Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Exploration and Development of the Tawau Geothermal Project, Malaysia

Peter R. Barnett[2], Susianto Mandagi[1], Tasrif Iskander [1], Zainal Abidin[1] Andrew Armaladdoss[2], Ramsey Raad[2]

[1] Green Asia Geotech, [2]Tawau Green Energy

5th. Floor, Wismar Perkasa, Jalan Gaya, 88821 Kota Kinabalu, Sabah, Malaysia.

peter.barnett@tgepower.com

Keywords: Malaysia geothermal, Apas Kiri, resource assessment, drilling, exploration and development strategy

ABSTRACT

Surface geothermal activity has been reported at Tawau in Sabah in NW Borneo, since 1960 and various aspects have been studied and reported irregularly through to the present time.

In 2010, Tawau Green Energy secured an exploration concession and carried out a comprehensive surface exploration program comprised of detailed geology, MT geophysics and geochemistry surveys. The results of this program have confirmed the existence of an active geothermal system centered on the SE slopes of Mt Maria, a young andesitic to dacitic volcano of Miocene to Quaternary age resulting from subduction on the NW facing Sulu arc. The resource is structurally controlled by a series of NW trending transcurrent faults and transpressional tectonics from the late Pliocene to the present day. The chemistry of surface springs suggest a deep underlying neutral chloride fluid rising and outflowing the SE and the South with a deep temperature of about 200^{o}C. An initial resource assessment has been made this yields approx. 85 MWe of potential development capacity at a probability of 50% for a resource abandonment temperature of 170^{o}C.

TGE is now preparing to drill two deep exploration wells into the central portions of the Mount Maria upflow. These will commence in July 2014 and the results of the drilling program plus well testing are expected to be available for inclusion in this paper by the time it has to be finalized

1. INTRODUCTION

The Tawau Geothermal Project is located in North East Malaysia (Borneo), Figure 1. The field is being explored for geothermal power development by Tawau Green Energy (TGE), a Malaysian based renewable energy company. The field evidence is for a moderate sized volcanic geothermal field with medium grade temperature. Although the surface geothermal manifestation and potential of the area for geothermal development have been known since the early sixties (Kirk 1962), the field has been largely overlooked for development because of the indications for medium grade temperature which would produce only a small steam flash if developed as a conventional flashed steam power development. However, work by TGE over the past two years has changed this perception and it is now recognized that the field is prime for development with an organic Rankine cycle power plant operating at a geothermal resource temperature of around 200^{o}C and probably with pumped production wells The project is currently being prepared for a two well exploration drilling program expected to commence in July 2014 and it is expected that the results of drilling will be available at the time of presentation of this paper (in April 2015).

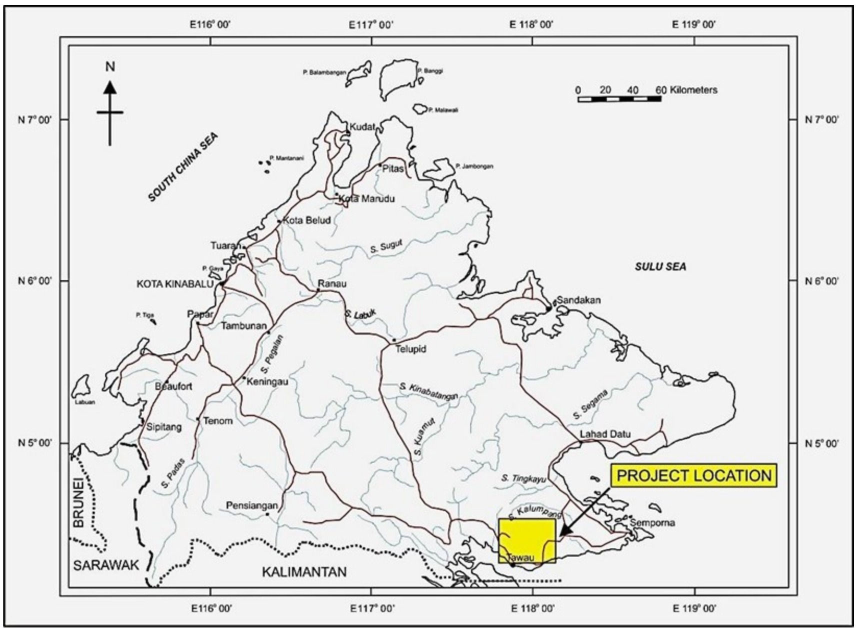

Figure 1: Location Map: Tawau Geothermal Project, Sabah, North West Malaysia

2. PREVIOUS WORK

Previous work at the Tawau project has been well reported by Chong et al (2000) who noted a significant level of interest from the early sixties through to the late eighties and that "momentum for research and development faded" thereafter. They recommended that the way forward for the project was for a geophysical survey followed by exploratory drilling. Significantly they noted that power generation via a binary cycle process would likely be feasible based on the results of chemical geothermometry from the Apas Kiri hot springs.

The results of a first geophysics survey at Tawau were reported by Daud et al (2010) which describes the results of a 42 MT station survey carried out over 15 lines spaced 1200 m apart on the southern slopes of Mt Maria and northern Mt Andrassy using MTU-5 units supplied by Phoenix Geophysics of Canada. TDEM measurements were also made to correct for static shifts in the MT sounding curves. Interpretation of the MT data so gained showed a dome shaped geothermal reservoir structure centered in the northern half of the survey area and open to the north.

TGE has continued exploration activities and extended this historical exploration work from 2011 onwards by resampling all surface thermal activity, with analyses being undertaken by GNS of New Zealand, completing detailed geological and structural mapping over the greater project area, and undertaking a further MT survey of 47 stations located to the north of the area of the Daud et al (2010) survey on the upper flanks of Mt Maria.

3. GEOTHERMAL SETTING

Sabah lies in the northern part of an important junction between the Eurasian, Indo-Australian Pacific and Philippines Sea Plates. It also occupies a central position between three marginal basins: the Sulu, Celebes and South China Seas. The Semporna Peninsular where the Tawau Geothermal prospect is found has been subject to two phases of volcanism. The first originated from the subduction in Late Eocene to Middle Miocene times of the Proto China sea plate southeastward beneath present day Northern Borneo and extension to the SE in the Celebes Sea and Makassar Strait. This produced melting in the down going slab and extensive surface volcanism forming an arc in the vicinity of the Semporna and Dent peninsulas in NW Borneo (Figure 2)

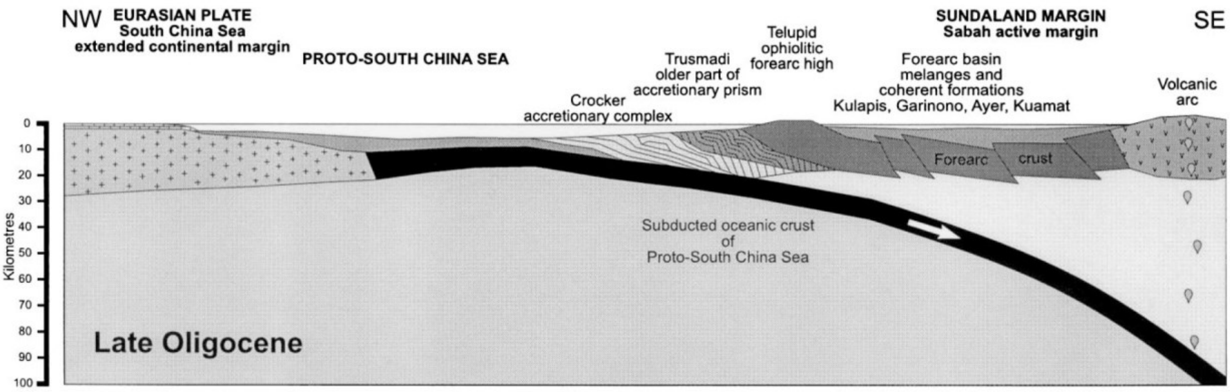

Figure 2: Plate Tectonic Structure of Borneo in Late Oligocene Times

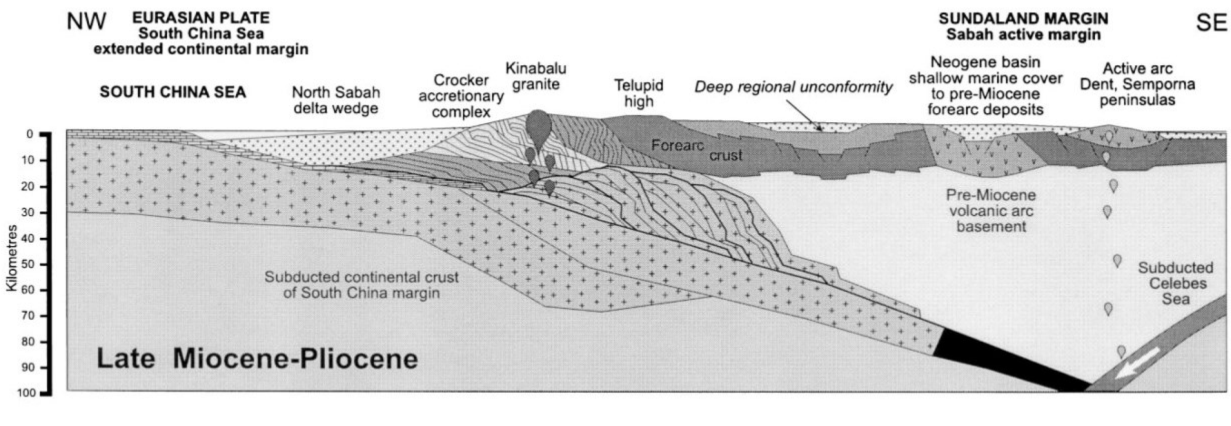

Figure 3: Plate Tectonic Structure of Borneo in Late Miocene to Pliocene Times

Secondly, subduction of the Proto South China plate ceased and subduction of the Celebes Sea Plate to the Northwest commenced about 11.6Ma and generated a NE trending arc of andesitic to dacitic activity of Miocene to Quaternary age in the Dent and Semporna Peninsulas (Figure 3). Transpressional movement along major strike slip faults in this region is possibly related to propagation of deformation from Sulawesi towards Sabah in late Pliocene times. This existing strike slip deformation which is well evident through the Tawau project area likely indicates a strongly structurally controlled and permeable structural network developed over the geothermal system at Tawau (TGE Geology)

4. LOCAL GEOLOGICAL SETTING

A geological map for the Tawau geothermal prospect is shown in Figure 4 (TGE 2013a). The Tawau geothermal project is located in a mountainous area known as the Tawau Hills which forms the backbone of the Semporna Peninsular. The Tawau Hills have been built up by Miocene to Late Pleistocene andesitic, basaltic and dacitic volcanic rocks as described above. Plesistocene dacites and andesites form Mounts Magdalena and Maria, the dominant topographical features in the area. The youngest volcanic rocks are olivine basalts erupted in the late Pleistocene time at Quoin Hill to the east of Mt Maria and Mt Bombalai to the west, which appear to be late stage eruptives located on the rim of a late stage circular collapse feature developed about Mt Maria (see Figure 4).

Thermoluminescence dating studies of the Tawau volcanic rocks have been reported by Takashima et al (2005). Of 12 samples dated, the youngest was found to be 0.09Ma from a monogenetic cinder cone. Ages of dacitic volcanic rocks from the foot of Mt Maria ranged from 0.34 to 0.45 Ma with the ages of underlying andesitic lavas ranging from 0.27 to 0.52 Ma. Ages for the occurrence of hydrothermal alteration in the project area were also determined with samples from the Upper Tawau Hot Springs (Figure 5) being 0.15 to 0.19Ma. Other ages were widely scattered from 0.27 to 0.66Ma.

The project areas has a strongly developed pattern of transcurrent faulting on a NW-SE trend with subordinate N-S and NE–SW trending faults (see Figure 4) (TGE 2013a) . This is consistent with the structural framework and regional stress regime of the Borneo region showing strike slip faulting and transpressional tectonics from the late Pliocene to the present day which probably caused most structural development (Belagaru and Hall, 2009).

Overall the Tawau geothermal prospect is considered to be well situated with respect to plate tectonics, has a long history of magamatism and recent volcanism and has a well-developed structural fabric with good potential for high structural permeability.

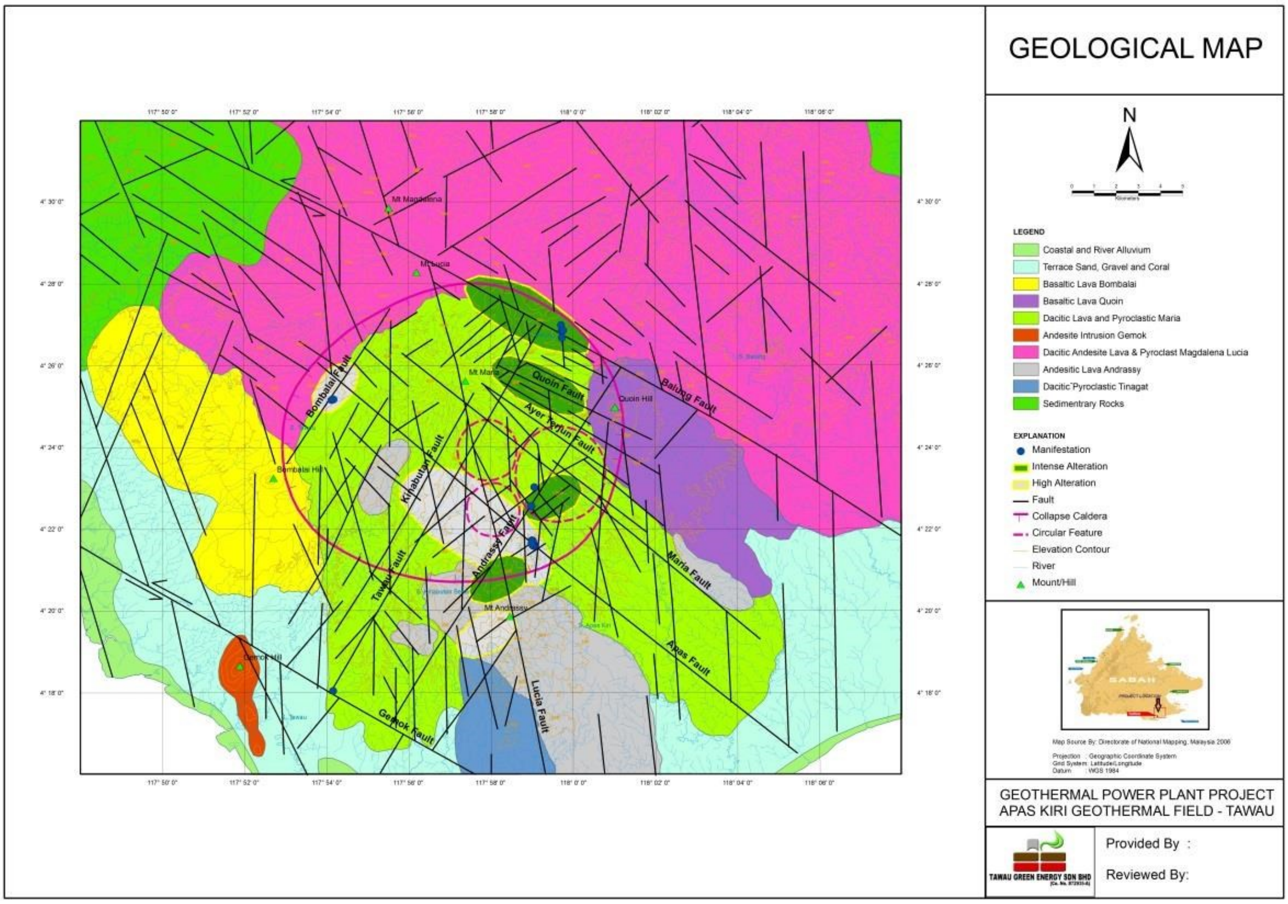

Figure 4: Geological Map of the Tawau Geothermal Project, Sabah (From TGE 2013a)

5. GEOCHEMISTRY

TGE has completed a thorough reexamination and re-sampling of all known springs. Chemical analyses of the springs are given in Table 1 and computed chemical geothermometers are given in Table 2.

Surface thermal activity at Apas Kiri consist mainly of warm and hot springs ranging up to 78^{o}C and these have arbitrarily been divided into 4 groups based on spatial and chemical considerations (see Figure 5). These include: A-Block (Apas Kiri hot spring, of Na-Cl type water with a maximum temperature of 78^{o}C and 1400 mg/kg Cl), B-Block (Balung hot springs, maximum 56^{o}C, is a CaSO4 water with slightly acidic pH of 6.0 to 6.4, about 1000mg/kg SO4, 1 mg/kg Cl and some Sulfur deposition), T-1 Block (Tawau city hot spring, a mixed anion type water with Cl at 353 mg/kg) and T-2-Block (Tawau Hill conservation area hot springs, maximum 34°C, is a Ca-SO4 water with acidic pH of 4.0 to 4.4 and 324 to 491 mg/kg SO4 , 8-11 mg/kg Cl and some Sulfur deposition) (see Figure 5). There are no fumarole manifestations in the area.

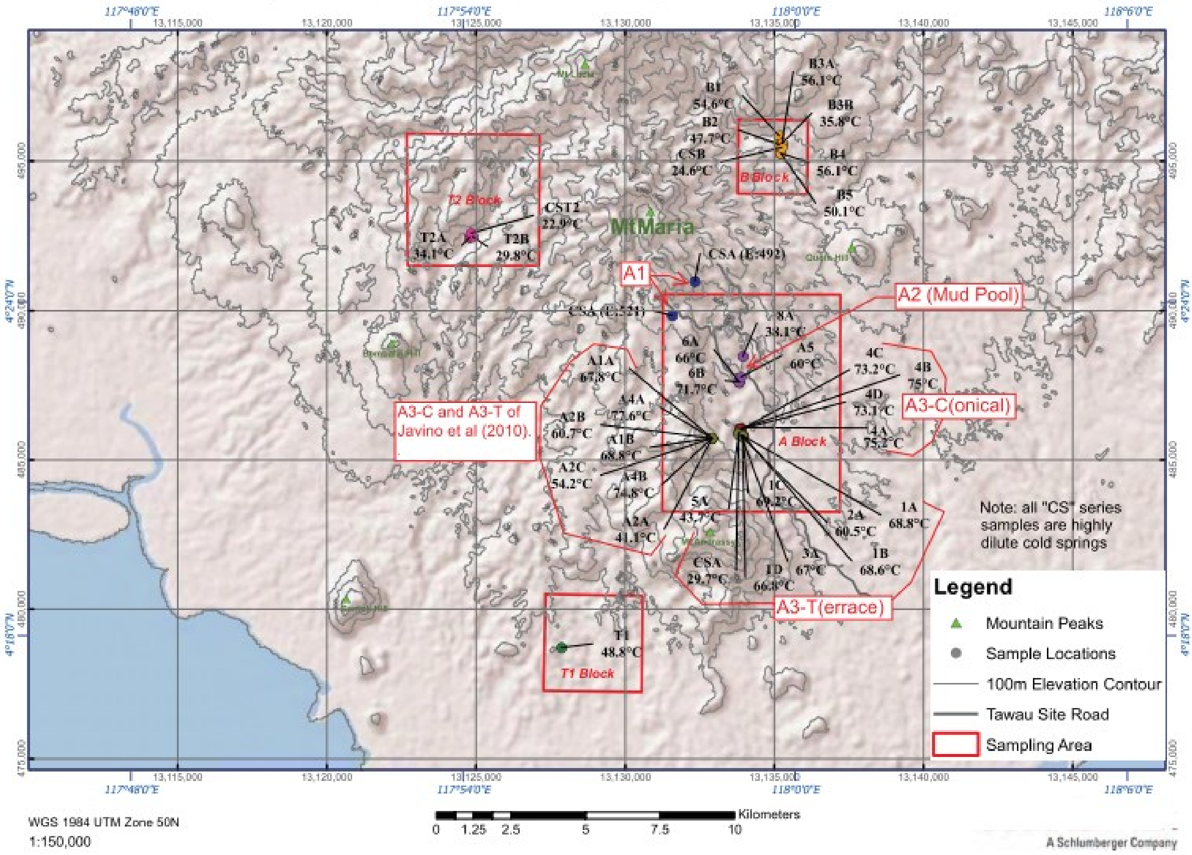

Figure 5: Apas Kiri: Location of thermal features (after GeothermEx, 2014)

Table 2 lists a set of standard chemical geothermometry applied to the 4 blocks described above. In relation to this tabulation (GeothermEx 2014) notes:

- chemical geothermometers don't apply to the waters of T2 Block and B Block because they are shallow and would not have equilibrated at high temperatures
- The T2 Block hot spring isn't listed but presents evidence of a system maximum of about 100 to 115°C
- Two forms of the Na/K geothermometer are listed. One is calibrated by Fournier and the other is a relatively new calibration by Santoyo and Diaz-Gonzales (2010)
- Table 2 does not list the commonly cited Na/K and K-Mg temperatures of Giggenbach (1988) because they produce higher temperature estimates than do other calibrations thereby increasing the risk to the project of over estimating the resource
- Table 2 also lists the sulfate-water oxygen isotope temperature using the data available in Jovino et al (2010) and the anhydrite (CaSO4) geothermometer calculated by GeothermEx (2014) using the Watch 24 computer code for geochemical thermodynamic speciation applied to a set of representative samples.

Different geothermometry computations can yield very different results of different responses to cooling from highest temperature conditions at depth. The general sequence of response rate (most resistant to least resistant) is sulfate-water $^{18}0$ isotope > Na/K Na-Ca-K> quartz> (Na-K-Ca-Mg, K-Mg, Anhydrite, Chalcedony) - GeothermEx, 2014). The isotope geothermometer in particular takes a long time to equilibrate, estimated at 18 years at 200°C. Other processes such as mixing oxidation and precipitation can also affect results.

These geochemical data are interpreted as follows - the hydrothermal system that feeds the Apas Kiri Hot springs appears to rise from a deep upwelling under Mt Maria at about 180 to 220^{0}C, resides for a long time at about the same temperature and then cools to about 120°C in an outflow to the south and south east before discharging at the Apas Kiri hot springs. There is a large O-18 shift that is displayed by the hot springs that implies a long residence time that in turn implies time for complete equilibration of the isotope temperature.

6. GEOPHYSICS

The results of the TGE extended MT survey are taken to indicate that the region surveyed has a four layer resistivity structure divided approximately as follows (TGE 2013b):

- Layer 1 – near ground surface, with a resistivity of > 300ohm-m
- Layer 2 – Cap rock (hydrothermal alteration layer) with a resistivity of 1 to 20 ohm-m
- Layer 3 – reservoir with resistivity's ranging from 20 to 200 ohm-m, with the top of this layer ranging from 400 to 800m depth and the bottom layer from 700 to 1400m and with a thickness of 300 to 600m over an areal extent of 15.4 to 19.4km^2
- Layer 4 - resistivity basement, with resistivity's of > 250 ohm-m and a depth of > -1800m ASL.

Table 1: Geochemical Analyses of Surface Thermal Activity. Compiled by GeothermEx 2014

No.	Sample T (C)	Long	Lat	Elev (m)	Zone	Port	Name	Sample Date	Data setc	Lab	Flow	pH	Ca	Mg	Na	K	Alk_HCO3	SO4	Cl	As	B	SiO2	Li	Fe	F	Cs	Rb	NH4
Zone:		**A-1**																										
01		117°58'11.2"	04°24'22.1"	492	A1	riv	Apas Kiri North	11/10/2013	TGE, 2014	GNS									0.79									
02		117°57'46.7"	04°23'45.3"	521	A1	riv	Apas Kiri North	8/11/2013	TGE, 2014	GNS									0.76									
04	60			270	A2	spr	Apas Kiri Middle (Mud Pool)	1/07/1991	Javino, 2010 (after Lim, 1991)			6.7	142.37	12.9	925	93.5	544.12	476	1410	250	60	75	5	0.2	0.63			
Zone:		**A-2**																										
05	60	117°59'01"	04°22'39"	270	A2	spr	Apas Kiri Middle (Mud Pool)	27/04/2004	Javino, 2010			8.02	165	13.1	858	86.8	239	297	1336		55.6	83.1	4.73					
08	38.1	117°59'03.4"	04°23'01.6"	275	A2	spr	Apas Kiri Middle (Mud Pool)	19/09/2013	TGE, 2014	GNS		5.9	34	14.3	223	31	321	28	318	0.9	14	40	1.3	0.1	0.27	0.54	0.22	0.7
07	71.7	117°58'59.1"	04°22'33.8"	271	A2	spr	Apas Kiri Middle (Mud Pool)	19/09/2013	TGE, 2014	GNS	0.01	6.3	167	14.1	879	102	505	288	1391	4.8	56	82	4.9	0.08	0.64	2	0.83	2.8
06	66	117°58'59.4"	04°22'33.5"	268	A2	spr	Apas Kiri Middle (Mud Pool)	19/09/2013	TGE, 2014	GNS	0.01	6.7	166	13.9	873	101	518	279	1389	4.8	56	82	4.9	0.08	0.64	2	0.82	2.6
Zone:		**A-3C**																										
10	77.6	117°58'30"	04°21'33"	180	A3-C	spr	Apas Kiri Lower - Conical Spout	27/04/2004	Javino, 2010			7.46	215	16.8	837	82.9	606	323	1246		52.5	77.8	4.28					
09	74.8	117°58'30"	04°21'33"	180	A3-C	spr	Apas Kiri Lower - Conical Spout	27/04/2004	Javino, 2010			7.44	214	16.7	838	81.1	668	323	1237		52	81.8	4.18					
12	75.2	117°59'00.0"	04°21'43.4"	190	A3-C	spr	Apas Kiri Lower - Conical Spout	2/10/2013	TGE, 2014	GNS	0.02	6.4	210	18	838	90	760	348	1302	4	51	84	4.5	1	0.76	0	0	2.3
11	75	117°59'01.1"	04°21'43.0"	192	A3-C	spr	Apas Kiri Lower - Conical Spout	2/10/2013	TGE, 2014	GNS	0.21	6.4	199	18.1	848	89	722	106	1232	3.8	52	86	4.5	0.08	0.75	0	0	2.3
13	73.2	117°59'01.3"	04°21'42.3"	187	A3-C	spr	Apas Kiri Lower - Conical Spout	2/10/2013	TGE, 2014	GNS	0.01	6.8	205	18.2	843	90	695	339	1280	3.8	51	84	4.5	0.08	0.73	0	0	2.4
14	73.1	117°59'00.5"	04°21'42.5"	186	A3-C	spr	Apas Kiri Lower - Conical Spout	2/10/2013	TGE, 2014	GNS	0.01	6.5	212	17.7	827	90	725	302	1258	3.6	52	84	4.4	0.26	0.73	1.6	0.59	2.2
Zone:		**A-3T**																										
15	60				A3-T	spr	Apas Kiri Lower - Terrace	1/07/1991	Javino, 2010 (after Lim, 1991)			7.4	150.9	34.1	760	77.5	705.16	312.5	1250	150	21	86	5.4	0.3	0.65			
17	54.2	117°58'30"	04°21'33"	160	A3-T	spr	Apas Kiri Lower - Terrace	27/04/2004	Javino, 2010			7.75	208	16.1	847	75.5	627	317	1231		51.3	69.9	4.17					
18	60.7	117°58'30"	04°21'33"	160	A3-T	spr	Apas Kiri Lower - Terrace	27/04/2004	Javino, 2010			7.69	208	16.1	792	76.2	619	315	1213		51.1	74.3	4.07					
19	67.8	117°58'30"	04°21'33"	163.5	A3-T	spr	Apas Kiri Lower - Terrace	27/04/2004	Javino, 2010			7.56	212	16.7	815	77.9	668	312	1198		45.5	80.2	4.12					
16	41.1	117°58'30"	04°21'33"	160	A3-T	spr	Apas Kiri Lower - Terrace	27/04/2004	Javino, 2010			7.66	194	14.6	716	68.5	567	281	1078		46.1	71.1	3.66					
20	68.8	117°58'30"	04°21'33"	163.5	A3-T	spr	Apas Kiri Lower - Terrace	27/04/2004	Javino, 2010			7.83	211	16.5	810	78.4	649	313	1218		51.4	81.9	4.15					
23	29.7	117°58'58.6"	04°21'37.3"	167	A3-T	spr	Apas Kiri Lower - Terrace	18/09/2013	TGE, 2014	GNS		7.52	7.2	2	3	1	39	8	2	0.02	0.3	30	0.01	0.04	0.02	0.02	0.01	0.01
21	67	117°59'01.1"	04°21'36.5"	170	A3-T	spr	Apas Kiri Lower - Terrace	18/09/2013	TGE, 2014	GNS	0.01	6.5	212	18.2	847	88	788	321	1278	3.9	52	85	4.5	0.08	0.74	0	0	2.2
22	43.7	117°58'59.1"	04°21'38.9"	170	A3-T	spr	Apas Kiri Lower - Terrace	18/09/2013	TGE, 2014	GNS		6.9	161	15.3	712	74	504	258	1124	2.8	45	72	3.7	0.08	0.58	1.3	0.51	0.03
28	66.8	117°59'02.9"	04°21'35.0"	168	A3-T	spr	Apas Kiri Lower - Terrace	2/10/2013	TGE, 2014	GNS	1.38	6.3	205	17.8	820	87	747	297	1270	3.3	49	83	4.4	0.08	0.71	0	0	2.1
24	60.5	117°59'01.1"	04°21'35.9"	177	A3-T	spr	Apas Kiri Lower - Terrace	2/10/2013	TGE, 2014	GNS	0.01	6.3	199	16.7	766	81	686	268	1201	3.6	46	78	4	0.08	0.67	0	0	1.8
25	68.8	117°59'03.7"	04°21'35.6"	171	A3-T	spr	Apas Kiri Lower - Terrace	2/10/2013	TGE, 2014	GNS	2.72	6.2	213	17.9	817	86	719	297	1277	3.7	50	84	4.3	0.08	0.67	0	0	2.1
26	68.6	117°59'03.8"	04°21'35.3"	171	A3-T	spr	Apas Kiri Lower - Terrace	2/10/2013	TGE, 2014	GNS	4.75	6.2	213	18	819	87	720	301	1245	3.7	50	83	4.4	0.08	0.7	0	0	2.1
27	69.2	117°59'03.1"	04°21'35.7"	173	A3-T	spr	Apas Kiri Lower - Terrace	2/10/2013	TGE, 2014	GNS	3.36	6.3	214	18.1	826	88	721	305	1268	3.6	51	84	4.4	0.08	0.8	0	0	2.1

Table 2: Computed Geothermometry. Compiled by GeothermEx 2014

								Geothermometers, °C [1]																	
								Quartz 0° - 330°		Chalcedony 0° - 250°		Moganite 0° - 200°		Amor 0° - 250°	Na - K - Ca 4° - 340°				Na-K-Ca-Mg 4° - 340°		Na/K (F) >150°	Na/K (SDG)	K-Mg (Fg) 30° - 350°	δ18O-H2O - SO4	Anhyd.
Num	Name	Date	Type	T°C	Flow lpm(s) t/h(w)	pH	Cl mg/l	Con.	Ad.[2]	Con.	Ad.[2]	Con.	Ad.[2]		SQ-CaNa	B= 4/3	B= 1/3	Final Temp	Fact. R	Final Temp					
Group:	**APAS KIRI**																								
	Zone:	**A1**																							
01	Apas Kiri North	11-Oct-13	riv				1	----	----	----	----	----	----	----		----	----	----	----	----	----	----	----		
02	Apas Kiri North	08-Nov-13	riv				1	----	----	----	----	----	----	----		----	----	----	----	----	----	----	----		
	Zone:	**A2**																							
04	Apas Kiri Middle (Mud Poo	01-Jul-91	spr	**60**		6.70	1410	122	----	93	----	46	----	3	1.48	173	194	194	10	142	218	195	119		
05	Apas Kiri Middle (Mud Poo	27-Apr-04	spr	**60**		8.02	1336	127	----	99	----	51	----	8	1.72	163	192	192	9	145	218	195	117	182	130
08	Apas Kiri Middle (Mud Poo	19-Sep-13	spr	**38.1**		5.90	318	92	----	61	----	21	----	----	3.00	142	199	199	32	51	247	233	72		
07	Apas Kiri Middle (Mud Poo	19-Sep-13	spr	**71.7**	0.01	6.30	1391	127	----	99	----	51	----	7	1.69	171	200	200	10	148	230	211	121		132
06	Apas Kiri Middle (Mud Poo	19-Sep-13	spr	**66**	0.01	6.70	1389	127	----	99	----	51	----	7	1.69	170	200	200	10	148	230	210	121		
	Zone:	**A3-C**																							
10	Apas Kiri Lower - Conical S	27-Apr-04	spr	**77.6**		7.46	1246	124	----	96	----	48	----	5	2.01	151	187	187	10	141	216	193	112		125
09	Apas Kiri Lower - Conical S	27-Apr-04	spr	**74.8**		7.44	1237	126	----	98	----	50	----	7	2.00	150	186	186	10	141	214	191	112		
12	Apas Kiri Lower - Conical S	02-Oct-13	spr	**75.2**	0.02	6.40	1302	128	----	100	----	52	----	8	1.99	156	192	192	10	139	223	202	114		
11	Apas Kiri Lower - Conical S	02-Oct-13	spr	**75**	0.21	6.40	1232	129	----	101	----	53	----	10	1.91	157	192	192	11	136	221	199	113		
13	Apas Kiri Lower - Conical S	02-Oct-13	spr	**73.2**	0.01	6.80	1280	128	----	100	----	52	----	8	1.95	157	192	192	11	138	223	201	114		
14	Apas Kiri Lower - Conical S	02-Oct-13	spr	**73.1**	0.01	6.50	1258	128	----	100	----	52	----	8	2.02	156	193	193	10	141	224	203	114		
	Zone:	**A3-T**																							
15	Apas Kiri Lower - Terrace	01-Jul-91	spr	**60**		7.40	1250	129	----	101	----	53	----	10	1.86	158	191	191	23	79	219	196	97		
17	Apas Kiri Lower - Terrace	27-Apr-04	spr	**54.2**		7.75	1231	118	----	90	----	42	----	----	1.96	148	182	182	10	139	207	182	110	204	
18	Apas Kiri Lower - Terrace	27-Apr-04	spr	**60.7**		7.69	1213	121	----	93	----	45	----	3	2.09	148	185	185	10	140	214	190	111	181	128
19	Apas Kiri Lower - Terrace	27-Apr-04	spr	**67.8**		7.56	1198	125	----	97	----	49	----	6	2.05	148	185	185	10	139	213	189	111	166	128
16	Apas Kiri Lower - Terrace	27-Apr-04	spr	**41.1**		7.66	1078	119	----	90	----	43	----	1	2.23	143	184	184	10	141	213	189	109	167	
20	Apas Kiri Lower - Terrace	27-Apr-04	spr	**68.8**		7.83	1218	127	----	99	----	50	----	7	2.06	149	186	186	10	140	214	191	111	159	
23	Apas Kiri Lower - Terrace	18-Sep-13	spr	**29.7**		7.52	2	80	----	48	----	14	----	----	#####	19	182	19	30	----	348	375	-16		
21	Apas Kiri Lower - Terrace	18-Sep-13	spr	**67**	0.01	6.50	1278	128	----	101	----	53	----	9	1.97	155	190	190	10	138	220	198	113		
22	Apas Kiri Lower - Terrace	18-Sep-13	spr	**43.7**		6.90	1124	120	----	91	----	44	----	1	2.05	153	190	190	11	133	220	198	111		
28	Apas Kiri Lower - Terrace	02-Oct-13	spr	**66.8**	1.38	6.30	1270	127	----	99	----	51	----	8	2.01	155	191	191	11	138	222	201	113		
24	Apas Kiri Lower - Terrace	02-Oct-13	spr	**60.5**	0.01	6.30	1201	124	----	96	----	48	----	5	2.11	151	190	190	10	139	222	200	112		
25	Apas Kiri Lower - Terrace	02-Oct-13	spr	**68.8**	2.72	6.20	1277	128	----	100	----	52	----	8	2.05	153	190	190	10	139	221	200	112		
26	Apas Kiri Lower - Terrace	02-Oct-13	spr	**68.6**	4.75	6.20	1245	127	----	99	----	51	----	8	2.05	154	191	191	10	139	222	201	113		115
27	Apas Kiri Lower - Terrace	02-Oct-13	spr	**69.2**	3.36	6.30	1268	128	----	100	----	52	----	8	2.03	154	191	191	10	139	222	201	113		

GeothermEx (2014) reviewed the TGE MT resistivity model and commented further as follows:

- The MT data clearly suggests the presence of a low resistivity layer in the shallow subsurface of the type conventionally considered to be the hydrothermal alteration cap over an extant or former geothermal reservoir
- The possible reservoir areas as defined by the shallow resistivity anomaly extends somewhat to the NE of the survey area and the outline shown of 14km2 could underestimate its extension in that direction. In contrast, the SE boundary and E boundary of the anomaly is within the survey area but somewhat poorly defined (See Figure 6.)

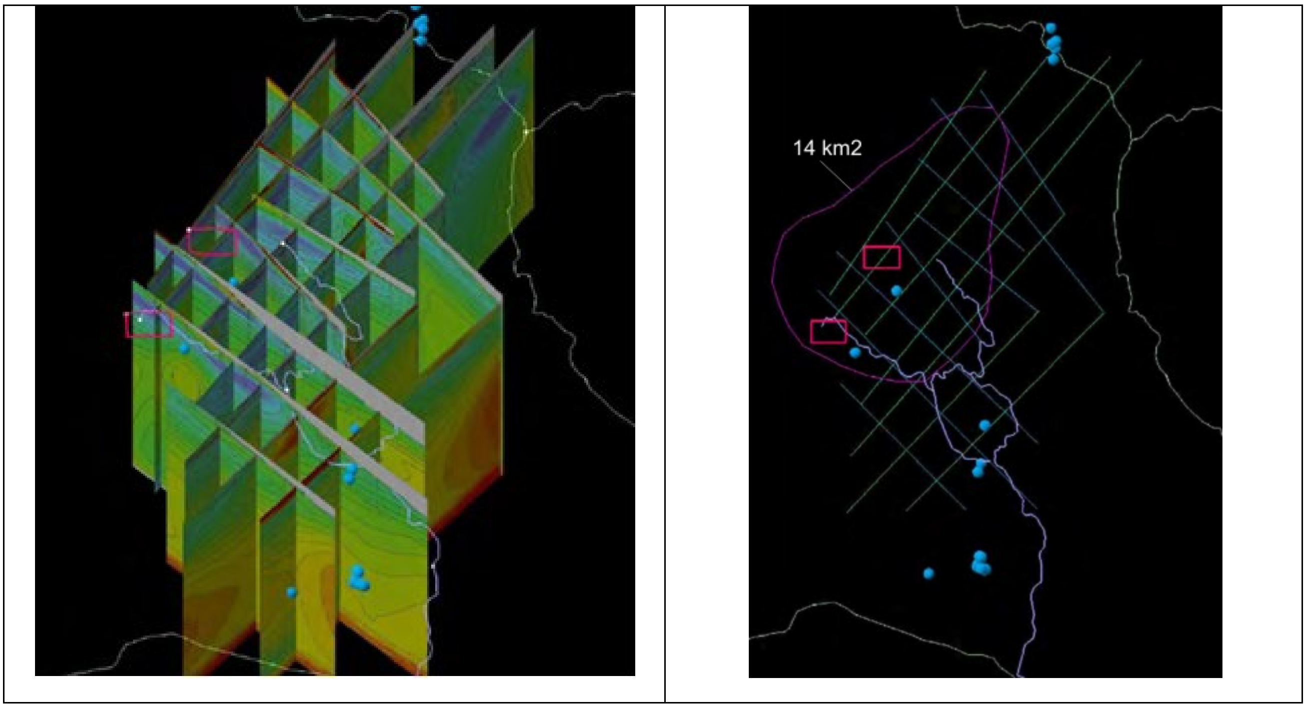

Figure 6: Petrel Model of the MT data for the Apas Kiri Project showing MT resistivity cross sections, planned well pads (red rectangles, spring sampling locations (blue spheres) and project roading. (From GeothermEx, 2014)

7. CONCEPTUAL EXPLORATION MODEL

Figure 7 shows a conceptual model for the Apas Kiri Reserve that synthesizes the salient geological, geochemical and geophysical features of the Apas Kiri Resource. It is based on a N-S section through the project area. The section includes the northern rim of the Mt Maria caldera upon which the Balung spring is located.

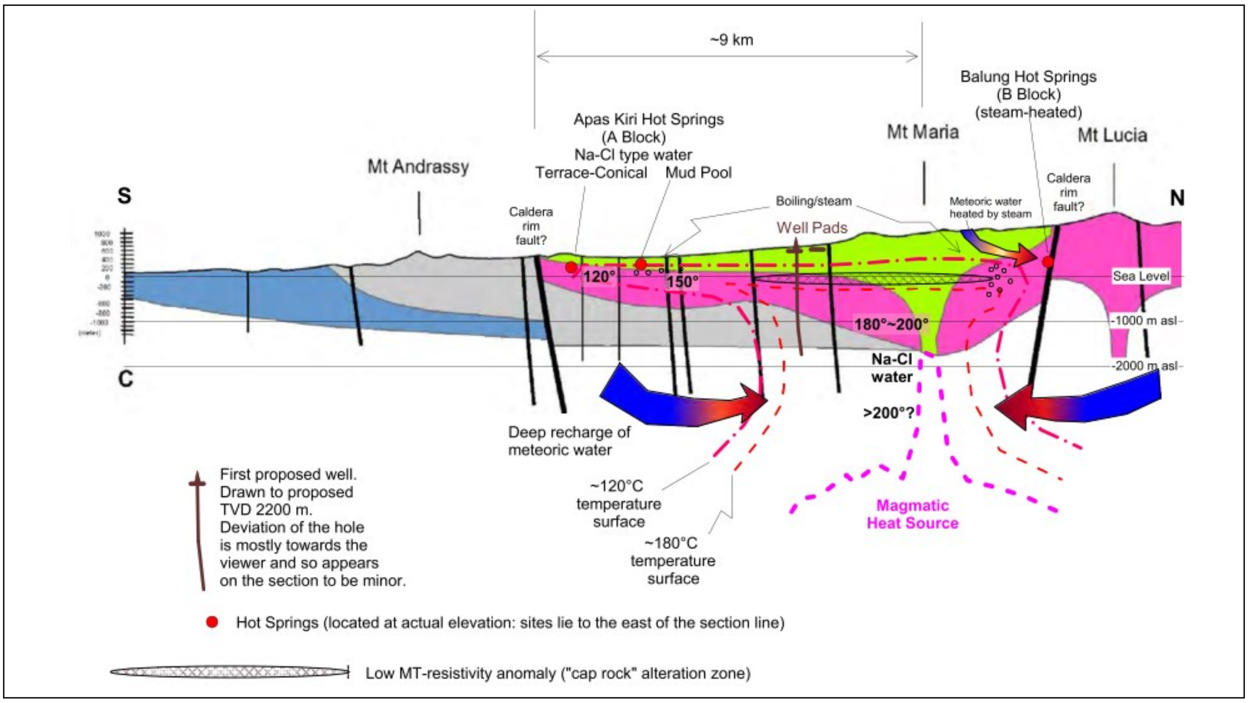

Figure 7: Preliminary Conceptual Hydrogeological model for the Apas Kiri geothermal field (after GeothermEx 2014)

The geothermal resource is centered approximately under Mt Maria with an upflow temperature of 180 to 220°C. Minor outflow occurs to the NE toward the steam heated Balung hot springs and a shallow plume of hot water with minor boiling flows to the South with discharge at the mud pool and Apas Kiri springs. This southern plume is shown with a strong convective overturn and with cooler water beneath it. The model might over emphasize this overturn but discharge plumes that are long and narrow like that shown in Figure 7 have been well documented elsewhere. The flow to the hot springs occurs either along the contact between younger Mt Maria volcanics and the older volcanics of Mt Lucia, and or within the Mt Lucia voclanics. It is mostly confined beneath the lower resistivity anomaly, interpreted as a cap of hydrothermal alteration over the reservoir. The overall resource area is conservatively estimated at 14 km^2.

8. PRELIMINARY ASSESSMENT OF RESOURCE CAPACITY

A probabalistic volumetric estimation method (Monte Carlo simulation) has been used to assess the nominal heat capacity of the Apas Kiri geothermal resource (GeothermEx 2014). The results were then modified with reasonable assumptions made about the percentage of heat that can be expected to be recovered at the well head and the efficiency of converting the wellhead heat to electrical energy. This procedure and the manner which it is reported here is more or less consistent with the approach proposed in the Australian Geothermal Resource Reporting Code, AGEA and AGEC (2010).

The critical resource parameters and ranges used in the assessment are supplied by the resource model (Table 3). Of note is the resource abandonment temperature which means that the resource at an assumed mean temperature of 185C has heat extracted done to only 170°C and all further production is then abandoned . However the heat in the rock could be extracted down to about 100°C using Organic Rankine cycle technology thus this method of assessment is conservative. Additionally the most likely resource temperature of 185C (essentially based on the H_20-SO_4 O-18 geothermometer) is also a conservative value and it may well prove that the resource temperature is more than 220°C (the average temperature of all eight Na/K geothermometer estimates is 221°C- see Table 2).

The results of the Monte Carlo simulation based on the parameters described above give a calculated 50% probability distribution for recoverable reserves for 30 years of 85 MWe (net), see Figure 8. Under the Australian Reporting Code this estimation is for an "Inferred Resource"

Table 3: Summary of Input Parameters for Resource Capacity Assessment (From GeothermEx, 2104)

Variable	Minimum	Most Likely	Maximum
Variable Parameters			
Reservoir area (sg.km.)	7.00	14.00	17.50
Reservoir thickness (m)	1000	1250	1500
Rock Porosity	0.03		0.07
Reservoir Temperature (°C.)	170	185	195
Recovery Factor	0.05		
Fixed Parameters			
Rock Volumetric Heat Capacity	2613	kJ cu m°C	
Rejection Temperature	26		
Ultization Factor	0.45		
Plant Capacity Factor	0.9		
Power Plant Life	30	years	
Resource Abandonment Temperatire	170	°C	

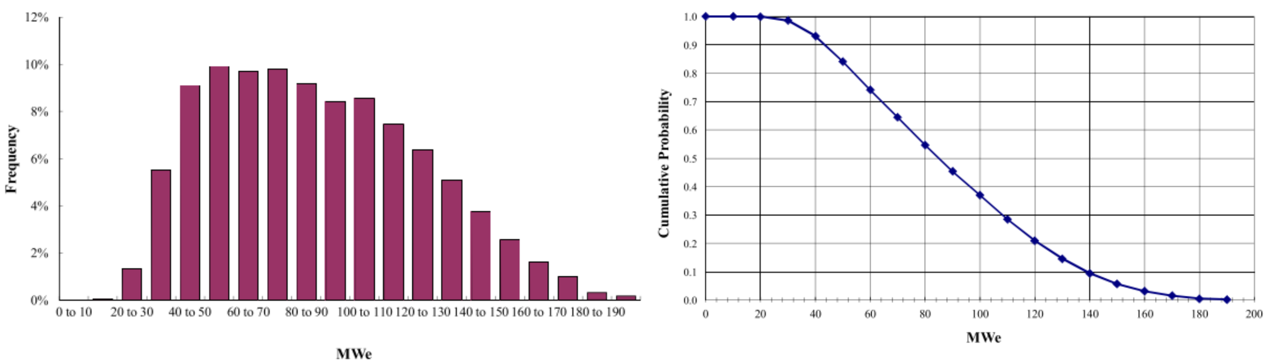

Figure 8: Histogram of recoverable geothermal resource (left) and Cumulative Probability of Recoverable Energy Resource (right), at 50% Probability Level. (From GeothermEx, 2104)

9. EXPLORATION DRILLING STRATEGY

The objectives with exploration drilling are to initially prove geothermal resource temperature at or above about 200°C and then prove that the resource has good permeability over sufficient resource volume to generate the desired 35 MWe of net plant capacity. From the resource assessment the power density for the Apas Kiri Resource averages about 7 MWe//km^2. To prove up 35MWe will then require the drilling and design of about 5km^2 of geothermal resource. The two wells pads shown in Figure 6 have been chosen to give a good test of about 5km^2 of geothermal resource in what is indicated to be the hottest portion of it. The resource may yet extend further to the North and West and more MT is being undertaken to confirm this and drilling may yet be undertaken in these areas.

The project has an exceptionally well developed geological structure with a number of major transcurrent faults running through it. This argues that the likelihood of encountering strong fault related permeability during drilling is high. In order to maximize this potential, the two exploration wells will be drilled directionally, orientated on azimuths of 90 and 180 degrees to maximize structural intersections with the dominant NW-SE and NW-SW trending fault patterns.

With a moderate resource temperature of about 200°C and relatively high well elevations (of up to 600m MSL) it is unlikely that the Apas Kiri wells will sustain geothermal production thus TGE plan to install a down hole shaft pump into each production well. An additional advantage is that this will allow for the resource to be produced at whatever production rate well permeability will allow and this will tend to minimize the initial number of production wells required for the development and limit the number of "Make up and Replacement wells" required to be drilled with production time to compensate for resource pressure run down. Another advantage of using an organic Rankine power cycle is that project will achieve 100% reinjection thus further minimizing pressure run down in the production wells.

The major surface geothermal manifestations at Apas Kiri deposit calcium carbonate scale at their points of surface discharge. The resource fluids at 120°C are therefore clearly carbonate oversaturated and this may pose problems with calcite scaling in surface equipment in any field development, However the use of downhole pumps can be used to maintain high pressure through the steam field fluid collection system and through the organic Rankine cycle power plant heat exchangers to inhibit or at least minimize carbonate scale problems.

10. CONCLUSIONS

A surface exploration study has been successfully completed by TGE at the Apas Kiri Geothermal field in Eastern Malaysia. The results provide good evidence for an exploitable geothermal resource of about 14km^2 areal size and with temperature about 200°C and with about 85 MWe of resource capacity at a P50 level of probability.

Given the moderate resource temperatures it will likely prove that the production wells will need to have down well production pumps installed and that due to steam flash limitations, a power plant based on an organic Rankin cycle power cycle will need to be installed. This has a number of technical advantages including:

- Maximizing production wells flow thus minimizing the number of production well required
- 100% reinjection which will minimize the number of "make-up and replacement" wells that need to be drilled with production time
- The use of production pumps will allow production pressure throughout the steam field collection systems and organic Rankin cycle power plant to be maintained above saturation thus mitigating potential scaling problems with calcium carbonate

TGE is now in the late stages of preparing to drill two deep and deviated exploration wells. These are being targeted with close attention to the well-defined structural geologic fabric of the project area. The drilling of these two wells will prove up a resource volume of some 5km^2 which should be adequate to develop a 35 MWe (gross) power plant.

REFEREENCES

AGEA and AGEG, (2010): The Geothermal Reporting Code - Australian Code for Reporting of Exploration Results, Geothermal Resource and Geothermal Reserves, Second Edition 2010. Prepared by the Australian Geothermal Code Committee, AGEA and AGEG.

Balagaru A. and R. Hall (2009): Tectonic evolution and sedimentation of Sabah. North Borneo, Malaysia. AAPG International Conference and Exhibition, Cape Town, South Africa, (2009).

Chong L.H.H. and Mohd N, D. (2000): Tawau Hill Park springs, Sabah, Malaysia, GHC Quarterly Bull, Vol 21(4) 3-4. (2000).

Daud Y., Javino F., Nordin M.N.M., Razak M., Amnan I., Saputra R., Agung L., and Sucandra, (2010): The first magneto telluric investigations of the Tawau Geothermal Project, Sabah, Malaysia. (2010). Procs. World Geotherm, Congress (2010), Bali Indonesia, 25 – 29 April 2010.

Fournier R.O: (1990): The interpretation of Na-K-Mg relations in geothermal waters. Geoth. Res, Council Trans Vol 14 Part II pp 14210 1425 (1990).

GeothermEx (2014): Apas Kiri Geothermal Project, Sabah, Malaysia – Assessment of exploration data and conceptual model, resource capacity estimate, drilling sites and targets, Unpublished Letter Report (2014), prepared by GeothermEx dated 21 March 2014 R1.

Giggenbach W.F. (1988), Geothermal Solute Equilibria, derivation of Na-K-Mg-Ca geoindicators. Geochemica and Cosmochimica Acta 52(12) 2749 -2765. (1988).

Jovino F., Suratman S., Pang Z., Choudhry, M.A., Caranto J., Ogena, M., and I Amnan (2010): Isotope and geochemical investigations on Tawau Hot Springs in Sabah, Malaysia. Procs. World Geotherm, Congress (2010), Bali Indonesia, 25 – 29 April 2010.

Kirk, H.J.C; The Geology and mineral resources of the Semporna Peninsular, North Borneo, Borneo Geol. Survey Mem 14:178, 1962.

Santoyo E. and L. Dias-Gonzales (2010): A new improved proposal of the Na/K geothermometer to estimate deep equilibrium temperatures and their uncertainties in geothermal systems, Procs. World Geotherm, Congress (2010), Bali Indonesia, 25 – 29 April 2010.

Takashima I., Nazri A.A., Siong L.P., Takahiro K., Mouri Y., Asnawir N., and I.G.N. Eddy Sucipto (2005): Precise thermoluminescence dating for heat source volcanic rocks and alteration products at the Tawau geothermal Area, Sabah, Malaysia, Procs. World Geotherm, Congress (2005), Anatalya, Turkey, 24 – 29 April 2005.

TGE (2013a): Magneto Telluric (MT) Prospecting, Geothermal Power Plant Project, Apas Kiri Geothermal Field, Final Report; Tawau Green Energy Sdn. Bhd., December 2013 (unpublished Report).

TGE (2013b): Geology of Apas Kiri Geothermal Prospect, Tawau, Sabah, Malaysia; Final Report, Tawau Green Energy Sdn. Bhd., TGE Geothermal Power Plant Project, 2013 (unpublished Report).