

# Geothermal Exploration on the Island of Montserrat, Caribbean\*

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## Abstract

Montserrat is located in the Caribbean and, as with many of the islands of the Caribbean Lesser Antilles, is volcanic in origin. As a result, many of the islands have a potential for geothermal electrical power generation.

EGS, Inc. (EGS) was contracted in 2009 by the Government of Montserrat to conduct a scoping survey on geothermal activity on the island, and to develop a conceptual resource model based on existing and new exploration data. EGS is also taking part in the drilling of two full-scale wells in the first quarter of 2013.

The exploration work completed by EGS included geologic, geophysical and geochemical surveys; lithologic correlation and structural interpretation constitute the geologic part of the work; the geophysical work included Magnetotelluric, Time-Domain Electromagnetic Induction techniques as well as a microseismicity study. Fluid geochemistry analyses consist of both a set of data from previous surveys and a new set of samples.

All the data compiled led to a high probability for the occurrence of a geothermal system in the southwestern portion on the island. Priority areas for exploratory drilling were defined in a zone protected from volcanic hazard and corresponding to the intersection of faults and where a clay cap has been defined by the geophysical survey. The first exploratory well spud early in 2013 and preliminary drilling results will be presented.

## References Cited

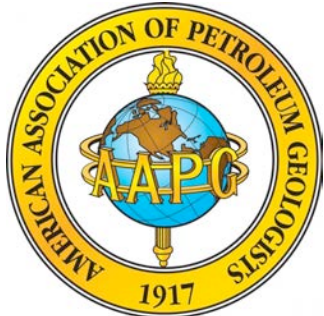
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Shalev, E., C.L. Kenedi, P. Malin, V. Voight, V. Miller, D. Hidayat, R.S.J. Sparks, T.A. Minshull, M. Paulatto, L. Brown, and G.S. Mattioli, 2010, Three-dimensional seismic velocity tomography of Montserrat from the SEA-CALIPSO offshore/onshore experiment, *in* B. Voight, and R.S.J. Sparks, (eds.), Eruption of Soufriere Hills Volcano, Montserrat, the CALIPSO PROJECT, and the SEA-CALIPSO arc-crust imaging experiment: Geophysical Research Letters, v. 37, p. Citation L00E17.

# Geothermal Exploration on the Caribbean island of Montserrat



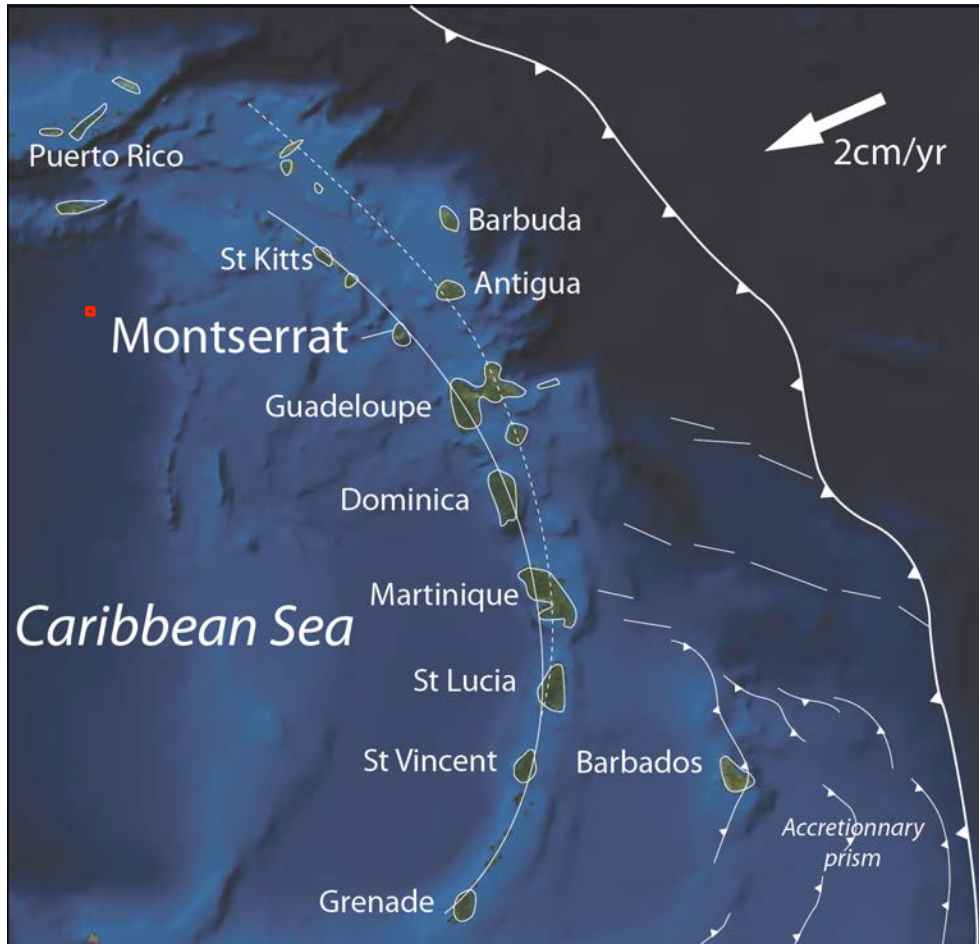
*Soufriere Hills Volcano*



B. Poux, P. Brophy & G. Suemnicht  
April 22, 2013



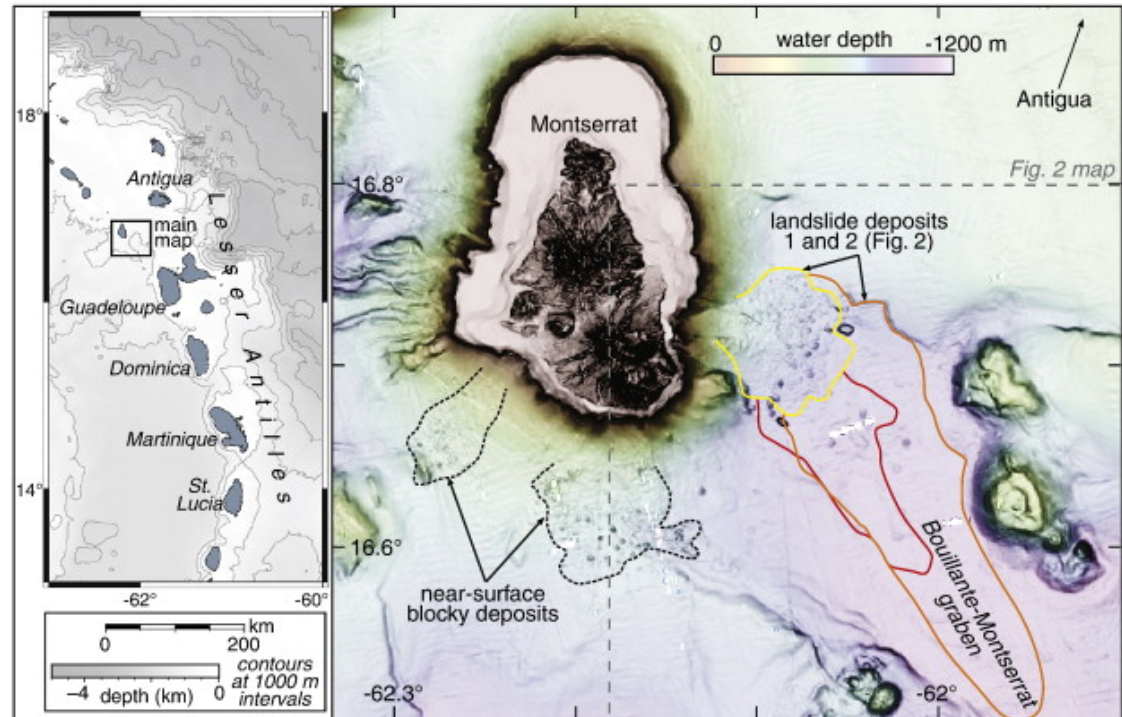
# Caribbean Geology



- Northern Lesser Antilles
- Volcanic arc
  - Oblique subduction of American/Atlantic plate under Caribbean plate
  - Old oceanic crust
  - Slow convergence rate (2cm/yr)
  - Low volcanic production rate
  - Low seismicity
  - Single back –arc spreading phase

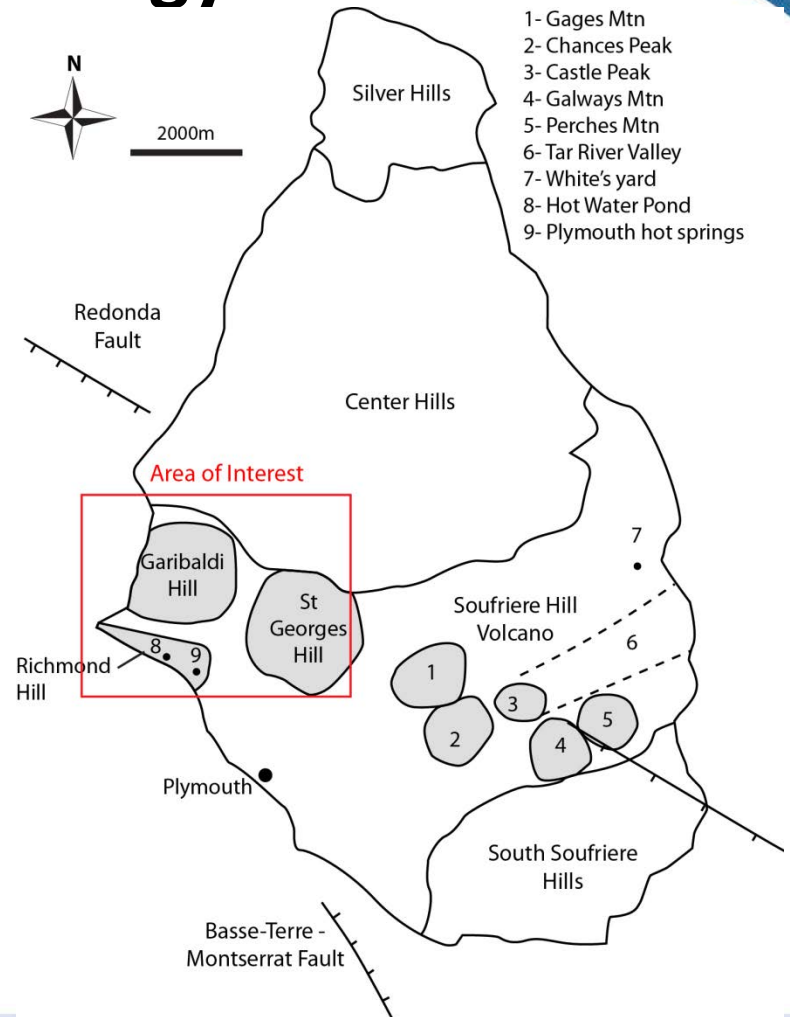
# Montserrat Geology

- Young eruptive history
  - 2.58 my to Recent
  - Predominantly andesitic
- Eruptive progression
  - North to South
- Bathymetric plateau
  - Island built on ????



# Montserrat Geology

- Andesitic eruptive centers
  - Silver Hills – 2.58 to 1.16 my
  - Center Hills – .954 and .550 my
  - Soufriere and South Soufriere Hills – Recent
- Fault systems
  - NNW striking Basse-Terre Montserrat fault
  - WNW striking Redonda fault
- Soufriere Hills andesite domes
  - ESE-trending zone
- **Area of interest** - SW part of the island





# Eruptive Activity

- Past volcanic crises:
  - 1897-1898 (?)
  - 1933-1937
- **1995**: Recent activity began - phreatic explosions, earthquake swarms, lava dome growth
- **1997**: Dome collapse, ash eruptions and pyroclastic flows.
  - Destruction of Plymouth city
  - 19 fatalities
- **1997-2013**, lava dome growth, regular ash eruptions and pyroclastic flows





*Garibaldi  
Hill*

*Richmond  
Hill*

*St Georges  
Hill*



0 0.5 1 2 Kilometers



# Geothermal Exploration Program

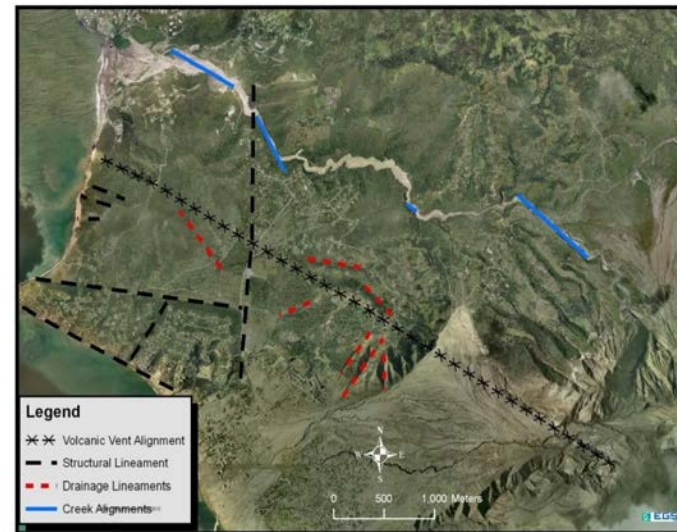
- Geology
  - Lithology & Structure
  - Hydrothermal alteration
- Geophysics
  - Magnetotelluric (MT) and Time Domain Electromagnetic (TDEM) survey
  - Microseismicity and Velocity Tomography
- Geochemistry
  - Major and trace elements
  - Light stable isotopes
  - Geothermometry

# Geology

- Structure- Morphological elements :  
Garibaldi Hill and St George's Hill
  - Modern flank deposits derived from lava dome
  - Deformed by ~E-W striking fault
  - On strike with Redonda fault
    - M6.3 eq 1985
  - Separated by probable N-S fault
- Hydrothermal alteration
  - Advanced argillic alteration near summit fumarole field
  - Altered debris avalanche clasts



Garibaldi Hill cliffs



Structural map of the AOI

# Geophysics

## MT/TDEM survey

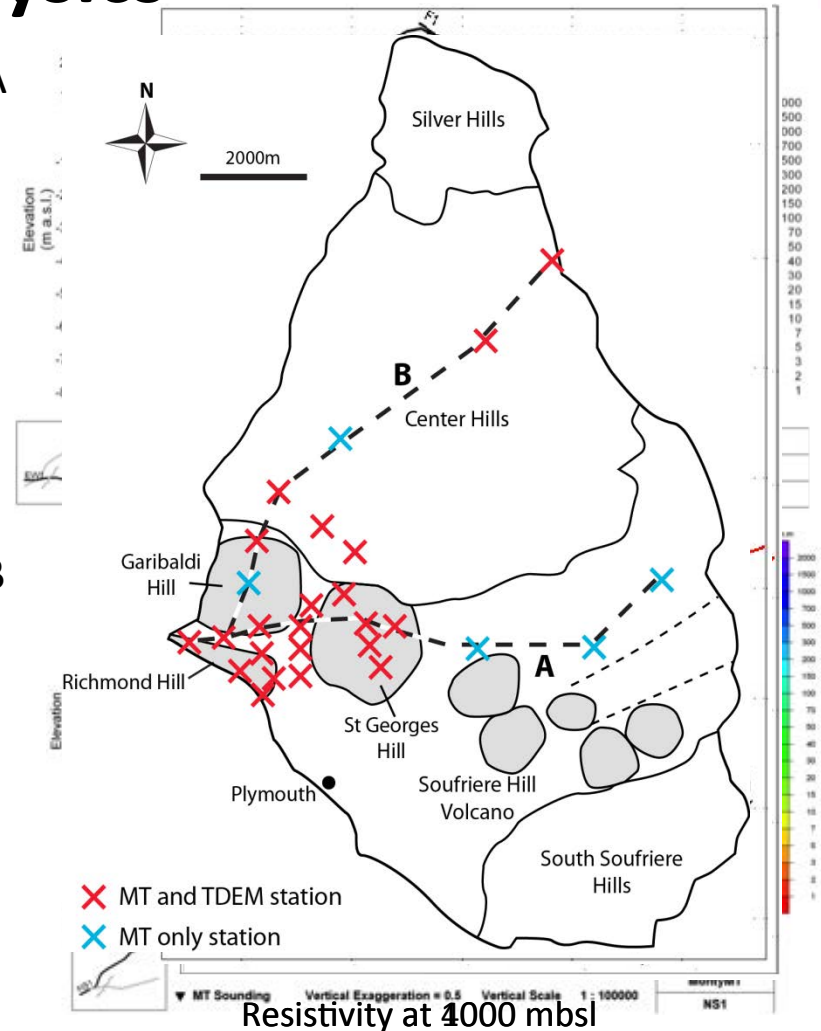
- Acquisition parameters
  - 28 MT sites, 22 TDEM sites
  - MT Frequencies 320-0.001Hz
  - Restricted sites

## • Results

- Resistivity maps
- 2-D resistivity sections

Section A

Section B

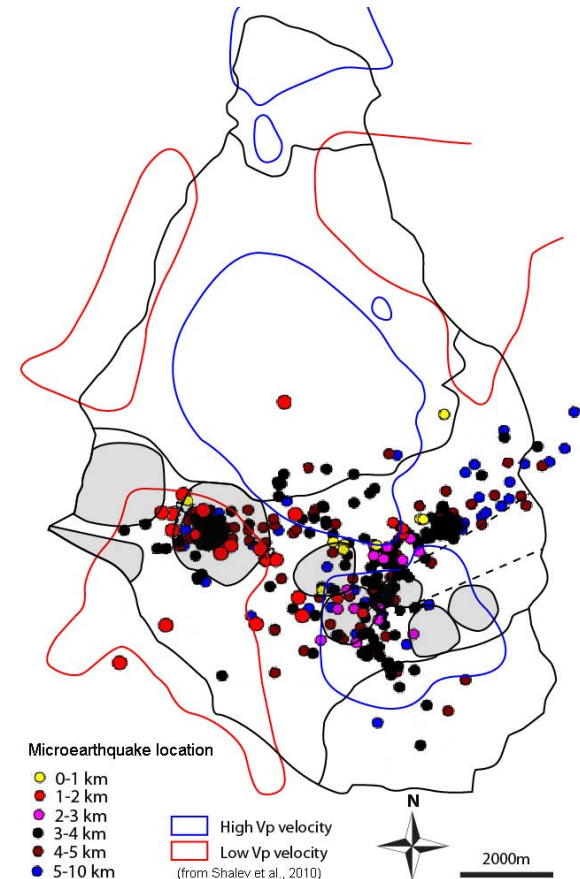


# Geophysics

- **Microseismicity**
  - Most earthquakes between 3 and 5 km
  - Along NW and NE trending fault zones
  - Epicenter cluster around St George's Hill
- **Velocity Tomography**
  - Acquired by the SEA-CALIPSO in 2007
  - Distinguish low velocity zones and high velocity zones

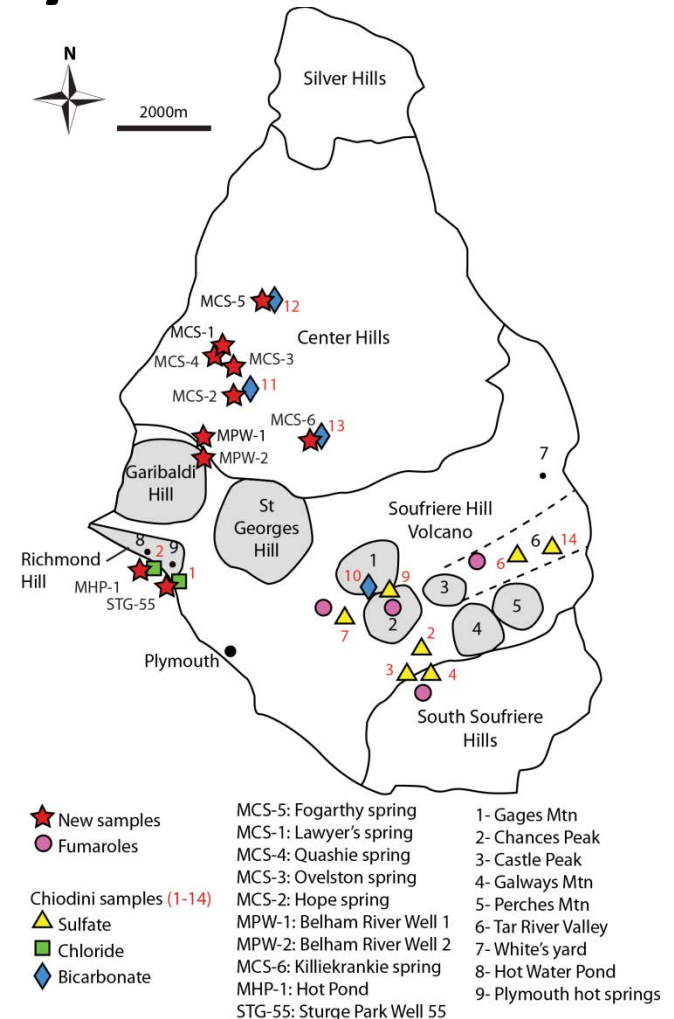
**High resistivity** and velocity below Centre Hill:  
cooling magma

**Low resistivity** and velocity in the Area of Interest:  
fractured zone, alteration.



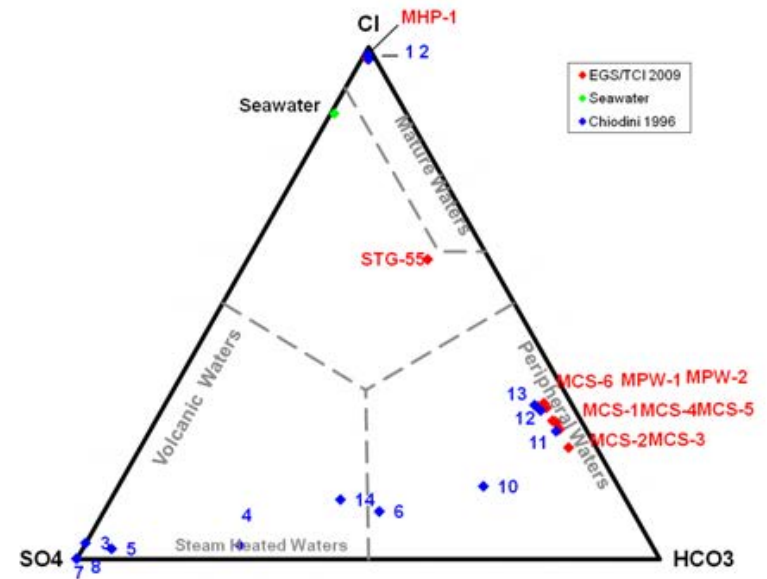
# Geochemistry

- Fewer surface manifestations after 1995
  - Destroyed-Tar River, Gages and Galways Soufrieres fumaroles
  - Buried-Plymouth thermal springs and Hot Water Pond
- Chemical analysis results
  - High temperature chloride springs in the Area of Interest
  - High temperature sulphate springs
  - Low temperature Bicarbonate water in Center hills



# Geochemistry

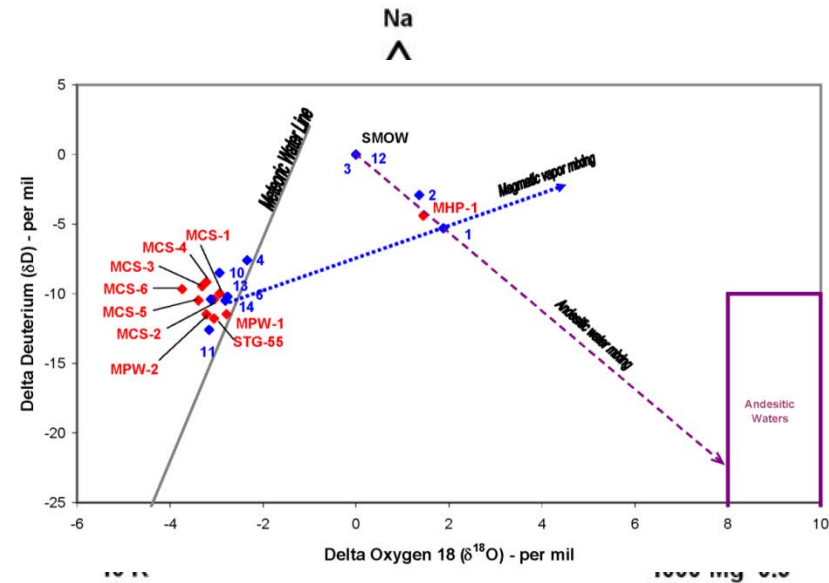
- Limited samples for geothermal potential (Chiodini 1&2, MHP-1, STG-55)
- Chloride springs - reworked seawater
  - Processes:
    - Sulfate deposition (remove Mg and SO<sub>4</sub>)
    - Re-equilibration at high T° with silica-rich minerals
    - Dilution (?) with steam heated water (lower pH and elevated HCO<sub>3</sub>)
    - Dolomitization within carbonate units



Series ID	Sample	Temp °C	pH	Na	K	Ca	Mg	SiO <sub>2</sub>	B	Cl	SO <sub>4</sub>	HCO <sub>3</sub>
EGS/TCI 2009	MHP-1	59	5.57	7233	1001	1944	247	259	22	16340	222	161
EGS/TCI 2009	STG-55	38	7.33	396	35	52	24	91	0	553	100	292
Chiodini 1996	1	90	6.60	7880	1030	2510	302	315	23	18220	161	128
Chiodini 1996	2	48	6.00	6200	458	2070	454	232	19	15000	174	195
Seawater	Seawater	10	6.80	10500	390	410	1350	6	5	19000	2700	142

# Geochemistry

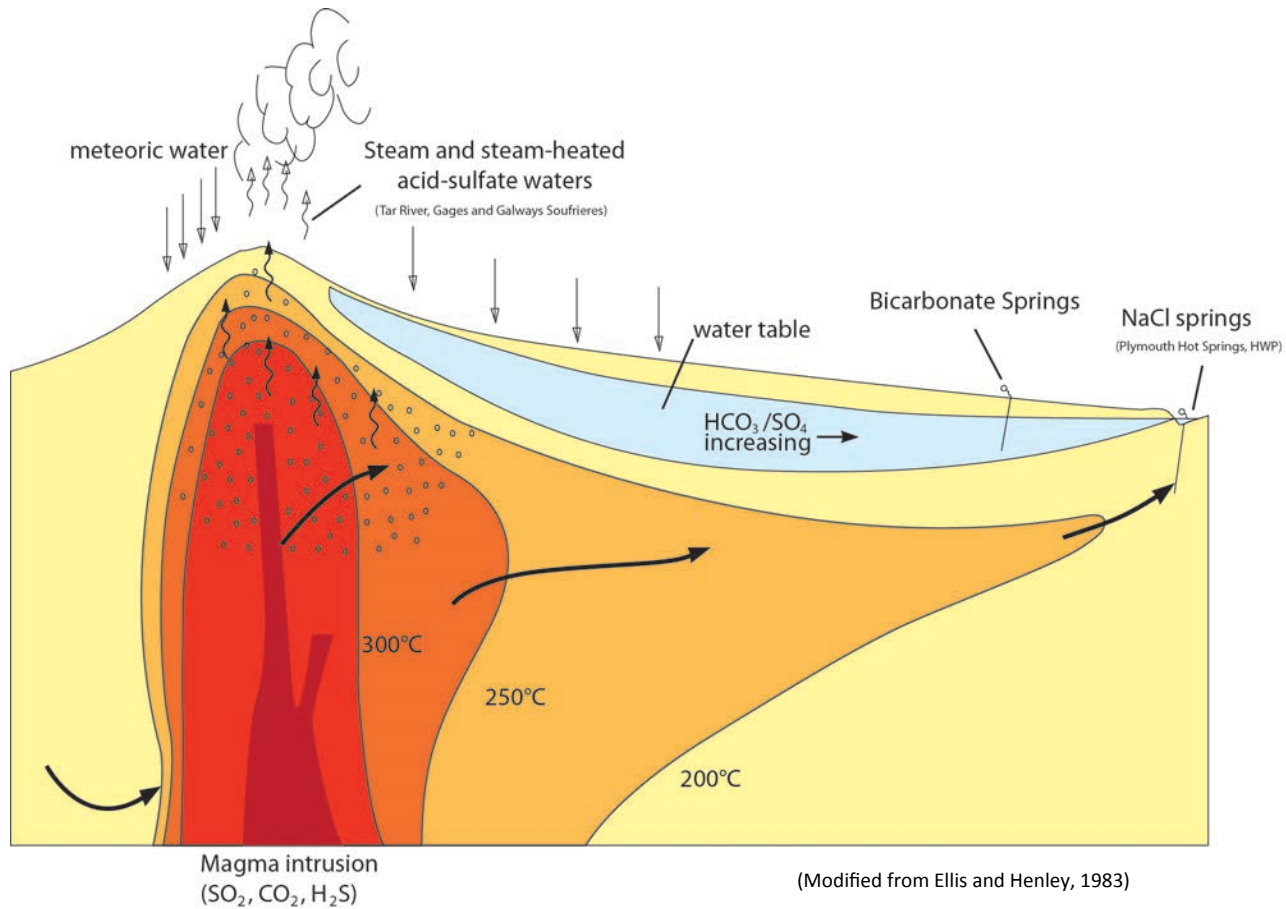
- Light stable isotopes
  - $^{18}\text{O}$  - D suggest arc-magmatic type water
  - $^3\text{He}/^4\text{He}$  of 8.3 to 5 Ra
  - Long term magmatic heat source
- Geothermometer estimates
  - Si geothermometers most reliable
    - 180 - 198°C
  - Na/K questionable
    - 260°C



Series ID	Sample	Chalcedony conductive	Quartz conductive	Quartz max steam loss	Na-K-Ca	Na-K-Ca Mg corr	Na/K (Giggenbach)	K/Mg (Giggenbach)
EGS/TCI	MHP-1	180	199	183	229	132	260	153
EGS/TCI	STG-55	105	132	129	180	40	223	87
Chiodini	1	198	215	195	225	131	255	151
Chiodini	2	171	191	177	187	73	209	118



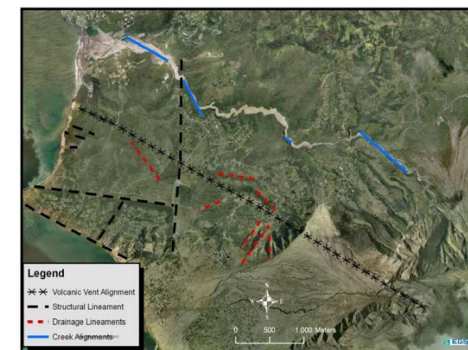
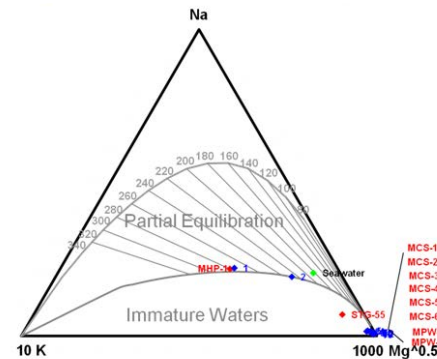
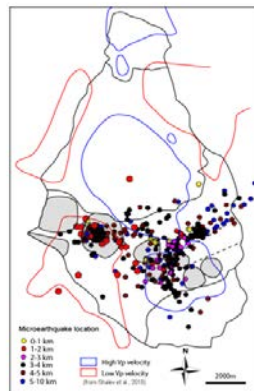
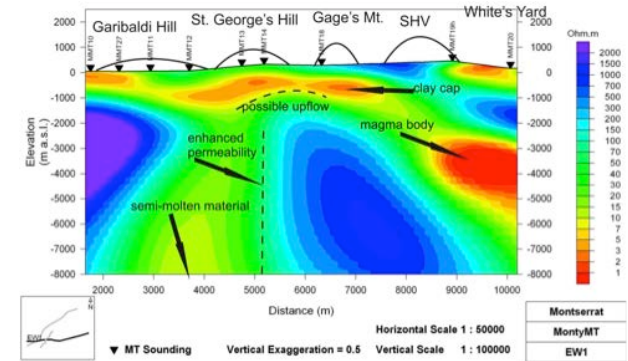
# Geothermal Conceptual Model



# Geothermal Conceptual Model

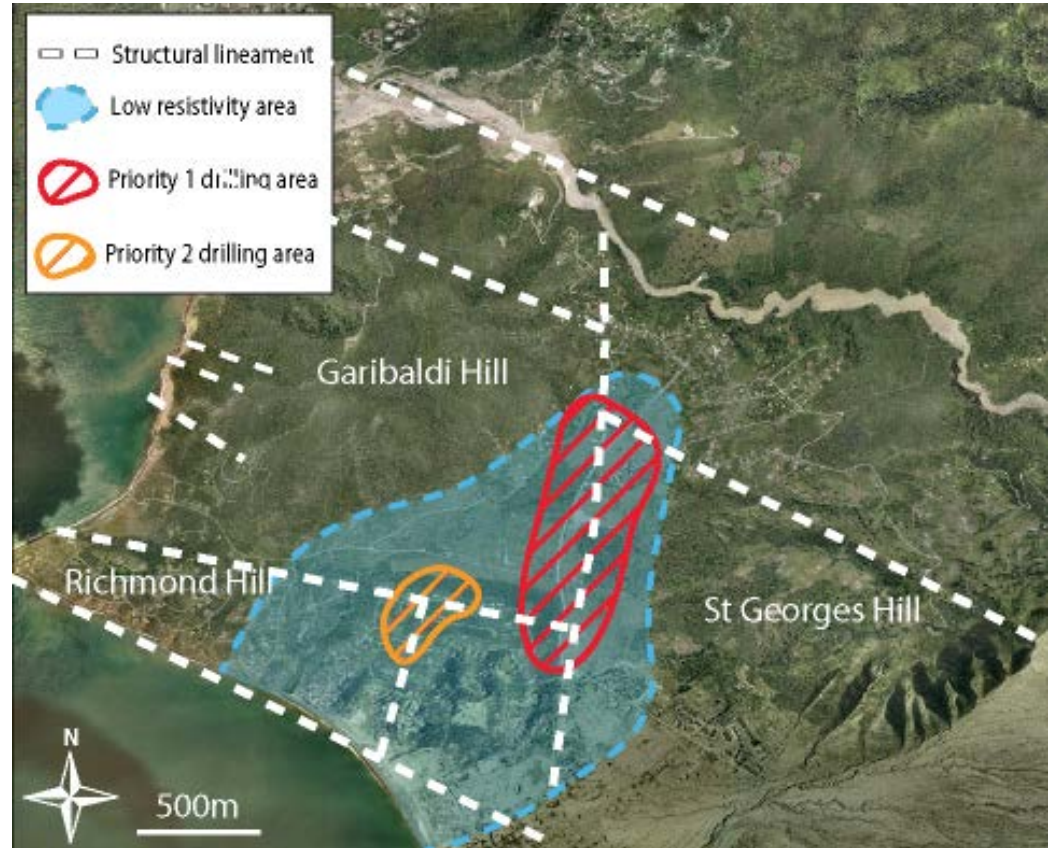
Favorable elements in the Area of Interest:

- Shallow magmatic heat source
- Identified fracture system (Structure/Permeability)
- Altered clay cap 800 - 1200m
- Reservoir temperature estimate 180 - 200°C
- Seawater convecting in hot silicic rocks



# Drilling Recommendations

- Sites selection:
  - Structure interpretation
  - Resistivity contrasts
  - Volcanic hazard(s)
- Exploratory well to at least 2000m
  - Below the clay alteration cap.
- Fault intersections as higher permeability targets.



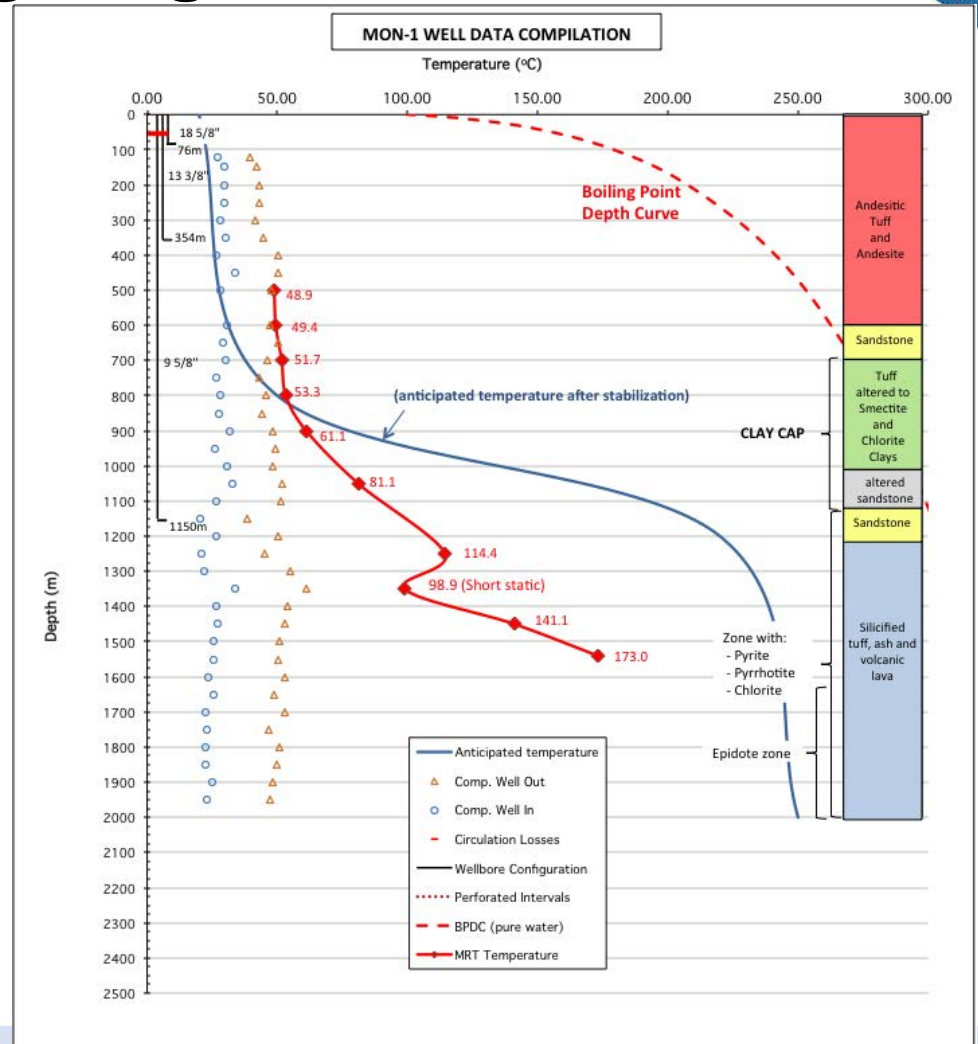
# Drilling Progress

- Spud - March 17, 2013
- Nearing planned 2200-2400m completion depth
- Progressively higher temperatures.



# Drilling Progress

- Lithology:
  - Montserrat flows and volcanoclastics to 600m
  - Sandstone, clay and limestone to 1100m
    - Altered clay (cap) section
    - Close correlation w/ MT
  - Deeper volcanic sequence
- Permeability:
  - Fault intersections as priority targets.



# Conclusion and discussion

- Recent eruptive activity – Minimal geothermal resource impact
  - Surface manifestation geochemistry unchanged
    - Exclusive of manifestations buried
- Potential geothermal resource SW part of Montserrat
- Exploratory well drilling in progress
  - Lithology/alteration as anticipated
  - New bathymetric platform revelations
  - Favorable temperatures ~200°C
  - Permeability ?

*Thanks*



*Pyroclastic flow, Soufriere Hill Volcano, December 2010*