HEAT AND GOLD EXPLORATION ON FIJI ISLANDS

Holger Sommer[1], Klaus Regenauer-Lieb[2], Lisa Tannock[2], Manman Hu[2] and Ankita Singh[2]

[1]School of Earth Sciences, University of South Pacific, Suva, Fiji

[2]School of Minerals and Energy Resources Engineering, UNSW Sydney, 2052, Sydney Australia,

info@holgersommer.de

Keywords: *Hot Springs, Geothermal Power, Mineralized water, Gold Mining.*

ABSTRACT

In this study we present an exploratory study of the relation of gold in mineralized waters and the possible use of geothermal power. The Vautakola gold mine in northern Viti Levu features a high geothermal activity in and outside of the mine site itself. Temperature in the 900m deep underground mine are around 60º C and the water is of magmatic origin. Ongoing investigations of the mineral content in the mine water suggest that high levels of dissolved gold can be found.

A parallel study on the adjacent island Vanua Levu already has revealed 0.77 ppb Au at surface water derived from a magmatic intrusion in Tabia, North Vanua Levu. This value is about 100 time higher than normal seawater and higher gold content can be expected at depth due to higher solubility at higher temperatures.

The hot springs on both islands are of intermediate to high temperature in the 60-100º C bracket. Investigations are under way to win electricity from the hottest location in Savusavu (South Vanua Levu) and Waiqele (North Vanua Levu). Aside from electricity generation the temperature of the surface springs is sufficient for direct heat use such as food drying, refrigeration and desalination. The latter technology is of particular interest to the potential harvesting of gold from these mineralized waters and a suitable Multi-Effect-Distillation is presented in our companion presentation on mineral extraction by MED desalination technique (Chua and Regenauer-Lieb, 2018).

1. INTRODUCTION

1.1 Geological setting of the Fiji islands

The North Fiji Basin or "Plateau" is a morphologically complex marginal basin lying between the New Hebrides arc and Fiji. According to the normally accepted view of basin island arc polarity is a reversed marginal basin. The North Fiji Basin is a part of the Pacific plate, which overrides the Indian plate along the Hebrides arc. Conversely, the adjacent South Fiji Basin (Packham and Falvey., 1971; Falvey., 1975) is part of the Indian (Australian) plate which overrides the Pacific plate of along the Tonga-Kermadec arc.

The regional seismicity presented by Chase (1971) reflects this tectonic situation. Epicentres occur beneath both trench arc systems, and show a west dipping slab beneath the Tonga Kermadec arc, and east dipping slab beneath the new Hebrides arc. Other distinct lineations of epicentres occur along the Fiji Fracture Zone (north of Fiji) and the Hunter Fracture Zone (Southwest of Fiji). Left lateral first motions have been computed for the Fiji Fracture Zone indicating transform motion between the Pacific and India plates. Thus, the Fiji Islands form an isolated microplate in the South Pacific region (Fig. 1).

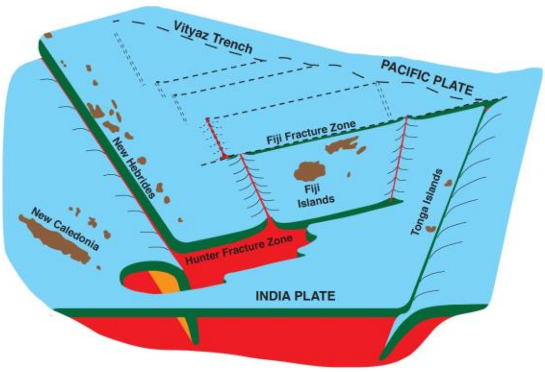


Figure 1: Diagram of the North Fiji Basin region with the subduction zones, transforms, as well as active and extinct spreading centres (modified after Falvey., 1975).

1.2 Petrology, Geochronology and Geochemistry

In order to understand the nature of rocks and water samples from Fiji, a detailed petrological, geochronological and geochemical approach has been made.

1.2.1 Petrology, Geochronology and Geochemistry of Fijian rocks

Most rocks on the Fijian island are of igneous origin, volcanic and plutonic. Biogenic and chemical sediments like limestones are present as well. More rarely are garnet bearing greenschists, indicating low to medium grade metamorphic conditions at P ~5 kbar and T ~500°C. The igneous rocks mineral chemistry shows a wide variety, which ranges between gabbros, monzodiorites, tonalites and their volcanic equivalent rocks.

Figure 2: Hot spring in Savusavu town.

The oldest rock units are made up of gabbros (47.5 Ma) and the youngest just recently. Hf (εHf = ~ 13) and O (δO = ~ 4.8) isotopes are very homogenous and indicate that these melts have been formed by pure mantle melts without any contamination (Sommer and Kröner., unpublished data).

Furthermore, the geochemical measurements indicating that the felsic rocks are fractionated and differentiated from the originally mafic parental melt (Sommer and Kröner., unpublished data). In summary, these results show, that the rock units on the Fiji island are still very hot with high magmatic activity, which can be seen in the formation of numerous hot springs (Fig. 2).

1.2.1 Geochemistry of Fijian water collected from the hot springs

For the geochemical approach of water from the hot springs on the Fiji Islands Viti Levu and Vanua Levu, we sampled the water and analysed it with ICPMS. Therefore, following elements have been analysed: Ag, Al, As, Au, B, Ba, Bi, Br, C, Ca, Cl, Co, Cr, Cs, Cu, Fe, I, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, Rb, S, Sb, Sc, Se, Si, Sr, Ti, Tm, U, V, W, Y, Zn, Zr. Our analyses show a strong enrichment in Au, up to 100 times compared to seawater as well as a strong enrichment S. The distribution of all elements are indicative of a high magmatic component and furthermore reflecting the chemistry source.

2. GEOTHERMAL ENERGY

Our petrological, geochronological and geochemical approach give evidence that the Fiji Islands are a textbook example for the use of geothermal energy. This can be done in form of geothermal cities and geothermal mining.

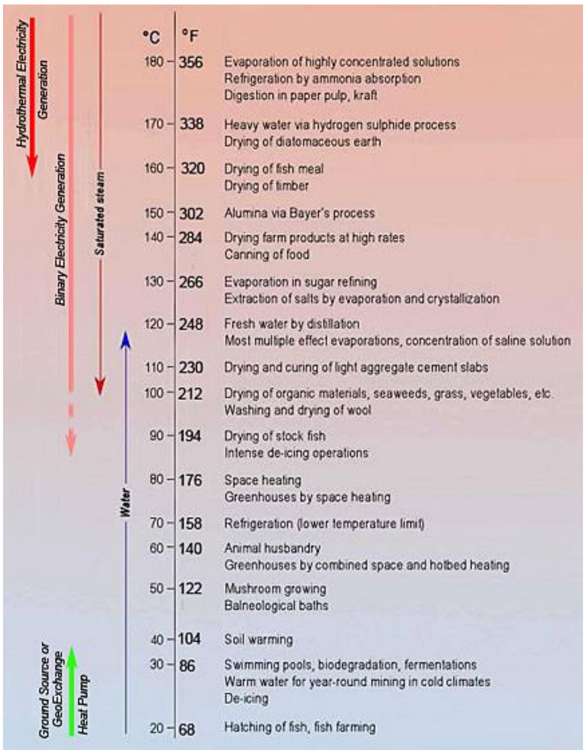


Figure 3: Direct Heat in the Lindal diagram (source http://coloradogeologicalsurvey.org/energy-resources/geothermal-2/uses-2/direct-use/)

2.1 The 'geothermal cities' design

The concept of geothermal cities was developed in 2007 by Regenauer-Lieb in the Western Australian Geothermal Centre of Excellence. The key idea is to design new cities in the developing world based on its targeted electricity use thermodynamic bottoming cycles to design efficient use of the waste heat according to the Lindal diagram (Figure 3). The optimal use of the thermal source is defined by the global minimum of the entropy production for the design life time of the geothermal installation. This defines a self-sufficient city in appropriate geothermal settings. Geothermal power is the most promising green energy source for this design. It can be used in many different ways. *i)* in a first stage it can be used to generate geothermal electricity, by extracting heat from the earth upper crust and driving steam turbines or OCR, Kalina power stations; *ii)* the waste heat can be used to drive industries, food processing, geothermal refrigeration, desalination, greenhouses, aquaculture. The large volumes of water that are created downstream of the electricity plant can support increasing employment opportunities as the lowest end-member technologies are the most difficult to be automated. The immediate opportunity for the South Pacific to combat poverty and health issues in the rural communities. Another advantage of the concept is that the low temperature end-members can be installed individually and do not require high capital investment thus preparing the ground for large scale geothermal investments. Before describing such a potential low-key installation, the geothermal potential of the Fiji islands archipelago is summarised.

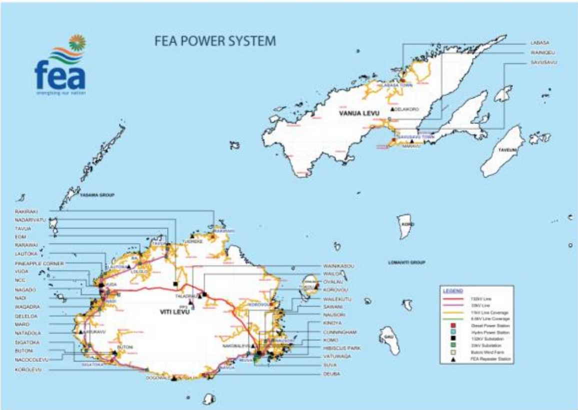
2.2 Fiji's electric needs

The Fiji has a total installed generation capacity of 258.9 MW electric (IRENA, 2015) 19.5 MW of which are generated in Vanua Levu through Industrial Diesel Generators and a 800 kW Micro-Hydro Plant. The diesel generators in Savusavu have a capacity of only 5.2 MW and the transmission line is not connected to the larger grid in Lambasa. The small 33-kV transmission system on Vanua Levu is planned to be interconnected in the near future (IRENA, 2015). The Fiji Electricity Authority (FEA) has according to the IRENA report a power development plan that considers a 132 kV Undersea cable between the main island but this would only be justified if a major geothermal capacity (on the order of 50-100 MW) is developed in Savusavu. For the development of a business case for electricity generation the electricity requirements can be bracketed between:

- 5 MW electric (replacement of Savusavu's Diesel Generator);
- 100 MW electric (justifying an undersea cable between both islands).

An upper bound for the geothermal power production would be 300 MW which would imply that Fiji is 100% geothermally powered.

The heating ventilation and air conditioning requirement in Savusavu is currently negligible as the local construction is light and the population enjoys the fresh ocean breezes. The requirement for a centralized freezing and refrigeration plant would require further developments. The social economic impact of such a facility is deemed to be more positive than a distributed HVAC system as it would support the growth of local businesses. A conservative estimate of the current total thermal need for a pilot project is:

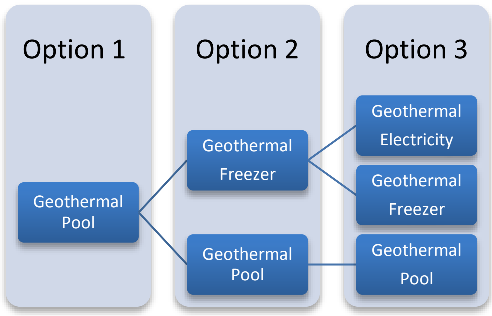


Source: FEA

Figure 4: Fiji's electricity grid source (IRENA, 2015)

- 0 MW thermal (in the case that no commercial customer for the chilling plant can be found)
- 5 MW thermal (assuming that the chilling plant is mainly driven by the minimum waste heat from the electric power station)

It is premature to build a business model without consultation with landowners, lease holders and government, however, at this stage we would like to highlight the benefit for considering a decision tree for cascaded heat use. The scale of operation would be governed by the lead process and constrained by the following cost-benefit matrix.



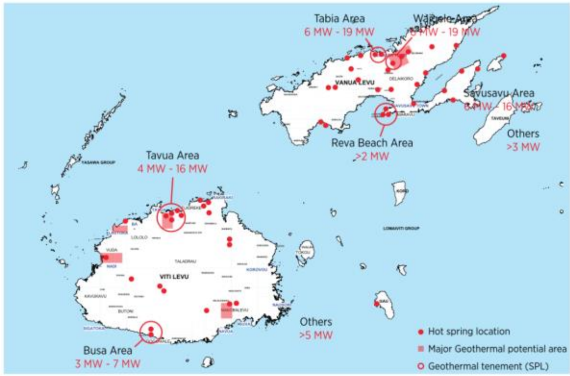
	Option 1	Option 2	Option 3
Lead Process	Geothermal Pool	Geothermal Freezer	Geothermal Electricity
Licensing & Legal			
Exploration			
Cost of Drilling			
Cost of Infrastructure			
Temperature	> 40°C	>95°C	>125°C
Energy		0-5 MW	5-100 MW

Figure 5: Cost-benefit matrix for geothermal installations

2.2 Fiji's Geothermal potential

The IRENA (2015) report suggests that the most promising site in Fiji is Savusavu hot spring area and the Waiqele in South and North Vanua Levu, respectively. The World Bank and the Fijian government currently hold the lease under moratorium to estimate potential geothermal installations.

The boiling springs in Savusavu are used by local people for cooking purposes and were described by the early explorers (Cox, 1981). The botanist H.B. Guppy described in 1898



Source: Government of Fiji, 2014

Figure 6 Fiji's Geothermal potential (IRENA, 2015)

geothermal activity that turned the springs into intermittent fountains which were reported by locals to have ejected hot water up to 12 - 18 m high. The intermittent geyser activity ceased after several months to boiling spring activity.

Ásmundsson (2008)**,** provides in the report "*South Pacic Islands Geothermal energy for Electricity Production, IIDA (Icelandic International Development Agency), Reykjavík"* the most recent scientific description of the hot spring activity. He reports: *"There are at least eight thermal springs along the Savusavu peninsula, and infrared imagery of the area suggests the possible existence of others. The hottest spring water temperatures are near boiling, but chemical analysis of the water indicate that temperatures of about 170°C are found in the geothermal system, mixed with very little seawater. Aeromagnetic surveys point to there being a trending range at depths of less than one km. It is recommended that confirmatory slim holes be drilled to a depth of at least 800 metres."*

Although the site appears to be suitable for electricity production we propose to follow a step by step approach, first using a small fraction of the available geothermal power for a central refrigeration and chilling plant (Cool Store). We also recommend to revisit early exploration work on the site (Cox, 1981). This proposal concurs with Ásmundsson's (2008) suggestion for slow and careful steps to implement growth in this sector. The advantage of providing a direct heat facility as a first step is threefold: (1) it allows a comparatively low cost demonstration of the use of geothermal power for hot spring areas that are too low in temperature to be suitable (without deep drilling) for electricity production; (2) it can be used to explore and test the reservoir further in order to reduce risk, this is important for the larger capital investment of deeper drilling including the geothermal power plant; (3) it slots in ideally to a geothermal electric power plant, where the chiller could switch from direct geothermal waters to instead using the hot water coming out of the electric power plant. The waste heat from the electricity production can thereby be used in a heat cascade. Further cascading of the geothermal waters downstream of the chiller plant is recommended for geothermal pools and fish farming. The immediate availability of the Savusavu site for a pilot project depends on the decision of the Fijian Government and the World Bank on the next steps of the installations.

2.3 Low key geothermal installation off-grid

A lower risk project may be a suitable first step to give the Fijian community an opportunity to train local geothermal engineers and geoscientists. A smaller project benefits from a smaller scale (provision for e.g. ~5000 villagers) and a somewhat simpler management as the decision lies with the traditional landowners of off-grid villages.

Many opportunities exist in Fiji that would be primarily driven by the humanitarian and health aspects. An example is Natewa and Vusasivo village. Most villagers have basic infrastructure (Post office, Church, Small Clinic) but lack any possibility for keeping food fresh and have no clean water and sewerage installations. This leads to significant provision problems and enhances the risk of food poisoning and diseases. A hot spring system between villages could provide a central Cool Store for the region as well as ice for distribution in transportable cool boxes to cover every day individual needs. Chilled water could also be pumped into a small morgue. Currently the villagers in off-grid Natewa consume red meat only during funeral celebrations. Significant costs are born through purchasing a cow (FJ$800). The red meat needs to be consumed quickly as no cooling is available. Additional, costs are incurred through transporting the deceased person to Savusavu's morgue and back (FJ$200 each way) in preparation for the funeral festivities. A geothermal operation would immediately increase the standard of living of the villagers addressing squarely their basic needs.

Therefore, the timing of lending international development support appears to be just right. This may be happening in the near future with the support of the World Bank in collaboration with the Fijian Government but it would be a large scale project where overseas expertise will be used to implement the project. However, additional opportunities exist by exploring support from the industry. A particular opportunity is the extraction of minerals from geothermal waters. This is discussed in further details in our companion article (Chua and Regenauer-Lieb, 2018). A brief summary of the opportunities are giving in the next section.

2.4 Geothermal mining

Gold and copper are very common in the South Pacific region. Unfortunately, mining costs are driven by the immense amount of energy needed for operation. For example, the Vautakola Gold mine in northern Viti Levu needs 25,000 litres of fuel every day mainly for rock crushing and pumping the contaminated waste water of hydrothermal origin beneath the mine out of the shaft. This is not only very expensive, it is also environmentally very problematic because of the CO_2 production from fossil fuel driven electricity production. Additional environmental concerns are through potential waste water leaks from the tailing dams.

In our companion paper (Chua and Regenauer-Lieb, 2018) we propose a green mining technique solution overcoming following problems: *i)* the immense operation costs of electric power generation of ~ 20MW which can be replaced by geothermal power; *ii)* the hot waste water from deep within the mine can be absorbed in an earlier stage and the hot water of ~ 60°C can be used to cool the mine shafts and allow deeper mining.

The most radical proposition would be to specifically drill into the geothermal reservoir below the gold mine to harvest the gold by a desalination process rather than a rock crushing process. This would create clean distilled water as a waste product as the mineral abstraction is based on the brine use coming out of the desalination process. This 'green mineral' harvesting opportunity could mark a new era for the mining industry.

3. CONCLUSION

In summary, geothermal power is ideal for the volcanic island in the South Pacific region. The adjoining nations need to help in kickstarting the geothermal installations. The outcome of this investment is to solve the ongoing power problems, increasing the standard of living of some of the poorest nations in the South Pacific. The geothermal city concept is designed as a future standard to improve overall health, combating unemployment and increasing the prosperity of the South Pacific nations in an environmentally sensitive way. Moreover, the installations could become a beacon for the participation of developing nations for the grand challenge climate debate currently headed by the Fijian Government.

ACKNOWLEDGEMENTS

The authors are very thankful to Sue Naco and Satendra Kumar for assistance during the field trip. This project is a contribution to the SRT funded by USP and the IGD fund from UNSW, Sydney as part of UNSW global mission to support the collaboration and student training in the South Pacific.

REFERENCES

Ásmundsson, R. K. (2008). South Pacific Islands Geothermal energy for electricity production, *Icelandic International Development Agency* 24.

Chua, H.T., and Regenauer-Lieb, K., (2018) Mineral recovery through geothermal desalination, 40th *NZGW conference 14-16 November 2018*

Chase, C. G., (1971) Tectonic history of the Fiji Plateau, *Bulletin of Geological Society of America*, 82, 3987-3110

Cox, M. (1980). Preliminary investigations in the Savusavu Area. *Geothermal Report No.1*.

Cox, M. (1981). Geothermal Investigations in the Savusavu Area. *Geothermal Report No.5 ISSN 0250-7277*.

IRENA, *Fiji Renewable Readiness Assessment.* (2015)

Falvey, D. A., (1975) Arc reversals, and a tectonic model for the North Fiji basin, *Bulletin of Australian Exploration Geophysics*, 6, 47-49

Packham, G. H. and Falvey, D. A., (1971) An hypothesisfor the formation of marginal seas in the Western Pacific, *Tectonophysics*, 11, 79-109

Skinner, N. (1983). Heat Flow measurements in Fiji. *Geothermal Report No.6* ISSN 0250-7277.

Woodrow, P. (1976). Geology of South East Vanua Levu. *Bulletin No. 4*