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GEOTHERMAL ACTIVITY AND DEVELOPMENT IN EAST CARIBBEAN ISLANDS

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ABSTRACT

The geothermal activities on the 11 islands of the Eastern Caribbean have increased in the last six years. These islands, hosting 21 volcanoes were estimated by USDOE to have collectively 16,310 MWe of geothermal energy. In 2004 Guadeloupe upgraded its 4.7MWe plant to 15.7MWe and is the only island in the Eastern Caribbean having a geothermal plant. The Organisation of American States funded a programme that carried out geochemical, geological and geophysical studies on Nevis; geological and geophysical studies on Dominica; and reinterpreted the data from St. Lucia in 2004 and 2005. In 2007 Nevis gave a licence for exploratory work to West Indies Power Holdings (WIPH). In 2008 the government of Dominica signed an agreement for exploration, development, and export of power with the French islands of Martinique and Guadeloupe from the Wotten Waven area. They also signed an agreement with WIPH for the Galion-Soufriere area. WIPH began negotiations with the government of Saba. Three slim-hole wells were drilled in Nevis with attendant steam from two. In 2009 Nevis Island Administration signed a government contract and a power purchase agreement for the supply of geothermal power from WIPH. The initial power supplied will be 10MWe to Nevis and then another 25MWe to St. Kitts. In 2010, the Government of St. Lucia signed a MOU with UNEC Corporation of United States a subsidiary of Qualibou Energy Inc. to develop 120MWe of geothermal power by 2015 with 15MWe installed by 2012.

1. INTRODUCTION

The geothermal activity within the eastern Caribbean has been documented as early as the 1950's by P.H.A. Martin-Kaye. The archipelago of islands starting with Saba (Netherlands Antilles) in the north through Grenada in the south (Figure 1) show high geothermal possibilities. Since the 1700s, the hot springs baths in the islands such as Nevis and St. Lucia have been used by the rich and famous as well as locals for therapeutic reasons. There have also been numerous eruptions, the last being Montserrat in 1995. The reason for the active volcanism in the Caribbean is due to the fact that the Caribbean islands occupy a crustal plate that forms a "tongue" or

FIGURE 1: Map of the Eastern Caribbean (amazingsnorkeling, 2005)

buttress along the sides of which the North and South American Plates move westward and beneath the Caribbean plate. The Atlantic Plate subduction has created volcanic arcs typical of plate boundaries and in the Caribbean, each volcano or group of volcanoes has formed the foundation of a discrete island (Huttrer, 2000). The eastern (outer) arc is older and has extinct volcanoes while the western (inner) arc is younger and has dormant to active volcanoes. The two arcs are joined at Martinique and trend southward into the Paria Peninsula of Venezuela (Huttrer, 2000). There are a total of 21 volcanoes in this chain of islands with Dominica hosting 9 of the 21 volcanoes (Table 1). Six of these volcanoes have erupted in the past 400 years (Joseph, 2008).

Despite the obvious existence of the geothermal possibilities in the Caribbean, only Guadeloupe has tapped into this renewable source of energy for electricity generation. Guadeloupe has a total installed capacity of 15.7 MWe as of 2004 (Yeung, 2006). The other islands are mostly in the early stage of development with the exception of Nevis and St. Lucia who are expected to start drilling shortly with plans to install a 10MWe (Green Island, 2009) and 15MWe (Kaye, 2010) plant respectively in their first phases of development.

The Caribbean region being a chain of small islands, finds it very difficult to attract investors. This is mainly due to the small population of the islands which reflect a very small power demand. The topography of the islands make it quite challenging to access the sites and very limited financing is available to local government to undertake the riskiest part of the development – the feasibility study to prove that there is a commercially viable geothermal resources and its most favourable location. Given that geothermal development is a relatively new science, awareness for the development of geothermal and knowledge of its benefits to the country especially countries in the Eastern Caribbean is greatly needed. It is needed to reduce the dependency on fossil fuel and to create a tourist friendly environment and the anticipated boost to the country's economy.

TABLE 1: Caribbean countries with volcanoes

Country	Name of volcano
Saba	Mt. Scenery
St. Eustatius	The Quill
St. Kitts	Mt. Liamuigua
Nevis	Nevis Peak
Montserrat	Soufrière Hills
Guadeloupe	La Soufrière
Dominica	Morne Aux Diables
	Morne Diablotins
	Morne Trois Piton
	Wotten Waven/Micotrin
	Watt Mt.
	Valley of Desolation
	Morne Anglais
	Grand Soufrière Hills
	Plat Pays Volcanic Complex
Martinique	Montagne Pelée
St. Lucia	Soufrière Volcanic Centre
St. Vincent	The Soufrière
Grenada	Kick 'em Jenny
	Ronde/Caille
	Mt. St. Catherine

2. GEOTHERMAL ACTIVITY IN THE EASTERN CARIBBEAN

2.1 Saba

Saba is a small island of 13 km^2 and has a central volcano (Figure 2) with 15 andesitic domes on its flanks (Battoceletti, 1999). The last volcanic eruption(s) occurred less than 1000 years ago. In the study done by USDOE in 1998, 3,000MWe was estimated from the data gathered (Joseph, 2008). Among the geological and geochemical data collected, visual manifestation of the existence of geothermal activity includes the numerous hot springs along the shoreline and off shore and also the high degree of fractures (Battoceletti, 1999) causing a rise in the temperatures of hot springs over the years. In 2008, the government of Saba signed an agreement with West Indies Power Holdings (WIPH) to conduct exploratory work for geothermal resources and such work started in 2009.

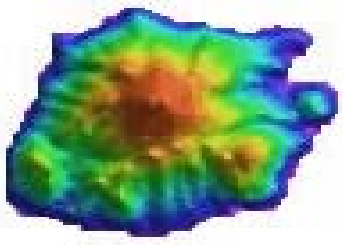

FIGURE 2: Saba (Stewart, 2000)

2.2 Saint Eustatius (Statia)

The island of Statia (Figure 3) is 21 km^2 and form part of the Netherlands Antilles with Saba. Unlike Saba, there are no apparent surface manifestations and only reports of thermal waters in two drinking water wells have suggested geothermal activity on the island (Huttrer, 1998). The geological and geochemical work done by the USDOE study in 1998, show very low potential for geothermal resource development and as such estimated a potential of 0MWe (Joseph, 2008). Since this is a conservative conclusion, it is possible with deep prospecting like resistivity profile and even thermal gradient drilling may prove a more positive result.

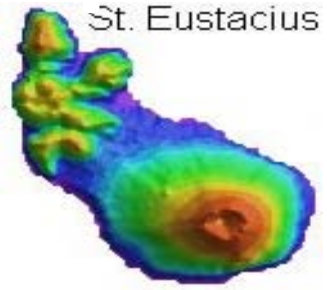

FIGURE 3: Saint Eustatius (Stewart, 2000)

2.3 St. Kitts

St. Kitts (Figure 4) covers a total area of 176 km^2. The geophysical and geochemical studies done (Huttrer, 1998a) by USDOE allowed them to estimate a geothermal potential on the island to be approximately 500MWe. From the study, the best location is at Brimstone Hill which is a National Park and hence no development can take place there. Other sites of geothermal indication on the island are at the crater of Mount Liamuiga where there is moderately large areas of steaming ground and hot springs along the western shoreline. Unfortunately, the reports states that these indicators on St. Kitts are not well defined (Huttrer, 1998a) and recommended that it will be easier and cheaper to develop geothermal sites on the sister island of Nevis.

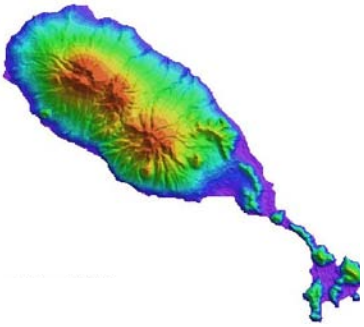

FIGURE 4: St. Kitts (Stewart, 2000)

2.4 Nevis

Nevis (Figure 5) is 93 km^2 in size and is likely to be the next island in the Caribbean where a geothermal plant will be installed. Prior to studies done by WIPH, four major studies exploring the geothermal potential of the island were conducted. These studies were P.H.A. Martin-Kaye (1959); Hutton and Nockholds (1978); Geotermica Italiana (1992) and Morgan & Vichabian (2004).

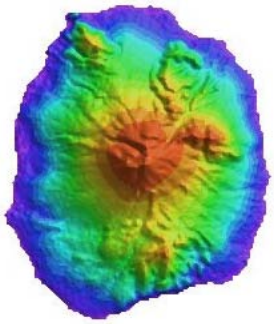

FIGURE 5: Nevis (Stewart, 2000)

Radiometric age dating has shown Nevis to have rock between the ages of 3.4 to 0.1 million years (Hutton and Nockolds, 1978). The report by Hutton and Nockolds, 1978 evaluated the age of the various volcanic centres on the island and found them to be as follows:

- Windy Hill volcanic – 3.4 ± 0.5 Ma
- Cades Bay volcanic – 3.22 ± 0.16 Ma
- Hurricane Hill volcanic – 2.7 ± 0.5 Ma
- Saddle Hill volcanic – 1.80 ± 0.3 Ma
- Butlers volcanic – 1.10 ± 0.16 Ma

The fluid chemistry of the geothermal resource was found to be thermally altered seawater with retrograde minerals (GeothermEx Inc., 2005). The isotopes of helium have been measured in gas samples and mixed water thermal outflow by GeothermEx Inc. (2005) and LaFleur and Hoag (2010) respectively throughout the western side of the island. The results of their findings suggest that there is a definite magmatic origin existing on the western side of the island.

TABLE 2: Slim hole wells information (WIPH, 2008a and b)

Well	Year	Depth (m)	Pres. (bars)	Temp (ºC)
Nevis 1	Jun. 2008	1065	82	250
Nevis 2	Jul. 2008	732	-	260
Nevis 3	Oct. 2008	899	16	201

Extensive geophysical analyses have been carried out by OAS (GeothermEx Inc., 2005) in the form of self-potential (SP) and gravity testing and by WIPH (LaFleur and Hoag, 2010) in the form of controlled source audio frequency magneto-telluric method (CSAMT), magneto-telluric method (MT) and transient electromagnetic method (TEM). However, until 2008 all of the findings were based on surface exploration. In 2007 a contract was signed between Nevis Island Administration (NIA) and WIPH giving WIPH the right to explore for this resource with the ultimate objective to harness the geothermal fluid for electricity generation. Table 2 gives a summary of the information published in WIPH website press releases. It gives the basic information concerning the reservoir condition. Nevis wells 1 and 3 were found to be self-flowing wells with down hole and well head pressure of 82 and 16 bars respectively, however, Nevis 3 was the more impressive of the two. Nevis 2 did not flow since upon reaching a depth of 732 m the drill bit got stuck and since a temperature of 260ºC was reached at this point, drilling was abandoned and operation moved to the subsequent well now known as Nevis 3.

USDOE estimates potential of 800MWe in their study in 1998 and WIPH estimates that between Nevis 1 and 3 lies 300MWe.

2.5 Montserrat

Montserrat (Figure 6) volcano is one of the six volcanoes that have erupted in the past 400 years. Since record keeping began back in 1635, it has been active in 1897/98; 1933/37; 1966/67 (Yeung, 2006) and again in 1995 until present time. Prior to the last eruption, the southwestern flank of Soufrière Hills volcano was the site of solfataric activity and of thermal springs. The USDOE report estimated a potential of 940MWe. However, the greatest potential for geothermal exploration is now located in the restricted zone. Also, because of the massive migration after the 1995 eruption in order to make a geothermal project financially viable in Montserrat, the investor will have to look at the possibility of exporting the power to a neighboring island such as Antigua.

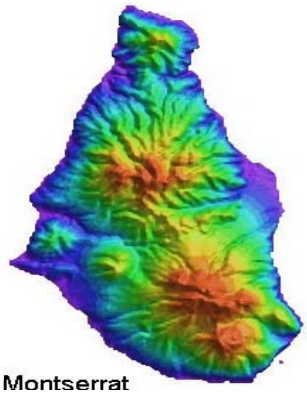

FIGURE 6: Montserrat (Stewart, 2000)

2.6 Guadeloupe

Figure 7 shows the active side of the butterfly shape island of Guadeloupe. This island is a French territory and has the only geothermal plant in the Eastern Caribbean.

In 1969 to 1970, three wells were drilled and named Bouillante 1, 2 and 3 accordingly. Bouillante 1 reached a depth of 800 m at 220 ºC but was deemed a poor producer. Bouillante 2 with less than half the previous depth had higher temperatures and pressure of 242 ºC and 14 bars respectfully. In 1991 and 1994 Bouillante 2 was tested and retested, the first test being for a prolonged period of 6 months. Bouillante 3 was drilled to 445 m and it crossed a sandy layer at 410-440 m with temperature close to 240ºC (Battocletti, 1999). It was later deepened to 850m but with little change in the production rate. Bouillante 4 was drilled to 1200 m but was a poor producer.

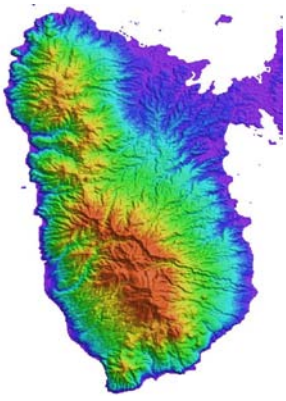
FIGURE 7: Guadeloupe (Stewart, 2000)

Guadeloupe has the only geothermal power plant in the Caribbean. In 1984 a 4.5 MWe double flash power plant at Bouillante came online and supplied the leeward coast of Basse-Terre with electricity. The Bouillante plant had intermittent problems caused by relatively high amounts of non-condensable gases and associated sulphuric acid (H_2S0_4), which seem to have been mitigated by Compagnie Française de Géothermie (CFG) (Joseph, 2008). In 2004, the plant in Guadeloupe was explanted to 15MWe. However, more expansion is possible in the future since USDOE estimated a total potential of 3,500MWe for the island.

2.7 Dominica

The Commonwealth of Dominica (Dominica) (Figure 8) is expected to be the island with the most potential in the Eastern Caribbean. However, due to its terrain, it may prove to be quite difficult to develop. In 1977, the French Bureau de Recherches Géologiques et Minières (BRGM) started geothermal exploration on Dominica. They identified 3 areas namely, Wotten Waven, Boiling Lake and Soufrière. In 1982 BRGM expanded its exploration program and focus on Boiling Lake and Wotten Waven. As part of the USDOE study in 1998, a power potential of 1,390 MWe was estimated. WIPH was granted license in 2008 to explore and develop the geothermal resources in the Soufrière area and they are presently doing exploratory work there. The government of Dominica continues the development of the Wotten Waven area.

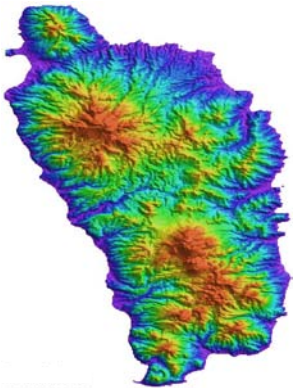

FIGURE 8: Dominica (Stewart, 2000)

2.8 Martinique

The ever active Montagne Pelée (Figure 9) appears an obvious point of possible geothermal resources. There are solfataras, hot springs, earthquake epicenters nearby and well developed fracture systems (Huttrer, 1998b). With the success of the Guadeloupe, expansion in 2004, the EDF/CFG conducted geophysical studies and shallow drilling that year. The results were inconclusive and will require deep drilling to further prove resource. Martinique has an estimated 3,500 MWe of geothermal power potential.

FIGURE 9: Martinique (Stewart, 2000)

2.9 St. Lucia

St. Lucia (Figure 10) is one of the countries in the Caribbean where there have been a large amount of geothermal survey done. Evaluation of the island's geothermal potential started in 1951 with a field study conducted by Gunnar Bodvarsson in the Sulphur Spring area. In the 1970s, a comprehensive geothermal resource exploration program was done by the United Kingdom's Ministry of Overseas Development. Merz and McLellan drilled seven wells to depths of 116 to 725 m; four wells were productive. In the 1980s, Aquater (Italy), Los Alamos National Laboratory (funded by USAID), and the UN Revolving Fund for Natural Resources Exploration (UN/RFNR) and USAID conducted prefeasibility studies which included drilling production-size exploratory wells. Two deep wells drilled (SL-1 at Belford, SL-2 at Sulphur Springs); only SL-2 (1413 m) was productive with a flowing enthalpy of 2900 kJ/kg and a flow rate of 9.3- 17.5 kg/s. Fluids from SL-2 had a high gas/steam ratio (up to about 25% in weight), high H_2/H_2S ratio, HCl in the condensed steam, and high acidity (pH of 2.8). Estimated electrical output potential of SL-2 is 3 MWe. The most significant geological information obtained from the drilling

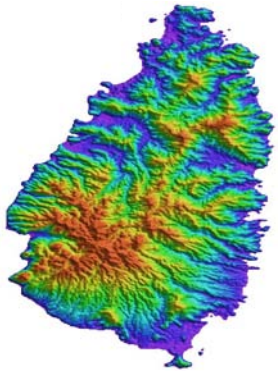

FIGURE 10: St. Lucia (Stewart, 2000)

cores and cuttings is that the formations crossed by the wells SL-1 and SL-2 indicate an almost complete lack of juvenile pyroclastic products. This leads to the perception that the area under exploration may not be the center of a strong pyroclastic activity.

At present the government of St. Lucia has a memorandum of understanding (MOU) with UNEC Corporation of United States a subsidiary of Qualibou Energy Inc. to develop a 120MWe plant by 2015 starting with 15MWe by 2012 in the first stage (Kaye, 2010). Drilling is expected to start shortly in the exploratory area of Soufrière. Qualibou estimates that the geothermal potential near the small town of Sulphur Springs should provide 170MWe.

2.10 St. Vincent

The Soufrière volcano located on the north western side of the island (Figure 11) is the youngest on St. Vincent and one of the most active in the entire Caribbean island arc, having erupted in 1902, 1971 and 1979. Numerous surface manifestations such as fumaroles and hot springs in river valley are evident on the southeastern and western sides of the dome flank (Huttrer, 1996).

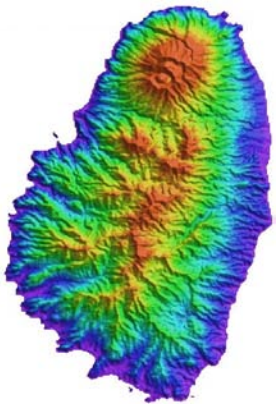

FIGURE 11: St. Vincent (Stewart, 2000)

Between1995-1996 prefeasibility studies were conducted by USAID. Geothermometer analysis of fluid samples show temperatures of 155-190 ºC. In 1997 to 1998, Growth Capital Holdings (GCH) and American company, signed a MOU with the government to conduct geological studies and selected drilling target. WIPH formed a joint venture with Government to develop the geothermal resources on the island and conducted geological, geophysical and geochemical surveys in 1998. USDOE also conducted geological and geochemical surveys and concluded that the island has a 890MWe potential (Huttrer, 1996).

2.11 Grenada

OLADE observed a possible resource of high enthalpy in the area of Mount Catherine in 1981 which was later confirmed in 1992 as part of the UN/DTCD program. Grenada was estimated to have geothermal potential of 1,110MWe. The prefeasibility study done documented a small solfatara on Mount Saint Catherine, several small thermal springs in ravines radial to the central volcano, and numerous relatively young phreatic explosion craters. Additionally, the sub-sea volcano "Kick-em-Jenny" lies only five miles off Grenada's north coast suggesting that the zone between it and central northeastern Grenada may have geothermal potential (Joseph, 2008).

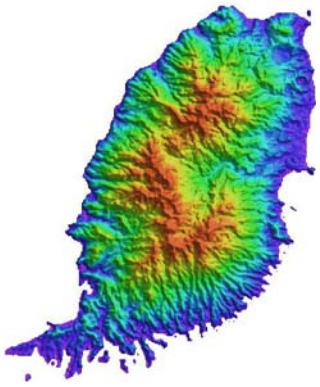

FIGURE 12: Grenada (Stewart, 2000)

3. CONCLUSIONS

Since the 1700s, the Eastern Caribbean islands were known for their geothermal potential with the numerous hot springs which were scattered among the islands both on and off shore. They were used primarily for therapeutic reasons for ailments such as arthritis. This archipelago of islands hosts a total of 21 volcanoes and 6 of which have erupted in the past 400 years. The most recent eruption was the Soufrière Hills volcano of Montserrat in 1995 and it is on-going.

Geothermal activity in terms of prefeasibility study started back as early as the 1950s and most of the island have not moved much further than this level. To date only Nevis, Guadeloupe, Martinique and St. Lucia of these islands in the Eastern Caribbean had slim hole or production size exploratory wells drilled and only Guadeloupe has a geothermal plant (15.7MWe) installed. The fundamental reason for

the slow rate of development is the lack of awareness of the potential of geothermal for electricity generation, therapeutic, agricultural, tourism in the form of carbon credits etc. Outside of Trinidad (with oil and natural gas), St. Vincent and Dominica (with some hydro plants that contribute to some of the electricity generation) all of the islands in the Eastern Caribbean have to import all of the oil for electricity generation. With the hike in oil prices, the utilities in the region are forced to employ a fuel surcharge to compensate for to the rising prices of oil.

Another reason is the access to financing. Many financial institutions regard geothermal exploration and all activities up to production to be a risky undertaking. Therefore most governments are unable to raise the finance and private companies while being more capable in that respect, have great difficulty in raising the required amounts until the resource is proven.

However, with this great resource available the region must now seek to harness its power. For the islands in the outer arc whose volcanoes have gone extinct, due to the close proximity of the islands, can create a grid network and reduce the regions collective dependence on fossil fuel.

In 2011, it is expected that geothermal activities will increase exponentially in the Eastern Caribbean as Nevis and St. Lucia should start the drilling of production wells. Nevis and St. Lucia is said to be installing 10MWe and 15MWe respectively by 2012. The government of Dominica in 2010 invited bids for tender for the drilling of production wells in the Wotton Waven area. The activities that took place in Nevis over the last two years have encouraged the governments in the region to press forward in the development of geothermal projects.

In conclusion, the activities over the last 60 years have generally been slow for the development of geothermal project in the Caribbean as it has been for most parts of the world. Nonetheless, the activities have increased significantly and it is expected to advance rapidly as the benefits to gain for these developments become more apparent.

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