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NATIONAL ENERGY AUTHORITY

LECTURES ON GEOTHERMAL ENERGY IN THE PHILIPPINES

Bernardo S. Tolentino

Geothermal Training Programme
Reykjavík, Iceland
Report 12, 1986

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PREFACE

Since the foundation of the UNU Geothermal Training Programme in 1979, it has been customary to invite annually one geothermal expert to come to Iceland as a UNU Visiting Lecturer. The UNU Visiting Lecturers have been in residence in Reykjavik from about two weeks to about two months. They have given a series of lectures on their speciality and held discussion sessions with the UNU Fellows attending the Training Programme. The lectures of the UNU Visiting Lecturers have also been open to the geothermal community in Iceland, and have always been very well attended. It is the good fortune of the UNU Geothermal Training Programme that so many distinguished geothermal experts with an international reputation have found time to visit us. Their contribution to the Training Programme has been very significant. Following is a list of the UNU Visiting Lecturers from 1979-1985:

1979	Donald E. White	USA
1980	Cristopher Armstead	UK
1981	Derek H. Freeston	New Zealand
1982	Stanley H. Ward	USA
1983	Patrick Browne	New Zealand
1984	Enrico Barbier	Italy
1985	Bernardo S. Tolentino	Philippines

It is a special pleasure to welcome the UNU Visiting Lecturer of 1985, Mr. Bernardo S. Tolentino, Geoscientific Manager of the Energy Development Corporation of the Philippine National Oil Company. He has been one of the key persons in leading the remarkable development of geothermal resources in the Philippines over the last decade. He participated in the international UNU Geothermal Workshop in 1978, where it was decided to encourage the UNU and the Government of Iceland to establish the UNU Geothermal Training Programme, and he nominated from his staff the first two scientists who received UNU Fellowships for geothermal training in Iceland. We hope that his visit will further strengthen the very strong ties between the geothermal communities in the Philippines and Iceland. In this report are presented some of the lectures that Bernie Tolentino gave Reykjavik in September 1985.

Ingvar Birgir Fridleifsson,
Director,
United Nations University,
Geothermal Training Programme.

Geothermal Development in the Philippines
Update and Program

Bernardo S. Tolentino and Balbino C. Buñing
Geothermal Division
PNOC-Energy Development Corporation

INTRODUCTION

The Philippines, like most developing countries, was shocked by the 1973 oil crisis. As it was almost 95% dependent on imported oil for its energy requirement, the supply uncertainties threatened to abort on-going programs on economic and social development of the country. Its oil bill went up to astronomical proportions from US$230 million in 1974 to US$2.6 billion in 1982.

The Government's initial steps to expand its participation in the oil industry – from refining to marketing, and even international and inter-island oil movement – provided some cushion to dampen the impact of the crisis. It became increasingly clear that the country could not forever depend on imported oil and thus, alternative energy sources must be tapped to ultimately achieve self-reliance. Under this scenario, the Government embarked on an energy development strategy which will reduce the country's dependence on foreign petroleum.

This strategy mandates, among other things, the implementation and maintenance of a comprehensive, aggresive and accelerated energy resource development program. Thus, diversification from depletable to renewable sources of energy became the main objective of the program with emphasis on indigenously-abundant and regenerative forms. And slowly but steadily, geothermal energy has risen to become the most viable and reliable alternate source of energy, substantially cutting down the country's dependence on oil.

THE CONTRIBUTION OF GEOTHERMAL ENERGY

In 1983, geothermal energy accounted for 7.03 million barrels-of-oil-equivalent (MMBOE) of the total energy used in the Philippines, or an equivalent of 7.14% contribution to the mix. The following year, 1984, saw its contribution rose to 8.33% or 7.80 MMBOE worth about US$27 million. That ranks geothermal energy second to hydro resources at 10% of the supply mix. It was a major leap for the share of the geothermal sector from a low 2.73 MMBOE in 1979 with 223 MWe of generating capacity to 894 MWe in 1984. At this time also, the country's dependence on foreign oil has been reduced to 58% from 64.5% of 1983 (Fig. 1). This is already closed to the 50% self-reliance targetted at the end of 1985, which is also the end of the 10-year energy program which started in 1973 designed to overcome the adverse effects of the energy crisis.

THE PAST - A RESUME

The Philippines has a "geothermal advantage" by being located within the so-called Circum-Pacific Belt of Fire where vast geothermal resources associated with decadent volcanism have been proven to exist. Early workers from the Commission on Volcanology (now Philippine Institute of Volcanology and Seismology or PIVS) obviously recognized this advantage when they started local studies on geothermal energy in 1962. In cooperation with the National Science Development Board (now National Science and Technology Authority or NSTA), they conducted geothermal exploration initially in the Tiwi area in Albay (Fig. 2) and later in some other localities with known surface thermal manifestations such as Tongonan in Leyte, Palinpinon in Negros Oriental and Makiling-Banahaw in Luzon near Manila.

The Tiwi research project gained more momentum when some electric bulbs were lighted by geothermal power for the first time in the Philippines on April 2, 1967. And before the end of that year, the Philippine legislature passed a law facilitating access to geothermal prospect areas and setting aside such areas as national geothermal reservations. Thus, long before the onset of energy crisis in 1973, the Philippines had already laid down the groundwork for the exploration of the country's geothermal resources.

Continued but small scale exploration at Tiwi by the then Commission on Volcanology resulted in the successful installation of a 2.5 kw non-condensing pilot plant utilizing geothermal energy. This plant paved the way for the Government's decision to start the commercial development of the Tiwi field. The National Power Corporation (NPC) was given the task of exploring and developing the field through a service contract with Philippine Geothermal, Inc. (PGI), a fully-owned subsidiary of Union Oil of California (UNOCAL).

While Tiwi was being developed, NPC, and later the Philippine National Oil Company's Energy Development Corporation (PNOC-EDC), continued to explore more prospects, notably Tongonan and Palinpinon in the Visayas and Makiling-Banahaw (Mak-Ban) in Luzon (Fig. 2). The national effort paid off with the installation of a 3-MW semi-commercial geothermal power plant in Tongonan in July, 1977 and the subsequent commercial utilization of geothermal energy in the country in 1979 with the harnessing of 220 MWe for the Luzon grid from two 55-MWe units each in the Tiwi and Mak-Ban fields. The ensuing years saw the continuous build-up of geothermal generating capacity proceeding with the upgrading of the Tiwi and Mak-Ban fields in 1980, 1982 and 1984 and the commissioning by PNOC-EDC of a 112.5 MWe plant each in Tongonan and Palinpinon in 1983 (Table 1). By the end of 1984, a total of 894 MWe was already on stream, supplying 660 MWe to the Luzon grid and the rest to the Visayas (Table 2).

FIELD DEVELOPMENTS

Assessments of the geothermal potential of developed fields such as Tongonan, Palinpinon, Tiwi, Mak-Ban and lately Bacon-Manito indicate that reserves are in excess of present and planned generating capacities (Fig. 3). Tiwi at present has a proven capacity of 545 MWe at the wellheads of 87 productive wells.

Mak-Ban: The second area developed by PGI, Mak-Ban in Laguna has 415 MWe of proven capacity and presently generates 330 MWe for the Luzon power grid. Todate, 69 wells have been reported completed of which 14 are reinjection wells. The third 110-MWe power plant in this field was commissioned in 1984.

Tongonan: So far, the Tongonan field in the Visayas appears to have the largest reserves in the country. The sector of the field that has been adequately tested has an assessed potential of 450 MWe for an estimated plant life of 25 years. The total field reserves is placed at 885 MWe. A total of 52 deep wells have been completed since the start of exploration drilling and field development in 1976; 38 are tested production wells, 9 are reinjection wells and the rest are either unproductive or to be tested yet. While 360 MWe have been confirmed at the wellheads of the 38 production wells, only 12 of them were sufficient to fully support the first 112.5 MWe power plant in the field. Another 37.5 MWe generating unit is planned for installation in 1989 when the projected industrial consumption of electricity in Leyte and the neighboring island province of Samar will have increased.

Palinpinon: A second field in the Visayas, Palinpinon on the island province of Negros, is also in an advanced stage of development. Palinpinon I, the first 112.5 MWe power plant in the field, was put in operation in 1983 and plans are underway for the development and installation of a second 112.5 MWe power facility in the 1990's. A total of 53 deep wells have already been drilled todate, including the 2 exploration wells in Dauin, an extension of the project. Thirty-two of these wells are productive, 12 are for reinjection purposes and the rest are either non-productive or have yet to undergo testing. A total of 180 MWe have been confirmed from the tested production wells, 21 of which are hooked up to Palinpinon I. Assessments done on the field have put its reserves at about 700 MWe for a 25-year plant life.

Bacon-Manito: The fifth geothermal field in an advanced stage of development is Bacon-Manito (Bac-Man) in the provinces of Albay and Sorsogon, southern Luzon. Fifteen deep wells have been completed by the middle of 1985 in the development area called Palayang Bayan. Eleven of these wells have a tested output of 76.3 MWe, all of them for hook-up to the first power facility. The rest are part of the programmed wells intended for reinjection purposes. Recent assessments on the resource within the drilled area of 12 sq. km. indicate that reserves of about 150 MWe for a 25-year plant life have already been delineated. Plans for a 110 MWe power facility are thus on the way for a projected full commissioning in early 1990. Three more exploratory wells have been drilled for direct utilization in the lowland area of Manito, an extension of the Bac-Man Project, north of the present site for 110 MW development.

EXPLORATION ACTIVITIES BY PNOC-EDC

Today, there are at least 27 identified geothermal prospects in the country, dotted by more than a hundred surface thermal manifestations that occur as hot and warm springs, cold springs, geysers, solfataras, fumaroles, altered grounds, boiling mud pools and others. Most of these prospects have been identified with about 25 volcanic centers over the entire length of the archipelago.

Luzon Island

Mt. Pinatubo: PNOC-EDC completed a year-long comprehensive geoscientific investigation of the Mt. Pinatubo prospect in Zambales in early 1984. Evaluation of the data indicate a resource with possible subsurface temperature of 300 deg. C situated within a geological environment typical of most Philippine geothermal fields, i.e., within the peripheries of coalescing Tertiary to Quaternary andesitic volcanoes. Extensive thermal manifestations, such as steaming vents, altered grounds and warm springs characterized the area's physical features. Its strategic location with respect to power consumer centers in Central Luzon and its proximity to the power-hungry Metro Manila area makes it a good candidate for development in the near future.

Irosin-Bulusan: This prospect in the province of Sorsogon, southern Luzon also promises to be a viable geothermal power project in the near future. The area is situated about 35 km south of the Bacon-Manito field at the western limb of the active Bulusan volcano. PNOC-EDC started geoscientific investigation in the area in 1984.

Visayas Region, Central Philippines

Biliran and Burauen: In the Visayas Region, the Biliran and Burauen prospects in the province of Leyte top the list of priority areas for future development. Both prospects lie along the trace of the master fault of the country known as the Philippine Fault. Three deep exploration wells had been drilled in Biliran. All of them were able to sustain discharge for a total tested output of 8 MWe. A maximum temperature of 332 deg. C was measured in one of the wells suggesting its proximity to the probable center of the resource. Additionally, vertical electrical soundings (VES) taken at 19 stations in early 1984 provided information supportive of the indications from the well data.

Detailed geochemical, geological and geophysical investigations in the Burauen prospect were completed in 1983. Evaluation of the data indicated an extensive and high temperature resource at a range greater than 300 deg. C.

Mindanao-Palawan Region, Southern Philippines

Manat-Amacan: In the Mindanao-Palawan Region, seven geothermal localities have been identified. The Manat-Amacan prospect in Davao del Norte had received the most extensive exploration activities including 3 shallow exploration wells (957 to 1067 m deep) and 1 deep exploration well at 2692 m that was completed and tested in 1983. A maximum temperature of 267 deg. C was recorded in the deep well and indications from well tests data favor the existence of a probable resource nearby. This well, which builds up pressure and discharge without stimulation, however, displays a cyclic behaviour on flowing condition and dies within a few hours after each discharge. The poor permeability in the well is interpreted to be causing the said behaviour.

Mt. Apo-Kidapawan: Another promising geothermal area in Mindanao is the Mt. Apo-Kidapawan prospect located at the slopes of the famous Mt. Apo, the highest peak in the Philippines. Data from a complete suite of geoscientific surveys have been evaluated recently and sites and targets for the initial 3 to 4 wells exploration program have already been identified. Traverse and sounding data from Schlumberger resistivity surveys defined a geophysical target area of 15 to 28 sq. km. at the northwestern side of the mountain. Reservoir temperatures greater than 240 deg. C. have been estimated from the geochemistry of the thermal fluids discharging from numerous warm and hot springs, gas seepages and solfataras.

Initial studies ranging from reconnaissance surface investigations to shallow exploratory drilling have been undertaken at other prospects over the length of the archipelago, such as; Mt. Cagua, Mabini-Lemery, Montelago-Naujan, Marinduque Island, Anahawan, Mambucal, Panay Island, Balingasag, Manlindang, Mt. Matutum and Surigao. Further work in these areas will be conducted in accordance with national priorities on energy development.

EXPLORATION BY OTHER AGENCIES

PNOC-EDC is not alone in the teask of exploring for geothermal resource areas in the Philippines. The Bureau of Energy Development (BED) of the Ministry of Energy (MOE) also does exploration work to upgrade the data on the known resource areas in the hope of attracting participation from the private sector and foreign investors.

Luzon Island

Daklan and Buguias: BED, in cooperation with the Japan International Cooperation Agency (JICA) started the exploration of Daklan and Buguias in 1980. However, Buguias project has been suspended since August, 1981 and only works in Daklan can be completed in 1983 with Electroconsult of Italy and PNOC-EDC joining in drilling and testing 5 deep exploration wells. Evaluation of the field and well data provided evidence for the presence of a geothermal resource beneath the area. However, the limited zones of permeability intersected by the wells had restrained commercial steam production, with only 1 well producing 3 MWe then dying after one year continuous testing.

Acupan-Itogon: JICA's interest on Buguias was shifted to a new area, the Acupan-Itogon prospect in Benguet, in 1981. Thorough surface geological, geophysical and geochemical investigations were conducted by JICA, represented by Bishimetal of Japan, and BED followed by the drilling of 7 shallow thermal gradient holes until early 1984. Prior to the drilling of the first deep exploration well, PNOC-EDC conducted shallow resistivity traverse surveys over an area of 326 sq. km. in an attempt to correlate the resistivity anomalies found in Daklan to those of Acupan. Results revealed an isolated 6 sq. km. resistivity anomaly associated with the thermal manifestations about a volcanic breccia pipe near the center of the prospect. Because of limited pad space, the well was drilled directionally and completed at a depth of 1677 m. in mid-February 1985. The well was spudded-in in late December 1984. Its total length is 2001 m. with a throw of 942.5 m. Maximum temperature was 240 deg. C. recorded at the bottom after 19 days shut condition. Two attempts were made to discharge the well using a package boiler to stimulate flow. Both attempts failed.

Batong-buhay: In 1982, Caltex (Philippines), Inc. was awarded an exploration permit by BED for the exploration of Batong-buhay in the Kalinga/Apayao provinces in the Central Cordillera of northern Luzon. The award was extended to June 1983 for additional work in the area where a 10 ohm-meter anomaly was defined over an area of approximately 6 sq. km. The exploration also resulted in the identification of more hot springs and fumaroles in previously unexplored terrain and the preliminary siting of deep exploratory wells. It was reported that GeothermEx, Inc., a U.S.-based consulting company, did the above work for CPI.

Mainit-Sadanga: Work in the Mainit-Sadanga prospect involved an assessment of the operating conditions for exploration as well as a survey of the sites for 3 temperature gradient holes and resistivity survey stations.

In southern Luzon, two prime prospects for geothermal energy resource were also investigated by two foreign exploration firms under a one-year non-exclusive geothermal exploration permit granted by BED.

Mt. Labo: Total Exploration (TOTAL) and Philippine Oil and Geothermal Exploration, Inc. (POGEI) conducted geo-scientific works over 120,000 hectares of land in the Mt. Labo prospect. Preliminary analyses of photogeological and volcanogeological data and resistivity information indicate the possible existence of a 15-sq. km. resource area with a postulated temperature greater than 260 deg. C.

Isarog-Iriga: The Iriga-Isarog prospect, not too far from the Mt. Labo area, was surveyed by Ultrana Nuclear and Minerals Corporation (with Canada Northwest Energy, Ltd.) in 1983. Reconnaissance geological and geochemical studies were conducted in the area.

DIRECT HEAT UTILIZATION

Geothermal energy development in the Philippines is not confined to electrical power generation. Considerable effort has been spent also on direct industrial application, with the Philippine Institute of Volcanology and Seismology (PIVS), formerly Commission on Volcanology (COMVOL), at the forefront.

In March 1973, a salt-making experimental plant utilizing geothermal steam for evaporating sea water was first put to operation in Tiwi, Albay. Various studies on other non-electrical utilization of geothermal energy produced encouraging results. A fish canning process utilizing geothermal steam has been developed by PIVS in 1983 at its pilot plant in Tiwi. The results proved the absence of microbial growth and the acceptability of the product.

Research on the feasibility of extracting magnesium and potassium chloride from the pilot plant's waste products is also underway.

The establishment of an industrial estate in the Manito lowlands, the northern extension of the Bacon-Manito geothermal project, is also being studied by PNOC-EDC. Results from tests conducted in 3 exploration wells in this area proved that sufficient mass and heat are available for direct heat application of geothermal energy. In the list of possible uses offered to the private sector are grain drying and abaca fiber processing, two of the leading sources of livelihood of the Manito folks, aside from fish-drying.

GEOTHERMAL MANPOWER DEVELOPMENT

Coupled with the Government's aggressive energy development strategies is also an extensive manpower development program. On-the-job training with experts from New Zealand has been successfully implemented. Special studies from short training missions to masterate and doctorate studies for the local geothermal scientists and engineers have been given full support by the Philippine Government and sponsoring countries and international agencies, such as New Zealand, Iceland, Japan, Italy, USA and the United Nations Development Program (UNDP). In-house personnel development programs have also been pursued by the government agencies involved in geothermal exploration and development in the country, all of which are geared towards the development of a highly capable and sufficient indigeneous manpower base.

OUTLOOK

The Philippines, at present, has a total of 5,099 MWe installed capacity, of which 894 MWe (17.5%) is from geothermal source. With this capacity, the 8 commercial geothermal power plants in 4 producing fields in the country produced a combined output of about 4,540 gigawatt-hours (GWh) in 1984, which was 25.5% of the total electrical energy generated that year (Table 3).

With the planned commissioning of the first nuclear power plant in the country before the end of 1985 and other power plants in the succeeding years, geothermal's contribution to the total energy demand is expected to decline percentage-wise. Nonetheless, the completion of a 110-MWe geothermal power plant in the Bacon-Manito field, Luzon Island, and an additional 37.5 MWe generating unit in Tongonan field, Leyte, will bring the nationwide installed geothermal power generating capacity to 1,041.5 MWe and a projected utilization of 6,535 GWh by 1990 (Table 3). Sustained exploration of more prospects throughout the country, not only by government-owned agencies, but also by interested foreign investors can eventually make the Philippines the world's leading producer of geothermal power and a major user of geothermal energy for direct industrial applications before the turn of the century.

ACKNOWLEDGEMENT

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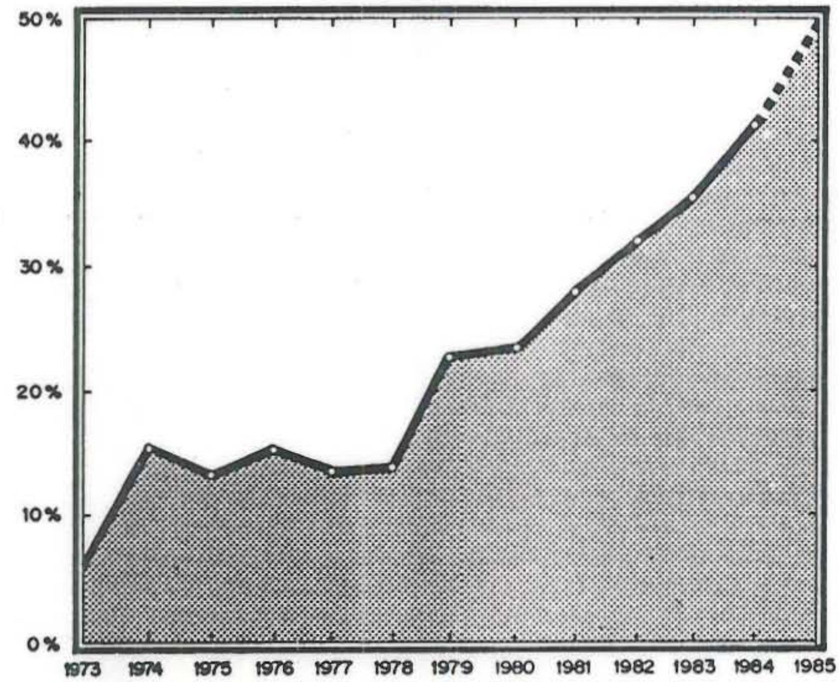

Fig. 1 Energy self-reliance 1973-1985 (in percentage independence from foreign oil)

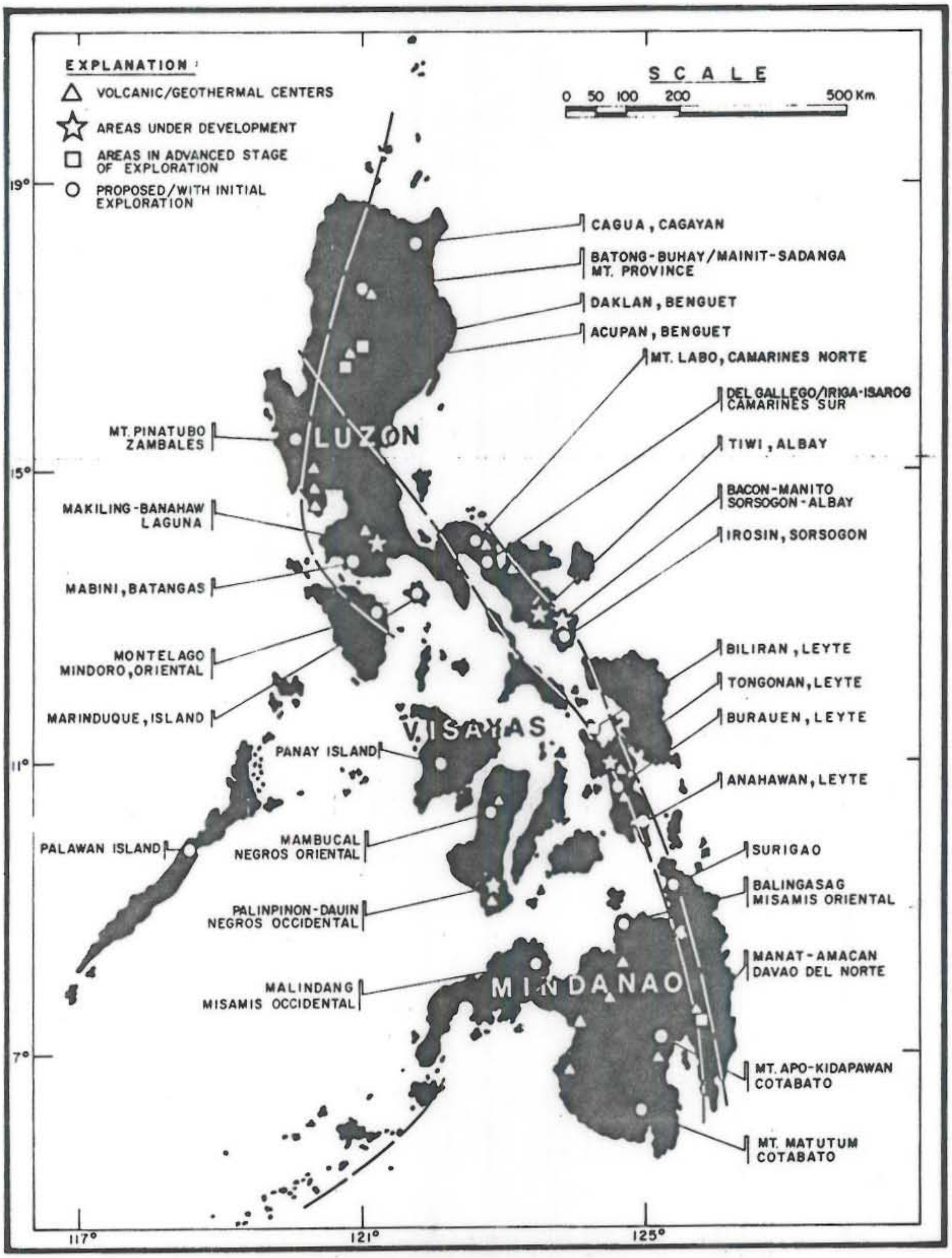

Figure 2. Philippine geothermal areas undergoing exploration and development

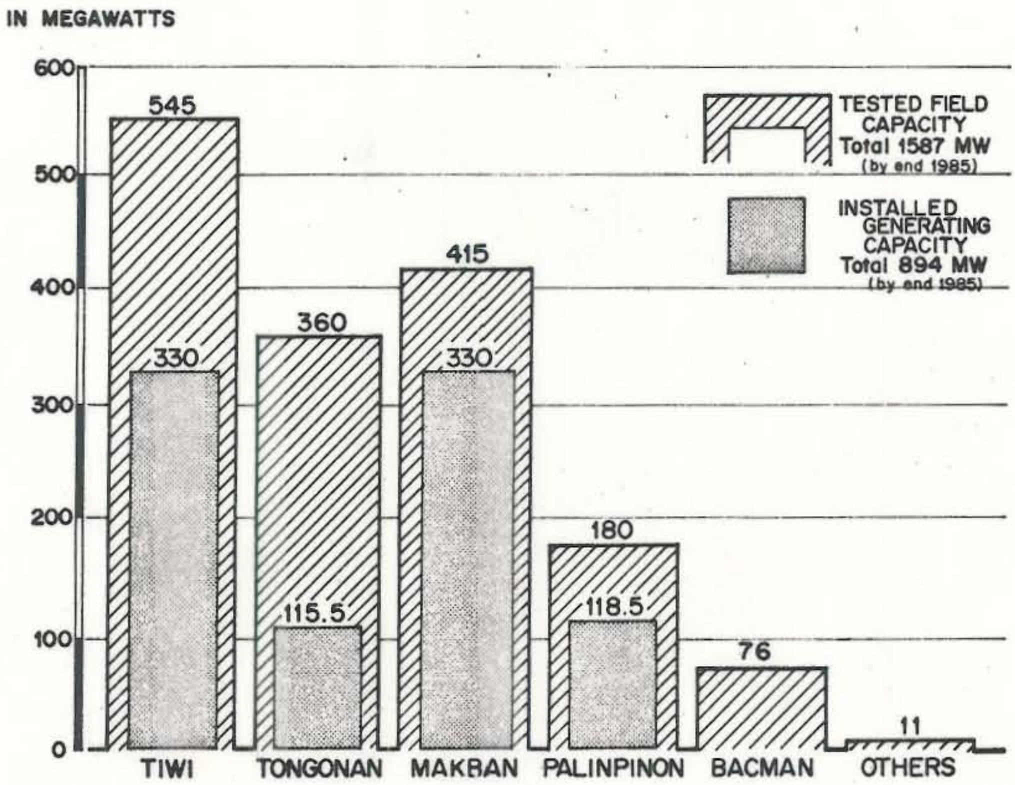

Fig.3 Geothermal development status

Table 1. National Geothermal Power Expansion Program* Installed and Planned Capacities (in MWe)

FIELD	1983	1984	1985	1989	1990	Total 1990
Tiwi	330.0					330.0
Mak-Ban	220.0	110.0				330.0
Tongonan	115.5			37.5		153.0
Palinpinon	118.5					118.5
Bacon-Manito					110.0	110.0
TOTAL	784.0	110.0		37.5	110.0	1041.5
CUMULATIVE TOTAL	784.0	894.0	894.0	931.5	1041.5	

*SOURCE: National Power Corporation Expansion Program, June 1984.

Table 2. National Power Expansion Program* Installed and Planned Capacities (in MWe)

		1983	1984	1985	1989	1990	Total 1990
Geothermal	Luzon	550.0	110.0		0.0	110.0	
	Visayas	234.0	0.0		37.5		
	Mindanao	0.0	0.0		0.0		
	Sub-total	784.0	110.0		37.5	110.0	1,041.5
Fossil Fuels	Luzon	2,230.0			0.0	0.0	
	Visayas	238.3			0.0	0.0	
	Mindanao	172.9			100.0	100.0	
	Sub-total	2,641.2			100.0	100.0	2,841.2
Hydroelectric	Luzon	1,126.2				23.0	
	Visayas	2.0				0.0	
	Mindanao	435.6				0.0	
	Sub-total	1,563.8				23.0	1,586.8
Nuclear	Luzon			620.0			620.0
	Sub-total						620.0
	TOTAL	4,989.0	110.0	620.0	137.5	233.0	
Cumulative Total		4,989.0	5,099.0	5,719.0	5,856.5	6,089.5	6,089.5

*SOURCE: National Power Corporation Power Expansion Program, June 1984.

Table 3. Philippines Energy Generation Mix (GWh)*

ENERGY SOURCE	1983		1984		1985		1988		1989		1990	
Geothermal	4,093	21.9%	4,540	25.5%	4,686	24.5%	5,682	24.4%	6,131	24.5%	6,535	24.4%
Fossil Fuels	11,623	62.2%	7,727	43.5%	6,000	31.4%	6,247	26.8%	7,142	28.5%	8,266	31.0%
Hydroelectric	2,965	15.9%	5,514	31.0%	6,526	34.2%	7,873	33.7%	7,957	31.8%	8,142	30.4%
Nuclear	0	0 %	0	0 %	1,900	9.9%	3,531	15.1%	3,803	15.2%	3,803	14.2%

*SOURCE: National Power Corporation Expansion Program, June 1984.

APPENDIX A

Table 1. Present and Planned Production of Electricity

	Geothermal		Fossil Fuels		Hydroelectric		Nuclear	
	Capacity MW_e	Utilization GWh/yr	Capacity MW_e	Utilization GWh/yr	Capacity MW_e	Utilization GWh/yr	Capacity MW_e	Utilization GWh/yr
In operation January 1985	894.0	4,686.0	2,641.2	6,000.0	1,563.8	6,526.0	620.0	1,900.0
Under construction January 1985	—	—	—	—	—	—	—	—
Funds committed, but not yet under construction January 1985	—	—	—	—	—	—	—	—
Total projected use by 1990	1,041.5	6,535.0	2,841.2	8,266.0	1,586.8	8,142.0	620.0	3,803.0

Table 2. Present Utilization of Geothermal Energy for Direct Heat

*Type of Use

I = Industrial process heat
C = Airconditioning
A = Agricultural drying
F = Fish and other animal farming
D = District Heating
B = Bathing and swimming
G = Greenhouses
O = Other (specified by footnote)

**Enthalpy information is given only if there is steam or two-phase flow.

Locality (Footnote for Comments)	Type*	Maximum Utilization						Average Annual Utilization					
		Flow Rate kg/s	Temperature °C		Enthalpy** kJ/kg			Flow Rate kg/s	Temperature °C		Enthalpy** kJ/kg	
			Inlet	Outlet	Inlet	Outlet		Inlet	Outlet	Inlet	Outlet
Tiwi[1]	I,A,F	2.1	126	100	—	—					

[1] Well CV-T-7 in Tiwi (see Table 3 also) is now used to feed hot water to a multi-purpose geothermal experimental plant.

Table 3. Information About Geothermal Localities

Rock[1] = Main type of reservoir rock.
Water[2] = Total dissolved solids, in mg/kg, before flashing. Put v for vapor dominated.
Status[3]

N = Identified geothermal locality, but no assessment information available.
R = Regional assessment
P = Pre-feasibility studies
F = Feasibility studies (reservoir evaluation and engineering studies)
U = Commercial utilization

Locality	Location To Nearest 0.5 Degree		Reservoir		Status[3]	Reservoir Temp. °C	
	Latitude	Longitude	Rock[1]	Water[2]		Estimated	Measured
Luzon and Neighboring Islands							
Acupan, Benguet	16.0 N	120.5 E			P	>240	
Bacon-Manito, Sorsogon	13.0	124.0	Andesite/tuff breccia		F	>300	326
Batong-Buhay, Mt. Province	17.5	121.0					
Cagua, Cagayan	18.0	122.0			N		
Daklan, Benguet	16.0	120.5	Volcaniclastics		P		283
Del Gallego-Iriga-Isarog, Camarines Sur	13.5	123.0			R		
Irosin-Bulusan, Sorsogon	12.5	124.0			R	>300	
Mabini-Lemery, Batangas	14.0	121.0			N		
Mainit-Sadanga Mt. Province	17.5	121.0			N		
Makiling-Banahaw Laguna, Batangas	13.5	121.0	Andesite/pyroclastics/ volcaniclastics		U		287-315
Marinduque Island	13.0	122.0			N		
Montelago-Naujan, Oriental Mindoro	13.0	121.0			N		
Mt. Labo Camarines Norte	14.0	122.5			R	>260	
Mt. Pinatubo Zambales	15.5	120.0			R	>300	
Tiwi, Albay	13.5	123.5	Andesite/pyroclastics		U		260-315
Vasayas							
Anahawan, Leyte	10.0	125.0			N		
Palinpinon-Dauin, Negros Oriental	9.0	123.0	Andesite/Diorite/ sedimentary units		U	>300	320
Biliran, Leyte	11.5	124.5	Volcaniclastics/andesite		P	>300	332
Burauen, Leyte	10.5	125.0			R	>300	
Tongonan, Leyte	11.0	125.0	Andesite		U		320
Mambucal, Negros Occidental	10.0	123.0	Andesite/sedimentary units		P	>250	
Panay Island	11.0	122.0			N		
Mindanao/Palawan							
Balingasag, Misamis Oriental	8.5	125.0			N		
Malindang, Misamis Occidental	8.0	123.5			N		
Manat-Amacan, Davao del Norte	7.0	126.0			P	>267	
Mt. Apo-Kidapawan, Cotabato	6.0	125.0			R	>240	
Mt. Matutum, Cotabato					N		
Surigao, Surigao del Norte	9.0	125.5			N		
Palawan Island	9.5	119.0			N		

Table 4. Wells Drilled For Electrical Utilization of Geothermal Resources to January 1, 1985
(Does not include thermal gradient wells less than 100 m deep)

Type of well*
T = Thermal gradient or other scientific purpose E = Exploration P = Production I = Injection

Locality (Footnote for comments)	Year Drilled[1]	Well Number	Type of* Well	Total Depth (meters)[2]	Maximum Temp. °C	Flowing Enthalpy kJ/kg	Flow Rate kg/s[3]
Tongonan Geothermal Field, Leyte Geothermal Project, Tongonan, Ormoc City, Leyte Island, Philippines							
Lower Mahiao Sector	1977	103	P	1407.2	312	1600	48
	1978	1R10	I	1546.2	255	—	Untested
	1982	105d[4]	P	1786.7	314	1324	118
	1979	101	P	1421.0	305	1977	57
	1979	102	P	1641.3	310	2000	39
	1979	108	P	1820.7	317	1970	25
	1979	106	P	1823.6	321	1953	22
	1980	IR3	I	1903.0	270	1240	85
	1982	IR5D	I	2398.1	280	1090	75
Lower Sambaloran Sector	1977	202	P	1896.9	304	1450	65
	1979	208A[5]	P	1997.6	316	2100	18
	1980	209A[6]	P	2504.9	318	1800	84
	1978	213	P	1602.7	308	1560	70
	1979	212	P	1519.0	313	1775	68
	1979	214	P	1992.4	290	1400	70
	1979	2R2	I	1531.6	304	1775	30
	1979	215	P	1562.0	303	1563	49
	1981	2R4D	I	2186.2	284	1366	75
	1981	2R3D	I	2272.5	270	1208	85
South Sambaloran Sector	1979	303	E	1942.0	280	1275	90
	1982	301D	E	2446.6	280	1319	102
Upper Mahiao Sector	1977	401[7]	E	1942.1	323	2230	27
	1977	404	P	1668.2	313	1940	28
	1977	407	P	1605.4	316	1790	35
	1978	406	P	1794.5	323	1870	40
	1980	402	E	2373.0	263	1579	6
	1980	405	E	2288.0	260	1300	96
	1980	403	E	2464.9	296	1434	30
	1980	408	E	2696.0	314	1378	11
	1981	409	P	2399.8	311	1730	49
	1981	410	P	2365.9	322	1900	29
	1983	411D	E/P	2795.0	292	1300	39
Mamban-Mahanagdong Sector	1979	MN-1	E	2486.9	199	—	Untested
	1980	MG-1	E	2335.0	282	1272	90
	1981	MG-2D	E	2210.7	252	1160	100
	1983	MG-5D	E	2703.7	300	1375	34
Malitbog Sector	1978	501	P	1665.0	284	1273	114
	1979	503	P	1985.7	306	1257	77
	1979	502	P	1995.0	281	1160	53
	1980	5R4	E/I	2342.0	245	1133	42
	1980	505D	E	2647.8	273	0	0
	1981	506D	E	2647.8	275	0	0
	1981	5R7D	E/I	2887.1	262	1116	19
	1981	508D	P	2623.8	279	1168	80
	1981	509	P	2361.3	265	1187	62
	1981	510D	P	2579.7	280	1218	65
	1981	511D	P	2538.8	287	1328	63
	1982	515D	P	2084.0	292	1330	102
	1982	514	P	2750.3	319	1250	58
	1982	513D	P	2718.1	298	1269	38

Table 4 Continued.

Locality (Footnote for comments)	Year Drilled[1]	Well Number	Type of* Well	Total Depth (meters)[2]	Maximum Temp. °C	Flowing Enthalpy kJ/kg	Flow Rate kg/s[3]
Malitbog Sector (continued)	1982	5R1D	I	952.5	230	1040	100
	1982	516D	P	2787.5	286	1280	22
Tongonan Geothermal Field	1973	TGE-7	T	576.9	148		
	1974	TGE-1	T	464.2	181		
	1974	TGE-2	T	362.5	80		
	1974	TGE-3	T	585.5	125		
	1974	TGE-5A	T	420.6	194		
	1974	TGE-8	T	610.2	77		
	1975	TGE-4	T	310.9	197		
	1975	TGE-6	T	615.7	138		
	1975	TGE-9	T	610.5	93		
	1976	TGE-10[8]	T/I	593.5	254		
	1976	TGE-11	T	620.5	113		
Southern Negros Geothermal Project, Valencia, Negros Oriental, Philippines							
Palinpinon I Sector	1980	OK-7	P	2882.8	318	1410	86
	1980	OK-9D	P	2543.0	322	1340	49
	1981	OK-10D	P	2435.8	273	1350	51
	1981	PN-13D	P	2697.1	317	1360	46
	1982	PN-14	P	3077.1	312	1373	30
	1981	PN-15D	P	2715.6	283	1150	79
	1982	PN-16D	P	3104.7	326	1414	41
	1981	PN-17D	P	2954.4	290	1070	54
	1982	PN-18D	P	3147.1	306	1242	43
	1982	PN-19D	P	3024.4	303	1328	47
	1982	PN-20D	P	2690.9	330	1346	49
	1982	PN-21D	P	2862.2	288	1023	39
	1982	PN-22D	P	2698.6	318	1296	49
	1982	PN-23D[12]	P	2878.9	323	1313	79
	1982	PN-24D	P	3105.9	319	1387	26
	1982	PN-26	P	2773.8	309	1330	95
	1983	PN-27D	P	2860.2	291	1353	72
	1983	PN-28	P	2893.2	303	1350	59
	1983	PN-29D	P	2808.0	299	1250	65
	1983	PN-30D	P	2920.7	312	1239	54
	1983	PN-31D	P	2695.5	265	1728	53
	1981	OK-12D	E/I	2666.8	297		142
	1982	PN-1RD	I	2941.4	278		143
	1982	PN-2RD	I	3394.0	304		46
	1982	PN-3RD	I	3132.4	294		Untested
	1982	PN-4RD	I	3085.1	284		130
	1983	PN-5RD	I	2540.5	235		54
	1983	PN-6RD	I	2589.3	252		147
	1983	PN-7RD	I	2562.0	266		152
	1983	PN-8RD	I	3046.7	291		107
	1983	PN-9RD	I	3039.5	267		96
Palinpinon II Sector	1978	OK-5	E	1975.2	308	2000	32
	1980	OK-6	E	2770.8	285	1280	80
	1983	OK-8RD	E/I	2436.9	274		Untested
	1981	OK-11D	E	2461.0	274		0
	1981	SG-1	E	2762.8	277	1150	53
	1981	SG-2	E	2944.6	283	1275	85
	1983	SG-3D	E	2642.2	281	1263	73
	1982	NJ-1D	E	2848.5	285		No MTD
	1982	NJ-2D	E	2892.2	279		0

Table 4 Continued.

Locality (Footnote for comments)	Year Drilled[1]	Well Number	Type of* Well	Total Depth (meters)[2]	Maximum Temp. °C	Flowing Enthalpy kJ/kg	Flow Rate kg/s[3]
Palinpinon II Sector (continued)	1983	NJ-3D	E	2693.4	263	1269	88
	1983	NJ-4D	E	2760.9	282	1140	54
	1983	NJ-5D	E	2781.9	298	1248	52
	1983	NJ-6D	P	2600.5	288		Untested
	1983	NJ-7D	P	2836.6	273		Untested
	1983	NJ-8D	P	2922.4	280		Untested
Other Southern Negros Wells	1976	N-1	E	603.3	206	845	26
	1976	N-2	E	610.5	175	415	5
	1978	N-3	E	970.9	240	1103	40
	1978	OK-1	E	1978.9	190		0
	1978	OK-2	E	1164.4	254	1420	25
	1978	OK-3	E	1521.8	224		0
	1978	OK-4	E	2130.0	299		0
	1983	PN-25D	E	3329.3	293		0
		DN-1	E	2623.6	240	806	46
		DN-2	E	2670.2	198		0
Bacon-Manito Geothermal Project, Boundary of Albay and Sorsogon Provinces, Bicol Peninsula, Philippines							
	1979	MAN-1	E	1367.8	214		0
	1979	MAN-2	E	1636.7	248		0
	1981	CN-1	E	2553.1	269	1280	100
	1981	IM-1	E	2583.0	252	2050	77
	1981	PB-1A	E	2662.1	254		0
	1982	CN-2D	E	1708.1	237	1320	11
	1982	PAL-1	P	2480.4	274	1110	46
	1982	PAL-2D	P	2707.6	293	1910	29
	1983	PAL-3D	P	2154.7	282	1330	52
	1983	PAL-4D	P	2641.1	302	1420	36
	1983	PAL-5D	E	2761.6	268	1200	47
	1983	PAL-6D	E	2833.9	274	1590	10
	1983	PAL-8D	P	2973.0	306	1700	82
	1983	PAL-7D	P	2153.2	268	1300	24
	1983	PAL-1RD	I	1852.0	252		Untested
	1984	PAL-2RD	I	1517.9	238		Untested
	1984	PAL-9D	E/P	2409.3	258	1235	27
	1984	PAL-10D	E/P	2485.1	325	1361	42
	1984	PAL-3RD	I	2103.5			Untested
Biliran Geothermal Project, Biliran Island, Philippines							
		BN-1	E	2424.4	254		16
		BN-2	E	2439.8	210	983	25
		BN-3	E	2469.6	332	1824	23
Daklan Geothermal Project, Benguet Province, Philippines							
		DK-1A	E	2692.5	284	1285	14
		DK-2	E	1622.3	209		0
	1981	DK-3	E	2743.1	246		0
	1981	DK-4	E	2748.0	286		0
		DK-5	E	2836.9	260		0
Northern Negros (Mambucal) Geothermal Project, Negros Occidental, Philippines							
		MC-1	E	1220	189		0
		MC-2	E	1433	169		0

Table 4 Continued.

Locality (Footnote for comments)	Year Drilled[1]	Well Number	Type of* Well	Total Depth (meters)[2]	Maximum Temp. °C	Flowing Enthalpy kJ/kg	Flow Rate kg/s[3]
Davao (Manat-Amacan) Geothermal Project, Davao del Norte, Philippines							
	1977	TGH-1	T	137	29		0
	1977	TGH-3	T	198	34		0
	1977	TGH-5	T	121	92		0
	1977	TGH-6	T	153	71		0
	1977	TGH-9	T	183	29		0
	1977	TGH-11	T	129	29		0
	1977	TGH-12	T	128	24		0
	1977	TGH-13	T	126	70		0
	1979	TGH-14	T	244	52		0
	1979	TGH-15	T	244	24		0
	1979	TGH-16	T	146	32		0
	1979	TGH-17	T	232	32		0
	1979	TGH-18	T	244	53		0
	1979	TGH-19	T	244	58		0
	1979	TGH-20	T	245	57		0
	1978	MANAT-1	E	1067	104		0
	1978	MANAT-2	E	957.3	98		0
	1978	PANI-BASAN-1	E	919.2	48		0
	1983	AMACAN-1	E	2692.4	267	1610	5
Tiwi Contract Area							
Naglagbong	1975	7		2743.20	275		45
		9		1847.09	287		54
		10		579.12	252		36
		11		1584.96	273		87
		12		1798.93	283		58
	1976	13		2033.02	279		41
		14		2276.86	294		54
		15		2888.89	276		40
		16		712.01	289		165
		17		1699.87	231		19
		18		1524.00	281		150
		19		1379.83	285		133
	1977	20		2168.96	284		36
		21		886.97	283		55
		22		2275.03	264		68
		23		2268.63	277		67
		24		1674.88	277		104
		25		2133.60	281		16
		26		2129.03	274		51
		27		2118.36	275		107
	1978	28		2164.99	307		82
		29		2316.48	279		9
		30		1514.86	297		127
		31		1293.27	307		169
		32		2200.05	293		62
		33		2096.11	284		73
	1979	34		1558.75	229		3
		35		2112.26	300		54
		36		1608.73	274		43
		37		492.56	274		51
		38		1127.76	289		44
		39		1234.44	256		31

Table 4 Continued.

Locality (Footnote for comments)	Year Drilled[1]	Well Number	Type of* Well	Total Depth (meters)[2]	Maximum Temp. °C	Flowing Enthalpy kJ/kg	Flow Rate kg/s[3]
Naglagbong (continued)		40		1219.20	277		26
		41		479.76	230		33
		43		1263.70	284		6
		44		772.06	285		54
		45		759.26	234		15
		46		1593.80	242		24
		47		1335.33	294		65
	1980	48		1354.84	288		46
		49		1190.24	286		45
		50		635.51	266		59
	1982	51		1219.20	279		21
	1983	52		1414.27	273		18
	1980	53		907.39	218		30
		54		893.67	269		171
	1982	55		1173.48	241		31
	1980	56		2170.48	282		34
	1982	57		255.12	206		33
	1981	58		198.12	206		4
		59		647.70	246		86
		60		731.52	235		18
	1981	62		897.03	257		8
		63		570.59	231		24
	1982	64		936.35	227		15
	1983	65		1233.22	274		9
Bariis	1981	1		1751.38	195		11
		2		2252.78	302		10
		3		2489.61	319		144
Sadurong	1982	1		1200.91	239		102
Kapipihan	1979	1		1476.15	272		74
		2		1449.02	278		32
		3		1787.65	296		13
		4		2118.97	284		70
	1980	5		1260.04	292		36
		6		1928.16	278		39
		10		1200.91	291		12
		11		1130.20	273		107
		12		1363.37	288		29
		13		1307.59	287		19
	1981	16		1169.52	290		30
	1980	17		938.17	266		28
		18		1454.51	291		23
	1981	19		1216.15	256		18
		20		1428.90	269		28
	1980	21		1714.50	293		61
	1981	22		1691.34	288		37
		24		1655.67	248		27
		25		1658.42	270		46
	1980	27		1364.89	257		68
Matalibong	1980	1		1316.43	260		74
	1983	2		2782.82	267		7
	1981	3		1242.36	294		30
	1980	8		1065.89	272		24
	1981	14		2688.34	284		36
		15		1203.96	298		37
		17		2413.10	297		92

Table 4 Continued.

Locality (Footnote for comments)	Year Drilled[1]	Well Number	Type of* Well	Total Depth (meters)[2]	Maximum Temp. °C	Flowing Enthalpy kJ/kg	Flow Rate kg/s[1]
		Mak-Ban Contract Area					
Bulalo		1			313		59
	1975	2	I	2423.16	283		
		3A		987.25	284		43
		4	I	2502.41	313		
	1976	5	I	2457.91	269		
	1976	6		906.48	279		128
		7		1909.57	329		45
		8		1402.08	311		43
		9		1224.08	274		47
		10		1678.53	334		50
		11		1061.92	293		64
	1977	12		2133.60	325		38
		13		1057.66	290		65
		14		1121.66	284		65
		15		2669.44	331		38
		16		1563.01	266		56
		17		2259.79	332		17
		18	I	2600.25	328		
		19		2874.57	346		10
		20		954.33	269		24
	1978	21		1786.13	324		40
		22		2688.34	311		9
		23		992.43	252		28
		24		1723.95			9
		25		1671.83	258		0
		26		875.69	267		23
		27		1629.77	306		79
		28		1879.40	279		47
		29		1920.24	317		42
		30		2861.46	241		0
	1979	31A	I	2798.98	264		
		32	I	2485.64	324		
		33	I	2670.05	282		
		34		2449.37	319		55
		35		1965.35	317		19
		36		1559.36	276		12
		37	I	2377.44	301		
		38		1889.76	326		36
		39		1597.15	288		35
		40		2087.88	313		49
		41		2065.02	275		75
		42		1266.14	267		51
		43	I	1607.82	304		
		44		2223.21	296		53
		45		2415.24	333		79
		46		2255.52	303		25
		47		1605.08	308		14
		48	I	2353.06			
		49		1384.10	323		69
		50	I	2816.66	274		
		51		1756.26	288		36
	1980	52		1606.30	293		11
		53		2819.10	326		35
		54	I	1374.65	267		

Table 4 Continued.

Locality (Footnote for comments)	Year Drilled[1]	Well Number	Type of* Well	Total Depth (meters)[2]	Maximum Temp. °C	Flowing Enthalpy kJ/kg	Flow Rate kg/s[3]
Bulalo (continued)		55		2848.05	321		34
	1981	56		2599.33	305		71
	1980	57	I	2915.41	306		
	1980	58	I	2894.38	318		
		59		2946.50	319		35
		60		1022.60	278		68
		61		2510.33	317		20
	1982	62		1503.88	277		29
	1980	64		6555.32	259		27
	1982	65		3140.05	324		30
		67		2694.74	312		39
	1980	71		1761.74	302		30
	1981	75		2764.23	283		0
		76		2370.12	267		66
		79		1280.46	293		6

ADDITIONAL INFORMATION TO TABLE 4

(Applicable only to wells in Leyte, So. Negros, Bacon-Manito, Biliran, Daklan, Northern Negros, and Davao Geothermal Projects of PNOC-EDC.)

1. Year Drilled — The years quoted indicate the year each well was completed.

2. Total Depth — All depths quoted are true vertical depths measured from the casing head flange. These depths were measured during the completion of each well.

3. Flow Rate — The flow rates quoted were measured while the wells were being tested under full-bore discharge condition. Flow rates of injection wells are injection capacities, as against the discharge flow rates of production wells.

4. Well 105 was first completed on October 16, 1978 at a depth of 1796 m. It is basically an exploration/production well, but it was also used for low-temperature injection testing (flash temperature ≈ 120°C), using wells 101, 102 and 103 as injectors.

In November 1981, the well was redischarged. Its output, however, dropped from its rated capacity of 15MWe to about 5MWe, until it subsequently died down. Downhole surveys (go-devil and caliper) indicated a total blockage within the production casing (silica deposits).

The well was re-drilled (side-tracked) and completed on February 15, 1982 at a depth of 1786.7 m. Thus, it was renamed 105D to indicate that it is now a directional well. It is now one of the wells supplying steam to the Tongonan I 112.5 MWe Power Plant.

5. Well 208 was originally drilled as an exploration well in the northeastern portion of the Lower Sambaloran Sector, Tongonan Geothermal Field. It was completed on May 13, 1978 at a depth of 834.6 m. The well did not register good temperatures and injectivity although it produced about 3.6 MWe. In the hope of finding better permeability, it was deepened and completed on February 24, 1979 at a depth of 1997.6 m. It was then renamed 208A to indicate deepening of an original bore.

6. Well 209 basically underwent the same deepening process as 208A. It turned out to be one of the best producers in the Tongonan Geothermal Field after its second completion. It is now one of the wells supplying steam to the Tongonan I Power Plant with a rated capacity (full-bore opening) of 18 MWe.

7. Well 401 was the first deep exploratory well drilled in Tongonan. It turned out also to be the first commercial producer in this field. Six months after its completion, it was hooked up to a 3-MWe noncondensing power plant in the project. It supplied wet steam to this pilot plant from July 1977 until the middle of 1983 when the 112.5 MWe Tongonan I Power Plant was commissioned for commercial utilization.

8. TGE-10 was renamed 4R1 when it was utilized as an injection well for effluents from 401 and the 3 MWe pilot plant.

9. Tongonan Geothermal Field has 115.5 MWe installed capacity on 3 x 37.5 MWe Mitsubishi turbines (Tongonan I) and 1 x 3 MWe Fuji noncondensing type turbine generator (pilot plant).

On the Tongonan I, there are 12 production and five injection wells on line. Of the 12 production wells, nine operate for base load and three can be operated for peak load with allowance for contingency.

With the three turbines in operation, the nine base-load-operated wells deliver 440 tons/hour of steam to generate 25 MWe, while the three other production wells can supply additional steam to generate a total of 45 MWe, which is the current average peak load of the plant.

The 3-MWe pilot plant has been put on standby operation since the commissioning of Tongonan I.

This plant, nevertheless, used to supply electricity to Ormoc City and the nearby localities, including the Tongonan field's base camp.

10. Tongonan I Production Wells: 101, 102, 103, 105D, 106, 108, 202, 209A, 212, 213, 214, 215.

11. Tongonan I Reinjection Wells: 1R3, 1R5D, 2R2, 2R3D, 2R4D.

12. During PN-23D's MTD tests, its mass flow was 230 tons/hour. Bore output measurements during commercial operation (when the well was cut into the Palinpinon I steam gathering system), however, indicated a mass flow of 286 tons/hour. The bore output data also suggested an improvement in its permeability.

13. Palinpinon I is PNOC's second geothermal field developed for electrical power generation. The same name has been adopted for the corresponding 112.5 MWe power plant of the National Power Corporation. Twenty one production and ten injection wells are hooked up to this plant.

14. Palinpinon I Production Wells: OK-7, OK-9D, OK-10D, PN-13D, PN-14, PN-15D, PN-16D, PN-17D, PN-18D, PN-19D, PN-20D, PN-21D, PN-22D, PN0-23D, PN-24D, PN-26, PN-27D, PN-28, PN-29D, PN-30D, PN-31D.

15. Palinpinon I Injection Wells: OK-12D, PN-1RD, PN-2RD, PN-3RD, PN-4RD, PN-5RD, PN-6RD, PN-7RD, PN-8RD, PN-9RD.

Table 5. Wells Drilled For Direct Heat Utilization of Geothermal Resources to January 1, 1985
(Does not include thermal gradient wells less than 100 m deep)

*Type or purpose of well and manner of production (Uses one symbol from column (1) and one from column (2)

(1)
T = Thermal gradient or other scientific purpose
E = Exploration
P = Production
I = Injection
C = Combined electrical and direct use

(2)
A = Artesian
P = Pumped
F = Flashing

**For wellhead temperatures less than 100°C, temperatures in °C are multiplied by 4.1868 to obtain the enthalpy.

Locality (Footnote for comments)	Year Drilled	Well Number	Type of* Well (1) (2)	Total Depth (meters)	Maximum Temp. °C	Flowing Enthalpy kJ/kg	Flow Rate kg/s
Malangto, Bacon	1982	MO-1	E-F	1570.8	223		34
Albay Province	1982	MO-2	E-F	1093.9	216		57
	1984	MO-3	E-F	1200.2	218		18
Tiwi, Albay	1968	CV-T-7	E-A	212.0	154		1
Lemergy, Batangas	1979	DDH-1	E	166.2	90		nil
Mabini, Batangas	1981	DDH-1	F	330.0	118		nil

Table 6. Allocation of Professional Personnel to Geothermal Activities
(Restricted to personnel with a university degree)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Programs
(6) Private Industry

	(Professional Man Years of Effort)					
Year	(1)	(2)	(3)	(4)	(5)	(6)
1975	16	30		6		12
1978	83	101		13	11	38
1980	171	204		22	20	80
1981	200	34		35	34	73
1982	217	33		49	36	75
1983	311	130		32	41	68
1984	308	130		11	40	67
1985	308	22		5	26	

APPENDIX B

PNOC-EDC Geothermal development module

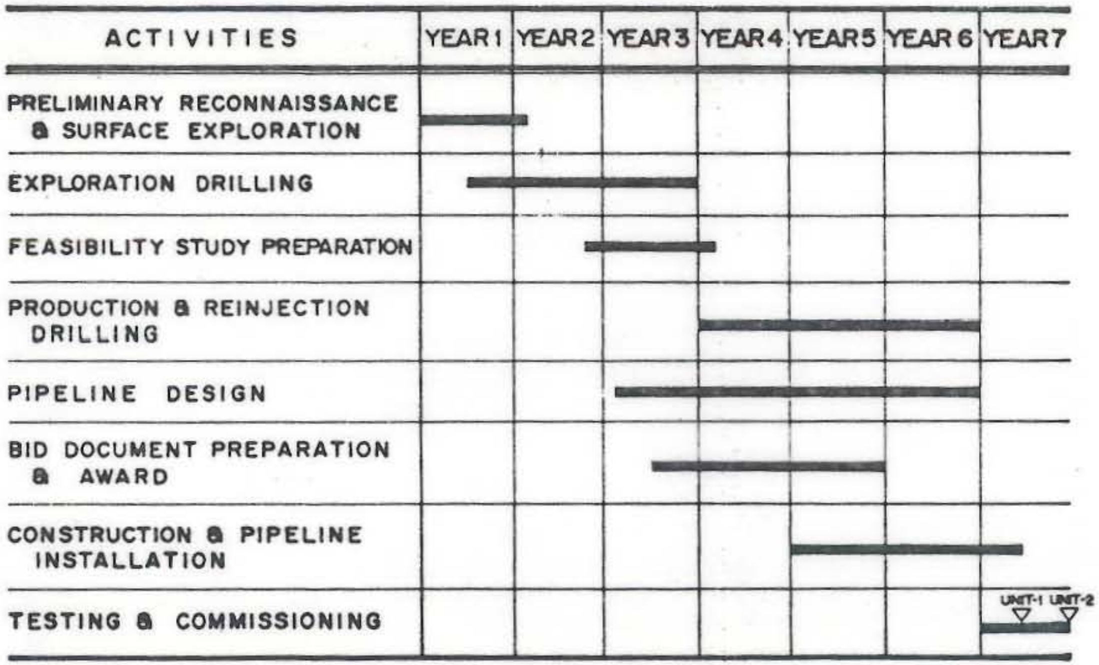

Figure 1

Table 1

INSTALLED GENERATION CAPACITIES
1985 - 1993
(IN MW)

PLANT TYPE	1985	1986	1989	1990	1991	1992	1993
HYDRO	1,859.0	2,114.0	2,194.0	2,194.0	2,194.0	2,194.0	2,442.0
GEOTHERMAL							
PGI	660.0	660.0	660.0	660.0	660.0	660.0	660.0
EDC	234.0	234.0	271.5	381.5	419.0	456.5	494.0
SUB-TOTAL	894.0	894.0	931.5	1,041.5	1,079.0	1,116.5	1,154.0
COAL THERMAL	360.0	415.0	415.0	415.0	415.0	415.0	415.0
NUCLEAR	620.0	620.0	620.0	620.0	620.0	620.0	620.0
OIL THERMAL	1,925.0	1,925.0	1,925.0	1,925.0	1,925.0	1,925.0	1,925.0
DIESEL	561.2	587.2	628.9	628.9	628.9	596.9	596.9
OTHERS							
LUZON	-	-	-	-	-	200.0	300.0
MINDANAO	-	-	-	-	100.0	200.0	200.0
SUB-TOTAL	-	-	-	-	100.0	400.0	500.0
TOTAL	6,219.2	6,555.2	6,714.4	6,824.4	6,961.9	7,267.4	7,652.9

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Table 2

GEOTHERMAL DEVELOPMENT PROJECT
110 MW Plant
Cost Breakdown

	COST PER YEAR (M$)	COST PER ACTIVITY (M$)	ACTIVITY UNITS	TOTAL COST FOR SEVEN (7) YEARS STEAMFIELD DEV'T (MM$)
WELL DRILLING				
Drilling Operations		1,866.67	20 - 40 wells	37.33 - 74.66
Rig Relocation		50.00	1 relocation/well	1.00 - 2.00
General Expense		200.28/well	20 - 40 wells	4.00 - 8.00
FIELD DEVELOPMENT				
Road Construction		32.63/km	0.5 to 1.5 km/well	0.33 - 1.96
Site Preparation		22.63/cellar	1 cellar per well	0.45 - 0.90
Others	373.32			2.61
GEOLOGICAL & GEOSCIENTIFIC				
Geological Survey		0.022	300 - 900 sq. km.	0.01 - 0.02
Explo Geochem		0.022	300 - 900 sq. km.	0.01 - 0.02
Geophysics				
SRS		0.059	300 - 1,000 stations	0.02 - 0.06
VES		0.202	40 - 70 stations	0.01 - 0.02
Gravity		0.003	250 - 300 stations	0.01
Well Logging		0.842	20 - 40 wells	0.02 - 0.03
Others	138.31			0.97
WELL DEVELOPMENT				
Well Testing	28.10	18.21/well	20 - 40 wells	0.56 - 0.93
Well Maintenance	42.84	1.05/well	20 - 40 wells	0.32 - 0.34
Others	124.84			0.87
STEAM GATHERING SYSTEM		19,208-24,500/system		19.21 - 24.50
TECHNICAL ASSISTANCE & TRAINING		1,091- 2,176/project		1.09 - 2.18
T O T A L				68.82 - 120.08

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Table 3

TYPICAL GEOTHERMAL PROJECT COSTS
AT 1985 PRICE LEVEL
(Million US Dollars)

	1	2	3	4	5	6	7	TOTAL
GENERAL & ADMINISTRATIVE	0.045	0.284	0.408	0.832	1.601	2.993	1.977	8.140
GEOLOGICAL & GEOSCIENTIFIC	0.002	0.029	0.092	0.034	0.083	0.169	0.063	0.472
FIELD DEVELOPMENT	0.004	0.384	0.419	0.474	0.637	1.162	0.349	3.429
WELL DRILLING	0.754	0.033	2.501	4.075	12.900	25.875	13.804	59.942
WELL DEVELOPMENT	0.002	0.005	0.043	0.134	0.371	0.737	0.275	1.567
TECHNICAL ASSISTANCE	-	-	-	-	0.417	0.446	0.228	1.091
STEAM GATHERING SYSTEM	-	-	-	-	0.160	12.581	6.467	19.208
OFFICE FACILITIES	-	-	-	-	0.021	0.449	0.778	1.248
T O T A L	0.807	0.735	3.463	5.549	16.190	44.412	23.941	95.097
NO. OF WELLS	2	1	5	3	6	14	9	40
For Hook-up	-	-	1	3	6	14	9	33
Not For Hook-up	2	1	4	-	-	-	-	7

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7.15.85

Table 4

COMPARATIVE SUMMARY
GEOTHERMAL VS OTHER ALTERNATIVES
COUNTRY ECONOMICS

	INVESTMENT LEVEL	FUEL COST MILLS/KWH	ELECTRICITY COST MILLS/KWH
GEOTHERMAL	$600/KW - $800/KW	25 - 28	38 - 45
COAL	$1,200/KW	20 - 22	47 - 49
NUCLEAR*	$3,000/KW	8	72
HYDRO	$2,500/KW	-	45
OIL	$1,000/KW	45	67

*Bataan Nuclear Plant

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7.20.85

THE TRAINING PROGRAM IN GEOTHERMAL TECHNOLOGY OF PHILIPPINE NATIONAL OIL COMPANY'S ENERGY DEVELOPMENT CORPORATION

Bernardo S. Tolentino[1]
Geothermal Division
PNOC-Energy Development Corporation

INTRODUCTION

Barely 9 years after the Philippine National Oil Company-Energy Development Corporation (PNOC-EDC) started serious exploration of the known geothermal resources of the Philippines, the country can now speak of a fast-growing number of Filipino specialists in the field of geothermal technology.

Initially, the country depended mostly on foreign consultants every inch of the way. However, PNOC-EDC, the lead government firm for the exploration and development of geothermal energy in the country, judiciously adopted, even in the yet early years of the program, a technology transfer scheme which is now showing signs that the Filipinos are indeed becoming increasingly self-reliant in the geothermal development field.

From over 30 Philippine-based and Auckland-based New Zealander consultants during the late 70's, PNOC-EDC has reduced this level to 10 bodies in 1984, with further reduction to 2 foreseeable at the start of 1986. The Government of New Zealand, recognizing the increasing technical capability of the Filipinos will terminate the consultancy portion of the Bilateral Aid Program at the end of 1985, therefore, limiting the New Zealand assistance to technical training to help the Philippines sustain its long-term high level manpower build-up.

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[1]Manager, Geoscientific Department

It is extremely difficult to quantify the degree of technology transfer received so far by the technical staff of PNOC-EDC. In 1983, Dr. Arturo P. Alcaraz, the acknowledged "Father of Philippine Geothermal Energy Exploration and Development" assessed the status of technology transfer in the Philippines in the following manner:

1. The Philippines has been the recepient of a fair amount of technology transfer in the area of geothermal energy exploration and development. Filipinos are now largely capable in the 3 main technologies involved in a full scale geothermal energy production.

2. In the exploration phase which demands expertise in geology, geochemistry and geophysics, the extent of knowledge acquired by the Filipinos is placed at 90%, the remaining 10% represents the fact that technology is an evolutionary process and therefore its transfer can never be completed.

3. For drilling management which involves largely the overseeing of programmed drilling operations, the Filipinos are rated as being 70% capable.

4. For engineering services or the design and construction of steam collection and effluent disposal systems, the extent of technology transfer is rated at 80%.

TECHNOLOGY TRANSFER - A MUST

To speed up technology transfer in all areas of operation, PNOC-EDC management elected to put the consultants directly in the LINE, whether they are funded under the bilateral aid programs or working within a commercial engagement. This arrangement has relieved them from their typical non-commital stance as plain advisers. The Filipino staff, is usually headed by an understudy who is carefully selected to work closely on a ONE-ON-ONE relationship with the expatriate supervisor or manager until the management is convinced that the Filipino counterpart can already take over.

While it would seem that New Zealand has been PNOC-EDC's steady source of technology, this is not to say it did not avail of the known expertise of other countries. P.V. Malixi, PNOC Vice-President who was at the helm of the program piloting it to success from 1976 to the time of his retirement in early 1985, has always stressed that "technology is an evolutionary process and is therefore not the sole or exclusive expertise of any one organization".

Over the years, technology transfer to PNOC-EDC geoscientists, engineers and technicians has been attained through the following:

1. Direct working experience with trained expatriates and Filipinos from PNOC and KRTA.

2. Exposure to various technology experts through scientific missions to the Philippines, or plain visits to the Philippines of experts from New Zealand, Iceland, Japan, Italy and the United States. They are literally "grabbed by the arm" when they happen to be around.

3. Attendance in conferences and seminars on geothermal energy technology, both domestic and foreign. The accidental participation of this author to the International Workshop on Training Needs in Geothermal Technology of Developing Countries held at Laugarvatn, Iceland in July 1978 opened a new and fresh area of training and linkage with experts in Iceland that tremendously helped PNOC-EDC during the early years when it has to crash its training program to develop the much needed skill in its technical staff in the earliest time possible. From 1979 to 1983, the UNU/Iceland Course successfully graduated 11 Filipinos adequately trained in the fields of borehole geology, geochemistry, geophysics and reservoir engineering.

4. Availment of formal training on the science and engineering of geothermal technology from local and foreign venues, viz:

   a) UNDP/NZ and RP-NZ Bilateral training program at the Geothermal Institute of Auckland University;

   b) Short training assignments from 2 to 6 months with the Department of Scientific and Industrial Research, Ministry of Works and Development and the Electricity Department of New Zealand funded under the RP-NZ Bilateral Aid Program better known as the RP-NZ Geothermal Energy Cooperation Program (RP-NZ GECP);

   c) UNU/Iceland-funded specialization courses at Orkustofnun, Reykjavik, Iceland;

d) JICA-funded geothermal overview course at the Kyushu University for supervisors and potential managers;

e) Post-graduate course in geothermics at Pisa, Italy; and

f) UNDP-funded Geothermal Reservoir Assessment and Management Course currently being conducted in the Philippines. Forty Filipinos have been participating in the course which was rated to be equivalent to a masteral program. The course covers lectures and practicum that commenced in early 1982. Expected completion of the course is end of 1986.

What is also considered as a key element to the successful transfer of technology to the technical personnel of PNOC-EDC is the fact that the company has done fairly well in its recruitment program. Its management has even agreed to the extent of over-staffing the organization so that training can be sustained over the long term without jeopardizing the work program.

A SUCCESS STORY

When people talk of the success story of PNOC's geothermal exploration and development program, they speak primarily in terms of the absolute figures, viz:

1) the first 3 MW semi-commercial geothermal power plant in Tongonan, Leyte which was rendered operational

within a span of 9 months from the time the discovery well was drilled in October 1975 to the hook-up of the power station in early July 1977;

2) the 225-MW installed capacity in Tongonan, Leyte and Palinpinon, Negros Oriental which represents about 25% of existing installed capacity in the country; and

3) the high number of successful wells drilled todate — nearly 90% success rate in a total of 150 wells.

To PNOC, however, success is also defined in terms of the infrastructures it had put up, the ancillary industries that had thrived because of its operations, the employment opportunities that its projects had generated, and the social improvements it has introduced in its project areas.

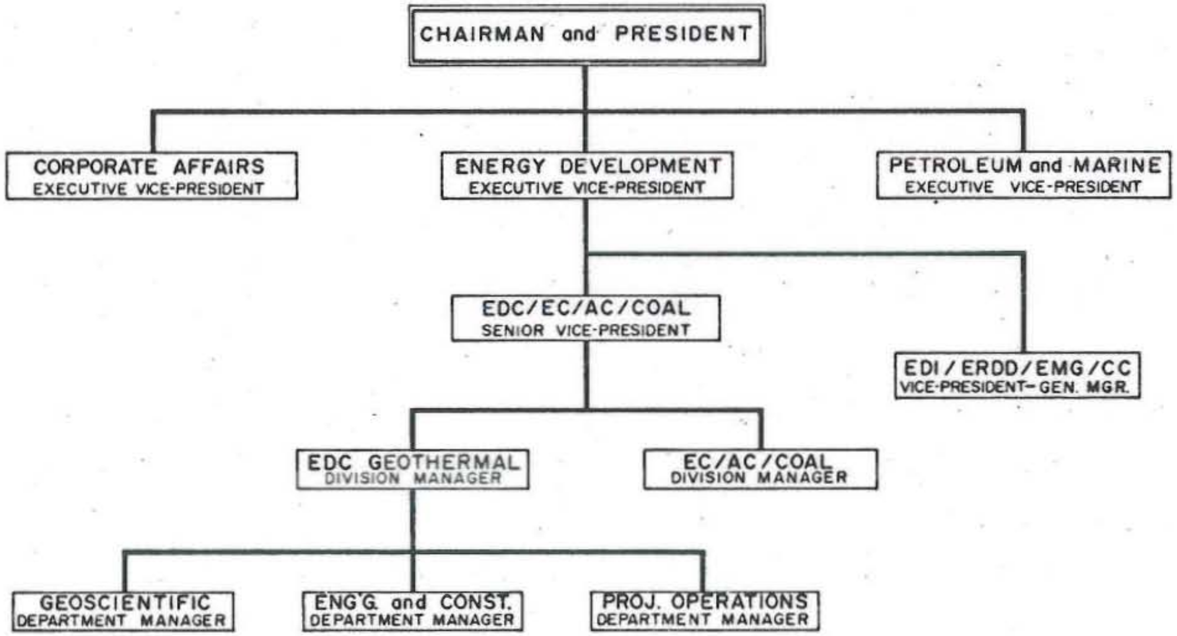
Another aspect of success directly associated with the geothermal program is the development of indigeneous technical capability and transfer of technology which has been an on-going concern of PNOC since it ventured into the energy development field. PNOC now has a pool of geothermal operations experts, from geoscientific to reservoir engineering, thanks to the technical assistance of New Zealand, Iceland, Japan, Italy and the UNDP.

The Filipino people view the success of PNOC's training program in geothermal technology with high regard. Even a KRTA manager was heard expressing a sentiment of optimism about the success of the training program. He said, "It is now possible to foresee the time ahead when the present pupil takes up the role of the teacher in his own right." (1983, Inauguration of Tongonan I Geothermal Power Station).

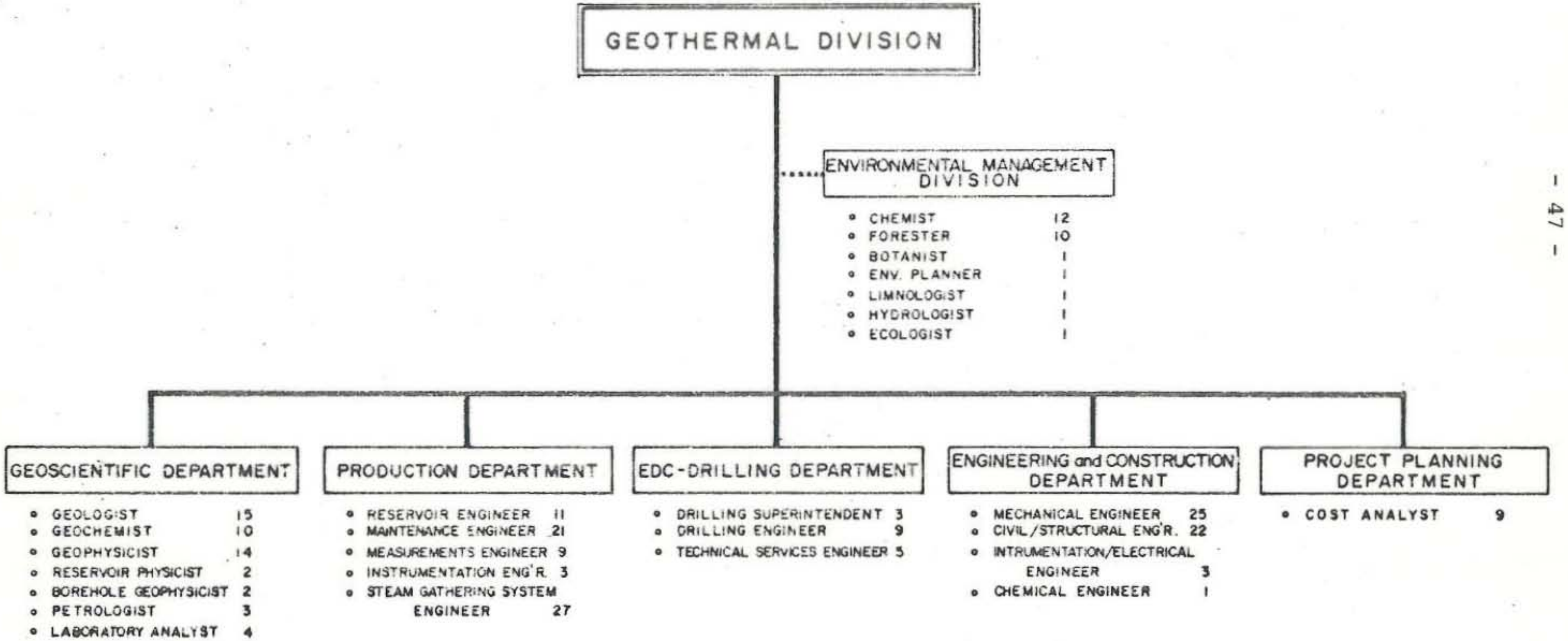
CONCLUDING STATEMENT

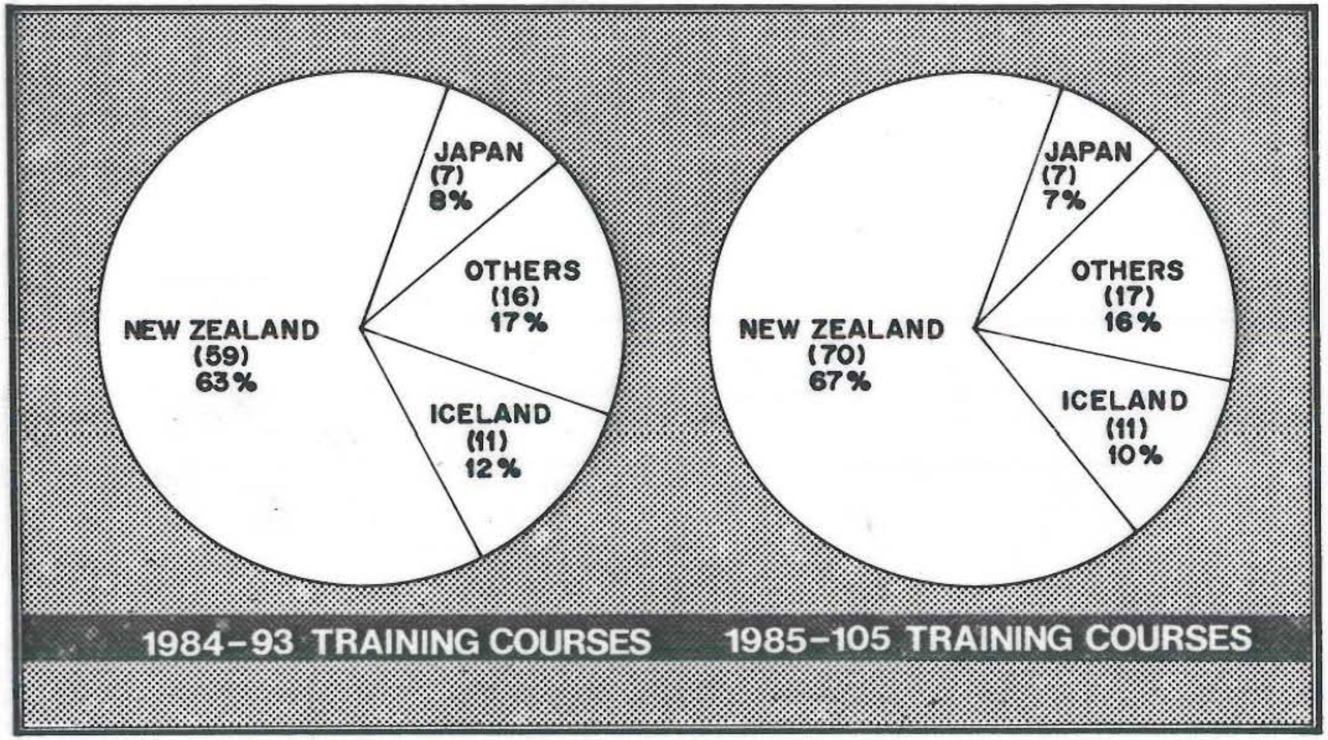
Despite this success, PNOC still maintains its belief that its management would always benefit from consulting with international experts who could render independent second opinions on important issues affecting project management and operations. Geothermal operations, just like any other exploration venture, involves tremendous financial risks. The decision for a minimum exploration drilling program involving 3 wells, for example, is already a US$5 million or more worth of a decision. PNOC would prefer to approach this kind of a decision from all possible viewpoints in order to lessen if not minimized the risks involved.

EDC GEOTHERMAL DIVISION WITHIN THE PNOC ORGANIZATION

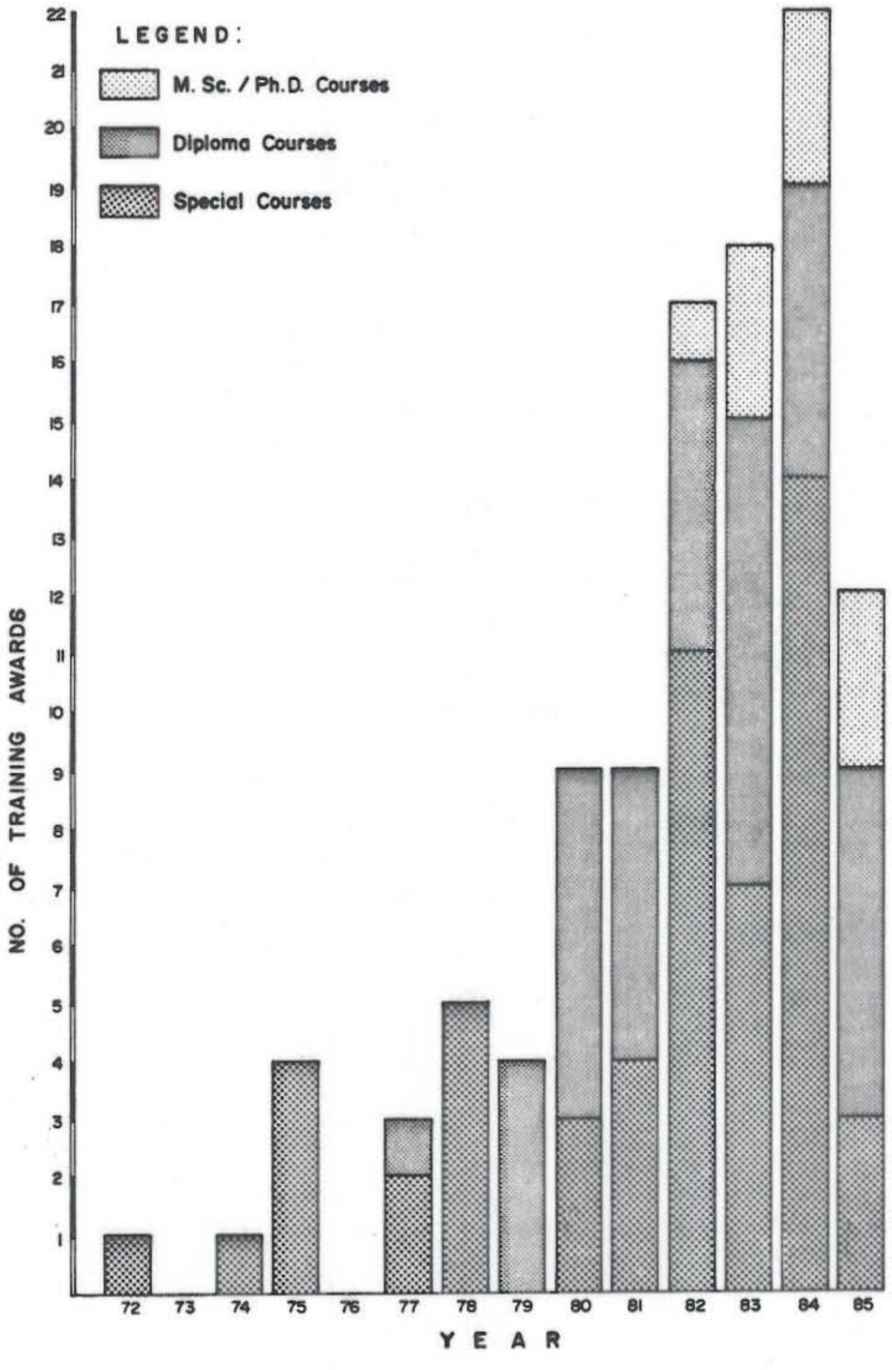


GEOTHERMAL DIVISION

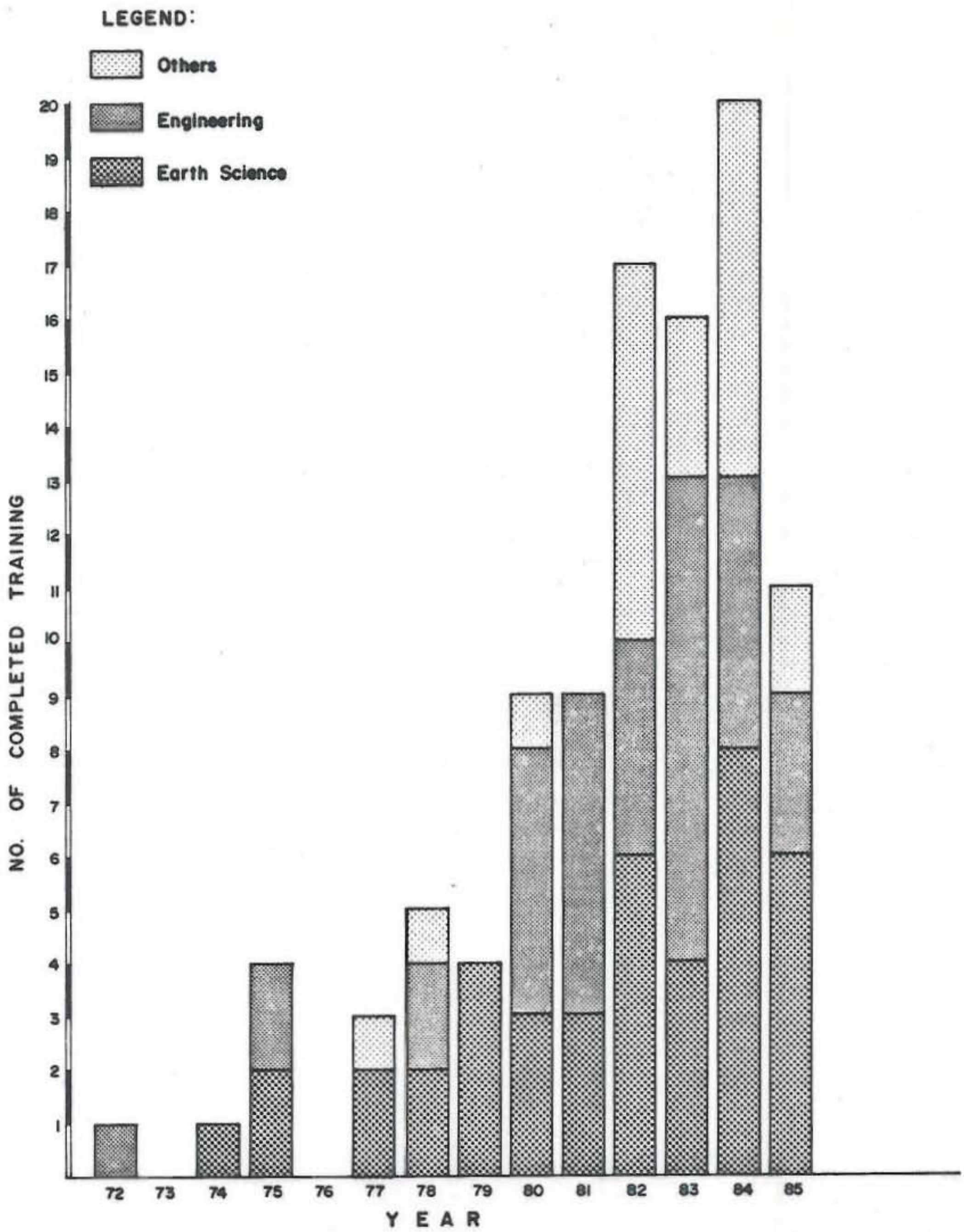




Foreign training courses availed of by EDC staff



FOREIGN TRAINING MIX
Yearly total availed of by EDC staff



FOREIGN TRAINING MIX
Yearly total availed of by EDC staff

PNOC ENERGY DEVELOPMENT CORPORATION
Geothermal Division

SUMMARY OF FOREIGN TRAINING AS OF DECEMBER 1985
(per discipline)

	NAME	SCHOOL/VENUE	PROGRAMME	DATE	PRESENT POSITION IN THE ORGANIZATION
I. Doctorate					
1) Ph.D. in Geochemistry	J.R. Ruaya (on-going)	Victoria University, New Zealand	RP-NZ GECP	1986	Geochemist, Exploration, Head Office
II. Masterate					
1) M.Sc. in Geochemistry	J.R. Ruaya	Victoria University, New Zealand	RP-NZ GECP	1984	Geochemist, Exploration, Head Office
2) M.Sc. in Petrology	H.P. Ferrer	Univ. of California, Riverside, USA	Fulbright-Hays	1982	Supervising Geologist, Exploration, Head Office
3) M.Sc. in Petrology	A.G. Reyes	Univ. of Auckland, New Zealand	RP-NZ GECP	1985	Sr. Petrologist, Exploration, Head Office
4) M.Sc. in Geophysics	C.P. Ignacio	Univ. of Auckland, New Zealand	RP-NZ GECP	1985	Geophysicist, Exploration, Head Office
5) Masters of Engineering in Energy Technology (Planning)	R.C.M. Malate	Asian Institute of Technology, Thailand	Shell Int'l	1983	Borehole Geophysicist, Exploration, Head Office
6) M.Sc. in Reservoir Physics	R.M. Castillo (on-going)	Univ. of Auckland, New Zealand	RP-NZ GECP	1986	Reservoir Physicist, Exploration, Head Office
7) M.Sc. in Geophysics (Electrical Methods)	M.C. Vergara (on-going)	Victoria University, New Zealand	RP-NZ GECP	1987	Supervising Geophysicist, Exploration, Head Office
8) M.Sc. in Structural Geology	L.F. Bayrante (on-going)	Univ. of Auckland, New Zealand	RP-NZ GECP	1987	Geologist, Exploration, Head Office
9) M.Sc. in Reservoir Engineering	J.M. Salera (on-going)	Univ. of Auckland, New Zealand	RP-NZ GECP	1987	Reservoir Engineer, Reservoir Engineering, LGP

III. Diploma Course

A. Geoscientific

		NAME	SCHOOL/VENUE	PROGRAMME	DATE	PRESENT POSITION IN THE ORGANIZATION
1)	Geothermal Technology	R.C. Rodriguez	Univ. of Auckland, New Zealand	UNDP	1980	Geophysicist, Exploration, Head Office
2)	Geothermal Technology	V.C. Clemente	Univ. of Auckland, New Zealand	UNDP	1981	Supervising Geochemist, Exploration, Head Office
3)	Geothermal Technology	J.R. Ruaya	Univ. of Auckland	UNDP	1982	Geochemist, Exploration, Head Office
4)	Geothermal Technology	A.C. Licup, Jr.	Univ. of Auckland	UNDP	1984	Wellsite Geologist, Geoservices Head Office
5)	Geothermal Technology	B.C. Buñing	Univ. of Auckland	UNDP	1985	Borehole Geophysicist, Exploration, Head Office
6)	Geothermal Technology	M.C. Vergara	Univ. of Auckland	RP-NZ GECP	1983	Supervising Geophysicist, Exploration, Head Office
7)	Geothermal Technology	L.F. Bayrante	Univ. of Auckland	RP-NZ GECP	1984	Geologist, Exploration, Head Office
8)	Geothermal Technology	J.S. Seastres, Jr.	Univ. of Auckland	RP-NZ GECP	1985	Geochemist, Exploration Head Office
9)	Geothermal Technology	R.C. Gonzalez	Univ. of Auckland	RP-NZ GECP	1985	Wellsite Geologist, Geoservices, Head Office
10)	Borehole Geology	A.G. Reyes	United Nations Univ/ National Energy Autho. of Iceland	UNU	1979	Sr. Petrologist, Exploration, Head Office
11)	Geochemistry	A.S.J. Baltasar	UNU/National Energy Authority of Iceland	UNU	1980	Project Geochemist, Geoservices, BMGP

		NAME	SCHOOL/VENUE	PROGRAMME	DATE	PRESENT POSITION IN THE ORGANIZATION
12)	Geophysics	D.B. Layugan	UNU/National Energy Authority of Iceland	UNU	1981	Geophysicist, Exploration, Head Office
13)	Geochemistry	O.T. Jordan	UNU/National Energy Authority of Iceland	UNU	1982	Acting Supervisor, Geoservices, SNGP
14)	Geophysics	C.P. Ignacio	UNU/National Energy Authority of Iceland	UNU	1982	Geophysicist, Exploration, Head Office
15)	Geothermics	E.S.D. Olympia	International School of Geothermics, Pisa, Italy	UNESCO/Italian Government	1977	Geotechnical Assistant, Geoservices, Head Office
16)	Geothermics	L.B. Villaseñor	International School of Geothermics, Pisa, Italy	UNESCO/Italian Government	1984	Geochemist, Exploration, Head Office
17)	Geothermal Technology	E.M. Arevalo (resigned)	Univ. of Auckland, New Zealand	UNDP	1979	Project Geologist, SNGP (Resigned, 1982)
18)	Geothermal Technology	R.O. Obusan (resigned)	Univ. of Auckland, New Zealand	UNDP	1979	Project Geologist, BMGP (Resigned, 1983)
19)	Geothermal Technology	M.M. de Leon (resigned)	Univ. of Auckland, New Zealand	UNDP	1983	Geoservices Supervisor, BMGP (Resigned, 1984)
20)	Borehole Geology	N.G. Bagamasbad (resigned)	UNU/National Energy Authority of Iceland	UNU	1979	Geoservices Supervisor, SNGP (Resigned, 1985)
B.	**Production & Geodata**					
1)	Geothermal Technology	W.N. Algopera	Univ. of Auckland	UNDP	1980	SGS Supervisor, Production, SNGP
2)	Geothermal Technology	D.A. Maxino	Univ. of Auckland	UNDP	1981	Well Maintenance Supervisor, Production, SNGP
3)	Geothermal Technology	A.D. Sarit	Univ. of Auckland	UNDP	1981	Reservoir Engineer, Reservoir Engineering, LGP

	NAME	SCHOOL/VENUE	PROGRAMME	DATE	PRESENT POSITION IN THE ORGANIZATION
4) Geothermal Technology	E.C. Peromingan	Univ. of Auckland	UNDP	1982	Measurement Engineer, Production, LGP
5) Geothermal Technology	J.M. Salera	Univ. of Auckland	UNDP	1983	Reservoir Engineer, Reservoir Engineering, LGP
6) Geothermal Technology	N.O. Rodis	Univ. of Auckland	UNDP	1984	Reservoir Engineer, Reservoir Engineering, LGP
7) Geothermal Technology	A.E. Amistoso	Univ. of Auckland	RP-NZ GECP	1983	Reservoir Engineer, Reservoir Engineering, SNGP
8) Geothermal Technology	A.T. Torrejos	Univ. of Auckland	RP-NZ GECP	1984	Reservoir Engineer, Reservoir Engineering, SNGP
9) Geothermal Technology	F.X.M. Sta. Ana	Univ. of Auckland	RP-NZ GECP	1985	Reservoir Engineer, Reservoir Engineering, BMGP
10) Geothermal Technology	P.P. Gerona	Univ. of Auckland	RP-NZ GECP	1985	Reservoir Engineer, Reservoir Engineering, SNGP
11) Borehole Geophysics/ Reservoir Engineering	Z.F. Sarmiento	UNU/National Energy Authority of Iceland	UNU	1980	Supervising Reservoir Engineer, Reservoir Engineering, Head Off.
12) Reservoir Engineering	D.C. Catigtig	UNU/National Energy Authority of Iceland	UNU	1983	Superintendent, Production, BMGP
13) Borehole Geophysics	M.C. Paete	UNU/National Energy Authority of Iceland	UNU	1983	Supervising Measurement Engineer, Production, LGP
14) Well Logging and Instrumentation	N.S. Maceda	UNU/National Energy Authority of Iceland	UNU	1983	Equipment Engineer, Production, Head Office
15) Reservoir Engineering	J.R. Regalado (resigned)	UNU/National Energy Authority of Iceland	UNU	1981	Coordinator, Geodata, Head Office

	NAME	SCHOOL/VENUE	PROGRAMME	DATE	PRESENT POSITION IN THE ORGANIZATION
16) Geothermal Technology	R.A. Camales	Univ. of Auckland	UNDP	1980	Reservoir Analyst, Geodata, Head Office
17) Geothermal Technology	G.J. Batayola (resigned)	Univ. of Auckland	UNDP	1983	Reservoir Engineer (Resigned, 1985)
C. **Drilling**					
1) Geothermal Technology	G.G. Aznar	Univ. of Auckland	UNDP	1980	Drilling Superintendent, Drilling Department
2) Geothermal Technology	C.V. Parcon (resigned)	Univ. of Auckland	RP-NZ GECP	1982	Drilling Supervisor (Resigned, 1985) .
D. **Engineering & Construction**					
1) Geothermal Technology	F.G. Varias	Univ. of Auckland	UNDP	1985	Supervising Inst. Engineer, E & C, Head Office
IV. **Special Training/Courses**					
A. **Geoscientific**					
1) Volcanology and Geothermal Exploration	O.S. Española	DSIR-New Zealand	NZ-Geothermal Assistance	1974	Manager, Exploration, Head Office
2) Geothermal Geology and Petrology	J.B. Pornuevo	DSIR/NZGS New Zealand	NZ-Geothermal Assistance	1978	Sr. Geologist, Exploration, Head Office
3) Methods in Isotope Hydrology	S.E. Garcia	Inst. of Radiohydro-metry, Munich, West Germany	Carl Duisberg Gesellschaft	1982	Project Geochemist, Geoservices, Head Office
4) Petrological Laboratory Management & Techniques	E.L. Bueza	Federal Inst. of Geosciences and Natural Resources Hannover, West Germany	Carl Duisberg Gesellschaft	1981	Petrologist, Exploration, Head Office

		NAME	SCHOOL/VENUE	PROGRAMME	DATE	PRESENT POSITION IN THE ORGANIZATION
5)	Seismology and Earthquake Monitoring	D.M. Rigor	International Inst. of Seismology and Earthquake Eng'g. Tsukuba, Japan	JICA	1982	Seismologist, Exploration, Head Office
6)	Geothermal Energy Technology	O.S. Española	Kyushu University Japan	JICA	1983	Manager, Exploration, Head Office
7)	Geothermal Energy Technology	C.M. Recio	Kyushu University Japan	JICA	1978	Manager, Geoservices, Head Office
8)	Radioactive (Nuclear) Tracing	A.S.J. Baltasar	DSIR-Inst. of Nuclear Sciences, New Zealand	RP-NZ GECP	1984	Project Geochemist, Geoservices, BMGP
9)	Radioactive (Nuclear) Tracing	O.T. Jordan	DSIR-Inst. of Nuclear Sciences, New Zealand	RP-NZ GECP	1984	Acting Supervisor, Geoservices, SNGP
10)	Geochemical Laboratory Management and Techniques	W.L. Sunga	DSIR-New Zealand	RP-NZ GECP	1984	Sr. Chemist, Exploration, Head Office
11)	Geochemical Laboratory Management and Techniques	R.P. Solis	DSIR-New Zealand	RP-NZ GECP	1984	Project Chemist, Geoservices, BMGP
12)	Fluid Inclusion Geothermometry	M.C. Zaide	Univ. of Auckland	RP-NZ GECP	1983	Petrologist, Exploration, Head Office
13)	Flowmeter Orientation Training	R.M. Castillo	DSIR-MWD New Zealand	RP-NZ GECP	1982	Reservoir Physicist, Exploration Head Office
14)	Geothermal Energy Technology	C.C. Panem	Kyushu University Japan	JICA	1975	Geologist, Exploration, Head Off.
15)	Geochemical Exploration Techniques	E.J. Galia (resigned)	DSIR-New Zealand	NZ Geothermal Assistance	1977	Geochemist, SNGP (Resigned, 1981)
16)	Stable Isotope	V.C. Clemente, Jr.	DSIR	RP-NZ GECP	1985	Supervising Geochemist, Exploration, Head Office

	NAME	SCHOOL/VENUE	PROGRAMME	DATE	PRESENT POSITION IN THE ORGANIZATION
B. Project Management, Operations, Production and Geodata					
1) Geothermal Field Management	A.S. Teves	MWD, New Zealand	NZ Geothermal Assistance	1977	Manager, Project Operations, SNGP
2) Geothermal Field Management	E.B. Patanao	MWD, New Zealand	NZ Geothermal Assistance	1978	Manager, Project Operations, LGP
3) Geothermal Field Management	L.M. Ote	MWD-DSIR-NZED	RP-NZ GECP	1984	Manager, Drilling Department
4) Geothermal Field Management	O.S. Abejo	MWD-DSIR-NZED	RP-NZ GECP	1984	Superintendent, Production, LGP
5) Geothermal Field Management	F.A. Palafox	MWD-DSIR-NZED	RP-NZ GECP	1983	Manager, Project Operations, BMGP
6) Geothermal Field Management	J.L. Achacoso	MWD-DSIR-NZED	RP-NZ GECP	1983	Superintendent, Field Support, LGP
7) Geothermal Field Management	C.R. Catacutan	MWD-DSIR-NZED	RP-NZ GECP	1982	Engineering Assistant, Project Operations, SNGP
8) Geothermal Field Management	A.S. Conui (resigned)	MWD-DSIR-NZED	RP-NZ GECP	1982	Superintendent, Field Support, LGP (Resigned, 1985)
9) Well Testing and Measurement	O.S. Abejo	MWD	NZ Geothermal Assistance	1972	Superintendent, Production, LGP
10) Well Testing and Measurement	R.P. Lagasca	MWD	NZ Geothermal Assistance	1978	Superintendent, Production, SNGP
11) Maintenance, Instrumentation and Control	V.T. Manuel	Masoneilan Company,	Supplier Trng.	1981	SGS Supervisor, Production, LGP

		NAME	SCHOOL/VENUE	PROGRAMME	DATE	PRESENT POSITION IN THE ORGANIZATION
12)	Production Monitoring and Control	F.V. Chavez	MWD-DSIR-NZED	RP-NZ GECP	1983	Instrument Engineer, Production, LGP
13)	Production Monitoring and Control	A.V. Catacutan	MWD-DSIR-NZED	RP-NZ GECP	1983	Acting Supervisor, Measurements, SNGP
14)	Production Monitoring and Control	E.C. Lucero	MWD-DSIR-NZED	RP-NZ GECP	1984	Instrument Engineer, Production, SNGP
15)	Process Egnineering and Control	A.R. Amador	DSIR-MWD	RP-NZ GECP	1984	Process Engineer, Production, Head Office
16)	Process Engineering and Control	W.L. Ferrolino	DSIR-MWD	RP-NZ GECP	1984	Supervising Inst. Engineer, Production, Head Office
17)	Geophysical Exploration Techniques	W.S. Loo	DSIR	NZ Geothermal Assistance	1975	Acting Coordinator, Geodata, Head Office
18)	Flowmeter Orientation Training	F.B. de Lara (resigned)	MWD-DSIR	RP-NZ GECP	1982	Measurement Engineer, Production BMGP
19)	Computer Database Management	J.M.O. Mercado (resigned)	MWD-DSIR	RP-NZ GECP	1984	Geologic Analyst, Geodata, Head Office (Resigned, 1985)
C.	**Drilling**					
1)	Cementing Operations	I.J. Tumanda	CPC-Taiwan	CPC	1980	Drilling Engineer
2)	Pipe Inspection	N.M. Bulandres	Vetco-Singapore	VETCO	1981	Sr. Drilling Engineer
3)	Geothermal Energy Technology	F.E. Mendita	Kyushu University Japan	JICA	1978	Drilling Superintendent, Drilling Department
4)	Cementing Operations	A.L. Pioquinto (resigned)	CPC-Taiwan	CPC	1980	Cementing Engineer (Resigned, 1985)
5)	Pipe Inspection	R.A. DyBuco (resigned)	Vetco-Singapore	VETCO	1981	Drilling Engineer (Resigned, 1985)

	NAME	SCHOOL/VENUE	PROGRAMME	DATE	PRESENT POSITION IN THE ORGANIZATION
6) Geothermal Energy Technology	J.G. Galao (resigned)	Kyushu University Japan	JICA	1982	Drilling Coordinator, Drilling Dept., Head Office (Resigned, 1985)
7) Geothermal Drilling Operations	J.G. Galao (resigned)	MWD-New Zealand	NZ Geothermal Assistance	1975	Drilling Coordinator, Drilling Dept., Head Office (Resigned, 1985)
D. **Engineering & Construction**					
1) Corrosion Engineering	C.M. Ilao	MWD-DSIR	RP-NZ GECP	1982	Quality Assurance Engineer, E & C, Head Office
2) Geothermal Energy Technology	A.F. Vitente	Kyushu University Japan	JICA	1975	Engineering Assistant, E & C, Head Office
E. **Environmental Management Department**					
1) Study Tour of Energy Projects on Environmental Procedures	P.E. Legaspi (resigned)	MWD-NZED-DSIR NZFS-WVA	RP-NZ GECP	1982	Environmental Planning Supervisor (Resigned, 1985)
2) Study Tour of Energy Projects on Environmental Procedures	E.R. Collantes	MWD-NZED-DSIR NZFS-WVA	RP-NZ GECP	1982	Environmental Chemist, Environmental Management Department
3) Study Tour of Energy Projects on Environmental Procedures	A.R. Villamarzo	MWD-NZED-DSIR NZFS-WVA	RP-NZ GECP	1982	Ecologist, Environmental Management
4) Watershed Management	A.C. de Jesus	MWD-DSIR-NZFS-WVA	RP-NZ GECP	1983	Supervisor, Watershed Management Environmental Management Dept.
5) Environmental Impact Assessment: Methods for Marine Environment	J.R.D. Garcia	Marine Research Center, ENEA, La Spezia, Italy	ASEAN-EEC	1984	Limnologist, Environmental Mgt. Department

		NAME	SCHOOL/VENUE	PROGRAMME	DATE	PRESENT POSITION IN THE ORGANIZATION
6)	Techniques on Chemical/Biological Degradation and Analysis of Oil and Oil Products	E.R. Collantes	Dunnstaffnage Marine Laboratory, Oban, Argyll, Scotland	ASEAN-EEC	1984	Environmental Chemist, Environmental Management Department
7)	Studies on Environmental Dimensions of Energy Policies (Biomass Energy)	D.C. Babor	East-West Center Honolulu, Hawaii USA	East-West Center	1980	Chemical Engineer, Environmental Management Department
8)	Techniques and Procedures in Environmental Impact Assessment with the UK North Sea Oil and Gas Industry as Case Example	D.C. Babor	Inst. of Offshore Engineering Heriot-Watt University Edinburgh, Scotland	ASEAN-EEC	1984	Chemical Engineer, Environmental Management Department
9)	Improved Methods for Conducting Toxicity Testing and Bioassay Extraction in the Determination of Trace Metals and Toxic Elements in Environmental Samples	D.C. Abalos	Geochemical Environmental Laboratory, ENEA, Rome, Italy	ASEAN-EEC	1985	Lab Analyst, Environmental Mgt. Department
10)	Methods for Screening Terrestial Organisms as Biological Monitors for Oil, Geothermal and Coal Pollutants	A.R. Villamarzo	ENEL Laboratories, Rome, Italy	ASEAN-EEC	1984	Ecologist, Environmental Mgt. Department
11)	Study Tour of Energy Projects on Environmental Procedures	M.C. Berbano	MWD-NZED-DSIR NZFS-WVD	RP-NZ GECP	1985	Manager, Environmental Mgt. Department

NON-ELECTRICAL APPLICATIONS OF GEOTHERMAL ENERGY: OPENING A NEW FRONTIER IN GEOTHERMAL ENERGY UTILIZATION IN THE PHILIPPINES

Bernardo S. Tolentino, Arturo P. Alcaraz
& Domingo R. Mendoza
PNOC-Energy Development Corporation

INTRODUCTION

The history of geothermal exploration in the Philippines dates back to the early 60's when the Commission on Volcanology (COMVOL), now Philippine Institute of Volcanology and Seismology (PHIVOLCS), commenced a small-scale geoscientific investigation of the Tiwi hot springs located at the southern apron of a Quaternary volcanic center known as Mt. Malinao. The place is called Naglabong where large chloride springs and extensive sinter deposits are found.

Several shallow thermal gradient holes were drilled inside a defined resistivity anomaly mapped using the Wenner array. One of these holes delivered steam and hot water to which a small steam turbine-generator borrowed from a technical school in Manila was hooked-up. In April 12, 1967, the simple set-up installed by COMVOL generated enough power to light some electric bulbs in the pilot station, heralding the modest beginnings of what will be a major technical achievement of the Filipino people 10 years later. In 1969, COMVOL inaugurated a 2.5-kw test facility in Barrio Cale of Tiwi, using a grant from the National Science Development Board, now the National Science and Technology Authority (NSTA). The years that followed saw the successful operation of the pilot power station and the implementation of small research activities on possible non-electrical uses of geothermal energy. The priorities of the limited research work was focused on salt-making and grain drying. In 1974, a full-scale test facility for manufacturing salt from sea water using geothermal energy from the same well supplying the 2.5-kw power generating unit was installed jointly by COMVOL, NSDB and the Philippine Navy who fabricated all the needed hardwares. The plant continued to produce good quality salt until 1979 when commercial geothermal power generation in Tiwi begun. In the year that followed, 220 MWe capacity was in full operation in Tiwi. This massive development had greatly dessipated the research effort of COMVOL, until recently when PNOC-Energy Development Corporation (PNOC-EDC) extended the exploration of the Bacon-Manito geothermal field to include the lowland areas (Fig. 1) at the town of Manito for possible industrial estate development. Three wells, drilled to an average depth of 1000 meters confirmed a moderate enthalpy resource in the Manito lowland with downhole temperatures from 200°-220°C (Fig. 2). This resource was modelled as an outflow from the upwelling region beneath the thickly-forested highlands 10 km to the south of the town of Manito.

The Manito lowland, which PNOC-EDC plans to develop into a geothermal-based industrial estate will be the subject of a UNDP-Assisted study aimed at establishing the feasibility of utilizing geothermal energy for direct agro-industrial applications within the context of the prevailing and future socio-economic environment in the provinces of Albay and Sorsogon (Fig. 3).

THE PROJECT

The idea of developing an industrial estate based on industries that can utilize geothermal energy directly without first converting it to electrical energy was crystallized by

A.P. Alcaraz sometime in 1983 when exploration data from the Bacon-Manito field showed a potential area of medium grade geothermal resource underneath the rolling terrain of the Manito lowland. His recommendations became the take-off point for a number of studies that provided the bases for an application for a UNDP grant directed toward establishing the feasibility of using geothermal energy for non-electrical applications in the Philippines. Project PHI/85/003, entitled "Development of Geothermal Energy for Power and Non-electrical Uses" has been scheduled to commence in March 1986. The other on-going UNDP-Assisted project is the training course on Geothermal Reservoir Assessment and Management which started in 1982. Said project will be completed by the end of 1986.

Project PHI/85/003 aims to assist the Government of the Philippines through PNOC-EDC attain self-sufficiency in energy through the development of geothermal resources both for power generation and non-electrical/industrial application. More specifically, its immediate objectives intends to create sufficient capability among participating Filipino scientists and engineers in the following areas of geothermal energy development:

(1) Application of geothermal fluid which is not suitable for power generation to agro-industrial processing and other non-electrical applications;

(2) Abatement of hydrogen sulfide and other non-condensible gases and disposal of geothermal wastewater;

(3) Alternative means of generating power given different characteristics and conditions of available geothermal fluids; and

(4) Geothermal project engineering using computer aided design (CAD) systems.

The development of technical capability on non-electrical applications has come in the heels of a massive geothermal power development program which helped brought down the country's dependence on foreign crude to about 50% at the end of 1985. Now that the pace of geothermal activities in the Philippines has considerably slowed down, the Government feels it is now ready to explore the possibilities of using medium grade geothermal resource for agro-industrial uses to improve employment and production in the countryside.

The development of the proposed 110-MWe BacMan I geothermal power plant in the Bicol Region has provided the Government with the opportunity to investigate the technical and economic feasibility of using geothermal resources not suitable for power generation for pilot agro-industrial application in the Manito lowlands. There are presently three (3) exploration wells in the area two (2) of which can deliver the geothermal fluids for a pilot facility utilizing the local agricultural produce as inputs from the surrounding farms near Albay Gulf (Fig. 3). The study will undertake technological and economic feasibility analyses including pricing studies for the use of geothermal fluids, testing the merits of various types of heat exchangers, financial analysis and other related pre-investment investigations.

The project contains a training component which will allow the key staff of the Geothermal Division of PNOC-EDC who are participating in the program to visit appropriate plants and installations in the United States, Europe and other countries to gain first-hand exposure and collect ample data and reference materials on the following (Table 2):

(a) Successful applications and the state-of-the-art of design and engineering practices on the use of geothermal fluids for direct agro-industrial processes;

(b) Operational concepts on various abatement methods employed in geothermal installations abroad;

(c) Design and operational aspects of various methods of geothermal wastewater disposal;

(d) Performance of alternative methods of upgrading megawatt output of generating units; and

(e) Applicability and capabilities of commercially available CAD softwares as actually used in existing plants.

THE PROJECT MANNING COMPLEMENT

The implementing agency of the Philippine Government, the Geothermal Division of PNOC-EDC, will start the project in the following manner:

(a) One part time National Project Director (NPD) who will spend a total of 11 man-months intermittently during the execution of the program. The NPD must have a thorough knowledge of the design aspect and operation of geothermal power plants.

(b) One Project Officer to serve for 14 man-months. He must have a solid background in project analysis particularly for agro-industrial plants and a familiarity with geothermal engineering.

(c) Two analysts with experience in engineering economics, finance and marketing aspects of projects. Their total time for the project is 14 man-months.

(d) One full time geothermal process engineer for a period of 24 man-months to work on process design activities for agro-industrial projects.

(e) Four geothermal design engineers for a period of 8 months each, deployed as follows:

- two process/mechanical engineers well versed in geothermal piping and equipment design
- one civil/structural engineer experienced in geothermal design and construction implementation
- one instrument engineer proficient in control equipment and instrumentation design and operation.

(f) One geothermal production engineer who will support the team headed by the NPD. He will be involved for a period of 8 months.

(g) Two staff engineers with experience in mechanical and civil engineering on geothermal projects for a total input of 48 man-months.

(h) A geochemist for a period of 8 man-months.

(i) An agronomist for a duration of 8 man-months.

(j) A biologist for a period of 8 man-months.

(k) Three administrative staff composed of 2 clerks and one messenger/driver for a total period of 80 man-months.

The staffing to be provided by UNDP:

(a) A Chief Technical Adviser for initially 12 man-months from start of the project. His total involvement will span a period of 18 months. The CTA must possess an overall knowledge of geothermal engineering applications for power generation but his main expertise must be in the non-electrical applications of geothermal energy, with experience in project analysis, materials selection for heat exchangers and the implementation of non-electrical applications program. The CTA must also have previous experience in organizing and conducting technical training seminars and workshops.

(b) A consultant in the field of gas abatement methods for 3 man-months.

(c) A consultant well versed in the design and evaluation of geothermal wastewater disposal; for 3 man-months.

(d) A consultant in the field of different power generating processes, design and material specifications of turbines and other rotating equipment; for 3 man-months.

(e) An economist, locally-hired, for 4 man-months intermittently.

Table 1 summarizes the inputs of the Philippine government in the implementation of the project. The tentative work plan is shown in Table 2.

OTHER COOPERATING ORGANIZATIONS

Several local resource organizations have been identified to insure the successful implementation of the project (Fig. 4):

(1) Ministry of Agriculture - This office will provide data on land and marine products and seasonal and non-seasonal programming. Statistics on the density of yield per area, schedules of harvest and conditions of crops and other related information will come from the Ministry of Natural Resources, National Food Authority and the University of the Philippines at Los Baños laboratory.

(2) Ministry of Trade and Industries - This office will furnish data on industrial development programme.

(3) Regional Government Agencies - This will facilitate availability of information on industrial development in the municipal/provincial level including those from the private sectors.

PROJECT OUTLOOK

The planners of this project forsee considerable gains for the local geothermal industry in the future especially because the success of the project will open a new frontier on the utilization of geothermal energy in the country which can eventually lead to the diversification of the commercial usage of the known geothermal resources in the Philippines. At present, the application of geothermal energy in the country has focused singly on the production of electricity. The most foreseeable gain would be in the development of agriculture-based industries in the countryside which could result to a wider dispersion of industry and employment and finally the upliftment of rural livelihood and economy.

Medium grade geothermal resource areas abound over the entire length of the Philippine Archipelago. Most of them are located in areas that are easily accessible by sea and land transportation (Fig. 5). These areas are known outflow regions of high grade geothermal fields like Tiwi and Manito in the province of Albay, Dauin in Negros Oriental and Biliran in Leyte. Others are by itself low to medium grade resources found in Mabini, Batangas; Montelago, Mindoro Oriental and Mainit, Surigao. Those areas in the long-ranged program for possible non-electrical use in addition to their potential as possible source of power are Mt. Pinatubo, Zambales; Mt. Labo, Camarines Norte; Irosin-Bulusan, Sorsogon; Anahawan, Leyte; Mambucal (Mt. Canlaon), Negros Occidental; Balingasag, Misamis Occidental; Marinduque and Palawan.

The Philippines, with its vast geothermal energy resource potential, can also become a leading country in the non-electrical utilization of geothermal energy as it is in power generation. There is so much natural resources in the islands where geothermal energy can be applied in many ways (Table 3). As a developing country still largely dependent on imported energy, the Philippines is expected to profit well in applying geothermal energy for direct use. PNOC-EDC anticipates this will be a major thrust in the country's utilization of geothermal energy in the near future.

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Commission on Volcanology, 1973 - The Geothermal Salt-Making Research Plant (A Joint Research Project of the Naval Shore Establishment, Philippine Navy, Commission on Volcanology and National Science Development Board)

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Urbino, Ma. Elena G., 1985 - A Study on the Suitability for Non-Electrical Uses of the Low Enthalpy Fluids Discharged by Wells Drilled at Manito Lowlands, Albay and Okoy Valley, Negros Oriental, Internal Report

PNOC-EDC, 1985 - Project Proposal for the Development of Geothermal Energy for Power and Non-Electrical Uses, Internal Report

PNOC-EDC, 1984 - Recommendation for the Siting of Two Farther Exploratory Wells in the Manito Lowlands, Internal Report jointly prepared by PNOC-EDC and KRTA, Ltd.

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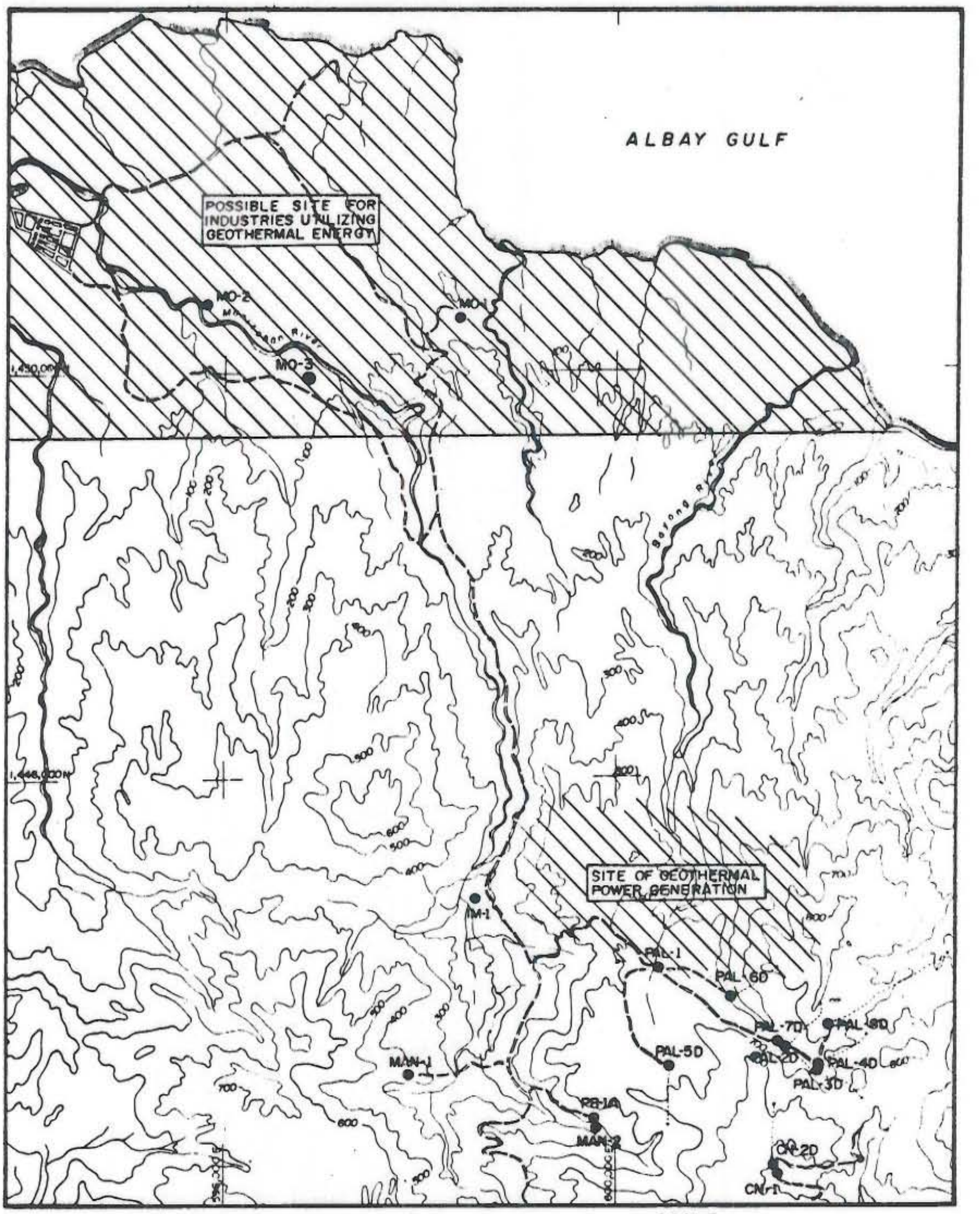


Fig. 1
BACON - MANITO GEOTHERMAL PROJECT

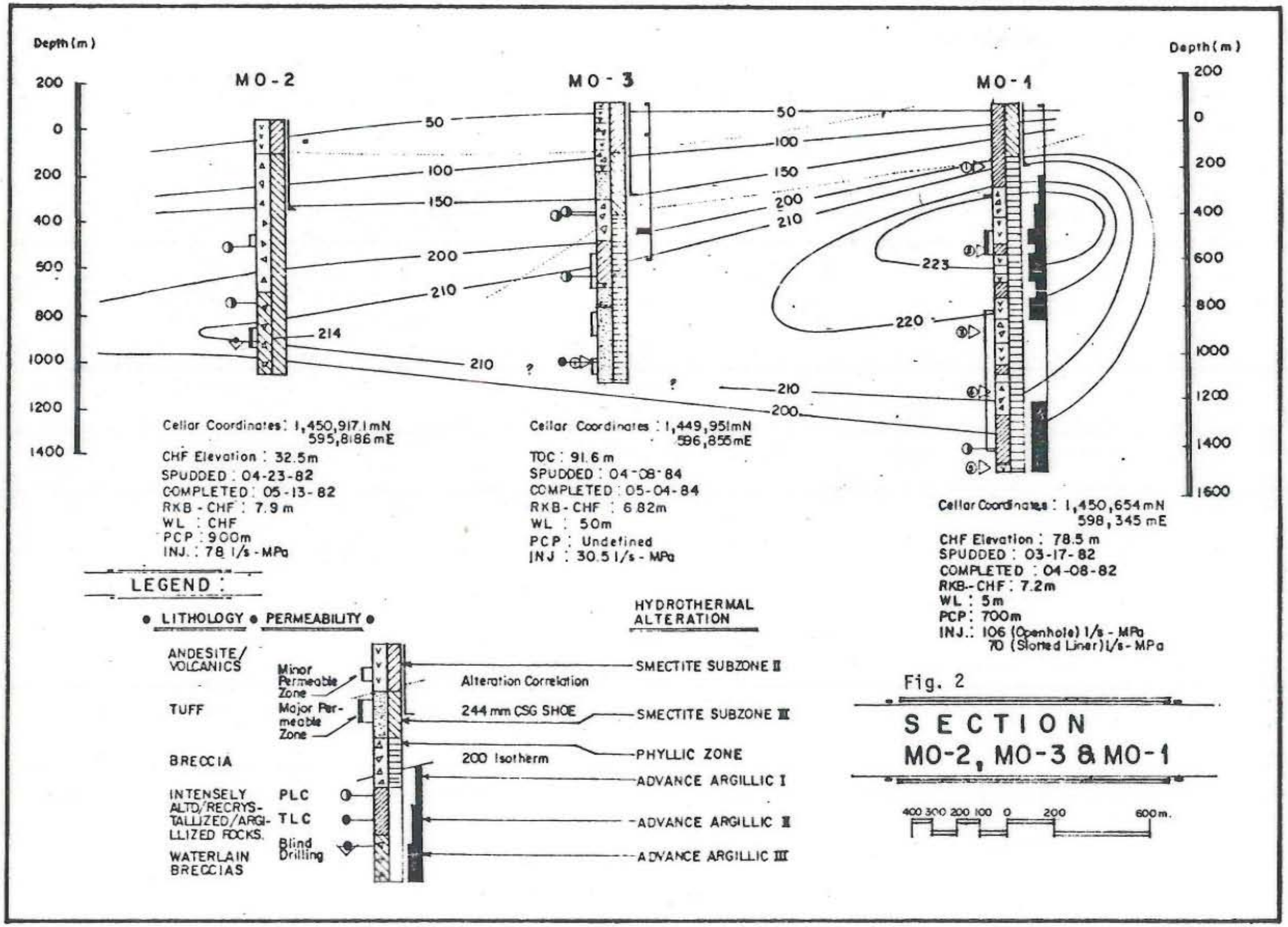


Fig. 2

SECTION MO-2, MO-3 & MO-1

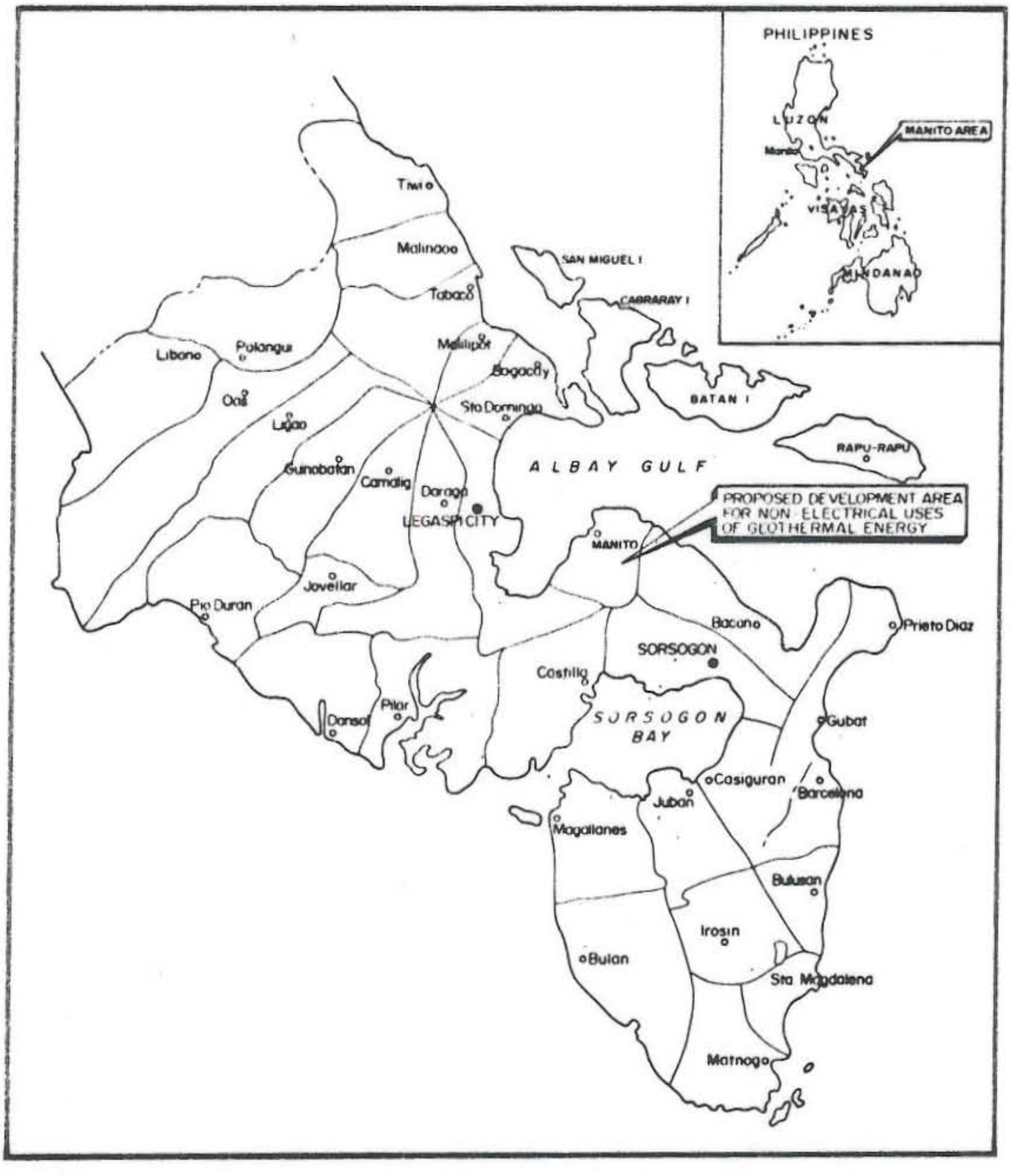


Figure 3. LOCATION MAP OF ALBAY & SORSOGON (REGION V)

10 5 0 10 20 30 Km

GRAPHIC SCALE

LEGEND

o MUNICIPALITY

● CITY/ PROVINCIAL CAPITAL

Table 1. GOVERNMENT INPUTS

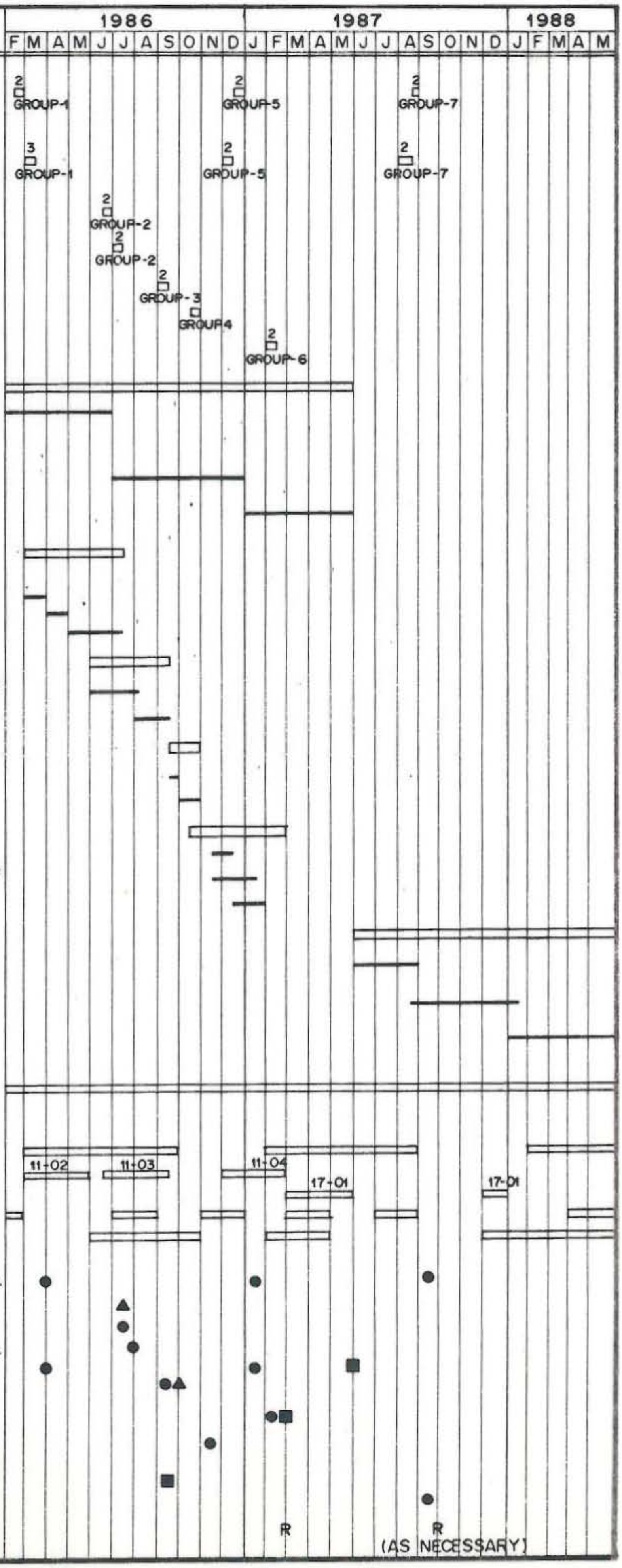
INPUTS	DURATION (M/M)			DEPARTMENT CONCERNED	EARLIEST DATE REQUIRED
	86	87	88		
1. Project Personnel					
a) National Project Director (1)*	5	4	2	E & C	Jan. 1986
b) Project Officer (1)	7	5	2	E & C	Mar. 1986
c) Analysts (2)	8	3	3	Planning	Mar. 1986
d) Geothermal Process Engineer (1)	12	12	--	E & C	Jan. 1986
e) Geothermal Design Engineers (4)	32	--	--	E & C	Mar. 1986
f) Geothermal Prod'n. Engineer (1)	8	--	--	Proj. Opns.	Mar. 1986
g) Staff Engineers (2)	24	24	--	E & C	Jan. 1986
h) Agronomist (1)	4	4	--	Environmental	Mar. 1986
i) Biologist (1)	4	4	--	Environmental	Mar. 1986
j) Administrative Support (H/Q)	36	36	8	E & C/OSD	Upon arrival of CTA
k) Field Support (Sites)	24	24	6	E & C/ Proj. Opns.	Jan. 1986
2. Non-Expendable Equipment					
a) Manila Service Vehicle	12	12	4	OSD	Upon arrival of CTA (Feb. 1986)
b) Site Facilities	As Required			E & C/ Proj. Opns.	- do -
c) Communication	As Required			OSD	Jan. 1986

*(1) - Denotes the number of input required for the project. In this case, only one National Project Director is needed.

Table 2. PROJECT SCHEDULE

ACTIVITY

1. TRAINING
   a. Attendance in workshop, symposia, seminars and other conferences related to Geothermal Power Engineering and other topics in line with local Energy Resource development.
   b. Plant visits and study tours to existing agroindustrial processing plants utilizing geothermal heat including attendance in workshops and seminars.
   c. Acquisition of data in the operational concept of abatement methods.
   d. Operational and design concept of effluent disposal system.
   e. Identification of applicable CAD system.
   f. Familiarization on the features of purchased CADS.
   g. Operational and design technology of alternative generating units.
2. NON-POWER USE OF GEOTHERMAL ENERGY
   a. Evaluation, assesment and review of the physical features of Manito, existing socio-economic conditions, Transport facilities of the area and developmental impact of the people.
   b. Assessment of geothermal fluid for direct process use and identification of processing industries.
   c. Formulation of preventive techniques against expected technical problems.
3. H_2S ABATEMENT AND ELIMINATION OF OTHER CONDENSIBLE GASES.
   a. Investigation of existing PNOC-EDC Installations.
   b. Fluid chemistry analysis.
   c. Identification of solution to potential problems.
4. GEOTHERMAL WASTE WATER DISPOSAL SYSTEM
   a. Identification of schemes and determination of adoptable method of effluent disposal
   b. Analysis and recommendation.
5. COMPUTER AIDED DESIGN SYSTEM
   a. Analysis and recommendation of commercially available CAD system.
   b. Procurement of softwares.
6. ALTERNATIVE POWER GENERATING SYSTEM
   a. Assessment of Bacman well pads.
   b. Design of suitable rotary separator turbine and downhole turbines or other alternative system.
   c. Equipment specification of recommended units.
7. FRAMEWORK FOR AGROINDUSTRIAL DEVELOPMENT
   a. Assesment of agricultural and marine production capabilities and products marketing.
   b. Evaluation of operating scheme and options for pricing of progress heat.
   c. Determination of incentives, financial/economic feasibilities project engineering and implementation.
8. PROJECT PARTICIPATION OF LOCAL STAFF UNDER THE GOVERNMENT INPUT
9. KEY PROJECT PERSONNEL
   a. CTA
   b. International consultant
   c. Local consultant
   d. ND
   e. PO
10. REPORTS, RECOMMENDATIONS & DOCUMENTATION
   a. Reports derived from workshops, seminars, symposia, etc.
   b. Abatement method and preventive measures.
   c. Reports on comparative abatement methods.
   d. Reports on comparative waste water disposal system.
   e. Preliminary study and guidelines for agroindustry.
   f. Report on the features of CADS available.
   g. Designs and specifications of alternative generating system.
   h. Report on the capabilities purchased CAD.
   i. Design and specification of effluent disposal system.
   j. Master plan for agroindustrial development project.
11. TRIPARTITE REVIEWS (R)



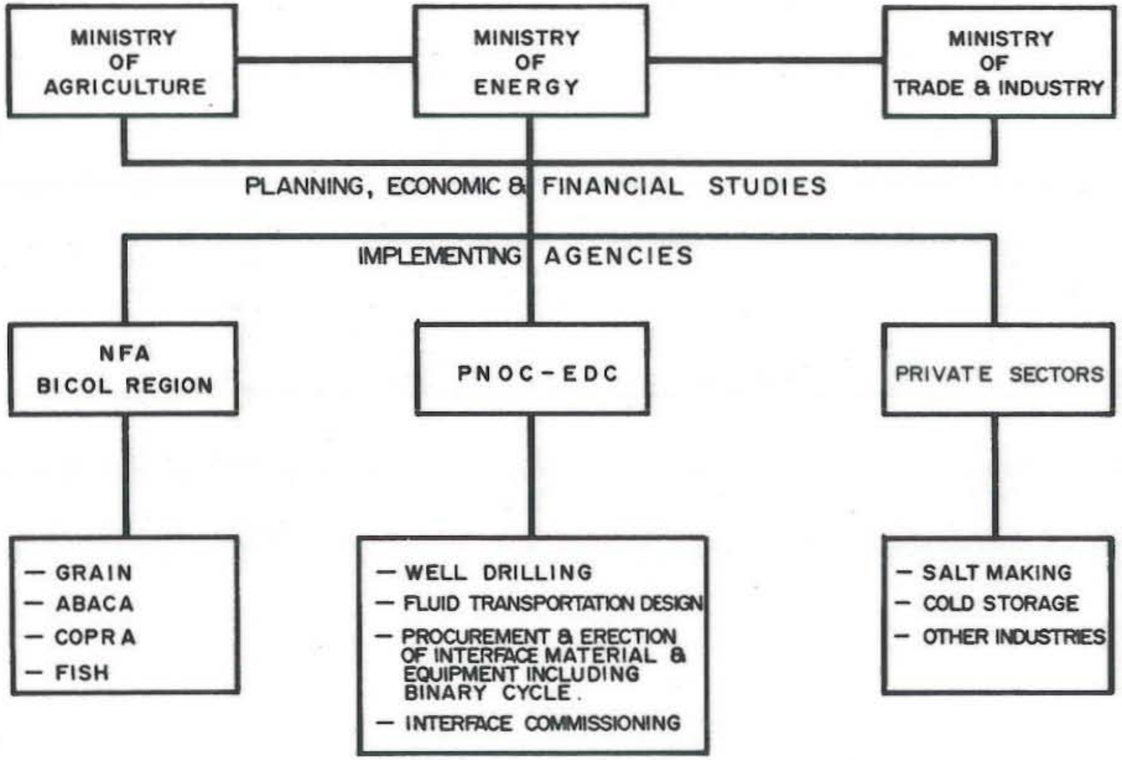


Figure 4 ORGANIZATION & MANAGEMENT SET-UP

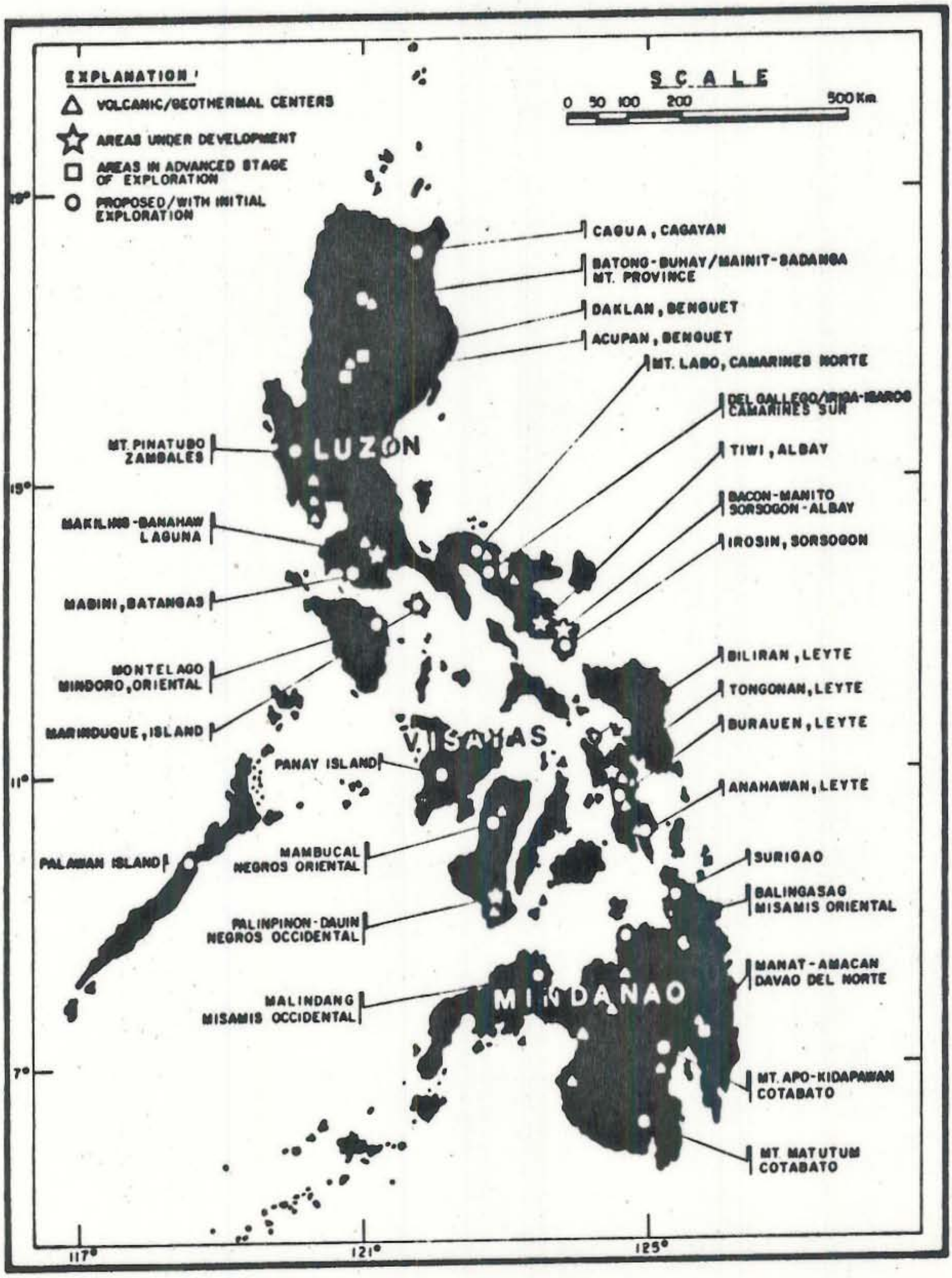


Fig. 5 - PHILIPPINE GEOTHERMAL AREAS UNDERGOING EXPLORATION AND DEVELOPMENT

POSSIBLE NON-ELECTRICAL USES OF GEOTHERMAL RESOURCES IN THE PHILIPPINES

(AFTER A.P. ALCARAZ, 1984)

INDUSTRIAL APPLICATIONS

1. WOOD AND PAPER INDUSTRY

   A. PULP AND PAPER
   B. VENEER FACTORY
   C. TIMBER DRYING

2. CHEMICALS

   A. SALT PLANT
   B. SODA ASH
   C. CAUSTIC SODA (BY-PRODUCT: CHLORINE)
   D. ALCOHOL (BY-PRODUCT: ETHYLENE)

   CHLORINE + ETHYLENE WILL PRODUCE VCM (VINYL-CHLORINE-MONOMER) WHICH CAN BE TURNED INTO PVC (POLY-VINYL-CHLORIDE)

   E. DRY ICE
   F. BORIC ACID
   G. CALCIUM AND POTASSIUM CHLORIDES

3. BEER BREWERY AND DISTILLATION INDUSTRIES

4. CONFECTIONARY INDUSTRY

AGRICULTURAL APPLICATIONS

1. DRYING PURPOSES (GRAINS, COPRA, SEAWEEDS, ETC.)
2. FOOD PROCESSING -

   A. CANNING INDUSTRY
   B. CONVERSION OF ORGANIC WASTE TO PROTEIN
   C. LEAF-PROTEIN EXTRACTION

3. AQUACULTURE

   A. ALLIGATOR CROCODILE BREEDING
   B. EEL BREEDING

TABLE 3

MANITO LOWLAND RESOURCE
SUMMARY OF FINDINGS/OBSERVATIONS

1. Geophysical, geochemical and geological evidence is consistent with the Manito Lowlands resource being an outflow from a large, hotter geothermal resource to the southeast.

2. Geothermal fluids similar to those in MO-1 and MO-2 probably underlie much of the Manito Lowlands (Fig. 1).

3. Investigation drilling in the Manito Lowlands has shown that temperatures of 200-220°C can be expected at depths of 600-1200 m (Fig. 2).

4. The two wells drilled both sustain discharge, have an enthalpy of 800-900 kJ/kg and a mass flow of 30-60 kg/s. This is adequate for direct use in many industrial processes.

5. Calciting is likely to be a problem if MO-2 is typical of wells in this area, and if wells are discharged at a low wellhead pressure.

6. Silica deposition from separated fluids from wells like MO-2 is not considered to be a problem above about 90°C because reservoir temperatures, and concentrations of silica are lower than in the more usually encountered high grade type of geothermal resource.

7. MO-1 discharges fluid which is too acidic to be exploited with conventional geothermal engineering. The acid zone may, however, be restricted to certain geological structures and may not influence most of the resource.

8. Delineation of the acid zone, or, more strictly, proving a substantial portion of the resource to have neutral-fluids, will be a major objective of future investigation. Acid conditions in MO-1 have produced a distinctive hydrothermal alteration mineral assemblage which can be easily recognized.

9. The acid nature of fluid produced from MO-1 does not prevent drilling other wells in this area and using them for possible reinjection.

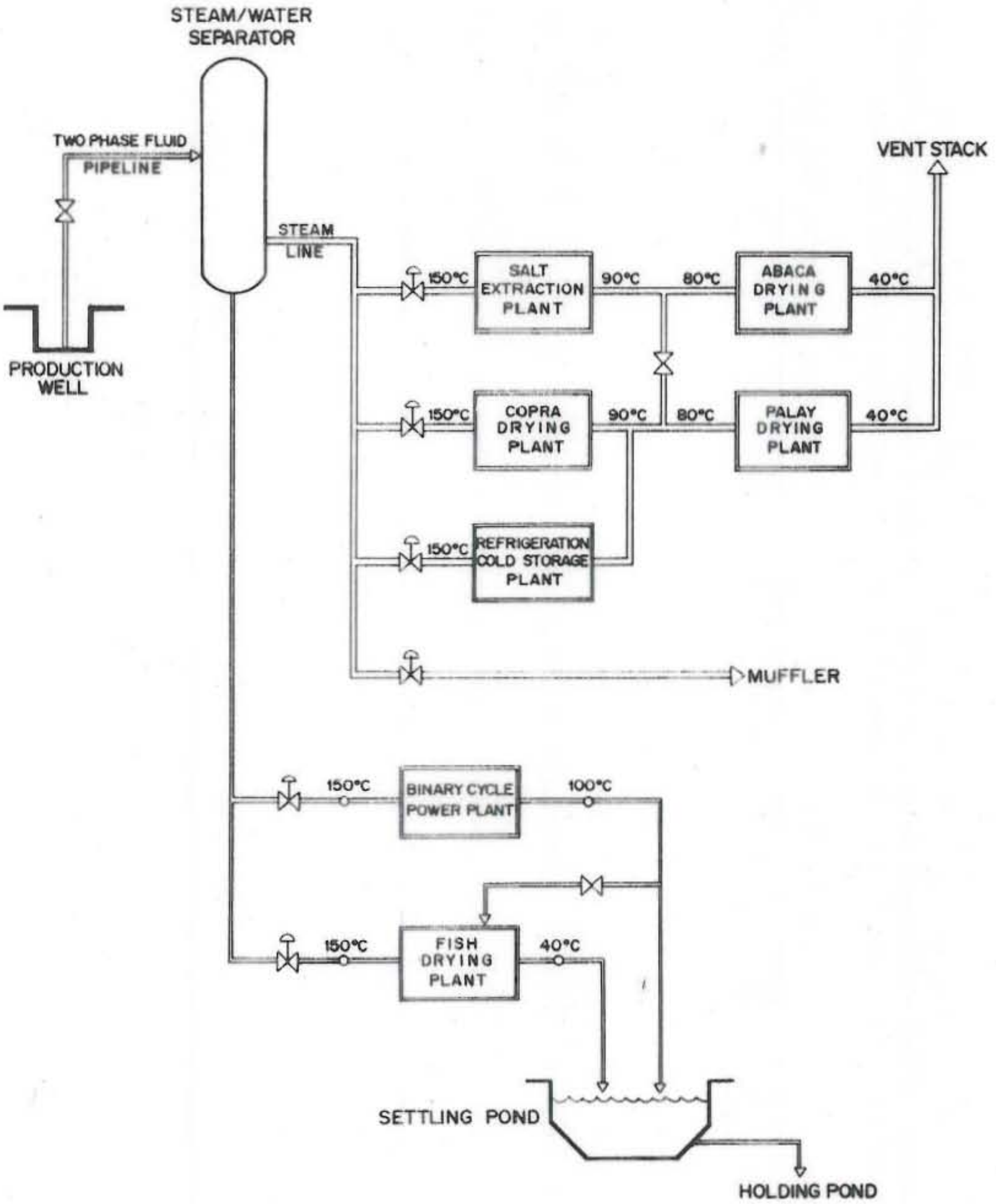
10. Seawater incursion into wells in this area which is close to the coast remains a remote possibility, but has not yet been confirmed.

11. Any resource estimation should include heat-exchanger options as well as flashed-steam exploitation.

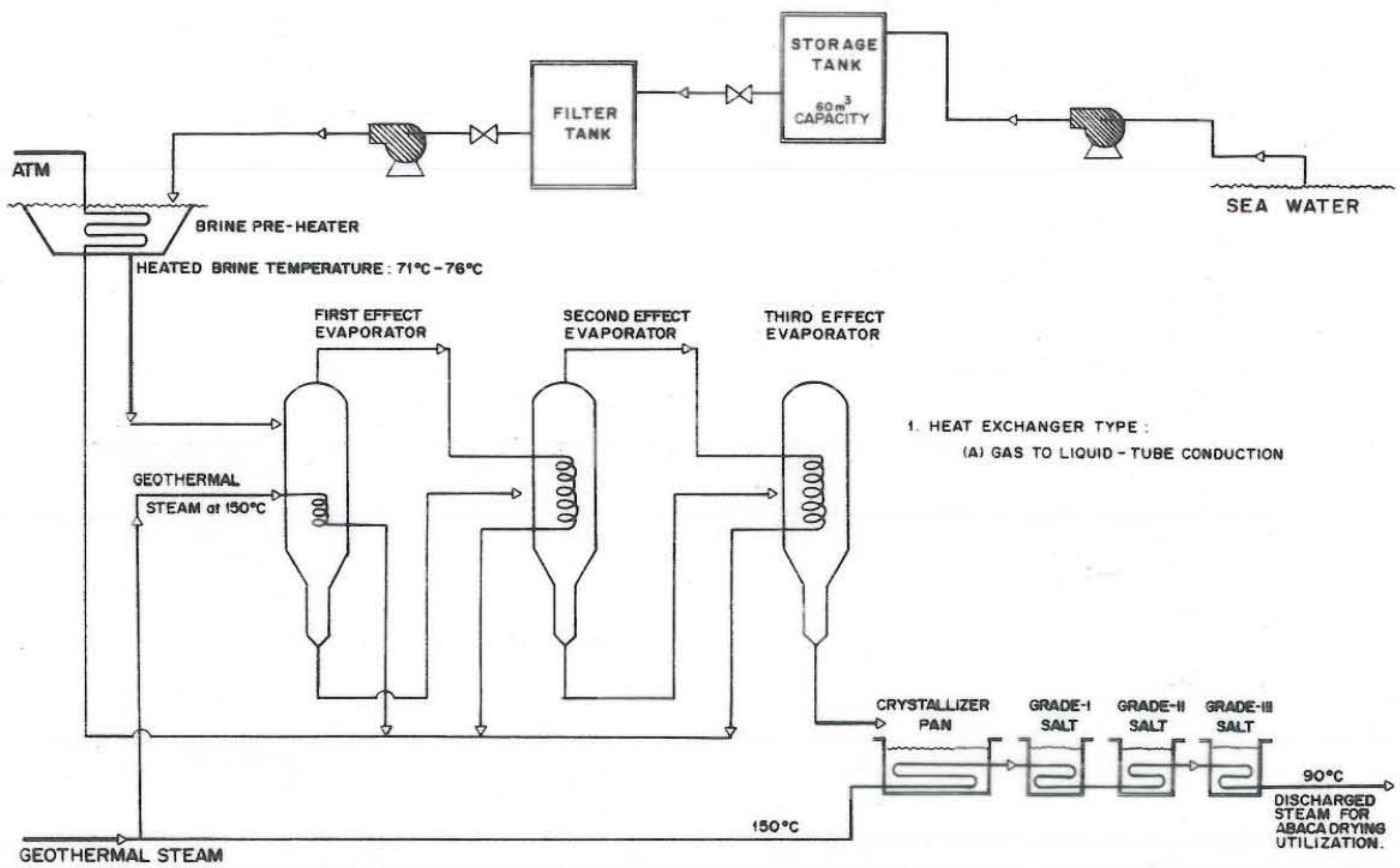
12. Provided that sufficient economic incentive exists for direct use of the geothermal resource, initial indications are that it is worth continuing to investigate the Manito Lowlands area for large-scale industrial development.

WELL DATA AND INTERPRETATIONS OF THE MANITO LOWLAND WELLS

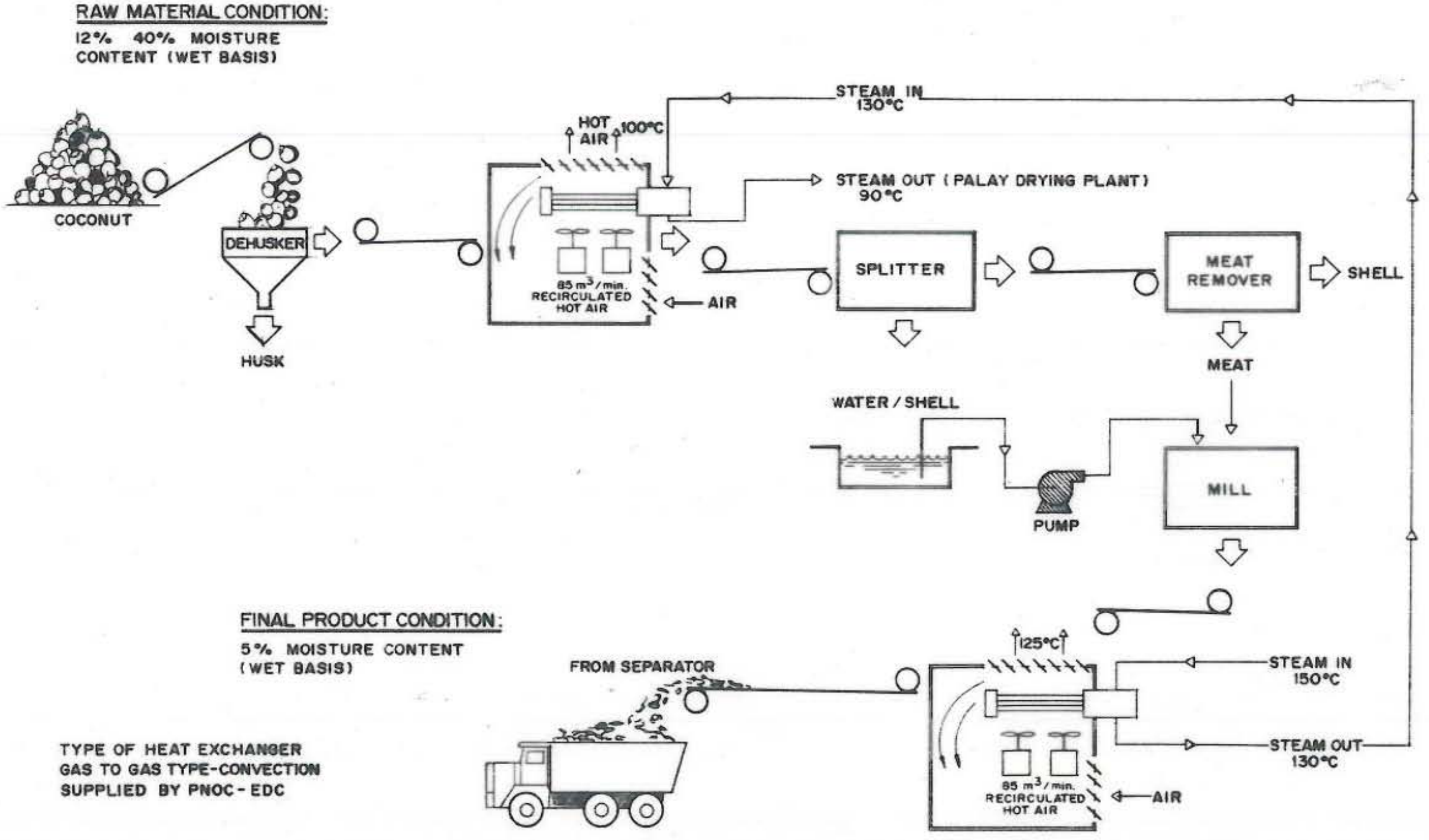
	MO-1	MO-2	MO-3
1. BASIC WELL DATA			
Total Depth	1572.8	1092.0	1200.2
CHF Elevation, mAMSL	78.0	32.5	91.5
CHF Coordinates, mE	598345.1	595818.6	596855.0
mN	1450654.5	1450917.1	1449951.0
Bottom Coordinates, mE			
mN			
Top of Liner	230.8	320.6	361.8
Bottom of Liner	1560.8	1034.0	1196.9
Casing Shoe	264.8	396.0	396.3
Kick-Off Point			
Date Spudded (MMDDYY)	31782	42382	40884
Date Completed	41282	51382	50484
2. PERMEABLE ZONES			
Main Permeable Zone, From	550	900	650
To	800	1000	800
Minor Permeable Zone (1), From	300	500	900
To	400	600	1000
(2), From	1300	400	1100
To	1500	425	1175
(3), From			
To			
(4), From			
To			
3. PERMEABILITY/INJECTIVITY			
Transmissivity (dm)	7.0	13.6	2.4
Injectivity (l/s-MPa)	70.0	78.0	30.5
Skin Factor	-3.0	-3.0	-4.5
4. MID DISCHARGE DATA			
Wellhead Pressure (MPag)	0.87	0.55	0.23
Total Mass Flow (kg/s)	34.0	56.7	17.7
Enthalpy (kj/kg)	990	930	1010
Power Potential ($MW_{thermal}$)	33.66	53.66	17.8
5. MISCELLANEOUS			
A. TEMPERATURE			
Max Measured Temperature (C)	227	217	218
Depth	700	975	700
KT Survey (KT-XXX)	33	46	22
B. BLOCKAGE			
Blockage, Depth			
Composition			
Date (MMDDYY)			
C. PRESSURE CONTROL POINT			
PCP Depth	700	850	700
Pressure (MPag)	5.70	7.50	5.80



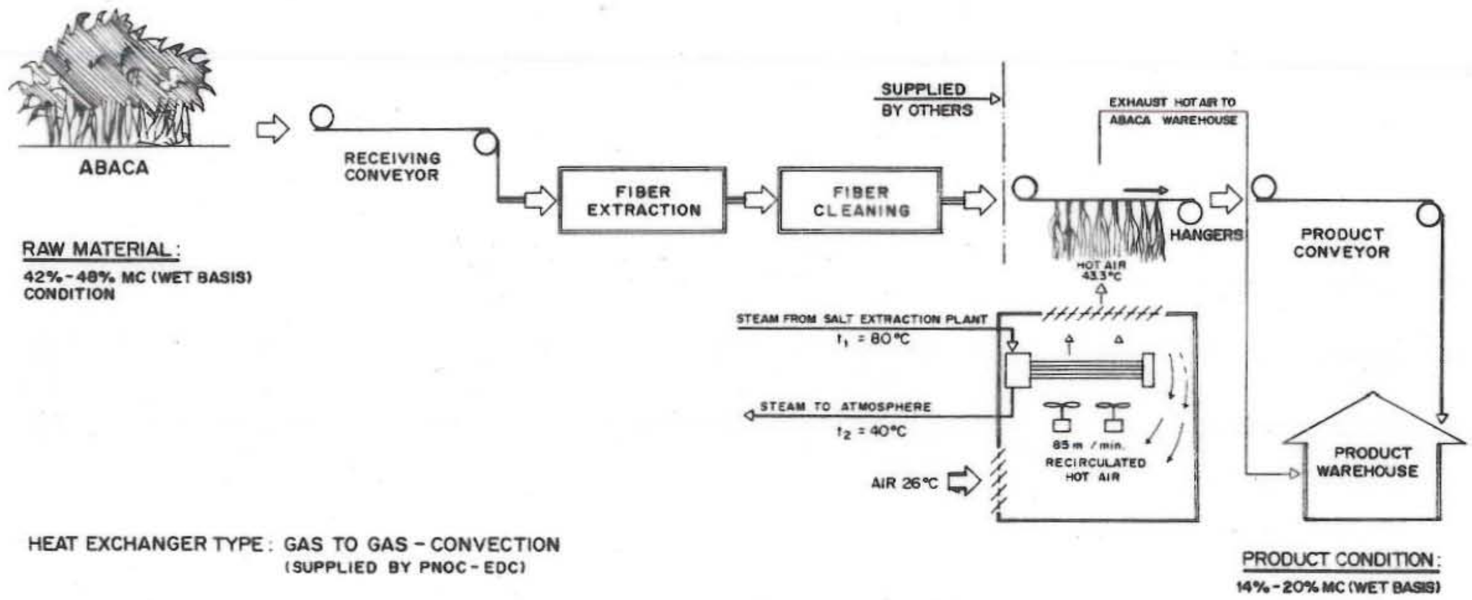
AGROINDUSTRIAL COMPLEX
GEOTHERMAL PROCESS FLOWCHART



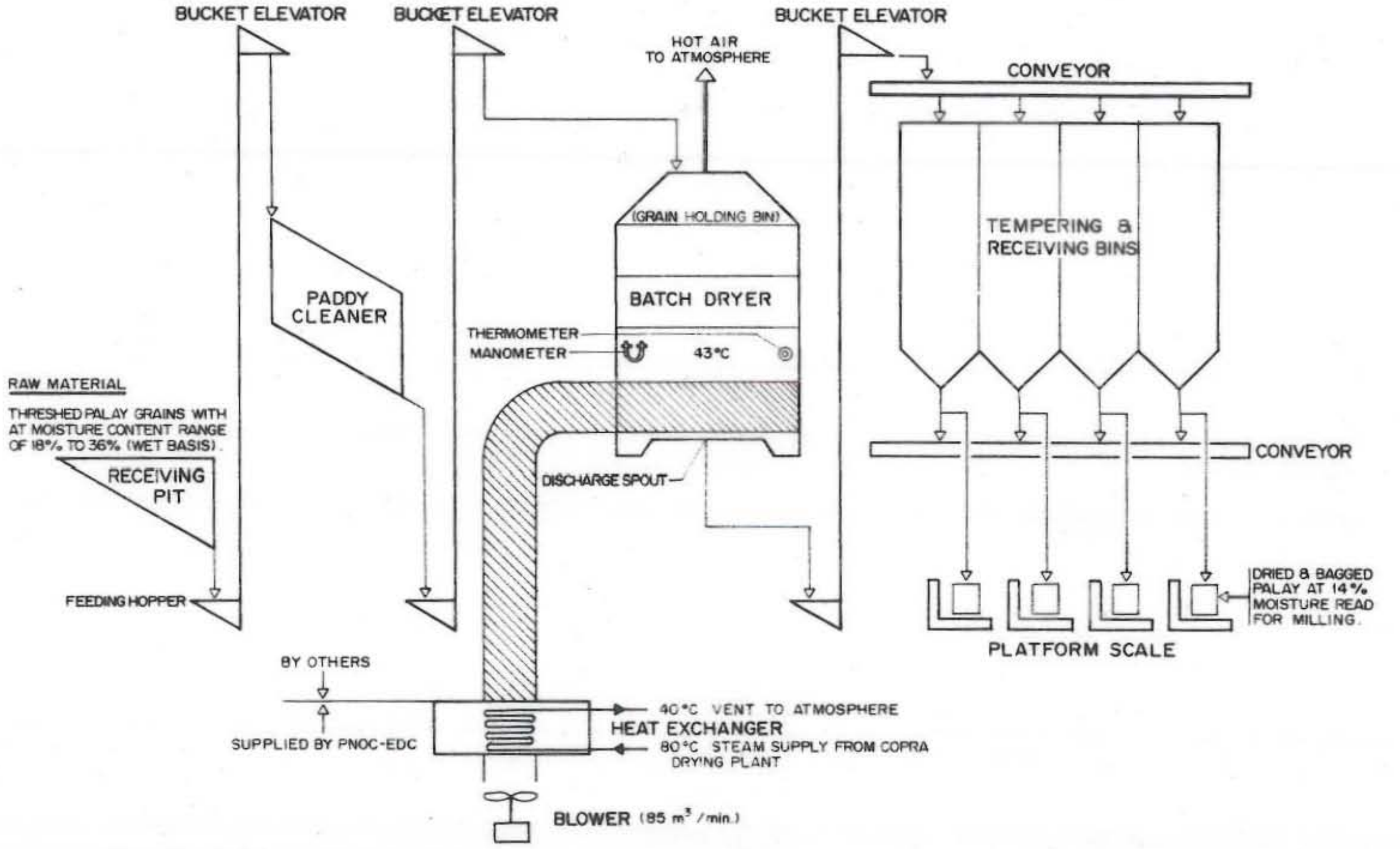
SALT EXTRACTION PLANT
MODEL: 30 TONS/MONTH CAPACITY



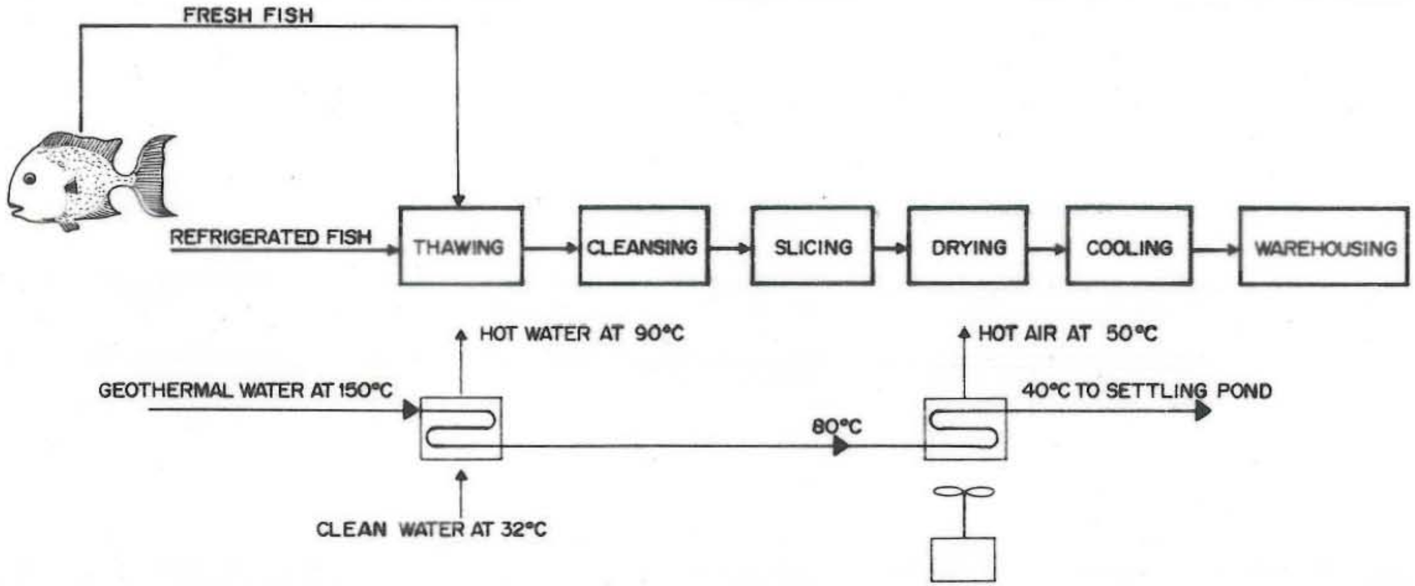
COPRA DRYING PLANT
MODEL: 9,000 NUTS/DAY CAPACITY



ABACA DRYING
MODEL: 10 TONS/MONTH CAPACITY



PALAY DRYING PLANT
MODEL: 60 TONS/MONTH CAPACITY



FISH DRYING PROCESS DIAGRAM
MODEL: 10 TONS/MONTH CAPACITY

STRATEGIES RELATING TO THE EXPLORATION AND DEVELOPMENT OF A GEOTHERMAL FIELD: A CASE FOR BACON-MANITO GEOTHERMAL PROJECT, ALBAY/SORSOGON PROVINCES PHILIPPINES

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INTRODUCTION

Geoscientific investigation of the Bacon-Manito geothermal project by PNOC-Energy Development Corporation (PNOC-EDC) commenced in September, 1977 after it was identified as a geothermal prospect by an earlier survey made by the Philippine Commission on Volcanology (COMVOL), now Philippine Institute of Volcanology and Seismology (PIVS). The geothermal reservation occupies a land area of about 200 sq. km. or 20,000 hectares.

The initial findings were tested with 2 medium-depth exploratory wells, MAN-1 and MAN-2. These wells were located at the upstream region of a broad low resistivity anomaly (Fig. 4) mapped using the Schlumberger resistivity survey (SRS) traversing technique with a fixed electrode spacings of AB/2 equals 250 and 500 m. The wells lacked adequate permeability needed to initiate and sustain flow, but they confirmed the presence of geothermal fluids within a thick section of andesite tuffs and lavas and encouraging temperatures towards the east. Deep vertical soundings (VES) to a maximum AB/2 of 1200 m were undertaken to substantiate these findings.

The first deep exploratory well Cawayan-1 (CN-1) was subsequently drilled in 1981 from a pad about 2 km south-southeast of MAN-2 to confirm the direction of increasing temperature measured from the 2 medium depth wells and to test a likely permeable target inside a 20 ohm-m resistivity

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anomaly in the Cawayan sector of the field. Well CN-1 was drilled blind with water for nearly 1400 m and was later completed to become a very successful well with a maximum down-hole temperature of 270°C at 2400 m CHF and a discharge output equivalent to 11.3 MW of electric power.

Todate, there are 17 wells already completed in the development site for the first 110 MWe BacMan I geothermal power station. Four of these wells are dedicated for rein-jection. Eleven of them were funded using an exploration loan grant from the World Bank.

The power facility is at present in the early design stage. Its capacity will add to the existing 660 MWe geothermal power installation in Luzon and up the nationwide total to 1041 MWe by early 1990.

In 1983, geothermal energy accounted for 7.03 MMBOE of the total energy used in the Philippines for a contribution equiva-lent to 7.14%. By 1984, this share rose to 8.33%, second only to hydrosources which provided 10%. At about this time, the country's dependence on foreign oil had been reduced to 58% from 64.5% in 1983.

INITIAL EXPLORATION STRATEGY

PNOC-EDC's method for initial geothermal exploration is simple and straightforward, developed through years of fruitful experience in Tongonan, Leyte and Palinpinon, Negros Oriental. In those projects, wide-ranging shallow resistivity traversing at fixed electrode spacings of 250 and 500 m was carried-out with reconnaissance to semi-detailed geological mapping and detailed geochemical investigation. Later, a VES survey was made over the promising area.

This strategy was repeated at Bacon-Manito where the prospect, like Tongonan, Palinpinon, Tiwi and Mak-Ban, is closely associated with Plio-Pleistocene andesite volcanoes (Fig. 2, 3 & Table 1). An initial model was developed at the end of the geoscientific surveys showing a possible resource at the upstream region of the broad low resistivity anomaly (Fig. 4) within which are also found hot chloride and sulfate springs. Permeability is thought to be largely due to nearly vertical faults with not-so-predominant north-south and northwest orientations.

Two medium depth exploratory wells were drilled in less than two years after full-scale surface investigations begun. Both wells reached good temperatures, however, they lack the necessary permeability to support production. Well MAN-1 has a temperature of 213°C at 1350 m (CHF) while well MAN-2 to its east has 248°C at 1620 m depth. The results from these wells were nevertheless considered a success in the geoscientific sense.

REASSESSMENT OF THE INITIAL MODEL OF THE RESOURCE

The second major step was to reassess the initial model of the field before any further exploratory drilling is undertaken. Additional resistivity work was needed to supplement the indication of increasing temperature towards the eastern highlands as demonstrated by the two medium depth wells. This additional information further extended the resistivity anomaly to the southeast (Fig. 5), indicating a possible shallow hot water outflow or an alteration zone caused by an outflow in that direction. Resistivity soundings were carried out over the Palayang Bayan sector to check the range of resistivities beneath a pile of young, fresh volcanics composed mainly of andesite lavas and pyroclastics. The sounding sections showed low resistivities beneath a highly resistive layer of 300 to 500 meters thickness.

A new closure (Fig. 5), approximating the premium region of the resource area was drawn inputing the new data and some additional geochemical information on the gas seepages near the east-southeast edge of the closure. In the developed field at Palinpinon in Negros Oriental, manifestations of large, cold gas leakages exhuding CO_2 and H_2S mainly, are found on high grounds, about 1100 m above sea level (ASL), proximate to the upflowing region of the reservoir.

The new model puts exploratory well MAN-2 almost at the center of the postulated upflow. Three deep exploratory wells were drilled between September 1981 and March 1983 to test the model. The distribution of the wells with respect to the postulated center of the resource was considered already adequate to test for the suspected center, and the two suggested outflow directions (Fig. 5). These wells are Puting-Bato-1A (PB-1A), Cawayan-1 (CN-1) and Inang Maharang-1 (IM-1). Well CN-1 was drilled first and on completion, turned out to be the discovery well of the resource. The well built up pressure after a few days then allowed to discharge by itself. Medium term testing placed the capacity of the well at 11.3 MWe. This well seems to have intersected a hot outflow in the east-southeast direction. Well IM-1, on the other hand, flowed at a rate 5.5 MWe and proved the outflow to the northerly direction.

Well PB-1A, which was thought to be at the center of the anticipated resource, was impermeable and colder than CN-1 (Fig. 6).

WHERE IS THE UPFLOW REGION?

The result from the 3 deep exploratory wells point to an area farther east of well CN-1 as the possible upflow region. However, further fine-tuning of available geoscientific data with substantial detailing work in the field must be done, specifically at Palayang Bayan plateau, north and northeast of CN-1, before any follow-up deep exploratory drilling can be undertaken. More VES measurements and detailed geological mapping were done in and around the plateau area after which a pre-feasibility study was made.

The pre-feasibility report presented by PNOC-EDC and KRTA concluded that the wells so far drilled have confirmed the existence of an extensive hydrothermal convection system with temperatures of at least 270°C and possibly higher. Subsurface temperature distribution, together with inferences from the pattern of both shallow and deep resistivities strongly suggest that an exploitable resource extends to the north and east of well CN-1 with possible continuation to a lesser degree to the west and south.

The report recommended further exploration/delineation drilling to confirm that the resource can support a 110-MWe development. The new set of drilling targets were Palayang Bayan-1 (PAL-1), PAL-2D, PAL-3D and PAL-4D (Fig. 7) and are distributed to the NE and NW of the highly successful well CN-1 beyond the so-called Cawayan topographic divide. Development south of this divide around CN-1 was negated by what environmental scientists of PNOC-EDC see as serious foreseeable repercussions to the ecology of the Cawayan catchment and the downstream users of the river if further roadwork and disposal of geothermal effluent are carried out inside the catchment area.

DELINEATE THE RESOURCE

The exploration/delineation drilling program went ahead to drill 6 wells, 5 of which were directional wells. Except for PAL-6D, these wells have demonstrated acceptable productive capacity during long term testing (Tables 2 and 3). Drilling strategy proceeded with an easterly bias, towards the area of Pliocene to Pleistocene volcanic cones near the center of the revised closure, C-3 (Fig. 7 & 8). This stage of the program was culminated by a Feasibility Report which estimated the recoverable energy equivalenet to be about 7140 MWe-years for the exploitable area, considering the constraints imposed by the severe topography and the reach of the biggest rig of PNOC Energy Drilling Inc., capacity 6000 m for vertical drilling. In terms of a 25-year plant life, this corresponds to an electrical output equivalent of approximately 160 MWe (Fig. 8a).

The report proposed 2 principal 2-phase pipeline corridors, one along the Masakrot ridge where PAL-5D is located and another on the floor of the Gayong river valley (Fig. 9). Water disposal is to take place by reinjection in 2 sectors, following the philosophy of deep and dispersed reinjection applied to the Palinpinon field in Negros Oriental.

BEAT THE ECONOMIC WOES

Production and delineation drilling carefully went hand in hand with two rigs operating on funds from an exploration loan from the World Bank. This loan was committed to fund the drilling of 11 delineation/production wells, starting with PAL-1, for an amount of about US$16 million.

Well PAL-8D, a long directional well thrown to the east under Mt. Pangas, a Pleistocene volcanic edifice, produced a power potential of 15.7 MWe, the largest well in the field, so far (Fig. 8). This big success validated the proposed easterly bias of development and became the reason for changing the early conceptual design of a 2-main pipeline steam gathering system to a single pipeline system totally dependent on the eastern wells to be accessed from pads C, H and E at the head of the Gayong river valley (Fig. 10-13).

MAJOR OBSTACLE TO THE DEVELOPMENT PLAN

Present capacity from 11 tested production wells to be hooked-up to the system is 76.3 MWe. The combined injection capacity of the 4 drilled reinjection wells is 420 kg/s. The system when completed will utilize a total of 18 production wells and 6 reinjection wells including one well for condensate disposal.

Production from wells PAL-9D, 10D and 11D, all biased to the east towards the center of the revised and upgraded geo-scientific closure, C-3, did not come close to PAL-8D in terms of production capacity. Well PAL-10D is hot (Table 2), in fact the hottest of the drilled wells todate at a maximum downhole temperature of 326°C, however, its production capacity is only moderate at 5.6 MWe. PAL-11D, after sometime of on-and-off testing, stayed at 7.7 MWe and PAL-9D at 3.0 MWe. This means the balance of the production wells to be collared from pads E and H may not meet the design criterion of 8 MWe average per well. What went wrong?

The strong possibility of completing low capacity production wells to fulfill the balance of the steam supply requirement of BacMan I is presently a subject of a thorough investigation by in-house specialists of PNOC-EDC. The geologists have suggested lines of evidences which taken together present a strong case for a cauldron or caldera environment at BacMan (Fig. 14, 15). This brings to light the experience undergone by UNOCAL in their Baca project situated in the Valles caldera of New Mexico. The principal parties mutually agreed in 1982 to terminate the project when difficulty in obtaining the expected steam rate from new production wells was encountered inspite of early successes. The reservoir definition and drilling problems met by UNOCAL are somehow similar to those facing BacMan today. The Baca Report also mentioned that the Comission Federal de Electricidad of Mexico is experiencing some of the same problems in developing a geothermal system in La Primavera caldera, which is geologically akin to the Valles caldera. It would seem, therefore, that there are certain inherent difficulties in developing a geothermal prospect in this kind of geologic environment.

THE FUTURE IS STILL BRIGHT

For the BacMan development to successfully proceed, there is an urgent and imperative need to establish a logical and verifiable geological explanation for the reservoir. The pursuit of the following measures is underscored:

(1) It is important in the finalization of the developmental strategy that exploration targets for wells PAL-12D and 13D be attained. All effort is, therefore, to be exerted to overcome drilling difficulties so that targets of future wells can be reached and tested. Accurate definition of these targets is necessary if a logical and verifiable geological explanation for the reservoir is to be developed.

(2) If drilling difficulties due to collapsing formations above the production depth prove to be unsurmountable under present day state-of-the-art on drilling practices, other sections of the resource area previously proven must be considered for development. This means drilling a limited number of wells to the east and going back to the original engineering design of using 2 main 2-phase lines, one along Masakrot ridge and another along Gayong valley floor (Fig. 9). Drilling to the south and southeast from pads at Masakrot is expected to be less problematic although this may result in more production wells to compensate for the lower production anticipated from the Masakrot area. Planners predict an average of 5 MWe per well for this sector of the field.

Wells PAL-12D and 13D were completed and tested before the end of 1985. The principal geological targets were reached by the wells, their production exceeding the 8-MWe average expected from the block with PAL-12D being rated at 12.3 MWe and PAL-13D at 9.4 MWe. At the start of 1986, a full-scale testing of the production wells scheduled for hook-up to BacMan I will be undertaken for a period of 6 months, after which the last stage of development drilling will resume. The objectives of this testing program are three-fold, viz:

(1) Approximate the stable discharge state of the boreholes.
(2) Verify the extent of the gas-rich zones observed in some of the production wells.
(3) Test the effects of the known acid zones in some of the wells during long-term production.

CONCLUDING STATEMENT

PNOC-EDC is forging ahead with the development of the BacMan field fully aware of the problems which look unique to the project. Tongonan and Palinpinon were both free of the difficulty brought about by the sloughing characteristics of pyroclastic rocks in BacMan. More often than not, this problem prevents the drilling engineers from reaching the geological targets of each hole. Then the definition of the geology of the geothermal reservoir suffers accordingly.

The success of wells PAL-12D and 13D has temporarily set aside the Masakrot option, however, PNOC-EDC strategists still look at it as a very viable reserve in case something goes wrong with some of the easterly wells during exploitation.

In the middle of 1986, PNOC-EDC will drill 2 deep exploratory wells at the eastern side of Mt. Pangas which is also the eastern half of the geoscientific closure, C-3, of the BacMan geothermal field. The success of this Stage II exploration program in BacMan will usher the development of a potential second 110-MWe power facility for the Luzon grid in the next 7 years or so.

PNOC-EDC is a young company. In less than 10 years though, it has put up two major operating geothermal fields in the country, namely, Tongonan and Palinpinon, and managed in the process to build a technical staff of highly experienced geo-scientists, engineers and technicians totalling to about 300 people. PNOC-EDC has relied almost wholly on this pool of trained and experienced staff to bring the Bacon-Manito project to its present stage, four years away from the scheduled commissioning of the first 110-MWe BacMan I geothermal power plant in January 1990.

ACKNOWLEDGMENTS

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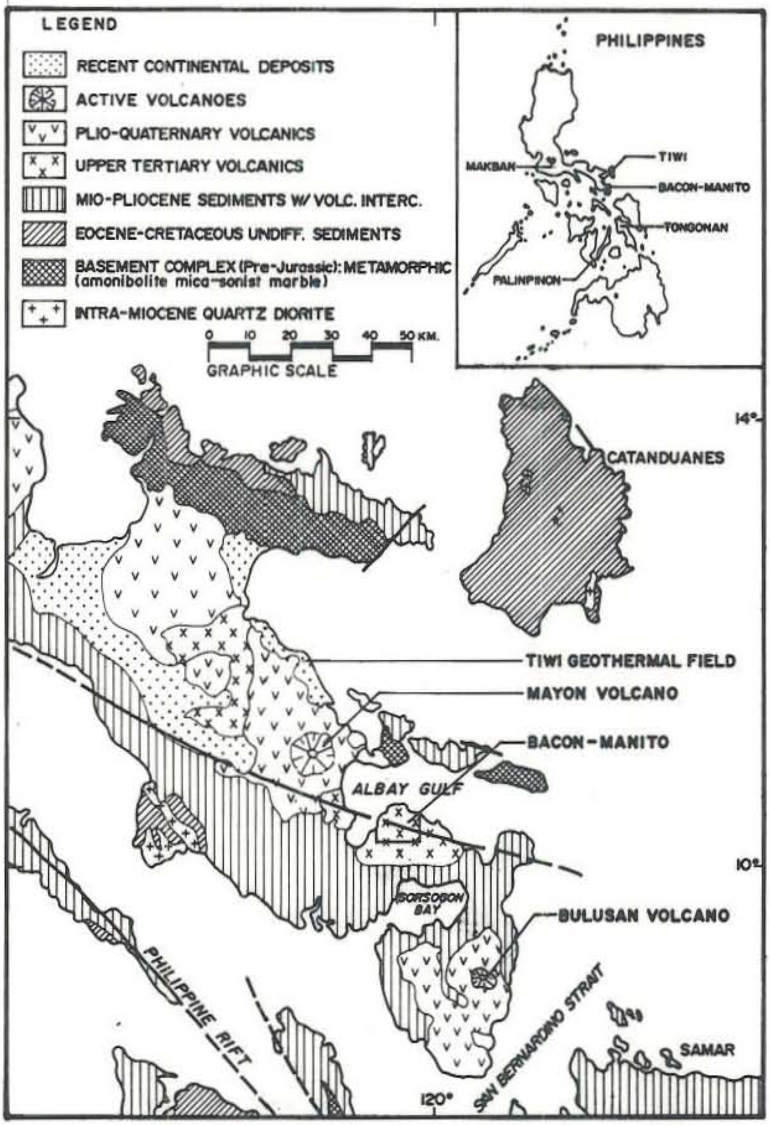


FIG. 1 REGIONAL GEOLOGIC SKETCH MAP

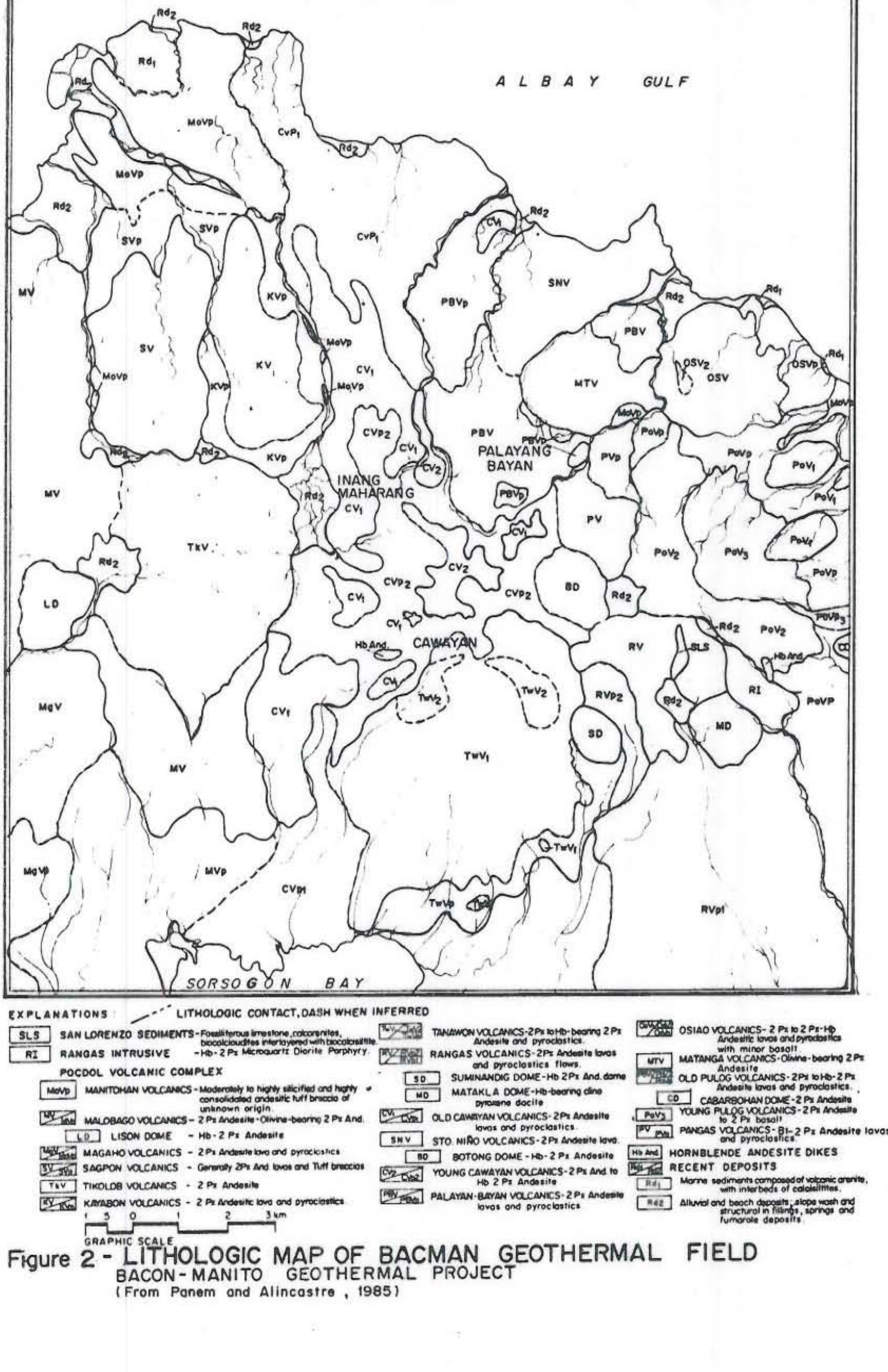
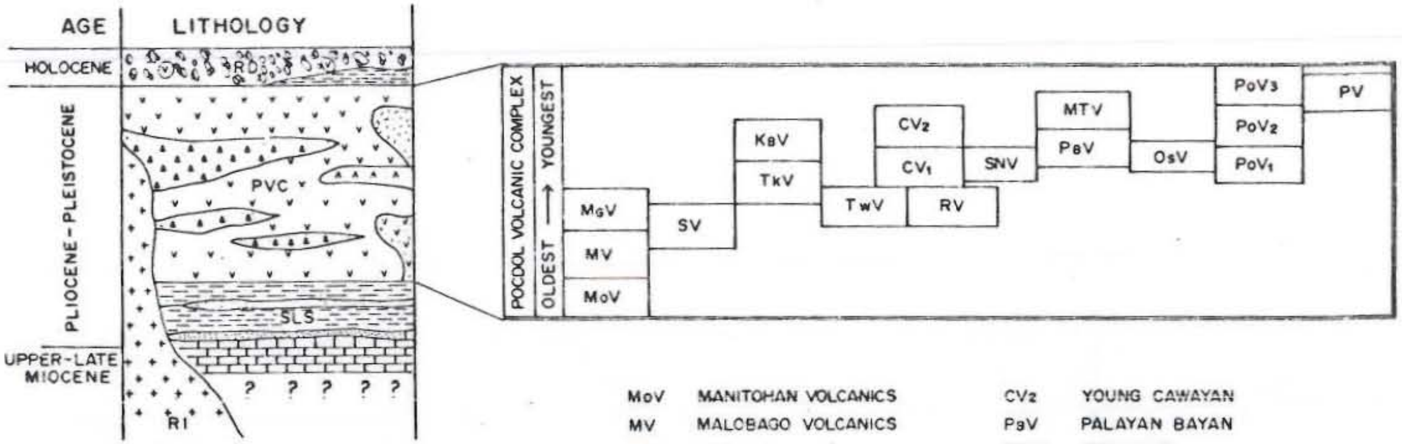


Figure 2 - LITHOLOGIC MAP OF BACMAN GEOTHERMAL FIELD
BACON-MANITO GEOTHERMAL PROJECT
(From Panem and Alincastre, 1985)



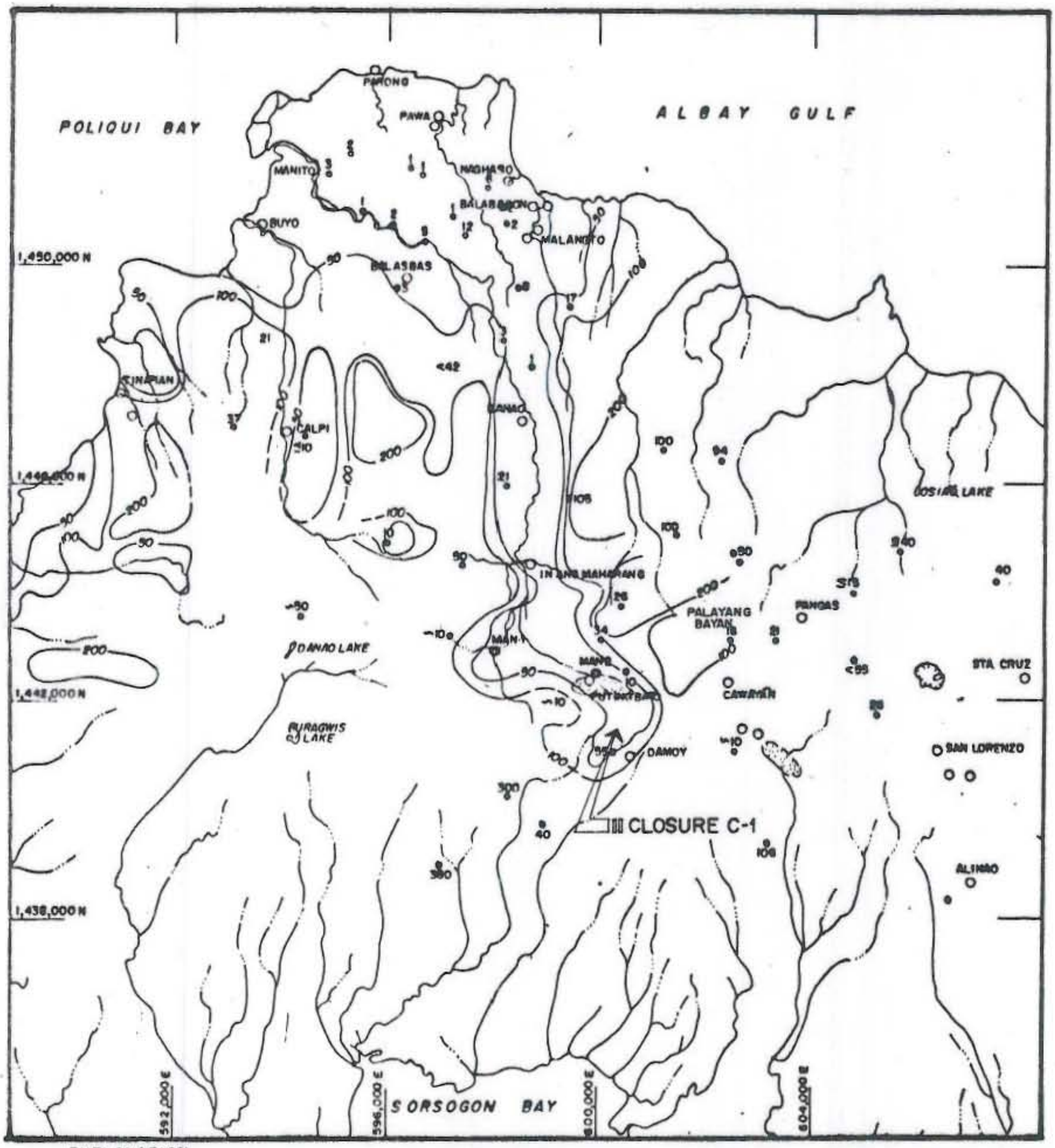
SLS	SAN LORENZO SEDIMENTS
PVC	POCDOL VOLCANIC COMPLEX
RI	RANGAS INTRUSIVE
RD	RECENT DEPOSITS

MoV	MANITOHAN VOLCANICS	CV2	YOUNG CAWAYAN
MV	MALOBAGO VOLCANICS	PaV	PALAYAN BAYAN
MgV	MAGAHO	SNV	STO. NINO
SV	SAGPON	OsV	OSIAO
TkV	TIKOLOB	MTV	MATANGA
KaV	KAYABON	PoV1	OLD PULOG
TwV	TANAWON	PoV2	MIDDLE PULOG
RV	RANGAS	PoV3	YOUNG PULOG
CV1	OLD CAWAYAN	PV	PANGAS

Figure 3 GENERALIZED STRATIGRAPHIC COLUMN
BACON - MANITO GEOTHERMAL PROJECT
(From- Panem and Alincastre , 1985)

	SYMBOL	DEFINITION	DESCRIPTION OF UNIT
	Rd_2	Recent Deposit	Alluvial and beach deposits, slope wash and structural in-fillings, springs and fumarole deposits.
	Rd_1	Recent Deposit	Marine sediments composed of volcanic arenite, with interbeds of calcisiltites.
		PRODUCT OF WHICH VOLCANIC CENTER	
POCDOL VOLCANIC COMPLEX	PV/PVp	Pangas	Lavas and pyroclastics of younger eruptive centers with still preserved vents and/or well-defined crater. Also with active solfataric activity within crater, i.e., Pangas. Little alteration observed on rocks. Composition varies from two-pyroxene basaltic andesite to two-pyroxene andesite with occasional occurrence of olivine and hornblende.
	PoV_3/PoVp	Young Pulog	
	MTV	Matanga	
	OSV_2	Young Osiao	
	PBV/PBVp	Palayang Bayan	
	CV_2/CVp_2	Young Cawayan	
	OSV_1	Old Osiao	Lavas and pyroclastics of moderately dissected, eroded volcanic crater with noted hydrothermal activity still present at Cawayan. Generally, two-pyroxene andesite in composition with occasional occurrence of hornblende andesite.
	PoV_2 PoV_1 PoVp	Old Pulog	
	CV_1/CVp_1	Old Cawayan	
	SnV	Sto. Niño	
	KV/KVp	Kayabon	Lavas and pyroclastics of moderately dissected and eroded volcanic vents which are usually occupied by volcanic plugs. Locally hydrothermal altered. Composition varies from two-pyroxene andesite to hornblende-bearing two-pyroxene andesite.
	TkV	Tikolob	
	RV RVp_1 RVp_2	Rangas	
	TwV_2 TwV_1 TwVp	Tanawon	
	SV/SVp	Sagpon	
	MgV/MgVp	Magaho	
	MV/MVp	Malobago	Lavas and pyroclastics of deeply dissected, eroded volcanic center. Locally altered with composition range from 2-px to olivine-bearing 2-px andesite
	MoVp	Unknown	Moderately to highly altered tuff breccias of unknown origin.
	SLS	San Lorenzo Sediments	Fossiliferous limestone, calcarenite, biocalcirudites interlayered with biocalcisiltites.
	RI	Rangas Intrusive	Hb-two-pyroxene MicroQuartz Diorite Porphyry.

TABLE 1. STRATIGRAPHY OF BACON-MANITO GEOTHERMAL FIELD
(from Panem and Alincastre, 1985)



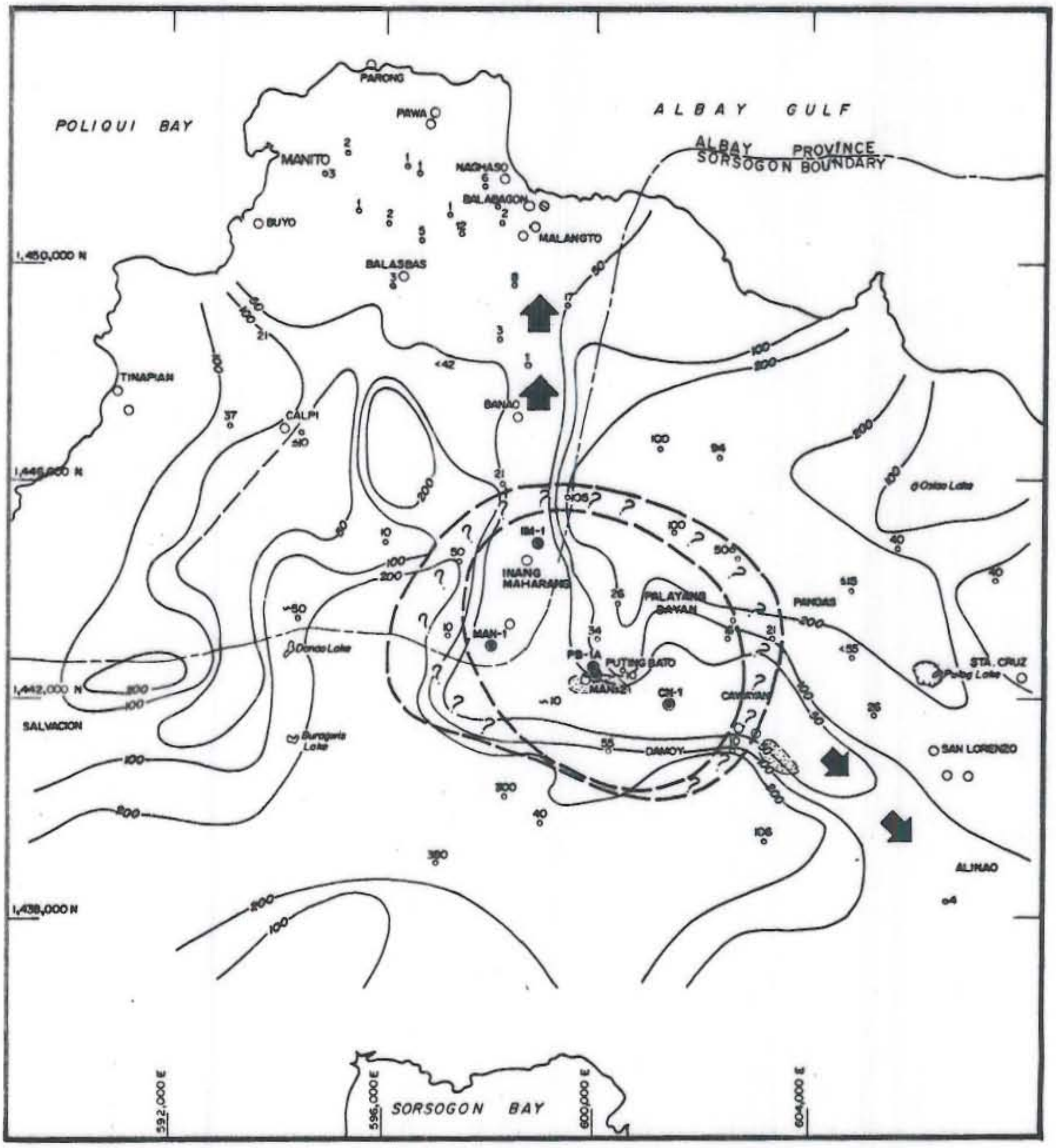
EXPLANATION

- SOUNDING STATION & VALUES
- HOT SPRING
- ALTERED GROUND
- APPARENT ISO-RESISTIVITY (Ωm) AT AB/2 = 500m.
- DRILLED WELLS

FIG. 4 INITIAL ISO-RESISTIVITY MAP OF BACON-MANITO PROJECT WITH PROVISIONAL FIELD CLOSURE C-1

1 .5 0 1 2 3 4 KM.

GRAPHIC SCALE
(After Vergara, 1979)



EXPLANATION:

- ◦ SOUNDING STATION
- 10 "TRUE" RESISTIVITY VALUE AT BOTTOM
- —50— APPARENT ISORESISTIVITY (Ω m) AT AB/2=500 m
- ○ HOT SPRING
- ● DRILLED WELLS
- ➡ DIRECTION OF OUTFLOW

GRAPHIC SCALE (0 .5 1 2 3 4 Km)

Figure 5. PROVISIONAL FIELD CLOSURE C-2
BACON-MANITO GEOTHERMAL PROJECT

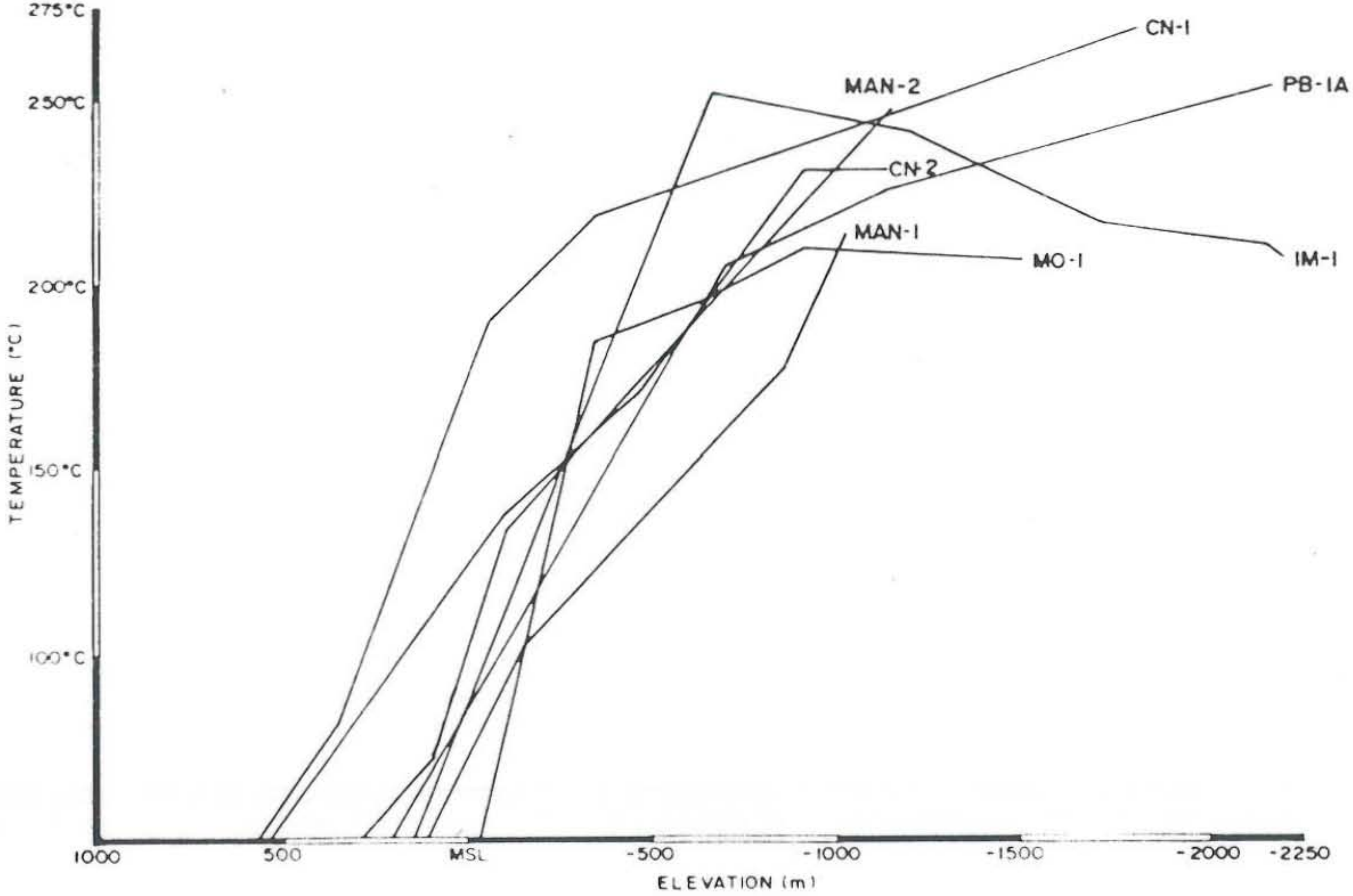


FIG. 6. ESTIMATED STABLE FORMATION TEMPERATURES
BACON – MANITO GEOTHERMAL PROJECT
(PNOC-EDC / KRTA Report, 1982)

Table 2. BASIC WELL DATA*

Well Classification	Well	(MPag) WHP	H kj/kg	MF (kg/s)	Dryness	MWe**	Injectivity (l/s-MPa)	Total Depth mVD	Max. Measured Temp (°C)
I. BACMAN I Use									
A. Production	PAL-1	0.70	1140	44.7	0.21	3.8	32.0	2480.4	281
	PAL-2D	0.80	1520	37.9	0.40	6.0	26.0	2707.6	293
	PAL-3D	0.74	1330	52.1	0.31	6.4	15.0	2154.0	285
	PAL-4D	0.54	1450	35.2	0.33	4.7	11.0	2641.1	307
	PAL-7D	0.45	1330	22.9	0.27	2.5	9.4	2153.2	277
	PAL-8D	0.98	1680	82.4	0.48	15.7	147.0	2973.0	313
	PAL-9D	0.65	1320	29.2	0.30	3.5	17.2	2409.3	280
	PAL-10D	1.10	1470	37.3	0.37	5.6	31.3	2485.1	325
	PAL-11D	1.50	2044	29.5	0.65	7.7	22.4	1492.0	270
	PAL-12D	0.96	1350	98.0	0.31	12.3	84.0	2117.5	298
	PAL-13D	0.72	1465	65.4	0.36	9.4	41.5	2326.2	316
B. Reinjection	PAL-1RD						61.5	1852.0	260
	PAL-2RD						11.5	1517.9	275
	PAL-3RD						16.2	2103.5	271
	PAL-4RD						15.6	1993.1	217
II. Exploration	MAN-1	0.00	-	00.0	-	0.0	5.0	1367.8	214
	MAN-2	0.00	-	00.0	-	0.0	11.0	1636.7	248
	CN-1	0.71	1280	99.5	0.28	11.3	100.0	2553.1	271
	CN-2D	0.43	1120	9.5	-	NC	10.0	1708.1	246
	IM-1	0.73	1050	76.5	0.17	5.2	32.0	2583.0	252
	PB-1A	0.00	-	0.0	-	0.0	8.5	2662.1	255
	PAL-5D	0.65	1190	48.7	0.24	4.6	20.0	2761.6	270
	PAL-6D	0.22	1560	10.2	-	NC	11.0	2833.9	286
III. For Direct Application	MO-1	0.87	990	34.0	0.14	1.9	70.0	1572.8	227
	MO-2	0.55	930	56.7	0.11	2.6	78.0	1092.0	217
	MO-3	0.23	1010	17.7	-	NC	30.5	1200.2	218

*As of February 28, 1986; Source - Production Section

**Corrected for gas; based on 0.70 MPag separation pressure and 2.5 kg/s of steam/MWe

NC - Non-commercial output

Table 3. BASIC WELL CHEMISTRY DATA*

Well Classification	Well	pH	Cl ppm	NCG (% wt @ 0.70 MPag)
I. BACMAN I Use				
A. Production	PAL-1	7.8	8320	1.7 - 1.9
	PAL-2D	7.0	8730	5.5 -10.1
	PAL-3D	8.1	9230	1.0 - 1.2
	PAL-4D	7.7	9545	2.8 - 3.4
	PAL-7D	7.3	8960	1.9 - 2.0
	PAL-8D	7.5	13030	4.2 - 4.3
	PAL-9D	7.5	9360	1.3 - 1.4
	PAL-10D**	7.7	9160	4.9 - 5.0
	PAL-11D	Discharge chemistry not yet stable		
	PAL-12D	7.7	10580	2.5
	PAL-13D	7.2	10610	5.1 - 5.2
B. Reinjection	PAL-1RD	7.9	8280	0.8
	PAL-2RD	Unable to discharge		
	PAL-3RD	Unable to discharge		
	PAL-4RD	Unable to discharge		
II. Exploration	MAN-1	Unable to discharge		
	MAN-2	Unable to discharge		
	CN-1	7.7	8690	0.5 - 0.6
	CN-2D	Acidic discharge		
	IM-1	7.9	8090	0.6
	PB-1A	Unable to discharge		
	PAL-5D	7.9	8090	0.4 - 0.5
	PAL-6D	Non-commercial		
III. For Direct Application	MO-1	3.1	8120	0.6
	MO-2	7.8	7520	0.8
	MO-3	Acidic discharge		

*As of February 1, 1986

**Water samples collected from reinjection line under pressure using webre separator; all others were from the weirbox

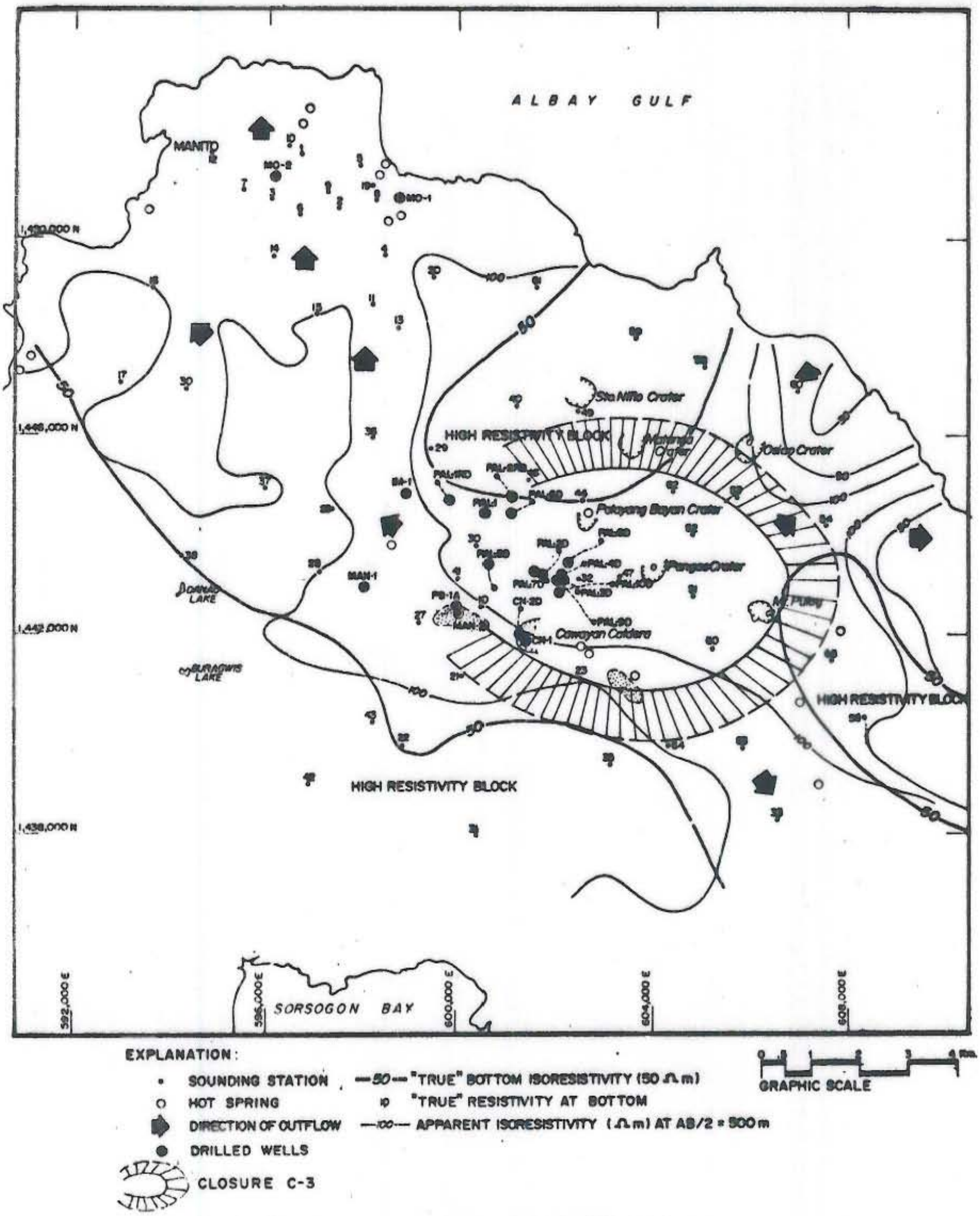
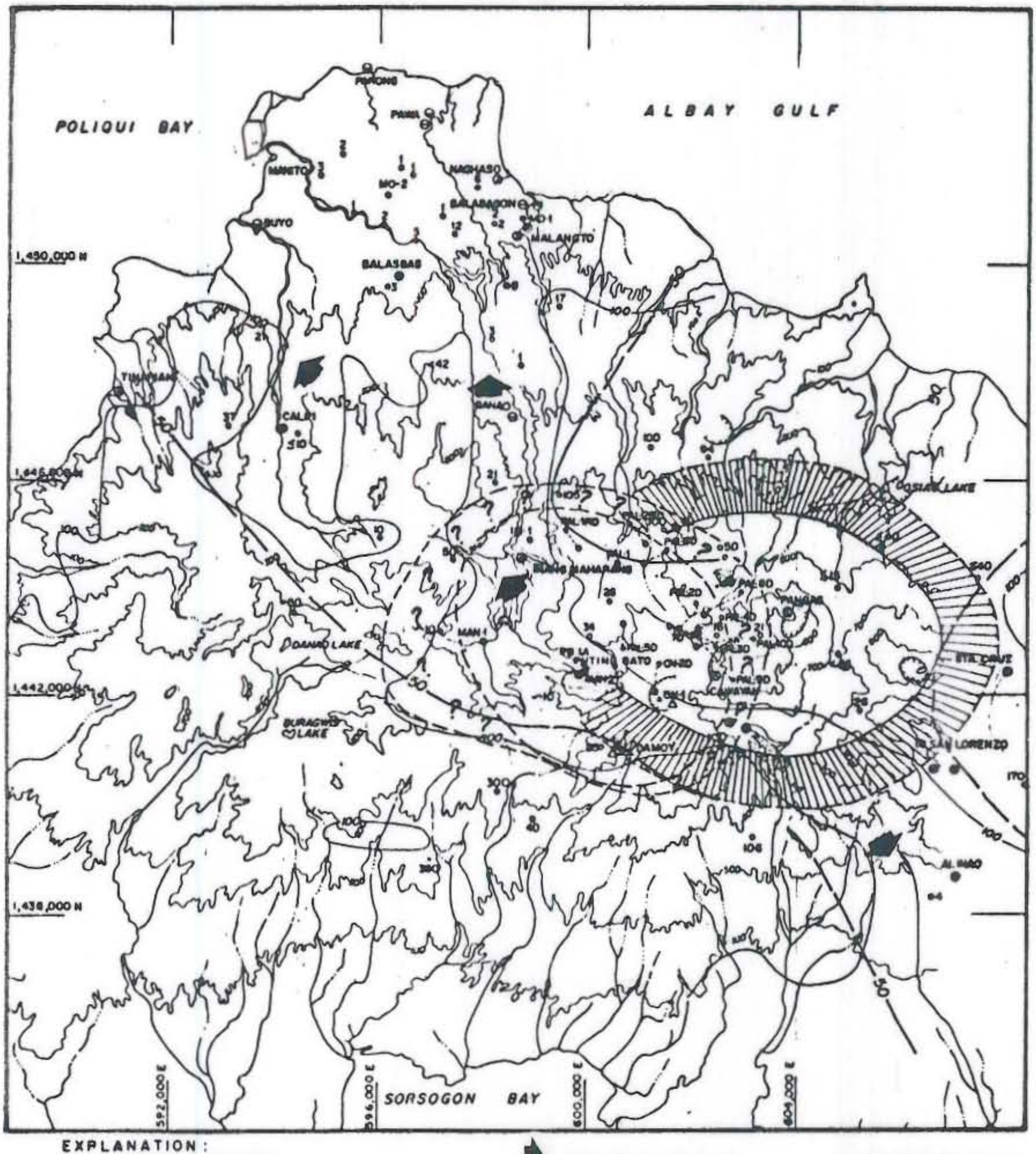


Figure 7. PROVISIONAL FIELD CLOSURE C-3
BACON-MANITO GEOTHERMAL PROJECT



EXPLANATION:

- SOUNDING STATION
- "TRUE" RESISTIVITY VALUE AT BOTTOM
- "TRUE" BOTTOM ISO-RESISTIVITY (in Ω m)
- APPARENT ISO-RESISTIVITY (Ω m) AT AB/2=500 M.
- CLOSURE C-2
- CLOSURE C-3
- DIRECTION OF OUTFLOW
- ACID SULFATE SPRING
- ACID CHLORIDE-SULFATE SPRING
- NEUTRAL Na-SO_4-HCO_3 SPRING
- NEUTRAL CHLORIDE SPRING
- BICARBONATE SPRING
- SOLFATARA
- ALTERED GROUND
- CRATER

1 .5 0 1 2 3 4 KM.

GRAPHIC SCALE

FIG. 8. COMPOSITE MAP OF BACON-MANITO PROJECT

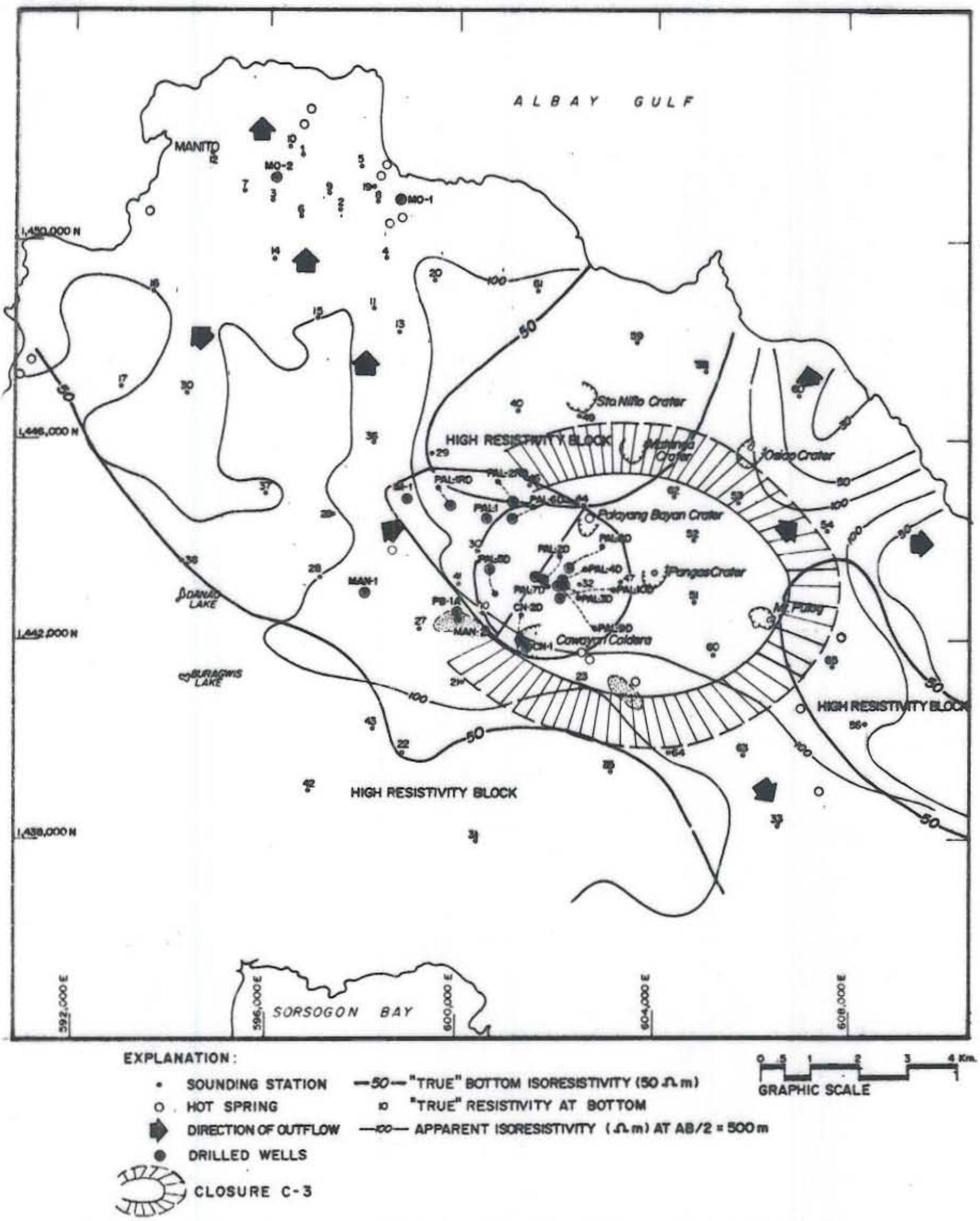


Fig. 8a. RESOURCE AREA DEDICATED TO BAC-MAN I DEVELOPMENT INSIDE PROVISIONAL FIELD CLOSURE C-3
BACON-MANITO GEOTHERMAL PROJECT

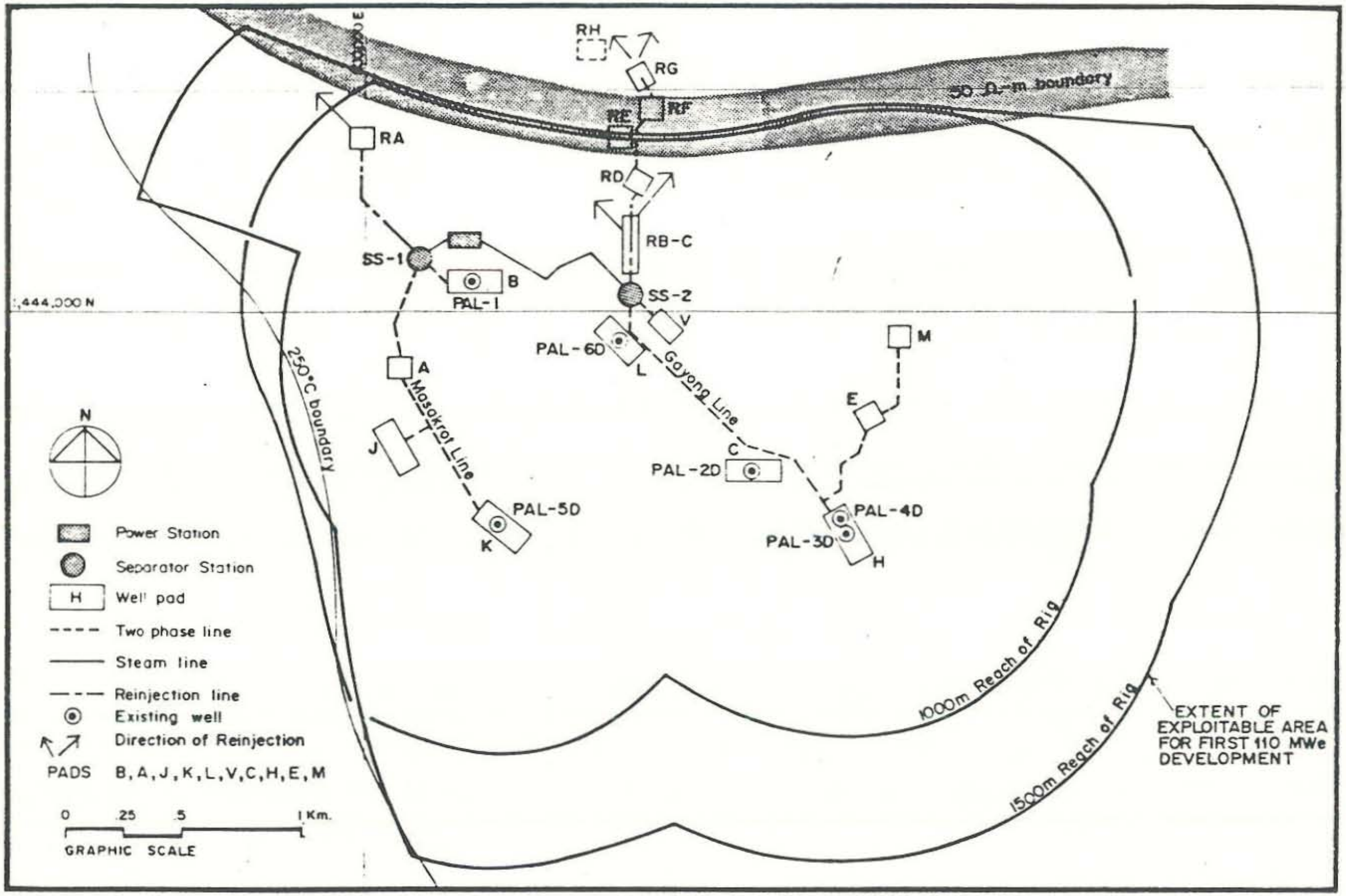


FIGURE 9. MASAKROT, GAYONG, OSIAO RIDGE, PALAYANG BAYAN SECTOR
BACON - MANITO GEOTHERMAL PROJECT
(After PNOC-EDC / KRTA Report, 1982)

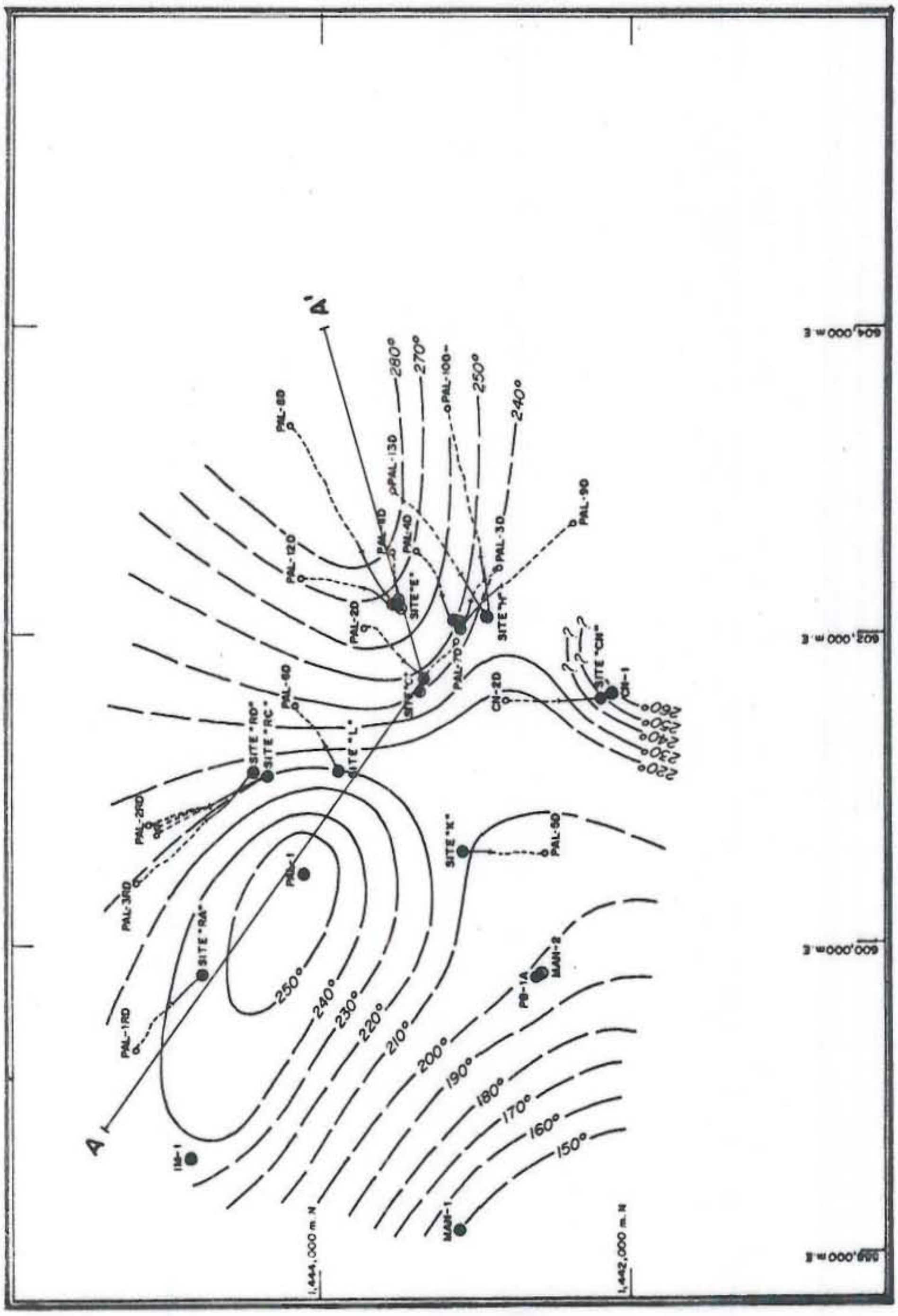


Fig. 10. TEMPERATURE CONTOURS AT LEVEL - 600 m.
BACON - MANITO GEOTHERMAL PROJECT

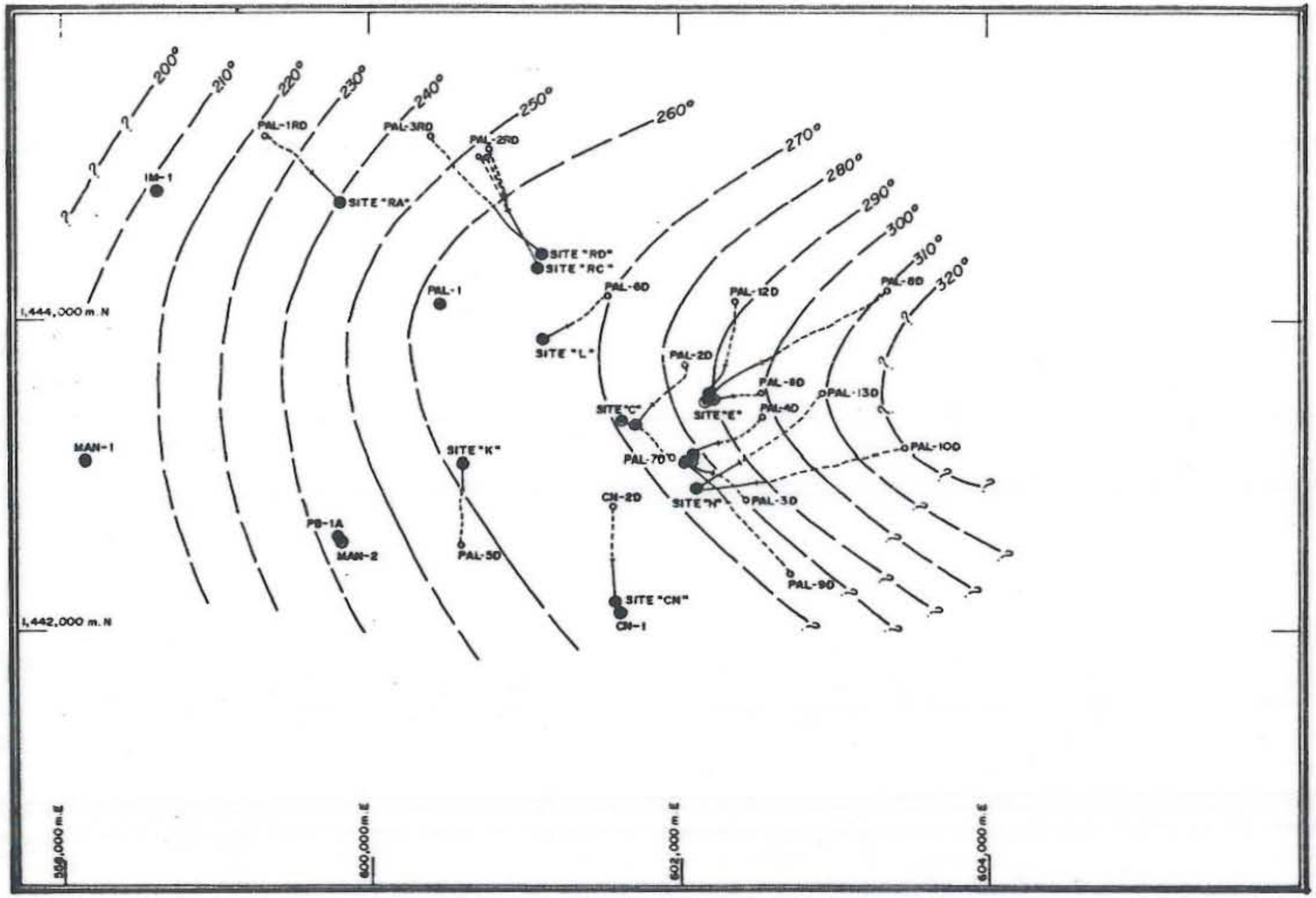
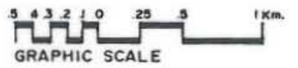


Figure 11. TEMPERATURE CONTOURS AT LEVEL -1400m.
BACON-MANITO GEOTHERMAL PROJECT



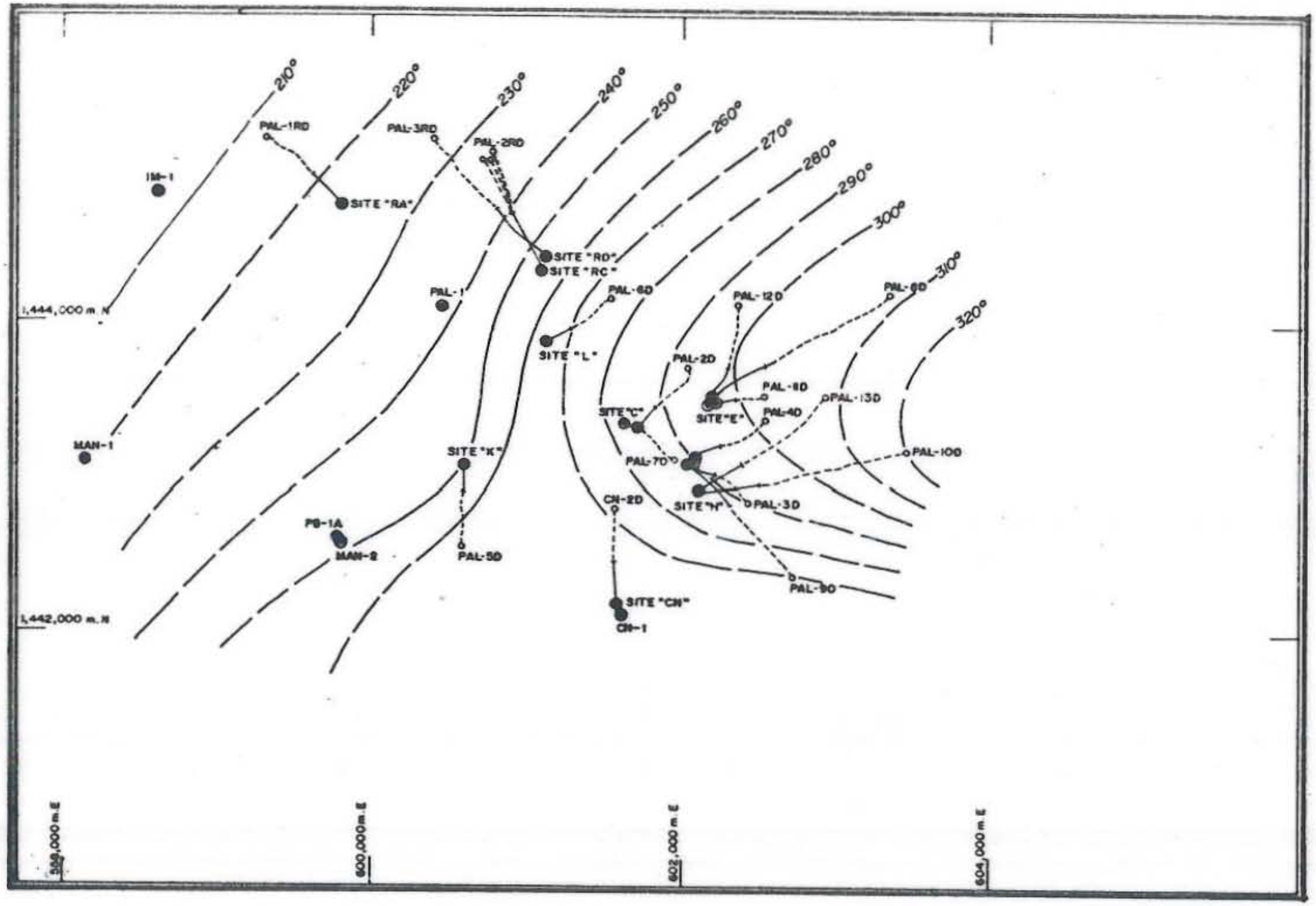


Figure 12. TEMPERATURE CONTOURS AT LEVEL -1800 m.
BACON - MANITO GEOTHERMAL PROJECT

5 4 3 2 1 0 25 50 1 Km.
GRAPHIC SCALE

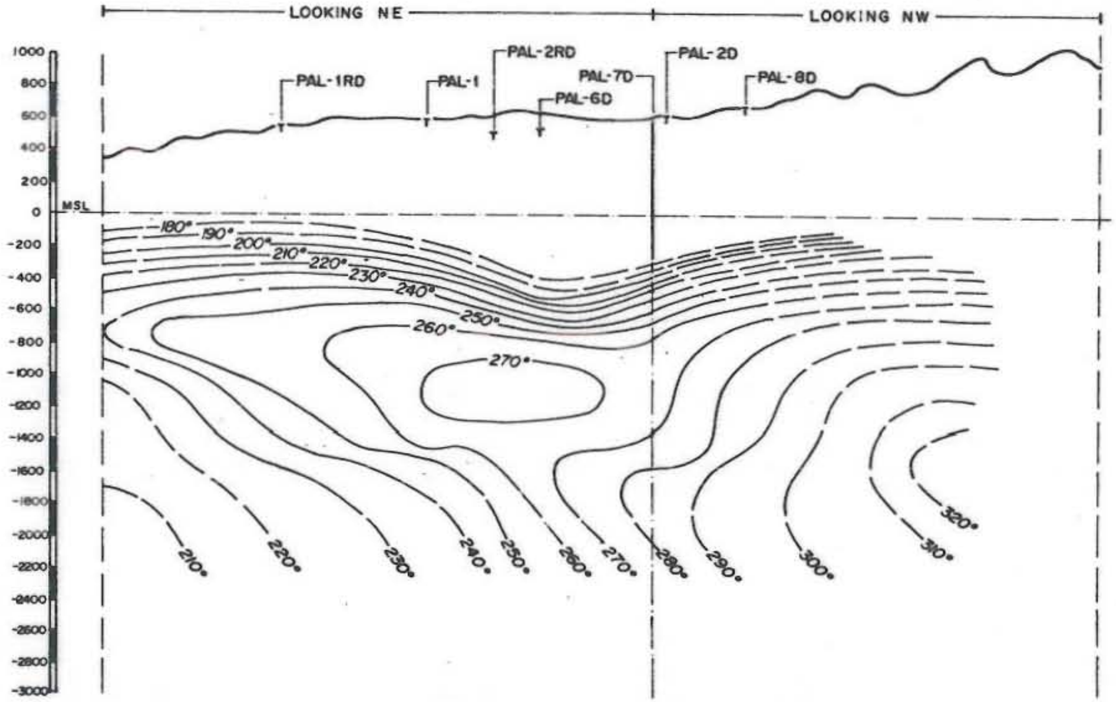
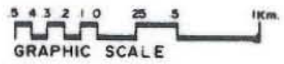


Fig.13. TEMPERATURE PROFILE ALONG CROSS-SECTION A-A'
BACON-MANITO GEOTHERMAL PROJECT



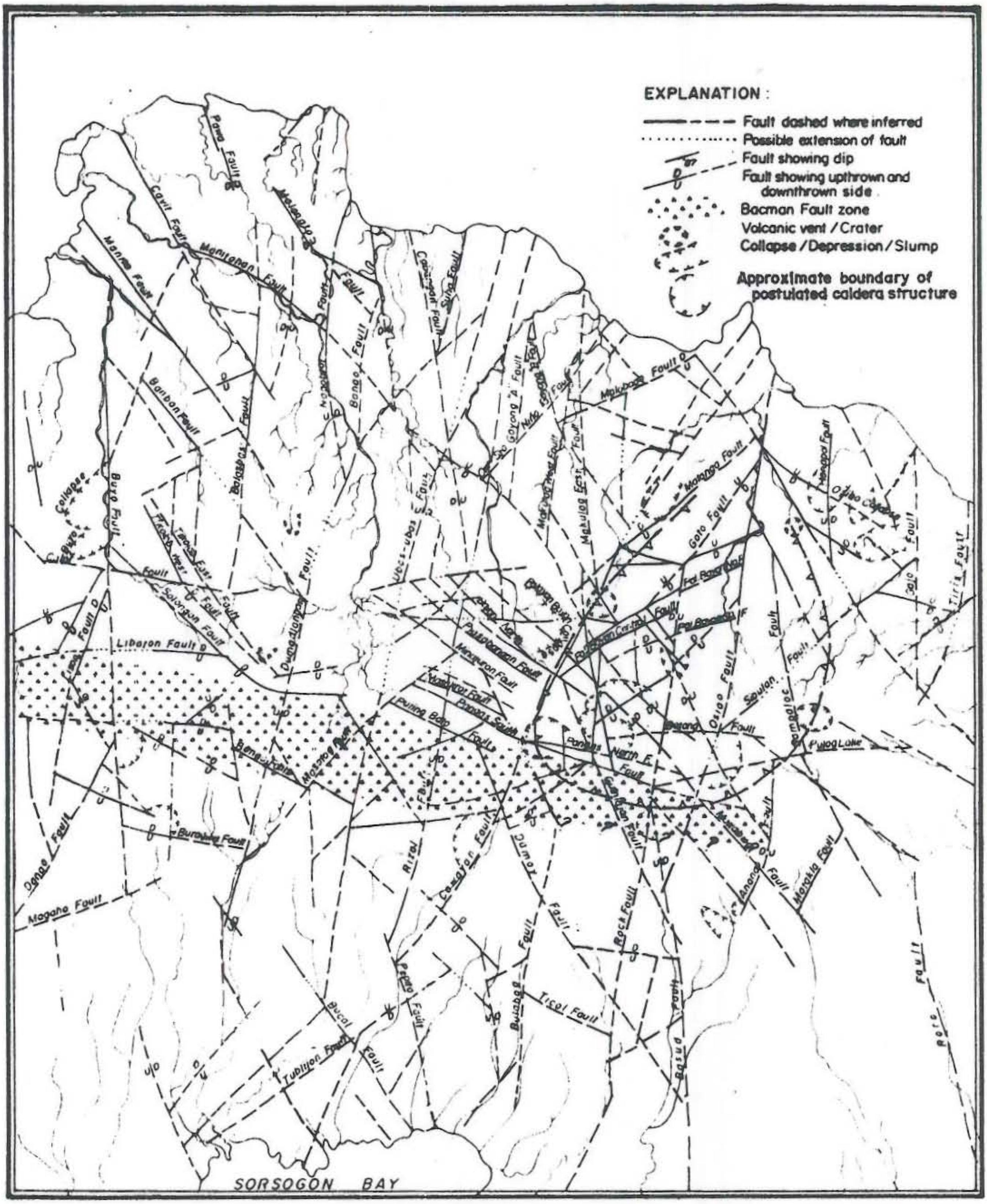


Figure 14. STRUCTURAL MAP OF BACMAN GEOTHERMAL FIELD
BACON-MANITO GEOTHERMAL PROJECT

GRAPHIC SCALE

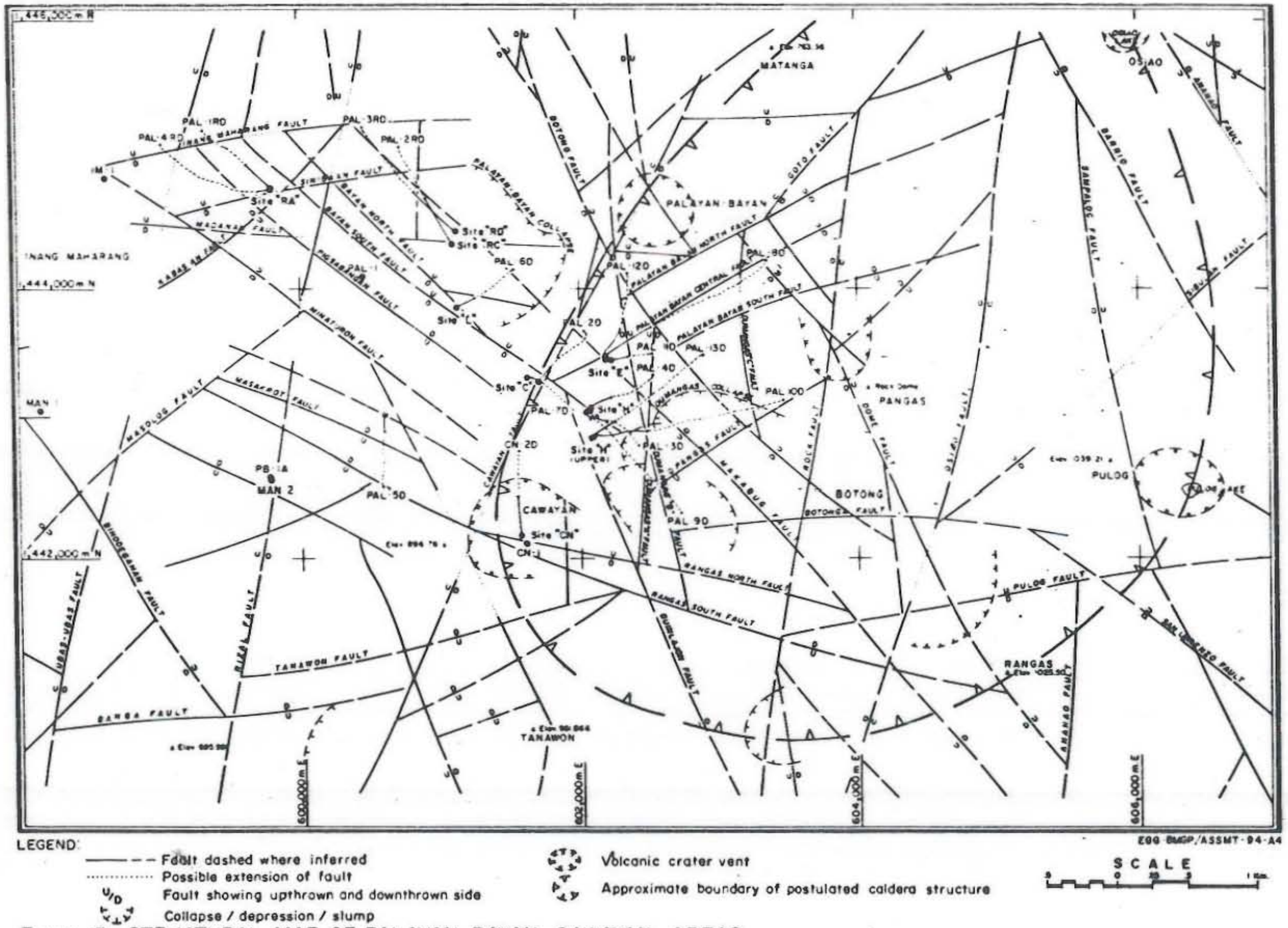


Figure 15. STRUCTURAL MAP OF PALAYAN BAYAN-CAWAYAN AREAS

THE PALINPINON GEOTHERMAL FIELD, VALENCIA, NEGROS ORIENTAL, PHILIPPINES: A CASE FOR A COMPACT DEVELOPMENT SCHEME

by

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INTRODUCTION

Initial exploration studies at Palinpinon (Fig. 1) were made in mid-1973 by the Philippine Commission on Volcanology (COMVOL) now Philippine Institute of Volcanology and Seismology (PIVS). These surveys mapped the area along the coalescing slopes of Mt. Cuernos de Negros and Mt. Guinsayawan where a large number of surface thermal manifestations are found, primarily along the banks of Okoy River. At elevations greater than 300 m, sulfate springs and steam-heated grounds are found. The emergence of chloride springs starts at about 200 m above sea level.

In 1975, the new Geothermal Division of National Power Corporation (NPC) continued the work started by COMVOL. One year later, PNOC-Energy Development Corporation (PNOC-EDC) took over the project and the pace of exploration activities doubled from thereon.

Two shallow exploratory wells were drilled to about 600 m in late 1976 as soon as the initial resistivity data showed a closure about the main thermal features. Both wells intersected a strong cross flow believed to be an outflow originating from the west of well Negros-1 (N-1). The temperature of this well is 206 deg. C while well N-2 has 175 deg. C or a difference of 31 deg. C over a distance of 4.5 km between the two wells (Fig. 2).

In 1978, five exploratory wells were drilled over a depth range of 971 m to 2130 m. These are wells N-3, OK-1, OK-2, OK-3, OK-4 and OK-5. These wells confirm a sector of the resource believed to be adequate for at least a 100-MWe development. In 1980, drilling of production/delineation wells started. Three years later, a 112.5-MWe geothermal power plant, consisting of 3 x 37.5 MW units was commissioned to supply both the domestic and industrial energy requirements of the two Negros provinces. The major industrial consumers were the mining companies with the sugar mills constituting a small minority.

At present, the 112.5-MWe Palinpinon geothermal power facility stands as a showcase featuring a compact reticulation system made up of 21 production and 10 reinjection wells. Eighteen of the production wells were drilled directionally to access the resource from four multi-cellared pads. On the other hand, the reinjection wells were all directionally drilled away from the production borefield (Fig. 3).

Exploratory wells drilled inside the western half of the resistivity anomaly demonstrated the feasibility of a second geothermal power station at the Nasuji-Sogongon area (Fig. 4). Eleven of the fifteen exploration/delineation wells drilled there has a tested output equivalent to 75 MWe. Assessment made of this sector showed it is capable of supporting another 100 MWe power facility. Most likely, the development plan will follow the scheme of Palinpinon I because of the severity of the terrain in this area.

CONSTRAINTS TO A CONVENTIONAL DEVELOPMENT SCHEME

The development of Tongonan I in Leyte features an almost conventional approach wherein the required number of wells to supply the steam to the power station were drilled vertically to reach the nearly lateral permeable contact zone between the Mahi-ao intrusive complex and the overlying andesite (Fig. 5 and 5A). The terrain allowed a well pad distribution wherein which a reasonable well interval can be maintained. Because of good permeabilities demonstrated by the exploratory/delineation wells, a spacing of not more than 200 m between production wells was deemed satisfactory for a sound exploitation of the Mahi-ao/ Sambaloran sector of the Tongonan geothermal resource (Fig. 6).

The development of the Palinpinon field presented three main constraints which negated the conventional approach that so far seemed to have worked pretty well in Tongonan. These constraints are summarized as follows:

Tight Terrain

All known geothermal areas in the Philippines are directly related to dormant/extinct andesite volcanoes in steep Plio-Pleistocene volcanic terranes (Fig. 7). In Palinpinon, the elevation over the resource area ranges from 730 m to 1200 m, allowing very little flattish surface for the necessary infrastructures such as well pads, separator stations, pipeline corridors and the power plant itself. A mere 45 hectares of land has to accommodate all surface civil works consisting of four multi-cellar well pads for 18 directional and 3 vertical production wells, 3 multi-cellar pads for 10-reinjection wells, a 12-vessel separator station, the entire surface reticulation system and the 112.5-MW power station, cooling tower and switchyard (Fig. 8).

Need for a Distant Reinjection Sector Relative to the Main Production Borefield

While many countries have already undertaken reinjection studies in their respective geothermal fields, e.g. Japan, Mexico, El Salvador, New Zealand and Iceland, much has remained uncertain about the good and deliterious effects of reinjected brine to the geothermal reservoir undergoing a so-called managed exploitation. PNOC-EDC has maintained a very cautious attitude and approach to this problem. In Palinpinon, for example, our reinjection policy was made to contain the following practical elements:

(a) Reinject as far away as possible from the production boreholes;
(b) Reinject as deep into the outflow as may be allowed by the hydrology of the geothermal system;
(c) Disperse the reinjected brine.

In an area as tight as Palinpinon's, the above conditions could only be met by drilling directionally to the north of the production field. To attain better dispersion and management of the reinjected brine, the reinjection wells were drilled in three groups to the NE, N and NW. PNOC-EDC finds out though that the distances between bottoms of production and reinjection wells cannot really be separated real far for lack of ample pad space notwithstanding the limits imposed by the capacity of the rig and the sound economics of the steam gathering and effluent disposal system. In most of the directional wells, a throw of about 1.5 km was attained with the rigs. On completion of the scheme, therefore, we see that between bottoms of production and reinjection wells, the nearest distance is about 500 m, the farthest approximately 2300 m (Fig. 3).

Fault Controlled Permeabilities

Circulation of thermal fluids in the system is thought to be controlled mainly by a network of high angle faults which strike NE and NW. This scenario became evident after delineation wells Okoy-7, Okoy-9 and Okoy-10 had been completed and tested. Horizontal permeability is interpreted to be minor, provided by lavas and breccias of the Southern Negros formation (SNf) and the Okoy sedimentary formation. Directional drilling has provided the desired flexibility for targetting to as many productive fault-related open fractures as possible, an objective which can be hardly met had the project developers opt to drill vertical wells.

ADVANTAGES FAVORING A COMPACT DEVELOPMENT SCHEME

There are several advantages that can be realized in applying a compact development strategy. These are:

1. More faults are intersected by well: Certainly, intersecting more faults do not guarantee a full success in terms of attaining large production. What really matters is that the right structures are the ones intersected by the well. Directional drilling, therefore, becomes a mandate in exploring and delineating a geothermal field whose reservoir hydrology is largely influenced by faults. With this technique, more geologic structures are explored and tested early in the drilling program. This information becomes extremely important in later planning the development strategy for the field. The Palinpinon project is such a case. The most important observation that can be drawn from the experience at Palinpinon is the fact that later wells were more successful as they were planned and designed to reach known producer faults verified from exploration/delineation wells drilled earlier (Fig. 3).

2. Limited civil works: In a compact development, this advantage is the one that is most visible. Not only is it environmentally healthy, it is also economical from the maintainance point of view – shorter roads and lesser number of well pads facilitating easy access to pipes, valves and pressure vessels. In a tight terrain like Palinpinon's, scattering the pads for 21 production wells and 10 reinjection wells over the 16 sq. km. resource area is not only a tall order for the civil engineers, but also a strategy that requires extensive expenditures especially so if the environmental sanctions are followed. One requirement in constructing roads and pads in steep countries is to haul the spoils

to a specified dumping site which in Palinpinon would be some 15 to 20 km dowstream of the construction site.

3. The wellhead can be maintained at a low elevations relative to the piezometric surface of the reservoir fluid: In Palinpinon, wells have to be stimulated to start discharge because of the depressed water level of the geothermal reservoir. At the site of Palinpinon I in Puhagan, wells have to be stimulated by compressed air to start discharge. The elevation at this location is around 730 m. In Nasuji-Sogongon, site of the proposed Palinpinon-II power station, discharge can be commenced only by stimulating the well with 2-phase fluid from a nearby discharging well or from a package boiler if the area is still in the very early stage of exploratory drilling. In Palinpinon, PNOC-EDC was able to bring down the elevation of the drill pads because of the flexibility that was offered by directional drilling technology. From the map (Fig. 3), one would easily see that most if not all of the drilling targets are underneath very high and precipitous terrain.

4. Ease in security and maintainance of wellheads, pipelines, roads and well pads over the long term: It is difficult to put numbers to quantify this advantage, however, common sense will tell us that lower security and maintainance cost can be easily realized in such a scheme. The movement of the operating and maintainance crews between wells is minimal with shorter roads and a few well pads to upkeep. All of these will redound to long term savings for the field operator.

In the case of Palinpinon-I, one would easily see the advantages that can be realized in using directional wells for the development of the field far outweigh the disadvantage of higher development cost. PNOC-EDC estimated that the developer must spend an additional 15% to 25% per directional well over the cost of drilling an equivalent vertical well.

This additional cost includes rental of directional drilling tools and services and the cost of possibly longer drilling time that has to be spent in the hole due to drag and other difficulties attendant to drilling directional wells such as the more frequent incidents of tight spots. All this additional cost, however, can be overcome by cheaper land development expenses and shorter and compact fluid gathering and disposal system. Over the long term, savings must also be realized in lower security, maintenance and operating cost as a compact steam-gathering system and plant facility would mean reduced operating and maintenance personnel and vehicular movements within the installation.

There is one reservoir-related disadvantage that we cannot quantify yet and this is the closer spacing between wells that could develop within the shallower production zones of the field. In the development of Palinpinon-I, PNOC-EDC took caution by casing off the shallow production zones from 700 m to 1100 m CHF in about 26% of the 21 production wells. This is done to preclude possible early interference between wells during the economic life of the power station.

CONCLUDING STATEMENT

As a whole, the Palinpinon-I geothermal field is an engineering showcase of a compact development scheme over a resource expected to supply an equivalent of 120 MWe of steam energy to a 112.5 MWe power station over a sustained 25-year operation. Chances are, this compact system is the only one existing in the world today. In addition to its being compact, another unique feature of steam-gathering system is that it is supplying a non-baseload power market, which is not a usual case for big geothermal power plants operating at capacities of 100 MWe or greater.

The cost of field development of Palinpinon-I is USD845,330/MW installed. The cost of power plant facility is USD537,680/MW installed. In 1985, electricity cost for geothermal based on country economics is 38-45 mills/kwh against 47 mills/kwh using oil as source of energy (Table 1). With such a slight advantage and the continuing decline in oil prices, a development strategy of this nature may not be economically viable in the near future except when the Philippines would desire to protect its national interest being a non-oil producing nation. The Bacon-Manito field in the provinces of Albay and Sorsogon, Southern Luzon (Fig. 7) is scheduled to supply an additional 110 MWe to the Luzon grid by 1989 using the compact development scheme applied in Palinpinon-I.

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Table 1

COMPARATIVE SUMMARY
GEOTHERMAL VS OTHER ALTERNATIVES
COUNTRY ECONOMICS

	INVESTMENT LEVEL	FUEL COST MILLS/KWH	ELECTRICITY COST MILLS/KWH
GEOTHERMAL	\$600/KW - \$800/KW	25 - 28	38 - 45
COAL	\$1,200/KW	20 - 22	47 - 49
NUCLEAR*	\$3,000/KW	8	72
HYDRO	\$2,500/KW	-	45
OIL	\$1,000/KW	25	47

*Bataan Nuclear Plant
(7.20.85)

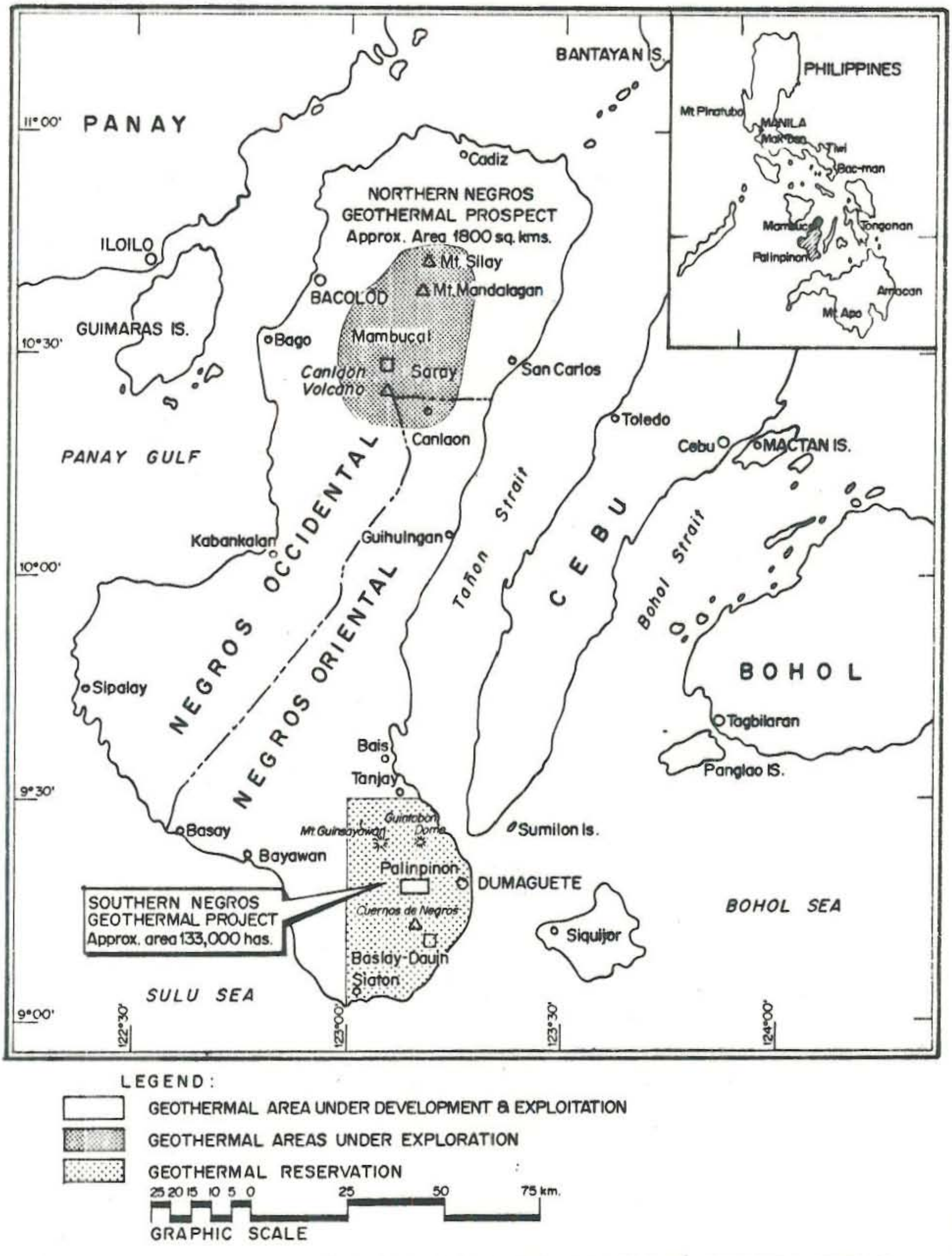

Figure 1. LOCATION MAP OF PALINPINON GEOTHERMAL FIELD
SOUTHERN NEGROS GEOTHERMAL PROJECT

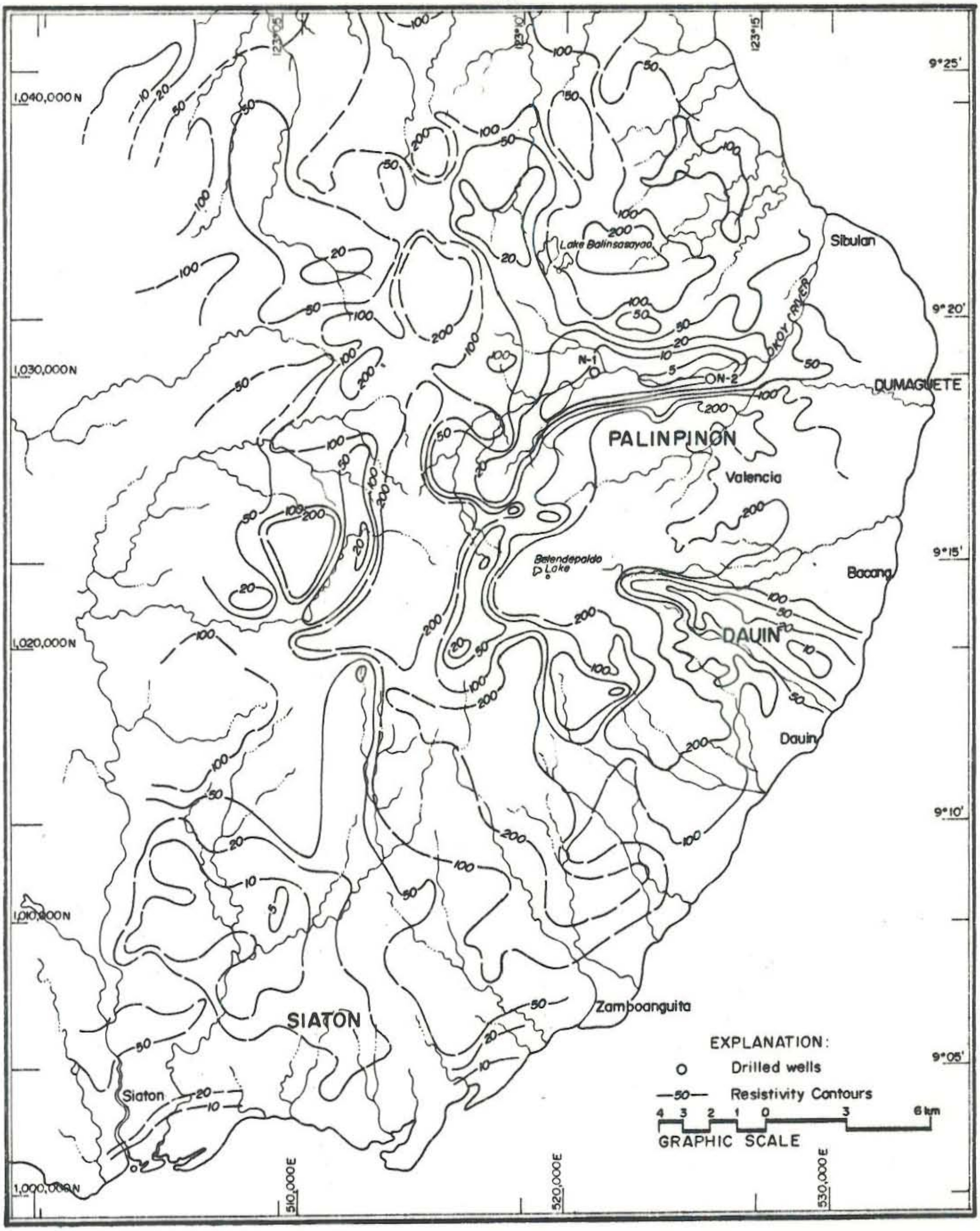

Figure 2. ISORESISTIVITY MAP AT AB / 2 = 500 m SHOWING PALINPINON FIELD & LOCATION OF SHALLOW EXPLORATORY WELLS N-1 & N-2 INSIDE THE OKOY RESISTIVITY ANOMALY
SOUTHERN NEGROS GEOTHERMAL PROJECT

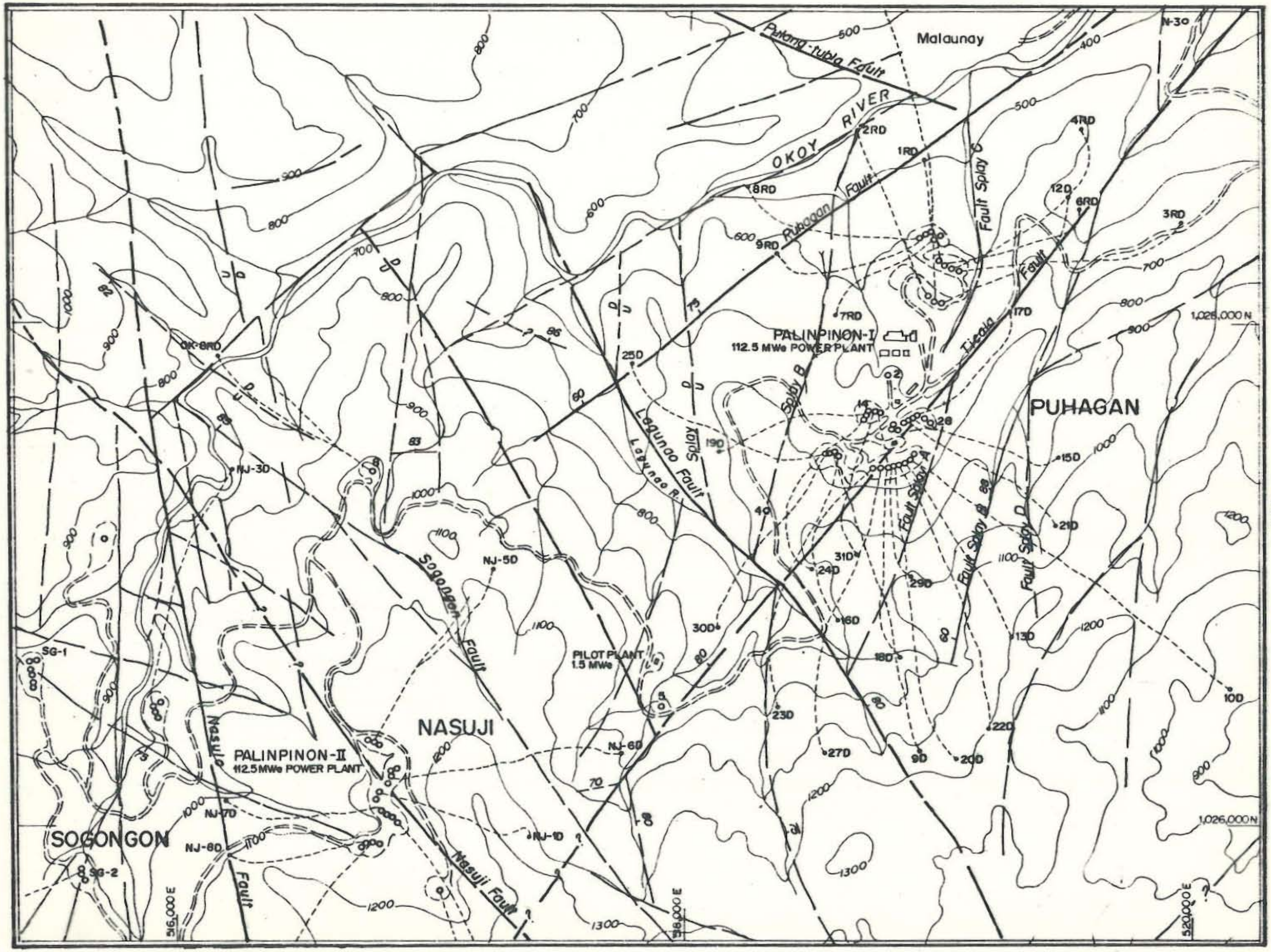

Figure 3. MAP OF PALINPINON GEOTHERMAL FIELD SHOWING WELL LOCATIONS AND FAULTS

400 300 200 100 0 200 400 600m.

GRAPHIC SCALE

(After Pornuevo and Obusan, 1983; Alcaraz, 1984)

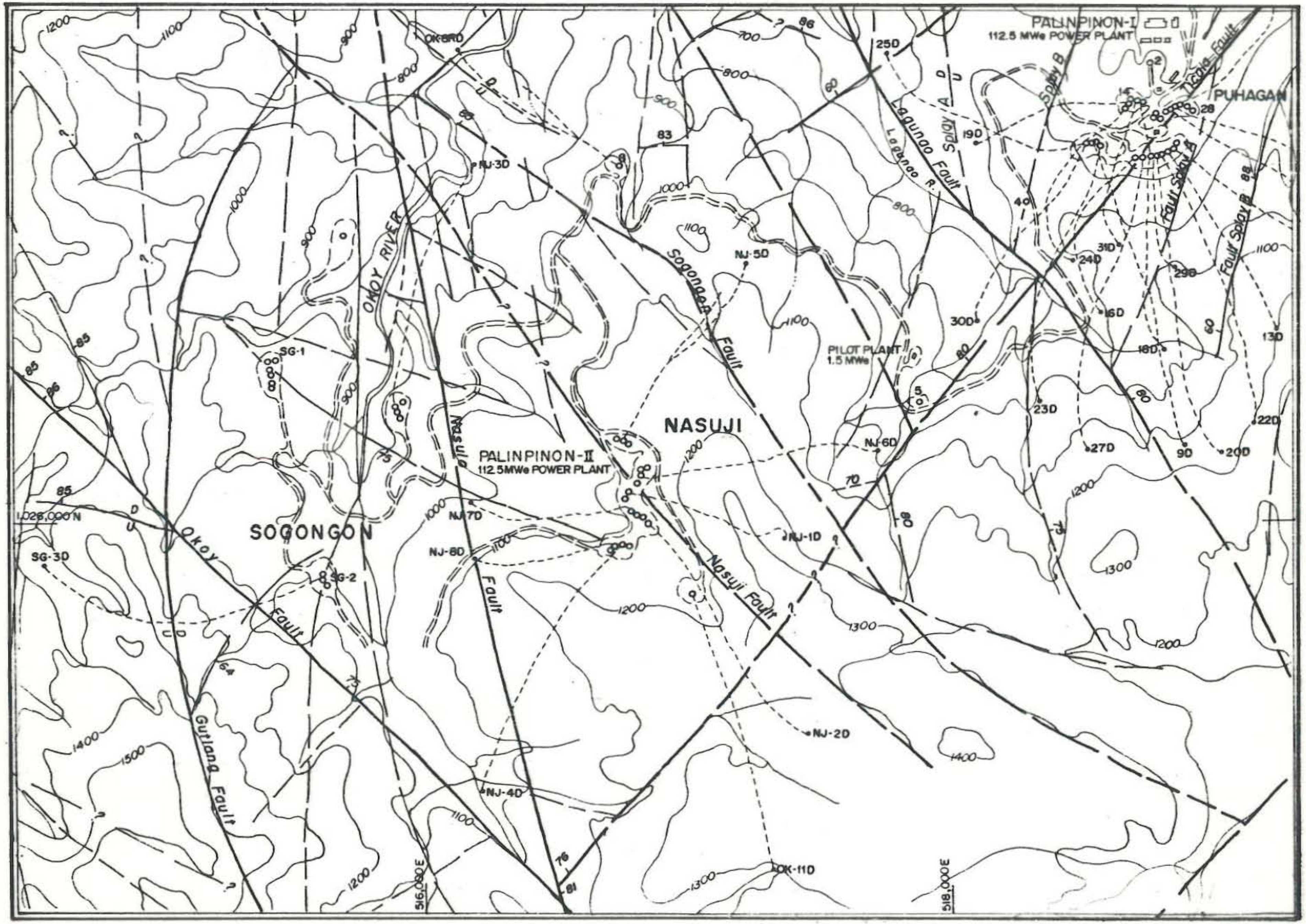

Figure 4. MAP OF PALINPINON GEOTHERMAL FIELD SHOWING WELL LOCATIONS AND FAULTS

(After Pornuevo and Obusan ; 1983 ; Alcaraz, 1984)

400 300 200 100 0 200 400 600m.

GRAPHIC SCALE

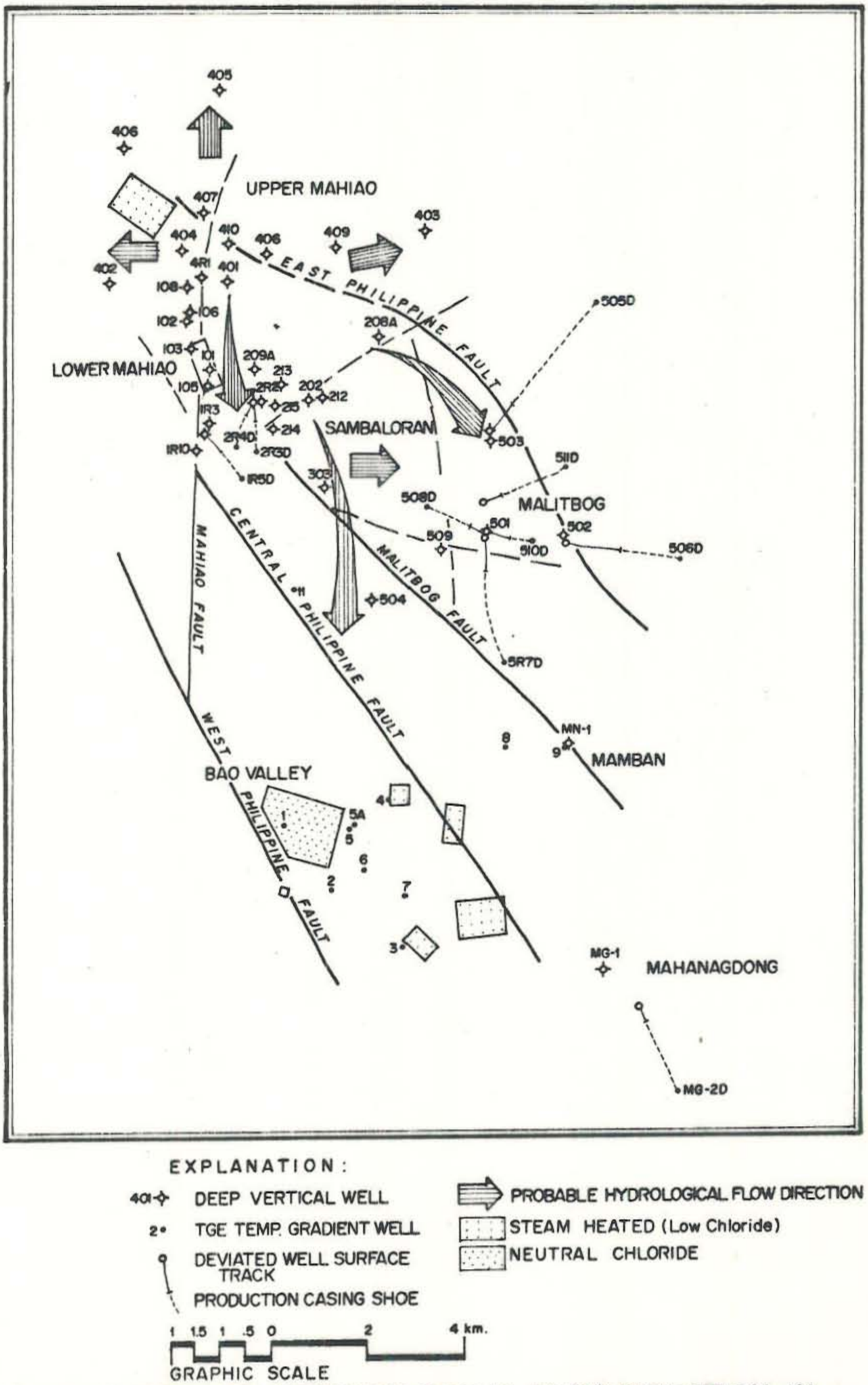

Figure 5. PROBABLE HYDROLOGICAL FLOW DIRECTION IN TONGONAN RESERVOIR
LEYTE GEOTHERMAL PROJECT
(After Lovelock, Cope and Baltazar, 1982)

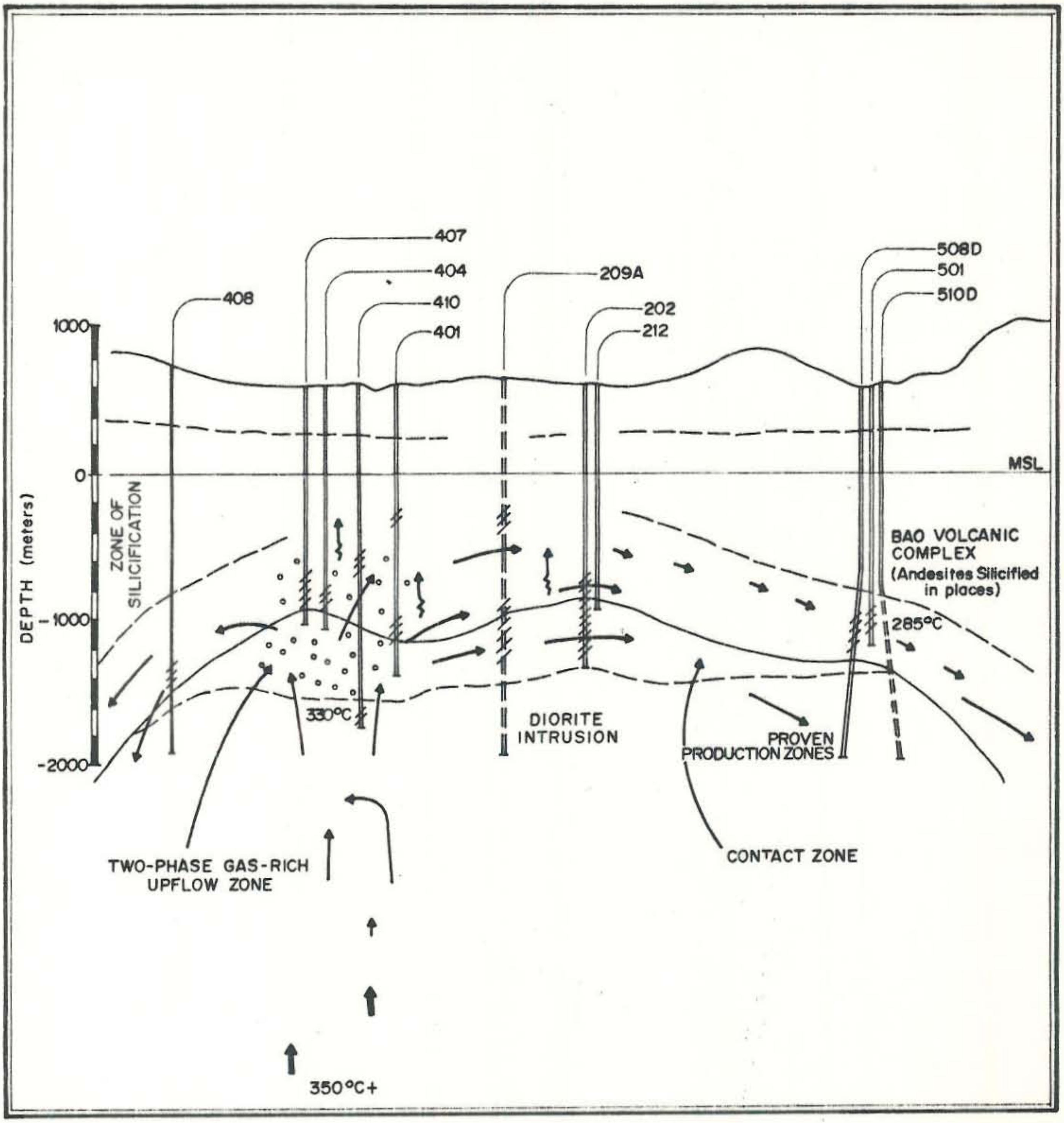

Figure 5A. SECTION ALONG WELL 408 TO WELL 510
TONGONAN GEOTHERMAL PROJECT, LEYTE, PHILIPPINES

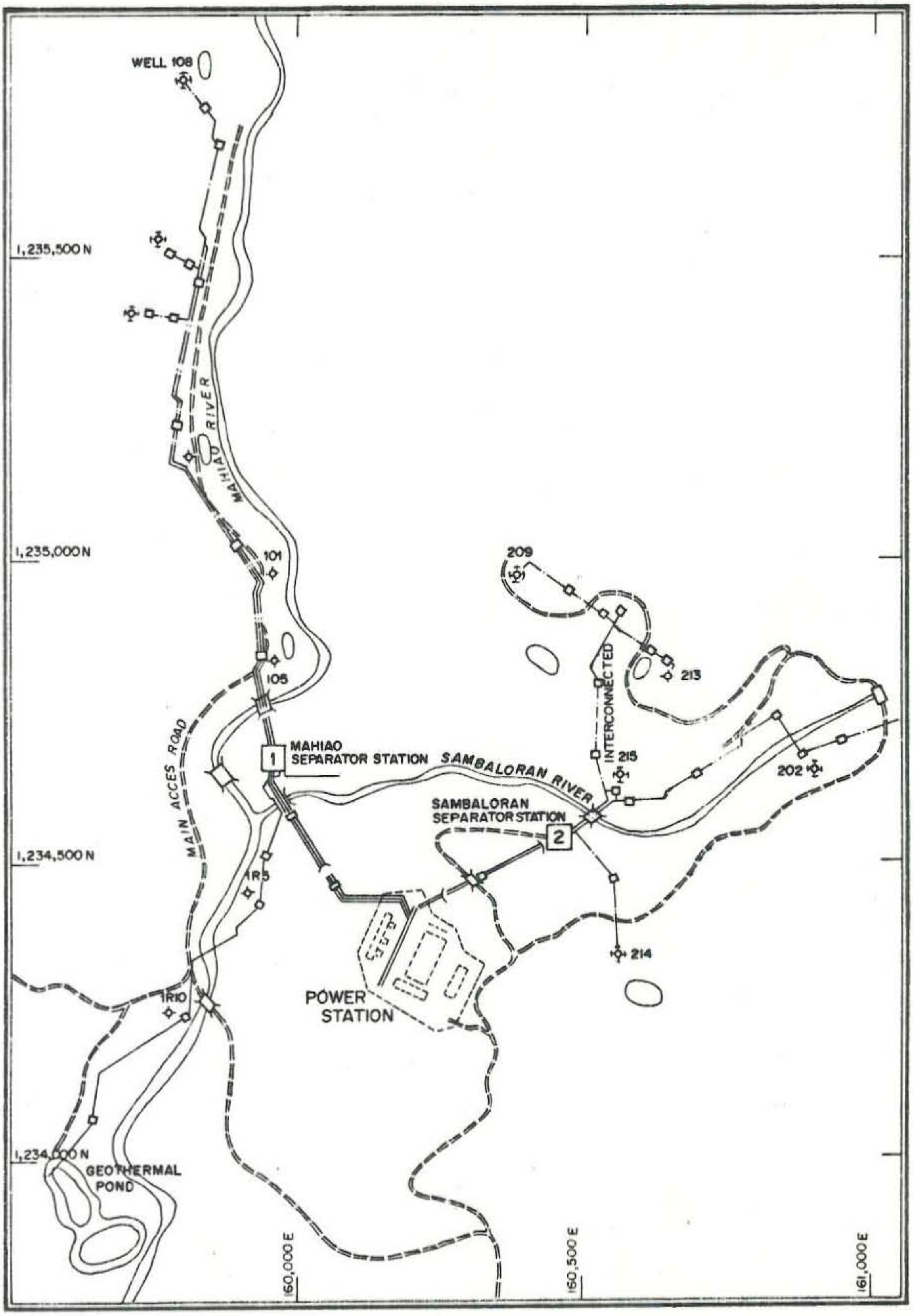

Figure 6 LAY-OUT OF TONGONAN 1
LEYTE GEOTHERMAL PROJECT

200 150 100 50 0 100 200 300 m.
GRAPHIC SCALE

(After Vasquez, 1985)

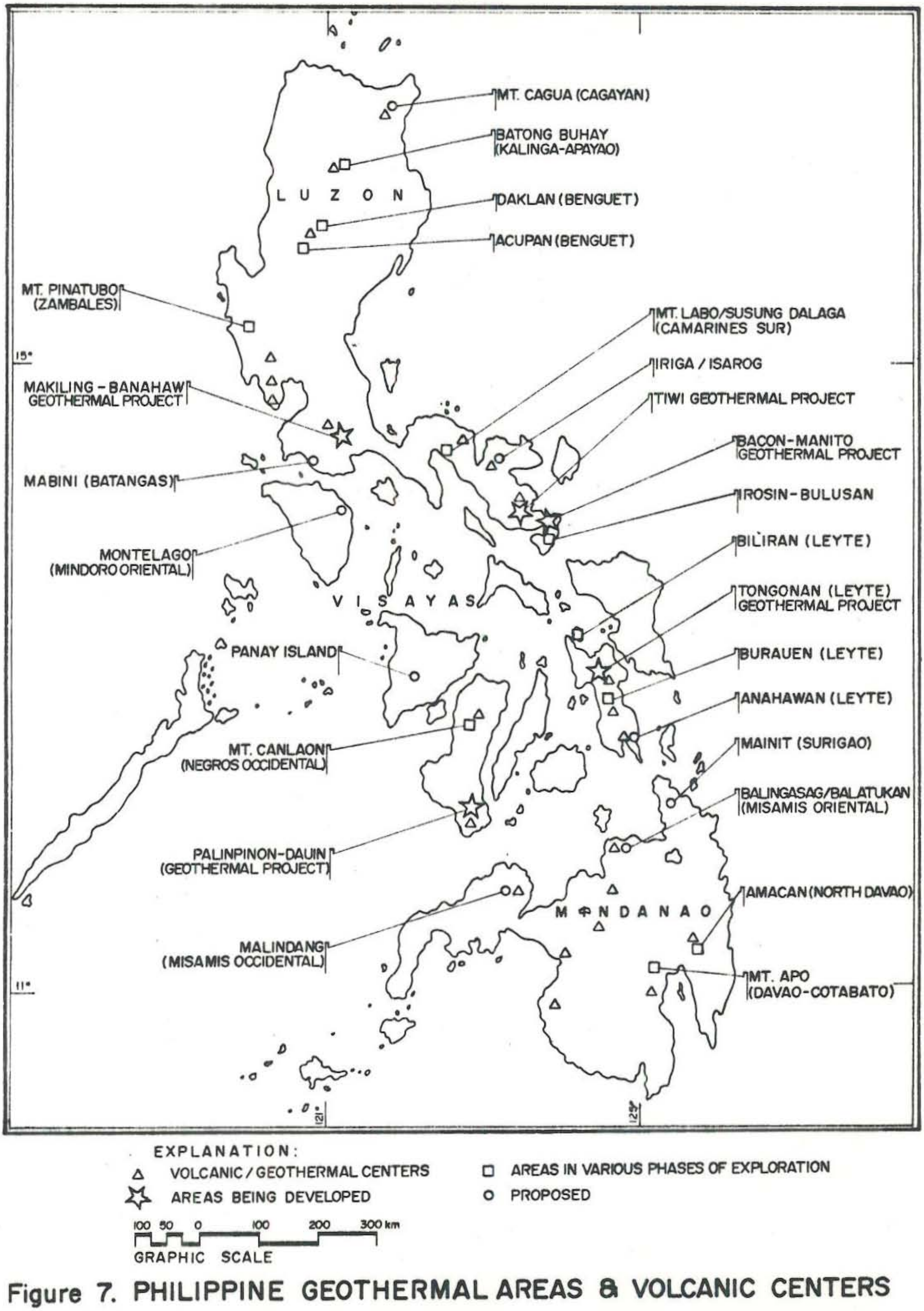

Figure 7. PHILIPPINE GEOTHERMAL AREAS & VOLCANIC CENTERS

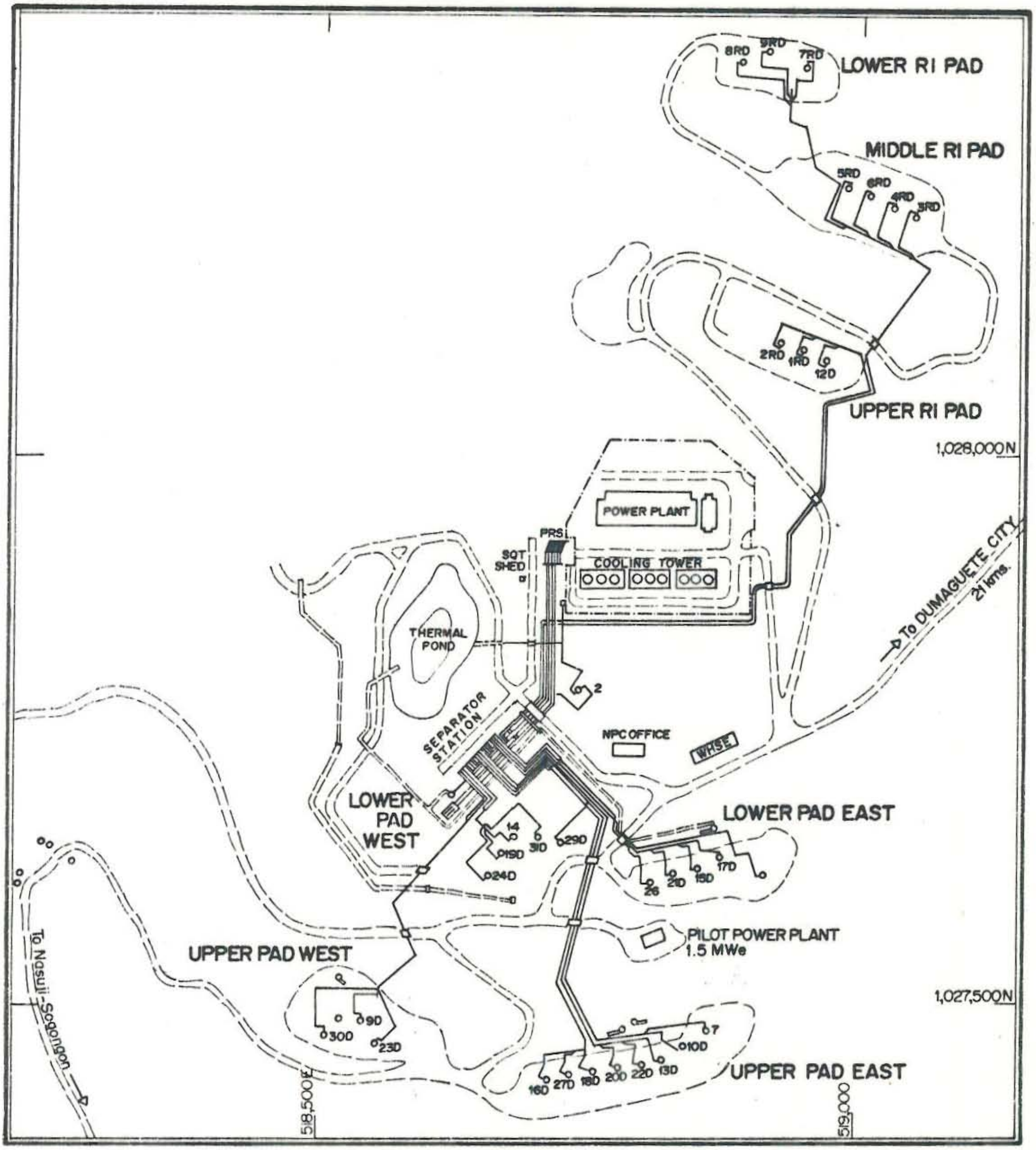

Figure 8. STEAM GATHERING AND EFFLUENT DISPOSAL SYSTEM OF 112.5 MW PALINPINON-I GEOTHERMAL POWER PLANT
SOUTHERN NEGROS GEOTHERMAL PROJECT

BASIC PRE-EXPLOITATION WELL DATA
Palinpinon Geothermal Field, Negros Or., Philippines

Well Name	Date Completed	Type/Use of Well	Total Depth	Permeable Zones
OK-1	04/07/78	Vertical, Exploratory	1979	Main: 1240-1360 Minor: 1900-1970
OK-2	05/29/78	"	1164	Main: 940-1100 Minor: 780- 830
OK-3	08/19/78	"	1522	Main: 670- 750 Minor: 1030-1150
OK-4	09/17/78	"	2130	Main: 980-1065 Minor: 800- 900
OK-5	12/02/78	"	1975	Main: 1450-1550 Minor: 1100-1200
OK-6	01/21/80	"	2771	Main: 2300-2700 Minor: 1340-1550
OK-7	04/05/80	Vertical, Production	2883	Main: 2600-2800 Minor: 1550-1700
OK-8	08/07/80	"	2982	Main: 2300-2400 Minor: 1700-1900
OK-9D	10/24/80	Directional, Production	2543	Main: 2105-2280 Minor: 1425-1590
OK-10D	10/03/81	"	2436	Main: 1300-1500 Minor: 2350-2436
OK-11D	03/20/81	Directional, Exploratory	2461	Main: 2330-2450 Minor: 1430-1570
PN-13D	07/07/81	Directional, Production	2697	Main: 1400-1530 Minor: 1625-1900 1950-2050
PN-14	05/12/82	Vertical, Production	3078	Main: 2600-2900 Minor: 1400-1500 2100-1400
PN-15D	09/02/81	Directional, Production	2716	Main: 1555-1650 Minor: 2075-2125 1175-1270

Well Name	Date Completed	Type/Use of Well	Total Depth	Permeable Zones
PN-16D	07/23/82	Directional, Production	3105	Main: 1860-2430 Minor: 2800-2944
PN-17D	11/18/81	"	2954	Main: 1930-2080 Minor: 1565-1650 2950
PN-18D	10/05/82	"	3147	Main: 1950-2140 Minor: 2620-2990 1500-1655
PN-19D	03/10/82	"	3024	Main: 2050-2800 Minor: 1270-1370
PN-20D	09/22/82	"	2691	Main: 1720-1950 Minor: 1200-1400
PN-21D	05/30/82	"	2862	Main: 2100-2200 Minor: 1180-1250 1625-1720
PN-22D	08/21/82	"	2699	Main: 1460-1800 Minor: 2060-2370 2620
PN-23D	11/08/82	"	2879	Main: 1900-2300 Minor: 1300-1615 2550
PN-24D	07/29/82	"	3106	Main: 1850-2040 Minor: 1400-1550 2780-2900
PN-25D	01/29/83	"	3329	Main: 3000-3250 Minor: 1550-1750
PN-26	10/05/82	Vertical, Production	2774	Main: 1600-1700 Minor: 1900-2000 2100-2350
PN-27D	02/08/83	Directional, Production	2860	Main: 1230-1580 Minor: 1925-2185 2715-2850
PN-28	04/03/83	Vertical, Production	2893	Main: 1400-1600 Minor: 1100-1200 2450-2700

Well Name	Date Completed	Type/Use of Well	Total Depth	Permeable Zones
PN-29D	06/05/83	Directional, Production	2808	Main: 1425-1650 Minor: 2040-2300 2450-2550
PN-30D	06/10/83	"	2921	Main: 1800-2050 Minor: 1300-1430 2770-2870
PN-31D	09/21/83	"	2696	Main: 1000-1100 Minor: 2600-2690 2130-2330
OK-12RD	04/23/81	Directional, Reinjection	1935	Main: 1935 Minor: 1375-1645
PN-1RD	04/22/82	"	2941	Main: 1380-1480 Minor: 1770-1960 2740-2780
PN-2RD	07/10/82	"	3394	Main: 2550-2730 Minor: 1200-1570 3100-3310
PN-3RD	09/14/82	"	3132	Main: 2800-3000 Minor: 2200-2400 1800-2050
PN-4RD	11/29/82	"	3085	Main: 2759-2881 Minor: 1920-2297
PN-5RD	04/27/83	"	2541	Main: 1350-1550 Minor: 1060-1120 1700-1900
PN-6RD	06/17/83	"	2589	Main: 1740-1930 Minor: 900-1170 1360-1550
PN-7RD	08/01/83	"	2562	Main: 2400-2560 Minor: 700- 850 980-1270
PN-8RD	08/17/83	"	2929	Main: 1640-1920 Minor: 875- 970 1060-1260

Well Name	Date Completed	Type/Use of Well	Total Depth	Permeable Zones
PN-9RD	11/02/83	Directional, Reinjection	3039	Main: 2620-2915 Minor: 1200-1375 2400-2525
NJ-1D	02/02/82	Directional, Exploratory	2848	Main: 1710-1905 Minor: 2300-2500
NJ-2D	10/15/82	"	2892	Main: 2510-2770 Minor: 1890-2100
NJ-3D	02/26/83	"	2693	Main: 1675-1915 Minor: 2310-2460 2670-2690
NJ-4D	04/21/83	"	2761	Main: 2080-2290 Minor: 1770-1870 2600-2680
NJ-5D	08/23/83	Directional, Delineation	2782	Main: 1450-1810 Minor: 2450-2600 2100-2280
NJ-6D	12/23/83	"	2600	Main: 1350-1500 Minor: 1650-2070 2380-2540
NJ-7D	11/30/83	"	2837	Main: 1440-1500 Minor: 1690-2010 2350-2600
NJ-8D	12/23/83	"	2922	Main: 1870-2150 Minor: 2450-2550
SG-1	07/06/81	Vertical, Exploratory	2763	Main: 2550-2650 Minor: 1550-1650
SG-2	10/11/81	"	2945	Main: 2050-2150 Minor: 1400-1600 2500-2700
SG-3D	01/08/83	Directional, Exploratory	2642	Main: 1550-1850 Minor: 1150-1375

Well Name	Max. Temperature Deg. C	Depth	WHP MPag	Enthalpy kJ/kg	Mass Flow kg/s	MW Rating
OK-1	197	700	(unable to discharge)			
OK-2	239	1150	0.7	1420	25	3.1
OK-3	224	954	(unable to sustain discharge)			
OK-4	299	1981	(unable to discharge)			
OK-5	310	1973	1.0	2000	32	7.3
OK-6	295	2450	1.1	1280	80	8.0
OK-7	321	2800	1.2	1410	86.5	10.6
OK-8	295	2450	0.62	1290	32	3.3
OK-9D	329	2890	0.72	1340	49.5	5.5
OK-10D	284	1611	0.69	1350	51.5	5.8
OK-11D	283	2800	(unable to discharge)			
PN-13D	324	2605	1.15	1360	32	5.8
PN-14	312	2700	0.75	1373	29.9	3.5
PN-15D	283	1833	1.15	1150	78.5	6.1
PN-16D	321	3087	0.53	1414	40.6	5.0
PN-17D	293	2954	0.59	1070	54	3.4
PN-18D	309	2990	0.68	1242	43.3	4.0
PN-19D	306	3022	0.66	1328	47	5.1
PN-20D	330	2679	0.85	1346	49.3	5.5
PN-21D	298	2860	0.76	1037	38.8	2.2
PN-22D	324	2710	1.16	1296	48.7	5.0
PN-23D	323	2850	1.47	1313	63	6.7
PN-24D	318	3106	0.63	1387	25.5	3.0
PN-25D	326	3338	(unable to sustain discharge)			

Well Name	Max. Temperature Deg. C	Depth	WHP MPag	Enthalpy kJ/kg	Mass Flow kg/s	MW Rating
PN-26	298	2690	1.0	1330	95.0	10.3
PN-27D	312	2850	1.76	1353	71.9	8.1
PN-28	289	2890	1.26	1350	59.1	6.6
PN-29D	324	2750	0.75	1250	65	6.2
PN-30D	320	2873	0.65	1239	53.6	5.0
PN-31D	319	2329	0.58	2067	93.7	22.1
NJ-1D	291	2797	(unable to sustain discharge)			
NJ-2D	281	2888	(unable to sustain discharge)			
NJ-3D	296	2671	1.02	1269	88	8.6
NJ-4D	301	2464	1.13	1140	53.7	4.1
NJ-5D	301	2776	0.68	1248	52.2	4.9
NJ-6D	311	2597	0.90	1238	68.1	6.8
NJ-7D	284	2827	0.95	1387	83.6	9.9
NJ-8D	284	2833	1.10	1182	39.5	3.3
SG-1	277	2650	0.69	1150	53	4.1
SG-2	283	1425	1.02	1275	85	8.4
SG-3D	285	2152	1.05	1263	73.1	7.1

Notes:

1) All depths are in meters vertical referred to CHF
2) MW rating is computed based on fullbore and 0.72 MPag separator pressure/vertical discharge