ST LUCIA GEOTHERMAL PROJECT

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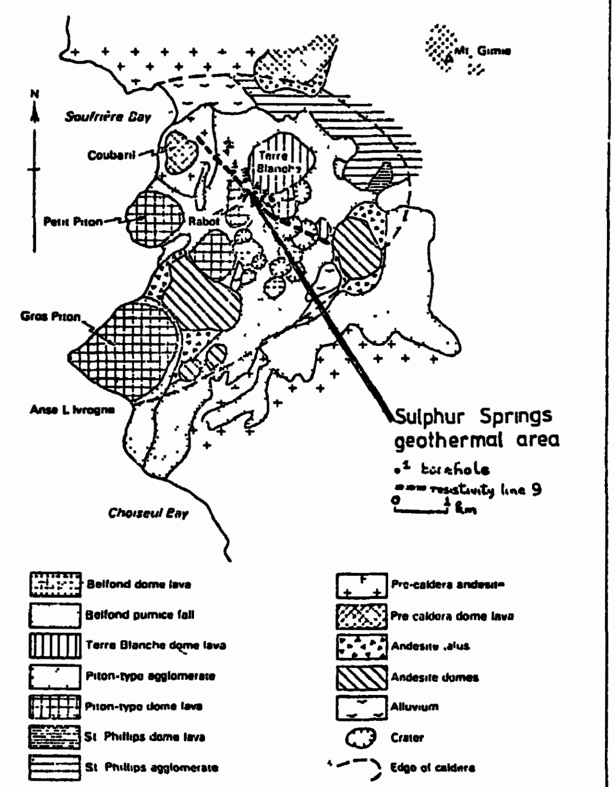
The St. Lucia Project is the first geothermal study overseas undertaken by the Institute of Geological Sciences. It was commissioned by the Ministry of Overseas Development (U.K.) and carried out in conjunction with Merz and McLellan, Consultant Engineers. The University of the West Indies also participated in studies of the geology and seismicity of the areas. The object of the investigations was to develop geothermal steam for electric power.

St. Lucia is one of the islands of the Lesser Antilles which is a chain linking the northeast of Venezuela with Puerto Rico and the Greater Antilles. It has a roughly elliptical shape 45 x 22 km. The island is entirely volcanic with ages ranging from Lower Miocene to fairly Recent (40,000 years B P). Steam fumaroles and boiling pools, known as Sulphur Springs, occur in the Soufriere area in S. W. St. Lucia, and are associated with the Qualibou Caldera, the youngest of the volcanic centres (figure 1). The caldera is about 6 km in diameter and is thought to have collapsed during the mid Pleistocene with the peripheral fault having a throw of the order of 250 meters. Sulphur Springs is an area of fumaroles and boiling pools located in a narrow valley between the domes of Rabot and Terre Blanche. The area of present activity extends over some 20,000 sq.m and the surface valley fill in the vicinity is intensely altered and kaolinised with formation of sulphur and gypsum. During the recent investigations, pool water temperatures showed a range from 63-96°C and the maximum temperature of the fumaroles was 185°C.

Boiling mudpools, steam vents, thermal springs and a number of cold springs and waterwells within the Qualibou Caldera were sampled and analysed for major elements, some minor elements (Si, B, Sr) stable isotopes of oxygen and hydrogen, and tritium levels.

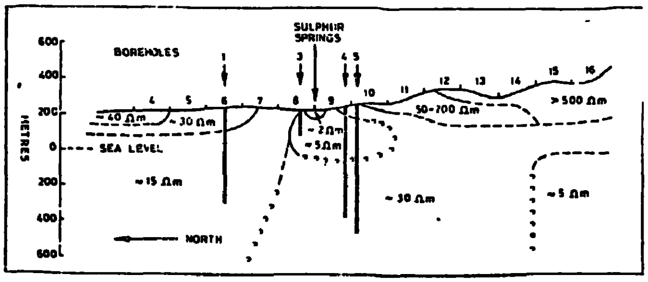
Recently developed mudpools were found to be acid sulphate type (pH 3.0) while older ones were slight acid or neutral (pH around 5-7) and sodium calcium sulphate type. Temperatures within the mudpools

Figure 1 Qualibou Caldera



ranged from 66-96°C. The highest reported temperature from a steam vent was 185°C, and noncondensable gas associated with this steam contained 92% CO_2 and 2% H_2S. Low tritium levels in the steam condensate indicated that the turnover time for the reservoir fluids was in excess of twenty years. The stable isotope compositions of oxygen and hydrogen showed a considerable enrichment in ^{18}O relative to surface to meteoric water, which suggested that extensive steam-wallrock reaction had occured. Boron levels within the mudpools (up to 1000 mg/1) were anomalously high with respect to a background level of less than 0.1 mg/1.

Thermal springs sampled in the area typi-



LINE 9 ESTIMATED TRUE RESISTIVITY SECTION

Fig 2 Line 9 Resistivity model

cally had low flow rates (5 - 100 l/min), were roughly neutral (6.0 - 8.0 pH) and could be classified as sodium bicarbonate type with low mineralisation. This water is derived from a shallow aquifer within pyroclastic debris infilling the Sulphur Springs Valley, contained between the massive dacitic domes. Boron levels within these thermal springs (up to 14 mg/l) were also well above the background level.

The very high levels of the volatile element boron in mudpools, their acid sulphate composition, and the occurence of steam in a fumarole with an enthalpy exceeding the maximum enthalpy of saturated steam, all point to the existence of a vapour dominated reservoir at depth.

GEOPHYSICS

A number of deep resistivity profiles in the region of the Qualibou Caldera were carried out using a Scintrex 2.5 kW commutated direct current system with the dipole-dipole electrode configuration. A total of 50 line - km of apparent resistivity cross-sections, extending to a maximum depth of 1 km, were constructed from the data.

Throughout the survey area, apparent resistivity values were low (3-500Ωm) and typically less than 50Ωm. The most interesting anomalies occurred on survey line 9 which passed close to the Sulphur Springs emanations. On this line the apparent resistivity cross-section in the vicinity of the Springs suggested a zone of low resistivity (<5Ωm) near the surface and another of comparatively high resistivity at depth. This was consistent with a model for a vapour-dominated geothermal reservoir in which a low resistivity upper zone of condensing steam overlies a comparatively high resistivity zone where rock pores are vapour filled. However, computer modelling studies showed that the apparent high resistivity zone at depth was probably due to near surface lateral variations in resistivity. (figure 2). The geological complexity, coupled with severe topography in this area, made the resistivity method difficult to carry out in the field and difficult to interpret. HOwever an area of generally low resistivity (5Ωm) surrounding a very low resistivity (2Ωm) zone was identified at Sulphur Springs. Deeper anomalies (say below 400 m) would probably not be detectable in this environment.

A total of seven holes were drilled (figure 1), ranging in depth from 116 to 726 meters. Steam was produced from four of these and it is hoped that the two most successful can be utilised for producing electricity. Holes 1 (527 m) and 2 (116 m) were drilled to the north of Sulphur Springs and sited mainly on the evidence of the northerly extension of kaolinised rocks and on the presence of hot springs to the north, particularly near Terre Blanche. Both holes were cold. Hole 3 (133 m) was drilled very close to the emanations and as was feared, low pressure, low volume steam was encountered at shallow levels requiring the hole to be terminated at an uneconomic depth. Hole 4 (610 m) and 5 (726 m) were both good steam producers although 5 had eventually to be plugged because of surface blow-outs. Hole 6 (692 m) drilled only 100 m from Hole 5 had comparable high temperatures but did not produce steam. Hole 7 (254 m) was finally drilled closed to Hole 4 and is a good producer. The main steam zone yet encountered in the vicinity of 4, 5, 7 is between 250/300 m below ground level. Hydrothermally altered material corresponding with the steam producing zone occurs within the basal dacites overlying the Pre-Caldera rocks.

A number of physical and chemical tests were performed on the discharge from Holes 4 and 7, to determine their output characteristics over a range of operationg pressures and to determine the chemical and isotopic composition of the steam and associated gases. Hole 4 produced 2.1 $kg.s^{-1}$ of steam with 10°C superheat at 10 bars (gauge) wellhead pressure, while Hole 7 produced 4.5 $kg.s^{-1}$ with 40°C superheat of 10 bars (gauge).

Back pressure curves were constructed using bottom hole pressures deduced theoretically from wellhead values. Analysis, of the curves indicated turbulent flow in the formation around well 7, laminar flow around well 4 and kh (intrinsic permeability x formation thickness) values of 10-20 darcy.meters for well 7 and 2-5 darcy.meter for well 4. Pressure build-up tests were also conducted on the wells and similar kh values obtained from HOrner build-up plots.

Chemical and isotopic analyses were carri-

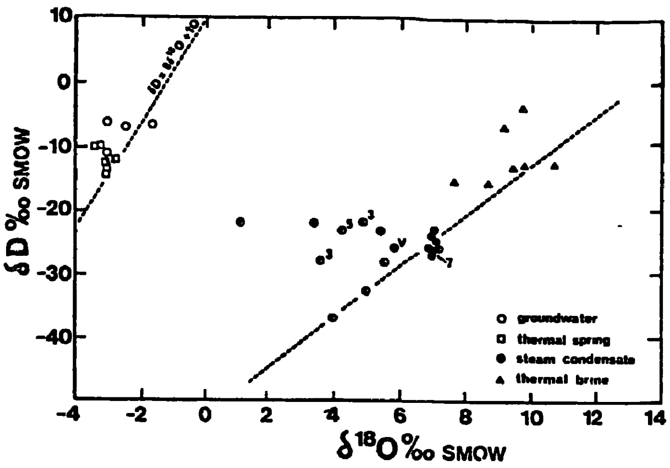


Figure 3

Conventional Delta-Diagram for waters in Sulphur Springs geothermal area.

Stable isotope compositions of hydrogen and oxygen are shown.

Steam condensate samples are from borehole 4, or boreholes 3, 5, 7 where indicated. "V" denotes a natural steam vent.

ed out on the steam condensates, entrained liquids (on Hole 4) and noncondensable gases. A very high noncondensable gas content, 21% by weight, was measured consistently on both holes throughout the test period. The gas composition was approximately 90% CO_2, 2% H_2S, 6% H_2, 1% N_2, 0.5% CH_4. Although this gas content may have been expected to diminish slowly with time, no significant change was detected over an eight month observation period. Large quantities of concentrated brine were discharged from well 4 during wet/dry cycling. The salinities of the samples varied up to levels of Cl at 70,000 mg/1, although 25000 mg/1 was probably a more reasonable figure for the reservoir itself. A likely origin for the chloride is from leaching from the volcanic host rock which the drilling had shown to be extensively altered.

The stable isotope compositions of oxygen and hydrogen for the thermal fluids provide further evidence of extensive reaction with deep reservoir rocks. In figure 3, these compositions are plotted using the δ notation in per mil (‰) variation from a standard (SMOW - Standard Mean Ocean Water).

The samples representing shallow groundwater (open symbols in figure 3) are seen to plot on the isotopic trend ($\delta D = 8\delta^{18}O + 10$) representing equilibrium fractionation processes in meteoric waters. On the other hand, steam condensates and thermal brines (from Well 4 only) have isotopic compositions which are considerably enriched in ^{18}O relative to the meteoric waters : up to + 13‰ $\delta^{18}O$ heavier. The δD values for brine samples are roughly similar to those for shallow groundwater samples. This coupled with the measured Cl/Br ratio, 60,000 approx. by weight (c.f.marine Cl/Br = 290) suggest that the source of deep fluids is meteoric and not marine. The trend, represented by the dashed line in figure 3, and having a slope of 5, between brine and steam samples demonstrates the evolution of the latter by non-equilibrium evaporation from the thermal brine. The shift of 13‰ in $\delta^{18}O$ of water implies a low proportion of water to rock (supporting the earlier hypothesis of brine evolution from rock leaching alone) and also a high temperature of interaction.

The extent of the reservoir and the location of the heat source have not yet been established. Further information on the heat source will be obtained from a microearthquake study recently completed, and future pressure transient tests using downhole recorders in the producing boreholes may help to define the limits of the reservoir. It is hoped that a back pressure turbo-generator capable of producing 1 MW can be installed to utilise steam produced from wells 4 and 7.

ACKNOWLEDGMENTS

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