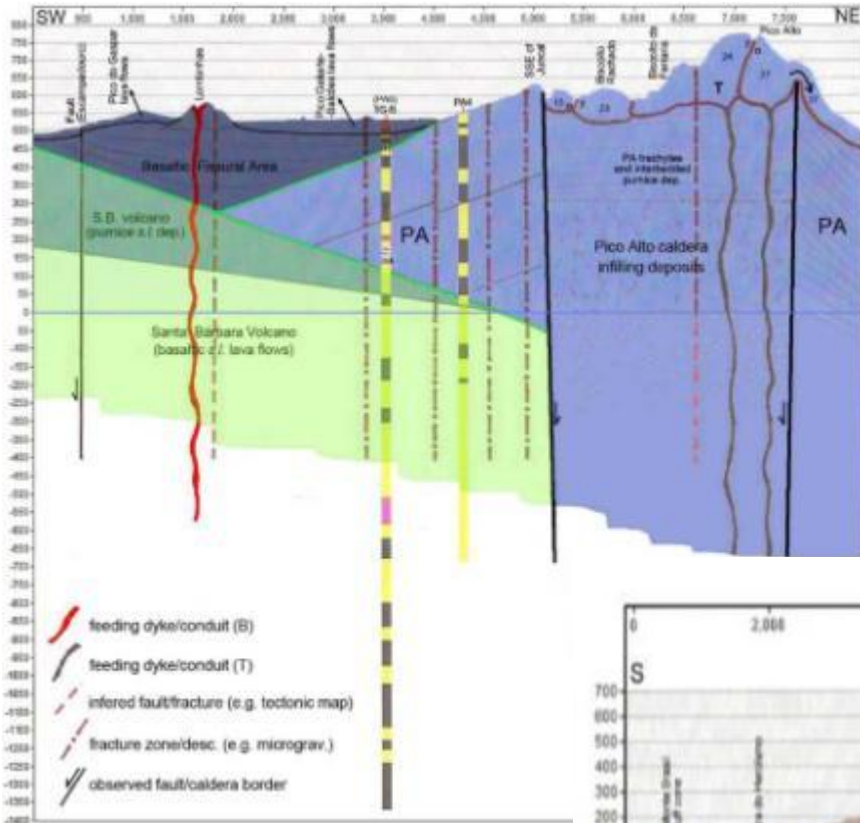
Geological Exploration



2013-2015

TERCEIRA GEOTHERMAL PROJECT

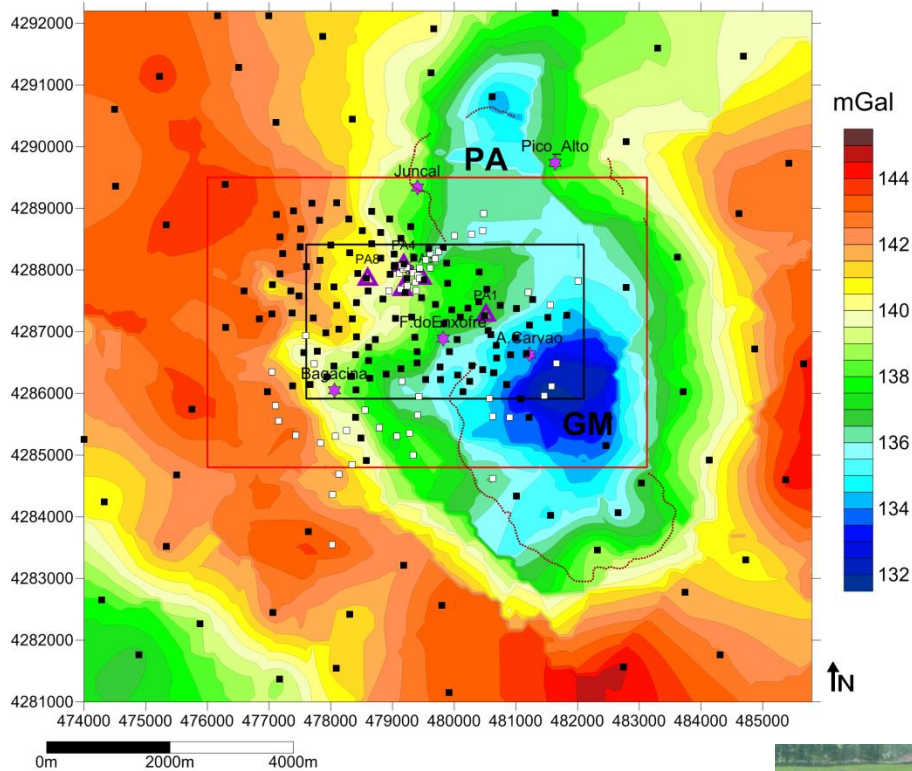
Pico Alto Geothermal Field



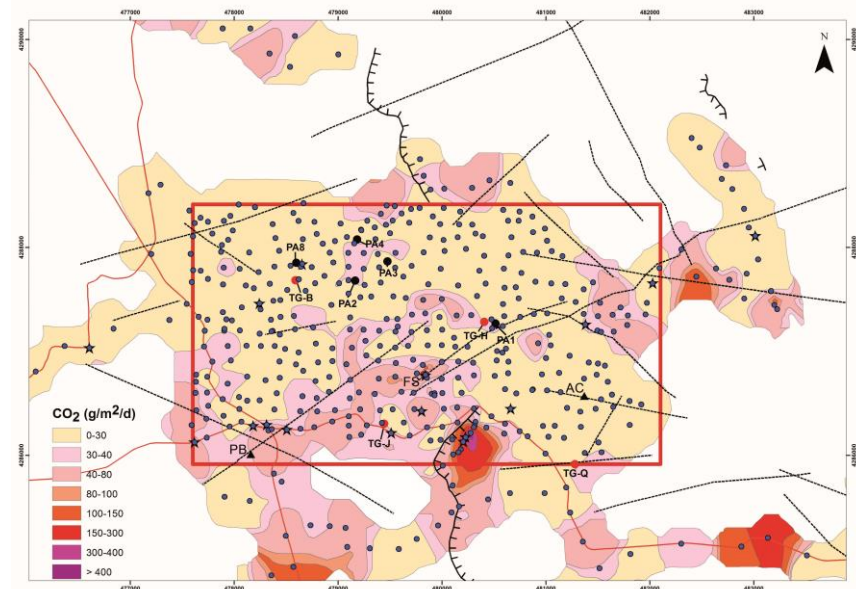
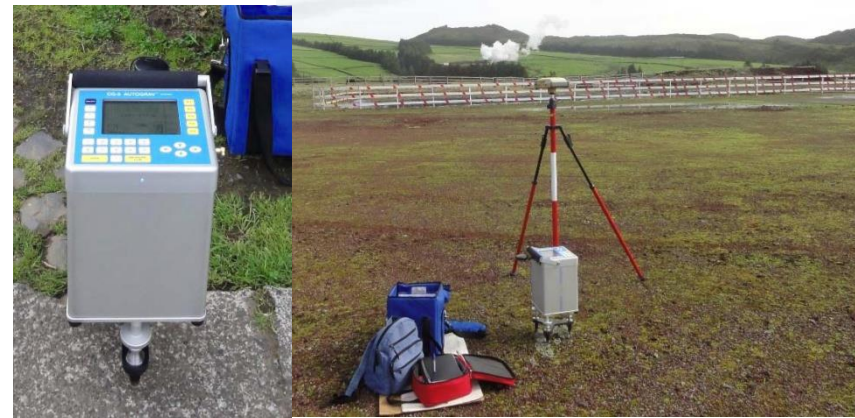
...on a (very) complex geological setting!

TERCEIRA GEOTHERMAL PROJECT

Geophysical & Geochemical Exploration



----- Guilherme Moriz (GM) and Pico Alto (PA) calderas
 ▲ Geothermal well ★ Locations ■ Gravity Stations □ Gravity Stations

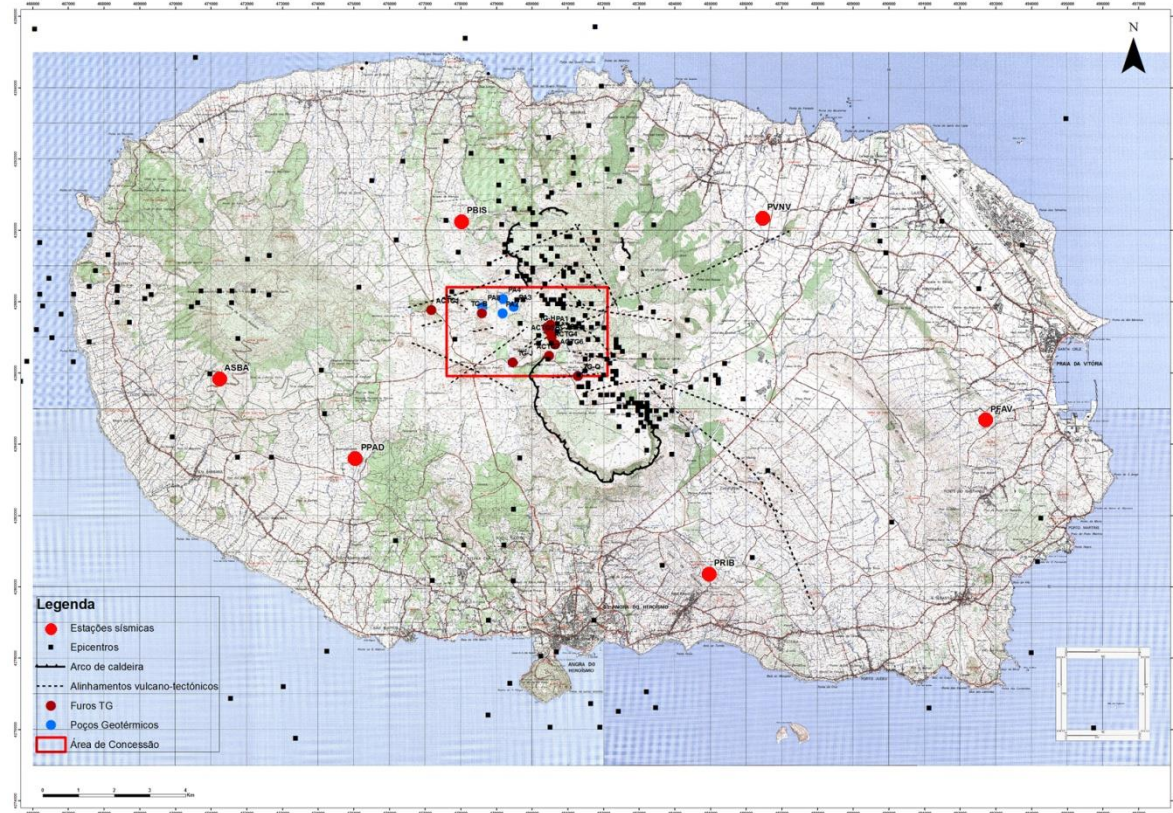


2013-2015

TERCEIRA GEOTHERMAL PROJECT

Geophysical Exploration

2013-2015

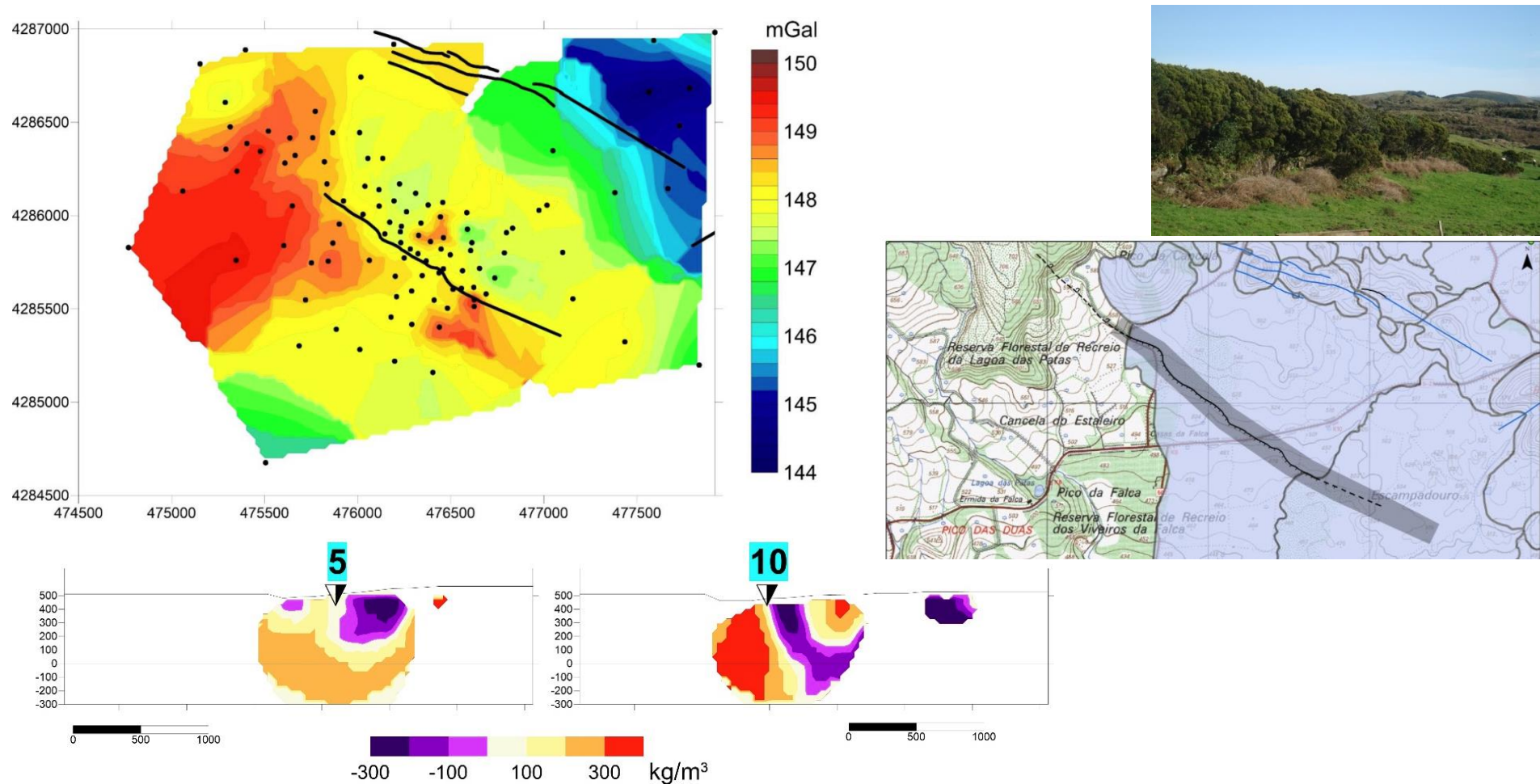


Earthquake epicenters in Terceira Island (April, 2003 to March, 2011)

**A NEW PROPOSAL/APPROACH: MAPPING ACTIVE FAULTS AND FOCAL MECHANISMS
ASSESSMENT OF MICROEARTHQUAKES IN THE PICO ALTO GEOTHERMAL FIELD
(TERCEIRA IS., AZORES)**

TERCEIRA GEOTHERMAL PROJECT

Geophysical Exploration...in 2016

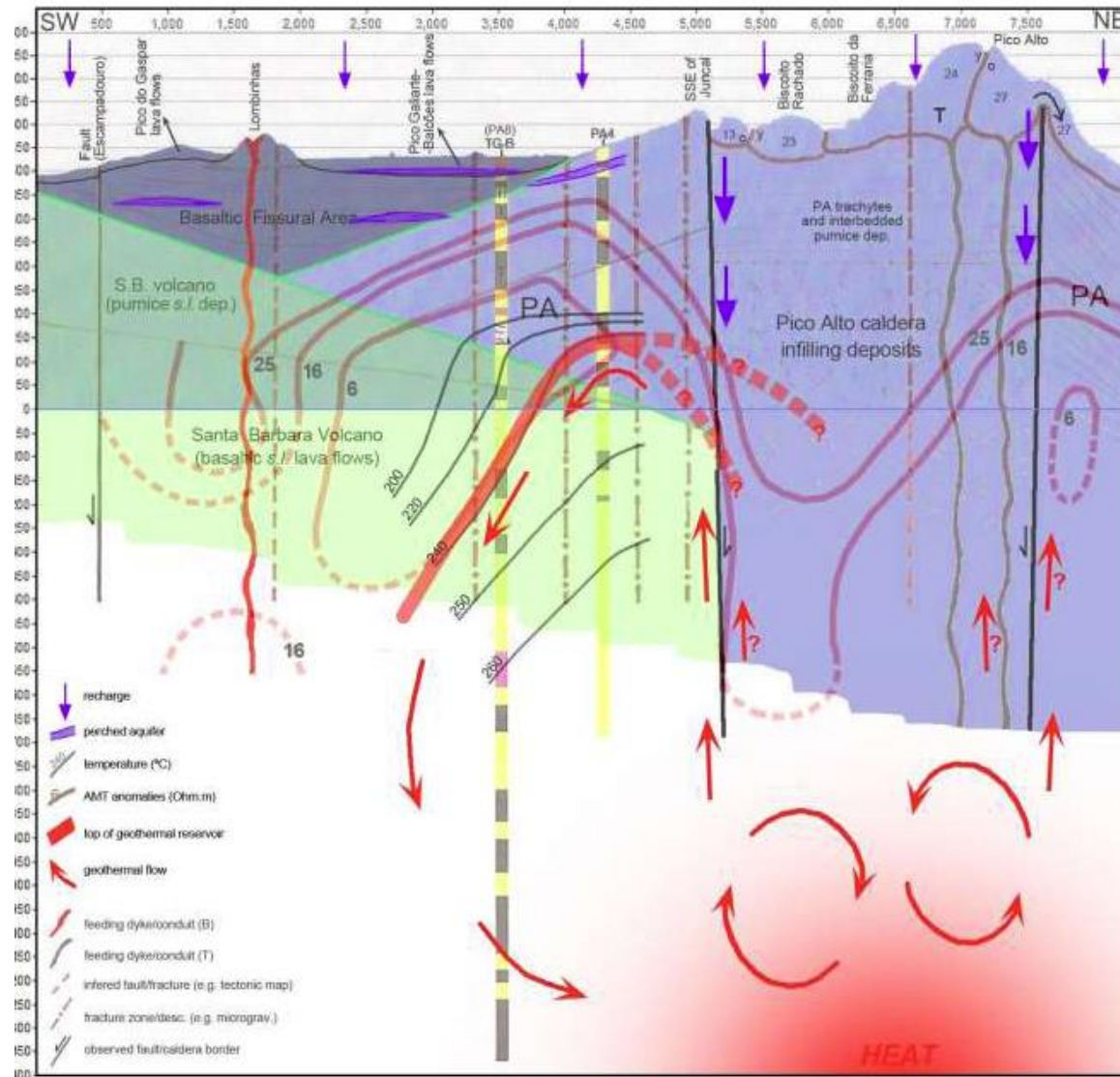


CARACTERIZAÇÃO GEOFÍSICA DE ESTRUTURAS TECTÓNICAS DO CAMPO GEOTÉRMICO DO PICO ALTO (ISLA TERCEIRA – AZORES): UMA ABORDAGEM MICROGRAVIMÉTRICA

...AS A TOOL TO (NEAR FUTURE) EXPLORATION STUDIES FOCUSED ON BURIED FAULTS/STRUCTURES

TERCEIRA GEOTHERMAL PROJECT

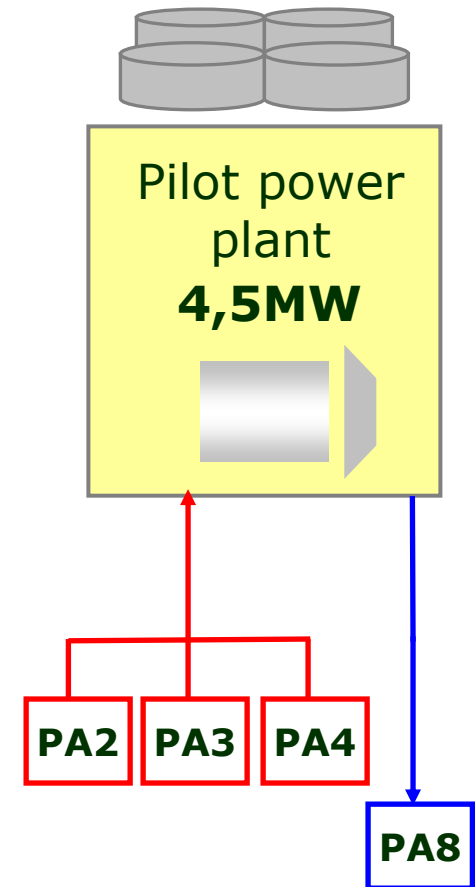
Pico Alto Geothermal Field conceptual model



TERCEIRA GEOTHERMAL PROJECT

General Overview

- in April 2014 recommended the installation of a pilot power plant of 2.5-3.0 MWe fed by two/three wells up to 1,800 m deep;
- All the geothermal fluid re-injected in well PA8



- a binary Pilot Power Plant of 4,5 MW (total capacity) is running since August, 2017
- production of 20,6 GWh (2018) ...~11% Terceira Island / ~3% Azores Archipelago

TERCEIRA GEOTHERMAL PROJECT

General Overview



...a binary Pilot Power Plant of 4,5 MW running since August,2017

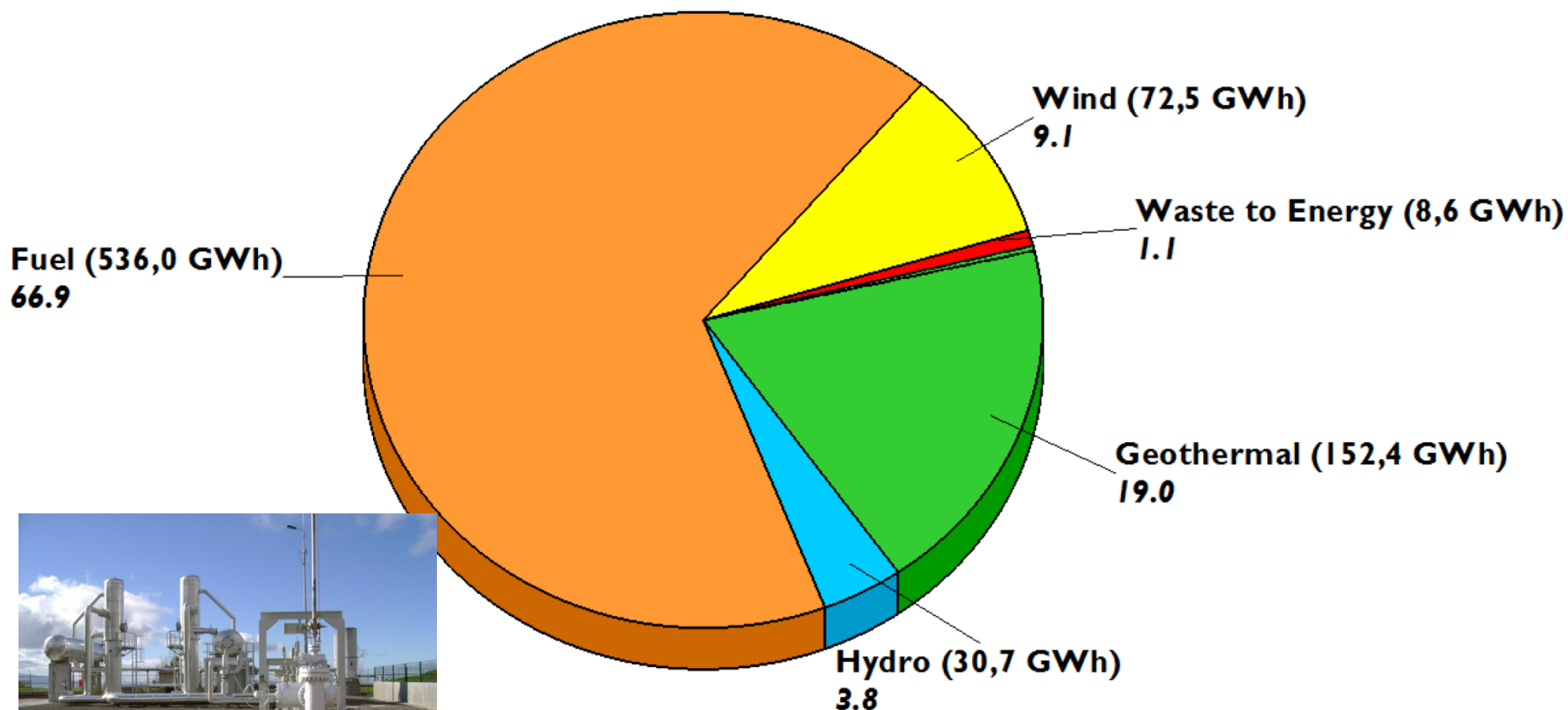
Geothermal Energy at the Framework of Renewable Energies in the Azores Islands



...in a glance!

Geothermal Energy at the Framework of Renewable Energies in the Azores Islands

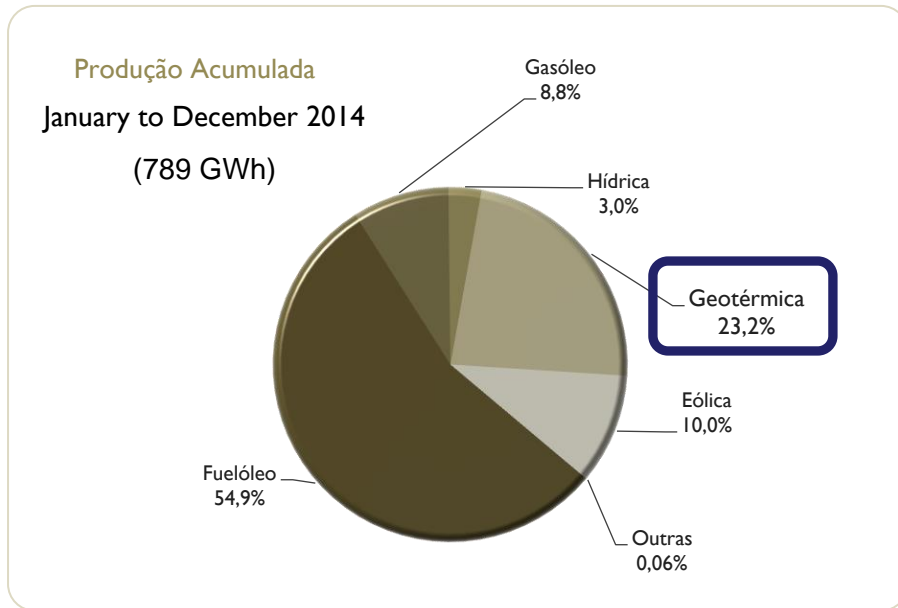
AZORES (800 GWh)



2016

Electricity Production (2014)

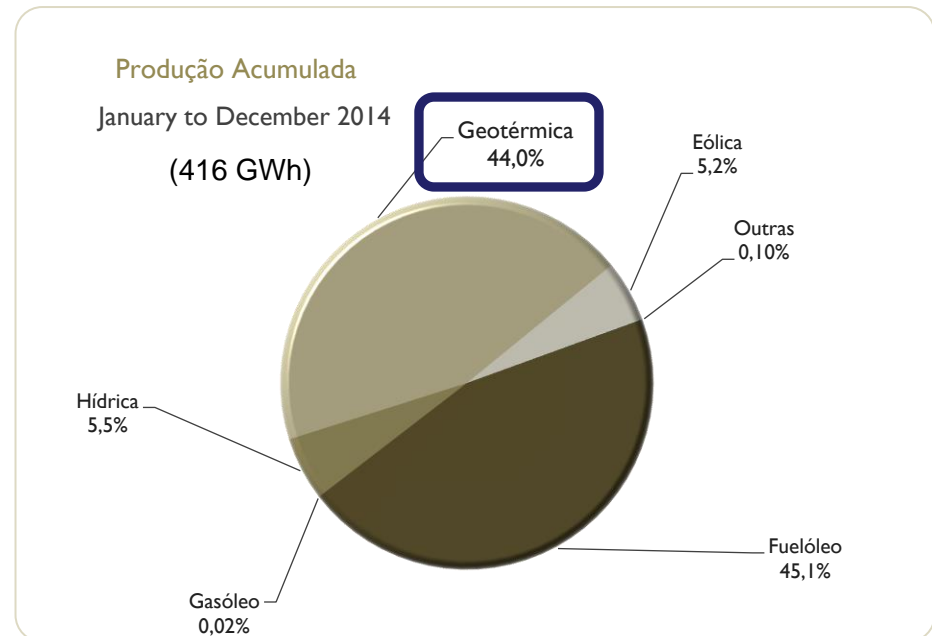
...and Geothermal Energy penetration



...in Azores

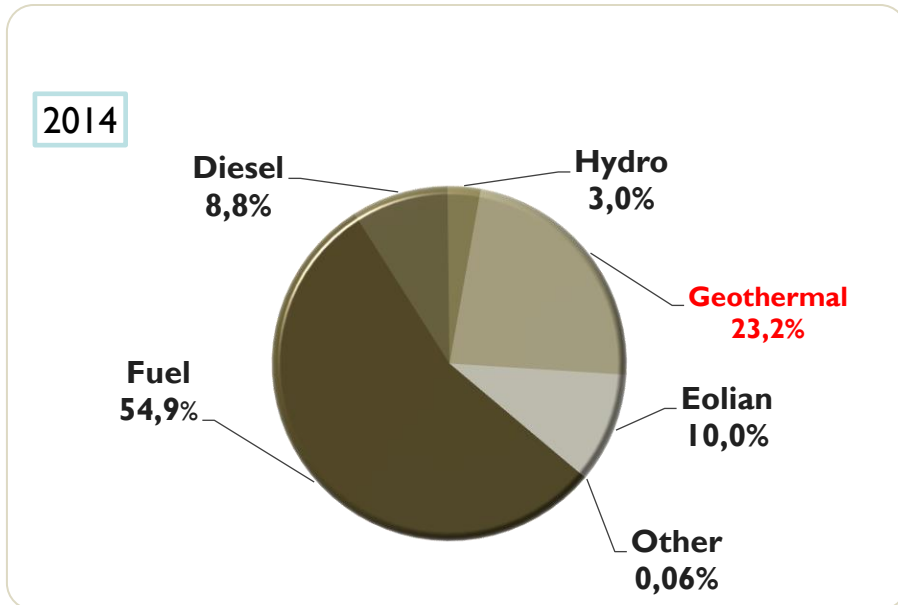
The annual geothermal production more than doubled after 2006 increasing from approximately 80 GWh to 170 GWh

...in S. Miguel Is.

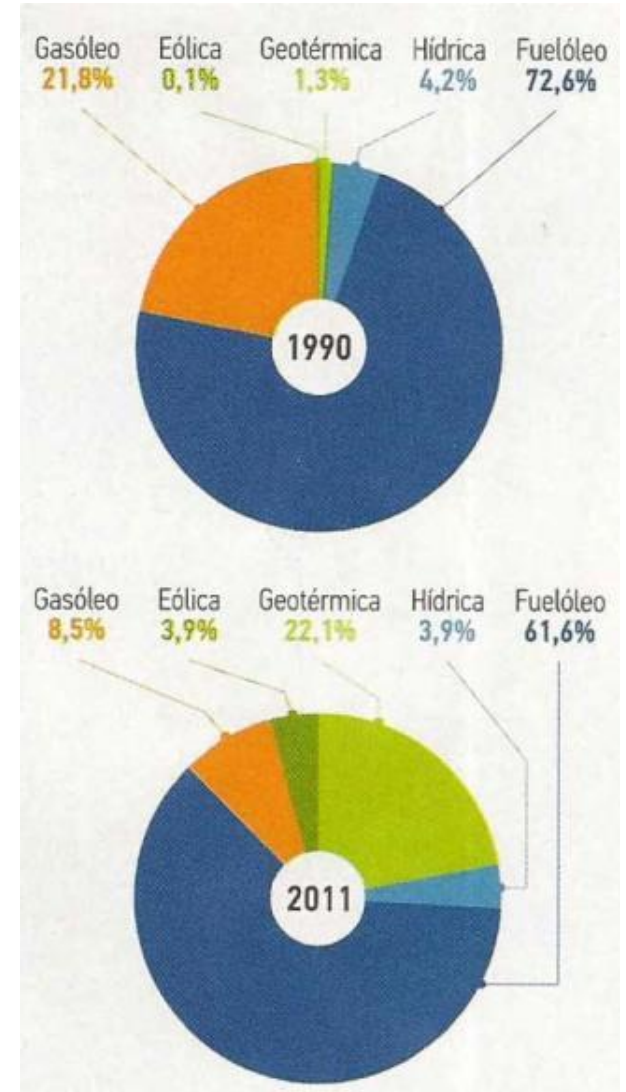


ELECTRICITY PRODUCTION IN THE AZORES

Evolution of primary sources production in ALL ISLANDS...

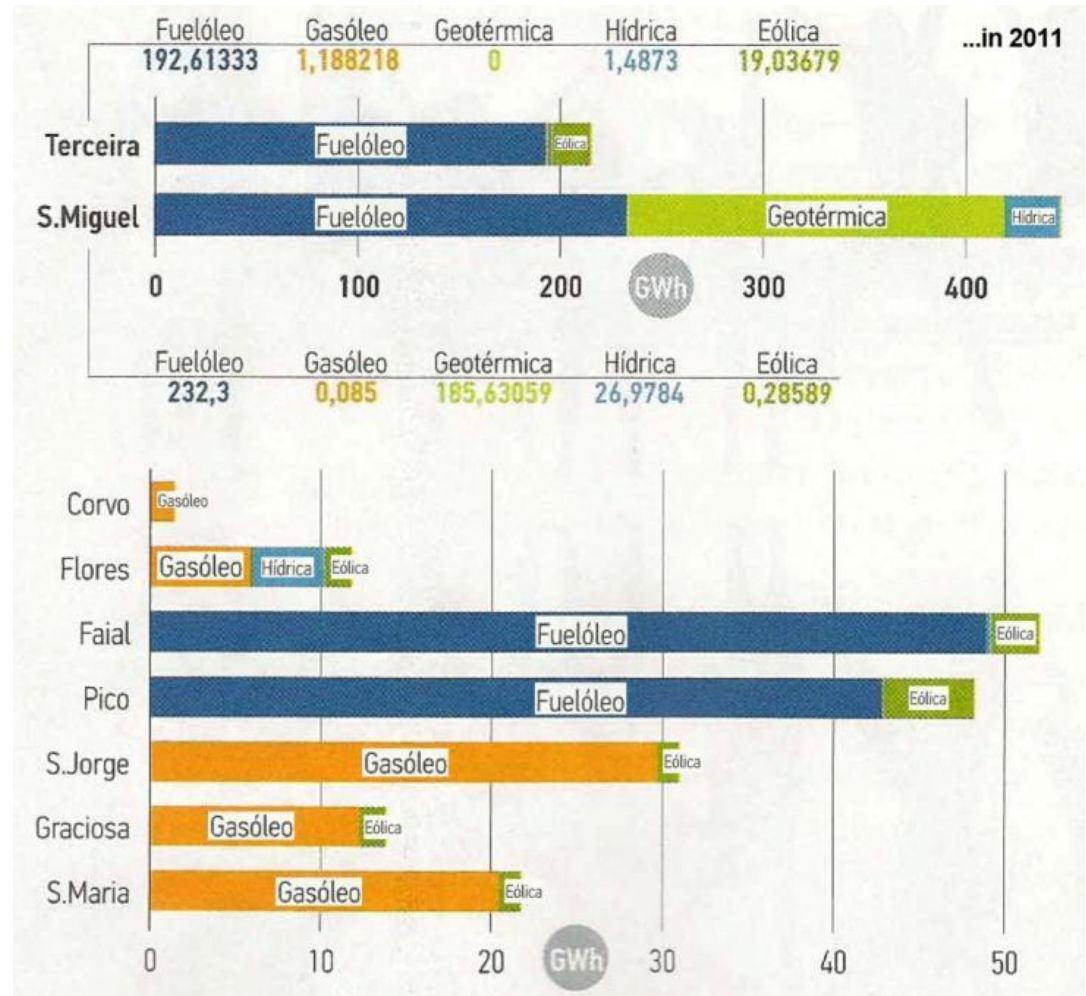


Adapted from C. Bicudo da Ponte, 2012
(INGENIUM, 64)



ELECTRICITY PRODUCTION IN THE AZORES

Primary sources production in 2011 FOR EACH ISLAND...



ELECTRICITY PRODUCTION IN THE AZORES ...the EDA **role** on the Regional Strategy!

AÇORES

2014 | 2020

PROGRAMA OPERACIONAL

Fundo Europeu de Desenvolvimento Regional - FEDER
Fundo Social Europeu - FSE

INDICADOR RESULTADO

Penetração dos recursos renováveis na produção de energia elétrica

Situação partida: 34,7% (2013)

Valor- alvo: 61% (2023)



GOVERNO DOS AÇORES



UNIÃO EUROPEIA

...HORIZON
2020 Strategy

...LOW ENTHALPY / DIRECT USES



...LOW ENTHALPY / DIRECT USES !

DIRECT USE OF THE GEOTHERMAL FLUID

Till now: (marginal) Direct Uses in Azores...
...e.g. the INOVA Institute **greenhouses**, from
1997 to 2005, when reinjection started!



...LOW ENTHALPY / DIRECT USES !

DIRECT USE OF THE GEOTHERMAL FLUID

In the near future: valuing the geothermal fluid in:

- Heating (e.g. swimming pools)
- Dermocosmetics uses (*)

(*) physico-chemical studies and tests (e.g. using experimental tanks) needed in advance!

IMPORTANT: high amounts of **As** (up to 1mg/L) unable the use of geothermal fluid in swimming pools/thermal baths!



...LOW ENTHALPY / DIRECT USES !

CALDEIRAS DA RIBEIRA GRANDE
DIRECT USE OF THE
GEOHERMAL FLUID



05-09-2014 09:23:54

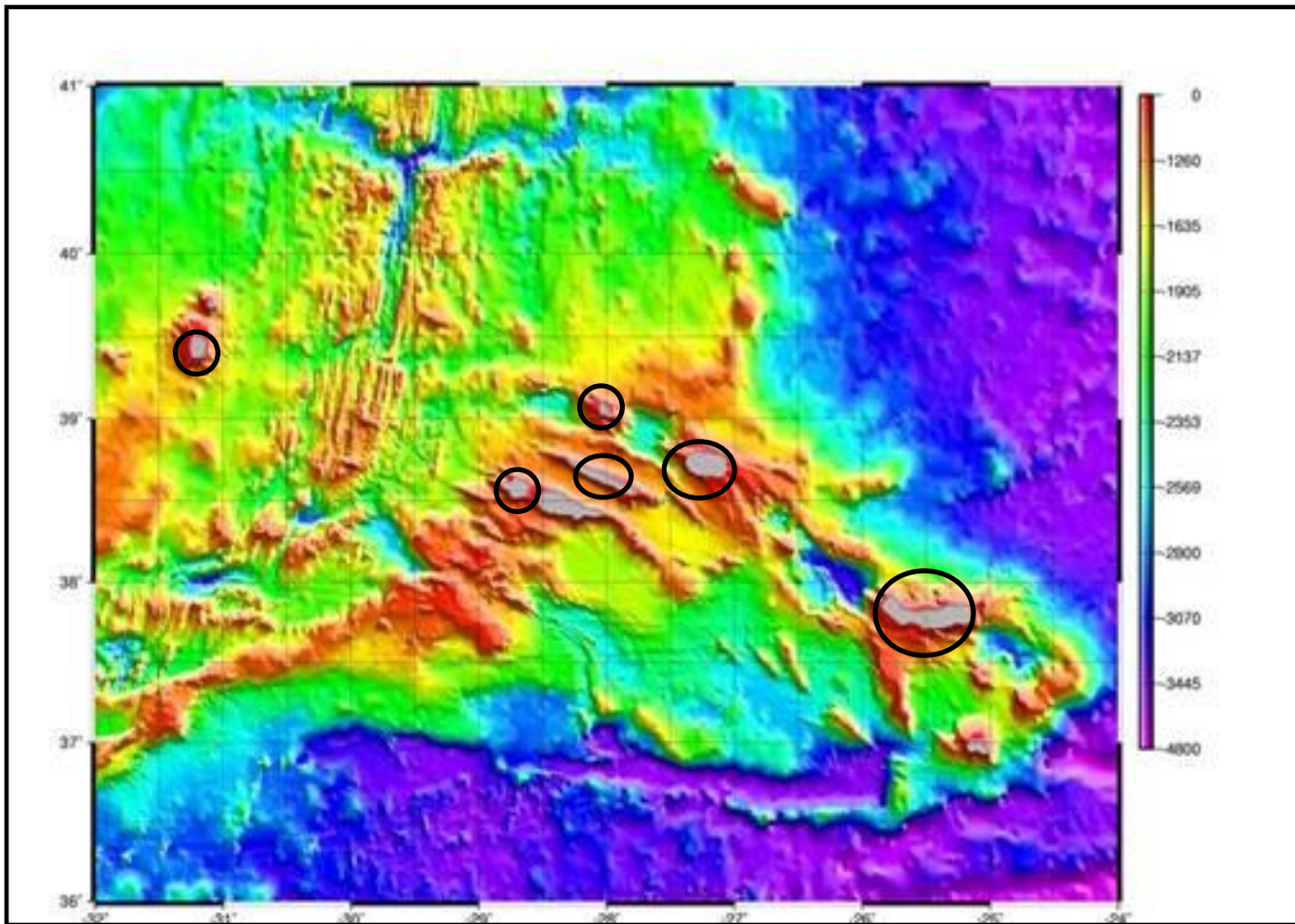


DC_2950.jpg



... a negative impact that became an opportunity!

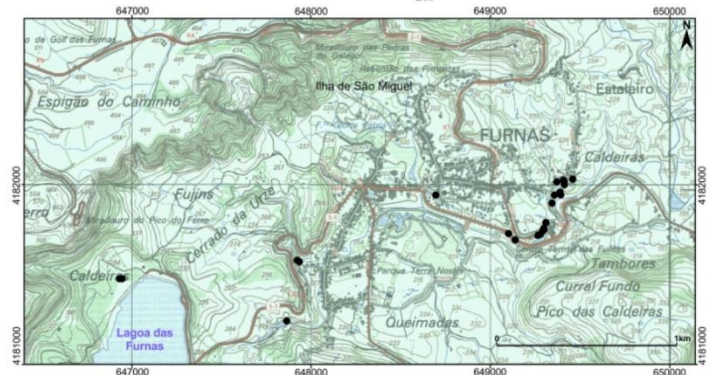
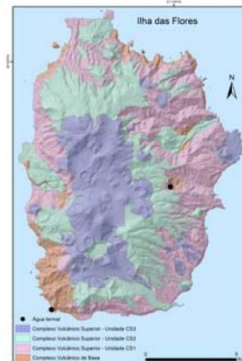
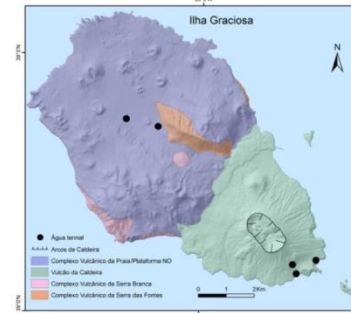
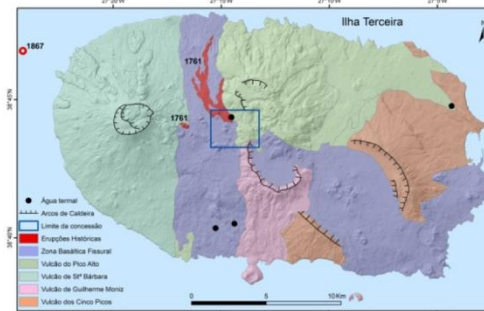
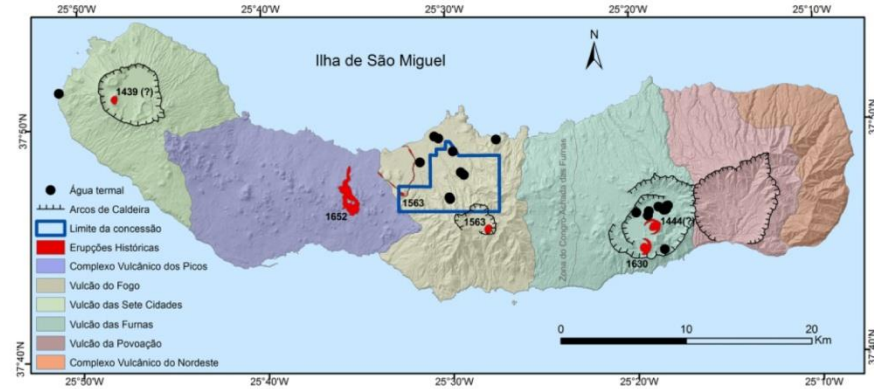
...LOW ENTHALPY / DIRECT USES



...**48 thermal springs/wells** at S. Miguel, Terceira, Faial, Graciosa, S. Jorge and Flores Islands ... traditionally used for balneotherapy/balneology

...the work done by the **INOVA Institute**, since 2004

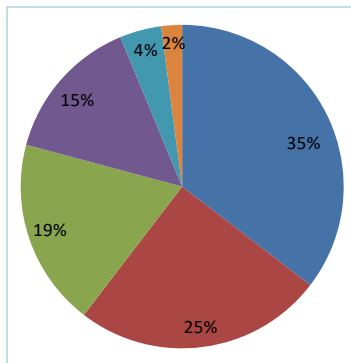
...LOW ENTHALPY / DIRECT USES !



50% of Azores thermal waters are at the Furnas Volcano caldera (e.g. “Hidrópole das Furnas”)

...thermal = $T > 22^{\circ}\text{C}$!

...LOW ENTHALPY / DIRECT USES



Nº de Ocorrências

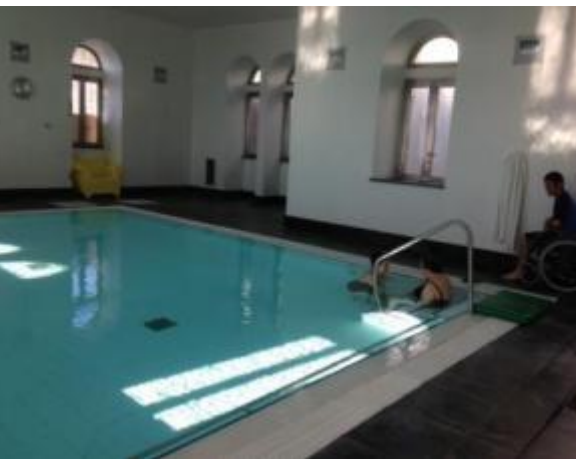
- Sulfúrea - 17
- Bicarbonatada - 12
- Gasocarbónica - 9
- Cloretada - 7
- Sulfatada - 2
- Silicatada - 1

...debit usually 1 - 4 L/s!

Nº	Designação	Temperatura máxima registada (°C)	Quimismo	Mineralização	Observações
1	Água da Prata (*)	24	Gasocarbónica, sulfúrea, bicarbonatada, sódica, fluoretada, ferruginosa	Fracamente mineralizada	Vulcão das Furnas - S. Miguel
2	Água Férrea (*)	39	Gasocarbónica, bicarbonatada, sódica, ferruginosa, fluoretada	Mesossalina	Vulcão das Furnas - S. Miguel
3	Bica da Água Santa (*)	96	Sulfúrea, bicarbonatada, sódica, fluoretada	Fracamente mineralizada	Vulcão das Furnas - S. Miguel
4	Caldeira Barrenta (Lagoa das Furnas)	68	Gasocarbónica, sulfúrea, sulfatada, sódica, ferruginosa, fluoretada	Mesossalina	Vulcão das Furnas - S. Miguel
5	Caldeira da Lagoa das Furnas	94	Sulfúrea, sulfatada, sódica, ferruginosa, fluoretada	Fracamente mineralizada	Vulcão das Furnas - S. Miguel
6	Caldeira da Ribeira dos Tambores	97	Sulfatada, sódica, fluoretada, ferruginosa	Mesossalina	Vulcão das Furnas - S. Miguel
7	Caldeira do Asmodeu (*)	88	Sulfúrea, bicarbonatada, sódica, fluoretada	Hipersalina	Vulcão das Furnas - S. Miguel
8	Caldeira do Esguicho (*)	93	Sulfúrea, bicarbonatada, sódica, fluoretada	Mesossalina	Vulcão das Furnas - S. Miguel
9	Caldeira dos Vimes (*)	73	Sulfúrea, bicarbonatada, sódica, ferruginosa	Fracamente mineralizada	Vulcão das Furnas - S. Miguel
10	Caldeira Grande (*)	98	Sulfúrea, bicarbonatada, sódica, fluoretada	Mesossalina	Vulcão das Furnas - S. Miguel
11	Caldeirão do Chalet (*)	78	Sulfúrea, bicarbonatada, sódica, fluoretada	Fracamente mineralizada	Vulcão das Furnas - S. Miguel
12	Encosta (*)	60	Bicarbonatada, sódica, ferruginosa, fluoretada	Mesossalina	Vulcão das Furnas - S. Miguel
13	Grutinha (*)	44	Gasocarbónica, bicarbonatada, sódica, fluoretada, ferruginosa	Mesossalina	Vulcão das Furnas - S. Miguel
14	Grutinha/Ernesto Correia (*)	41	Gasocarbónica, bicarbonatada, sódica, fluoretada, ferruginosa	Mesossalina	Vulcão das Furnas - S. Miguel
15	Morangueira (*)	33	Sulfúrea, bicarbonatada, sódica, fluoretada, ferruginosa	Mesossalina	Vulcão das Furnas - S. Miguel
16	Padre José (*)	58	Sulfúrea, bicarbonatada, sódica, fluoretada, ferruginosa	Fracamente mineralizada	Vulcão das Furnas - S. Miguel
17	Poça da Dona Beija	39	Bicarbonatada, sódica, ferruginosa, fluoretada	Fracamente mineralizada	Vulcão das Furnas - S. Miguel
18	Poço (*)	47	Bicarbonatada, sódica, ferruginosa, fluoretada	Mesossalina	Vulcão das Furnas - S. Miguel
19	Quenturas (*)	59	Bicarbonatada, sódica, fluoretada, ferruginosa	Mesossalina	Vulcão das Furnas - S. Miguel
20	Rego (*)	57	Sulfúrea, bicarbonatada, sódica, fluoretada, ferruginosa	Mesossalina	Vulcão das Furnas - S. Miguel
21	Ribeira de Nossa Senhora/Terra Nostra	42	Bicarbonatada, sódica, ferruginosa, fluoretada	Fracamente mineralizada	Vulcão das Furnas - S. Miguel
22	Ribeira Quente	44	Bicarbonatada, sódica, fluoretada, ferruginosa	Mesossalina	Vulcão das Furnas - S. Miguel
23	Sanguinhal	36	Bicarbonatada, sódica, fluoretada	Fracamente mineralizada	Vulcão das Furnas - S. Miguel
24	Torno (*)	40	Bicarbonatada, sódica, fluoretada, ferruginosa	Mesossalina	Vulcão das Furnas - S. Miguel
25	Três Bicas (*)	57	Bicarbonatada, sódica, fluoretada, ferruginosa	Mesossalina	Vulcão das Furnas - S. Miguel
26	BEL Portugal	40	Cloretada, sódica	Hipersalina	Vulcão do Fogo - S. Miguel
27	Caldeira Velha - Fumarola	98	Sulfatada, sódica, potássica	Fracamente mineralizada	Vulcão do Fogo - S. Miguel
28	Caldeira Velha - Nascente	31	Silicatada, cloretada, bicarbonatada, sódica, ferruginosa	Hipossalina	Vulcão do Fogo - S. Miguel
29	Caldeiras da Ribeira Grande - Fumarola	59	Sulfúrea, sulfatada, sódica, ferruginosa, fluoretada	Fracamente mineralizada	Vulcão do Fogo - S. Miguel
30	Cerâmica Vieira	58	Cloretada, sódica	Mesossalina	Vulcão do Fogo - S. Miguel
31	INSULAC	28	Bicarbonatada, sódica, potássica	Fracamente mineralizada	Vulcão do Fogo - S. Miguel
32	Ladeira da Velha	30	Gasocarbónica, bicarbonatada, sódica	Fracamente mineralizada	Vulcão do Fogo - S. Miguel
33	Monte dos Frades	28	Bicarbonatada, sódica	Fracamente mineralizada	Vulcão do Fogo - S. Miguel
34	Pocinha	29	Sulfúrea, cloretada, bicarbonatada, sódica, ferruginosa	Fracamente mineralizada	Vulcão do Fogo - S. Miguel
35	Ferraria - Furo AC3	61	Cloretada, sódica, ferruginosa	Hipersalina	Vulcão das Sete Cidades - S. Miguel
36	Juncal	23	Sulfúrea, cloretada, sódica	Mesossalina	Vulcão dos Cinco Picos - Terceira
37	ER1	27	Gasocarbónica, bicarbonatada, sódica	Fracamente mineralizada	Vulcão do Pico Alto - Terceira
38	Terra Chã	25	Sulfúrea, bicarbonatada, cloretada, sódica, fluoretada	Fracamente mineralizada	Zona Basáltica Fissural - Terceira
39	Terra Chã - Furo Caminho Posto Santo	39	Sulfúrea, bicarbonatada, sódica, fluoretada	Mesossalina	Zona Basáltica Fissural - Terceira
40	Carapacho - Furo AC1	43	Cloretada, sódica, ferruginosa	Hipersalina	Vulcão da Caldeira - Graciosa
41	Carapacho - Furo PS2	39	Cloretada, sódica	Hipersalina	Vulcão da Caldeira - Graciosa
42	Homiziados	56	Cloretada, sódica, ferruginosa	Hipersalina	Vulcão da Caldeira - Graciosa
43	Guadalupe - Furo Courelas	42	Gasocarbónica, cloretada, sódica, ferruginosa	Hipersalina	Plataforma NO - Graciosa
44	Pontal	28	Cloretada, sódica	Hipersalina	Plataforma NO - Graciosa
45	Azeda da Caldeira de Santo Cristo	22	Gasocarbónica, bicarbonatada, sódica	Fracamente mineralizada	Ilha de S. Jorge
46	Capelo	40	Sulfúrea, cloretada, sódica, ferruginosa	Hipersalina	Península do Capelo - Faial
47	Lajedo	48	Sulfúrea, cloretada, sódica, fluoretada	Hipersalina	Ilha das Flores
48	Poio Moreno	25	Bicarbonatada, sódica	Mesossalina	Ilha das Flores

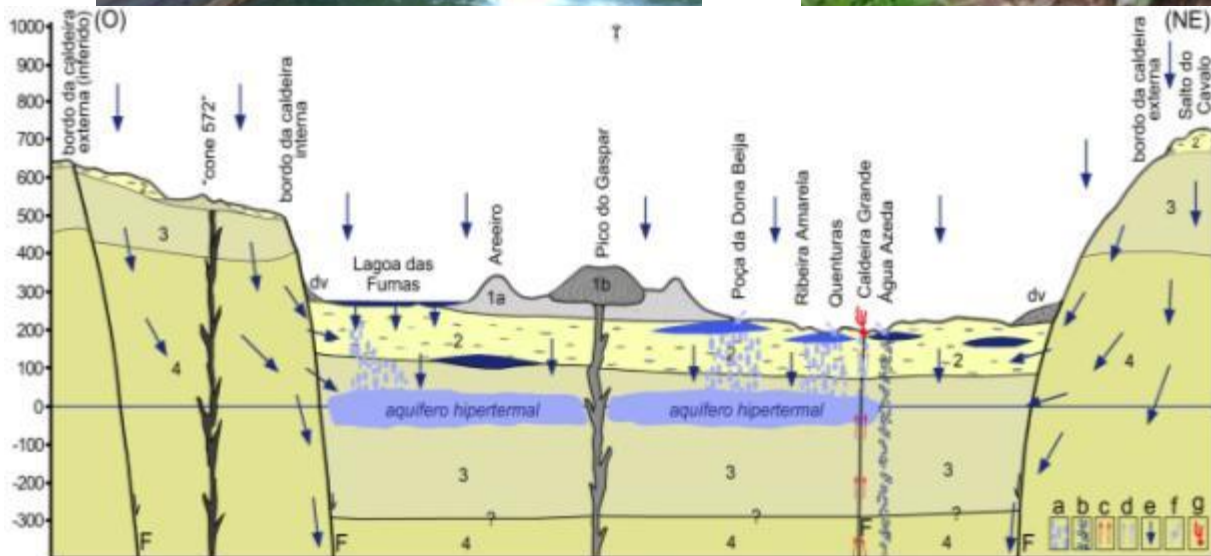
SOME ACHIEVEMENTS: Carapacho (Graciosa Is.) & Ferraria (S. Miguel Is.)
Thermal Baths

...LOW ENTHALPY / DIRECT USES



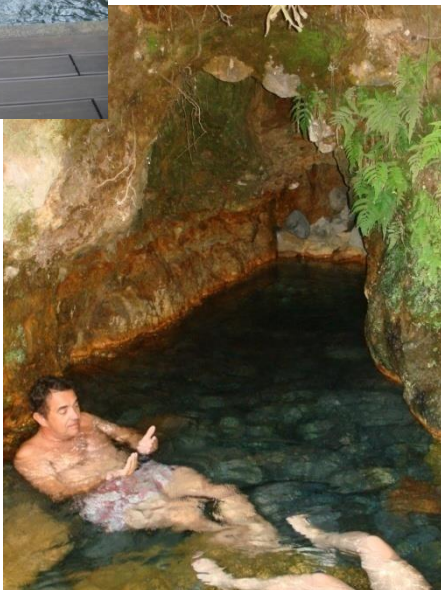
SOME ACHIEVEMENTS: Furnas Boutique Hotel Thermal & Spa (S. Miguel Is.)

...LOW ENTHALPY / DIRECT USES



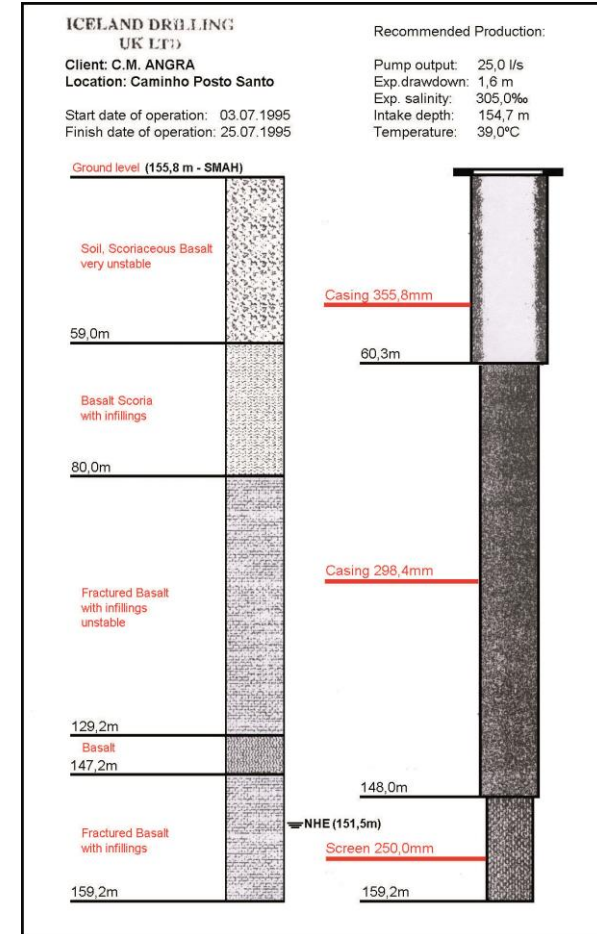
SOME ACHIEVEMENTS: Caldeira Velha & Poça da Dona Beija (S. Miguel Is.)
Thermal Areas

...LOW ENTHALPY / DIRECT USES !



SOME ACHIEVEMENTS...AND ONGOING / FUTURE R&D: Caminho do Posto Santo thermal well (Terceira Is.)

...LOW ENTHALPY / DIRECT USES !



SOME ACHIEVEMENTS...AND ONGOIN / FUTURE R&D:

Dermocosmetic studies and testing

...thermal muds

...LOW ENTHALPY / DIRECT USES !



Scientific Support:

- Fac. Farmácia U.Porto
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Partnership:
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Partnership: *Azores Live Science*



THANK YOU

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