GRENADA GEOTHERMAL SURFACE EXPLORATION

Luis Urzua[1], Oscar Benavente[1], Alastair Brookes[1] and Greg Ussher[1]

[1]Jacobs New Zealand, 12-16 Nicholls Lane, Parnell, Auckland, New Zealand, Telephone +64 9 928 5641

luis.urzua@jacobs.com

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ABSTRACT

In 2014, the Government of Grenada requested technical assistance from the Government of New Zealand to investigate geothermal resources on the Island of Grenada and assess their suitability for use in the generation of electricity.

A comprehensive geothermal investigation program was undertaken by Jacobs New Zealand Ltd in 2015 to assess the existence of a geothermal system in Grenada. The results indicate the presence of a considerable (between 4 km^2 and 8 km^2), high-temperature resource (200°C to <290°C) associated with the Mount Saint Catherine volcano. These indications suggest that the geothermal resource would be of sufficient size to more than meet the base load electricity demand of Grenada, assuming that the resource can be proven through exploration drilling and the project reaches commercial operation.

The preliminary conceptual model proposes that the upflow of the system could be located near the thermal features on top of Mount Saint Catherine. The geothermal fluids would ascend through the sedimentary deposits of the Tufton Hall Formation and the volcanic deposits of Mount Saint Catherine volcano. The reservoir fluids reach the surface, after mixing with shallow groundwaters, at Castle Hill and Chambord at levels between 20 and 200 metres above sea level. The geothermal fluids also reach the surface as steam heated features at Hapsack, Mt Hope, Plaisance Estate, Clabony, Adelphi, Belair and Peggy's Whim at levels between 200 to 560 metres above sea level.

The next development stage should seek to refine the proposed boundaries of the field through additional infill MT survey and a detailed field exploration programme in the area of Belair Estate. In addition, a gravity survey is recommended to identify the interface of the Mount Saint Catherine volcanic sequences and the Tufton Hall formation.

1. INTRODUCTION

Investigations of the geothermal resource in Grenada date back to 1981, but prior to the work reported here, only preliminary surface exploration activities have been completed (e.g. Geotermica Italiana, 1981; Huttrer and Michels, 1993). These preliminary results characterised the geothermal resource in Grenada as a medium temperature (~200°C) system, with initial power potential estimates in the range of 30MW – 50MW (Huttrer and Michels, 1993). The key indicators of a potentially exploitable geothermal system on Grenada include:

- the existence of active heat sources associated with the volcanic structures
- reported solfatara on Mt. St. Catherine
- reported sulphurous and gassy conditions
- chloride- and boron-rich thermal waters at elevations above 200 m a.s.l.

The New Zealand Ministry of Foreign Affairs and Trade (MFAT) has committed to assisting Caribbean countries with the development of their geothermal energy potential and has signed a Partnership Framework with Grenada for this purpose. This Framework states that key technical assistance will be provided in the form of a geoscience study to evaluate the geothermal potential in the island. Jacobs New Zealand Ltd (Jacobs) was appointed by MFAT to undertake this geoscience exploration programme which comprised geology, geochemistry and geophysical surveys. The main objectives of these surveys were to:

- Determine the extension of the geothermal system including characteristics, temperature & depth.
- Understand the relationship of the system with the volcanic structures in the island.
- Recognise the distribution of faults and primary permeability.
- Propose a hydrogeochemical model for the geothermal system hosted in the island.
- Determine electrical power generating potential of the resource.
- Identify requirements for further exploration activities

Fieldwork was undertaken to complete the surveys between 19 February 2015 and 17 April 2015.

2. GEOLOGY

2.1 Tectonic Environment

Grenada is a small (~344 km^2) Caribbean island nation on the southern tip of the Lesser Antilles arc, located ~125 km northeast of the Venezuelan coast (Figure 1). The arc, which is ~800 km long and extends from Saba in the north to Grenada in the south, consists of three segments traced by faults in the overlying plate and kinks in the underlying slab (Wadge and Shepherd, 1984). A notable feature is a bifurcation of the arc north of Martinique. To the west are the active Volcanic Caribees and to the east lie the older, inactive Limestone Caribees. Activity in the eastern arc was mainly from Eocene to mid-Oligocene, whereas the western arc has been active from Early Miocene to present.

The Lesser Antilles island arc volcanism has occurred since the Eocene at the eastern boundary of the Caribbean plate where the Atlantic crust of Upper Cretaceous age has being subducted (Arculus, 1976). Such subduction produces a well-defined inclined seismic plane (Wadati-Benioff zone) beneath the Lesser Antilles arc reaching a present depth of about 200 km (Wadge and Shepherd, 1984). A notable feature of the Wadati-Benioff zone is that the arc is segmented: to the north of Martinique, the arc segment trends about N30°O and the Wadati-Benioff zone dips at 50–60°. The southern segment, trending N20°E, has a dip of 45–50° in the north but is almost vertical in the south (Wadge and Shepherd 1984).

Plate-tectonic reconstructions of the sector suggest that the present-day Caribbean plate was generated in the eastern Pacific as a Late Cretaceous oceanic plateau that advanced eastward relative to the North American and South American plates, about 1100 ka since the Eocene (Pindell and Dewey, 1982; Burke, 1988; Pindell and Barrett, 1990). The eastward movement took place along strike-slip faults and was accompanied by significant lithospheric shortening which occurred as inner deformation of the Caribbean plate (Speed et al., 1993). The latter is supported by the pattern of internal deformation of the Caribbean plate which is dominated by orthogonal NW- and NE-trending fractures and faults (Speed et al., 1993).

GPS studies of the region give an average present-day, eastward movement of the Caribbean plate relative to the South American plate of ~20 mmy-1, although the rate of convergence is faster in the north (~37 mmy-1 relative to North America) than in the south (~13 mmy-1 relative to South America) [Perez et al., 2001; Weber et al., 2001; Trenkamp et al., 2002]. Compared to other arc systems, the Lesser Antilles has low magma production rates, which is believed to be a consequence of the slow convergence rates between the Caribbean plate and the Atlantic crust (Wadge, 1984). Wadge estimated magma production rates in the Lesser Antilles over three time periods. For the past 300-year, 10,000-year and 100,000-year periods, the rates have been 4, 2 and $3x10^3$ km^3Ma-1 respectively. These values are an order of magnitude lower, over the same periods, than those for Central America, where convergence rates have been around four times higher (Wadge 1984).

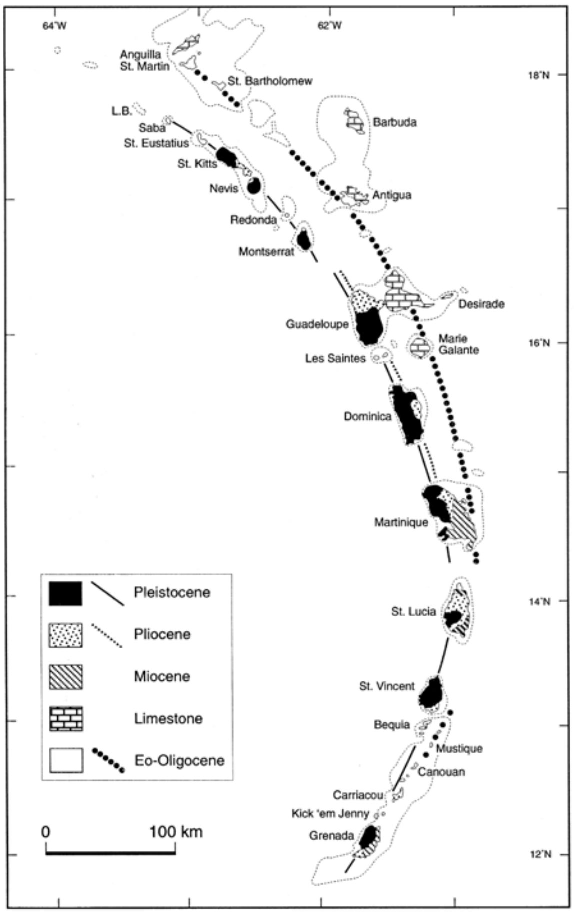

Figure 1: Map of the Lesser Antilles arc, showing the location of Greanda, ages of the exposed rocks and the positions of the volcanic front during the Eocene–Oligocene (black circles), Pliocene (dotted line, for the central segment) and Pleistocene (solid line). Modified from Wadge (1986).

2.2 Local Geological Setting

The local geological setting indicate that the most promising geothermal area of Grenada is centred on Mt. St. Catherine volcano, in the central part of the island. Interpretation of this geological evidence is summarised in a geological model of the resource, presented in the cross-section below (Figure 2).

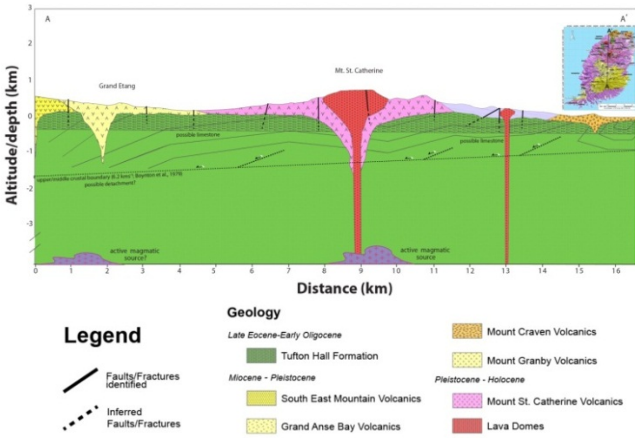

Figure 2: Geological cross section through Mt. St. Catherine and Grang Etang.

Mt. St. Catherine and the nearby area have a long and complex volcanic history with basalt, andesite and dacite lava flows that have erupted up to Pleistocene times (~0.94 My). Petrological and geochemical evidence suggest that the silicic magmas were produced by crystal fractionation of the basic parental magmas within a shallow magma chamber underneath the area comprising Mt. St. Catherine. The latter requires a large volume of basic magmas residing for a long time (103 to 105 y) at shallow depth (<10 km; Macdonald et al., 2000). Such shallow magma chamber(s) can be considered to be acting as the heat source of a potential geothermal system associated with Mt. St. Catherine.

The distribution of the most recent explosion craters and scoria cones, which are located along the NE-SW axis of the island, suggests that a zone with no current volcanic activity occurs at Mt. St. Catherine and the immediate area. The latter indicates the NE-SW main axis of the island that could correspond to a major lithosphere discontinuity produced by the tectonism acting on Grenada, and also supports the probable occurrence of a shallow magmatic chamber below Mt. St. Catherine.

The geology of Grenada is dominated by volcanic deposits of variable age and nature, overlying a sedimentary basement. In the area nearby Mt. St. Catherine the volcanic rocks lie directly on a sequence of highly fractured and folded turbidites (Tufton Hall Formation). Given the distribution of this sedimentary sequence and the elevation of its known outcrops (<250 m a.s.l.), it seems unlikely that high temperature aquifers could be hosted within the volcanic rocks given the limited thickness of Mt. St. Catherine volcanic pile (<800 m). The geothermal reservoir could be hosted in permeable horizons within the Tufton Hall Formation or underneath this rock formation.

The Tufton Hall Formation correspond to shales, marls and siltstones which are rocks with relatively low intrinsic permeability. However, in Grenada such rocks are highly faulted and folded making them potentially permeable at depth (Figure 2). Given the distribution of this deposit at surface, a minimum thickness of 300 m has been proposed for this formation (neither the top nor the base of this formation are known). It is important to note that XRD and MeB results carried out by Jacobs indicate that the Tufton Hall Formation samples contain smectite with up to 17 wt.% , with no significant mixed-layer illite-smectite.

From the geology of the southern Islands of Lesser Antilles, it is known that at the time of the sedimentation of the Tufton Hall Formation (upper Eocene), the palaeography of the area was characterized by the presence of carbonate platforms and older volcanic rocks, from which the Tufton Hall rocks would have been formed by the erosion of these rocks. This would suggest that a potentially permeable limestone sequence lies under the sedimentary sequence, and such rocks should be as faulted and folded as the Tufton Hall rocks. The depth of the limestones cannot be estimated because the total thickness of the Tufton Hall formation is not known.

The occurrence of a smectite-rich basement in Grenada has important implications for interpretation of the magnetotelluric (MT) regarding the area and depth of a conductor capping the geothermal system. It is expected that the silty, shaley and tuff layers within the Tufton Hall Formation would have an intrinsic low resistivity response given the high smectite content measured by Jacobs. This is relevant as most low resistivity layers capping geothermal systems are rich in smectite, smectite – illite clays. Therefore both structures should have similar resistivity values (<10 ohm-m).

Weathering is very effective in Grenada as indicated by the abundance of thick lateritic soils. The latter suggests that, in spite of the very high rainfall rates on the island (up to 5000 mm per year), only a limited part of meteoric water infiltrates at depth. Most of the rain water probably flows on the surface above the impermeable soil. Infiltration of the rain water would be controlled by an orthogonal fracture/fault systems (NE-SW and NW-SE oriented) and by the existence of permeable horizons within the volcanic pile (lava layers).

Additionally, mobilization of thermal fluids could be controlled by the orthogonal fracture/fault systems in Grenada. Considering the distribution of the volcanic center along the island axis, it is likely that only NE-SW trending fractures are kept open and permeable to a significant extent.

3. CHEMISTRY

The island of Grenada hosts several thermal areas such as Castle Hill South, Chambord, Belair Estate, Peggy's Whim, Hermitage, Hapsack, Mt. Hope, Clabony, Plaisance Estate and Adelphi-St. Cyr. The distribution of these features is shown in Figure 3.

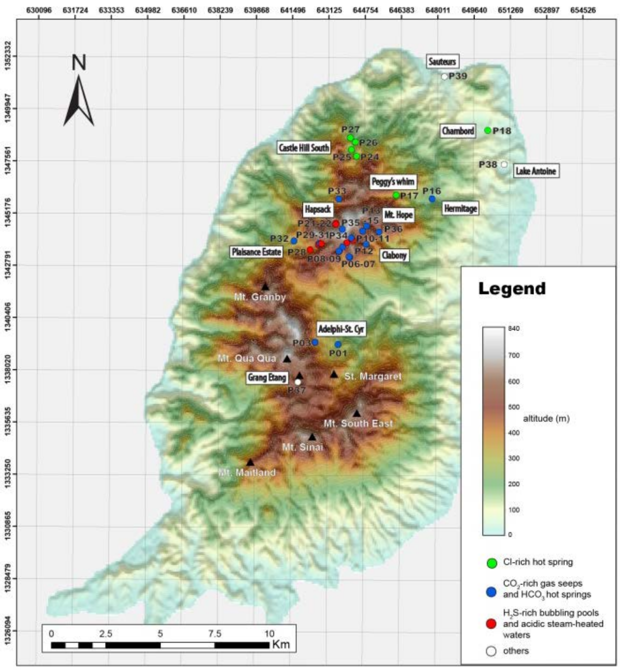

Figure 3: Distribution of thermal features in Grenada.

The thermal features in Grenada occur in the central and northern portions of the island, on the upper and lower flanks of Mt. St Catherine volcano. Surface features emerge along riverbeds that can be broadly grouped into areas located radially around Mt. St. Catherine. Thermal manifestations include bubbling pools and hot springs at elevations between ~20 and 560 m a.s.l. and temperatures ranging between 20.6 and 76.8°C. Most of the springs are characterized by a clear water flow.

Neither fumaroles nor steaming ground were found in Grenada during this survey. Bob Lawrence and Assoc., (1999) reported a small solfatara on Mt. St. Catherine, but did not report the coordinates of this feature. Efforts to verify the existence of the solfatara were unsuccessful. According to local guides, none of the known thermal areas in Grenada host features with characteristics similar to that of a solfatara (e.g. gas emerging at boiling temperature or higher and native sulphur deposition), which is consistent with the findings of this survey.

However, the highest temperatures recorded (63.8 and 76.8°C) were measured in two bubbling pools located at high elevation (~560 m a.s.l) on the west slope of Mt. St. Catherine (Hapsack-Red River; Figure 3). The area nearby to both bubbling pools is characterized by a "rotten egg" H_2S smell consistent with the facts that (i) the gas detector measured more than 100 ppm of H_2S in both gas discharges, and (ii) pH of the water associated with both bubbling pools varied between 3 and 3.5. Bubbling pools enriched in H_2S (>100 ppm measured on detector) were also found in Mt. Hope and Plaisance Estate, but the temperature of these discharges is lower than 29°C. The hosting rock is characterized by andesitic lava flows altered to acid clay minerals. Native sulphur deposits were also identified in the area, but at none of these is being actively deposited. Other areas exposing similar hydrothermal alteration were found at Clabony, Mt. Hope and Plaisance Estate areas.

Extinct travertine sinters occur on the north and north-eastern flanks of Mt. St. Catherine Chambord, Castle Hill South, Peggy's Whim and Mt. Hope areas at altitudes in the range of 20 to 361 m a.s.l. U-Th dates reported by Geotermica Italiana (1981) for the travertine deposits at Chambord indicate that the hydrothermal activity in this area has been active at least for the last ~10,000 y. The travertine terraces are associated with salty-tasting water discharges. Excluding the thermal features from Castle Hill South, most water discharges are associated with odourless bubbling activity. The temperature and pH of the gas/water discharges vary from 21°C to 49°C and 6 to 7 respectively.

Other thermal features on the island include warm springs, bubbling pools and cold gas seeps located in between the other hydrothermal zones, and in the southern flank of Mt. St. Catherine, at altitudes in the range of 120 and 550 m a.s.l. These thermal features are quite gassy and odourless, no H_2S was measured by the gas detector. The springs have temperatures ranging between 20.6°C and 43.5°C with slightly acidic pH (5.5 to 6).

Water samples were collected and analysed in New Zealand Geothermal Analytical Laboratory (NZGAL, Tables 1 to 4) and were interpreted by Jacobs together with the analyses of the surveys conducted by Geotermica Italiana (1981)

The overall impression of the thermal activity in Grenada is of a mature geothermal system centred in the area of Mt. St Catherine. Interpretation of the chemistry and isotopic composition of the thermal features of Grenada can be summarised in a hydrogeochemical model with the following key features ;

- The thermal areas of Grenada can be grouped into three different types of thermal features emerging radially from Mt. St. Catherine. There are zones that suggest the presence of an upflow located in Mt. Hope, Plaisance and Hapsack. Such areas are characterised by H_2S-rich bubbling pools and steam-heated SO_4-rich acidic waters. Cl-rich saline waters can be found in the Chambord, Peggy's Whim and Castle Hill areas, to the north and northeast of Mt. St. Catherine. These saline Na-Cl waters are associated with gas seeps and travertine deposits and might represent the outflow the system. In between these two type of thermal features, there are several CO_2-rich bubbling pools and HCO_3-rich waters.

- A liquid-dominated reservoir centred on Mt. St. Catherine, mainly recharged by meteoric water and with shallow and deeper temperatures of 200-220°C and possible <290°C, respectively. These relatively high temperatures are in agreement with the chemical (high Na/Mg ratios and high Li and B contents) and isotopic (positive $\delta^{18}O$ shifting) signatures of the Na-Cl springs.
- The high Cl content of the Na-Cl discharges (up to 16000 mgL-1) indicates that these waters have been in contact with sedimentary sequences, likely the carbonaceous formation that form the basement of the island (Tufton Hall rocks), and therefore such rocks may be acting as the geothermal reservoir as also indicated by the relatively high limestone contribution (up to 91%) for the CO_2 and He discharged by some bubbling gases.
- The relatively low altitude differences (<300 m) between the emergence spots of the steam-heated SO_4-rich acidic waters and the Cl-rich saline waters suggest that the liquid-dominated Cl-rich reservoir should be emplaced at shallow depth (<1 km).
- The re-equilibrated chemistry of the cation and silica geothermometers, the Na-Cl discharges at Castle Hill, Chambord, and to a lesser degree Peggy's Whim, represent a distant outflows of the liquid-dominated reservoir centred on Mt. St. Catherine, which indicate that the reservoir is partially open to the north and northeast.
- The presence of travertine deposits associated with Na-Cl saline water discharges suggests that calcite scaling in wells or surface facilities should be a consideration in a development scenario.

Previous reports mention the existence of fumaroles in Grenada, but these were not found during the survey most likely because they were covered by landslides following heavy rain and hurricanes. However, near boiling and acid features located near these areas were found during the current survey. These features are considered a strong indicator of a high temperature reservoir (>200°C) as these are the results of H_2S condensation into perched aquifers.

4. GEOPHYSICS - MAGNETOTELLURICS

Jacobs subcontracted Moombarriga Geoscience Pty Ltd (Moombarriga) to undertake the MT survey in Grenada , between March 2015 and April 2015. Moombarriga utilized four acquisition units concurrently with a unit at a remote reference site. These were Metronix ADU-07(e) and Metronix magnetometers (serial 8094-0038). The remote station was installed south east from the zone of exploration. This station was utilised during the survey to improve the quality of the MT data through a robust remote-referenced processing algorithm, based on codes described in Larsen (1996).

The survey comprised 60 unique acquisition sites, with spacing of approximately 1km as shown in Figure 4. Prior to acquisition, individual sites were scouted to determine accessibility, suitability and obtain permission from land owners where necessary. Prior to data acquisition, a parallel sensor test of each component was completed to ensure acceptable noise levels for each acquisition system.

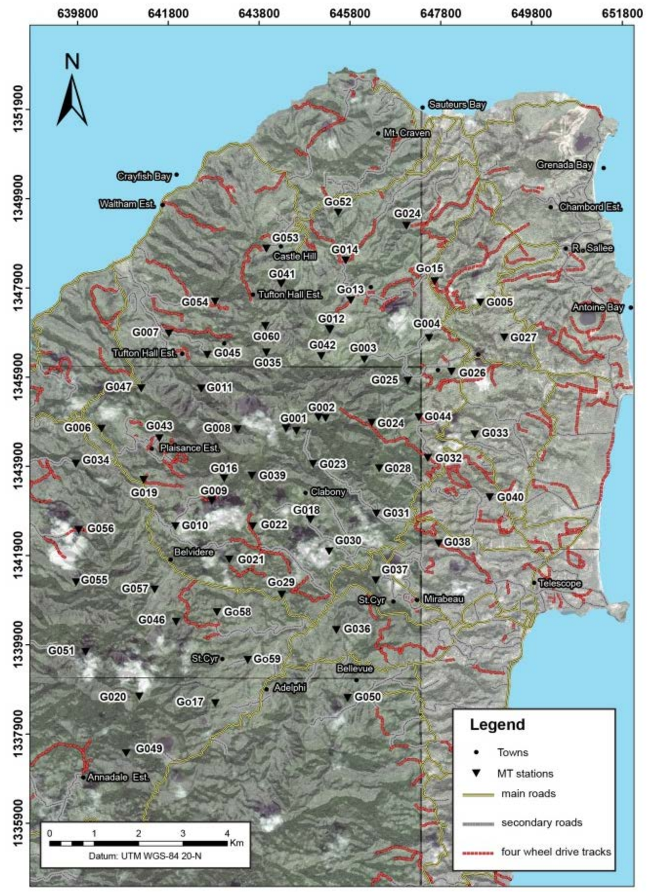

Figure 4: Plan view of Grenada showing the layout of the MT survey (Moombarriga, 2015).

Data was collected and checked for consistency by Moombarriga and then transferred to CGG in Milan, Italy, for processing and delivery of final Electronic Data Interchange (EDI) files and 3D model. The processed data and 3D model was submitted to Jacobs for interpretation.

4.1 Data Interpretation

A 1D and 3D modelling approach was undertaken in Grenada. A conductive layer is the dominant feature seen in all modelled maps and sections with a resistivity ranging from 1 to 10 ohm-m (Figure 5).

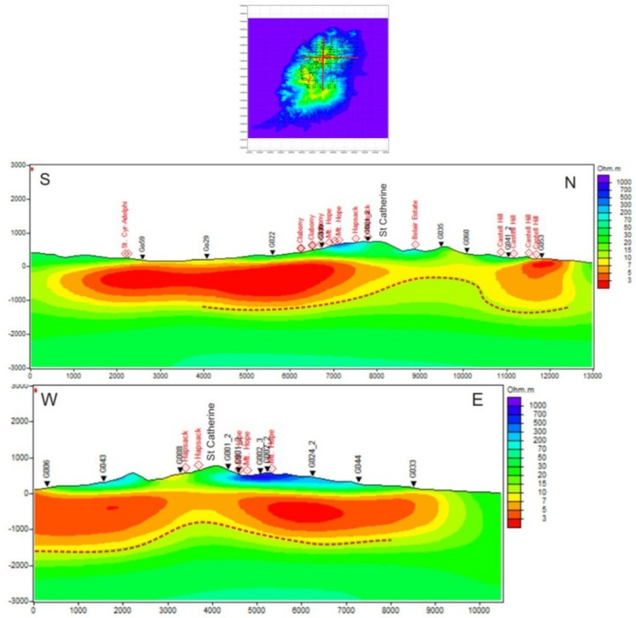

Figure 5: Cross sections NS and WE based on a 3D model. Dotted red line highlights the base of the conductor indicating the interpreted top of a high temperature reservoir (200- 220°C? isotherm). NS section provides a complete view of the hydrology of the deep reservoir including the location of the thermal features at surface.

This layer broadly domes upwards beneath the northern flank of the Mt. St. Catherine volcano and is thick on the sides forming a similar pattern to that seen on other volcanic complexes hosting a geothermal system. In Grenada, this thick shallow conductor is expected to be enhanced by native smectite in the deposits of the Tufton Hall Formation.

The resistivity structure occurring in a geothermal area is usually linked to a geothermal origin based on its shape and its relationship with the distribution of the thermal features in the area. In Grenada, Jacobs consider that the top of the conductor is well imaged by the 1D model. The sections show that the low resistivity layer follows the terrain and rises to its highest elevation under the area delimited by Hapsack, Mt Hope and Belair Estate. In general terms, the doming of the top of the conductor in Grenada matches the area of thermal features in Hapsack, Belair and Castle Hill. In addition, it is important to note the top of low resistivity layer would cover shallow and deep volcanic deposits of Mt San Catherine. This suggests that the clay cap is not purely controlled by the occurrence of native smectite.

The conductor is shallowest in the area of Hapsack, Belair and Castle Hill. The correspondence of this zone with the area of observed SO_4 rich features indicates that thermal conditions most likely exist beneath Mt. St. Catherine.

As seen in Figure 5 (and 1D models) the *base of the conduct*or rises to the north of Mt. St. Catherine, under Belair and Hapsack (section NS, Figure 5). This high elevation of the base of the conductor is contained in the north - northwest of Mt. St. Catherine. This is consistent with the chemistry and thermal features distribution seen in this direction (from Hapsack, to Castle Hill).

A doming of the base of the conductor indicates that there is a possibility for an upflow to be found beneath NNW flank of Mt St. Catherine (under Hapsack or Belair). The doming structure seems to have a direct correlation with surface thermal features. Therefore, the case for this representing a potential geothermal resource is strong.

An important consideration on the interpretation of the extensive (~4-8 km^2) and intense geophysical anomaly mapped in Grenada (1 to 10 ohm –m) is the reservoir rock postulated to host the geothermal reservoir. This corresponds to the Tufton Hall Formation, a sedimentary marine formation that contains native smectite. The low resistivity layer underneath Grenada most certainly is a combination of smectite associated with alteration products of the geothermal system and smectite occurring in the Formation. This consideration would explain the intensity and extensive distribution of the clay cap in the surveyed area. It is possible to postulate that the thinning or doming of the conductor under Belair Estate and mainly seen in the 3D sections (Figure 5) represents the upflow of the system. The thinning of the clay cap could be interpreted as high temperature conditions directly underneath, which would force the smectite to transform to illite or another high temperature mineral assemblage. However, in this case it would be expected that the destruction or thinning of the clay cap would allow waters from the deep reservoir (as described in the chemistry findings) reach the surface at higher flow and boiling temperature than observed. This is not the case for the thermal features of Belair Estate and Castle Hill. On the other hand, the top of the conductor is better defined by the 1D sections. These show the alteration trough low resistivity value of the shallow volcanic deposits of the Mt. St. Catherine volcano. This alteration pattern is explained as an alteration product between thermal fluids associated with the Hapsack and other SO_4 rich thermal features. Therefore, at this stage of the exploration it is considered that the upflow of the system is located to the south of Castle Hill and Belair Estate areas and the alteration pattern in Hapsack is a combination of native smectite in the Tufton Hall Formation and smectite produced by high temperature fluids from a geothermal reservoir.

A deepening of the conductor on the west and on the east seen in the 1D and 3D models, matches well with the absence of thermal features in both directions (Figure 5, section EW). Additionally, the models show the conductor extending at depth to the north and south of Mt. St. Catherine (Figure 5, section NS). On a plan view, the 3D resistivity maps show the conductor as a large conductive zone oriented NS- NE overlaying what appears to be the outflow of the system in these two directions (Castle Hill and Chambord, Figure 6).

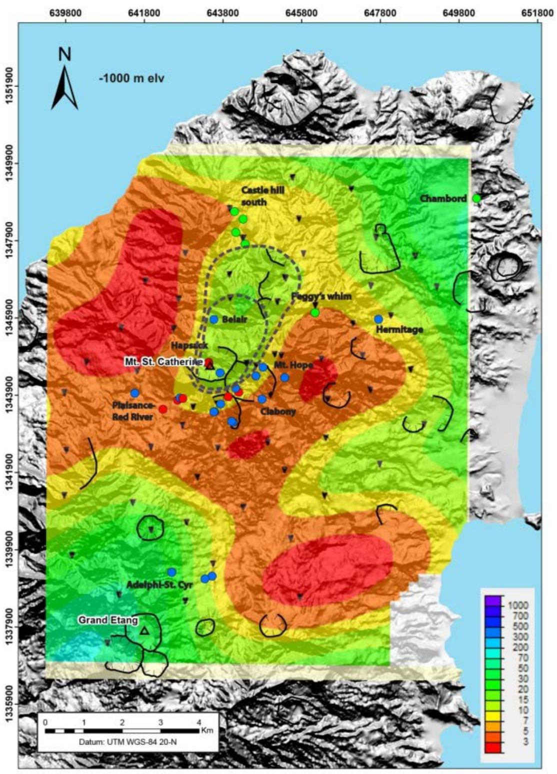

Figure 6: 3D model resistivity map to -1000 m elv. showing potential extension and direction of the upflow and outflow (dotted lines)

In the area of Castle Hill the conductor becomes thinner (Figure 5, section NS). This would explain the outcropping of chloride rich waters in this area. On the south the conductor deepens towards Adelphi (section NS). Initially it was proposed that these thermal features could derive from the shallow steam heated thermal features in Hapsack, Clabony, Plaisance Estate and Mt. Hope. However, chemistry results suggest that the thermal features in Adelphi have a deep origin.

In Grenada, the results of the MT study indicate resistivity patterns typical of a high temperature geothermal reservoir. These geophysical results, combined with the geology and geochemistry, are promising because they suggest the presence of a high temperature geothermal reservoir.

5. CONCLUSIONS

The outputs of the surveys provide good indications that the thermal activity in Grenada is of a mature high-temperature geothermal system centred in the area of Mt. St. Catherine with temperatures ≥240°C. The results of the MT study indicate resistivity patterns typical of a high-temperature geothermal reservoir within the limits proposed, to cover a small area of 4 km^2 and a larger area of 8 km^2.

A conceptual model of the system has been developed with the following key features:

- The heat source is related to the magma that surfaced as the Mt. St. Catherine volcano up to 0.94 million years ago and which is probably now associated with the magma from which submarine volcanism to the north of Grenada is currently developing (Kick-em-Jenny and Isle de Caille).
- The reservoir may be hosted in fractured lavas in the central part of the island where the volcanic pile is thick enough to reach depths of several thousand meters and within the carbonate formations that underlie the Tufton Hall Formation sediments in the northern parts of the island.
- The higher mountains of Grenada receive over 4000 mm of rain annually. It is expected that a significant portion of this rainfall gets into the fault/fracture conduit system and permeates far enough to recharge the reservoir. It is also expected that this large amount of water acts as thick shallow groundwater aquifer constantly flowing to the plane and diluting geothermal fluids emerging to the surface (e.g., Castle Hill).
- The thermal areas of Grenada suggest the presence of an upflow located in Mt. Hope, Plaisance Estate and Hapsack. Such areas are characterised by H_2S-rich bubbling pools and steam-heated SO_4-rich acidic waters. Cl-rich saline waters can be found in the Chambord, Peggy's Whim and Castle Hill areas, to the north and northeast of Mt. St. Catherine. These saline Na-Cl waters are associated with gas seeps and travertine deposits and represent the outflow the system. In between these two type of thermal features, there are several CO_2-rich bubbling pools and HCO_3-rich waters.
- The chemistry results suggest a liquid-dominated reservoir underneath or near Mt. St. Catherine, mainly recharged by meteoric water with temperatures ranging from ~200°C and <290°C. These relatively high temperatures are supported by the high Na/Mg ratios and high Li and B contents, isotopic positive $\delta^{18}O$ shifting signatures of the Na-Cl springs and the updoming feature in the clay cap.
- The high Cl content of the Na-Cl discharges (up to 16000 mgL-1) indicates that these waters have been in contact with sedimentary sequences, most likely the carbonaceous formation that form the basement of the island (Tufton Hall rocks). This is also suggested by the relatively high limestone contribution (up to 91%) for the CO_2 and He discharged by some bubbling gases. The relatively low altitude differences (<300 m) between the emergence spots of the steam-heated SO4-rich acidic waters and the Cl-rich saline waters suggest that the liquid-dominated Cl-rich reservoir should be emplaced at shallow depth (<1 km).

- A conductive layer with resistivity values of 1 to 10 ohm-m is the dominant feature seen in all modelled maps and geophysical sections. The conductive layer broadly domes upwards beneath the northern flank of Mt. St. Catherine and is thick on the sides, forming a similar pattern to that seen on other volcanic complexes hosting a geothermal system.
- As seen in the 1D and 3D geophysical models, the base of the conductor rises to the north of Mt. St. Catherine, under Belair and Hapsack. This high elevation of the base of the conductor seems to be contained in the north - northwest of Mt. St. Catherine. This is consistent with the chemistry and thermal features distribution seen in this direction (from Hapsack, to Castle Hill). Therefore, the case for this representing a potential geothermal resource is strong.
- An important consideration on the interpretation of the extended and intense geophysical anomaly in Grenada, are the marine sedimentary deposits of the Tufton Hall Formation. These deposits contain smectite and, therefore, the clay cap or low resistivity layer underneath Grenada is most likely a combination of a smectite associated to alteration products of the geothermal system and smectite naturally occurring in or above the reservoir. This would explain the intensity and large distribution of the 1 to 10 ohm-m structure.
- Resistivity maps at different depths suggest the presence of an upflow to the south of Belair, under Hapsack and potentially under Plaisance Estate as depth increases. This would suggest the presence of an asymmetric geothermal system with an upflow located under Hapsack- Plaisance Estate outflowing to the north (Castle Hill) and northeast (H Peggy's Whim and Chambord). This matches with the chemistry and surface distribution of the thermal features.

At this stage of the exploration programme the main risk before drilling a deep well are:

- Reservoir Temperature - absence of boiling thermal features and in particular the absence of fumaroles have forced the estimation of a reservoir temperature based on the analogues according to the exploration team experience.
- Permeability - volcanic high temperature geothermal fields usually are hosted in volcanic deposits with abundant primary and secondary permeability. In the case of Grenada, the most likely reservoir would correspond to sedimentary deposits adding to the permeability risk.
- Size of the reservoir – the existence of native smectite in the Tufton Hall Formation could distort the size of the clay cap in the area of interest, subsequently over estimating the size of the reservoir.

It is recommended that exploration drilling be pursued, however additional work is required ahead of exploration drilling. The next development stage should seek to refine the proposed boundaries of the field through additional infill MT survey and a detailed field exploration programme in the area of Belair Estate. In addition, a gravity survey is recommended to identify the interface of the Mount Saint Catherine volcanic sequences and the Tufton Hall formation.

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REFERENCES

Arculus, R.J. *Geology and geochemistry of the alkali basalt–andesite association of Grenada, Lesser Antilles island arc*. Geological Society of America Bulletin 87: 612–624. (1976).

Bob Lawrence and Assoc., Geothermal Resources in Latin America and the Caribbean. Report prepared for Sandia Laboratories. (1999).

Burke, K. *Tectonic evolution of the Caribbean*. Annual Review of Earth and Planetary Sciences 16, 201–230. (1988)

Geotermica Italiana, *Reconnaissance study of the geothermal resources of the Republic of Grenada*: Final Report to Latin, American Energy Organization, 132 pp. (1981).

Huttrer G.W., and Michels D.E., *Final Report Regarding Prefeasibility Studies of the Potential for Geothermal Development in Grenada, W.I.: Prepared under Geothermal Mgmt. Co., Inc, Frisco, Colo.*, Submitted to National Geothermal Association, March, 73 pp. and appendices. (1993).

Larsen,J.C. Robust smooth magnetotelluric transfer functions, Geophys. J. Int., v. 124, pp. 801-819. (1996).

Macdonald, R., Hawkesworth C.J., Heath E. (2000).The Lesser Antilles volcanic chain: a study in arc magmatism. Earth-Science Reviews 49, pp. 1–76. (2000).

Perez, O., Bilham, R., Bendick, R., Velandia, J., Hernadez, C., Hoyer, M., Kozuch, M, Velocity field across the southern Caribbean plate boundary and estimates of

Caribbean–South American plate motion using GPS geodesy 1994–2000. Geophysical Research Letters 28, 2987–2990. (2001).

Pindell, J.L. and Barrett, S.F. Permo-Triassic reconstruction of western Pangea and the evolution of the Gulf of Mexico/Caribbean region. Tectonics 1 (2), 179–212. (1982).

Pindell, J.L. and Dewey, J.F. Geological evolution of the Caribbean region: a plate tectonic perspective. In: Dengo, G., Case, J.E. (Eds.). The Caribbean Region, the Geology of North America. Geological Society of America, Boulder, CO, pp. 405–432. (1990).

Speed, R.C. and Smith-Horowitz, P.L. Perch-Nielsen K.v.S., Saunders J.B., Sanfilippo, A.B. Southern Lesser Antilles Arc Platform: Pre-Late Miocene Stratigraphy, Structure, and Tectonic Evolution. GSA Special Papers 1993, v. 277, p. 1-98. doi: 10.1130/SPE277-p1. (1993).

Trenkamp R., Kellogg, J.N., Freymuller, J.T., Mora, H.P. (2002). Wide plate margin deformation, southern Central America and northwestern South America, CASA GPS observations. Journal of South American Earth Sciences 15, 157–171. (2002).

Wadge, G. Comparison of volcanic production rates and subduction rates at the Lesser Antilles and Central America. Geology 12, 555–558. (1984).

Wadge, G. and Shepherd, J.B. Segmentation of the Lesser Antilles subduction zone. Earth Planet. Sci. Lett. 71, 297–304. (1984).

Weber J.C., et al. GPS estimate of relative motion between the Caribbean and South American plates, and geologic implications for Trinidad and Venezuela. Geology 29 (1), 75–78. (2001).

Table 1: Thermal Feature Water Chemistry. Datasets from the survey conducted by [i]Geotermica Italiana (1981) and [g]Hutter and Michels (1993) are also reported. ΣCATS: Sum of cation charge (mEq/L). ΣANS: Sum of anion charge (mEq/L). BAL: Ion Balance (% Diff). TDS: Total Dissolved Solids (mg/kg). n.r.: non reported. n.a.: non analised.

Location	Code	Date	Coordinates mE	mN	Elev	Temp	pH	Li	Na	K	Ca	Mg	Fe	Cl	F	Br	SO_4	$tHCO_3$	B	SiO_2	ΣCATS	ΣANS	Ion Bal	TDS
					mRSL	°C	lab							mg / kg							mEq/L	mEq/L	%	mg/kg
Castle Hill South	i8	1981	n.r	n.r	n.r	37.2	5.76	n.r	7360	508	2204	279	n.r	16307	n.r	n.r	230	915	161.0	120	466	480	-1%	28080
Castle Hill South	i2	1981	n.r	n.r	n.r	28.9	6.42	n.r	32	4	36	13	n.r	35	n.r	n.r	5	195	0.1	90	4	4	1%	410
Castle Hill South	g10	1993	n.r	n.r	213	46.7	6.92	15.0	3668	309	1243	151	8.3	8248	0.22	36.4	137	457	115.0	133	242	243	0%	14520
Castle Hill South	g11	1993	n.r	n.r	305	40.6	6.53	5.3	1323	105	394	55	4.3	2726	0.14	11.8	125	302	35.0	59	84	85	0%	5150
Castle Hill South	g18	1993	n.r	n.r	183		7.47	0.8	216	25	77	16	0.0	440	0.08	2.0	16	101	5.4	53	15	14	3%	950
Castle Hill South	g12	1993	n.r	n.r	198		6.10	0.0	31	5	30	12	n.r	39	0.12	0.7	7	163		84	4	4	1%	370
Castle Hill South	Point25	25/02/2015	644154	1348146	223	49.0	6.77	n.a	1544	179	542	67	n.a	3198	0.11	15.3	52	454	50.0	135	104	99	3%	6240
Castle Hill South	Point26	25/02/2015	644339	1348493	179	40.2	7.30	n.a	4106	401	1226	167	n.a	8755	0.18	42.0	29	407	129.0	90	264	255	2%	15350
Chambord	i9	1981	n.r	n.r	n.r	36.1	6.13	9.7	3680	168	962	352	n.r	8154	n.r	n.r	30	1220	45.0	120	241	251	-2%	14740
Chambord	i11	1981	n.r	n.r	n.r	28.9	7.87	0.8	368	7	136	58	n.r	709	n.r	n.r	13	433	4.1	64	29	27	4%	1860
Chambord	i10	1981	n.r	n.r	n.r	28.9	7.74	0.2	117	5	68	44	n.r	191	n.r	n.r	15	364	1.0	78	12	12	2%	880
Chambord	g5c	1993	n.r	n.r	15	35.0	6.83	9.7	3655	167	1020	349	n.r	7929	0.10	34.0	33	725	71.0	115	243	237	1%	14110
Chambord	g5b	1993	n.r	n.r	15	33.3	7.14	9.4	3554	164	955	346	8.5	7504	0.13	32.0	28	978	61.0	121	235	229	1%	13760
Chambord	g5a	1993	n.r	n.r	15	33.3	6.10	8.6	3300	144	834	311	2.5	6991	0.10	30.0	29	725	60.0	101	214	210	1%	12540
Chambord	g5	1993	n.r	n.r	12	27.8	7.31	0.3	198	9	74	51	0.03	345	0.16	2.3	14	364	2.3	78	17	16	2%	1140
Chambord	Point18	23/02/2015	650271	1349050	23	32.9	6.84	n.a	3248	175	971	322	n.a	6706	0.05	34.0	25	1104	63.0	123	221	208	3%	12770
Hermitage-Peggy´s whim	i6	1981	n.r	n.r	25	27.8	8.31	0.1	48	4	30	13	n.r	85	n.r	n.r	6	134	0.9	53	5	5	1%	370
Hermitage-Peggy´s whim	i5	1981	n.r	n.r	25	27.2	5.60	n.r	16	2	134	57	n.r	28	n.r	n.r	13	671	0.9	33	12	12	0%	950
Hermitage-Peggy´s whim	g9	1993	n.r	n.r	31	38.9	6.10	2.5	736	50	281	91	12.1	1383	0.18	6.1	9	828	19.3	167	55	53	2%	3580
Hermitage-Peggy´s whim	g4	1993	n.r	n.r	23	25.0	6.80	n.r	17	1	95	31	0.1	27	0.15	n.r	14	417	0.1	37	8	8	1%	640
Hermitage-Peggy´s whim	Point17	23/02/2015	646168	1346072	287	37.9	6.71	n.a	656	49	283	87	n.a	1368	0.18	6.1	7	923	20.0	160	51	54	-3%	3560
Clabony-MT Hope	i7	1981	n.r	n.r	n.r	33.9	5.59	0.1	55	7	60	26	n.r	34	n.r	n.r	4	421	1.0	150	8	8	-2%	760
Clabony-MT Hope	g3	1993	n.r	n.r	320	35.6	6.88	1.4	354	31	134	42	18.6	609	0.19	2.8	4	527	9.8	163	26	26	1%	1900
Clabony-MT Hope	g1	1993	n.r	n.r	472	22.2	3.15	n.r	22	7	18	9	14.8	37	0.19	n.r	384		0.9	107	3	9	-44%	640
Clabony-MT Hope	g8	1993	n.r	n.r	411	35.0	6.68	0.1	55	7	60	28	6.3	34	0.12	n.r	5	389	0.9	155	8	7	3%	740
Clabony-MT Hope	g2	1993	n.r	n.r	488	22.8	4.95	n.r	13	7	4.3	1	0.2	24	0.05	0.5	3		20.0	27	1	1	16%	100
Clabony	Point7	21/02/2015	644069	1343251	399	33.2	6.52	n.a	56	7	59	26	n.r	33	0.08	0.1	4	489	1.5	146	8	9	-8%	820
Clabony	Point8	21/02/2015	643629	1343485	410	32.2	6.62	n.a	65	8	84	27	n.r	38	0.11	0.1	32	540	0.7	148	9	11	-6%	940
Clabony	Point9	21/02/2015	643784	1343701	474	23.7	6.17	n.a	15	3	20	10	n.r	11	0.04	0.0	2	205	0.1	88	3	4	-19%	350
MT Hope	Point11	22/02/2015	644257	1344007	509	20.6	3.31	n.a	9	1	4.8	3	n.r	13	0.03	0.0	62	131	0.1	28	1	4	-45%	250
MT Hope	Point36	10/03/2015	645415	1344389	362	35.2	6.56	n.a	382	34	158	44	n.r	710	0.15	2.9	4	659	12.5	167	29	31	-3%	2170

Continuation of Table 1.

Location	Code	Date	Coordinates mE	Coordinates mN	Elev mRSL	Temp °C	pH lab	Li	Na	K	Ca	Mg	Fe	Cl	F	Br	SO_4	$tHCO_3$	B	SiO_2	ΣCATS mEq/L	ΣANS mEq/L	Ion Bal %	TDS mg/kg
								mg/kg																
Plaisance-Red River	i18	1981	n.r	n.r.	n.r.	38.9	5.68	n.r.	106	16	114	13	n.r.	57	n.r.	n.r.	302	256	5.1	150	12	12	-1%	1020
Plaisance-Red River	i22	1981	n.r	n.r.	n.r.	26.1	6.01	n.r.	18	1	62	12	n.r.	13	n.r.	n.r.	6	262	0.2	90	5	5	1%	460
Plaisance-Red River	i21	1981	n.r	n.r.	n.r.	25.0	5.71	0.0	23	4	34	7	n.r.	12	n.r.	n.r.	144	0	0.6	66	3	3	0%	290
Plaisance-Red River	i20	1981	n.r	n.r.	n.r.	25.0	3.63	0.0	19	4	68	15	n.r.	6	n.r.	n.r.	365	0	0.0	78	6	8	-15%	550
Plaisance-Red River	i19	1981	n.r	n.r.	n.r.	22.8	6.00	n.r.	13	2	22	5	n.r.	7	n.r.	n.r.	86	15	0.0	51	2	2	-2%	200
Plaisance-Red River	g13	1993	n.r	n.r.	396	24.4	3.12	n.r.	18	6	13	6	26.0	27	0.07	n.r.	101	0		82	3	3	0%	280
Plaisance-Red River	g14	1993	n.r	n.r.	389	25.6		0.1	23	5	23	7	2.4		n.r.	n.r.				81	1003	0	100%	140
Plaisance	Point32	28/02/2015	641601	1343966	305	27.5	6.54	n.a.	48	6	36	14	n.a.	36	0.04	0.1	13	299	1.3	122	5	6	-8%	580
Adelphi-St CYR	I3	1981	n.r	n.r.	n.r.	32.8	5.92	0.1	81	10	130	63	4.6	39	0.17	n.r.	4	915	0.3	132	15	16	-2%	1380
Adelphi-St CYR	I4	1981	n.r	n.r.	n.r.	25.0	7.85	n.r.	9	1	11	9	5.3	11	0.11	n.r.	3	85	0.0	26	2	2	-2%	160
Adelphi-St CYR	g7	1993	n.r	n.r.	213	32.8	7.06	n.r.	85	10	114	63	n.r.	41	n.r.	n.r.	4	812	0.4	136	15	15	1%	1260
Adelphi-St CYR	g6	1993	n.r	n.r.	309	34.4	6.88	0.1	33	5	68	29	n.r.	16	n.r.	n.r.	5	412	0.1	136	7	7	0%	700
Adelphi-St CYR	Point1	20/02/2015	643592	1339245	239	32.0	6.62	n.a.	82	11	123	62	n.a.	37	0.11	0.1	3	954	0.7	137	15	17	-5%	1410
Adelphi-St CYR	Point3	20/02/2015	642556	1339339	344	28.0	6.39	n.a.	35	6	76	31	n.a.	12	0.07	0.0	5	603	0.4	141	8	10	-13%	910
Hapsack	g16	1993	n.r	n.r.	549	54.4	4.50	n.r.	25	5	28	8	2.7	13	0.08	n.r.	152	0	0.1	113	3	4	-3%	350
Hapsack	g17	1993	n.r	n.r.	552	48.9	3.03	n.r.	10	20	4	3	13.7	13	0.06	n.r.	159	0		107	2	4	-22%	340
Hapsack	Point21	24/02/2015	643479	1344780	555	63.8	3.01	n.a.	12	22	6.7	4	n.a.	9	0.03	0.0	205	61	0.3	122	3	6	-33%	440
Grand Etang	Point37	11/03/2015	641806	1337515	527	22.1	7.40	n.a.	5	1	2	3	n.a.	9	0.03	0.0	1	21	0.1	7	1	1	-4%	50
Lake Antoine	Point38	11/03/2015	651020	1347505	9	21.7	8.54	n.a.	211	12	30	104	n.a.	361	0.06	1.1	2	491	1.4	26	20	18	3%	1240
Seawater Sauteurs	Point39	11/03/2015	647524	1351821	11	27.4	8.07	n.a.	11561	510	464	1410	n.a.	19505	0.89	57.0	2810	122	10.7	1	655	611	3%	36450
Average Seawater Caribbean	sw					28.0	8.00	0.1	10561	380	400	1272	n.r.	18980	1.40	65.0	2649	142	4.6	3	-	-	-	-

Table 2: Chemical composition of bubbling gases from Grenada. CO_2, H_2S, NH_3, He, H_2, Ar, N_2, CH_4 and CO_2 in %mol/mol. H_2Ar: Hydrogen-Argon geothermometer (Giggenbach 1991). CO_2Ar: CO_2-Argon geothermometer (Giggenbach 1991). Xg: total gas/water ratio as defined by Taran (2005).

					sample analysis:								calculations				
Name	comments	Temp °C	Elev m	pressure atm	CO_2	H_2S	He	H_2	Ar	N_2	CH_4	O_2	N_2 ---- Ar	CO_2Ar °C	Xg calculated mol/mol	Xwater calculated mol/mol	log (H_2/H_2O) calculated
								Mole % in Dry Gas									
Point3	St. Cyr-Adelphi	28.0	344	0.95990	99.40	< 0.10	< 0.0001	0.0014	0.0056	0.41	< 0.0005	0.180	73.2	295	0.004	0.996	-5.25
Point7	Clabony	33.2	399	0.95356	99.30	< 0.10	< 0.0001	< 0.0001	0.0076	0.51	0.0033	0.160	67.1	289	0.003	0.997	-6.53
Point8	Clabony	32.2	410	0.95238	98.60	< 0.10	0.0001	0.0003	0.0100	1.04	0.0930	0.240	104.0	283	0.002	0.998	-6.18
Point11	Mt. Hope	20.6	509	0.94115	97.90	< 0.10	0.0004	0.0005	0.0049	1.84	0.1300	0.094	375.5	298	0.005	0.995	-5.64
Point15	Mt. Hope	23.9	494	0.94278	97.70	< 0.10	0.0004	0.0002	0.0083	1.94	0.1400	0.190	233.7	287	0.003	0.997	-6.27
Point34	Mt. Hope	21.7	552	0.93625	98.10	< 0.10	0.0004	0.0002	<0.0001	1.77	0.1000	0.026			0.224	1.000	
Point36	Mt. Hope	35.2	362	0.95785	99.20	< 0.10	0.0001	0.0001	0.0069	0.58	0.0048	0.170	84.1	291	0.003	0.997	-6.49
Point36	Mt. Hope	35.2	362	0.95785	99.40	< 0.10	0.0001	0.0004	0.0046	0.44	0.0057	0.130	95.7	299	0.005	0.995	-5.71
Point16	Hermitage-Peggy's Whim	23.6	127	0.98507	97.40	< 0.10	0.0007	0.0001	0.0093	2.20	0.0990	0.240	236.6	284	0.002	0.998	-6.62
Point18	Chambord	32.9	23	0.99733	90.00	< 0.10	0.0009	0.0002	0.1400	6.10	0.0260	3.600	43.6	225	0.000	1.000	-7.56
Point21	Hapsack	63.8	555	0.93590	97.90	< 0.10	0.0004	0.0230	0.0070	1.87	0.0240	0.070	267.1	290	0.003	0.997	-4.13
Point22	Hapsack	76.8	555	0.93589	97.80	< 0.10	0.0004	0.0430	0.0074	1.95	0.0280	0.100	263.5	289	0.003	0.997	-3.89
Point35	Hapsack	21.5	640	0.92637	97.70	< 0.10	0.0001	0.0004	0.0084	1.99	0.0710	0.200	236.9	286	0.003	0.997	-5.98
Point31	Plaisance Estate	28.9	470	0.94553	93.70	< 0.10	0.0005	0.0012	0.0420	5.00	0.1100	1.070	119.0	252	0.001	0.999	-6.21

Table 3: Isotopic data of the thermal feature s from Grenada reported by [1]Pedroni et al., (1999) and [2]Van Soest et al., (1998). $\delta^{13}C-CO_2$ as ‰ referred to VPDB. Measured and corrected He isotopic composition as R_M/R_A and R_C/R_A , respectively. $\delta^{18}O$ and δD (‰V-SMOW). The measured $CO_2/^3He$ ratios in bubbling pools are also reported. L, S and M are the limestone, organic sediments and mantle end-members (%), as defined by Sano and Marty (1995). n.r.: none reported

ID	Place	type	T °C	R_M/R_A	R_C/R_A	$CO_2/^3He$ (in mol/mol)	$\delta^{13}C$ (‰ V-PDB)	M	S	L	author
951sg1a	Sallee River	bubbling pool	32.0	6.5	6.6	5.15E+09	-6.00	29.12%	15.15%	55.74%	1
96LAG1a-5	Sallee River	bubbling pool	32.5	5.8	5.8	3.81E+10	-6.40	3.92%	20.68%	75.40%	1
951sg2a	Peggy's Whim	bubbling pool	35.0	2.9	2.9	3.47E+13	-2.70	0.00%	9.00%	91.00%	1
95LSG3a	Hampsack Hall	bubbling pool	54.1	5.8	5.8	2.64E+10	-2.70	5.67%	8.06%	86.28%	1
951sg9a	Mirabeau	bubbling pool	33.9	2.5	2.7	2.86E+13	-3.40	0.00%	11.33%	88.67%	1
95LSG9a	Mirabeau	bubbling pool	33.9	1.5	1.5	2.49E+13	n.r.				1
BGL5AK	St.Cyr	bubbling pool	n.r.	5.8	5.9	7.79E+11	-4.69	0.18%	15.60%	84.22%	2
BST41AK	St.Cyr	bubbling pool	n.r.	5.8	5.9	6.88E+11	-4.75	0.20%	15.80%	84.00%	2
BST39AK	Clabony	bubbling pool	n.r.	5.8	6.1	3.90E+12	-3.10	0.02%	10.33%	89.65%	2
BST26AK	Telescope	Fumarole	n.r.	6.7	6.7	5.67E+10	-2.61	2.63%	8.26%	89.11%	2
BGL7AK	Telescope	Fumarole	n.r.	6.7	6.8	1.84E+10	-2.6	8.14%	7.24%	84.62%	2
BST31AK	Hapsack	Fumarole	n.r.	6.3	6.3	3.06E+10	-2.5	4.90%	7.58%	87.52%	2
BST30AK	Hapsack	Fumarole	n.r.	6.4	6.4	2.87E+10	-2.6	5.20%	7.83%	86.96%	2
BST21AK	St. John	bubbling pool	n.r.	6.7	6.7	2.30E+10	-2.6	6.50%	7.45%	86.05%	2
BST23AK	Salle River	bubbling pool	n.r.	5.7	5.7	1.52E+10	-6.6	9.83%	20.23%	69.94%	2

Table 4: δ^{18}O-H2O and δD-H_2O (‰V-SMOW) isotopic data of the thermal features from Grenada. Data from from Pedroni et al., (1999) is also reported.

Code	Area	Type	Date	Temp °C	δD ‰	δ^{18}O ‰	author
Point 1	Adelphi – St. Cyr	hot spring	20-Feb-15	32.0	-9.06	-2.42	this work
Point 3	Adelphi – St. Cyr	hot spring	20-Feb-15	28.0	-8.73	-2.52	this work
BW35	St. Cyr	hydrothermal brine		33.0	-10.00	-3.05	Pedroni et al. (1999)
Point 7	Clabony	bubbling pool	21-Feb-15	33.2	-8.95	-2.69	this work
Point 8	Clabony	bubbling pool	21-Feb-15	32.2	-9.12	-2.83	this work
Point 9	Clabony	bubbling pool	21-Feb-15	23.7	-8.56	-2.50	this work
BW10	Clabony	hydrothermal brine		36.0	-8.50	-3.22	Pedroni et al. (1999)
BW73	Clabony	hydrothermal brine		36.0	-8.10	-3.42	Pedroni et al. (1999)
Point 11	Mt. Hope	bubbling pool	22-Feb-15	20.6	-2.83	-1.75	this work
Point 36	Mt. Hope	bubbling pool	10-Mar-15	35.2	-9.00	-2.47	this work
Point 16	Hermitage	bubbling pool	23-Feb-15	23.6	-9.22	-2.74	this work
Point 17	Peggy's whim	hot spring	23-Feb-15	37.9	-10.43	-2.78	this work
Point 18	Chambord	bubbling pool	23-Feb-15	32.9	-12.82	-1.50	this work
BW64	Salle River	hydrothermal brine		34.5	-13.10	-2.60	Pedroni et al. (1999)
BW59	Salle River	hydrothermal brine		33.0	-12.00	-1.80	Pedroni et al. (1999)
Point 21	Hapsack-Red River	bubbling pool	24-Feb-15	63.8	-6.84	-3.46	this work
BW17	Hapsack-Red River	hydrothermal brine		43.0	-7.70	-1.70	Pedroni et al. (1999)
BW67	Hapsack-Red River	hydrothermal brine		56.0	-10.60	-2.54	Pedroni et al. (1999)
Point 25	Castle Hill South	hot spring	25-Feb-15	49.0	-10.91	-1.97	this work
Point 26	Castle Hill South	hot spring	25-Feb-15	40.2	-12.41	-0.72	this work
Point 32	Plaisance	warm spring	28-Feb-15	27.5	-10.18	-2.59	this work
BW21	Grand Anse	rainwater			8.20	-0.82	Pedroni et al. (1999)
Point 37	Grand Etang	cold water	11-Mar-15	22.1	0.51	-0.97	this work
Point 38	Lake Antoine	cold water	11-Mar-15	21.7	20.01	4.24	this work
Point 39	Seawater Sauteurs	seawater	11-Mar-15	27.4	8.85	1.68	this work
MW 1	Adelphi – St. Cyr	meteoric water	20-Feb-15	23.0	-7.49	-2.24	this work
MW 15	Mt. Hope	meteoric water	22-Feb-15	22.1	-8.15	-2.36	this work
MW 36	Mt. Hope	meteoric water	10-Mar-15	21.3	-9.00	-2.47	this work
MW-16	Hermitage	meteoric water	23-Feb-15	20.3	-7.77	-2.24	this work
MW-22	Hapsack-Red River	meteoric water	24-Feb-15	20.1	-6.44	-2.49	this work
MW-26	Castle Hill South	meteoric water	25-Feb-15	20.6	-7.96	-2.16	this work
MW-31	Plaisance	meteoric water	28-Feb-15	20.7	-6.86	-2.45	this work