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Geology, energy potential and development of Indonesia's geothermal prospects

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Abstract: Indonesia's regional geologic setting creates suitable conditions for the occurrence of commercial geothermal resources. A complex interaction of the Indo-Australian, Eurasian, and Pacific megaplates, as well as smaller plates, has led to island arc volcanic activity and major faulting throughout Indonesia. The combination of volcanic island arcs with shallow crustal magmatic heat sources and fault related zones of fracturing and enhanced permeability provides Indonesia with the world's largest concentration of geothermal prospects.

Indonesian geological surveys have identified 142 high enthalpy geothermal prospects for a country-wide estimated potential of approximately 16,000 megawatts. The geothermal prospects are generally characterized by vigorous thermal manifestations associated with late Pleistocene to Recent andesitic stratovolcanos and dacitic volcanic centers. Two prospects on Java, Kamojang and Awibengkok, are regarded as commercial power generation centers. Kamojang, a vapor-dominated field, has an installed capacity of 140 megawatts and is operated by PERTAMINA and PLN. The field has been producing reliably since 1983 with annual electrical generating capacity factors exceeding 80%. Awibengkok, a liquid-dominated field, is being developed by PERTAMINA, PLN and UNOCAL. A 110 megawatt power plant is expected to begin commercial operations in early 1994. Further expansion plans for both fields are currently under discussion.

Indonesia's electric power sector is experiencing rapid growth. PLN, the State Electric Company, and private power companies are expected to add 21,825 megawatts of new generating capacity by the year 2000. Geothermal energy development for electric power generation will make up approximately 1,200 megawatts of this new capacity. Future geothermal developments will be located in Java, Sumatera, and Sulawesi. The expansion of geothermal capacity will free up petroleum resources for export to earn foreign exchange and for domestic transportation uses. The geothermal capacity will also add to the development of a more diversified and environmentally preferred electrical generation fuel mix.

INTRODUCTION

To meet a rapidly increasing demand for electricity, to reduce the national consumption of oil, and to minimize environmental impact, Indonesia is committed to developing alternative sources of energy for electrical generation. An important and plentiful resource that has yet to be fully exploited is geothermal. This paper provides a general overview of the favorable geologic environment in Indonesia and examines the government's plan to increase electrical generation from its geothermal resources.

REGIONAL GEOLOGIC SETTING

The present day tectonic configuration of the Indonesian archipelago is produced by the interaction of three major crustal plates: the westward moving Pacific plate, the northward moving Indo-Australian plate and the southward moving Eurasian plate (Fig. 1). Interactions along the plate margins, in particular subduction, generate active tectonism, magmatism and recent volcanism within the archipelago. A prominent subduction zone extends eastward from Burma to East Nusa Tenggara. The oceanic trench resulting from the subduction lies off the western coast of Sumatera and the southern coasts of Java and the islands further east. The subduction zone dips northward beneath the island chain (Hamilton, 1988). Along the west coast of Sumatera, the subduction of oceanic crust is oblique. The stresses produced by the oblique subduction are relieved by dextral strike-slip faulting along the Sumatera Fault System that runs along the entire length of Sumatera.

In northeastern Indonesia, the Pacific Plate, Eurasian plate, and several minor plates are interacting in a very complex manner. This region

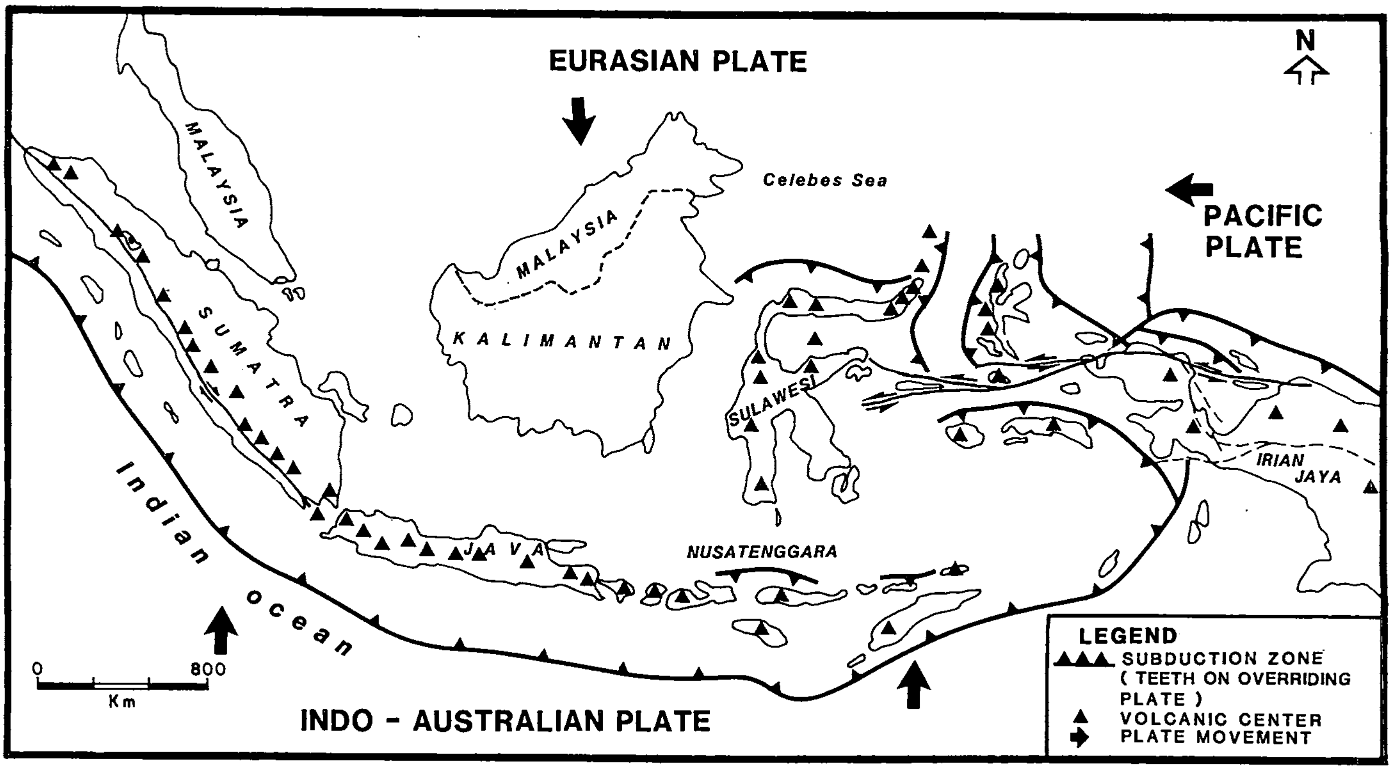

Figure 1. Regional tectonics and volcanic centers in the Indonesian Archipelago (Hamilton, 1979; Departemen Pertambangan dan Energi, 1979).

possesses several small subduction zones, the most important of which, in a geothermal sense, occur along the eastern and northern coasts of Sulawesi. In this region the stresses produced along the minor plate boundaries are relieved along prominent sinistral strike-slip faults.

Subduction related magmatism has given rise to chains of volcanos, known as island arcs, that run parallel to the subduction zone. Figure 1 shows that the most prominent volcanos in the Indonesian island arc systems occur on Sumatera, Java, Nusa Tenggara, and Sulawesi (Departemen Pertambangan dan Energi, 1979). In general, island arc volcanism produces stratovolcanos of andesitic composition. In Sumatra the volcanos tend to be concentrated along a major zone of crustal weakness created by the Sumatra Fault System. Generalized cross sections of the island arc settings in Sumatra, Java, and Sulawesi are provided in Figure 2. These cross sections show the relationship of the volcanos to the subduction zones, the nature of the crust overlying the subduction zones, and the distribution of natural resources in these geologic settings (Katili, 1985).

GEOTHERMAL RESOURCE CHARACTERISTICS

Distribution of Resources

Geologic surveys throughout Indonesia have identified a total of 217 geothermal prospects (Fig. 3). These prospects fall into two general categories: low to moderate temperature (<200°C) and high temperature (>200°C). The low to moderate temperature resources often result from the deep circulation of meteoric water along faults. These waters, which are heated by the regional geothermal gradient, are usually not suitable for electrical generation because of their low enthalpy. However, 142 prospects do possess high temperature potential. The high temperature prospects are associated with the volcanic centers in the island arc settings and are distributed as follows: fifty-seven prospects are on Sumatera, forty-nine on Java and Bali, twenty-four on Sulawesi, six on Nusa Tenggara, and six on Maluku and Irian Jaya (Dept. of Mines and Energy, 1992).

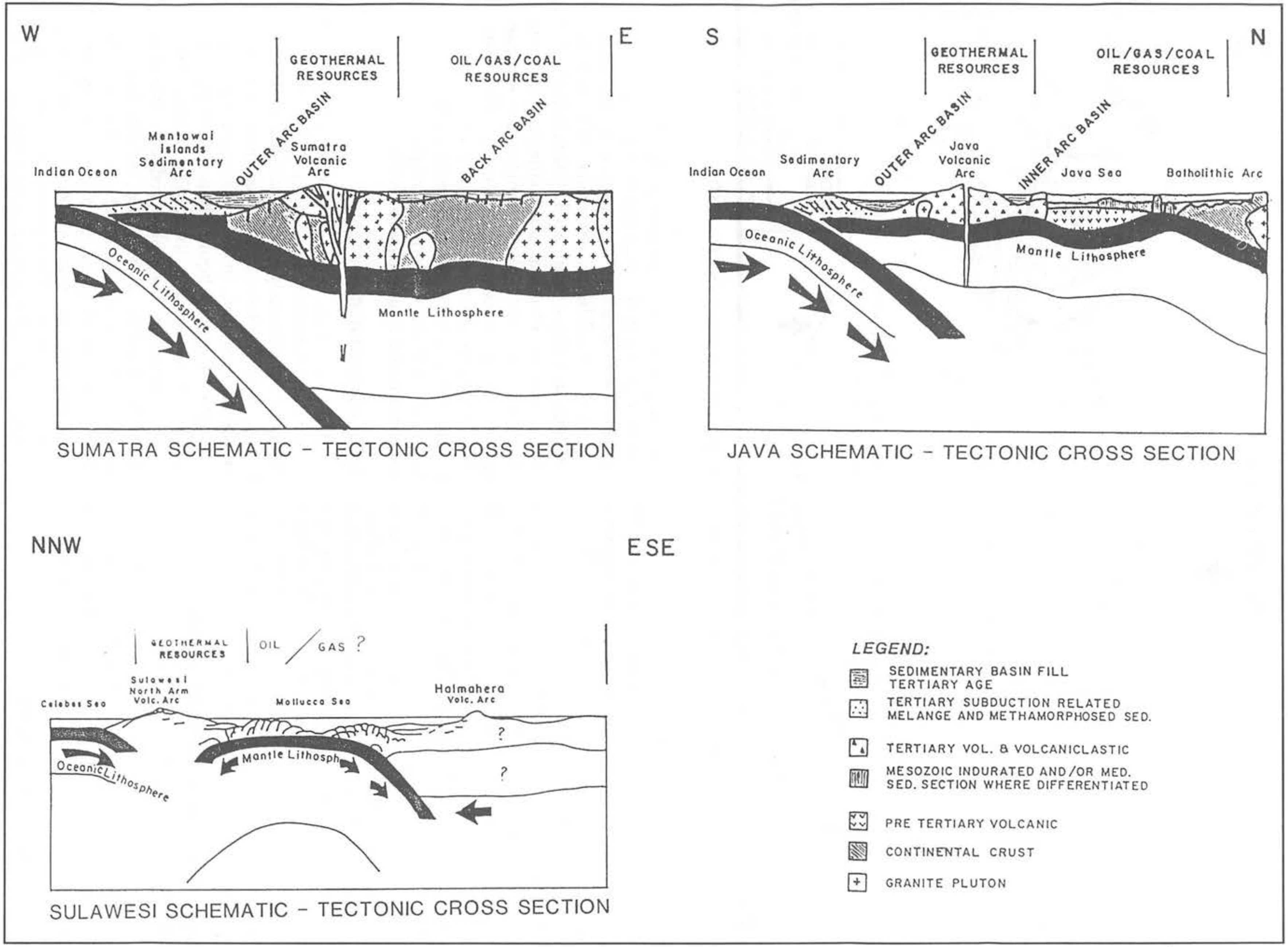

Figure 2. Schematic cross sections through the Sumatra, Java, and Sulawesi island arc settings (modified from Katili, 1985 and Simandjuntak, 1992).

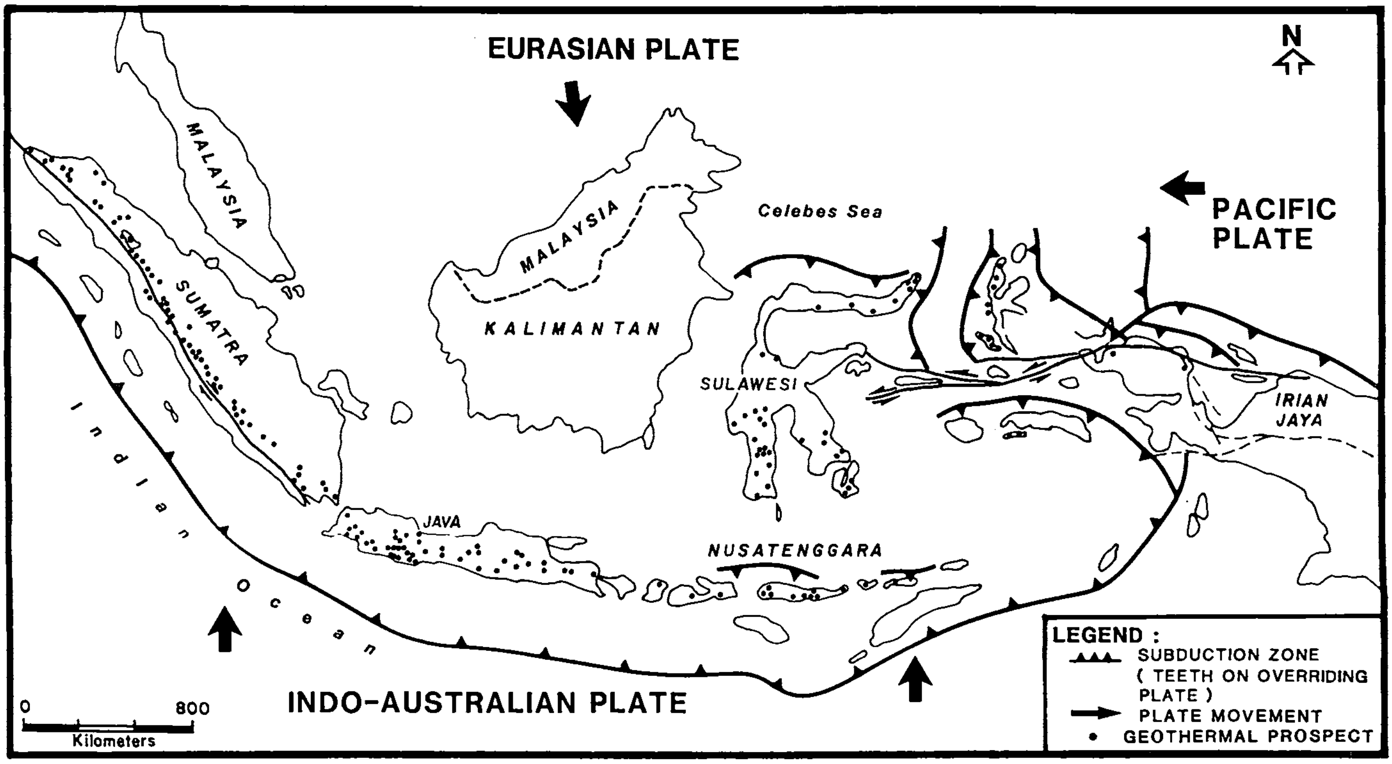

Figure 3. Distribution of geothermal prospects in Indonesia (GENZL, 1987).

Local Geologic Setting

The high temperature geothermal resources in Indonesia are primarily associated with andesitic stratovolcanos or other volcanic centers. These volcanos can be extinct, dormant, or active. Exploitable geothermal systems are most likely to become developed beneath volcanic complexes that are fed by shallow magma chambers. Commercial viability is enhanced if the prospects are highly fractured by recent faulting. The combination of shallow heat sources and fault-enhanced permeability allows for the shallow circulation of hydrothermal fluids that can be accessed by drilling.

Viable geothermal prospects are first identified by the occurrence of surface thermal manifestations associated with young volcanic centers. The surface manifestations often consist of fumaroles, hot springs, steaming ground, mud pools, cold gas seeps, and hydrothermally altered rocks.

Classification of High Temperature Geothermal Systems

High temperature geothermal systems fall into two major classifications, vapor-dominated and liquid-dominated (White *et al.*, 1971). Prospects of both types have been discovered in Indonesia.

Vapor-Dominated Systems

Vapor-dominated geothermal systems are relatively rare throughout the world. In a vapor-dominated reservoir, fractures are filled with steam, although pores in the rock matrix usually contain water. Vapor-dominated systems can also overlie very deep-seated liquid reservoirs. The pressure gradient in a vapor-dominated system is controlled by the pressure of steam, and temperatures are in the vicinity of 240°C. Wells completed in a vapor-dominated system typically discharge 100% steam. This production characteristic gives a vapor-dominated system a definite economic advantage because of reduced capital requirements for separators and liquid disposal wells.

Liquid-Dominated Systems

The most common type of geothermal reservoir is the liquid-dominated system. The reservoir volume is substantially in the liquid phase, although boiling near the top of the reservoir can produce localized steam caps. In these systems the pressure is controlled by the liquid phase. Temperatures can range widely and frequently exceed 300°C. Under production, the wells produce a two-phase mixture of vapor and liquid, which must be separated. Generally the liquid is a sodium-chloride brine. The percentage of steam produced by a well is controlled by the reservoir temperature and the separator pressure. The separated water phase is normally injected into wells on the margins of the reservoir to support reservoir pressure and longevity.

A COMPARISON OF TWO COMMERCIAL GEOTHERMAL FIELDS IN INDONESIA

Two geothermal fields on West Java provide examples of vapor-dominated and liquid-dominated systems. These fields are Kamojang and Awibengkok, respectively.

Kamojang

Geological Setting

Kamojang, which is located in West Java about thirty-five kilometers southeast of Bandung (Fig. 4), represents an excellent example of a typical vapor-dominated system. The Kamojang geothermal field is situated in the east-west trending Rakutak-Guntur volcanic chain at an elevation of about 1500 m above sea level. The system is associated with the Quaternary Pangkalan and Gandapura andesitic volcanic centers and appears to occupy a graben bordered by the Citepus and Kendeng Faults (Figs. 5 and 6; Sudarman, 1992)). A caldera rim of the Pangkalan volcano provides an attractive drilling target along the southwest margin of the field because of its association with high steam productivity.

Surface thermal features at Kamojang consist of fumaroles, steaming ground, turbid hot lakes, mud pools, and hydrothermally altered ground. The temperatures of these manifestations are close to boiling. The lower temperature Citepus hotsprings occur at the southern edge of the proven reservoir area.

Resource Characterization

The top of the Kamojang reservoir is found at an average depth of about 1200 m below the surface (Fig. 6). The productive reservoir is overlain by a thick, low permeability caprock consisting of volcanics with a pervasive argillic alteration. Fifty wells including five shallow exploration wells have been drilled in the reservoir, with the deepest well attaining a depth of 2200 m. Down hole temperature and pressure measurements indicate that the reservoir temperature ranges within 240–245°C and that the reservoir pressure is 36 bars. The wells are completed within the vapor-dominated section and most wells produce 100% steam. Water saturation in the matrix, however, is estimated to be on the order of 25–35% (PERTAMINA, 1990). The average Kamojang production well produces 53 tonnes/hr steam at a normalized wellhead pressure of 15 bars. The non-condensible gas content of the steam is less than 1% by weight (PERTAMINA, 1992a). Values of reservoir permeability-thickness are in the range of 500–140,000 millidarcy-meters with the productive wells displaying values generally greater than 4,900 millidarcy-meters (PERTAMINA, 1990). Table 1 provides the summary of well production characteristics and principal facts for Kamojang.

Based upon the well results and geophysical studies, a proven area of 14 km^2 has been established. Reservoir simulation studies demonstrate that the reservoir is capable of sustaining production of 200 megawatts for 30 years. If the reservoir extends further out, providing a total area of 21 km^2, then the potential would exist to increase the generation to 300 megawatts (PERTAMINA, 1990).

Development Strategy

The development at Kamojang has followed a strategy of incremental installations of power plants. Power plants of 30, 55 and 55 megawatts were installed in the first three stages of development. The first stage of 30 MW commenced operations in 1982 and is supported by steam taken from the central part of the Kamojang reservoir. The second and third stages, commissioned in July and September 1987, are supported by steam produced from the northern and south-western part of the reservoir.

The fourth stage of power plant installation is scheduled to generate another 55 megawatts beginning in 1996. Steam for this power plant is to be produced from the eastern part of the field.

Power Plant Performance

To illustrate the good performance of the power plants, Kamojang fieldwide capacity and availability factors are listed in Table 2 (PERTAMINA, 1992b, c). The capacity factor compares the actual electricity generated by the turbine with its rated capacity. The availability factor measures the actual turbine operating hours versus the total hours in a specified period of time (months or years).

The electricity generating facilities have been on-line since 1983. Annual capacity and availability factors have averaged 85% and 90%, respectively, over the period 1983–1992.

Awibengkok

Geological Setting

The Awibengkok geothermal field, which is located in West Java about 75 km south of Jakarta (Fig. 4), is a typical liquid-dominated geothermal system. An overview of the field was recently provided by Noor *et al.* (1992). The Awibengkok reservoir is associated with the Salak-Perbakti volcanic complex of Pleistocene to Recent Age. The volcanic products overlie eroded Plio-Pleistocene volcanics which in turn unconformably overlie

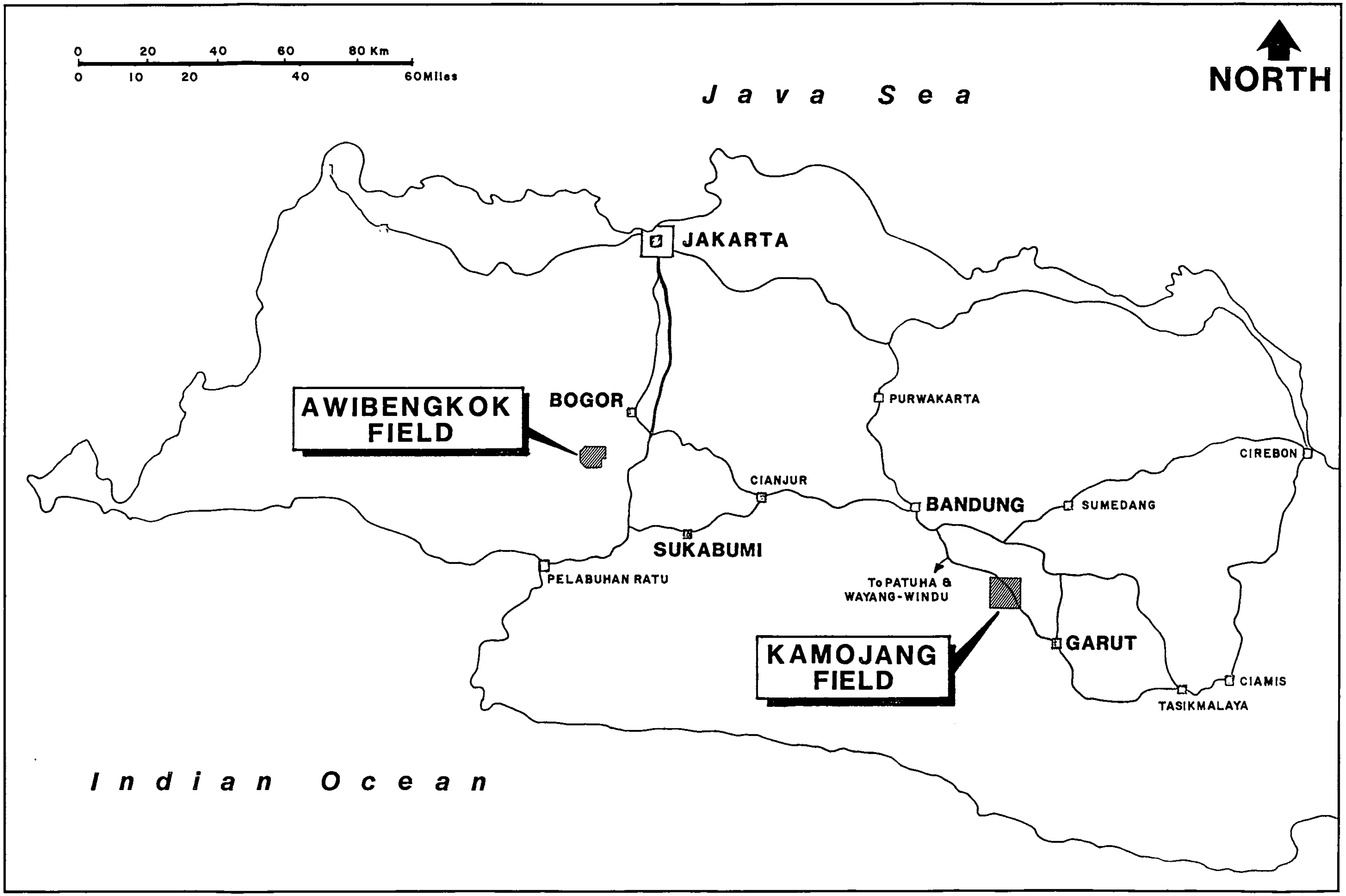

Figure 4. Field location map for the Kamojang and Awibengkok geothermal fields.

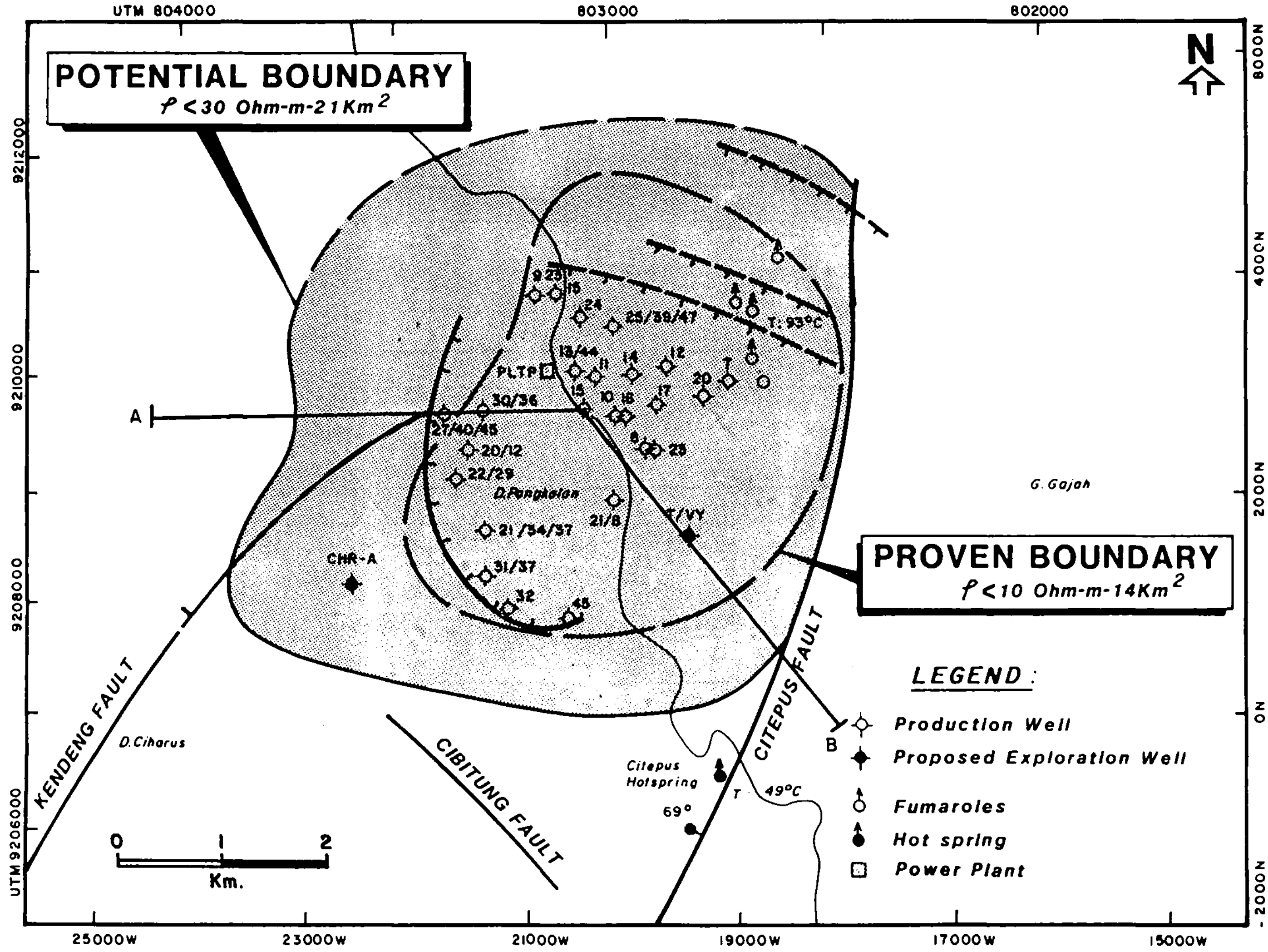

Figure 5. Kamojang field, showing proven and potential resource area (Sudarman, 1992).

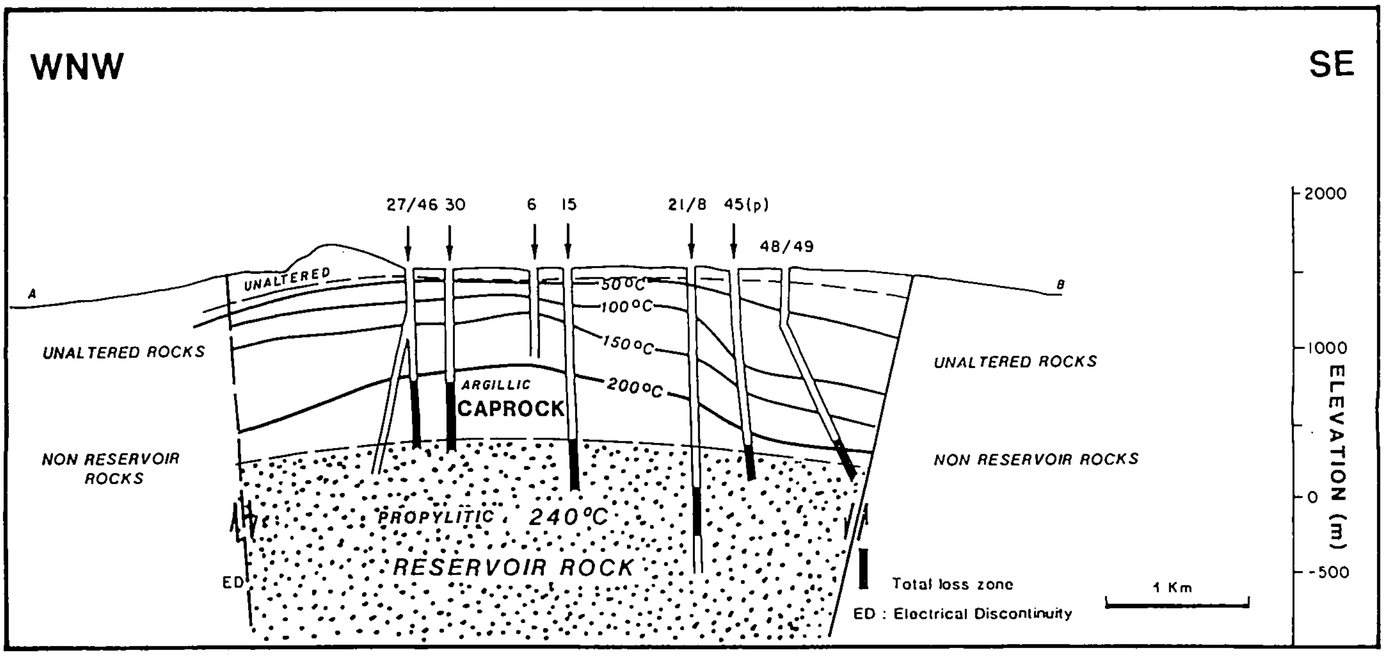

Figure 6. Schematic cross section through the Kamojang reservoir (Sudarman, 1992).

Table 1: Principle facts of the Kamojang and Awibengkok geothermal reservoirs (After PERTAMINA, 1990; Unocal Geothermal of Indonesia, 1992, pers. comm.).

SIZE	KAMOJANG	AWIBENGKOK
Proven Productive Area (km²)	14	17.4
Total Proven Resource (MW)	200	280
RESOURCE		
Phase	Steam	Liquid
Temperature (°C)	240–245	221–312
Steam Flash (%)	100	17–31
Permeability (MDM)	To 140,000	To 150,000
CHEMISTRY		
Liquid	—	NaCl brine, 13,000 ppm TDS
NCG in steam, by weight	<1 %	<1 %
DRILLING		
Number of wells	50	12
Depth of wells (m)	500–2200	1250–2590
Average Production		
Standard Completion (kg/hr)	54,000 (7 MW)	36,400 (4 MW)
Big hole Completion (kg/hr)	—	186,000 (20.5 MW)
FUTURE PLANS		
Kamojang: Increase installed capacity to 195 MW in fiscal year 1996/97. Awibengkok: Begin commercial operation of the first 110 MW power plant in early 1994. (MDM = milli Darcy-meter) (NCG = Non Condensible Gas)		

Table 2: Kamojang field average annual capacity and availablity factors (After Pertamina, 1992b and c).

Fiscal Year	Capacity Factor	Availability Factor	Installed Capacity
1983/1984	83.7%	ND	30 MW
1984/1985	82.6%	86%	30 MW
1985/1986	85.1%	90%	30 MW
1986/1987	88.4%	90%	30 MW
1987/1988	86.0%	ND	140 MW
1988/1989	82.3%	89%	140 MW
1989/1990	82.1%	87%	140 MW
1990/1991	91.8%	95%	140 MW
1991/1992	85.6%	89%	140 MW

Miocene volcanics and sediments. The volcanic complex is composed mainly of basaltic andesite, andesite and dacite with minor rhyolite. Permeability is enhanced by the intersection of two prominent fault patterns that trend in northwest-southeast and northeast-southwest directions.

Surface geothermal features of this field are characterized by three major fumarolic areas, numerous bicarbonate hot springs and one sodium-chloride warm spring (Fig. 7).

The geothermal reservoir is located primarily within fractured volcanic rocks that were produced by the Salak and Perbakti volcanos. Propylitic alteration, with an assemblage of chlorite-epidote-illite-quartz-calcite-pyrite, characterizes the high temperature reservoir. Like Kamojang, the reservoir is overlain by a low permeability caprock with pervasive argillic alteration (Fig. 8).

Reservoir Characterization

The Awibengkok development area lies at an elevation between 1000 and 1400 meters. The reservoir is found between 700–1100 m below the surface. Twelve wells have been completed in the field with the deepest well being completed at 2600 m depth. Five wells have standard completions (7 inch perforated liner in 8½" hole), and seven wells have big hole completions (9⅝" perforated liner in 12¼" hole). Average well productivity is four megawatts for a standard completion and 20.5 megawatts for big hole completion. Production tests indicate that the wells produce from a single-phase liquid reservoir that yields between 17% to 31% steam flash at the separator. The fluids are saline with a total dissolved solid content of 13,000 ppm and non-condensable gas content in the separated steam of less than 1% by weight. Well testing indicates reservoir permeability-thickness products as high as 150,000 millidarcy-meters. Reservoir temperatures range from 220°C to 312°C. Table 1 provides the principal facts of the Awibengkok field (Unocal Geothermal, 1992, pers. comm.).

The proven productive area of Awibengkok is estimated as 17.4 km^2 with reserves of 280 megawatts for thirty years. Development drilling has yet to confirm the field margins, and the potential resource area is considerably larger.

Development Strategy

The Awibengkok geothermal field is currently being developed to support a 110 megawatt power plant. Commercial production is scheduled to begin in early 1994. To support this generation, twelve big hole completions are required, consisting of six production wells, five liquid injection wells and one well for steam condensate disposal. The steam will be produced from the shallower interior area and the produced water will be injected deep along the margins of the reservoir (Fig. 9).

GEOTHERMAL ENERGY POTENTIAL AND DEVELOPMENT PLANNING

Geothermal Energy Potential

Presently the Indonesian government is focusing its exploration efforts on 36 of the 142 high temperature prospects (Fig. 10; Komarudin *et al.*, 1992). The status of this exploration effort is summarized in Table 3 (Ganda *et al.*, 1992). This table lists the activities that have taken place at each of the 36 prospects. The initial exploration program consists of surface work, such as geological, geochemical, and geophysical surveys. Upon the completion of these surveys, the prospects are ready for exploratory drilling.

Based upon the results of the geothermal exploration and development activities to date, several estimates of resource potential have been generated (Table 4; Sudarman, 1992). The status of the geothermal energy potential in Indonesia is divided into four categories as follows (Akuanbatin, 1992):

1) **Resource potential** is the broadest measure of the maximum potential for a prospect. Normally, this is based solely on regional exploration and the potential is calculated from the size of the prospective area.
2) **Possible reserve potential** is a refinement of the resource potential that draws upon the results of the geological, geochemical, and geophysical surveys.
3) **Probable reserve potential** requires that a prospect have at least one deep exploration well in addition to the geological, geochemical, and geophysical studies.

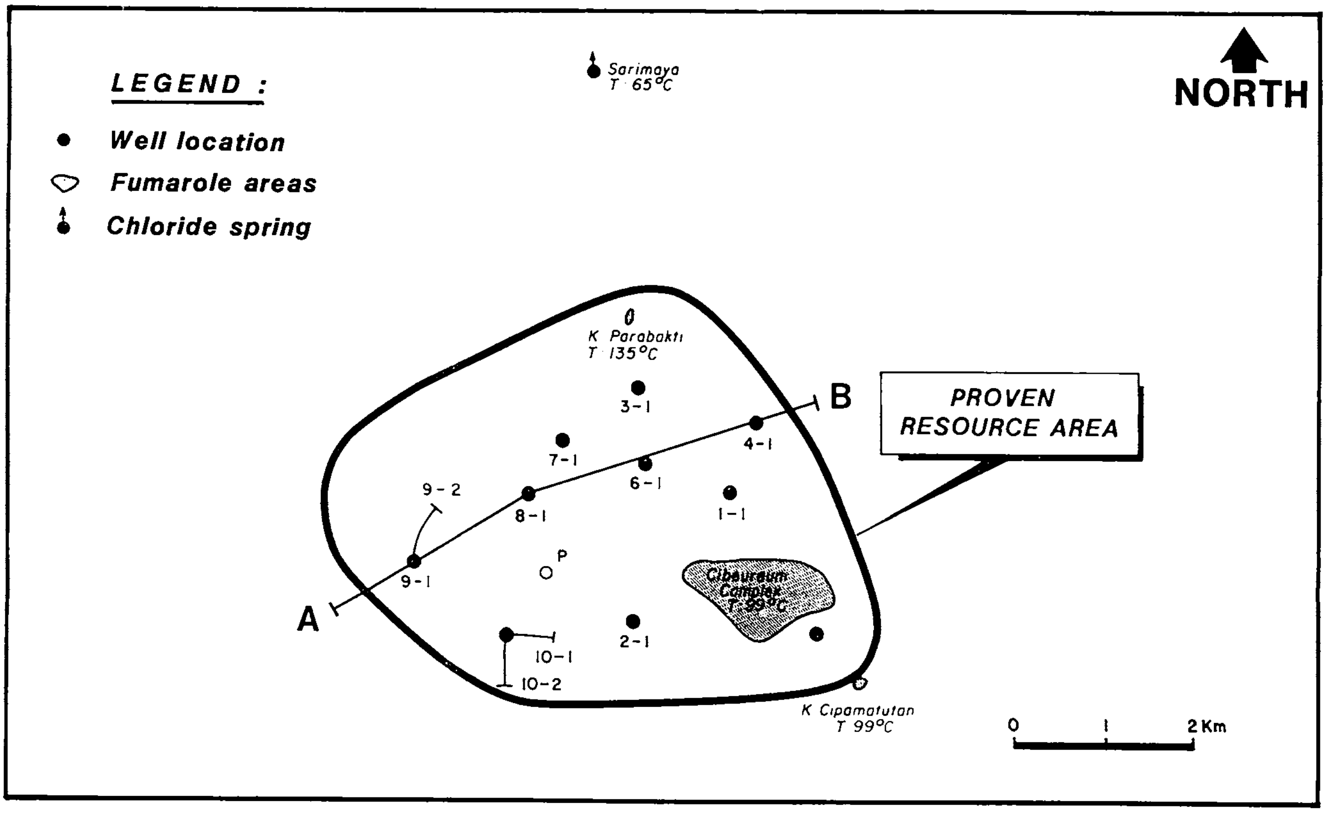

Figure 7. Well location map and proven area of the Awibengkok field (adapted from Noor *et al.*, 1992).

Table 3: The status of geothermal exploration in Indonesia as of January *1992* (After Ganda *1992*).

Geology:
A = Photogeology
B = Detail Mapping
C = Alteration Mapping

Geochemistry:
D = Cl seepage
E = Hg and CO_2
F = Isotope

Geophysics:
G = Resistivity
H = Gravity
I = Magnetic
J = MT-5Ex
K = C.S.A.M.T

Drilling: #
L = Exploration
M = Production

numbers of well

* survey has been done

Locality	Geology			Geochemistry			Geophysics					Drilling	
	A	B	C	D	E	F	G	H	I	J	K	L	M
Sumatera:													
1. Seulawah	*												
2. Sibayak	*	*	*	*	*	*	*	*	*			2	
3. Tarutung	*	*		*	*								
4. Sarulla	*			*	*		*	*					
5. Sibual-Buali	*	*	*	*	*	*	*	*	*				
6. Pusuk Bukit	*												
7. SorkMerapi	*	*	*	*	*	*	*	*	*				
8. Muaralaboh	*	*		*	*		*	*					
9. Sungaipenuh	*	*		*	*		*	*	*			2	
10. Lempur	*	*					*	*	*				
11. Lumut Balai	*					*							
12. Ranau	*												
13. Suoh Sekincau	*	*	*	*	*	*	*	*	*				
14. Ulubelu	*	*	*	*	*	*	*	*	*				
15. Rajabasa	*	*	*	*	*	*	*	*	*				
Java-Bali:													
16. Banten	*	*	*	*	*	*	*	*		*		1	
17. Cisolok	*	*		*	*	*	*	*		*		1	
18. Awibengkok	*	*		*	*	*	*	*	*	*		12	
19. Tangkuban P.	*	*	*	*	*	*	*	*		*			
20. Patuha	*	*	*	*	*	*	*	*		*			
21. Wayang-Windu	*	*	*	*	*	*	*	*	*	*		1	
22. Derajat	*	*	*	*	*	*	*	*	*	*	*	7	
23. Kamojang	*	*	*	*	*	*	*	*	*	*	*	17	33
24. Karaha	*	*	*	*	*	*	*	*	*	*			
25. Telagabodas	*	*	*	*	*	*	*	*	*	*			
26. Dieng	*	*	*	*	*	*	*	*	*	*		10	13
27. Ungaran	*	*	*	*	*	*	*	*	*	*			
28. Telomoyo	*	*	*	*	*		*	*	*	*			
29. Ngebal-Wilis	*	*	*	*	*	*	*	*		*			
30. Ijen	*	*		*	*	*	*	*	*	*			
31. Bali/Bratan	*	*		*	*	*	*	*		*			
Flores:													
32. Flores/Ulum	*	*		*	*	*	*	*					
Sulawesi:													
33. Lahendong	*	*	*	*	*	*	*	*		*		7	2
34. Tompaso	*	*	*	*	*	*	*	*		*			
35. Kotamubagu	*	*	*	*	*		*	*	*				
36. Bituang	*												

Table 4: Indonesia's geothermal energy potential and current installed capacity as of October 1992 (After Sudarman, 1992).

Area	Installed (MW)	Proven (MW)	Probable (MW)	Possible (MW)	Resource (MW)
Sumatera:					
1. Sibayak	–	–	140	140	240
2. Sarulla	–	–	–	280	380
3. SiBual-Buali	–	–	–	600	750
4. Sorik-Merapi	–	–	–	200	250
5. Sumurup	–	–	–	–	270
6. Kerinci	–	–	–	75	115
7. Lumut Balai	–	–	–	300	400
8. Margabayur	–	–	–	–	250
9. Pilamasin	–	–	–	–	125
10. Suoh Sekincau	–	–	–	375	500
11. Ranau	–	–	–	–	125
12. Ulubelu	–	–	–	300	690
13. Ratai	–	–	–	–	125
14. Rajabasa	–	–	–	30	125
Others	–	–	–	2295*	540**
Sub Total	**–**	**–**	**140**	**3595**	**4885**
Jawa-Bali					
15. Kamojang	140	210	300	300	300
16. Awibengkok	–	280	280	370	600
17. Patuha	–	–	–	400	685
18. Wayang Windu	–	200	200	260	420
19. Darajat	–	120	200	250	420
20. Karaha	–	–	–	200	250
21. Talagabodas	–	–	–	200	300
22. Dieng	2	280	280	575	1430
23. Ngebel-Wilis	–	–	–	100	170
24. Bali	–	–	–	215	325
Others	–	–	–	2050	3200
Sub Total	**142**	**1090**	**1260**	**4920**	**8100**
Sulawesi					
25. Lahendong	2.5	65	175	175	300
26. Tompaso	–	–	–	–	400
27. Kotamobagu	–	–	–	–	300
Others	–	–	–	–	500
Sub Total	2.5	65	175	175	1500
Other Islands					
28. Ulumbu (Flores)	–	–	200	200	350
Others	–	–	850	850	1200
Sub Total	–	–	–	1050	1550
TOTAL	**144.5**	**1155**	**1575**	**10520**	**16035**

* Total Area ** Total Area + 6

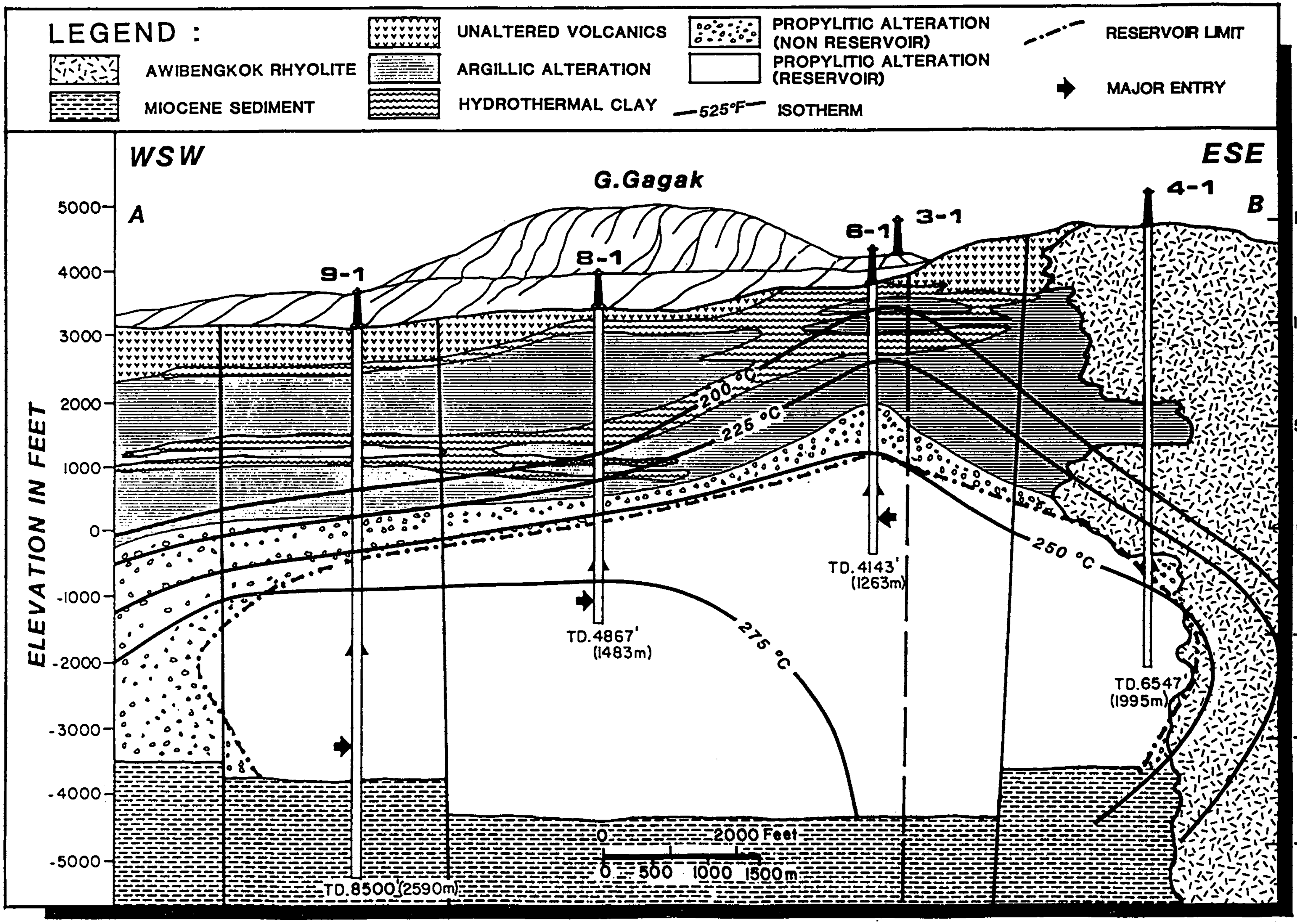

Figure 8. Schematic cross section through the Awibengkok reservoir (Noor *et al.*, 1992).

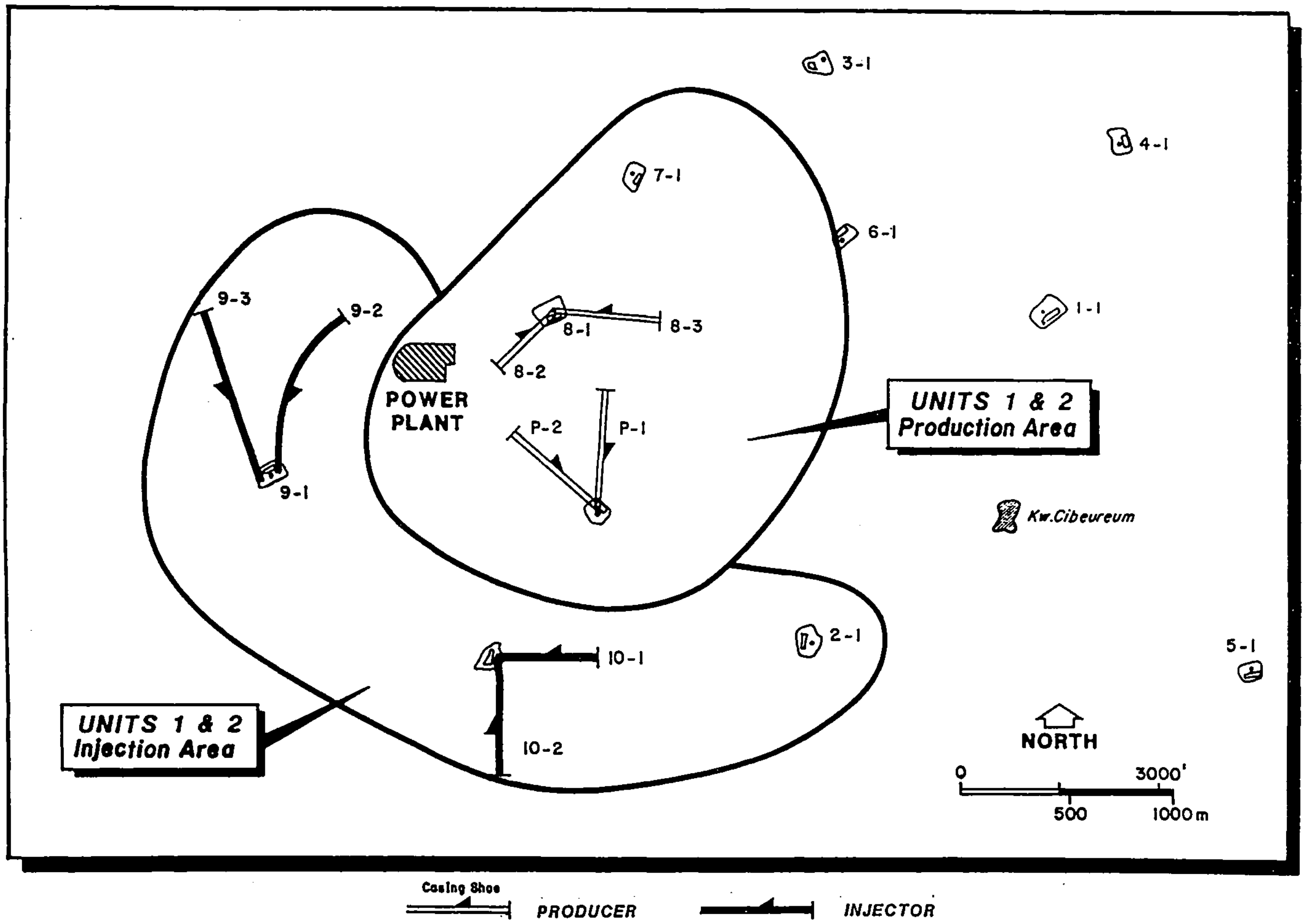

Figure 9. Development plan for the Awibengkok reservoir (Noor *et al.*, 1992).

4) **Proven reserve potential** is restricted to those prospects where proven area has been demonstrated, which normally requires at least three exploration wells.

The total country-wide resource potential from the 142 high temperature prospects is estimated to be over 16,000 megawatts (Akuanbatin, 1992; Sudarman, 1992). Java (including Bali) has the highest resource potential of 8100 megawatts, while the second highest potential of 4885 megawatts is located on Sumatera. Sulawesi is estimated to have 1500 megawatts geothermal energy potential, and the remaining potential is mostly located in the more remote islands of eastern Indonesia.

Presently only 144.5 megawatts of geothermal capacity has been installed in Indonesia (Radja, 1992), which is less than 1% of the total resource potential. Of this total, 140 megawatts are being generated at Kamojang, while 2 and 2.5 megawatt pilot projects are established at Dieng in Central Java and Lahendong in Sulawesi, respectively.

Development Planning

Role of Geothermal Energy

The consumption of electrical energy has been growing at a fast rate during the past decade. From 1984 to 1989, consumption increased at an annual rate of 16.2%, and increased to 18.4% from 1989 to 1990. The growth in consumption has been fueled by an increase in industrial consumption of 25.1% and household consumption of 13% over the past two years (Patmosukismo, 1992). Future projections foresee no decline in Indonesia's growing demand for electricity.

PLN's installed capacity in year 1991 is 9171 megawatts, with 6363 megawatts located on Jawa and 2808 megawatts on other islands. Between 1981 and 1991 the annual growth rate of installed capacity is 11.7%.

To meet the increasing demand for electricity, PLN and private power companies are expected to add 21825 MW of new generation capacity by the

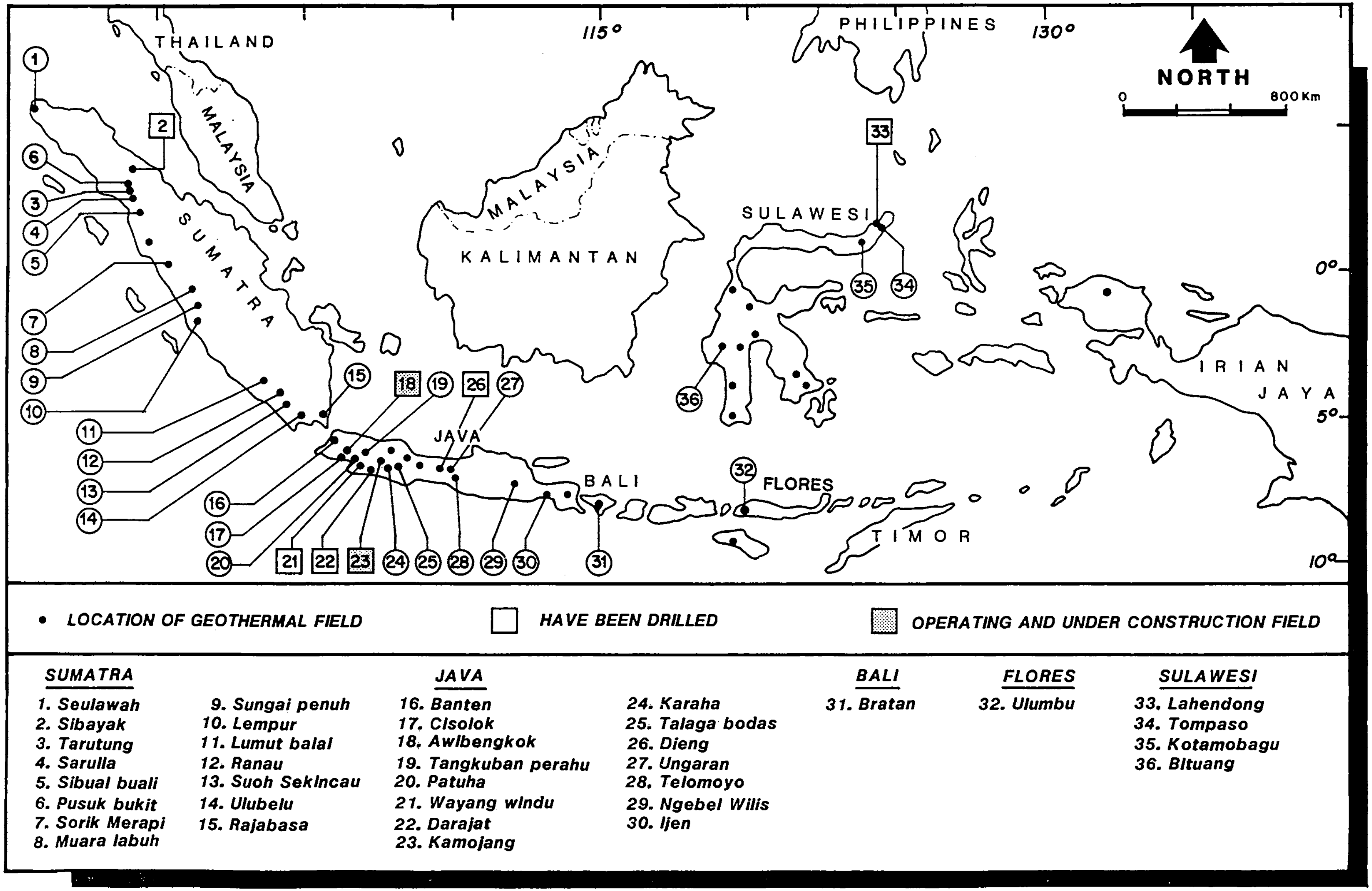

Figure 10. Location of high temperature geothermal prospects currently under investigation in Indonesia (Komarudin *et al.*, 1992).

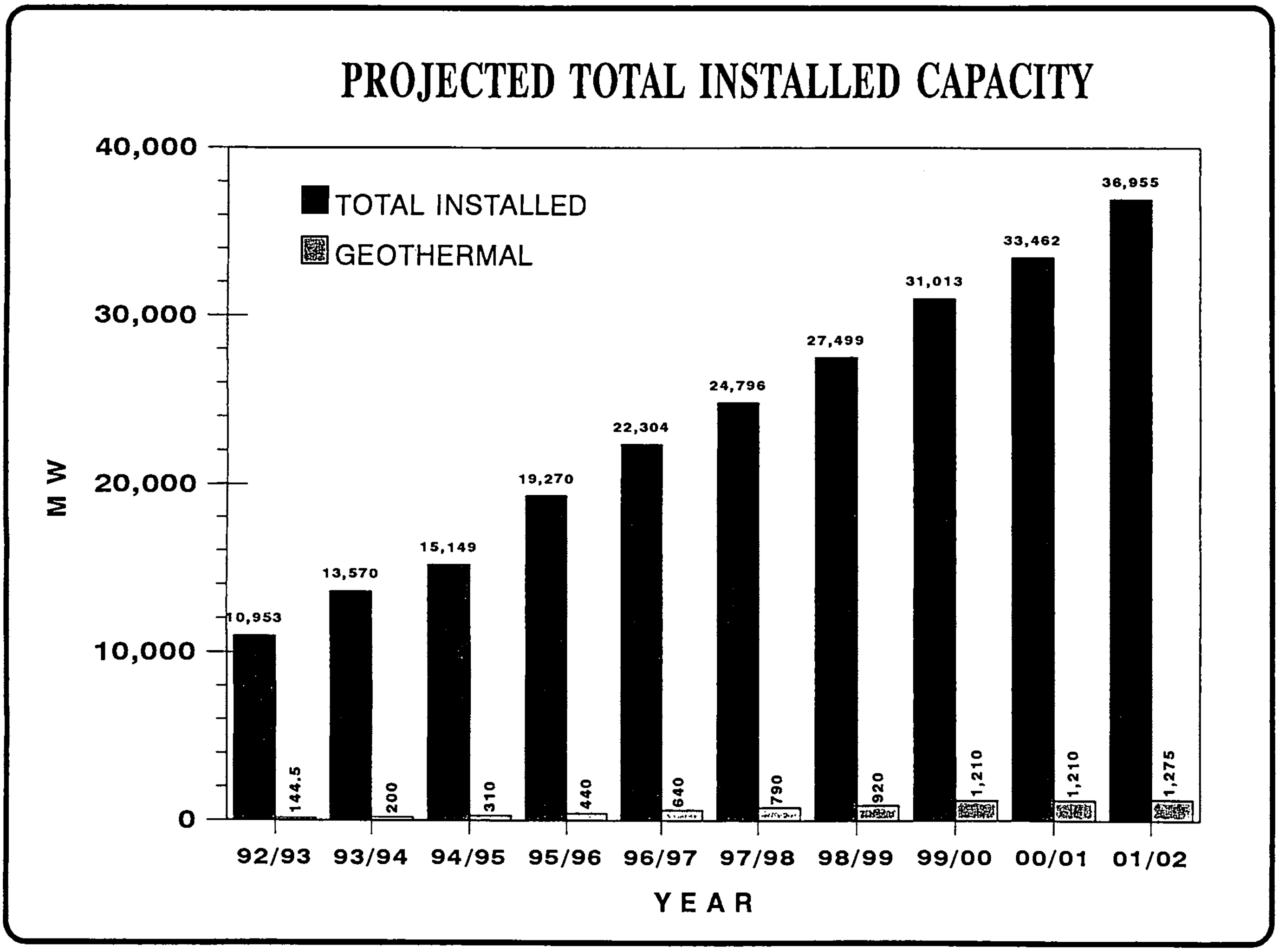

Figure 11. Projected installed electrical generating capacity in Indonesia through the year 2003 (Budihardjo, 1992 and Sudarman, 1992).

year 2000 (Fig. 11). Geothermal energy is scheduled to supply approximately 1200 megawatts of this new capacity from resources located on Java, Bali, Sumatera and Sulawesi (Akuanbatin, 1992; Radja, 1992). Table 5 shows the anticipated increase in installed geothermal capacity through the year 2020.

In addition to meeting Indonesia's increasing electrical demand, the government wants to reduce the consumption of oil for electrical generation. The diversification into non-oil fuels for electrical generation will allow the government to continue to export oil for foreign exchange revenue to support economic development. The reduced dependency upon oil is reflected in Table 6, which shows an increased dependency upon coal for future power generation.

Although geothermal is expected to provide only a small percentage of the electrical energy demand by the year 2000, geothermal can make a significant contribution to energy diversification. For example, at Kamojang the production of 140 MW of geothermal energy offsets the consumption of 6000 barrels of oil per day. In addition, geothermal energy is a very clean, non-polluting energy resource, especially when compared to coal. Therefore, additional geothermal capacity can contribute to both a more diversified and environmentally preferred generation fuel mix.

Table 5: Geothermal development scenario until the year 2020 (small scale development are not included, after Akuanbatin, 1992)

AREA	MW					
	1995	2000	2005	2010	2015	2020
Sumatera	–	270	540	810	1000	1000
Jawa-Bali	417	900	1000	1100	1200	1300
Sulawesi	22.5	40	80	120	160	200
Total	439.5	1210	1620	2030	2360	2500

Table 6: Estimated percentage of installed electrical generating capacities for various fuel resources (references: Patmosukismo, 1992)

ENERGY	1978/1979 %	1983/1984 %	1988/1989 %	1993/1994 %	2000 %
Coal	1.2	0.8	21.9	25.2	60
Hydro Power	28.9	35.9	32.9	25.7	16.6*
Geothermal	0	1.3	3.6	5.2	3.5*
Gas	0	0	3.1	19.9	12.3*
Oil	70.4	62.0	38.5	24.0	7.5

* Percentage decrease results from rapidly increasing generation from coal.

Geothermal Development Incentives

To accelerate geothermal development in Indonesia, the Government has issued Presidential Decrees No. 45/1991 and 49/1991. Decree No. 45 allows PERTAMINA or other Statutory Bodies, including the Private Sector, to sell steam or electricity to PLN or other customers. In order to make geothermal more competitive with other energy resources, Decree No. 49 reduces the total tax payment to the government from 46% to 34% of the net operating income for the companies which develop geothermal energy.

With these incentives now in place, PERTAMINA is now inviting Statutory Bodies, including the private sector, to enter into Joint Operating Contracts for the development of Indonesia's geothermal resources. PERTAMINA's goal is illustrated in Table 5 — to raise geothermal capacity from 144.5 MW in 1992 to 2500 MW in the year 2020.

CONCLUSIONS

A complex interaction of the Indo-Australian, Eurasian, and Pacific megaplates has produced an attractive island arc volcanic setting favorable to the development of geothermal resources. Approximately 142 high temperature prospects provide Indonesia with an estimated resource potential of 16000 MW. The exploration and exploitation of these geothermal resources is receiving increasing government support in order to meet the rapidly increasing electrical demand in the country and to provide diversification in the energy sector.

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