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The Geothermal Potential Of Indonesia

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An upsurge of interest in the indigenous geothermal potential of Indonesia has followed the Governments encouragement to develop other energy resources as alternatives to oil for the generation of electricity. Accordingly fresh estimates for the geothermal potential of known prospects is proposed.

Only the major fields in Java, Bali, Sulawesi and Sumatra, and which are expected to be developed rapidly, are considered. A brief description of each field is included in the paper and the basis on which the estimates are made is given. Using a modification of the concept, estimation and terminology used in defining mineral reserves, these estimates are quantified. Other factors, expected to influence either way the actual rate of development, are included.

The geothermal potential that is conservatively estimated can be developed in the next 10 - 15 years, is predicted as totalling 1500 MW (e) for the whole of Indonesia. Of this some 900 MW (e) is confined to Java which has the main demand for power.

As well as these major fields, numerous other good prospects are known. Together they may increase the ultimate potential of Indonesia many times what is here suggested. As they are thought unlikely to be rapidly exploited they are not included in these estimates which have been kept deliberately conservative.

A method by which these and future prospects can be ranked in priority is suggested. Based on crude statistical probabilities, the method allows for the combination of factors, other than geothermal, to be taken into account. The resultant quantitative combination, which gives an overall and relative priority, can be of assistance in future planning.

1.0 Introduction

Worldwide concern for future energy supplies, coupled with escalating prices for liquid fuels, has led many countries to reassess their indigenous energy resources. These include hydro, oil, natural gas, coal, and more recently nuclear, solar and geothermal. Only when such an inventory is complete can planning of a future energy policy be contemplated.

Indonesia is particularly fortunate in having an abundance of indigenous resources which allow a choice to be made as to the way the country's future energy demands are to be met. Once an optimum energy mix is formulated it should be recognised that it can never remain static but must remain sensitive to changes that develop both internally as well as externally. How quickly such changes occur was demonstrated in 1977 at an Energy Workshop held in Jakarta when fresh estimates for proven oil resources in Indonesia were calculated as being sufficient for only 19 years at the then current rates of production.

While further discoveries are anticipated, the use to which these reserves can be put is expected to change dramatically. With the growing rate of domestic consumption and assuming constant output the whole of the domestic production is predicted to be absorbed internally before 1995. The comparative decline in revenue that must result from this smaller amount of oil available for sale and its effect on the total economy has encouraged the Indonesian Government to support the substitution of other forms of energy and restrict where possible the domestic consumption of oil.

While coal is expected to be the major replacement of oil in new electrical generation developments, geothermal energy has also been recognised as an alternative in the total energy scene. It is this potential, which can be exploited in the near future, that is accordingly examined.

The exploration and development, on which the following estimates are based, is part of a bilateral agreement between the Indonesian and New Zealand Governments. Our good friends and counterparts have been provided by PERTAMINA, Perusahan Umum Listrik Negara (PLN) and what is now the Volcanological Survey of Indonesia (VSI). In conjunction with these agencies GENZL, as the executing agency for the New Zealand Government, has enjoyed participating in this assessment of the geothermal resources of Indonesia.

2.0 Previous Work

Van Dijk (1) was the first to propose the utilisation of geothermal energy for electric power generation in Indonesia. Despite opposition it was supported by Taverne (2) who instigated detailed geological investigations in a number of volcanic areas. Exploration drilling followed these studies at Kamojang in West Java where five shallow wells were sunk, one of which continues to discharge to this day. Results from these early investigations were summarised by Stehn (3) but the experiment to utilise the steam was not pursued. After the war a report by Kusumadinata (4) renewed interest in possible geothermal development which led to reconnaissance surveys being undertaken by Indonesian teams drawn from the Power Research Institute, the Bandung Institute of Technology and the Geological Survey of Indonesia. These surveys were followed by others which included experts drawn from UNESCO, UNDP, France, United States of America and New Zealand; recent participants have been drawn from Japan and Italy.

Reports and recommendations from these surveys are summarised by Sigit (5) Zen and Radja (6) and, Radja (7), but significantly all groups fully supported further geothermal investigations in Indonesia. What none could claim, without more data, was to quantify on a rational basis, the potentials for the individual prospects they supported.

The first open publication, which attempted to allocate values for the potentials of given prospects was by Djajadi et al (8). By then considerable detailed exploration had taken place and a better understanding gained with some types of Indonesian fields. In a prudent appraisal Djajadi proposed values that, while conservative, were the first realistic estimates suitable for planning purposes. Since then further exploration and production drilling at a number of different locations has led to a better appreciation of their underground reservoirs. This and the improved interpretation of results from exploration surveys and reservoir engineering has encouraged this fresh estimation.

3.0 Estimated Potential Of Major Geothermal Fields In Indonesia

Reconnaissance, Exploration and Development Programmes carried out by VSI, PLN and PERTAMINA, and assisted in many instances through the New Zealand Aid Programme, have identified considerable geothermal potential throughout Indonesia. Before attempting to quantify this potential it is clearly desirable to indicate the likely reliability of these estimates. One based on mining practice is proposed. The concept, estimation and terminology of defining ore reserves have become better based in recent years and are now usually disclosed under one or other of the two sets of headings, either proven/probable/possible or measured/indicated/inferred. Corresponding degrees of confidence, used here for estimating the geothermal potential of a prospect, rely on a proposed modification to that used by the U.S. Bureau of Mines and are as follows:-

Proven/measured is computed from results from exploration drilling as well as surface exploration. From these results the potential of the field is calculated from:

(a) the areal extent of the reservoir
(b) the depth, porosity and saturation of the rocks constituting the reservoir
(c) the measurement, recoverable reserves and the characteristics of the fluids discharged
(d) other assumptions that are specified.

The potential of the reservoir, calculated from the analysis of this data, is judged to be accurate either within stated limits or if not given, to be within 25 per cent of the computed figure.

Probable/indicated is the best estimate of the field at the completion of surface exploration but before completion of sufficient production wells to compute the potential. The boundaries of the reservoir, its structure, and geologic setting are known but assumptions are not confirmed as to type, conditions, and recoverable energy in the underground reservoir. Estimates in this group are less reliable than for measured and rely heavily on experience and familiarity with other exploited resources.

Possible/inferred is a quantitative estimate based upon a broad knowledge of the geothermal character of the prospect but from which only limited data is available. These estimates, whose quality will depend on how far exploration has proceeded, rely on assumed continuity or similarity with better known fields. Thus values range from crude estimates, made following a reconnaissance, with steady improvement as exploration of the prospect continues. Inferred figures therefore progress to the indicated category as work on a prospect proceeds.

In the table that follows exploratory and production drilling at Kamojang and Darajat has confirmed earlier estimates and both fields are now in the measured category. Similar success reported by PERTAMINA at Dieng and PLN/VSI at Minahasa will allow these estimates to be upgraded once detailed results become available. In the meantime they remain as indicated reserves together with Salak, Bali and Cisolok/Cisukarame. The estimates proposed for Banten and the whole of Sumatra remain in the inferred category.

Additional to these named prospects, numerous others are known, many of which are too isolated to be considered for any immediate power development programme but could become part of small rural electrification schemes. Here they are grouped together regardless of individual classification.

Only fields which have been investigated by GENZL, either jointly or in consultation, are included in this table. While they represent only part of the total geothermal potential of Indonesia they are believed to include all the major fields likely to be developed in the near future. In total they represent a potential generating capacity of 1500 MW (e) of which nearly 900 MW (e) is located in Java.

Estimated Potential of Major Geothermal Fields in Indonesia

		MW (e)
JAVA	Kamojang	150
	Darajat	150
	Dieng	150
	Salak	240
	Cisolak/Cisukarame	150
	Banten (more doubtful)	50
	TOTAL FOR JAVA	890
BALI	Bratan Caldera	150
SULAWESI	Minahasa Region (2 × 90)	180
SUMATRA	Lampung Province (3 × 90)	270
RURAL ELECTRIFICATION		10
	TOTAL FOR INDONESIA	1500 MW (e)

Brief commentaries are appended for each of the fields specified in the table and include the basis on which estimates are made. All rely on published work, to which reference is made or to unpublished reports prepared for the Indonesian Government under the auspices of the Aid Programme. Their locations are indicated in the map of Indonesia **Fig 1** and more specifically for Java in **Fig 2**.

3.1 Java

The greatest present need for additional electric power in Indonesia remains in Java, with its population of over 90 million. In the past, limitations in the transmission and distribution systems have caused as much restriction as lack of generating capacity, but are expected to disappear with recent construction under the power development programme.

This programme recognises that estimates of potential for Java total 900 MW (e). Proposals to ensure speedy development are being prepared and with the first 30 MW (e) becoming operational by the end of 1982, other construction is expected to follow.

3.1.1 Kamojang And Darajat

Because of their close proximity and concurrent exploration, the Kamojang and Darajat fields have always been considered together. Both are situated in the Priangan Mountains about 40 km to the southeast of Bandung, capital of West Java. Separated by about 10 kms, the two fields form a couplet suitable for concurrent development. Provision for this has been assured by the construction of an enlarged switchyard at Kamojang to connect Darajat to the main transmission grid.

Kamojang is the most extensively explored geothermal field in Indonesia and its development in conjunction with PERTAMINA and PLN is described by Wilson (9). The field itself lies in the Pangkalan caldera, an older part of the Gandapura/Guntur volcanic complex with its northeast and southeastern limits marked by faulting and subsidence. Details of this and a tentative model of the field, have already been published Hochstein (10) Kartokusumo et al (11). In essentials the model predicted a shallow groundwater zone close to the surface below which formed a "condensate layer" of variable thickness. In this layer a continuous water phase is retained in the pores of the rock and in which is maintained a substantial thermal gradient between the bottom and the top of the zone.

Below this condensate layer the true "vapour dominated" zone is developed, in which steam is the continuous phase, with some liquid also present. This constitutes the reservoir proper and is the zone penetrated by the production wells to supply steam for the field's development. At still greater depths geochemical evidence supports the possible existence of a hot brine layer from which steam would continue to evaporate and recharge the reservoir. This has yet to be substantiated.

Production drilling has confirmed the model, and measurements from these wells allow further refinements to be made. This leads to a revision of the potential of the field which is now estimated as a measured resource of 150 MW (e) with a life expectancy greater than 40 years.

The exploration programme at Darajat produced data so alike to that from Kamojang that it strongly suggested the fields were very similar Drilling has confirmed this to be true and with the reservoir known to be of comparable size, the Darajat field is judged equivalent to Kamojang with a measured potential of 150 MW (e).

Combined, the Kamojang and Darajat fields are estimated to have a measured potential of 300 MW (e) and are sited on or near a main transmission network. The first generation at Kamojang is expected to be functional late in 1982 and further rapid development of both fields is expected to follow.

3.1.2 Dieng

Although many observers previously reported favourably on the Dieng prospect, the first extensive survey followed a request by the Indonesian Government to the United States Agency for International Development. An exploration programme was jointly carried out by teams from the Power Research Institute and the Geological Survey of Indonesia, in conjunction with members of the United States Geological Survey. The results of these investigations and from the subsequent exploration drilling have been described by Zen (12) and Radja (7).

Since then development of the Dieng field has become the responsibility of PERTAMINA who have overseen an extensive exploration programme and completed the drilling of three deep wells. All the wells are productive, some discharging steam alone, others a mixture of steam and water. In all cases the steam carries with it a high content of non-condensible gases.

The field is thought to be very extensive but confirmation from wells sited near the periphery of the assumed boundary remains to be carried out. While the full extent of the reservoir remains somewhat imprecise a highly conservative estimate is followed, based on earlier surveys and natural heat flows. These alone would support a measured potential for the field of some 150 MW (e). A potential of considerably greater than this has been suggested but this lower figure is considered prudent until more is known of the field.

3.1.3 Salak

Extensive investigations were completed by 1976 in the geothermal region to the west of Gunung Salak. Two separate fields were identified, a large vapour dominated system designated the Kiraberes/Perbakti field and a smaller system, the Salak field. Although independent at the surface, the two systems are expected to be linked at depth or to rely on a common heat source.

Detailed geological, geochemical and geophysical exploration has been completed for the whole area and the boundaries of the field established. From these a detailed model of the Kiraberes/Perbakti field has been described consistent with the data collected and the natural features that are present. From this, estimates of the extent and the type of reservoir predict a cross-sectional area that exceeds 20 km², making this the largest single thermal system presently identified in West Java.

Drilling is needed to confirm this potential but an indicated figure of 240 MW (e) is predicted. This is based on sufficient similarities with the Kamojang and Darajat fields to allow interpretation of the data to be made with considerable confidence.

While access remains a problem, the very size and location of the resource favours rapid exploitation. It is situated close to Bogor from where it can connect to the transmission grid linking Jakarta and Bandung all of which points to early development. Negotiations for this are believed to be close to agreement and rapid progress is then expected.

3.1.4 Cisolok-Cisukarame

Surface indications of this field are the well known spouting springs at Cisolok near Pelabuhan Ratu. Less well known are other springs at Cisukarame in the adjacent valley to the east. Both groups are fed from a large outflow of hot water from a reservoir located to the north.

Regional investigations have been completed but further resistivity measurements are needed to define the reservoir. The total heat flow, embodied in the drainage of the outflow from the reservoir, is very large and its composition points to the field being a high temperature hot water type. While different from some of the fields, natural heat flow measurements in the drainage outflow predict an indicated potential of 150 MW (e).

While Cisolok is situated away from any rapidly developing area, this is unlikely to seriously delay exploitation once geothermal development is proceeding. Additional transmission costs will be incurred in linking it to the main grid but these are not expected to make development uneconomic.

3.1.5 Banten

More problematic is estimating the potential for the area enclosed within the Danau caldera. Considerable exploration has been undertaken already by PERTAMINA but problems remain before drilling reduces to an acceptable level of risk. While geochemistry of the associated hot springs is not encouraging, Ismet Akil (13) has shown that the geology and regional structure sufficiently resemble other prospects that the area's potential cannot yet be discounted.

As with any prospect in Java, the Banten field if proven, would connect to the main national grid and with this planned for the large Suralaya coal-fired station, only a short branch extension would be required. For these reasons, a continuation of the exploration programme is recommended, but it would be imprudent to infer a potential of more than 50 MW (e) to this prospect and even this may not eventuate.

3.2 Bali

An extensive exploration programme located a vapour dominated field beneath the Tapak/Bratan Caldera, Bali. The field, sometimes referred to as North Tabanan, is of particular interest in that the associated hot springs are all located more than 15 kms from the reservoir.

An extensive drainage outflow feeds these springs with hot water that has undergone both dilution and chemical modification in its passage underground down the flanks of the caldera. During the time the fluids take to reach the surface, a changing chemical equilibria is established with the rocks through which they percolate and is the explanation for the apparent contradiction between the geochemistry of the springs and the predicted underground temperatures.

The flow itself originates from a break in the southeast corner of the caldera and has been identified as extending over more than 50 km² downhill. Within the caldera the boundaries of the reservoir have been delineated and enclose more than 15 km². Once this was located, a search revealed a small and previously unrecognised surface feature which served to confirm the model and to improve confidence in the prediction.

Virtually all the heat transferred naturally away from the system is contained in this leakage of hot water, originating from the condensate layer above the reservoir. Estimates made for the energy contained in this outflow confirm it to be at least comparable in amount with similar measurements made at Darajat. Coupled with the greater size of the reservoir, indications are that the potential is greater than either Kamojang or Darajat but is prudently estimated as an indicated resource of 150 MW (e).

3.3 North Sulawesi

In the Minahasa region of North Sulawesi, two separate fields have been identified at Lahendong and Tompaso. Investigations covering the whole region have been completed jointly with the geophysical survey being undertaken exclusively by VSI. Both fields have excellent prospects with reservoirs extending over 10 km² in size and with isotopic equilibria results indicating underground temperatures in excess of 200° C. The Lahendong field was predicted as vapour dominated in the upper parts of the reservoir, overlying a zone of hot chloride water at an undetermined depth. With at least one well completed successfully by VSL, exploration drilling has confirmed the model and the present intention of PLN is to install a Monoblok generator of 1.0 MW (e) early in 1982.

Additional hydro power is currently under construction but exploitation of geothermal resources is possible in the future as both fields have potentials greatly in excess of present demand. In the meantime the measured/indicated potential of the Lahendong field is estimated at 90 MW (e) with a similar inferred potential at Tompaso of 90 MW (e).

Besides the Minahasa development, further prospects in the Kotamobagu area have recently been studied with attention focused on the Ambang volcanic complex. While some prospects appear promising it is premature to comment until further data becomes available.

3.4 Sumatra

Considerable geothermal activity extends throughout Sumatra, mainly associated with the Barisan Mountains which lie close and parallel to its west coast.

Numerous prospects have been identified and more will be discovered as exploration continues. Although the geothermal potential appears encouraging, the alternative resources of coal and hydro are enormous and are expected to be developed first. However as geothermal is most efficient when supplying a base load it could well be planned to supplement, rather than to compete with hydropower. at present all the geothermal potential of Sumatra is placed in the inferred category and is summarised under four arbitrary regions rather than as individual prospects.

3.4.1 Banda-Aceh

Early reconnaissance in the area did not yield promising results but, with a continuing demand for power in the region, further exploration has proceeded. The most promising area is in the Seulawaih volcanic complex where several centres of natural thermal activity have been located despite the very dense forest cover. The geology and structure are sufficiently promising to inspire hope that a worthwhile field may be discovered. This cannot be confirmed but recent field work by VSI should help to clarify the position.

3.4.2 North Sumatra

More than fifty areas of thermal activity have been identified in Tanah Karo, Tapanuli Selatan and Tapanuli Utara by Akbar (14). While most have only been examined superficially as part of a regional inventory, a few have received sufficient attention to infer promise.

Their rapid development in this area is however unlikely in view of the Asahan hydro development designed to sevice the aluminium smelter and to supply limited power to the local grid.

3.4.3 West Sumatra And Jambi

Two prospects lie to the northwest and southeast respectively of Gunung Kerinci and have been investigated together with VSI. That near Sungai Penuh in the Upper Merangin Valley shows some promise and easy access. Early prognosis was for a hot water field with sufficiently high underground temperatures to be suitable for exploitation. However resistivity profiling has so far failed to resolve if the springs are fed directly through NW - SE aligned faults or if they form part of a drainage outflow pattern. Questions also remain as to the precise depth and location of the reservoir and further exploration is necessary. Although the present power demand is small the prospect, if confirmed, could be harnessed for rural electrification in a progressive area.

The corresonding prospect, situated to the northwest of Kerinci, is Murah Labuh. From the head of the valley a series of hot springs discharge at progressively lower levels forming a coherent drainage pattern. Their geochemistry evidences a similar high temperature hot water system with sufficient promise to warrant further exploration if justified by local demand.

3.4.4 Lampung

Four separate and promising prospects have been identified in the Semangko depression in Lampung Province which forms part of a block-faulted graben or a fault angle depression. The whole is infilled with tuffs, pumice, breccias and ignimbrites. This rock assemblage, the geological structure and the association of young volcanics makes it resemble the Taupo Volcanic Zone and the recent so called phreatic eruptions at Suoh have their equivalents in New Zealand.

The prospects at Kalianda, Wai Narip, Suoh and Antatai appear to be hot water fields with excellent prospects. Their rapid development is much less assured with the development of the Bukit Assam coalfield and small local demand. Because they total an inferred potential of 270 MW (e) they may be expected to develop as the Sumatran grid becomes established. In the meantime they may have some potential for rural electrification in support of the transmigration programme.

4.0 A Proposal For Ranking Prospects In An Order Of Priority For Future Development

Surveys of geothermal surface features have proceeded in Indonesia for many years and cover prospects not described herein. Limitations of manpower, finance and demand will retard development of many of these prospects and some order of priority is clearly desirable. It may be pertinent to recall a method used to determine priorities for some of the areas identified in this paper.

Two steps are suggested for assessing any prospect. The first ranks it on strictly technical grounds based on its ability to produce sufficient energy at a sufficient temperature for a sufficient time. The second is a composite ranking of mixed socio-economic factors, alternate energy sources and the proximity of the resource to the demand.

While many of these factors can be identified they cannot all be quantified and a simple cost/benefit analysis then becomes inappropriate. This difficulty is not unique to geothermal energy but is common to all similar situations where risk factors can be defined but not measured eg when a mining venture arrives at the point where further finance is required to "prove-up" the deposit. Such decisions may be helped by crude statistical techniques. One such method was used by the Mineral Resources Council of New Zealand (15) to quantify the worth of "total probable mineral production" and a modification of this approach was first used in Indonesia after the 1971 reconnaisance (16).

While initial estimates of potential may be uncertain more, precise figures are likely to be known for the local power demand and the minimum acceptable size of increment; both are required for power planning and are unrelated to any specific energy source. Clearly a field with a potential of less than an acceptable increment will not be developed, but one with greater resources can be developed in stages as future demand increases. What then is important for this exercise is the minimal size of increment.

The method used to quantify and combine the various factors is an follows. For convenience each prospect is considered separately and probabilities assigned to factors in accordance with below :

Column A — The minimum size of geothermal development for a specific area.

Column B — That a geothermal resource at least as large as that designated in Column A will be found in the specified area.

Column C — That a resource if found will be exploited in the next 10 - 15 years.

Finally, the adjusted value of the Geothermal Potential of an area is calculated as the product of A X B X C and the resultant sum used to determine an order of priority on which future work can be recommended. An example based on Indonesian experience is given in the accompanying table. While convenient to describe the method, the actual values assigned in this table are purely personal and do not necessarily represent those of the Indonesian Government.

AREA	Possible size of minimum of geothermal Potential likely to be developed in MW. (A)	Finding a power source large enough to justify development. (B)	Exploiting such a resource if found. (C)	Geothermal Potential of area adjusted for size and probabilities. (A) x (B) x (C)	Proposed order of Priority.
WEST JAVA					
1. KAWAH KAMOJANG	30	0.9	0.9	24.3	1
2. DARAJAT (KAWAH MANUK)	30	0.7	0.8	16.8	2
3. KAWAH CIBEUREUM (SALAK/ KIARABERES)	30	0.5	0.8	12.0	3
4. CISOLOK — CISUKARAME	20	0.4	0.5	4.0	4
BALI					
BRATAN CALDERA	20	0.6	0.3	3.6	6
NORTH SULAWESI					
1. SARONSONG — LAHENDONG	20	0.5	0.4	4.0	4
2. TAMPOSA — LANGOAN	20	0.3	0.3	1.8	7
SOUTH SULAWEST					
SULILI AND MASEPE	2	0.05	0.1	0.01	12
WEST SUMATRA					
MUARA LABUH	1	0.3	0.1	0.03	11
JAMBI					
UNGAI PENNUH	2	0.4	0.1	0.03	8
SOUTH SUMATRA					
SEMANGKO, SUOH, ANTATAI	2	0.4	0.1	0.08	8
ACÈH					
SARAH GLIMA	5	0.05	0.2	0.05	10

5.0 Summary

Geothermal energy in Indonesia is poised for rapid development with numerous prospects identified. With the greater understanding of the several unique features of specific fields, fresh estimates are proposed for the potential likely to be developed in the near future. This is predicted as 1500 MW (e) for Indonesia as a whole, with 900 MW (e) in Java. Further prospects are expected to be discovered and they may increase substantially this amount. In the meantime it represents what is considered a conservative and realistic figure suitable for future planning.

6.0 Acknowledgements

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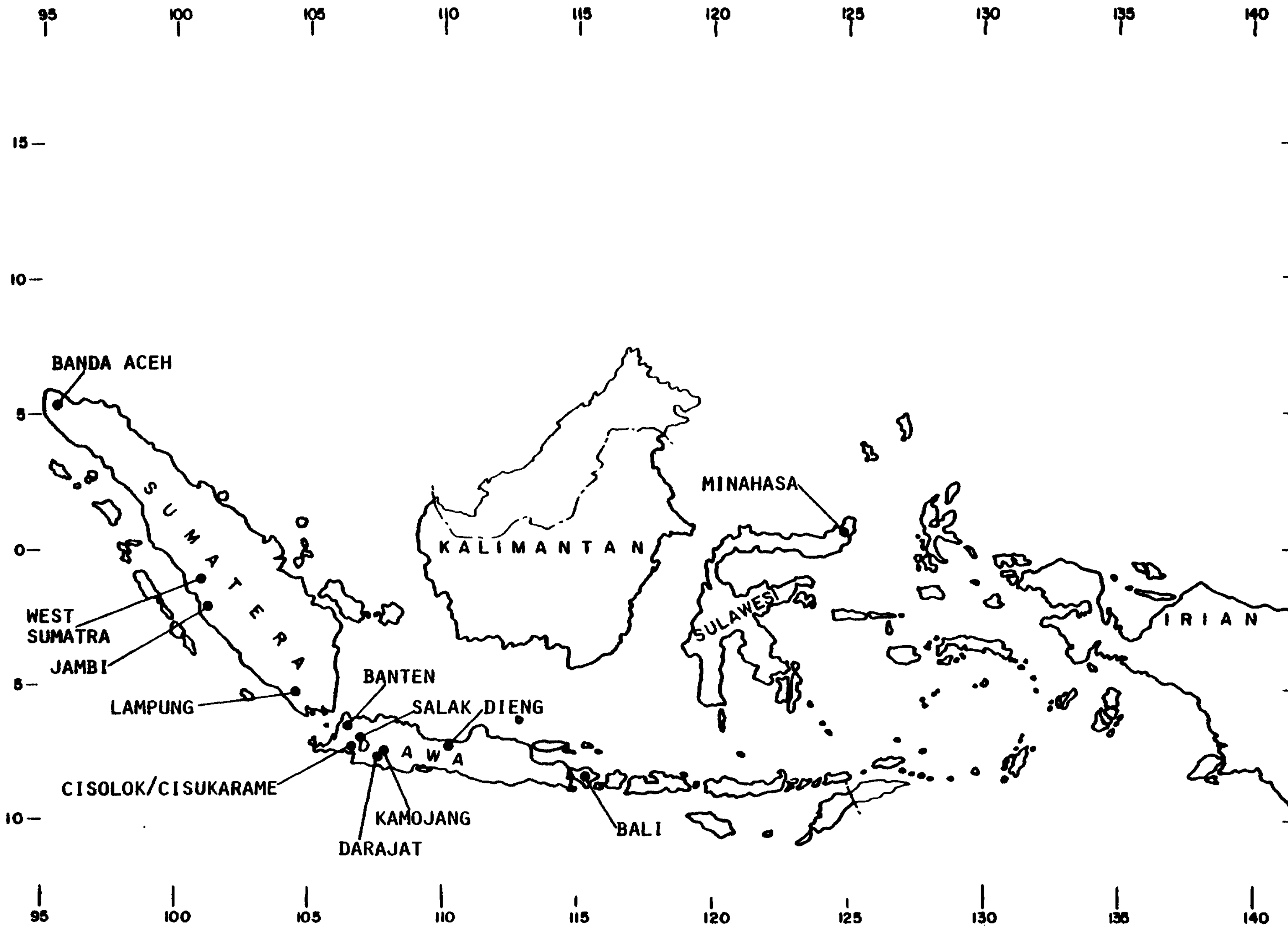

Fig 1. Map of Indonesia showing areas of identified geothermal prospects.

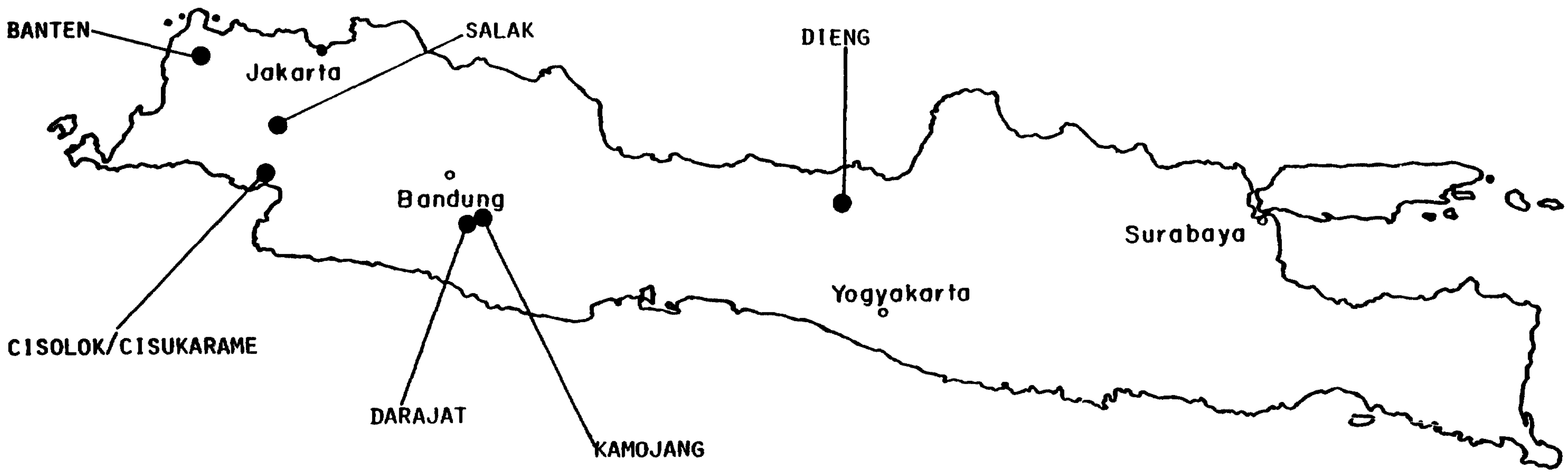

Fig 2. Map of Java showing specific geothermal fields.