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EXPLORATION AND EVALUATION OF THE DARAJAT GEOTHERMAL FIELD WEST JAVA, INDONESIA

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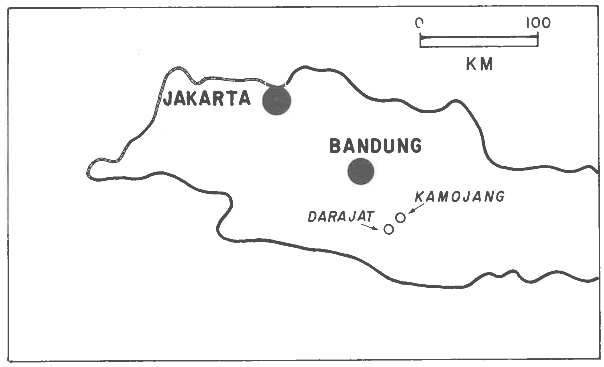
ABSTRACT

The Darajat Geothermal Field is located in the mountains of West Java 100 miles southeast of Jakarta, Indonesia (Fig. 1). Extensive exploration was started under a New Zealand aid agreement, continued by PERTAMINA, the Indonesian Government Oil Company, and completed by Amoseas Indonesia Inc. Exploratory and evaluation work done consists of geologic mapping, geochemical surveys, geophysical surveys, environmental surveys, drilling, well testing and reservoir modeling. Amoseas work has confirmed that the Darajat reservoir is dome-shaped, trending northwest-southeast and contains vapor dominated, two phase fluid. Pressures of 37 bars abs. and temperatures of 245°C are recorded. Of the seven wells drilled, five have reached the reservoir and three produce commercial quantities of steam. A computer simulation of the five square kilometer reservoir has shown it to contain sufficient reserves to supply a 55 MW plant.

INTRODUCTION

The Darajat Geothermal Field lies in rugged terrain in West Java (Fig. 2), about 50 kilometers SE of Bandung and nine kilometers SW of the producing Kamojang Geothermal Field (140 MW). Both fields are vapor-dominated resources in an area near Bandung where several other areas of geothermal potential are indicated by hot spring and fumarolic activity (Soetantri, 1986).

Exploration began in 1972 with reconnaissance of the Darajat fumarolic area by J. Healy (NZ-DSIR) and was followed by geochemical surveys of the fumaroles, hot springs and streams by Mahon and resistivity surveys by Hochstein. Geological mapping was also completed. Two slim-hole wells were located based on the results of the surveys and drilled to 760 meters in 1976-77 by GENZL for Pertamina under a New Zealand aid agreement with the Indonesian Government. The second well encountered reservoir conditions which encouraged Pertamina to drill the Darajat-3 well (DRJ-3) to 1521 meters with a full scale drilling rig in 1978. DRJ-3 encountered 600 meters of reservoir at 240°C and 35 bar and produced a flow of 12 kg/s (6 MWe) of high enthalpy steam (Radja 1983).



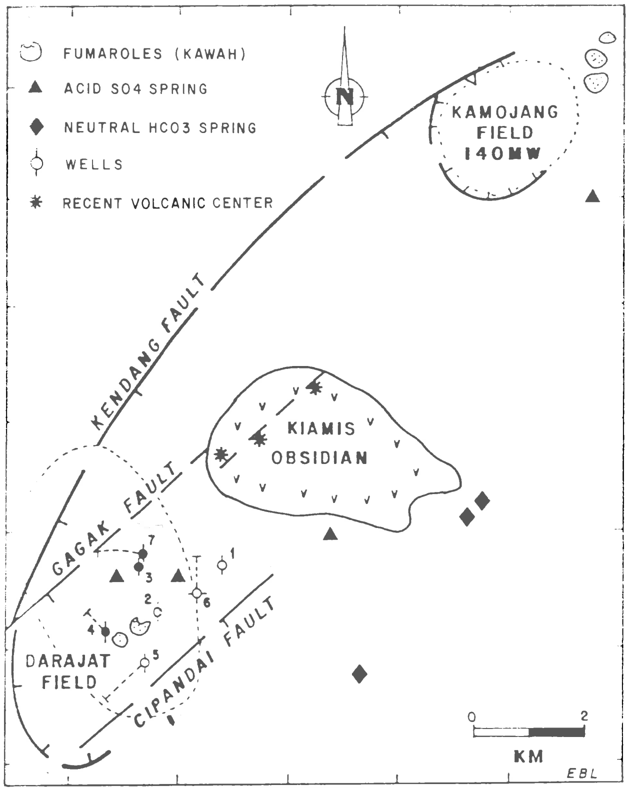
WEST JAVA-INDONESIA FIG. 1

Efforts by the Government of Indonesia to encourage geothermal development led to the signing by Amoseas Indonesia Inc., jointly owned by Chevron Corp. and Texaco Inc., of a Joint Operations Contract with Pertamina to further explore and develop the Field. Amoseas has undertaken an extensive exploration program of geologic mapping, geochemical surveys and geophysical surveys. Additionally four deep wells have been drilled to delineate the field and have determined that the resource is large enough for commercial development. Development of the first generating unit is in the planning stage and the reserves may be extended by future drilling.

FIELD STRUCTURE - GEOLOGY

The field is situated on the rugged eastern flanks of Mt. Kendang in a north-south trending Quaternary volcanic range. The volcanics vary from andesites to basalt and include poorly differentiated lavas and breccia. Some volcanoes in the area have been active, in historical time, including Papandayan (1772) and Gunter (1840). In modern times Galunggung (1982) mantled the region with ash during a year long eruption. There is also evidence of silicic volcanism at Gunung Kiamis, located four kilometers from Darajat, where young obsidian rhyolite extrusives suggest the existence of a shallow, differentiated magma chamber.

The surface volcanic rocks are highly altered near the Darajat kawahs (hot springs) but most of



DARAJAT & KAMOJANG FIELDS FIG.2

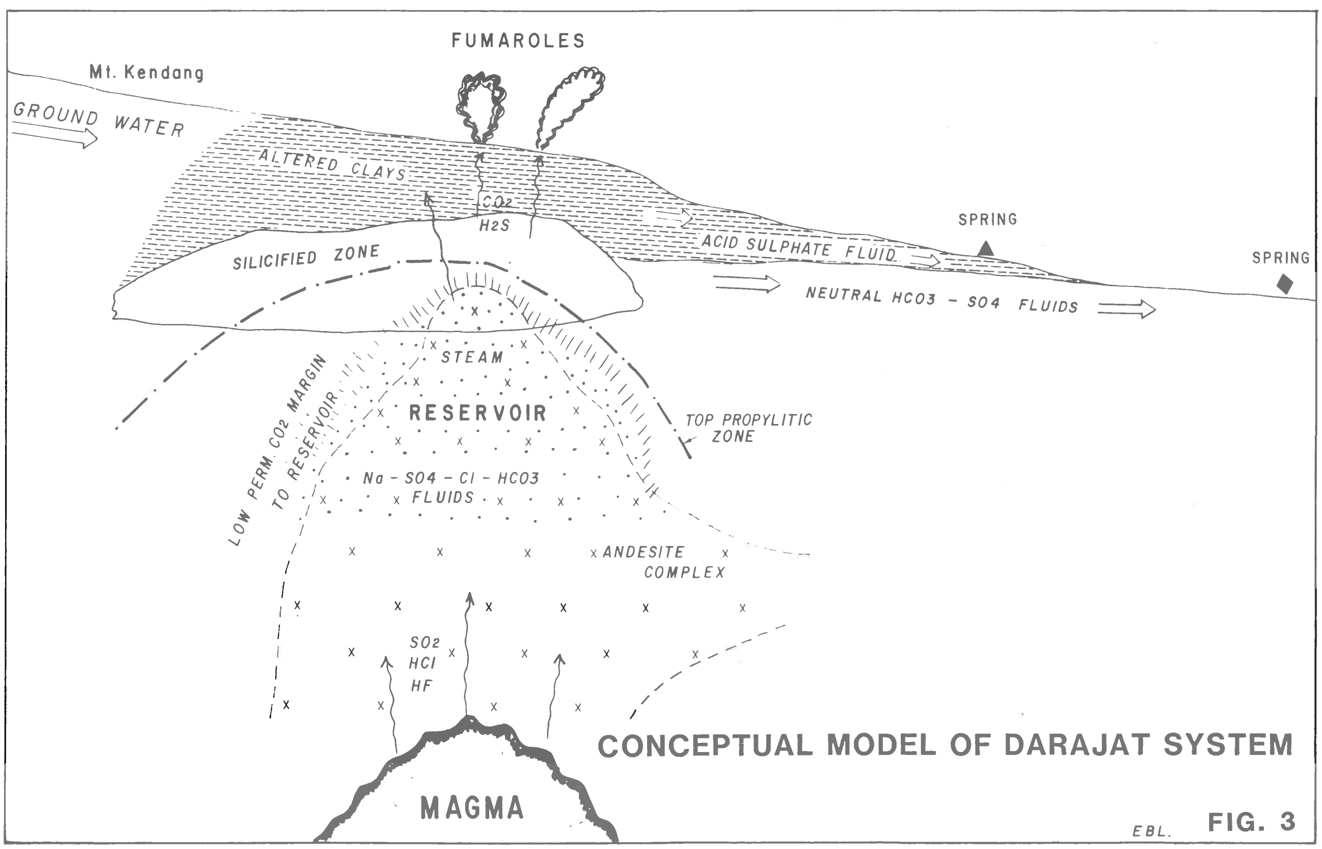
the alteration is hidden by vegetation and surficial ash layers. However, the altered zone is seen to coincide with a shallow thermal anomaly identified by shallow gradient wells which reveal a warm near surface aquifer moving from the higher elevation kawahs to the lower elevation hot springs (Fig. 3).

The Kendang Fault, running NE-SW, links the Kamojang and Darajat fields (Fig. 2). This connection plus an association of volcanic centers and soil mercury anomalies along its route suggest a correlation between the fault and a deep heat source. Northeast trending faults (Gagak and Cipandai) are an indication of a local structural fabric imposed on the field.

GEOCHEMISTRY

A model of the Darajat geochemical system can be pieced together from the geochemical data which has been collected (Fig. 3). Starting at the highest elevations of Gunung (Mount) Kendang, meteoric water falls from the abundant rainfall in the area and is absorbed into the surface groundwater.

The Darajat Kawahs, located at 1920 to 1990 meters elevation are comprised of numerous fumaroles, mud pots, boiling pools with high gas flux but minimal outflow and hot springs. The thermal energy has been estimated at 66 MWth, similar to Kamojang. Temperatures at the



CONCEPTUAL MODEL OF DARAJAT SYSTEM

FIG. 3

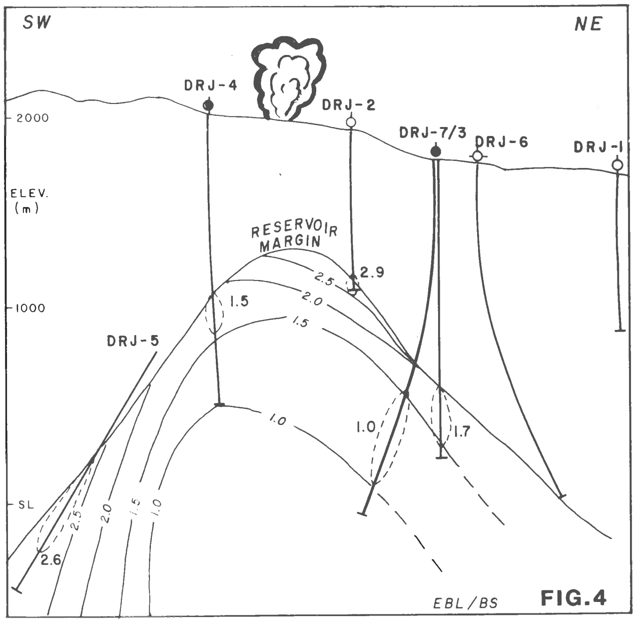


FIG.4

STABILIZED GAS CONTENT (wt %) IN PRODUCED STEAM

fumarole vents have been measured at 103°C and range down to 50°C at some hot springs. The surface waters are acid-sulphate in nature, with pH values ranging from 1.8 to 2.7 and are characteristic of shallow meteoric water which has been steam heated (Table 1). Boron content is indicative of a high temperature source. Fumarolic gas compositions are generally typical of geothermal areas with CO_2 by far the dominant gas but with minor H_2S. The gas contents are similar to but slightly higher than those at Kamojang. Some SO_2 and HCl have been seen which is evidence of magmatic contributions to the steam. Sulphuric acid has been found to form from the SO_2 and oxidized H_2S in the geochemical samples collected.

Four hot springs are found at elevations of 1873 to 1345 meters above sea level where fluid content is also acid-sulphate but diluted to lower dissolved solids and higher pH values (2.5-3.3). Warm springs further down the hydraulic gradient at 1325 to 1260 meters above sea level are near neutral sulphate-bicarbonate water containing CO_2 and H_2S but no significant chlorides. These are considered to be outflow from the deeper reservoir fluids.

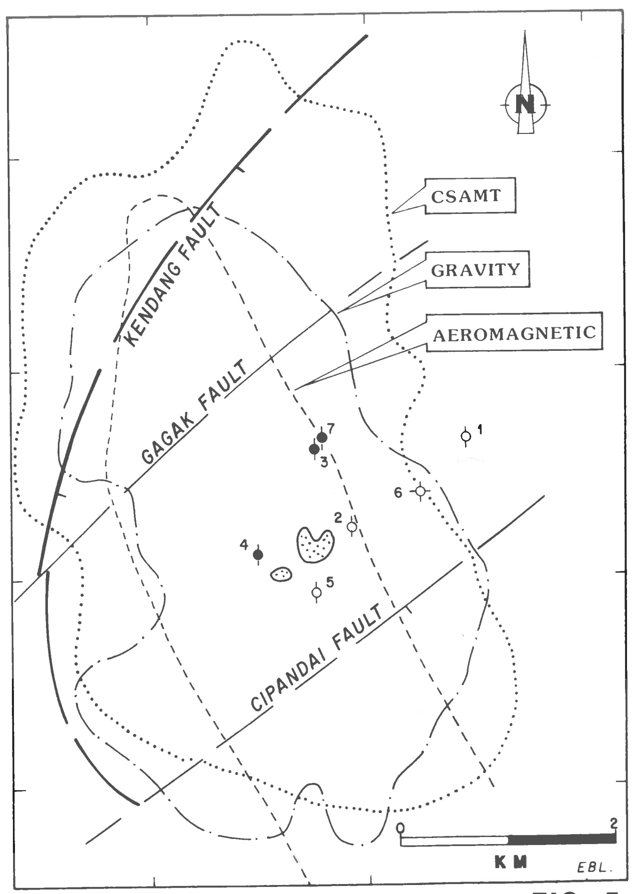
Discharges from completed wells are largely dry steam but can be wet on initial flow or at higher wellhead pressures. Gas contents are also initially high but stabilize within a week at 1.0 to 2.9% by weight and average below 1.5%. Differences occur in the spacial variations of gas content in the reservoir with higher concentrations apparent towards the top and margins (Fig. 4). CO_2 is the most common gas at 85 to 95%. Ratios of CO_2/H_2S up to 80 are recorded but the average is between 15 and 20. Concentrations apparent towards the top and margins

(Fig. 4). CO_2 is the most common gas at 85 to 95%. Ratios of CO_2/H_2S up to 80 are recorded but the average is between 15 and 20. Concentration of NH_3 and CH_4 are 0.4% and 0.2% respectively. Traces of SO_2 at 0.2 to 5 mmole/mole are also recorded. Both Na-K-Ca and Silica geothermometers were found to indicate 235° to 240°C, suggesting the neutral fluids are derived from the reservoir.

A corrosion study has been performed which revealed no special metallurgical problems from the steam, separated water or condensate.

GEOPHYSICS

Extensive geophysical work has been carried out at Darajat. Electrical resistivity surveys including Schlumberger soundings were taken by New Zealand consultants in 1973, 1974 and 1976, followed by magneto-telluric surveys done for Pertamina in 1979 and 1980 (Sudarman 1983). Starting in 1985, surveys done for Amoseas included a 700 station gravity survey, 11 (eleven) controlled source audio-magneto-telluric (CSAMT) profiles, an aeromagnetic survey and sample surveys of dipole-dipole resistivity, head-on resistivity, spontaneous potential (SP), Schlumberger soundings and magneto-telluric soundings. The most significant data were obtained from the gravity, CSAMT and aeromagnetic surveys.



GEOPHYSICAL ANOMALIES FIG. 5

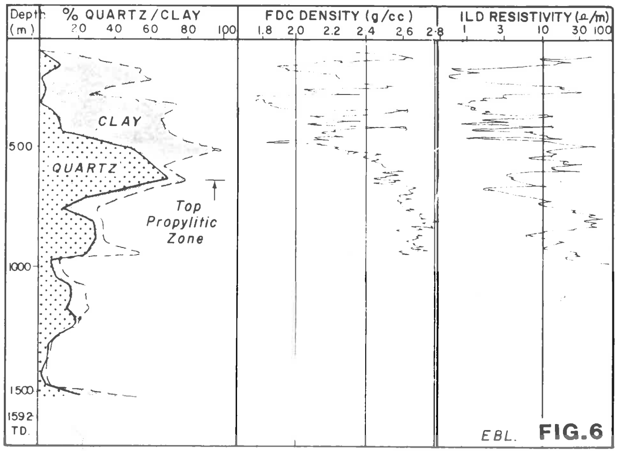


FIG.6

DRJ-4 ALTERATION AND GEOPHYSICAL LOG

The gravity survey identified a 7 by 14 kilometer positive anomaly with a maximum amplitude of 3.5 milligals (Fig. 5). It is elongate north south with a center of mass calculated at 750 meters below the surface. Drilling has shown that the anomaly coincides with a layer of massive silicification overlying the reservoir as indicated by a comparison of lithology and density log data from DRJ-4 (Fig. 6).

The eleven CSAMT profiles, totalling 83 km, were carried out at one kilometer spacing, and revealed a shallow conductive zone overlying a deep resistive body (Fig. 7). This has been correlated using well log data, to highly conductive rocks in shallow argillic and silicic zones overlying weakly altered rocks in the propylitic zone (Figs. 6&8). The resistive body was believed to correspond to the steam reservoir prior to drilling of the Amoseas wells.

The drilling showed that both the gravity and CSAMT anomalies covered a larger area than the underlying reservoir. DRJ-5 found low permeability in what is now believed to be the SW margin of the reservoir even though mineralogic

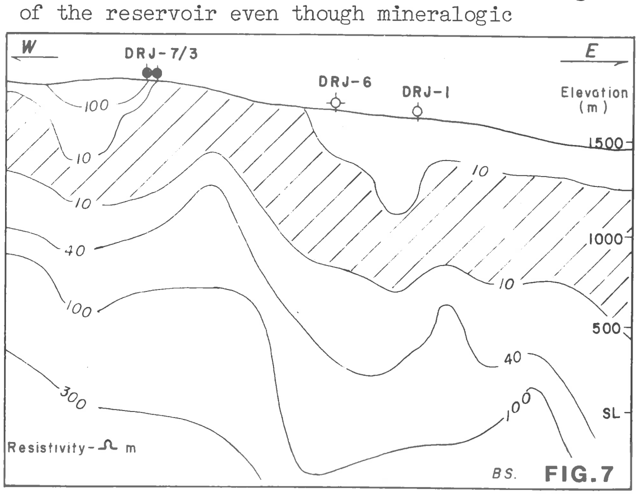


FIG.7

CSAMT RESISTIVITY CROSS-SECTION W-E

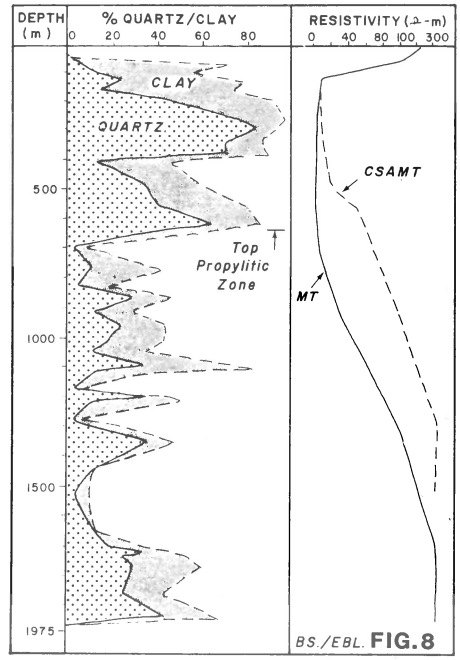


FIG.8

DRJ-7 ALTERATION AND RESISTIVITY SOUNDINGS

temperature indicators (epidote, actinolite and biotite) suggest that much higher temperatures were previously present (Fig. 9). This is attributed to collapse of an earlier larger reservoir to the present smaller reservoir.

A significant positive anomaly was also found by the aeromagnetic survey. This anomaly is consistent with a deep, magnetic, massive, andesite complex penetrated in three of the wells (Fig. 10) and which roughly coincides with the presently known reservoir. It may be that the more brittle rocks of this complex better support the open fractures necessary for the existence of the present steam reservoir.

FAULT AND RACTURE ANALYSIS

Interraction of major steam producing zones at Darajat results in abrupt loss of drilling fluid associated with a sharp drilling break indicating little or no resistance to the bit for up to several meters. That these are well defined zones of high permeability has been confirmed by injection temperature logs and spinner surveys. All four wells drilled by Amoseas were directionally drilled because it was considered highly likely that the fault or fracture zones might dip at high angles. It was considered important to verify this and to determine, if possible, whether there was any preferred orientation to the faults and fractures. The faults interpreted from surface geology and head-on resistivity profiling indicate trends of N-S to NE-SW though dominated by the NE-SW trend (Fig. 11). Veins and fractures from all cores in vertically drilled parts of holes show that 50% of the dips

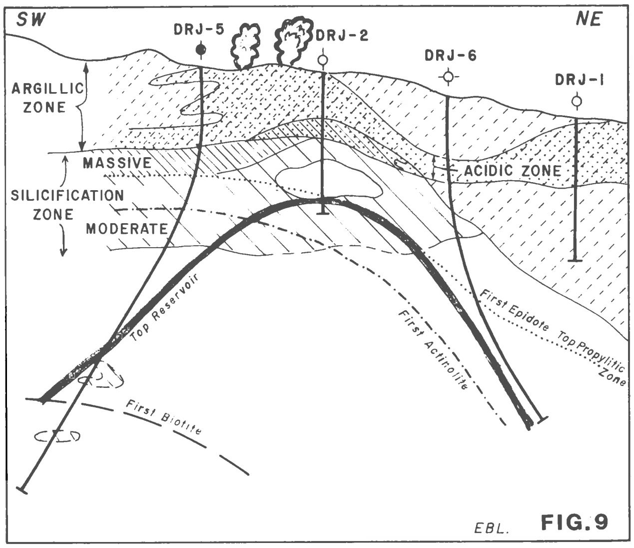


FIG.9

HYDROTHERMAL ALTERATION

were above 70°, 89% were above 50° and none below 30° (Fig. 12). Data from Schlumberger dipmeter processing in DRJ-7 from 340 m to 1130 meters indicated fracture trends from N-S to NE-SW (Fig. 13) and nearly all picks were greater than 60° with dips to the East or Southeast. It was concluded for future drilling that wells directed to the west and northwest would carry the lowest risk.

DRILLING RESULTS AND RESERVOIR GEOMETRY

Results of the wells drilled to date are mixed (Table 2). This is due in part to the reduced size of the reservoir relative to the gravity and CSAMT anomalies, the amount of reservoir penetrated and casing sizes. DRJ-1 was shallow and intersected an outflow zone outside the field area. DRJ-2 just penetrated the top of the reservoir and has small casing. DRJ-3 was initially a large producer but a 7" tie back string was run to the surface to repair a leak in the 9-5/8" casing. DRJ-4 and DRJ-7 are into the main part of the reservoir while DRJ-5 and DRJ-6 are on the south-west and north-east margins respectively (Fig. 14).

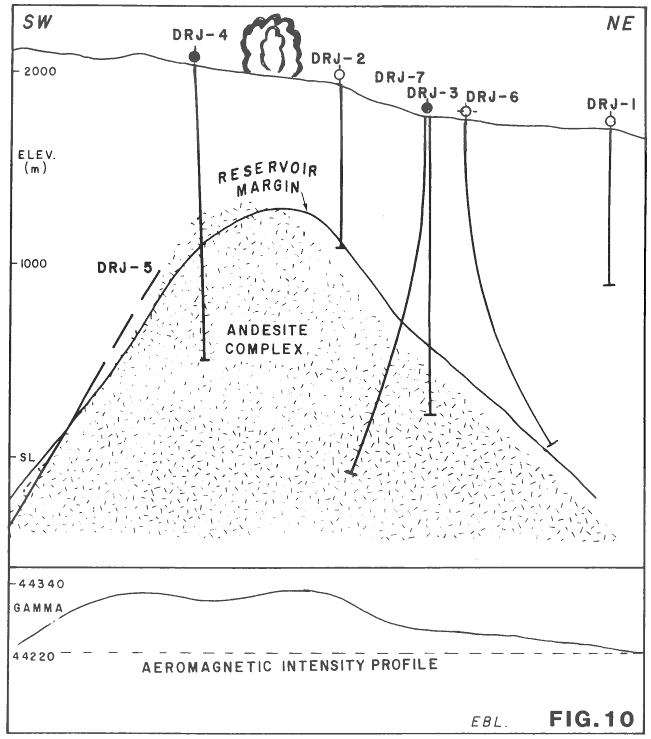
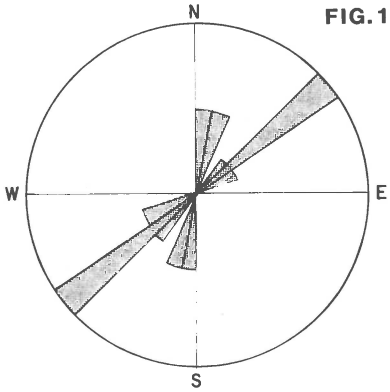


FIG.10

GEOLOGIC AND AEROMAGNETIC SECTIONS

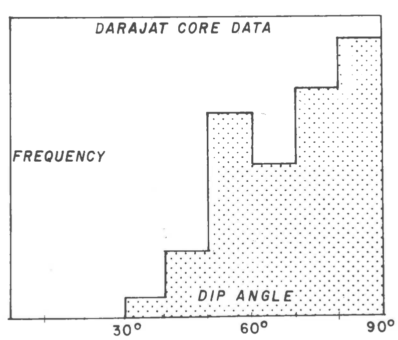
DRJ-4 was successfully drilled to the north-west, encountered the reservoir top at 1134 meters asl. and penetrated 680 meters of the reservoir including three significant fractures zones. To the south west DRJ-5 reached 390 meters below sea level but encountered poor permeability and a conductive temperature gradient. While temperatures and pressures in the well are close to reservoir conditions it appears to be in a partly sealed margin of the reservoir. The well found extensive alteration including silicification and evidence of former higher temperatures in mineralogic logs. Cross-overs on down-hole neutron density electric logs indicate CO_2 gas accumulations at shallow depths and this plus tests below this zone which had high gas content, suggest the well is situated in a gas rich margin of the field (Fig. 4). The well holds water at 100 meters asl. DRJ-6 drilled northward and, although it almost

FIG.11



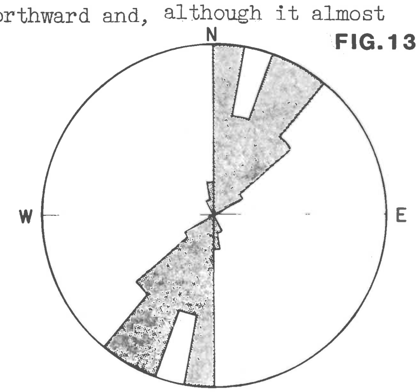
STRIKE OF SURFACE FAULTS EBL.

FIG.12



FREQUENCY OF VEIN/FRACTURE DIPS GAR.

FIG.13



STRIKE AZIMUTH FROM DRJ-7 DIPMETER LOG GAR.

reached sea level, found no significant permeability. Temperatures while drilling were below that of the reservoir but the well was abandoned without any stabilized temperature surveys being run. Finally DRJ-7 was directed to the west from a surface location next to DRJ-3 and encountered significant permeability. It is the most productive well drilled in the field to date. It was tested at a stable 24kg/s (12 MWe) for a period of two months.

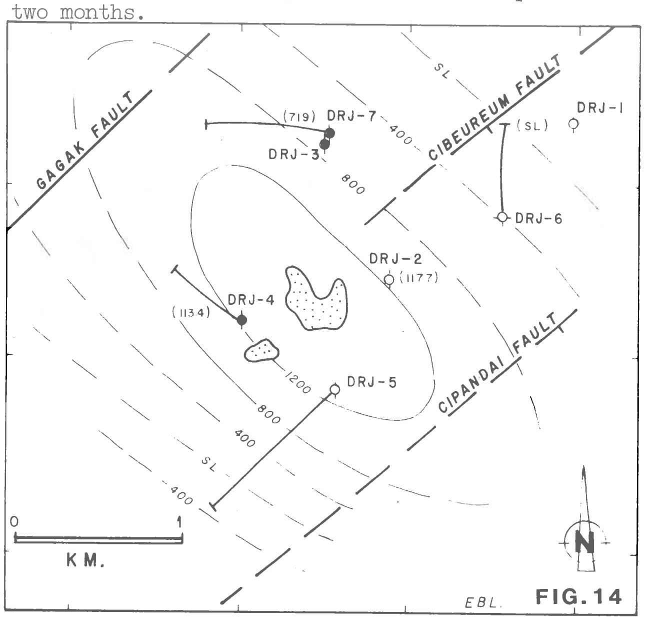


FIG. 14

RESERVOIR TOP ELEVATION

RESERVOIR DESCRIPTION

The simplest description of the Darajat reservoir (Fig. 14) is to say it is a "dry steam" (vapor dominated) system very similar to its neighbor Kamojang (Grant 1979). The reservoir rocks are propylitized andesites, lavas and breccia, frequently fractured and faulted. Micro-fractures are evident from cores and are important in providing access to the bulk of the fluid mass in the rock matrix. The reservoir mobile fluid is steam in fractures but the rock matrix contains liquid water with an estimated total reservoir saturation of 33%. A liquid - vapor interface may exist at an elevation of 100 meters asl. or 1100 meters below the highest recorded steam zones. Reservoir temperatures at 235° to 245°C and pressures at 33 to 37 bar are normal for a vapor dominated reservoir. The reservoir pressure gradient is twice vapor static. Lateral gradients are expected.

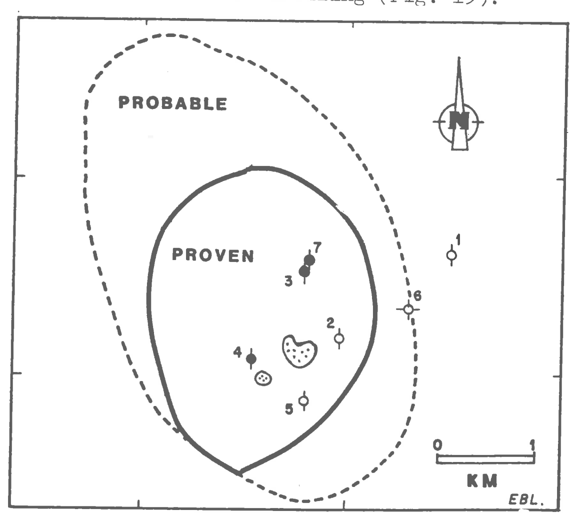
Numerical simulations of reservoir performance were run using Chevron Corporation's Geothermal Simulator. The reservoir model included over 2000 cells to simulate the reservoir parameters, known faults, existing wells and future producing wells. The reservoir was considered "proven" within 500 meters of a producing well giving a proven area or 5 sq. kilometers and a volume of 6 cu. kilometers and a mass of reservoir fluid in place of 160 to 260 million tones. Simplified models were used to refine variations of the main case studies. These studies have shown that sufficient reserves are available to supply a 55 MW plant for 25 years and that the proposed development is feasible.

DEVELOPMENT PLANNING

The Amoseas development plan is to use the existing producing wells plus three additional wells to supply the first plan. Existing locations will be used for the required new production drilling. Studies have indicated that larger diameter (13-3/8" production casing with 9-5/8" liner) will provide at least 50% more steam than the present completions (9-5/8" production casing with 7" liner) given the same reservoir conditions. Therefore only three new wells are initially planned to provide the additional steam needed for the plant.

Amoseas has also closely examined the plant operating pressure requirements. Computer simulations of the reservoir performance indicate that turbine inlet pressures as high as 14 bar (193 psi) are possible for a 25 year field life. High operating pressures are advantageous in conserving the resource because a lower steam consumption rate is needed to supply the same amount of power. High pressures may also contribute to savings in requiring fewer wells, in plant construction costs, and in pipeline costs. The turbine inlet pressure is still under study and has not been finalized. Declining reservoir pressure is a major concern in geothermal fields but the application of modern reservoir evaluation techniques and greater knowledge of the performance of other reservoirs provides the confidence that high pressures can be used in this case.

Pipelines are planned to follow existing access roads for ease of erection, servicing and to provide minimum environmental disruption. Cooling tower blow-down will be gravity fed into an existing exploratory well for disposal. Additional extension of the field may be possible based on the results of the new drilling (Fig. 15).



RESERVE AREAS FIG. 15

CONCLUSIONS

Between 1984 and 1989 Amoseas Indonesia Inc. performed significant exploration and evaluation work at the Darajat field. Four new wells were drilled and tested and a vapor dominated field with proven reserves of over 65 MW has been identified. Planning is in progress for the State Electric Company (PLN) to install a 55 MW plant but a future extension awaits development of additional reserves.

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TABLE 1

REPRESENTATIVE FIELD CHEMISTRY

SAMPLE NO.	(1)	(2)	(3)	(4)	(5)	(6)
pH	1.8	3.3	6.3	6.35	3.4	4.8
TDS (105±C)	4260	310	240	1380	719	38
SiO_2	377	107	21	415	340	4
B	1	1	-	87	8.0	1.6
Na	15.7	16.4	20.0	219	96	0.3
K	6.8	4.9	7.5	10.4	15.1	0.3
Ca	31	18.4	27.0	30.2	2.5	1.4
Mg	19.2	4.0	11.0	1.1	0.6	0.1
NH_4	1.0	0.1	-	-	-	-
Fe	100	2.6	0.08	0.37	1.8	4.8
Al	133	13.7	-	-	-	0.1
HCO_3	-	-	160	111	23.0	23
Cl	1.1	1.0	3	205	58	-
SO_4	3060	148	44	216	130	-
F	0.34	1.7	-	-	-	0.1

(1) Kawah Darajat - Acid sulphate waters (1950 m elevation)
(2) Surface Acid Sulphate (1325 m elevation)
(3) Surface Neutral Bicarbonate - Sulphate, (1250 m elevation)
(4) Down hole sample DRJ-5 (2132 m depth)
(5) separated water - wet discharge DRJ-3
(6) Condensate sample DRJ-7

TABLE 2

SUMMARY OF DARAJAT WELL RESULTS

WELL NO.	1	2	3	4	5	6	7
Elevation (m)	1674	1872	1762	2020	1919	1752	1762
Depth (m)	761	760	1521	1592	2585	1822	1975
Vert. (m)	761	760	1521	1470	2312	1687	1770
Casing Shoe (m)	438	315	888	914	913	397	1143
Liner OD (in)	4.5	4.5	7	7	-	-	7
T max (0°C)	144	239	247	243	239	-	241
P (bars-abs)	-	32	36	37	35	-	37
kh (Darcy-m)	-	6	7	32	3	-	33
Output (kg/s)*	-	3.0	6.2**	22.5	1.02	-	24.6
(MWe)	-	1.5	3	11	0.5	-	12
Steam	-	dry	wet	dry	dry	-	dry
Gas wt%	-	2.87	1.70	1.46	2.35	-	1.0

NOTE:
* at 7 bars WHP
** output DRJ-3 restricted by 7" tieback string