Seismic Research Unit
The University of the West Indies
St. Augustine
Trinidad
Phone ++1-868-662-4659
Fax ++1-868-663-9293
E-mail: sruuwi@tstt.net.tt

Geochemical monitoring of Sulphur Springs, St. Lucia: implication for health and safety

By Erouscilla Joseph

September 2004

Introduction

In September 2002 the management of the Sulphur Springs Park in St. Lucia contacted the Seismic Research Unit indicating their concern regarding the welfare of the staff and patrons using the facility. They were particularly concerned about exposure of individuals to hazardous volcanic gas emissions, and they expressed interest in implementing an effective environmental gas monitoring system to regularly check the level of emissions. This was considered an important contribution towards minimizing risks to the health and safety of persons using the park. The monitoring program would be used in conjunction with an evacuation plan, developed by the National Emergency Management Organization (NEMO), for controlling human activity within Sulphur Springs Park. This report contains advice and recommendations regarding the implementation of such a gas monitoring program.

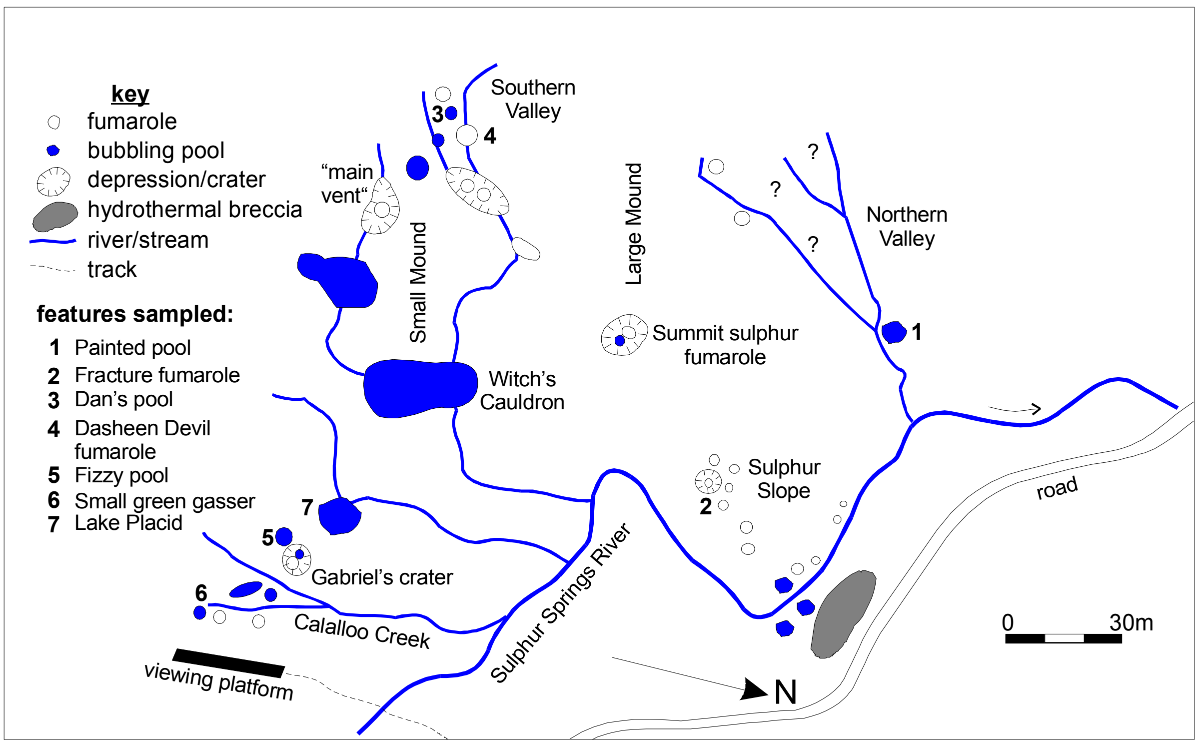
Geological setting

St. Lucia is one of the volcanic islands of the Lesser Antilles. It has several areas of geothermal activity of which Sulphur Springs is the most important. Sulphur Springs itself is located within the much larger Soufrière Volcanic Centre. Early workers interpreted the Soufrière area as a caldera that formed over 40,000 years ago at the conclusion of a period of intense volcanic activity (Tomblin 1964). However, age data obtained in the 1980's and new geologic mapping (Roobol et al. 1983) shows that the Soufriere depression probably formed by a combination of flank collapse and down-faulting along NE-SW trending regional faults. Some workers (e.g.(Wohletz et al. 1986)) believe that a little over half the area within the Soufrière depression is occupied by a caldera referred to as the Qualibou caldera. Studies investigating the potential geothermal resources of the Sulphur Springs area (e.g. (UNRFNRE 1989), (LANL 1984), (GENZL 1992)) have revealed that the Sulphur Springs is the surface manifestation of a high-temperature, sub-surface geothermal field with good energy producing potential. A possible magma body beneath the Belfond/Terre Blanche area is believed to be the heat source for the Sulphur Springs geothermal system and the young volcanism of the Soufrière Volcanic Centre (Gandino et al. 1985).

Sulphur Springs

Sulphur Springs is located within the Qualibou caldera on the northeastern flank of Rabot ridge. It consists of an area of strongly hydrothermally altered clay-rich ground approximately 200 x 100 m in size (Lindsay et al. 2002). Current activity in the area is concentrated on the western side of the Sulphur Springs Road, and some smaller features are present on the western edges of Terre Blanche. Geothermal manifestations in the area include numerous hot springs, bubbling mud pools, boiling springs, and fumaroles. Many fumaroles have temperatures of up to 100^{o}C or hotter, with temperatures of up to 172^{o}C being recorded on occasion. The area beneath the viewing platform, which encompasses Gabriel's crater, does not appear on early maps or photographs of the Sulphur Springs (Robson and Willmore 1955) and is therefore thought to be a relatively recent area of activity (Lindsay et al. 2002).

Figure 1. Sketch map of the Sulphur Springs Geothermal Field, St Lucia, showing the features sampled by the Seismic Research Unit (nb. the names for these features may be different to those used in Saint Lucia). (Question marks indicate areas too dangerous to visit).



Hazards associated with the geothermal activity at Sulphur Springs

There are a number of dangers associated with an active geothermal field that can impact human life, property, and the environment. Several of these hazardous phenomena are explored in greater detail below.

Landslides

Acidic waters circulating under geothermal areas induce intense rock alteration that leads to the creation of unstable, soft, clay-rich ground. Such unstable ground is susceptible to slumps or landslides, particularly in geothermal fields located on steep slopes with an absence of vegetation. Earthquakes may also trigger landslides. There is some evidence for recent slumping on the upper slopes of the Sulphur Springs geothermal area near Rabot (Lindsay et al. 2002) and this area is considered to be very unstable. Landslides themselves can alter the underground network of the system, leading to the unblocking of some vents and the sealing of others.

Phreatic and Hydrothermal eruptions

In addition to the constant, low-level geothermal activity observed at the Sulphur Springs, small phreatic and hydrothermal eruptions might be generated from its craters. Hydrothermal eruptions usually result from local depressurization that allows water to boil and flash to steam. This releases sufficient energy to break up and eject surrounding rocks. Phreatic eruptions, like hydrothermal eruptions, are steam driven but eject more ash than rock and are generally more short lived (Lindsay et al. 2002). The material expelled is ash-like and comprises mud, old altered rock, and mineral fragments. Material expelled in a phreatic or hydrothermal eruption is not juvenile, i.e. these eruptions do not involve fresh magma. In early 2001, minor phreatic eruptions from the fumaroles in Gabriel's crater and the main vent ejected ash-like material that reached the viewing platform and surrounding vegetation. In intense geothermal systems such as Sulphur Springs it is common for boiling mud pools and fumaroles to eject small amount of mud and debris. While these minor phreatic eruptions are considered to be a result of local adjustments in the geothermal system, an increase in their number and intensity may signify the commencement of a genuine magmatic eruption and would need to be closely monitored.

Boiling pools

Pools of hot water are present in some places beneath the thin crust of ground at Sulphur Springs. In certain areas where the ground has become very soft as a result of alteration by percolating acidic waters, it is very easy to penetrate the crust. In the 1980s there was an incident in which one of the guides at Sulphur Springs was seriously burnt after falling into a hole (Lindsay et al. 2002). It is now the practice of the guides to describe the features of the Springs from the security of the viewing platform without actually walking through the field. It is advisable that activity in geothermal fields such as Sulphur Springs be kept to a minimum and that proper gear be worn at all times (Allen et al. 2000).

Volcanic gases

Magma contains dissolved gases that are released into the atmosphere during eruptions. Gases are also released from magma that either remains underground or is rising towards the surface. In these instances, gases may escape continually into the atmosphere from the degassing of soil, volcanic vents, fumaroles, and hydrothermal systems. The composition of volcanic gases is dependent on the volcano's eruptive state and type. Volcanic gases are primarily composed of water vapour, carbon dioxide and compounds of sulphur and chlorine. Minor components are carbon monoxide, fluorine, boron compounds, and ammonia. Hazardous gases that are typically found in geothermal areas include carbon dioxide, sulphur dioxide, hydrogen sulphide and carbon monoxide (Miller 1989). These gases can affect human and animal health, property, and the environment in different ways.

Carbon Dioxide (CO_2)

Volcanoes release more than 130 million tones of carbon dioxide into the atmosphere every year (USGS 2001). CO_2 is a colorless, odorless, tasteless gas that has a vapour density of 1.52 g/L relative to air and its solubility in water at 20^{o}C is 0.04g/L. Its natural balance in air is 0.13%, however, anthropogenic sources are causing an increase in this percentage. This has resulted in its increased contribution toward global warming. In addition, because it is denser than air, it can settle into low-lying areas, depressions and valleys. This can pose a serious hazard and can result in the asphyxiation and death of humans and animals if CO_2 concentrations are greater than 30%. At a 5% concentration in air, respiratory rates noticeably increase with shortness of breath, headaches, dizziness and sweating observed at 6-10%. Concentrations of 10-15% cause impaired coordination and abrupt muscle contractions, while at 20-30% there is loss of consciousness and convulsions (Hathaway et al. 1991). In addition to being emitted during passive volcanic degassing, in certain circumstances CO_2 can be released from volcanoes in a density current. Degassing of carbon dioxide through the soil can lead to oxygen deprivation of plant roots resulting in the death of the surrounding vegetation.

Sulphur Dioxide (SO_2)

Sulphur dioxide is a colorless gas with a characteristic pungent odor. Its density with respect to air is 2.26 g/L. SO_2 has a solubility of 10 g/L in water at 20^{o}C, and is soluble in alcohol, acetic acid, and sulfuric acid. It is corrosive to organic materials and dissolves in water to form sulfurous acid, H_2SO_3. The negative impacts of SO_2 gas on humans include irritation of the skin, tissues and mucus membranes of the eyes, nose, and throat. It mainly affects the upper respiratory tract and bronchi. The World Health Organization recommends a concentration of no greater than 0.5 parts per million (ppm) over 24 hours for maximum exposure. Emission rates of SO_2 from an active volcano can range from <20 tonnes/day to >10 million tonnes/day according to the style of volcanic activity as well as the type and volume of magma involved (USGS 2001). The Earth's short term weather patterns are greatly impacted by the influences of SO_2 (Fischer 1997). Sulphur dioxide emitted into the atmosphere reacts with water vapour to form sulphuric acid (H_2SO_4), which condenses in the stratosphere to form fine sulphate aerosols. These aerosols increase the reflection of radiation from the sun back into space and consequently cool the Earth's lower atmosphere or troposphere. They also absorb heat radiated from the Earth thereby warming the stratosphere (McGee et al. 1997). H_2SO_4 is a contributor to acid rain, which can cause harm to humans and animals, destruction of vegetation and the corrosion of concrete and metal structures.

Hydrogen sulphide (H_2S)

Hydrogen sulphide is a colorless, flammable gas with a characteristic offensive odor (rotten eggs). Its density in air is 1.19 g/L and it has a solubility in water of 2.9 g/L. It is highly toxic and has been responsible for numerous fatalities. Exposure to 20–150 ppm of H_2S causes irritation to the eyes and respiratory tract. Symptoms of exposure include headache, fatigue, dizziness, excitement, staggering gait, and diarrhea. In large amounts it results in paralysis of the respiratory center and death. Long-term exposure of low concentrations may cause pharyngitis and bronchitis (Williams-Jones and Rymer 2000). Since it has a higher density than air it may accumulate in caves and depressions and pose a hazard to those who come into contact with the gas.

Carbon Monoxide

Carbon monoxide is a colorless, odorless gas. It interferes with the ability of blood to transport oxygen to organs and tissue throughout the body (DEQ 2002). Depending on the amount inhaled, this gas can impede coordination, worsen cardiovascular conditions, and produce fatigue, headaches, weakness, confusion, disorientation, nausea, and dizziness. Very high levels can cause death (NSC 2002). The symptoms are sometimes confused with the flu or food poisoning. Fetuses, infants, elderly, and people with heart and respiratory illnesses are particularly at high risk of adverse health effects due to carbon monoxide. It acts by displacing oxygen molecules that are attached to hemoglobin in the blood thereby forming carboxyhemoglobin (COHb), and as a result deprives living tissue of sufficient gas to maintain metabolic function. The guideline values for permissible concentration levels and exposure times listed in the table below were derived based on periods of time-weighted average exposure during which the COHb level of 2.5% in the blood was not exceeded.

Hydrogen Chloride or Hydrochloric acid (HCl)

Chlorine gas is emitted from volcanoes in the form of hydrochloric acid. It is a colorless gas or fuming liquid with an irritating pungent smell (Williams-Jones and Rymer 2000). Its density is

1.27 g/L in air and solubility in water is 62 g/L. The odor of HCl gas is detectable at concentrations of 1-5 ppm by most people. Chlorine gas has a negative impact on both humans and the environment. HCl breaks down in the atmosphere to form chlorine and chlorine monoxide (ClO) molecules. The sulphate aerosols in the stratosphere, produced by the reaction of SO_2 with water vapour, act as reaction sites for the breakdown of the HCl. The reactive chlorine produced from volcanic sources acts together with chlorine generated from human activities to destroy ozone (Fischer 1997). This process is a significant contributor to the depletion of ozone in the Earth's ozone layer. The ozone layer is an important shield against harmful ultra-violet (UV) radiation from the sun. Hazardous effects of the harmful UV rays, known as UV-B rays, include damage to cellular DNA in animals and plants. Short-term exposure of individuals to HCl gas include irritation of the mucus membranes of the eyes and respiratory tract coupled with burning, choking, and coughing (Williams-Jones and Rymer 2000). Exposure to concentrations of >35 ppm result in irritation of the throat, breathing difficulties, and skin inflammation. Concentrations >100 ppm cause pulmonary edema, and often laryngeal spasm.

Hydrogen Fluoride (HF)

Fluorine gas is emitted from volcanoes in the form of an aerosol called hydrogen fluoride. Hydrogen fluoride is a clear, colorless, fuming corrosive liquid or gas. It has a strong irritating smell. Its density in air is 0.7 g/L and is miscible with water in all proportions. Excess exposure of HF to humans cause irritation and corrosion of the skin and mucus membranes. Contact with the eyes will cause burns and can lead to permanent visual impairment if the source is not quickly removed. Inhalation of the vapour may cause ulcers of the upper respiratory tract and concentrations of 50–250 ppm are dangerous for even brief exposures ((Williams-Jones and Rymer 2000)). Prolonged contact with low concentration may lead to changes in bone structure as well as chronic irritation of the nose, throat and lungs. The WHO recommends permissible levels of 3 ppm in air for a period of eight hours. Fluorine can also condense in rain or on ash particles that are deposited on nearby vegetation and in lakes and streams (Fischer 1997). Excess fluorine is dangerous to humans and animals. Eating fluorine-contaminated vegetation poisons animals and can lead to fluorisis. This illness can kill the animals by destroying their bones.

Volcanic gases at Sulphur Springs

The table below lists the main hazardous gases present at Sulphur Springs and their permissible levels of exposure, and briefly describes their impact on human health.

Table 1. Recommended Permissible levels and effects on human health[1].

GAS SPECIES		CARBON DIOXIDE	HYDROGEN SULPHIDE	SULPHUR DIOXIDE	HYDROGEN CHLORIDE	HYDROGEN FLUORIDE
OCCUPATIONAL EXPOSURE LIMIT (ppm)	15 MIN	5000	10	5	5	50
	8 HR	15000	15	2	-	3
AIR QUALITY STANDARD			7 ug/m (30 min)	100 ppb (15 min)	-	-
DETECTION LEVEL (ODOUR) (ppm)		50000	0.02	1	0.8	-
SEVERE SENSORY IRRITATION (humans) (ppm)		-	100	120	100	120
30 minute lethal concentration (mammals) (ppm)		15%	1000	300 – 500	1600 – 6000	900 – 3600
ERPG-1		-	0.1	0.3	3.0	3.0
ERPG-2		-	-	3.0	10.0	20.0
ERPG-3		-	0.3	15.0	30.0	100.0
ASSOCIATED HEALTH EFFECTS		Headaches, sweating, shortness of breath, rapid breathing, drowsiness	Eye and upper respiratory tract irritation, headaches, dizziness, fatigue	Irritation of eyes and respiratory tract, coughing, breathing difficulties	Irritation of mucus membranes, choking and coughing. Prolonged exposure may lead to erosion of teeth and skin rash	Irritation and corrosion of the skin and mucus membranes. Irritant to nose, throat, and lungs.

1 Adapted from the book “Hunter’s Diseases of Occupations” 9th ed. (Baxter 2000).

ERPG – 1 Capable of causing mild, transient and reversible effects.

ERPG – 2 Concentrations may cause irreversible effects.

ERPG – 3 Concentrations are considered life threatening.

Emissions Monitoring at Sulphur Springs Park

In November 2002 Ms. E. Joseph and Dr. Jan Lindsay visited the Sulphur Springs Park as part of an ongoing geothermal monitoring program. On this visit we were allowed the use of a Toxic Rae Meter that had been purchased by the Soufrière Foundation for emissions monitoring of the Sulphur Springs Park. Mr. Alexander told us that the unit was purchased on the advice of Prof. Dale Morgan, of the Massachusetts Institute of Technology, in response to his concerns about the health of the staff and visitors of the Park. The meter has the capability of monitoring several gases including carbon monoxide, hydrogen sulphide, sulphur dioxide, nitrogen dioxide, ammonia, and chlorine. It operates with the use of specific gas sensors that can be interchanged. The Foundation is currently in possession of three sensors: carbon monoxide, hydrogen sulphide, and sulphur dioxide. The meter has the ability to give real time measurements, time weighted average and short-term exposure level as well as the peak value recorded of the toxic gas concentrations being investigated. It can also activate an alarm signal whenever the exposure exceeds preset limits. Dr. Peter Baxter, a leading expert on hazardous gas emissions and its effect on humans, advised us that the main gas of concern in geothermal areas is sulphur dioxide. This may be because SO_2 causes adverse effects in humans even at low levels. With this in consideration we monitored SO_2 concentrations using the Toxic Rae meter to test its sensitivity and suitability for monitoring purposes. Our investigations in the Park required that we actually work in the geothermal field itself and not be confined to the visitor viewing platforms. As a result we were much closer to the actual sources of gas emissions at the Park. The table below lists the results of gas monitoring during our investigation.

Table 2. Results of Sulphur Dioxide monitoring at Sulphur Springs Park (November 2002)

Specific reading taken	**DAY 1 (14.11.02) Concentration (ppm)**	**DAY 2 (15.11.02) Concentration (ppm)**
Instantaneous (actual gas concentration at the time)	0.0	0.0
Stel (average concentration over last 15 minutes)	0.0	0.0
TWA (accumulated average over 8 hours)	0.0	0.0
Peak (Maximum gas concentration)	3.5	6.3
Run time in **hours** (accumulated time since unit switched on)	17.5	1.6

The results indicated above were recorded at the end of each sampling trip to the Park. On day 1 the unit was also left to record SO_2 concentrations during the night. The peak observed on day 2 was recorded from gaseous emissions at “fracture fumarole” on Sulphur slope (Fig. 1). It should be noted that while the peaks recorded on both days were well over 0.5 ppm, the TWA reading remained at 0 ppm indicating no serious long term risk. However, short-term exposure to concentrations of 6 ppm is known to trigger asthma attacks in asthmatics and a lot of non-asthmatics if they exercise (Baxter 2002).

Mr. Alexander informed us that in the past, staff used to regularly monitor gas emissions using the H_2S sensor during their tours. This monitoring was discontinued due to malfunctioning of the meter, which has subsequently been repaired.

Recommendations

Based on our knowledge of the hydrothermal emissions at Sulphur Springs Park and the capabilities of the Toxic Rae meter owned by the Park's management, we recommend that its use be continued. The primary gas monitored should be sulphur dioxide, for reasons explained earlier; however checks of hydrogen sulphide and carbon monoxide should also be maintained. The method of monitoring used in the past (frequency and location of measurements) as recommended by Prof. Dale Morgan should be continued. The table presented in this document should be consulted to ensure that concentrations remain within acceptable limits. If concentrations exceed acceptable limits, then steps should be taken to reduce exposure to the emissions. The Seismic Research Unit should also be contacted, as large increases in emissions or gas concentrations may indicate changes in the underlying magmatic system.

We also strongly recommend that the Soufrière Foundation consult Dr. Peter Baxter on matters relating to the health of visitors and staff that are exposed to emissions at the Park. He would be able to provide detailed information concerning the frequency of medical check ups for the staff, what tests are most relevant, and what actions should be taken in individuals that may be negatively affected. He could also give advice on any suitable alternative monitoring techniques given his experience of monitoring emissions at active volcanic and geothermal areas around the world.

Dr. Baxter is expected to visit Montserrat in the near future. If arrangements can be made during this visit for him to travel from Montserrat to St. Lucia he would be very willing to visit the Soufriere Foundation and look into the conditions at the Sulphur Springs Park. His contact details are as follows:

Dr Peter J Baxter
Institute of Public Health
University of Cambridge
Robinson Way
Cambridge CB2 2SR

Phone +44 1223 336590
Fax +44 1223 336584

pjb21@medschl.cam.ac.uk.

REFERENCES

Allen, A. G., P. J. Baxter, and C. J. Ottley. 2000. Gas and particles emissions from Soufrière Hills Volcano, Montserrat, West Indies: characterization and health hazard assessment. *Bull. Volcanology* 2000 (62): 8 - 19.

Baxter, Peter. 2000. Gases. In *Hunter's diseases of occupation*, edited by J. M. Harrington. London: Arnold.

———. 2002. St. Lucia Sulphur Springs. St. Augustine, 12th November 2002.

DEQ, Department of Environmental Quality. 2002. *Meet the Air Pollutants* [Internet]. DEQ 2002 [cited 30th October 2002]. Available fromwww.deq.state.id.us.

Fischer, Richard. 2002. *Effects of Volcanic Gases* [Internet] 1997 [cited 30th October 2002]. Available from http://magic.geol.uscb.edu/~fischer/gas.htm.

Gandino, A, F. Piovesana, R. Rossi, and L. Zan. 1985. Preliminary evaluation of Soufriere geothermal field, St. Lucia (Lesser Antilles). *Geothermics* 14 (4): 577-590.

GENZL. 1992. St. Lucia Geothermal Project. Well-2 discharge testing, well safety evaluation and resources assessment: St. Lucia Electricity Services Ltd. (LUCELEC).

Hathaway, G.L., N.H. Proctor, J.P. Hughes, and M.L. Fischman. 1991. *Proctor and Hughes' chemical hazards of the workplace*. 3rd ed. New York: Van Nostraud Reinhold.

LANL. 1984. Report of St. Lucia Geothermal Resources: Los Alamos National Laboratory.

Lindsay, J., J. David, J. Shepherd, and J. Ephraim. 2002. Volcanic Hazard Assessment for St. Lucia, Lesser Antilles. Unpublished report presented to the Government of St. Lucia, August 2002.

McGee, Kenneth, Michael Doukas, Richard Kessler, and Terrance Gerlach. 1997. Impact of Volcanic Gases on Climate, the Environment, and People. *U.S. Geological Survey Open-File Report* 97 (262).

Miller, Dan. 2002. *Potential Hazards from Future Eruptions in California*. United States Geological society 1989 [cited 30th October 2002]. Available from http://vulcan.wr.usgs.gov/Glossary/Emissions/description_gas_fumaroles.html .

NSC, National Safety Council. 2002. *Carbon Monoxide* [Internet]. NSC, 1st February 2002 [cited 30th October 2002]. Available from www.nsc.org.

Robson, G. R., and P.L. Willmore. 1955. Some heat measurements in West Indian soufrieres. *Bulletin of Volcanology*: 13-39.

Roobol, M. J., J. V. Wright, and A. L. Smith. 1983. Calderas or gravity-slide structures in the Lesser Antilles island arc? *Journal of Volcanology and Geothermal Research.* 19 (1-2): 121-134.

Tomblin, J.F. 1964. The Volcanic History and Petrology of the Soufriere region, St. Lucia. Unpublished PhD thesis, University of Oxford.

UNRFNRE, United Nations Revolving Fund for Natural Resources. 1989. St. Lucia geothermal exploration project. Final Report Volume II, Wells SL-1 and SL-2.

USGS. 2002. *Volcanic Gases and Their Effects* [Internet]. United States Geological Society (USGS) 2001 [cited 30th October 2002]. Available from http://volcanoes.usgs.gov.Hazards/What/VolGas/volgas.html.

Williams-Jones, Glyn, and Hazel Rymer. 2000. Hazards of Volcanic Gases. In *Encyclopedia of volcanoes*, edited by H. Sigurdsson. San Diego: Academic Press.

Wohletz, Kenneth, Grant Heiken, Mark Ander, Fraser Goff, Francois David Vuataz, and Geoff Wadge. 1986. The Qualibou Caldera, St. Lucia, West Indies. *Journal of Volcanology and Geothermal Research.* 27 (1-2): 77-115.