# POTENTIAL FOR GEOTHERMAL DEVELOPMENT IN GRENADA, WEST INDIES

Gerald W. Huttrer'
Donald E. Michels[2]

'Geothermal Management Co., Inc. P.O. Box 2425, Frisco, Colorado 80443
'Don Michels Associates, P.O. Box 8652, Missoula, Montana 59807

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ABSTRACT

Pre-feasibility studies were conducted between August 1992 and March 1993. Resource assessment included literature reviews. air photo evaluations, on-site geology and acquisition of new data for hydro-geochemistry. Additionally, interviews with key representatives of the Grenadan public and private sectors yielded insight on how geothermal development could proceed in this island environment.

Geological and hydro-geochemical studies identified six sites with surface manifestations in central and northern Grenada and apparently commercial temperatures, 320-420°F. Additional study of the three most prospective sites is recommended on the basis of accessibility and apparent resource quality.

The national power Utility, GRENLEC, forecasts the decommissioning of several small diesel powered electric generators by 1995, with need to replace about 10 MWe of capacity. Additional new demand can be expected. For several reasons, privatization of island infrastructure will become practical during the next few years. Power sales contracts could be obtained at prices exceeding today's fuel price, $US 0.088 per KWh.

Economic modelling based on rite-specific conditions and plausibilities suggests a 7.5 MWe facility could yield about 18% per year internal rare of return.

SCOPE OF WORK

Pre-feasibility studies were conducted between August 1992 and March 1993 to determine the potential for commercial development of geothermally-fueled electric power generation in Grenada, W.I. These included

- review 51 publications identified via the 'GEOREF" CD/ROM files (USGS and Colorado School of Mines)
- acquisition and review of 67 framer of 1:10,000 color air photos[3]
- review a previous reconnaissance of geothermal resources in Grenada: (Geatermica Italiana, 1981)
- field geologic and hydra-geochemical studies in 1992.

Field work. October 11-27, 1992. included geologic reconnaissance and sampling of 17 thermal springs. Some of there were indicated in Geotermica Italiana (1981) and others were located with the help of renowned Grenadan hiker and guide, Telfor Bedeau.

Though the most important aspect of any geothermal development is the availability of a commercial-quality resource, it is also critical that several conditions unrelated to the resource be favorable. Non-resource related information summarized in subsequent sections was gleaned via conversations with 28 Grenadan representatives of the public, private, academic and industrial sectors.

NON-RESOURCE FACTORS

Important information was obtained in regard to:

- demand for and present price of electric power
- institutional and environmental factors that promote or hinder geothermal development
- factors and incentives regarding taxes. economics, and finances
- available labor and logistical facilities.

Details are provided in Huttrer and Michels (1993). highlights are given below.

Electric demand in Grenada in 1991 peaked at 11.6 MWe, with an average bare load of 6.0-7.5 MWe. Peak was expected to rise to 14.8 MWe by 1995, reflecting the expected continuation of a 10% annual increase in power sales.

[3] NW Geomatics, Ltd, Vancouver. B.C, Canada

In 1991, Grenada Electricity Services, Ltd. (GRENLEC), the national electric utility, had a nameplate generating capacity of 18.5 MWe, all provided by small to medium-sized diesel generators that were 10 to 23 yearn old. Although several of these had been refurbished and rebuilt since 1985, GRENLEC plans to decommission several plants before 1995 so that about 10 MWe of new capacity will be needed. Geothermally generated power Could economically provide this electricity.

GRENLEC's 1991 fuel costs were reported to be $US 0.088 per KWh while their generation costs are raid to be SUS 0.0688 per KWh. GRENLEC charger a commercial rate of $US 0.2029 per KWh. With reasonable allowances far the costs of transmission, distribution, O&M and administrative costs, there is still room far incorporation of geothermal power into the fuel mix, at an estimated $US 0.09 per KWh, without adversely affecting the cost of power to the public.

Institutional factors are favoring the privatization of infrastructure components. For example. GRENLEC has historically been Owned and controlled by the government. But, recently it, like the national telephone service (GRENTEL), was bought by a private entity. These sales are the first in what appears to be a trend towards privatization of infrastructure in Grenada. Their consummation has resulted in the Creation of laws, rules, and regulations that help the initiation of other private projects, such as geothermal power generation.

Interviews with government officials indicated that the few existing laws that might be perceived as barriers to energy projects are being favorably modified.

Tax and other investment incentives are now provided in Grenadan law that should significantly enhance the economics of a geothermal project. They reflect the growing government effort to entice all kinds of new businesses to Grenada. Grenada's financial and economic conditions are not robust, but they are improving and currently constitute a neutral factor with regard to geothermal development.

Environmental regulations are such that they would not constitute impediments to geothermal development. Grenadans are quite conscious of their rtill-pristine environment, but their laws are practical and reasonable.

The labor force in Grenada is Strong and willing. The logistical components (port facilities, roads, telephones, etc.) range from adequate to excellent.

In summary, all non-resource related conditions are favorable for geothermal development. Economic conditions in Grenada are improving and are comparable to, or better than those in other developing nations in which geothermal projects have been successfully built.

PLANT ECONOMIC ANALYSIS

Proforma economic analyses of hypothetical, reasonably structured projects were made. One example is provided here; basic assumptions were:

| | |
|---|---|
| 7500 KW capacity | 20-year project life |
| 90% capacity factor | 15 year loan period |
| 70% debt, 30% equity | 10.5% interest rate |
| 3% inflation rate | $1200/KW power plant cost |
| 4 prod. wells, 2 inj. wells | 5000 ft prod. well depth |
| US$200/ft well cost | 3000 ft inj. well depth |
| US$0.10/KWh in year one | 13%/yr insurance and O&M costs |
| 20-yr tax holiday | US$1.5 million for exploration |
| Power sales begin in year 3 | |

**Results:**

Positive cash flow in year 8
Cumulative cash flow after 20 years is US$57.5 million
Internal rate of return is 17.8%.

GEOLOGY OF GRENADA - A BRIEF DESCRIPTION

Since Cretaceous time, regional compressional forces oriented ENE-WSW have persistently acted on Grenadan rocks. These forces are due to the westward and southward subduction of the North Atlantic Plate beneath the relatively immobile Caribbean plate. (Figure 1). The results of the subduction and the compression hare been:

- development of NNW-SSE folds within the sediments, in basalt dikes intruding the sediments, and in many volcanic units
- faulting with predominantly orthogonal NE-SW and NW-SE trends with lesser N-S trends
- generation of magmas that have risen above sea level. forming Grenada and ten other islands to the north in this Caribbean archipelago.

Rocks underlying Grenada can he divided into five groups: the sedimentary basement, the volcanic pile, rocks related to Kick-'em-Jenny/Isle de Caille, intrusive rocks, and hot spring deposits. The sedimentary basement includes greywackes and sandstones of the Oligocene age Tufton Hall formation. The Tempe Pamassus-Hope Vale limestone may have been deposited slightly later than or contemporaneous with the Tufton Hall.

The volcanic pile in Grenada comprises the products of eight eruptive stages that began in the early Miocene (21 MYBP) and ended less than 1 MYBP. From oldest to youngest, these volcanic units are listed in Table 1

There is no prominent pattern to the geographic distribution of these eruptive rocks with respect to time, but, the most recent activity seems to be toward the north central and northeastern parts of the island.

A volcanic seamount. Kick-'em-Jenny, is building about four miles northeast of the Grenadan shore. At least eight eruptions have occurred since 1939 involving alkali basalts. Kick-'em-Jenny and its companion island. Isle de Caille, are the youngest and most active volcanoes in the Caribbean. Since the seamount and the island are so close to the north shore of Grenada, they may be considered as part of the main edifice. In the near geologic future. they seem likely to grow and rise above the waters now separating them.

TABLE 1: VOLCANIC ROCKS OF GRENADA

| Name | Age (MYBP) | eak Types | Part of σ |
|---|---|---|---|
| Mt. Craven | 21 | Andesite, Dacite, Basalt | Northern |
| Mt. South-East | =14 | Andesite, Basalt | South-Central |
| Lavera Hill | 7.1 | Andesite | Northeastern |
| Grand Anse | Pliocene | Andesite, basalt | Southwest |
| Mt. Sinai | 1.7-1.L | Basalt, tuff. lahar | South-Central |
| Mt. Granby | Pliocene/ Holocene | Basalt, Andesite | Central |
| Mt.St.Catherine | 11-1.6 | Andesite, Basalt, Dacite | North-Central |
| Antoine Series | 1.47-.94 | Basalt, Andesite | Southwest and Northeast |

Explosion Craters of various ages and sizes are apparent in air photos, especially away from the Steep interior. One of the largest appears to form the harbor at St. Georges (largest town) which is relatively old and eroded. Younger examples with complete perimeters and enclosing circular ponds occur in the northern part of the island.

A travertine deposit occurs at Chambord Estate, just north of Lake Antoine (an explosion crater of Recent ape) near the northeast end of the island. Travertine covers an area about 250 feet long by 100 feet wide formed by coalescence of several thermal outflows. Uranium thorium dating of the travertine yielded a young age. 10 Ka, with large uncertainty (+55Ka, -36Ka). Warm springs (95 to 96°F) flaw weakly from six craterform orifices in the travertine, evidencing the continued existence of a nearby heat source.

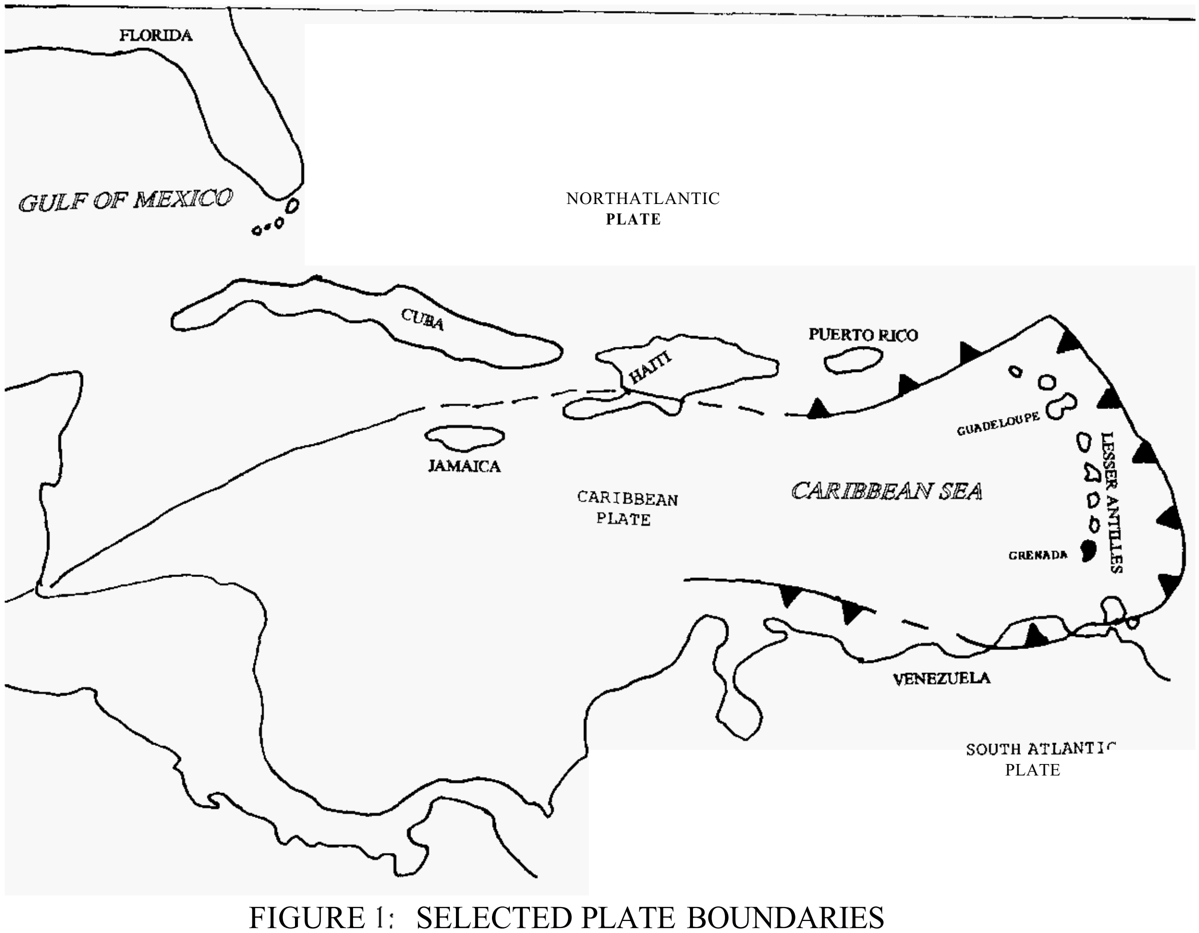



FIGURE 1: SELECTED PLATE BOUNDARIES
IN THE CARIBBEAN REGION
HASHURES ON UPPER PLATE

Intrusive rocks appear to be **scarce** on Grenada. Only two bodies have been mapped to date, quartz diorite and dacite porphyry located in the Castle Hill area of the north-central part of the island. These rocks have both intruded the sedimentary basement **rocks** and they **are** both overlain by the Mt. St. Catherine volcanics. Thus fheir **age** is between 21 and 11 MYBP. Both these intrusives host anomalous amounts **of** zinc. lead and copper. Their **presence** suggests the existence of other. yet unmapped, shallow intrusives that could be heat sources far geothermal cells.

Thermal waters are mostly located in valleys eroded along the traces of prominent faults. This is evidence that the "plumbing" network needed to sustain viable geothermal cells is open, permeable and conducting thermal **waters** to the surface in Grenada. Significant rainfall in Grenada. 1 to **4** meters per **year,** depending on elevation. imparts significant dilution **and** cooling to the emergent thermal waters.

## HYDROGEOCHEMISTRY FOR THERMAL WATERS OFGRENADA

Seventeen water samples collected in 1992 represent six prospective geothermal sites in the northern part of Grenada. Four of these **appear** to have Commercial temperatures and at least three of those deserve additional work to outline the associated **resource.**

Same of the **areas** were also sampled in 1981 (Geotermica Italiana). Because the chemical data from their sampling and **ours** are generally consistent bath sets of results were combined (Table 2) for this overall assessment. The significant chemico-thermal areas are shown in Figure 2.

Groups of sampled spring waters from single prospective areas show **a** wide range of dilution. In fact, it is the apparent dilution of otherwise common compositions that define these potential resources. The geographic Clustering of sample sites With common chemical characteristics permits assigning the chemical features to proscribed areas. For three groups especially, Castle Hill South, Chambord, and Hermitage-Peggy's Whim, dilution by more than **two** orders of magnitude (to more that 1001 dilution) still yields mired compositions that can be recognized as belonging to one **group** and not **some** other.

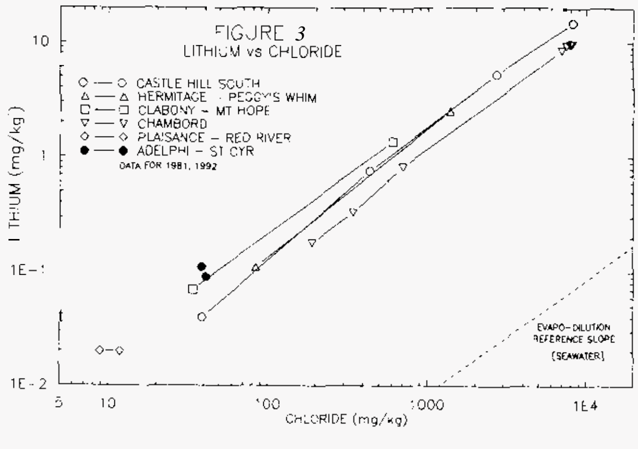
The effects of dilution must be recognized in order that the geothermometer temperatures may be cautiously interpreted. Figure 3 (Li vs Cl) and Figure **4** (K YE l) show how distinctly the **groups** are defined by what **we** may call their dilution profiles. These figures are examples to show how related sample data yield remarkably light fits to straight lines. In these **log-log** plots, all liner that are parallel to the reference lines represent dilution effects'. Both linearity and parallelism in the plots tend to become lost when chloride Concentrations are diluted to **less** than about ***50*** mg/kg.


**FIGURE 2:** PROSPECT **LOCATIONS**

TABLE 2: **CHEMICAL** DATA FOR GRENADAN GEOTHERMAL SITES
**(mg/kg)**

| ID# | Elev ft | deg F | pH | Cl | Na | Ca | HCO3 | K | Mg | SO4 | B | SiO2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | CASTLE HILL SOUTH | | | | | | | | |
| i8 | | W | 5.76 | 16307 | 7360 | 2204 | 915 | 508 | 279 | 230 | 161 | 120 |
| g10 | 700 | 116 | 6.92 | 8248 | 3668 | 1243 | 457 | 309 | 151 | 137 | 115 | 133 |
| g11 | 1000 | 105 | 6.53 | 2726 | 1323 | 394 | 302 | 105 | 55 | 125 | 35 | 59 |
| g18 | 600 | | 7.47 | 440 | 216 | 77 | 101 | 24.6 | 16.3 | 16 | 5.44 | 53 |
| g12 | 650 | | *6.M* | 39 | 31 | *30* | 163 | 4.7 | 12.3 | 7.1 | | *Q4* |
| i2 | | *e4* | 6.42 | 35 | 32 | 36 | 195 | 4.3 | 13.4 | 4.8 | 0.14 | 90 |
| | | | | CHAMBORD | | | | | | | | |
| i9 | | 97 | 6.13 | 8154 | 3680 | 962 | 1220 | 168 | 352 | *30* | 45 | *120* |
| g5c | 50 | 95 | 6.83 | *7929* | 3655 | 1020 | 725 | 167 | 349 | 33 | 71 | 115 |
| g5b | 50 | 92 | 7.14 | 7504 | 3554 | 955 | 978 | 164 | 346 | 28 | 61 | 121 |
| g5a | 50 | *92* | 6.W | 6991 | 3300 | 834 | *725* | 144 | 311 | 29 | 60 | 101 |
| i1 | | 84 | 7.87 | 709 | 368 | 126 | 433 | *IT* | 58 | 13 | 4.13 | *e4* |
| g5 | *40* | 82 | 7.31 | 345 | 198 | 74 | 364 | 8.5 | 51 | 14 | 2.34 | 78 |
| i10 | | *e4* | 7.74 | 191 | 117 | 68 | 3e4 | 4.7 | *44* | 15 | 1.01 | 78 |
| | | | | HERMITAGE-PEGGY'S WHIM | | | | | | | | |
| g9 | 1000 | 102 | 6.W | 13113 | 736 | 281 | 828 | 49.5 | 90.9 | 9 | 19.3 | 167 |
| i6 | | *82* | 8.31 | *85* | 48 | 30 | 134 | 4.3 | 13.4 | 5.8 | 0.92 | 53 |
| i5 | | 81 | 5.60 | 28 | 16 | 134 | 671 | 1.6 | 57.1 | 13 | 0.89 | 33 |
| g4 | 580 | 77 | 6.80 | 27 | 17 | 95 | 417 | 1.0 | 30.6 | 14 | 0.14 | 37 |
| | | | | CLABONY-MT HOPE | | | | | | | | |
| g3 | 1050 | 96 | 6.88 | 609 | 354 | *134* | 527 | 30.7 | 41.7 | 3.7 | 9.77 | 163 |
| g1 | 1550 | 72 | 3.15 | 37 | 22 | 18 | | 7.26 | 9.0 | 384 | 0.86 | 107 |
| i7 | | 93 | 5.59 | 34 | 55 | 60 | 421 | 7.04 | 25.5 | 3.9 | 0.95 | 150 |
| g8 | 1350 | 95 | 6.68 | 34 | 55 | 60 | 389 | 6.83 | 27.7 | 5.3 | 0.86 | 155 |
| g2 | 1600 | 73 | 4.95 | *24* | 13 | 4.3 | | 7 | 0.93 | 3.1 | 20 | 27 |
| | | | | PLAISANCE-RED RIVER | | | | | | | | |
| i18 | | 102 | 5.68 | 57 | 108 | 114 | *256* | 16 | *13.4* | 302 | 5.14 | 150 |
| g13 | 1300 | 76 | 3.12 | 27 | 18 | 13 | | 6.4 | 6.3 | 101 | | *82* |
| g14 | 1275 | 78 | | | 23 | 23 | | 4.7 | 6.6 | | | 81 |
| i22 | | 79 | 6.01 | 13 | 18 | 62 | *262* | 1.2 | 12.1 | 6.2 | 0.15 | PO |
| i21 | | 77 | 5.71 | 12 | 23 | 34 | | 3.9 | 6.7 | 144 | 0.56 | 66 |
| i20 | | 77 | 3.63 | V | 19 | 68 | | 3.9 | *14.6* | 365 | 0.02 | 78 |
| i19 | | 73 | 6.00 | 7 | 13 | 22 | 15 | 2.3 | *4.9* | 86 | 0.02 | 51 |
| | | | | ADELPHI-ST CYR | | | | | | | | |
| g7 | 700 | 91 | 7.06 | 41 | 85 | 114 | 812 | 9.9 | 62.6 | 3.7 | 0.46 | 136 |
| i3 | | 91 | *5.92* | 39 | 81 | 130 | 915 | 10.2 | 63.2 | 3.8 | 0.25 | 132 |
| 96 | 1015 | *e4* | *6.88* | 16 | 33 | 68 | 412 | *4.8* | 28.6 | 5.0 | 0.08 | 136 |
| i4 | | 77 | 7.85 | 11 | 9 | 11 | 85 | 1.2 | 9.0 | 2.50.03 | | 26 |

"g" samples collected in 1992 by Geothermal Management Co
"i" samples taken in 1981 by Geotermica Italiana




Same plots have Slightly shallower **slopes** than the reference lines. This is due to the dilution fluid (local groundwater) being not **pure** water, but containing elements weathered from **rock.** (Weathering components exceed the concentrations due to sea salt entrained with the original rain.] Background chloride concentration **appears** to be about 10 to 13 mg/kg and may be presumed due to **aerosols** of **sea** salt incorporated into local rain. Higher concentrations ***of*** chloride indicate **a** thermal water Component

[4] **In linear by linear plots, straight lines represent mixing of two distinct components, which includes pure dilution (and its inverse, evapo-concentration), but the line slopes are not confined to families. Using log-log plots causes all dilution-related compositions, and no others (except the inverse), to plot as a family of parallel lines. Thus, the log-log plot may be considered a device for screening samples to determine which are related by this specific factor.**

Same sites are notably gassy, but no gas sampler were taken. Thermal area6 Seem especially indicated by elevated concentrations of chloride (50 to 16,000 mg/kg). Spring surface temperatures are only slightly elevated, a further indication of the substantial dilution effects in the near-surface zones. Conductive coaling also appears important because there is negligible Correlation between spring temperature and chloride concentration.

High chloride concentrations were viewed earlier (Geatermica Italiana, 1981)as due to a seawater connection. but consideration of the observed chloride concentrations with Cl/X ratios for conserved and non-conserved elements convinces us that seawater is not involved. Some representative values are shown in Table 3. Graphical representations of seawater dilutions are given in Figures 3, 4. 5, and 6 (Li, K, B, SO,). Figure 6 shows that at high chloride concentration sulfate tends to be relatively less than in seawater whereas far dilute chloride (<50 mg/kg) sulfate tends to be relatively greater than in seawater. Correlations of Cl versus SO, and of Cl versus $HCO_3$ (not shown) are poor at all concentrations, indicating separate origins.

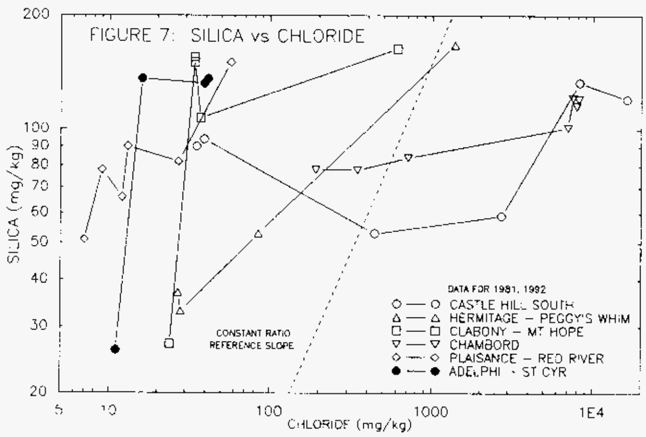
TABLE 3: REPRESENTATIVE CL/X WEIGHT RATIOS

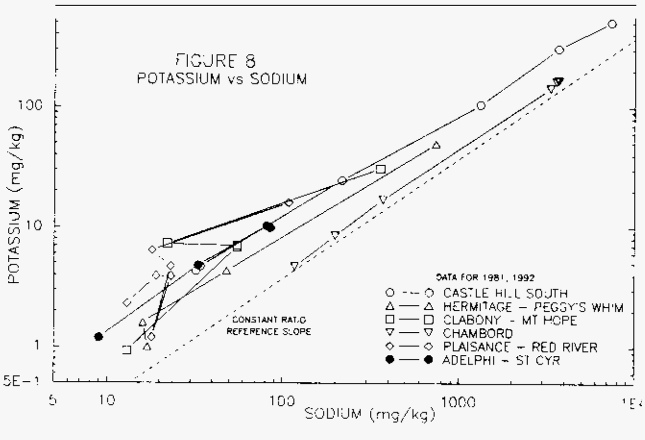
| | Cl/Br | Cl/B | Cl/Li | B/Li | Max Cl |
|---|---|---|---|---|---|
| Seawater | 289 | 4210 | 108000 | 26 | 19100 |
| Castle "ill South | 225 | 77 | 1300 | 17 | 16307 |
| Chambord | 235 | 115 | 830 | 7.2 | 8154 |
| Hermitage-Peggy's Whim | 230 | 82 | 660 | 8.0 | 1383 |
| Clabony-Mt Hope | 218 | 60 | 470 | 7.8 | 609 |
| Plaisance-Red River | | 11 | | | 57 |
| Adelphi-St Cyr | | 90 | 400 | 4.4 | 41 |
| Hapsack | - | 160 | . | | 13 |

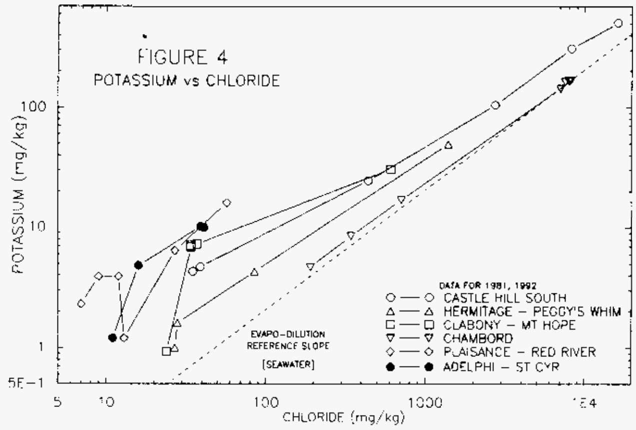
Geothermometers

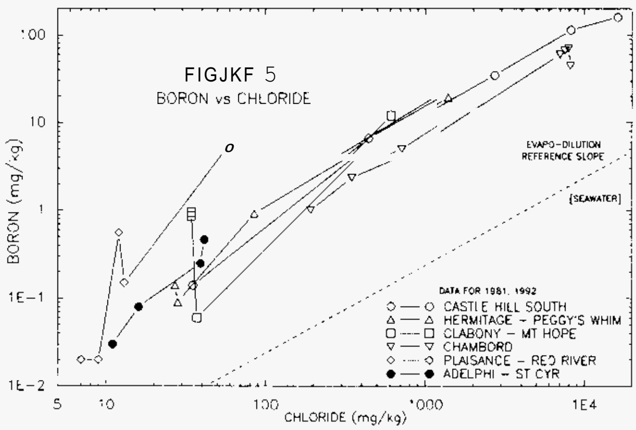
One objective of chemical studies aims to estimate the deep thermal temperatures that these resources may have. The approach is less than straightforward because of substantial dilution of thermal waters by shallow near-surface waters.

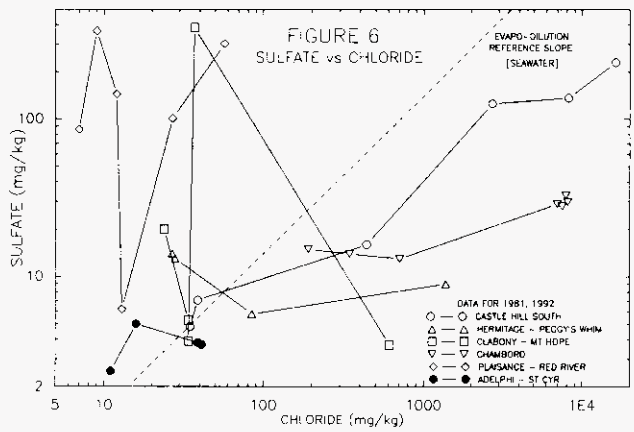
Silica geothermometers were judged to be not reliable, based on poor to negligible correlation with chloride (Figure 7) and relatively low Concentrations. Although quartz solubility would limit silica to about I I mg/kg, it is generally absent from the surface volcanic racks from which weathering can deliver up to about 50 mg/kg $SiO_2$ from other minerals. Higher silica Concentrations are viewed as residual from a thermal water component. One could suspect that silica deposition occurred prior lo mixing and possibly afterward in some Circumstances.




Ratios of Na/Cl and K/Cl were often highly preserved over large dilution factors: Figure 8 shows the Na vs K correlations for the prospect sites. Accordingly. Na/K geothermometers were selected as most reliable. To help verify this, three-component plots of Na:K:Mg were made in accordance with Giggenbach (1988) and Fournier (1990). These also indicate that the diluted Na/K ratios are valid estimates of the pre-dilution temperatures.

From among the several versions of Na/K geothermometers, that due to Arnorsson et al (1983) was preferred here because it was calibrated against basalis, which most closely match the predominant lithology of Grenada. Selected geothermometer results, with some associated data, are shown in Table 4.

Results of the NaKCa geothermometer are variously higher and lower than the Na/K results. For all groups, the mismatch increaser with increasing dilution, evidence of bias due to the dilution waters being relatively enriched in calcium. Far Castle Hill South and Chambord, $T_{NaKCa} > T_{Na/K}$ for the least diluted samples. In there cases the Na/K temperature value is suspected to be numerically more accurate because its calibration was against a more relevant rock type.

TABLE 4: SELECTED DATA - GRENADAN GEOTHERMAL SITES
SPRING TEMPERATURES AND GEOTHERMOMETERS

------CASTLE HILL SOUTH-------

| Sample | Cl mg/kg | Temperatures (°F) Na/K | NaKCa | Meas |
|---|---|---|---|---|
| i8 | 16307 | 320 | 399 | 99 |
| g10 | 8248 | 352 | 363 | 116 |
| g11 | 2726 | 343 | 303 | 105 |
| g18 | 440 | 407* | 229* | |
| g12 | 39 | 446* | 131* | |
| i2 | 35 | 440* | 120* | 84 |
| Best | | 320 | 363 | |

-----------CHAMBORD----------

| Sample | Cl mg/kg | Temperatures (°F) Na/K | NaKCa | Meas |
|---|---|---|---|---|
| i9 | 8154 | 260 | 322 | 97 |
| g5c | 7929 | 260 | 318 | 95 |
| g5b | 7504 | 261 | 319 | 92 |
| g5a | 6991 | 254 | 314 | 92 |
| i11 | 709 | 260* | 283* | 84 |
| g5d | 345 | 252* | 162* | 82 |
| i10 | 191 | 243* | 125* | 84 |
| Avg | | 259 | 318 | |

----CLABONY-MT HOPE-----

| Sample | Cl mg/kg | Temperatures (°F) Na/K | NaKCa | Meas |
|---|---|---|---|---|
| g3 | 609 | 358 | 230 | 96 |
| g1 | 37 | 686* | 166* | 72 |
| i7 | 34 | 430* | 137* | 93 |
| g8 | 34 | 426* | 135* | 95 |
| g2 | 24 | 321* | 100* | 73 |
| Best | | 358 | 336 | |

----HERMITAGE-PEGGY'S WHIM----

| Sample | Cl mg/kg | Temperatures (°F) Na/K | NaKCa | Meas |
|---|---|---|---|---|
| g9 | 1383 | 316 | 247 | 102 |
| i6 | 85 | 362 | 133 | 82 |
| i5 | 28 | 375* | 33* | 81 |
| g4 | 27 | 294* | 25* | 77 |
| Best | | 316 | 247 | |

--------ADELPHI-ST CYR--------

| Sample | Cl mg/kg | Temperatures (°F) Na/K | NaKCa | Meas |
|---|---|---|---|---|
| G7 | 41 | 413 | 140 | 91 |
| i3 | 39 | 428 | 136 | 91 |
| G6 | 16 | 462* | 105* | 84 |
| i4 | 11 | 446* | 78* | 77 |
| Avg | | 420 | 324 | |

"Best" temperatures are based on higher chloride concentrations
* probably not reliable due to severe dilution

Two areas not shown in Table 4 are Plaisance-Red River and Hapsack. Fluids from both of there sites were too dilute to yield reasonable geothermometer components. At Plaisance-Red River. abundant alteration of rocks near fractures. but with near-background chloride levels. is interpreted as an effect of steam. The small Cl/B ratio is consistent with this view. No fumaroles or elevated temperatures were found there. The Hapsack area, near the top of MI. St. Catherine. the highest point in Grenada (elev 2757 ft), included a fumarole with the highest temperature found. 154°F. Chloride concentrations of associated liquids were 13 mg/kg, not distinguishable from background. but possibly related to evapo-concentrated condensate.

## SUMMARY AND CONCLUSIONS

### Geology

Grenada has all the attributes necessary for the existence of commercial quality geothermal systems. Reservoirs may be within fractured lavas in the central part of the island where the volcanic pile is thick enough to reach depths of several thousand feet. Plausibly, the underlying carbonate formations may be involved in the northern part of the island, particularly beneath Cantle Hill and Chambord.

Some heat sources may be a Continuation of magma intrusion that surfaced as the Mt. St. Catherine volcanics (0.94 Ma), expressed now as the buildup of Kick-'em-Jenny. Intermediate age magma activity has built Isle de Caille and one may presume that unexposed intrusives underlie some northern parts of Grenada in addition to the Chambord area.

Conduits for thermal and non-thermal fluids are almost certainly associated with the regional orthogonal fracture/fault systems. These features are likely supplemented by interconnected networks of cracks and fractures within the reservoir rocks. Probably. these conduits are kept open and permeable by Contemporary seismicity that characterizes the plate subduction which generates the volcanic Caribbean islands, including Grenada.

Water for recharge of the hydrothermal circulation systems is widely available. The higher mountains of Grenada are drenched by over 4000 mm (160 in.) of rain annually. while coastal areas get about 1 meter annually. The sub-surface water circulation system is quite complex within strato-volcanos. Inter-flaw boundaries. fractures, and buried weathered surfaces provide a three-dimensional mix of conduits and barriers which assures that mort, or all, porosity beneath the shallow water table will be saturated.

### Prospective Areas

CASTLE HILL SOUTH (Figure 2) involves the highest concentrations of chloride. Samples were mainly collected from the walls of the Duchesne valley, where bedrock volcanics are exposed near the river. Chloride-rich water trickles from several zones of nearly horizontal traces of fractures through the volcanic rocks above the Stream level. Highest chloride Concentrations were generally found at higher elevations of this valley. Measured concentration of chloride in stream water at lower elevation was 400 mg/kg, indicating a Significant collective contribution of thermal water to the stream.

Measuring chloride concentrations in surface waters to expose a pattern may be a useful exploration tool for this resource. The Na/K and NaKCa geothermometers vary with chloride concentration, but their trends are of opposite sense (Table 4). Both indicate substantially more than 300°F far the least diluted samples. From the limited data available, this area appears to be the most promising in terms of elevation. extent, accessibility, and thermal characteristics.

THE CHAMBORD AREA, in nearly level terrain with elevation 25 to 50 feet. includes a travertine terrace about *250* feet long by 100 feet wide formed by coalescence of several thermal outflows. Currently, the pools have negligible discharge rates. Elevated chloride in the adjacent stream, 10 to 15 feet below the pool elevations, indicates substantial hidden contribution from the thermal source. Uranium-thorium dating of the travertine yielded a young age. 10 Ka, with large uncertainty (+55Ka, -36Ka). This terrace may be the largest geothermal deposit an the island. However, its relatively low temperatures for surface flow and geothermometer suggest it may not be rhe best prospect. However. a careful survey focussing on water temperatures, chloride concentrations, and flow rates of surface waters deserves to be made here as an effort to define the amounts of heat discharged and to better resolve the deep temperature.

CLABONY-MT. HOPE involves steep terrain at higher elevation (>1000 feet asl) and four widely separated sample points. One sample, apparently much diluted, but with chloride at more than 50 times background, yields an encouraging Na/K temperature. The other three samples have chloride concentrations of about three times background, but their associated geothermometer temperatures are likely not reliable.

HERMITAGE-PEGGY'S WHIM involves less steep terrain at lower elevations than Clabony-Mt. Hope. One sample Contains chloride at more than 100 times background with a significant chemical temperature. The mismatch between Na/K and NaKCa geothermometer values indicates that it is substantially diluted. These two latter areas deserve more study to define better their prospective natures.

ADELPHI-ST. CYR yielded sampler with chloride concentrations up to four times background. indicating a prospective area. However, the samples are too dilute to give credence to geothermometer temperatures. The location, in mild terrain (01000 feet elev) east of Gran Etang (2nd highest peak in Grenada, elev 2509 ft), suggests favorable recharge in the vicinity of significant volcanism. Further study there seems warranted.

### Plant Economics

A project structured reasonably around production wells 5000 feet deep with average capability of 3 MWe and a power sales price of US$0.10/KWh can forecast an internal rate of return near 18%/year.

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