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Geothermal Potential of East Timor

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ABSTRACT

Geologically, Timor is situated in the collision zone between the Banda volcanic arc and the Australian continental margin. The volcanism associated with this collision zone forms the Inner Banda Arc, 100 km to the north of East Timor. On mainland East Timor, there has not been any recent active volcanism and there is no evidence for any intrusive magmatism. Geologically therefore, there is little expectation that magmatically-heated, high temperature geothermal systems will be found here.

The hot springs on mainland East Timor are dilute, alkaline, sodium-bicarbonate waters with variable chloride up to 540 mg/kg and a maximum temperature is 62°C. The composition suggests they are deeply circulating meteoric waters that have encountered temperatures up to 100°C.

Hot springs on Atauro island (25 km from the mainland) have temperatures up to 70°C and a thermally altered seawater source. Unlike the mainland, there is evidence here for recent volcanism and possibly a higher-temperature, magmatic-related geothermal system.

1. INTRODUCTION

Following independence in 1999, the economy and infrastructure of East Timor is in poor condition. There are about 800,000 people in East Timor and a current electrical demand of about 20 MW, though there is probably considerable suppressed demand and with a reliable source of power, significantly more than 20 MW could be used quite quickly

The Asian Development Bank funded a country-wide power sector study in early 2003 which included and investigation of geothermal power generating potential. There are currently no geothermal power generating plants on East Timor, nor any major activities that utilise geothermal fluids, apart from tourism. Prior to this study, there had been no systematic investigation of potential geothermal resources on East Timor.

This paper presents results of a surface geothermal reconnaissance of East Timor conducted in 2003, under funding from the Asian Development Bank. The objective of the survey was to assess the power-generating potential of the country's geothermal resources.

2. GEOLOGICAL SETTING

The Indonesian archipelago is predominantly made up of a series of volcanic arcs, representing a complex interaction of large and small tectonic plates (Figure 1). Many of the islands of Indonesia therefore have geothermal and epithermal mineral potential, including the Banda Arc which runs just north of East Timor. Most authors describe this region as an arc-continental collision zone in which the Banda volcanic arc is colliding with the Australian continental plate (Figure 2).

The Banda Arc consists of an inner volcanic arc and a non-volcanic outer arc which includes East Timor. The inner arc has been active since the late Miocene. The outer arc is formed principally of sedimentary and metamorphic rocks of Permian to Quaternary age, which represent material accumulated in the collision zone between the volcanic arc and the Australian continental margin. East Timor is made up of uplifted and folded parautochthonous rocks derived from Australian continental shelf sediments. These in turn are overlain by allochthonous nappes including pre-Cretaceous metamorphic rocks and cherts, limestones and flysch deposits of upper Jurassic to Eocene age. These in turn are overlain by Quaternary raised coral reefs and alluvial terraces and Pliocene-Quaternary turbidites.

Some authors have considered all of Timor to be a chaotic melange formed in a subduction setting although it is now widely accepted that the geology is not that simple. The Bobonaro Scaly Clay represents the predominant melange formation on East Timor. Barber *et al.* (1986) have suggested that this is the product of shale diapirism while Harris *et al.* (1998) has suggested there the variable composition represent different melangé facies formed at different structural positions in the developing orogenic wedge.

The sub-aerial volcanism associated with the Banda arc collision zone lies at least 100 km to the north of Timor and includes the islands of Flores, Alor and Wetar. The parts of this inner arc closest to Timor (Wetar and Alor) have been inactive since the late Pliocene although younger sea-mounts have recently been recognised and active volcanism continues to the west and east (Snyder *et al.* 1996). The East Timor island of Atauro was formed by this inner arc volcanism. The closest commercially proven geothermal resources are on Flores island, 250 km west of Timor.

The geology of the Timor region is reasonably well studied because of the offshore oil and gas potential but the geology of on-shore East Timor is less well known. The most recent published geological map of the whole country is that of Audley-Charles (1968) at 1:500,000.

2.1 Atauro Island

Atauro Island lies 25 km north of Dili. It is the only part of East Timor composed of young volcanic rocks with the potential for hosting a high-temperature geothermal system. It was generally accepted that volcanism on Atauro island ceased 3 million years ago which is towards the maximum age where residual heat may still be present. However, observations made during the field reconnaissance suggest much younger ages in the northeast of the island. The volcanic rocks of Atauro island comprise andesitic lavas, pyroclastics and minor intrusives.

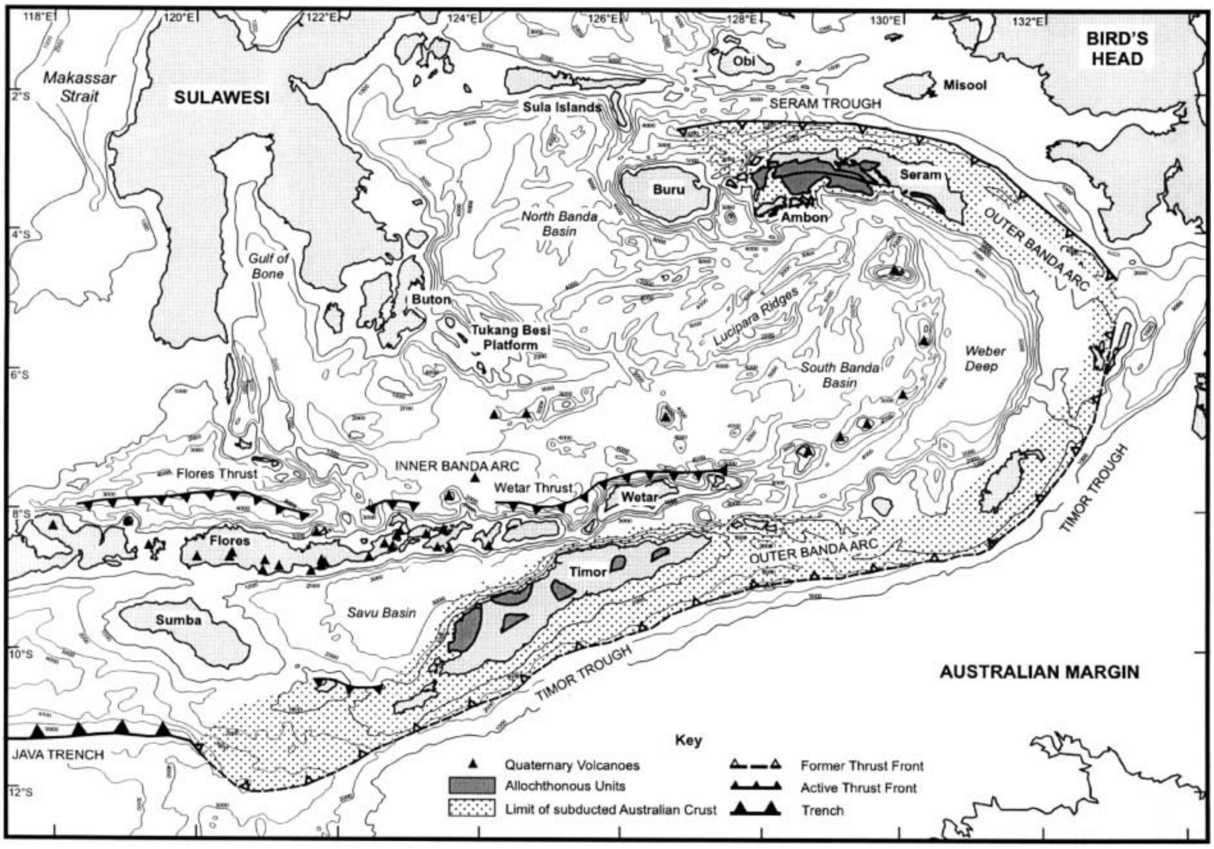

Figure 1. Tectonic map of the Banda Arc plate margin region (from Hall and Wilson, 2000)

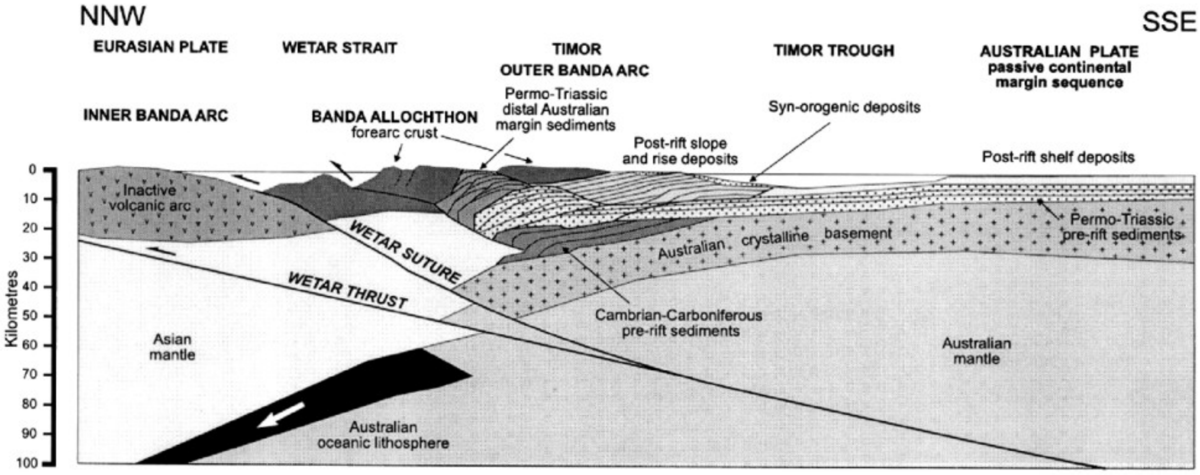

Figure 2. Schematic cross-section through the Timor section of the Banda Arc plate boundary (from Hall and Wilson, 2000).

The island is elongate, about 20 km long north to south and 10 km across at the widest point (Figure 4. The south of the island is composed of high (1000 m) volcanic edifices representing two separate eruptive centres which have been dated to about 3.2 m.y. (Abbot and Chamalaun, 1976). The northwestern quadrant has lower relief but is still predominantly volcanic and probably of similar age to the southern part of the island. The northeastern quadrant has more subdued relief but, interestingly, does not have the raised reef limestone that encircles the rest of the island. The absence of reef limestone suggests that the volcanism here post-dates the uplift that has left the limestone exposed, estimated to have begun ~120,000 b.p. The alternative explanation, that the limestone was removed by erosion or landslides, is not consistent with the numerous outcrops of lavas and pyroclastics along the coast. The more subdued relief in the north may be the result of a more explosive style of volcanism, although an eruptive centre has not been identified. If the northeastern sector is indeed younger than in the south, it may correlate with a sea-mount 40 km to the north of Atauro Island has been dated at 400,000 b.p. (Breen *et al.*, 1989)

3. GEOTHERMAL ACTIVITY

The geothermal reconnaissance was conducted over 5 days in March 2003, near the end of the wet season. The springs visited were known to the Ministry of Energy and Natural Resources, although no detailed descriptions were available. It is believed that only one significant spring was not visited, a feature at Laclota which could not be reached in the time available because of access difficulties.

The springs are described below and approximate locations are shown on Figure 3. All springs visited were sampled and photographed, temperature measured and flowrate estimated. 1:25,000 topographic maps were used for reference and there was reasonable agreement with GPS readings which are recorded below for all mainland springs. On Atauro Island there was a discrepancy of several hundred meters between topographic maps and GPS readings, so both values are given here. Full descriptions of the features and details of access were documented by Sinclair Knight Merz (2003).

3.1 Mainland Springs

Mare Naun Kura Springs (Aileu District).

Location (spring MNK I): 806440 E, 9037691 N, elevation 353 m. These springs are located within alluvial flats alongside the Mota Noru river. There are three groups of springs (MNK I, II and III) within 200 m of each other. Maximum measured temperature within each group ranges from 55 to 62°C with total flowrate estimated to be 10-20 kg/s. The springs discharge clear water with slight bubbling and minor odour. The geology of the area comprises ridges of Aileu Formation Permian schists and shales. The alluvial terraces around the springs are mainly composed of fragments of schist, but boulders of limestone

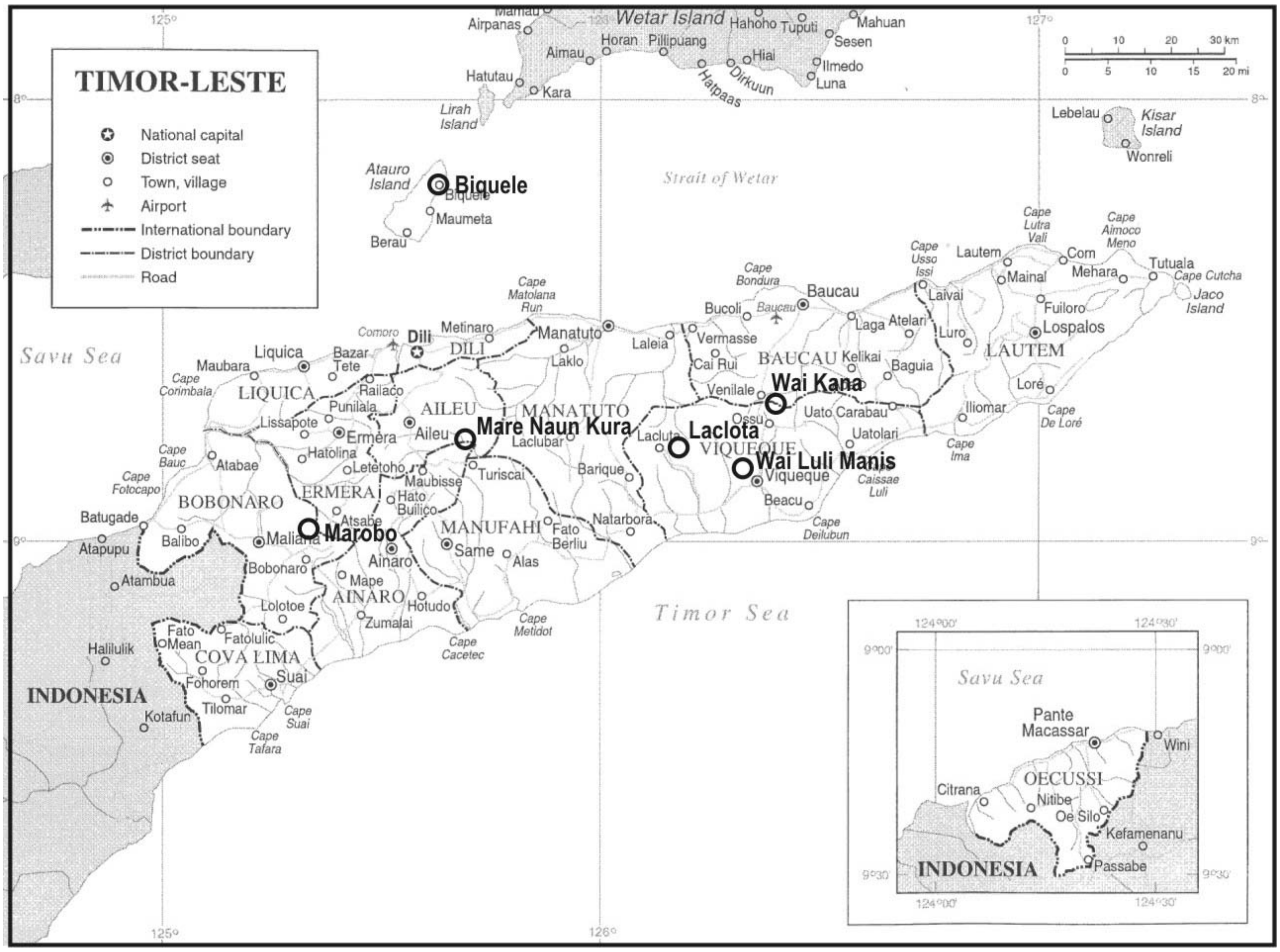

Figure 3. Spring Location Map

from the Maubisse Formation are found near MNK I. It is likely that the springs occur at a fault contact between the two formations.

Wai Kana Springs (Ossu District).

Location: 817490 E, 9043351 N, elevation 388 m. The main spring emerges as a strong flow from a small limestone cave and flows to a basic swimming pool. It has a temperature of 32°C, emits some gas (slight odour of H_2S) but has no deposition. The limestone from which the spring emerges is probably the Oligocene Barique Formation. No obvious structural or stratigraphic control on the location of the spring was recognised.

Wai Luli Manis Springs (Viqueque District).

Location (spring WLM I): 204905 E, 9022910 N, elevation 193 m. The main spring, located in a small limestone cave, discharges clear water with a temperature of 57 °C and estimated total flow of 10 kg/s. The water has a slight odour of H_2S but no gas is visible. The limestone is mapped as Upper Miocene Viqueque Formation by Audley-Charles. A second smaller spring is found 50 m to the north.

Laclota Springs (Viqueque District).

Location: Approximately 126° 8” E, 8° 46” S. These springs have not previously been reported and could not be reached during the reconnaissance. No description was available, but it was stated that the Indonesian Army used to cook their noodles in the springs, implying a temperature of at least 60°C. This is consistent with the fact that people who had visited both the Laclota and Wai Luli Manis springs described the Laclota ones as hotter.

Marobo Springs (Bobonaro District).

Location (spring M I): 754465 E, 9005792 N, elevation 459 m. A second spring (M II) lies 20 m to the west. M I is a non-flowing pool with temperature of 47°C and strong gas ebullience. M II discharges clear 46°C water with a flow of 10 kg/s. It forms a sludgy deposit of calcite and possibly some gypsum and sulphur. There was a minor odour of sulphur. The geology of the area consists of Pliocene Ainaro Gravel with limestone outcropping on ridges above the springs. An off-set in this formation suggests the springs are located on a fault contact.

Other Mainland Locations

Warm water was reported at Beacu, east of Viqueque, but it was described as a mud volcano and so was not visited.

Audley-Charles (1968) reported an oil seep associated with a hot spring beneath Gunung Fatu-lulik, but this mountain is not shown on the published geology map. There is a town of this name near the SW border with Indonesia and staff at the Ministry of Energy and Natural Resources reported a gas seep at “Foto Lulik”, which is probably the same occurrence. The flowrates and temperature were not reported, and the location is very poorly described.

3.2 Atauro Island Hot Springs

Spring locations on Atauro Island are shown on Figure 4. All of the hot springs observed are sub-tidal. The time of the visit ran from about half tide to full tide, out of a total range of about 1.5 m. It is likely that other hot seepages exist and some were referred to by local people, but these were not located at the time of the survey because they were underwater.

Nussalo Springs

These spring occur some 3.5 km south of Aikrema village, just north and south of a low but prominent headland referred to as Buku Nussalo. Both sets of springs occur within shallow, muddy lagoons with mangroves and are still easily visible at high tide.

Nussalo I. 791104 E, 9096849 N (GPS), 790760 E, 9096800 N. (Topo map). The springs are in a muddy basin, emerging vertically from numerous small, shallow pits. The water is clear with a maximum temperature of 57°C, but is diluted by seawater and it could possibly be hotter at source. Total flow was estimated at 10 kg/s, but this assessment was not very precise because of the distributed nature of the outflow.

Nussalo II. 790916 E, 9096491 E (GPS), 790720 E, 9096640 N on 1;25.000 (Topo map). Located 250 m south of Nussalo I, this group includes numerous small springs and seepages over a length of about 100m of the foreshore. The water is clear with a maximum temperature of 46°C but is mixed with incoming seawater. Total flow was estimated at 20 kg/s but with no great degree of accuracy.

Biquele

Location: 790338 E, 9094773 N (GPS), 790100 E, 9094850 N (Topo Map). Also known as Pala, after the small village of same name.

Numerous small springs and seepages emerge from cracks in a low rocky outcrop on the beach platform. The maximum temperature measured was 70°C and total flow was estimated at 10 kg/s, but with no great degree of accuracy because of the numerous vents. The water was clear with no odour and the only deposition was a weak coating of iron hydroxide gel where it mixed with the seawater. The host rock is a massive andesitic volcanic, thinly fractured in places and infilled with cristobalite, probably recrystallised from opal deposited with the hot water. There were no relic deposits found that indicate hotter temperatures existed in the past.

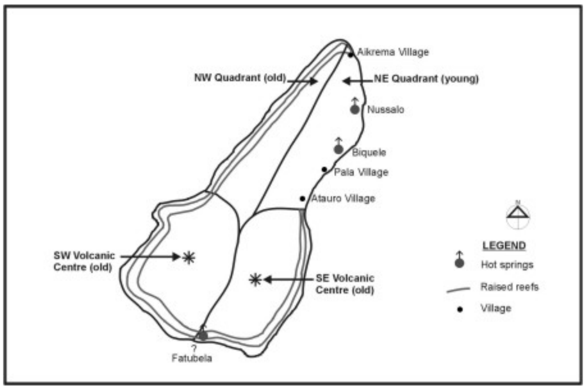

Figure 4. Schematic map of Atauro Island showing spring locations

Other Features on Atauro Island

Local people reported warm springs at Fatubela on the south coast but could not give a precise location and said that they were underwater, except at low tide. These were not visited. A guide reported subtidal springs at the first headland south of Aikrema village but these could not be positively located.

4. WATER CHEMISTRY

Water samples have been collected from all the major springs in East Timor. No steam is found at the surface and gas samples were not collected. Results of analyses are tabulated in Table 1. Most of the mainland springs have a dilute Na-HCO_3 composition and represent deeply circulating meteoric waters without any direct magmatic association. Only the water from Wai Luni Manis has significant chloride (540 mg/kg). Since there has been no recent volcanism in mainland East Timor the chloride could be derived from residual interstitial brine contained in marine sediments. The origin of the bicarbonate is unclear but is unlikely to be derived from the reef limestone since bicarbonate concentrations are not matched by calcium. Geothermometer temperatures are tabulated in Table 1. For the mainland springs, the highest geothermometer temperatures are seen for the water from Wai Luli Manis which has the highest chloride and lowest magnesium. The T_{NaK} and T_{NaKCa} geothermometers indicate temperatures up to 160°C, although the high bicarbonate casts some doubt on this. Silica geothermometer temperatures lie between 70°C (chalcedony) and 100°C (quartz), which is not significantly higher than maximum measured temperatures.

The sub-tidal Atauro Island waters have much higher chloride (>10,000 mg/kg) which is clearly derived from seawater as indicated by the high calcium and magnesium and relatively low boron (high Cl/B ratio). However, comparison of spring chemistry with that of fresh seawater indicates that it is thermally modified, as shown by the Cl/Mg, Cl/Ca and Cl/SO_4 ratios. Modification of seawater as a result of heating is well studied (Bowers and Taylor, 1985), the main processes being:

- Almost complete removal of magnesium at >150°C by uptake into secondary alteration minerals.
- leaching of calcium from primary silicates to balance loss of magnesium
- loss of sulphate by deposition of anhydrite
- loss of some sodium by albite-forming reactions

The loss of sodium from heated seawater is only small at temperatures below 150°C (Bowers and Taylor, 1985) but magnesium removal is almost complete. Therefore, the loss of sodium from the Biquele springs suggest that the upflow waters are thermally altered but have a significant fraction of fresh seawater added near surface, as indicated by the high magnesium. If it is assumed that the upflow water has 10 ppm magnesium, seawater mixing calculations indicate that the deep thermal water has chloride and silica concentrations of 10,400 ppm and 240 ppm respectively.

Cation geothermometry is difficult to apply unambiguously to seawater systems because sodium and potassium concentrations in fresh seawater are not controlled by the Na-K feldspar equilibria on which published geothermometers are based (e.g; fresh seawater has a T_{NaKCa} value of 173°C). The Biquele spring has a T_{NaKCa} value of 157°C which suggest a shift towards equilibrium temperatures below 173°C. Using the inferred upflow silica concentration of 240 ppm silica, T_{QTZ} and T_{CHAL} values of 179 and 175°C are obtained. Taken together therefore, the geothermometry indicates source water temperatures of 160-180°C.

The Nussalo spring water has a larger fresh seawater component (~80%) but the temperature of the spring is still significant (57°C). It is possible that the temperature was measured in a position less contaminated by fresh seawater than the sample collected.

5. SUMMARY

Consideration of the known geology of mainland East Timor and the chemistry of the samples collected indicates that it is unlikely that a large hot geothermal system exists. Thermal features characteristic of high-temperature (>250°C) geothermal systems (boiling chloride springs, fumaroles etc) are not found on the mainland. Several moderately high flowrate springs were found but these are considered to have deep-seated tectonic origin. Therefore deep temperatures are likely to follow a gradually increasing conductive gradient and it would be necessary to drill to considerable depth to access temperatures significantly higher than found at the surface. The most appropriate use of the main thermal resource is for direct use, tourism-orientated bathing.

The springs on Atauro Island appear to have higher source temperatures (160 – 180°C) than springs on the mainland and this is possibly related to the younger volcanism in this region. Nevertheless, the inferred temperatures are still relatively low for large-scale power development. However, the island does have some tourism potential and it may be possible to develop a small-scale tourism-based ‘cascaded’ development, comprising binary generating plant with downstream direct use of the residual water (bathing, domestic heat).

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Table 1 Chemistry of East Timor Springs (March 2003)

														molar ratios:							*geothermometers:*			
Location	Code	Est. Flow	Temp	pH	Na	K	Ca	Mg	Cl	SO_4	$tHCO_3$	B	SiO_2	Cl/Na	Cl/Mg	Cl/Ca	Cl/B	Cl/SO_4	Na/K	Na/Ca	T_{QTZ}	T_{CHAL}	T_{NaK}	T_{NaKCa}
		t/h	°C						mg/kg*												°C	°C	°C	°C
Mainland East Timor																								
Mare Naun Kura I	MNK I	2	62	7.63	147	3.8	31	17.9	29	21	491	0.9	47	0.13	1.1	1.1	10	4	65.8	8	99	69	123	62
Mare Naun Kura III	MNK III	5	61	7.33	109	2.6	44	19.0	21	56	445	0.8	37	0.12	0.8	0.5	8	1	71.3	4	88	57	119	42
Wai Luli Manis	WLM	10	57	8.10	504	26.0	35	13.4	538	127	509	8.7	50	0.69	27.5	17.4	19	11	33.0	25	102	72	166	160
Wai Kana	WK I	-	32	7.29	16	3.5	77	18.5	13	32	327	<0.1	18	0.54	0.5	0.2	-	1	7.5	0	60	28	-	24
Marobo	M II	10	46	7.52	297	8.0	53	24.0	201	42	775	5.6	28	0.44	5.7	4.3	11	13	63.1	10	77	45	126	82
Atauro Island:														-										
Nusalo	N I	10	57	-	9644	375	667	998	~17,000	2784	-	5.6	38	1.14	12	28.8	926	17	43.7	25	89	59	147	171
Biquele	B I	10	70	6.63	5283	223	1496	207	11,768	675	153	11.4	205	1.44	39	8.9	315	47	40.3	6	182	161	153	158
Biquele (calculated upflow composition, see text)					*4307*	*194*	*1699*	*10*	*10,434*	*310*	*155*	*12.7*	*243*	*1.57*	*716*	*6.9*	*251*	*91*	*37.8*	*4*	*194*	*175*	*157*	*157*
Seawater Chemistry (examples):														-										
Fresh Seawater (average)			20	8.50	10561	380	400	1272	18,980	2649	142	4.6	<9	1.17	10	53.6	1258	19	47.3	46	-	-	143	173
Svartsengi (240°C well)			240	7.50	8037	1245	1343	1.6	17,010	41	45	9.0	534	1.37	7203	14.3	576	1124	11.0	10	258	253	258	244

Notes: Svartsengi data from Ragnarsdottir *et al*. (1984)

T_{QTZ} - Quartz Geothermometer, no steam loss (Fournier, 1981)
T_{CHAL} - Chalcedony geothermometer (Fournier, 1981)
T_{NaK} - Sodium-Potassium, empirical (Fournier, 1979)
T_{NaKCa} - Sodium-Potassium-Calcium, empirical (Fournier and Truesdell, 1973)