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THE CHEMISTRY OF GEOTHERMAL FLUIDS IN INDONESIA AND THEIR RELATIONSHIP TO WATER AND VAPOUR DOMINATED SYSTEMS

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ABSTRACT

As part of the initial assessment of the geothermal power potential of Indonesia an electronic model, (IGSEP), Mahon, (1987), was developed to prioritise the most favourable resources and determine the least cost development scenarios for generating geothermal electricity. The model was tested and assessed using data from 100 different geothermal prospects in the country. This involved researching and collating the scientific information and in particular reviewing the chemistry of discharge fluids.

These chemical relationships are discussed in reference to the formation of water dominated geothermal systems and, in some cases, their subsequent evolution to vapour dominated systems. There is also a close relationship between active volcanism and meteoric-derived geothermal fluids.

The unique geographical location of many Indonesian geothermal systems at high elevations of 1500-2000 m.a.s.l has lead to a characteristic set of chemical compositions in the shallow and deeper fluids associated with the individual systems.

1. INTRODUCTION

Serious exploration of the geothermal resources of Indonesia commenced in the early 1970s. Major development of these resources began in the late seventies and has continued to the present day. Figure 1 shows some of the developed geothermal areas of Indonesia discussed in this paper. Generation of geothermal electricity had grown to around 550 MWe by the beginning of 1999. Much of the early work, both exploration and development, was progressed under aid programmes supported jointly by the New Zealand and Indonesian Governments and also to a lesser extent by funding through a US aid programme. More recently, developments have been undertaken by independent power producers, (IPP's) and by joint ventures between the Indonesian Government and private companies.

Assessment of the geothermal resources of Indonesia was initially determined with an electronic programme written to prioritise the various resources within the country on a least cost development basis. The programme, generally know as IGSEP, the Indonesian Geothermal Study and Evaluation Programme, was discussed in some depth by Mahon et al, (1995) at the IGAWGC meeting. In essence over 100 geothermal systems were reviewed and catalogued in this exercise. As part of this assessment the chemistries of many geothermal systems were reviewed and results tabulated within the model and programme.

Indonesia is a land of volcanoes being one of the most prolific and active zones of volcanism in the world. The volcanoes of geothermal interest are dominantly andesitic and the characteristic cones of strata volcanoes can be recognised throughout the landscape of the country. Many of the countries geothermal areas occur on or adjacent to these volcanic edifices and complexes. Frequently, more than one geothermal area was found to be associated with a volcanic complex although only a part of the complex was still volcanically active, e.g. Guntur and Kamojang. Calcareous sediments of Tertiary age frequently underlie much of the Quaternary andesitic volcanism and play a role in the chemical evolution of the local hot fluids. The 1500 to 1800 m elevations of many of the local geothermal systems give rise to specific physical and chemical characteristics in the systems.

The extensive volcanism and the presence of many geothermal systems throughout Indonesia makes the country an attractive target for the generation of geothermal electricity. Geothermal energy similarly provides an alternative renewable energy resource to diesel or mini-hydro for rural electrification. In recent years the reducing cost of geothermal exploration and drilling and the use of slim wells in exploration has increased the viability of small-scale geothermal developments. The operation of small geothermal turbines of between 0.25 to 5 MW is now being undertaken. With time the use of geothermal energy for industrial processing is likely to play a more significant role in the economics of small-scale island and rural electrification.

2. THE NATURE AND CHEMISTRY OF SURFACE MANIFESTATIONS AND DEEP FLUIDS.

2.1 General Considerations.

Major geothermal developments have occurred at sites throughout Indonesia, Figure 1. These sites encompass Java, Sumatra, Sulawesi and a number of smaller islands, including Bali and Flores to the west of Java. The number, variety and characteristics of the sites provide an excellent coverage of the geothermal resources of the country.

Early exploration and geothermal developments at Kamojang and Darajat in Java suggested that they were vapour dominated and similar in their physical and chemical characteristics to systems elsewhere such as Matsukawa in Japan. The physical similarity (although to a lesser extent because of the major differences in geology), could be extended to other vapour dominated systems such The Geysers in California and Larderello in northern Italy. However, the investigations carried out during the IGSEP program indicated that many of the geothermal systems were water dominated containing sodium chloride as the major water constituent. As such they were considered to be similar to Wairakei in New Zealand, Tongonan in the Philippines or Kakkonda in Japan.

The association between many hot neutral chloride water spring areas and the local volcanism did not become apparent until deep drilling at a number of sites was carried out. The elevation of the local terrain and volcanic edifices, and their hydrological settings allowed deep up-welling hot sodium chloride waters to migrate considerable distances, 10 km or more, from their original source. This had also been recognised in the Philippines, particularly during the early work at Tongonan, (Lovelock et al, 1987). A similar type of long distance hot water migration had been identified at El Tatio in the Chilean Andes (Cusicanqui et al, 1975). It was apparent, following the major IGSEP reconnaissance and some deep drilling, that the main heat sources and geothermal reservoirs, giving rise to hot spring activity, particularly of the sodium chloride water type, could lie some considerable distance from the sites of hot springs. In contrast, the fumaroles, steaming ground and other types of hot spring waters were located much closer to the upflow or high temperature zones of the active geothermal systems.

The physical relationship, chemical characteristics of fluids and genealogy between vapour and water dominated geothermal systems have followed a natural learning curve as more and more systems have been researched and discovered. The desire for steam production has often overwhelmed the need to elucidate the nature of the fluids producing the steam. A considerable time elapsed before the nature of the fluids at some of the vapour dominated sites was published and discussed in general scientific forum. The nature of the end members of each type of system was researched and considered in great detail but little was published on the transient nature of both systems and the conversion of one into the other. Obviously the increasing number of high elevation geothermal systems investigated in detail over the last twenty years, has enabled a much better understanding of the relationships between the two types of systems.

2.2 Fluid Compositions

Table 1 shows representative chemical compositions of a number of hot springs in Indonesia and gas compositions of steam from a number of fumaroles from two locations. The table also includes the compositions of waters discharged from geothermal wells in the same locality or sampled from wells, in the locality, using down-hole sampling devices. Concentrations are given in mg/kg. The gas samples are not extensive as the results are used only to indicate the effect and influence that steam compositions could have on different waters associated with the local geothermal systems. The steam compositions in different geothermal areas vary in the absolute concentrations of the gases present. However, the overall compositions and relative proportions of the gases in the different geothermal areas throughout the country are very similar. Gas compositions in geothermal areas in Indonesia are the subject of a further paper in preparation.

During the early investigations at Kamojang in Java, both shallow and deep production wells, were drilled to define the system. This enabled a full suite of water samples from different depths within the system to be collected, analysed and reviewed. Although not as detailed, similar sample collections were made at an early exploration stage at Darajat. Some of these results appear in Table 1. A reasonably comprehensive set of chemical data is thus available from two of the best known of the vapour-dominated geothermal systems in the country.

2.3 Chemical Nature of Fluids

Chloride Waters

The appearance and discharge of near neutral, boiling, chloride water at higher elevations in the various Indonesian systems is relatively rare. Certainly it is far less frequent than is found in springs of geothermal systems that are located near to sea level and close to the local cold water table. However, chloride water is present in a large number of the local springs as mixed chloride waters, where the sulphate and bicarbonate ions are present at concentration levels similar to the chloride concentrations. These springs are generally not boiling but have temperatures of around 50-80°C. Most of the springs are located both on the lower flanks and at considerably lower elevations on the volcanic complexes and offset some lateral distance from the main hot water reservoirs. Geophysical techniques such as magnetotellurics (Anderson et al. 2000), have proven to be a very useful exploration tools for locating upflow zones by defining the subsurface profile of conductive clay alteration above these deep systems.

The neutral hot chloride water within the main geothermal reservoir is unable to reach the surface near the system but is driven by the hydraulic gradient of cold ground water to lower elevations. Given favourable geological and hydrological surface expression, it emerges as hot chloride water springs somewhat diluted and compositionally changed by groundwater contamination. Typical systems where this occurs are shown by samples S5, S6, S7, S8 and S9 in Table 1.

In other systems there is no compelling evidence for the presence of chloride water, either at shallow or deep levels, in the environments of the systems. One concludes that these systems are devoid of this constituent and water type, at least at levels down to two to three thousand metres. Alternatively if these waters do exist they are diffused through the system and are not readily available to any surface or well discharge. Kamojang and Darajat are generally characteristic of this situation although there is evidence from shallow wells at Darajat that there is/was some diluted chloride water at shallower levels in the system.

Similarly early discharge evidence from several deep wells at Kamojang indicated the presence of chloride water at deeper levels. Nevertheless no chloride water appeared in the discharges of surface manifestations, (springs or fumaroles), from either of these areas. The detection of chloride water is most likely to be made during the early discharges of wells before there is any local dry out of the reservoir. In many explored and developed vapour dominated systems this information was never made available due to the methods employed in drilling and testing wells.

The appearance of near boiling, neutral, chloride water at the surface in Indonesia is thus very much related to the topography, the local surface hydrology and the hydraulic gradient relative to the local cold water sink. If conditions are not favourable, then the chloride water is dispersed into the local ground waters and disappears, never appearing on the surface. In the case of Gunung Salak very little chloride water appears on the surface in the close vicinity of the volcanic complex. The water that does reach the surface, although of reasonably high chloride content, is only tenuously attached and connected to the system. It appears as though the deeper chloride water of around 4000-6000 mg/kg underlying the system and discharged by the deep production wells has little access to the surface. A similar situation occurs at Wayang Windu where no chloride water has been recognised in surface discharges. However, concentrated brine of around 20000 mg/kg occurs at depth. In the early exploration history of these two systems Salak was always considered to be water dominated whereas Wayang Windu was considered to have a high likelihood of being a vapour dominated system. The major reason for this hypothesis was that chloride waters were evident at Salak but not at Wayang Windu.

Although some of the surface hot springs in Indonesia have relatively high chloride concentrations, (several thousand mg/kg) the majority contain low to medium concentrations of the order of several hundred to a thousand mg/kg. For comparison the chloride concentrations in hot springs discharged from hot chloride water reservoirs in andesite hosted geothermal systems world-wide are frequently of the order of several thousand mg/kg. The surface hot chloride waters in Indonesia would be considered to be of the more diluted type and this dilution is probably related to the height to which the water must rise before it becomes accessible to the surface.

In contrast, fluids in active volcanic craters and areas of active volcanism in Indonesia do contain high concentrations of chloride, as well as sulphate, in surface discharges. The chloride concentrations that can rise to 20000 mg/kg or more, and the frequency of associated acidity in the waters, (pH<2), are commensurable to the addition of magmatic gases and/or volcanic fluids to the surface waters. Ijen Crater Lake in east Java, (sample L14 in Table 1) and some of the fumarolic steam and surface hot waters from Papandayan, near Darajat, are typical of this type of fluid.

There is now significant chemical evidence to suggest that magmatic fluids tend to be concentrated and perhaps even confined into zones of magmatic gas emissions from active volcanic vents and craters. Pools rather than reservoirs are formed and there appears little general dissemination of these fluids thoughout a reservoir system, Mahon and McDowell, (1977). Kelimutu on Flores in East Indonesia has three lakes, two of which are magmatic (e.g. Keli Tin - sample L16) while an adjacent lake, several hundred metres away (KeliTam – sample L15) is geothermal with no magmatic input.

Although the deep chloride water and the associated reservoir can be confined to a deep level and may never appear at the surface, the steam and gases boiled from the reservoir can migrate almost vertically to the surface. Some of this steam and gas appears as fumaroles or/and steaming ground and steam heated ground water. Depending on the shape and nature of the local catchment area, large volumes of near boiling sodium/calcium/ bicarbonate/sulphate water can accumulate above the chloride water reservoir, (discussed below). Due to the reactivity of the gases and the alteration minerals formed as a result of hydrothermal alteration, the upper reservoir can become an entity by itself and sometimes becomes separated and isolated from the underlying chloride water reservoir.

Non Chloride Waters

Most of the hot waters occurring above and on the sides of the reservoirs of near neutral chloride waters, in water dominated systems, contain sodium, calcium, and magnesium as major cations with bicarbonate, carbonate and sulphate as the major anions.

The predominance of carbonate, bicarbonate and sulphate as the major anions in these waters particularly the bicarbonate and sulphate ions, is due to the way in which these waters are formed. Steam derived from the deeper chloride water reservoir migrates towards the surface, often nearly vertically due to the buoyancy of the steam, heating, condensing in and reacting with the local cold ground water. This upper reservoir is initially cold, low chloride ground water of meteoric origin. The major gases contained in geothermal water and steam associated with andesitic volcanism are carbon dioxide and hydrogen sulphide. Condensation of gaseous hydrogen sulphide and carbon dioxide into oxygenated near surface waters results in the formation of sulphuric acid and carbonic acid. This gives rise to a variety of solution compositions and conditions varying from highly acid to near neutral waters or in some cases to rather alkaline environments. Where hydrogen sulphide oxidation controls the water pH, the waters may become very acid (S1 and S3), whereas when only carbon dioxide is present neutral to alkaline solutions are prevalent. The concentrations of hydrogen sulphide in the waters depends on the distance travelled by the migrating steam. Once this gas is removed, by oxidation or rock/water interaction, the solution pH becomes dependant on the carbon dioxide/bicarbonate or bicarbonate/carbonate buffer. Water compositions thus tend to vary depending on their distance from a source or reservoir of geothermal fluid.

As the upper reservoir develops and thermal equilibrium is attained a balance is reached between the proportion of original cold meteoric water and added steam condensate. At Kamojang, in its pre-development stage, isotopic evidence indicated that there was approximately a 50% mix between these two fluids. This is a dynamic reservoir with steam and heat addition from the base and ground water addition and replenishment as well as extraction from the top. The throughput and quantities of non condensable gas in the system is immense and this is frequently seen as the ebullition of gases in the crater lakes atop these systems, as for example that occurring in the crater lake at Darajat.

The shallower, although they may extend for several kilometres, non chloride waters form the bulk of the fluids in vapour dominated systems and in fact are the dominant waters occurring in and discharged from hot springs in Indonesia. Where the tops of these reservoirs outcrop at the surface, the waters are discharged as hot springs. Similarly where geological or other permeable features, such as degrading rivers intersect the reservoirs, the water is discharged to the surface at an elevation commensurable to the permeable feature. This situation occurs at both Kamojang and Darajat where the major rivers draining the areas contain a high proportion of this type of water.

A relatively detailed study of the relationship between the shallow neutral bicarbonate sulphate waters and the deep reservoir at Kamojang suggested that the waters had attained a significant amount of chemical stability with the confining rocks for the measured water/reservoir temperature. In this sense, they behaved similarly to the deeper chloride waters in other systems in that both waters attained mineral equilibrium. Although the minerals controlling the various temperature dependent equilibrium were in some cases different, many were the same. For example the main mineral controlling the concentrations of silica in both types of water, certainly above 200°C, was quartz. Even the water/rock equilibrium controlling the alkali geothermometers in chloride waters, such as Na/K and Na/K/Ca, appeared to be present at medium to higher temperatures of 150 to 230°C, in the non-chloride water reservoir. The thermal equilibrium that existed in the shallower parts of the reservoir indicated that the upper non-chloride reservoir was an integral part of the geothermal system and indeed was probably as important a component in the system, as the lower chloride water reservoir.

The ready deposition of calcite and anhydrite in the shallow reservoir and the general reactivity of the chemical species present, give rise to a relatively impermeable rock matrix. In contrast, the steam and non-condensable gas pressures and the changing acidity of the fluids present in the upper parts of the deep reservoir both add to the ability of the reservoir to retain major mass permeability. Wells drilled into this matrix may produce very large amounts of steam even though the overall matrix permeability is rather small. Similarly the permeability and rock porosity are very much in favour of steam rather than hot water production.

Above the main zones of stabilised fluids, stabilised in the sense that the waters are partly or wholly in temperature equilibrium with the confining rocks, the hot surface water compositions are mainly controlled by rock water interaction, oxidation and mineral precipitation.

Distribution of Water Types in Different Indonesian Systems

At Kamojang, the water table in the shallow (600-700m) exploration wells occurred at around 135 to 170m depth below the surface. The surface temperature of this water was around 60°C and it was slightly acid. It contained as major constituents sodium, and calcium bicarbonate and sulphate although bicarbonate occurred as carbonic acid near the surface acid interface zone. No calcite was found in cores taken from the wells near this depth commensurable to the slightly acid nature of the water and the instability of calcium carbonate under these conditions. With increasing depth within the reservoir, the waters gradually increased in temperature, not necessarily with boiling point for depth, although this relationship was found in a number of wells. The composition of the waters changed from calcium and magnesium rich to sodium rich with decreasing amounts of both sulphate and bicarbonate with increasing temperature (W10). The alteration mineralogy showed increasing calcite with associated anhydrite, as water pH's increased to neutral or slightly alkaline at the temperature.

No permanent chloride water was found in down-hole water samples collected from the shallow wells at depths up to around 700m. The samples were collected previous to well discharge or shortly thereafter. In contrast, chloride water was detected in a number of the deeper wells before the wells went dry on discharge. In the case of well 13 this water discharged for some time and also showed an anomalously high maximum temperature of 260°C at different times. This compared with the 230-240°C present in the rest of the local Kamojang system that is characteristic of the physical conditions in most vapour dominated systems. Kartokusumo et al, (1975), showed that there was some chemical homogeneity in the chloride waters detected at Kamojang and suggested that they represented a residual fluid from a chloride water reservoir. However, the absolute concentrations of chloride were significantly different at the locations where the water was detected, indicating that concentration, dilution and dispersion of any original chloride water reservoir had certainly occurred.

A band or zone of quartz mineralization was discovered in a number of wells at a depth close to the shallowest level that chloride water was detected. This zone appeared to represent a boiling surface at the upper level of a chloride water reservoir. It also appeared to represent the boundary between the underlying chloride water system and the development of the upper non-chloride reservoir. Concentration of the mineral forming constituents, such as calcium, bicarbonate, sulphate and silica, in this interface zone, from boiling and loss of steam, resulted in mineral deposition and the development of brine in this zone. As indicated in an earlier section, the quartz and alkali ion concentrations in the upper Kamojang reservoir were in equilibrium at the measured temperatures with the associated andesitic rocks, demonstrating thermal and chemical stability within the zone.

Fluid conditions and chemical compositions at Darajat were somewhat similar. The major volume of shallow water below the local water table, down to a depth of six or seven hundred metres, is near neutral sodium bicarbonate sulphate water. However, the concentrations of chloride in the water in the shallow wells (W11) in some cases appeared higher than the background level in the local cold water environment. These localised high concentrations were not seen in any of the active hot fluid discharges or the hot waters draining the area. Similarly, the elevated concentrations occurred at the deeper levels of the shallower reservoir and appeared to be related to the stagnant but hot parts of the reservoir. It appeared that they resulted from localised boiling, either before or after the wells had been drilled.

3. CONCLUSIONS

The ability for deep-seated convecting chloride water dominated reservoirs in Indonesia to reach the ground surface, and discharge as hot springs, is dependent on a number of physical parameters operating in the system. The relationship between the hot hydrostatic pressure in the reservoir and the external cold water pressure in the local cold water sink determines the main hydraulic drive in the deep convecting fluid. The high elevation of the majority of Indonesian geothermal systems requires a relatively high driving force/pressure to enable the hot water to ascend to the surface and discharge. When the systems are young the driving force/pressure is appreciable and surface discharges of chloride water and shallower chloride water reservoirs can be expected.

However, the geological environment of the Indonesian geothermal systems and the overall difficulty of the chloride water reaching the surface are more conducive to the formation of major shallow reservoirs of non-chloride waters confined within major volcanic edifices and complexes.

During the transition from active volcanism to the development of geothermal reservoirs there is a general cooling of the environment as the magma temperatures decrease with time. At shallower depths fluid temperatures and vapour pressures decrease, reducing and restricting the height to which the deep chloride water can rise and reducing its mobility to circulate. The effect with time is to slowly confine the chloride water to levels and depths inaccessible to the surface. Steam and gas can continue to form from this reservoir and migrate upwards using the buoyancy of the vapour. The vapour acts as both a heat and chemical source for the upper non-chloride reservoir. As the chloride water reservoir loses its ability to reach the surface and falls in altitude and its temperature decreases, so the size of the upper non-chloride reservoir can grow.

The connection between the deep geothermal reservoir, the local cold water sink and the environment is crucial to the formation and structure of the entire system. Younger systems are likely to have chloride water reservoirs closer to the surface and when tapped by geothermal wells, to discharge this fluid. Older systems are likely to have reservoirs of non-chloride water reaching to deeper levels and to discharge steam and sodium/chloride /bicarbonate/sulphate waters from deep wells. There are transitional areas where the chloride water is still present at deeper levels in production wells. The major accessible parts of the system, however, remain in non-chloride water environments and as indicated earlier steam is more likely to be produced from wells than water.

Due to boiling in the upper part of the chloride water reservoir the salinity of this upper transitional zone is likely to increase as time goes on. The possibility, and in fact the probability of a brine, or highly saline 20000 mg/kg sodium chloride water developing near the interface zone between deep and shallow reservoirs is high. An example of this more concentrated brine interface zone may be present at Wayang Windu (W13).

The progression from one dominant form of system to another can perhaps be illustrated by four of the better know systems in Java. Kamojang and Darajat are vapour dominated, Wayang Windu is transitional and Gunung Salak is water dominated. Further study will help determine whether the transition is related to age, to changing hydrological conditions or to other factors.

REFERENCES

Anderson, E.B., Crosby, D.D.B., and Ussher, G.N.H. (2000). Bulls-eye! - Simple Resistivity Imaging to Reliably Locate the Geothermal Reservoir. In Press. Proc. WGC 2000.

Cusicanqui, H. and Mahon, W.A.J., Ellis, A.J. (1975). The Geochemistry of the El Tatio Geothermal Field Northern Chile. Proc. 2nd UN Symposium on Development and Use of Geothermal Resources. Vol. 1, pp 703-711

Harvey, C.C., Anderson, E.B., Johnstone, R.D, and Christyono (1998). Sokoria, East Indonesia: A classic volcano-hosted hydrothermal system. Proc. 20th NZ Geothermal Workshop 1998.

Kartokusumo,W., Mahon, W.A.J., and Seal, K.E. (1975). Geochemistry of the Kawah Kamojang System, Indonesia.. Proc. 2nd UN Symposium on the Development and Use of Geothermal Areas. Vol.1, pp 757-759.

Lovelock, B.G., Cope, D.M., and Baltasar, A.J. (1982). A Hydrogeochemical Model of the Tongonan Geothermal Field. Proc. 4th NZ Geoth. Workshop. Pt 1.

Mahon,W.A.J. (1987) The Indonesian Geothermal Study and Evaluation Report (IGSEP). GRC Bulletin, 11/87.

Mahon, W.A.J. and McDowell, G.D. (1977). Magmatic-volcanic steam: its role in geothermal systems. In Geochemistry 1977. A.J.Ellis (Ed)., D.S.I.R.., N.Z.

Mahon,W.A.J., Ussher, G.N., and Anderson, E.B. (1995). Exploration of Geothermal Systems through the eyes of a Geothermal Consulting Company. Proc. WGC 1995, pp. 2925-2927.

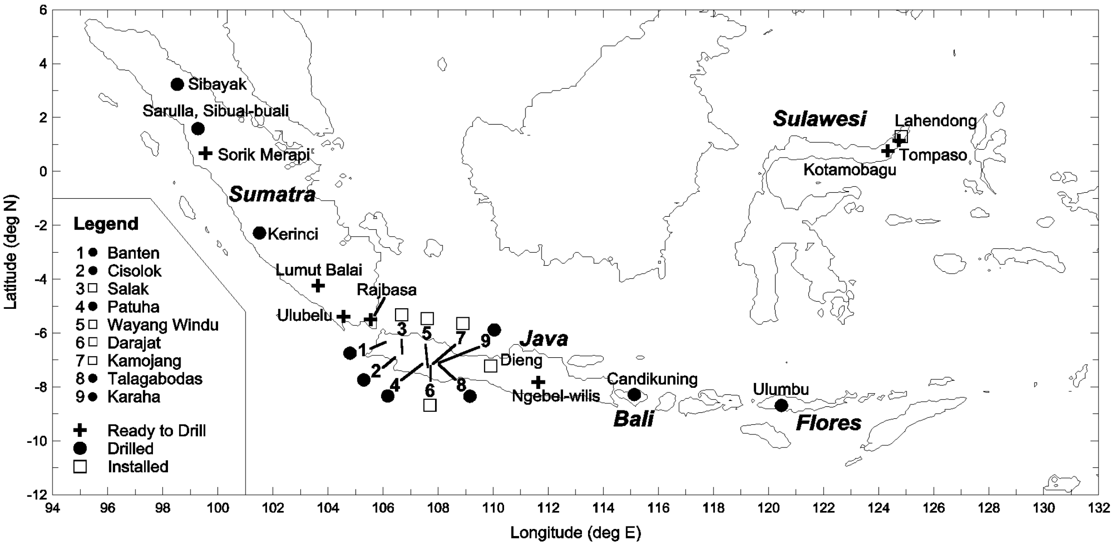

Figure 1 - Some of the developed geothermal areas of Indonesia

Table 1 - Chemical Composition of Springs and Geothermal Wells in Indonesia (Partial Analysis).

Location	Temp deg C	Sample Date	Elevation (m)	pH	Li	Na	K	Mg	Ca	Cl	B	F	CO2	SO4	SiO2
Kamojang S1	96	1972	1640	2.9	0	20	5	14.6	30.3	17	0.15		NIL	335	212
Kamojang S2	51	1972	1500	8.2	0.02	40	15	26	37	13	0.4		340	80	156
Darajat S3	77	1974	1850	3		13	5.7	10	17.5	3	0.5		NIL	1150	200
Darajat S4	40	1974	1620	4-5		6.3	2.6	6.2	1.6	14			100	430	150
Garut S5	40	1972	715	6	0.15	181	31	148	59	110	2.4		350	700	135
Cisolok S6	98	1974	240	8.7	2	440	31.5	2.2	8.8	405	23	1.9	150	130	200
Lahendong S7	88	1972	750	8.7	1	350	14	0.1	0.4	290	7.4		285	85	315
Ijen S8	52	1972	950	8.3	0.25	220	47	10.4	20.5	105	7.6		680	10	160
Sibayak S9	57	1989	1380	6.7	0.25	72	29.5	45	150	110	0.14		665	65	49.5
Kamojang W10	100	1974	1620	4-6	0.75	100	10	<0.1	<1.0	2			0-100	290	415
Darajat W11	100	1985	1800	7.1	1.4	1460	44	4.9	22.5	220	23.4		2680	685	255
Salak W12	100	1983	1200	6.7	12.4	3675	876	1	268	6810	258		37	20	495
Wayang Windu W13	100	1996	1700	6.3	33	11250	3060	0.6	885	22160	692		<10	75	355
Ijen Crater Lake L14	33	1972	2000	<1.0		800	1020	680	770	21800		400	NIL	62400	210
Keli-Tam L15	18	1994	1354	2.9	0.03	43	4	32	434	100	135	10	0	1475	178
Keli-Tin L16	32.7	1994	1394	0.3	1.5	1042	630	1194	1032	25600	135	2450	0	47000	183

S = Spring L = Lake W = Well conc. mg/kg

Fumarole Gas Compositions Kamojang & Darajat. Average Values

	CO2 Mole%	H2S Mole%	Residuals Mole%
Kamojang	96.6	1.85	1.65
Darajat	95	2.8	2.2

Residual gases are N2, H2, NH3 & CH4