GEOTHERMAL ENERGY PROPECTING FOR THE CARIBBEAN ISLANDS OF NEVIS AND MONTSERRAT

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ABSTRACT

Geothermal energy exploration is vastly dependent on the findings of geophysical surveys and other exploratory methods that may yield sub-surface characteristics of potential reservoirs, such as rock morphology, fault lining, and fluid dynamics. The main focus of this paper is to capture and explore the geological and geophysical methods required to generate an enhanced understanding of southern Montserrat and western Nevis. In addition, the location of deep fracture networks that are necessary for fluid circulation in hydrothermal systems will be identified through seismic analysis.

INTRODUCTION

Physical manifestation of stresses within the Earth is represented by fractures, as well as faults. Once rock is compelled beyond its elastic limit (its ability to deform) fractures are generated. It should be noted that all stresses, be it localized or regional stress systems, can be assessed based on fault orientation. There exists a major fault system on the island of Montserrat known as the Belham Valley Fault (BVF). The BVF not only dominates southern Montserrat but also influences the pattern of volcanism and alignment of vents within the Soufriere Island morphology (Kenedi 2010).

The Caribbean islands are situated on a crustal plate that moves eastward along the North and South American Plates, and subducting eastward beneath the Atlantic Plate, hence the reason for active volcanism (Huttrer, 1999). High temperature sources that are concentrated in regions of active or volcanic islands of the Eastern Caribbean chain are the most desirable area (Haraksingh & Koon Koon, 2011).

Heat mining from the earth can theoretically supply the world at present energy demand for many millennia (Sanyal, 2010). The conclusion implicitly assumes that the world's energy demand will not increase indefinitely in the future. From Figure 1 the assumption is justified, as it illustrates the projection of the world's population and energy demand worldwide by various parties which indicates that both the population and energy demand worldwide would peak by about the year 2050, proceeding this point both would start declining.

THEORY

Geothermal energy can be described as the stored thermal energy in, or heat produced from, the Earth's interior. An accurate and simplistic characterization of geothermal energy is that of heat mining. The high temperatures of geofluids are enhanced by the friction associated with grinding of tectonic plates against each other, resulting in the fracturing of rocks and thus facilitating fluid flow at depth and hence transport thermal energy towards the Earth's surface.

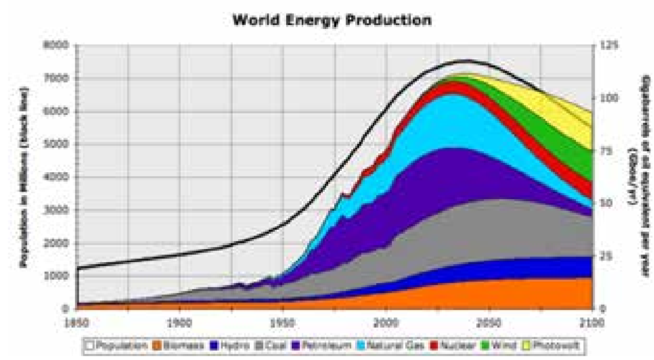

Figure 1. Forecast of World Population and Energy Production (from The Quaker Economist, Vol. 7, No. 155, March 2007).

In any geothermal power generation project, whether it be a low-or-high enthalpy system, it is very important to understand the geology, structural and tectonic regime of the area, and subsurface characteristics based on surface geophysical methods, as well as geochemical characteristics of the geothermal waters and gases (Chandrasekharam & Bundschuh, 2008).

The regions highlighted in Figure 2, illustrate subduction and strike-slip faults. A frequent occurrence of these areas includes constant tectonic readjustments resulting in regular earthquakes. Shown in the figure is a major subduction line which moves 18 mm per year and lies on the Eastern region of the Caribbean archipelago (Lesser Antilles) (Haraksingh & Koon Koon, 2011). Furthermore, other significant tectonic zones are oceanic transform fault, oceanic convergent boundary, and oceanic rift illustrated.

Figure 2. Caribbean Plate Tectonics (Source: Google Earth).

MINERALOGY OF THE GEOTHERMAL SYSTEM IN NEVIS

Faults and fractures are the primary source of permeability in crystalline rocks, however, many active hydrothermal systems exhibit active precipitation of minerals and chemical alteration, which then dictates that fracturing of conducting fluids in the subsurface will often seal and permeability will be lost. In contrast, recurrent brittle fractures and frictional failure in low porosity crystalline rocks produce dilation owing to surface roughness along the fracture wall (Brown, 1987) and the formation of breccias and micro-cracks during fault slip (Lockner and Beeler, 2002).

Figure 3 illustrates the ages of eruptions and the mineralogy of Nevis which is rather diverse. At Round Hill which is located in the northwest region of the island is concentrated with hornblende-pyroxene and phyric dacite. At Hurricane Hill, Cades Bay, Saddle Hill Red Cliff, Butler's Mountain, and Nevis Peak there are pyroxene-phyric dacite, porphyritic dacite, volcanic breccias, porphyritic and orthopyroxene-phyric dacite respectively (Hutton and Nockolds, 1978).

GEOLOGY OF NEVIS

Radiometric age dating of the almost exclusively volcanic rock of the island of Nevis shows a history of island-forming eruptions that initiated 3.4 million years ago, whilst the youngest only 0.1 million years before present. Pyroclastic rocks with a dacite composition is the dominant rock type hence hinting the presence of a high-level, evolved magmatic center of the type that maintains high heat flux in the near-surface.

One interesting feature is that of a sector collapse, which can be shown by topography in the western portion of the island (Figure 4). The apparent sector collapse extends within the range of the northern boundary of the Spring Hill Fault Zone and the southern boundary of Grandee Ghut Fault.

Figure 4. Sector collapse on the western portion of Nevis.

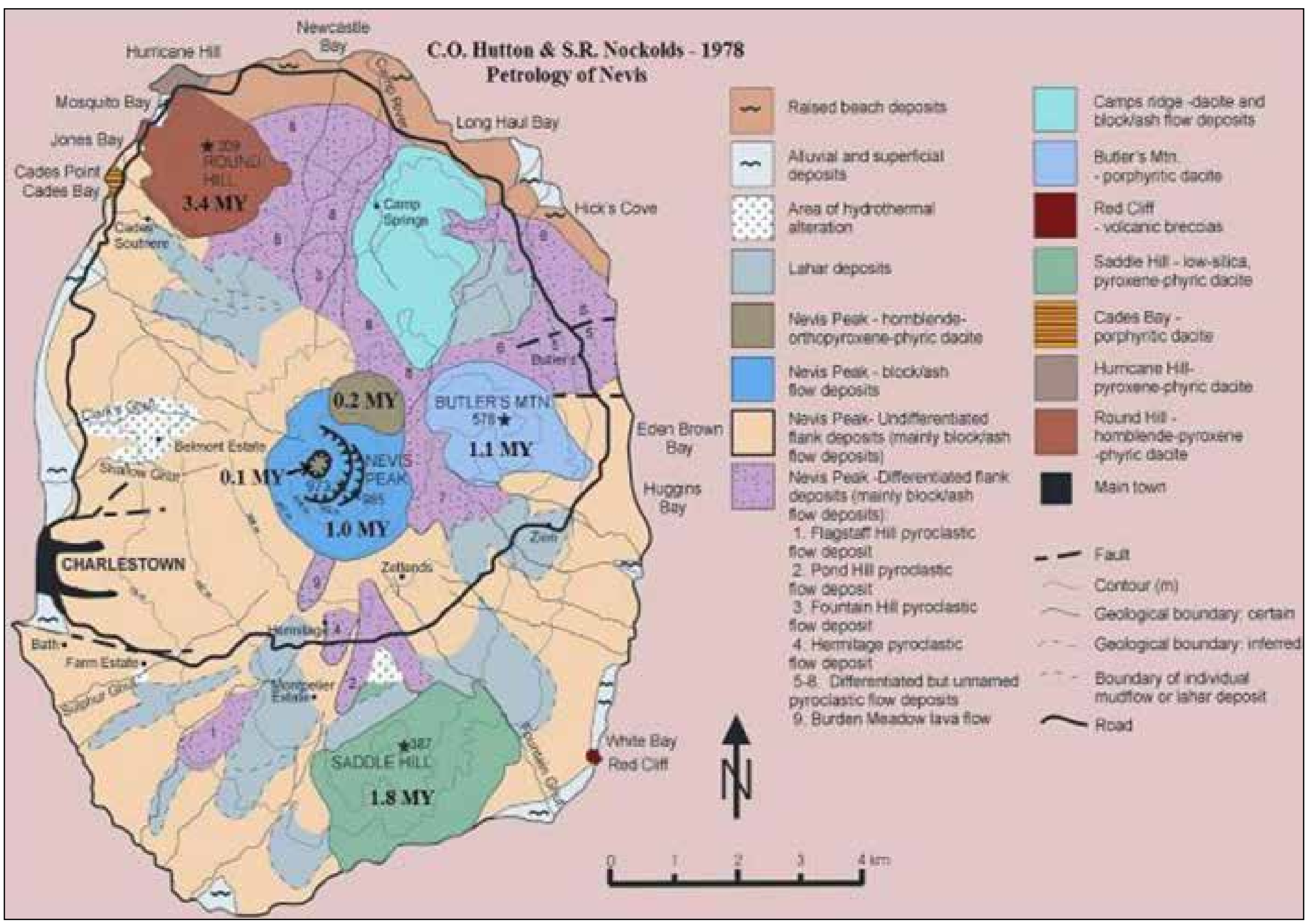

Figure 3. Ages of eruptions. Mineralogy of Nevis (Hutton and Nockholds, 1978).

NEVIS GEOCHEMISTRY

Two wells are of particular interest, Spring Hill, and #10 tee well, having chemistries consistent with the outflow and the upflow zones respectively. At Spring Hill it yields a temperature of 83, high chloride concentrations, and relatively high concentration of boron and lithium, which then indicates that some fluids originate from the outflow of fluids from a deep geothermal system. At the #10 tee well it has high sulphate and a temperature of 74 and the low pH of adjacent wells are indicative of gas rich fluids rising along an upflow zone.

The results of helium isotopic data are shown in Figure 5. It illustrates a distribution of high helium ratios that occurs in almost every sample taken on the western part of the island indicating a magmatic source for the helium.

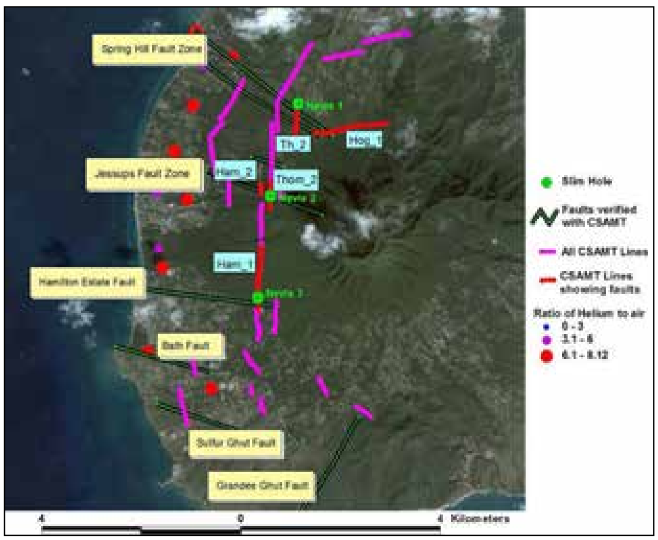

Figure 5. Helium ratio, CSMAT lines, faults and slim-hole locations.

DRILLING SITES

N-1 slim-hole was drilled at depth of 1,134 meters which penetrated predominantly volcanoclastic deposits of hornblende-bearing dacite with lesser amounts of andesite. At 1,134 meters an attempt was made to retrieve a core sample, in this endeavor the HQ drill string became stuck 15.2 meters off the bottom.

N-2 slim-hole is located to the Jessups Fault region. The Belmont Estate extensive area of sulfateric alteration is downhill from N-2. The alteration zone at N-2 is the second hottest domestic water well on the island at 75°C.

And finally N-3 slim-hole was sited adjacent to the Hamilton Estate fault. A volcanic source of the lava flow that is evident along Pump Road lies south of the Hamilton Estate fault. An exploration well test hole that was drilled by BEAD, LLC for the Nevis Water Department was first drilled at this site.

THE UPS AND DOWNS THE ISLAND BLUES

The island of Nevis is primarily a volcanic island, as a result it is inherent to be a host of active hot springs and presumably a large geothermal reservoir. This palm-fringed paradise has enough potential energy to cast it as the first nation in the world near self-sufficiency from renewable energy sources. This title can only be challenged by Iceland, with its abundance of hot springs. The island consumes a maximum of 10 megawatts (MW) of energy annually, and its closest neighbor, St Kitts that lies two miles northwest of Nevis consumes 45 MW at most each year. Via drilling of slimholes at three sites in Nevis, results have shown that the geothermal reservoir can produce up to 500 MW of constant base-load power year-round.

However, this dream has encountered many hurdles that have hindered the progress of attaining such a goal. There has been accusations of cronyism and mismanagement coupled with the global economic crisis have seen its current prospects to remain stagnant and uncertain (Jackson, 2012). Mr. Parry said that, "the geothermal project could be underway if the Export Import Bank of the United States had not been discouraged from lending US$63 million to build the controversial plant", furthermore, he states, "this is not fiction, this is fact" (Washington, 2011).

Geothermal energy exploration was initiated in Nevis in 2007, which was led by key individuals. This team comprised of the Chief Executive Officer of West Indies Power Nevis Limited, Kerry Mc Donald, General Manager Rawlinson Isaac, Duke University geothermal expert Reed Malin and Ernie Stapleton met to hold conversations on real possibilities of launching this project forward (Observer, 2011).

The exciting possibility of constructing geothermal power plants on Nevis is on the rise, as the first plant alone can still yield the accolade of the greenest place on the planet to this island. But accepting the mistakes of its tortured history is fundamental in carving a road to true success.

GEOLOGY OF THE ISLAND OF MONTSERRAT

Three andesitic volcanic centers dominate Montserrat: Silver Hills (~1-2Ma), Centre Hills (~0.4-1Ma), and Soufriere Hills-South Soufriere Hills (~0.3Ma to present) (Harford et al., 2002; Le Fraint et al., 2008). Since 1995, Silver Hill Valley (SHV) activity has included dome building and collapses that produced onshore and offshore pyroclastic and debris flows and deposits (Deplus et al., 2001; Le Fraint et al., 2009; Le Fraint et al., 2004; Loughlin, 2010; Trofimovs et al., 2006).

In Figure 6 the gray line track of the RRS James Cook. The circles are volcanic centers. Red squares are tectonic uplifts. The fault symbols are normal faults from profiles, apparent dip as indicated. Thick dashed lines are major faults of the fault systems, including Belham Valley Fault (BVF) and possible extension to Roche's Bluff (RB). Large black arrows: Extension direction (Feuillet et al., 2001).

On and west of Silver Hills Volcano (SHV), young andesitic domes (<300 ka) and structurally uplifted areas (Harford et al., 2002) are aligned due to normal faulting as part of the extensional Montserrat-Harvers fault system (MHFS) (Feuillet et al., 2010). The MHFS includes an ESE-trending lineament interpreted as the Belham Valley fault (BVF) (Harford et al., 2002).

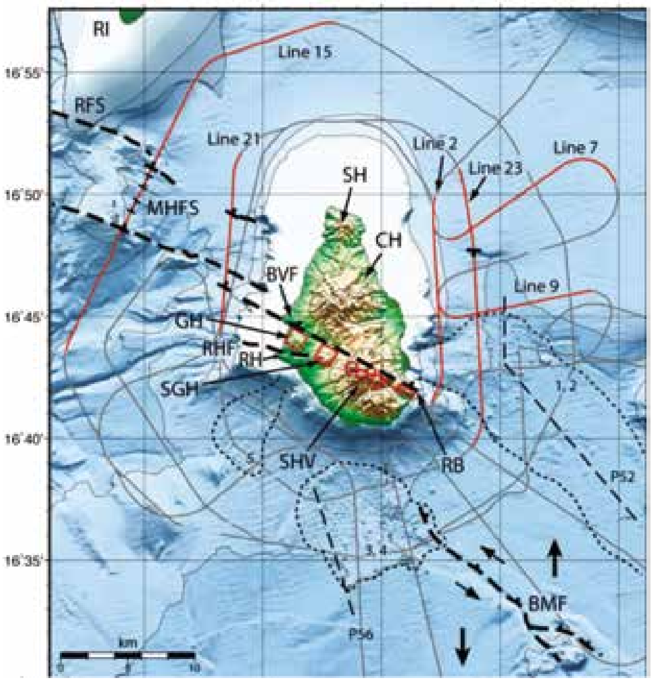

Figure 6. Montserrat bathymetry and tectonic model.

SEA CALIPSO MARINE CRUISE DATA

The December 2007, SEA-CALIPSO experiment (Seismic Experiment with Airgun-source – Caribbean Andesitic Lava Island Precision Seismo-geodetic Observatory) at Montserrat, Lesser Antilles, was an onshore-offshore seismic study the crust and magmatic system under Montserrat and the Soufriere Hills volcano (SHV) (Paulatto et al., 2010; Shalev et al., 2012; Voight et al., 2010). The experiment included a 48 channel, 600 m streamer, and 2600 in3 airgun seismic reflection survey that explored local submarine deposits and faults and expanded knowledge based on previous seismic and bathymetric studies (Feuillet et al., 2001; Feuillet et al., 2002).

GEOLOGICAL AND TECTONIC SETTINGS

The volcanic island of Montserrat is located in the northeastern Lesser Antilles. The three andesitic volcanic centers of the island that have been active are: Silver Hills (~1-2Ma), Centre Hills (~0.4-1Ma), and Soufriere Hills-South Soufriere Hills (~0.3Ma to present) as shown in figure 10. Through the process of continuous dome collapsing and building, accumulating piles of pyroclastic and debris flows and deposits the centers are eventually built. These deposits accumulate in large wedges offshore from direct flows and erosion and also as major collapse features; it is estimated that at least 50% of erupted products are transported offshore (Le Friant et al., 2008).

Due to its complicated tectonic setting as a result of its upper arc, where oblique subduction causes large scale left lateral shear accommodated by regional extension and arc-perpendicular normal faulting (Feuillet et al., 2001). Feuillet et al., (2001) have shown that on the southern edge of Montserrat of the Havers-Montserrat Fault System (HMFS), part of a series of regional right-stepping en echelon normal fault systems (Kenedi, 2010).

Figure 7. Oblique aerial view of Montserrat from the SW.

In the figure above the grey land cover is a collection of ash, mud and pyroclastic debris from multiple dome collapse and lahar events since 1995. The dashed black lines are faults (Belham Valley Fault-BVF, Richmond Hill Fault-RHF, St. George's Hill-SGH, Garibaldi Hill-GH, Richmond Hill-RH). The extensional faulting of southern Montserrat appears to have influenced the location of volcanism, as the volcanic centers of SHV align in a WNW-ESE trend. The faulting has influenced the topography of the region, causing the major uplifts of St. George's and Garibaldi Hills along the Belham Valey Fault (BVF) (Harford et al., 2002; Kenedi et al., 2010).

PROBABLE LOCATION(S) OF HYDROTHERMAL SYSTEMS IN MONTSERRAT

The presence of deep faulting in conjugate sets is supported by both field observation and geophysical evidence such as gravity data indicating a NNW- striking fault through Centre Hills (Hautmann et al., 2008).

In the vicinity of St. George's Hill (SGH), it constitutes transfer zones, where stress is shifted between faults. Both the relay ramp and the region of interacting faults are characterized by increased permeability by the formation of a fracture network (Curewitz and Karson, 1997). In addition, the faulting around SGH is validated also by seismic reflection data of Montserrat as well as earthquake locations, hence a deep enough system to coincide with the hydrothermal system.

As seen by Hill (1997) who modeled earthquake swarms as occurring in network mesh, which is consistent with a cloud of seismicity that cannot be resolved into specific faults (Kenedi, 2010). A similar fracture mesh has been documented as enabling fluid circulation in hydrothermal systems (Rowland & Sibson, 2004; Sibson, 1996; Sibson, 2000).

CONCLUSION

Extensive hydrothermal system of at least 3.5 miles in the N-S direction along the west and northwest flank of Mount Nevis are evident by the drilling results and surface manifestations. Furthermore, surface hydrothermal manifestations of Nevis are situated on the western side of the island as well, coinciding with the sector collapse. The island of Nevis not only has the potential to supply 45 MW electrical power demand to its citizens but in addition, to supply the adjacent island of St. Kitts. This dream has encountered many hurdles that have hindered the progress of attaining such a goal. However, once the lessons of its tortured past have rigorously learnt from Nevis can attain the accolade of being the greenest place on the planet. With respect to the island of Montserrat within the vicinity of St. George's Hill (SGH), it constitutes transfer zones, where stress is shifted between faults. But the fact remains that there exist few financial or insurance firms that are willing to participate in a geothermal project on the flanks of a very active volcano.

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