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A REVIEW OF PHILIPPINE GEOTHERMAL EXPLORATION STRATEGY

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ABSTRACT

Extensive geothermal exploration studies have been conducted in the Philippines over the past decade leading to the detailed surface investigation of sixteen prospects. Eleven of these have been drilled and four have been developed to a total of 894 MW(e). The proceedurs used during these exploration studies are discussed, and the characteristics of a typical Philippine geothermal system are described.

1. INTRODUCTION

Although the development of Philippine geothermal resources has long been identified as a viable source of electrical power, early geothermal exploration was sporadic. it was not until the nineteen seventies that serious exploration was undertaken with the intention of reducing the country's dependance upon imported fuel oils for the generation of electricity.

Todate, more than forty prospective geothermal resource areas have been identified (Fig. 1). Thirty one of these have been reconnoitred, sixteen explored, eleven test drilled, and four have been developed with 894 MW(e) total of generating plant now installed and commissioned, constituting approx. 20% of the country's currently installed power generating capacity. (Table 1).

In response to such extensive regional geothermal investigation, a systematic proceedure has progressively evolved over the past decade for exploring for, and assessing Philippine geothermal resources. This consists of the following stages of sequentially higher level investigation -

(i) regional identification of prospective target areas.

(ii) geoscientific surface prospecting methods.
(iii) exploration and delineation well drilling.
(iv) assessment of resource potential.

2. REGIONAL IDENTIFICATION OF PROSPECTS

During early geothermal exploration in the Philippines, regional target identification was based exclusively on an association of surface thermal activity proximal to prominent Quaternary volcanic land forms. More recent-

subduction zones, either at individual volcanic centres, or along the Philippine Fault Zone where it intersects a volcanic front (Fig. 2).

This subduction/volcanic front model provides a very useful predictive method for identifying potential geothermal resources, and has now directed exploration interest toward -

(i) an examination of the entire length of volcanic fronts for geothermal potential, rather than to obvious volcanic centres only.

(ii) central Mindanao, which is barely explored, but where there are a number of large volcanic complexes associated with active subduction at the Davao Trough, the southern and of the Negros Trench, and possibly the Cotabato Trench.

3. GEOSCIENTIFIC PROSPECTING

Geoscientific prospecting is commenced following identification of a potential resource area. Through considerable exploration experience gained in the young, rugged volcanic terraines characteristic of most Philippine geothermal prospects, the investigative methods as detailed in Table 2 have been found to be well suited to providing largely definitive data together with rapid areal coverage and cost effectiveness.

Although exploration prospecting is carried out through 3 geoscientific disciplines, a geothermal prospect can only be fully evaluated from a multidisciplinary standpoint. Much emphasis is thus placed on this when developing a conceptual model of a prospect at the conclusion of a geoscientific survey programme.

The multidisciplinary integration of exploration data frequently proceeds along the following lines:

(i) A hydrologic model of a prospect is prepared from careful consideration of all resistivity and sounding data. The three dimensional distribution of hydrothermal reservoir fluids to a maximum depth of 1 km, regions of fluid upflow and outflow, and areas of reduced permeability around much of the periphery of a system can be deduced from this model.

(ii) Geochemical data are overlain on the hydrologic model. Genetic water types are correlated with position within the model and elevation of surface discharge; gas and solution geothermometers are used to estimate subsurface fluid temperatures in the upflow and outflow regions of the model, and isotope geochemical techniques are used to verify the inferred hydrology.

(iii) Geological data proves very useful in determining permeability controls on fluid upflow, outflow and surface discharge, the reliability of

PHILIPPINES CURRENTLY INSTALLED AND PROJECTED INSTALLED GEOTHERMAL POWER GENERATING CAPACITY

Field	Operators	Installed Plant Capacity (MWe x No. of units)		Projected Additional	Installed Capacity
Tongonan	PNOC-EDC/NPC	37.5 x 3 3.0 x 1	112.5 3.0	37.5 x 9	337.5
Palinpinon	PNOC-EDC/NPC	37.5 x 3 1.5 x 4	112.5 6.0	37.5 x 3	112.5
Bacon-Manito	PNOC-EDC	-		55.0 x 2	110.0
Tiwi	PGI/NPC	55.0 x 6	330.0	?	
Makiling	PGI/NPC	55.9 x 6	330.0		
			894. MW(e)		+ 560 MW(e)

PNOC-EDC Philippine National Oil Compnay - Energy Development corporation
NPC National Power Corporation
PGI Philippine Geothermal Inc.

tectonic and hydrothermal history of an area. The nature of a possible heat source may also be inferred from a consideration of geologic, aeromagnetic and gravity data.

4. EXPLORATION AND DELINEATION DRILLING

Any model of a geothermal resource as conceptualized from exploration data acquired at surface can only be tested satisfactorily by drilling.

Test drilling proceeds in two stages:

(i) an initial 3 well exploration drilling programme to confirm the presence of a high temperature resource. These are typically drilled vertically to 2000-2500m depth. Providing the terrain permits, it is desirable to locate one well in the centre of the resource as indicated by the exploration model. The other 2 wells are sited within the inferred resource area at locations suck that the 3 wells collectively test a block of about 5 km^2 of potential resource area. Drilling then ceases until the results obtained from exploratory drilling have been fully evaluated.

(ii) findings obtained from the 3 exploration wells generally result in refinements being necessary to the exploration model. Adjustments are made and if indications remain encouraging, an additional 4 delineation wells are sited with the objective of testing the exploration model outwards to its boundaries. Extensive use of long throw deviated well drilling is made during field delineation in order to maximize boundary information from infield wellheads which can later be piped up as production wells. Vertical drilled depths of 2500-3000m with horizontal deviations (throws) of 1.3 to 1.5 km are typical during delineation drilling.

5. RESOURCE POTENTIAL

Successful geothermal development requires not only a knowledge of the amount of energy in the reservoir but also the quantity of energy that can be recovered, and the rate of which it can be extracted. This determines the electrical generating capacity that a resource can support (KRTA Limited, 1980).

5.1 The Amount of Stored Energy

The geothermal resources developed by the Energy Development Corporation of the Philippine National Oil Company (PNOC-EDC) have been sized, for the purpose of initial commitment, using a method of volumetric stored heat calculation (see for example Donaldson and Grant, 1981). The method considers the total heat stored in both fluid and rock within a closed system to which no fluid or heat recharge occurs. The method is not particularly sensitive to the value assumed for rock porosity, and yields a conservative estimate of the energy content of the resource because of the production commences.

5.2 Recoverability of Stored Energy

The amount of energy that can be recovered from a stored heat resource and the rate at which it can be 'mined' or recovered is principally a function of reservoir permeability (assuming liquid dominated reservoir conditions). For an isotropic reservoir where permeability is wholly primary the rate of heat extraction is optimal. On the otherhand where permeability is secondary in nature, heat recovery will proceed less efficiently and will depend on individual fracture size, fracture spacing and the degree to which fractures connect into a field-wide 3 dimensional network (Donaldson and Grant, 1981). To allow for the uncertainties that variable permeability introduces on heat recoverability, a recoverability factor is used to downgrade the amount of stored heat available, to a level of recoverability which is considered to be consistent with the mixed primary and secondary permeability controls characteristic of Philippine geothermal systems.

By the above methods, an assumed potential for a resource is arrived at. This potential must then be validated for each development sector by means of well testing and analysis of reservoir performance (KRTA Limited, 1980). Ideally, at the completion of the delineation drilling programme and prior to commitment to development, sector output tests would commence with production drilling being deferred until the sector performance tests had been completed. Because of the tight schedule in the Philippine geothermal development over the past decade, this deferment in drilling has generally not been possible. Instead, interference testing has been conducted in place of sector output testing as a means for predicting early reservoir performance.

6. CHARACTERISTICS OF A 'TYPICAL' PHILIPPINE GEOTHERMAL SYSTEM

With approx. 200 deep wells now drilled in 11 Philippine geothermal systems it has been found that they have many physical and chemical characteristics in common. Considering that these systems are associated with volcanic fronts derived from melting of subducting oceanic crust, similarities are then to be expected because it is the geological environment which predominantly controls the physical and chemical characteristics of a hydrothermal system.

The Philippine systems are classified as island-arc volcanic geothermal systems and are dominantly liquid in the pre-exploited state. They may or may not be solfataric. A general schema for such systems has recently been published (Henley and Ellis, 1983) which has been modified in Fig. 3 to more closely describe the 'typical' Philippine system.

The principal elements of these systems are:

(i) The central reservoir area is dominated by a near vertical plume of ascending neutral alkali

Fig. 2 VOLCANO TECTONIC SETTING OF THE PHILIPPINES (Modified from Bogle and Palma , 1984)

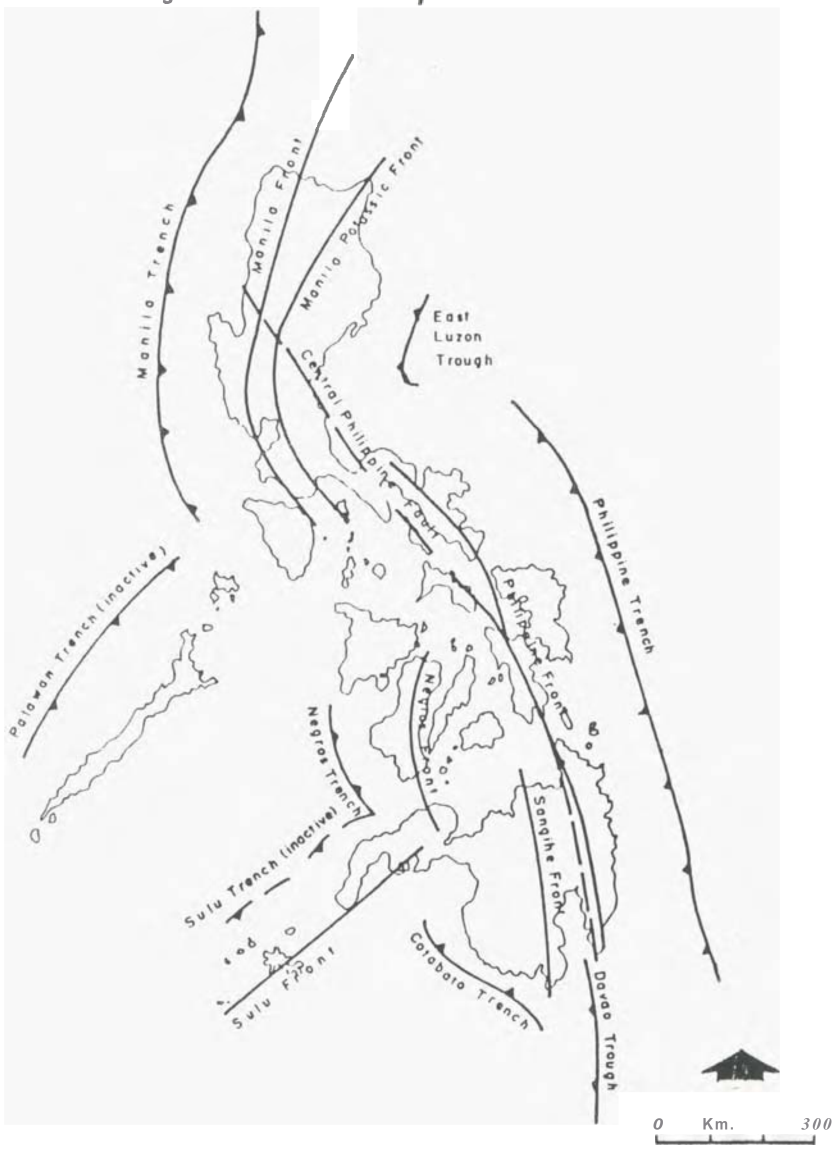

FIG.1.

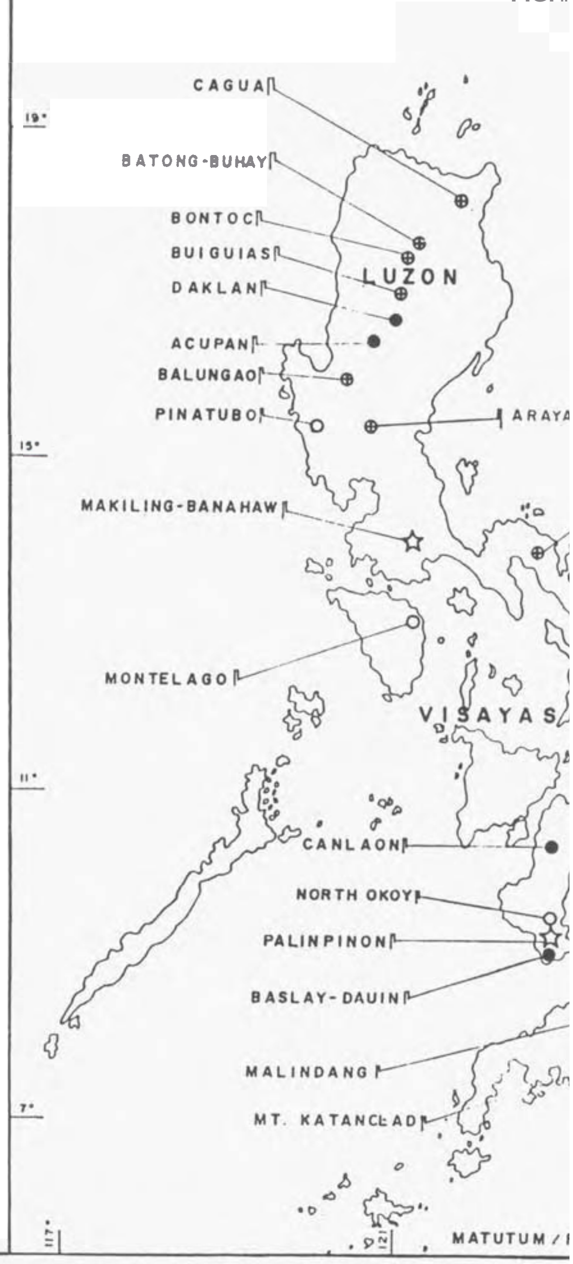

Table 2.

PHILIPPINE GEOSCIENTIFIC PROSPECTING METHODS

Discipline	Techniques	Examples
Geology	·Photogeology ·Field mapping ·Structural geology ·Hydrothermal alteration petrology ·K/Ar & C-14 geochronological studies	Lawless & Gonzales (1982) Sayrante (1981) Lawless et alia (1983)
Geophysics	·Schlumberger array resistivity Surveying complemented by vertical electrical soundings (VES) and dipole-dipole resistivity surveying	-Bromley and Española(1982)
	·Gravity	-Ignacio and Bromley (1982)
	·Aeromagnetics	-Bromley and Ignacio (1983)
Geochemistry	·Sampling and geochemical analysis of hot, warm and cold springs, sublimates and fumarolic gases	Harper and Arevalo (1982) Lawless and Gonzales (1982)
	·Application of (i) solution, mineral and gas geothermometry methods	-Bogie (1983)
	(ii) chemical mixing models	
	(iii) isotopic chemistry for hydrologic modelling	-Stewart et alia (1982)

Fig.3 'Typical' Philippine Solfataric Geothermal System
(Modified after Henley & Ellis, 1983 & Leach, 1962)

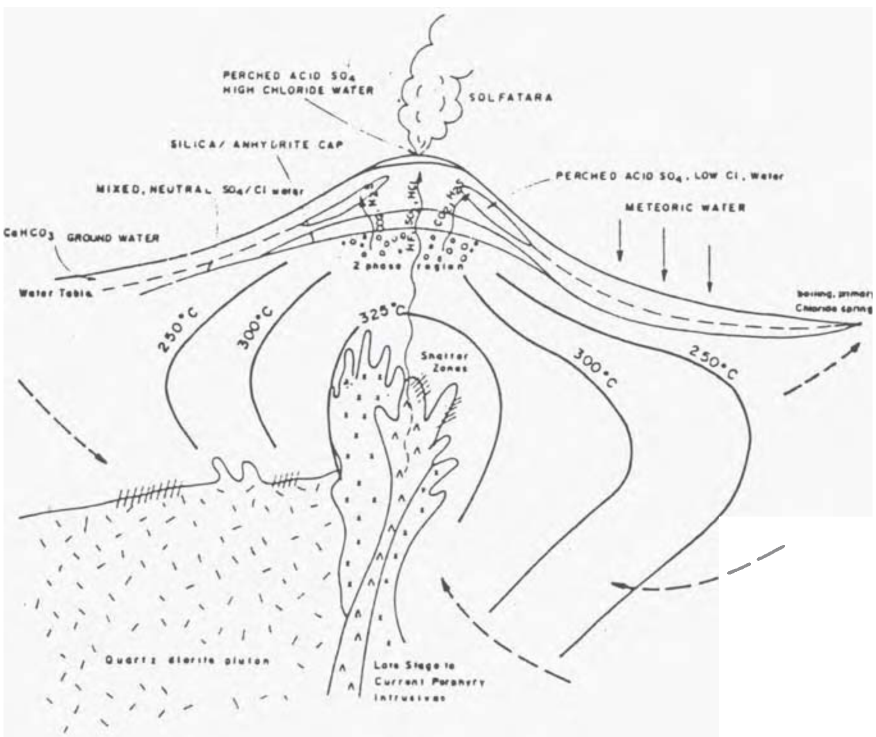

Table 3.

TYPICAL PHILIPPINE WELL CHEMISTRIES (At atmos pressure/local boiling temperature)

Field	Well	Date	pH (25°C)	Li	Na	K	Rb	Cs mg/kg	Cr	Mg	Cl	SO,	8	SiO_2	HCO_3*
Palinpinon	Okoy 7	9/80	7.62	1C.2	3350	1000	5.35	4.00	117	0.09	7232	35.5	86.11	1122	43
Tongonan	209A	6/21	6.79	28.2	7534	2119	IU.I	4.95	189	0.26	13592	21.0	269	1175	13
Bacon Manito	Pal-4D	12/83	7.50	11.0	4714	1010	4.4	0.80	164	0.90	a934	22.9	61.7	928	23
Tiwi	Nag-2	12/73	6.5		3476	809			54		6058	10	70		38
Biliran	BN-3	12/82	2.56	2.83	1675	375	1.29	3.61	1.9	39.3	2940	4004	430	1314	
Amacan	AM-1	6/63	7.9	3.5	1374	289	1.12	-	24.0	1.2	2183	57	112	835	163
Daklan	DK-1A	10/81	7.15	24.7	7749	1981	6.76	5.61	308	1.30	14704	23	192	8C5	49

NOTES:
1) HCO_3 value equals total carbonate expressed as HCO
2) Tiwi data from proceedings Ascope Conference, Manila, 1982, Pg 500
3) All other data from PNOC-EDC

with reducing pressure where it spreads laterally and moves down a hydraulic gradient away from the plume. Chloride springs are almost invariably found at some considerable distance from the plume (10-20 km) where the chloride water gradient first intersects the topography. During early exploration of Philippine geothermal resources, attention was frequently misdirected to the outflow regions of resources due to the prescence of obvious temperature anomalies in shallow temperature gradient wells, pronounced Schlumberger resistivity anomalies, and considerable surface discharge of boiling chloride water from a shallow source fluid at 200-240°C.

(ii) Above the chloride water, the systems are frequently capped by a zone of silica and anhydrite deposition. Where reservoir temperatures closely follow boiling point for depth conditions (for example Tongonan - see Whittome & Smith, 1979) then considerable accumulation of free steam and gas occurs forming vapour dominated pockets beneath the cap.

It is also apparent that free gas can accumulate beneath the cap of a non boiling system due to gas stripping from the deeper chloride water in response to declining gas solubilities with decreasing pressure during upward fluid movement. Migration of CO_2 + H_2S through cap fractures and oxidation in shallow vadose zones produces acid sulphate low chloride fluids above the cap zone.

(iii) Although Philippine geothermal systems are frequently solfataric the frequency of occurrence of magmatic volatiles in well fluids is surprisingly low. This probably reflects that no large scale mixing occurs between magmatic and meteoric waters unless deep permeabilities are exceptionally high (Bogie and Palma, 1984). Where magmatic volatiles have been detected they are manifest as HCl, HF, SO_2 rich steam emissions at surface and show a close association to single, prominent geologic structures. At slightly lower elevations to such magmatic contaminated emissions, distinctive acid chloride sulphate springs occur due to gas scrubbing in shallow ground waters (see for example Lawless & Gonzales, 1982).

(iv) Most of the Philippine geothermal systems are underlain at shallow depth (approx 3 km) by large plutonic bodies of gabbroic to granodioritic composition (see for example Ignacio and Bromley, 1982). As these masses are quite old, typically 10 m.y. BP, it is believed that the active systems are heated by late to current stage intrusions of porphyries along the periphera of the older plutonic bodies (Leach, 1982). This association is well documented in relict Philippine geothermal systems, exhumed by uplift and erosion, and now being mined for porphyry copper ore (see for example Loudon, 1976).

(v) The size of the economically exploitable fluid resource (down to 180°C) in a typical active Philippine geothermal system is generally 15 to 25 sq. km. in surface area; yielding a recoverable stored heat resource of up to 25000 MW(e) years energy equivalent.

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