FIJI GEOTHERMAL ENERGY RESOURCE ASSESSMENT AND DEVELOPMENT PROGRAMME

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Abstract - The Fiji Department of Energy (DOE) has a comprehensive resource assessment programme which assesses and promotes the use of local renewable energy resources where they are economically viable. DOE is currently involved in the investigation of the extent of geothermal resources for future energy planning and supply purposes. The aim is to determine (a) whether exploitable geothermal fields exist in the Savusavu or Labasa areas, the two geothermal fields with the greatest potential, (b) the cost of exploiting these fields for electricity generation/process heat on Vanua Levu and, (c) the comparative cost per mega-watt-hour (MWh) of geothermal electricity generation with other generating options on Vanua Levu. Results to date have indicated that prospects for using geothermal resource for generating electricity lies in Savusavu only - whereas the Labasa resource can only provide process heat. All geophysical surveys have been completed and the next stage is for deep drilling to verify the theoretical findings and subsequent development.

Background - Historyof Geothermal Surveys in Fiji

The first systematic reconnaissance survey of the hot springs of Fiji was made in 1956 by John Healy[ref. 1]. Although he visited only a quarter of the hot springs known on Viti Levu and 8 of the 25 on Vanua Levu. he did include the observations of earlier works thereby compiling a fairly complete catalogue of locations and relevant preliminary data. Figure 1 shows the location of the Geothermal Prospects in Fiji.

During the early 1970's further detailed analyses *were* made of many of the hot springs of Fiji[ref. 2]. At this stage it was realized that more careful investigation of the Savusavu and Labasa hot spring areas might yield useful results, since these areas contained the hottest springs in Fiji - this work was started in 1975. The results can be found in five reports published by the Fiji Mineral Resources Department (MRD)[ref. 3,4,5,6,7]. This work was followed by a gradient drilling programme throughout Viti Levu and Vanua Levu by N J Skinner[ref. 8]. As part of the work commitment for offshore oil prospecting, a further reconnaissance study of Fiji was undertaken in 1978 by Pacific Energy and Minerals Ltd. In 1979. the above work was reviewed by Dr K.H.Williamson in order to improve understanding of the geothermal potential in Fiji[ref. 9].

In Sept. 1981, building on what was known, J.R. McNitt carried out an assessment of furthei requirements for geothermal explorations in Fiji[ref. 10]. In 1982, MRD put forward proposals for further investigations on the Savusavu hot spring area. The objective was to establish a detailed programme of investigation upto a stage prior to deep exploratory drilling. A change in the Government policy later that year resulted in the postponement of the programme.

In Dec. 1987, Department of Scientific and Industrial Research (DSIR) of New Zealand (NZ) surveyed the hot springs at Savusavu. This data was analysed and a conceptual model of the geothermal prospect was proposed. A similar survey was carried out in Labasa[ref 11]. All investigations till this stage concluded that a deep electrical resistivity survey should be carried out in the Savusavu area especially around Mt. Suvasuva and the Savusavu peninsula.

In 1991, KRTA Ltd of New Zealand (now called Kingston Morrison) undertook deep *DC* electrical traversing and sounding resistivity surveys of the Savusavu peninsula from September to November 1991 - Fiji DOE and MRD co-ordinated and assisted in this survey. Other associated teste and surveys such as gas sampling, isotope, chemical analyses, geochemical/petrographic studies of the hat springs at Savusavu and Labasa were also conducted by KRTA. All this work was aimed at refining the conceptual model of the geothermal prospects. The survey clearly identified a geothermal field an the Savusavu peninsular with possible power production capability of approximately 25 MW[ref. 12]. In mid 1992 a deep electrical resistivity survey was conducted over the Labasa hot springs system to determine a geothermal anomaly - the results indicated that only process heat for industries would be available from the Labasa geothermal prospects[ref. 13].

In December 1992, an independent consultant, Dr Malcom E Cox, was recruited by DOE to assess all work conducted on the hot springs of Fiji to date. A report was submitted at the end of this consultancy. Dr Cox recommended that all surface studies on the hot springs of Fiji have been conducted and the next step was to deep drill to correlate the theoretical finding[ref. 14]. Both sites require deep drilling to confirm the geophysical hypotheses.

In October 1993, Prof P R L Browne and Mr N Dench were contracted to assess the drilling equipment available in Fiji and the local infra-structure, compile drilling methodology from available drilling data and samples from prospect sites, determine an overall drilling programme for Fiji, etc, . The report submitted indicated that a complete deep dnlling programme and testing of the potential would costs around F$3.5m and take approximately 2 years[ref. 15,16].

In December 1994, Dr Supri Soengkono, of the Geothermal Institute of Auckland University, studied the aeromagnetic data over the Labasa area[ref. 17] - draft report was submitted.

SAVUSAVU PROSPECT

The Savusavu hot springs are at sea level and lie along the coastal line on either side of the Savusavu peninsula - the system consists of approximately 15 prominent hot springs and a couple of cold springs. Detailed reports on electrical resistivity surveys, aeromagnetic data, Infra-red imagery and heat flow are available from the Fiji Mineral Resources Department.

Electrical Resistivity Surveys

An electrical resistivity survey to gather data on the extent and hydrology of the system was commissioned in 1991 and undertaken by KRTA[ref. 12]. All the electrical measurements in this survey were conducted using the Schlumberger electrode configuration.

Traversing and Sounding data

A total Of 147 traversing Stations were occupied in the Oct-Nov 1991 survey by KRTA and *apparent* resistivities for 500 m and 1000 m were calculated[ref. 12]. The Savusavu Peninsula, including the areas of known thermal outflow and the adjacent parts of Vanua Levu are characterised by resistivities which are generally less than 100 Ωm while further to the north-east. the resistivities increase to between 100-300 Ωm. It is considered therefore that the low resistivities measured on the Savusavu Peninsula, surrounding areas of known thermal outflow. represent the effects of a geothermal system. Given that the rocks around Savusavu are thought to be Miocene to Pliocene in age and their weathering in the relatively high local rainfall giving reduced resistivity, KRTA used the 100 Ωm contour to delineate the margin of the geothermal field. Within the 100 Ωm contour, the resistivity decreases towards the south-west reaching below 20 Ωm on both 500 m and 1000 m AB/2 spacing only west of a line connecting the Savusavu Town and Naidi Bay and remain relatively constant over the surveyed depth.

A total of 15 soundings were conducted during the survey. Figure 2 shows the sounding locations, apparent resistivity curves and 1000 m traversing resistivity contours. Note that all but three of the sounding curves detected apparent resistivities of less than 30 Ωm over nearly all of the curves. This observation shows that low resistivity rocks extend from depths of several hundred meters nearly to the surface over much of the Savusavu Peninsula.

Aeromagnetic Data and Infra-red Thermal Imagery and Heat Flow

Aeromagnetic data for Vanua Levu are available from Barringer Research Ltd.[ref. 2]. The data available from Savusavu have been interpreted by Caldwell[ref. 19] and Cox[ref. 7]. The major feature of the aeromagnetic data for the Savusavu area is an elongated negative anomaly which extends from Mt. Suvasuva east, parallel to the Coast to the Summit of Mt. Tumbuningalotyu. West of Mt Suvasuva, the anomaly rapidly dies out, and is hardly apparent over the Savusavu Peninsula or Sanggayaya ridge. Cox[ref 7] suggested that the anomaly might be caused by a shallow intrusive body related to the Savusavu Basalt. Caldwell[ref. 9] suggests that the anomaly is a topographic effect related to a range of hills which runs parallel to the coast. He implies that the lack of a strong magnetic anomaly west of Mt. Suvasuva, suggests that this region has undergone sufficient hydrothermal alteration to destroy most of the magnetite.

Cox[ref. 3] reported the results of infra-red thermal imagery flows in 1980. These detected anomalies corresponding to the known major thermal areas, but did not conclusively detect any other significant anomalies.

A one meter soil temperature survey was carried out by Ibbotson in 1980: it is reported on by Cox[ref. 3] who also undertook additional measurements. These surveys show temperature anomalies only in the close vicinity of the known springs. There is a little heat flow to surface other than that discharged by the springs themselves. Cox[ref. 3] estimated that the springs were discharging a total of 60 l/s of thermal fluid, with a heat flow of almost 1 MW(th).

Geochemistry and **Geology** and Petrology Surveys

Samples from various Springs at Savusavu and Labasa were collected and analysed by various consultants along with available historical data. It is seen that the water chemistry for the Savusavu springs has been stable for at least 120 years [earliest analyses were in 18721 and the temperatures far even longer. KRTA[ref. 2] survey included water chemistry, water geothermometry [cation and silica geothermometry, anhydrite saturation temperatures], mixed trends, isotopes in water and solutes, $^{18}O/^{16}O$ in sulphate and water, gas chemistry, gas isotopes and gas geothermometry studies.

The most thorough summary of the geology of Vanua Levu is that of Woodrow[ref 18] with accompanying 1:50,000 scale geological maps. Additional information relating more specifically to the Savusavu area is provided by Healy[ref. 1], Cox[ref. 3, 7] Colley[ref. 20] and Skinner[ref 8] which conclude that the Savusavu Peninsula is part of a thick pile of volcaniclastic formations of basaltic to andesitic composition, erupted from several centers. However. the hydrothermal system could be related to a later intrusion and this is not inconsistent with the tectonics. Hydrothermal alternation of the surface formations is widespread, particularly in the western part of the Savusavu Peninsula, and Savundrondro.

In contrast. relict high-temperature alteration is exposed at Savundrondro, implying deep erosion, but this is clearly outside the currently-active hydrothermal System[ref. 12].

SAVUSAVU GEOTHERMAL AND HYDROTHERMAL ACTIVITY MODEL

Figure 3 outlines the model proposed by KRTA[ref. 12] and Cox[ref. 14] for Savusavu.

Heat Source, Hydrogeological and Recharge Models

KRTA[ref. 12] concluded that there is no evidence for any connection between this geothermal system and others on the main part on Vanua Levu. with which Cox[ref. 14] agrees. KRTA[ref. 12] discuss the Caldwell[ref. 19] models of tectonic and magmatic type. Both favour what they describe as a "magmatic" type system, but refer respectively to "molten rack" and "magma". A geothermal gradient of 80°c/km and groundwater circulation to 2 km depth would encounter temperatures of 180°C. At depths of 2.5 km temperatures would be 225°C. It is considered here that there is no need to refer to a "magma" as a heat source, and therefore no need to expect magmatic fluids.

Various fluid flow models are discussed by KRTA[ref. 12] and conclude with a "magmatic-related hydrothermal system" of an upflow zone relatively near to the springs. An alternate model is considered here - basically it is of a fractured (and partly lithological) reservoir of thermal fluids below the peninsula (Figure 3). The source of the water is from recharge over approximately 15 km to the east from the ranges of Vanua Levu. Considering the dominant SE Trade winds and the development of windward rainfall coasts this could explain the isotopically heavier nature of the thermal water relative to local creek water at Savusavu (of immediately local origin).

This model also allows the development of a significant hydraulic head from higher level recharge. Perhaps this could drive the system (with thermal enhancement) including pushing the water through to discharge along the Savusavu Coastline. With such a model there could be hotter, deeper waters moving within fault channelways (approximately 225°C at 2.5 km). This water may then enter the peninsula reservoir where it could re-equilibrate at the lower temperatures of 150-160°C. Such a reservoir and re-equilibration within it could a l help explain the very law gas, lack of oxygen isotope shift (enrichment) and the widespread hydrothermal alteration .

LABASA PROSPECT

The main Labasa hot springs lie with a basin South of Labasa Town with a number of hot springs towards the West and East of the main Springs.

Electrical Resistivity Surveys

The Labasa geothermal fields were subject to deep electrical resistivity surveys, by KRTA Ltd[ref. 13], in 1992.

Traversing and Sounding data

A total of 220 traversing stations were occupied during this survey - apparent resistivities for the 500 m and 1000 m [AB/2] electrode spacing were calculated. The study area extended south from Waiqele and Vunicuecue hot springs and is characterised by resistivities generally less than 20 Ω m . The ratio of the 500 m to 1000 m [AB/2] apparent resistivity is significant as it shows how the true resistivities are increasing with depth. Further to the south, the 500 m [AB/2] resistivities are low, less than 10 Ω m, being equal to or less than the 1000 m spacing resistivities, suggesting that the resistivities are constant or decreasing with depth. The deep low resistivities implied by these results are consistent with hydrothermal alteration at depth and as such may represent an upflow of geothermal fluid.

A total of 8 soundings were conducted by KRTA[ref. 13] in 1992 and data incorporated with the 12 soundings conducted by Cox[ref. 4] in 1981 - Figure 4 shows the sounding locations, apparent resistivity curves and 1000 m traversing resistivity contours. The curves can be divided into two groups - all of Cox's soundings and S4 have very clear upturns which imply that they are underlain successively by a relative thin layer of low resistivities [<200 m] and a high resistivity basement. The rest of the curves show relatively constant resistivities which suggest that the soundings are underlain by relatively constant low resistivities from the surface to depth.

Aeromagnetic Surveys and Heat Flow

There are several features in the contoured aeromagnetic data which are worth noting, the most prominent are:

[a] the several small bipolar- anomalies that provide further support for the existence of intrusions at depth

[b] a large magnetic low [around 8 km in diameter] which may well reflect a substantial zone of hydrothermal alteration [producing a breakdown of magnetic rock minerals] at depth. It is however possible that this alteration may be relict [fossil]

The hottest Springs are boiling - geothermometers indicted that the deep reservoir temperature of water is around 120-130^{0}C. Cox infers that it would he possible that slightly higher temperatures may be encountered within drillable depths in the upflow zone [possibly 500-750 m]. There are discrepancies in the various reported calculations of heat lost from the system - subsurface measurements are required.

Geochemistry and Geology and Petrology Surveys

A substantial part of KRTA Geochemistry studies is summarising the historic MRU investigations, results and interpretations. KRTA fluid geochemistry includes: Conventional water chemistry and several additional minor elements; in situ pH measurements; preliminary gas geochemistry; sulphur isotopes [$^{34}S/^{32}S$]; reassessment of stable isotopes [oxygen and hydrogen]; application of chemical geothermameters. Gas samples show atmospheric association [Ar, N_2 and He] and there were no gases, such as H_2 and H_2S, that would indicate magmatic source. Water chemistry shows that the thermal water is a Na,Ca-SO_4,HCO_3 type: river waters are Ca, Na-HCO_3 type; pH of the water is near neutral to alkaline. Stable isotopes analyses show that the thermal water is relatively local recharge and is of meteoric origin.

The Labasa system is within a basic structure although there is some disagreement whether it is inter- or intra-volcano. What is important is that the system appears to be one largely with formations of permeable rocks,such as coarse sediments [sandstones], and volcaniclastic rocks and breccias. Cox[ref. 6] suggests that the youngest volcanism is apparently Pliocene, but there were later dyke swarms through much of the immediate and surrounding area which show the presence of intrusive rocks at depth and it is these racks that may be best considered a heat Source.

There are several dominant fault trends but the intersection of faults may be of prime importance because virtually all the hot springs are located with streams [faults and topographic lows]. The reservoir may be a combination of bath structure [faults and associated fracturing] and lithology [permeable rocks such as sandstone].

LABASA GEOTHERMAL AND HYDROTHERMAL ACTIVITY MODEL

Figure 5 outlines the model proposed by KRTA[ref. 13] and Cox[ref. 14] for Labasa. Fallowing are listed the main indicated features of the system based an surveys to date:

- Faults are the main control on fluid migration, especially in a vertical direction.
- There is a Central upflow zone from around 1000 m depth, or greater, associated with Intersections of large faults, and around 3-4 km in diameter.
- To the east and west of the upflow are zones of outflow, possibly from 500 m depth. The permeability to allow this fluid movement may be bath Structural and lithological.
- At shallow depth. 20 m to 150 m, the thermal groundwater has spread laterally mostly within sandstones and breccias. This "body" of thermal water is commonly 100 m thick, but it may not be uniformly continuous. The top of the thermal water zone may be at a depth of about 30 m at the Center of the overall zone, but is becomes deeper to the northeast and southwest, where it may be to 50 m.

System Type and Geothermal Fluids

KRTA[ref. 13] considered this system to be a transitional between the tectonic and magmatic geothermal systems. There is deep circulation of meteoric water (eg. to ?3 km) within a zone of a slightly elevated geothermal gradient. (The average gradient in the earth's crust is 30^{0}C/km).

At the surface there is no visible gas discharge and only very minor steam condensing with cooler air conditions. The deep fluids are probably slightly alkaline with a Ca,NA-SO4 chemical type. The waters are near saturation with respect to anhydrite and this mineral is likely to deposit.

Development prospects

Geothermal resources have the potential to he developed to supplement Fiji's presently predominant Hydro Electricity Power [HEP] generated energy supply. This could only be made possible once the economic viability of geothermal resource is assessed and proven through this assessment programme. This is particularly important for Vanua Levu where the prospects for a significant sized HEP potential is severely limited. There is potential for private sector involvement in this area if any prospect is identified and proven viable.

It is to be noted that an exploration deep drilling programme has also been drawn up by GENZL for the Savusavu and Labasa prospects in 1993.

Future Programme

The next step of the assessment programme is deep drilling to prove the resource. Fiji proposed - along with other Pacific Island Countries with geothermal fields (Vanuatu, Solomons) - during the 22nd Annual Session of the South

Pacific Applied Geoscience Commission (SOPAC) to participate in a Regional Geothermal Programme which will be coordinated by SOPAC. It is envisaged that the deep drilling phase of geothermal investigation in Fiji will be funded under this regional programme. SOPAC is currently negotiating with the New Zealand Government far funding of this regional geothermal programme.

A Japanese organisation (NEDO) has also shown interest in undertaking geothermal investigation in Fiji - adeep drilling funding proposal is to be submitted to NEDO shortly.

If such a programme proved an exploitable geothermal resource. the Government of Fiji would favourably view a Build-Own-Operate-Transfer (BOOT) scheme proposal as a means of realising this resource.

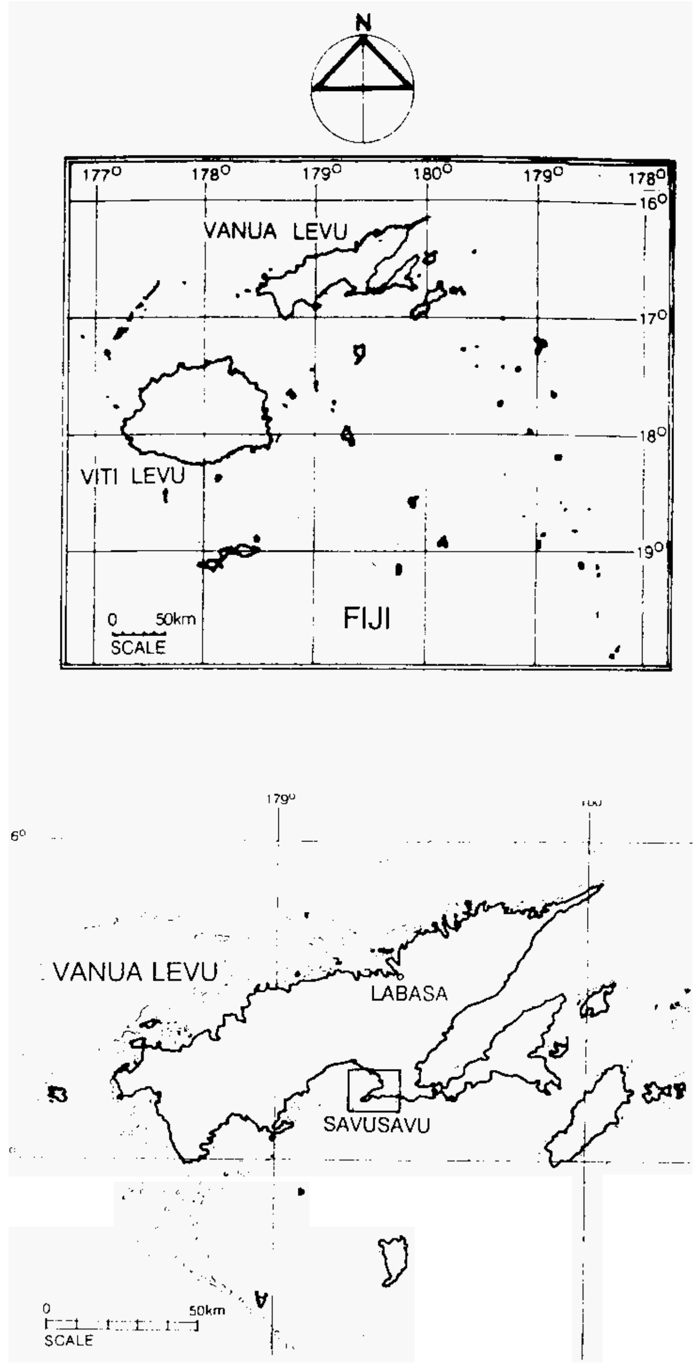

Fig. 1

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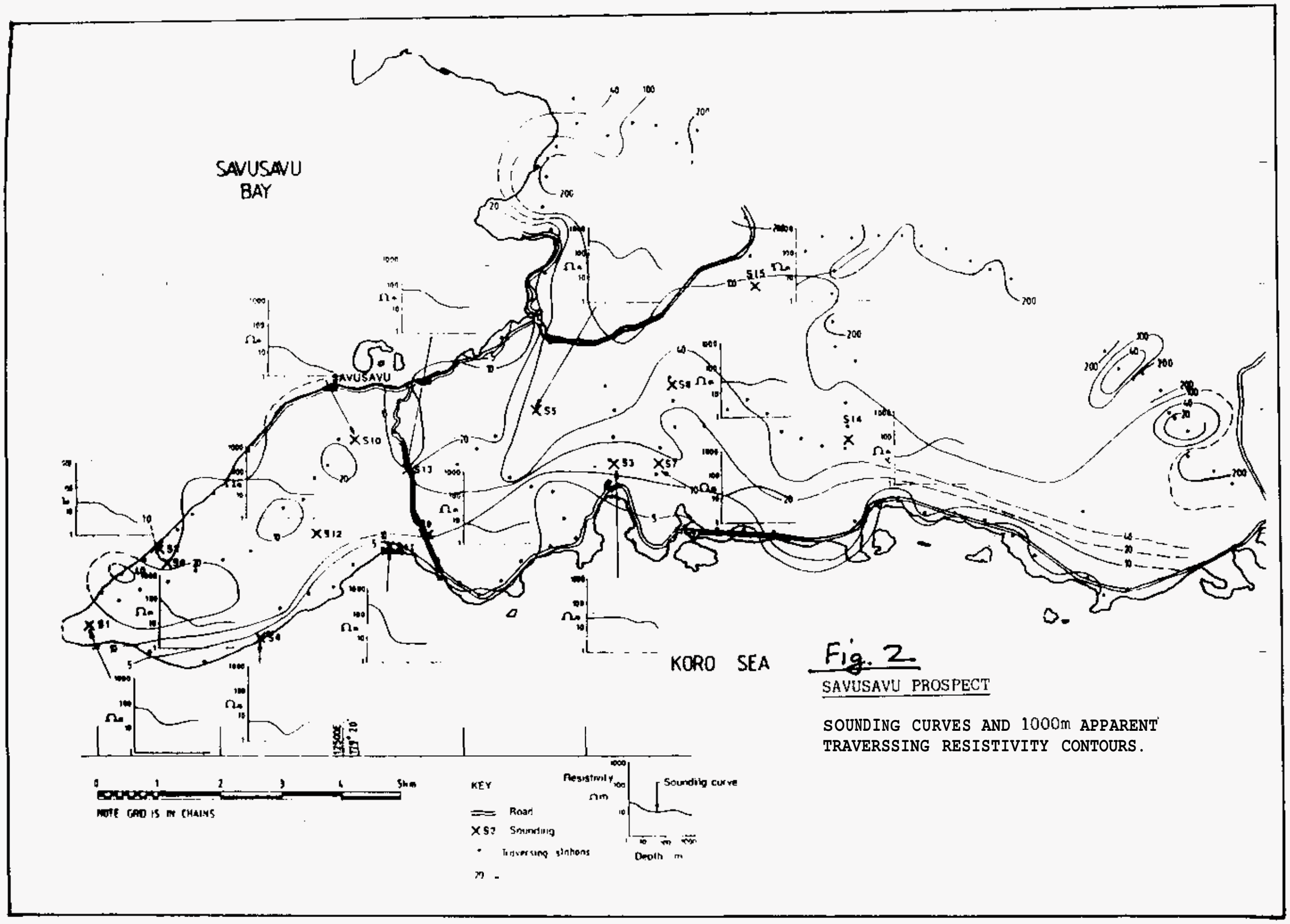

Fig. 2

SAVUSAVU PROSPECT

SOUNDING CURVES AND 1000m APPARENT TRAVERSSING RESISTIVITY CONTOURS.

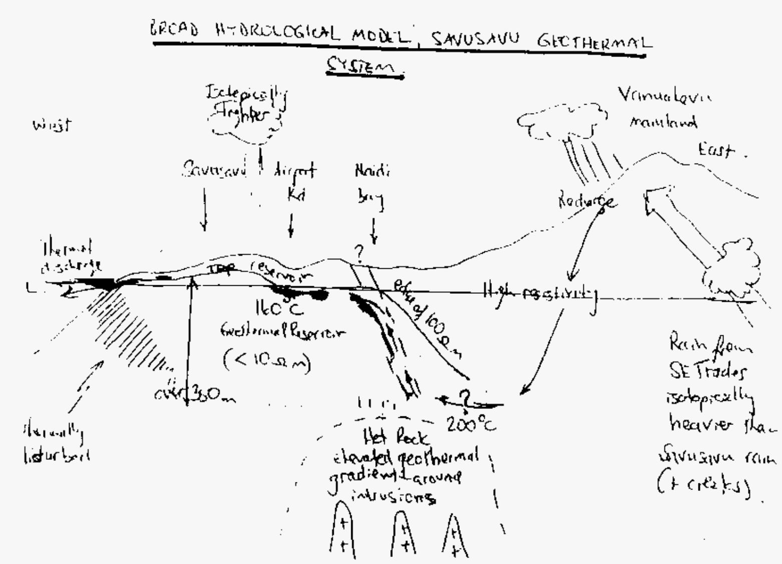

Fig. 3

Idea of a structural reservoir (partly lithological) below peninsula with medium deep re-equilibration. Possibly higher temperatures (? 200°C) at depths of 2 km in far eastern end, within fault channelways.

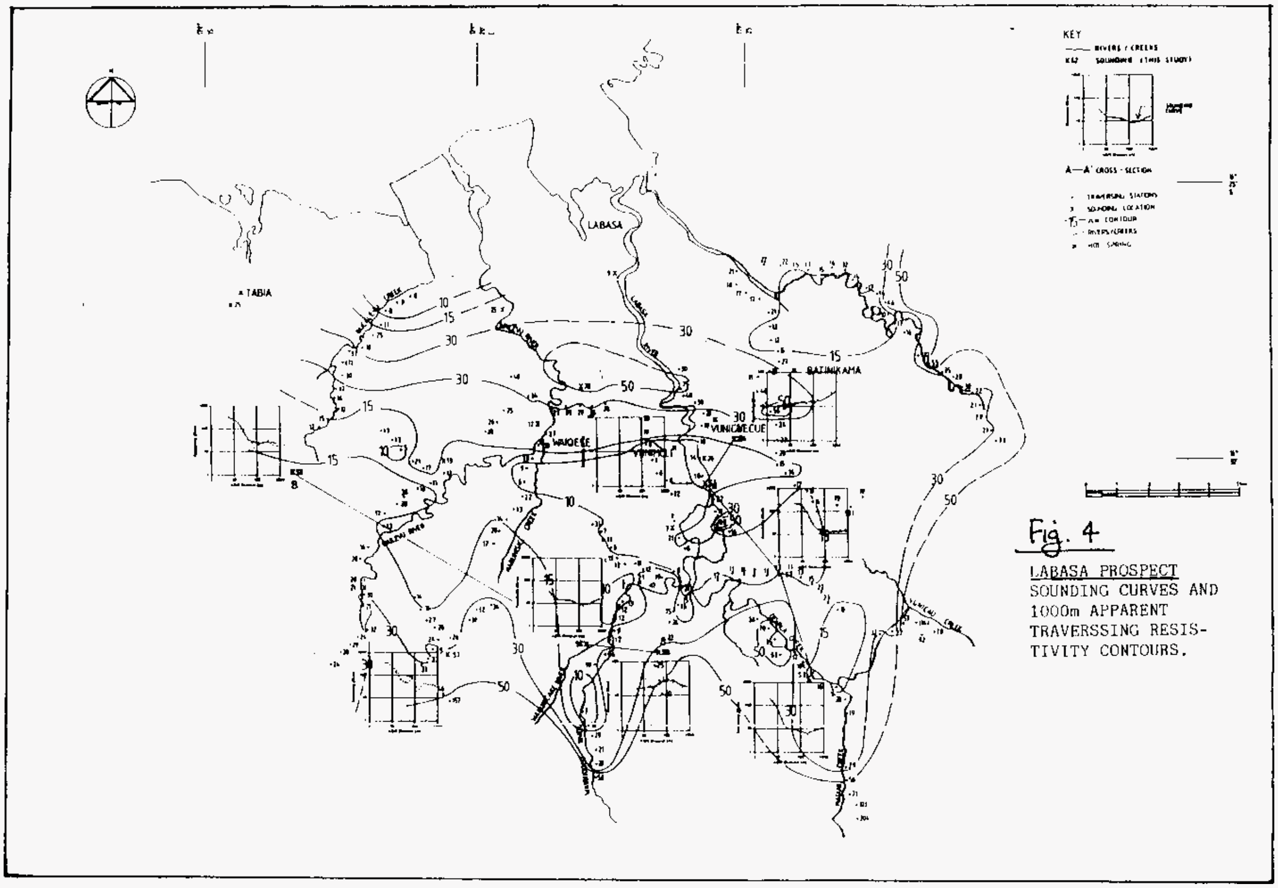

Fig. 4

LABASA PROSPECT
SOUNDING CURVES AND
1000m APPARENT
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TIVITY CONTOURS.

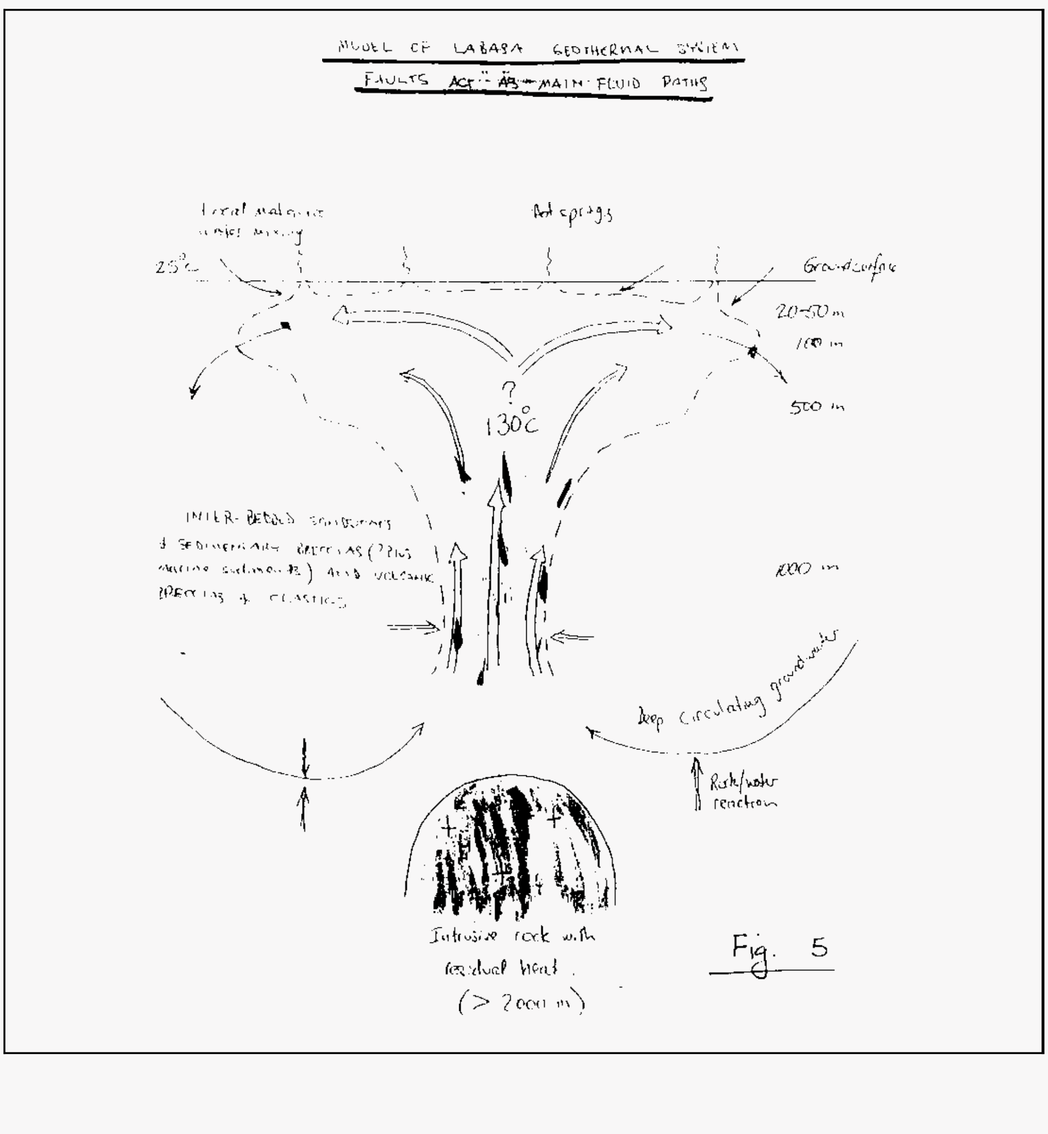

Fig. 5