

## GEOTHERMAL RESOURCES IN THE PACIFIC ISLANDS: THE POTENTIAL OF POWER GENERATION TO BENEFIT INDIGENOUS COMMUNITIES

Alex J. McCoy-West<sup>1,2</sup>, Sarah Milicich<sup>1</sup>, Tony Robinson<sup>3</sup>, Greg Bignall<sup>1</sup> and Colin C. Harvey<sup>1</sup>

<sup>1</sup>GNS Science, Wairakei Research Centre, Private Bag 2000, Taupo 3352, New Zealand  
s.milicich@gns.cri.nz, g.bignall@gns.cri.nz, c.harvey@gns.cri.nz

<sup>2</sup>Research School of Earth Science, The Australian National University, Canberra, Australia  
alex.mccoywest@anu.edu.au

<sup>3</sup>Ministry of Research, Science and Technology, Wellington 6145, New Zealand  
Tony.Robinson@morst.govt.nz

### ABSTRACT

The nations and territories of the southwest Pacific depend greatly on imported fossil fuels for electricity generation, and have interest in utilising their renewable energy resources (including their untapped geothermal resources) for cost effective power production and direct-use applications. As part of the international Energy Development in Island Nations (EDIN) programme, the New Zealand Ministry of Research, Science and Technology commissioned GNS Science in 2009 to review the geothermal activity, socio-economic climate and energy demand profile of 20 selected Pacific Island nations and territories, with our findings detailed in this paper. Eight countries/territories were identified as having “high” or “high-moderate” potential for geothermal

resource utilisation, with a prioritisation list of Papua New Guinea, Vanuatu, Samoa, Tonga and Northern Mariana Islands selected for detailed investigation, with recommendations for future pre-feasibility geoscientific exploration, risk evaluation (i.e. for resource capacity, hazard and financial modelling), and assessment for small (including “off-grid”) plant development. (Fiji, New Caledonia and Solomon Islands were identified as having high-moderate potential, but were not considered for further study).

### INTRODUCTION

Geothermal energy is an under exploited resource throughout the world, yet it can provide a clean and efficient means of generating electricity in remote areas, if suitable resources exist. Island nations of the

**Table 1:** Summary of the geothermal resource potential of nations and territories in the southwest Pacific

	Youngest Volcanism <sup>1</sup>	Heat Source	Geothermal Locations	Geothermal Surveys	Temp. Range <sup>2</sup>	Power Demand <sup>3</sup>	Renewable Energy <sup>4</sup>	Development Barriers	Development Potential
Papua New Guinea	Active	Excellent	41 thermal areas	Development	36-101	2674	46%	Rugged Terrain	High
Vanuatu	Active	Good	20 thermal areas	Reconnaissance	30-78	40	19%	Active Volcanism	High to Moderate
Samoa	Active	Good	Prospective Rift Valley	None	-	101	42%	-	Moderate
Tonga	Active	Good	Hot springs	None	-	43	0%	Distance to population	Moderate
N. Marianas Islands	Active	Excellent	Submarine only	Reconnaissance	-	4	50%	Active Volcanism	High to Moderate
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Fiji	Recent	Excellent	53 thermal areas	Detailed	31-102	970	82%	-	High
Solomon Islands	Active	Good	8 thermal areas	Reconnaissance	57-99	70	0%	-	High to Moderate
New Caledonia	Unknown	Unknown	2 thermal areas	Reconnaissance	22-43	1490	24%	-	Moderate
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French Polynesia	Recent	Possible	Submarine?	None	-	442	39%	-	Low to Moderate
American Samoa	~1 Ma	Possible	None	None	-	167	0%	-	Low
Cook Islands	1.5 Ma	Possible	None	None	-	28	10%	-	Low
Pitcairn	0.45 Ma	Possible	None	None	-	< 0.5	0%	-	Low
Palau	~20 Ma	None	None	None	-	122	0%	-	Extremely Low
Guam	~32 Ma	None	None	None	-	1664	0%	-	Extremely Low
Niue	> 20 Ma	None	None	None	-	4	0%	-	Extremely Low
Kiribati	~80 Ma	None	None	None	-	9	0%	-	Extremely Low
Marshall Islands	~80 Ma	None	None	None	-	100	1%	-	Extremely Low
Micronesia	Unknown	None	None	None	-	179	0%	-	Extremely Low
Nauru	Unknown	None	None	None	-	29	0%	-	Extremely Low
Tuvalu	Unknown	None	None	None	-	Unknown	0%	-	Extremely Low

1) Active: volcanism in the last 500 years; recent: volcanism in the last 50 ka. 2) Observed hot spring temperatures in °C. 3) Annual power consumption in M kWh. 4) Renewable energy refers to the percentage of power generated from sources other than fossil fuels. Electricity demand and generation sources are taken from Energy Information Agency (2009).

Pacific are highly dependant on imported fossil fuels for electricity production, and therefore there is considerable interest in opportunities to exploit clean and efficient renewable energy sources.

As part of the Energy Development in Island Nations (EDIN) programme, the New Zealand Ministry of Research, Science and Technology commissioned GNS Science to undertake a review of the geothermal potential of 20 Pacific Island nations and territories: American Samoa, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Micronesia, Marshall Islands, Nauru, New Caledonia, Niue, Northern Marianas Islands, Palau, Papua New Guinea, Pitcairn, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu). This constituted the first stage of a review to locate areas of the Pacific in which investment in the development of geothermal energy resources could be undertaken, findings of the overview study are summarised in Table 1.

Based on a desk-top review of public information eight Pacific Island countries/territories were identified as having geothermal resource potential. Two countries have high potential for geothermal resource utilisation (Papua New Guinea and Fiji), three countries have high-moderate potential (Vanuatu, Solomon Islands, and Northern Mariana Islands), and three countries have moderate potential (Samoa, Tonga and New Caledonia). Prioritisation on the basis of socio-economic factors resulted in five countries/territories (shown in Figure 1) being selected for detailed research, on the basis that they

have moderate-high potential for geothermal resource utilisation: these where Papua New Guinea, Vanuatu, Samoa, Tonga and Northern Mariana Islands.

### **PAPUA NEW GUINEA**

Geothermal activity in Papua New Guinea (PNG) is associated with active/dormant volcanism along the Melanesian Arc. Reconnaissance geological (exploration) surveys have been carried out in many areas, particularly in New Britain. Geothermal resources occur mostly in isolated locations (remote from large population centres, but where there is prospectivity for metals, such as gold and copper).

The potential for geothermal utilisation in PNG has been proven by the resource on Lihir Island, where electricity is being generated from a >300°C reservoir (Ellis and Smith, 2004). Power generation was commissioned in April 2003, and in February 2007 power generation was expanded to a capacity of 56 MWe. Elsewhere, interest has been expressed from mining companies who use diesel generation in their operations. The large base load demand of geothermal energy development in PNG is likely to be a mining company, although local populations would benefit from development.

### **Geothermal Prospects**

There are 55 known areas of surface geothermal activity in PNG (Figure 2), with the majority associated with active volcanism in the Melanesian Arc. Geoscientific information on most prospects is

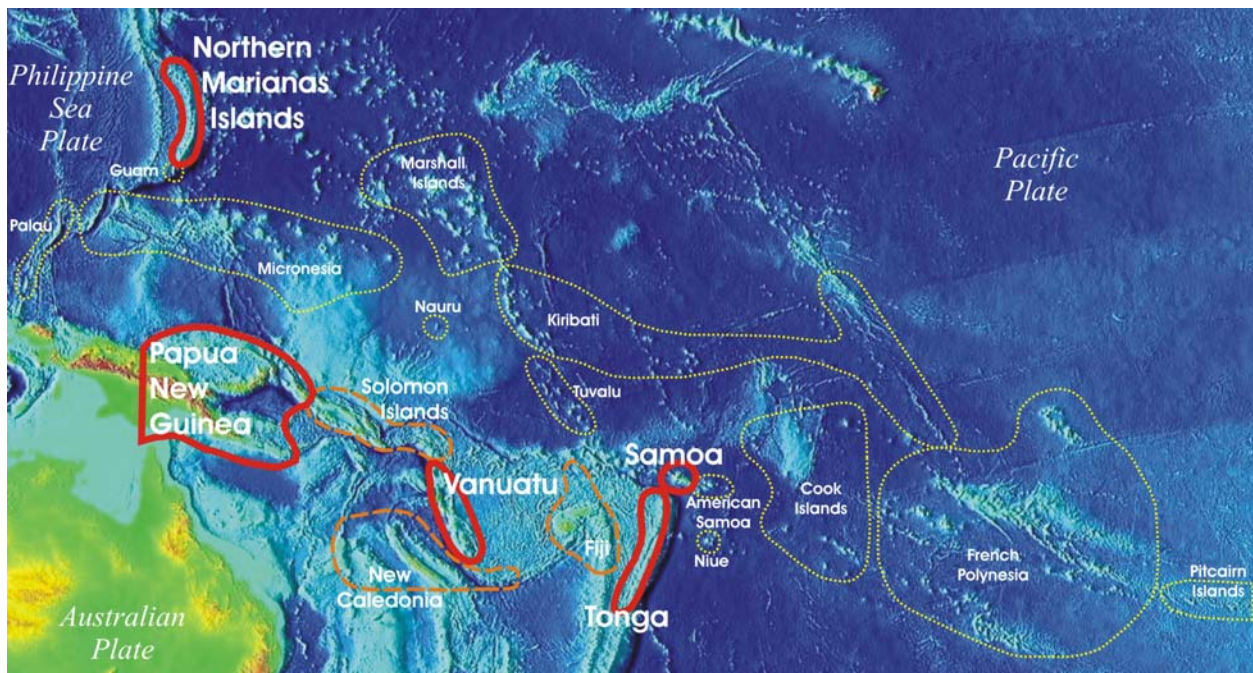


Figure 1: Map of the southwest Pacific. Red: nations reviewed in detailed; Orange: nations with high to moderate geothermal potential; Yellow: nations considered to have low to extremely low geothermal potential.

sparse, although reconnaissance chemical surveys have been undertaken, especially in west New Britain (Studt, 1961; Heming, 1969; Heming and Smith, 1969; Grindley and Nairn, 1974a). Geophysical surveys (i.e. resistivity and magneto-tellurics (MT)) are only known to have been undertaken at Lihir.

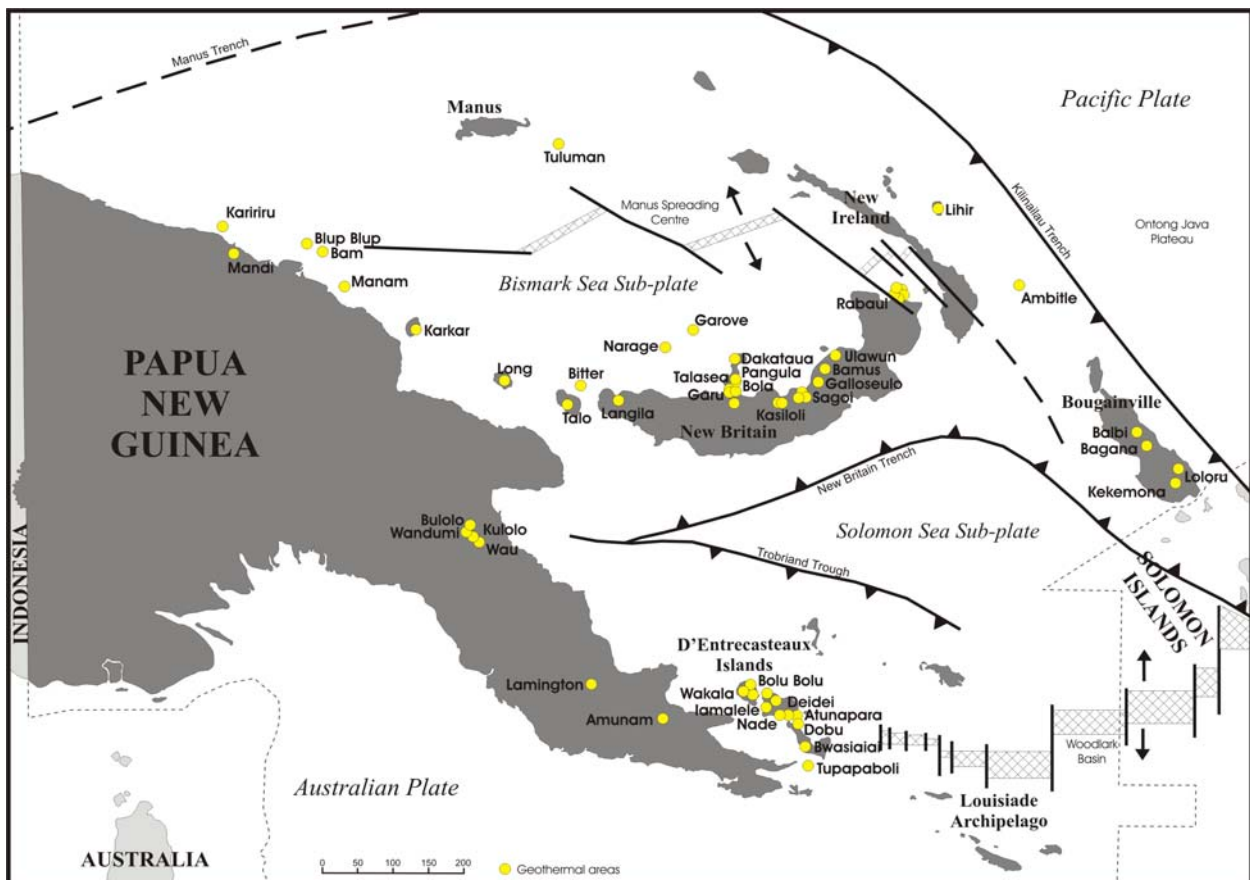
The most prospective region for electricity generation from geothermal resources is New Britain (Figure 2), which are associated with calc-alkaline volcanism and subduction at the New Britain Trench. There are at least seven geothermal prospects (Bamus, Walo, Kasiloli-Hoskins, Garbna, Bola, Pangalu-Talasea and Galloseulo) which host hot springs, fumaroles and mud pools, with measured temperatures of 90-101°C. Chemical surveys have been undertaken, with silica and chloride contents of the surface manifestations interpreted to indicate reservoir temperatures up to ~300°C (Grindley and Nairn, 1974a).

Another prospective area is the D'Entrecasteaux Islands, where 12 thermal areas are known. Surface studies suggest the most prospective resources occur at Deidei and Iamelele, where inferred reservoir temperatures are >200°C (Heming, 1969; Ellis, 1970). Grindley and Nairn (1974a) estimated the total heat discharge at Deidei was 30 MW(t).

### Summary

Papua New Guinea is endowed with geothermal resources, although scientific information is sparse. It has been estimated that the country may have potential to generate 3,000 to 4,000 MW of geothermal power (Hairai, 2004). Areas of interest are New Britain and the D'Entrecasteaux Islands. The locations of these resources are typically remote from large population centres but close to areas of mineral exploration. Early development of such resources may be attractive for established mining operations. Some coastal towns in New Britain, such as the rapidly growing Kimbe (pop. 20,000+) might benefit from small scale geothermal developments.

A number of geothermal areas are prospective, and warrant further investigation. Geochemical and geophysical data in these areas, is sparse or lacking. The high quality of many of the prospects necessitates further prioritisation, to identify which have the greatest potential (on the basis of population, social and economic needs). Reconnaissance surveys, including geological, geophysical and geothermal surveys should then be carried out to provide a preliminary assessment of resource potential, sufficient to justify moving to a detailed exploration phase.



**Figure 2:** Map of Papua New Guinea showing the locations of known geothermal areas from Mosusu (2008) and Heming (1969). The plate/micro-plate boundaries are modified from Williamson and Hancock (2005).

## VANUATU

Geothermal activity in Vanuatu is associated with active volcanism along the New Hebrides Arc (Figure 3). Surveys have been carried out on Efate and Vannua Lava at a reconnaissance level. Several areas are prospective for geothermal energy generation, especially on Efate, due to the relatively close proximity to major population centres (e.g. Port Villa). A geophysical resistivity survey identified a large low resistivity anomaly in the northern part of Efate. Previous studies suggest sufficient work has been undertaken to justify exploration drilling. We are aware of at least one Australian geothermal exploration company who has filed for exploration rights at specific areas within Vanuatu.

### Geothermal Prospects

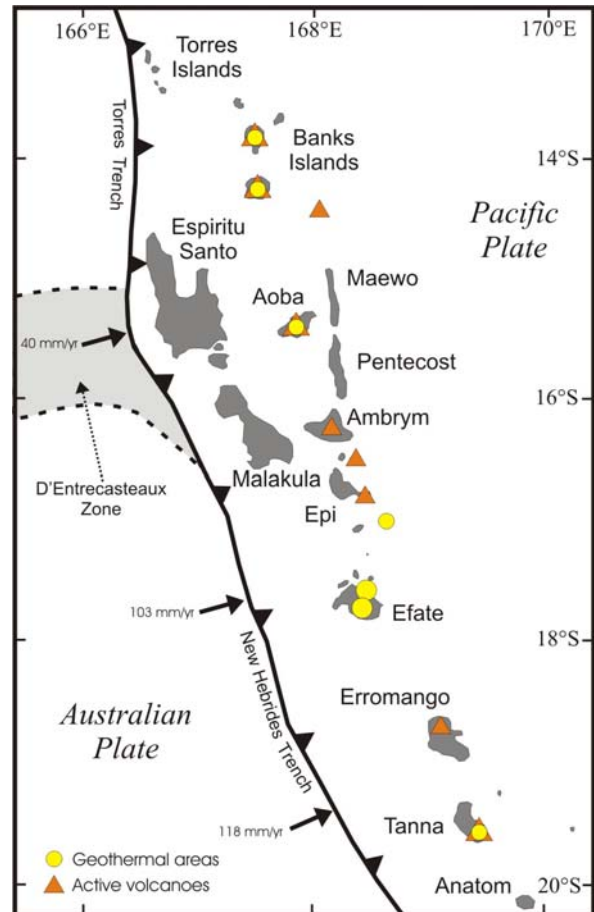
There are at least seven known thermal areas in Vanuatu (Figure 3). The most prospective sites are on Efate (i.e. Takara and Teuma). Highly solfataric areas are also reported on the islands of Vanua Lava, Gaua, Aoba and Tanna (Mallick and Ash, 1970; Grindley & Nairn, 1974b; Heming et al., 1984).

Warm springs discharge at 18 locations on Efate with temperatures ranging from 30-78°C (Burgess et al., 1983; Anderson et al., 1986). Coastal occurrences have lower temperatures (30°C) due to mixing with saline waters. Active geothermal areas have been identified with temperatures >50°C at Takara (northern Efate) and in the Teuma Graben, these areas are inferred to be separate on the basis of their chemistry, although they may be heated by a single heat source (i.e. cooling volcanic pluton; Burgess et al., 1983).

The Takara thermal area is a prospective site for geothermal electricity generation. Five neutral chloride hot springs discharge in the Takara area, with the highest measured water temperatures (88-92°C) occurring in the Airfield Bore (KRTA and GENZL, 1987). Geothermometry indicates thermal waters discharging at Takara last equilibrated at 160-175°C, with the temperature of the deep reservoir fluid assumed to be >160°C (Burgess et al., 1983). Total convective heat discharge from the Takara area is >20 MW(t). A resistivity survey of Efate in 1985-86 identified a large ~100 km<sup>2</sup> area with low resistivity in the northern part of the island (Anderson et al., 1986). Geothermometry conducted in the Teuma Graben suggest reservoir temperatures of 200-210°C (KRTA and GENZL, 1987).

### Summary

The geothermal resource potential of Vanuatu is moderate to high. A moderate level of geoscientific investigations have been undertaken, which support the view that the development of geothermal power production warrants further consideration. Efate is



**Figure 3:** Map of Vanuatu showing the locations of known geothermal areas and active volcanoes (Olson, 1987). Plate motion vectors from Handley et al. (2008).

likely to be the only island in the Vanuatu archipelago with a sufficiently large population to support geothermal power generation.

Scientific studies have been undertaken in northern Efate with the objective of proving the existence of a medium-high temperature geothermal resource. The interpretation of the geoscience surveys is complex, and no low risk drill targets have yet been identified. Drilling in the preferred area for future geothermal resource investigation (i.e. Sussunatarr Plateau) is likely to require well depths of at least 1000 m.

Investment in the development of a geothermal power plant (e.g. 5-20 MWe) on Efate would increase Vanuatu's renewable energy production and, along with recent wind developments, move Vanuatu to having a very high percentage of electricity generated from renewable sources. A comprehensive review should be undertaken to identify gaps in the data on geothermal resources in Efate. The thrust of the review should be to identify possible exploration targets for drilling, or data gaps that need to be filled prior to recommending drill targets.

## **SAMOA**

Whilst there are no surface manifestations, Samoa is regarded as a moderate level geothermal prospect due to the existence of an active, long-lived heat source below the island of Savai'i. Here, we highlight the similarity of the geological setting of Samoa, and the nature of its recent volcanism with Hawaii, where geothermal resources have been developed.

### **Geothermal Prospects**

Samoa lies on the Pacific plate ~120 km from the northern terminus of the Tongan Trench (Figure 1), in a zone of intense crustal stress, near to the inferred South Pacific Superplume. Savai'i, the largest of the Samoan islands, consists of a massive basaltic shield volcano constructed along a west-northwest east-southeast trending rift (Kear and Wood, 1959). The majority of sub-aerial volcanic rocks on Savai'i are younger than 0.4 Ma (Workman et al., 2004), although volcanism is still active, with Mauga Afi, Aopo and Matavanua volcanoes having erupted in 1760, 1902 and 1905, and 1911 respectively (Olson, 1987).

Although there are no surface geothermal features, Savai'i and Upolu both host well developed rift systems that may provide a suitable environment for development of thermal reservoirs. Recent volcanism on Savai'i has focused geothermal investigations on this island. Whilst no hot springs are noted, Waring (1965) indicated large fumaroles accompanied volcanic eruptions on Savai'i, which emitted "steam and acid vapour". It has been suggested that hot springs, solfataras and other manifestations may have been present during periods of volcanic quiescence, (Olson, 1987; Depledge and Dench, 1995).

The long history of volcanic activity on Savai'i means an extensive magmatic chamber / heat source may occur beneath the island. The active volcanoes on Savai'i are aligned along an east-west trending rift that is comparable to the lower East Rift Zone, near Kilauea Volcano (Hawaii), where a geothermal system has been developed (the Puna Geothermal Power Plant has been in operation since 1993, and produces 30 MWe). The similarity between the Hawaiian and Samoan geological setting, and potential for deep-seated geothermal resources on Samoa, warrants further geophysical and geological investigation.

### **Summary**

Samoa has moderate geothermal potential. Although no surface geothermal features are observed, the existence of an active heat source beneath Savai'i could be a measure of the geothermal prospectivity. Approximately 25% of the population resides on Savai'i while the major population centre (Apia) is on Upolu, ~20 km from Savai'i.

## **TONGA**

Geothermal activity in Tonga is associated with subduction related volcanism along the Tongan Trench. A geothermal system occurs on the active volcano on Nuiabo'u in the Niua islands. Currently only 650 people live on Niua island. Submarine hydrothermal activity is also found on the South Tonga Ridge and Valu Fa Ridge. To date, no detailed geothermal investigations have been undertaken.

### **Geothermal Prospects**

Geothermal activity in Tonga is scarce, although manifestations do occur on Nuiabo'u island (Olson, 1987). Extensive submarine hydrothermal activity occurs on seamounts along the South Tonga Ridge.

Nuiabo'u is the most northerly island in Tonga (~574 km north of Tongatapu), and part of the Niua group of islands. The volcano was active in the early 20th century, with eruptions in 1853, 1912, 1929, 1935, 1936, 1945 and 1946 (Smithsonian, 2009).

Active submarine hydrothermal systems are found on the South Tonga and Valu Fa Ridges (Hekinian et al., 2008). Eleven thermal areas are known emanating from seven oceanic volcanoes, with temperatures of 245-265°C recorded at depths of 385-540 m (Massoth et al., 2007). There are many active submarine volcanoes within 50 km of Tongatapu, but because of their undersea location they are not an energy source that can be harnessed using current geothermal technologies.

### **Summary**

Tonga is a moderate level geothermal prospect, with a history of island-arc volcanism, and evidence of submarine hydrothermal activity. Although not viable for development, submarine hydrothermal activity does point to near surface, high heat flow. These attributes are consistent with a heat flux that may be sufficient for maintaining active geothermal systems.

Tonga's reliance on fossil fuels for electricity power generation means geothermal exploration could be of great strategic importance for the country. However, the widely dispersed nature of the Tongan population counts against the practicality of servicing the islands from a single geothermal development. If further work is to be undertaken, then preliminary reconnaissance survey work should include: prioritized exploration of thermal areas and identification of elevated thermal gradients based on surface measurements.

## **NORTHERN MARIANAS ISLANDS**

Geothermal activity in Northern Marianas Islands is associated with active-arc volcanism. High heat flow and nearby submarine hydrothermal systems are

positive indicators of geothermal resource potential. To date no detailed geothermal investigations have been undertaken. However, a large of geological and geophysical database exists on the Marianas, collected as part of the United States Geological Survey (USGS) volcano monitoring network. These islands are prospective for geothermal resources, and have been investigated by scientists from the USGS and Southern Methodist University.

### Geothermal Prospects

The Northern Marianas Islands form a chain of arc volcanoes resulting from the westward subduction of the Pacific plate beneath the Philippine Sea plate (Figure 1). Volcanic activity along the Marianas arc extends from Esmeralda Bank to Farallon de Pajaros, with historic eruptions (after 1850) recorded from 12 volcanic edifices (Rowland et al., 2005). Although no surficial geothermal features are reported in Marianas Islands, a high potential heat source is presumed, due to their location in one of the most tectonically active arcs on Earth. Blackwell et al. (2008) suggest the Marianas could produce enough geothermal energy to supply the island chain with a sustainable supply of electricity.

An assessment of the geothermal resources of Pagan Island determined the island has an active geothermal system with an estimated capacity of 50-125 MWe (Quick, 2009). Volcanic activity is subdued at the old and small South Pagan volcano, offering a region of low hazard to conduct resource exploration. Saipan is the largest island (115 km<sup>2</sup>) in the Northern Marianas Islands, and has a population (>60,000) that is growing rapidly due to an expanding tourism sector. Temperatures above thermal background have been observed in two groundwater well, which point to an active geothermal system at Saipan that may be capable of supporting small scale electricity generation (Quick, 2009). A survey of submarine hydrothermal activity along the 1200 km Mariana arc mapped >50 submarine volcanoes, and active thermal features at 12 sites (Embley et al., 2004).

### Summary

Although scientific data specific to its geothermal resource potential is lacking, the Northern Marianas Islands are considered a moderate to high prospect for geothermal development due to the abundance of magmatic heat along the Marianas arc. Whilst the most prospective islands have low populations, excess generated electric power may be able to be exported to Guam, via a submarine cable (~200 km).

### SUMMARY

GNS Science was commissioned by MORST to undertake a review of the geothermal potential of 20 Pacific Island nations and territories. Detailed examination of the geothermal potential of Papua

New Guinea, Vanuatu, Samoa, Tonga and the Northern Mariana Islands has shown that:

- Papua New Guinea is an excellent prospect for geothermal development: a highly successfully power plant operates on the island of Lihir, and several fields on New Britain have inferred reservoir temperatures of >300°C.
- In Vanuatu, the island of Efate has sufficient population for development to be viable. Several geoscientific studies have already been completed for prospects (especially at Takara).
- Samoa is a hotspot volcanic island, located on the margin of the Pacific Superplume. Prolonged volcanism at Savai'i points to a large magmatic plumbing system at depth.
- Tonga is located adjacent to an active subduction zone, and is a viable exploration target.
- The Northern Marianas are located at an active subduction plate margin, and is an attractive target for geothermal exploration.

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