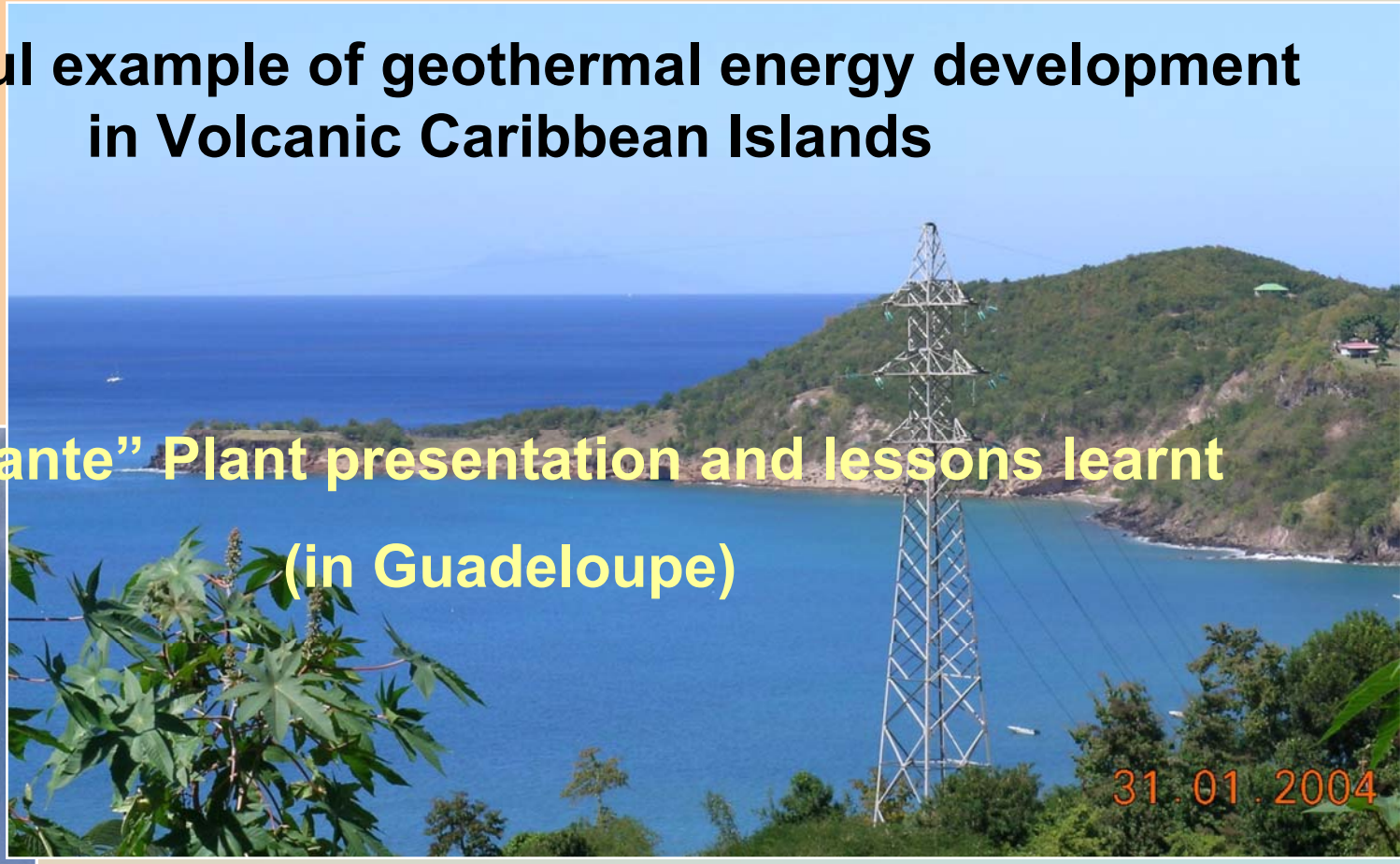
Successful example of geothermal energy development in Volcanic Caribbean Islands



"Bouillante" Plant presentation and lessons learnt (in Guadeloupe)

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ADEME 2006

- Staff: 850 (65 on Renewable energy technologies - RET)
- 26 Regional offices (4 overseas)
- Budget 2006: 300 M€ (70 M€ on RET)

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ADEME: Geothermal energy background (1)

- Heat production and distribution:

☐ support to low enthalpy geothermal operations: 34 operations fully competitive (300 MWth)

☐ plan launched to have 10 additional projects (+ 100 MWth) by 2010

☐ risk reduction financial fund (RRFF): established in the 80's and managed by ADEME with the involvement of all stakeholders

- drilling risk reduction: up to 65% of drilling costs (if dry well)
- long term risk reduction to address geological events which could affect project viability (t°, Q, scaling)
- 10 M€ to be paid on the period as financial compensations
- RRFF to be expanded financially in 2006 to integrate new projects

☐ World Bank consultant to run the GEOFUND project (Eastern Europe, Federation of Russia, Central Asia)

ADEME: Geothermal energy background (2)

- Electricity generation:

☐ Project support in Guadeloupe, Martinique and Reunion Regions in partnership with the Regional Councils on feasibility studies, exploration work, RRFF implementation

- Guadeloupe: launch of Bouillante phase 3 - 2006-2010 (10-30 MWe) under the EDF/BRGM leadership

- Martinique and Reunion: exploration works (geological surveys and drilling)

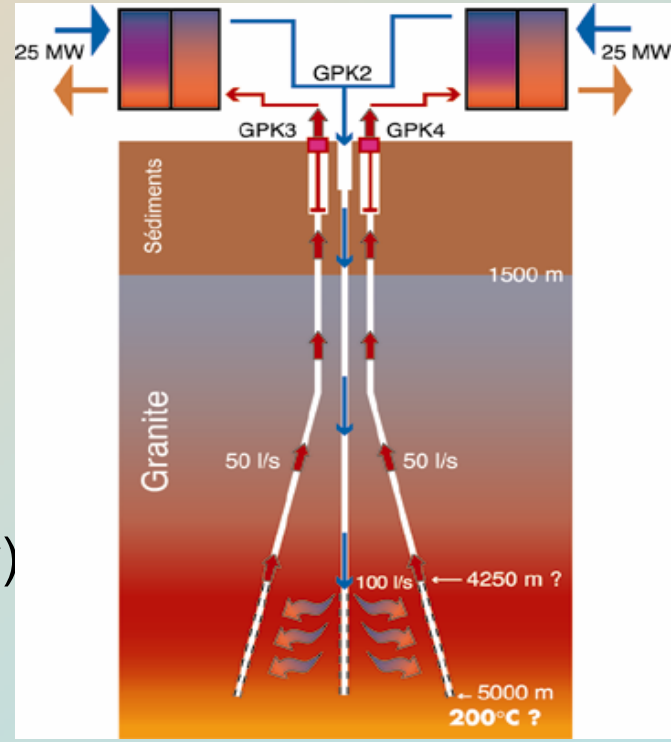
ADEME: Geothermal energy background (3)

- Electricity generation:

☐ R&D project on HDR (Hot Dry Rocks / Deep heat mining): pilot plant (4.5 MWe) and three wells 5 000 m deep to validate new concepts

- Phase 2 (2004-2008): 21 M€ supported by ADEME (France), BMU (Germany) and EU Commission, with EDF/EDS as leader of the EU consortium

- Technology transfer possible in the Caribbean (stimulation to increase permeability)



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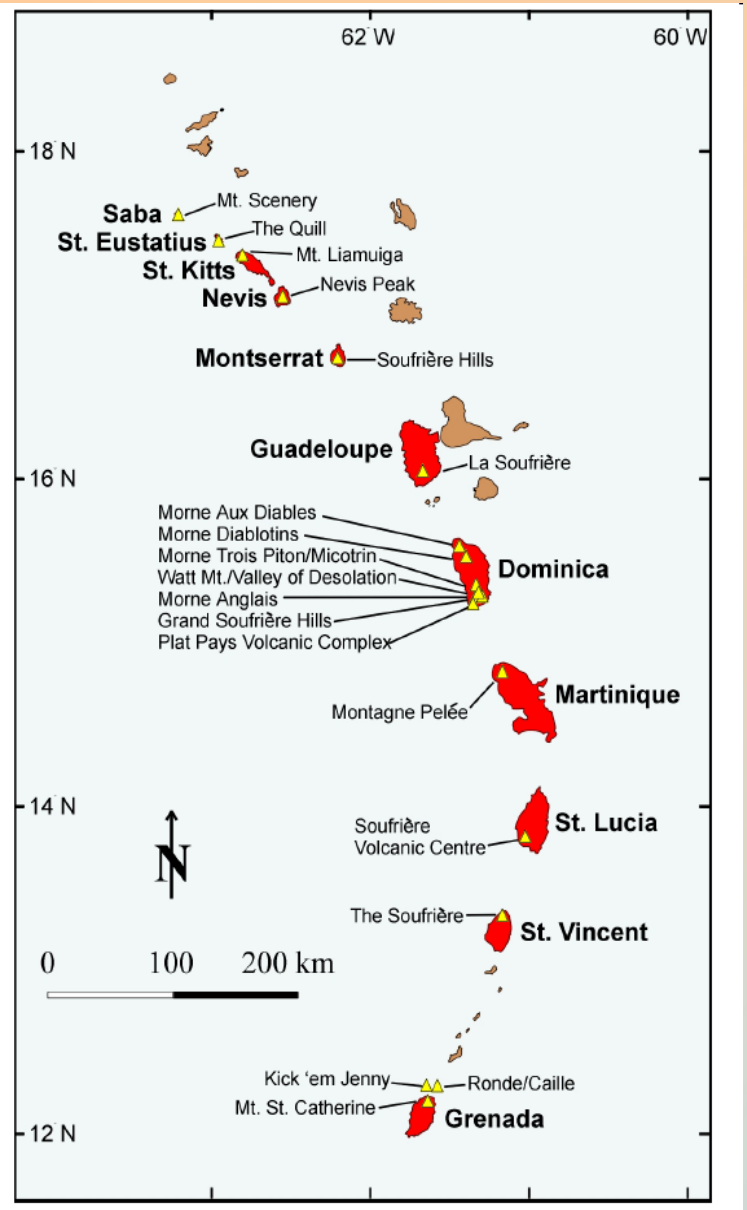
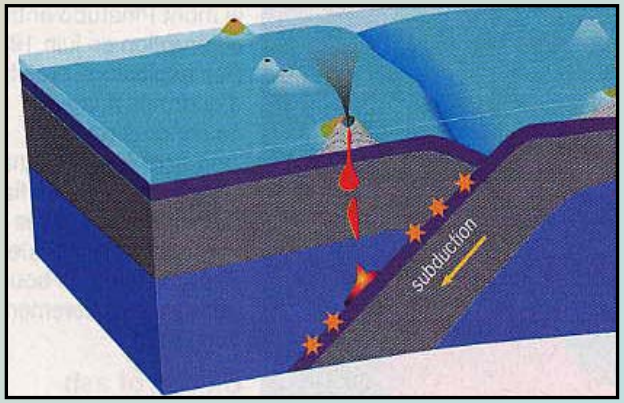
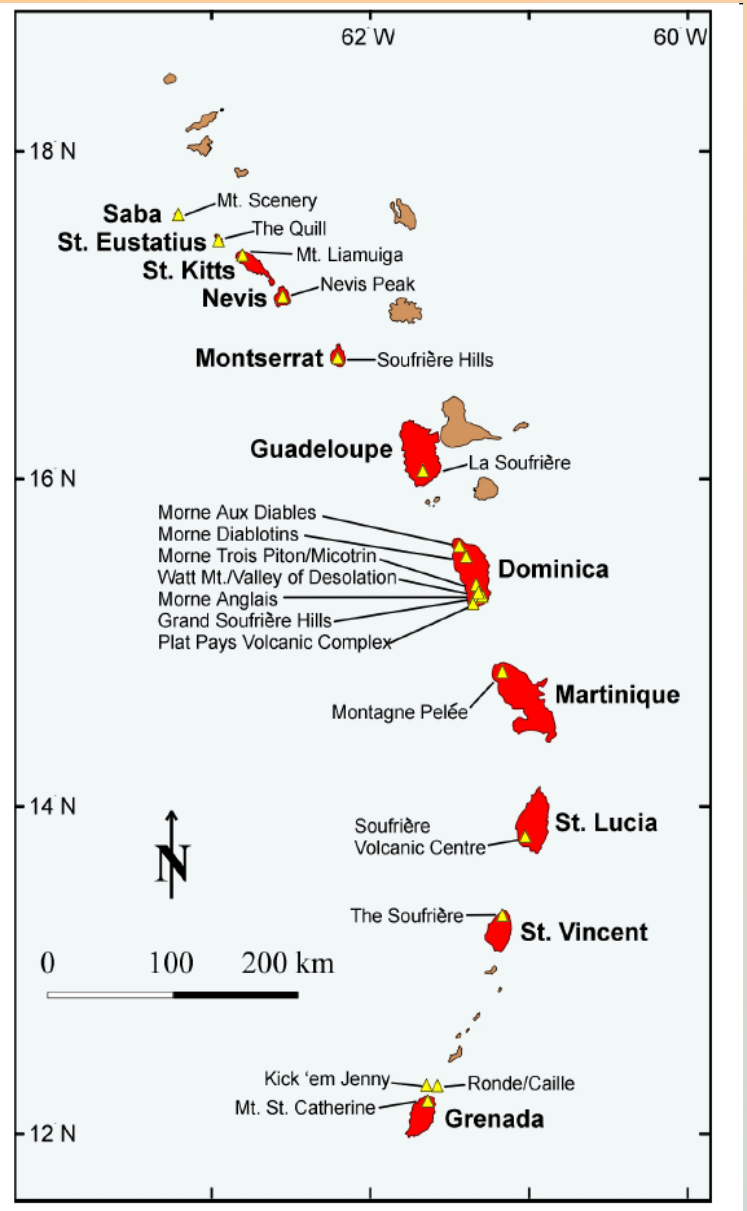


Map of the Caribbean volcanic islands (red color) and their active or recent volcanoes.



Subduction of the Atlantic Plate below the Caribbean Plate



Energy in the Caribbean

- More than 90% of electricity generated from fossils fuels, with strong Greenhouse gas impacts
- Low contribution of Renewable energy sources at this stage :
  - Biomass
  - Hydro
  - Solar
  - Wind
  - **Geothermal**
- Electricity needs increase by 4-5% every year.

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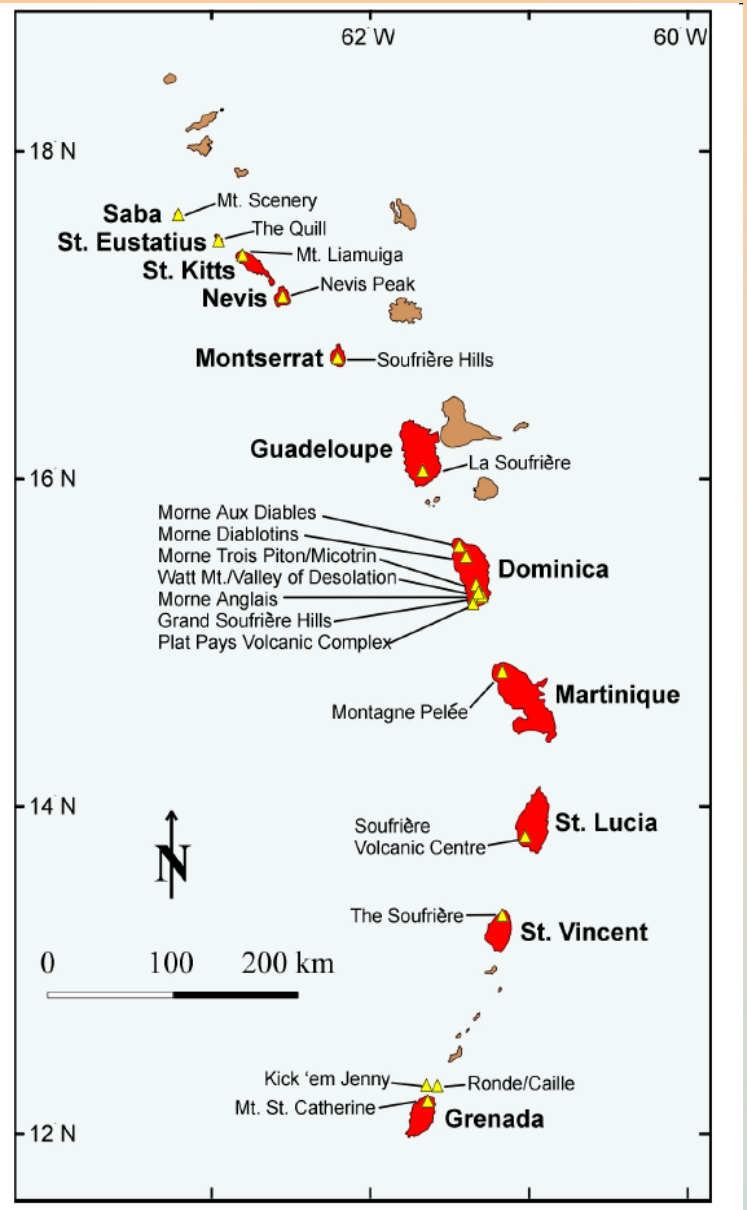
Geothermal Development in the Caribbean – Bouillante Plant Presentation



Volcanic Islands	*Survey*	*Pre-feasibility*	*Deep drillings*	*Installed capacity (MWe)*	*Expected Potential (MWe)*
Saba	yes				
St Eustatius	yes				
St Kitts	yes				
Nevis	yes				**10-50**
Montserrat	yes	yes			
Guadeloupe	yes	yes	yes	**15**	**30 - 50**
Dominica	yes	yes			**50 -100**
Martinique	yes	yes	yes		**10- 50**
Ste Lucia	yes	yes	yes		**10-50**
St Vincent	yes	yes			
Grenada	yes				

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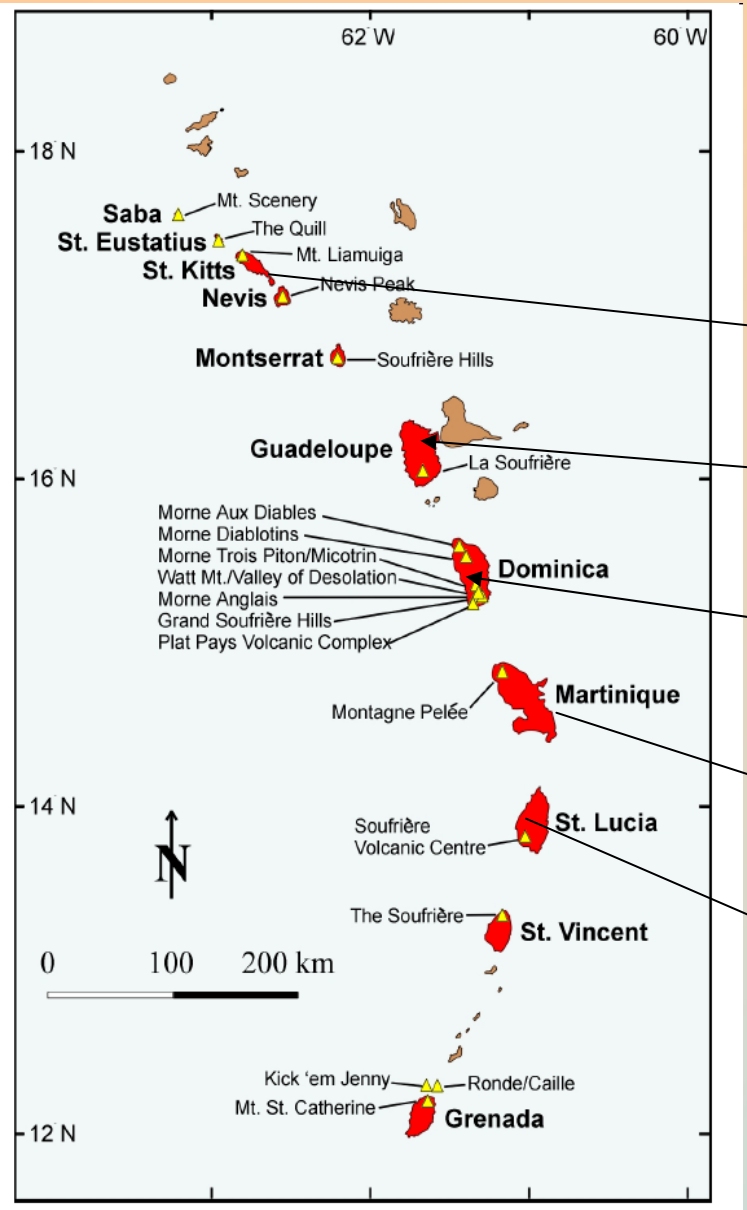

Geothermal resources might contribute to power generation in some islands instead of fossil fuels

St Kitts and Nevis, promising areas

Bouillante, the case history in Caribbean

Dominica, the most promising geothermal potential

Martinique, promising areas in the north and in the south

Sainte-Lucie, promising areas

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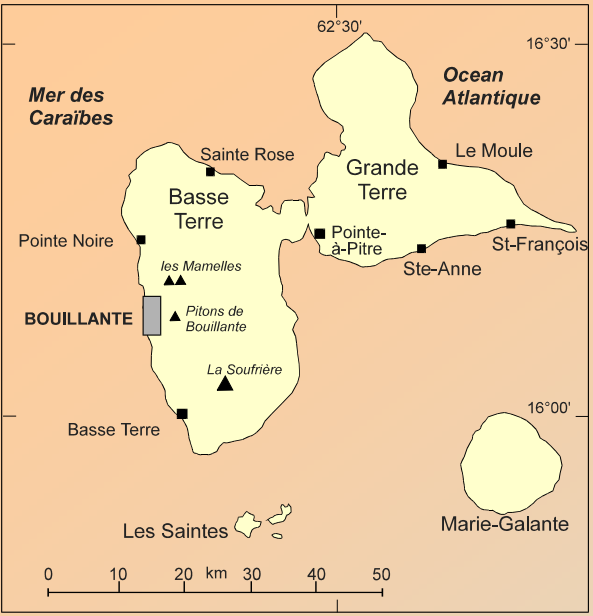
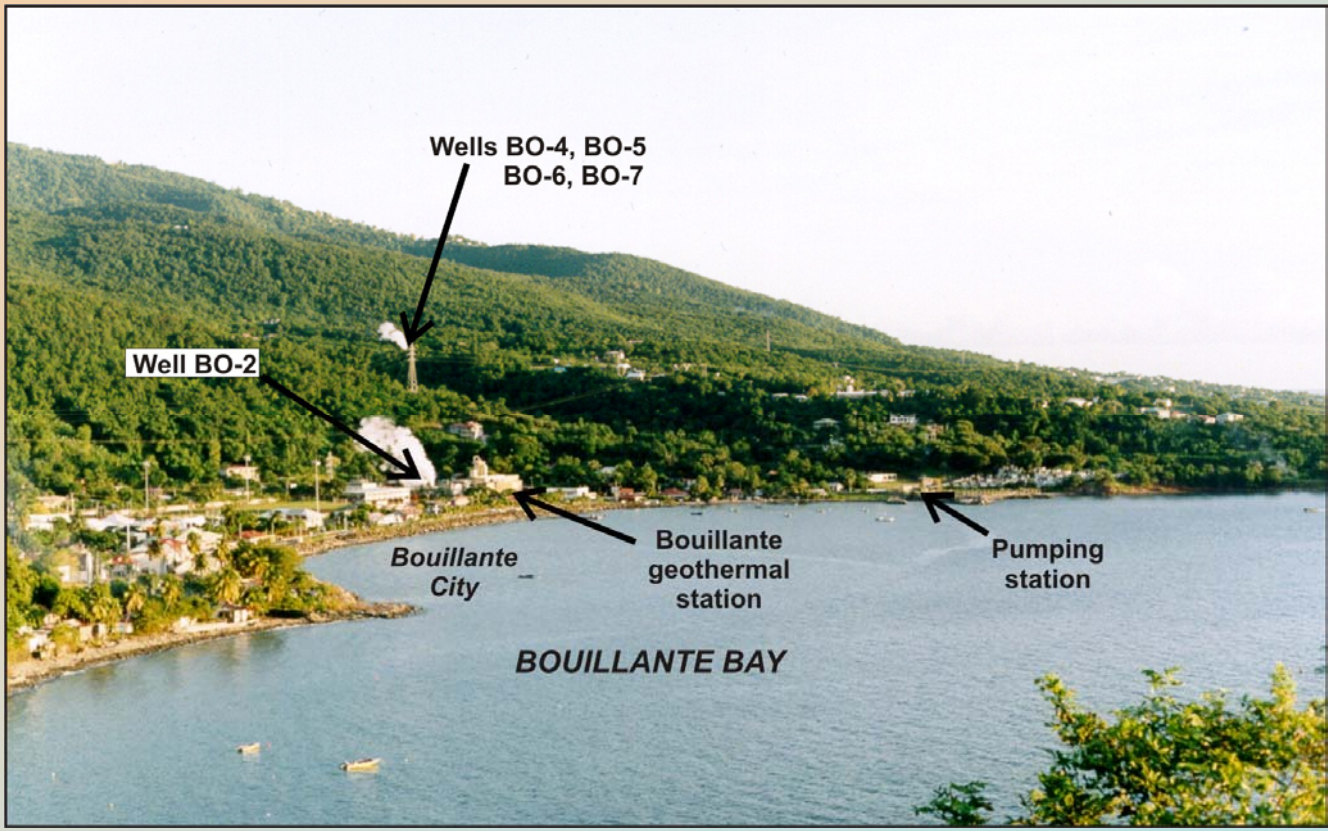


The Bouillante geothermal field, Guadeloupe



Urban area
Steep topography area
Sea proximity

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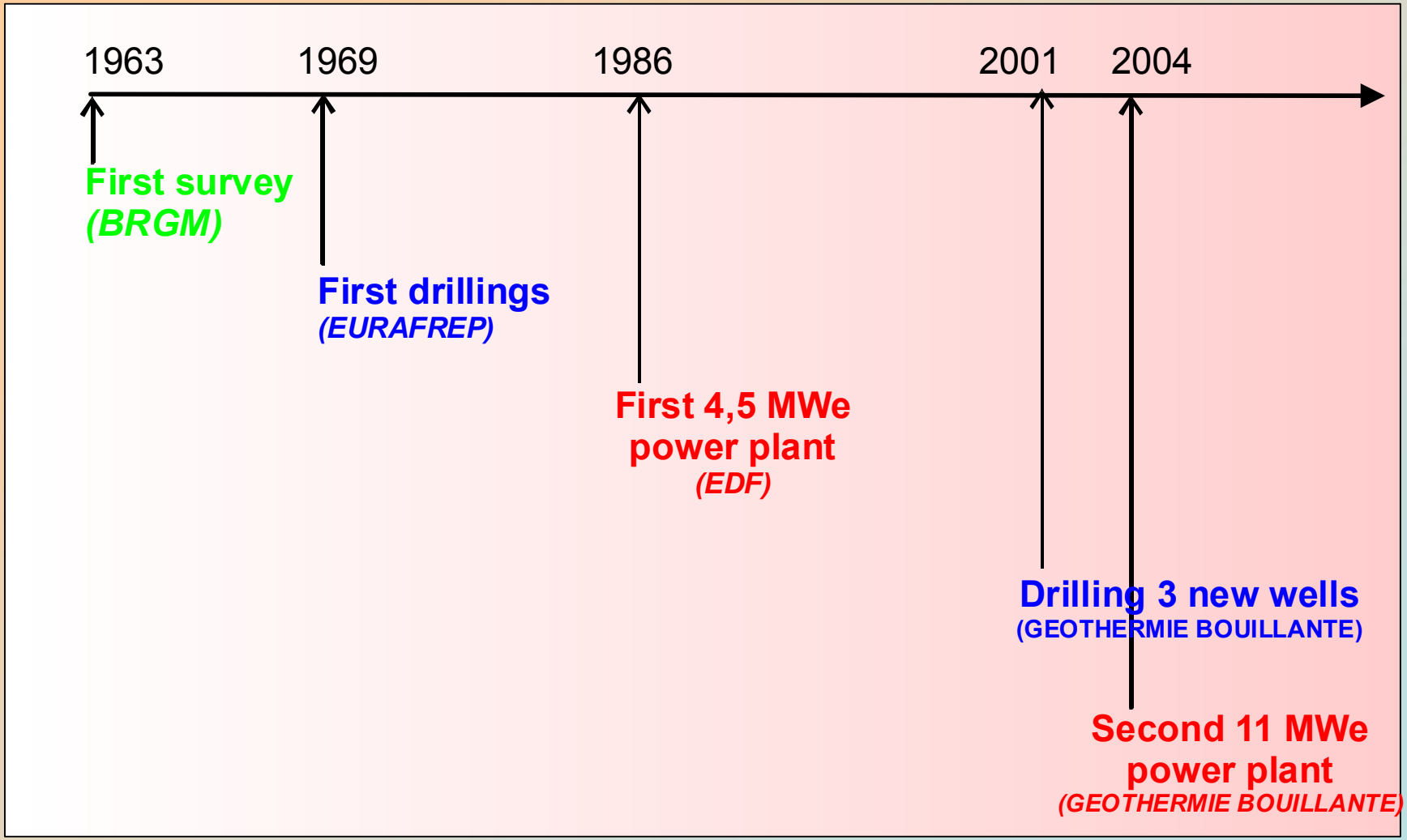
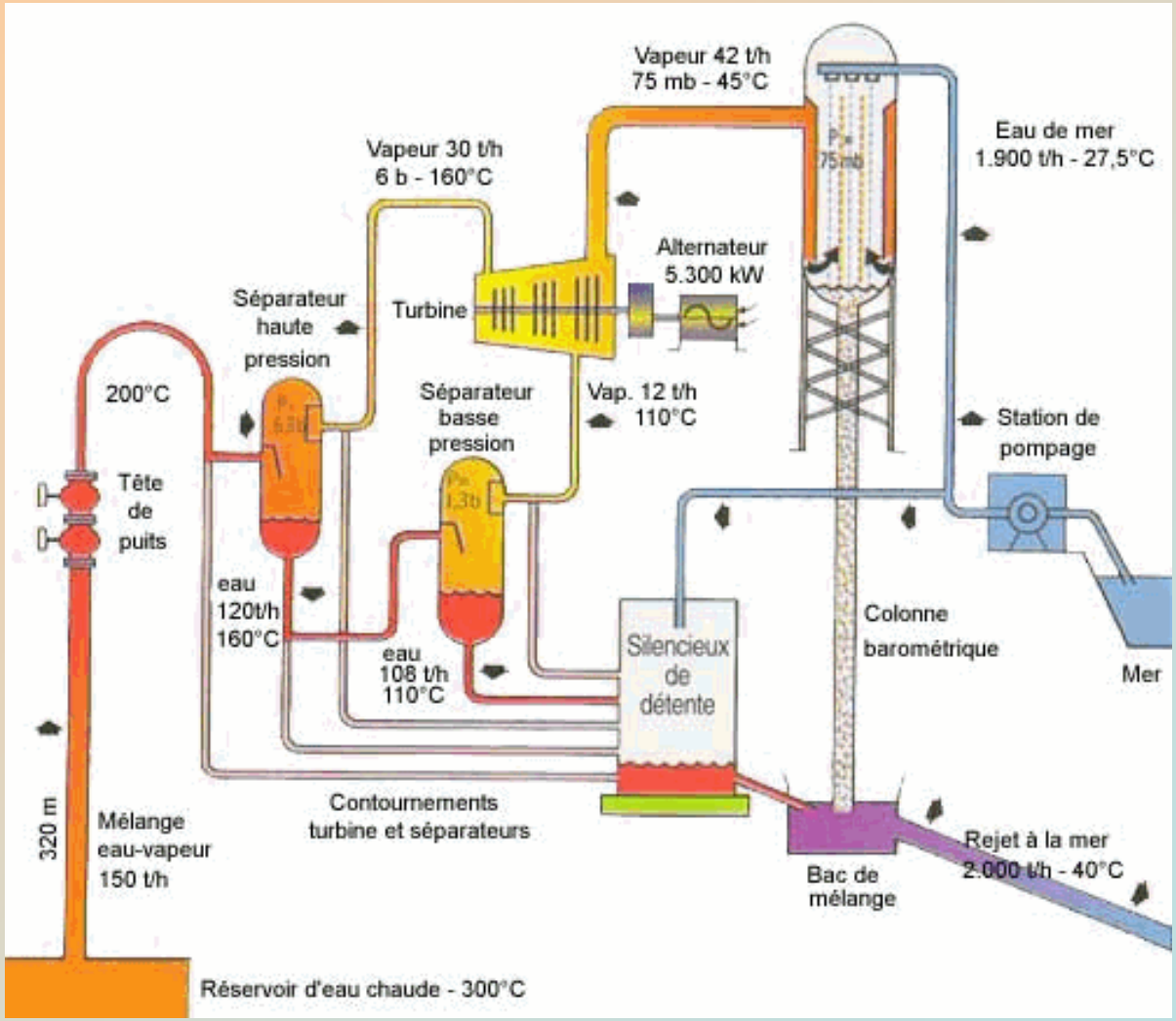
The story of the Bouillante geothermal exploitation



Bouillante Unit 1 (4.7 MW)

Schematic view of the plant (4.7 MW)



Vue aérienne de l'exploitation géothermique actuelle "Bouillante 1"
(lors d'un test de coloration du rejet pour une étude d'impact)

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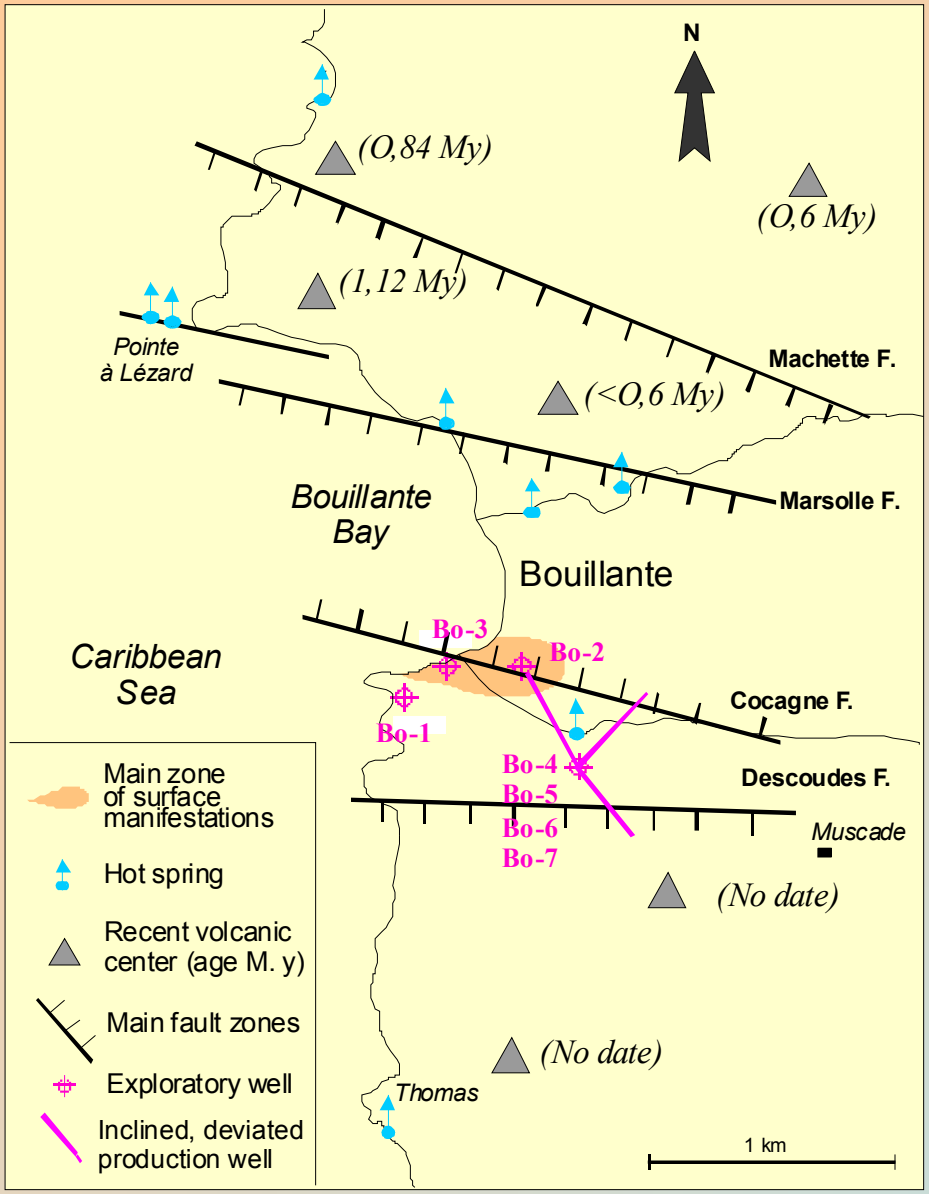


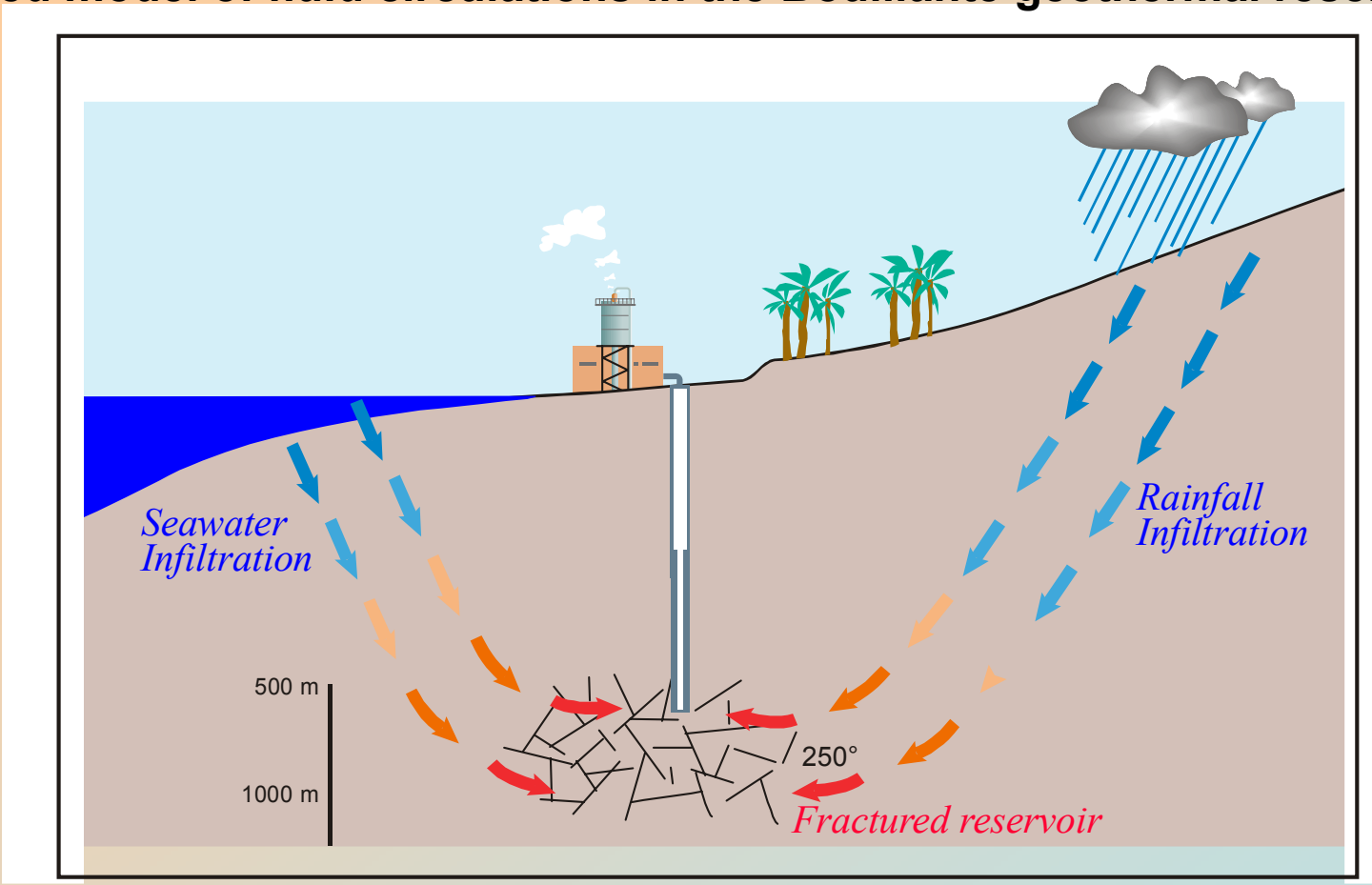
The Bouillante geothermal field

- Several recent eruptive centers (<1 MA) around the Bouillante Bay, with the possible occurrence of shallow magmatic intrusion under cooling;

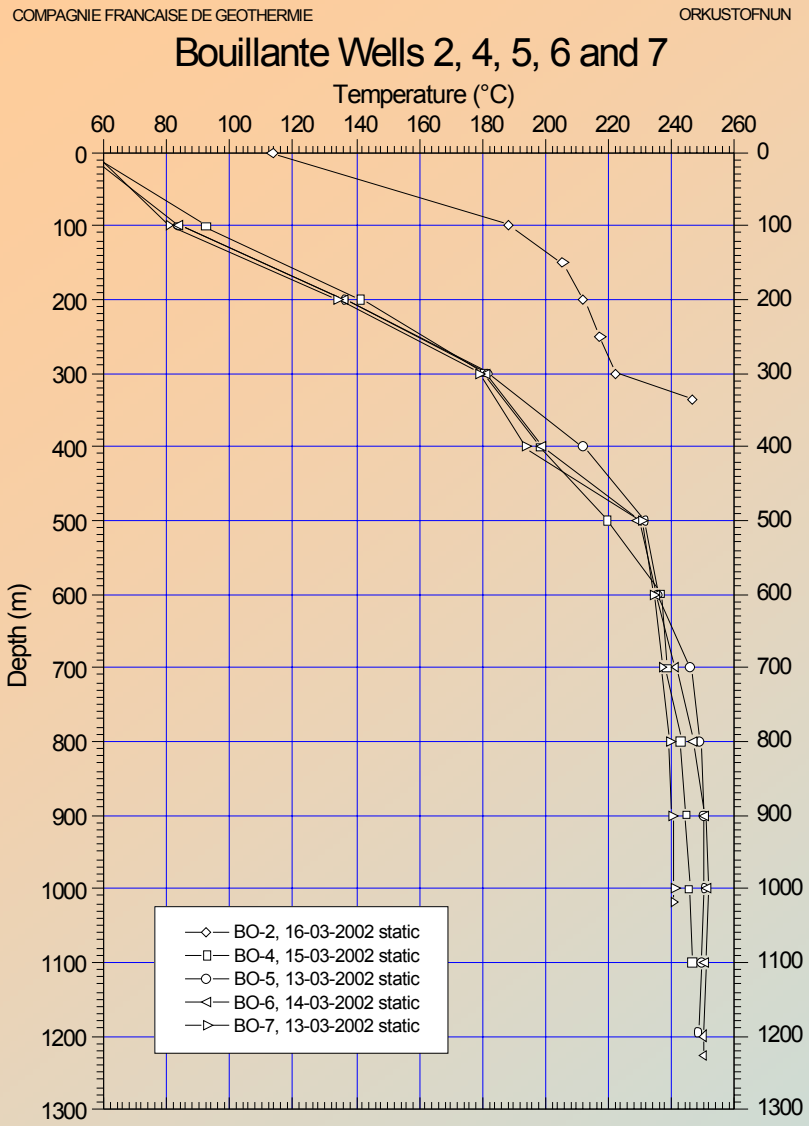
- Several main normal faults which promote permeability and fluid circulations at depth and represent potential fractured reservoirs;

- Only a part of the reservoir is now exploited through BO-4 vertical production well, BO-5 and BO-6 deviated and inclined production wells which intersect the Cocagne Fault.

Simplified model of fluid circulations in the Bouillante geothermal reservoir



Simplified cross-section along a West-East profile within the Bouillante geothermal field showing the assumed model of fluid circulation with seawater and rainfall recharge, mixing (60% seawater + 40% rainfall) and heating to 250-270°C.



Selected temperature profiles in the Bouillante wells.

240°C at shallow level (well BO-2)

Reservoir temperature around 250°C

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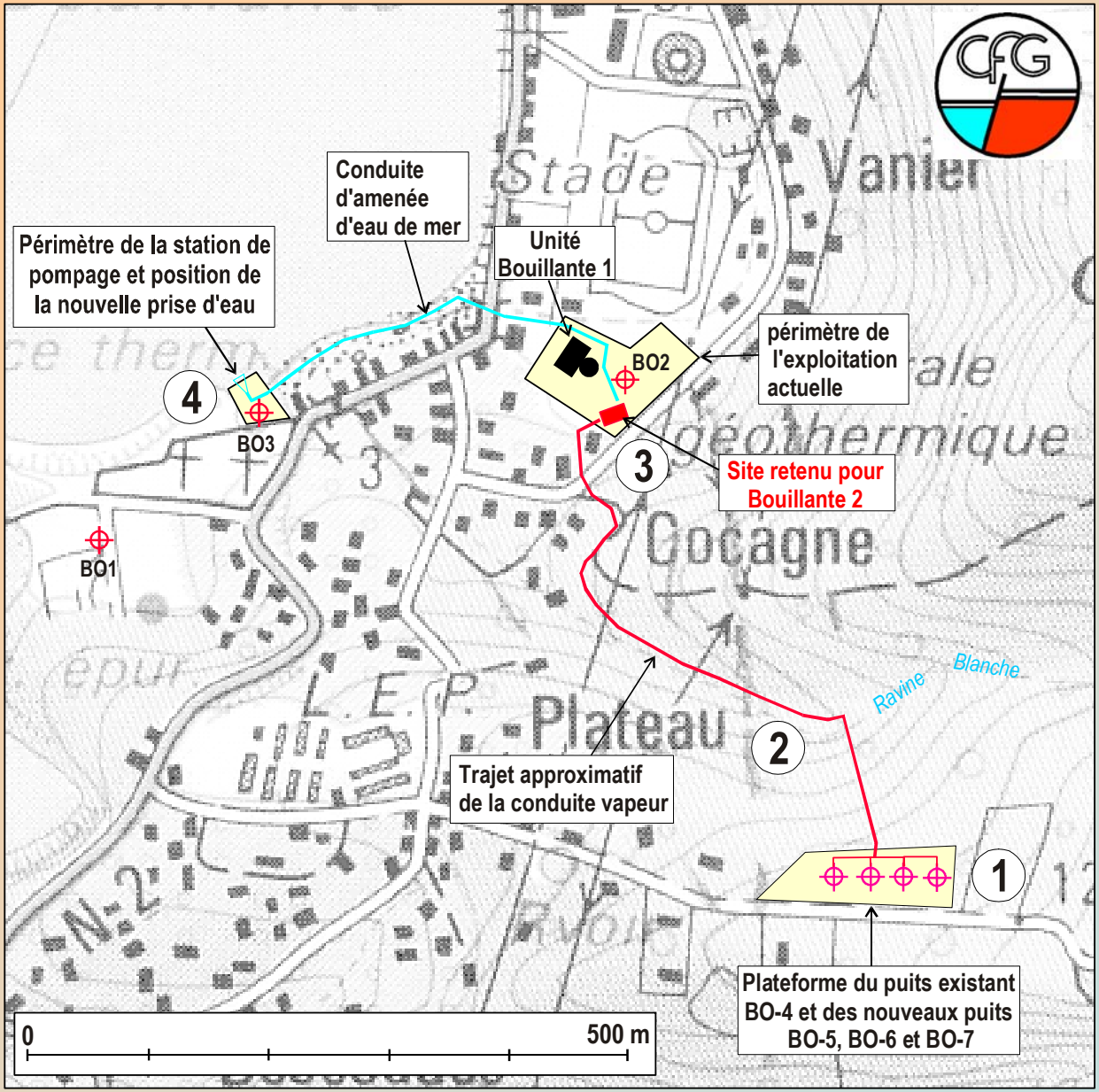


Layout of main existing equipements

The well platform and the equipment used for drilling directional wells BO-5, BO-6 and BO-7 (Dec. 2000 - May 2001). The Caribbean sea in background

View of the well pad for drilling operations of the three new wells- BO-5, BO-6 et BO-7- in Bouillante. Above (left), details of the BO6 wellhead and above (right) vapor discharge during a production test (May 2001)

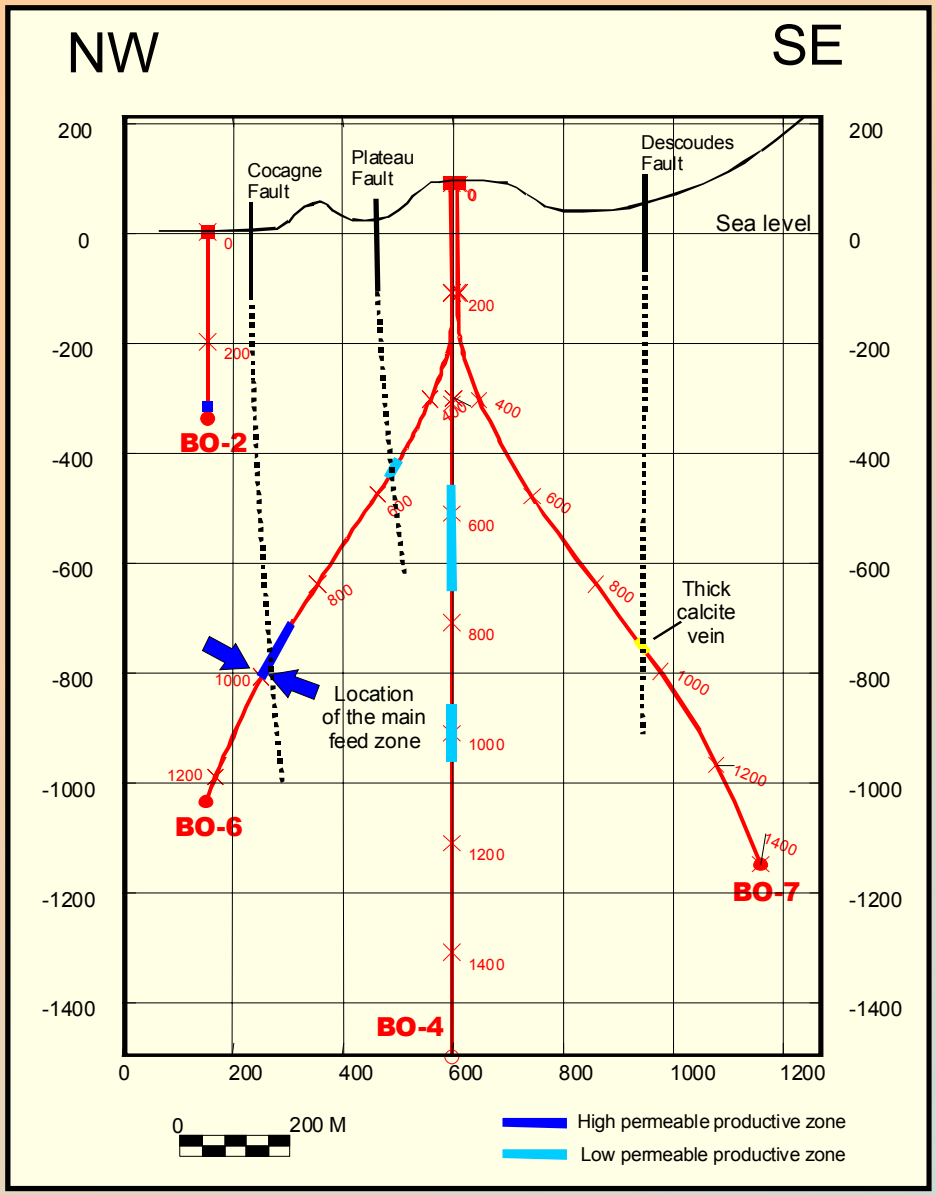
Partial view of the well pad with four well heads BO-4 to BO-7, at the end of the construction work and of the geothermal fluid transportation pipe to the power plant

(March 2002).

Main characteristics of the 7 deep wells drilled at Bouillante

Well	*Year*	*Trajectory*	*Total length (m)*	*Bottom hole T (°C)*	*Result*
BO-1	1969	vertical	850	(225)	No HP production
BO-2	1970	vertical	350	245-250	Producer
BO-3	1970	vertical	850	(245)	No HP production
BO-4	1974-77	vertical	2 500	250	Low producer *(Stimulation needed)*
BO-5	2001	deviated	1 197	250	Good producer
BO-6	2001	deviated	1 248	250	Good producer
BO-7	2001	deviated	1 400	240	No HP production

High temperature conditions at shallow depth (< 1000 m deep) but strong anisotropy in permeability related to fracture network and possibly to scaling (carbonates, silica).



Cross-section along a NW-SE profile showing well trajectories, location and quality of permeable zones in relation with faults deduced from surface geology.

- Only the Cocagne Fault appears to be highly permeable.
- Plateau Fault shows low permeability.
- Descoudes Fault has no permeability possibly due to carbonates scaling

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Partial view of the constuction phase with the geothermal fluid transportation two-phase pipe and the fluid separator (December .2001)

Aerial view of the well pad and the pipe route.

Steep topography and urban area reduce land availability for well pads, pipe routes, etc…, and consequently may hinder best locations for production and reinjection zones.

Aerial view of the geothermal plant located within the city

Bouillante 1 Unit (4,5 MWe)

Bouillante 2 Unit (11 MWe)

The location of the plant within the city induced strong environmental constraints (no noise, no steam plume, …).

Sea proximity also reduces surface availability for well siting and might require to reduce distances between production and reinjection zones.

Bouillante plants – main characteristics

- **Bouillante 1**

Double flash unit

Nominal Power capacity : 4,7 MW

One well (350 m depth)

- **Bouillante 2**

Single flash unit

Nominal Power capacity : 11 MW

3 wells (depth between 1 000 and 1 150 m)

- **Other characteristics**

Production : 30 GWh/y (Bouillante 1) and 72 GWh/y (Bouillante 2)

Availability factor : 90%

Energy contribution : 9% of the electricity consumed in Guadeloupe

"Bouillante" show case: lessons learnt

• Valuable experience for future developments in the region from a scientific and operational perspective (modeling tools for geothermal field definition, design of exploration phase, sitting of exploitation wells to maximise success factor, monitoring of exploitation work),

• Feed in tariff at 8 c€/kWh acceptable for electricity generation from geothermal energy within a context of high electricity costs in islands (15 c€/kWh or more)

• Successful implementation by ADEME/EDF of a drilling risk reduction financial fund (based on expected outputs - vapor production)

CONCLUSIONS

Guadeloupe show case

"High enthalpy" geothermal energy exploitation in Caribbean Volcanic islands has been demonstrated as a key technology for electricity generation in competitive conditions.

Bouillante and other fields (will) have to face challenges related to :

- Permeability anisotropy within the geothermal reservoir: wells have to intersect main faults in order to be good producers,
- Steep topography and limited land availability for well pad, pipe routes…
- Environmental constraints due to urban areas or national park,
- Remote location (extra costs for surveys, drilling, logging, stimulation and work over operations, plant maintenance,…),
- Large scale project feasible (up to 100 MW) if risk assessment from drilling work to full operation is correctly addressed.