HISTORY OF GEOTHERMAL EXPLORATION IN INDONESIA (1970-2010)

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ABSTRACT

The overview covers four decades between 1970 and 2010 and highlights exploration and developments of Indonesian geothermal prospects that began during the 1st decade with a US Aid study (Dieng 1970/1). It was followed by a NZ aid project with a survey of five prospects leading to exploration drilling at Kamojang and Darajat (1972/79). Indonesian counterpart organizations joined developments, involving VSI, PLN and Pertamina. Each group undertook surveys of new prospects and engaged already overseas consultants from France, Japan and Italy. A pilot plant (30 MWe) was under construction at Kamojang at the end of the 1st decade.

At the start of the 2nd decade, a presidential decree allowed Pertamina to enter joint operation contracts (JOC) with local and international partners such as Unocal and Amoseas to develop the Salak and Darajat fields. Pertamina started to use MT, airborne magnetic, soil gas, and T gradient surveys, mainly in Java, with variable success. VSI explored prospects in Sumatra and Sulawesi with drilling sponsored by Japanese Aid. Increasing overseas training was provided by Iceland, Italy and NZ. At the end of the 2nd decade, the installed power plant capacity was 140 MWe (Kamojang).

At the beginning of the 3rd decade, ten JOCs were signed with Pertamina as counterpart. These contracts involved mainly US companies to develop 4 prospects in Sumatra, five in Java, and one in Bali (all signed in 1993/4). The developers undertook their own earth-science surveys. Accelerated drilling confirmed productive sectors outlined in part by new geophysical methods, e.g CSAMT, MAM, MEQ, and deep T gradient (cored) holes. Significant formal training was offered by Iceland, Japan, and NZ. All JOC projects came to a halt with the 1997 financial crisis. At the end of the 3rd decade, the installed total capacity of 4 geothermal plants was c. 530 MWe.

A review of geothermal licensing occurred during the 4th decade. The Ministry (MEMR) together with regional governments were assigned the role of issuing new licenses (WKP) through a bidding and control process (Law 27/2003). This attracted private developers. Exploration of Banda Arc Islands projects involved mainly VSI and PLN groups. By the end of 2010, a total of c. 55 geothermal prospects had been explored by ground surveys and c. 20 prospects had been tested by deep exploratory drilling. The installed capacity of seven developed Indonesian geothermal fields had reached c. 1200 MWe by 2010.

1. INTRODUCTION

Exploration of Indonesian geothermal prospects with the aim of finding suitable resources for electric power generation covers now c. 4 decades. At the beginning, the location and characteristics of exploitable geothermal resources were poorly known. Organizations, trained manpower, supporting infrastructure, and adequate legislation, administration and planning had still to be created and established. Structured exploration using earth-science disciplines had to be developed with geophysical surveys soon assuming a major role in locating targets.

Selecting highlights of exploration and development of Indonesian geothermal resources during the 4 decades (1970-2010) requires a discussion of actual developments and a realistic assessment of achievements and failures. For an adequate overview, we used (among other information listed in the References) the following sources: Hochstein and Sudarman (2008), GeothermEx, Inc (2010 WB Report), and (Indonesian) country update reports in the Proceedings of World Geothermal Congress sessions (Sudarman et al. 2000, Surya Darma et al. 2010).

A geothermal map of Indonesian geothermal prospects that have been surveyed in some detail during the 4 decades is shown in Fig.1. The figure shows the location of c. 67 high-and intermediate T systems of which ten are now under exploitation; a total of 17 prospects have been explored by deep drilling. In addition, about 40 prospects (green dots) warrant further exploration to assess their development potential. Separate clusters of single low-T spring systems are also shown. The discussion of the history of geothermal exploration of Indonesian prospects refers to sites shown in Fig.1. The role of geophysical surveys in the discovery of geothermal reservoirs is highlighted due to their impact during the 4 decades of exploration and developments.

2. THE FIRST DECADE (1970-1980)

Exploration of geothermal prospects using a multi-disciplinary approach started at Dieng in 1970 as a bilateral (France and US) assistance project with Indonesian staff from VSI/ITB/PLN as counterpart. In 1971 a bilateral (Colombo Plan) aid project was sponsored by the NZ Government covering reconnaissance surveys of four prospects in Java (Kamojang, Darajat, Salak-Perbakti, Cisolok) and the Bratan Caldera on Bali. Counterpart for the aid project was VSI (Volcanological Survey of Indonesia). From 1974 onwards, Pertamina (Indonesian State Oil Co.) became responsible by Presidential Decree (PD) 16/74 for the exploration of prospects in Java and Bali (exploration of geothermal prospects outside Java and Bali was to be continued by VSI).

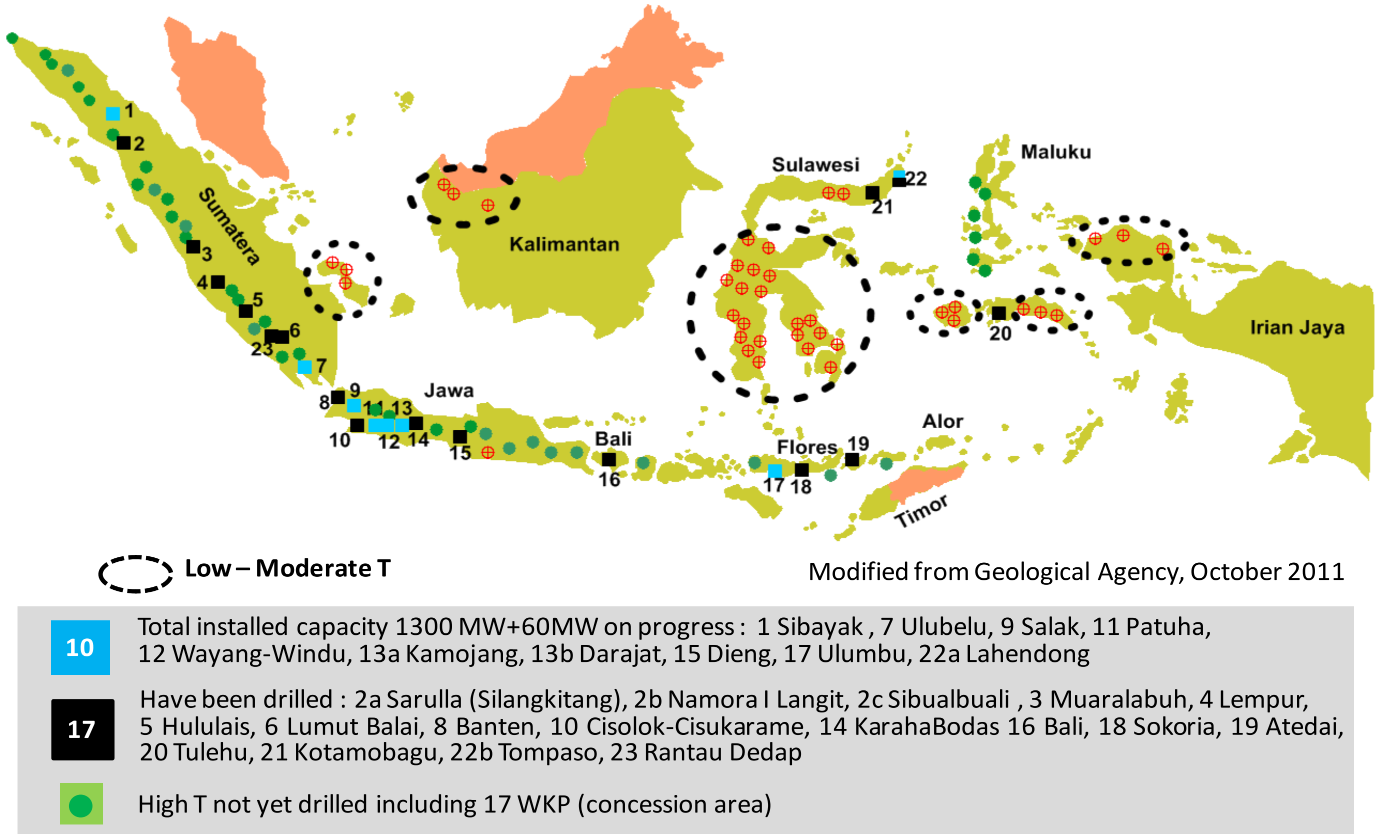

Figure 1: Map of Indonesian geothermal prospects

The selection of prospects was based on earlier VSI inventory data and site visits assessing characteristics of manifestations, type of thermal fluids and indicated natural heat losses (c. 100 MW for most projects selected during the first decade). Pertamina had taken over the Dieng project in 1974 and completed exploration surveys in collaboration with a French contractor. Deep exploratory drilling at Dieng (to 1.9 km depth at DNG-1 and DNG-2) began in 1977.

Standard DC-resistivity surveys were used to outline the likely extent of concealed, conductive, thermally altered rocks. The presence of inferred high T fluids had been tested by shallow drill holes at Dieng and Kamojang drilled in the colonial era (1920's). The wells at Kamojang had shown that a high-T resource occurs beneath the prospect. After completion of reconnaissance resistivity surveys (Kamojang example presented by Hochstein, 1975), the productivity of the Kamojang and Darajat reservoirs was tested by c. 0.7 km deep wells in 1976 and provided evidence for two separate vapour-dominated systems. This finding led to an extension of the NZ aid program involving additional sponsoring of production drilling (1976-78) to secure steam supply for a 30 MW geothermal plant at Kamojang to be built and owned by the national electric utility (PLN) with NZ Govt. funding. The Salak-Perabakti reconnaissance survey could not be completed during the NZ bilateral program and was handed over to Pertamina in 1977. Another reconnaissance survey was undertaken at Cisolok (also covered by the NZ aid program). The proposed conceptual model of a coherent large outflow structure beneath the Cisolok-Cisukarame manifestations was not accepted and led to additional, although unsuccessful surveys of the same prospect by Pertamina using a Japanese contractor at the end of the 1st decade. A large concealed outflow structure ('advective flow') was discovered by DC–resistivity and temperature gradient (TG) surveys beneath the outer S and NW slopes of the Bratan Caldera in Bali (Fig. 2). The Bali survey covered more than 100 km2 and traced an alteration pattern caused by secular migration of thermal fluids down-slope over a distance of 18 km from the caldera centre (Mulyadi and Hochstein, 1981).

Pertamina also explored prospects in the Banten area between 1975 and 1979, using consultants from France and Japan. A joint VSI-Japanese aid (JICA) survey was started at the end of the decade near the G. Kunyit strato-volcano in Sumatra. Reconnaissance surveys of a few geothermal prospects in North Sulawesi were also undertaken by VSI, ITB, and PLN teams at the same time. A summary of exploration activities and related references can be found in the overview paper by Hochstein and Sudarman (2008).

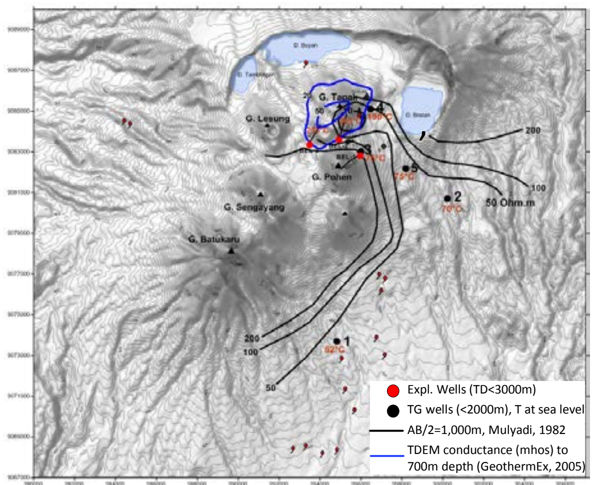

Figure 2: Map of apparent resistiviy at AB/2 = 1000m (1973-77) of Bratan Caldera prospect (Bali). Shown also are results of a later TDEM survey and the locations of deep wells (1996/97).

During each survey with foreign expert input, significant 'hands on' training took place involving some transfer of technology (a summary of inputs by donor countries is shown in Table 1). A few Indonesian professionals had attended during the first decade short term geothermal training courses at Pisa and Kyushu and at the Geothermal Diploma course at the University of Auckland (starting in 1979).

3. THE SECOND DECADE (1980-1990)

At the beginning of the 2nd decade, Pertamina's geothermal drilling capacity was stretched with deep drilling plans for Kamojang (production wells for a 2 x 55 MWe extension project adopted in 1984), ongoing drilling at Darajat and Dieng and commitments at Salak-Perbakti and Lahendong. The first 30 MW pilot plant at Kamojang was commissioned in 1983. Outside assistance for the projects was required which led the Indonesian Government to issue the PD 22/1981 decree allowing Pertamina to enter joint venture contracts (JOC) to continue with the development of geothermal fields although construction and running of geothermal power plants remained with PLN.

Union Oil Co (later Unocal Geothermal Indonesia, UGI) was awarded the first JOC contract for the joint steam field development of the Salak-Perbakti field in 1982. Another JOC was signed with Amoseas Indonesia Inc for the development of the Darajat field in 1984. Both developers also undertook further exploration surveys.

The first deep exploration well was drilled by UGI in the Perbakti sector (the Awibengkok field) in 1983; eight deep exploration wells, with a production potential of c. 150 MWe, were completed by 1986 which showed that the prospect was a liquid-dominated system, adjacent to the smaller volcanic geothermal system of G. Salak. Additional drilling was stalled to wait for the construction of the first power plant by PLN which was only commissioned during the 3rd decade. A total of 5 deep exploration wells, with a production potential equivalent to 55 MWe, had been completed at Darajat by 1988. Here, further production drilling also was halted because of delays in the construction of the first power plant by PLN. Pertamina undertook an MT survey of the Darajat field in 1979 and continued exploration with Amoseas under the 1984 JOC. This included gravity, resistivity (CSAMT and additional MT), airborne magnetic and micro-earthquake surveys. Similar follow-up surveys were used at Kamojang (Sudarman et al., 1990). An airborne magnetic survey was undertaken in 1986 (Fig. 3) which provided evidence for the extent of thermally altered, demagnetised rocks at Kamojang (Soengkono et al., 1988). Two 55 MWe power plants were commissioned at

	1970-1980	1980-1990	1990-2000	2000-2010
New Zealand	OJT and FTC **Aid Program (KM, DRJ, SLK, Bali) ;** **30 MW Plant (KMJ)**	OJT and FTC **(ULB)**	FTC	
France	OJT **(DNG)**			
Japan *Italy* *Iceland*	OJT and FTC **(CSL, BTN)** *FTC (Exploration)*	OJT and FTC **(LPR)** *FTC (Exploration)* *FTC*	OJT and FTC (**MTL, AT**) *FTC*	
JOC-1 (Unocal, Amoseas) JOC-2 (CalEnergy, Caitness, Magma)	OJT **(SLK)**	OJT **(SLK, DRJ)**	OJT **(SIL, NIL, SIB)** **(DNG, PTH, BALI, KRB, WW)**	
Self Development (PTM, VSI/GA)		LBD (**KMJ Ext, DNG, LHD, CSL, BTN, WW, PTH, SIB, ULB**)	LBD (**KMJ Ext, LHD, SBY, UBL, WW**)	LBD (**LMB, HLS, KTM, TPS, MTL, SR**)
Cumulative (MW)	30	140	530	1200

Table 1. Capacity Building and Transfer of Technology concepts (Indonesian geothermal projects 1970-2000); inputs by donor countries and joint-operation contracts.

Legend (Acronyms and Abbreviations of Projects): PTM=Pertamina, now PGE; VSI=Volcanological Survey of Indonesia; GA=Geological Agencies; PLN=Perusahaan Listrik Negara; OJT=On the Job Training (surveying, drilling, production testing); FTC=Formal Training Course (scholarship, certificate and diploma); LBD=Learning By Doing; SUMATRA: HLS=Hululais; LMB=Lumutbalai; LPR=Lempur-Kunyit; Sarulla (NIL=Namora-I-Langit, SIL=Silangkitang, SIB=Sibualbuali); SBY=Sibayak; UBL=Ulubelu; JAVA-BALI: Bali; BTN=Banten; CSL=Cisolok; DNG=Dieng; DRJ=Darajat; KMJ=Kamojang; KRB=Karaha-Bodas; PTH=Patuha; SLK=Salak-Perbakti; WW=Wayang Windu; SULAWESI: KTM=Kotamobagu; LHD=Lahendong; TPS=Tompaso; NUSA TENGGARA; AT=Atedai; MTL=Mataloko; SR=Sokoria; ULB=Ulumbu

Kamojang in late 1987.

At Dieng, Pertamina drilled 14 deep exploratory wells in the Sikidang sector during the 2nd decade encountering acidic fluids which might have induced the collapse of the majority of wells by the end of the decade. However, in 1984 the adjacent Sileri field, exhibiting non-corrosive fluids, had been found with the DNG-10 well. This allowed some partial development of the Dieng prospect during the next decade.

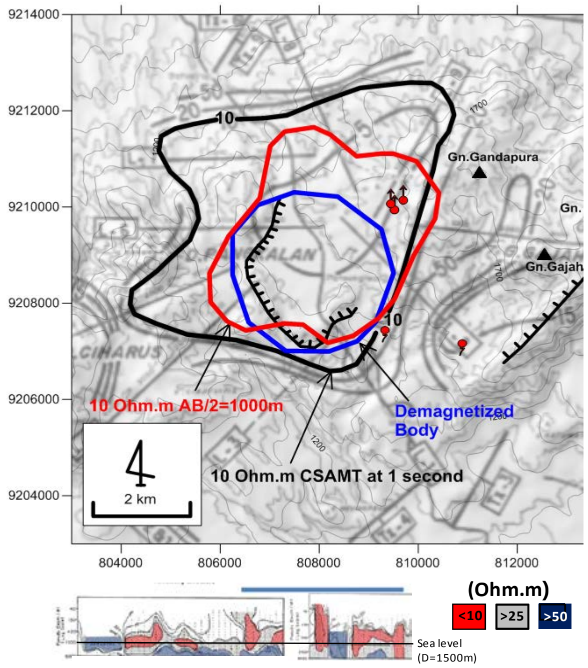

Figure 3: Map of apparent resistivity at period 1 second and an E-W resistivity structure obtained from radial CSAMT survey at 100m spacing in the Kamojang field (1989). The map is also superimposed with 10 Ohm.m of DC-Schlumberger at AB/2 = 1000m (Hochstein, 1975) and circular polygon demagnetized body below 300m depth obtained with airborne magnetic survey (Soengkono et al, 1988).

Apart from supporting exploration and drilling activities at Dieng, Kamojang, Darajat, and Salak-Perbakti, Pertamina was also involved in exploration activities of 10 other geothermal prospects during the 2nd decade. On Java, the Cisolok prospect was re- surveyed leading to the siting and drilling in 1986 of the CIS-1 deep well which encountered a thick low- T, concealed outflow and ended in failure. The detailed survey of the Banten Caldera prospect led 1985 to the drilling of the deep BTN-1 well at the Citaman spring site encountering also a low-T outflow structure similar to that at Cisolok. Other Pertamina surveys of prospects on Java included during the 2nd decade the surveys of the Wayang-Windu-, Ungaran- and G.Wilis fields and the Ijen Caldera-, Patuha-, Karaha-, Tangkuban Perahu-, and G. Arjuno-Welirang prospects.

On Sulawesi, the Lahendong prospect had earlier been explored by the VSI group with support of a Japanese aid (JICA) program. It led to siting and drilling of 3 slim holes near the acidic Lake Linau in 1981 which all failed. The Indonesian Govt. asked Pertamina to continue with the exploration of the Lahendong field which resulted in drilling of the deep LHD-1 well in 1983 and 5 more wells until 1986. This showed that Lahendong was an exploitable liquid-dominated system, albeit with an acidic core. Other prospects nearby were also explored by Pertamina such as the nearby Tompaso and Kotamobagu prospects.

On Sumatra, VSI also was assisted by the JICA aid program to explore the G. Kunyit-Lempur prospect between 1981 and 1984; it included drilling of two (c. 1 km deep) exploratory wells in 1983 and 1988 that encountered only intermediate T (185 and 220 deg C) at bottom hole. Since the prospect lies in a natural park, it was no further explored. Exploration of several other geothermal prospects on Sumatra was taken over by Pertamina after 1987 and included surveys of the Sibayak-, Sorik Merapi-, Sibualbuali- and the Silangkitang prospects and a reconnaissance survey of the Ulubelu field. Other prospects on Sumatra were also studied by VSI during the 2nd decade, such as Suoh and Rajabasa. Exploration of geothermal prospects on the Banda Arc islands and the Maluccas was continued by VSI with PLN assistance (Ulumbu prospect on Flores, for example).

On the whole, geothermal exploration of Indonesian prospects during the 2nd decade was carried mainly by Pertamina and produced overall rather mixed results. Resistivity surveys employed still standard DC-methods together with MT- and CSAMT studies but encountered apparent complex resistivity structures, especially in steep terrains. MT surveys, introduced for the first time during the 2nd decade and undertaken by a French contractor, also produced mixed results caused in part by 'noisy' equipment and static shift effects. Airborne magnetic surveys over Darajat and Kamojang, however, had been successful.

The total installed capacity of geothermal power plants had increased towards the end of the decade to 140 MWe (all at Kamojang). Overseas geothermal training involved c. 70 Indonesian candidates, who attended the annual Diploma Course at Auckland, and other smaller groups who enrolled in shorter courses conducted in Pisa and Kyushu during the 2nd decade. An overview of exploration methods used during the 4 decades is shown in Table 2.

	Geology	Geochemistry	Geophysics
NEW ZEALAND	Mapping + alteration, borehole geology	Water, gas, isotope	**DC-resist., grav**., **TG** ,heat loss
FRANCE	Mapping + alteration, rad. dating, borehole geology	Water, gas, isotope	**DC-resist., grav, MT, TG**
JAPAN	Mapping + alteration, dating, borehole geology	Water, gas, isotope, (soil gas) Hg and CO_2	**DC-resist., grav, MT, CSAMT, TG**
JOC1	Mapping + alteration + dating, borehole geology	Water, gas, isotope	**MT, CSAMT, airborne magnetics, grav, TG, seismics**
JOC2	Mapping + alteration, borehole geology	Water, gas, isotope	**MT, grav, TCH**
Self Development (Pertamina, VSI/GA)	Mapping + alteration + dating, borehole geology	Water, gas, isotope, Hg and CO_2 soil, rad. dating	**DC-resist., grav, MT, ground & airbone magnetics, CSAMT, MAM, MEQ, TG, T2m**

Table 2. List of Exploration Methods used during exploration of Indonesian geothermal projects by donor (aid project) countries, joint operation contracts and Indonesian institutions

Legend: (List of abbreviations used): **DC-resist**.: DC resistivity surveys using dominantly Schlumberger arrays; **MT**: magneto-telluric soundings; **CSAMT**: controlled source magneto-telluric surveys; **MAM**: mise-a-la-masse roving resistivity array surveys; **TG:** temperature gradient survey in drill-holes; **TCH**: temperature survey in cored holes; **T2m**: Ground temperature survey in 2 m holes; **grav**.: gravity surveys; **magnetics**: magnetic surveys; **seismics**: seismic reflection surveys; **MEQ**: micro-earthquake surveys.

4. THE THIRD DECADE (1990 -1999)

Delays and uncertainties in the PLN commitment to construct electric power plants at three developed fields increased the overall risk of future geothermal developments. The Indonesian Govt. issued a new decree (PD 45/1991) to encourage private development of geothermal resources that also allowed JOC parties to build and to operate power plants and to sell electricity to PLN, i.e. a total project development concept, thus removing a PLN monopoly. This new regulation also applied to investments in coal-fired power plants which benefitted most from the decree and its implementations outlined in the (PD 49/ 1991) decree.

4.1 Extended joint operation contracts and other developments during the first half of the decade

Pertamina offered 10 new joint operation contracts (JOC 1 and JOC 2 in Table 1) to several groups. JOC contracts were offered for the development of geothermal prospects in the large 'Sarulla Block' (N Sumatra), including the Silangkitang-, Namora-I-Langit (NIL)-, Donotasik- and Sibualbuali fields. Another JOC was signed for the development of the Sibayak field whose productivity had been proven by a deep well (SBY-1) drilled by Pertamina in 1992. The second group of JOC's included five prospects on Java (Wayang Windu, Patuha and Cibuni, Dieng, Karaha and Telaga Bodas) and the Bedugul prospect on Bali. Pertamina had undertaken detailed exploration of most fields and had proven production by deep drilling at Dieng and at Wayang Windu (discovery well WWD-1 completed in 1991 by Pertamina).

The JOC's for the 'Sarulla Block' fields were accepted by Unocal N- Sumatra Geothermal Ltd (UNSG) in 1992. This led to repeat surveys of each field and the drilling of discovery wells SIP-1 at Sibualbuali and SIL-1-1 at Silangkitang in 1994. Exploration drilling at Namora-I-Langit was delayed until 1997 due to access problems. The JOC for the Sibayak field was signed by a private Indonesian group (Dizamatra Powerindo). The JOC for Wayang Windu was signed with Mandala Nusantara in 1994, an Indonesian private company with controlling interest of a NZ investment group. Additional exploratory and productive wells were drilled between 1995 and 1998 and showed that a thick vapour layer system had been discovered.

Patuha Power Ltd (a joint venture between CalEnergy and Mahaka Energy) signed up for the Patuha JOC, also in 1994, and drilled 17 deep, slim hole-type wells and one productive deep well (PPL-01) until 1998. The prospect was also found to be a vapour layer type system similar to that at Wayang Windu. – The Cibuni field is an enclave of the Patuha field. A separate JOC led to the drilling of a single well (CBN-1) in 1994. For Dieng, a JOC was signed with Himpurna California Energy Ltd (HCE) in 1994 which led to an accelerated development, resulting in the drilling of 18 deep production wells between 1995 and 1998 (16 wells in the Sileri field). It finished with the completion of a 60 MWe plant in 1998 (commissioned during the next decade). The JOC contract for the Karaha-Bodas was taken up in 1994 by Karaha Bodas Co (a joint venture of two US companies: Caithness Corp. and Florida Power Co). Their development included a detailed MT survey, followed between 1995 and 1998 by drilling of 11 fully cored slim holes and 8 deep production wells. Wells in the Telaga Bodas sector encountered a volcanic geothermal reservoir with magmatic fluids but non-corrosive fluids in the Karaha field.

The JOC for the Bratan Caldera (Bedugul) prospect was signed at the end of 1994 with Bali Energy Ltd (BEL), a subsidiary of CalEnergy and an Indonesian private Co. An MT survey was conducted together with the drilling of 6 fully cored slim holes (1 to 1.6 km depth) and was followed by directional drilling of 3 deep (2.8 km) production wells, completed by 1998 (Fig.2 shows the location of cored slim holes drilled to confirm the thermal reservoir structure and their bottom hole T).

There were other important developments. The resistivity boundary structure of the Kamojang field was investigated with detailed CSAMT and mise-a-la-mass (M-A-M) surveys (Sudarman et al., 2000). A summary view of the resistivity patterns is shown in Fig.4. Monitoring studies of producing fields using various geophysical methods became an important management tool, especially monitoring of mass changes and fluid reinjection effects in the reservoir by micro-gravity and micro-earthquake surveys, respectively.

PLN power plants (with a total capacity of 220 MWe) were finally commissioned at Salak and Darajat in 1994. After completion of another plant (Unit 3) at Salak in 1997 and the first 20 MWe PLN unit at Lahendong, construction and running of later power plants was taken over by the Independent Power Producer (IPP) group working under JOC agreements with Pertamina. On Sumatra, the first deep exploratory well (UBL-1) was brought down in the Ulubelu field in 1995; it encountered an outflow structure.

Another outflow structure was found in the Ulumbu prospect (Flores) where the first well (ULB-1) was drilled to c. 1.9 km depth in 1994. The prospect had been explored by VSI/PLN with follow-up studies and drilling supported by a small bilateral NZ aid project. Although two additional wells confirmed the potential of the resource, it would take almost 20 years before a pilot plant was constructed. The NZ aid programme was extended to assess another geothermal prospect on Flores (Sokoria) in 1997.

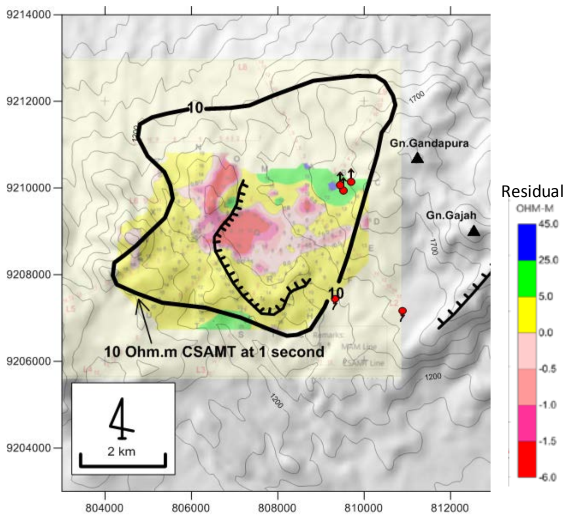

Figure 4: Residual resistivity map of the Kamojang reservoir obtained with the Mise-a-la-mass (M-a-m) method (coloured pattern) taken from P.Sumintadireja, 1999.

4.2 The Asian financial crisis (1997-1998) and its effect on developments

The value of the Indonesian rupiah had dropped by a factor of 4 during the crisis. Since electricity sales contracts of most JOC supported projects were in terms of US dollars,

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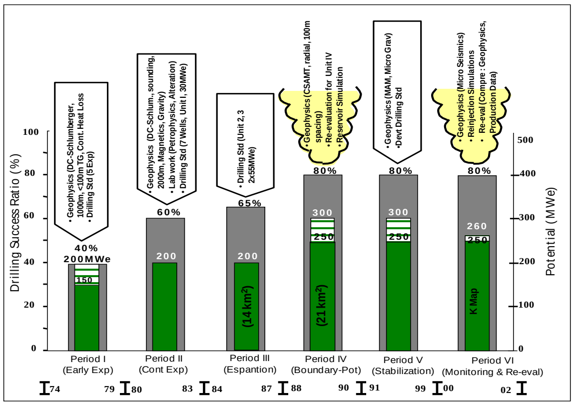
PLN could not pay the agreed prices with the result that some projects went into default or had to shut down temporarily. In late 1997, the Indonesian government had to cancel several energy projects and issued the PD 39/1997 decree that defined the extent of cancellations. It affected the development at Dieng, where the Unit 1 plant was ready for commissioning in 1998, and ongoing constructions at Darajat and Wayang Windu as well as loan agreements for developments of the Patuha-, Karaha-, and Bedugul (Bali) projects.

Lawsuits were started and lead to arbitration at international courts which decided, for example, that Pertamina and PLN had to pay significant compensation (plus interest) to Karaha Bodas Co. Another arbitration panel awarded full payment to the successors of Himpurna (HOC) for expenditures and opportunity lost income resulting from the closure of the Dieng field operations and also to Patuha Power Ltd. Initial payments were advanced by the Overseas Private Insurance Corp. (OPIC) at the end of 1999 which negotiated an agreement to return the Dieng and Patuha fields to the Indonesian Government. Management of both fields was then transferred to the new PT Geodipa Energi group, created as a joint subsidiary of PLN and Pertamina in 2002. A full financial settlement of the Karaha-Bodas issue has not yet been achieved with the result that some original exploration data for all 3 fields have still to be returned to the original JOC partner. Exploration results of the Karaha-Bodas survey were, however, presented at the Stanford 2002 Workshop (including an MT study by Raharjo et al.).

Other companies involved in the JOC sponsored developments continued as best as they could manage. Development of prospects in the Sarulla Block almost stopped; re-negotiations of the price of electricity were unsuccessful and Unocal (UNSG) sold its equity for the whole Sarulla Block to PLN during the next decade (in 2005). At Wayang Windu, its Unit 1 plant (110 MWe capacity) was completed in 1999 but the company went into default. PT Star Energy became the new owner in 2004 using a new subsidiary (MNL) as operator of the project. The fate of the Patuha, Karaha and Dieng prospects had been settled, at least in part, by financial settlements. Activities at the Bedugul (Bali) project had stopped; it changed owners several times after 1998 and has remained inoperative due to environmental issues.

Other geophysical methods were tested on a larger scale. Exploration studies by Pertamina included air-borne magnetic surveys of several new prospects in 1990, such as the Ijen Caldera, Iyang-Argopuro, and Ungaran prospects, where each prospect showed up with demagnetised but also paleo-magnetic structures (Ijen). The importance of extended geophysical monitoring studies during exploitation and their likely impact on production drilling success could be demonstrated at Kamojang for various stages of development (summarized in Fig. 5). Seismic methods (standard reflection surveys) were used during the exploration of the Sarulla Block prospects with little success. Most additional geophysical surveys of JOC prospects were undertaken by foreign contractors, thus not involving Indonesian staff and not contributing significantly to knowledge transfer. Such transfer, however, continued through overseas geothermal training courses with a total of c. 70 Indonesian students attending the annual Auckland Geothermal Diploma course during the 3rd decade, with smaller groups attending similar but shorter courses at Kyushu, Pisa and Iceland. Teaching of geothermal earth-science and engineering topics had been introduced at several Indonesian universities and a special in-house training for Pertamina staff was given by UniServices Auckland during the 3rd decade. The running capacity of 4 geothermal plants was 540 MWe in 2000.



S. Sudarman et al, INAGA-Workshop, 2003

Figure 5: Kamojang project: Effect of geophysical exploration and follow-up studies upon drilling success ratio (exploration and production wells) and estimated power potential.

5. THE FOURTH DECADE (2000 – 2010)

Major government policy changes were introduced to restart geothermal developments. The PD 76/2000 decree was designed to encourage private investment and to reduce Pertamina's dominant role in field development. The decree also involved regional governments in the licensing and supervision of future geothermal developments. A new Law 22/2001 aimed at restructuring of the energy industry and confirmed the national interest in geothermal development. Another decree (PD 15/2002) revoked the previous decree that had suspended the development of 7 fields with JOC contracts in 1997. By 2002, several new power plants had been commissioned at Darajat, Dieng , Salak, and Wayang Windu which increased the total installed capacity to c. 800 MWe during that year.

5.1 New regulations (Geothermal Law 2003)

Pertamina and PLN were reconstructed as limited liability Government companies (PERSERO). In 2003, following the PD 31/2003 regulation, the geothermal division of Pertamina became the PT Pertamina Geothermal Energy (PGE) company. The new Geothermal Laws (22/2001 and 27/2003) shifted essentially control of geothermal exploration and developments to the Ministry of Energy and Mineral Resources (MEMR) with the national Geological Agency (Badan Geologi) given a key role in preparing the selection of new geothermal prospects and associated exploration, including issues of working permits (WKP), leaving the administrative control to regional government offices. The issue of geothermal exploration licenses had not been strictly controlled in the past since only about 18 such licenses had been issued during the first three decades.

After Pertamina relinquished their interest in less attractive prospects, their exploration data were returned to the Ministry (MEMR). Together with data from other exploration studies sponsored by aid projects and the in-house VSI pool of data, exploration licenses for a group of c. 20 prospects were prepared by the Geological Agency during the 4th decade. Unfortunately, too much emphasis was given to electric power potential estimates (Qe in MWe). This parameter was obtained in most cases from sparse data assessing the possible extent and volume of an inferred reservoir (using apparent resistivity anomalies, for example) and inferred reservoir Ts. Exploration data of earlier surveys were combined into a preliminary assessment document of a given geothermal prospect (Dokumen Lelang). Interested investors had to purchase the bidding document and to prepare a work program, an estimate of development costs and the electricity price at which electric power could be produced and sold to PLN (with the risk of not knowing whether an exploitable resource did exist). The investor with the best bid would obtain an exploration and development licence for 35 years through the regional government subject to caveats. During the short period between 2003 and 2010, over 25 working permits (WKPs) were issued by regional governments after successful biddings. Faulty basic assumptions and duplication of efforts by national and regional agencies became and still are significant impediments.

The National Energy Policy of 2003 placed much confidence on power potential predictions and decreed that some 10,000 MWe of new renewable energy should be installed by 2025 (c. 70% of it as geothermal power). The tendency of quoting poorly researched and unproven electric power potential data was already used by Pertamina in 1999 to predict c. 10,000 MWe for partially proven reserves and c. 10,000 MWe for mostly unknown geothermal resources (GeothermEx Inc, 2010). The Center for Geological Resources presented an 'upgraded' total potential of c. 27,600 MWe for 256 sites with active thermal manifestations in 2007 of which up to half appear to be single, low T thermal spring systems indicated by early preliminary surveys (Sukhyar (ed.), 2010).

The first 7 new working permits were issued in 2007. To increase prospection of poorly known geothermal prospects, an exemption clause in the Geothermal Law (2003) was used to issue short term exploration licenses (usually of one year duration) to investors who would undertake at their costs some exploration surveys. The results were returned to the Ministry and included in a bidding document with bidding usually won by the prime investigator since they have the right to match other bids. This procedure led, for example, to the successful completion of exploration of the Muaralaboh, Rajabasa and Rantau Dedap prospects on Sumatra after 2007.

5.2 Other developments during the 4th decade

Construction and completion of power plants by PGE and PLN continued with commissioning of the Kamojang Unit 4 (60 MWe) plant, a second 20 MWe unit at Lahendong, a pilot plant (10 MWe) at Sibayak, and Unit 2 plant (117 MWe) at Wayang Windu, all commissioned in 2008/9. At the end of the decade, the installed total capacity of seven plants (see Fig.1) had reached almost 1,200 MWe.

Exploration drilling continued at the PGE prospects on Sumatra, namely at Ulubelu, Lumut Balai, and Hulu Lais. The Ulubelu prospect has recently been recognised as an outflow system associated with a convective system beneath the flanks of the G. Rindingan strato-volcano. The interpretation of an older micro-earthquake survey found significant activity beneath its S flank (Suharno et al., 2001). The first producing wells in up-slope locations were drilled in 2006/7 at Ulubelu; this was followed by rapid drilling, steamfield development, and the construction of a 2 x 55 MWe power plant, commissioned recently.

There were some minor, although locally important surveys of geothermal prospects in Banda Arc Islands (Hochstein et al., 2010). The Mataloko prospect (on Flores) was explored as part of a VSI-Japan Govt. aid project between 1997 and 2002. It included drilling of a few shallow wells (between c. 200 and 600 m depth) which confirmed the existence of a small steam-cap type reservoir. A 2.5 MWe plant was prematurely built and could not be used because of insufficient steam supply. Another c. 530 m deep well (SR-1) was drilled on Flores to test the Sokoria (Mutubusa) prospect in 2006; it only encountered intermediate Ts. Such conditions were also found at Atedai (Lembata Island) in an 830 m deep well (AT-1) by GA VSI.

Geothermal training at overseas institutions continued with some interruption during the 4th decade. Withdrawal of NZ Government sponsorship had led to the closure of the annual Geothermal Diploma course in Auckland in 2002. A reconstituted shorter course at Auckland attracted again sponsorship from 2007 onwards. Since the short-term Pisa and Kyushu courses had closed, there was an increase in demand for geothermal studies which, in part, was taken up by the Icelandic (UN University) sponsored course. The number of students enrolled in geothermal courses at Indonesian universities also increased, resulting in significant intakes of candidates and increasing Indonesian geothermal research.

Overview papers showing transfer of geothermal technology and covering development of geothermal projects (already started during the first and second decade) were circulated and published during and towards the end of the 4th decade in Proceedings of international workshops and World Geothermal Congresses (WGC). A few papers, mainly of Indonesian professionals, are cited here in random order: Sudarman et al. (2000) for Kamojang, Raharjo et al. (2010) for Kamojang and Lahendong (see Fig.6); Hadi et al. (2005) for Darajat; Stimac et al. (2010) for Salak (Awibengkok), and Mulyadi et al. (2005) for Bali (Bedugul).

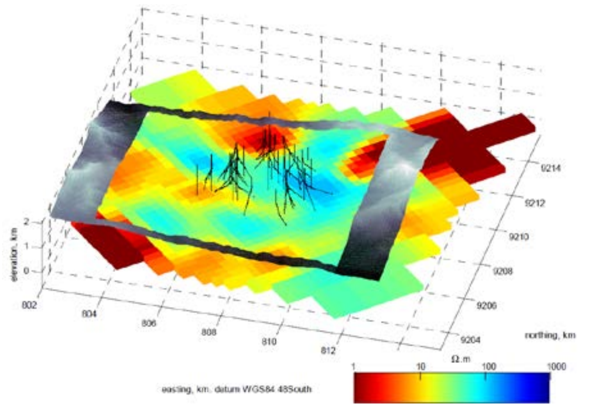


Figure 6: Deep resistivity structure developed from a 3D MT model of the Kamojang field (Raharjo, 2010).

6. SUMMARY AND OUTLOOK

The discussion of the geothermal exploration history of Indonesia during the past 4 decades (1970 to 2010) has shown that during this period up to 60 high and intermediate T systems have been explored with almost half tested by deep drilling (refer to Fig.1); these exploration studies have led to the development and present exploitation of 10 high T systems. Exploration during the first 2 decades involved mainly staff from two government organisations (the Volcanological survey VSI (now Geological Agency) and Pertamina) and two overseas companies. The activities involved significant 'on the job' training of Indonesian staff through private and bilateral aid groups as well as contractors.

Exploration intensity increased significantly during the third decade when a total of 10 new prospects were investigated under joint operation contract (JOC) agreements with Pertamina, mainly with US based companies. Many developments (and exploration activities) came to a halt during the Asian financial crisis (1997/8) when many projects went into default. This resulted in a series of litigations which went against the Indonesian government.

Geothermal developments and geothermal exploration were restored in part by a sequence of government decrees and a new 'Geothermal Law' at the start of the 4th decade which reduced the dominant exploration role of Pertamina (now PGE) and the government electricity authority (PLN). Licensing of exploration of new geothermal prospects was taken over by the Ministry (MEMR) and its affiliated Geology Agency with issuing and control of licenses delegated to regional authorities. For licensing a bidding process was used, involving prepared bidding documents; a bid was won by investors who could quote acceptable development and electricity generation costs for projects according to inferred electric power potentials. The process led to further exploration by successful bidding parties. The increase in number of licenses was in part the result of a Government policy adopted in 2010 to encourage more rapid development of electric plants at 6 fields under exploitation and of 34 new geothermal prospects with an inferred total capacity of up to c. 4000 MWe by the end of 2014 (MEMR Permen 15/2010). Only < 10% of that target has presently been achieved.

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