ENGINE- *Geothermal Lighthouse Projects in Europe*

Information gathered during the ENGINE co-ordination action (ENhanced Geothermal Innovative Network for Europe)
http://engine.brgm.fr/
Last update April 2008

Project Name: BOUILLANTE
Project Institute/Company Leader: GEOTHERMIE BOUILLANTE, CFG-SERVICES, BRGM
Contact Person: H. Traineau, D. Tournaye (CFG-Services),
B. Sanjuan, A. Genter (BRGM)
Web-site: No Web-site
Country: France
Location: Guadeloupe (French West Indies)

Type(s) of resource: High Enthalpy
Main on-site operators [Drilling, Stimulation, Power plant, Monitoring]:
GEOTHERMIE BOUILLANTE, CFG-Services, BRGM, ORKUSTOFNUN, COFOR

Number of wells [w. Total Depth pr. well]: 7 wells (BO-1 to BO-7) but only 3 wells are presently producing (BO-4, BO-5 and BO-6)
Type of wells: Production
Well configuration: Single wells
Distance between well at Depth [Horiz. Dist at Depth]: approximately 500 m
Temperature at total depth: 250-260°C
Combination with other energy sources [Gas, Waste, Biomass, etc.]: No

Potential of the geothermal resource [TJ/yr at Date]: Not available
Average flow rate [kg/s at Date (if expected)]: 150 kg/s of fluid (30 kg/s of steam) since January 2005

Main production: Power
Installed/Expected capacity: 15 MWe since January 2005
Running/Expected capacity [MW/*time* at Date (if expected)]: 13-14 MWh

Short description of ***Exploration History*** ***(Limit this section; no more than 200 words)*****:**

The Bouillante high enthalpy geothermal power plant, located in Guadeloupe (French West Indies), is the only French installation of this type.

- **Objective of project:** to develop the Bouillante geothermal field in terms of extension and production, optimise the exploitation and the monitoring of this field using on site measurements and modelling, and re-inject the production fluids in the geothermal reservoir.

- **Important dates**:

• 1963-1964: First exploration studies of the Bouillante geothermal field, financially supported by SPDEG (Société de Production d'Electricité de la Guadeloupe) and carried out by BRGM. These studies mainly included geology and temperature gradient surveys in shallow drill-holes. A very high thermal flow close to 1.5 10^{-4} cal/(cm^2.s) was estimated in the hottest area.
• 1970: Drilling of three wells (BO-1, BO-2 and BO-3) by EURAFREP. Only BO-2 drilled at a depth of 338 m showed a capacity of large production of geothermal fluid (about 30 tons/h of steam and 120 tons/h of water; deep temperature close to 242°C).
• 1974-77: Drilling of the well BO-4 at a depth of 1,200 m. Even after its deepening down to 2,500 m, the low steam output of this well was not considered economical.
• 1982: Construction of a pilot geothermal plant by EDF (Electricité de France), with a 4,5 MWe turbine (GB1) only feed by the well BO-2. This experimental plant was operating from 1986 to 1992 and then was stopped.
• 1996: Total rehabilitation and re-starting of the GB1 power plant by Géothermie Bouillante S.A. Company (subsidiary of the BRGM and EDF Groups) for an industrial production of electricity. In 1998, GB1 unit supplied 23 GWh, which represented 2% of the annual electricity requirement in Guadeloupe.
• 1995-1999: Several research studies carried out by BRGM and CFG Services in order to identify favourable areas for drilling new wells. Main indices of geothermal activity concentrated in and around the Bouillante Bay. Discovery of numerous submarine hydrothermal springs and gas escapes in the north of the Bouillante Bay. In 1998, improvement of the productivity of BO-4 after a stimulation experiment by thermal cracking induced by cold seawater injection. After these studies, Géothermie Bouillante launched the Bouillante 2 project.
• 2000-2001: Drilling of three new deviated wells (BO-5, BO-6 and BO-7) by COFOR at depths close to 1,000-1,200 m. BO-5 and BO-6 discharged a geothermal fluid similar to that discharged from BO-2 and BO-4, with a deep temperature close to 250-260°C. BO-7 was not productive.
• 2002-2004: BO-2 was definitively disconnected from GB1 in 2002. A 600 m-long fluid pipe has been implemented between the well pad and the plant. The GB1 power plant was alternatively feed by wells BO-5 or BO-6. In 2004, within the framework of the Bouillante 3 project, additional exploration studies were carried out by BRGM and CFG Services in order to drill exploration wells in the north of the Bouillante Bay.
• 2005: The new GB2 power plant (11 MWe) was commissioned and started operation together with the former GB1 power plant. The two turbines are feed by wells BO-4, BO-5 and BO-6. The Bouillante power plant delivered about 7-8% of the annual electricity requirement in Guadeloupe (450,000 inhabitants).

- **Main geological context:** island arc volcanism (andesite, tuffs, volcanic lavas, volcano-sedimentary formations, basalts), E-W oriented graben-type faults and oriented NNW-SSE shear fault systems (Basse-Terre/Montserrat), thermal terrestrial and submarine springs, fumaroles, altered areas, high thermal flow

- **Expected CO_2 emission saving:** not available

- **Project funding:** owner (Géothermie Bouillante) with subordinate public supports from ADEME, Regional Council of Guadeloupe, BRGM, EDF, European Union (FEDER, 5th FP).

- **Distribution network:** state-owned EDF company.

Reservoir Characteristics (Limit this section; no more than 200 words):

Keywords:

- Fractured reservoir: E-W oriented normal faults provide permeability within non-permeable submarine volcanic formations.
- **Hosted lithology/rock/mineralogy:** volcanic lavas and tuffs (quartz, albite, K-feldspar, anhydrite, calcite, disordered dolomite, illite, chlorite, zeolites)
- **Geothermal reservoir fluid:** NaCl fluid, with a TDS of about 20 g/l and pH close to 5.3. Origin: mixing of 58% seawater and 42% freshwater which reacts with volcanic rocks at 250-260°C in the reservoir. The Gas-Steam Ratio is about 0.4-0.5% (4-4.5 kg CO_2/ton steam because CO_2 is predominant (95% in volume) in the associated gases; H_2S content is about 2.5% in volume).
- Fracture system: a main E-W fault network and a secondary N-S fault network.
- Stress field: not available
- **Temperature range:** 250-260°C

- **Main reservoir characteristics:**

- Estimated porosity: 10-15%
- Permeability: not available
- Intrinsic Transmissivity Kh: 24-34 D.m
- Hydrogeological storage capacity S: 0.04-0.16
- Relatively good recharge for the reservoir

- **Wells characteristics:**

- BO-2: 150 tons/h fluid (30 tons/h steam); Production level depth: 300-330 m TVD
- BO-4: 130 tons/h fluid (26 tons/h steam; maximum production);
relative Transmissivity: 0.5-0.7 10^{-8} m^3/Pa s; Storage capacity: 1-5 10^{-8} m/Pa;
Production level depth: 560-1050 m TVD
- BO-5: > 220 tons/h fluid (44 tons/h steam); relative Transmissivity: 5-10 10^{-8} m^3/Pa s;
Storage capacity: 4-5 10^{-8} m/Pa; Production level depth: 900-1150 m TVD
- BO-6: 300-320 tons/h fluid (60 tons/h steam); relative Transmissivity: 2 10^{-8} m^3/Pa s;
Storage capacity: 4-10 10^{-8} m/Pa; Production level depth: 900-1150 m TVD
- BO-7: very low production; relative Transmissivity: 1-2 10^{-8} m^3/Pa s;
Storage capacity: 2-10 10^{-8} m/Pa; Production level depths: 600-700; 900-1000 m TVD

- Stimulation by thermal cracking carried out in the well BO-4 in 1998 using about 8,000 m^3 of cold seawater with IDOS-130 as an inhibitor of anhydrite scale deposit. Improvement of the permeability and productivity of this well

- Connectivity between wells: pressure interferences but complex hydraulic connections between wells (an organic tracer injected in the well BO-4 was observed in the wells BO-5 and BO-6 16 months later)

- Estimated reservoir fluid volume using tracer test results (Na-benzoate and 1,6-nds): > 30 millions tons

Exploitation (Limit this section; no more than 200 words):

Keywords:

- Direct power plant: double flash (GB1) and single flash (GB2) steam turbines
- **Exploited fluid:** NaCl fluid (TDS about 20 g/l; 25 g/l after steam separation)
- **Cooling system:** seawater
- No fluid re-injection

- Annual production [GWh_e or GWh_t at Date (if expected)]: 80-100 GWh
- Seasonal production: no
- Capacity factor (%): not available

- Need for special tools [pumps, turbine etc.]: seawater pumping station

- **Geochemical monitoring of the production fluids**: on site measurements, Gas-Stream Ratio, water and gas chemical and isotopic analyses (major and trace species, δD, $\delta^{18}O$, $^{87}Sr/^{86}Sr$, $\delta^{13}C$, $\delta^{18}O_{SO4}$, $\delta^{34}S_{SO4}$, $\delta^{7}Li$, $\delta^{10}B$, etc.)

- **Study of the scaling deposits in the wells and superficial installations**

- **Development/improvement of methods:** Use of organic tracers such as naphthalene disulfonate for tracer tests, installation of a broadband seismometry network for monitoring and exploration, microgravity monitoring, radar interferometry

- **Monitoring and optimising of field/area using computer models:** use of hydrodynamic, thermal and geochemical models in research programs

- **Assessment of environmental impact:** Monitoring of the evolution of the soil temperatures and fluid geochemistry in the vicinity of the power plant (altered and hot areas, thermal springs, fumaroles, etc.). Possible fluid re-injections in the reservoir (not done for the moment).

On-going or future works planes (Limit this section; no more than 200 words):

Keywords:

– **Next important events:**

• new development project intended to increase the exploitation of the geothermal reservoir and the installed production capacity
• Optimisation of the present production using modelling codes
• Improvement of the conceptual model of the Bouillante geothermal field

– **Future plans:**

- o New exploration phase in the north of the Bouillante Bay
- o New exploration and production wells in the north of the Bouillante Bay
- o Building a new power plant in the north of Bouillante Bay
- o Studies about the fluid re-injection in the reservoir
- o EGS technological platform
- o Possible EGS in the peripheral areas of the Bouillante geothermal field
- o Implementation of new geochemical and geophysical methods

ENGINE partners involved in the Project:

- Use list of partners from ENGINE Web-site http://engine.brgm.fr/partners.asp

Main References *(no more than 5 references):*

Correia H., Sigurdsson O., Sanjuan B., Tulinius H. and Lasne E. (2000) - Stimulation of a high enthalpy geothermal well by cold water injection. In Geothermal Resources Council Transactions, Davis, California, USA, vol. 24, 129-136.

Fabriol H., Bitri A., Bourgeois B., Debeglia N., Genter A., Guennoc P., Jousset P., Miehe J.M., Roig J.Y., Thinon I., Traineau H., Sanjuan B. and Truffert C. (2005) - Geophysical methods applied to the assessment of the Bouillante geothermal field (Guadeloupe, French West Indies). *Proceedings World Geothermal Congress 2005, Antalya, Turkey, 24-29 April 2005.*

Sanjuan B., Lasne E. and Brach M. (2001) - Bouillante geothermal fluid: mixing and water/rock interaction processes at 250°C. *Proceedings, 10th Water-Rock Interaction (WRI-10), Cagliari, Italy, June 10-15,* p. 911-914.

Sanjuan B., Le Nindre Y.M., Menjoz A., Sbai A., Brach M., Lasne E. (2004) - Travaux de recherche liés au développement du champ géothermique de Bouillante (Guadeloupe). Rapport BRGM/RP-53136-FR, 166 p.

Traineau H., Sanjuan B., Beaufort D., Brach M., Castaing C., Correia H., Genter A., Herbrich B. (1997) - The Bouillante geothermal field (F.W.I.) revisited: new data on the fractured geothermal reservoir in light of a future stimulation experiment in a low productive well. In: *Proceedings, Twenty-Second Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, January 27-29, 1997,* SGP-TR-155, p. 97-104.

Photo of the Bouillante geothermal power plant located within the City and close to the seaside. the distance between the plant and the well pad is about 600 m.

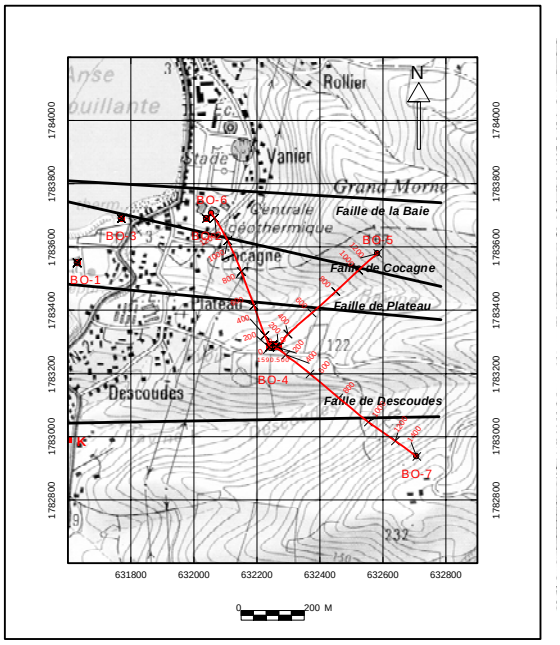


Figure 2 : Localisation map of the wells drilled in the geothermal Bouillante field (CFG Services document).

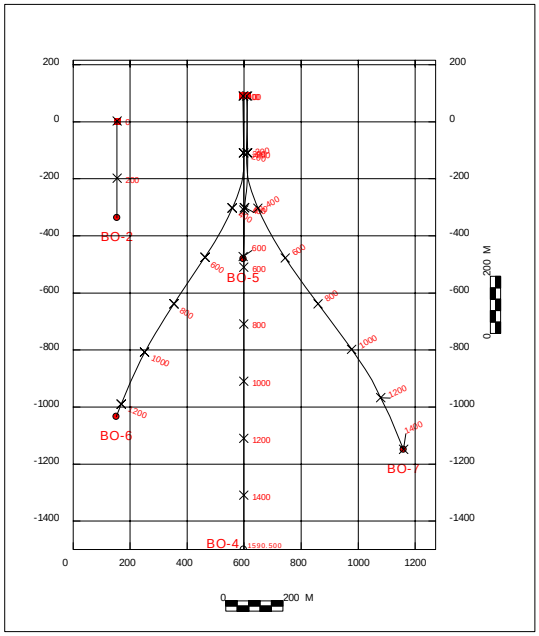


Figure 3: Vertical section along a NW-SE profile showing well geometry (CFG Services document).

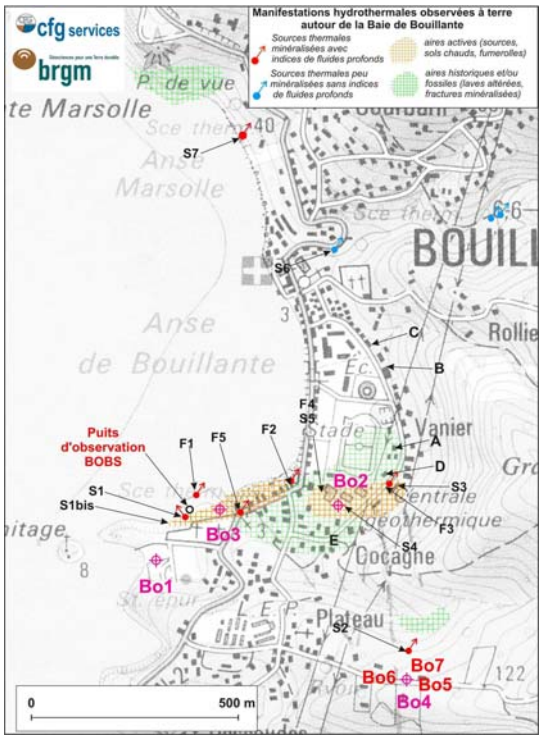
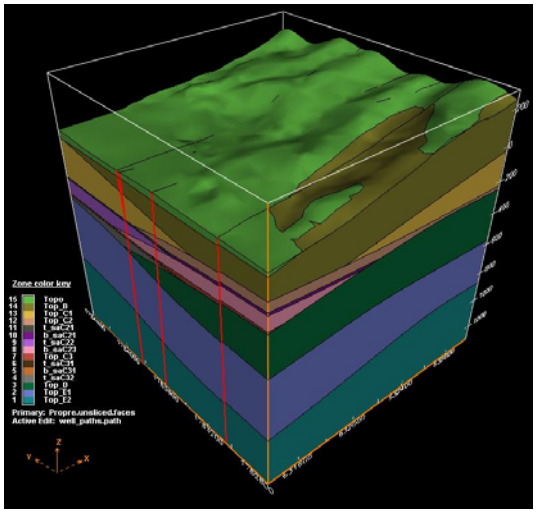
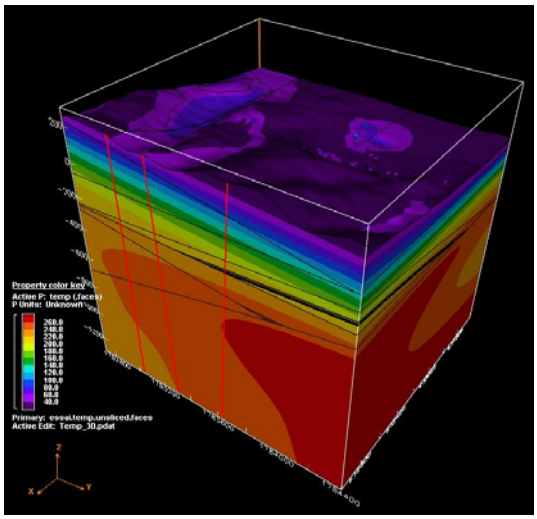


Figure 4: Localisation map of the main hydrothermal manifestations around the present power plant (Sanjuan et al., 2004)

Figure 5 : 3D-model of the Bouillante geothermal field using the EARTHVISION code (area of the production wells)



Geological formations



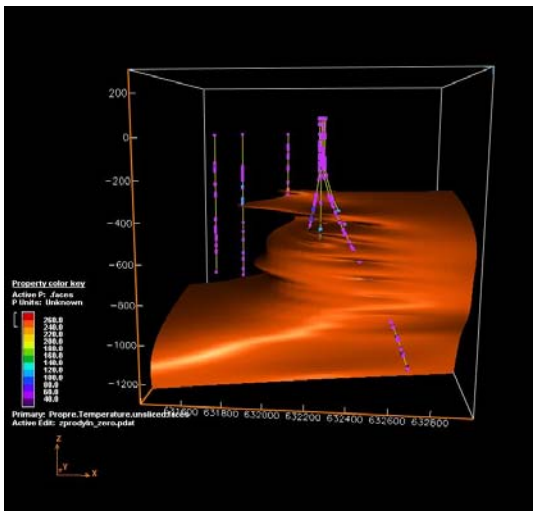
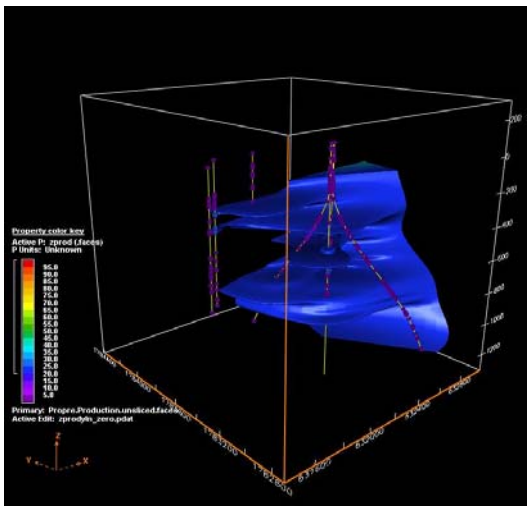


Figure 5a : Thermal profiles



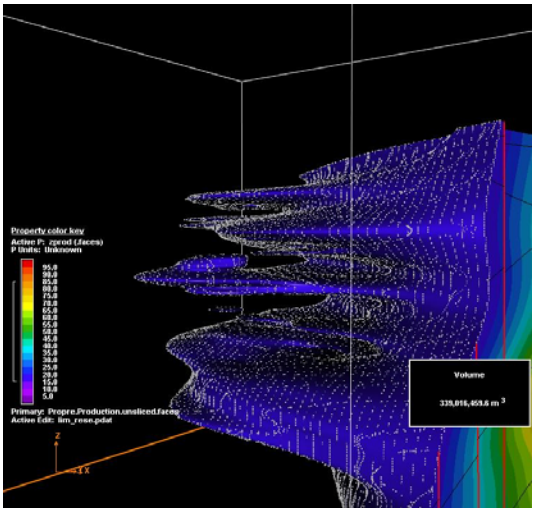


Figure 5b : Estimated representation of the geothermal reservoir